A Practical Guide to the Wiring Regulations

BS 7671

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Third Edition

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Preface to the Third Edition

The national Standard for electrical installation works, BS 7671: 1992 *Requirements for electrical installations*, has undergone a number of changes since it was first published as the *Sixteenth Edition of the Wiring Regulations* in 1991. With Amendments in December 1994, December 1997 and April 2000, the Standard was revised as BS 7671: 2001 in June 2001.

Amendments are required from time to time to take account of the technical requirements of CENELEC Harmonised Documents which have been published since the last issue of the National Standard. Additionally, account is required to be taken with previously published Harmonised Documents (HDs) which have undergone alteration.

Perhaps the most significant of the more recently published CENELEC HDs is HD 384.1: *Scope Objects and Fundamental Principals* which has necessitated Part 1 of BS 7671 being fully revised and expanded. However, other changes to the National Standard include a new Section 443 on protection against overvoltages of atmospheric origin or due to switching, and a new Section 482 on precautions to be taken where particular risks of dangers of fire exist. Amendments have been made to Chapter 43 (protection against overcurrent), Chapter 46 (isolation and switching), Section 604 (construction site installations) and Section 611 (highway power supplies, street furniture and street located equipment).

While many changes have been associated with CENELEC HDs, a number of modifications made have been initiated in the United Kingdom. Such national changes include a substantial revision of Section 607 (earthing requirements for the installation of equipment having high protective conductor currents). Chapter 73 (periodic inspection and testing) and Chapter 74 (certification and reporting) have been revised and BS 7671: 2001 incorporates the new zoning requirements for locations containing a bath or shower.

In my professional experience both on the staff of the Institution of Electrical Engineers and the National Inspection Council for Electrical Installation Contracting I have been asked, and attempted to answer, numerous questions over the years relating to the regulatory requirements and their implementation. While most practitioners will recognise where a proposed solution will not, or does not, meet the requirements, many find it difficult to attribute a precise regulation number to it or what action to take in solving the problem. This is not surprising since the subject of electrical installations is vast and complex. Those that believe that all issues are crystal clear (or black and white) and that there is only one possible solution to a design problem are deluding themselves. As there are many ways of killing a cat (besides electrocution) so too are there many design and installation options so long as the basic constraints are met.

An attempt has been made in this Guide to make life a little easier and topics are addressed with the pertinent Regulation numbers listed where appropriate. However, the Guide will be most useful to those who have at least a working knowledge of earlier editions of the National Standard. This Guide is not intended for use by the DIY enthusiast unless, of course, he or she happens to be competent in this field.

Where I have considered it necessary, some background guidance is given together with worked examples embodied in the text at the appropriate place. It is hoped that this Guide will serve both as a useful aid to designers, installers and verifiers of electrical installations and to others not directly professionals in the industry but who have an interest in the safety aspects of electrical installations perhaps as 'duty holders' as defined by the Electricity at Work Regulations 1989. It is also expected that it will be of use to those students of the industry who are endeavouring to come to grips with all the many facets of electrical safety.

Extensive use has been made of tables which draw together the various relevant Regulations and options. Where appropriate, tables have also been employed as check lists for reference for those who find such listings useful in their day-to-day activities. Similarly, numerous figures have been used to more clearly identify specific points which I have thought worthy of mention.

No single book can ever cover all the aspects of this topic and I have had to take the view that this Guide should include guidance on the issues that are more frequently encountered, leaving aside some of the more esoteric aspects. Inspection, testing, verification, certification and reporting come in for special attention as I believe many electrical contractors would welcome some guidance in this respect.

As with earlier editions of this Guide, some design calculations have retained the recognition of an allowance to be made for the increase in impedance due to a temperature rise from normal operating temperature during clearance of a fault. While making such an allowance is strictly not necessary where the overcurrent protective device is one of those mentioned in Appendix 3 of BS 7671: 2001 (according to Regulation 413–02–05), the calculations remain unaltered in order to show how such considerations apply where the overcurrent protective device is not mentioned in Appendix 3.

The views expressed here are my own and should not be regarded as coinciding with those of any authoritative body, though I believe they do not differ materially.

Geoffrey Stokes

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Notation

BCMC	British Cable Makers' Confederation
BS	British Standard
BS EN	Harmonised European Standard
BSI	British Standards Institution
CENELEC	Comité Européen de Normalisation Electrotechnique (European Committee for Electrotechnical Standardization)
CIBSE	Chartered Institution of Building Services Engineers
CONSAC	Concentric Solid Aluminium Core (cable)
ccc	current-carrying capacity
cpc	circuit protective conductor
csa	cross-sectional area
DoE	Department of Environment
DOL	Direct-on-Line
DP	Double-Pole
ED	Electricity Distributor
EEBADS	Earthed Equipotential Bonding and Automatic Disconnection of Supply
EIILC	Electrical Installation Industry Liaison Committee
EL	Emergency Lighting
ELV	Extra-Low Voltage
ESR	Electricity Supply Regulations 1988, as amended
EWR	Electricity at Work Regulations 1989
FA	Fire Alarm
HBC	High Breaking Capacity
HD	Harmonised Document
HSE	Health and Safety Executive
HV	High Voltage
ICEL	Industry Committee for Emergency Lighting
IEC	International Electrotechnical Commission
IEE	Institution of Electrical Engineers
LPG	Liquid Petroleum Gas
LSC	Luminaire Supporting Coupler
LSHF	Low Smoke, Halogen Free
LV	Low Voltage
M	Maintained (emergency lighting)
MCB	Miniature Circuit-Breaker
MCCB	Moulded Case Circuit-Breaker
MET	Main Earthing Terminal

MICC	Mineral Insulated Copper Cable
NHBC	National House-Building Council
NICEIC	National Inspection Council for Electrical Installation Contracting
NM	Non-Maintained (emergency lighting)
PEN	Protective Earth and Neutral (conductor)
Ph	Phase
PME	Protective Multiple Earthing
PRCD	Portable Residual Current Device
PTTA	Partially Type-Tested Assembly
PVC	Polyvinyl Chloride
RCD	Residual Current Device
RCCB	Residual Current Circuit-Breaker
RCBO	Combined MCB and RCD
SELV	A particular Extra-Low Voltage system (see definition in the Wiring Regulations)
SP	Single-Pole
SP&N	Single-Pole and Neutral
TDM	Time-Division-Multiplexing
TP	Triple-Pole
TP&N	Triple-Pole and Neutral
TTA	Type-Tested Assembly
XLPE	Cross-Linked Polyethylene or Ethylene propylene rubber insulation
4P	Four-Pole

Symbols

α_{20}	resistance/temperature coefficient at 20°C
B	reciprocal of temperature coefficient of resistivity
C_a	correction factor for ambient temperature
C_d	correction factor for type of overcurrent protective device $C_d = 1$ for HBC fuses and MCBs $C_d = 0.725$ for semi-enclosed (rewirable) fuses
Cg	correction factor for grouping of conductors
C_i	correction factor for conductors embedded in thermal insulated materials
$\cos \phi$	power factor
C_t	correction factor for the operating temperature of the conductor
D_e	cable diameter (mm)
I_a	current causing automatic disconnection within stated time (A)
I_b	design current of circuit (A)
I_d	first-fault fault current of circuit (IT systems) (A)
$I_{\Delta n}$	rated residual current of an RCD (A or mA)
I_F	fault current (both short-circuit and earth fault depending on the context in which it is used) (A)

I_{FLC}	full-load current (A)
I_{inst}	current causing instantaneous (within 100 ms) operation of protective device (A)
I_L	earth-leakage current (mA)
$I_{L(T)}$	total earth-leakage current (mA or A)
I_n	nominal current rating of protective device (A)
I_{pf}	prospective fault current (A)
I_t	tabulated current-carrying capacity (A)
$I_{t(min)}$	minimum tabulated current-carrying capacity required (A)
I^2t	energy let-through (A^2s)
$I^2t_{(pa)}$	pre-arcing energy let-through (A^2s)
$I^2t_{(t)}$	total energy let-through (A^2s)
$I_{(sec)}$	transformer secondary current (A)
I_z	effective current-carrying capacity (A)
I_2	current causing effective operation of protective device on overload (A)
j	imaginary part of a complex variable ($j = \sqrt{-1}$)
k	a constant attributed to a particular conductor
L, l	length (m)
ln	log to the base e
π	pi, geometric constant (3.1416)
P	active power (W or kW)
Φ	diameter (mm)
ϕ	phase angle
Q	reactive power (var or kvar)
Q_c	volumetric heat capacity of a conductor (J/°C mm^3)
Q_{20}	electrical resistivity of conductor material at 20°C (Ω mm)
ρ	resistivity (Ω m)
$\bar{R}$	resistance (generally) (Ω)
R	resistance of bonding conductor (Ω)
R_A	the sum of the resistances of the installation earth electrode and protective conductor (Ω)
R_n	circuit neutral conductor resistance (Ω)
R_t	conductor resistance at temperature t (Ω)
R_1	circuit phase conductor resistance (Ω)
R_2	circuit protective conductor resistance (Ω)
R_{20}	conductor resistance at temperature of 20°C (Ω)
S	apparent power (VA or kVA)
S	conductor cross-sectional area (mm^2)
S_p	protective conductor cross-sectional area (mm^2)
θ_i	initial temperature of conductor (°C)
θ_f	final temperature of conductor (°C)
t	temperature (°C)
t	time (s)
T_d	time delay (s)
t_p	maximum permitted operating temperature (°C)
U_n	nominal voltage (V)
U_o	nominal voltage to Earth (V)

U_t	touch voltage (V)
V_d	voltage drop (V or mV)
$V_{d(r)}$	resistive voltage drop (V or mV)
$V_{d(x)}$	reactive voltage drop (V or mV)
V_{FL}	full-load voltage (V)
$V_{L\text{-}L}$	phase-to-phase voltage (V)
V_{ph}	phase voltage (V)
V_{NL}	no-load voltage (V)
Z_{dpc}	impedance of distribution circuit protective conductor (Ω)
Z_e	external phase-earth loop impedance (Ω)
Z_{ph}	phase impedance (Ω)
$Z_{p\text{-}n}$	phase-neutral loop impedance (Ω)
$Z_{p\text{-}p}$	phase-phase loop impedance (Ω)
Z_{pu}	per unit impedance
Z_1	impedance of circuit phase conductor (Ω)
Z_2	impedance of circuit protective conductor (Ω)
Z_s	phase-earth fault loop impedance (Ω)
Z_s*	phase-earth fault loop impedance (IT systems) (Ω)
$Z_{s(max)}$	maximum permitted phase-earth fault loop impedance (Ω)
X	reactance (Ω)
X_L	inductive reactance (Ω)
X_C	capacitive reactance (Ω)

Chapter 1

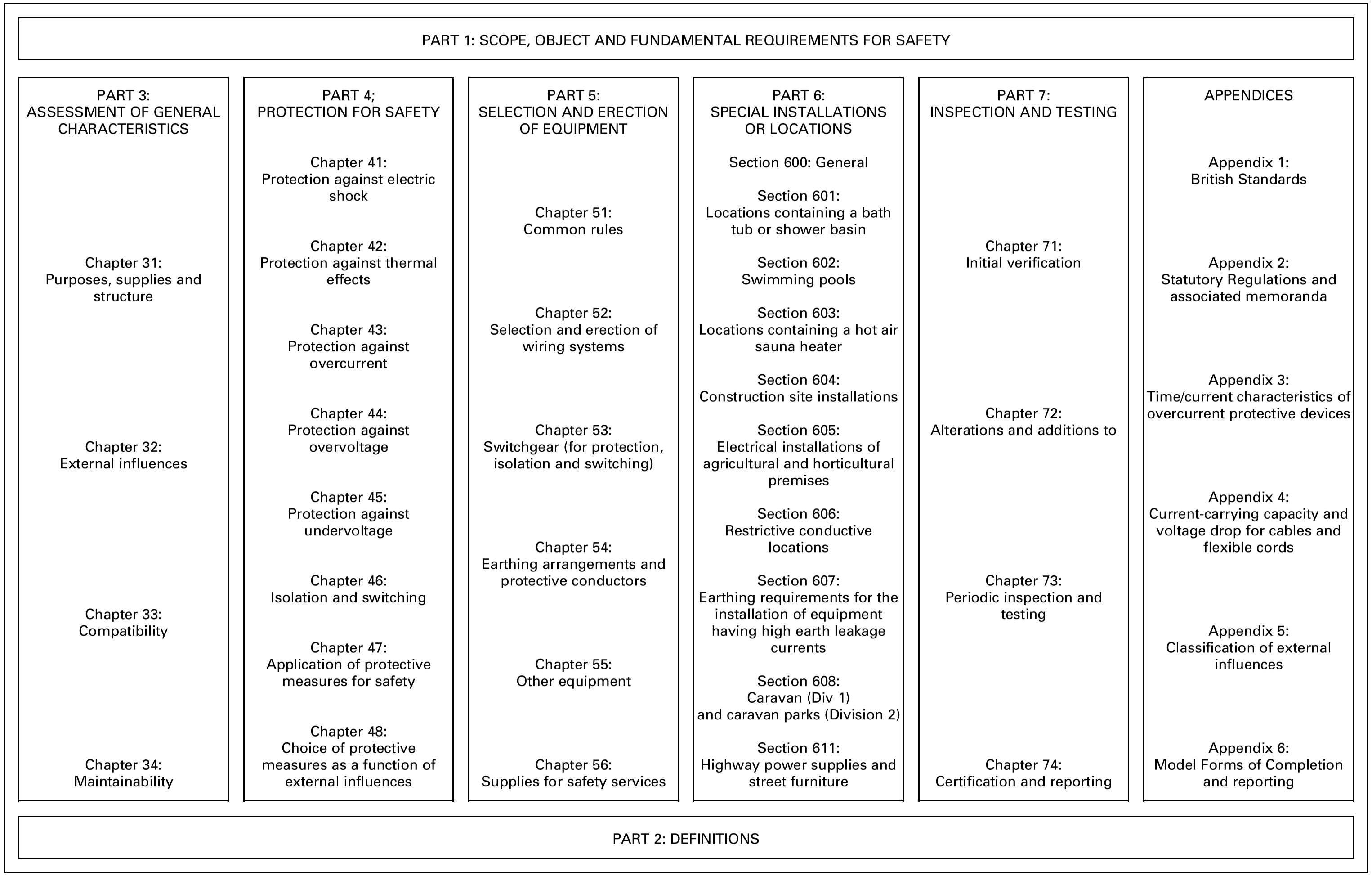
Plan and Terminology of BS 7671 : 2001 and Supporting Publications

1.1 Plan of BS 7671 : 2001

BS 7671 : 2001 is based, as was the 1992 version, on the International Electrotechnical Commission's (IEC's) publication 364, the international rules for electrical installations. The pattern of BS 7671 : 2001 uses the same logical plan of earlier versions although there are some minor changes to detail. Figure 1.1 gives a diagrammatical representation of the plan and shows the main routes through the various parts to assimilate all the necessary requirements for the electrical design. The routes shown should not be regarded as exhaustive or the only feasible routes and indeed reference to other Parts and Sections, on an iterative basis, will always be necessary.

Although the plan of BS 7671 does follow a logical sequence in that the hazards, the protective measures and their application precede the requirements of protective devices, it may not follow the generally accepted sequence undertaken by designers. For example, a designer's sequence may take the form of:

- assessment of general characteristics (Part 3),
- assessment of the number and type of circuits (Part 3, Section 314),
- selection of wiring system(s) (Chapter 52),
- assessments of design currents including taking account of diversity, where appropriate, and any special operating conditions (Sections 311 and 433),
- assessment of environmental conditions including external influences (Section 522),
- selection of overcurrent protective devices (Section 533),
- selection of protective devices for indirect contact (Sub-section 531–01 and/or Sub-section 531–02),
- determination of current-carrying capacities (Section 523),
- assessment of voltage drop (section 525),
- assessment of isolation and switching requirements (Chapter 46),
- consideration of the 'application' Regulations (Section 471 – Electric shock, Section 473 – overcurrent, Section 476 – Isolation and switching and Chapter 53 – protective devices),
- consideration of the earthing and equipotential bonding requirements (Chapter 54).



PART 1: SCOPE, OBJECT AND FUNDAMENTAL REQUIREMENTS FOR SAFETY

PART 3: ASSESSMENT OF GENERAL CHARACTERISTICS
- Chapter 31: Purposes, supplies and structure
- Chapter 32: External influences
- Chapter 33: Compatibility
- Chapter 34: Maintainability

PART 4; PROTECTION FOR SAFETY
- Chapter 41: Protection against electric shock
- Chapter 42: Protection against thermal effects
- Chapter 43: Protection against overcurrent
- Chapter 44: Protection against overvoltage
- Chapter 45: Protection against undervoltage
- Chapter 46: Isolation and switching
- Chapter 47: Application of protective measures for safety
- Chapter 48: Choice of protective measures as a function of external influences

PART 5: SELECTION AND ERECTION OF EQUIPMENT
- Chapter 51: Common rules
- Chapter 52: Selection and erection of wiring systems
- Chapter 53: Switchgear (for protection, isolation and switching)
- Chapter 54: Earthing arrangements and protective conductors
- Chapter 55: Other equipment
- Chapter 56: Supplies for safety services

PART 6: SPECIAL INSTALLATIONS OR LOCATIONS
- Section 600: General
- Section 601: Locations containing a bath tub or shower basin
- Section 602: Swimming pools
- Section 603: Locations containing a hot air sauna heater
- Section 604: Construction site installations
- Section 605: Electrical installations of agricultural and horticultural premises
- Section 606: Restrictive conductive locations
- Section 607: Earthing requirements for the installation of equipment having high earth leakage currents
- Section 608: Caravan (Div 1) and caravan parks (Division 2)
- Section 611: Highway power supplies and street furniture

PART 7: INSPECTION AND TESTING
- Chapter 71: Initial verification
- Chapter 72: Alterations and additions to
- Chapter 73: Periodic inspection and testing
- Chapter 74: Certification and reporting

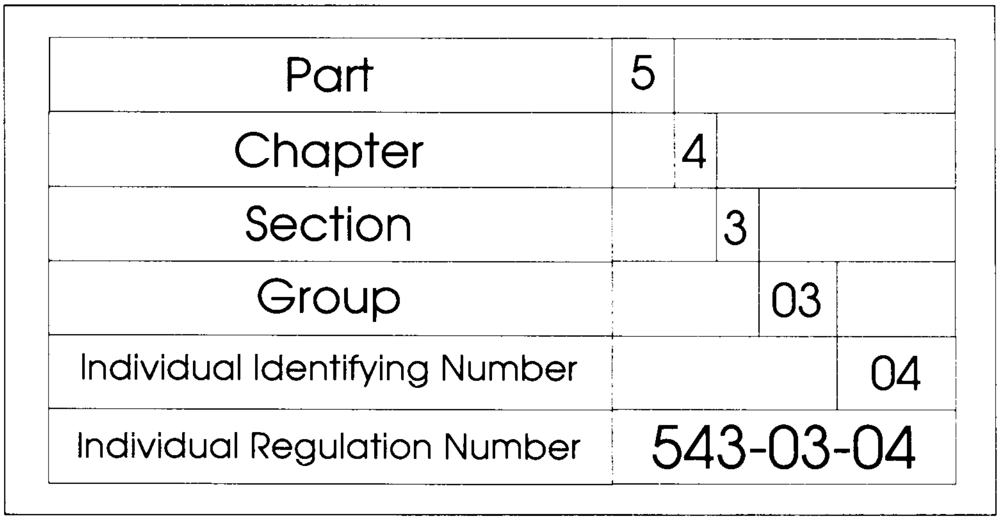
APPENDICES
- Appendix 1: British Standards
- Appendix 2: Statutory Regulations and associated memoranda
- Appendix 3: Time/current characteristics of overcurrent protective devices
- Appendix 4: Current-carrying capacity and voltage drop for cables and flexible cords
- Appendix 5: Classification of external influences
- Appendix 6: Model Forms of Completion and reporting

PART 2: DEFINITIONS

Figure 1.1: Plan of BS 7671 : 2001

It can be seen that the example of the design process given above does not follow the layout of BS 7671 and even the example shown is an over-simplification of the real process. However, the designer familiar with the earlier versions would have no difficulty in applying BS 7671 : 2001. In essence the designing process will inevitably mean numerous references back and forth throughout BS 7671 and only experience will reduce the iterative procedure.

The numbering system in BS 7671 uses both five-figure and seven-figure numbers. This is in line with the IEC and CENELEC numbering system. Additionally, a group of associated Regulations are covered by a side-heading or group heading (e.g. 531–03 – Residual current devices in a TN system). The index of BS 7671 refers to the five-figure (grouped) Regulations as well as individual numbers. Figure 1.2 illustrates how the numbers are formulated and applies to all Parts except Part 6 in which Sections take the place of Chapters.



Part	5				
Chapter		4			
Section			3		
Group				03	
Individual Identifying Number					04
Individual Regulation Number	543-03-04				

Figure 1.2: Regulation numbering system

BS 7671 is less a design code of practice than a standard for safe practice and is more of a framework document like the emergent CENELEC Harmonised Documents.

Part 7 addresses inspection and testing in a format with individual chapters allocated to initial verification, alterations and additions, periodic inspection and testing, and certification and reporting.

Part 6 – Special Installations or Locations is based on, but not identical to, the IEC publication 364, Part 7.

1.2 Terminology of BS 7671:2001

Part 2 of BS 7671:2001 deals with definitions which are inherently an essential part of any set of rules giving precise meaning to the terms used throughout. The British Standard now contains some 160 definitions, some of which have been added or modified, to a greater or lesser extent, in the new Edition of BS 7671. The reader is strongly encouraged to become familiar with the definitions, which will be beneficial in acquiring a broader understanding of the regulatory requirements.

1.3 Supporting publications

The Institution of Electrical Engineers has published a number of supporting publications which give background information as well as guidance to the installation designer, installer, verifier and others in the implementation and application of BS 7671. The guidance documents comprise:

- IEE Guidance Note No 1: *Selection and erection*,
- IEE Guidance Note No 2: *Isolation and switching*,
- IEE Guidance Note No 3: *Inspection and testing*,
- IEE Guidance Note No 4: *Protection against fire*,
- IEE Guidance Note No 5: *Protection against electric shock*,
- IEE Guidance Note No 6: *Protection against overcurrent*,
- IEE Guidance Note No 7: *Special locations*
- IEE On-site Guide: *Guidance for the small installation*.

The Guidance Notes published by the IEE are essential reading for all those involved in electrical installation work and constant reference to these documents, in addition to BS 7671 and this Guide will assist in achieving safe and economic installation designs.

THe NICEIC's *Inspection, Testing and Certification* book is also considered to be essential reading for those involved in the verification of new installations as well as those who carry out periodic inspection and testing of existing installations.

Chapter 2

Electricity, the Law, Standards and Codes of Practice

2.1 General

It is not the intention here to examine in detail all the statutory requirements relating to the hazards of electricity but merely to draw the reader's attention to the fact that such requirements do exist. The Regulations made under the various Acts should therefore be consulted to enable those involved with electricity to meet their statutory obligations. Table 2.1 summarises some of the statutory documents relating to electrical installations and serves only as a quick reference. A rigorous commentary and analysis of the implications of these Statutory Regulations is given in *Electrical Safety and the Law* by Ken Oldham Smith and published by Blackwell Science.

References to a British Standard Code of Practice (CP) is intended only to bring to the designer's (and installer's and verifier's) attention the fact that the requirements of the CP need to be met in addition to those embodied in BS 7671.

2.2 Electricity – the hazards

The principal hazards envisaged by the statutory Regulations relate both to electrical machines and other current-using equipment and to the fixed installation. BS 7671 (see Regulation 130-01-01) addresses the requirements for safety for fixed installations where the hazards are perceived to be:

- shock currents
- excessive temperatures likely to cause burns, fires and other injurious effects
- mechanical movement of electrically actuated equipment, in so far as such injury is intended to be prevented by electrical emergency switching or by electrical switching for mechanical maintenance of non-electrical parts of such equipment
- explosion.

The Health and Safety Executive (HSE), in a note to BS 7671, states that it regards an electrical installation carried out in accordance with the requirements of BS 7671 as likely also to afford compliance with the relevant aspects of the Electricity at Work Regulations 1989.

Table 2.1: Acts, statutory regulations and associated legal requirements

Ref	Title	Comment
A	Electricity Supply (Amendment No 2) Regulations 1994 (ESR).	Applies to all installations which obtain their supply from the public network. Part VI deals with the supply to consumers' installations. Failure to comply with the fundamental requirements for safety (Chapter 13 of BS 7671) may result in the Supplier discontinuing supply (See Regulation 29 of ESR). Where the supply is PME, the consumer must comply with ESR particularly as regards main equipotential bonding.
B	The Health and Safety at Work etc Act 1974.	Applies generally in all places where a work activity is undertaken.
C	The Management of Health and Safety at Work Regulations 1999.	Generally applicable.
D	The Provision and Use of Work Equipment Regulations 1998.	Generally applicable.
E	Electricity at Work Regulations 1989 (EWR).	Applies to all installations in places where a work activity is undertaken. For guidance see HSE HS(R)25 *Memorandum of Guidance on the Electricity Regulations 1989* – ISBN 0 11 8839632. Regulation 15 addresses the requirements for adequate working space and means of access.
F	Electricity at Work Regulations (Northern Ireland) 1991 (EWR).	Applies to all installations in places where a work activity is undertaken. For guidance see Health and Safety Agency's *HSA 55 Memorandum of Guidance on the Electricity at Work Regulations (Northern Ireland) 1991* – ISBN 0 337 11169 3. Regulation 15 addresses the requirements for adequate working space and means of access.
G	The Personal Protective Equipment at Work Regulations 1992.	Generally applicable.
H	The Workplace (Health, Safety and Welfare) Regulations 1992.	Generally applicable.
I	The Manual Handling Operations Regulations 1992.	Generally applicable.
J	The Health and Safety (Display Screen Equipment) Regulations 1992.	Generally applicable.
K	The Low Voltage Equipment (Safety) Regulations 1989.	Equipment must comply with European ENs, IEC Standards, national safety provisions, and/or national Standards.
L	The Plugs and Sockets etc (Safety) Regulations 1994.	Applies to domestic type installations. Relates to requirements for safety in plugs, sockets, adaptors and fuses, etc.
M	Cinematograph (Safety) Regulations 1955 (made under the Cinematograph Act 1955 and/or the Cinematograph Act 1952).	Applies to cinemas and the like. Where the general lighting and the safety lighting is by electricity there must be at least two power sources of supply (i.e. there must be a source to power emergency lighting on failure of general lighting by, for example, mains failure).
N	Caravan Sites and Control of Development Act 1960.	Applies to caravan park installations. Model Standards (1977) issued by the Department of Environment.
O	Consumer Protection Act 1987.	Generally applicable.
P	Approval of Safety Standards Regulations 1987.	Generally applicable.
Q	Consumer Safety Act 1987.	Generally applicable.
R	Trading Standards Act 1968.	Generally applicable.
S	Restrictive Trade Practices Act 1976.	Generally applicable.

Table 2.1 continued: Acts, statutory regulations and associated legal requirements

Ref	Title	Comment
T	Fire Precautions Act 1971.	Generally applicable.
U	Agricultural (Stationary Machinery) Regulations 1959, as amended.	Applies to agricultural and horticultural installations. Specific requirements relating to starting and stopping rotating and other machines.
V	Highly Inflammable Liquids and Liquefied Petroleum Gases Regulations 1972.	Applies to all installations where such substances are used. See HSE Guidance Note HS(G)41 for guidance on petrol filling stations.
W	Petroleum (Consolidation) Act 1928.	Applies to all installations where such substances are used. Under this legislation, Local Authorities are empowered to grant licences for premises where such substances are stored. Substances other than petroleum are included.
X	Local Government (Miscellaneous Provisions) Act 1982.	Applies to installations in the UK mainland in places of public entertainment. Includes theatres, places for dancing and music, etc.
Y		Applies to installations in the UK of HV luminous tube signs. See also BS 559 *Specification for electric signs and high-voltage luminous-discharge-tube installations*.
Z	The Local Government (Miscellaneous Provisions) (Northern Ireland) Order 1985.	Applies to petrol filling station installations in Northern Ireland.
A1		Applies to installations in Northern Ireland in places of public entertainment. Includes public houses, clubs, dance halls and church halls, etc.
B1	Civic Government (Scotland) Act 1982.	Applies to installations in Scotland in places of public entertainment. Includes theatres, places for dancing and music, etc.
C1		Applies to installations in Scotland of HV luminous tube signs. See also BS 559 *Specification for electric signs and high-voltage luminous-discharge-tube installations*.
D1	Building Standards (Scotland) Regulations 1990.	Subject to certain exemptions, applies to installations in Scotland. Compliance with the Wiring Regulations is deemed to afford compliance with the statutory requirements. Enforcement by Local Authorities. Administered by the Secretary of State for Scotland.
E1	The Building Regulations 1991.	Applies generally to buildings and indirectly related to electrical installation work except in respect of smoke detection in new housing where direct requirements are stated – see Row F1 of this table and Chapter 13 of this Guide.
F1	Approved Document B (The Building Regulations 2000 as amended by the Building Regulations (Amendment) (No. 2) Regulations 1999) – Fire Safety.	Requirements given for means of escape, internal and external fire spread together with access and facilities for fire services (installation of self-contained smoke alarms included).
G1	Building (Amendment) Regulations (Northern Ireland) 1993.	Applies generally to housing and to fire detection and alarm systems therein.
H1	The Health and Safety (Safety Signs and Signals) Regulations 1996.	Applies generally. Intended to remove confusion in the message intended to be conveyed by the sign.
I1	Factories Act 1961. The Electrical Equipment (Safety) Regulations 1994. The Construction (Design and Management) Regulations 1994.	Applies to factories generally. Applies generally. Applies generally.

Note: This listing is intended as a guide only to some of the statutory requirements and should not be regarded as exhaustive.

2.3 The law

2.3.1 Electricity Supply Regulations 1988, as amended (ESR)

The Electricity Supply Regulations 1988, as amended, which replaced the Electricity Supply Regulations 1937, are applicable to both public and private electricity supplies. The Regulations are intended to prevent danger to the public and livestock including domestic animals. The hazards envisaged are burns, electric shock, injury from mechanical movements and fire arising from the generation, transformation, transmission, supply and use of electricity. The requirements apply to all work undertaken from the introduction of the Regulations on 1 October 1988. The provisions are not retrospective except that when material alterations are carried out to existing works the new requirements will need to be met.

The Regulations cover, for example, such matters as definitions, voltage ranges and limits, neutral continuity and earthing, underground cables, overhead lines, safety and reliability, maximum voltages, limits on supply voltages, protective measures, inspection, enclosed spaces and consumers' installations.

At the time of preparing this Third Edition of this Guide the Government had proposed to replace the Electricity Supply Regulations 1988, as amended, with the Electricity Safety, Quality and Continuity Regulations.

2.3.2 The Electricity at Work Regulations 1989 (EWR)

The Electricity at Work Regulations 1989, made under the umbrella of the Health and Safety at Work etc. Act 1974, came into force on the mainland on 1 April 1990 and are intended to protect all persons at their work environment except domestic servants in households (alas a dying breed); in rare cases, an exemption certificate may be granted by the HSE. A similar set of Regulations, entitled *The Electricity at Work Regulations (Northern Ireland) 1991* came into force in Northern Ireland on 6 January 1992.

Alleged infringement of certain aspects of these Regulations may result in criminal proceedings against those responsible who would only have Regulation 29 to use in defence; such defence would require the duty holder to establish that he took all reasonable steps and exercised all due diligence to prevent such an offence. (See also Chapter 3 of this Guide, item 3.5 for correlation between the fundamental requirements for safety embodied in BS 7671 and the EWR statutory requirements.)

The authoritative guidance to these Regulations is given in *Memorandum of Guidance on the Electricity at Work Regulations 1989 (HS[R]25)*, published by the Health and Safety Executive, for the mainland. For Northern Ireland a similar document is published entitled *Memorandum of Guidance on the Electricity at Work Regulations (Northern Ireland) 1991*. Further guidance in the province may be obtained from the Department of Economic Development.

2.4 Standards and Codes of Practice

2.4.1 The IEE Wiring Regulations – BS 7671

The requirements of BS 7671 are not statutory requirements but are referred to in the Electricity Supply Regulations 1988 (as amended) as being an acceptable standard which will satisfy those statutory Regulations. Additionally, the HSE considers that compliance with BS 7671 will afford compliance with the relevant aspects of the Electricity at Work Regulations 1989. BS 7671 also often forms part of a contract but when so used it must be cited in its entirety and not selectively quoted. Although the Regulations in BS 7671 are recommendations only, the designer and installer should consider their use desirable in order to fulfil all the requirements of the various statutory regulations.

2.4.2 Electric signs and high-voltage luminous-discharge-tube installations – BS 559

The installation of electric signs and HV luminous-discharge-tube installations is now within the scope of BS 7671. Installations therefore need to meet those requirements and the recommendations laid down in BS 559 *Specification for electric signs and high-voltage luminous-discharge-tube installations*.

2.4.3 Emergency lighting – BS 5266

Emergency lighting installations are now embraced by BS 7671 and such installations will need to comply with both the recommendations of BS 7671 and BS 5266 *Emergency Lighting* and in particular Part 1 *Code of practice for the emergency lighting of premises other than cinemas and certain other specified premises used for public entertainment*.

2.4.4 Electrical apparatus in potentially explosive gas atmospheres – BS EN 60079 and BS EN 50014

Electrical installations in potentially explosive atmospheres now fall within the scope of BS 7671. Such installations therefore need to comply with both BS EN 60079 and BS EN 50014. In particular, Parts 10, 14 and 17 are applicable to electrical installation work. BS EN 50014 will also need to be considered when selecting equipment for hazardous areas.

2.4.5 Electrical equipment for use in the presence of combustible dust – BS EN 50281

BS EN 50281 applies to the selection, installation and maintenance of equipment protected by enclosures. It also addresses methods of determining minimum ignition temperatures.

2.4.6 Electrical installations in opencast mines and quarries – BS 6907

This standard addresses, among other things, general recommendations for the protection – direct contact and indirect contact.

2.4.7 Fire detection and alarm systems for buildings – BS 5839

Installations of fire detection and alarm systems for buildings are now embraced by BS 7671. Such installations will need to comply both with BS 7671 and the recommendations given in BS 5839 *Fire detection and alarm systems for buildings* and in particular with Part 1. The Standard has the following parts:

- Part 1 *Code of practice for system design, installation and servicing*,
- Part 2 *Specification for manual call points*,
- Part 3 *Specification for automatic release mechanisms for certain fire protection equipment*,
- Part 4 *Specification for control and indicating equipment*,
- Part 5 *Specification for optical beam smoke detectors*,
- Part 6 *Code of practice for the design and installation of fire detection and alarm systems in dwellings*,
- Part 8 *Code of practice for the design, installation and servicing of voice alarm systems*.

2.4.8 Telecommunications systems – BS 6701

Installations which are subject to the Telecommunications Act 1984 are now included within the scope of BS 7671. The electrical installation part of such installations will need to comply with the requirements of BS 7671 and BS 6701 *Code of practice for installation of apparatus intended for connection to certain telecommunications systems* and, in particular, Part 1 *General recommendations*.

2.4.9 Electric surface heating – BS 6351

Requirements for the installation of electrical surface heating are included in BS 7671 and BS 6351 *Electric surface heating*. BS 6351 has three parts:

- Part 1 *Specification for electric surface heating devices*,
- Part 2 *Guide to the design of electric surface heating systems*,
- Part 3 *Code of practice for the installation, testing and maintenance of electric surface heating systems*.

2.4.10 Lightning protection – BS 6651

BS 7671 does *not* embrace the various aspects of the installation of lightning protection systems which are covered by BS 6651 *Code of practice for protection of structures against lightning*, except to the extent that requirements are given with regard to equipotential bonding of the lightning protection systems to the electrical installation.

2.4.11 Lift installations – BS 5655

The aspects of lift installations covered by BS 5655 *Lifts and service lifts* are not addressed by BS 7671. BS 5655 is made up of twelve parts:

- Part 1 *Safety rules for the construction and installation of electric lifts*,
- Part 2 *Safety rules for the construction and installation of hydraulic lifts*,
- Part 3 *Specification for electric service lifts*,
- Part 5 *Specification for dimensions of standard lift arrangements*,
- Part 6 *Code of practice for selection and installation*,
- Part 7 *Specification for manual control devices, indicators and additional fittings*,
- Part 8 *Specification for eyebolts for lift suspension*,
- Part 9 *Specification for guide rails*,
- Part 10 *Specification for testing and inspection of electric and hydraulic lifts*,
- Part 11 *Recommendations for the installation of new, and the modernisation of, electric lifts in existing buildings*,
- Part 12 *Recommendations for the installation of new, and the modernisation of, hydraulic lifts in existing buildings.*

Electrical installation aspects not covered by the Standard should meet the requirements of BS 7671.

2.4.12 Equipment

The legal requirements relating to all equipment, embodied in the Low Voltage Electrical Equipment (Safety) Regulations 1989, demand that the order of precedence of safety standards be:

- Harmonised European Standards (Euro Norms – ENs),
- International safety provisions (e.g. IEC Standards),
- National safety provisions.
- Standards published by national standards-making bodies approved in accordance with the Approval of Safety Standards Regulations 1987.

Additionally, all equipment must be '*fit for purpose*', as the law demands, bearing in mind the purpose to which the equipment is to be put, its use and the environmental conditions in which it is to be used.

Chapter 3

Scope, Object and Fundamental Principles

3.1 General

Part 1 of the BS 7671: 2001 is divided into three chapters: Chapter 11 deals with the scope, Chapter 12 addresses the object and effects and finally Chapter 13 lays down the fundamental principles for safety. As we shall see later, the measures for safety are given in Chapters 41 to 46 whilst the application of these measures is set out in Chapter 47 though reference to other Parts of the BS 7671: 2001 will, of course, be necessary. Chapter 48, which is new, addresses the choice of protective measures as a function of external influences, as does Chapter 44 *Protection against overvoltage*.

BS 7671, and this Guide, commonly use the term 'equipment' as an abbreviation for 'electrical equipment' which is defined in Part 2 of the BS 7671: 2001 as:

> 'Any item for such purposes as generation, conversion, transmission, distribution or utilisation of electrical energy, such as machines, transformers, apparatus, measuring instruments, protective devices, wiring materials, accessories, appliances and luminaires.'

When so used, the term 'equipment' collectively relates to all and, unless further specified, to every item of installation material. Where there is doubt as to the suitability of equipment to purposes for which it is to be used, the designer must consult the manufacturer in order to establish that the equipment is appropriate for the intended use and compatible with other proposed equipment.

The phrase 'so far as is reasonably practical' is used in a number of Regulations and where compliance with protective measures stipulated in Parts 3 to 7 is achieved, the broad based fundamental principles for safety in Chapter 13 are likely to be satisfied. Where alternative measures are used, the designer would need to be able to argue that these provide for no less a degree of safety.

The whole of Part 1 of BS 7671: 2001 has been fully revised and expanded, and its title has been modified.

3.2 Scope

3.2.1 General

The regulations in Chapter 11 of BS 7671: 2001 have been reorganised as shown in Table 3.1.

Table 3.1: Re-organisation of Chapter 11 Regulations

BS 7671: 1992 (as amended)	**BS 7671: 2001**
110–01 General	110–01 General (includes content of Regulation (110–03–01)
110–02 Exclusions from scope	110–02 Exclusions from scope
110–03 Voltage ranges	110–03 Equipment
110–04 Equipment	110–04 Relationship with statutory regulations
	110–05 Installations in premises subject to licensing

The first part of Regulation 110–01–01 gives a fairly comprehensive, but not exhaustive, list of electrical installations to which the Regulations apply. The list now includes:

- Residential premises
- Commercial premises
- Public premises, and
- Prefabricated buildings

Additionally, certain of the familiar categories have been modified as indicated in Table 3.2.

Table 3.2: Modifications to certain types of installations

BS 7671: 1992 (as amended)	**BS 7671: 2001**
Caravans and caravan parks	Caravans, caravan parks and similar sites
Construction sites	Construction sites, exhibitions, fairs and other installations in temporary buildings
Highway power supplies and street furniture	Highway power supplies and street furniture, and outdoor lighting

It is clear that the types of electrical installations listed in the regulation are for illustrative purposes, and that other types of installation may also fall within the scope of BS 7671.

The second section of this Regulation is new. It gives a list of types of circuit and wiring systems to which BS 7671: 2001 applies which includes:

- circuits supplied at nominal voltages up to and including 1000 V a.c. or 1500 V d.c. For a.c., the preferred frequencies which are taken into account are 50 Hz, 60 Hz and 400 Hz. The use of other frequencies for special purposes is not precluded.
- circuits other than the internal wiring of apparatus, operating at voltages exceeding 1000 V and derived from an installation having a voltage not exceeding 1000 V a.c., such as discharge lighting, electrostatic precipitators
- any wiring systems and cables not specifically covered by an appliance standard
- all consumer installations external to buildings
- fixed wiring for communication and information technology, signalling, control and the like (excluding internal wiring of apparatus)
- the addition to, or alteration of, existing installations and also those parts of existing installations that are affected by the addition or alteration.

This regulation lists instances where BS 7671 may need to be supplemented by the requirements or recommendations of other British Standards, or by the requirements of the person ordering the work. In this section, the previous reference to BS 5345 for electrical apparatus in potentially explosives gas atmospheres has been updated to BS EN 60079 and BS EN 50014. A new reference has been added for electrical apparataus in the presence of combustible dust, namely BS EN 50281.

Table 3.3 summarises the standards to which reference is made in the regulation, the requirements of which supplement the requirements of BS 7671 for particular installations. As will be seen from Table 3.3, reference is made to BS 6907 to include electrical installations for opencast mines and quarries. However, Regulation 110–02–01 confirms that those aspects of mines and quarries specifically covered by Statutory Regulations are still excluded from the scope of BS 7671.

Very significantly, as with the earlier edition, there is no distinction made, in terms of safety, between permanent and temporary installations. It therefore follows that both permanent and temporary installations need to comply fully with the requirements of BS 7671.

3.2.2 *Exclusions from the Scope*

Regulation 110–02–01 details those installations which have been excluded from the Scope. The list of exclusions given is the same as BS 7671: 1992, namely:

- supplier's work as defined by the Electricity Supply Regulations as amended
- railway traction equipment, rolling stock and signalling equipment

Table 3.3: Related standards

Standard No	Title of Standard
BS 559	Electric signs and high voltage luminous tube installations
BS 5266	Emergency lighting
BS EN 60079 BS EN 50014	Electrical apparatus for explosive gas atmospheres
BS EN 50281	Electrical apparatus for use in the presence of combustible dust
BS 5839	Fire detection and alarm systems in buildings
BS 6701, Part 1	Installations subject to the Telecommunications Act 1984
BS 6351	Electric surface heating systems
BS 6907	Electrical installations for open cast mines and quarries

- equipment of motor vehicles, except those to which the requirements of the Regulations concerning caravans are applicable
- equipment on board ships
- equipment on mobile and fixed offshore installations
- equipment of aircraft
- those aspects of mines and quarries specifically covered by Statutory Regulations
- radio interference suppression equipment, except so far as it affects safety of the electrical installation
- lightning protection of buildings covered by BS 6651
- those aspects of lift installations covered by BS 5655

3.2.3 Equipment

BS 7671 does not apply to equipment except to the extent of the selection and erection of that equipment. Constructional requirements of prefabricated equipment are covered separately by appropriate specifications, usually British Standards, CENELEC Standards and/or IEC Standards. Regulations 110–03–01 covers this point and further demands that the equipment complies with the appropriate specification.

3.2.4 Relationship with Statutory Authorities

As stated in Regulation 110–04–01, the rules in BS 7671 are not statutory requirements. However, they may be cited in a court of law in order to claim compliance with statutory requirements or indeed to claim non-compliance. Reassuringly, the Regulation also states that where the supply has been given in accordance with the *Electricity Supply Regulations 1988*, as amended, it is deemed that the connection with the neutral of the supply is permanent and, by implication, reliable. At the time of drafting this Third Edition, there is a DTI proposal to replace the *Electricity Supply Regulations 1988*, as amended, with new statutory regulations entitled *Electricity Safety, Quality and Continuity Regulations 2002*.)

3.2.5 Installations in premises subjected to licensing

Regulation 110–05–01 states that for installations, which are subject to licensing conditions or where another authority exercises statutory control, not only have that Authority's requirements to be ascertained but they must also be adhered to both in the design of the installation and its execution. In the case of licensing, the Authority's requirements should also be sought with regard to periodic inspection and testing of installations.

3.3 Object and effects

3.3.1 General

The contents of this chapter in BS 7671: 2001 have been reduced from five Regulation Groups to two, the existing requirements having been transferred elsewhere in Part 1. Table 3.4 summarizes the changes.

Table 3.4: Regulation revision

BS 7671: 1992 (as amended)	**BS 7671: 2001**
120–01 General	120–01 General
120–02 Relationship with Statutory Regulations	120–02 New materials and inventions
120–03 Installations in premises subject to licensing	Transferred to Regulation 110–05
120–04 Use of established materials, equipment and methods	Requirements appear elsewhere in BS 7671
120–05 New materials and inventions	Transferred to Regulation 120–02–01

Regulation 120–01–01 now states: *This Standard contains the rules for the design and erection of electrical installations so as to provide for safety and* ***proper functioning*** *for the intended use*. It is important to note the inclusion, for the first time, of a reference to *proper functioning* for the intended use.

Regulation 120–01–02 states that Chapter 13 of BS 7671 addresses the fundamental principles but does not give the specific technical requirements. It therefore follows that Parts 3 to 7 give greater detail of the methods of achieving the fundamental principals laid down in Chapter 13.

As indicated in Regulation 120–01–03, the various Parts of BS 7671 giving technical requirements intended to afford compliance with the fundamental principles are listed:

- Part 3: Assessment of general characteristics
- Part 4: Protection for safety
- Part 5: Selection and erection
- Part 6: Special installations or locations
- Part 7: Inspection and testing

The regulation goes on to say that any intended departure from BS 7671 should receive special consideration by the installation designer, and must be recorded on the Electrical Installation Certificate. It is important to note that this 'dispensation' of sanctioning a departure is not afforded to anyone other than the designer, who must accept responsibility for such non-compliance.

3.3.2 New materials and inventions

From time to time, new ideas for equipment are brought to the industry which naturally have not been tried and tested over time in service conditions. It is not the intention of BS 7671 to suppress such innovations and their introduction into electrical installations and this fact is acknowledged in BS 7671. If a new material or invention is used within an installation then the designer is required, by Regulation 120–02–01, to ascertain that the degree of safety is no less than that which would have prevailed had he not used the new material or new invention. This would, in all probability, involve a third-party certification body who would be requested to make an assessment of the product and certify the degree of safety provided by it in use. When used, the new product would nevertheless constitute a deviation from BS 7671 and, consequently, would need to be recorded on the Electrical Installation Certificate. It goes without saying that any departure from BS 7671 needs very careful consideration by the designer.

3.4 Fundamental principles

3.4.1 General

Regulation 130–01–01 makes clear that BS 7671 is intended to protect persons, property and livestock against dangers and damage which may occur when the installation is used as intended. BS 7671 assumes that in providing protective measures for safety, the installation will be used in the manner intended and with reasonable care, which may include preventative maintenance as well as proper routine attention.

Chapter 13 of BS 7671: 2001 has been completely revamped, with many of the requirements of existing regulations of the BS 7671: 1992 being transferred elsewhere in BS 7671: 2001. The chapter still sets out the fundamental principles for safety on which all the detailed technical requirements are based, and three new sections have been added.

Table 3.5 summarizes the changes to section 130 of Chapter 13.

Table 3.5: Summary of changes to Chapter 13

BS 7671: 1992 (as amended)		**BS 7671: 2001**	
Regulation No	**Issue addressed**	**Regulation No**	**Issue addressed**
130–01	Workmanship and materials	1300–1	General
130–02	General	130–02	Protection against electric shock
130–03	Overcurrent protective devices	130–03	Protection against thermal effects
130–04	Precautions against each leakage and earth fault currents	130–04	Protection against overcurrent
130–05	Protective devices and switches	130–05	Protection against fault current
130–06	Isolation and switching	130–06	Protection against overvoltage
130–07	Accessibility of equipment	130–07	Additions and alterations to an installation
130–08	Precautions in adverse conditions		
130–09	Additions and alterations to an installation		
130–10	Inspection and testing		

Regulation 130-01-01 states in new terms the hazards of electricity addressed by BS 7671. These are summarised in Table 3.6.

Table 3.6: Changes in terminology of the hazards

BS 7671: 1992 (as amended) (Regulation 120–01–01)	**BS 7671: 2001 (Regulation 130–01–01)**
Protection against electric shock	Risk of injury which may result from shock currents
Protection against fire	Risk of injury which may result from excessive temperatures likely to cause burns, fires and other injurious effects
Protection against burns	
Protection against injury from mechanical movement (see Regulation for full description)	Risk of injury which may result from mechanical movement (see Regulation for full description)
	Risk of injury which may result from an explosion

3.4.2 Electric shock – direct contact

Regulation 130–02–01, dealing with protection against direct contact under normal conditions, refers in a new way to two methods by which such protection can be accomplished:

- Preventing a current from passing through the body of any person or any livestock, or
- Limiting the current which can pass though a body to a value lower than the shock current.

3.4.3 Electric shock – indirect contact

In dealing with protection against indirect contact under single fault conditions, Regulation 130–02–02 permits the two methods given above relating to protection against direct contact to be employed, as well as:

- Automatic disconnection of the supply in a determined time on the occurrence of a fault likely to cause a current to flow through a body in contact with exposed-conductive-parts where the value of that current is equal to or greater than the shock current.

The regulation goes on to confirm that, in the application of protective measures against indirect contact, the equipotential bonding is one of the important principles for safety.

3.4.4 Protection against thermal effects

So far as is reasonably practicable, Regulation 130–03–01 requires protection to be provided against:

- the risk of flammable materials being ignited due to high temperature or electric arc, and
- the risk of burns to persons and livestock.

With regard to protection against harmful thermal effects of heat or thermal radiation emitted by electrical equipment, Regulation 130–03–02 requires protection to be provided, particularly where there are likely to be any of the following consequences:

- combustion, ignition or degradation of materials
- risk of burns
- impairment of the safe function of installed equipment.

3.4.5 Protection against overcurrent

Regulation 130–04–01 requires that persons or livestock are protected against injury, and that property is protected against damage due to excessive temperatures or electromechanical stresses caused by any overcurrents likely to arise in live conductors.

3.4.6 Protection against fault current

Regulation 130–05–01 requires conductors and any other parts likely to carry fault current to be capable of carrying that current without attaining excessive temperature. The regulation goes on to say that compliance with Regulation 130–04 for live conductors (protection against overcurrents, see above) assures their protection against fault currents.

3.4.7 Protection against overvoltage

Regulation 130–06–01 requires that persons and livestock are protected against injury, and that property is protected against any harmful effects, resulting from:

- a fault between live parts of circuits supplied at different voltages, and
- overvoltages likely to arise from switching and atmospheric phenomena.

3.4.8 Additions and alterations to an installation

Regulation 130–07–01 requires that for an alteration or addition to an existing installation the rating and condition of the existing equipment which is utilised for the altered or addition installation must be confirmed as being satisfactory, including the supply. Additionally, where the alteration or addition used EEBAD as the protective measure against indirect contact, the earthing and bonding must also be of sufficient cross-sectional area.

3.4.9 Design

BS 7671: 2001 has three new sections embodied in Chapter 13:

- Section 131 – Design
- Section 132 – Selection of electrical equipment
- Section 133 – Erection, verification and periodic inspection and testing of electrical installations.

The first section (Regulation 131–01–01) deals with provisions for which the installation has been designed, in terms of protecting persons and livestock, and property. For the first time, there is provision for the proper functioning of the installation for the intended use.

Regulation 131–02–01 addresses the supply characteristics in terms of current, nominal voltage and earthing arrangements, together with calling for the supplier's requirements to be determined.

The above regulations and the remainder of the section on design are summarised in Table 3.7.

Table 3.7: Summary of Section 131 – Design

Regulation Group	Title	Dealing with
131–01	General	Installation to protect persons, livestock and property **and to function properly for the intended use**
131–02	Characteristics of available supply or supplies	Characteristic of supply(ies) to be determined
131–03	Nature of demand	Number and type of circuits to be established
131–04	Emergency supply or supplies for safety services	Characteristics of supply for safety services, and circuits to be supplied, to be determined
131–05	Environmental conditions	Equipment to be suitable for environmental conditions **including risk of fire or explosion**
131–06	Cross-sectional area of conductors	Conductors to be of adequate cross-sectional area
131–07	Type of wiring and method of installation	Wiring system and method of installation to be suitable for location etc.
131–08	Protective equipment	Protective devices to be suitable for application
131–09	Emergency control	Emergency interrupting devices to be easily recognisable and operable
131–10	Disconnecting devices	Disconnecting devices to be provided for maintenance, testing, fault detection and repair
131–11	Prevention of mutual detrimental influence	Harmful influences between electrical installation and other installations to be avoided, including electromagnetic interference
131–12	Accessibility of electrical equipment	Adequate space to be provided for installation, replacement, maintenance, testing, fault detection and repair
131–13	Protective devices and switches	Single pole devices in phase conductor only and requirements when switches are inserted in earthed neutral conductors
131–14	Isolation and switching	Removal of voltage from equipment including electric motors to prevent danger

3.4.10 Selection of electrical equipment

Section 132 of BS 7671: 2001, containing eight regulations, requires equipment to be suitably selected as summarized in Table 3.8.

Table 3.8: Summary of Section 132 – Selection of electrical equipment

Regulation group	**Title**	**Dealing with**
132–01–01 132–01–02	General	Equipment to comply with standards unless agreed otherwise
132–01–03 132–01–04 132–01–05 132–01–06	Voltage Current Frequency Power	These four regulations require equipment to be selected to suit voltage, current, frequency and power
132–01–07	Conditions of installation	Equipment to be selected to be suitable for the environmental conditions, or otherwise protected
132–01–08	Prevention of harmful effects	Electrical equipment not to cause harmful effects on other equipment or the supply

3.4.11 Erection, verification, and periodic inspection and testing of electrical installations

The requirements for erection, verification and periodic inspection and testing of electrical installations are contained in section 133 and are summarised in Table 3.9.

Table 3.9: Summary of Section 133 – Erection, verification, and periodic inspection and testing of electrical installations

Regulation Group	**Title**	**Dealing with**
133–01–01		Good workmanship and proper materials
133–01–02		Characteristics of equipment not to be impaired during erection of installation
133–01–03		Conductors to be identified
133–01–04		Electrical joints and connections to be adequate
133–01–05		Design temperatures not to be exceeded
133–01–06		Equipment causing high temperatures or arcs to be suitably located or guarded
133–02–01	Verification	Appropriate inspection and testing to be performed upon completion of construction or completion of an addition or alteration
133–03–01	Periodic inspection and testing	Recommendation for subsequent periodic inspection and testing required

As in previous editions of BS 7671, the requirement contained in Regulation 133–01–01 for good workmanship and proper materials to be used is, as one would expect, retained; these essential elements are the cornerstones of sound installation erection work. By implication, the regulation requires that established methods, equipment and materials are to be used but does not rule out the use of new materials provided they offer no less a degree of safety. Regulation 133–01–02 goes on to require that equipment must not be impaired by the installation process.

Chapter 4

Assessment of General Characteristics

4.1 General

Part 3 of BS 7671 requires the electrical installation designer to make an assessment of the entire electrical system. An electrical installation forms part of the complete system, the other constituent parts being the LV supply source and the interlinking LV distribution lines.

Regulation 300–01–01 requires this assessment to include the characteristics of the installation such as the purpose to which the installation is to be used, its structure generally, the nature of the supply to the installation, the external influences to which equipment will be exposed and the compatibility and maintainability of that equipment in service. The need for this assessment is obvious in that the particular characteristics of the supply and installation will influence, if not dictate, the methods used to protect against the hazards of electric shock, burns and fire. They will also have a bearing on the choice of equipment and wiring systems.

Additionally, before any design of the installation is contemplated an assessment of the supply characteristics is required and due account will need to be taken of the implications of those characteristics on the installation design.

4.2 Loading, maximum demand and diversity

4.2.1 General

Whilst 'maximum demand' and 'diversity' are not defined in BS 7671 it is necessary to be clear that such terms are understood by all concerned in the design process. For example, 'maximum demand' may mean different things to the supply engineer and the installation design engineer. In this text the following meanings have been assigned to the terms used:

- Maximum demand – the maximum anticipated installation load plus any allowance for future loading (i.e. the potential load),
- Connected load – the total of all electrical loads,
- Diversity – the ratio of maximum demand to the connected load.

Diversity can therefore be represented by Equation 4.1:

$$\text{diversity} = \frac{\text{maximum demand}}{\text{connected load}} \qquad (4.1)$$

From Equation (4.1) it can be readily seen that diversity is never going to be more than unity, or 100% in percentage terms (the more usual way of expression). Whilst the connected load is fairly straightforward to assess, the prediction of the maximum demand calls for considerable skill and judgement by the electrical designer. To apply a diversity of one (or 100%) would, of course, meet all the safety requirements but an installation designed on this basis might prove to be exceedingly costly and much 'over-engineered'. To provide an economic design which meets the safety requirements needs design experience, skill, and not a little judgement, in establishing a figure for the actual load (i.e. maximum demand).

In load assessments, certain assumptions have to be made with regard to actual current drawn by equipment. Fixed loads are easy but this is not so for socket-outlet circuits which may have a theoretical load many times that which is likely to be drawn in service. For example, a final ring circuit may have twelve 13 A socket-outlets protected by a 32 A MCB, each socket-outlet capable of supplying, at least for short periods, a load of 2.99 kW at 230 V (13 A × 230 V), giving a total circuit current of 156 A (12 × 13 A). Clearly, such a senario is not likely to occur in the real world and the current likely to be drawn in this case must be based on all the known information related to usage of the circuit and the loads of portable and fixed equipment connected to it (the maximum permitted sustained load to be drawn by this circuit would, of course, be 32 A).

As mentioned earlier, assumptions have to be made in the assessment of maximum demands and those regarding the load current of current-using equipment and at points of utilisation (e.g. socket-outlets) are given in Table 4.1 which is based on Table H1 of the IEE Guidance Note *Selection and erection*.

When selecting ratings of distribution boards and consumer units it is important to do so taking into account the connected load without diversity and it should not be forgotten that the nominal rating of the equipment does not necessarily imply that it would take this current continuously or for substantially long periods. Where continuous or long duration loading is in excess of the 'long term' rating a significantly higher temperature is attained within the equipment which may cause premature operation of overload devices. In all cases the designer should consult the appropriate British or CENELEC Standard and/or the manufacturer of the equipment.

4.2.2 Lighting – loading and diversity

To assess the maximum demand for loading of lighting circuits, it is simply necessary to add the sum of all the lamp wattages of luminaires connected to it. The current is obtained by dividing the rated wattage of the lamp(s) by the nominal voltage (i.e. W/U_n). Where luminaires operate at a power factor less than unity (e.g. power-factor uncorrected fluorescent luminaires), and in the absence of more precise information, a multiplying factor of 1.8 (see item 10.4.2 of this Guide) must be applied to the calculated current derived from the wattage rating. Where the actual wattage of a luminaire is not known a minimum of 100 W per lamp must be allowed (see Item H of Table 4.1 of this Guide).

Diversity for lighting circuits will depend on the type of premises and in Table H2 of the IEE Guidance Note *Selection and erection* these are given as:

- domestic premises – households including flats 66%
- commercial premises – shops, offices, stores and other business premises 90%
- commercial premises – guest houses, small hotels, boarding houses 75%

By way of example, three shop lighting circuits with connected load (and maximum demand) of 15 A, 7 A, and 12 A would represent (after applying

Table 4.1: Load demand of current-using equipment and points of utilisation

Ref	Equipment or point of utilisation	Assumed maximum demand	Comments/Examples
A	63 A socket-outlet.	63 A	In the absence of precise loading, allow for maximum rated load.
B	32 A socket-outlet.	32 A	In the absence of precise loading, allow for maximum rated load.
C	16 A socket-outlet.	16 A	In the absence of precise loading, allow for maximum rated load.
D	13 A socket-outlet.	13 A	Conventional circuits excepted.
E	5 A socket-outlet.	5 A	Conventional circuits excepted.
F	2 A socket-outlet.	0.5 A	The value of load demand given should be regarded as a minimum.
G	Known luminaires.	Actual load	Account to be taken of power factor of luminaire.
H	Other lighting outlets (e.g. pendants).	Not less than 100 W (0.43 A at 230 V)	Minimum of 100 W per lamp.
J	Electric clocks.	Zero	To be ignored.
K	Shaver sockets.	Zero	To be ignored.
L	Bell transformers.	Zero	To be ignored.
M	Load of not more than 5 VA (22 mA at 230 V).	Zero	To be ignored.
N	Cooker (domestic type).	10 A plus 30% of remainder of load	E.g. 20 kW (86.95 A) cooker on 230 V. Loading = 10 A + (0.3 × 86.95) = 39 A.
O	Cooker (domestic type) with integral socket-outlet on control unit.	10 A plus 30% of remainder of load plus 5 A	E.g. 24 kW (104.35 A) cooker on 230 V. Loading = 10 A + (0.3 × 104.35) + 5 = 46.3 A.
P	Stationary equipment.	Rated current	Consult the manufacturers and/or the Standard and/or rating plate.

Note: Where loadings have a power factor other than unity, allowance must be made for the current drawn at stated power factor.

an allowance for diversity of 0.9) a load of 30.6 A (i.e. 0.9[15 + 7 + 12]) on the supplying distribution board.

4.2.3 *Heating – loading and diversity*

Assessment of heating loads is straightforward and the current is obtained by dividing the rated wattage, W, of the loads by the nominal voltage of the circuit (i.e. W/U_n). Power factor for such load is normally at unity unless the heater convection is fan assisted, in which case account should be taken of the motor power factor. This is generally likely to be approaching unity for the whole appliance. For thermal storage heating circuits (e.g. off-peak heaters) and for floor warming installations, no allowance for diversity is permitted.

Diversity for heating circuits will depend on the type of premises and in Table H2 of the IEE Guidance Note *Selection and erection* these are given as:

- domestic premises – households including flats: 100% of first 10 A plus 50% of remainder;
- commercial premises – shops, offices, stores and other business premises: 100% of largest heater plus 75% of remaining heaters;
- commercial premises – guest houses, small hotels, boarding houses: 100% of largest heater plus 80% of next largest heater plus 60% of remaining heaters.

By way of example, five boarding house heaters, three rated at 3 kW and two rated at 2 kW are fed from a common distribution board. With allowance for diversity, these heaters would represent a load of 9.6 kW (i.e. $[1 \times 3] + [0.8 \times 3] + [0.6 \times 3] + [0.6 \times 2] + [0.6 \times 2]$).

4.2.4 *Cookers – loading and diversity*

Diversity for cooker circuits will again depend on the type of premises and in Table H2 of the IEE Guidance Note *Selection and erection* these are given as:

- domestic premises – households including flats: 100% of first 10 A plus 30% of remainder plus 5 A if socket-outlet is integral to the cooker control unit;
- commercial premises – shops, offices, stores and other business premises: 100% of largest cooker plus 80% of second largest cooker plus 60% of remaining cookers;
- commercial premises – guest houses, small hotels, boarding houses; 100% of largest cooker plus 80% of second largest cooker plus 60% of remaining cookers.

By way of example, three small hotel cookers, two rated at 12 kW and one rated at 10 kW are fed from a common distribution board. With allowance for diversity, these cookers would represent a load of 27.6 kW (i.e. 12 + [0.8 × 12] + [0.6 × 10]).

4.2.5 Water heaters – loading and diversity

Diversity for instantaneous water heater circuits will depend on the type of premises and in Table H2 of the IEE Guidance Note *Selection and erection* these are given as:

- domestic premises – households including flats: 100% of first and second largest water heater plus 25% of remainder;
- commercial premises – shops, offices, stores and other business premises; 100% of first and second largest water heater plus 25% of remainder;
- commercial premises – guest houses, small hotels, boarding houses: 100% of first and second largest water heater plus 25% of remainder.

There is no allowable diversity for water heaters which are thermostatically controlled (e.g. immersion heaters and storage water heaters).

By way of example, three office instantaneous water heaters, two rated at 7 kW and one rated at 3 kW are fed from a common distribution board. With allowance for diversity, these water heaters would represent a load of 14.75 kW (i.e. 7 + 7 + [0.25 × 3]).

4.2.6 Motors – loading and diversity

Diversity for motor circuits will depend on the type of premises and in Table H2 of the IEE Guidance Note *Selection and erection* these are given as:

- commercial premises – shops, offices, stores and other business premises: 100% of first and second largest motor plus 80% of second largest motor plus 60% of remainder;
- commercial premises – guest houses, small hotels, boarding houses: 100% of first and second largest motor plus 50% of remainder.

By way of example, three motors in an office boiler house, two rated at 7.5 kW and one rated at 3.5 kW (and all operating at 0.8 power factor) are fed from a common distribution board. With allowance for diversity, these motors would represent a load of 22.25 kW (i.e. {7.5 + 7.5 + [0.8 × 3.5]} ÷ 0.8). This value represents the steady-state loading and allowance should also be made for the high starting currents associated with the particular motors. The motor manufacturer must be consulted where there is doubt about the starting currents (typically six times the steady-state current). Consideration should also be given to simultaneous starting of motors and the effects on distribution circuits. Sequential starting may need to be adopted to prevent unacceptable cumulative starting currents. Lift motors are the subject of special consideration and reference should be made to the requirements of BS 5655.

4.2.7 Stationary equipment – loading and diversity

The loading of stationary equipment will be that given by the manufacturers and any diversity allowance which may apply will depend on the operational requirements. In the absence of precise information, the allowance given for heating may be used with caution, if appropriate.

4.2.8 Conventional circuits – loading and diversity

Conventional circuit arrangements are detailed in Appendix E of the IEE Guidance Note *Selection and erection*. Diversity for conventional circuits will depend on the type of premises and in Table H2 of the IEE Guidance Note *Selection and erection* these are given as:

- domestic premises – households including flats: 100% of largest circuit plus 40% of remainder;
- commercial premises – shops, offices, stores and other business premises: 100% of largest circuit plus 50% of remainder;
- commercial premises – guest houses, small hotels, boarding houses: 100% of largest circuit plus 50% of remainder.

By way of example, three conventional circuits in a shop, two rated at 32 A (ring final circuits) and two rated at 20 A (radial circuits) are fed from a common distribution board. With allowance for diversity, these circuits would represent a load of 68 A (i.e. 32 + 0.5[32 + 20 + 20]).

4.2.9 Socket-outlet circuits other than conventional circuits – loading and diversity

Diversity for socket-outlet circuits other than conventional circuits will depend on the type of premises and in Table H2 of the IEE Guidance Note *Selection and erection* these are given as:

- domestic premises – households including flats: 100% of largest point plus 40% of remainder;
- commercial premises – shops, offices, stores and other business premises: 100% of largest point plus 75% of remainder;
- commercial premises – guest houses, small hotels, boarding houses: 100% of largest point plus 75% of all other points in main rooms plus 40% of remainder.

There will be many occasions where the designer will find the installation will not fall neatly into any one of the above three categories and will need to use professional judgement and experience to assess diversity.

4.3 Arrangement of live conductors and type of earthing

4.3.1 Arrangement of live conductors

Regulation 312–02–01 requires that an assessment be made of the number and type of live conductors. Examples given in these regulations are single-phase two-wire a.c., and three-phase four-wire a.c.; other arrangements which could be cited are two-wire d.c. and three-phase three-wire a.c. systems but it is accepted that those quoted in the above regulations are the ones more likely to be encountered in the normal course of events. In the case of public supplies the proposed arrangements can easily be established by consultation with the Electricity Distributor (ED) concerned. In the event of a private supplier, consultation again will be sufficient to establish the relevant parameters. In the case of on-site generation, the designer will only need to consult the generator manufacturer or the generator nameplate to determine the arrangements of live conductors of the source.

4.3.2 Type of earthing

It is important that the requirements of Regulations 312–03–01 are met in that an assessment of the type of earthing has to be made before the design of the installation commences. The type of earthing will have implications with regard to the value of the external earth loop impedance and to the magnitude of prospective earth fault current. In the case of public supplies, it is worth remembering that the EDs have no obligation, legal or otherwise, to provide facilities for earthing of the installation, it being the sole responsibility of the consumer; it may be that the EDs may offer such a facility and, if so, the consumer must take the conscious decision whether or not to accept the facility, bearing in mind its suitability for the intended purpose. Usually this responsibility is delegated to the consumer's electrical designer or electrical contractor to exercise on behalf of the consumer.

There are five basic types of earthing arrangements embodied in the systems identified by TN-C, TN-S, TN-C-S, TT and IT and these are shown in Figures 4.1 to 4.5 and detailed in Part 2 of BS 7671. In the figures, the line configuration in each case represents a three-phase source with the star/neutral point earthed where appropriate. For single-phase sources, one pole of the secondary circuit would normally be earthed as indicated in the figures for the neutral point. The meanings attributed to each letter are given in Table 4.2.

In the TN-C system, which is shown in Figure 4.1, the source is earthed through a low impedance earth electrode effectively 'typing' one pole to Earth in a single-phase system and the star point to Earth in a three-phase system. The functions of neutral conductor and protective conductor are combined in a single conductor, known as a PEN conductor, both in the distribution supply cables and in the consumer's installation. In other words, a TN-C system combines these functions throughout the entire system and an example of this would be an earthed concentric system.

Table 4.2: Designation letters and their meanings as they relate to the type of systems and earthing arrangements

First letter	**Second letter**	**Subsequent letters**
Source earthing arrangements	**Arrangement of connection of exposed-conductive-parts of the installation with Earth**	**Arrangement of protective and neutral conductors**
'T' Direct connection of source with Earth at one or more points (e.g. one pole of a single-phase source and the star point of a three-phase source).	**'N'** Exposed-conductive-parts of the installation connected *directly* by protective conductor with the source Earth (e.g. source earthed neutral in a.c. systems)	**'C'**(4) Single conductor provides for both neutral and protective conductor functions.
		'S' Separate conductors for neutral and protective conductor functions.
		'C-S' Neutral conductor and protective conductor combined in the supply and separate in the installation.
	'T' Exposed-conductive-parts of the installation connected, via an independent installation earth electrode, by protective conductor with the source Earth.	
'I'(2) All source live parts isolated from Earth or connected by a high impedance to Earth.		

Notes: (1) All systems 'reading left to right'.
(2) The Electricity Supply Regulations 1988, as amended do not permit 'IT' systems for use on public supply networks although they may be used, where appropriate, on private supplies.
(3) A combination of different systems may be used on the same premise – e.g. TN-C-S and TT.
(4) Earthed concentric wiring is an example of an TN-C system but specific authorisation is required for its use from the appropriate authority.

In the TN-S system, which is shown in Figure 4.2, the source is earthed through a low impedance earth electrode effectively 'tying' one pole to Earth in a single-phase system and the star point of a three-phase system. The functions of neutral conductor and protective conductor are separate both in the distribution supply cables and in the consumer's installation. In other words, a TN-S system employs separate conductors for neutral and protective functions throughout the entire system and an example of this

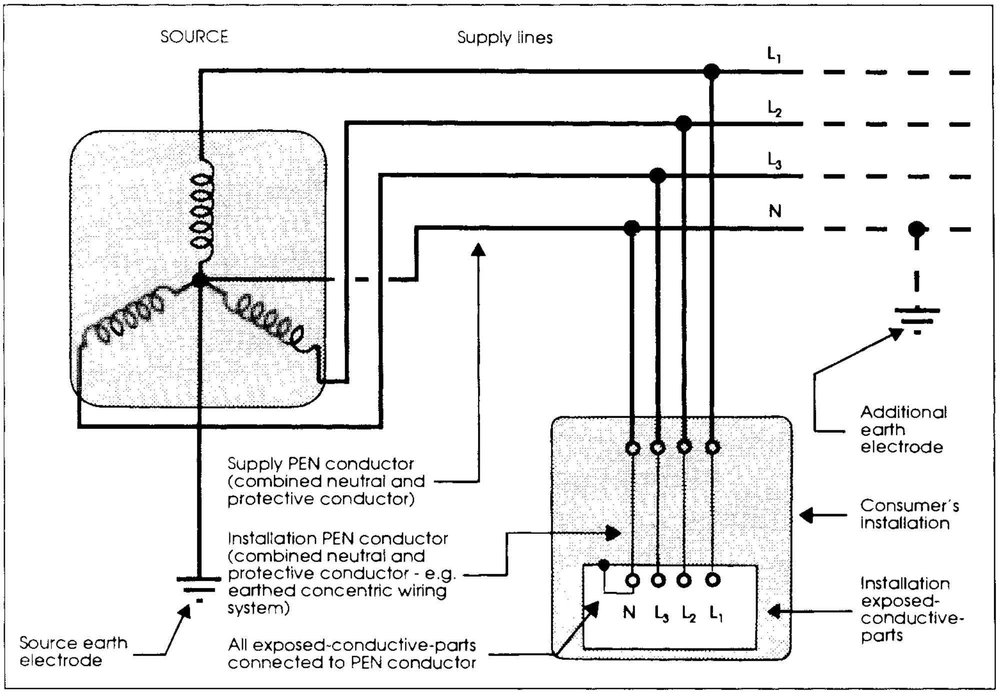


Figure 4.1: TN-C system (three-phase installation)

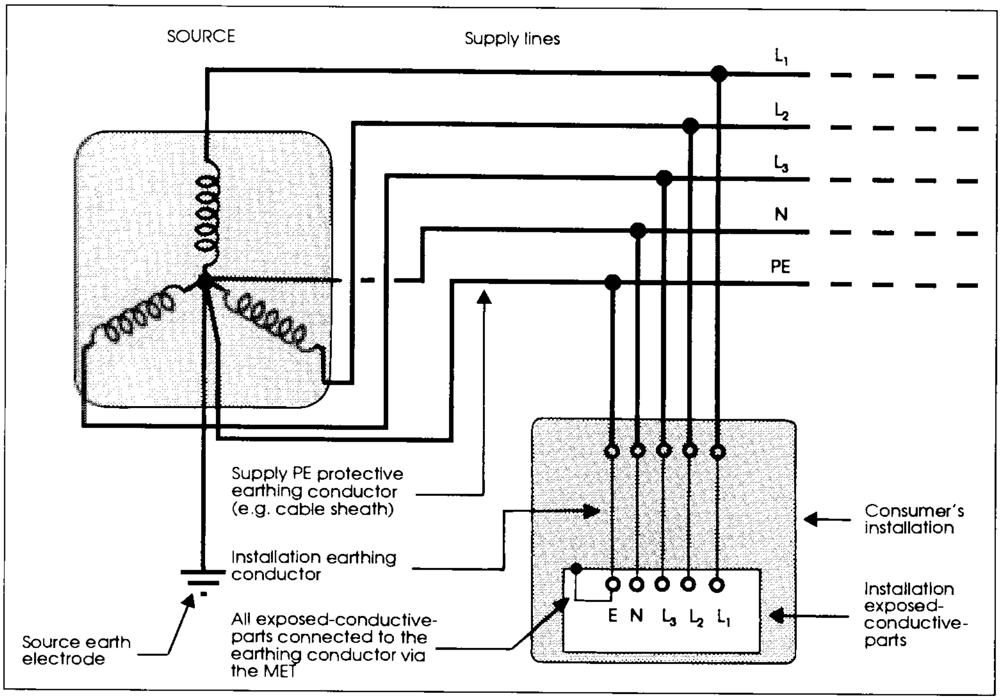


Figure 4.2: TN-S system (three-phase installation)

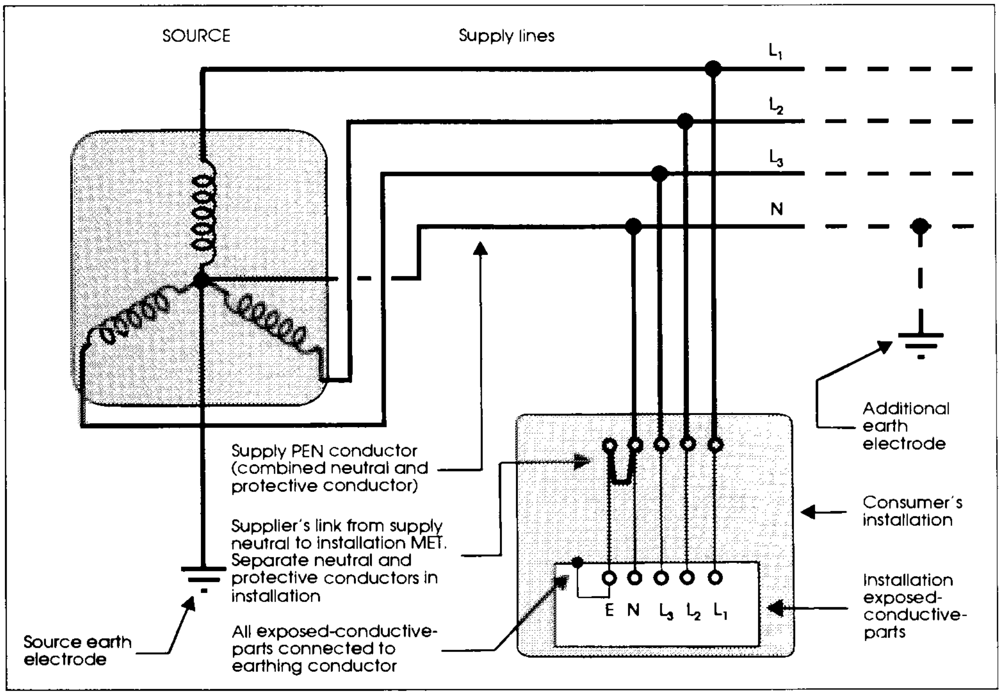


Figure 4.3: TN-C-S system (three-phase installation)

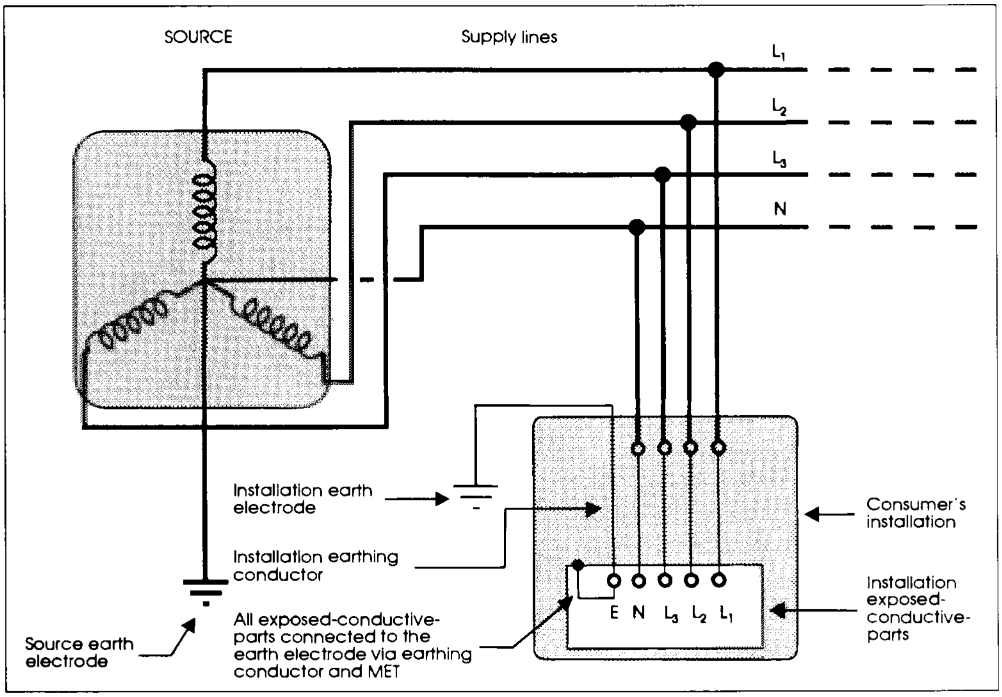


Figure 4.4: TT system (three-phase installation)

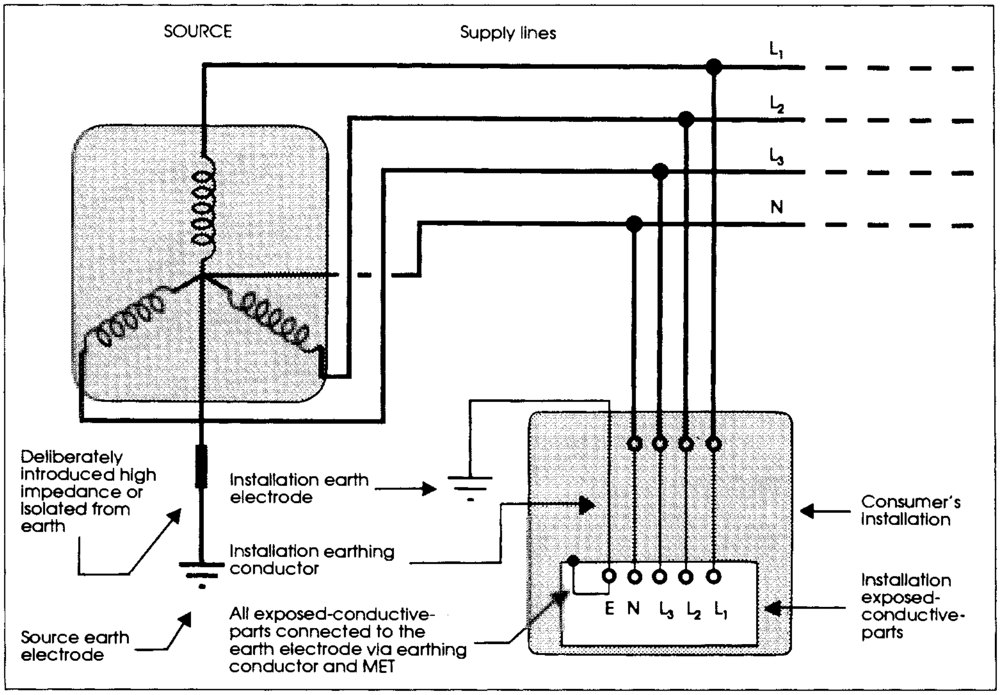


Figure 4.5: IT system (three-phase installation)

would be a supply cable sheath earth connecting directly with the star/neutral point of the source.

In the TN-C-S system, which is shown in Figure 4.3, the source is earthed through a low impedance earth electrode effectively 'tying' one pole to Earth in a single-phase system and the star point of a three-phase system. The functions of neutral conductor and protective conductor are combined in the distribution supply cables up to the consumer's terminals. In other words, a TN-C-S system employs separate conductors for neutral and protective functions throughout the installation but combines the functions in the distribution supply cables. An example of this would be a Protective Multiple Earthing (PME) supply on which the neutral is effectively earthed to the star point of the source and via suitable earth electrodes at a number of points along the length of the supply cable.

In the TT system, which is shown in Figure 4.4, the source is earthed through a low impedance earth electrode system effectively 'tying' one pole to Earth in a single-phase system and the star point of a three-phase system (on a public supply this impedance does not generally exceed 20 Ω). The function of neutral conductor in the distribution supply cables up to the consumer's terminals is quite separate from the protective function. The path for earth fault current to flow to the earthed point of the source is provided by the general mass of the Earth together with earth electrodes (both source and installation) and separate protective conductors. These TT systems are often encountered in rural locations where the EDs are unable to offer an earthing facility. Additionally, TT systems are sometimes employed where the installation designer declines the ED's offer of an earthing terminal on the grounds of its unsuitability for use on a particular installation or part of an installation; for example, petrol filling station electrical installations. Indeed, many PESs will not offer a PME earthing facility for filling stations.

In the IT system, which is shown in Figure 4.5, the source is isolated from Earth or earthed through a high impedance earth system. This system is seldom used in the UK and is indeed not permitted on public supplies unless special permission is granted for its use by the Secretary of State for Energy or the Secretary of State for Scotland.

4.4 Nature of supply

4.4.1 General

Regulation 313–01–01 lists the particular characteristics of the supply to be assessed; the nominal voltage(s), the nature of current and frequency, the prospective short-circuit current at the origin of the installation, the earth fault loop impedance of that part of the system external to the installation (Z_e, the suitability for the requirements of the installation, including maximum demand and, finally, the type and rating of the overcurrent device(s) acting at the origin of the installation.

4.4.2 Voltage

Assessment of the nominal voltages and voltage tolerances is straightforward in that if the source is a private one, for example, a generator, details of the characteristics, including no-load and rated-load voltages, will be available from the generator manufacturer and would usually be given on the generator nameplate together with other relevant design details. If the source is derived from the public supply, then the EDs are required to maintain the voltage of supplies to not exceeding the range +10%/$-$6% of the declared nominal voltage to meet the statutory requirements under the Electricity Supply Regulations 1988, as amended. For a single-phase supply of nominal voltage of 230 V this would mean a lower limit of 216 V and an upper limit of 253 V. A three-phase supply at a nominal voltage of 400 V at these tolerances would be in the range of 376 V to 440 V. In practice, it is unusual for the supply voltage to transverse this range, even over short periods, and in most cases the 'base' voltage is within this range and small variations occur due to the effects of loading of the installations and/or other loads connected to the same source. However, the installation design would need to take account of the whole range since it can reasonably be anticipated that changes will take place in the supply network which should always be treated as a dynamic (always changing) constituent part of the system.

With Amendment No 2 to BS 7671 came the introduction of voltage bands. There are two voltage bands as follows:

Band I, covers:

- installations where protection against electric shock is provided under certain conditions by the value of voltage,
- installations where the voltage is limited for operational reasons, such as telecommunications, signalling, bell, control and alarm installations.

Normally extra-low voltage will fall within voltage band I.

Band II covers:

- Band II contains voltages for supplies to household, and most commercial and industrial installations and where such voltages do not exceed 1000 V a.c. rms or 1600 V d.c. between conductors or 600 V a.c. rms or 900 V d.c. between conductors and earth (i.e. low voltage).

4.4.3 The nature of current and frequency

The most common forms of current are direct current (d.c.) and alternating current (a.c.). In most power systems, a.c. is one of the sinusoidal or distorted sinusoidal waveform. Frequency, applying only to a.c., needs to be assessed because of its effect on impedance; the inductive reactance of a constituent part of a system increases and decreases in direct proportion to the frequency and conversely capacitive reactance varies in inverse proportion to the frequency. EDs are required, again under the Electricity Supply Regulations 1988, as amended, to maintain the frequency of public supplies to 50 Hz $\pm 1\%$.

4.4.4 Prospective short-circuit current

An assessment of the prospective short-circuit current at the origin of the installation is required by Regulation 313–01–01 in order to establish that devices, such as overcurrent protective devices, at the origin and elsewhere have short-circuit capacities (breaking capacity for fuses and making/ breaking capacities for protective devices other than fuses – for example, miniature circuit-breakers) of not less than the prospective short-circuit currents.

Although the Regulation refers only to short-circuit currents at the origin, the designer should not ignore earth fault current which may in certain circumstances be greater than short-circuit current. Depending on the source and transmission supply cables, earth fault currents can be of the order of 5% greater than short-circuit currents due to the zero-sequence impedances being lower or non-existent in the earth fault path.

The Regulation gives four options for methods of assessment of this and other parameters: *calculation, measurement, enquiry* and *inspection*. The last option is not applicable to the assessment of prospective short-circuit current, it being totally impracticable to be carried out by any amount of inspection.

If the assessment is to be carried out by calculation, then all the constituent impedances of the system need to be known, together with the anticipated fault-level of the high-voltage feeder to the power transformer. The fault-level of the HV feeder may be obtained from the ED in the case of public supply and in the absence of this information may be taken as 250 MVA for an 11 kV system. This may actually be slightly higher than the true value but would, in any event, tend to give a somewhat exaggerated value of fault current and the approximation would tend to be on the safe side, for prospective fault current considerations.

The method of assessment by measurement is straightforward but, of course, such measurements do need the supply to the installation to be *in situ* and made live. For a new installation this method is often impracticable because the supply is not available sufficiently early to allow decisions to be made, amongst other things, regarding protective device specification. The measurements themselves are straightforward provided good quality instruments are used together with a safe system of work whenever such tests are undertaken. The test instrument will need to be equipped with two test probes (suitably insulated, fused, shrouded and with spring-loaded retractable contacts). The measurement taken between phase and neutral at the origin will give the phase-neutral (P-N) short-circuit current and that between phase and the main earthing facility will give the earth fault current. Similarly, phase-phase (P-P) and three-phase prospective fault currents can be obtained in a comparable way. It must be remembered that the values so obtained relate to the particular time at which the tests were undertaken and that allowance should be made for any increase likely to occur due to modifications of the supply network, which should always be regarded as dynamic – this is particularly important when the supply is derived from the public network.

The third, and final, viable option given is that of enquiry; that is, enquiry of the Electricity Distributor, normally an ED. As required by the Electricity Supply Regulations 1988, as amended, a supplier is obliged to provide this information which is usually done by quoting a maximum value of prospective short-circuit current. Often the actual value will be less than that quoted but the EDs maintain this policy for two main reasons: the actual value at each individual supply point would be difficult to give and there is always the possibility, if not the likelihood, that changes will be made to the supply network by, for example, transfer of an installation load to a different, possibly larger or nearer, transformer with perhaps a lower impedance and consequent higher prospective fault level.

For supplies obtained from the public distribution network, information on this subject is given by the Electricity Association (formerly Council) in their Engineering Recommendation P.25 entitled *Short circuit characteristics of Electricity Board's distribution networks and co-ordination of overcurrent protective devices on 240 V single-phase supplies up to 100 A*. Another publication by the Association, P26, gives similar information relating to three-phase supplies. Chapter 7 of this Guide gives further guidance on this subject.

4.4.5 External earth fault loop impedance

Regulation 313–01–01 also requires an assessment of the '*earth fault loop impedance of that part of the system external to the installation, (Z_e)*'. This impedance is the phasor (vector) sum of all the constituent parts of the earth loop up to the origin of the installation and would include the transformer secondary winding, the phase conductor of the supply cable and the earth fault path back to the earthed point of the transformer. In a more rigorous analysis the contribution made by the HV supply would need to be included by referring its equivalent impedance to the secondary LV loop impedance.

Again there are basically three methods by which this assessment can be made: *calculation, measurement* or *enquiry*, all of which can be obtained by similar methods described in the assessment of prospective fault current. Enquiry is generally the only option at the design stage but confirmation, by testing, is always required as soon as practicable.

It should be noted that where from enquiry the maximum prospective fault current and maximum external loop impedance value are given, these values will be mutually exclusive; they are the worst case values which do not occur simultaneously. For example, a supplier may quote a Z_e of 0.35 Ω and a prospective fault current of 16 kA which, from a simple application of Ohm's law, will show that the two conditions do not happen at the same time. It therefore follows that the design will need to take account of the range of these parameters. For example, for TN-C and TN-C-S systems, the implications are that Z_e will be in the range of 14.4 mΩ (230 V ÷ 16 000 A) to 0.350 Ω and the corresponding prospective fault level range will be 657 A to 16 kA. The designer will need to take account of these ranges when considering circuit length (limiting Z_s values), short-circuit capacities of protective devices, and discrimination – can the last named be maintained over the range?

4.4.6 Suitability of supply

Regulation 313–01–01, item (v), demands an assessment to be made of the suitability of the supply for the requirements of the installation, including maximum demand. This may appear an obvious requirement and one which could be 'taken as read'. However, in practice, all too often this matter is not considered sufficiently early in the installation design and problems arise later at the commissioning stage which are difficult to solve. Where, for example, step-loads (suddenly-applied loads) have not been properly considered in terms of their effects on other loads, problems can, and do, arise which can result in difficult and sometimes costly remedies. Particular attention should be given to the effects of large loads on, for example, lighting loads which may, if proper consideration is not given, present problems with luminaires 'dipping', 'flickering' or giving other unwanted and distractingly unsatisfactory visual effects. For example, it is desirable to connect fluorescent luminaire circuits over three phases wherever practicable to avoid the strobe/flicker effects that can sometimes occur.

The installation load profile always needs careful analysis to confirm that the supply characteristics can match the installation loads at all times. To obtain a meaningful profile it is necessary to know the full details of the intended utilisation of the installation and in particular the times and duration of the various loads including the times when intermittent loads are switched ‘in’ and ‘out’. Computers can, and do, provide a useful and time-saving function in this analysis but such profiles need the judgement of a professional engineer who can draw on his experience of similar projects and their performance over a period. This load profile, when completed, should show diagrammatically the maximum demand of the installation load.

In the case where the supplier’s tariff includes an availability charge, an over-estimation of the maximum demand may prove costly in terms of penalty costs for ‘unused’ maximum demand; it is therefore very important that an accurate assessment is made. However, commercial considerations are not within the ambit of BS 7671 which addresses, in this context, only the safety aspects of the suitability of supply.

4.4.7 Type and rating of overcurrent device at the origin

Regulations 313–01–01, item (vi), requires the type and rating of the overcurrent protective device at the origin of the installation to be determined. This can only be done by inspection or enquiry and it is necessary to establish the nominal rating, short-circuit capacity and its type in terms of British Standard or other performance specification. The purpose of this assessment is to ascertain that the nominal rating is not less than the connected load, allowing for any permissible diversity, that the short-circuit capacity is adequate for the prospective fault current and that connected wiring systems, including meter tails, are adequately protected against overload and fault currents.

Once the type and rating have been established, it is important to check the characteristics of the device in the relevant British or other Standard performance specification so that it can be considered in terms of the protection of wiring systems connected to it.

In the case of public LV supplies, most EDs now use BS 1361 Type 11 (either 60, 80 or 100 A) HRC fuses (33 kA short-circuit capacity) on new supplies. However, it should never be assumed that a particular type or rating of device has been used and the details should always be ascertained by inspection or enquiry.

4.5 Supplies for safety services and standby purposes

As called for in Regulation 313–02–01, supplies for safety services and standby supplies must be determined and confirmed that they are reliable and of adequate capacity. In the case of supplies from an ED or other electricity supplier, the designer must consult that supplier regarding those matters and the switching arrangements, where appropriate, particularly where such services represent a substantial load.

Such safety services would include, for example, fire alarm and detection systems, emergency lighting (including emergency exit signs), fire pumps and sprinkler systems. Wiring systems for these services and their routes should be chosen carefully and the provisions and requirements of Chapter 56 of BS 7671 must be met. The supplies are classified as automatic or non-automatic, as appropriate. Chapter 14 of this Guide gives further guidance on supplies for safety services.

4.6 Installation circuit arrangements

The four regulations under Section 314 of BS 7671 set out the requirements for the circuit arrangements. Essentially, circuits must be provided in sufficient number so that danger is prevented, and inconvenience minimised, both under normal and fault conditions and arranged so that operation, inspection, maintenance and testing may be carried out in a safe manner. Compliance with other chapters of BS 7671 should affirm that these basic requirements are met but it is imperative that a sufficient number of circuits are provided so that equipment unaffected by a fault condition remains safe and functioning when another circuit develops a fault. The designer would need to consider the effects, in terms of consequential events, of the operation of a single protective device.

Regulation 314–01–04 calls for each circuit to be electrically separate and connected individually and detached from all other circuits where they terminate in a distribution board. Implicitly, the connection of each circuit phase(s), neutral and cpc conductors must follow a logical sequence at their termination in the distribution board.

4.7 External influences

Regulation 300–01–01, and more particularly Chapter 32 and Appendix 5 of BS 7671, deal with external influences which need to be assessed by the designer and then taken into account in the subsequent installation design and its construction. Item 10.2 of this Guide provides some guidance in this respect.

4.8 Compatibility

Regulation 331–01–01 demands an assessment to be made of the characteristics of all equipment likely to have harmful effects on other equipment or on the supply. Where equipment is liable to have adverse effects on the supply, this regulation calls for the supplier to be consulted; such equipment may, for example, include large step loads (suddenly-applied loads), electronic switch-mode inverters or any load capable of generating low-order harmonics.

This Regulation (331–01–01) was amended by Amendment 2 and again by the 2001 version to the extent that examples of the characteristics which may adversely affect other services or the supply are now given as:

- overvoltages
- undervoltage
- fluctuating loads
- unbalanced loads
- power factor
- harmonic currents
- starting currents
- protective conductor currents
- d.c. feedback
- high frequency oscillations
- the necessity for additional connections to earth

In effect, there has been no real change in the regulatory requirements for the designer who would have had to consider all the listed items to meet the previous wording of the Regulation.

4.9 Maintainability

Whilst it is important that an installation is designed, constructed and verified to afford compliance with BS 7671 and to meet the operational and functional needs of the user, it is equally imperative that it can be readily and easily maintained throughout the life of the installation (Regulation 341–01–01). This aspect should not be ignored or overlooked at the design stage; it is of the utmost importance that this issue is addressed by the designer at a very early stage of his design.

Legislation, such as the Electricity at Work Regulations 1989, imposes responsibilities on employers to maintain their installations in a safe condition at all times; this applies to all places of work including shops, schools, factories, hospitals, etc. It is therefore incumbent on the installation designer to be cognisant of all the maintenance requirements and to make due provision for them in his design. Materials used should be of sufficiently high standard to be serviceable throughout the lifetime of the installation. The designer should place little emphasis on the installation user's ability to exercise sound precautions in the use of the installation, and materials and equipment selected should be suitable for their environment and be of good quality. Equipment manufactured to an appropriate British or CENELEC Standard should be used wherever possible.

Unless an installation is under the *strict* supervision of a competent authority, the operation of essential safety measures such as isolation and switching should be made absolutely clear by provision of *legible* and *durable* identification labels which leave no room for misunderstanding.

Where equipment is likely to have a limited life expectancy which is less than that of the remainder of the installation equipment, then provision should be made for its periodic replacement prior to it becoming unsafe in use. If, for example, a piece of equipment is intended for a particularly hostile environment, the designer has the option of selecting that material with the capability of withstanding that environment for the whole lifetime of the installation or, alternatively, the equipment may be selected to have a deliberately short lifespan and arrangements made for its periodic replacement. It is very often a matter of simple economics as to which method is chosen provided, of course, that safety is not compromised at any time.

BS 7671 demands that, in addition to the initial verification of the installation, periodic inspection and testing are required over the lifetime of the installation. It is therefore of paramount importance that access to equipment and wiring system terminations is maintained at all times. Equipment should be so constructed and installed that inspection and testing activities may be carried out safely. Where an item of equipment is less accessible, its degree of reliability must correspondingly be greater in terms of maintaining safety unless its failure cannot cause danger.

Earlier the installation circuit arrangements were discussed and, in the context of maintainability, the designer should take account of circuit arrangements also in terms of the implications of maintaining such equipment served by these circuits.

Every installation carried out in a place where persons work requires an Operating and Maintenance Manual to enable the user and person responsible for maintenance to discharge his responsibilities under the Health and Safety at Work etc. Act 1974, paragraph 6. This manual should include, amongst other things, instructions for proper operation and list all the items that need maintenance together with comprehensive details of how the maintenance should be undertaken (see item 10.11 of this Guide).

Chapter 5

Protection against Electric Shock

5.1 General

Before discussing the requirements relating to protection against electric shock it is important to have a clear perception of the two different risks which are encountered concerning electric shock. First there is the risk of *direct contact* which, as the term suggests, is when contact (by persons or livestock) is made directly with a live part and which is likely (almost certain) to cause current to flow through a body to the injury, perhaps fatal, of that person or animal. *Indirect contact* is when contact is made with an exposed-conductive-part (e.g. a metal enclosure of a Class I heating appliance) which is not live under normal conditions but which may become live under earth fault conditions. This hazard arises when the protective measures against direct contact have ceased to be effective where, for example, there is failure of insulation.

It is important to recognise that an overcurrent protective device and an RCD will not provide automatic disconnection when human contact is made between two live parts only (e.g. phase and neutral) though an RCD may automatically disconnect if contact is also made simultaneously with earthy parts. It should also be noted that a human (or livestock) making contact between live parts, between live parts and exposed-conductive-parts, between live parts and extraneous-conductive-parts or between exposed-conductive-parts and extraneous-conductive-parts, will be subjected to a voltage (a touch voltage or the full line voltage, depending on the particular parts contacted).

Contact by a person with an exposed-conductive-part whilst a fault occurs on that part, or other electrically connected parts (indirect contact), would surely cause current to flow through his/her body, but if adequate protective measures have been applied to the circuit concerned then injury should be prevented, though it is likely that that person would 'perceive a shock'.

The International Electrotechnical Commission's (IEC) rules for electrical installations and BS 7671 take account of the research work done internationally of the effects of electric current through a human body when determining the limits on the magnitude and duration of earth fault currents. IEC TC 64, Working Group 9 has made an in-depth study of disconnection times and related matters and their report in this respect has been published by the British Standards Institution as PD 6519 *Effects of current passing through the human body* (Part 1 *General aspects* and Part 2

Special aspects); this document addresses the magnitude and duration of electric current through the body and the consequential results in terms of perception and severity of the physiological effects.

The fundamental requirements for protection against electric shock are given in Regulations 130–02–01 and 130–02–02. Chapter 41 gives the basic protective measures to be adopted but as mentioned in Regulation 400–01–01 the order in which they are addressed is not to be taken as the order of relative merit or importance of the various options. Regulation 400–02–01 again makes it clear that where there is an increased risk of electric shock, further measures may need to be taken. If the location or installation is dealt with in Part 6, then the additional requirements will need to be met by *supplementing* or *modifying* the Part 4 requirements as necessary. Section 471 of Chapter 47 details the requirements relating to the application of the protective measures whilst Section 531 of Chapter 53 sets out requirements for protective devices which may be employed in achieving a particular protective measure. Additionally, when considering protective measures associated with indirect contact, Chapter 54 *Earthing arrangements and protective conductors* cannot be overlooked and indeed is of particular importance when considering the protective measure termed Earthed Equipotential Bonding and Automatic Disconnection of Supply (EEBADS). The sequence shown, left to right, in Table 5.1, hopefully clarifies the necessary considerations to be made when articulating the requirements for protection against electric shock. The sequence shown should not be regarded as exhaustive and in many instances reference to other Parts, Chapters, Sections and individual regulations will be necessary.

Table 5.1: Protection against electric shock – sequence (left to right)

Fundamental requirements	**Protective measures**	**Application of measures**	**Overcurrent devices**	**Earthing and protective conductors**
Part 1 Chapter 13 130-02-01 130-02-04 130-04-01 to 130-04-04	Part 4 Chapter 41 (all)	Part 4 Chapter 47 Section 471 (all)	Part 5 Chapter 53 Section 531 (all)	Part 5 Chapter 54 (all)
Part 6 *Special installations or locations* (*particular requirements*).				

Chapter 41 outlines the appropriate measures for protection against electric shock and embodies the requirements for the two distinct aspects of electric shock and two alternative ways of providing the necessary protection. The chapter is divided into three discrete sections as follows:

- Section 411 *Protection against both direct contact and indirect contact*,
- Section 412 *Protection against direct contact*,
- Section 413 *Protection against indirect contact.*

These two aspects and three sections will now be dealt with in this order but before doing so it is worth noting that Regulation 410–01–01, which gives the outline requirements, makes it clear that protection against electric shock must be provided by adoption of the measures detailed in Section 411 (Protection against both direct contact and indirect contact) *or* a combination of those given in Section 412 (direct contact) and Section 413 (indirect contact). It is also a requirement of this regulation that the measures adopted are applied in accordance with Section 471 of Chapter 47 *Application of protective measures for safety*. The first application Regulation, 471–01–01, relating to this protection (electric shock) notes that Regulations 471–02 to 471–14 generally apply to situations where conditions are dry and where a person is assumed to have conventional body impedance and is not in direct contact with Earth potential. It must also be noted that Regulations 471–15 and 471–16 give additional requirements for when the risk of electric shock is increased by virtue of a reduction in body impedance or by body contact with Earth, or both.

As mentioned earlier, Part 6 of BS 7671 deals with nine special installations or locations but there may be others which will need further consideration; Part 6 should not be regarded as having addressed all special installations or locations, or indeed all unusual circumstances that need special treatment. Part 6 *Special installation or locations* is dealt with separately in Chapter 16 of this Guide and it is not the intention here to invoke Part 6 of BS 7671 except to refer to it in passing where appropriate.

5.2 Protection against both direct contact and indirect contact

5.2.1 General

Only two general regulations in Section 411 address this protection, Regulation 411–01–01 and 411–01–02, but these call up others depending on the particular measure to be adopted. There are three sub-sections under this general heading but, as will be seen, only one of two alternative methods may be used. Table 5.2 shows the relevant section and subsections. Protection by functional extra-low voltage is *not* an acceptable method of protection against both direct contact and indirect contact and is precluded by Regulation 411–01–02. Protection by SELV and the limitation of

Table 5.2: Protective measures for both direct contact and indirect contact

Requirements	**SELV**	**Limitation of energy**
General requirements	410-01-01 411-01-01	410-01-01
Protective measures	411-02-01 to 411-02-11	411-04-01
Application of protective measures	471-02-01	471-03-01

discharge of energy are both acceptable measures of protecting against both these dangers (i.e. direct contact and indirect contact).

5.2.2 Protection by SELV

Separated Extra-Low Voltage (SELV) is a protective-measure that is generally applicable, as is confirmed by Regulation 471–02–01, which recognises that in some installations or locations of increased shock risk, SELV will be the *only* acceptable measure. In such circumstances, a reduction in the nominal voltage will be required as will other means of protection against direct contact, irrespective of nominal voltage. SELV systems are entirely separated from Earth and higher voltages by virtue of the isolating characteristics of their sources and the method of installation of the downstream equipment.

A safety source suitable for SELV may be, and commonly is, a safety isolating transformer complying with BS 3535 (BS EN 60742) but other sources may be equally acceptable. An electric motor driven generator can be used providing the motor and generator windings are separated by an equivalent degree to that of a BS 3535 transformer. Batteries too are acceptable as is an engine drive generator or any other source independent of a higher voltage. If an electronic device is to be used then special in-built features are required such as a facility to limit the output voltage. A system supplied from a higher voltage system is not suitable (unless there is the necessary degree of separation) and cannot therefore be deemed to comply with the provisions necessary to provide protection against both dangers. Other unacceptable sources include potentiometers (or voltage dividers), transformers not complying with BS 3535 and auto-transformers, semiconductor devices or any other device which does not provide an equal degree of separation to that provided by a BS 3535 transformer. It will be seen that the purpose of this electrical separation is to prevent higher voltages of the 'primary' of a source being transmitted to the 'secondary' during both normal operation and under fault conditions, thus losing what protection there may have otherwise been. Where a mobile source is used, Regulation 411–02–04 calls for it to be selected and erected so that protection is provided by Class II equipment or equivalent insulation. In practice, the most commonly used source will be a transformer complying with BS 3535. Regulations 411–02–02 and 411–02–03 detail the acceptable and the unacceptable SELV sources which are summarised in Table 5.3.

Regulation 411–02–05 requires that a live part of a SELV system be electrically separated from *any* other higher voltage system; in terms of conductors of the SELV and those of a higher voltage system, the separation is not to be less than that provided between the primary and secondary windings of a transformer complying with BS 3535. The same regulation emphatically demands that a live part of the SELV system is *not* to be connected to Earth or to a live part of *any* other system; this would include a connection to the primary side of the source. In other words, a SELV system must not have any electrical connection with any other system or to

Table 5.3: Summary of acceptable and unacceptable SELV sources

Acceptable SELV sources	**Unacceptable SELV sources**	**Regulation**
Safety isolating transformer to BS 3535 (BS EN 60742).	Any transformer without the necessary electrical separation.	411-02-02 411-02-03
Motor/generator with equivalent isolation as BS 3535 transformer.	Autotransformer.	411-02-02 411-02-03
Battery or other electrochemical source.	Potentiometer (voltage divider).	411-02-02 411-02-03
Engine driven generator.	Semiconductor device.	411-02-02 411-02-03
Electronic device, if proper measures are taken to limit output voltage.	Electronic device, if no proper measures are taken to limit output voltage.	411-02-02 411-02-03
Mobile SELV source protected by Class II or equivalent insulation.	Mobile SELV source not protected by Class II or equivalent insulation.	411-02-02 411-02-03 411-02-04
	Any source supplied from a higher voltage without the necessary electrical separation.	411-02-03

Earth. In practice, unless only a SELV system was used throughout the installation (which is very unlikely), this requirement would preclude the use of metallic conduit and metallic trunking or bare metallic cable sheaths since these, if not deliberately connected to earth, are likely to make fortuitous contact with earthy parts of other systems or equipotentially bonded parts such as, for example, the structural steel of the building. This requirement is reinforced by Regulation 411–02–06 (ii).

Regulation 411–02–06 calls for SELV circuit conductors to be physically separate from conductors of other circuits but recognises that this may not be practicable, or indeed possible, and gives suitable alternative arrangements which are equally acceptable. This physical separation is required to be maintained within relays, auxiliary switches, contactors and the like. Four alternative options to give compliance where physical separation is not practicable are as follows:

- the SELV circuit conductors to be insulated to the highest voltage present,
- the SELV circuit conductors to be enclosed in an additional sheath in addition to their basic insulation. Basic insulation required to SELV voltage level only,
- higher voltage conductors to be separated from the SELV conductors by an earthed metallic screen or sheath,
- where SELV conductors form part of a multi-core cable or otherwise grouped conductors, the SELV conductors to be insulated to the higher or highest voltage present either individually or collectively.

Additionally, the arrangements of electrically separating the SELV live parts from those of any other system extend to include relays, contactors, auxiliary switches and the like.

The requirements of Regulation 411–02–07 reinforce or duplicate those already given in other regulations and confirm that no exposed-conductive-part of a SELV system is to be connected with Earth or with any exposed-conductive-part or protective conductor of any other system. Additionally, this regulation calls for *no* connection to be made between an exposed-conductive-part of the SELV system and an extraneous-conductive-part. There is an exception to this requirement which relates to where SELV equipment forms an integral part of an extraneous-conductive-part or there is inherently a necessary connection between the two parts. In these cases further measures need to be taken to prevent the exposed and extraneous-conductive-parts from exceeding the SELV voltage as specified in Regulation 411–02–01.

Very importantly, Regulation 411–02–08 states that where contact is made between exposed-conductive-parts of an extra-low voltage system and exposed-conductive-parts of other systems, it cannot be deemed to be a SELV system even if supplied by an acceptable safety source and cannot therefore give adequate protection against both direct contact and indirect contact. Contact may, for example, be made between the parts by virtue of independent contacts with Earth which have been made deliberately and intentionally or may have been made quite fortuitously. In other words, when this contact is made, the system should be treated as a functional extra-low voltage system and other measures need to be taken to provide protection against direct contact and further compliance with Section 413 is necessary with regard to indirect contact.

Regulation 411–02–09 makes clear that a SELV system with a voltage exceeding 25 V a.c. (or 60 V ripple-free d.c.) cannot of itself provide the necessary protection against direct contact and stipulates further measures, such as barriers or enclosures to IP2X (or IPXXB) or better or by the insulating of live parts with insulation capable of withstanding a 500 V rms a.c. type-test for at least one minute.

Regulations 411–02–10 and 411–02–11 impose constraints on installation equipment for use in SELV systems when used for protection against both dangers. The first regulation calls for socket-outlets and associated plugs to be dimensionally incompatible with those of other systems in the same premises. Additionally, such accessories are not to embody a protective conductor contact and the latter regulation precludes the use of Luminaire Supporting Couplers (LSCs), having such a protective conductor contact, on a SELV system.

5.2.3 Protection by other extra-low voltage systems

As Regulation 411–03–01 makes clear, where extra-low voltage systems are employed, but not all the measures for safety relating to SELV are embodied into the system, then it cannot be considered to provide the necessary protection against both direct contact and indirect contact. In this case, other measures need to be invoked, such as those described for functional extra-low voltage systems.

5.2.4 Protection by limitation of discharge of energy

As stated in Regulation 411–04–01, this method is an option only where the equipment has been specifically designed to incorporate a device for limiting the available current to a safe level. This device would need to limit the current available, both under normal and fault conditions, to pass through a body of a human or livestock, from both direct contact and indirect contact shock hazards. Such equipment would be the subject of a British or CENELEC Standard specification which would have addressed these safety aspects. Where this protective measure is chosen as a sole means of protection, the equipment must be separated from other systems all as described for a SELV system providing protection against both dangers. Regulation 471–03–01 additionally requires this measure to be applied only to individual items of current-using equipment or, where the BS or CENELEC Standard allows, to extensions of that equipment. This would apply, for example, to an electric fence supplied from a controller complying with BS EN 61 011.

5.3 Protection against direct contact

5.3.1 General

The very first regulation in this Section, Regulation 412–01–01, outlines the four basic measures for protection against direct contact (which is the prevention of contact directly with live parts – phase(s) and neutral in a.c. systems and positive and negative in d.c. systems). At least one measure needs to be employed but, of course, a number of these measures may be used together. Part 4, Chapter 41, Section 412 deals with these measures and Chapter 47, Regulations 471–04 to 471–07 addresses the application of these measures. Table 5.4 shows the correlation between the measures and their application while Figure 5.1 gives examples of four basic measures.

Table 5.4: Protection against direct contact – correlation between the measures and their application

Protective measures	**Application of protective measures**
Part 4, Chapter 41, Section 412	Part 4, Chapter 41, Section 471
General 412-01-01	Section 471
Insulation of live parts – 412-02-01	471-04-01
Barriers or enclosures – 412-03-01 to 412-03-04	471-05-01 471-05-02
Obstacles – 412-04-01 and 412-04-02	471-06-01 (see also 471-13-01 to 471-13-04)
Placing out of reach – 412-05-01 to 412-05-04	471-07-01 (see also 471-13-01 to 471-13-04)
Supplementary protection – 412-06-01 and 412-06-02	471-16-01 and 471-16-02

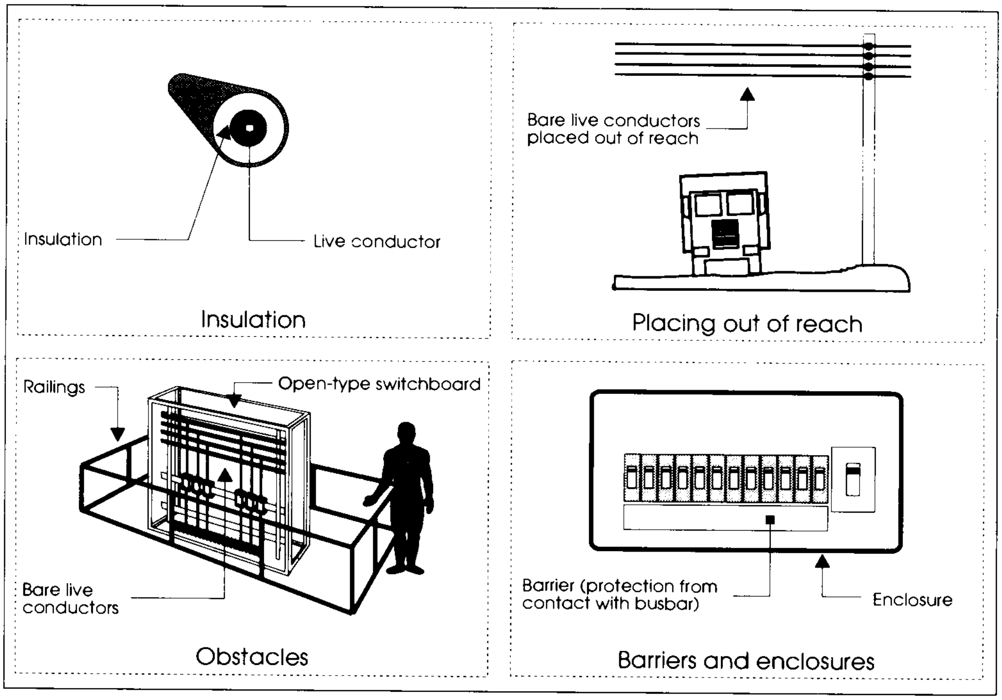


Figure 5.1: Examples of the four basic measures for protection against direct contact

5.3.2 Insulation of live parts

This, the first of the four measures, is by the insulation of live parts and is probably the most common method of compliance with the requirements; it is basic insulation which prevents physical and electrical contact with the live parts so insulated. To state the obvious, conductors are usually allocated this protective measure. Conductor insulation must have a suitable voltage rating appropriate to the circuit operating voltage and must be suitable for its intended use in service.

Regulation 412–02–01 calls for live parts to be covered by insulation which can only be removed by destruction; in other words, a sleeve or tape of insulating material is inadequate if only because it may be removed without destruction. If the insulation is applied on site during erection of the installation, then it is required to meet the appropriate type tests as required in the British or CENELEC Standard for similar material. In all cases, insulation must be such as to be capable of durably withstanding all the mechanical, thermal, chemical and electrical stresses under both normal and fault conditions. Site applied insulation should be avoided wherever possible because of the practical difficulties of application and subsequent high voltage testing procedures. Application Regulation 471–04–01 adds little to the requirements other than to confirm that this measure is intended to prevent contact with live parts and is generally applicable to protect against direct contact. It is to be used in conjunction with protective measures against indirect contact. Conductors should be insulated and, where necessary, they must also be further protected. This additional protection should be regarded as including protection against external influences such as mechanical damage (e.g. from impact, vibration, etc.) and ingress of solids and liquids. In this context it is necessary to enclose all insulated-only conductors (i.e. non-sheathed), excepting protective conductors, in conduit, trunking or ducting as required by Regulation 521–07–03.

It is important to ensure that, during erection of the installation, the insulation (and sheathing) of conductors and cables are not damaged by, for example, rough handling and bad workmanship by electrical operatives and other tradesmen. It will often be necessary to provide additional temporary mechanical protection to cables during the course of construction. When using a cable for the first time, it will be necessary to seek the manufacturer's advice regarding, for example, installation methods and temperature tolerances both for installation and in service – some cable sheaths and insulations are liable to fracturing when handled at low temperatures (see also Chapter 10 of this Guide).

Some equipment may contain live parts which have functional insulation only (e.g. varnishes, paint and lacquers as in motors) and these should not be regarded as providing the necessary insulation to protect against direct contact and must therefore be within enclosures or behind barriers in order to provide the necessary protection.

5.3.3 Protection by barriers or enclosures

Four regulations, namely Regulations 412–03–01 to 412–03–04, deal with this protective measure which is one that is commonly used, in conjunction with insulation, in the manufacture of electrical installation equipment. It is a requirement that live parts are to be inside enclosures or behind barriers which provide a degree of protection to at least IP2X or IPXXB (see BS EN 60 529 and Table 10.10 of this Guide) ingress protection: preventing ingress of 12 mm diameter objects such as fingers (see the standard test finger in BS 3042). There is, however, an exception to this rule in that larger apertures are permitted if such are necessary to facilitate either replacement of parts or to allow proper functioning of the equipment. This exemption is only permitted if suitable precautions are taken to prevent unintentional contact (by persons or livestock) with live parts. It also has to be ascertained that persons, such as operators, are fully aware that such live parts should not be touched. Understandably, because of the practical difficulties involved, this exception of the rule is rarely invoked. Regulation 412–03–02 lays down an additional condition relating to the top surface of an item of equipment which is also readily accessible in that IP4X degree of protection is required for that surface: preventing ingress by objects of 1 mm diameter such as small wires, tools, insects and general debris.

Additionally, barriers and enclosures need to exhibit the necessary stability and durability to maintain the necessary IP degree of protection for the lifespan of the installation, taking account of the environmental conditions and external influences. It should go without saying (but Regulation 412–03–03 does just that) that barriers and enclosures need to be properly constructed and securely affixed in their intended place in order to fulfil their intended function.

Regulation 412–03–04 lays down the alternative conditions relating to the removal of a barrier or opening of an enclosure. The removal or opening must only be achievable by the use of a key or a tool (e.g. screwdriver). If this arrangement is not available, or otherwise impracticable, then arrangements need to be made within the equipment so that live parts are isolated from the supply *before* it is possible to open the enclosure or remove the barrier. Restoration of supply is prohibited before the refitting of those parts. Alternatively, an intermediate barrier (to IP2X or IPXXB) is to be fitted which again is to be removable only by use of a key or tool. Equipment excepted from this general rule are ceiling roses (BS 67), pull-cord switches (BS 3676), bayonet cap lampholders (BS 5042 and BS EN 61184) and Edison screw (ES) lampholders (BS EN 60 238) (i.e. access to live parts is permitted to these accessories without the use of a tool).

The regulations concerning the application of these measures, Regulations 471–05–01 and 471–05–02, add very little in terms of requirements and essentially reiterate that this measure is intended to prevent or deter contact with live parts. Where the exception to the rule of requiring IP2X or IPXXB is invoked then the opening is to be as small as is consistent with proper functioning or the replacement of parts.

5.3.4 Protection by obstacles

The requirements of Regulations 412–04–01 and 412–04–02 are intended to prevent unintentional contact with live parts by providing a physical obstacle to those parts. It is not the intention to embody measures that would prevent intentional contact by deliberate circumvention of the obstacle. An obstacle may be effected in one of two ways or both; by providing obstacles to prevent unintentional contact with live parts when energised. Furthermore, the latter regulation requires the obstacle to be secure so as prevent unintentional removal.

This measure may only be used in areas accessible only to skilled persons or instructed persons directly under the supervision of a skilled person (471–06–01) and, not surprisingly, it is not a measure suitable for applying to special installations or locations including those addressed in Part 6. Regulation 471–13–01, in granting special provisions and exceptions, permits, in areas to which only skilled or instructed personnel have access, the use of an obstacle or by placing out-of reach where both the following conditions are met:

- areas reserved for skilled or instructed personnel to be clearly designated and labelled, and
- each passageway or working platform for an open-type switchboard or the like to be adequate for operating and maintaining equipment.

Additionally, sufficient space to be provided to allow personnel to back away from equipment and to pass one another without difficulty.

5.3.5 Protection by placing out of reach

Regulation 412–05–01 addresses the situation of installing conductors between buildings and structures or, of course, within a building and calls for the standards laid down in the Electricity Supply Regulations 1988 (as amended) to be adopted for such work; this requirement applies equally to bare and insulated overhead lines. Regulation 412–05–02 stipulates that no live part is to be within 2.5 m or 'arm's reach' of any exposed-conductive-part, any extraneous-conductive-part or any bare live part of any other circuit (see Figure 6.4 for 'arm's reach'). Regulation 412–05–03 permits 'arm's reach' to be measured from an obstacle formed by a handrail, mesh, screen or the like, if it affords at least IP2X degree of protection. There is a recognition, in Regulation 412–05–04, that where bulky or long conductive objects are handled, the distances given in the preceding regulations may need to be modified. This would apply, for example, where long metallic ladders or mobile scaffolding are likely to be used in the normal course of events. Agricultural and industrial premises and construction sites are examples of locations where long metallic ladders etc. may be encountered.

As with obstacles, this measure may be used in areas accessible only to skilled persons or instructed persons directly under the supervision of a skilled person (471–07–01). It is not, of course, a measure suitable for applying to special installations or locations including those addressed in Part 6. In any event the measure should be treated as a 'last resort' and used only where other measures are wholly impracticable in the particular circumstances. If used within, or in the vicinity of, buildings, particular care is needed in siting conductors. Consideration of the normal activities (including working practices) of the site and maintenance procedures is essential. Where this measure is used, the exposed (bare) conductors would be kept to an absolute minimum required for the operational reasons, positioned at a minimum of 'arm's reach' (see Figure 6.4). A sufficient number of warning notices should be placed in conspicuous positions to warn personnel of the dangers from touching live conductors. Access to such areas should, where necessary, be restricted by, for example, locks and/or permits. Persons authorised to work in such areas would have received sufficient training and have acquired the necessary protective gear. If practical, RCD protection of such conductors should also be considered by the designer in these circumstances.

5.3.6 Special provisions and exceptions

Regulation 471–13–01 calls for only skilled or directly supervised persons (see item 5.3.8 of this Guide for definitions) to be permitted access to areas in which the protective measure of 'obstacles' or 'placing out-of-reach' is used. Regulation 471–13–03 goes on to require that such reserved areas be visibly marked with clear and unambiguous warning signs forbidding unauthorised entry (see Figure 9.14 for an example of such a notice).

In the case of an open-type switchboard or other equipment having dangerous exposed live parts, the requirements for the working platform and passageways are laid down in Regulation 471–13–02 which calls for adequate space for authorised operatives to:

- operate the equipment, and
- maintain the equipment, and
- have sufficient room for at least two persons to pass each other without the risk of danger, and
- have abundant space to allow operatives to back away from equipment.

5.3.7 Supplementary protection against direct contact by residual current device

It has long been recognised that some measure of supplementary protection against direct contact can be provided by a residual current device. For example, where a fixed cable or flexible cord sheath and insulation has been damaged, perhaps accidentally, to the extent that live conductors are exposed to touch, a residual current device would provide a measure of protection to a person coming into contact with that live part and with earthy parts. It should however be stressed that a residual current device will not 'see' any current flow in the case of contact between live parts only (e.g. between phase and neutral) and therefore no protection can be afforded in this respect.

Regulation 412–06–01 clearly states that this measure cannot be used as a *sole* means of protection against direct contact and requires at least one of the four measures previously described to be employed. Additionally, according to Regulation 412–06–02, where supplementary protection is to be provided, the residual current device needs to have a 30 mA (or more sensitive) rated residual operating (tripping) current and must operate within 40 ms when a residual test current of $5I_{\Delta n}$ (e.g. 150 mA where $I_{\Delta n} =$ 30 mA) is applied (see BS 4293, BS 7071, BS 7288, BS EN 61 008–1 and BS EN 61 009–1, as appropriate, and IEE Guidance Note No 3).

This measure is intended to reduce the risk of electric shock where basic insulation or other protective measures against direct contact has broken down due to mechanical damage or other actions which have rendered it ineffective. Examples of the use of residual current devices to provide this supplementary protection may include laboratories, vehicle test bays, garage workshops and repair shops and, in the domestic housing environment, where portable or mobile equipment, such as electric lawnmowers, are used outside the earthed equipotential zone.

5.3.8 Protection against direct contact, general points

The four basic protective measures and the application of those measures are intended to prevent contact with live parts and Table 5.5 lists these

Table 5.5: Direct contact protective measures and their applications and restrictions

Protective measure	**Examples of application**	**Restrictions**
Insulation.	Conductors, switchgear, etc. Appliances.	None.
Barriers and enclosures.	Switchgear, etc. Appliances.	None.
Obstacles.	Factory sub-station switchboards.	Access only by skilled and instructed persons. Not for use in locations of increased shock risk, including those addressed in Part 6 of BS 7671.
Placing out of reach.	Overhead distribution conductors. Overhead electric cranes.	Access only by skilled and instructed persons. Not for use in locations of increased shock risk, including those addressed in Part 6 of BS 7671.
Supplementary protection by RCD.	Generally applicable.	Never to be used as the sole protective measure.

measures and gives examples of their application together with restrictions on their use, as appropriate.

'*Skilled person*' is defined in Part 2 of BS 7671 as '*a person with technical knowledge or sufficient experience to enable him/her to avoid dangers which electricity may create*'.

'*Instructed person*' is defined in Part 2 of BS 7671 as '*a person adequately advised or supervised by skilled persons to enable him/her to avoid dangers which electricity may create'.*

5.4 Protection against indirect contact

5.4.1 General

Where measures intended for protection against direct contact break down (e.g. insulation failure) this usually results in a fault between live conductors (short-circuit) and/or an earth fault. Consequently exposed-conductive-parts may become live and there is a hazard from indirect contact for which the protective measures employed must perform a vital role in preventing electric shock (as defined).

There are five basic measures for providing protection against indirect contact (which is the contact made by persons or livestock with exposed-conductive-parts made live under earth fault conditions). The prescribed protective measures take account of the likely touch voltages and the duration that the fault may persist and restrict these parameters to safe limits.

Part 4, Chapter 41, Section 413 deals with this subject and Section 471 addresses the application aspects of these protective measures. Table 5.6 shows the correlation between the protective measures and their application. Additionally, other Parts, Chapters and Sections are listed where they are particularly relevant.

Table 5.6: Protection against indirect contact – correlation between the measures and their application

Ref	Protective measure and Regulations		Application Regulation	Objective	Applications	Other relevant references
	Measure	Regulation				
A	General.	413-01-01	471-08	To prevent electric shock from indirect contact.	General.	Chapter 53 *Switchgear,* Chapter 54 *Earthing arrangements and protective conductors.* Part 6 *Special installations or locations,* Rows J, K, L, M, N and O in this table below.
B	EEBADS – General.	413-02-01 to 413-02-05	471-08-01 to 471-08-08	To provide the necessary protective measures so that the magnitude and duration of the voltages occurring between simultaneously accessible (conductive) parts under earth fault conditions do not cause danger.	General.	
C	EEBADS – TN systems.	413-02-06 to 413-02-17			General – in TN systems.	
D	EEBADS – TT systems.	413-02-18 to 413-02-20			General – in TT systems.	
E	EEBADS – IT systems.	413-02-21 to 413-02-26			General – in TT systems.	
F	Class II or equivalent insulation.	413-03-01 to 413-03-09	471-09-01 to 471-09-04	To prevent any exposed-conductive-parts becoming live by requiring reinforced or supplementary insulation in addition to basic insulation.	General and for special locations where equipment is of suitable construction.	713-05-02
G	Non-conducting location.	413-04-01 to 413-04-07	471-10-01	To prevent simultaneous contact between conductive parts which may become charged through insulation failure.	Installations of a special nature and under effective supervision.	713-08-01 713-08-02
H	Earth-free local equipotential bonding.	413-05-01 to 413-05-04	471-11-01	To prevent dangerous voltages occurring between conductive parts by maintaining accessible parts at substantially the same potential.	Earth-free installations of a special nature and under effective supervision.	—
I	Electrical separation.	413-06-01 to 413-06-05	471-12-01	To prevent exposed-conductive-parts from attaining a potential with respect to Earth.	Can be applied to individual circuits supplying one item of current-using equipment or to installations of a special nature and under effective supervision.	—

Table 5.6 continued: Protection against indirect contact – correlation between the measures and their application

Ref	Protective measure and Regulations		Application Regulation	Objective	Applications	Other relevant references
	Measure	Regulation				
				Other related subjects		
J	Main equipotential bonding.	413-02-02	—	To maintain conductive parts at substantially the same potential.	Required where EEBADS is employed.	547-02-01 and 547-02-02
K	Supplementary equipotential bonding.	413-02-27 413-02-28	See 471-08-01	To maintain conductive parts at substantially the same potential, locally.	Required where EEBADS is employed in special locations and elsewhere.	547-03-01 to 547-03-05
L	Special provisions and exceptions.	—	471-13-01 to 471-13-04	To make provision for special areas restricted to skilled and instructed personnel.	Applicable only to areas restricted to skilled and instructed personnel.	—
M	Automatic disconnection and reduced low voltage systems.	—	471-15-01 to 471-15-07	To provide particular requirements peculiar to this measure.	Section 604 *Construction site installations.*	—
N	Functional extra-low voltage.	411-03-01	471-14-01 to 471-14-06	To provide particular requirements peculiar to this measure.	Note: Other references listed are the principal ones but reference to other parts of BS 7671 will be required as necessary.	
O	Supplies for portable equipment outdoors.	—	471-16-01 471-16-02	To provide particular requirements to meet the additional hazards associated with the use of equipment outdoors.		

Regulation 413–01–01 sets out the five basic protective measures relating to indirect contact and calls for at least one of these to be employed. It further makes reference to Section 471 which addresses the application aspects of the measures. Generally these measures will be used separately though it may sometimes be appropriate for more than one measure to be used together (e.g. non-conducting location and electrical separation).

Obviously, some of these measures are more widely used than others and restrictions in their use are placed on more than one in certain circumstances. Protection by earthed Equipotential Bonding and Automatic Disconnection of Supply (EEBADS) is by far the most commonly applied measure of providing the necessary protection. It is worth noting that automatic disconnection of supply is *not* on its own an option and therefore earthed equipotential bonding will always be required if this method is used.

The various requirements for EEBADS depend to a large extent on the type of system and in particular the earthing arrangements of the supply and of the installation. In addition to the general requirements, particular demands are made with regard to TN systems (supply source earthed with earthing conductor provided to installation), TT systems (supply source earthed without provision of earthing conductor to installation) and IT systems (source isolated from Earth or earthed through a high impedance). IT systems are not widely used in the UK and indeed public suppliers of electricity are required by the Electricity Supply Regulations 1988, (as amended) to earth their systems and this is usually effected by earthing the star-neutral point of their transformers. Thus for supplies derived from the public supply network, an IT system will not be available by virtue of this requirement to earth the system source via a low impedance earth electrode (normally not exceeding 20 Ω).

5.4.2 General requirements for EEBADS

The fundamental principle of the EEBADS method of protection against electric shock (indirect contact) is that the characteristics of the device(s) providing protection must be co-ordinated with the system earthing arrangements and the phase-earth loop impedance of the circuit so protected. This is necessary to limit the touch voltages between simultaneous parts (both exposed and extraneous) to such magnitude and duration so as not to cause danger during earth fault conditions. The underlying principle for this method of protection is that fault current is detected by the circuit protective device, automatic disconnection results and therefore the fault is not allowed to persist indefinitely (Regulation 413–01–04). Chapter 11 of this Guide deals with protective devices that are commonly used for protection against indirect contact.

Figure 5.2 illustrates the various touch voltages that occur during earth fault conditions between exposed-conductive-parts and between exposed-conductive-parts and extraneous-conductive-parts. Four items of current-using equipment with exposed-conductive-parts (connected to the MET via circuit protective conductors) are shown together with an extraneous-conductive-part (connected to the MET via a main equipotential bonding

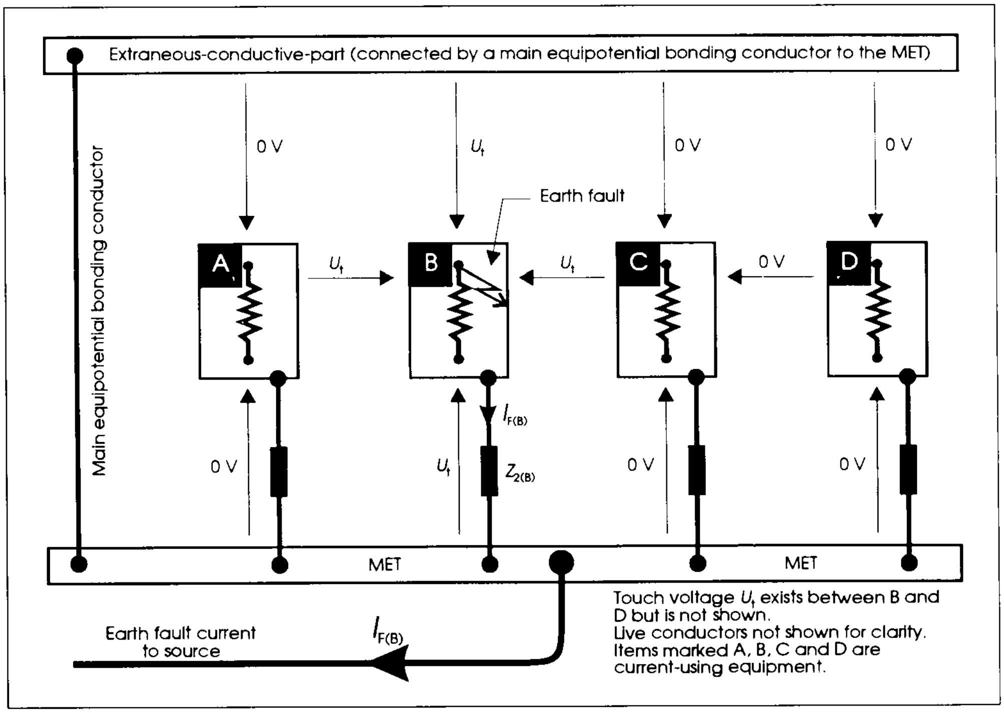


Figure 5.2: Voltage distribution between conductive parts under earth fault conditions

conductor). For clarity, only earthing, bonding and circuit protective conductors are shown.

An earth fault (of negligible impedance) has occurred on the exposed metalwork of item B and earth fault current, $I_{F(B)}$, flows from the source through the phase conductor, through the cpc to the MET and on via the earthing conductor to the supply source earthed neutral point. The magnitude of the earth fault current $I_{F(B)}$ will depend on the nominal voltage to Earth, U_o, and the total phase-earth loop impedance, $Z_{s(B)}$, at equipment item B, as given in Equation 5.1:

$$I_{F(B)} = \frac{U_o}{Z_{s(B)}} \tag{5.1}$$

The voltage, U_t, between the earthed metalwork of equipment B and the MET will be the product of the fault current $I_{F(B)}$ and the cpc impedance, $Z_{2(B)}$, of the circuit feeding equipment B given by Equation (5.2) or, if preferred, that given in Equation (5.3).

$$U_t = I_{F(B)} \times Z_{2(B)} \tag{5.2}$$

$$U_t = \frac{U_o \times Z_{2(B)}}{Z_{s(B)}} \tag{5.3}$$

By way of example, take the cpc impedance of circuit B to be 0.38 Ω and the total phase-earth loop impedance of that circuit to be 0.9 Ω. If the circuit nominal voltage to earth, U_o, is 230 V, by substituting these values in to Equation (5.3) the value of 97.1 V for U_t is obtained as given in Equation (5.4).

$$U_t = \frac{230 \times 0.38}{0.9} = 97.1 \text{ V} \tag{5.4}$$

From this example it can be seen that substantial touch voltages can exist during fault conditions and these will be present not only between equipment B and the MET but also between it and other exposed-conductive-parts and extraneous-conductive-parts which will be (assuming insignificant fault current flow in the main equipotential bonding conductor) at approximately the same potential as the MET. Voltages will therefore also be present between B and A, B and C, B and D, and B and the extraneous-conductive-parts.

It will be seen that in this example, the touch voltage was at a considerably higher level than is generally considered to be a safe (50 V for dry conditions) value. It is therefore necessary to establish proper protective device co-ordination so that the duration of these touch voltages does not give rise to danger and it may be necessary, in certain circumstances, to provide supplementary equipotential bonding to reduce such touch voltages.

Regulation 413–02–01 acknowledges that this protective measure (EEBADS) is for general application and refers to the particular regulations applicable when using this option with regard to the system type and earthing arrangements. Regulation 471–08–01 confirms this view and goes on to make clear that for some installations and locations of increased shock risk (including some of those addressed in Part 6 of BS 7671) protection against indirect contact will be by means of an RCD and the maximum permissible fault clearance times reduced. Additionally, where appropriate, supplementary equipotential bonding may be required.

Regulation 471–08–07 precludes the use of an RCD in a circuit which employs a Protective Earth and Neutral (PEN) conductor for the obvious reason that the protective conductor and neutral conductors need to be separate for the RCD to sense fault currents or earth leakages.

For all installations employing the EEBADS method of protection against indirect contact, a circuit protective conductor (cpc) is required to be provided to, and properly terminated in, every electrical point within the wiring system and at every accessory, except lampholders, which have exposed-conductive-parts.

As mentioned earlier and confirmed by Regulation 413–02–02, main equipotential bonding is required if this measure is to be used. This bonding will need to meet the requirements of Section 547 *Protective bonding conductors* (which is discussed in Chapter 12 of this Guide). The regulation gives a list of examples of extraneous-conductive-parts which need to be bonded to the Main Earthing Terminal (MET) of the building:

- water service pipes,
- gas service pipes,
- other service pipes,
- central heating and air conditioning systems,
- exposed metallic structural parts of the building,
- lightning protection systems.

This list should not be regarded as exhaustive and in particular cases there may well be other services (e.g. oil supply line) or the like entering the earthed equipotential zone which may fall within the definition of an extraneous-conductive-part (i.e. likely to introduce a potential, generally Earth potential) and which would therefore also need main bonding.

The purpose of providing equipotential bonding is to create an earthed equipotential zone. An earthed equipotential zone is one in which exposed-conductive-parts and extraneous-conductive-parts are connected together (and to the means of earthing) so that the potential differences, or touch voltages, under earth fault conditions are such that they will not cause electric shock, as defined. In fact, it is only truly equipotential under earth fault conditions where the fault occurs on the supply feeder (i.e. outside the zone). Earth faults developing in the installation will produce touch voltages between the relevant exposed-conductive-part of the faulty circuit and other conductive parts (exposed and extraneous). In effect, this equipotential bonding provides the circumstances where the maximum touch voltage created by an earth fault within the zone is the voltage appearing between the MET and the point at which the earth fault occurs (i.e. the product of the cpc impedance and the earth fault current, in most cases). Additionally, this main equipotential bonding provides protection in the event of an earth fault developing on the supply cable (or distribution circuit) which would result in a fault voltage appearing on the MET, with respect to 'true earth'. By bonding, all conductive parts are substantially maintained at this potential and there is no dangerous touch voltage between conductive parts and risk of electric shock is prevented, at least within the earthed equipotential zone. This Regulation also calls for the bonding of any metallic sheaths of telecommunications cables but requires that the cable owner's consent be obtained (preferably in writing) before such bonding is carried out.

Water service pipes now come both in metallic and insulating material form with the latter used for supply pipework and internal services pipework including closed circuit heating applications. The introduction of such non-metallic pipework has created a few problems for the electrical installation designer. The questions of whether or not such pipework needs to be bonded has to be addressed and if it needs to be bonded how to overcome the practical difficulties in effecting such a bonding connection.

As to the first question, the designer needs to determine whether or not the non-metallic pipework is an extraneous-conductive-part, as defined (i.e. likely to introduce a potential). Whilst water in its distilled form is relatively non-conductive on par with soil (resistivity of water: 10^2–10^5 Ωm, soil resistivity: 10^2–10^4 Ω), *raw* water with all its various elements held in suspension, must, in the absence of more precise knowledge, be considered to be conductive so a further question is posed: ‘how conductive?’ This question needs to be addressed. Throughout the United Kingdom the conductivity of water varies enormously and in the absence of more detailed knowledge the designer should consider it such as to fall within the definition of an extraneous-conductive-part.

Regulation 413–02–02 now also calls for each separate building to be subjected to the main equipotential bonding requirements and therefore these separate buildings will each need their own MET. In many cases, these METs will also need linking by suitable protective conductors to the MET in the building in which electricity is supplied (this is discussed further in Chapter 12 of this Guide; see Figure 12.8).

Regulations 413–02–03 stipulates that simultaneously accessible exposed-conductive-parts are to be connected to the same earthing system and, of course, this may be effected individually, or in groups or all together collectively as in, for example, a trunking system used as a protective conductor.

There are three important issues for consideration when employing the EEBADs method as detailed in Regulation 413–02–04:

- the characteristics of the protective device providing automatic disconnection,
- the earthing arrangements, and
- the impedance of the circuit to be protected.

These three issues need careful assessment and co-ordination such that the duration and magnitude of touch voltages appearing between conductive parts do not give rise to danger.

The various requirements relating to protection by EEBADS are laid down in Regulations 413–02–06 to 413–02–26 but other measures, not identified, are not ruled out provided they are no less effective in terms of safety.

Temperature rise of circuit conductors during the clearance of a fault, and the effect of that rise on conductor impedances, needs to be carefully assessed. Fault currents can be, and very often are, of the order of several thousand amperes resulting in conductor temperature rise above their normal operating temperature and a consequential increase of conductor resistance and hence impedance. Inductive and capacitive reactance is not a function of temperature and it is only necessary to consider the temperature effects on resistance. An assessment may be made by applying the formula given in Equation (5.5) (see also Figure 5.3).

In consideration of the effects on the resistance of copper conductors (Regulation 413–02–05) from ambient temperature or operating temperature to a higher temperature, it is normal to take the approximate value of copper resistance/temperature coefficient at 20°C, α_{20}, of 0.004 per °C and application of the following Equation:

$$R_t = R_{20}\,[1 + \alpha_{20}(t - 20)] \tag{5.5}$$

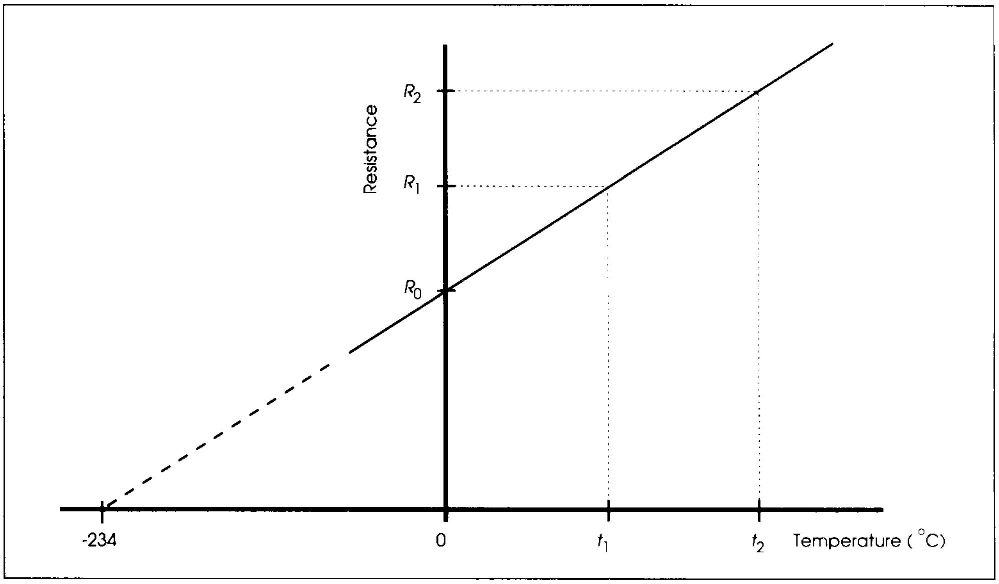


Figure 5.3: Variation of resistance of copper with temperature

where R_{20} = the conductor resistance at 20°C
R_t = the conductor resistance at temperature t
α_{20} = the resistance/temperature coefficient at 20°C
t = temperature considered (°C)

5.4.3 EEBADS for TN systems

The first regulation applicable to TN systems, 413–02–06, calls for exposed-conductive-parts to be connected by a protective conductor to the MET and then on to the earthed point (neutral) of the supply source (usually a transformer). This regulation refers also to Regulations 542–01–02, 542–01–03 and 542–01–05 which relate to the arrangements for earthing conductors which is dealt with in Chapter 12 of this Guide.

There are only two types of protective devices, listed in Regulation 413–02–07, as suitable for protection against indirect contact on TN systems:

- overcurrent protective devices (e.g. fuse, MCB or MCCB, etc.), or
- residual current devices.

It should be noted that BS 3871 is now an obsolete standard, and miniature circuit breaker (MCB) is no longer the correct term, being replaced by the generic term ‘circuit-breaker’. However, as ‘old habits die hard’ and the fact that data of these devices will still be needed when reviewing existing installations, both reference to the standard and MCB is retained.

This Regulation additionally demands that where an RCD is used on a TN-C-S system, a PEN (Protective Earth and Neutral) must not be used on the load side of the device and that the load protective conductor connection must be made on the supply side of the device. Without this latter provision, the RCD would not 'see' any earth fault current and would not provide the necessary detection and consequential automatic disconnection.

The co-ordination required by Regulation 413–02–04 is satisfied for TN systems, according to Regulation 413–02–08, if, and only if, Equation (5.6) is satisfied:

$$Z_s \leqslant \frac{U_o}{I_a} \tag{5.6}$$

where Z_s = earth fault loop impedance
U_o = nominal voltage to Earth
I_a = current causing automatic disconnection within the permitted time given in Table 41A of BS 7671, or within 5 s when the requirements of Regulations 413–02–12 and 413–02–13 are met (e.g. additional bonding carried out).

It should be noted that the maximum disconnection times given in Table 41A of BS 7671, embodied in Regulation 413–02–08, and summarised in Table 5.7, must be modified (reduced) when applied to some special installations and locations including those detailed in Part 6 of BS 7671. Also worthy of note is that nominal voltages (to Earth) of below 120 V are not given here but are dealt with, to some extent, elsewhere in BS 7671.

As made clear by Regulation 413–02–09, the maximum disconnection times given in Table 41A relate solely to circuits supplying portable or hand-held Class I equipment (with earthed metallic parts). It does not

Table 5.7: Maximum permitted disconnection times for TN systems (non-special installations and locations)

Nominal voltage to Earth, U_o	**120 V**	**230 V**	**277 V**	**400 V**	**> 400 V**	**Regulation**
Socket-outlet circuits.	0.8 s	0.4 s	0.4 s	0.2 s	0.1 s	413–02–08 413–02–09
Socket-outlet circuits and final circuits supplying portable and hand-held equipment, where cpc impedance does not exceed the values given in Table 41C of BS 7671.	5.0 s	5.0 s	5.0 s	5.0 s	5.0 s	413–02–12
Final circuits for portable equipment.	0.8 s	0.4 s	0.4 s	0.2 s	0.1 s	413–02–09
Final circuits for hand-held equipment.	0.8 s	0.4 s	0.4 s	0.2 s	0.1 s	413–02–09
Distribution circuits.	5.0 s	5.0 s	0.5 s	5.0 s	5.0 s	413–02–13
Circuits for stationary equipment where the requirements of Regulation 413–02–09 do not apply.	5.0 s	5.0 s	5.0 s	5.0 s	5.0 s	413–02–13

Notes: (1) The nominal voltages given apply to voltages maintained within statutory limits.
(2) For intermediate values of voltage, take the higher value.

relate to final circuits feeding stationary equipment connected by a plug and socket-outlet provided precautions are taken to prevent the use of the socket-outlet for hand-held equipment. This may be effected by, for example, the use of a non-standard socket-outlet or by other acceptable means. Table 41A does not relate to reduced low voltage circuits which are addressed separately by Regulations 471–15–01 to 471–15–07.

Regulations 413–02–10 and 413–02–11 set out the references to tables detailing maximum phase-earth loop impedances for particular devices for both 0.4 and 5 s disconnection times. These are summarised in the Table 5.8.

Table 5.8: Tables for maximum Z_s for 0.4 s and 5 s disconnection for $U_o = 230$ V

Protective devices	**0.4 s disconnection**	**5 s disconnection**
MCB Type B (BS EN 60 898)	Table 41B2	Table 41B2
MCB Type C (BS EN 60 898)	Table 41B2	Table 41B2
MCB Type D (BS EN 60 898)	Refer to manufacturer	Refer to manufacturer
HBC fuses (BS 88 'gG')	Table 41B1	Table 41D
HBC fuses (BS 88 'gM')	Refer to British Standard	Refer to British Standard
HBC fuses (BS 1361)	Table 41B1	Table 41D
Cartridge fuses (BS 1362)	Table 41B1	Table 41D
Semi-enclosed (rewirable) fuses (BS 3036)	Table 41B1	Table 41D
Other devices	Refer to British Standard or manufacturer	Refer to British Standard or manufacturer

It is important to note that the tables given in BS 7671 have not changed in the data given for 230 V as opposed to the 240 V nominal voltages previously referred to. The following derivations hold true for the current tables based on 230 V.

The tabulated maximum values of phase-earth loop impedance, Z_s, given in Tables 41B1, 41B2 and 41D of BS 7671 are derived from the time/current characteristic for the various protective devices given in Appendix 3. For example, for a BS 88 'gG' (Parts 2 and 6) fuse of nominal rating, $I_n = 40$ A, the operating current, I_a, for 0.4 s disconnection, is given as 280 A which, if related to a nominal voltage 240 V, the maximum Z_s is 0.857 Ω ($Z = V \div I = 240 \div 280$). This derived value, rounded up to 0.86 Ω, will be found in Table 41B1 of BS 7671. It is important to note that although the nominal voltage of supplies is often 230 V, the tabulated values in Tables 41B1, 41B2 and 41D have remained unchanged and remain based on 240 V. Regulation 471–08–02 makes clear that tabulated maximum permissible Z_s values in the tables of the Regulations apply if, and only if, the circuit's exposed-conductive-parts and extraneous-conductive-parts are located within the earthed equipotential zone.

For convenience Table 5.9 lists the limiting earth loop impedance values for common protective devices used for protection against indirect contact. It should be noted that the data given relate to the design and not the measured values which will need modification due to temperature considerations (see Regulation 413–02–05 and Chapter 17 of this Guide).

It should be noted that the BS 1362 cartridge fuse fitted in a 13 A plug is there for the purpose of protecting the flexible cord against short-circuit.

Table 5.9: Limiting values of earth-loop impedances (Ω) for common circuit protective devices, for indirect contact, operating on 230 V

Ref	**Nominal rating (A)**	**Fuses**								**Miniature circuit-breakers to BS 3871 or BS EN 60 898** (2)					
		BS 88 'gG' Parts 2 and 6		**BS 1361**		**BS 3036**		**BS 1362**(3)		**Type 1**	**Type 2**	**Type B**	**Types 3 and C**	**Type D**	**Type 4**
		0.4s	**5s**	**0.4s**	**5s**	**0.4s**	**5s**	**0.4s**	**5s**	**0.1 and 5 s**					
A	5	—	—	10.90	17.10	10.00	18.5	2.53	4.00	12.00	6.86	—	4.80	2.40	0.96
B	6	8.89	14.10	—	—	—	—	—	—	10.00	5.71	8.00	4.00	2.00	0.80
C	10	5.33	7.74	—	—	—	—	—	—	6.00	3.43	4.80	2.40	1.20	0.48
D	13	—	—	—	—	—	—	2.53	4.00	—	—	—	—	—	—
E	15	—	—	3.43	5.22	2.67	5.58	—	—	4.00	2.29	—	1.60	0.80	0.32
F	16	2.82	4.36	—	—	—	—	—	—	3.75	2.14	3.00	1.50	0.75	0.30
G	20	1.85	3.04	1.78	2.93	1.85	4.00	—	—	3.00	1.71	2.40	1.20	0.60	0.24
H	25	1.50	2.40	—	—	—	—	—	—	—	—	—	—	—	—
I	30	—	—	1.20	1.92	1.14	2.76	—	—	2.00	1.14	—	0.80	0.40	0.16
J	32	1.09	1.92	—	—	—	—	—	—	1.88	1.07	1.50	0.75	0.37	0.15
K	40	0.86	1.41	—	—	—	—	—	—	1.50	0.86	1.20	0.60	0.30	0.12
L	45	—	—	0.60	1.00	0.62	1.66	—	—	1.33	0.76	1.07	0.53	0.26	0.10
M	50	0.63	1.09	—	—	—	—	—	—	1.20	0.69	0.96	0.48	0.24	0.09
N	60	—	—	0.40	0.73	0.43	1.17	—	—	—	—	—	—	—	—
O	63	0.48	0.86	—	—	—	—	—	—	0.95	0.54	0.76	0.38	0.19	—
P	80	—	0.60	—	0.52	—	—	—	—	0.75	0.42	0.60	0.30	0.15	—
Q	100	—	0.44	—	0.38	—	0.56	—	—	0.60	0.34	0.48	0.24	0.12	—
R	125	—	0.34	—	—	—	—	—	—	—	—	0.38	0.19	0.09	—
S	160	—	0.27	—	—	—	—	—	—	—	—	—	—	—	—
T	200	—	0.20	—	—	—	—	—	—	—	—	—	—	—	—
U	250	—	0.16	—	—	—	—	—	—	—	—	—	—	—	—
V	315	—	0.12	—	—	—	—	—	—	—	—	—	—	—	—
W	355	—	0.09	—	—	—	—	—	—	—	—	—	—	—	—
X	400	—	0.08	—	—	—	—	—	—	—	—	—	—	—	—
Y	450	—	0.07	—	—	—	—	—	—	—	—	—	—	—	—
Z	500	—	0.06	—	—	—	—	—	—	—	—	—	—	—	—
A1	560	—	0.05	—	—	—	—	—	—	—	—	—	—	—	—
B1	630	—	0.04	—	—	—	—	—	—	—	—	—	—	—	—
C1	670	—	0.04	—	—	—	—	—	—	—	—	—	—	—	—
D1	710	—	0.03	—	—	—	—	—	—	—	—	—	—	—	—
E1	800	—	0.03	—	—	—	—	—	—	—	—	—	—	—	—

Notes: (1) The entries denoted by — represent either that the device is not commonly available or that by virtue of its characteristics it is not appropriate for protection against indirect contact.

(2) The impedance values are based on the 'worst case' limits allowed by the Standard and in certain cases where the manufacturer can claim closer limits than the Standard permits the values may be accordingly modified.

(3) The values given for the 5 A BS 1362 fuse are those for 13 A fuses because of the ease of replacement by electrically unskilled persons.

Where used in a fused connection unit (spur) it may be regarded as an acceptable means of protecting against indirect contact where circuit conditions allow.

Whilst the use of Type 4 was not precluded as devices for protection against indirect contact, their characteristics are such as to place severe restrictions on their use for such purposes owing to the high magnitude of fault current needed to effect operation and the consequential very low Z_s

limits. For other protective devices (e.g. MCCBs), reference to the relevant Standard and/or manufacturer will be necessary to obtain their operating characteristics.

It is important to note that the tabulated values in BS 7671 give maximum permissible impedances relating only to a nominal voltage, U_o, of 230 V. If other nominal voltages are to be used then the impedance values need modifying accordingly by the application of a factor equal to ($U_o \div 230$). For example, if U_o is 220 V, then a factor of 0.956 (i.e. 220 ÷ 230) would need to be applied to the impedance values given for 230 V. It will be seen that the overriding consideration is the magnitude of the fault current which will flow and not the impedance.

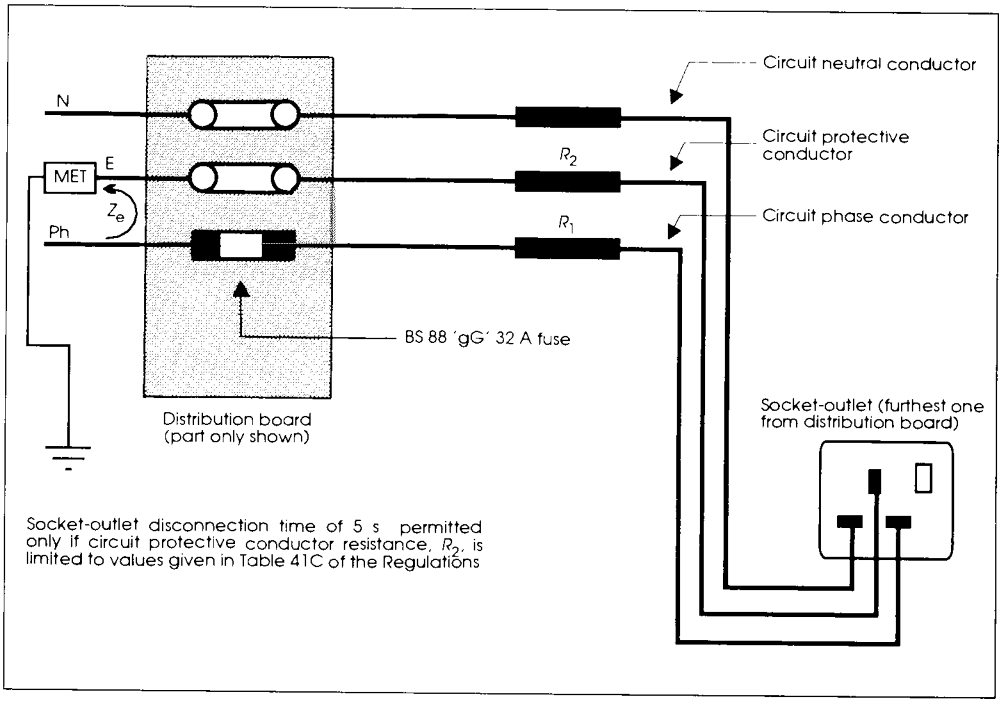
It is also worth noting that the values given in Table 41B2 of BS 7671 in respect of MCBs (to BS 3871 or BS EN 60 898) for 0.4 s and 5 s disconnection are in fact the same. The reason for this will be apparent when the time/current characteristics are viewed and it will be seen that for both disconnection times the device operates instantaneously (defined as within 100 ms) when the operating current, I_a, is flowing.

Regulation 413–02–12 embodies the 'alternative' method previously contained in Appendix 7 of the 15th Edition of the Wiring Regulations. It allows circuits feeding socket-outlets which would otherwise need disconnection in 0.4 s to be disconnected within 5 s provided the cpc impedance is limited to the values given in Table 41C of BS 7671. It will be seen that in permitting the longer disconnection time, restrictions are placed on the cpc impedance and hence the touch voltage.

Figure 5.4 illustrates a 230 V socket-outlet circuit (normally requiring disconnection in 0.4 s) which is permitted to disconnect in 5 s providing the cpc impedance, R_2, is limited to that given in Table 41C of BS 7671. By way of example, is a 32 A circuit protected by a BS 88 'gG' 32 A fuse where, according to Table 41D of BS 7671, Z_s is limited to 1.92 Ω for 5 s disconnection. The operating current, I_a, (for 5 s) is given by ($U_o \div Z_s$) = (230 ÷ 1.92) = 119.8 A. The limit on cpc impedance, R_2, for this device (given in Table 41C) is 0.34 Ω which would imply a touch voltage between the MET and the remote end of the cpc of 40.73 V (i.e. 119.8 × 0.34). Other than for some special installations or locations, this touch voltage would be considered safe, even for hand-held equipment, for the duration of 5 s.

Regulation 413–02–12 makes clear that the impedance of the cpc, R_2, relates to the point at which main equipotential bonding has been carried out or if additional bonding (see Chapter 12 of this Guide) has been undertaken, to that point.

For the first time in the Wiring Regulations, distribution circuits are addressed specifically in BS 7671 and Regulation 413–02–13 gives the maximum disconnection time as 5 s. Distribution circuits are, again for the first time, defined and may be equated to what are sometimes referred to as 'sub-main circuits'. This regulation also addresses circuits with differing disconnection times emanating from the same distribution board or distribution circuit. There has long been the recognition that an earth fault appearing on a circuit requiring disconnection within 5 s will affect other circuits which require a 0.4 s disconnection. There was the real possibility,



Socket-outlet disconnection time of 5 s permitted only if circuit protective conductor resistance, R_2, is limited to values given in Table 41C of the Regulations

Figure 5.4: Five second disconnection of socket-outlet circuits

not to say probability, that a touch voltage appearing on a distribution board, as a result of a 5 s earth fault clearance, being 'exported' to exposed-conductive-parts of a 0.4 s disconnection circuit (for example, a socket-outlet circuit feeding hand-held equipment). This touch voltage at the distribution board (and on the exposed-conductive-parts of the 0.4 s circuits) would remain for the 5 s duration of clearance. Clearly, this was most undesirable and this regulation, remedying the situation, demands further requirements to obviate this risk. So, when circuits of differing disconnection times emanate from a common distribution board or circuit, one of two alternative additional measures is required:

- equipotential bonding, sized as for main bonding (547–02–01) to be carried out at the distribution board connecting all extraneous-conductive-parts together with the protective conductor for the distribution circuit, or
- the final distribution circuit protective conductor impedance is limited to the values given in Table 41C of BS 7671 (or to (50 $Z_s \div U_o$) if the protective device employed to protect the distribution circuit is not listed in that table); where Z_s, is the limiting impedance for that device relating to 5 s disconnection.

Figure 5.5 illustrates the requirements relating to circuits with differing disconnection times emanating from a common distribution board. It

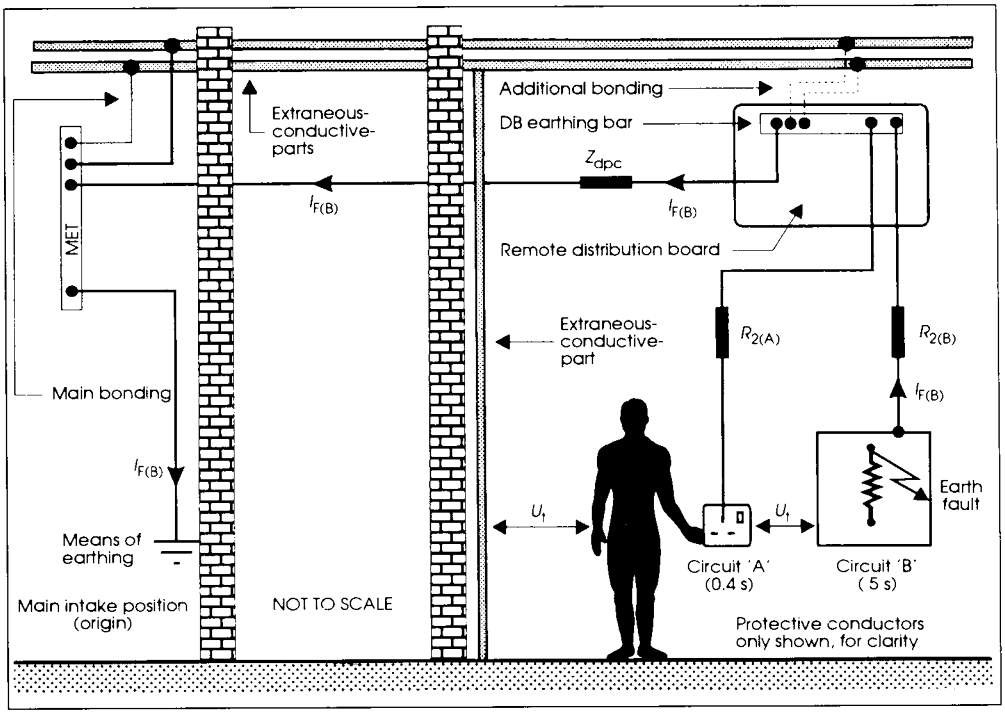


Figure 5.5: Circuits emanating from a common distribution board

represents the situation where a remote distribution board is fed via a distribution circuit (sub-main cable) from the main switchboard at the origin of the installation where main equipotential bonding connects the extraneous-conductive-parts to the MET. The distribution board feeds a number of 230 V final circuits, two of which are shown in the figure. Circuit A is a socket-outlet circuit requiring disconnection within 0.4 s to which a Class I hand-held appliance is plugged. Circuit B feeds fixed equipment requiring disconnection within 5 s. The figure shows only the protective conductors and their impedances are represented by resistors; Z_{dpc} represents the impedance of protective conductor of the distribution circuit (sub-main cable). $R_{2(A)}$ represents the impedance of circuit protective conductor of circuit A. $R_{2(B)}$ represents the impedance of circuit protective conductor of circuit B. For the purposes of this illustration the impedances of main equipotential bonding conductors may be neglected. It is assumed that no fault current will flow through any parallel paths which may be present.

By way of illustrating the requirements, circuit A is protected by a BS 88 'gG' 20 A fuse and circuit B is similarly protected by a BS 88 'gG' but rated at 32 A fuse. In order to show the voltages present under fault conditions it is necessary to attribute values to the various parameters. So let us assume that:

- the external earth loop impedance, Z_e, is 0.2 Ω,
- the impedance of the protective conductor of the distribution circuit, Z_{dpc}, is 0.6 Ω,

- the phase-earth loop impedance at the fixed equipment of circuit B, Z_s, is 1.92 Ω (the limit),
- the impedance of the circuit B cpc, $R_{2(B)}$, is 0.3 Ω.

Under earth fault conditions on the fixed equipment, circuit B, an earth fault current, $I_{F(b)}$, of approximately 120 A (i.e. 230 ÷ 1.92) and the approximate voltages appearing between various parts of the installation are as follows:

- between MET and distribution board: 72 V (i.e. 120 × 0.6),
- between distribution board and circuit B fixed equipment: 36 V (i.e. 120 × 0.3),
- between MET and circuit B fixed equipment: 108 V (i.e. 72 + 36),
- between extraneous-conductive-parts and circuit B fixed equipment: 108 V (i.e. 72 + 36).

It will be evident that the voltage, U_t, with respect to the MET (and with respect to the extraneous-conductive-parts) appearing on the distribution board (72 V) will also be 'exported' down the cpc of circuit A and on to the hand-held apparatus. This voltage will remain for the duration of clearance of the fault condition of up to 5 s. Clearly, this is an unsatisfactory state of affairs and must be remedied in accordance with Regulation 413–02–13 either:

- by effecting equipotential bonding between the distribution board and all extraneous-conductive-parts (sized as if for main equipotential bonding in accordance with Regulation 547–02–01), or
- by design of the distribution circuit protective conductor so that it complies with Table 41C of BS 7671 (which requires this distribution circuit protective conductor impedance not to exceed the values given in Table 41C of BS 7671 and this for 32 A BS 88 'gG' fuses is given as 0.34 Ω).

By taking the second option it can be seen in the above cited example that the touch voltage, U_t, between the hand-held appliance and extraneous-conductive-parts would be 40.8 V and by adoption of the alternative way of equipotential bonding the same touch voltage would be 36 V. Both methods are appreciably safer than had neither alternative method been employed, where U_t would be 72 V.

Had circuit B been protected by a similar but higher rated fuse, or indeed if there were other such larger rated fuses within the distribution board, the limiting value of the distribution circuit protective conductor impedance, Z_{dpc}, would be different in accordance with Table 41C of the Regulation. For example, had the distribution board fed a circuit which was protected by a BS 88 'gG' 50 A, Z_{dpc} would have been limited to 0.19 Ω.

Whilst the regulatory requirements relate to circuits emanating from a common distribution board, the designer should not ignore the situation where a number of distribution boards are located together and linked electrically by earthed metalwork (either deliberately or fortuitously). Where circuits of different disconnection times emanate, not from a common distribution board but from the same position in terms of electrical distribution, these should be considered in the same way as circuits from a common distribution board.

It may be argued that where miniature circuit-breakers to BS 3871 or BS EN 60 898 are used for all final circuits emanating from a common distribution board, consideration of the requirements of 413–02–13 need not be addressed. Disconnection will occur instantaneously (within 100 ms, as defined) whether or not they have been designed for 0.4 s or 5 s disconnection.

Similarly, with the smaller installation served only by one distribution board, or consumer's unit, no further consideration is necessary in this respect because the main equipotential bonding would meet the second alternative option given in the Regulation, namely that of additional bonding.

Where circuit-breakers are used to meet the requirement of this Regulation, the maximum phase-earth loop impedance must satisfy the formula given, $Z_s \leqslant (U_o \div I_a)$. If the device is listed in Table 41B2 of BS 7671, then the values given may be used if, and only if, the nominal voltage to earth, U_o, is 230 V. Where fuses are employed for such purpose, Table 41D of BS 7671 (413–02–14) may be used again if, and only if, U_o is 230 V. For devices not listed in the table and for nominal voltages to Earth other than 240 V, the formula $Z_s \leqslant (U_o \div I_a)$ must be observed.

Interestingly, Regulation 413–02–04 addresses the long recognised problem encountered when prescribed disconnection times cannot be met. This problem is often found on distribution circuits (or sub-mains) where the phase-earth loop impedance is such as to make automatic disconnection within the normal time limit of 5 s impossible when using an overcurrent protective device. For example, take a small distribution circuit protected against indirect contact (and overcurrent) by a BS 88 'gG' 200 A fuse. To disconnect within 5 s, the fault current would need to be not less than 1200 A and consequently Z_s must not exceed 0.20 Ω. If the phase-earth loop impedance was (calculated or measured), say, 0.25 Ω, then disconnection will take longer than 5 s and therefore further measures need to be applied. For the larger nominal current circuit the situation would be worse.

In such cases, where automatic disconnection times cannot be met by an overcurrent device, Regulation 413–02–04 requires the adoption of one of two alternative measures:

- local supplementary bonding to carried out at the remote end of the distribution circuit, or
- distribution circuit protection provided by an RCD.

The supplementary bonding requirement is a straightforward option whilst protection by RCD needs careful consideration. Not least amongst this consideration are the disruptive aspects associated with its operation. Inconvenience may be caused where, for example, an earth fault develops on a final circuit resulting in the operation of the RCD protecting the distribution circuit unless further measures are taken. Discrimination between an RCD and a downstream overcurrent protective device would be difficult, if not impossible, to achieve. The designer would also need to consider RCD protection of final circuits emanating from the distribution board. Discrimination between RCDs in series cannot be achieved on a fault current magnitude basis and can only be designed utilising the 'time' parameter. A timed delay on the upstream RCD can provide the necessary discrimination with a downstream RCD with no timed-delay operation (or shorter time delay) and if this method is adopted much of the inconvenience mentioned would be alleviated.

Regulation 413–02–04 also makes clear that where disconnection *cannot* be achieved within the prescribed time limits by using overcurrent devices (and either supplementary bonding or an RCD is employed to protect against indirect contact), consideration must also be given to protection against overcurrent. For example, a distribution circuit which may disconnect in 12 s may be perfectly acceptable from the viewpoint of indirect contact (provided supplementary bonding has been undertaken), but the requirements for overcurrent protection also need to be met for this disconnection time; it may be that a earth fault of 12 s will increase the temperature of the circuit conductors above the prescribed limiting temperature.

Where protection is provided by an RCD, the equation $Z_s I_{\Delta n} \leqslant 50\,\text{V}$ (see also modifications to this equation where some special installations and locations are involved) needs to be satisfied as required by Regulation 413–02–16; Z_s being the phase-earth loop impedance and $I_{\Delta n}$ being the rated residual operating current of the device, in amperes (see also Table 5.10 of this Guide). Regulation 413–02–17 also gives the option that where RCD protected circuits extend beyond the earthed equipotential zone (for example a remote or detached building), the exposed-conductive-parts of the extended installation *need not* be connected to the MET of the main installation. This extended installation would then need to be treated as part of a TT system with its own separate protection, including earth electrode, as detailed under TT systems (Regulations 413–02–18 to 413–02–20).

5.4.4 EEBADS for TT systems

TT systems are such that there is no direct connection between the installation MET and the earthed supply source (earthed neutral or starpoint)

Table 5.10: Maximum values for R_A corresponding to $I_{\Delta n}$ for RCD protected circuits

$I_{\Delta n}$ (Residual operating current of RCD) (mA)	**R_A (Resistance of earth electrode plus protective conductor resistance) (Ω)**
10	5000
30	1666
100	500
200	250
300	166

other than through the general mass of the Earth, and therefore particular additional requirements are necessary.

Regulation 413–02–18 states that every exposed-conductive-part protected by a single protective device must be connected to the MET and hence to a common earth electrode. It also recognises that where a number of RCDs are employed in series, these may each have their own electrode.

In such a TT system, protection against indirect contact may be provided in one of two ways as laid down in Regulation 413–02–19:

- by overcurrent protective devices, and/or
- residual current devices.

It should be noted that the Regulation states that RCD protection is the preferred option for reasons that will become obvious when considering the requirements of Regulation 413–02–20. This requires the equation, $R_A I_a \leqslant 50$ V, to be satisfied (where R_A is the sum of earth electrode and protective conductor resistances and I_a is the operating current of the device, which in the case of an RCD is $I_{\Delta n}$ (see Table 5.10)).

Only one application Regulation, 471–08–06, imposes additional requirements relating to an installation which forms part of a TT system; it calls for *all* socket-outlet circuits to be protected by an RCD complying with Regulation 413–02–16 (i.e. meeting the formula $Z_s I_{\Delta n} \leqslant 50$ V). Where socket-outlet circuits are likely to supply portable equipment for use outdoors, the RCD residual operating current must not be more than 30 mA for compliance with Regulation 412–06–02. For some Part 6 locations, the formula given here is modified to $Z_s I_{\Delta n} \leqslant 25$ V.

5.4.5 EEBADS for IT systems

The IT system, as stated earlier, is one in which the source is not earthed or is earthed via a high impedance. Regulation 413–02–21 reinforces this requirement in calling for no direct connection between a live conductor and Earth. When a connection is necessary it must be made through a high impedance such that if a single fault should occur, the fault current would be of such low magnitude so as not to cause danger from electric shock. A connection is sometimes required (via a high impedance) to reduce overvoltage and to dampen voltage oscillations but when used it is required to be such that any danger from electric shock from a single fault is obviated. Additionally, Regulation 413–02–24 requires that an insulation monitoring device be employed to detect and indicate a first fault condition between a live part and an exposed-conductive-part or Earth.

When the above conditions are met, it is not essential to disconnect a single fault occurring to an exposed-conductive-part or to Earth. As Regulation 413–02–22 points out, precautions still need to be taken to safeguard against the risk of electric shock from two faults occurring at the same time, by employing overcurrent protective devices or RCDs. Insulation monitoring devices may be used where, for example, a very high degree of reliability of the system is necessary and where an indication of a first fault is required in order for remedial work to be instigated.

Regulation 413–02–23 calls for all exposed-conductive-parts of the installation to be earthed and that Equation (5.7) be satisfied:

$$R_A \times I_d \leqslant V \tag{5.7}$$

where R_A = the sum of resistances of the installation earth electrode and the protective conductor(s) connecting it to the exposed-conductive-parts

I_d = first fault current (fault of negligible impedance between a phase conductor and an exposed-conductive-part (taking account of leakage currents, if any).

The treatment of a second fault condition depends on whether the exposed-conductive-parts are collectively earthed (by a single protective conductor) or earthed separately or in groups. For situations where a single protective conductor is to be employed, the requirements relating to TN systems are applied (Regulation 413–02–25) except that one of the two Equations (5.8) and (5.9) need to be satisfied.

For the situations where the neutral is *not* distributed (three-phase, three-wire system)

$$Z_s \leqslant \frac{\sqrt{3} \times U_o}{2 \times I_a} \tag{5.8}$$

where Z_s is the impedance of the phase-earth loop (phase conductor plus protective conductor of the circuit(s)), or

$$Z_s^* \leqslant \frac{U_o}{2 \times I_a} \tag{5.9}$$

where the neutral is distributed (as in single-phase or three-phase, four-wire systems),

where Z_s^* = impedance of the phase-earth loop (phase conductor plus protective conductor of the circuit(s))

I_a = fault current sufficient to cause disconnection in accordance with Table 41E of BS 7671 (or 5 s if permitted by Regulation 413–02–13).

For situations where exposed-conductive-parts are earthed in groups or individually, the requirements relating to TT systems need to be applied, in particular Regulation 413–02–20 and Equation (5.10):

$$R_A \times I_a \leqslant 50\ V \tag{5.10}$$

where R_A = the sum of earth electrode and protective conductor resistances

I_a = operating current of the device which in the case of an RCD is $I_{\Delta n}$. (See Table 5.10 of this Guide.)

Table 41E of BS 7671 gives maximum disconnection times for IT systems dependant on whether or not the neutral is distributed. Where the neutral is not distributed, disconnection needs to be much faster for compliance (e.g. for $U_o = 230$ V, disconnection is required within 0.4 s if the neutral is *not* distributed but otherwise 0.8 s for compliance with the Table 41E).

5.4.6 EEBADS – supplementary equipotential bonding

There are but two Regulations relating to the protective measure of supplementary equipotential bonding, 413–02–27 and 413–02–28. The former states that this measure is only applicable to Regulation 413–02–04 and to special installations or locations including those addressed in Part 6 of BS 7671. Regulation 413–02–04, as mentioned earlier, deals with the situation where automatic disconnection *cannot* be met by using an overcurrent device to also protect against indirect contact. It gives two alternative options, one of which is supplementary bonding (the other by RCD). As previously alluded to, the option of bonding should not be regarded as a 'soft' option *instead* of automatic disconnection because, at the very least, further consideration is required relating to the protection against overcurrent.

Supplementary equipotential bonding, where it is required to fulfil the requirements, would, of necessity, connect together all the exposed-conductive-parts and extraneous-conductive-parts. Compliance with Regulations 547–03–01 to 547–03–05 would also be required (dealt with in Chapter 12).

Regulation 413–02–28 provides a formula, $R \leqslant (50 \div I_a)$, for the value of resistance of the supplementary bonding and where, as is normal, a number of protective devices have an influence on this bonding, then the worst case value must be used (i.e. the higher or highest I_a value). The current I_a is the operating current of the device for 5 s disconnection and in the case of an RCD, $I_{\Delta n}$. It is important to note that this formula will need amending (by reducing the maximum R values) when applied to special installations or locations (see Regulation 471–08–01).

5.4.7 Protection by use of Class II or by equivalent insulation

The classification of equipment relating to protection against electric shock is addressed in the IEC publication 536 (BS 2754). It relates only to protection against electric shock considerations. The international document refers to four such classifications (Classes 0, I, II and III). For completeness the four IEC Classifications are set out in Table 5.11. Class 0 is not permitted in the United Kingdom (see the Low Voltage Electrical Equipment (Safety) Regulations 1989).

Indirect contact protection provision by use of Class II equipment or equivalent insulation does not rely on automatic disconnection triggered by earth fault current flow. Instead, this means of protection is provided by the selection of suitable equipment (Class II or equivalent) which by its

Table 5.11: IEC 536 classifications (electric shock)

	Class 0	**Class I**	**Class II**	**Class III**
Main equipment characteristics.	Means for protective earthing not provided.	Provided with means of protective earthing.	Additional insulation but no means of protective earthing provided.	Designed for supply by SELV.
Safety precautions necessary.	Earth-free environment.	Connection to protective conductor and Earth.	None.	Connection to SELV systems only.

construction will provide the necessary degree of safety with regard to electric shock.

Regulation 471–09–01 states that this measure is generally applicable. It is more usual in practice for the measure to be applied to individual items of equipment rather than to the whole installation. As previously mentioned, where the entire installation is so protected it is required to be under effective supervision. Unthinking replacement of equipment may at best negate the protective measure or at worst render the installation potentially dangerous.

There are a number of alternatives from which to select equipment, as set out in Regulation 413–03–01 and summarised in Table 5.12.

Table 5.12: Class II or equivalent equipment

Equipment	**Comments**
Double or reinforced insulated equipment (Class II); type-tested and marked with relevant Standard.	See definition in Part 2 of BS 7671 and IEC publication 536.
LV switch and controlgear having total insulation; type-tested and marked with relevant Standard.	See BS EN 60 439 *Specification for low-voltage switchgear and controlgear assemblies.*
Supplementary insulation applied to equipment as a process in the erection of the installation.	Must provide at least an equal degree of safety to above two alternatives; must also comply with Regulations 413-03-03 to 413-03-09.
Reinforced insulation applied to un-insulated live parts in a process of erection of installation.	Must provide at least an equal degree of safety to above first two alternatives; must also comply with Regulations 413-03-03 to 413-03-09. Only to be used where constructional features prevent application of double insulation.

Regulation 413–03–02 calls for the installation of Class II equipment having double or reinforced insulation and LV switch and control gear having total insulation to be selected, and erected in such a manner, so as not to negate the in-built safety features of that equipment. Where such equipment embodies metalwork, this must not only be protected by basic insulation but must also be applied with double or reinforced insulation. In such cases, this metalwork would *not* be regarded as an exposed-conductive-part.

Any enclosure for this type of equipment is required, by Regulation 413–03–03, to not adversely affect the operation of the equipment. Such operation would involve such considerations of safety, correct functioning and heat dissipation (and temperature rise).

All conductive parts, if only separated from live parts by basic insulation, are required (Regulation 413–03–04) to be contained in an insulating enclosure giving at least IP2X (or IPXXB) degree of protection. Regulation 413–03–05 goes on to demand that such enclosures must be capable of resisting mechanical, electrical and thermal stresses both for normal operation and under fault conditions. Paint or varnish is only acceptable if the enclosure has been type-tested to the relevant standard and only where that standard admits such a method. As required by Regulation 413–03–06, where an insulated enclosure has not been tested previously, a test must be carried out to confirm that the necessary degree of protection (IP2X or IPXXB) is maintained and that the enclosure is capable of withstanding an applied voltage test, similar to that specified by the British or CENELEC Standard for similar equipment, without breakdown or flashover.

Great care must be exercised in the installation of such equipment particularly with regard to piercing or penetrations. Other than for circuit conductors, no penetrations should occur, except possibly by non-conductive parts, in order to comply with Regulation 413–03–07. This Regulation also calls for the enclosure not to contain insulated screws which could, perhaps inadvertently, be replaced by non-insulating (metallic) screws thus negating the protection otherwise afforded. If any piercing or penetrations are required for operating handles, screws and the like, it must be done in such a manner so as not to impair the protection.

As called for in Regulation 413–03–08, for enclosures with lids or doors which are openable without the use of a key or tool, all conductive parts which would be accessible on opening the lid or door would need to be located behind an insulating barrier which prevents contact with live parts (to IP2X or IPXXB) and which itself may only be opened by a key or a tool.

Regulation 471–09–02 requires a cpc for all circuits supplying Class II or equivalent equipment except where, as stated in Regulation 471–09–03, this is the only protective measure employed (for indirect contact) for the whole installation. Where Class II is the only protective measure for indirect contact, the installation must also be under effective supervision. The intention here must be to provide a cpc to each accessory (except lampholders with no exposed-conductive-parts) so that in the event that this protective measure is ever abandoned by, for example, the replacement of Class II equipment with Class I equipment (requiring earthing), then provision of a cpc would facilitate this change without the risk of the omission of earthing. This being so, where circuit protective conductors are necessary (i.e. where the whole installation does not employ only this protective measure and is not under effective supervision) other measures, such as EEBADS, will be required to protect the circuit protective conductors from earth faults.

Careful attention is needed for the installation of Class II equipment (Regulation 413–03–02) in that metalwork (necessarily unearthed) of Class

II equipment must not be, or become, in contact with any part of the installation which is in contact with a protective conductor. This would include, for example, electrically bonded structural metalwork, other exposed-conductive-parts of the installation and other extraneous-conductive-parts in all forms. Regulation 471–09–03 states the obvious by demanding that this protective measure is not to be applied to *any* final circuit feeding socket-outlets into which Class I appliances may be plugged.

As stated in Regulation 413–03–09, where protective and other conductors run through Class II equipment on their way to other equipment (and this practice should be avoided, if possible) any joints and connections will need to be insulated and marked appropriate to their function. Naturally, where circuit protective conductors are installed to Class II equipment they will be required to be properly terminated.

Regulation 471–09–04 indicates that cables having a non-metallic sheath or enclosure must not be regarded as being of Class II construction. The outer sheath of a cable, say to BS 6004, provides protection against mechanical damage rather than further insulation. Such wiring systems can however be used to feed Class II equipment as this regulation affords them a '*deemed to comply*' status and they can therefore provide the necessary degree of protection against direct contact and indirect contact.

5.4.8 Protection by non-conducting location

The very first regulation relating to this measure, 413–04–01, makes clear that this protective measure is not recognised for general application. It must only be considered for special situations which are under effective supervision. This means of protection is intended to prevent simultaneous contact with parts that may be at a difference in potential because of failure of basic insulation of live parts. It is important to note that this measure is not one which may be applied to special installations or locations including those detailed in Part 6 of BS 7671. Regulation 471–10–01 confirms that this protective measure is intended to prevent simultaneous contact with parts that may be, or may become, charged at different potentials. It also reiterates that it is not a measure for general use or for special installations or locations and, furthermore, it may only be employed where the installation is under effective supervision.

When this protective measure is employed, great care must be taken through design, as mentioned in Regulation 413–04–02, so that no two exposed-conductive-parts or a conductive part and an extraneous-conductive-part are so positioned that simultaneous contact can be made by a person. Regulation 413–04–07 reinforces these requirements and amplifies how they may be met. Table 5.13 summarises the requirements where the location has an insulating floor and insulating walls.

Protective conductors are not required and must not be used (Regulation 413–04–03) in this location and neither must socket-outlets and Luminaire Supporting Couplers(LSCs) with earthing contacts and protective conductor contacts respectively.

Before declaring that floors and walls are or are not insulating,

Table 5.13: Protection by non-conducting location. Separating distances (Regulation 413-04-07)

Parts	**Minimum separation distances (m)**	**Alternative arrangements**
Exposed-conductive-part and other separated exposed-conductive-part. (*Parts within the zone of arm's reach*)	2.50	Interposition of adequate barriers (insulating and isolated) extending the separation distances.
Exposed-conductive-part and other separated exposed-conductive-part. (*Parts out of the zone of arm's reach*)	1.25	Interposition of adequate barriers (insulating and isolated) extending the separation distances.
Exposed-conductive-part and extraneous-conductive-part. (*Parts within the zone of arm's reach*)	2.50	Interposition of adequate barriers (insulating and isolated) extending the separation distances, *or* insulation of extraneous-conductive-parts.
Exposed-conductive-part and extraneous-conductive-part. (*Parts out of the zone of arm's reach*)	1.25	Interposition of adequate barriers (insulating and isolated) extending the separation distances, *or* insulation of extraneous-conductive-parts.

measurements of the resistance of these building components are required to satisfy the requirements of Regulation 413–04–04. Such measurements need to be carried out in accordance with Regulations 713–08–01 and 713–08–02. Measurements are required to be taken at not less than three points on each and every surface, one of which must be taken at a point between 1.0 m and 1.2 m from each and every extraneous-conductive-part. Where the nominal voltage to earth, U_o, is not greater than 500 V, the resistance between points should not be less than 50 kΩ. Where the nominal voltage to earth, U_o, is greater than 500 V but not exceeding 1000 V a.c. or 1200 V d.c., the resistance between points should not be less than 100 kΩ. If these values are not achieved, the floors and walls must be considered to be extraneous-conductive-parts and treated accordingly. Applied insulation or insulating arrangements for extraneous-conductive-parts (to meet Regulation 413–04–07) must be tested in accordance with Regulation 713–08–02 (see Chapter 17 of this Guide).

Where this protective measure is used, Regulations 413–04–05 and 413–04–06 call for permanent protective arrangements to be made if portable or mobile equipment is used and for precautions to be taken so that extraneous-conductive-parts cannot transmit a potential outside the location.

It has to be said that this method of protection has very limited application and there is always the danger that circumstances may change rendering the measure ineffective. It is difficult to prevent other conductive parts (e.g. metallic water pipes) being introduced into the area at some later date. Although BS 7671 does not specifically call for a notice, it is always a good idea to have suitable warning signs advising the unwary that this particular measure is in existence in the location. These notices would be located at points of access to the location and would indicate that the location was ‘a non-conducting location’ and provide the name of the person who is responsible for the supervision.

5.4.9 Protection by earth-free local equipotential bonding

Again this measure is not generally applicable and is restricted to special circumstances which are earth-free as stated in Regulation 413–05–01. It is intended to prevent the appearance of dangerous voltages between simultaneous accessible parts even under conditions of failure of basic insulation conditions. Regulation 471–11–01 makes it clear that installations protected by this measure must be under effective supervision and applied *only* in situations which are *earth-free*. Wherever it is used, a warning notice, complying with Regulation 514–13–02, must be affixed in a prominent position adjacent to every access point to the location (see Figure 9.10). This measure must not be considered for application in special installations or locations detailed in Part 6 of BS 7671.

The requirements for equipotential bonding are similar to those associated with an EEBADS protected installation *except that* this bonding *must not* be connected to, or be in contact with, Earth (Regulations 413–05–02 and 413–05–03).

Regulation 413–05–04 recognises that a risk may exist between the earth-free location and another location in which other protective measures are employed. It calls for special precautions to be taken to obviate the risk. This risk may, for example, manifest itself where a conductive floor in the earth-free location and appropriately bonded may butt up to a floor which is itself connected, either deliberately or fortuitously, to Earth. A person walking over both floors near an access point may experience a difference of potential which may result in electric shock when contact is made with both floor surfaces simultaneously. Precautions may include, for example, provision of an insulated floor section between the two locations of sufficient width to prevent simultaneous contact between the two surfaces.

5.4.10 Protection by electrical separation

This measure is generally applicable but requirements for its use are split into two distinct sets of regulations; one for where the measure is used for individual circuits and one for where several items of equipment are so protected. Regulation 413–06–01 confirms this treatment of the two cases and states that for both, Regulations 413–06–02 and 413–06–03 are applicable. For individual circuits Regulation 413–06–04 is applicable and for the situation where a number of items of equipment are involved Regulation 413–06–05 must be applied.

In an individual circuit this measure is intended (Regulation 471–12–01) to prevent the possibility of electric shock occurring through contact with exposed-conductive-parts in the event of basic insulation failure. For protection of several items of equipment from a common source, the intent is the same but this Regulation requires that such installations be under effective supervision and a warning notice is required to be affixed in a prominent position adjacent to every point of access to a location where this measure has been used. This warning notice is to be in compliance with Regulation 514–13–02 and is the same as that required for earth-free local equipotential bonding.

Regulation 413–06–02 makes demands on the source of supply when this protective measure is used and places an upper voltage limit of 500 V for the electrically separated circuit. Suitable sources are:

- isolating transformer to BS 3535 Part 1 (BS EN 60 742),
- motor generator with winding giving equivalent degree of safety to that of a BS 3535 transformer.

In both cases there is the requirement that *no* connection be made between the output winding and the body (or enclosure) of the source or to the protective conductor of the primary (or input) circuit.

Where a mobile source, fed from a fixed installation, is used, the source needs to be selected and installed in accordance with Regulations 413–03–01 to 413–03–09 and to meet the requirements for protection by Class II equipment or equivalent insulation. These requirements also apply to fixed sources of supply and they too need to comply with these Regulations. However, for these sources the requirements may be substituted by the provision of separation of the output from the input and from the enclosure by insulation which would meet the requirements of Regulations 413–03–01 to 413–03–09. Where several items of equipment are fed from the source, the exposed-conductive-parts of the equipment are *not* to be connected to exposed-conductive-parts of the source.

In the case of a single separated circuit, Regulation 413–06–03 calls for there to be *no* electrical connection, either deliberate or fortuitous, between the live parts of the separated circuit and any point in any other circuit or to Earth. In order to avoid the potential risk of an earth fault, special care is needed with regard to the insulation of live parts from Earth. This is particularly important when considering flexible cables and the like. For this reason, all flexible cables and cords, liable to damage from mechanical impact or general wear and tear, must be visible throughout their length so that any damage occurring in service may be spotted and promptly remedied. It is always preferable to use separate wiring systems for separated circuits but, where this is not feasible or economic, multicore cables may be used provided they do not have a metallic sheath. Insulated conductors in an insulated conduit is also an acceptable wiring system but they must be voltage-rated for the highest voltage likely to occur and, additionally each separated circuit requires to be protected against overcurrent.

All live parts of each separate circuit must be electrically separate from all other circuits and the degree of separation is that required by BS 3535 with regard to the primary and secondary windings. This requirement for separation applies equally to relays, contactors and any other equipment where separated circuits may otherwise come into contact with other circuits.

As called for in Regulation 413–06–04, where a separated circuit supplies one item of equipment, care must be taken to determine that no exposed-conductive-part of that circuit is electrically connected, either deliberately or fortuitously, with the source protective conductor or to any exposed-conductive-part or protective conductor of any other circuit.

Where a source is used to supply a number of items of equipment, Regulation 413–06–05 calls for precautions to be taken to protect the protected circuit from all types of damage and from insulation failure and envisages all the following conditions being embraced:

- all exposed-conductive-parts of the separated circuit connected together by an insulated non-earthed protective conductor which must *not* be connected to any exposed-conductive-part of any other circuit or to any extraneous-conductive-part, and
- all socket-outlets to be provided with a protective conductor contact which, in turn, is connected to the protective conductor referred to above, and all flexible cables to equipment, other than Class II or equivalent equipment, to include an protective conductor contact to be used as an equipotential bonding conductor, and
- if two faults, from conductors of different polarity, can occur to exposed-conductive-parts, there is the need to verify that the associated overcurrent device will afford compliance with Regulation 413–02–05 (and 413–02–06 to 413–02–26) dependent on the system and earthing arrangements.

Finally, exposed-conductive-parts of the source must *not* be simultaneously accessible with any exposed-conductive-part of the separated circuit.

5.4.11 Dispensation of protective measures against indirect contact

There are a number of instances where protective measures against indirect contact may not be required (Regulation 471–13–04). These situations relate to where the risk of electric shock is judged to be negligible due to the very low probability of contact by a person or by livestock. Table 5.14 details the extent of this dispensation.

5.4.12 PELV and functional extra-low voltage systems

As stated in Regulation 471–14–01, where extra-low voltage systems are used which do not comply fully with the requirements for SELV, the system is known as either as PELV (Protective Extra-Low Voltage) or 'functional extra-low voltage'. With such systems, protective measures against both direct contact and indirect contact need to be taken for compliance with Regulations 471–14–02 for PELV and 471–14–03 to 471–14–06. PELV is defined as *an extra-low voltage system which is not electrically separated from Earth, but which otherwise satisfies all the requirements of SELV*.

A PELV system, which to all intents and purposes, can be thought of as a

Table 5.14: Dispensation of protection against indirect contact

Conductive part	**Qualifications (if any)**
Overhead line insulated bracket and associated metal parts.	Must not be within 'arm's reach' (see Figure 6.4).
Exposed-conductive-parts.	Which cannot be gripped, and which cannot be contacted by major surface of a human body, and connection to a protective conductor cannot readily be made or reliably maintained.
Small isolated metal parts (e.g. bolts and rivets).	Unlikely to become live.
Nameplates.	Up to 50 x 50 mm – unlikely to become live.
Cable clips.	Unlikely to become live.
Fixing screws for non-metallic accessories.	Only where there is no appreciable risk of contact with live parts.
Inaccessible lengths of conduit.	Not exceeding 150 mm in length.
Metal enclosures.	Where their purpose is to protect Class II or equivalent equipment.
Street furniture.	Only if unearthed and inaccessible in normal use and supplied by overhead line.

SELV system with a connection to Earth. Direct contact protection must employ at least one of two options;

- barriers or enclosures to IP2X or IPXXB, and/or
- insulation (capable of withstanding a 500 V rms a.c. type-test for one minute).

An exception to the above requirements may be applied where the PELV system is used in a building which has main equipotential bonding (see Regulation 413–02–02) and where the system voltage does not exceed 25 V a.c. rms or 60 V ripple-free d.c. when used in dry conditions, or 6 V a.c. rms or 15 V ripple-free d.c. in all other conditions.

Where a functional extra-low voltage system does not comply with the requirements for SELV in any respect other than the connection of exposed-conductive-parts as mentioned above, Regulation 471–14–03 calls for protection against direct contact to be provided by at least one of the two options given above. Unlike the previous case, indirect contact has not been given the *deemed to comply* status. It is also important to note that this regulation calls for equipment fed from a functional extra-low voltage source to be insulated for the primary voltage. Where equipment does not inherently have this insulation quality, then reinforced insulation is needed for all accessible insulated parts (insulation capable of withstanding a test voltage of 1500 V rms a.c. for one minute). Furthermore, protection against indirect contact needs to be carried out in accordance with Regulations 471–14–04 and 471–14–05.

In the case where the source is protected by automatic disconnection, all exposed-conductive-parts of the secondary circuit are to be connected to the protective conductor of the primary circuit as mentioned in Regulation 471–14–04. It goes on to say that this would not preclude a conductor of the extra-low voltage circuit being connected to the protective conductor of the primary thus allowing, for example, the earthing of one pole of the secondary.

In the case where the source is protected by electrical separation, Regulation 471–14–05 calls for the exposed-conductive-parts of equipment on the secondary circuit to be connected to the non-earthed protective conductor of the primary circuit. This, on the face of it, would appear to contravene Regulations 413–06–04 and 413–06–05 but again it is permissible to claim the *deemed to comply* status afforded by this Regulation on the basis that the primary and secondary circuits are viewed, for this purpose, as but one and the same circuit.

Finally, Regulation 471–14–06 demands that every socket-outlet and LSC used on a functional extra-low voltage system be dimensionally incompatible with those of any other system installed in the premises.

Table 5.15 summarises the requirements for functional extra-low voltage systems.

Table 5.15: Summary of requirements for functional extra-low voltage systems

Aspect	**As SELV but secondary not earthed**	**All other functional extra-low voltage systems**
Direct contact.	IP2X or IPXXB enclosure or insulation.	Barriers or enclosures (Regulation 412-03). Insulation (as for primary or 1500 V tested).
Indirect contact.	'Deemed to comply'.	Further measures required.
Automatic disconnection on primary.	N/A	Exposed-conductive-parts connected to Earth.
Electrical separation.	N/A	Exposed-conductive-parts connected to non-earthed primary protective conductor.
Socket-outlets and LSCs.	Dimensionally incompatible with others.	Dimensionally incompatible with others.

5.4.13 Automatic disconnection and reduced low-voltage systems

As indicated in Regulation 471–15–01, reduced low-voltage systems are permitted where, from functional or operational considerations, functional extra-low voltage is not practicable and for safety reasons, SELV is not necessary.

Phase-to-phase voltage of such systems must not exceed 110 V rms a.c. in order to meet the requirements of Regulation 471–15–02. This voltage limitation of 110 V phase-to-phase translates to 55 V phase to Earth on a single-phase centre-tapped system, and 63.5 V to earthed star point of a three-phase system, as indicated in Figure 5.6. Although these voltages to Earth exceed low voltages, they are much lower than the normal 230 V/ 400 V low voltage systems and consequently provide far less risk from indirect contact where the voltage on exposed-conductive-parts will not normally exceed 55 V and from direct contact where the voltage between live parts is not normally going to exceed 110 V.

As illustrated in Figure 5.6, the neutral star point of a three-phase and the

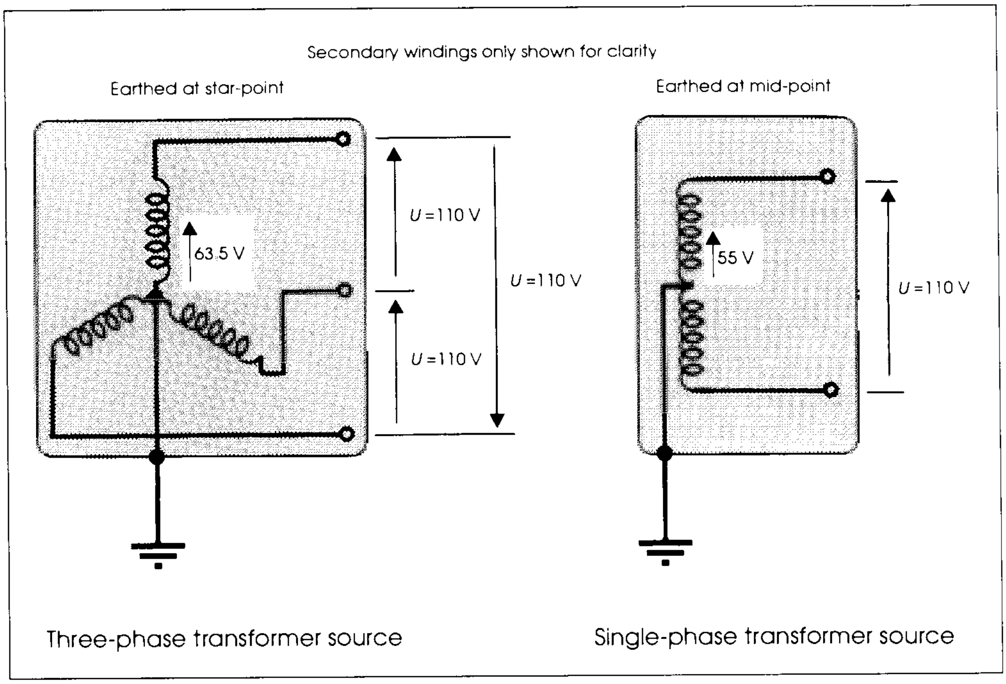


Figure 5.6: Reduced low-voltage sources

mid-point of a single-phase transformer must be earthed to afford compliance with Regulation 471–15–04.

The source of such a system is required by Regulation 471–15–03 to be selected from one of three acceptable options:

- double-wound isolating transformer (to BS 3535 Part 2), or
- motor generator (winding isolation equivalent to a BS 3535 Part 2 transformer), or
- any source independent of other supplies (e.g. combustion engine-driven generator).

It should be noted that when selecting a generator for this purpose care should be exercised in selecting one which has its output winding earthed at the mid-point (centre tapped). One which has only one pole earthed, providing an output voltage to Earth twice that of the former, would not meet the requirements for a reduced low-voltage source.

No concession is given by Regulation 471–15–05 with regard to protection against direct contact and therefore insulation (Regulations 412–02 and 471–04) and/or barriers and enclosures (Regulations 412–03 and 471–05) are necessary as if for a low-voltage system.

Automatic disconnection, to provide for protection against indirect contact, may be undertaken, according to Regulation 471–15–06, in one of two ways (or, of course, both):

- by overcurrent device, and/or
- by residual current device.

In both cases, the exposed-conductive-parts of the system must be connected to Earth via a protective conductor. Where an overcurrent device is employed, the phase-earth loop impedance at every point must be such as to provide for automatic disconnection within 5 s. This disconnection time limit applies equally to both 'stationawry' equipment and to socket-outlets. It should be noted that both poles must be protected against indirect contact (and overcurrent) and this is perhaps best achieved by the use of double-pole (or in the case of three-phase, by triple-pole) overcurrent protective circuit-breakers.

Where a circuit-breaker is employed for automatic disconnection, the phase-earth loop impedance, Z_s, is limited to a value, in ohms, not greater than $(U_o \div I_a)$ *or*, if the device is listed in Table 471A of BS 7671 to the tabulated values corresponding to the device Type and nominal rating. Similarly, data for fuses, if listed, may also be obtained from this table but otherwise may be obtained by applying the formula $Z_s \leqslant (U_o \div I_a)$, where I_a is the operating current of the device for 5 s disconnection and U_o is the nominal voltage to Earth ($U_o = 55$ V for single-phase and 63.5 V for three-phase). For devices not listed, I_a will need to be determined by reference to the relevant BS or CENELEC Standard or to the manufacturer. In the case of the residual current device protection, there is a requirement stipulated in this regulation in that the product of the RCD operating current and the phase-earth loop impedance must not exceed 50 (i.e. $Z_s I_{\Delta n} \leqslant 50$ V).

As previously mentioned, Table 471A tabulates values of maximum phase-earth loop impedances for MCBs Types 1, 2, 3, B and C and for BS 88 (Parts 2 and 6) 'gG' general purpose fuses up to and including a nominal rating of 100 A. The crucial factor in automatic disconnection using overcurrent devices is the current magnitude and it is important to note that because of the lower nominal voltages associated with the systems there is a consequent lowering of impedances. Table 16.9 of Chapter 16 of this Guide lists the limiting phase-earth loop impedances for common devices operating on 55 V and 63.5 V phase to Earth.

As with functional extra-low voltage systems, there is a requirement (Regulation 471–15–07) for all plugs, sockets and cable couplers of these reduced low-voltage systems to be dimensionally incompatible with any such accessories for use on another voltage or frequency in the same installation. Construction site installations are discussed in Chapter 16, item 16.5.

5.4.14 Supplies for portable equipment outdoors

When considering protection against indirect contact for equipment located outdoors, it is important to realise that when equipment is situated outside the earthed equipotential zone, the risks relating to electric shock are increased because the in-built measures of the zone do not influence the areas outside.

Regulation 471–08–03 calls for disconnection of circuits feeding outdoor fixed equipment (with exposed-conductive-parts which may be touched simultaneously with the general mass of the Earth) to be in accordance with Table 41A of BS 7671. For such a circuit with nominal voltage to Earth, U_o = 230 V, the phase-earth loop impedance would need to provide for automatic disconnection in not more than 0.4 s.

Regulations 471–16–01 and 471–16–02 make further demands for portable equipment for use outdoors. Any socket-outlet or circuit supplying portable equipment, rated at 32 A or less, which is reasonably expected to supply portable equipment outside a building, is required to be protected by an RCD (to reduce the risks associated with direct contact). The RCD would need to have a rated residual operating current of 20 mA or less (i.e. $I_{\Delta n} \leqslant 30$ mA) and would be required to operate within 40 ms when a residual current of 150 mA is applied (see BS 4293, BS 7071, BS 7288, BS EN 61 008–1 and BS EN 61 009–1, as appropriate.

The requirements of these Regulations (471–16–01 and 471–16–02) do not apply to circuits protected by SELV, electrical separation or to automatically disconnected reduced low-voltage systems provided such circuits meet all the relevant requirements for the particular protective measure employed. For circuits other than those protected by one of these three measures, supplementary protection is also required for circuits feeding portable equipment outdoors and connected other than by means of a plug and socket-outlet arrangement. This requirement applies to all such circuits with flexible cables or cords having a current carrying capacity of 32 A or less.

5.4.15 RCD special considerations

Whilst there are many circumstances where their use is essential, RCDs should not be regarded as a 'cure-all' for deficiencies in the installation design or construction. Notwithstanding their substantial cost, these devices, like any electromechanical mechanism, are not devoid of malfunction. There are occasions where the use of RCDs should be avoided if at all possible. Circuits particularly susceptible to loss of power (e.g. information technology equipment, freezers, etc.) should preferably be protected against indirect contact by some other means. Care should also be taken in assessing cumulative earth-leakages of all the current-using equipment served by such a device. Item 11.5.1 of this Guide sets out the circumstances where RCDs must be used.

Chapter 6

Protection against Thermal Effects

6.1 General

Chapter 42 of BS 7671 addresses the precautions required in relation to protection against the hazards of fire, thermal effects and burns. The thermal effects resulting from overload and fault current are not embraced in Chapter 42 but dealt with in the form of requirements for protection against overcurrent in Chapter 43. Providing the measures stipulated there are met in full, further consideration in respect of fire and burns relating to overcurrent is not necessary.

Fires from electrical causes are of great concern and statistics published by the Department of Trade and Industry show a steady increase over the years. Whilst the reasons for such fires are complex and sometimes unclear, some increase can be expected because of the sheer volume of electrical apparatus and appliances now prolific in almost every building. As far as the fixed installation is concerned, the statistics are encouraging. However, many fires could be avoided by the provision of an adequate number of points to serve the ever increasing number of appliances with some provision for anticipated additional equipment.

Many fires are, of course, attributable to appliances and not to the fixed installation with which Chapter 42 is solely concerned. Appliances used on inadequately rated circuits or connected via badly connected plugs are an obvious cause for concern. Fixed installation equipment selected without due consideration of the ambient temperature is another. A case in point relates to a standard BS 1363 plug and socket-outlet connection of the immersion heater in the airing cupboard. The concern here is twofold: first such a socket-outlet, though rated at 13 A, is not suitable to sustain this maximum rate continuously or even for long periods (see BS 1363) and when so loaded the temperature rise is likely to produce expansion and creepage (in the plug and socket-outlet) finally resulting in loose connections and a real risk of igniting material in close proximity. Secondly, the airing cupboard temperature is normally much higher and equipment fixed therein would generally need to be de-rated if limiting temperatures are not going to be exceeded.

With the introduction of a new set of requirements for protection against overheating, incorporated in Amendment No 1 to BS 7671 : 1992, Regulation 421–01–01 sets the scene for Chapter 42. It makes clear that the subsequent requirements relate to protection against harmful effects of heat from electrical equipment to persons, to fixed equipment and to fixed materials adjacent to that electrical equipment. The regulation cites a number of particular examples of such harmful effects, such as:

- Combustion, ignition or degradation of materials.
- Risk of burns.
- Impairment of the safe function of the installed equipment.

The concluding requirement of this regulation is that electrical equipment shall not present a fire hazard to adjacent material, and all subsequent regulatory requirements are tailored with this in mind.

As previously mentioned, Chapter 42 deals only with the fixed installation but current-using equipment including portable appliances should of course conform to the specifications given in the appropriate British or CENELEC Standard. Most British Standards for such equipment include a requirement for a heat test to be carried out under defined conditions. All components are then checked for temperature rise and the limits placed on this are 60°C for equipment intended for continuous operation and 65°C for other equipment, with the reference ambient temperature taken to be 20°C. Other specific tests are also undertaken to confirm that the equipment will perform without risk, if installed and used correctly.

Where fixed equipment has been specified by someone other than the installation designer, the onus to install the equipment so that provisions of Chapter 42 are met still rests with the installer. Of particular importance is the proximity of building fabric to the equipment and the thermal effects that may result.

Luminaires of the pendant type must be have the type T2 rated lampholder (see Table 11.12 of this Guide). Fluorescent and discharge tube luminaires must be mounted to take account of the requirements of BS 4533 *Luminaires* Part 101 (BS EN 60 598–1) *Specification for general requirements and tests*. In particular, it must be noted whether or not the luminaire exhibits the symbol given in Figure 6.1. Where it does not, the Standard requires that a suitable warning notice be provided with the luminaire (by the manufacturer) and the designer and the installer should note that such fittings are unsuitable for mounting directly on flammable materials. Most popular fluorescent luminaires are of this type and not therefore suitable for direct mounting unless the material to which they are to be mounted is not flammable. Emergency luminaires must be afforded the same consideration but units bearing the ICEL (Industry Committee on Emergency Lighting) certification do meet the relevant requirements of BS 4533 and are therefore suitable for direct mounting on flammable materials.

Notwithstanding the requirements of Chapter 42, other parts of BS 7671 contain prerequisite conditions which need to be met with respect to fire, harmful thermal effects and burns, including:

- Regulations 527–02–01 to 527–02–03
  Sealing of wiring system penetrations (fire barriers),
- Chapter 43 Protection against overcurrent,

- Regulations 510–01–01, 511–01–01 and 511–01–02
  Requirements relating to equipment standards and compliance with other Parts of BS 7671.

In terms of the fire hazard there are two distinct risks, namely the risk of ignition from equipment, including wiring systems, and the propagation of fire through a wiring system. Compliance with all the regulatory requirements relating to the installation design should obviate the former and providing wiring systems are sealed where they pass through walls and floors the spread of fire should be significantly retarded.

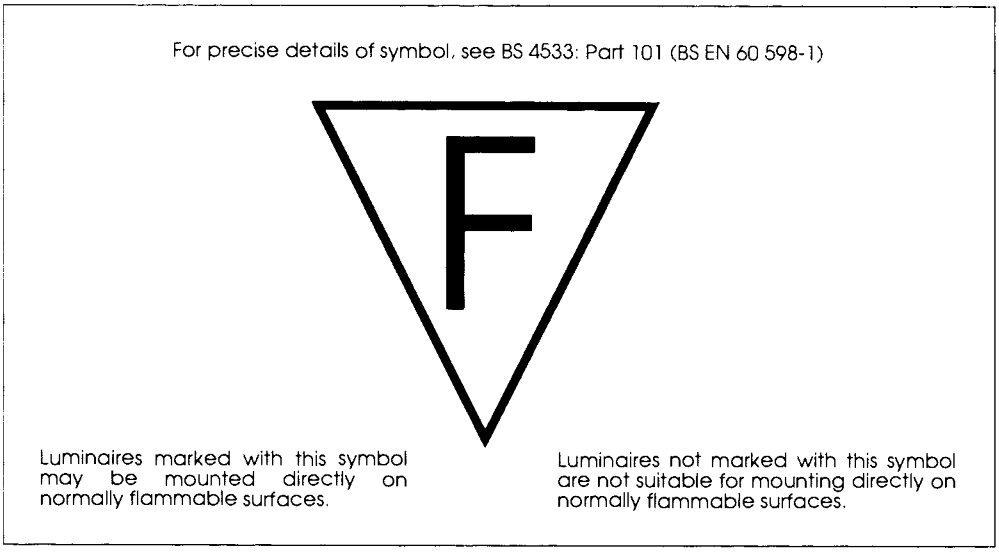


Figure 6.1: Symbol for fluorescent and discharge lamp luminaires

6.2 Fire and harmful thermal effects

6.2.1 Surface temperature

It is important to establish that all fixed electrical equipment does not have harmful effects on adjacent materials. Regulation 422–01–01 makes clear that heat generated by equipment must not be such as to cause a danger in terms of a fire hazard or have detrimental effects on other materials which may be in the proximity of the equipment. This requirement applies to all equipment, including luminaires, under normal and fault conditions and not just equipment intended to be a heat source. This regulation also calls for the equipment manufacturer's installation instructions to be observed. They are best placed to advise on such issues as temperature rise of their equipment and will have the necessary data from tests carried out to meet the specific safety tests laid down in the relevant British or CENELEC Standard to which the equipment is designed.

As stated in Regulation 422–01–02, where equipment is designed to have a surface temperature sufficient to cause a fire or have a harmful effect on surrounding materials then measures must be taken to obviate those risks. This must be done in one or more of three given ways:

- the equipment to be appropriately mounted and at an adequate distance from adjacent material so that heat is dissipated safely, and/or
- the equipment to be screened by material which can sustain the heat generated without the risk of igniting itself or other adjacent material or suffering other harmful thermal effects, and/or
- the equipment to be mounted in an enclosure or on a support without the risks of fire or other damaging thermal effects. Where a support is used it should have a low thermal conductivity (compare the values of aluminium with a thermal conductivity of about 236 W m^{-1} K^{-1} and porcelain at about 2.0 W m^{-1} K^{-1}).

In addition to the above mentioned risks and requirements, protection against burns from such equipment must not be overlooked (see item 6.3 of this Guide).

6.2.2 High temperature particles

There are three acceptable methods of protection from high temperature particles, as given in Regulation 422–01–03:

- containment of equipment, likely to give rise to arcing, in an enclosure of arc-resistant material, and/or
- equipment to be mounted at a sufficient distance from vulnerable material to provide for safe extinction of high temperature particles before any damage occurs, and/or
- screening by arc-resistant material so as to prevent harmful effects on materials likely to be damaged (arc-resistant materials must be non-ignitable, of low thermal conductivity and be adequately proportioned so as to provide mechanical stability).

Generally, equipment manufactured to meet the requirements relating to safety in the appropriate Standard will be equipped with all the necessary arc-containment or screening. Provided assembly and installation are in accordance with the manufacturer's recommendations, no further consideration is required in this respect. However, there is one common example of failure to meet the requirements in this respect in that one occasionally encounters evidence of the replacement of an HBC fuse with a semi-enclosed (rewirable) fuse without the necessary replacement of the carrier.

6.2.3 Live conductors

Irrespective of nominal voltage, Regulation 422–01–04 calls for all terminations of live conductors and joints between such conductors to be contained within an enclosure. By definition a live conductor includes all d.c. conductors and the phase and neutral conductors of a.c. circuits except that a PEN conductor (combined neutral and protective conductor) is, by convention, not defined as a live conductor.

The acceptable methods of containment, given in Regulation 526–03–02, are:

- within an equipment enclosure complying with an appropriate British Standard, or
- within a suitable enclosure complying with an appropriate British Standard, or
- within a suitable enclosure of material complying with the relevant glow-wire test of BS 6458 *Fire hazard testing for electrotechnical products* Section 2.1 *Glow wire test*, or
- within a suitable enclosure formed or completed by non-combustible building material. Non-combustibility assessment by application of the test defined in BS 476 *Fire tests on building materials and structures* Part 4 *Non-combustible test for materials*, or
- within a suitable enclosure formed or completed in part by building material having characteristic '*P*' as defined in BS 476 *Fire tests on building materials and structures* Part 5 *Method of test for ignitibility*.

This requirement will normally be satisfied by normal good installation practice but it is important to note that ELV live conductor terminations and joints should be treated as if LV in terms of containment. For an example of the fire hazard posed by exposed terminations and joints of, say, a 24 V system, consider an unsound, high resistance, exposed joint of resistance of 1.25 Ω. Assuming that the total circuit impedance is 2 Ω (including the resistance of the faulty connection), the current drawn would be 12 A. The power loss across the joint would be 180 W ($I^2R = 12^2 \times 1.25$) which would cause the temperature of the joint to rise considerably and present a very real fire hazard. Similarly, joints with intermittent contact could ignite material in close proximity by arcing. Hence the requirement to contain all such connections.

6.2.4 Flammable liquids

Regulation 422–01–05 states that where electrical equipment, in any single location, which accumulatively contain flammable liquids in quantities of more than 25 litres, precautions must be taken to prevent spread of flame, burning liquid and the products of combustion. Equipment containing flammable liquids includes switchgear and transformers containing oil as the insulating and cooling medium.

Figure 6.2 illustrates an example of where precautions against this hazard may need to be taken where the transformer shown contains more than 25 litres of oil. The transformer HV and LV cables are shown together with cable transits at the entrance to the cable duct. Figure 6.3 portrays a cable transit seal in more detail showing the principal components. Such seals are

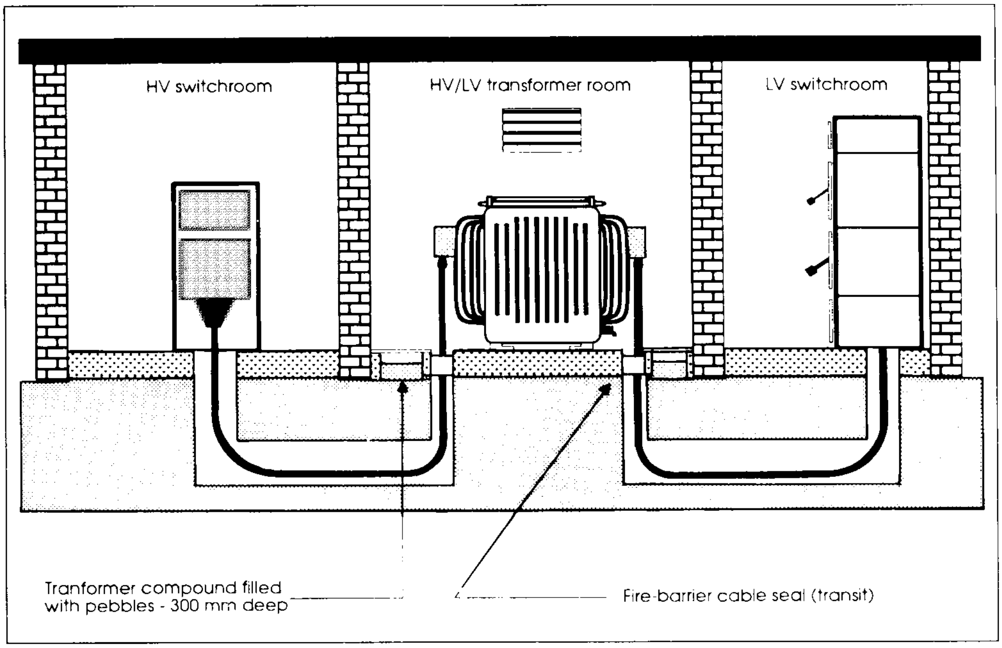


Figure 6.2: Sub-station layout showing cable transit barriers

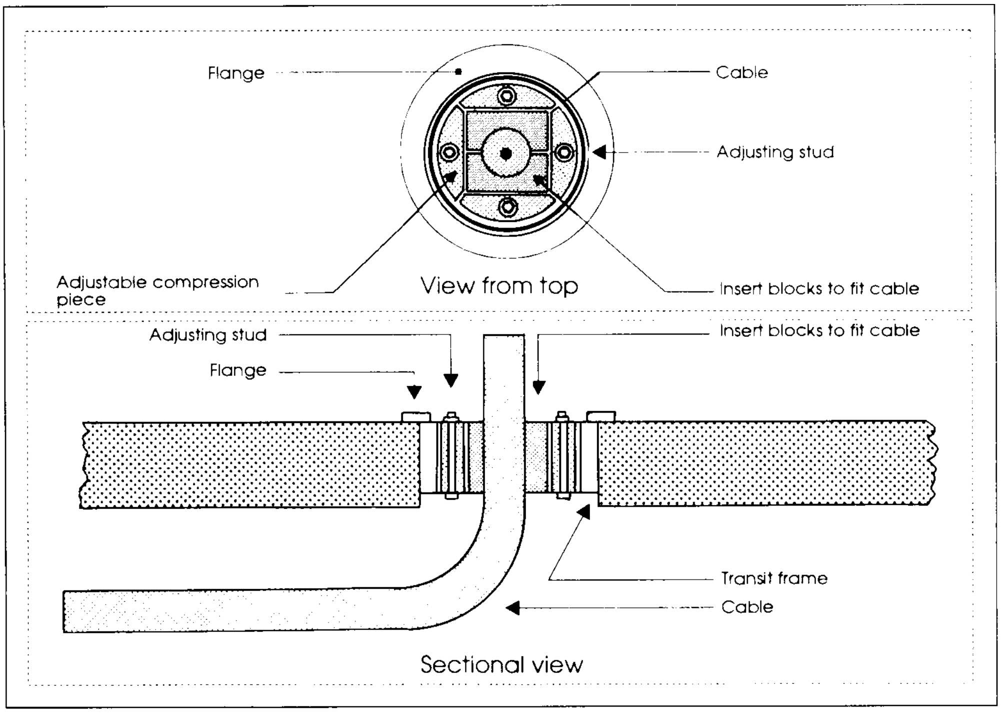


Figure 6.3: Example of cable transit sealing arrangement

available commercially in all shapes and sizes for cables and pipes and can be constructed to virtually any combination of cable and pipe sizes.

6.2.5 Position of equipment embodying heat sources

Regulation 422–01–06 introduces, for the first time, specific requirements directly relating to the positioning of equipment. It calls for equipment, which causes a focusing or a concentration of heat, to be sited at sufficient distance from any fixed object or building element, such that a dangerous temperature (in the object or building element) is not reached. For example, this regulation would have a direct bearing on the location of heaters and light sources, particularly those with tungsten filaments.

6.2.6 Construction of enclosures

It is important when selecting and installing enclosures for equipment that the material from which the enclosure is made has a resistance to fire and heat that is suitable, and which would meet the requirements of an appropriate product standard. Where no appropriate product standard exists or where an enclosure is constructed during installation, such an enclosure must be capable of withstanding the highest temperature likely to be produced by the enclosed equipment in normal service, as called for by Regulation 422–01–07.

6.3 Burns

There is only one regulation which addresses the subject of burns, namely Regulation 423–01–01. The requirement here is for accessible parts of fixed electrical equipment, within arm's reach, not to exceed the maximum temperatures given in Table 42A. This table differentiates between different types of equipment and between metallic and non-metallic materials (compare the thermal conductivity of aluminium of order of 236 $W\ m^{-1}\ K^{-1}$ with that of some plastics at about 0.20 $W\ m^{-1}\ K^{-1}$). Consideration of equipment complying with a British Standard which specifies a maximum temperature for that equipment is not the subject of these requirements. The concept of 'arm's reach', previously restricted to protection against direct contact, is now used for the first time in the consideration of protection against burns.

Table 6.1 summarises the maximum temperatures given in BS 7671. It will be seen that the different temperatures for metallic and non-metallic materials reflect their thermal conductivity. Where equipment, under normal load conditions, is likely to reach temperatures exceeding those given, even for short periods, precautions must be taken to guard against accidental contact. This may be achieved, for example, by the use of protective wire-guards or by positioning equipment out of arm's reach (see Figure 6.4).

Table 6.1: Limiting temperature for accessible parts of equipment under normal load conditions

Contact with equipment part	Limiting temperature (°C)	
	Metallic	Non-metallic
Hand-held means of operation.	55	65
Part intended to be touched but not hand-held.	70	80
Part which need not be touched for normal operation.	80	90

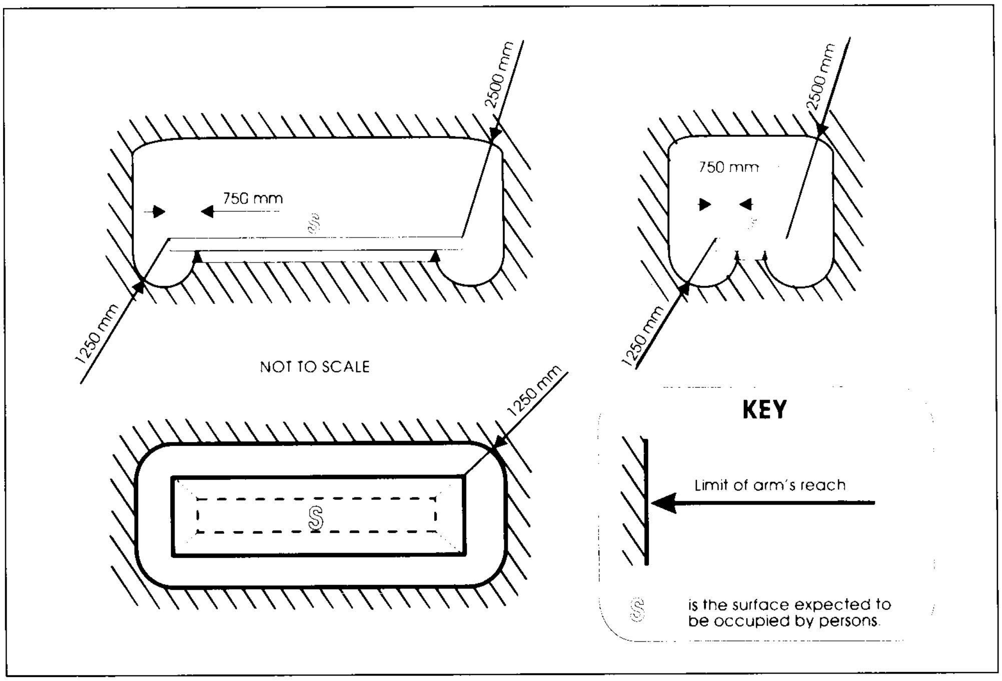


Figure 6.4: Zone of accessibility – arm's reach

One problem area exists in the siting of a lighting point in small store and airing cupboards when the luminaire is a pendant or a batten-holder with tungsten lamp. Often these are positioned where they can be an ignition hazard (igniting papers or blankets) and a burns risk because of the possibility of human contact on entering the room. Where siting out of 'arm's reach' is impossible, consideration should be given to the use of a totally enclosed luminaire or a low-energy fluorescent lamped luminaire thereby obviating both risks.

6.4 Protection against overheating

6.4.1 Forced air heating systems

Regulations 424–01–01 and 424–01–02 deal with the requirements relating to overheating of forced air heating systems, and call for the designed air flow to be established before the heating elements are activated. Similarly, the regulation demands that the heating elements are deactivated when the air flow is reduced or stopped. Additionally, two independent temperature limiting devices must be used to prevent the temperature in any part of the forced air system exceeding permissible limits, and the frame and enclosure containing the heating elements must be non-ignitable material. These requirements do not apply to central storage heaters.

6.4.2 Appliances producing hot water and steam

Appliances which produce hot water and steam must, as stated in Regulation 424–02–01, be protected against overheating, either by design or by a method of erection.

6.5 Precautions where particular risks of danger of fire exist

6.5.1 General

The 2001 version of BS 7671 introduced a new Chapter 48 on the protective measures as a function of external influences. At present this chapter includes only one section, the requirements of which are additional to those of Chapter 42 (protection against thermal effects) and section 527 (selection and erection of wiring systems).

As given in Regulation 482–01–01, the new requirements apply to locations where there are particular risks of fire due to the nature of processed or stored materials, such as where combustible materials are manufactured, processed or stored, or where combustible material such as dust and fibres may accumulate, for example in barns, woodworking factories, paper mills, textile factories and the like. They also apply to installations in locations constructed of combustible materials.

The requirements of the new section do not apply to installations in locations with explosion risks, which are subject to the particular requirements of BS EN 60079 (Electrical apparatus for explosive gas atmospheres) and BS EN 50014 (Electrical apparatus for potentially explosive atmospheres). Nor does the section apply to installations in escape routes, which are subject, for example, to the requirements of BS 5266 (Emergency lighting).

The additional precautions are based on the principle of selecting and erecting electrical equipment such that its temperature both in normal conditions and in the event of a fault is unlikely to cause a fire, taking due account of external influences. This can be achieved by the construction of the equipment or by additional measures taken during erection.

6.5.2 Locations with risks of fire due to the nature of processed or stored materials

Regulation Group 482-02 requires that electrical equipment must be restricted to that necessary for use in the location. Additionally, enclosures must be prevented from attaining too high a temperature where dust and fibres could collect on them. Electrical equipment must be both suitable for the location and have a degree of protection of at least IP5X.

Cables must meet specified fire propagation requirements except where completely embedded in non-combustible material such as plaster or concrete, or otherwise protected from fire. Although wiring systems not intended for electricity supply in the location are permitted to pass through the location, they must have a degree of protection of at least IP5X or meet specified fire propagation requirements. A wiring system passing through the location must have no electrical joint within the location unless the joint is placed in a suitable enclosure.

For TN and TT systems, wiring systems must be protected against insulation faults to earth by RCDs having a rated residual operating current ($I_{\acute{C}n}$) not exceeding 300 mA, except for mineral insulated cables and busbar trunking systems.

For IT systems, Regulation 482–02–06 calls for insulation monitoring with audible and visual signals and adequate supervision so that manual disconnection may occur as soon as possible. In the event of a second fault, automatic disconnection of the overcurrent protective device must occur in not more than 5s.

A PEN conductor must not to be used except for a wiring system passing through the location and every circuit must be capable of being isolated from all live supply conductors by a linked switch or circuit-breaker. However, circuits may share a common device.

Irrespective of the system type, exposed bare and live conductors must not be used and flexible cables must be a heavy duty type rated at not less than 450/750 V or be protected against mechanical damage.

Motors such as those that are not continuously supervised must be protected against excessive temperatures by a protective device with a manual reset. The surface temperature of luminaires in locations where there may be a fire hazard due to the presence of materials such as fibres must not exceed defined limits. Luminaires must be of a type that prevents lamp components from falling from the luminaire.

Except where the manufacturer's instructions are different, spotlights and projectors must generally be installed at minimum distances from combustible materials depending on lamp rating:

Luminaire rating	**Minimum distance from combustible materials**
up to 100 W	500 mm
100 to 300 W	800 mm
300 to 500 W	1,000 mm

Heating elements in heating and ventilating systems serving the location must not cause a fire hazard and all heating appliances must be fixed, and barriers must be provided to prevent ignition of any combustible materials in close proximity. Temperature limiting devices, required under Regulation 424–01–01, must have a manual reset facility.

Heat storage appliances must be of a type that prevents ignition of combustible dust or fibres by the heat storing core. Enclosures of equipment such as heaters and resistors must not attain surface temperatures higher than 90°C under normal conditions, or 115°C under fault conditions.

6.5.3 Locations with combustible constructional materials

As called for in Regulation Group 482–03, electrical equipment such as installation boxes and distribution boards installed in a combustible wall must comply with the relevant standards for enclosure temperature rise. Alternatively, the equipment must be enclosed in a suitable thickness of non-flammable material.

Cables and cords must comply with BS EN 50265–2.1 or 2.2, (relating to vertical flame test methods for cables under fire condition). The tests in these parts of the standard are more stringent than those required for cables in locations not covered by this new section, where compliance with BS EN 50265–1 is generally sufficient.

Conduit and trunking systems must comply with BS EN 50086–1 and BS EN 50085–1 respectively.

Chapter 7

Protection against Overcurrent, Undervoltage and Overvoltage

7.1 General

As ever, it is always useful to start with the definition of overcurrent and definitions relating the various forms of overcurrent which are summarised in Table 7.1. There are five regulations contained in Chapter 13 which set out the fundamental requirements for safety. Regulation 130–03–01 addresses the hazards caused by excessive temperatures and mechanical forces associated with fault conditions. Regulations 130–04–01 to 130–04–04 set out the requirements relating to earth leakage and earth faults again with respect to excessive temperatures and mechanical forces and, additionally, the risks of injury from electric shock. Fault currents can be, and often are, of the order of several thousand amperes and are capable of causing degradation of insulating materials from thermal effects, electromagnetic effects and electromechanical stresses to themselves and adjacent equipment. It is therefore necessary to limit the duration of fault current so that the 'destructive' energy released under fault conditions is restrained to acceptable levels.

The basic requirements for protective measures relating to overcurrent are given in Chapter 43 and Section 473 of Chapter 47 addresses the application of those measures. Section 530 deals with the common rules for switchgear and Section 533 more specifically includes application conditions for overcurrent protective devices. The designer should not overlook the point that the protective measures detailed in BS 7671 are related to protection of the wiring systems and that the protection of other equipment may need further consideration.

Table 7.1: Summary of overcurrent definitions

Parameter	**Definition**
Overcurrent.	A current exceeding the rated current (for conductors the rated current is the current-carrying capacity) embracing all the following terms in this table.
Short-circuit current.	An overcurrent resulting from a fault of negligible impedance between live conductors.
Earth fault current.	A fault current which flows to Earth.
Fault current.	A current resulting from a fault (short-circuit or earth fault).
Overload current.	An overcurrent occurring in a circuit which is *electrically* sound.

It is important to note from Table 7.1 that an overload current is *not* a fault current and is, in fact, an overcurrent which occurs *only* in a healthy, or an electrically sound, circuit. Also worthy of note is that both short-circuit current and earth fault current are now embraced by the term 'fault current' which when used may mean either or both depending upon the context in which it is used.

Stating the obvious, Regulation 431–01–01 requires *every* live conductor to be protected by at least one device capable of automatic interruption of the supply in the event of an overload current and when a fault current occurs. Regulation 431–01–02 goes on to require that the protection against both these risks is co-ordinated and, not unreasonably, Regulation 431–01–03 demands that no fault current be allowed to persist indefinitely. Generally speaking, every live conductor (phase and neutral conductors of an a.c. system and all poles of a d.c. system) must be protected against overcurrent by one or more devices which will automatically interrupt the supply in the event of a fault condition and an overload. In other words, overcurrent protection is specifically intended to protect persons, livestock and property from the hazards associated with a circuit drawing current in excess of its rated current which, normally, is the nominal current rating or pre-selected setting of the overcurrent protective device.

BS 7671 does not impose specific time limits on the duration of a fault other than to demand that there are no consequential risks. However, where such devices are also used to provide protection against electric shock (indirect contact), the maximum duration would not normally exceed 5 s and, for most purposes, this would be considered the maximum time allowed for clearing a fault current. Data for k values given in Table 54A of BS 7671 are based on a maximum of 5 s duration (see also item 7.5.3 of this Guide for the derivation of k).

7.2 Nature of protective devices

Regulation 432–01–01 calls for the protective devices employed to be suitable for the task that they are being asked to perform (i.e. protection against fault current and/or overload). With certain exceptions, devices providing protection for both fault current and overload need to be (Regulation 432–02–01) capable of breaking and, in the case of electromechanical devices, of making any fault current likely to occur. This includes the maximum prospective fault current at the point at which it is inserted into a circuit. Where a device is used for protection against overload only, it is permissible (Regulation 432–03–01) for it to have a fault breaking (and making) capacity of less than the prospective fault current. Where a device is employed for protection against fault current only it must clearly have a fault current capacity as if it provided protection against both risks (fault current and overload).

Regulation 432–02–01 recognises that a single device may provide protection against overload and fault current although separate devices may be employed to serve the two functions. Fault current magnitudes are usually of a much higher order than overload currents (e.g. 500 times higher).

Because the heat (I^2Rt) caused by overcurrent conditions is proportional to I^2 and the duration of the condition, the disconnection of fault currents is required in much shorter times than would be the case for an overload condition. An overcurrent protective device (e.g. a fuse or circuit-breaker) when used for all forms of overcurrent will take much longer to operate on overload compared with that of fault current as will be seen from its time/current characteristic. In general, there will be abnormal conditions which generate a current which in magnitude is greater than overload but substantially less than fault current. However, selecting a device, or devices, capable of protecting overload and fault current will, in most cases, be all that is required of the designer. Overcurrent protective devices and their performance are discussed in Chapter 11 (item 11.4) of this Guide. Figure 7.1 gives a pictorial representation of the various currents and other parameters.

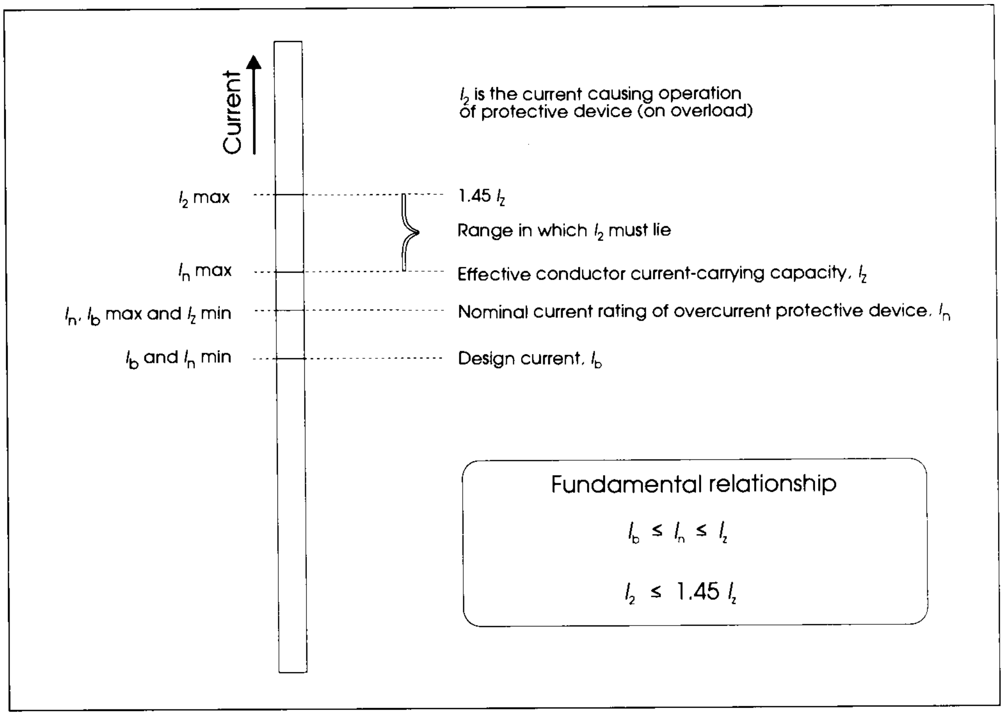


Figure 7.1: Current-carrying capacity and nominal and overload operating currents

7.3 Protection against overload

7.3.1 General

Overload is a current exceeding rated current which may be provoked by excessive loading, either unintentionally or deliberately, of the circuit by the installation user or by some malfunction of load (e.g. motor driven machinery subjected to mechanical loading in excess of the design load). The purpose of providing overload protection is to prevent damage to the cable, conductor insulation, joints and connections and the surrounding area by excessive temperature rise. Regulation 433–01–01 makes this point and goes on to call for every circuit design to be such that small overloads (those that would not be sufficient to operate the device) do not occur. This is an important aspect in the design and it is essential that load assessments are sufficiently accurate to confirm that currents are not drawn in excess of the rated current. For example, a circuit drawing a current of 10–15% over rated current will continue to function for an indefinite period without the operation of the circuit's overcurrent protective device. Whilst overload protective requirements are essentially for the purpose of protecting conductors, the circuit's accessories, switchgear, etc. would normally also be protected provided they had been selected on the basis of complying with the appropriate British or CENELEC Standard.

Regulation 433–02–01 sets out the requirements for the co-ordination between the protective device and the conductors to be protected against overload. The design load current of the circuit is represented by the symbol I_b while I_z, represents the lowest current-carrying capacity of any live conductors of the circuit in question. The nominal current rating, or current setting, of the protective device is designated I_n and the current causing operation of the device on overload is I_2. Current setting applies only to devices (e.g. MCCB) which have adjustable settings for current which might be less than the nominal rating of the device. Where used, the arrangement for setting the current of such a device must be inaccessible to non-skilled persons and sealed to prevent inadvertent adjustment. The co-ordination requirements for these parameters can best be summarised by the formulae given in Equations (7.1) to (7.4).

$$I_b \leqslant I_n \tag{7.1}$$

$$I_n \leqslant I_z \tag{7.2}$$

or by combining the two equations

$$I_b \leqslant I_n \leqslant I_z \tag{7.3}$$

also

$$I_2 \leqslant 1.45\ I_z \tag{7.4}$$

Regulation 433–02–02 confirms that where current-limiting fuses to BS 88 Part 2 'gG', BS 88 Part 6 and BS 1361 and circuit-breakers to BS 3871 Part 1 or BS EN 60 898 are used, compliance with the Equation (7.2) ($I_n \leqslant I_z$) also meets the requirements implicit in Equation (7.4) ($I_2 \leqslant 1.45\ I_z$). This is because the British Standards Institution has addressed these aspects in the design constraints of such devices. Type 'gG' fuses must not be confused with type 'gM', used for motor protection, and type ‘a’, which have only partial range short-circuit capacity, the latter two types not being suitable for overload protection.

Where a BS 3036 rewirable fuse (or semi-enclosed fuse as it is more accurately termed) is used, compliance is not assured in a similar way to the use of fuses and MCBs as previously described. Regulation 433–02–03 makes further demands in this case in that it modifies Equation (7.2) to $I_n \leqslant 0.725\ I_z$. This is necessary because the rewirable fuse has a fusing-factor of 2; the fusing factor being the ratio of the minimum fusing current to cause operation (‘blowing’) in 4 h to the nominal rating of the fuse. So, for example, for a 30 A circuit protected by a 30 A rewirable fuse and drawing an *overload* current of 60 A, disconnection on overload may take up to 4 h. Clearly this phenomenon needs to be taken into account for all cables, except MICC, and this is done by the application of the 0.725 factor as a multiplier to the current-carrying capacity of the circuit cable. One effect of using a rewirable fuse to BS 3036 is therefore to increase the required cable csa for a given load, other parameters being equal. The factor of 0.725 is derived by application of the two formulae in Equations (7.5) and (7.6).

$$I_2 = 2\ I_n \tag{7.5}$$

$$I_2 \leqslant 1.45\ I_z \tag{7.6}$$

By combining the two foregoing equations:

$$2\ I_n \leqslant 1.45\ I_z \tag{7.7}$$

so that

$$I_n \leqslant \frac{1.45}{2} \qquad \text{or} \qquad I_n \leqslant 0.725\ I_z \tag{7.8}$$

Overload protective devices are normally positioned at a point where a reduction in the current-carrying capacity of a cable or conductors occurs. As Regulation 473–01–01 points out, there are a number of reasons why a reduction in current-carrying capacity may occur other than the obvious one – a reduction in conductor csa. I_z will always be the lower or lowest of the current-carrying capacities of conductors downstream of the overload protective device (unless other protective devices are employed downstream). Factors affecting current-carrying capacity would include:

- change in cross-sectional area, and/or
- change in ambient temperature (on cable route), and/or
- change in type of conductor, and/or
- change in environmental conditions *en route* (e.g. thermal insulation), and/or
- change in grouping (of conductors or cables).

Whilst overload devices are normally located at the point of reduction of current-carrying capacity, this is not always practical or even desirable as in, for example, the case of the electric motor where it is often positioned in an enclosure (starter) adjacent to the motor. Regulation 473–01–02 allows such a practice but demands in such cases that there be no branch circuits or outlets between the point at which there is a reduction in current-carrying capacity and the device (see item 7.3.2 of this Guide). However, this relaxation cannot be applied where there is a high risk of fire or explosion, or where special considerations are appropriate.

As envisaged by Regulation 473–01–04, there are situations where overload devices may be omitted and there is one case where such a device *must not* be inserted, namely in the secondary winding of a current transformer where extremely high voltages can occur on secondary circuit interruption. Table 7.2 details the situations where overload protection may be omitted. Regulation 473–03–03 permits the omission of overload protection in a one phase conductor in an IT system with neutral, provided an RCD is located in each circuit.

Table 7.2: Omission of overload protection

Situations where overload protection may be omitted	**Restrictions or qualifications**
Secondary circuits of current transformers.	May be omitted.
At a location of reduction in current-carrying capacity of conductors.	Where supply characteristics are such that overload is unlikely to occur. Where load characteristics are such that overload is unlikely to occur. Where overload protection is provided by an upstream device.
At the origin of installation.	Where Supplier's overload device is used and affords adequate protection (with Supplier's express agreement).
At any position.	Where the current-carrying capacity of the live conductors is greater than the current the source can deliver.
Exciter circuits of rotating machines.	May be omitted.
Supply circuits of lifting magnets.	May be omitted.
Circuits supplying a fire extinguishing device.	May be omitted.
One phase conductor in IT system without neutral – RCD in each circuit	May be omitted

Note: Regulation 473–01–03 requires consideration to be given to the provision of overload alarm for circuits not provided with protection against overload.

Regulation 473–01–05 states that the relaxation permitted by Regulations 473–01–02 and 473–01–04 may only be applied to an IT system where conductors are protected by a RCD or by use of Class II or equivalent insulation. It should he noted that overload protection may only be omitted where protection is provided by some other means or where a greater danger would be created by the operation of the overload device. In the assessments of other dangers and risks, the designer would need to consider all the scenarios that may occur in practice and weigh the implications of omitting the device very carefully. Regulation 436–01–01 confirms that where the current-carrying capacity of live conductors is greater than the current that the sources can deliver, no further overload protection is necessary.

7.3.2 Protection against overload – motors

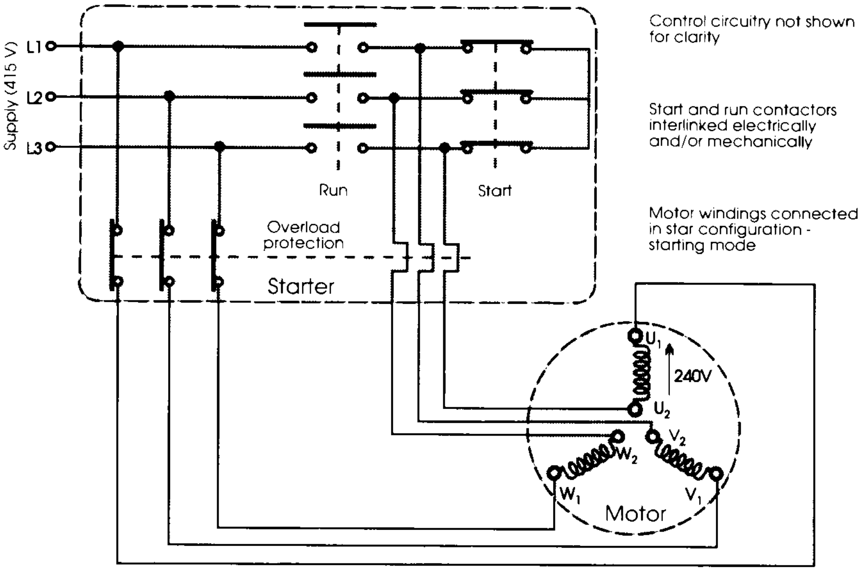
Requirements for overload protection for circuits supplying motors are generally the same as for other circuits in that the overload operating current, I_2, must not exceed 1.45 times I_z. The detailed examination of the many different types of motors and their characteristics is outside the scope of this Guide. However, there is one particular case which is worthy of mention, regarding overload protection, and this is the star/delta starting technique of the three-phase motor.

A commonly accepted 'rule of thumb' has involved the final connection cables, to the motor from the starter, to be selected so as to be half the csa of the cables supplying the starter. This method may be too generous in its assumptions and the final connection cables may not be adequately protected against overload. Figure 7.2 shows in (a) the motor windings connected in star configuration for starting mode and (b) shows the reconnected windings in the delta configuration for the running mode. The starting current when connected in star is much reduced owing mainly to the voltage across each winding being reduced to $1/\sqrt{3}$ (0.577) of the supply phase-to-phase voltage.

Generally speaking, the starting period in star configuration is relatively short and, although the starting currents can, for example, be as high as ten times the normal running current, the conductors are unlikely to suffer any damage from excessive temperature rise in the short starting time. Consequently, the overload device would not normally be called upon to operate under starting conditions.

It can be seen from Figure 7.2 that the overload protection is generally in the winding phase conductors and not in the supply lines. In running mode, the current in the supply is $\sqrt{3}$ times the current in each winding or, to put it another way, the current in each winding is approximately 0.58 times the supply current ($1\sqrt{3} = 0.577$). It should also be recognised that because the six cables connecting the motor to the starter are always loaded when the motor is running and are usually run grouped together in the same conduit or other wiring system, an allowance must be made for such grouping. In effect, these six cables represent two 'circuits' and the appropriate correction factor, C_g, must be applied. Should the final connection cables be of a different type and/or be subjected to different installation conditions then other appropriate correction factors must also be applied.

It can be seen that where the motor connections are grouped in conduit (installation method 3) the correction factor, C_g, of 0.80 is called for and this together with the 0.58 factor would require these conductors to have an

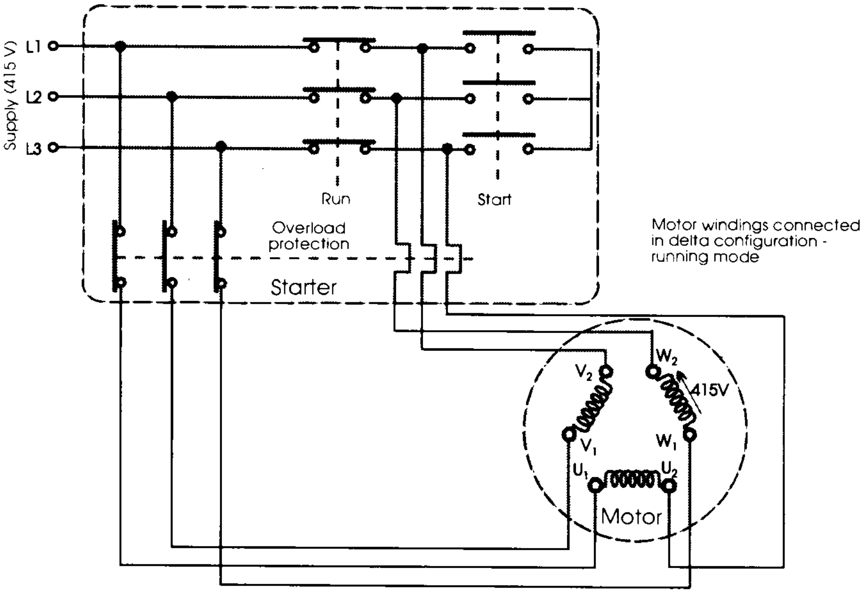


Control circuitry not shown for clarity

Start and run contactors interlinked electrically and/or mechanically

Motor windings connected in star configuration - starting mode

(a) 'Starting' connections in star configuration shown above



Motor windings connected in delta configuration - running mode

(b) 'Run' connections in delta configuration shown above

Figure 7.2: Star/delta starting of three-phase motor

effective current-carrying capacity of approximately 72% (0.58 ÷ 0.80) of that of the conductors supplying the starter.

In many cases it is just not desirable or even feasible to select a motor starter with sufficiently high fault capacity and, generally, it is not necessary to do so when used in conjunction with a fuse or circuit-breaker capable of providing the function of breaking fault current. However, a motor starter should be capable of closing on to a fault condition (e.g. stalled-rotor condition) without itself sustaining damage and, of course, be capable of interrupting the maximum overload current. It is important therefore that the starter does not attempt to operate under fault conditions before the associated overcurrent protective device has had a chance to interrupt the faulted circuit.

The motor 'back-up' overcurrent protective device must be capable of interrupting the fault current but must not operate under normal starting conditions. HBC fuses to BS 88 'gM' have been designed specifically for this purpose although it is possible to use fuses to BS 88 'gG', of a higher rating than would be suggested by the steady-state load current (i.e. $I_n \geqslant I_b$), for this purpose provided the device thermally protects the downstream circuit conductors under fault conditions.

Fuses to BS 88 'gM' have a dual rating, the first of which relates to the maximum continuous current and the second based on the characteristics of the load and, in particular, the starting current draw. The ratings are expressed as a code as, for instance, '100M160'. Take, for example, a direct-on-line starter and motor with a full-load current of, say, 99 A which would require a 160 A fuse to BS 88 'gG' but would also be adequately protected by a 100M160 fuse to BS 88 'gM'.

As regards co-ordination of protection, BS EN 60 947–4 identifies three levels of permitted damage to motor starters as a result of fault conditions. Type 2 co-ordination is required if the starter is expected, after examination and any necessary remedial work, to provide overload protection subsequent to experiencing a fault condition. This type does allow for light contact burning and the possible risk of welding of contacts but does not permit any permanent damage or permanent alteration of the starter's overload characteristic.

Motor overload devices are normally arranged to operate between currents exceeding full-load current and the overload limit of the motor as specified by the motor manufacturer. However, the overload device mechanism is usually time-delayed (e.g. damped by oil-filled dashpots or thermal device) to allow normal starting currents to flow without interruption. Fault-currents are allowed by the overload device to persist so as to be detected by the upstream overcurrent protective device.

The motor starter overload device can, and usually does, provide overload protection for circuit conductors as well as the motor but a check is always necessary to confirm that the highest setting of overload operating current, I_2, is not more than 1.45 I_z.

Motors having a duty cycle involving frequent starting and stopping require special consideration to take account of the accumulative heating effects of the recurrent starting currents.

7.3.3 Ring final circuits

The normal requirements relating to protection against overload are relaxed in the case of ring final circuits. Regulation 433–02–04 provides a *deemed to comply* status for protection against overload where certain conditions are a prerequisite:

- Circuit must be protected against overcurrent by a 30 A or a 32 A overcurrent protective device complying with BS 88, BS 1361, BS 3036, BS 387 or BS EN 60 898.
- Circuit accessories must be to BS 1363.
- Circuit live conductors must be copper, minimum cross-sectional area of 2.5 mm^2, unless mineral insulated 2 core cable (to BS 6207) is used where they may be 1.5 mm^2.
- The current-carrying capacity must not be less than 67% of the rated current of the overcurrent protective device ($I_z \geqslant 0.67\ I_n$).

7.4 Protection against fault current

As previously mentioned, fault current is an overcurrent caused by either a short-circuit (between live conductors) or an earth fault (between a live and an exposed-conductive-part or protective conductor). Faults occur as a result of insulation failure or by the bridging of conductive parts by some conducting material and there are a number of possible fault conditions which need consideration:

- short-circuit faults between phase and neutral,
- short-circuit faults between phase and phase,
- short-circuit faults between all three phases,
- earth faults between phase and exposed-conductive-parts or protective conductor.

Fault currents left unchecked would result in overheating and damage to insulation and possibly the risk of igniting material adjacent to the conductors either by raising the temperature or by arcing. The protective measures are therefore intended to prevent deterioration of insulation, damage to property including electrical equipment and the prevention of fire which would be a hazard to both persons and property. Because anticipated fault currents are high, it is necessary to have short disconnection times to prevent the rise in conductor temperature becoming excessive. Acceptable temperature limits for conductors are given in Table 43A of BS 7671 for live conductors and Tables 54B, 54C, 54D, 54E and 54F for protective conductors.

Regulation 434–01–01 calls for a fault current protective device to disconnect *all* fault current in the protected circuit before it causes danger from thermal or mechanical effects. Where devices protect only against fault current (and not overload), the nominal rating of the device, I_n, may be greater than the current-carrying capacity of the cable, I_z. This would not apply, of course, to where the device performs both functions of protection from overload *and* fault current.

As with overload devices, fault current protective devices generally must be positioned at the point where a reduction in current-carrying capacity occurs (i.e. where the conductor energy-withstand is reduced) as called for in Regulation 473–02–01. As before, the factors affecting current-carrying capacity would include:

- change in cross-sectional area, and/or
- change in ambient temperature (on cable route), and/or
- change in type of conductor, and/or
- change in environmental condition *en route* (e.g. thermal insulation), and/or
- change in grouping (of conductors or cables).

There is an exception to this rule of positioning the protective device which, according to Regulation 473–02–02, may be inserted in the circuit other than at the point where the reduction of current-carrying capacity occurs (see Figure 7.3) providing *all* of the following conditions are met:

- the distance between the device and the point at which the reduction of current-carrying capacity occurs does not exceed 3 m, and
- the 'unprotected' circuit cables between points to be installed such that the risk of a fault current occurring is minimised, and
- 'unprotected' circuit cables are installed in such a manner that the risk of fire is minimised.

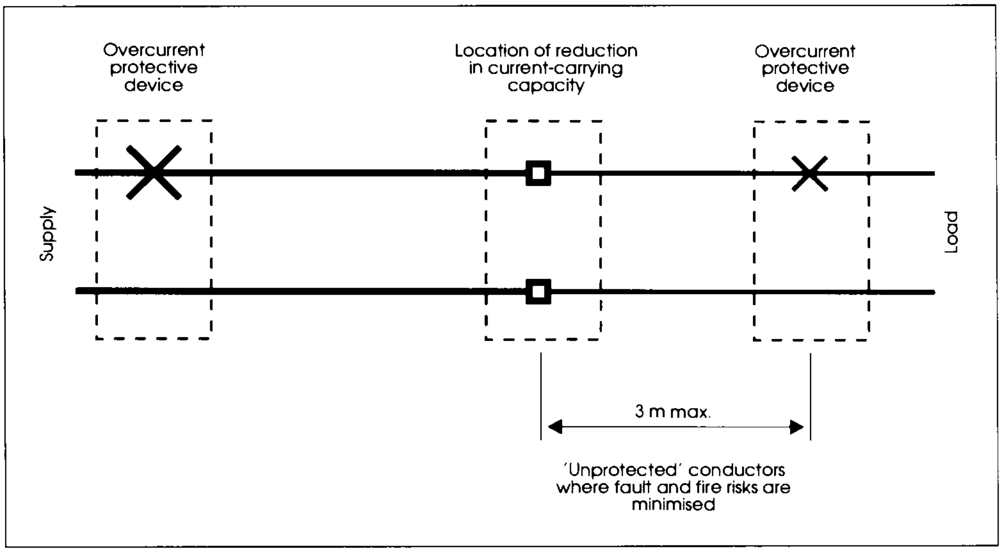


Figure 7.3: Placing of overcurrent device at other than the point of reduction of current-carrying capacity

As stated in Regulation 473–02–03, a fault current protective device may be placed anywhere in the circuit provided an upstream (supply-side) device affords the necessary protection envisaged by Regulation 434–03–03 (meeting the adiabatic equation so as to prevent unacceptable conductor temperature rise). There are a number of certain other cases where a fault current protective device may be omitted (Regulation 473–02–04) and these are summarised in Table 7.3. Again it should be noted that the Regulation states that such devices *may* be omitted and it is left to the installation designer to make the necessary engineering judgement in this respect. However, this relaxation cannot be applied where there is a high risk of fire or explosion, or where special considerations are appropriate.

Table 7.3: Omission of fault current protection

Situations where fault current protection may be omitted	**Restrictions or qualifications**
A conductor connecting a generator with its control panel.	On condition that fault current protection is provided in the panel an inter-connected cable is installed so that the risk of fault current occurring and the risk of fire are minimised.
A conductor connecting a transformer, rectifier or battery with its control panel.	On condition that fault current protection is provided in the panel an inter-connected cable is installed so that the risk of fault current occurring and the risk of fire are minimised.
In a measuring circuit.	Where disconnection would cause greater danger (e.g. secondary circuits of CTs).
In any circuit supplying equipment.	Where unexpected interruption causes greater danger than that of a fault current.
At the origin of an installation.	Provided the Supplier provides such device(s) *and where agreement is obtained* for its use to protect (part of) the installation.

Devices employed for protection against overcurrent must generally have a short-circuit capacity not less than the prospective fault current at the point at which they are located in the circuit. This is discussed in item 7.6 of this chapter.

7.5 Determination of prospective fault current

7.5.1 General

Regulation 434–02–01 demands that an assessment be made at every relevant point in the entire installation (i.e. at every point where a fault current protective device is positioned). This may be done by either calculation or measurement depending on the circumstances. Both methods should not be viewed as highly accurate and a margin of error must be assumed and allowances made accordingly. Where measured, this will need to be undertaken using a suitable test instrument, preferably giving direct prospective fault current readings, which is appropriate for the particular nominal voltage of the circuit under test. For small installations (i.e. nominally rated up to 100 A per phase), a portable hand-held instrument for measuring loop impedance may be used and the measured value can be used to determine the prospective fault current, I_{pf} (i.e. $I_{pf} = (U_n \div Z)$). For the larger installations, a more sophisticated instrument will be required. As with all testing and measurement taking, there is an element of danger to the operator of the instrument (and bystanders) and it is essential that tests are all undertaken by competent persons who have had experience in the field and are fully versed in the necessary safe systems of working.

In designing an installation it is essential for the designer to make an assessment of the fault levels with which protective devices will have to cope. For the most part, measurement of prospective fault current will not be an option and consequently calculations will need to be undertaken. To estimate fault current all that is required (applying Ohm's law) is a value for the source voltage and a value for the loop impedance at the point in question. The former is usually quite simply a matter of assuming that the source voltage will be the supply nominal voltage and will remain constant (i.e. an infinite busbar) under fault conditions. The latter parameter is more difficult to calculate unless all the constituent parts of the loop are known, if not in terms of impedance, in terms of length, csa, conductor material, cable construction from which a deduction can be made of the resistance and inductive reactance of the constituent parts.

In making such calculations, there is an enormous scope for error from different sources. For example, resistance is a function of temperature (which will rise under fault conditions) whereas inductive reactance is not affected in the same way. With the very high currents which will flow under fault conditions, inductive reactance will be difficult to predict with any degree of certainty and this parameter may be influenced by many unknowns as, for example, the actual inductive reactance of switchboards, busbar trunking, etc. Resistances of joints may also vary under fault currents. The calculations therefore need to be treated with caution and it will often be found by testing at a later stage that the calculated value of prospective fault current was more pessimistic than the measured value indicates. This of course is welcomed in consideration of short-circuit capacities of protective devices and the effects of electromagnetic forces but less welcomed with regard to the disconnection times (the lower the fault current, the longer the disconnection with fuses) and to the energy let-through which is likely to be greater at lower fault currents.

Regulation 533–03–01 calls for the maximum and minimum fault current to be considered in selecting an appropriate fault current protective device. The highest fault current will occur when the fault loop impedance is at its lowest value. This will be the case where a fault is considered immediately downstream of the protective device in question and when the conductors upstream are at the lowest temperature likely to be encountered during service. Unless better information and knowledge are available, this temperature will normally be taken as 20°C and it will be found that cable manufacturers publish cable data (for conductor resistances) at this temperature. In cases where a lower temperature is encountered (e.g. in a refrigerated building) or where a higher temperature is known (e.g. boiler plant room), the given resistance data need correction to allow for these different temperatures. The maximum value of fault current is crucially important in the consideration of short-circuit capacities and the effects of electromagnetic forces.

The minimum value of fault current will occur when conductors are at their maximum operating temperature (e.g. copper/PVC at 70°C) and when a fault occurs at the most remote end of the circuit in question. The crucial temperatures for the purposes of calculation are the maximum operating temperature and the limiting final temperature of the conductors. The resistance, for calculation purposes is taken as the average of the values given for the two different temperatures (see Table 43A of BS 7671). If the conductors upstream of the protective device and circuit under consideration are much larger (say, at least twice) than the downstream conductors, the fault current will have less effect in increasing their temperature (and resistance) and can, generally speaking, be assumed to maintain their normal temperature.

In the following calculations, a simplistic method has been adopted which should be appropriate for most design appraisals of fault-level. There may be times where a more rigorous approach will be required and, in such cases, reference to IEC 909 *Short-circuit calculation in three-phase a.c. systems* will be essential. The cited examples assume that the voltage will be constant throughout the fault (infinite busbar) and this will be acceptable where the supply is derived from the public supply network. For other sources, such as generators (normal and standby supplies), it may be necessary to consult the generator manufacturer in order to define the transient characteristics of the set under fault conditions.

It should be borne in mind that where items of large equipment, capable of energy storage, are part of the installation, these too may be a source (in tandem with the normal supply source) capable of feeding a fault. This may be the case, for example, where a large motor instantaneously converts to a generator in the event of a fault (and loss of supply voltage). This energy source therefore needs to be taken into account in the assessment of prospective fault current.

Figure 7.4 shows a TN-S system and identifies examples of the various fault conditions, each being dealt with in the following text. Equivalent circuits for short-circuit fault conditions are the same irrespective of system type and earthing arrangements whereas earth fault equivalent circuits do differ. In the figure the symbols given have the following meanings:

$\left.\begin{array}{l} R_{L1} \text{ and } X_{L1} \\ R_{L2} \text{ and } X_{L2} \\ R_{L3} \text{ and } X_{L3} \end{array}\right\} =$ the resistive and reactance components respectively of impedance of the supply source (transformer) and supply lines up to the origin of the installation (L1 = line 1 – red phase; L2 = line 2 – yellow phase; L3 = line 3 – blue phase)

R_N and X_N = the resistive and reactance components respectively of impedance of the neutral supply conductor

R_E and X_E = the resistive and reactance components respectively of the supply earthing conductor from the MET to the source star/neutral point

R_1 and X_1 = the resistive and reactance components respectively of the installation phase conductor(s)

R_n and X_n = the resistive and reactance components respectively of the installation neutral conductor

R_2 and X_2 = the resistive and reactance components respectively of the installation circuit protective conductor(s)

R_S = the resistance of the supply source earthing electrode

U_O = the source nominal voltage to Earth

U = the source nominal voltage phase-to-phase (or line-to-line).

Resistive and reactive components of impedance cannot be added together arithmetically since they are in quadrature (i.e. displaced by 90°). The addition must be made vectorially as shown in the ‘impedance triangle’ given in Figure 7.5. The triangle is right-angled so that the hypotenuse (impedance) is the square root of the sum of the resistance squared plus the reactance squared as given in Equation (7.9). The angle ϕ is the angular

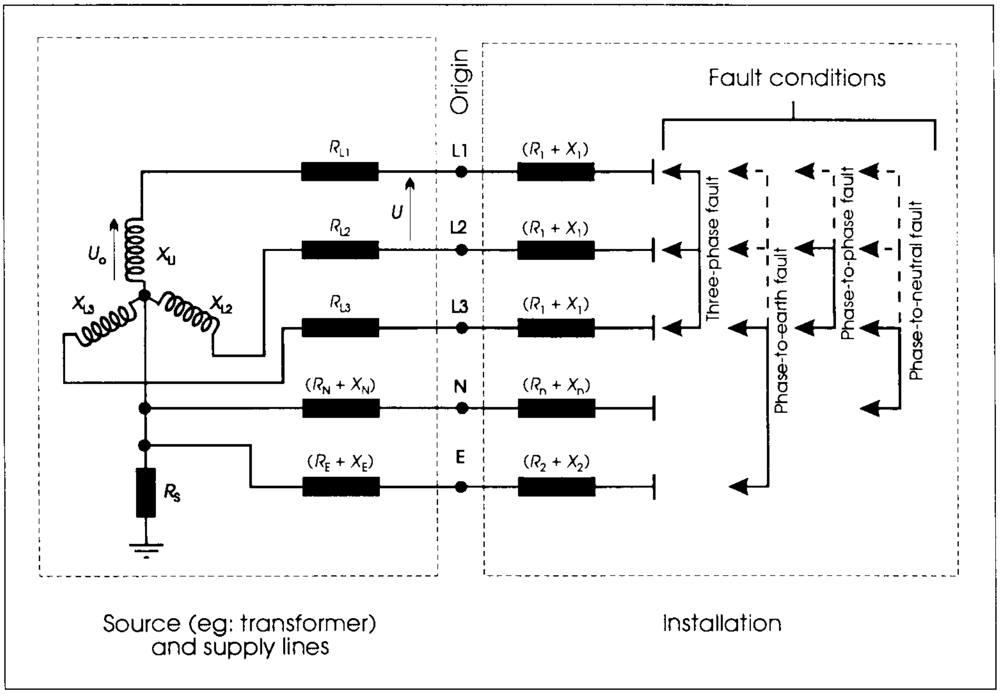


Figure 7.4: TN-S system – examples of the various fault conditions

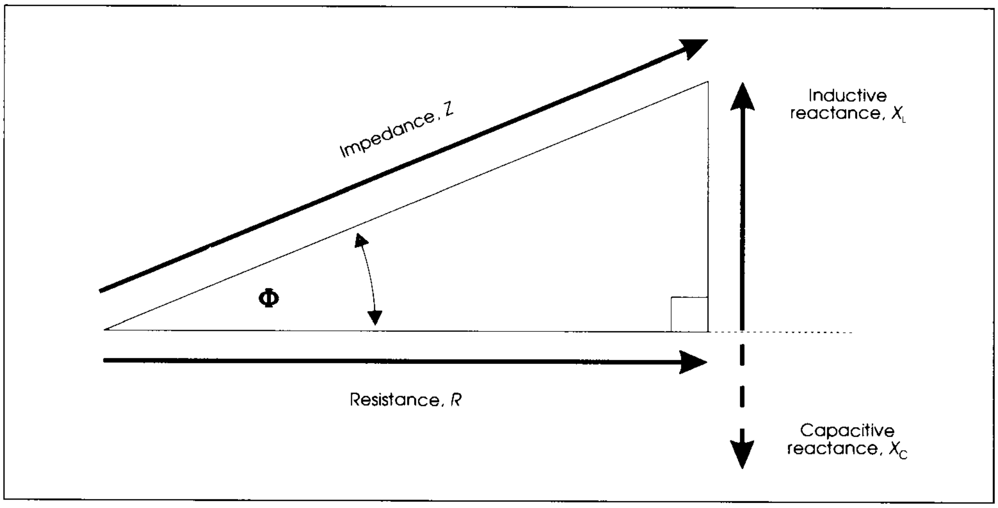


Figure 7.5: Impedance triangle

displacement between impedance and resistance and cos ϕ is the power factor.

$$Z = \sqrt{(R^2 + X^2)} \tag{7.9}$$

7.5.2 *Calculation of inductive reactance*

Because of space limitations, it is not the intention here to reiterate the examination of inductive reactance calculations which are dealt with admirably in the IEE Guidance Note No 6: *Protection against overcurrent*, but rather draw the designer's attention to the need to be aware of the complexities in the more rigorous analysis in determining fault current with some greater degree of accuracy.

Inductive reactance is a function of the mutual inductance between conductors carrying current and, for steady-state conditions, is only present in a.c. systems where the instantaneous current is continuously changing in magnitude. When considering fault current, it is normally more advantageous to consider each circuit component or conductor separately (e.g. phase, neutral and protective conductor) but the inductive reactance is a function of all the conductors combined in close proximity. For example, the reactance of two conductors close together will not be the same as three similar conductors in trefoil or when the two conductors are a distance apart. Additionally, the reactance will be different for the various fault conditions and IEE Guidance Note No 6: *Protection against overcurrent* addresses the various cases.

7.5.3 *Evaluation of* **k** *for different temperatures*

Data for the *k* values for the more commonly used conducting materials (copper and aluminium) with their insulating materials (e.g. PVC, rubber, etc.) are given in Table 43A of BS 7671. This table also lists the assumed initial temperatures and the limiting final temperature appropriate to the particular type of insulation. The data given for *k* values are only valid for fault current flow duration of up to 5 s. Where faults take longer to clear, the cable manufacturer should be consulted to clarify whether or not the cable is protected for a fault of this longer duration. Where greater accuracy is required than that obtained by the use of the adiabatic equation, the calculation should be carried out as laid down in BS 7454: 1991 (IEC 949) *Method of calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects*.

The factor *k*, used in the adiabatic equation of Regulation 434-03-03, is based on the resistivity of the conductor, the temperature coefficient and the heat capacity of the conductor material. Its value is also dependent on the initial temperature and final temperature of the conductor, the latter being dictated by the type of insulation. The factor is derived from the formula given in Equation (7. 10) and Table 7.4 provides the necessary data for its use.

$$k = \sqrt{\frac{Q_c(B+20)}{Q_{20}} \times \ln\left(1 + \frac{\theta_f - \theta_i}{B + \theta_i}\right)} \tag{7.10}$$

where Q_c = volumetric heat capacity of the conductor material (J/°C mm^3)
B = reciprocal of temperature coefficient of resistivity at °C for the conductor (°C)
Q_{20} = electrical resistivity of conductor material at 20°C (Ω mm)
θ_i = initial temperature of conductor (°C)
θ_f = final temperature of conductor (°C)
ln = log to the base e.

Equation (7. 10) can be much simplified by making the substitution given in Equation (7.11) for *C* (a constant for a particular conductor) which results in the formula given in Equation (7.12).

$$C = \sqrt{\frac{Q_c(B+20)}{Q_{20}}} \tag{7.11}$$

$$k = C\sqrt{\ln\left(1 + \frac{\theta_f - \theta_i}{B + \theta_i}\right)} \tag{7.12}$$

For example, if we take a copper conductor insulated with 90°C thermosetting with an initial temperature, θ_i, of 90°C and a final temperature of 250°C (as given in Table 43A of BS 7671) and apply these data together

Table 7.4: Material data for evaluating *k*

Material	**B (°C)**	**Q_c (J/°C mm³)**	**Q_{20} (Ω mm)**	**$C = \sqrt{\frac{Q_c(B + 20)}{Q_{20}}}$**
Copper	234.5	3.45×10^{-3}	17.241×10^{-6}	226
Aluminium	228.0	2.50×10^{-3}	28.264×10^{-6}	148
Lead	230.0	1.45×10^{-3}	214.000×10^{-6}	41
Steel	202.0	3.80×10^{-3}	138.000×10^{-6}	78

with those contained in Table 7.4, we get a *k* value, given in Equation (7.13) as 143, which is in agreement with that given in BS 7671.

$$k = 226\sqrt{\ln\left(1 + \frac{250 - 90}{234.5 + 90}\right)} \tag{7.13}$$

$$= 226\sqrt{(\ln 1.493)}$$
$$= 226 \times 0.633 = 143$$

There may be occasions where the designer has selected a conductor size with a current-carrying capacity much in excess of the design load current, perhaps because of volt-drop considerations. In such a case, the initial conductor temperature will be less than that assumed in Table 43A of BS 7671 and consequently a higher *k* coefficient will apply. Take, for example, a similar conductor to that given above and at an initial temperature of, say, 50°C. By applying the above equation we get a *k* coefficient of 165 as shown in Equation (7.14).

$$k = 226\sqrt{\ln\left(1 + \frac{250 - 50}{234.5 + 50}\right)} \tag{7.14}$$

$$= 226\sqrt{(\ln 1.703)}$$

$$= 226 \times 0.730 = 165$$

This calculation is really only worthwhile where there is a substantial difference between the initial temperature given in Table 43A of BS 7671 and the actual initial temperature and its application will be very limited. Where used, the average value of conductor temperature under fault conditions should also be recalculated.

7.5.4 Calculation of impedance of steel enclosures

The calculation of the impedance of steel enclosures requires special consideration in a.c. systems, because the magnetic effects of steel are significant and cannot be ignored. In the case of steel conduit the relationship of these magnetic effects is not linear and it is necessary, in order to simplify matters, to treat fault currents up to 100 A and those above 100 A quite separately and assume linearity in these two ranges. Both the resistive and reactance components of impedance are affected. As with steel conduit, the impedance of steel trunking is also affected by magnetic flux linkages. However, the corrective procedure in the case of trunking is simplified by virtue of the general acceptance that trunking is not acceptable as a protective conductor for circuits with a fault current exceeding 100 A. Though not a common practice, it ought to be appreciated that a protective conductor or complementary protective conductor should not be run outside, and in close proximity to, steel trunking and steel conduit. The magnetic screening effects will increase the impedance of that conductor to a point where it ceases to become an effective protective conductor.

Perhaps not always readily appreciated, the metallic sheath or armouring of a cable (e.g. steel-wire armour) is a conductor enclosure. As such it is subjected to similar considerations with regard to the magnetic effects and the resultant changes to resistance and reactance. In the use of aluminium-wire armoured single-core cables adjustment is also required to the resistance value. Generally speaking, such cables are bonded to Earth at both ends of their run (two-point bonding) and consequently earth fault current, in a three-wire system, will flow in the three parallel paths provided by the armouring of each of the single-core cables. The adjustments for resistance and reactance for MICC cables are much simpler because the magnetic effects are much less or non-existent. The IEE Guidance Note No 6: *Protection against overcurrent* gives detailed methods for making such adjustments to resistance and reactance where steel enclosures are involved in the wiring system.

7.5.5 Resistance and inductive reactance values

The values for resistance of most conductors may be obtained from BS 6360 *Specification for conductors in insulated cables and cords*. Alternatively, resistance and reactance values may be acquired by reference to the volt-drop tables in Appendix 4 of BS 7671. It is important to note however that the values so gained by these methods should be treated as the ‘base’ values and corrected to take account of the particular fault condition envisaged and the configuration of the conductors (e.g. trefoil or flat formation). IEE Guidance Note No 6: *Protection against overcurrent* addresses this subject in great depth. Additionally, resistance values need correction to take account of the rise in temperature under fault conditions (see item 7.5.6 of this Guide).

To illustrate by (an unlikely) example how the ‘base’ resistance and reactance values may be obtained from the volt-drop tables of Appendix 4, let us consider a circuit of two 240 mm^2 single-core cables to BS 6231, of length 200 m, run in conduit (reference method 3) with many draw-in boxes. From Table 4D1B of BS 7671, the resistance (r = 0.195 mV A^{-1} m^{-1}), inductive reactance (x = 0.260 mV A^{-1} m^{-1}) and impedance (z = 0.330 mV A^{-1} m^{-1}) are given. To obtain the values for the 200 m run the given data are simply multiplied by 200 and, to give ohms rather than mllllohms, divided by 1000. The values become: $R = 0.039\ \Omega$, $X = 0.052\ \Omega$ and $Z = 0.066\ \Omega$. In the case of data provided in the tables for three-phase, the volt-drop values, for each phase conductor, are $\surd 3r$, $\surd 3x$ and $\surd 3z$ as such should be divided by $\surd 3$ to obtain the resistance, reactance and impedance values (and multiplied by the run length) for conductors.

It is also important to note that the volt-drop data given in Appendix 4 of BS 7671 for single-core cables relate to axial spacing in the range of one or two cable diameters and when spaced at greater distances (i.e. more than one cable diameter between cables) the loop reactance is increased and due allowance should be made in this respect.

7.5.6 Temperature adjustments to resistance values

The values of resistances obtained (as detailed in item 7.5.5 above) need to be corrected for temperature. The correcting factor is different for faults occurring when the circuits are not loaded from those developing when the conductors are at their maximum permissible working temperature. The correction factors are given in Table 7.5 and should only be applied to the resistances and not to the reactances as these are not temperature dependent.

Table 7.5: Resistance/temperature correction factors for conductors on full-load and no-load

Ref	**Conductor on full-load (correction to working temperature)**			**Conductors without load (correction to 20°C)**	
	Conductor working temperature (°C)	Final temperature (°C)	Correction factor	Conductor maximum working temperature (°C)	Correction factor
A	60	200	1.24	60	0.86
B	70	160	1.15	70	0.83
C	70	140	1.12	—	—
D	85	160	1.12	85	0.79
E	85	140	1.09	—	—
F	85	220	1.21	—	—
G	90	250	1.25	90	0.78

7.5.7 Phase-to-neutral short-circuits

In a short-circuit between a phase conductor and the neutral conductor, the fault current, I_F, is limited only by the impedance of the short-circuit loop. Referring to Figure 7.6, the short-circuit current at the origin of the installation is given by Equation (7.15). For short-circuits elsewhere Equation (7.16) is appropriate.

$$I_F = \frac{U_o}{(R_L + R_N) + j(X_s + X_L + X_N)}$$

$$= \frac{U_o}{\surd[R_L = R_N)^2 + (X_s + X_L + X_N)^2]} \qquad (7.15)$$

$$I_F = \frac{U_o}{\sqrt{[(R_L + R_N + R_l + R_n)^2 + (X_s + X_L + X_N + X_l + X_n)^2]}} \tag{7.16}$$

where R_L = resistance of the supply phase conductor,

R_N = resistance of the supply neutral conductor,

X_s = source inductive reactance (note: the source resistance is, in this instance, considered to be small compared with the inductive reactance and is therefore neglected),

X_L = inductive reactance of the supply phase conductor,

X_N = inductive reactance of the supply neutral conductor,

R_l = resistance of the installation phase conductor (where appropriate, further identified by reference to the particular phase),

R_n = resistance of the installation neutral conductor

X_l = inductive reactance of the installation phase conductor, (where appropriate,, further identified by reference to the particular phase),

X_n = inductive reactance of the installation neutral conductor.

For the smaller single-phase, up to 100 A, 230 V, installation supplied from the public network the source phase-neutral impedance, Z_{p-n} (see Figure 7.6) may, generally speaking, be taken as a maximum of 0.8 Ω for a TN-S system supply (the maximum Z_{p-n} may be less, depending on the particular supply characteristics) and 0.35 Ω for TN-C-S supply although confirmation from the PES will always be necessary. The minimum value can be assumed to be 14 mΩ where the prospective fault current is given as 16 kA (230 V ÷ 16 000 A = 0.014 Ω). This range of values should be taken into account.

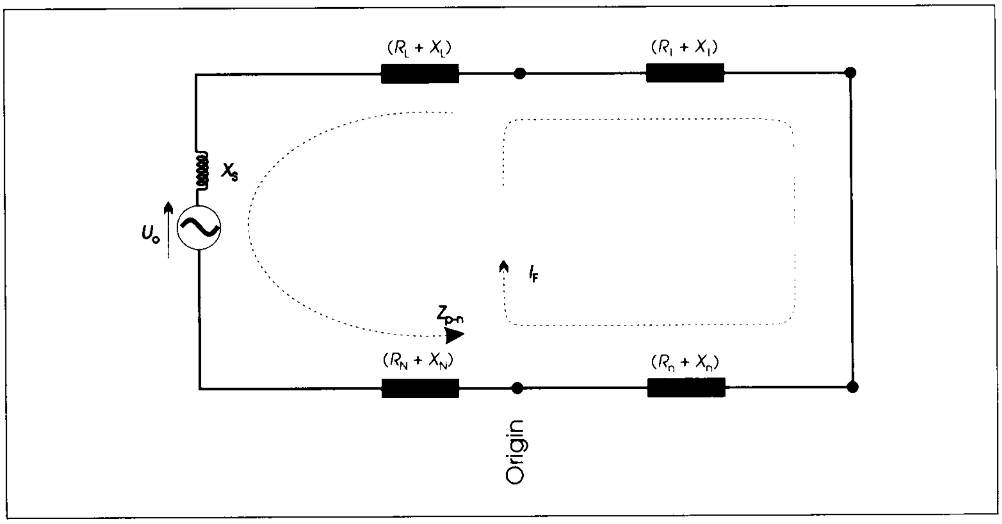


Figure 7.6: Phase-to-neutral fault equivalent circuit

It may be difficult to obtain the separate values for resistance and reactance of the source and supply lines and for the smaller installation, at any rate, and the Z_{p-n} quoted by the PES may have to be taken as wholly resistive. This would, for circuits up to 100 A (or up to 35 mm^2), tend to produce slightly optimistic results in the assessment of fault current. The formula for the calculation is given in Equation (7.17).

$$I_F = \frac{U_o}{(Z_{p-n} + R_l + R_n)} \tag{7.17}$$

For circuits above 100 A, the resistance and reactance terms of both the source and the installation circuit should be taken into account.

7.5.8 Phase-to-phase short-circuits

Phase-to-phase short-circuit currents are less than three-phase fault currents. Referring to the equivalent circuit in Figure 7.7, the general formula for calculating the prospective phase-phase short-circuit current is given in Equation (7.18). For assessment at the origin of the installation the simplified formula is given in Equation (7.19).

$$I_F = \frac{\sqrt{3}\ U_o}{(R_{L1} + R_{L2} + R_{1(L1)} + R_{1(L2)}) + j(X_{S1} + X_{S2} + X_{L1} + X_{L2} + X_{1(L1)} + X_{1(L2)})} \tag{7.18}$$

$$= \frac{\sqrt{3}\ U_o}{\sqrt{[(R_{L1} + R_{L2} + R_{1(L1)} + R_{1(L2)})^2 + (X_{S1} + X_{S2} + X_{L1} + X_{L2} + X_{1(L1)} + X_{(L2)})^2]}}$$

$$I_F = \frac{\sqrt{3}\ U_o}{\sqrt{[(R_{L1} + R_{L2})^2 + (X_{S1} + X_{S2} + X_{L1} + X_{L2})^2]}}$$

$$= \frac{\sqrt{3}\ U_o}{Z_{p-p}} \tag{7.19}$$

where Z_{p-p} is the external phase-to-phase impedance.

Where circuit conductors are not greater than 35 mm^2 the reactance terms are largely insignificant and may be neglected simplifying the formula further as given in Equation (7.20). If the installation circuit phase conductors are of the same resistance, as is usually the case, a further simplification is possible as shown in Equation (7.21) giving a somewhat optimistic assessment of fault current since the addition is arithmetic and not vectorial.

$$I_F = \frac{\sqrt{3}\ U_o}{(Z_{p-p} + R_{1(L1)} + R_{1(L2)})} \tag{7.20}$$

$$I_F = \frac{\sqrt{3}\ U_o}{(Z_{p-p} + 2R_1)} \tag{7.21}$$

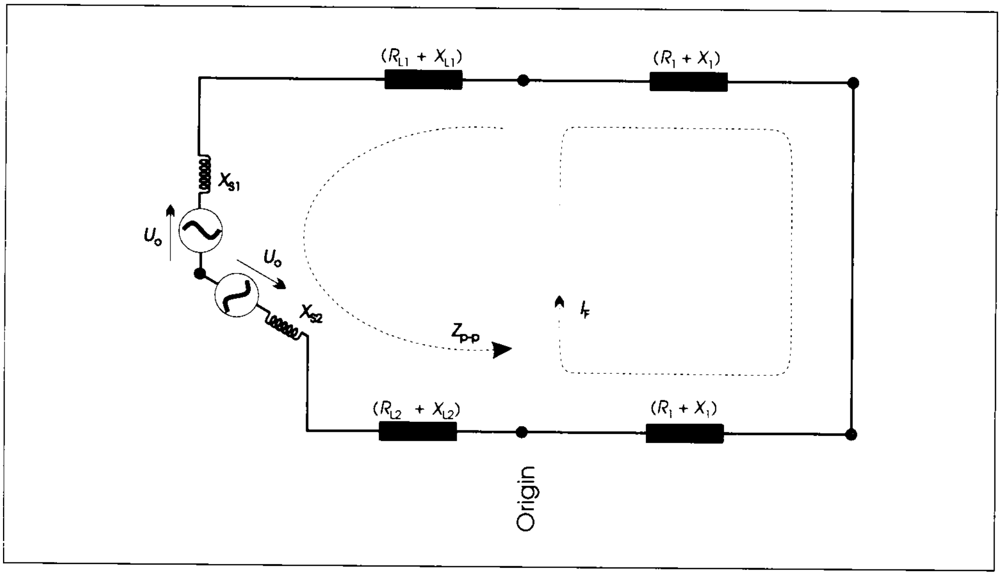


Figure 7.7: Phase-to-phase fault equivalent circuit

7.5.9 Three-phase short-circuit

Referring to Figure 7.8, the general formula for three-phase fault current is given in Equation (7.22) and for faults at the origin of an installation Equation (7.23) modifies the formula.

$$I_F = \frac{U_o}{(R_{L1} + R_1) + j(X_{S1} + X_{L1} + X_1)}$$

$$= \frac{U_o}{\sqrt{[(R_{L1} + R_1)^2 + (X_{S1} + X_{L1} + X_1)^2]}} \tag{7.22}$$

$$I_F = \frac{U_o}{R_{L1} + j(X_{S1} + X_{L1})} = \frac{U_o}{\sqrt{[R_{L1}^2 + (X_{L1})^2]}} \tag{7.23}$$

For supplies up to 100 A where the inductive reactances are negligible a further simplification to Equation (7.22) may be made, as given in Equation (7.24), again giving a somewhat optimistic assessment of fault current magnitude.

$$I_F = \frac{U_o}{\sqrt{(R_{L1} + R_1)^2 + (X_{S1} + X_{L1})^2}} = \frac{U_o}{Z_{p-p} + R_1} \tag{7.24}$$

As a matter of interest, the relationship between phase-earth voltage, U_o, and the phase-phase (or line-line) voltage, U, is shown in Figure 7.9. By way of explanation of the figure, the three phases are equi-separated by 120°

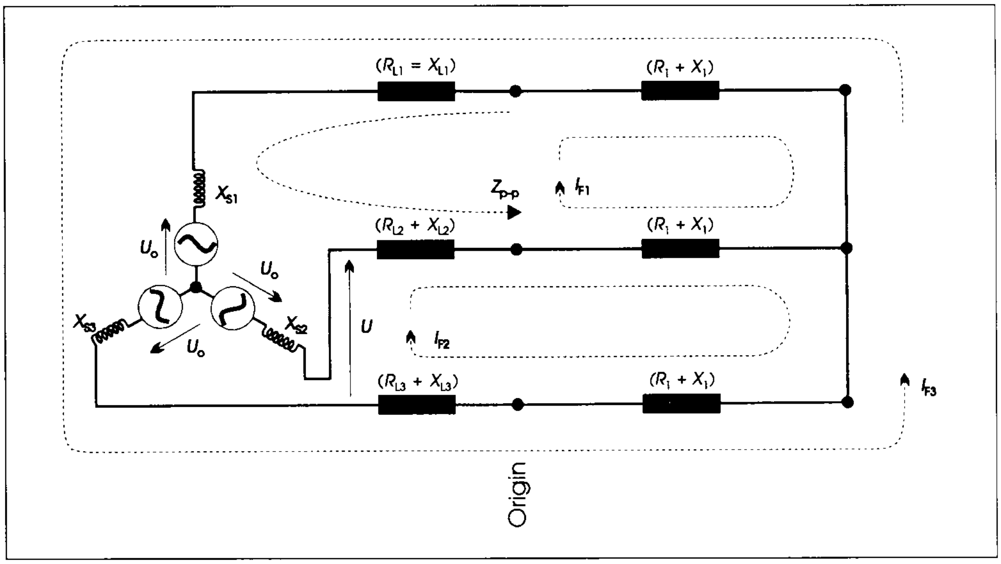
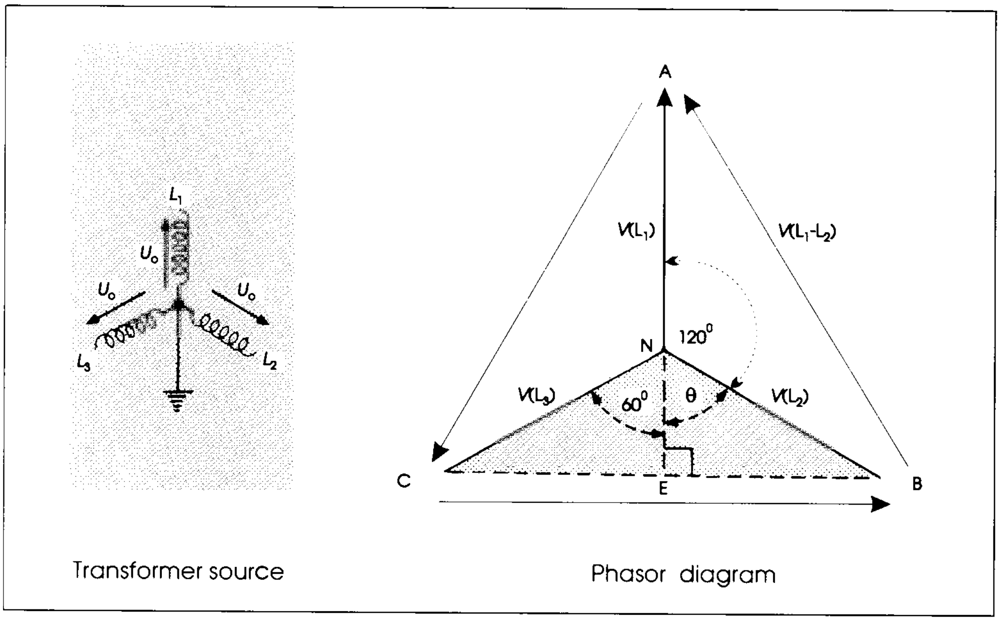


Figure 7.8: Three-phase fault equivalent circuit



Transformer source

Phasor diagram

Figure 7.9: Relationship between phase-neutral and phase-phase voltages

(i.e. 3 × 120 = 360°). Looking to the bisected triangle CNE the angle θ is 60° and the length E–B is given by sin θ which is sin 60° (which equals ($\sqrt{3} \div 2$)). If length N–B represents the phase to Earth voltage, U_o, and length C–B depicts the phase-to-phase voltage, U, it can be seen that U is portrayed by length C–B (twice the length E–B) which equals $\sqrt{3}\ U_o$.

7.5.10 Phase-to-earth faults

Evaluation of phase-earth loop impedance is essential not only because of the consideration of protection against indirect contact (touch voltage magnitude and disconnection times) but also from the standpoint of selection of phase conductor(s) in terms of energy withstand of equipment and the assessment of required short-circuit capacities of associated protective devices.

Prospective earth fault currents in TN systems (TN-C, TN-C-S and TN-S) are much higher than those in TT, principally because the former systems employ a metallic link between the installation and the source, whereas in the TT system part of the loop consists of the soil and associated electrodes.

The general formulae for calculating prospective earth fault current are given in Equations (7.25) and (7.26) and when considering fault current at the origin of the installation Equation (7.27) should be used. Figure 7.10 shows a phase-to-earth fault equivalent circuit.

$$I_F = \frac{U_o}{(R_{L1} + R_E + R_1 + R_2) = j(X_s + X_E + X_1 + X_2)} \tag{7.25}$$

$$I_F = \frac{U_o}{\sqrt{[(R_{L1} + R_E + R_1 + R_2)^2 + (X_s + X_E + X_1 + X_2)^2]}} \tag{7.26}$$

$$I_F = \frac{U_o}{\sqrt{[(R_{L1} + R_E)^2 + X_s^2]}} = \frac{U_o}{Z_e} \tag{7.27}$$

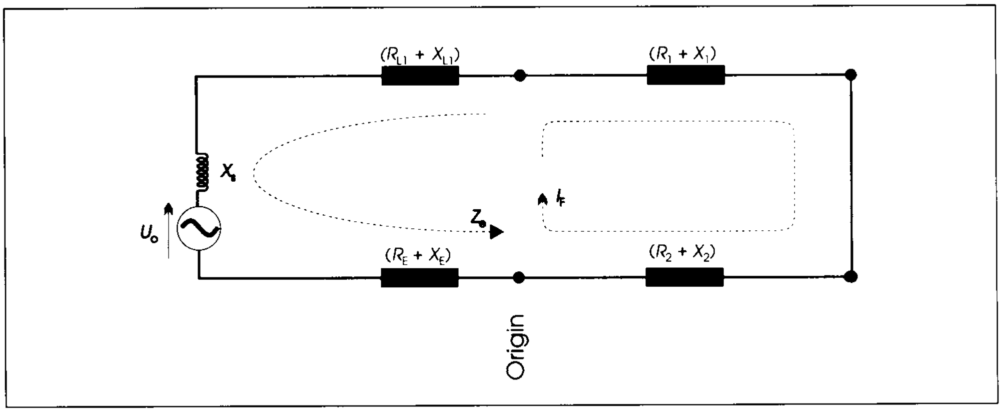


Figure 7.10: Phase-to-earth fault equivalent circuit

Where circuits up to 100 A (or csa $\leqslant$ 35 mm^2) the reactance of the conductors of that circuit is small and, for all practical purposes, may be ignored. The formula set out in Equation (7.25) can be thus simplified to that given in Equation (7.28). The assumption that these reactances may be neglected is restricted to where the phase and protective conductors are run together in close proximity and cannot be applied where this is not so or where the two conductors are separated by ferromagnetic material such as steel conduit or steel trunking.

$$I_{\mathrm{F}} = \frac{U_{\mathrm{o}}}{\surd[(R_{\mathrm{L1}} + R_{\mathrm{E}} + R_1 + R_2)^2 + X_{\mathrm{s}}^2]} \tag{7.28}$$

Where supplies are derived from the public LV supply network, the external phase-earth loop impedance may be obtained on request from the supplier. For other supplies, including generator supplies, reference to the supplier and source equipment manufacturer will be necessary (see also item 7.5.11 of this Guide).

7.5.11 Fault current at the origin of an installation

Irrespective of whether the supply is to be obtained from the public network or private generating plant, the designer will need to know the fault level at the origin of the installation as required by Regulation 313–01–01. In the case of public network supplies, the Engineering Association has published data for prospective fault current in their *Engineering Recommendations P25*, for the smaller installations of 100 A single-phase, and P26 for three-phase services.

For the 100 A single-phase public network supply, a prospective fault current of 16 kA is normally quoted by the PES but this is often referring to the 'tee off' point in the road or pavement and the linking supply cable to the installation will often reduce this to a much lower value. The reduction in fault level will depend on the csa and length of the service cable which is shown graphically in Figure 7.11. Providing the overcurrent protective devices near the origin are capable of coping with 16 kA, there should be no further need to consider the attenuation of the fault level in the linking supply cable. Consumer units, to BS 5486: Part 13, have a conditional rating and may be used on supplies with a fault level not exceeding 16 kA without difficulty. In areas of high population density, consideration and application of the attenuation of the supply service cable should be avoided owing to the continual changes to the network. For three-phase systems, higher fault levels can be anticipated. It is normally considered necessary to consult the supplier, at an early stage of design, to obtain values of fault level and external loop impedance.

Where supplies are taken at HV and where LV supplies are derived from a privately owned transformer, the fault level and impedances should be obtained from the HV supplier and the transformer manufacturer. These fault levels are often expressed in MVA and the derivation of prospective

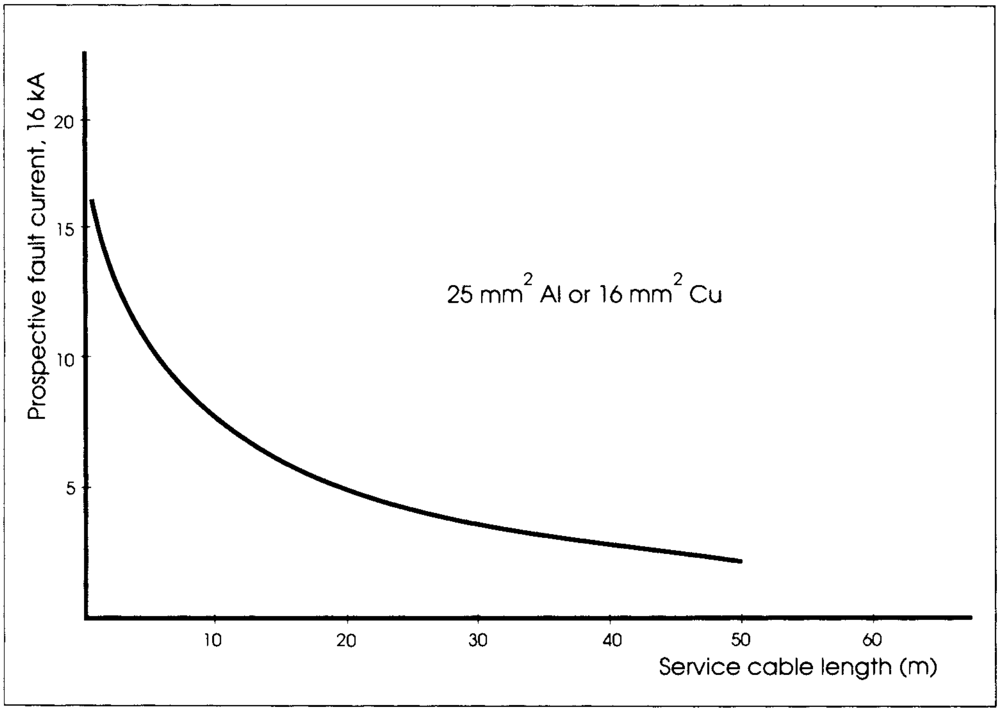


Figure 7.11: An example of attenuation of prospective fault current in service cable

three-phase fault currents and ohmic impedance values is given in Equations (7.29) to (7.31).

$$\textit{Fault level} = \frac{3 \times V_{\mathrm{ph}} \times I_{\mathrm{F}}}{10^6} = \frac{\sqrt{3} \times V_{\mathrm{L-L}} \times I_{\mathrm{F}}}{10^6}(\mathrm{MVA}) \tag{7.29}$$

$$I_{\mathrm{F}} = \frac{\textit{Fault level}\ (\mathrm{MVA}) \times 10^6}{3 \times V_{\mathrm{ph}}} \tag{7.30}$$

$$Z_{\mathrm{ph}} = \frac{3 \times V_{\mathrm{ph}}^2}{\textit{Fault level}\ (\mathrm{MVA}) \times 10^6} \tag{7.31}$$

Transformer impedances are normally expressed in per-unit or percentage terms which, when used with fault levels (MVA), makes life easier, and avoids complications, when working with different voltages as would be the case on the primary and secondary sides of a transformer. The impedance in per-unit terms is as given in Equation (7.32).

$$Z_{\mathrm{pu}} = \frac{Z_{\mathrm{ph}} \times \textit{Transformer rating}}{V_{\mathrm{ph}}^2} \tag{7.32}$$

In carrying out such calculations, the transformer manufacturer should always be consulted with regard to fault level and impedances but Table 7.6 gives typical values for per-unit impedances for some small 11/0.400 kV delta/star ('Dy 11') transformers.

Table 7.6: Typical per-unit impedance values for 11/0.400 kV delta/star transformer

Power rating (kVA)	Impedance(1) (pu)	Impedance (1) (percentage)
100 – 250	0.042	4.2
251 – 500	0.044	4.4
501 – 750	0.047	4.7
751 – 1000	0.050	5.0
1000 – 1500	0.053	5.3
1501 – 2000	0.056	5.6

Note: (1) Transformer impedances are predominantly inductive reactances (X) and in most cases the resistive component may be ignored.

The fault level of generators is again normally expressed in MVA and the impedance declared in per unit or percentage terms. To illustrate the process by example, take a three-phase 15 MW, 0.8 lagging power factor, operating at 11 kV and with an impedance of 1.59 Ω per phase. The phase voltage, V_{ph}, is given by Equation (7.33) and the three-phase fault current, I_{F}, by Equation (7.34).

$$V_{\mathrm{ph}} = \frac{V_{\mathrm{L-L}}}{\sqrt{3}} = \frac{11000}{\sqrt{3}} = 6350 \text{ V} \tag{7.33}$$

$$I_{\mathrm{F}} = \frac{V_{\mathrm{ph}}}{Z_{\mathrm{ph}}} = \frac{6350}{1.59} = 3994 \text{ A} \tag{7.34}$$

The fault level of this generator, the apparent power rating, S, and the per-unit (and percentage) impedance, Z_{pu} are as stated in Equations (7.35), (7.36) and (7.37), respectively. The active power, P, referred to in Equation (7.36) is the rated power of the generator (i.e. 15 MW).

$$\begin{aligned} \textit{Fault level} &= 3 \times V_{\mathrm{ph}} \times I_{\mathrm{F}} \\ &= 3 \times 6350 \times 3994 \simeq 76.0 \times 10^6 \text{ VA} = 76 \text{ MVA} \end{aligned} \tag{7.35}$$

$$S = \frac{P}{\textit{Power factor}} = \frac{15 \times 10^6}{0.8} = 18.75 \times 10^6 \text{ VA} = 18.75 \text{ MVA} \tag{7.36}$$

$$\begin{aligned} Z_{\mathrm{pu}} &= \frac{\textit{Power rating}}{3 \times V_{\mathrm{ph}}^2} \times Z_{\mathrm{ph}} \\ &= \frac{18.75 \times 10^6}{3 \times 6350^2} \times 1.59 = 0.246 \text{ (p.u.)} \end{aligned} \tag{7.37}$$

As previously mentioned. the use of per-unit (p.u.) terms is particularly advantageous in calculating fault levels in systems where different voltages are present as would be the case where a system employs 33 kV, 11 kV and 400 V voltages. It is beyond the scope of this Guide to address this topic fully in the way it deserves other than to draw attention to some of the considerations. A more rigorous analysis, involving positive, negative and zero sequence current study, may be required to be undertaken in all but the very small systems. Where more than one source can supply a fault, all such sources need consideration in the fault calculations, as would the short-circuit transient fault currents of generators. It should not be forgotten that a motor, which is running prior to a fault, may also contribute significantly to the fault level (release of stored energy). The designer should consult IEC 909: *Short-circuit current calculation in three-phase systems* for further guidance.

7.6 Characteristics of protective devices

In every case, except as stated later, Regulation 434–03–01 requires that the short-circuit capacity (breaking capacity of fuses and making/breaking capacity of circuit-breakers) of protective devices must not be less than the prospective fault current. Fault current, as mentioned earlier, embraces both short-circuit and earth fault currents. Whilst the currents are normally of the same order of magnitude, it is worth remembering that earth fault currents can in some cases be greater than short-circuit current at the same point in the circuit. Take, for example, the case of the remotely located switchboard fed with mineral insulated copper sheathed distribution (or, if you prefer, sub-mains) cables. The circuit protective conductor (cable copper sheath) is of substantially lower impedance than that of the associated live conductors resulting in a higher earth fault current than a short-circuit current at the same point in the circuit. There are other cases where, for different reasons, the earth fault current may exceed the short-circuit current by a considerable amount and this cannot be ignored.

The short-circuit capacity performance of protective devices is addressed in the appropriate British or CENELEC Standard and this feature is normally distinctively marked on each device. This marking is given, in many cases, in coded form making use of the letters S and M which are summarised, for common devices, in Table 11.5 of Chapter 11 of this Guide.

The general requirement for protection against fault current, given in Regulation 434–03–03, is that disconnection time under fault condition must not be greater than the time required to raise the conductor to its limiting temperature. The disconnection time, t, is limited therefore to that given in the adiabatic equation and repeated in Equation (7.38).

$$t = \frac{k^2 \times S^2}{I_F^2} \tag{7.38}$$

where: t = the time in which the temperature of the live conductors will be raised to the maximum limiting temperature (°C).
S = conductor cross-section area (mm^2).
k = the particular factor for the conductor (from Table 43A for common materials),
I_F = fault-current (rms for a.c.) (A).

The exception to the rule (Regulation 434–03–01) is that a protective device may have a lower short-circuit capacity than the prospective fault current provided that the energy let-through of an upstream (supply side) device does not exceed the capabilities of the device in question. In other words, it is capable of withstanding, without damage, the energy let-though of the upstream device.

Where a device is intended to provide protection against fault current and also meets the requirements for overload protection (Regulation 434–03–02) and it has a rated short-circuit capacity not less than the prospective fault current, then for radial circuits it may be assumed that the downstream live conductors are protected against fault current. For conductors in parallel and for non-current limiting circuit-breakers, this assumption should be checked (Regulation 434–03–03) to confirm its validity by the use of the following formula which should also be used where the device provides for protection against fault current only (and does not provide for overload protection).

From the adiabatic equation previously mentioned it will be seen that by transposing the elements Equation (7.39) is obtained.

$$(I^2 \times t) = (k^2 \times S^2) \tag{7.39}$$

I^2t is the energy let-through of the protective device and k^2S^2 is the energy withstand of the cable which must be the greater value if the cable is to be protected. In other words, Equation (7.40) must be satisfied.

$$(I^2 \times t) \leqslant (k^2 \times S^2) \tag{7.40}$$

Where the device operates in less than 100 ms (and asymmetry of fault current is of crucial importance) and for current-limiting devices, the k^2S^2 obtained may need to he higher than the I^2t quoted by the device manufacturer. Asymmetry of fault current is a very important consideration when evaluating the capabilities of overcurrent devices located near transformers. For example, a 1000 kV A 11/0.400 kV three-phase transformer with a 0.05 p.u. (or 5%) impedance would have a fault-level of about 20 MVA at its LV terminals. This would translate to a prospective symmetrical fault current of 28 kA rms or an asymmetrical current of about 65 kA. This problem decreases as the device is placed further from the transformer as the added impedance attenuates the prospective symmetrical fault current and the effect of asymmetry of current also decreases.

Table 43A of BS 7671 gives two values for k in some instances. The lower of the two should be used for cables of csa exceeding 300 mm^2. Knowing the k value and the csa, S, of a particular conductor it is fairly straightforward to plot the 'adiabatic line' on to the time/current characteristics for the more common overcurrent protective devices given in Appendix 4 of BS 7671. The procedure involves only the identification of two points and the connection of those two points with a straight line. The first step is to convert Equation (7.40) to the $\log_{10}$ scale to match the log/log scale given in the Appendix 4 time/current characteristics, as shown in Equation (7.41). Further rearrangement, given in Equation (7.42), makes the current, I, the subject and this enables further calculations to be made simpler.

$$2 \log I + \log t = 2(\log k + \log S) \tag{7.41}$$

$$\log I = \log k + \log S - 0.5 \log t \tag{7.42}$$

For a particular conductor both k and S are constants, so from Equation (7.42) it can been seen that the log/log representation of (k^2S^2) is a straight line with a gradient of –1/2 and hence it is possible to plot the adiabatic line knowing only one value. However, the two points will be calculated to reinforce the method. From the foregoing equations we obtain Equation (7.43).

$$I = \frac{kS}{\surd t} \tag{7.43}$$

For a disconnection time of 0.01 s (10^{-2} s) Equation (7.43) yields $I = 10\,kS$. For a disconnection time, t, of 1 s (10^0)., $I = kS$. To illustrate by example, take a 70°C copper/PVC conductor of csa of 25 mm^2 and with a k value (from Table 43A of BS 7671) of 115. At $t = 10^{-2}$ s, $I = 10(115 \times 25) = 28{,}750$ A and at $t = 10^0$, $I = (115 \times 25) = 2875$ A which gives the two points for plotting. It is worth noting that increasing the time from 0.01 s to 1 s (by a factor of 100) has the result of reducing the current that can be tolerated by a factor of 10. This, when related to the log/log scale, is a gradient of – 1/2 as previously mentioned.

It is important to recognise that in the case of MCBs the adiabatic line intersects the time/current characteristics in two places as shown in Figure 7.12. This implies that, for compliance with Regulation 434–03–03, only a certain range of fault current can be tolerated, as indicated in the figure.

7.7 Overcurrent protection of conductors in parallel

Regulation 473–01–07 stipulates that where parallel conductors are installed the effective I_z is the sum of the current-carrying capacity of both paralleled conductors.

Regulation 473–01–06 requires that, except for ring final circuits, there must not be any branch circuits or devices for isolation and switching in any of the parallel conductors when protected by a single overcurrent protective device.

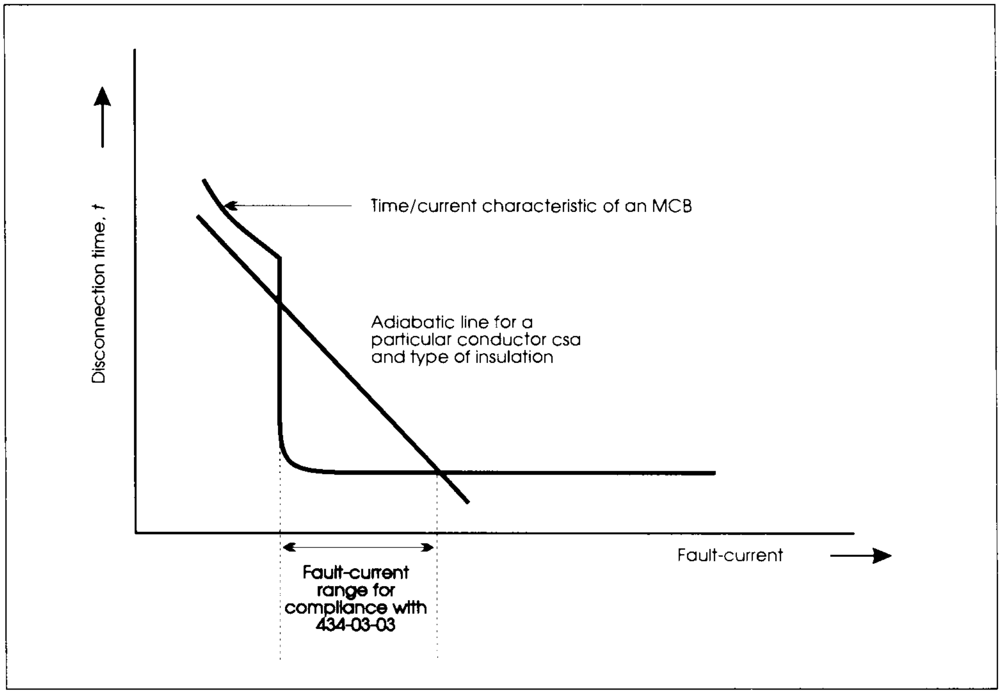


Figure 7.12: Range of fault current restriction of miniature circuit-breakers

Sharing of load current is addressed in Regulation 473–01–08 which requires equal load current in the parallel conductors. Where this is not possible, the requirements for overload protection of each of the parallel conductors must be considered separately.

The purpose of these requirements is to confirm that load current is shared equally in both ‘legs’ of the parallelled conductors and that the current-carrying capacity, I_Z, is the sum of the value of the current-carrying capacity of all the conductors. However, this may not be the case where more than two conductors are run in parallel. In the absence of more precise information, a ‘rule of thumb’ is to allow only, say, 75% of the individual current-carrying capacity of three or more conductors in parallel to contribute to I_Z. For example, a four-conductor line could be regarded as having a total I_Z of three times the current-carrying capacity of the individual conductors. The assumption of equal load current sharing may not be valid for some cabling arrangements and configurations. The IEE Guidance Note No 6: *Protection against overcurrent* addresses the issue of where current equality or otherwise may be expected. When considering current-carrying capacity and the correction factors for grouping of a parallelled conductor circuit, each conductor should be regarded as a ‘circuit’.

Even when the above requirements are met, further consideration is required in addressing all the locations where a fault may occur and the resultant fault current sharing of conductors. One possible solution to any difficult cases may be to employ overcurrent protection in each ‘leg’ arranged to disconnect both ‘legs’ under fault conditions.

Figure 7.13 shows the phase and circuit protective conductors in parallel configuration and Figure 7.14 illustrates the equivalent circuit for the arrangement. The symbols used in the figures and the following equations have the attributed meanings below.

U_0 = the nominal voltage to Earth (V)
Z_a = the impedance per unit length of each conductor in the phase ‘circuit’ (Ω/m)
Z_b = the impedance per unit length of each conductor in the protective conductor ‘circuit’ (Ω/m)
Z_A = the effective impedance in the phase ‘circuit’ up to the fault (Ω)
Z_B = the effective impedance in the protective conductor ‘circuit’ up to the fault (Ω)
Z_e = the phase-earth loop impedance upstream of the origin of the circuit (Ω)
I_F = the total earth fault current (A)
I_{F1} = the earth fault current in one leg (the longer path to the earth fault) of the parallel circuit conductors (A)
I_{F2} = the earth fault current in one leg (the shorter path to the earth fault) of the parallel circuit conductors (A)
L = overall length of parallel circuit (m)
x = distance from origin of circuit to location of earth fault (m)

F1, F2, and F3 are three positions where an earth fault (between one phase conductor ‘leg’ and one cpc ‘leg’) is considered.

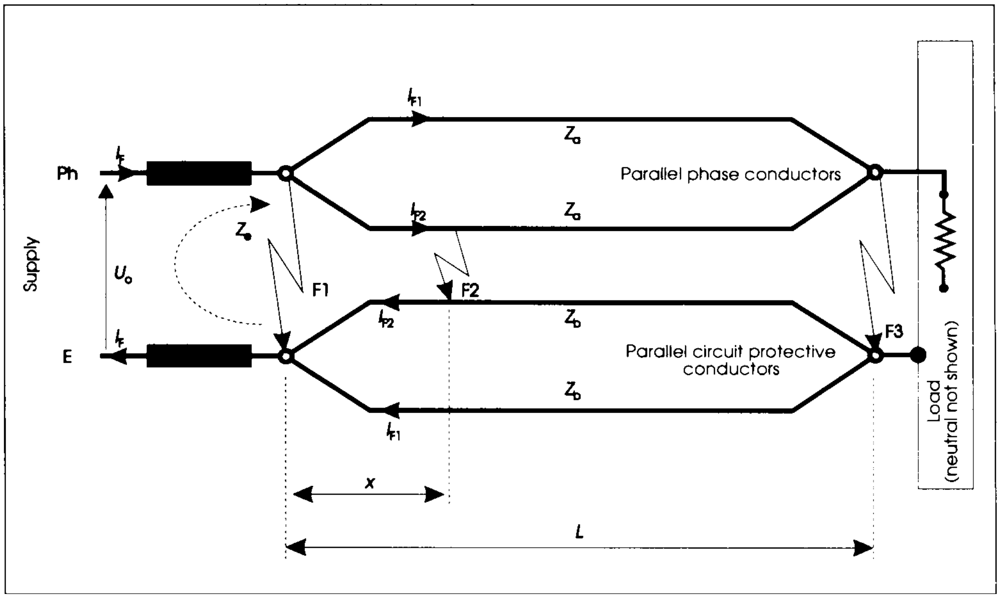


Figure 7.13: Earth faults in parallel conductors

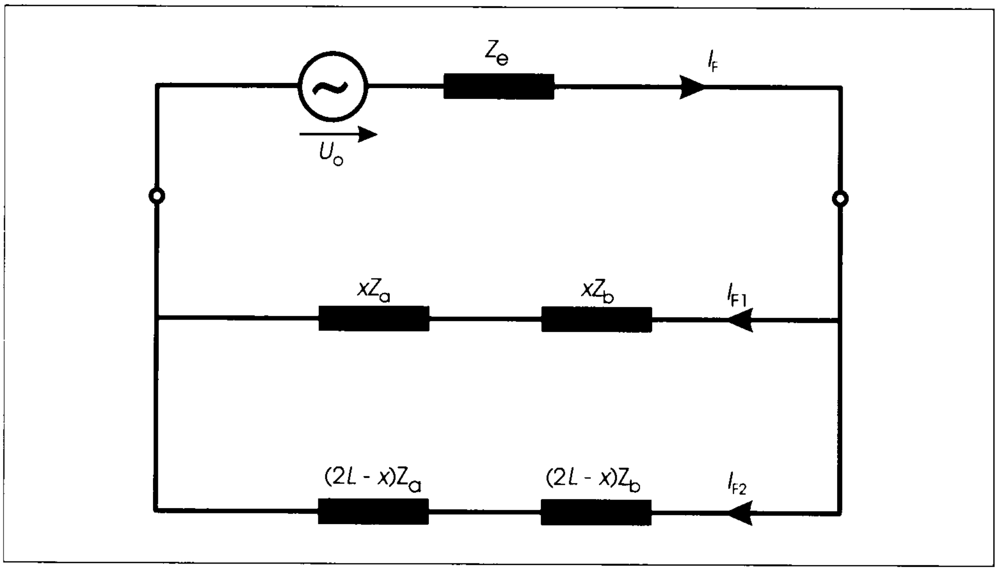


Figure 7.14: Earth faults in parallel conductors – equivalent circuit

It can be shown that the contribution made by the parallel phase conductors, Z_A, to the total phase-earth loop impedance for an earth fault developing anywhere in the circuit is as given in Equation (7.44).

$$Z_A = Z_a\left(\frac{2Lx - x^2}{2L}\right) \tag{7.44}$$

A similar equation can be obtained for Z_B and Equation (7.45) is an expression for the total effective phase-earth loop impedance, Z_{eff}, up to the point of the earth fault.

$$Z_{eff} = Z_e + \left[(Z_a + Z_b)\left(\frac{2Lx - x^2}{2L}\right)\right] \tag{7.45}$$

For an earth fault at the most remote end of the circuit, shown as F3 in Figure 7.13, Equation (7.45) can be simplified by substituting L for x, as given in Equation (7.46).

$$Z_{eff} = Z_e + \left[\frac{L(Z_a + Z_b)}{2}\right] \tag{7.46}$$

To illustrate the different magnitudes of fault currents, let us consider a parallel circuit with the following parameters:

$Z_e = 0.08\ \Omega$, $Z_a = 0.28\ \mathrm{m}\Omega/\mathrm{m}$, $Z_b = 0.41\ \mathrm{m}\Omega/\mathrm{m}$,
$L = 100$ m, $U_o = 230$ V.

First, let us consider an earth fault (F1) at the origin of the parallel circuit where $x = 0$. The earth fault current, I_F, will be 3000 A, as given in Equation (7.47), and the parallel conductor currents, I_{F1}, and I_{F2}, will be zero.

$$I_F = \frac{U_o}{Z_e} = \frac{230}{0.08} = 2875 \text{ A} \tag{7.47}$$

Let us now consider an earth fault (F3) at the remote end of the parallel circuit where $x = L$. Making use of Equation (7.46) and substituting values we get a total earth fault current, I_F, of 2009 A, as given in Equation (7.48). The fault currents in the two 'legs', I_{F1} and I_{F2}, will at 1004.5 A be equal in magnitude.

$$I_F = \frac{U_o}{Z_{eff}} = \frac{U_o}{\left[Z_e + \dfrac{L(Z_a + Z_b)}{2}\right]} \tag{7.48}$$

$$= \frac{240}{0.08 + \dfrac{100(0.28 + 0.41) \times 10^{-3}}{2}} = 2009 \text{ A}$$

Finally, let us consider an earth fault developing at a position (F2) some 30 m (i.e. $x = 30$ m) from the origin of the circuit. The total earth fault current will be 2356.5 A, as given in Equation (7.49) which utilises the effective impedance detailed in Equation (7.45).

$$I_F = \frac{U_o}{Z_{eff}} = \frac{230}{Z_e + \left[(Z_a + Z_b)\left(\dfrac{2Lx - x^2}{2L}\right)\right]} \tag{7.49}$$

$$= \frac{240}{0.08 + \left[(0.28 + 0.41) \times 10^{-3}\left(\dfrac{2 \times 100 \times 30) - 30^2}{2 \times 100}\right)\right]}$$

$$= 2356.5 \text{ A}$$

It can be shown that the fault currents in the parallel 'legs', I_{F2} and I_{F1}, will be in the ratio of x:$(2L - x)$ which in this case is 30:170. As given in Equations (7.50) and (7.51) respectively, I_{F1} is 353.5 A and I_{F2} is 2003.0 A.

$$I_{F1} = I_F\left(\frac{x}{2L}\right) = 2356.5\left(\frac{30}{200}\right) = 353.5 \text{ A} \tag{7.50}$$

$$I_{F2} = I_F\left(\frac{2L + x}{2L}\right) = 2356.5\left(\frac{200 - 30}{200}\right) = 2003.0 \text{ A} \tag{7.51}$$

The foregoing example illustrates the inequality of earth fault currents in the two legs of the parallel circuit other than at the remote end. As x goes to zero, I_{F2} will tend to I_F (2875 A) and this fault condition when considered on no-load will represent the maximum earth fault current which can flow in each 'leg'. The minimum earth fault current will occur when an earth fault occurs at the end under load conditions. Appropriate adjustments for resistances relating to the different temperatures may be necessary (see item 7.5.6 of this Guide).

7.8 Co-ordination of overload and fault current protection

Regulation 435–01–01 calls for the energy let-through of a protective device to be such that no damage is sustained by downstream equipment including cables. It is therefore necessary to consider the electrical characteristics of each protective device to establish that no damage will occur to downstream equipment when under fault conditions.

The concept of energy let-through is often best understood when presented in graphical form as in Figure 11.5 of Chapter 11 of this Guide. In most cases, this co-ordination will involve only ensuring that the energy withstand of conductors (k^2S^2) is not less than the energy let-through (I^2t) of the overcurrent device protecting the circuit. For motor circuits co-ordination may be provided in accordance with BS 4941 *Specification for motor starters for voltages up to and including 1000 V a.c. and 1200 V d.c.* (see also item 7.3.2 of this Guide).

7.9 Protection according to the nature of circuits and distribution systems

The requirements of this section of BS 7671 (473–03) are categorised in terms of phase conductors and neutral conductors as they relate to the different system types (e.g. TT, TN-S, TN-C-S, etc.).

Regulation 473–03–01 calls for overcurrent detection to be provided for each and every phase conductor; the detector arranged to disconnect that phase under overcurrent conditions. It is not necessary to disconnect simultaneously other live conductors (other phases and/or neutral) of that circuit unless, by not doing so, danger would be caused. This would be the case where, for example, the circuit related to a three-phase load such as a motor and here disconnection of all the three phases would need to be employed or other appropriate precautions would need to be taken to remove the potential for danger. Where the installation forms part of a TT system (Regulation 473–03–02) and where a circuit is supplied between phases and the neutral is not distributed (i.e. pure two-phase or pure three-phase circuit) overcurrent detection need not be provided for one of the phases provided the two following conditions are met:

- the circuit is provided with differential protection which would cause disconnection, when called upon to do so, to *all* phase conductors, and
- the neutral conductor is not distributed from an artificial point on the load side of the differential protection.

The requirements for neutral conductors in all systems except IT systems are addressed by Regulations 473–03–03 and 473–03–04 which state that in situations where the neutral conductor is of the same or greater csa than that of the associated phase conductor(s), overcurrent protection (detection and disconnection) is not necessary. In cases where the csa of the neutral conductor is less than that of the associated phase conductor, overcurrent detection is required as is a means of disconnection of the associated phase conductors (but not necessarily the neutral conductor). These requirements are waived when the two following conditions are both met:

- the associated phase conductor overcurrent protective device adequately protects the neutral conductor, and
- the maximum normal neutral load current is significantly less than the current-carrying capacity of the neutral conductor.

In the case of the IT system where the neutral is distributed, Regulation 473–03–05 calls totovercurrent detection in the neutral conductor of every circuit arranged to disconnect all live conductors (phases and neutral) of that circuit. These requirements need not be met where:

- the circuit is protected by an RCD with residual operating current not greater than 15% of the current-carrying capacity of the neutral conductor with the RCD being arranged to disconnect all live conductors,
- the neutral conductor is adequately and effectively protected by a device on the supply side (e.g. at the origin of the installation or, at any rate, upstream).

7.10 Protection against undervoltage

Undervoltage or the loss of voltage (loss of supply) can be a potential danger. Equipment having had no precautions taken against this phenomenon may be damaged by, for example, the drawing of excess current as in the case of a three-phase motor drawing current from only two phases. Additionally, there is the real danger of equipment starting unexpectedly on restoration of supply or improved voltage. Chapter 45 of BS 7671 deals with these dangers and stipulates precautions necessary to prevent them.

Regulation 451–01–01 makes clear that where a motor circuit is concerned, Regulation 552–01–03 calls for every motor to be equipped with a means to prevent automatic restarting on restoration of supply or restoration of full voltage after a period in which voltage has been reduced or lost. This applies only to situations where unexpected restarting of motors could cause danger. It would not necessarily apply to a number of motors being started sequentially (to minimise the effects of simultaneous starting currents on maximum demand metering), provided suitable precautions bad been taken to obviate any associated risks.

As stated in Regulation 451–01–02, if current-using equipment is likely to be damaged by a reduction in, or loss of, voltage, then either suitable precautions need to be taken to obviate the risk *or* confirmation obtained from the person responsible for the operation and maintenance of the equipment that the likely damage is an acceptable risk. Acceptable risks would not include those associated with danger to person or livestock from shock, fire, burns or injury from mechanical movement.

As Regulation 451–01–03 confirms, the device for protection against undervoltage may incorporate a time delay (time delay from sensing undervoltage to the time when device operates) provided the equipment so protected is not likely to be damaged during the period of the delay. Regulation 451–01–04 makes further demands in that any time-delay mechanism should not adversely affect the operation of any control or protective device (e.g. emergency switch or overcurrent device). Furthermore, as Regulation 451–01–06 requires, an undervoltage protective device must not automatically reclose unless such reclosure is unlikely to cause danger. Finally, all such devices, as called for in Regulation 451–01–05, are required to be suitable for the equipment they protect; reference will therefore be needed to the appropriate BS or CENELEC Standard to ascertain the specific requirements in this respect.

7.11 Protection against overvoltage

Chapter 44 has been introduced in BS 7671: 2001 and contains only one section – 443. It deals with the protection of electrical installations against transient overvoltages caused by lightning strikes on supply distribution systems, or due to switching overvoltages generated by equipment forming part of installations.

Where an installation is supplied by or includes low voltage overhead lines, and the anticipated thunderstorm activity in the area exceeds 25 thunderstorm days per year, Regulation 443–02–03 requires additional protection to be provided against overvoltages caused by lightning strikes, such as by means of surge protective devices.

Fortunately, such additional protection is generally considered to be unnecessary in the UK, where the number of thunderstorm days per year is between five and ten. However, the omission of additional protection is conditional on the impulse voltage withstand of equipment in the installation being in accordance with the new Table 44A.

Table 44A of BS 7671 sets out the required minimum impulse withstand voltage (in kV) for various categories of equipment. Examples of equipment within each category are given in the new Table 44B of BS 7671. If such equipment conforms with the relevant BS EN product standards, the impulse withstand voltage requirements can be assumed to have been met. In the UK, where products conforming to the relevant BS EN product standards are used, compliance with section 443 can generally be assumed.

Chapter 8

Isolation and Switching

8.1 General

It is worth noting that the isolation and switching arrangements make a major contribution to the overall safety of an installation. The Electricity at Work Regulations 1989 (Regulation 12) calls for the function of isolation to be a secure operation. Whilst the installation designer and constructor cannot be held responsible for the use of the installation, it is incumbent on them both to confirm that satisfactory provision is made for installed isolating devices so that they are accessible and, where necessary, securable. Isolation and switching cannot be properly provided for without first addressing the nature of the installation, its use and its operational procedural requirements.

The phrase 'isolation and switching' used throughout BS 7671 and elsewhere has significance and it is essential to appreciate that an isolating device may be something other than a switching device (e.g. a plug and socket). Hence the use of this phrase to embrace all the aspects which would not be covered by the term 'switching'. Isolation and switching embraces four distinct concepts each with its own particular requirements for safety, namely: (i) isolation, (ii) switching off for mechanical maintenance, (iii) emergency switching and (iv) functional switching. Figure 8.1 sets out these measures and identifies their purpose and the personnel who are intended to operate them.

Means of isolation is required for every installation whereas switching off for mechanical maintenance and emergency switching and emergency stopping will only be required where the type of installation and its usage demand such provision. The designer should consult, at an early stage, with the installation user regarding the intended utilisation of the installation and the level of skills, capabilities and competency of the persons involved in its usage. Other considerations needed to be addressed at an early stage include the assessment of all the external influences (e.g. water, dust, mechanical vibration and impact). This may well affect the designer's selection of types of devices and their positioning in order to expedite ready access for operation, inspection and testing, and maintenance of devices, as required by Regulation 513–01–01.

In many instances a number of items for isolation and switching will be located together in an allocated switchroom. In this case the designer should provide adequate space in the switchroom for electrically skilled persons to work on the equipment (switchboards and the like) without

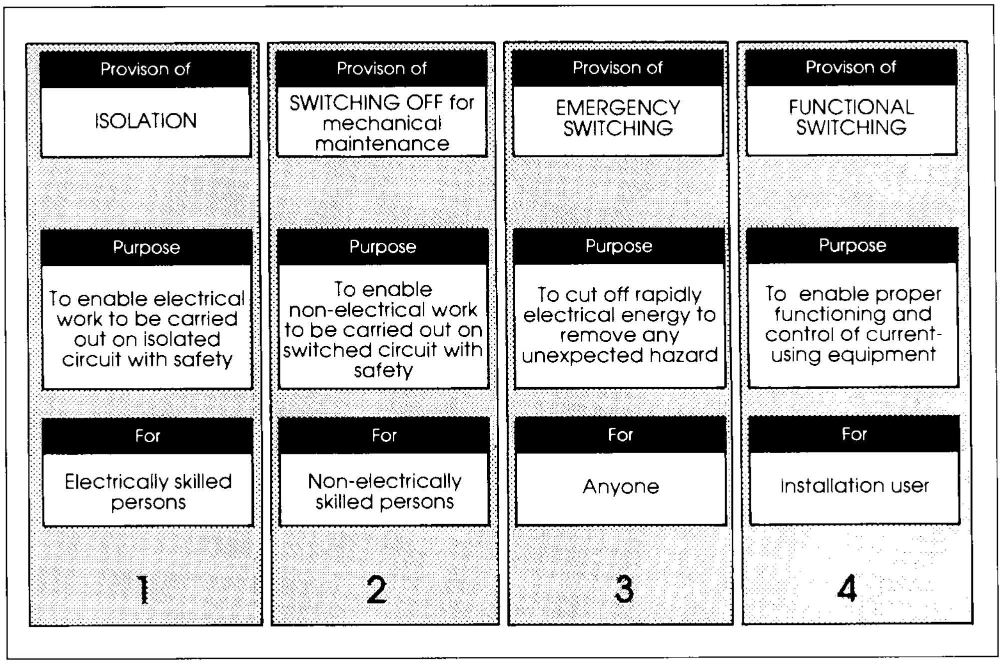


Figure 8.1: Isolation and switching – the four concepts

impediment and in safety. The installation owner/user should be made aware that switchrooms are not provided for the storage of paint, cardboard boxes, brooms and the like and should be kept free of such material at all times. When siting switchgear (e.g. distribution boards) the designer must confirm that access can be gained for maintenance without difficulty and that adequate working space is provided.

It is important to note that a switch is essentially an *on-load* mechanical device capable of making, carrying and breaking load current. It may also be capable of carrying, within specified limits (current magnitude and duration), overload current and in some cases it may be capable of making (but not breaking) fault current. Significantly, semiconductor devices (e.g. thyristors) are not considered to be switches as far as BS 7671 is concerned though, of course, their use as functional switching and control is not precluded.

An isolator is defined as 'a mechanical switching device which provides the function of isolation'. An isolator can be, and often is, an off-load device referred to as a 'disconnector' and as such access to it must be restricted to electrically skilled persons. An isolator provides for a specified contact clearance distance (allowing for creepage, etc.) when the device is in the 'open' or 'OFF' position (see BS EN 60 947–3). Isolating switches (switch disconnecters) complying with BS EN 60 947–3 may also serve as isolating devices and, because these devices are capable of switching load current, they may be operated by electrically unskilled personnel for non-isolation purposes. Devices for isolation include:

- isolator (disconnector) – off-load device,
- isolating switch (switch-disconnector) – on-load device,
- circuit-breaker – on-load device,
- fuse-switch – on-load device,
- switchfuse – on-load device,
- fuse – off-load device,
- solid link – off-load device,
- plug and socket-outlet – off-load device.

The use of a plug and socket-outlet for isolation purposes, as permitted by Regulation 537–02-10, is restricted to circumstances where it is located in close proximity to the equipment being isolated and where the electrically skilled person has the plug and/or socket-outlet under their control at all material times.

The purpose of providing isolation is to cut off the supply from the installation, or part of it, for the safety of electrically skilled persons in carrying out modification and/or electrical maintenance to the affected circuit(s). It is not a function of isolation to provide safety to non-electrically skilled personnel engaged in non-electrical maintenance, this being the subject of the provision of devices for 'switching off for mechanical maintenance'.

The fundamental requirements for isolation and switching are addressed in Regulations 130–06–01 and 130—06–02. These regulations call for effective means, located in a readily accessible position, to be provided for the cutting off of all voltage from every installation and, as is necessary to prevent danger, to cut off all voltage from every circuit and from all electrical equipment. The latter regulation calls for every *fixed* electric motor to be provided with an efficient means of switching off, again located in a readily accessible position, to which access may be gained without danger.

Regulation 460–01–01 requires that a means is provided for non-automatic isolation and switching to remove potential hazards associated with the electrical installation and electrical powered equipment, including machines; such provision to comply with Chapter 46 *Isolation and switching*, the application regulations in Section 476 and Section 537 *Isolation and switching devices*. Table 8.1 summarises the relevant Chapters, Sections and Regulations.

The number and siting of isolating devices need very careful consideration by the designer who would necessarily take into account the installation usage and operational requirements. A means of isolation is required in the main switch but, on some larger commercial and industrial installations, it may be necessary or desirable to have a main switch for a number of separate installations (e.g. security systems or fire alarms or standby supplies). Where such an arrangement is adopted, identification as to purpose and operational procedures is of crucial importance so that no misunderstanding or ambiguity can exist in the design purpose and limitations of operation of such devices. As Regulation 461–01–04 demands, provision needs to be made to obviate the risks associated with the inadvertent or unintentional energisation and re-energisation of the isolated

Table 8.1: Summary of regulations (in addition to the fundamental requirements) for isolation and switching

Aspect	Protective measure	Application of protective measure	Protective devices
Isolation and switching – generally.	Chapter 46 – General Section 460 460–01–01 to 460–01–06	Chapter 47 Section 476 476–01–01 and 476–01–03	Chapter 53 Section 537 537–01–01
Isolation.	Chapter 46 Section 461 461–01–01 to 461–01–05	Section 476 476–02–01 to 476–02–04	Section 537 537–02–01 to 537–02–10
Switching off for mechanical maintenance.	Chapter 46 Section 462 462–01–01 to 462–01–03	None	Section 537 537–03–01 to 537–03–05
Emergency switching.	Chapter 46 Section 463 463–01–01 to 463–01–05	Section 476 476–03–01 to 476–03–07	Section 537 537–04–01 to 537–04–06
Emergency stopping.	Chapter 46 Section 463 463–01–05	None	None
Functional switching, switching.	464–01–01 to 464–01–05 464–02–01	None	Section 537 537–05–01 to 537–05–05

circuit. The designer should also be mindful of the installation user's responsibility in effecting safe systems of work (e.g. permit to work) in the provision of such devices. Again, the designer's careful attention to the detailed requirements in this respect is essential and the following options should be considered:

- Locking of switchroom which houses the isolating device(s). This would necessitate the person carrying out the work on the isolated circuit holding the only key to the switchroom. This procedure may be inconvenient and, in some circumstances, may lead to danger where, for example, access by others to the switchroom for prompt disconnection may be delayed but, on the other hand, having more than one key presents obvious dangers.
- Padlocking or other means of locking provided for the individual isolating device – sole key available only to person working on isolated circuit(s).
- Appropriate warning notices put on devices only accessible to electrically skilled personnel – notices used on their own are not without risk as there is the possibility of the warning being ignored.
- Locking of switchgear enclosure cover – sole key available only to person working on isolated circuit(s) or a locking system for each person working on a circuit.
- Secure closure of switchgear enclosure cover together with warning notice – access only by means of a tool.

Where fuses and solid-links are used for isolation purposes, special care is needed to ensure that these are not withdrawn or reinstated under load, or indeed, fault conditions. Links removed should be retained by the person working on the isolated circuit and replacements must not be readily available to others who may unwittingly create a serious hazard by re-energisation of the circuit being worked upon.

As called for in Regulation 460–01–06, provision must be made for disconnecting the neutral conductor from the supply to facilitate testing procedures. Whether this facility is given in the form of a joint or disconnectable link, it must be in a readily accessible position, and be mechanically adequate to reliably maintain continuity throughout the lifetime of the installation.

8.2 Main switch

Regulations 460–01–02 and 476–01–03 call for a main linked switch or linked circuit-breaker to be provided at or near the origin of the installation. The origin is defined, in Part 2 of BS 7671, as ‘the position at which electrical energy is delivered to an installation’. In many, if not most, cases the origin of the installation will be at the load-side terminals of the supply meter(s). In practice, it would generally be necessary to install a main switch (or main circuit-breaker) adjacent to the supplier’s meter (say, within two or three metres). Where installations are supplied by more than one source, these requirements apply equally to each source and, in this case, notices will be required to warn of the dangers in that the installation may have more than one point of main isolation. Alternatively, the main switches (or main circuit-breakers) are to be provided with a suitable interlocking system (electrical and/or mechanical) to obviate the inherent dangers associated with installations which need isolation from more than one source.

The main switch or circuit-breaker must interrupt both phase and neutral conductors of a single-phase system and in a d.c. system all poles are required to be broken. As permitted by Regulation 460–01–04, in a three-phase TN system (TN-C, TN-C-S and TN-S) it is only necessary to interrupt the phase conductors whereas for a three-phase TT system it is obligatory to interrupt all live conductors (phases and neutral). Neutral conductor isolation at the main switch is deemed not necessary on TN-S and TN-C-S systems (for supplies compliant with the Electricity Supply Regulations 1988, as amended) because the source connection of the neutral to Earth is considered permanent and reliable and the voltage on the supply neutral to an installation is considered to be at, or near, earth potential. The same cannot be claimed for a TT system neutral. Where TN system supplies are provided which have not been subjected to the requirements of Electricity Supply Regulations, an assessment of the reliability and permanency of the source neutral/star point earthing is necessary to establish whether or not it is safe allow the neutral conductor to be unswitched.

Table 8.2 summarises the requirements relating to the main linked switch or linked circuit-breaker. Figure 8.2 illustrates the necessary isolation of

Table 8.2: Principal requirements for main switch or main circuit-breaker

Requirement	Regulation
Located at, or near, the origin of the installation.	460–01–02 (paragraph 1)
Non-automatic device (i.e. manually operated).	460–01–01
If more than one source, main switch required for each source.	460–01–02 (paragraph 2)
If more than one source, interlocking and/or warning notice required.	460–01–02 (paragraph 2)
Capable of providing isolation.	460–01–02 (paragraph 1)
Capable of switching supply *on load*.	460–01–02 (paragraph 1)
Identified as to purpose (appropriately labelled).	514–01–01
Interrupt both live conductors on a single-phase supply.	476–01–03

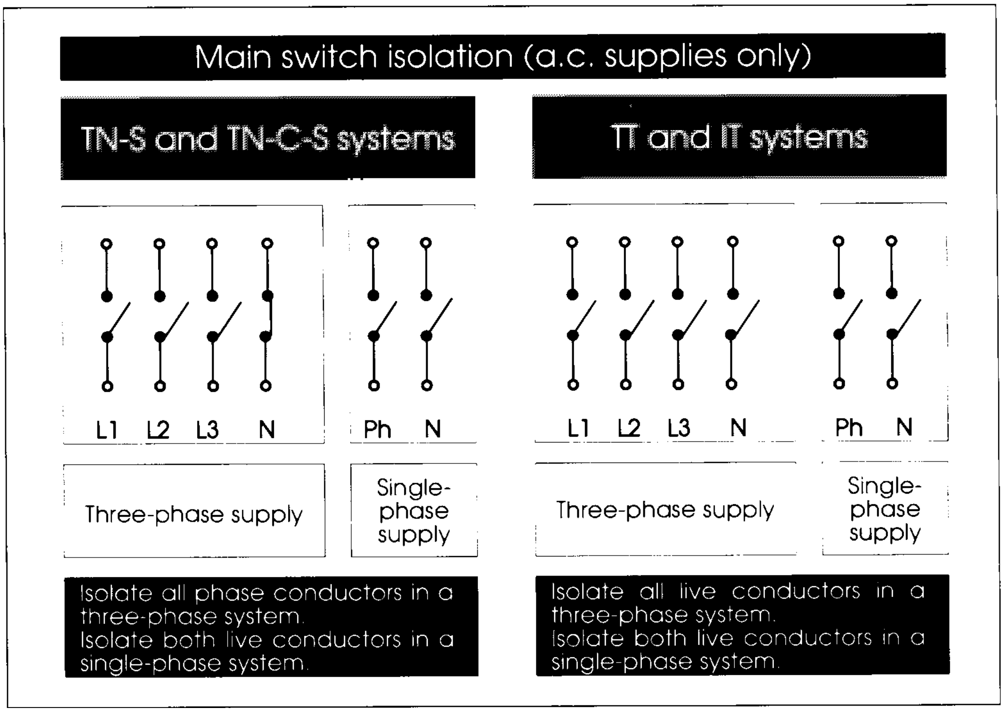


Figure 8.2: Pole isolation requirements for the main switch depending on system type

supply poles, for a.c. systems, relating to the different system types and earthing arrangements.

Regulation 460–01–03 precludes the use of devices, such as isolator or switches, from breaking a protective conductor, including a PEN (Protective Earth and Neutral) conductor (see also Regulation 464–01–05). There is an exception to this rule, envisaged by Regulation 460–01–03, in that where an installation is supplied by more than source, one of which needs a separate means of earthing independent of the other, then it is permissible, under certain conditions, to break the protective conductor, as indicated in Regulation 460–01–05. This exception, for example, caters for the circumstances of parallel generators feeding an installation. It may be necessary, on occasions, to switch the conductor connecting the neutral point of a source to Earth, to prevent winding damage otherwise resulting from excessive (third harmonic) circulating currents. In the case of a generator running in parallel with the public supply network, the PES must be consulted before such measures are implemented. Any such device for switching a protective conductor would also need to interrupt the associated live conductors at substantially the same time.

Application Regulations 476–01–0l and 476–01–02 call for every installation to be provided with a means of isolation and switching (in accordance with Chapter 46 of BS 7671). Additionally every circuit (including final circuits) requires a means of switching to break the supply on load. Where required for safety reasons, these requirements will need to be applied as necessary to parts (or sections) of the installation as well as for final circuits.

As confirmed by these Regulations (476–01–01 and 476–01–02), where the supplier of electricity provides the necessary isolating devices at the intake position, there is no need to duplicate such devices to protect the meter ‘tails’, provided that the supplier has agreed and has expressly confirmed the use of their equipment for this purpose. However, in any event, a main switch will be required at the downstream end of the meter ‘tails’.

Regulation 476–01–01 also calls for electrical switching for mechanical maintenance for certain parts of the installation and recognises that all the functions envisaged for isolation and switching may be performed by a common device provided that it meets all the various requirements for all the functions (reiterated in Regulation 537–01–01).

Before moving on to the other aspects of isolation and switching, it is worth noting that some requirements are common to all. Whilst it is important not to confuse the requirements, or the different concepts, it should not be overlooked that some devices will meet all the various requirements. It is not uncommon for devices to serve more than one function as in the case of the main switch which can act both as a means of isolation and as a means of emergency switching (and possibly, in some cases, functional switching). Similarly, a cord-operated switch can perform as a switch for mechanical maintenance (except two-ways and pull cord switches without contact indication) provided it is under the supervision of the person carrying out the work, as well as its functional role in switching the load. Take, too, the example of the milling machine with its own combined isolator and starter which can serve not only the functional requirements but can also provide for isolation, emergency switching (if equipped with no-volt release as required by Regulation 552–01–03) and meet adequately the needs for switching for mechanical maintenance if adjacent to the equipment it serves. Finally, the latch-OFF type push button may provide emergency switching and a device for switching off for mechanical maintenance (but see Figure 8.3) and, in some cases, also meet the functional requirements, provided, of course, that all the requirements are met for each function. Machine limit switches relate only to functional switching and should not be regarded as meeting the requirements for other aspects of isolation and switching.

8.3 Isolation

The purpose of providing isolation is so that live parts (normally energised) can be safely isolated (separated) from their source(s) so that work may be carried out on, or near, those parts without the risk of electric shock to electrically skilled persons. It should be noted that isolation is an *off-load* function.

Regulation 461–01–01 requires that every circuit must be capable of being isolated though it is permissible, in achieving this objective, to provide isolation to a group of circuits providing due consideration is taken of the operational requirements and service conditions. Clearly, to provide group isolation to circuits, many of which may need to be in constant use, is going to be highly inconvenient to the operator and is unlikely to satisfy the requirements of BS 7671. One undesirable consequence of grouped-circuit isolation is the temptation for work to be carried out with the circuit still live and for this reason, if none other, the designer would be ill advised to skimp on the number of isolating devices.

Similarly, if such devices are not located conveniently there will be the temptation to circumvent the isolation procedures in an effort to save time in total disregard of the safety implications.

As indicated by Regulations 460–01–02, 460–01–04 and 537–02–01, where the system is TN (TN-C, TN-C-S or TN-S), isolation of all phase conductors (not necessarily the neutral conductor) is required, whereas on TT or IT systems isolation of all live conductors (phases and neutral) is needed. Table 8.3 outlines the isolation requirements relating to the different system types and Table 8.4 provides a summary of where isolation is required (see also Figure 8.2 for pole isolation in the main switch).

Table 8.3: Isolation requirements relating to system types

System type	Number of phases	Isolation required for
TN-C	Single-phase	Phase only
	Three-phase	Three phases only
TN-C-S	Single-phase	Phase only
	Three-phase	Three phases only
TN-S	Single-phase	Phase only
	Three-phase	Three phases only
TT	Single-phase	Phase and neutral
	Three-phase	Three phases and neutral
IT	Single-phase	Phase and neutral
	Three-phase	Three phases and neutral

As called for in Regulation 461–01–02, precautions need to taken to prevent all equipment from being inadvertently or unintentionally energised. Where an item of equipment or an enclosure contains more than one circuit each with separate isolation (i.e. not isolated by a single device), Regulation 461–01–05 requires that the equipment or enclosure be

Table 8.4: Equipment and circuits where isolation is required

Isolation required	**Comments**
At origin of every installation.	Applies to every source (or tariff), usually provided in the form of main switch or main circuit-breaker located as near as possible to the origin of installation.
For every circuit or group of circuits.	Group isolation only if service conditions permit. Where isolating device is remote from the equipment it serves, it must be securable in the *OFF* position.
For every fixed motor and associated controlgear (e.g. automatic circuit-breakers and motor starters).	Where isolating device is remote from the equipment it serves, it must be securable in the *OFF* position.
For every discharge lighting installation operating at HV.	Isolation to be provided in LV circuit. Where isolating device is remote from the equipment it serves, it must be securable in the *OFF* position.
For every distribution board (for electrical servicing, maintenance and testing and inspection).	Where isolating device is remote from the equipment it serves, it must be securable in the *OFF* position.
For every switchboard (for electrical servicing, maintenance and testing and inspection).	Any isolating device used in conjunction with a circuit-breaker must be interlocked. Where isolating device is remote from the equipment it serves, it must be securable in the *OFF* position.

accompanied by a durable notice (see Figure 9.13 for example) permanently affixed on or near the equipment to alert persons of the dangers before gaining access to live parts. The notice should give advice on the need to isolate all devices and indicate where the isolation devices are located, to enable complete isolation to be performed. Alternatively, a suitable interlocking arrangement, ensuring isolation of all circuits, is to be provided which will prevent access to live parts.

As stated in Regulation 461–01–04, where inductive and capacitive loads are involved, suitable arrangements need to be taken to discharge any residual capacitive or inductive energy upon isolation (e.g. by automatic or manual discharge to Earth). Generally speaking, LV installations do not present too many problems in this respect but particular care is needed in consideration of isolation of equipment which contains capacitors (e.g. fluorescent luminaires, power factor correction equipment, etc.) and other components capable of storing energy.

All isolating devices need clear identification as to their purpose and Regulation 461–01–05 calls for clear and durable marking to this end (label to identify circuit(s) and equipment served). See also Chapter 9 of this Guide.

In situations where isolating devices are used in conjunction with a circuit-breaker (Regulation 476–02–01), to isolate main switchgear, the isolator must be interlocked with the circuit-breaker or, alternatively, be so positioned or safeguarded so that it may be opened only by skilled persons.

Where an isolating device is located remotely from the equipment it serves, it is necessary, for compliance with Regulation 476–02–02, for the device to be provided with a means of securing it in the open (OFF) position.

This can be achieved by, for example, a locking arrangement on an MCB, a locked distribution board with only one key or with a removable key or handle which is one of a kind. Most manufacturers have developed and now market locking devices for switchgear, including MCBs, which require the use of a tool for release or, if the padlocking type, a key to unlock.

Regulation 476–02–03 calls for every motor circuit to be provided with a disconnector arranged to disconnect the motor and any associated equipment including any automatic circuit-breaker.

For installation of electric discharge lighting operating at voltages exceeding LV (e.g. more than 1000 V a.c.), isolation must be provided in at least one of the following ways:

- self-contained luminaire with interlock arranged to automatically disconnect the supply *before* access to live parts can be gained, and/or
- local effective means of isolation of the circuit from the supply (isolation to be separate from any functional switch controlling the circuit), and/or
- be provided with a lockable switch or switch with removable handle provided that the switch, when remote, is lockable in the open position (Regulation 476–02–02), and/or
- be supplied by a distribution board which is lockable and securable (for compliance with Regulation 476–02–02).

Regulation 552–01–03 makes additional demands for isolation of autotransformers in that such isolation must be in all live supply conductors which includes, by definition, the neutral conductor, irrespective of system type and earthing arrangements. Similarly, electrode boilers warrant additional requirements (Regulation 554–03–02) in that all electrodes, including the neutral, require isolation.

Regulation 537–02–02 calls for the isolating distance between contacts (in the absence of international agreement, normally taken to be not less than 3 mm in the open position) to be not less than that called for in BS EN 60 947–3 *Low voltage switchgear and controlgear*, Part 3 *Switches, disconnectors, switch-disconnectors and fuse combination units*. Regulation 537–02-04 goes on to require that the contacts are either visible or *clearly* and *reliably* indicated; such indication only occurring *after* the specified isolating distance has been obtained in each and every pole. Semiconductor devices are precluded from meeting the isolation requirements by Regulation 537–02–03.

Multipole isolation, as Regulation 537–02–08 confirms, may be effected by a single device isolating all the necessary poles (as would be required for a three-phase, three-wire circuit) or by a number of single-pole devices (e.g. fuse-links) mounted together (as would be adequate for a three-phase, four-wire circuit with single-phase loads).

Regulation 537–02–05 requires that for a three-phase, four-wire supply and where a link is used for the neutral conductor connection at an isolator, the link must meet at least one of the following requirements:

- the link to be accessible to only skilled persons, and/or
- the link may only be removed by the use of a tool.

Regulations 537–02–06 and 537–02–07 call for isolating devices to be such that unintentional re-closure cannot occur (i.e. constructed or installed so that vibration or mechanical impact cannot re-close the device). Furthermore, provision is also required for the isolating device to be unsusceptible to inadvertent or unauthorised operation. This, in practice, means that suitable arrangements should be made for locking facilities, where necessary.

Table 8.5 summarises the requirements for isolating devices and Table 8.6 gives examples of acceptable and unacceptable isolating devices.

Table 8.5: Principal requirements for isolating devices

Requirement	**Regulation**
Non-automatic device (i.e. manually operated).	460–01–01
Contacts visible or reliably indicated.	537–02–04
Adequate contact separation (3 mm)	537–02–02
To incorporate means of discharge of inductive and capacitive charges, where appropriate.	461–01–04
Not susceptible to the effects of vibration or impact.	537–02–06 and 537–02–07
Lockable, if remote.	476–02–02
Identified as to purpose (appropriately labelled).	461–01–05 and 537–02–09
When used in conjunction with circuit-breaker, interlocking and/or safeguarding required.	476–02–01
When used for motor isolation, the device must isolate motor *and* associated equipment.	476–02–03
Semiconductor devices not acceptable.	537–02–03

It is important in the design and construction of isolation facilities that consideration is given to the intended use of the installation and the persons likely to operate such devices. In most cases the operator will be a ‘skilled person’ and/or an ‘instructed person’ under direct supervision (see definitions) and it would normally be assumed that only such persons would be permitted to operate these devices (unless, of course, the devices served other purposes). The designer should also be aware that the installation user will be required to have satisfactory procedural systems to effect safe isolation (e.g. safe systems of work, permits-to-work, etc.) and these should be borne in mind in the electrical design. Such procedures may, for example, include:

- opening up of isolating device,
- checking that all poles are fully open,
- proving dead (by testing),
- earthing of isolated live parts (usually associated with HV isolation but applies equally to LV system where a voltage to Earth may exist on the isolated live parts by virtue of, for example, capacitive and/or inductive loads),
- provision for safe and ready disconnection of isolated circuit (sometimes used for short-term isolation),
- padlocking facility or other means of securing for the prevention of danger to *all* persons working on the circuit(s),
- use of warning notices.

Table 8.6: Examples of acceptable and unacceptable devices for isolation

Device	Principal characteristic	Restriction on use as isolator
Isolator (disconnector).	Off-load device.	Only to be used where load current is zero or negligible.
Isolating switch (switch-disconnector).	Suitable for making and breaking load current.	None.
Miniature Circuit-Breaker (MCB).	Suitable for making and breaking load current.	None, providing the necessary contact separation is afforded by the particular device. Refer to manufacturers for advice.
Moulded Case Circuit-Breaker (MCCB).	Suitable for making and breaking load current.	None, providing the necessary contact separation is afforded by the particular device. Refer to manufacturers for advice.
Fuses.	Suitable for off-load operation only.	Generally acceptable for off-load isolation except for circumstances where the neutral also requires isolation (e.g. TT systems). *Note*: Whilst a fuse may be capable of making and breaking rated load current, it would be considered dangerous to replace a fuse on a faulted circuit.
Links (both phase and neutral).	Suitable for off-load operation only.	Generally acceptable for off-load isolation. *Note*: Whilst a link may be capable of making and breaking rated load current, it would be considered dangerous to replace a link on a faulted circuit.
Fused connection unit.	Suitable for off-load operation only.	Generally acceptable for off-load isolation of current-using equipment connected to it, except where neutral requires isolation (e.g. TT systems). This general acceptance presupposes that precautions are taken to remove the possibility of inadvertent fuse replacement.
Plugs and sockets and similar devices.	May or may not be suitable for making and breaking load current.	Refer to manufacturers for advice.
Semiconductor devices (e.g. thyristors and triacs).	Deemed not to provide the necessary degree of electrical separation.	Not to be used for isolation purposes.
Micro-gap switches (e.g. plate switches).	Deemed not to provide the necessary degree of contact separation.	Not to be used for isolation purposes.

The installation designer may find it beneficial to hold discussions with the installation user at the early stages of design to establish the proposed procedural safety system intended, so that due account of this may be implemented into the electrical design. Whilst BS 7671 does not address this aspect, the designer would need to be mindful of the installation user's duties and responsibilities under the Health and Safety at Work etc. Act 1974 and more particularly the Electricity at Work Regulations 1989. The designer should make himself aware of the user's intended procedures for isolation of equipment which may well take the form of 'permit-to-work' procedures. Such a procedure may commence with a check that the circuit(s) can be 'isolated without inconvenience or danger followed by isolation, taking care that if the isolating device is an off-load mechanism, the load current is zero. A check should now be made that all poles of the isolator are open and the downstream circuit conductors are proved 'dead' by application of a voltage detection test instrument (e.g. test lamp). The instrument used for testing the circuit should then be checked on a live circuit to confirm there is no possibility of a faulty condition. The isolating device now requires securing in the open position followed by the provision of warning notices and safety instructions, as appropriate. On completion of the work a check should be made that all enclosure covers and barriers, removed for the purpose of carrying out the work, are replaced and secured in place. The isolator can now be closed, with warning notices and safety instructions removed, to enable the final re-commissioning of the circuit(s) concerned.

8.4 Switching off for mechanical maintenance

Whilst there is no definition of 'switching off for mechanical maintenance', it is widely accepted to mean the electrical disconnection of equipment to facilitate work of a non-electrical nature to be carried out safely. 'Mechanical maintenance' is defined and relates to the refurbishment and replacement and cleaning of lamps and other non-electrical parts of equipment and electrically driven or electrically controlled plant and machinery. Since switching off for mechanical maintenance is not isolation of live parts, the cleaning and replacement of lamps (with live parts accessible) needs special consideration by the person responsible for the installation maintenance who should be mindful of the statutory requirements of the Electricity at Work Regulations 1989.

Devices for 'switching off for mechanical maintenance' should not be used where the maintenance work involves the access to live parts even though the predominant task is mechanical related. Any such work where live parts are exposed to touch, or are in close proximity, must be subjected to the more onerous requirements for isolation.

Mechanical maintenance and the need to switch off for carrying out such work relates to where electrically unskilled persons perform the necessary tasks without the risk of physical injury; these requirements are not therefore addressing isolation of live parts on which electrically skilled persons will work but *normal non-electrical maintenance*. The dangers associated with mechanical maintenance are those involving burns and injury from mechanical movement, as envisaged by Regulation 462–01–01. Switching for mechanical maintenance is therefore to protect non-electrically skilled persons from injury which may result from contact with electrically heated equipment and moving parts of electrically activated machinery. Conventionally, replacement and cleaning of lamps is considered to be mechanical maintenance for these purposes (though it is accepted that this may involve limited access to live parts, as in the case of lampholders) as is cleaning of non-electrical parts of equipment, plant and machinery. In cases where very large plant is involved, where it can be expected that persons undertaking non-electrical maintenance are required to work inside the plant, consideration should be given to providing isolation, rather than switching for mechanical maintenance, to obviate the risks of malfunction or misuse of the switching device.

There is a need to identify clearly the switching device, as to its purpose, and a need to locate it in a suitably accessible position (Regulation 462–01–02). If located at some position remote from the equipment it serves, precautions need to be taken (Regulation 462–01–03) to avoid inadvertent or unintentional closure or re-closure of the switching device (this may, for example, be achieved by the use of a suitable locking device). Where the switching device is under the control of the person undertaking the maintenance work and is adjacent to the equipment, locking arrangements may be unnecessary.

For items of equipment needing mechanical maintenance, the switching device must be in the main circuit supplying the equipment (Regulation 537–03–01), except in the case where the device has a control circuit. The control circuit may be switched provided the British or CENELEC Standard for the equipment permits such a method or, alternatively, an equal degree of safety is achieved by some other means. Special consideration is needed if the switch is not provided in the main circuit and the control circuit is switched instead; reflection on the effects of a fault on the control circuit (possibly causing the main circuit to be re-energised) will be paramount in assessing

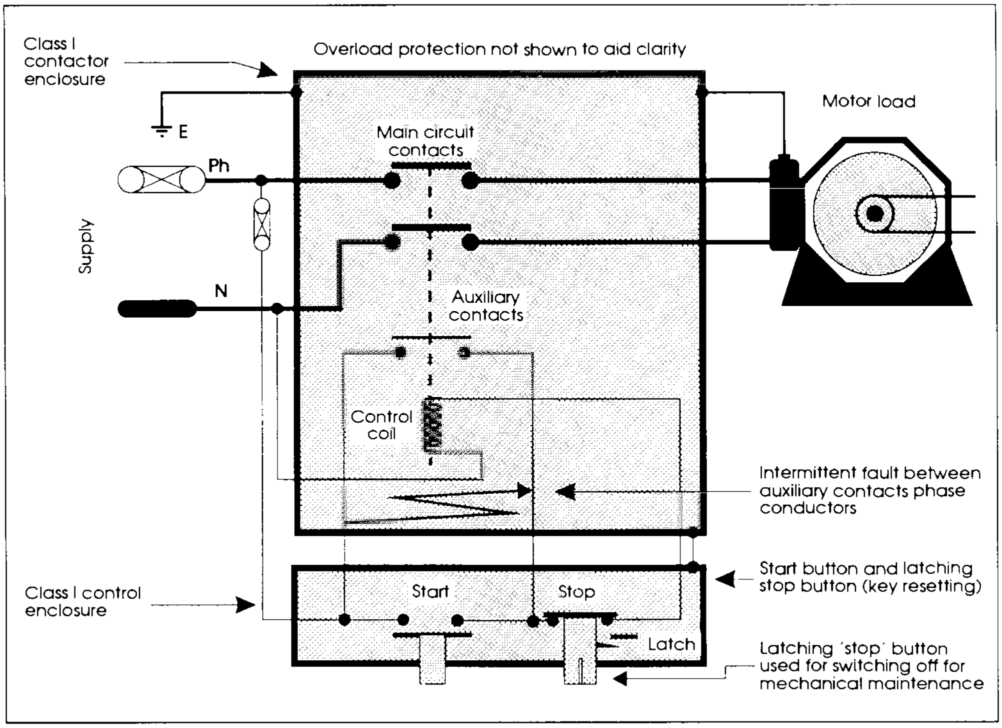


Figure 8.3: An example of an unsatisfactory arrangement for switching for mechanical maintenance

the degree of safety. Figure 8.3 illustrates an example where switching for mechanical maintenance, provided by a latching-type control circuit 'stop' button (with provision for resetting by key), is less than satisfactory. Consider an intermittent earth fault in the control circuit at the location shown in the figure. The intermittent fault between the auxiliary contacts phase conductors may cause the energisation of the coil which in turn would cause the motor contacts to 'make' starting the motor. With the auxiliary contacts now 'made' the motor would continue to run leading to serious hazards for the maintenance worker operating on the machinery driven by the motor.

The device (or control switch) must be manually operated (i.e. non-automatic) and its contact gaps must be visible externally or a clear and reliable indication of the contact position must be given by some other means (Regulation 537–03–02); the 'OFF' position indication only occurring after the contacts have opened sufficiently on each pole. The device must have the capability to interrupt the full load current of the circuit(s) concerned (Regulation 537–03–04) and must be selected and/or erected so that unintentional reclosure does not occur due to, for example, vibration or mechanical impact.

Table 8.7 gives a summary of the essential requirements for a device for switching off for mechanical maintenance.

Table 8.7: Principal requirements for devices for switching off for mechanical maintenance

Requirement	Regulation
Operated by hand.	537–03–02
Suitably located.	462–01–02
Capable of switching load current (off-load device unsuitable).	537–03–04
Contacts visible or reliably indicated.	537–03–02
Lockable, if remote	462–01–03
Not susceptible to the effects of vibration and impact.	537–03–03
Identified as to purpose (appropriately labelled).	462–01–02
Preferably to be inserted in the main supply to equipment.	537–03–01
Permissible to insert in control circuit if BS or CENELEC Standard permits or if equal degree of safety is provided.	537–03–01
Plug and socket-outlet up to 16 A.	537–03–05

The need for switching off for mechanical maintenance must be assessed individually for each item of electrical equipment bearing in mind all factors associated with its maintenance. It is essential that such switching is provided for:

- electric motor activated machines,
- equipment with electrically heated surfaces which may be touched (e.g. lamps, heaters, cooking appliances),
- electromagnetic equipment where there is a risk of an accident.

Table 8.8 provides examples of devices for switching off for mechanical maintenance.

Where a higher degree of hazard is evident, the more onerous

Table 8.8: Examples of devices for switching off for mechanical maintenance

Devices for switching off for mechanical maintenance	**Comment/Restrictions, if any**
Cord operated switch (pull-switch).	Only if it incorporates reliable contact indication (e.g. flag indication). Must be under the continuous control of person carrying out maintenance.
Miniature circuit-breaker.	If remote, to be locked *OFF*.
Moulded case circuit-breakers.	If remote, to be locked *OFF*.
Devices also providing isolation.	If remote, to be locked *OFF*.
Stop-lock switch.	If remote, the stop-lock circuit must have priority and cannot be over-ridden by starting circuit or starting method.
Stop-latch switch (emergency stop button).	Must be under the continuous control of person carrying out maintenance and must provide equal degree of safety as if device is located in main circuit (see also Figure 8.3).
Control switch operating contactor.	If remote, to be locked *OFF*.
Plug and socket or similar devices, such as a luminaire supporting coupler.	Must be adjacent to equipment and under the continuous control of person carrying out maintenance.

requirements relating to isolation should be considered together with suitable warning notices provided for added security and safety in performing such operations.

8.5 Emergency switching and other forms of switching for safety

8.5.1 General

The requirements for emergency switching must be applied to all equipment or parts of the installation which could otherwise present a potential danger. In such instances, if cutting off of electricity is not rapid, danger may occur or perhaps further danger would not be prevented (Regulation 463–01–01). The means of emergency switching adopted must be such that an additional hazard is not introduced and interference with the operation does not occur (Regulation 463–01–03). This will involve the installation designer taking account of the effects of the emergency switching of plant and machinery which may as a result create additional hazards. Regulation 463–01–01 demands that emergency switching devices are capable of acting speedily. This implicitly means that such devices must be uncomplicated in their switching action and normally capable of being activated by a single action. Not only must the device act promptly, but the effect on the equipment must also be rapid. This may necessarily also require provision for emergency stopping (see item 8.6 of this Guide). Generally speaking, emergency switching devices will be of the type that needs resetting after the event and that would require a deliberate act to re-energise the circuit concerned.

Emergency switching is intended, in general, for use by *any* person in the event of an emergency in order to prevent or remove a hazard. The installation designer should therefore make the installation user aware, not later than at handover, of the locations, purposes and functions of the emergency switching arrangements and devices installed. The hazards envisaged by BS 7671 include, for example, electric shock, burns, fire and injury from mechanical movement. Depending on the particular installation, there may well be other dangers which will necessitate the provision of emergency switching measures to electrical equipment. The facility for emergency switching is required anywhere where hazards may be reasonably envisaged from events such as fires, electric shock, explosions or accident. Such switching is required not only to safeguard persons but also to protect livestock and, where appropriate, property.

Emergency switching should not be confused with isolation (a different concept) and there will be many circumstances where emergency switching will not be required. However, emergency switching will be required for any equipment or any part of an installation where, by virtue of the particular characteristics of the equipment, it may be necessary to disconnect rapidly to prevent or remove a hazard or danger. Having commented that emergency switching and isolation are different in concept, tile requirements for pole switching depending on the system type and earthing arrangements are the same (see Figure 8.2).

Installations embodying electrically activated (powered or controlled) machines are particularly susceptible to this type of danger and would therefore need emergency switching facilities. Such machines would include individually operated machines as well as, for example, complex production lines comprising a number of drives operating simultaneously and which may need overall emergency switching in addition to individual switching. Escalators and conveyor systems are prime examples requiring emergency switching. Other examples would include electric cookers and other catering equipment likely to present hazards from fire and explosion. In all cases the emergency switching device(s) should be easily accessible and, as a rule of thumb, should not normally be more than 2 m from the equipment it serves and the normal pathway to the device must be unimpeded by obstructions, dangerous moving parts and heat sources.

Emergency switching devices for d.c. circuits need switching of all poles whereas in a single-phase a.c. system a double-pole device is required irrespective of the system type (e.g. TT and TN-S). In a three-phase system, the requirements depend on the system type and whether there is also the further danger of electric shock:

- TN systems (TN-C, TN-S and TN-C-S)
  switching of all phase conductors (but not essentially the neutral conductor, if any),
- TT and IT systems
  switching of all live conductors (includes the neutral conductor, if any).

Such devices must (Regulation 537–04–01) be capable of interrupting the supply on load (i.e. the full load current) and in the case of motors must be adequate to switch the much greater current associated with stalled-rotor conditions. The arrangement for switching must (Regulation 537–04–02) consist of:

- a single device (cutting off all poles of the circuit to the equipment), or
- a combination of a number of items of equipment capable of being operated by a single action (e.g. contactor controlled by emergency stop push) (see also item 8.6 in this Guide: Emergency stopping).

Regulation 463–01–02 calls for all devices to act as directly as is possible on the circuit supply conductors and in any event to be initiated by a single action. A plug and socket-outlet is *not* suitable for the function of emergency switching. The device must (Regulations 463–01–04 and 537–04–04) be clearly identified as to its purpose and, with account being taken of intended use of the premises, access to it must not be impeded by the emergency conditions that are envisaged (Regulation 476–03–01). Where there is a risk that by inappropriate operation of the device, an additional danger may be created, arrangements need to be made to restrict access to it to skilled and instructed persons, as required by Regulation 476–03–03.

The emergency switching requirements apply to all equipment where a hazard may be expected in normal use (Regulation 476–03–04). The device for such purposes must be located in a readily accessible position such that the operator is not put in danger in the act of operation. Emergency switching of a number of appliances in the same room is not precluded by the requirements and neither is the incorporation of the device into the appliance it serves, where appropriate.

Regulation 537–04–03 requires that where a circuit-breaker or contactor is used which is operated remotely (e.g. from a remote emergency push button), the arrangement is to be such as to open the circuit on *de-energisation* of the coil. The implication here is that emergency switching must not rely on energisation of a coil which will, in circumstances of power failure to the control circuit, be ineffective.

The handle or push button of the device, as required by Regulation 537–04–04, must also be readily accessible and in the vicinity in which the anticipated hazard may occur. This would not preclude duplicate emergency switching being located at other positions (including remotely). The push button must, as required by Regulation 537–04–05, be the latching 'OFF' type and the arrangement must be such that re-energisation does not occur on release of the push button or handle. In other words, a separate action is required for re-energisation by, for example a key switch (these requirements do not, however, apply in cases where the emergency switching device and the means of re-energisation is under the control of the same person). Table 8.9 gives a summary of the requirements for emergency switching devices.

For the more complex industrial installation where process machinery is involved, consideration should be given to the consequential effects of emergency switching off of one machine on other machines in the line process. Some form of sequential emergency switching (and emergency stopping) may be appropriate. The designer and the person responsible for process safety should consult in order to achieve the highest degree of safety in the workplace.

In, for example, electrical test room situations, emergency switching may

Table 8.9: Principal requirements for devices for general emergency switching

Requirement	**Regulation**
Where practical, non-automatic device.	460–01–01
If three-phase, switching of the three phases is required and, if there is a risk of electric shock, the neutral, if any, also needs switching.	463–01–01
Capable of switching load current.	537–04–01
In the case of motors, must be capable of switching stalled-rotor current.	537–04–01
To be single action device.	463–01–02
Identified as to purpose (appropriately labelled).	463–01–04 and 537–04–04
Device to act as directly as possible on circuit concerned.	463–01–02
Suitably located.	476–03–01
If device is used to operate contactor controlling the circuit, switching is required to *de-energise* coil.	537–04–03
If push button, must be the latching off type.	537–04–05
Plug and socket-outlet not acceptable.	537–04–02
Operating knob, lever or button preferably colour *RED*.	537–04–04
Where greater danger may be caused by emergency switching, operation only by skilled or instructed persons.	476–03–03

be referred to as ‘emergency tripping’; both terms should not be confused with ‘emergency stopping’ which refers to the arresting (stopping) of electrically activated mechanical movements whereas emergency switching refers only to rapid disconnection of the electricity supply to equipment. In rooms used by students or trainees, it may be appropriate to increase the number of emergency switching devices.

8.5.2 The fireman’s switch

The fireman’s switch is a particular form of switching for safety (and of isolation) and, as Regulation 476–03–05 requires, must be provided for LV circuits supplying all exterior installations operating at HV (more than 1000 V a.c. or 1200 V d.c.) and for all interior HV discharge lighting installations. ‘Exterior installations’ include covered markets, shopping arcades and shopping malls though a temporary installation of such equipment for exhibitions would not be required to meet these requirements. There is also a dispensation for portable discharge lighting luminaires up to 100 W provided they are fed by a readily accessible socket-outlet.

Regulation 476–03–07 demands that the provision of fireman’s switches shall comply also with the requirements of the local Fire Authority which may differ in one area from another. It is important therefore for the designer to consult the Authority at an early stage to establish its particular needs.

Where a number of such exterior installations exist which require provision of a fireman’s switch, the preferable method is to control all the installations by a single switch as envisaged by Regulation 476–03–06. Similarly, a separate single device is also required for all interior HV installations. Where a number of circuits require switching by a fireman’s switch, this may be effected by, for example, switches with multipole switching or by a contactor controlled by a fireman’s switch. This requirement may be difficult to achieve in practice where, for example, a number of items of equipment need switching through a single device and where they may be fed from separate supplies. In such cases, the Fire Authority must be consulted in an effort to resolve these practical difficulties.

The principal features of a fireman's switch and its mounting positions are summarised in Tables 8.10 and 8.11 respectively and Figure 8.4 illustrates these requirements pictorially.

Table 8.10: Principal requirements for the fireman's switch

Requirement	**Regulation**
Be coloured *RED*.	537-04-06
Be marked or labelled *Fireman's switch* – see (Figure 9.19).	537-04-06
Marking or labelling not less than 36 point.	537-04-06
Minimum dimension of marking or labelling – 150 x 100 mm.	537-04-06
ON and *OFF* positions clearly indicated.	537-04-06
ON and *OFF* positions clearly visible to fireman on ground or other standing.	537-04-06
Be constructed so that switch cannot be inadvertently switched *ON*.	537-04-06
Be constructed so as to facilitate operation by firemen (pole operated).	537-04-06

Table 8.11: Principal requirements for the positioning of the fireman's switch

For emergency switching of exterior installations	**For emergency switching of interior installations**
Fixed on outside of building in a conspicuous position adjacent to controlled equipment or affix notice to, or near, switch indicating where the controlled equipment is located.	Fixed on outside of building in a conspicuous position near main entrance or other position agreed with the Fire Authority.
Switch to be readily accessible (unimpeded access).	Switch to be readily accessible (unimpeded access).
Mounted at not more than 2.75 m from floor or hard-standing beneath the switch.	Mounted at not more than 2.75 m from floor or hard-standing beneath the switch.
Where more than one device, each to be identified clearly as to its purpose (labelled).	Where more than one device, each to be identified clearly as to its purpose (labelled).
Switch and positioning to meet *all* the requirements of the Fire Authority.	Switch and positioning to meet *all* the requirements of the Fire Authority.

8.6 Emergency stopping

Emergency stopping, as opposed to emergency switching, provides for the arresting of mechanical movement of electrically activated equipment and in most cases, of necessity, involves the rapid disconnection of the supply to the equipment (e.g. electric motor). Where necessary, further initiation of a stopping mechanism (e.g. *de-energisation* of a magnetic clutch or *energisation* of a magnetic or electrically operated brake is also required).

The requirements for emergency switching should be applied generally to emergency stopping which must, in any event, be provided where there is a risk from mechanical movement of electrically actuated equipment (Regulations 463–01–05 and 476–03–02). Such emergency stopping devices

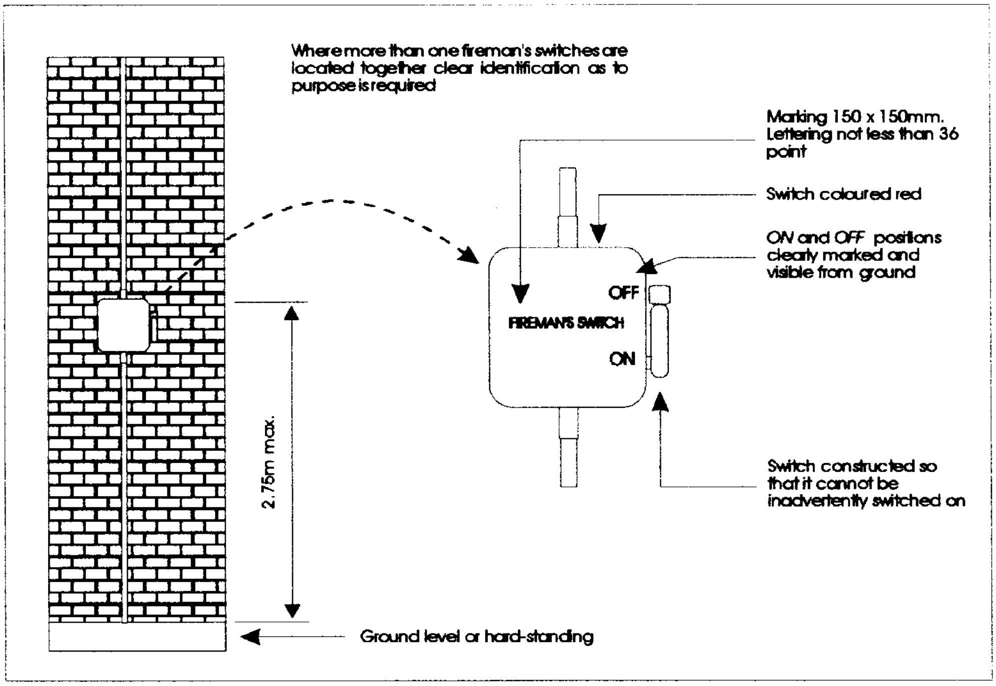


Figure 8.4: Requirements for a fireman's switch

must be readily accessible and in the cases where there is more than one means of starting a machine, interlocking or other precautions are required so as to obviate the risks of unexpected restarting.

In certain cases, retention of supply will be needed to, for example, effect an electric braking facility (e.g. electric crane) and Regulation 537–04–02 would not preclude this arrangement where it is necessary.

8.7 Functional switching

BS 7671 defines *functional switching* as *an operation intended to switch 'on' or 'off' or vary the supply of electrical energy to all or part of an installation for normal operating purposes*. Regulation 464–01–01 calls for a functional switch to be provided for each part of a circuit which may require to be operated independently of any other part or circuit. In other words functional switching can be described as *switching necessary for the everyday control and functioning of electrical equipment*.

Whilst Regulation 464–01–02 does not require a functional switch to control all live conductors (e.g. phase and neutral), it does stipulate that such switching must not be located in the neutral conductor alone. Although Regulation 464–01–03 recognises that a functional switching device may control a number of items of equipment which are intended to operate simultaneously, it does require that all current-using equipment be controlled by a suitable functional switching device. Examples of functional switching devices are easily recognised and would include:

- micro-gap switches (e.g. plate-switches, gridswitches and switches integral to switched socket-outlets),
- contactors and relays,
- electronic devices (e.g. thyristors, transistors, triacs, etc.),
- change-over devices,
- machine limit switches,
- devices serving other functions (e.g. isolating devices).

Regulations 464–01–04, 537–05–04 and 537–05–05 allow a plug and socket-outlet rated up to 16 A to be used for functional switching, except for d.c. where such application is expressly precluded. Regulation 537–05–05 permits a plug and socket-outlet rated above 16 A to be used for functional switching (except on d.c. supplies) where they have a breaking capacity suitable for their intended use. In any event, the plug and socket-outlet arrangement must not be selected (Regulation 537–04–02) as a device for emergency switching. Whilst the regulations permit the use of a plug and socket-outlet arrangement to be used for functional switching, it is recognised in practice that the need to do this is not great with currently available accessories. When so used, the life expectancy can be anticipated to be reduced, especially when used for functional switching 'on load'.

Functional switches are not precluded for use for other purposes (e.g. switching off for mechanical maintenance) provided they meet all the particular requirements for all the functions they are required to perform. In the case of appliances, the device for functional switching can be, and often is, an integral part of the appliance.

Off-load isolators, also known as disconnectors, must not be used for functional switching, and neither must fuses and links be used for such a purpose (see Regulation 537–05–03), and as called for in Regulation 537–05–01 devices for functional switching must be capable of undertaking the most demanding duty intended by the design. Regulation 537–05–02 recognises that functional switching devices may control the current without necessarily the opening and closing contacts, as might be the case of an electronic device in which the current waveform is modified by employing waveform chopping techniques.

Where a functional switching device is used for the change-over from one source to another, as might be the case where standby facilities have been provided, Regulation 464–01–05 calls for the device to switch **all** live conductors (phases and neutral). Additionally, the device must not be such as to connect more than one source in parallel, unless parallel operation was intended in the design, and that disconnection of the PEN must only be provided where the design expressly requires such switching (e.g. to prevent unwanted circulating currents). Particular attention must be paid to control circuitry, inasmuch as a malfunction is likely to occur as a result of a fault arising between the control circuit and other live conductors, protective and functional conductors, exposed-conductive-parts and extraneous-conductive-parts, as envisaged by Regulation 464–02–01.

8.8 Identification and notices

As with all switchgear, devices for switching for safety, need clear and unambiguous identification as required by Section 514 of BS 7671 (see also Chapter 9 of this Guide). Switchgear for isolation, switching off for mechanical maintenance, and emergency switching are also subject to the specific identification requirements in Regulations 461–01–05 and 461–01–07 (isolation), and 476–03–07 and 537–04–06 (emergency fireman's switching). Chapter 9 of this Guide provides examples of labels for identification of switchgear.

Chapter 9

Equipment Selection – Common Rules

9.1 General

Chapter 51 of BS 7671 deals with the common rules for selection and erection of equipment and is made up of five principal sections:

- compliance with Standards,
- operational conditions and external influences,
- accessibility,
- identification and notices, and
- mutual detrimental influences.

The requirements embodied in Chapter 51 are common rules and as such must be applied to every installation irrespective of its location and environment.

9.2 Compliance with Standards

In terms of selection and erection of equipment, the fundamental rule, contained in Regulation 511–01–01, is that equipment must be constructed to an acceptable current Standard appropriate to the intended use of that equipment, as follows:

- British Standard (BS . . .)
- Harmonised European (CENELEC) Standard (BS EN . . .).

Where any of the above Standards is inappropriate or inconvenient, equipment to a foreign national Standard based on the corresponding IEC Standard may be used provided the designer or specifier of the installation confirms that any differences between it and the appropriate British Standard or Harmonised European (CENELEC) Standard results in no less a degree of safety, as required by Regulation 511–01–02. BS 7671 recognises that equipment complying with a British Standard or European Standard is acceptable without further evidence of compliance with that Standard (i.e. certification or approval of conformity) providing it is installed in a proper manner and without modification other than that acknowledged by the Standard or recommended by the manufacturer. Where installed equipment is manufactured to a foreign Standard, and its degree of safety has been assessed as acceptable, care must be taken to confirm its compatibility with other installation equipment.

Essentially BS 7671 is concerned only with safety and where reference is made to acceptable British and CENELEC Standards this relates only to the safety aspects of those Standards. Occasionally, equipment may be subject to more than one Standard where, for example, one may refer to the safety considerations whilst another may refer to the performance specification. For compliance with BS 7671, only the relevant safety aspects need to be met. Generally, BS 7671 demands that equipment complies with a relevant and appropriate Standard but does not go so far as to insist on certification that the requirements have been met though the designer may well feel that this would be desirable.

Other equipment not complying with a British or CENELEC Standard is not ruled out provided the designer has verified, perhaps by the employment of a third party certification body, that the degree of safety is not less than that provided by the Standard relating to similar equipment.

Whilst BS 7671 does not address the performance of the equipment the designer would be advised not to ignore the other facets of good installation design:

- equipment performance – reference to Standard specifications,
- sound engineering principles and Codes of Practice,
- the correct functioning of equipment as specified by the user.

Equipment must be selected and erected so that it is fit for the purpose intended and, if there is any doubt in the designer's mind, the manufacturer's advice should be sought. Regulation 510–01–01 draws attention to the need for equipment to comply with all the relevant regulations in all Parts of BS 7671. Appendix I of BS 7671 lists the British Standards to which specific reference is made in the various regulations.

9.3 Operational conditions, external influences and accessibility

The equipment must, of course, be fit for purpose and suitable for all the relevant operating conditions and for the external influences, as summarised in Table 9.1. Electrically driven machines warrant special consideration in this respect in that motors must be matched with the mechanical load. The characteristics in terms of delivered power as a function of time are of critical importance particularly under starting conditions. The designer would need to assess the characteristics of the mechanical load and the number of starting/stopping operations required and select a suitable motor. The demands of the motor operation will have a significant effect on the fixed wiring system and related equipment. Selection of such equipment will need to take into account not only the steady-state load but also the dynamic behaviour particularly under starting conditions. Motor starting techniques also need very careful consideration of the effects of such operations on other equipment within the installation

Table 9.1: Summary of the operational and other conditions to be considered in the selection of equipment

Aspect	Regulation	Requirement
Voltage.	512–01–01	For TN and TT systems, equipment to be suitable for the nominal voltage to earth, U_o. Account to be taken of voltage variations. For IT systems, equipment to be suitable for the nominal voltage between phases. Account to be taken of voltage variations.
Current.	512–02–01	To be suitable for design current, I_b. Account to be taken of capacitive and inductive effects. To be suitable for fault current for the duration of the fault (determined by the protective device characteristics). When connected to conductors operating at more than 70°C the current rating of the equipment may need to be reduced (manufacturer to be consulted).
Frequency.	512–03–01	Where frequency affects the characteristics of the equipment, the rated frequency of the equipment must match that of the supply.
Power.	512–04–01	The power characteristics of the equipment to be suitable for the duty demanded.
Compatibility.	512–05–01	Equipment not to cause harmful effects to other equipment nor to the supply (including during load switching operations). Equipment producing third-harmonics needs special consideration.
External influences (see Chapter 32, Section 522 and Appendix 5: Classification of external influences).	512–06–01 (130–08–01)	Equipment to be of the appropriate design suitable for the environmental conditions likely to be encountered. The mode of installation to take account of testing required by Part 7 of BS 7671. Where equipment does not inherently possess the characteristics suitable to the external influences, then suitable additional protection will be required; such protection is not to affect the operation of the equipment adversely.
	512–06–02	Where equipment is likely to be subjected to a number of different external influences, the degree of protection of the equipment is also required to take account of any mutual effect.
Identification.	514–01–02	All wiring to be arranged or marked so that it can be readily identified.
Mutual detrimental influences.	515–01–01	Equipment to be selected and erected so that no harmful influence takes place between electrical equipment and between electrical equipment and any non-electrical service. Harmful influences may include electromagnetic radiation.
	515–01–02	Where it is expected that mutual detrimental influence may take place, the equipment must be effectively segregated.
Accessibility.	513–01–01 (136–07–01)	Equipment to be installed so as to allow its operation, inspection and maintenance. Additionally, access to every connection is required. Where mounted in an enclosure or compartment, access for such purposes is not to be significantly adversely affected. This requirement does not apply to cable joints exempted under Regulation 526–04–01.

and on the supply. Where large motors are concerned, consultation with the supplier will be essential to determine the extent of the effects on the supplier's network and the limits, if any, imposed on the starting current. Special consideration is also required in the selection of protective devices, switchgear and controlgear used in relation to loads which are highly inductive (e.g. motors, transformers, fluorescent loads, etc.) or capacitive (power factor correction equipment, etc.) as low power factors can seriously affect the equipment's ability to disconnect such loads. Consultation with the manufacturers of the equipment will be essential in many cases.

9.4 Identification and notices

Table 9.2 summarises the rules for identification of conduit, non-flexible and flexible conductors and Table 9.3 similarly outlines the requirements for notices including those for identification of switchgear, controlgear, and Figures 9.1 to 9.23 give examples of identification labels and warning notices to meet the requirements.

In the most part, BS 7671 does not prescribe the size of labels and warning notices but obviously they need to be adequately proportioned so that lettering is easily legible. There are, however, four instances where the minimum letter sizes (point sizes) are given: the periodic inspection notice (see Figure 9.1), the RCD test notice (see Figure 9.2) and the earthing and bonding connection notices (see Figures 9.9 and 9.10).

Cable core identification (colour coding) in BS 7671 has not changed from the 15th Edition of the Wiring Regulations except in the requirement for functional earths, as used for telecommunication systems, and these are now to be coloured 'cream' to distinguish them from protective conductors.

Where earth-free equipotential bonding is used as a means of protection against indirect contact, special care is required to identify further from the usual 'green/yellow' protective conductor connected to Earth. Regulation 514–13–02 calls for the connection to an earth-free equipotential bonding conductor to be identified by a warning notice, as shown in Figure 9.10, but further warning notices affixed along cable runs may be necessary in some cases. It will be appreciated that a connection of an earth-free equipotential bonding conductor to Earth will destroy the protective measures against indirect contact.

Where pictographic signs are used to give warning of the risks of electric shock they must accord with the Safety Signs Regulations (Statutory Instrument 1980 No 1471).

9.5 Mutual detrimental influences

As demanded in Regulations 515–01–01 and 515–01–02, in selecting electrical equipment the designer needs to confirm that, when installed, there is no detrimental influence between the various items of equipment. Electrolysis is of particular concern since this may occur at an unacceptable rate between dissimilar metals in damp or humid conditions and earth leakage current flow can accelerate metal degradation. Corrosion, too, needs special consideration and enclosures in damp environments should be selected from corrosion-resistant materials. Ferrous-based metals are particularly prone to corrosion where moisture and water is present and, where nonferrous materials are not available for selection, the use of a protective coating should be considered, taking care to avoid any adverse effects to the operation of the equipment so protected.

Another important aspect is the effect of different electrical systems on each other. Low voltage installations complying with BS 7671 would not normally have adverse effects on other electrical systems (or vice versa) compliant with current British Standards and British Standards Codes of Practice including:

- BS 6701 Parts 1 and 2 *Code of practice for installation of apparatus intended for connection to certain telecommunication systems*.
- BS 5266 Parts 1 and 3 *Emergency lighting*,
- BS 5839 Parts 1, 2, 3 and 4 *Fire detection and alarm systems for buildings*,
- BS 6739 *Code of practice for instrumentation in process control systems: installation design and practice*,
- BS 4737 Parts 1, 2, 3, 4 and 5 *Intruder alarm systems*.

Most electrical equipment allows current to leak to Earth and Table L1 of the IEE Guidance Note No 1 summarise the maximum earth leakage currents that are permitted. Again, equipment which does not exceed the permitted limits of earth leakage current should not have any adverse effect on other equipment and on other systems.

Regulations 515–02–01 and 515–02–02 deal with electromagnetic compatibility in two important respects:

- Electrical equipment must be selected so that their immunity levels are such as to be capable of coping with the likely electromagnetic influences in normal use from other equipment. In assessing the immunity levels, due account should be taken of the intended level of continuity of service of the application. In the absence of requirements of a particular standard for appropriate immunity levels, BS EN 50 082 should be consulted.
- Emission levels of electromagnetic influences of equipment must be such that the influences cannot cause unacceptable interference with other electrical equipment either by conduction or propagation through air. Where necessary, the effects of emissions must be minimised. In the absence of requirements of a particular standard for appropriate low emission levels, BS EN 50 081 should be consulted.

9.6 Compatibility

It is essential when selecting equipment that the consequential effects of the operation of such equipment on other equipment and other systems are

Table 9.2: Identification of conduit, non-flexible and flexible conductors

Ref	Item	Regulation	Identification
Non-flexible			
A	Conduit.	514-02-01	Coloured orange in conformity with BS 1710 where it is required to be distinguished from other service pipes.
B	Protective conductor – generally.	514-03-01	Coloured green/yellow (70:30 or 30:70). This colour combination not to be used for any other purpose.
C	Protective conductor – bare conductor and busbar.	514-03-01	To be identified by equal green and yellow stripes between not less than 15 mm and not more than 100 mm either throughout the length or in each compartment and at each accessible position. If adhesive tape is used it must be bi-coloured (green/yellow).
D	Everywhere.	514-06-02	The colour green on its own must not be used.
E	Rubber insulated and PVC insulated live conductors.	514-06-01 (i)	Single-phase: coloured red for phase and black for neutral for final circuits. Single-phase: coloured red for phase and black for neutral for distribution (sub-main) circuits or alternatively the phase may be coloured yellow or blue as appropriate. Three-phase: phases coloured red, yellow and blue as appropriate, and black for neutral. 2-wire d.c.: positive coloured red, negative coloured black. 2-wire d.c. derived from 3-wire system: Outer (positive or negative) to be red. 3-wire d.c.: positive coloured red, middle wire coloured black and negative coloured blue. Telecommunications functional earth: coloured cream.
F	Armoured PVC insulated auxiliary cables.	514-06-01 (ii)	As detailed under Ref E or cores to be numbered in accordance with BS 6346.
G	Paper insulated cables.	514-06-01 (iii)	Numbered cores in accordance with BS 6480; number 1, 2 and 3 to indicate phases and the number 0 to signify neutral (the number 4 to identify the fifth core, if any).
H	Thermosetting cables.	514-06-01 (iv)	As detailed under Ref E or cores to be numbered in accordance with BS 5467; number 1, 2 and 3 to indicate phases and the number 0 to signify neutral.
I	MICC cables.	514-06-01 (v)	At terminations by the use of coloured tapes, discs or sleeves – colours as for Ref E. (Sleeves and binding to BS 3858.)
J	Bare *live* conductors.	514-06-03	Identification by the use of coloured tapes, discs or sleeves or by painting – colours as for Ref E.
K	Cables buried in the ground.	522-06-03	Cables to be marked by covers or suitably marked by tape where not enclosed in ducts or conduit.
L	Switchboard busbar or other conductor.	514-06-04	Colours as Ref E.

carefully considered. Major problems can occur in the switching (on and off) of large loads particularly if these are inductive (e.g. motors). Switching of any load produces higher than normal transient voltages and these can be especially troublesome when substantial loads are switched. The effects of switching of large loads should not be overlooked with respect to the supply which may transmit voltage transients (spikes) to other consumers on the network.

Information technology equipment such as computers, data transmission facilities, electronic office equipment and point-of-sales apparatus are

Table 9.2 continued: Identification of conduit, non-flexible and flexible conductors

Ref	Item	Regulation	Identification
			Flexible
M	Flexible cables and flexible cords – general.	514-07-01 514-07-02	Core identification to be continuous throughout its length. The colours green and yellow must not be used except as a bi-colour for protective conductor. No other bi-colour is permitted.
N	Flexible cables and flexible cords – single core	514-07-02	If phase to be coloured brown, if neutral to be coloured blue: if protective conductor to be bi-coloured green/yellow.
O	Flexible cables and flexible cords – two core.	514-07-02	Phase to be coloured brown, neutral to be coloured blue. Where no neutral is required, blue core can be used for other purpose except as a protective conductor.
P	Flexible cables and flexible cords – three core.	514-07-02	Phase to be coloured brown, neutral to be coloured blue, protective conductor to be bi-coloured green/yellow. Where no neutral is required, the blue core can be used (marked L1, L2 or L3) for other purposes except as a protective conductor.
Q	Flexible cables and flexible cords – four and five core.	514-07-02	Phase to be coloured brown or black, neutral to be coloured blue, protective conductor to be bi-coloured green/yellow. Where no neutral is required, the blue core can be used (marked L1, L2 or L3) for other purposes except as a protective conductor. If more than one phase core the markings L1, L2 and L3 may be used as further identification.

Note: Identification of non-flexible cables is required at least at terminations but preferably throughout their length. For flexible cables and cords identification is required throughout the core length.

particularly prone to interference from high voltage spikes. Careful attention to circumventing potential problems will be required. Consideration of information technology equipment is beyond the scope of this book but guidance is available in the form of the *Applications Manual: Information Technology and Buildings* published by CIBSE.

9.7 Operation and Maintenance Manual

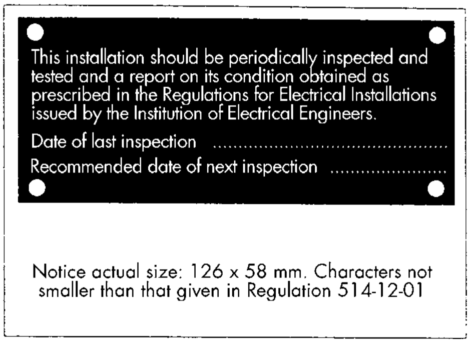
Guidance relating to the Operation and Maintenance Manual is beyond the scope of this Guide but the requirements and advice are readily available in the form of Section 6 of the Health and Safety at Work etc. Act 1974, BS 4884 *Specification for technical manuals* and BS 4940 *Recommendations for the presentation of technical information about products and services in the construction industry*.

Table 9.3: Warning notices and identification of switchgear and controlgear

Ref	Item	Regulation	Identification and warning notices	See Figure
A	Live parts not capable of being isolated by a single device.	461-01-05 514-11-01	Notice required to identify equipment that needs isolation at the appropriate locations and devices. The location of each isolating device must also be indicated.	9.13
B	Isolating devices.	461-01-07	Every device for isolation to be identified by durable marking to indicate relevant circuit(s).	9.12
C	Switches for mechanical maintenance.	462-01-02	Every switch for the purpose of switching off for mechanical maintenance requires identification by durable marking.	9.11
D	Areas restricted to skilled and/or instructed persons.	471-13-03	Notice required to identify areas restricted to skilled and/or instructed persons.	9.14
E	Voltages exceeding 250 V.	514-10-01	Where a voltage exceeding 250 V exist within an item of equipment and where such voltage would not be expected, a notice is required to warn skilled persons before access is gained to live parts. Not necessary for the label to be external providing it is seen before access to live parts is gained.	9.6
F			Where voltages exceeding 250 V exist between an item of equipment and another enclosure or accessory a notice is required to warn skilled persons of the voltages.	9.7
G			Where different nominal voltages exist in switchgear, etc. a warning notice is required to indicate the different voltages.	9.8
H	Diagrams, chart or table.	514-09-01	Information must be provided to indicate: type of circuit, points served, number and size of conductors, wiring system type, vulnerable circuits to testing, the location and function of protective devices (including isolating and switching devices) and the method of compliance with Regulation 413-01-01. Distribution boards and consumer's units should also be provided with such a chart or table.	17.19(d)
I	Equipment vulnerable to typical test.	514-09-01	Where vulnerable equipment is connected to a circuit, a notice indicating this fact and a warning given that testing with common instruments (e.g. 500 V insulation test and earth loop impedance test) may damage the equipment which should be tested separately. Ideally, a notice should be affixed at all points where tests are likely to be carried out and may be, for the smaller installation, in the form of a note appended to the circuit chart or diagram.	9.3 9.4 9.5
J	Residual current devices.	514-12-02	Wherever an RCD is installed a notice is required drawing the user's attention to the need to test (with the mechanical test button) at intervals not exceeding three months.	9.2
K	Periodic inspection and testing.	514-12-01	On completion of an installation, a notice at or near the origin is required to alert the user to the need for periodic inspection and testing.	9.1

Table 9.3 continued: Warning notices and identification of switchgear and controlgear

Ref	Item	Regulation	Identification and warning notices	See Figure
L	Earthing and bonding connections.	514-13-01	In an installation where EEBADS is used, a notice is required at every point of connection of an earthing conductor to an earth electrode and connection of a bonding conductor to extraneous-conductive-parts.	9.9
M		514-13-02	In an installation where protection by earth-free local equipotential bonding or by electrical separation is employed, a notice is required warning that such equipotential bonding must not be connected to Earth.	9.10
N	Earthing conductor connection.	542-03-03	Label (as in Row L above) to be affixed to the connection of the earthing conductor to electrode or other means of earthing.	9.9
O	Switchgear – generally.	514-01-01 514-08-01	Identified as to function and purpose. Additionally, if not in view of the operator and where this may be the cause of danger, then an indicator, complying with BS 4099 *Colour of indicator lights, push buttons, annunciators and digital readouts*, is required.	9.15
P	Controlgear – generally.	514-01-01	Identified as to function and purpose. Additionally, if not in view of the operator and where this may be the cause of danger, then an indicator, complying with BS 4099 *Colour of indicator lights, push buttons, annunciators and digital readouts*, is required.	9.15
Q	Protective device.	514-08-01	Devices to be identified so that circuit protected is easily recognised (may be identified on circuit chart – see Row H of this table).	—
R	Emergency switches.	463-01-04	Devices for emergency switching to be durably marked.	9.17
S	Emergency switches.	537-04-04	Operating handle or push buttons of emergency switches to be clearly identified and preferably coloured red.	9.18
T	Fireman's switch.	537-04-06	Fireman's switches to be equipped with durable nameplate *Fireman's switch.*	9.19
U	Fireman's switch location.	476-03-07	Notice required to identify location of fireman's switch if not positioned on outside of building adjacent to the equipment it serves.	9.20
V	Fireman's switch location.	476-03-07	Where more than one fireman's switch, identification is required as to the equipment each device serves.	9.20
W	Caravan electrical inlet recess.	608-07-03	Durable notice indicating rated current, nominal voltage and frequency of caravan installation.	9.21
X	Main isolating switch in caravan.	608-07-05	Permanently fixed durable notice required adjacent to the main isolating switch in a caravan giving instruction for the electricity supply.	9.23
Y	Highway power supply cables.	611-04-03	Ducting, cables tiles or marker tape required to identify supply cables.	—
Z	Highway power temporary supply units.	611-06-02	Durable label required on every temporary supply unit indicating maximum sustained current to be supplied by the unit.	9.22



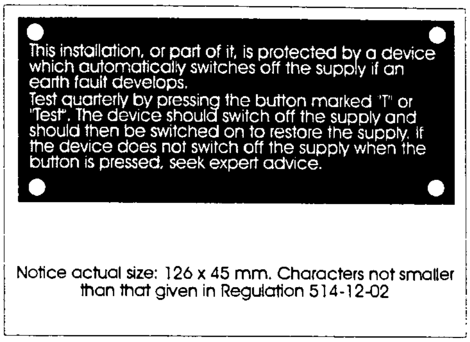
This installation should be periodically inspected and tested and a report on its condition obtained as prescribed in the Regulations for Electrical Installations issued by the Institution of Electrical Engineers.

Date of last inspection ....

Recommended date of next inspection ....

Notice actual size: 126 x 58 mm. Characters not smaller than that given in Regulation 514-12-01

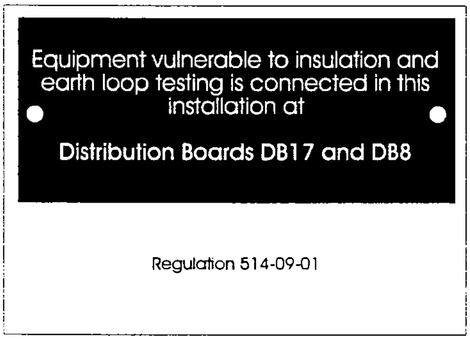
Figure 9.1: Periodic inspection notice



This installation, or part of it, is protected by a device which automatically switches off the supply if an earth fault develops.
Test quarterly by pressing the button marked 'T' or 'Test'. The device should switch off the supply and should then be switched on to restore the supply. If the device does not switch off the supply when the button is pressed, seek expert advice.

Notice actual size: 126 x 45 mm. Characters not smaller than that given in Regulation 514-12-02

Figure 9.2: RCD notice

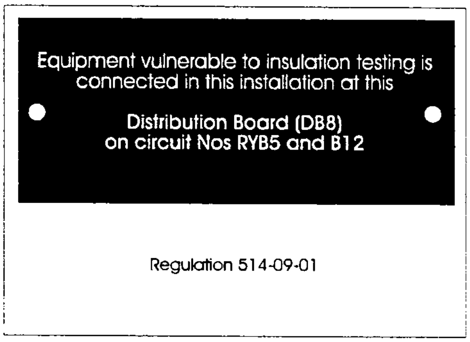


Equipment vulnerable to insulation and earth loop testing is connected in this installation at

Distribution Boards DB17 and DB8

Regulation 514-09-01

Figure 9.3: Equipment vulnerable to testing notice

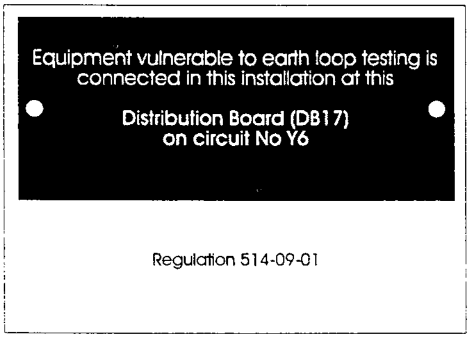


Equipment vulnerable to insulation testing is connected in this installation at this

Distribution Board (DB8)
on circuit Nos RYB5 and B12

Regulation 514-09-01

Figure 9.4: Equipment vulnerable to testing notice

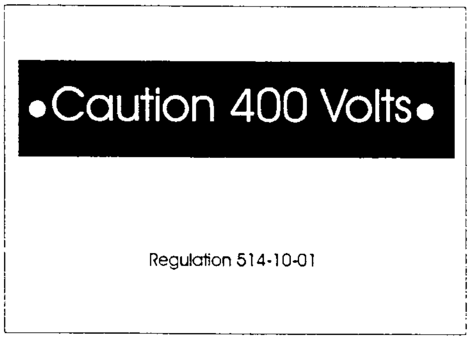


Equipment vulnerable to earth loop testing is connected in this installation at this

Distribution Board (DB17)
on circuit No Y6

Regulation 514-09-01

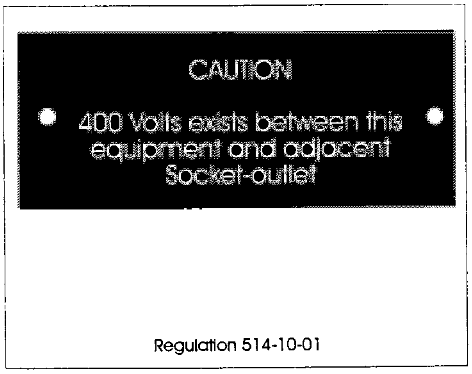
Figure 9.5: Equipment vulnerable to testing notice



•Caution 400 Volts•

Regulation 514-10-01

Figure 9.6: Caution 400 V notice

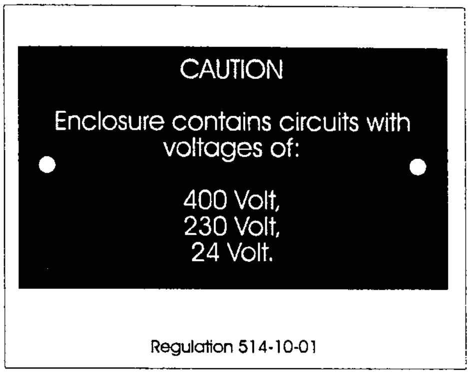


CAUTION

400 Volts exists between this
equipment and adjacent
Socket-outlet

Regulation 514-10-01

Figure 9.7: Caution 400 V (between equipment) notice



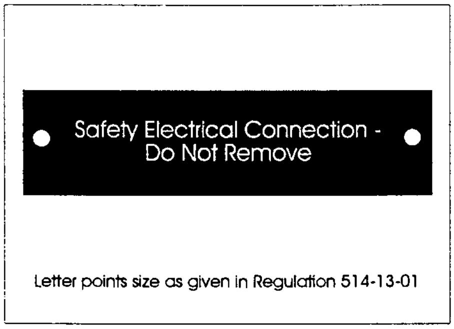
CAUTION

Enclosure contains circuits with
voltages of:

400 Volt,
230 Volt,
24 Volt.

Regulation 514-10-01

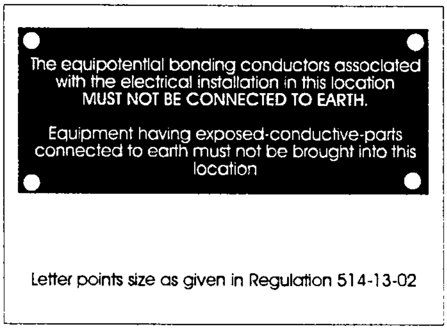
Figure 9.8: Different voltages notice



Safety Electrical Connection -
Do Not Remove

Letter points size as given in Regulation 514-13-01

Figure 9.9: Earthing and bonding connection notice

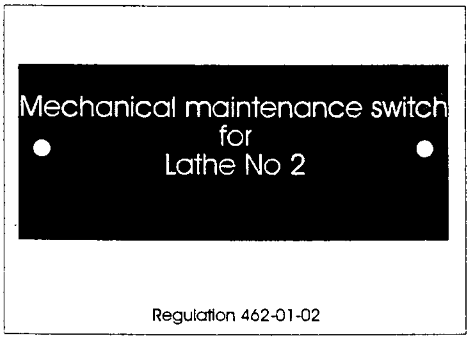


The equipotential bonding conductors associated
with the electrical installation in this location
MUST NOT BE CONNECTED TO EARTH.

Equipment having exposed-conductive-parts
connected to earth must not be brought into this
location

Letter points size as given in Regulation 514-13-02

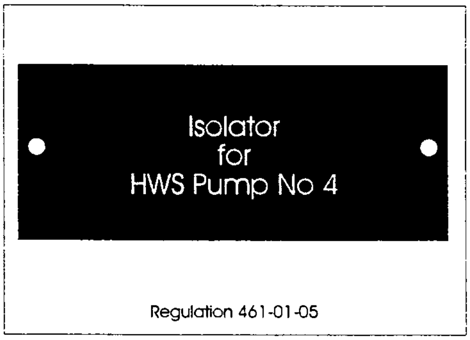
Figure 9.10: Bonding connection notice for earth-free installations



Mechanical maintenance switch
for
Lathe No 2

Regulation 462-01-02

Figure 9.11: Mechanical switch notice



Isolator
for
HWS Pump No 4

Regulation 461-01-05

Figure 9.12: Isolator notice

Before opening cover, this
equipment requires isolation
at two locations:
Distribution Board DB 6
Distribution Board DB 10

Regulations 461-01-05 and 514-11-01

Figure 9.13: Isolation required at more than one point notice

AREA RESTRICTED TO SKILLED AND
INSTRUCTED PERSONS

**UNAUTHORISED ENTRY
PROHIBITED**

Regulation 471-13-03

Figure 9.14: Unauthorised entry notice

MAIN SWITCH

Regulation 514-01-01 (514-08-01)

Figure 9.15: Main switch notice

CONTACTOR

(LOAD SHEDDING)
NON-ESSENTIAL SWITCHBOARD

Regulation 514-01-01

Figure 9.16: Contactor designation notice

**Emergency switch
for
Band saw**

Regulation 463-01-04

Figure 9.17: Emergency switch notice

Emergency
Stop

Regulation 537-04-04

Figure 9.18: Emergency stop notice

FIREMAN'S SWITCH

Regulation 537-04-06

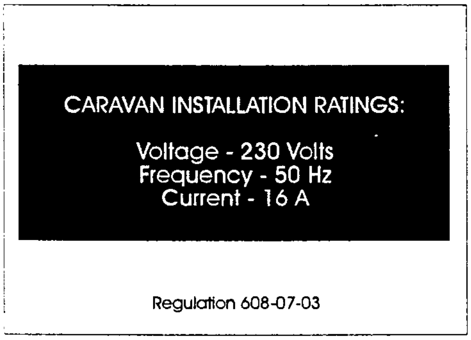
Figure 9.19: Fireman's switch notice

FIREMAN'S SWITCH

Controlling neon sign
on north exterior wall

Regulation 476-03-07

Figure 9.20: Remote fireman's switch notice

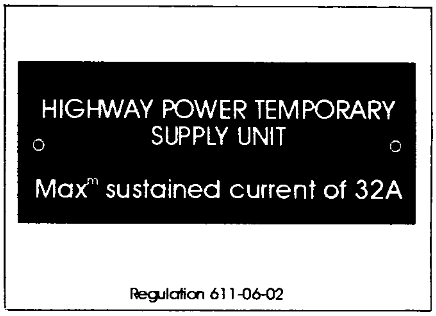


CARAVAN INSTALLATION RATINGS:

Voltage - 230 Volts
Frequency - 50 Hz
Current - 16 A

Regulation 608-07-03

Figure 9.21: Caravan installation ratings notice

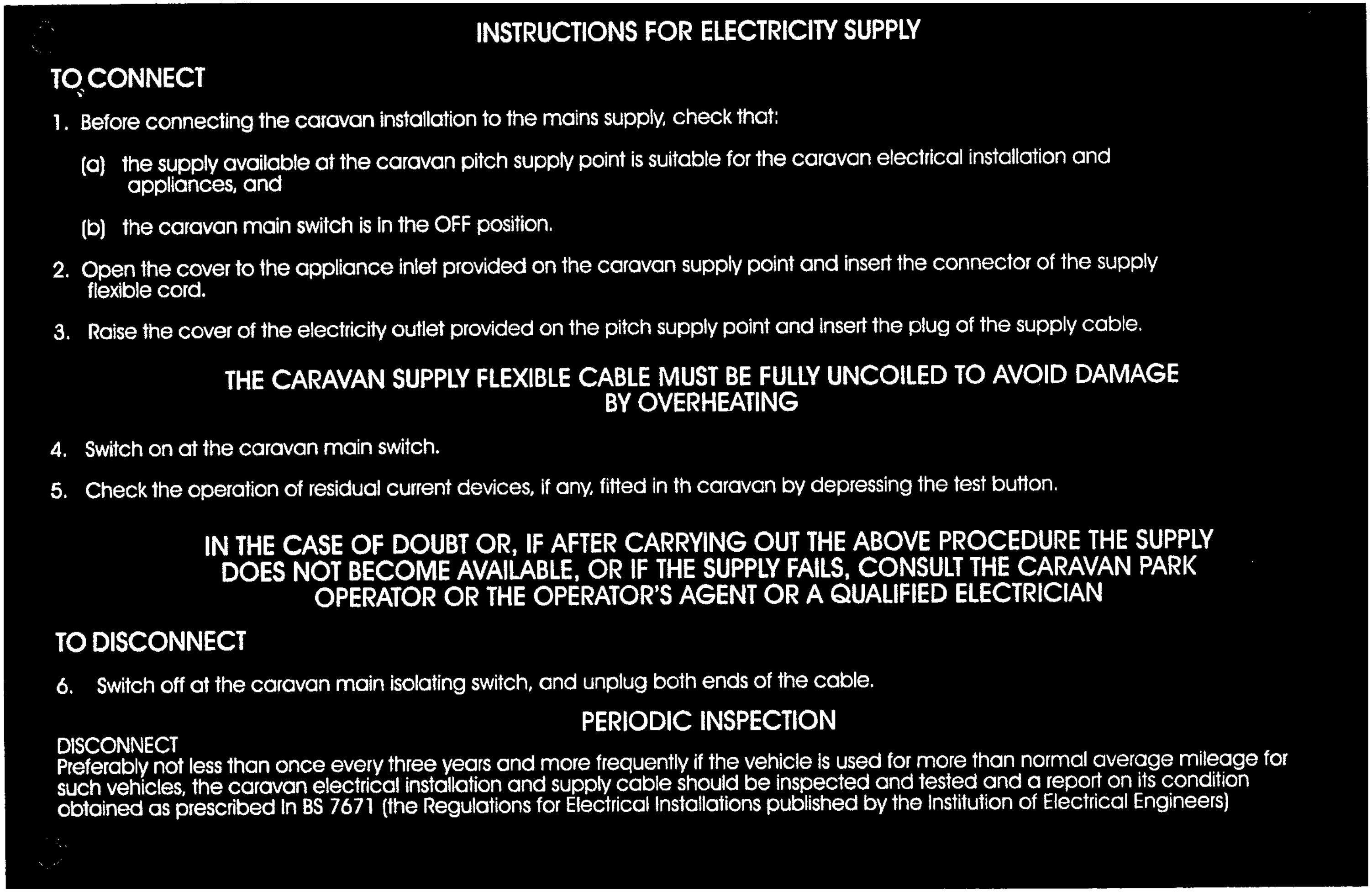


HIGHWAY POWER TEMPORARY
SUPPLY UNIT

Max^{m} sustained current of 32A

Regulation 611-06-02

Figure 9.22: Highway power temporary supply unit notice



INSTRUCTIONS FOR ELECTRICITY SUPPLY

TO CONNECT

1. Before connecting the caravan installation to the mains supply, check that:
   (a) the supply available at the caravan pitch supply point is suitable for the caravan electrical installation and appliances, and
   (b) the caravan main switch is in the OFF position.
2. Open the cover to the appliance inlet provided on the caravan supply point and insert the connector of the supply flexible cord.
3. Raise the cover of the electricity outlet provided on the pitch supply point and insert the plug of the supply cable.

THE CARAVAN SUPPLY FLEXIBLE CABLE MUST BE FULLY UNCOILED TO AVOID DAMAGE BY OVERHEATING

4. Switch on at the caravan main switch.
5. Check the operation of residual current devices, if any, fitted in th caravan by depressing the test button.

IN THE CASE OF DOUBT OR, IF AFTER CARRYING OUT THE ABOVE PROCEDURE THE SUPPLY DOES NOT BECOME AVAILABLE, OR IF THE SUPPLY FAILS, CONSULT THE CARAVAN PARK OPERATOR OR THE OPERATOR'S AGENT OR A QUALIFIED ELECTRICIAN

TO DISCONNECT

6. Switch off at the caravan main isolating switch, and unplug both ends of the cable.

PERIODIC INSPECTION

DISCONNECT
Preferably not less than once every three years and more frequently if the vehicle is used for more than normal average mileage for such vehicles, the caravan electrical installation and supply cable should be inspected and tested and a report on its condition obtained as prescribed In BS 7671 (the Regulations for Electrical Installations published by the Institution of Electrical Engineers)

Figure 9.23: Caravan supply instructional notice

Chapter 10

Wiring Systems

10.1 Wiring systems

10.1.1 Wiring systems – general

There are nowadays numerous types of wiring systems available to the designer and much will depend on the designer's preferences and on the particular type of installation, its use and its environment and also on any economic constraints. It is important, to afford compliance with BS 7671, to select a type of wiring system which is recognised as complying with the appropriate Standard. Table 10.1 identifies wiring systems and cables specifically mentioned in BS 7671 and cross-refers to regulation numbers and Appendix 4 Tables (of BS 7671) as, and where, appropriate. Table 10.2 lists some less familiar cables. Cables manufactured to other recognised standards, provided they meet an equivalent degree of safety are not precluded, but it is for the designer to confirm that such equivalence exists. Where necessary, it will be for the designer to obtain a 'Certificate of Compliance' from, for example, a third-party certification body but such a certificate is not required by BS 7671.

Table 10.3 lists some of the currently available cables with low emission of smoke and corrosive gases when subjected to fire conditions. These cables should be considered for locations where there is a high degree of public access where dense and rapid formation of smoke and fumes may induce panic or injury. Similarly, it is desirable that escape routes and the like, which should not ideally be impeded by smoke and fumes, should be evaluated with a view to using this type of cable (see BS 6207, 6724, 6883 and 7211 for further information on such cables). These low-emission cables, where used, should not be installed in non-metallic trunking and conduit unless they too are of the appropriate materials.

As called for in Regulations 521–07–01 to 521–07–03, bare live (phase and neutral) conductors must be installed on insulators and, excepting protective conductors, fixed-wiring non-sheathed cables must be enclosed in ducting, conduit or trunking. Regulation 521–01–01 permits cables for aerial suspension to incorporate a catenary wire and hard-drawn copper conductors, where appropriate. It also recognises that flexible cables and cords may incorporate a flexible metallic braid or screen and Regulation 521–01–04 allows flexible *cables* (not cords) to be used as fixed wiring provided their installation complies with the generality of BS 7671, and in particular with the requirements for protection against mechanical damage.

Table 10.1: Common wiring systems – Standards

Ref	Wiring system component	Regulation or Appendix 4 Table	British Standards	
Conduit, trunking and busbar systems				
A	Busbar systems.	521-01-02	BS EN 60439-2	
B	Steel conduit and fittings.	521-04-01	BS 31, BS EN 60423, BS EN 50086-1 Part 1.	
C	Steel conduit and fittings with metric threads	521-04-01	BS 4568, BS EN 60423, BS EN 50086-1 Part 1.	
D	Flexible steel conduit.	532-04-01	BS 731-1, BS 60423, BS EN 50086-1	
E	Non-metallic conduit and fittings.	521-04-01	BS 4607, BS EN 60423, BS EN 50086-2-1 Part 2 Section 2.2.	
F	Steel surface trunking and fittings.	521-05-01	BS 4678 Part 1.	
G	Steel underfloor trunking and fittings.	521-05-01	BS 4678 Part 2.	
H	Non-metallic trunking and fittings.	521-05-01	BS 4678 Part 4 or characteristic 'P' of BS 476 Part 5.	
I	Lighting track systems.	521-06-01	BS 4533 Part 2, Section 2.6.	
Cables				
J	Single-core PVC with and without sheath, non-armoured.	4D1A and 4DB1	BS 6004, BS 6231, BS 6346	**COPPER**
K	Multicore PVC with and without sheath, non-armoured.	4D2A and 4D2B	BS 6004, BS 6346,	
L	Single-core PVC, armoured.	4D3A and 4D3B	BS 6346.	
M	Multicore PVC, armoured.	4D4A and 4D4B	BS 6346.	
N	Single-core thermosetting with and without sheath, non-armoured.	4E1A and 4E1B	BS 5467, BS 7211.	
O	Multicore thermosetting, non-armoured.	4E2A and 4E2B	BS 5467.	
P	Single-core thermosetting, non-magnetic armoured.	4E3A and 4E3B	BS 5467, BS 6724.	
Q	Multicore armoured with thermosetting insulation.	4E4A and 4E4B	BS 5467, BS 6724.	
R	Single-core, non-armoured with 85°C rubber insulation.	4F1A and 4F1B	BS 6007, BS 6883.	
S	Multicore, sheathed, non-armoured with 85°C rubber insulation.	4F2A and 4F2B	BS 6883.	
T	60°C rubber insulated flexible cables (not cords).	4H1A and 4H1B	BS 6007.	
U	85°C and 150°C rubber insulated flexible cables.	4H2A and 4H2B	BS 6007.	
V	Flexible cords.	4H3A and 4H3B	BS 6141, BS 6500	
W	Mineral insulated (copper conductors and sheath).	4J1A and 4J1B 4J2A and 4J2B	BS 6207 (fittings to BS 6081).	

Continued on next page

Table 10.1 continued: Common wiring systems – Standards

Ref	Wiring system component	Regulation or Appendix 4 Table	British Standards	
Cables				
X	Single-core PVC (aluminium conductors) with and without sheath, non-armoured.	AK1A and 4K1B	BS 6004, BS 6346.	ALUMINIUM
Y	Multicore PVC (aluminium conductors), non-armoured.	4K2A and 4K2B	BS 6004, BS 6346.	
Z	Single-core, (aluminium conductors), non-magnetic armoured, PVC insulated.	4K3A and 4K3B	BS 6346.	
A1	Multicore, (aluminium conductors), armoured, PVC insulated.	4K4A and 4K4B	BS 6346.	
B1	Single-core thermosetting (aluminium conductors), non-armoured.	4L1A and AL1B	BS 5467, BS 6724.	
C1	Multicore thermosetting (aluminium conductors), non-armoured.	4L2A and AL2B	BS 5467.	
D1	Single-core thermosetting (aluminium conductors), non-magnetic armoured.	4L3A and AL3B	BS 5467, BS 6724.	
E1	Multicore thermosetting (aluminium conductors), armoured.	4L4A and AL4B	BS 5467, BS 6724.	

Table 10.2: Some less familiar cables

Ref	Cable type	British Standard	Possible utilisation
A	Impregnated paper-insulated aluminium-sheathed (CONSAC).	BS 5593	PME power supplies. See also Regulation 546-02-04(ii).
B	PVC insulated cables for switchgear.	BS 6231	Switchgear and panel wiring. See also BS 7671, Appendix 4, Table 4D1A.
C	Impregnated paper-insulated lead-sheathed.	BS 6480	HV power supplies. See Regulation 514-06-01 (iii) for identification of cores.
D	Rubber insulated flexible.	BS 6708	For use in mines and quarries.
E	Rubber insulated cables and cords.	BS 6726	Festoon and temporary supplies.
F	Flexible cables.	BS 6977	Lift installations.

Table 10.3: Cables with low emission of smoke and corrosive gases under fire conditions

Ref	Cable type	British Standard
A	Non-sheathed single-core thermosetting insulated.	BS 7211
B	Armoured thermosetting insulated.	BS 6724
C	Elastomer insulated (types C and D only), armoured and non-armoured.	BS 6883
D	Mineral insulated (except those served PVC overall) with fittings to BS 6081.	BS 6207

10.1.2 Fire performance of wiring systems

The toxic effects of PVC under fire conditions have long been recognised as a problem with regard to the effective escape of persons from buildings and the like. With the introduction of Low Smoke, Halogen Free (LSHF) cables, the designer should seriously consider their use in locations where smoke and fumes may have disastrous effects on people trying to escape from a fire even in its early stages especially where persons are likely to be panicked by the suggestion of toxic fumes. Equally, locations which house expensive computer and other electronic equipment should be considered for this treatment to prevent damage, by toxic gaseous substances (e.g. hydrochloric acid produced by burning PVC), to sensitive components.

Table 10.4, developed from BS 6387: 1994 *Specification for performance requirements for cables required to maintain circuit integrity under fire conditions*, gives a summary of the fire test methods and related performance. Three categories are listed:

- tests related to resistance to fire alone,
- tests related to resistance to fire with water spray, and
- tests related to resistance to fire with mechanical shock.

Table 10.4: Fire performance requirements (BS 6387)

Resistance to fire alone			**Resistance to fire with water spray**	**Resistance to fire with mechanical shock**	
Test duration (min)	**Test temperature (°C)**	**Designation letter**		**Designation letter**	**Test temperature (°C)**
180	650	A	W	X	650
180	750	B	W	Y	750
180	950	C	W	Z	950
20	950	D	W	Z	950

For example, a cable with the designation letters AWX indicates that it has met the requirements laid down by the Standard for a 650°C, 3 h fire resistance test with water spray and mechanical shock. The CWZ cable has met the most onerous performance requirements of a 3 h, 950°C test with water and mechanical shock and it is this category which designers may wish to consider for the most demanding tasks of fire survival and circuit integrity. Fire alarm bell circuits may be one such situation where cables with superior integrity and fire resistance may be worthy of consideration in this respect.

10.2 External influences

10.2.1 External influences – general

Section 522 of BS 7671 deals with the many external influences to which equipment, including wiring systems, may be exposed. Tables 10.5, 10.6 and 10.8 catalogue the various factors to be taken into account in the selection of equipment for a particular environment. These tables should be taken only as a guide and reference to BS 7671 will be needed in ascertaining the

Table 10.5: List of external influences

		Environmental considerations				
Ref		**Ambient temperature (AA) (°C)**	**Humidity (AB)**	**Altitude (AC) (m)**	**Water (AD)**	**Foreign bodies (AE)**
1	Range and designation letters.	AA1: –60 to +5. AA2: –40 to +5. AA3: –25 to +5. AA4: –5 to + 40. AA5: +5 to +40. AA6: +5 to +60.	AB	AC1: ≤ 2000. AC2: > 2000.	AD1: Negligible. AD2: Drops. AD3: Sprays. AD4: Splashes. AD5: Jets. AD6: Waves. AD7: Immersion. AD8: Submersion.	AE1: Negligible. AE2: Small. AE3: Very small. AE4: Dust.
		Corrosion (AF)	**Impact**	**Vibration**	**Flora**	**Fauna**
2	Range and designation letters.	AF1: Negligible. AF2: Atmospheric. AF3: Intermittent. AF4: Continuous.	AG1: Low. AG2: Medium. AG3: High.	AH1: Low. AH2: Medium. AH3: High.	AK1: No hazard. AK2: Hazard.	AL1: No hazard. AL2: Hazard.
		Radiation (AM)	**Solar (AN)**	**Seismic (AP)**	**Lightning (AQ)**	**Wind (AR)**
3	Range and designation letters.	AM1: Negligible. AM2: Stray Currents. AM3: Electromagnetic. AM4: Ionisation. AM5: Electrostatics. AM6: Induction.	AN1: Negligible. AN2: Significant.	AP1: Negligible. AP2: Low. AP3: Medium. AP4: High.	AQ1: Negligible. AQ2: Indirect. AQ3: Direct.	AR

Table 10.5 continued: List of external influences

Utilisation considerations						
		Capability (BA)	**Resistance (BB)**	**Contact with earth (BC)**	**Evacuation (BD)**	**Materials (BE)**
4	Range and designation letters.	BA1: Ordinary. BA2: Children. BA3: Handicapped. BA4: Instructed. BA5: Skilled.		BC1: None. BC2: Low. BC3: Frequent. BC4: Continuous.	BD1: Low density/ easy exit. BD2: Low density/ difficult exit. BD3: High density/ easy exit. BD4: High density/difficult exit.	BE1: No risk. BE2: Fire risk. BE3: Explosion risk. BE4: Contamination risk.
Building considerations						
Ref		**Materials (CA)**	**Structure (CB)**			
5	Range and designation letters.	CA1: Non-combustible. CA2: Combustible.	CB1: Negligible risk. CB2: Fire propagation. CB3: Structural movement. CB4: Flexible.			

Table 10.6: External influences – temperature, water, solid bodies and corrosion

Influence	Class'n	Regulation	Main effect(s)	Likely location(s)	Attention
Ambient temperature.	AA	522-01-01	Adverse effect, particularly on some cables, in use and in handling. Handling in low temperatures can cause damage to some cables (e.g. PVC).	Anywhere where temperatures are at variance (high and low) to normal and in particular where equipment is positioned close to heat sources. Floor heating systems. Cold rooms, etc.	Check temperature limits for in use and handling - use alternative equipment, if necessary. Also, if ambient temperature is significantly different from the 30°C, tabulated current-carrying capacities, given in Appendix 4 of the Wiring Regulations for 30°C, will need modification by application of correction factor from Tables 4C1 and 4C2. Avoid use of PVC cables in very low temperatures.
Heat sources.	—	522-02-01	Equipment degradation and in particular to wiring systems (PVC can suffer softening at temperatures approaching 115°C leading to decomposition and the emission of corrosive gases).	In direct sunlight and anywhere where heat is generated.	Placed away from source, shield, reinforced insulation, derate equipment and/or select alternative equipment.
		522-02-02		In luminaires where cables are in close proximity to heat sources (lamps and controlgear).	Cables to be suitable for highest temperature encountered or sleeved with material which is suitably temperature rated.
Water.	AD and AB	522-03-03	Equipment degradation by corrosion and electrolytic action and, in the case of waves, mechanical damage.	E.g. car wash plants, swimming pools, kitchens, exterior locations.	Select appropriate IP rating for equipment.
High humidity.		522-03-02		Collection of condensation in equipment in locations such as saunas, etc.	Provide drain holes where draining can be effective.
Waves.		522-03-03		E.g. marinas and water treatment works.	Provide mechanical protection (against impact, vibration and other stresses).

Table 10.6 continued: External influences – temperature, water, solid bodies and corrosion

Influence	**Class'n**	**Regulation**	**Main effect(s)**	**Likely location(s)**	**Attention**
Solid foreign bodies, including dust.	AE	522-04-01	Equipment degradation and overheating.	Locations generally.	Select appropriate IP rating for equipment.
	AE4 AE5 AE6	522-04-02	Dust etc. accumulations leading to potential explosion risks.	E.g. sawmills, quarries and cement works.	Select appropriate IP rating for equipment.
Corrosive and polluting substances.	AF	522-05-01	Equipment corrosion and deterioration.	E.g. chemical works and waste disposal works.	Select equipment made from materials resistant to such substances or otherwise provide protection to equipment.
	AF	522-05-02	Equipment degradation by erosion.	Damp and/or polluting atmospheres, generally.	Avoid liability to produce electrolytic action from different metals coming into contact with each other.
	AF	522-05-03	Mutual or individual equipment hazardous degradation.	Damp and/or polluting atmospheres, generally.	Ensure, as far as is practicable, that equipment is not placed in contact with other equipment.

precise requirements. The designation letters (e.g. AE) given in Table 10.5 are taken from Appendix 5 (see also Chapter 32) of BS 7671 but it is important to recognise that there is not a direct correlation between these letters and the International Protection (IP) Code given in BS EN 60 529 except in the case of the letters AD (water).

The classification of external influences and their coding has been developed internationally for IEC Publication 364 (the international wiring rules). Each code is given three digits the first of which indicates where it relates to environmental conditions (A), utilisation (B) or the construction of the building (C). The second digit signifies the particular external influence (e.g. E in the case of solid foreign bodies) and the last gives the degree or extent of the influence (e.g. 4 for dust); see Table 10.10 of this Guide.

Table 10.10 provides a summary of the International Protection (IP) Code, given in BS EN 60 529, and should be used only as a guide and reference should be made to the Standard for the precise wording used. The index gives information as to the resistance of equipment to the ingress of both solid foreign bodies and human body parts, and the ingress of water.

The designer's main task in this respect is first to establish and assess all the external influences in all the distinct areas of the installation and its environment. Where more than one external influence is present in any area, the designer will need to take account of them all in matching equipment, including wiring systems, to the external influences (i.e. to the most onerous conditions).

Having assessed the external influences by observation, enquiry and previous experience, the designer has then to confirm that all equipment selected and methods of installation meet the necessary requirements. With regard to the International Protection (IP) Code, it is helpful to remember that the first numeral relates to the resistance to solid objects in terms of A (see Table 10.10) – protection of persons from contact and B-protection of equipment from solid bodies. The second numeral refers to the protection of equipment from the ingress of water. When equipment is selected correctly, protection against ingress of solids and water will be achieved as will the necessary degree of protection against electric shock from the direct contact hazard.

Where BS 7671 demands a particular degree of protection and quotes, for example, an IP index such as IPX4, the X in place of the first numeral indicates that protection against the ingress of solid foreign bodies is not important in the context of the particular consideration and can be any numeral (0 to 6). If the equipment is electrical the X should be replaced by a minimum of 2 to give the necessary degree of protection against direct contact. Therefore, if IPX4 is required by a particular regulation and this equipment houses electrical parts, the necessary degree of protection would become IP24 because of the need to protect persons from contact with live parts. Where a product is claimed to meet the degree of protection of, say, IP20 or IP40 this means that there is no assessment of the degree of protection against the ingress of water.

10.2.2 Temperature

Ambient temperature is an important consideration for the designer in that it affects the type of wiring system to be selected. In this assessment, the highest and the lowest temperatures are important considerations. The highest is important because it is necessary to confirm that the maximum operating and final temperatures of the cable are not exceeded and to assess the current-carrying capacities of the conductors (tabulated values of current-carrying capacities given in Appendix 4 are based on an ambient temperature of 30°C). Where the ambient temperature(s) are not 30°C, application of the correction factors given in Tables 4C1 and 4C2 of BS 7671 will provide the corrected current-carrying capacities for the particular temperature condition under consideration. In lower temperatures some cables may suffer damage particularly during installation and it is always advisable when installing wiring systems to check with the manufacturers as to the performance of their products under different temperature conditions.

For most installations, 30°C may reasonably be taken as the norm though in most occupied buildings 25°C may be nearer the mark. Cables in loft spaces may well be subjected to an ambient temperature of 30°C (solar gain) during the summer months. However, whilst 30°C may be taken as the general ambient temperature, care should be taken where equipment is sited close to heat sources (e.g. radiant heaters, un-lagged water heaters, etc.). PVC insulation installed in high temperatures will soften and when subjected to temperatures approaching 115°C will severely soften with the ultimately consequence of decomposition and the emission of corrosive products which may attack adjacent material. Accessories too may be unsuitable for the temperatures reached and the designer should check with the Standard for the particular equipment to confirm that it will be suitable for the highest temperatures likely to be encountered before a selection is made (see also Table 10.6 of this Guide).

10.2.3 Water

The terms ‘drip-proof’, ‘splash-proof’, etc., though widely used, are not defined in any standard. The degrees of protection against the ingress of water (and solid bodies) claimed for products is that pertaining in their ‘unstalled’ condition. It is important to recognise that in order to maintain this protection during and after the product is installed, careful installation is paramount. Holes for cable entry or fixing should not be drilled unless they are necessary and care is taken to fill and seal them as necessary. All wiring system accessories such as cable glands should also maintain the same degree of protection.

Water can be in the form of drops (such as rain) and moisture (such as in damp humid conditions or fine spray). Where equipment, such as cable sheaths and armouring and metallic conduit and metallic trunking, are exposed to the weather or to damp conditions indoors, it and its fixings must be of the corrosion-resistant type (e.g. galvanised) or with a corrosion-resistant finish (e.g. plastic-covering). Metallic materials must not be in contact with dissimilar metals where electrolytic action is liable to erode one or other or both of the metals concerned. Where there is the likelihood of a wiring system being susceptible to the ingress of moisture, holes must be left for safe drainage of any build-up of condensation or other aqueous deposits.

Particular care is needed in selection of equipment with regard to terminations, including joints in cables. Where insulating material is used to seal enclosures, such sealing must be capable of withstanding the normal temperature range without losing its ability to provide a proper seal. Ducting, cable ducts and trunking must be sealed so that ingress of water is prevented or such enclosures should be located so that such ingress is not possible. Where equipment is liable to be affected by waves (e.g. marinas), special mechanical protection may be necessary (see item 10.2.6 and Table 10.6 of this Guide).

10.2.4 Solid foreign bodies

Protection against solid bodies (including dust) is required either to protect persons coming into contact with live parts or to prevent entry of other bodies, such as tools, into the equipment. Particular attention should be paid to prevent dust (e.g. cement), and other debris being deposited into flush conduit system during installation. This may be done by the use of temporary conduit box lids, stop-ends, etc., thus preventing blockages later when drawing in cables with the consequential potential for insulation and/or sheath damage.

Dust too can present problems to installations in service and can lead to overheating of equipment and eventually to being the cause of fire and, in some extreme cases, to a potentially explosive situation (see also Table 10.6 of this Guide).

10.2.5 Corrosive and polluting substances

There are a number of corrosive and/or polluting substances commonly in use in building works which may, if not properly considered in the context of the electrical installation, lead to erosion or other degradation of equipment, particular wiring systems. Lime, cement, plaster and materials containing magnesium chloride can cause problems with wiring systems in direct contact with these materials. This can often be avoided by the use of protective coatings applied to the wiring systems during erection or their separation from the offending materials by the use of some non-corrosive media (e.g. plastic capping). The corrosive reactions are usually intensified by the presence of water or damp conditions and special care is needed in the selection of equipment and its fixings in these conditions.

Flora and mould growth is another worrying problem as is the placing of wiring systems touching oak and other acidic woods. Again very careful consideration should be given to these materials when selecting wiring materials and physical separation by the use of non-corrosive covering should be considered. Some manufacturers can supply insulating backing materials for use in such circumstances.

As with damp situations, the designer should avoid contact with dissimilar metals which may otherwise be degraded by electrolytic action. Unplated or bare aluminium in contact with copper or brass (or any other alloy with a copper content) should be avoided. The use of plated materials minimises electrolytic action and, where necessary, metal materials should be placed in enclosures which prevent the ingress of moisture or be otherwise encapsulated in suitable material (e.g. bitumen).

In additional to all the many possible corrosive effects between the electrical equipment and building construction materials, another important consideration is the effect of the environment in which the installation is to be installed and used. Inhospitable environments can have very serious adverse effects on equipment including conductors (insulation, sheaths and armouring) and enclosures. In all cases of concern the designer should seek the advice of the product manufacturer to establish its performance under the environmental conditions perceived. Hydrocarbons (e.g. petroleum products, creosote, etc.) may attack rubber, and PVC and plasticisers have been known to migrate from polystyrene (a common heat insulator) to PVC (i.e. mutual detrimental influence). Where there is doubt about the environmental conditions, the designer would need to consult an expert in the particular environmental conditions before deciding on the selection of equipment (see also Table 10.6 of this Guide).

10.2.6 Mechanical damage – general

Equipment (switchgear, accessories and wiring systems) must generally be protected against impact, vibration and other mechanical stresses such as abrasion. Where, for example, the utilisation of the building is such that equipment is likely to suffer impact the equipment must be capable of withstanding that impact, or alternatively, the equipment must be protected at least in the area subject to the impact, without rendering it unsafe or unserviceable. By far the best solution, if practicable, is to locate equipment in positions where it is not susceptible to mechanical damage. Socket-outlets, for example, can by rule of thumb be positioned about 150 mm above finished floor level or above work surface where the threat of mechanical damage by furniture and household tools is likely to be minimal.

Care must also be taken of wiring systems where they pass through holes in walls and in metalwork where precautions need to be taken to prevent damage to the cables by abrasion against sharp edges This can usually be minimised, in the case of holes in walls, by proper supports of cables or properly formed ducts and, in the case of abrasion by metalwork, by brass/plastics bushes and grommets.

Table 10.7 summarises the requirements relating to mechanical damage from impact, vibration and other mechanical stresses.

Table 10.7: External influences – mechanical impact, mechanical stresses and vibration

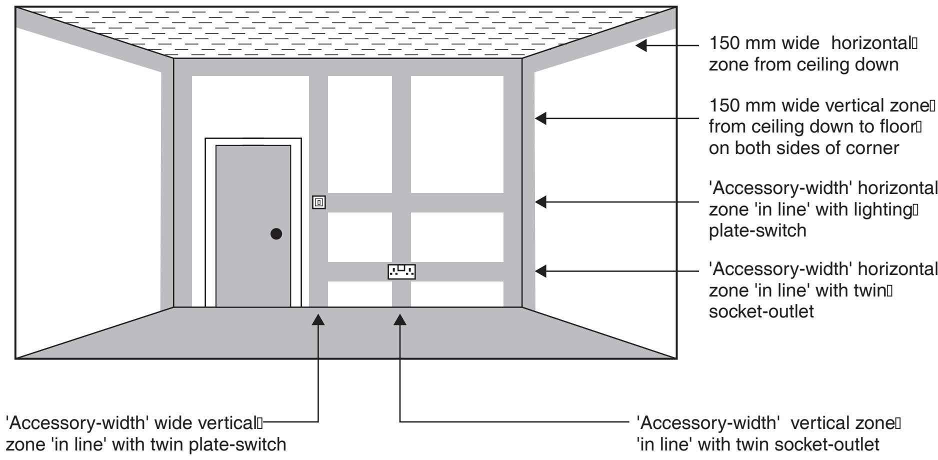
Influence	Class'n	Regulation	Main effect(s)	Likely location(s)	Attention
Mechanical impact.	AG	522-06-01	Unacceptable and potentially hazardous damage.	Generally.	Select equipment suitable for location, bearing in mind operational conditions.
	AG 2 and AG 3	522-06-02	Unacceptable and potentially hazardous damage from medium or high severity impact.		Select wiring system suitable for such impact or relocate equipment or provide additional mechanical protection.
	AG	522-06-03	Underground cable damage.		Underground cable to be of the earthed armoured or metal sheath type, or insulated concentric type (except cables in conduit or ducts). All cables to be marked by cable covers or marker tape.
		522-06-04	Damage to wiring systems in floors.		Select wiring system capable of withstanding any likely damage or provide additional mechanical protection.
		522-06-05	Damage to wiring systems in floor joists and ceiling battens.		Leave at least 50 mm between cable and top and bottom of joist or batten or use cable with earthed metallic sheath (e.g. MICC) or steel conduit system or protected by 150 mm lengths of un-earthed steel conduit (see 471-13-04 [v]).
		522-06-06	Damage to concealed wiring systems in walls.		Install cables more than 50 mm behind finished wall surface or vertically/horizontally from an electrical point, accessory or switchgear or where cables can be reasonably expected (i.e. see Figure 10.1).
		522-06-07			Where compliance with 522-06-06 is not possible or desirable, cables to have earthed metallic covering (e.g. MICC), steel conduit or steel plate protection.
Vibration.	AH 2 and AH 3	522-07-01	Stressed or loosening of connections.	Structures and equipment liable to medium and high severity vibration.	Select equipment, including wiring system (e.g. flexible cables) and support systems capable of withstanding the level of vibration.

Table 10.7 continued: External influences – mechanical impact, mechanical stresses and vibration

Influence	Class'n	Regulation	Main effect(s)	Likely location(s)	Attention
Mechanical stresses.	AJ	522-08-01	Damage to insulation, sheaths and connections of cables.	Generally, in installation, use and maintenance	Select suitable equipment and/or take adequate precautions.
		522-08-02	Cable damage during installation.		Provide adequately sized drawing-in points and, if laid in the structure, to be completed before circuit cables are drawn in.
		522-08-03	Cable suffering damage during installation and subsequently due to inadequate bend radii.		Carefully follow manufacturer's advice and official guidance publications.
		522-08-04	Unsupported cable suffering damage under own weight.		Provide adequate cable supports – consult cable manufacturer, if necessary. Provide adequate terminations (e.g. cable glands).
		522-08-05	Damage to terminations and connections.		
		522-08-06	Damage caused by excessive tensile and torsional stresses to flexible cables.		Select suitable equipment and provide adequate cable supports.

10.2.7 Mechanical damage – concealed and buried cables

Where non-metallic sheathed or armoured cables (e.g. PVC/PVC) are run on walls prior to plastering, they are sometimes encased in metal or plastic channelling and this method serves as a useful means of fixing cables and provides some measure of protection against the plasterer's trowel. However, it does not provide the necessary mechanical protection envisaged by Regulation 522–06–07. Regulation 522–06–06 gives a method of floating such cables in recognised zones of 150 mm wide; i.e., 150 mm from the ceiling horizontally, 150 mm from the corner between two adjoining vertical walls in both directions, or vertically and horizontally from an accessory or electrical point. Figure 10.1 graphically illustrates these zones. Where it is not possible to locate such cables in the prescribed zones, local mechanical protection will be required and this can be achieved by, for example, earthed steel conduit drops.



Wiring systems not within the designated zones must be not less than 50 mm from the surface or be adequately protected against mechanical damage by earthed metal or by the use of earthed metallic sheathed cables (e.g. MICC).

Figure 10.1: 'Safe' zones for mechanically unprotected non-metallic wiring systems

Wiring systems are frequently installed in roof spaces, buried in interfloor spaces and in partition walls and special care is needed in terms of locating these and providing additional mechanical protection where needed. Generally, cables need mechanical protection everywhere where they are likely to be penetrated by screws, nails and the like or be of a type incorporating an earthed sheath (e.g. MICC) or enclosed in steel conduit. Cables buried at more than 50 mm from the surface of a wall are not generally considered to be a potential risk.

Modern building methods sometimes employ narrow (e.g. 50 mm) partitioning boards and these can present problems for the installer in providing mechanical protection. There are the options of using either MICC or steel conduit but in many cases these wiring systems will be impracticable. An alternative approach would be to restrict all cables to the 'safe' zones (see Figure 10.1) and provide accessory points on both sides of the partition. For example, a socket-outlet on one side of the partition and a dummy box with blank plate on the other. This would indicate to others that cables may have been installed vertically or horizontally from these points.

Wiring systems (except earthing conductors – see Chapter 12 of this Guide) installed beneath the ground must be installed in ducts or pipes. Alternatively, they must be of the armoured or metal sheathed type (e.g. SWA cable) which must be earthed or be of the concentric type. Cables in ducts and pipes located in the ground should preferably also be of one of these types. Underground cables must be laid deep enough (usually taken as a minimum of 600 mm, in the absence of precise knowledge) so that they are unlikely to sustain mechanical damage from hand tools (e.g. spades, forks and picks). They must be identified by cable marking tiles or covers or by suitably marking tape, for compliance with Regulation 522–06–03. Figure 10.2 shows a typical section of a wiring system buried in the ground. Additionally, cable routes and their depth should be recorded on the installation's 'as-fitted' drawings for future reference.

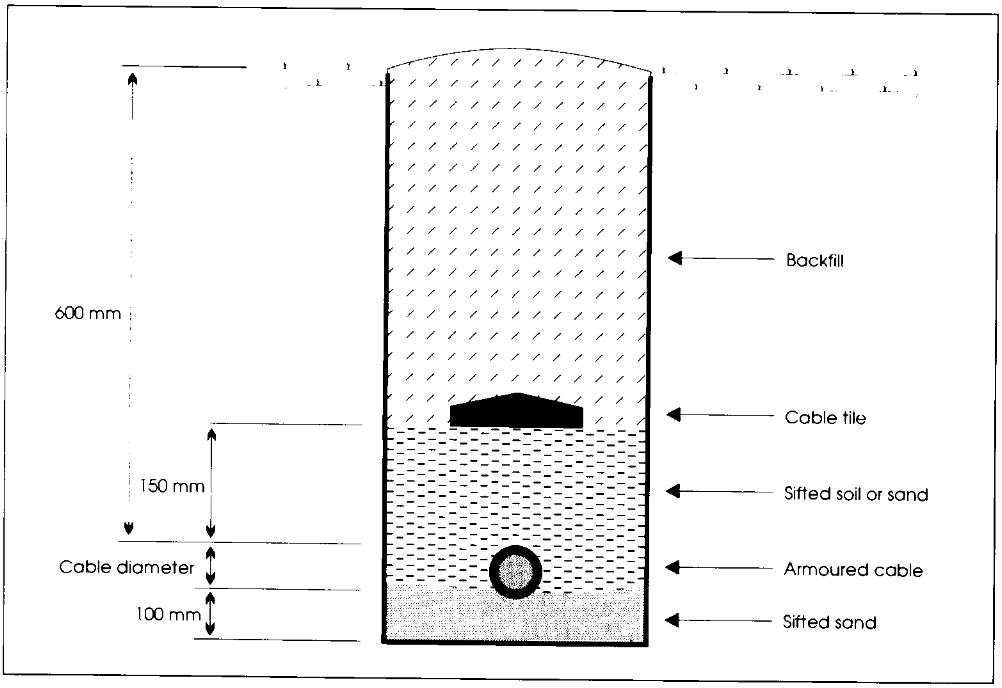


Figure 10.2: A typical section of a buried wiring system

Figure 10.3 shows four different methods of complying with the requirements of BS 7671 for cables taken through joists in intermediate floor spaces. Table 10.8 gives guidance with regard to forming notches and drilling holes in timber joists.

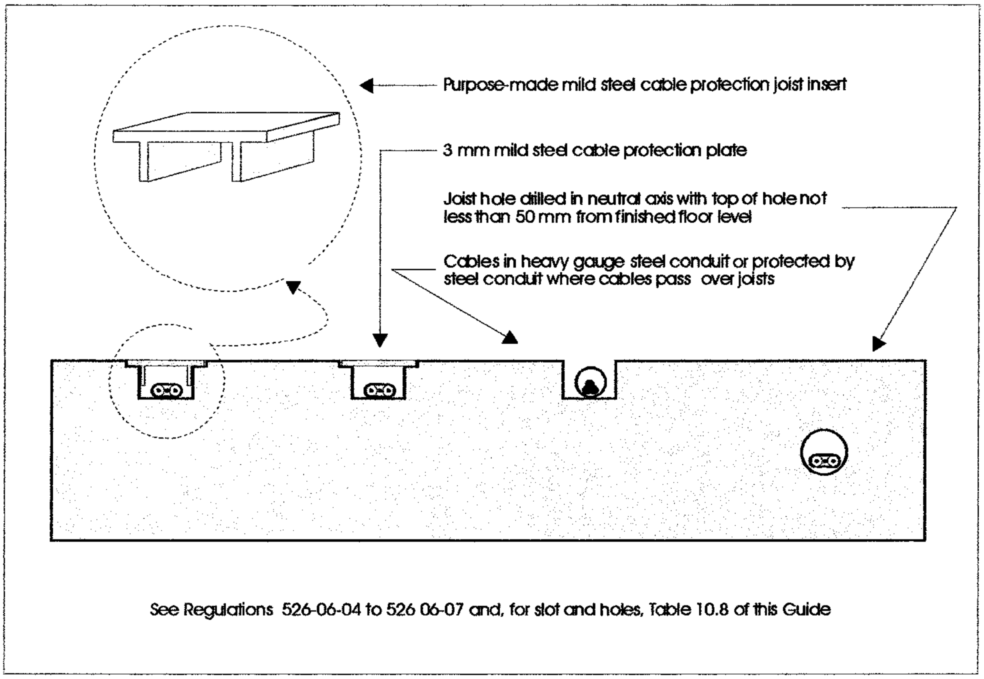


Figure 10.3: Cables through timber joists – four methods of mechanical protection

10.2.8 Damage by fauna, flora and mould growth

Just two Regulations, 522–09–01 and 522–10–01, deal with the external influences of fauna, flora and mould growth and call for suitable precautions to be taken against the effects of conditions likely to cause a hazard (AK2 in the case of flora and mould growth and AL2 in the case of fauna).

The term 'fauna' includes such animals as rats, mice and glis-glis and in locations where these may be present care should be taken in selecting the wiring system or making provision for additional protection. Mechanically unprotected cables, such as PVC and rubber, are liable to damage by gnawing by rodents particularly if the cables block their established run or what they consider to be a potential run. Depending on the extent of the problem, wiring systems should be selected to minimise the potential damage by such creatures and metal conduit and trunking systems and MICC would lend themselves to such applications.

Table 10.8: Notches and drilled holes in timber joists

	Position of notch/hole[1]	**Maximum depth of notch**	**Maximum Diameter of hole[2]**	**Minimum spacing between holes**
Notch	Between 0.07 and 0.25 times joist span form the joist supports	0.125 times the depth of joist	—	—
Hole	Between 0.25 and 0.4 times joist span form the joist supports	—	0.25 times the depth of joist	Spacing not less than 3 hole diameters (centre to centre)

Notes:
(1) No notches or holes permitted in roof rafters except where the rafter is birdsmouthed. Depth not to exceed 0.33 times the depth of the rafter.
(2) Holes to be drilled in the neutral axis.

10.2.9 Building design considerations

Regulations 522–12–01 and 522–12–02 call for precautions to be taken where there is the possibility of building structural movement and where there is a risk of fire propagation (CB2). These precautions would need to take account of relative movement of the building and cables and their supports arranged so as not to permit the conductors to be excessively stressed. More importantly, the systems of protection (e.g. overcurrent protection and protection against indirect contact) must be capable of tolerating any structural movement without impairing their operation in any way. Where the structure is considered to be flexible and/or unstable and is therefore subject to external influence CB4 (flexible structure), flexible wiring systems (i.e. flexible cables) must be employed in order that relative movement can be accommodated without damage to the electrical systems. Structural movement can, for example be expected in towers, masts, bridges and the like and the installation designer should consult with the structural engineer where the structural stability is in question.

10.2.10 Solar radiation

Regulation 522–11–01 calls for cables affected by direct sunlight to be resistant to damage by ultra-violet light. PVC cables to BS 6746 and synthetic rubber (but not natural rubber) to BS 6899 probably afford the best performance for outside locations not in the shade. Alternatively, general cables may be used provided they are shielded from the sun but it is essential that the shielding material does not restrict ventilation of the cable.

Another important consideration of direct sunlight is the solar gain which effectively increases the ambient temperature. In the absence of better data, it is generally considered prudent to allow a 20°C increase in ambient temperature from solar gain and this would translate to a decrease of about 7 to 13% in current-carrying capacity of the cables depending on the particular wiring system. In other words, as a rule of thumb the required current-carrying capacity of cables in direct sunlight without shielding should be increased by approximately 10%.

Table 10.9 summarises the requirements relating to solar radiation and also includes information concerning flora and fauna and building design considerations.

10.3 Proximity to other services – general

Regulations contained in Section 528 of BS 7671 set out the requirements for precautionary measures to be taken where electrical equipment, including wiring systems, are in close proximity to other electrical services and to non-electrical services. Regulations 528–01–01, 528–01–02, 528–01–04 and 528–01–07 deal with electrical systems interrelated with other electrical systems and Regulations 528–02–01 to 528–02–06 set out the requirements concerning the proximity of electrical services to non-electrical systems (e.g. water, oil, gas, steam, chemical and other services). Amendment No 2 deleted Regulations 528–01–03, 528–01–05, 528–01–06 and 528–01–08. Table 10.10 gives the International Protection (IP) code.

10.3.1 Proximity of electrical systems to other electrical systems

Amendment No 2 to BS 7671 drastically altered the requirements relating to Section 528–01 *Proximity of electrical systems*. Regulations 528–01–03, 528–01–05, 528–01–06 and 528–01–08 have been deleted on the basis that as far as BS 7671 was concerned only segregation for electrical safety reasons need be considered and if other requirements were to be necessary this should be the remit of the appropriate BS Code of Practice.

The current requirements as far as electrical safety is concerned are set out in Table 10:11 *Summary of requirements for circuits at different voltage bands* and Figure 10.4.

10.3.2 Proximity of electrical systems to non-electrical systems

Regulations 528–02–01 to 528–02–06 deal with wiring systems which are in proximity to other systems and where there may be a consequential potential hazard. If so, they must be provided with additional suitable protection so that deleterious effects on the electrical system, both by virtue of its proximity and all likely operations associated with the electrical and other systems, are avoided. Generally speaking, wiring systems should be located, where practicable, away from condensation, water, steam, smoke and fumes, compressed air systems and oil systems. Where this is not possible or desirable, preventative measures need to be taken to obviate the risks of mutual detrimental effects on the various systems, unless the systems are under constant effective supervision.

Where, because of the proximity of the systems, shielding of the electrical system is necessary, account must be taken of the effects of this shielding on

Table 10.9: Other external influences

Influence	Class'n	Regulation	Main effect(s)	Likely location(s)	Attention
Flora and mould growth.	AK2	522-09-01	Equipment degradation by vegetation etc.	Agricultural and horticultural and exterior locations generally.	Select suitable equipment and/or adopt special preventative measures.
Fauna.	AL 2	522-10-01	Equipment degradation by animals (e.g. rats, mice, etc.)		
Solar radiation.	AN 2	522-11-01	Damage to wiring system by significant exposure to direct sunlight (including ultra-violet). Temperatures approaching 115°C will have detrimental effects on natural rubber.	Generally on exterior locations.	Select suitable wiring system capable of withstanding the effects of direct sunlight or provide suitable shielding. Some cable sheaths have ultra-violet stabilisers. Cables subjected to solar gain will need their current-carrying capacity derated (as a general rule the ambient temperature of 50°C may be used).
Building design.	CB 3	522-12-01	Damage to wiring system and/or protective measures due to relative structural movement.	Building in which structural movement occurs.	Select suitable wiring system capable of withstanding the effects of structural movement and/or take precautions to prevent damage due to excessive mechanical stresses.
	CB 4	522-12-02	Damage to wiring system and/or protective measures due to movement of structure.	E.g. unstable and flexible structures.	

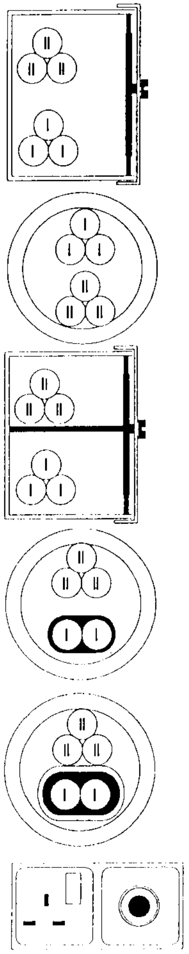
Table 10.10: International protection (IP) code

	First numeral		**Second numeral**
	Degree of protection		**Degree of protection**
	'A' represents protection of persons from contact with live or moving parts. **'B' represents protection of equipment against solid bodies.**		
0	A No special protection. B No special protection.	0	No special protection.
1	A Protection against accidental or inadvertent contact by large surface of body (e.g. hand) but not protected against deliberate access. B Protection against the ingress of objects greater than 50 mm diameter.	1	Protection provides for no harmful effects from water dripping on to the enclosure.
2	A Protection against contact of the ingress of the standard finger (see Standard). B Protection against the ingress of objects greater than 12 mm diameter and of length greater than 80 mm.	2	Protection provides for no harmful effects from water dripping on to the enclosure when tilted up to 15° from the vertical (sometimes referred to as 'drip proof').
3	A Protection against the ingress of objects such as tools and wires of greater than 2.5 mm thick. B Protection against the ingress of objects such as tools and wires of greater than 2.5 mm thick.	3	Protection provides for no harmful effects from rain falling at any angle from the vertical (sometimes referred to as 'rain proof').
4	A Protection against the ingress of wires and strips more than 1 mm thick. B Protection against the ingress of solid objects of more than 1 mm thick.	4	Protection provides for no harmful effects from water splashed from any direction (sometimes referred to as 'splash proof').
5	A Complete protection against contact assured. B Complete protection against harmful deposits of dust assured (dust may enter but not in sufficient amounts to interfere with operation).	5	Protection provides for no harmful effects from water projected by a nozzle from any direction, under defined conditions (sometimes referred to as 'jet proof').
6	A Complete protection against contact assured. B Complete protection against ingress of dust assured (sometimes referred to as 'dust tight').	6	Protection provides against ingress of water from heavy seas or power jets, under defined conditions. Protection against conditions on ships (sometimes referred to as 'watertight equipment').
Note:	The table has been developed from BS EN 60 529 (see the Standard for precise wording).	7	Protection provides against ingress of water from immersion, under defined conditions of pressure and time.
		8	Protection provides against ingress of water from indefinite immersion, under specified pressure.

Table 10.11: Summary of requirements for circuits at different voltage bands

Ref	Regulation number	Circuit in close proximity		Admissible	Conditions
A	528–01–01	HV circuit	Band I (e.g. ELV)	No	None.
B				Yes	Every cable insulated for the highest voltage present.
C				Yes	Each conductor of multicore cable enclosed in an earthed metallic screen with current-carrying capacity equal to that of the largest enclosed conductor.
D				Yes	Separate systems contained in compartment of ducting or trunking.
E		HV circuit	Band II (e.g. LV)	No	None.
F				Yes	Every cable insulated for the highest voltage present.
G				Yes	Each conductor of multicore enclosed in an earthed metallic screen with current-carrying capacity equal to that of the largest enclosed conductor.
H				Yes	Separate systems contained in compartment of ducting or trunking.
I	528–01–02	Band II (e.g. LV)	Band I (e.g. ELV)	No	None.
J				Yes	Every cable insulated for the highest voltage present.
K				Yes	Each Band I conductor of multicore cable or cord individually or collectively insulated for highest voltage present in the Band II circuit.
L				Yes	Each Band I conductor of multicore cable separated from Band II circuit by an earthed metallic screen with current-carrying capacity equal to that of the largest Band II conductor.
M				Yes	Separate systems contained in compartment of ducting or trunking.
N				Yes	Cables installed on tray or ladder, physically separated by a partition.
O				Yes	Circuits contained in separate conduit, trunking or ducting systems.
P	528–01–04	Telecom.	All other circuits	Yes	Segregation in accordance with BS 6701.
Q		FA		No	
R		EL		No	
S		FA	EL	No	
T	528–01–07	Band II (e.g. LV)	Band I (e.g. ELV)	Yes	For controls and outlets for Band I and Band II mounted in a common box, accessory or block, the cables and connections of the different voltage bands must be segregated by an effective partition, which, if metal, must be earthed.

Key: FA – Fire Alarms, EL – Emergency Lighting, HV – voltages above 1100 V a.c. or 1500 V d.c. Telecom. – telecommunications.



Band I and Band II circuits enclosed in the same trunking compartment, every cable Insulated for the highest voltage present.

Band I and Band II circuits enclosed in the same conduit system, every cable insulated for the highest voltage present.

Band I and Band II circuits enclosed in the same conduit or trunking system, each Band I conductor of multicore cable separated from Band II circuit by an earthed metallic screen with current-carrying capacity equal to that of the largest Band II conductor.

Band I and Band II circuits enclosed in the same trunking or conduit system, each Band I conductor of multicore cable separated from Band II circuit by an earthed metallic screen with current-carrying capacity equal to that of the largest Band II conductor.

Band I and Band II circuits enclosed in the same conduit or trunking system, each Band I conductor of multicore cable or cord individually or collectively insulated for highest voltage present in the Band II circuit.

For controls and outlets for Band I and Band II mounted in a common box, accessory or block, the cables and connections of the different voltage Bands must be segregated by an effective partition, which, if metal, must be earthed.

Figure 10.4: Examples of circuit segregation (Band I and Band II circuits)

Table 10.12: Minimum separation distances between low voltage a.c. cables and telecommunications cables

Ref	**Voltage range to Earth U_0 (V)**	**Location**	**Restriction(s)**	**Minimum distance (or other method) (mm)**
A	$50 < U_0 \geqslant 600$	Interior – generally.	None.	50
B			Low voltage cables enclosed in conduit in earthed metallic conduit.	Nil
C			Low voltage cables enclosed in conduit in earthed metallic trunking.	Nil
D			Low voltage cables are the mineral insulated type.	Nil
E			Low voltage cables are the armoured type.	Nil
F			Low voltage cables sharing the cable tray.	50
G		Interior – crossovers.	Where low voltage cables and telecom's cables, of necessity, crossover.	Additional site applied insulation required at cross-overs (except where either cable is armoured).
H	$600 < U_0 \geqslant 900$	Interior – generally.	None	150
I			Non-flammable, non-conductive and rigid divider to maintain separation between the two sets of cables.	50
J		Exterior – generally.	None.	150
K			Non-flammable, non-conductive and rigid divider to maintain separation between the two sets of cables.	50

the electrical system. In particular, the current-carrying capacities of wiring systems may be reduced owing to inhibited heat dissipation of the conductors due to the presence of the shield.

General installation wiring systems must not be run in lift shafts and hoist shafts unless they form part of the lift installation or hoist (as defined in BS 5655), as called for in Regulation 528–02–06.

10.4 Methods of installation of cables

10.4.1 General

There are only three Regulations (521–07–01 to 521–07–03) in Chapter 52 of BS 7671 dealing with the various methods of installation of wiring systems and most of the related information is embodied in Appendix 4: *Current-carrying capacities and voltage drop for cables and flexible cords.*

The tabulated values given in Appendix 4 of BS 7671 for current-carrying capacities and for voltage drop are based upon an ambient temperature of 30°C and a frequency of 49 to 61 Hz. Where these parameters are different, the tabulated values of current-carrying capacities will need correction by applying factors given in Tables 4C1 and 4C2 of BS 7671 in the case of temperature, and where the frequency is significantly outside the range given by applying a correction factor of $(f_1 \div 50)$ (where f_1 is the actual frequency of the system) to the reactance component of the voltage drop tabulated values given.

The twenty installation methods and the nine reference methods as they relate to current-carrying capacities are summarised in Tables 10.13(a) and 10.13(b) with references to pictorial representations given in Figures 10.5 to 10.13.

10.4.2 Current-carrying capacities, csa of conductors and conductor operating temperatures

Section 523 of BS 7671 deals with operational aspects as they relate to current-carrying capacities of conductors. The factors which affect the determination of the current-carrying capacity of a conductor are:

- conductor material, and
- conductor insulating material, and
- the method of wiring system installation [see Tables 10.13(a) and 10.13(b) and Figures 10.5 to 10.12], and
- grouping of conductors with other conductors.

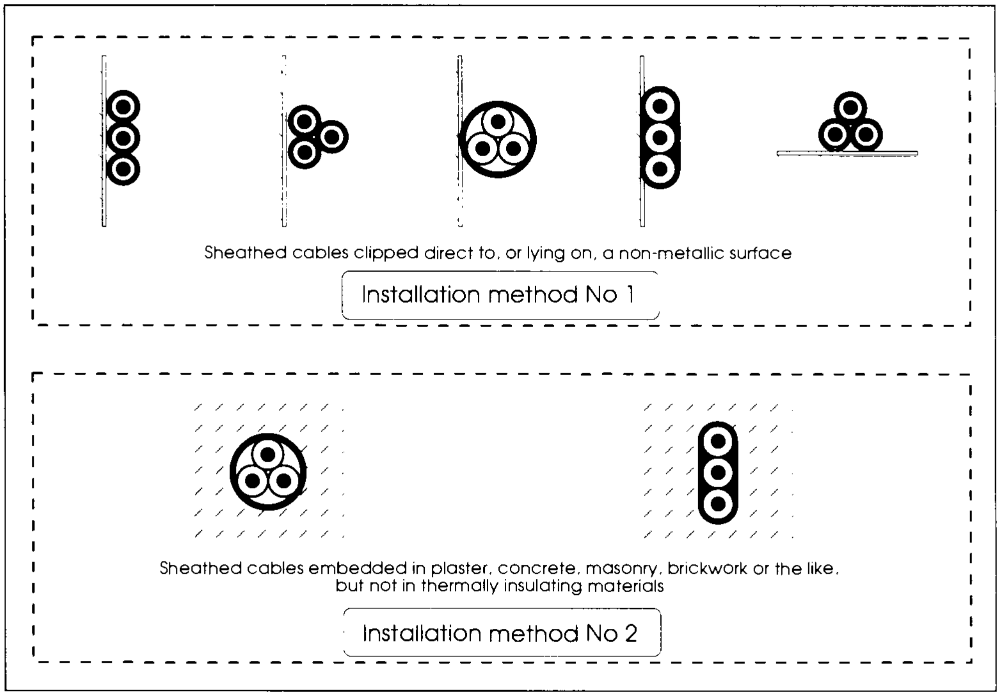


Figure 10.5: Reference method 1

Table 10.13(a): Methods of installation of wiring systems [see also Table 10.13(b)]

Ref	Reference method	Installation method description	Installation method	See Figure
A	1	Sheathed cables clipped direct to or lying on a non-metallic surface.	1	10.5
B		Sheathed cables directly embedded in masonry, brickwork, concrete, plaster, etc. but not in thermal insulants.	2	
C	3	Single-core non-sheathed cables in metallic or non-metallic conduit on wall or ceiling.	3	10.6
D		Multicore having non-metallic sheath in metallic or non-metallic conduit on wall or ceiling.	5	
E		Cables in conduit embedded in masonry, brickwork, concrete, plaster, etc. but not in thermal insulants.	7	
F		Cables in trunking fixed to wall or suspended in air.	8	
G		Cables in flush floor trunking.	9	
H		Single-core cables in skirting trunking.	10	
I		Sheathed cables in ducts or voids formed by the building structure but not in thermal insulants (ducts or voids to be of diameter greater than 5 times the cable diameter, D_e, or with a perimeter greater than 20 times D_e).	16(ii)	
J	4	Single-core non-sheathed cables in metallic or non-metallic conduit in a thermal insulated wall or above a thermally insulated ceiling where the conduit is in contact with a thermally conductive surface on one side.	4	10.7
K		Sheathed cables in metallic or non-metallic conduit in a thermally insulated wall or above a thermally insulated ceiling where the conduit is in contact with a thermally conductive surface on one side.	6	
L		Sheathed cables installed directly in a thermally insulated wall or above a thermally insulated ceiling where the conduit is in contact with a thermally conductive surface on one side.	15	
M		Sheathed cables in ducts or voids formed by the building structure but not in thermal insulants (ducts or voids of diameter not greater than 5 times the cable diameter, $D_e^{(3)}$ or with a perimeter not greater than 20 times $D_e^{(3)}$). Where perimeter is greater than 60 times $D_e^{(3)}$, use method 18 to 20 as appropriate.	16(i)	
N	11	Bunched and unenclosed sheathed cables installed directly on a perforated tray (perforated tray defined as one which has holes occupying not less than 30% of tray's surface area).	11	10.9

Continued on next page

The basic requirement, embodied in Regulation 523–01–01, is that the maximum permitted normal operating temperature of the conductor, t_p, is not more than the tabulated values given in Table 52B of BS 7671 (see Table 10.15 of this Guide). To achieve compliance with this requirement, tabulated values of current-carrying capacities, I_t, given in Appendix 4 of BS 7671, are to be used as a starting basis for calculating the effective current-carrying capacity, I_z, of the installed cable conductor under the

Table 10.13(a) continued: Methods of installation of wiring systems [see also Table 10.13(b)]

Ref	Reference method	Installation method description	Installation method	See Figure
O	12	Sheathed single-core cables in free air with any supporting metalwork under cables occupying less than 10% of the plan area. Cables, if more than one, vertically spaced one above the other at not less than ½ $D_e^{(3)}$ from wall and not less than $D_e^{(3)}$ from each other.	12(i)	10.8
P		Two or three single-core cables in free air with any supporting metalwork under cables occupying less than 10% of the plan area. Cables horizontally spaced at not less than ½ $D_e^{(3)}$ from wall and not less than $D_e^{(3)}$ from each other.	12(ii)	
Q		Three cables single-core in trefoil in free air with any supporting under cables occupying less than 10% of the plan area. Cables spaced at not less than ½ $D_e^{(3)}$ from wall and not less than ½ $D_e^{(3)}$ from nearest other cables.	12(iii)	
R		Sheathed single-core cables suspended from or incorporating a catenary wire.	14(i)	
S		Sheathed single-core cables supported on wall of open or ventilated duct spaced one above the other at not less than ½ $D_e^{(3)}$ from wall and not less than $D_e^{(3)}$ from each other.	17	
T	13	Sheathed multicore cables on ladder or brackets with cable separation not less than $2D_e^{(3)}$.	13(i)	10.10
U		Sheathed multicore cables in free air with cable not less than 0.3 $D_e^{(3)}$ from wall, any supporting metalwork under cables occupying less than 10% of the plan area.	13(ii)	
V		Sheathed multicore cables suspended from or incorporating a catenary wire.	14	
W		Sheathed multicore cables supported on wall of open or ventilated duct spaced one above the other at not less than ½ $D_e^{(3)}$ from wall and not less than 1 $D_e^{(3)}$ from each other.	17	

See notes at the bottom of Table 10.13(b).

particular installation conditions. Extra care must be taken where the conductor operates at a temperature greater than 70°C (e.g. 90°C or 105°C) to confirm that the equipment in which it terminates is not adversely affected by this higher temperature. In these circumstances the designer should consult the appropriate Standard and/or the equipment manufacturer to confirm that, as a consequence of using the cable with a higher operating temperature, the current rating of the connected equipment is adequate, bearing in mind that it may need to be reduced because of the higher operating temperature (see Regulation 512–02–01).

In determining the effective current-carrying capacity, I_z, of a particular conductor under the environmental conditions envisaged, the first step is to establish whether or not the circuit is to be protected against overload. If protection against overload is required the formula for calculating effective current-carrying capacity, I_z, is as given in Equation (10.1). Where overload is not required the formula for calculating I_z is that given in Equation (10.2).

Table 10.13(b): Methods of installation of wiring systems [see also Table 10.13(a)]

Ref	Reference method	Installation method description	Installation method	See Figure
X	18	Two single-core cables enclosed in trench (minimum dimensions – 300 mm deep including 100 mm cover, and 450 mm wide) separated by not less than $D_e^{(3)}$ from each other. Use rating factor of Table 4B3 of BS 7671.	18(i)	10.11
Y		Three single-core cables in trefoil touching enclosed in trench (minimum dimensions – 300 mm deep including 100 mm cover, and 450 mm wide). Use rating factor of Table 4B3 of BS 7671.	18(ii)	
Z		Multicore cables or groups of single-core cables enclosed in trench (minimum dimensions – 300 mm deep including 100 mm cover, and 450 mm wide) separated by not less than 50 mm from each other. Use rating factor of Table 4B3 of BS 7671.	18(iii)	
A1		Sheathed cables in ducts or voids formed by the building structure where perimeter is more than 60 $D_e^{(3)}$.	16	
B1	19	Six to twelve single-core cables in flat groups of two or three on vertical wall. Cables to be separated by a minimum of one cable diameter and groups by at least 50 mm.	19(i)	10.12
C1		Two to four groups of three single-core in trefoil with trefoils separated by 50 mm	19(ii)	
D1		Four to eight of two-core or three to six three or four-core cables separated by 75 mm. Cables in enclosed trenches of minimum dimensions of 240 mm wide × 600 mm deep including 100 mm of cover. All cables spaced not less than 25 mm from wall.	16	
E1	20	Single-core cables in trefoil groups of two or three in flat formation with cables to be separated by a minimum of one cable diameter. Minimum distance between groups of at least 50 mm.	20(i)	10.12
F1		Flat formation of two or three cables in a group separated by a minimum of 50 mm.	20(ii)	
G1		Eight to sixteen two-core cables or six to twelve three or four-core cables separated by not less than 50 mm. Cables in enclosed trenches of minimum dimensions of 600 mm wide × 760 mm including 100 mm of cover. Correction factors given in Table 4B3 of the Regulations must be used. All cables spaced at least 25 mm from wall.	16	

Notes: (1) The reference method number is the appropriate method for determining current-carrying capacities as stated in column 4 of Table 4A of BS 7671.
(2) The installation method number is installation method as stated in column 1 of Table 4A of BS 7671.
(3) D_e is the cable diameter or, if more than one cable, the sum of the diameters of all the cables.

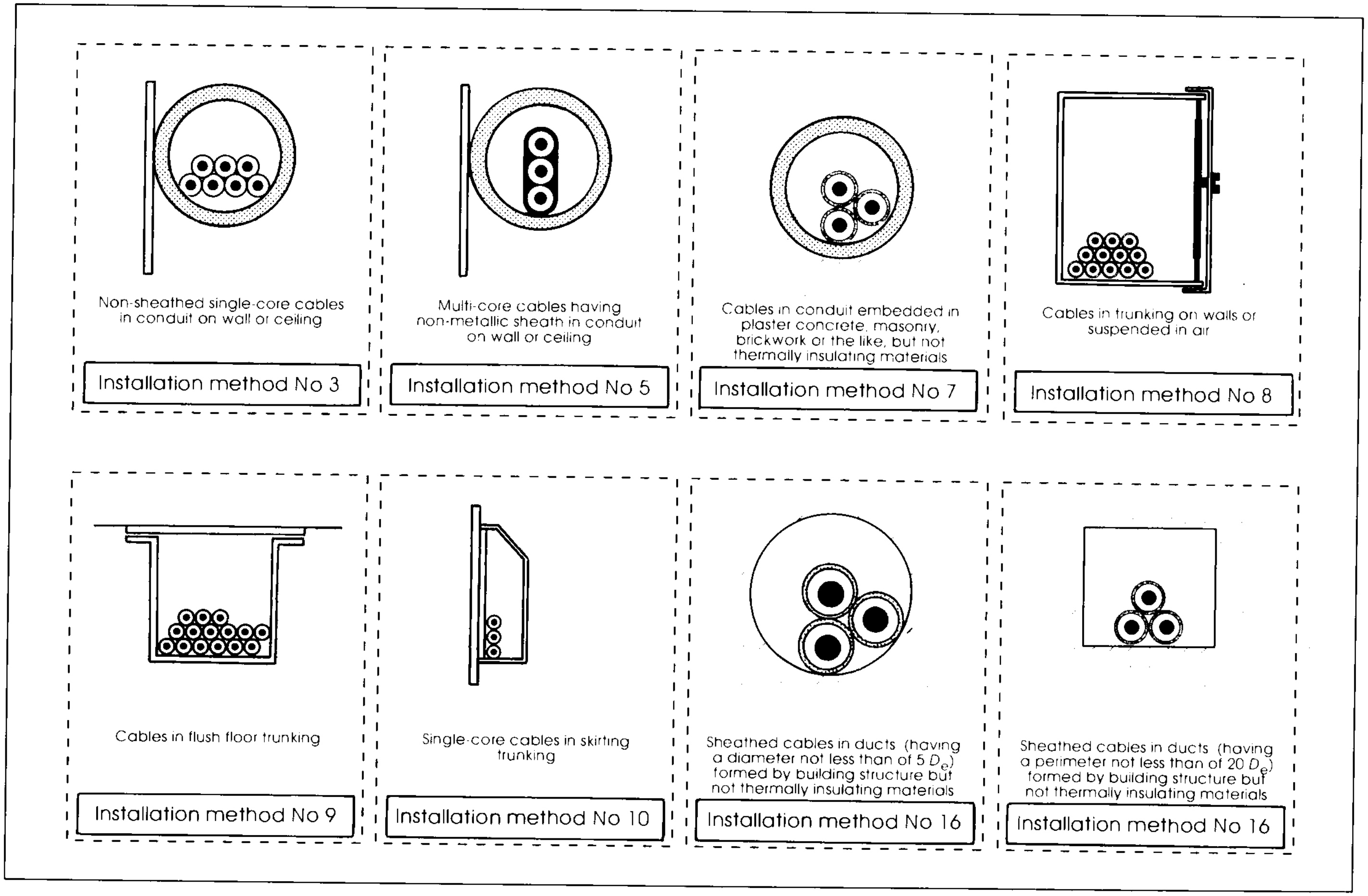


Figure 10.6: Reference method 3

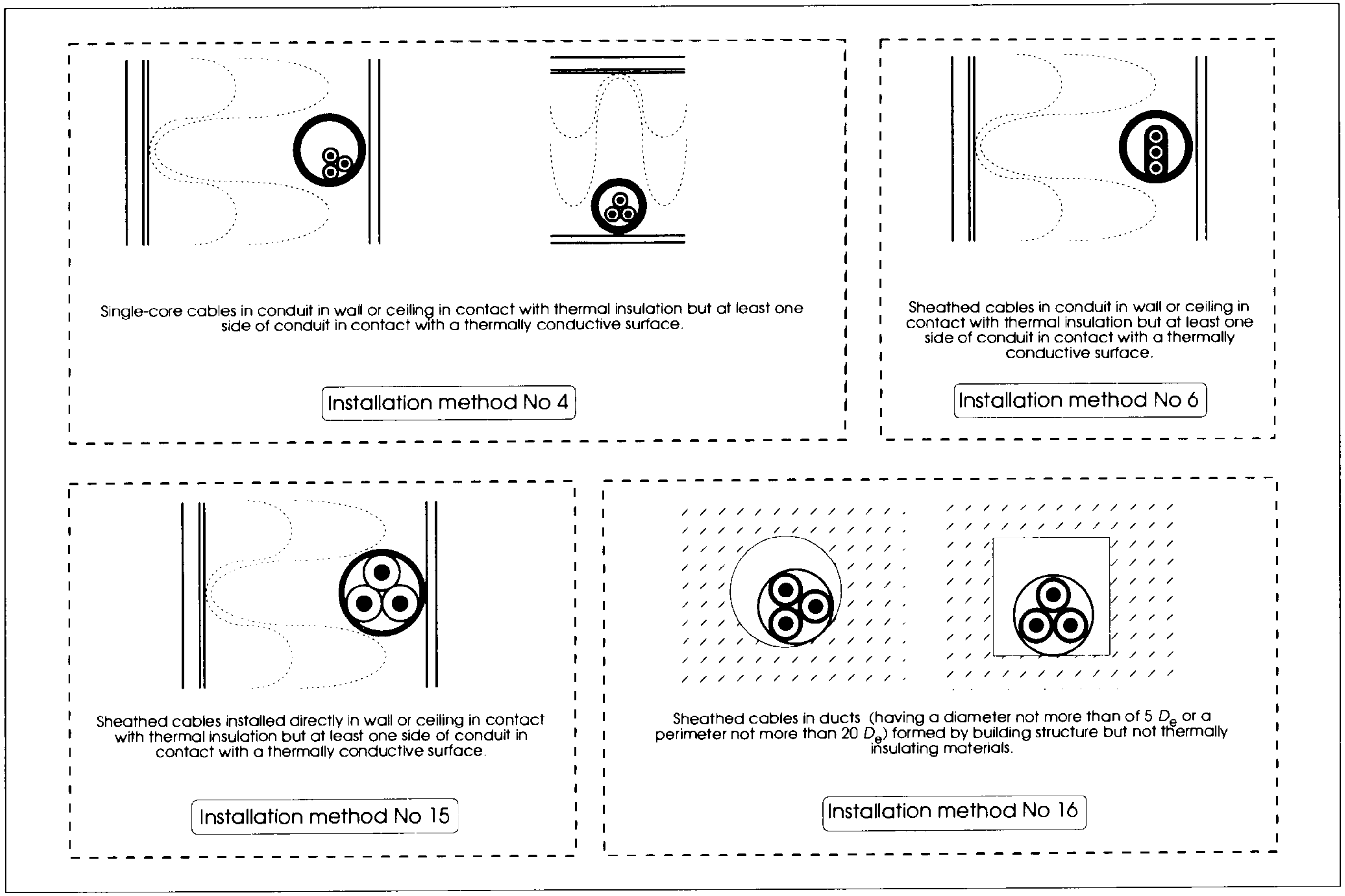
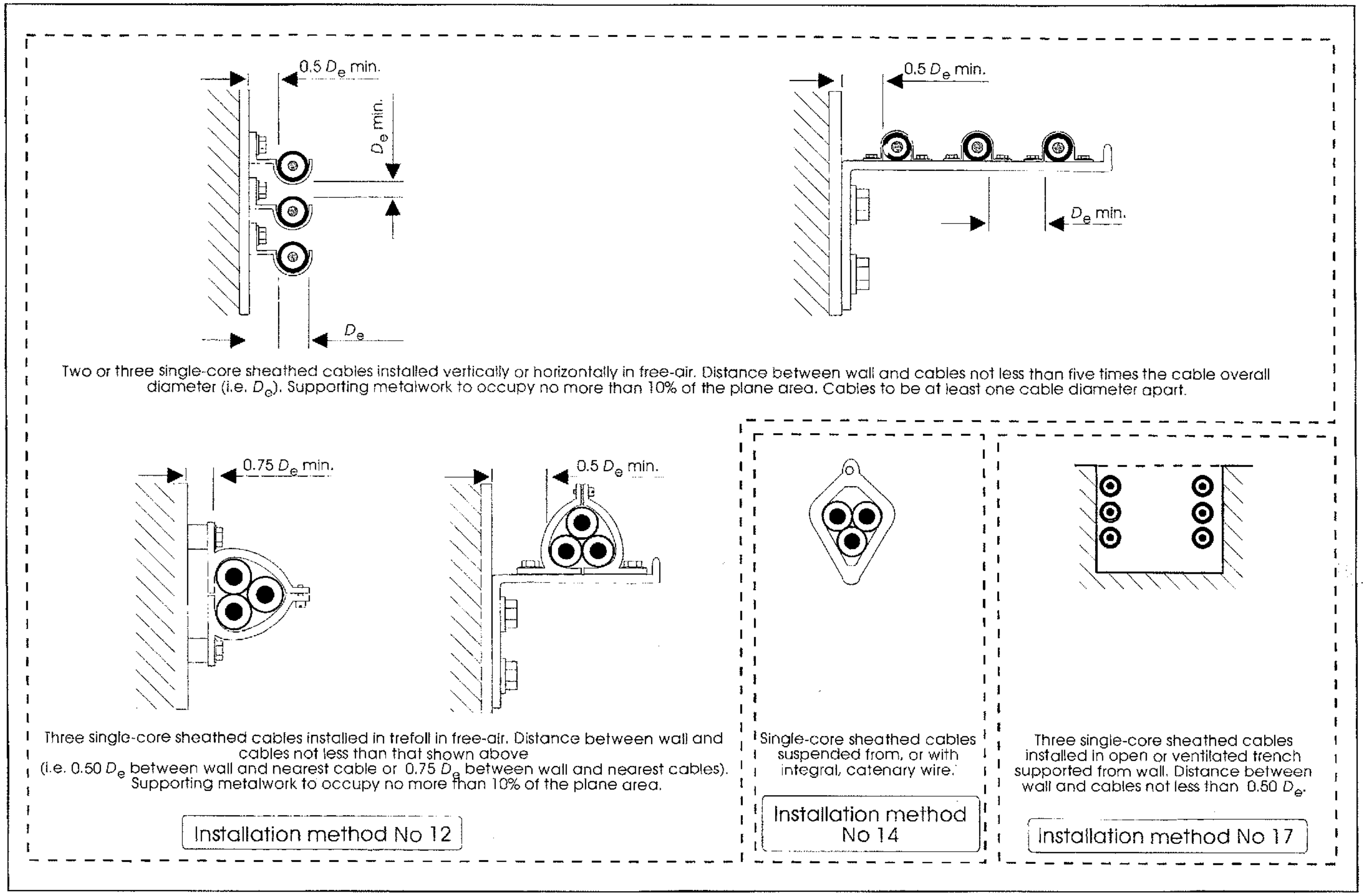


Figure 10.7: Reference method 4



Two or three single-core sheathed cables installed vertically or horizontally in free-air. Distance between wall and cables not less than five times the cable overall diameter (i.e. D_e). Supporting metalwork to occupy no more than 10% of the plane area. Cables to be at least one cable diameter apart.

Three single-core sheathed cables installed in trefoil in free-air. Distance between wall and cables not less than that shown above (i.e. 0.50 D_e between wall and nearest cable or 0.75 D_e between wall and nearest cables). Supporting metalwork to occupy no more than 10% of the plane area.

Installation method No 12

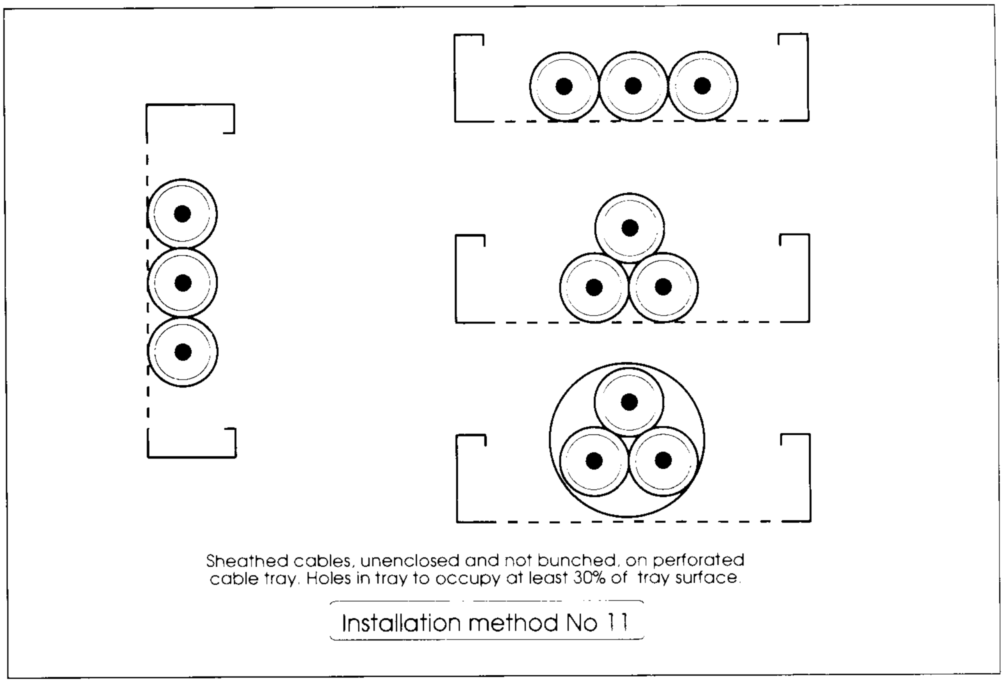
Single-core sheathed cables suspended from, or with integral, catenary wire.

Installation method No 14

Three single-core sheathed cables installed in open or ventilated trench supported from wall. Distance between wall and cables not less than 0.50 D_e.

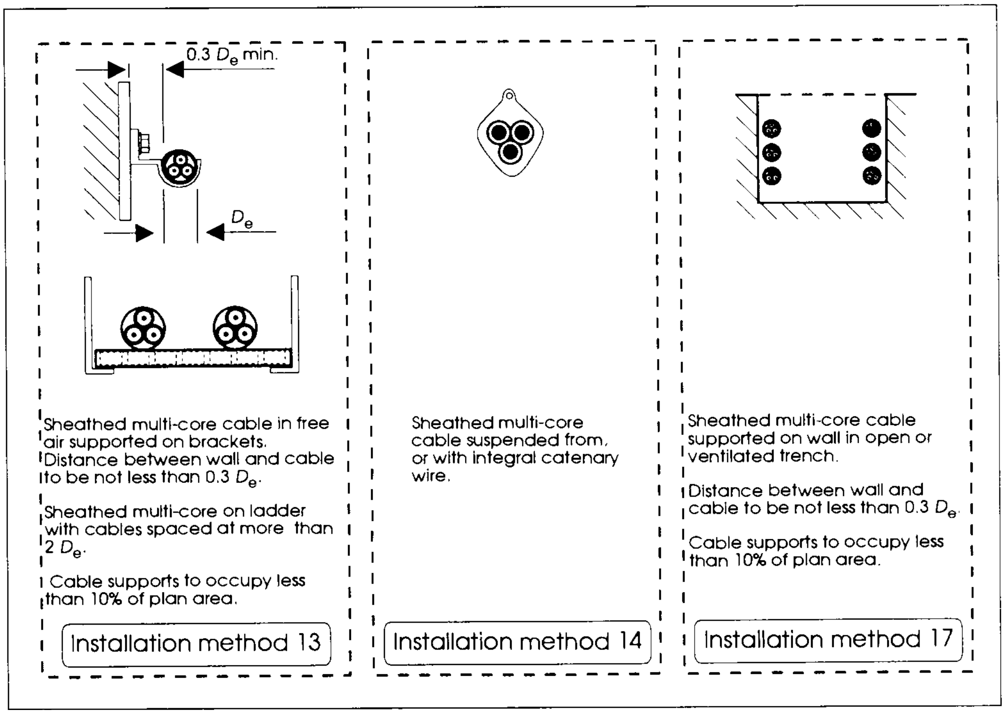
Installation method No 17

Figure 10.8: Reference method 12



Sheathed cables, unenclosed and not bunched, on perforated cable tray. Holes in tray to occupy at least 30% of tray surface.

Figure 10.9: Reference method 11



Sheathed multi-core cable in free air supported on brackets. Distance between wall and cable to be not less than 0.3 D_e.

Sheathed multi-core on ladder with cables spaced at more than 2 D_e.

Cable supports to occupy less than 10% of plan area.

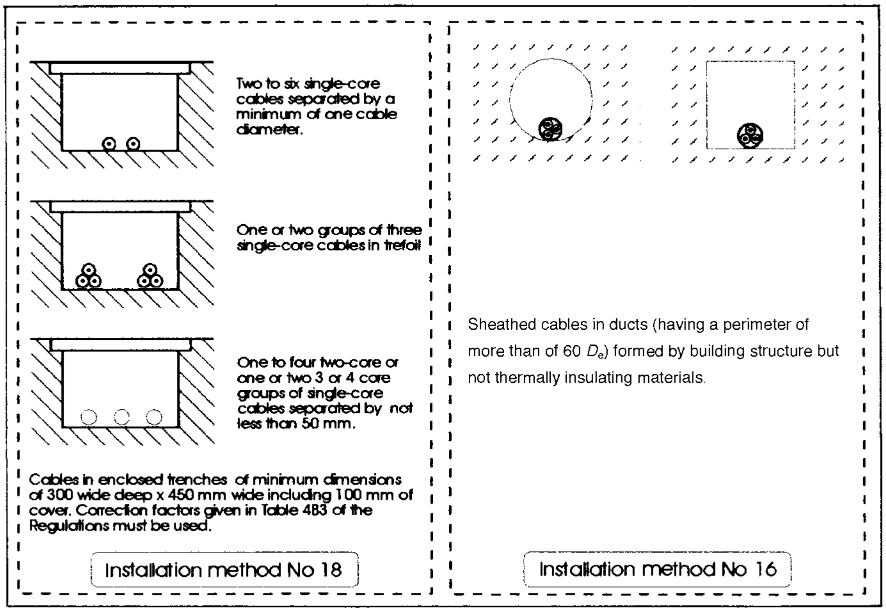
Sheathed multi-core cable suspended from, or with integral catenary wire.

Sheathed multi-core cable supported on wall in open or ventilated trench.

Distance between wall and cable to be not less than 0.3 D_e.

Cable supports to occupy less than 10% of plan area.

Figure 10.10: Reference method 13



Two to six single-core cables separated by a minimum of one cable diameter.

One or two groups of three single-core cables in trefoil

One to four two-core or one or two 3 or 4 core groups of single-core cables separated by not less than 50 mm.

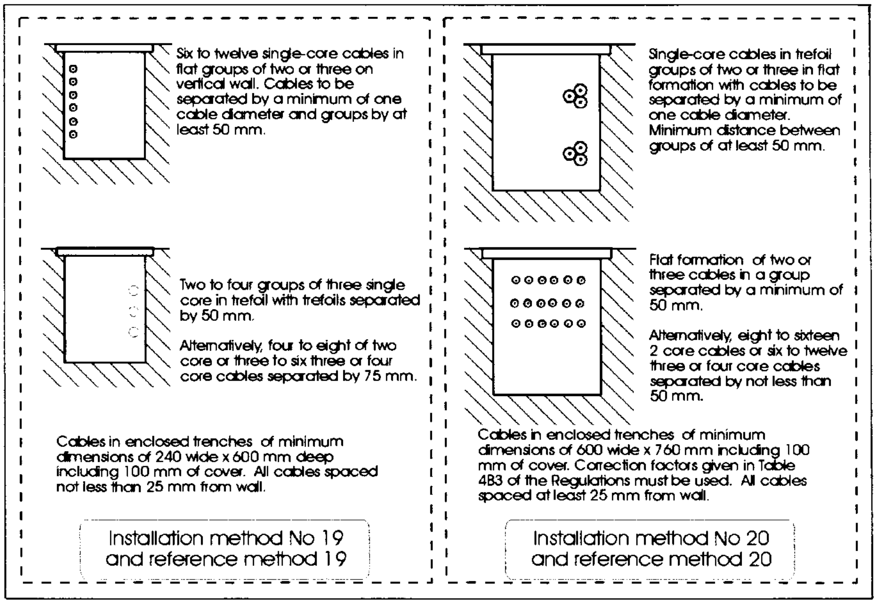
Cables in enclosed trenches of minimum dimensions of 300 wide deep x 450 mm wide including 100 mm of cover. Correction factors given in Table 4B3 of the Regulations must be used.

Installation method No 18

Sheathed cables in ducts (having a perimeter of more than of 60 D_e) formed by building structure but not thermally insulating materials.

Installation method No 16

Figure 10.11: Reference method 18



Six to twelve single-core cables in flat groups of two or three on vertical wall. Cables to be separated by a minimum of one cable diameter and groups by at least 50 mm.

Two to four groups of three single core in trefoil with trefoils separated by 50 mm.

Alternatively, four to eight of two core or three to six three or four core cables separated by 75 mm.

Cables in enclosed trenches of minimum dimensions of 240 wide x 600 mm deep including 100 mm of cover. All cables spaced not less than 25 mm from wall.

Installation method No 19
and reference method 19

Single-core cables in trefoil groups of two or three in flat formation with cables to be separated by a minimum of one cable diameter. Minimum distance between groups of at least 50 mm.

Flat formation of two or three cables in a group separated by a minimum of 50 mm.

Alternatively, eight to sixteen 2 core cables or six to twelve three or four core cables separated by not less than 50 mm.

Cables in enclosed trenches of minimum dimensions of 600 wide x 760 mm including 100 mm of cover. Correction factors given in Table 4B3 of the Regulations must be used. All cables spaced at least 25 mm from wall.

Installation method No 20
and reference method 20

Figure 10.12: Reference methods 19 and 20

$$I_z = \frac{I_n}{C_a \times C_d \times C_g \times C_i} \tag{10.1}$$

$$I_z = \frac{I_b}{C_a \times C_g \times C_i} \tag{10.2}$$

where C_a = correction factor for ambient temperature
C_d = correction factor for the type of overcurrent protective device
($C_d = 1$ for MCBs to BS 3871 or BS EN 60 898 and for fuses to BS 88 Parts 2 and 6 and BS 1361 Part 2. $C_d = 0.725$ for semi-enclosed (rewirable) fuses)
C_g = correction factor for grouping of conductors
C_i = correction factor for conductors embedded in insulating material.

If any of the correction factors is less than unity, I_z will be increased accordingly as can be seen in Equations (10.1) and (10.2). By way of example, is a circuit requiring overload protection protection against overload by a 10 A protective device ($I_n = 20$ A). The device correction factor, C_d, is 0.725 (rewirable fuse), the temperature correction factor, $C_a, = 0.87$ (cable run through room of ambient temperature of 45°C – see Table 4C2 of Appendix 4 of BS 7671, $C_g = 0.70$ (circuit grouped with two other circuits – see Table 4B1 of Appendix 4 of BS 7671) and $C_i = 0.89$ (cable runs through inter-floor space with insulation – see Table 52A of BS 7671). For the purpose of this example the grouping, insulation and ambient temperature conditions occur together; if they occurred at different parts of the circuit, the worst case correction factor would be taken to calculate I_z. The calculation is as given in Equation (10.3).

$$I_z = \frac{I_n}{C_a \times C_d \times C_g \times C_i} \tag{10.3}$$

$$= \frac{20}{0.87 \times 0.725 \times 0.70 \times 0.89} = 50.9 \text{ A}$$

Establishing the normal steady state current, I_b, of a connected load of known power, P (in watts) and power factor (cosine ϕ) operating at a nominal phase voltage to earth, U_o, is, for a single-phase load, given in Equation (10.4) and that for a three-phase load is as set out in Equations (10.5) and (10.6) for star and delta connected loads respectively.

$$I_b = \frac{P}{U_o \times \cos\phi} (\text{A}) \tag{10.4}$$

$$I_b = \frac{P}{3 \times U_o \times \cos\phi} (\text{A}) \tag{10.5}$$

$$I_\mathrm{b} = \frac{P}{\sqrt{3} \times U_\mathrm{n} \times \cos\phi} (\mathrm{A}) \tag{10.6}$$

Power factor can be determined from the relationship given in Equation (10.7) where S is the apparent power (VA):

$$\text{power factor} = \cos\phi = \frac{P}{S} \tag{10.7}$$

To apply the above formula it is necessary to know both the power rating (in terms of watts) and the apparent power, S, (in VA) and these are usually readily available from the current-using equipment manufacturer as is a rating for the power factor for most equipment.

In the case of discharge lighting, the assessment of the design current, I_b, is not a straightforward matter in that an allowance has to be made for control gear losses and low-order harmonics. In the absence of detailed information, a first order approximation of I_b is given in Equation (10.8). This assumes a corrected power factor of not less than 0.85 lagging (phase angle $\phi \leqslant -31.8^\circ$). Where luminaires are not power factor corrected they will typically have a power factor of between 0.5 leading and 0.3 lagging (ϕ between $+60^\circ$ and 72.5°) and this equation may not be valid.

$$I_\mathrm{b} = \frac{1.8 \times P}{U_\mathrm{n}} \tag{10.8}$$

where P = sum of the lamp rated wattage (W)
U_n = nominal voltage of circuit (V).

The next step is to determine the ambient temperature and hence the ambient temperature correction factor, C_a. This may be assessed by a suitable thermometer in the case where the building is already operational but, where the building is itself in the design stage, consultation with other professionals involved in the design process will be inevitable. Where the ambient temperature(s) have been assessed, the correction factor is obtained from Tables 4C1 and 4C2 of Appendix 4 of BS 7671 as appropriate. Where values are not given in these tables, special further consideration is required to establish an appropriate correction factor (e.g. where cables are affected by solar radiation or other heat sources – see item 10.2.10 of this Chapter). Figure 10.13 shows the typical relationship between temperature correction factor (and hence current-carrying capacity) and the ambient temperature.

Reference to Tables 4B1, 4B2 and 4B3 of Appendix 4 of BS 7671 will be necessary to obtain the grouping factor, C_g, for the particular wiring system selected and the installation method(s) to be employed.

Regulation 523–04–01 calls for cables preferably to be run in such a way as to avoid thermal insulating materials. Where this is not practicable, this regulation requires that the current-carrying capacity of the cable be reduced according to the length through which it passes through the insu-

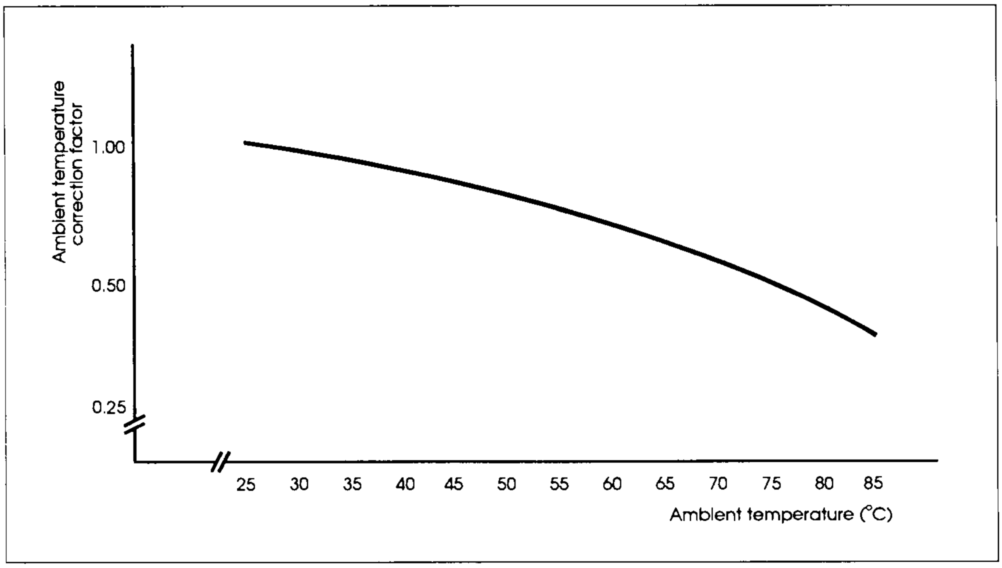


Figure 10.13: Typical temperature correction curve

lation. Where cables are installed in a wall or above a ceiling which is thermally insulated and one side of the cable touches a thermally conductive material on one side, installation method 4 is appropriate and the current-carrying capacities given in the relevant table of Appendix 4 of BS 7671 need no further correction in this respect. Where a cable (up to 10 mm^2) is totally surrounded by insulating material (e.g. in a cavity wall insulated with vermiculite granules or the like having a thermal conductivity of the order of 0.0625 W/K m) the appropriate factor given in Table 52A of BS 7671 should be used if the length of the affected cable is up to 400 mm. Where this length is 500 mm or more, the correction factor may be taken as 0.50 unless better, more precise, information is to hand. For cables greater than 10 mm^2 routes through thermal insulation should be avoided unless suitable authoritative advice is available in respect of derating of current-carrying capacities. It should be noted too that where cable penetrations through walls etc. are sealed, for compliance with Regulations 527–02–01 to 527–02–03, with material that is thermally insulating, the current-carrying capacities of the cables should be reduced accordingly. Figure 10.14 gives a pictorial representation of the derating factor, C_i, to be applied.

Table 10.14 gives data in terms of current-carrying capacities using installation reference method 1 and those when the derating factors are applied for two-core and cpc copper cables to Bs 6004.

The correction factor for the overcurrent protective device, C_d, is unity unless the device is a semi-enclosed fuse to BS 3036 (rewirable fuse) when a factor of 0.725 must be used.

Excepting ring final circuits, where a circuit comprises two or more cables in parallel, the routes of the cables must be identical as must the cable

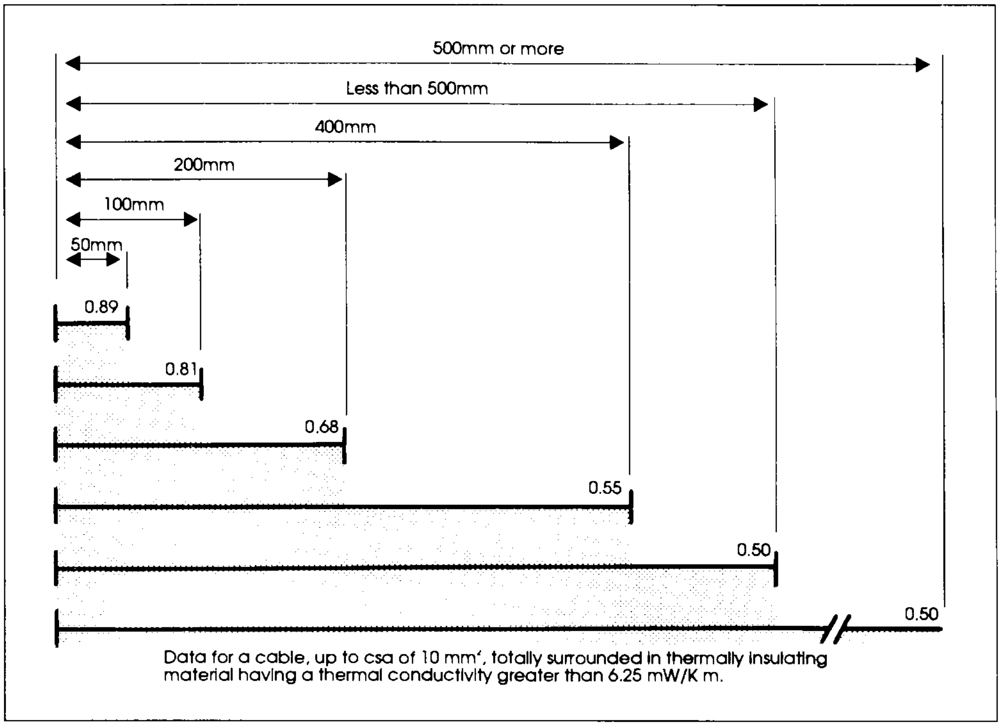


Figure 10.14: Derating of a cable when installed in thermally insulating material

construction, csa, disposition and length (as called for in Regulation 523–02–01) so that load current may be shared equally in conductors. Such cases need very careful consideration with regard to fault current (wherever the fault may occur) and its effect on each conductor to confirm that automatic disconnection will occur, for protection against overcurrent and indirect contact where appropriate (see also item 7.7 of this Guide).

Table 10.14: Current-carrying capacities of two-core and cpc copper cables to BS 6004

Ref	**csa (mm^2)**		**Length cables run through thermal insulation**				
			50 mm	**100 mm**	**200 mm**	**400 mm**	**500 mm**
		Derating factor	**0.89**	**0.81**	**0.68**	**0.55**	**0.50**
			Current-carrying capacities (A)				
		Reference method 1					
A	1.0	15.00	13.35	12.15	10.20	8.25	7.50
B	1.5	19.50	17.35	15.79	13.26	10.72	9.75
C	2.5	27.00	24.03	21.87	18.36	14.86	13.50
D	4.0	36.00	32.04	29.16	24.48	19.80	18.00
E	6.0	46.00	40.94	37.26	31.28	25.30	23.00
F	10.0	63.00	56.07	51.03	42.84	34.65	31.50
G	16.0	85.00	75.65	68.85	57.80	46.75	42.50

As Regulation 523–01–01 points out, where cable connections are made directly to bare conductors or bare busbars, the designer needs to establish that the cable insulation is not adversely affected by the operating temperature of the busbars. This may be considerably higher than the temperature the conductor insulation can tolerate without damage. Where the cable insulation will not cope with this temperature, the insulation should be stripped back where safe to do so, or replaced by site-applied insulation of suitable temperature rating.

Regulation 521–07–03 calls for cables of different temperature rating run in the same enclosure to be assessed at the lower or lowest of the temperature ratings. For example, if two cables run in a conduit, one having a rating of 70°C and the other 90°C, then they should be assessed as both having a maximum normal operating temperature of 70°C as far as current-carrying capacity is concerned.

The maximum conductor operating temperatures are given in Table 52B (Regulation 523–01–01) of BS 7671 and are reproduced in somewhat different format in Table 10.15. It is important to note that it is the insulating material, not the conductor, which determines both the conductor operating temperature and the final fault temperature limit.

Table 10.15: Maximum conductor operating temperatures

Ref	**Conductor and insulation materials**	**Cross-sectional area (mm^2)**	**Conductor operating temp. limit (°C)**	**Limiting final operating temp. (°C)**	**BS 7671 Appendix 4 Table**	
A	Copper with 70°C PVC (general purpose).	<300	70	160	4D1, 4D2, 4D3 and 4D4	**COPPER**
B	Copper with 70°C PVC (general purpose).	≥ 300	70	140		
C	Copper with 85°C PVC.	All	85	160	—	
D	Copper with 90°C thermosetting.	All	90	250	4E1, 4E2, 4E3 and 4E4	
E	Copper with 60°C rubber.	All	60	200	2H1	
F	Copper with 85°C rubber.	All	85	220	4F1 and 4F2	
G	Copper with impregnated paper.	All	80	160	—	
H	Aluminium with 70°C PVC (general purpose).	<300	70	160	4K1, 4K2 4K3 and 4K4	**ALUMINIUM**
I	Aluminium with 70°C PVC (general purpose).	≥ 300	70	140		
J	Aluminium with 90°C thermosetting.	All	90	250	4L1, 4L2 4L3 and 4L4	
K	Aluminium with 60°C rubber.	All	60	200	—	
L	Aluminium with 85°C rubber.	All	85	220	—	
M	Aluminium with impregnated paper.	All	80	160	—	
N	Copper conductors and sheathed mineral insulated. Exposed to touch (bare and plastic covered).	All	70	160	4J1	**MICC**
O	Copper conductors and sheathed mineral insulated. Bare but not exposed to touch nor in contact with combustible materials.	All	105	250	4J2	

Regulation 524–01–01 lays down the rules for the minimum cross-sectional areas of *phase* conductors of a.c. circuits and live conductors of d.c. circuits. Table 52C of BS 7671 stipulates the minimum cross-sectional areas in terms of insulated conductors and cables, bare conductors and flexible connections with insulated conductors and cables. For copper conductors either insulated or within cables, a minimum of 1 mm^2 csa is required for power and lighting circuits. For the same use, an aluminium conductor would need to be 16 mm^2 which rules it out for most practical applications. Where bare conductors are used for power circuits, a minimum of 10 mm^2 is required for copper and 16 mm^2 for aluminium. Where aluminium conductors are used, the terminating connectors must be tested and approved for their specific use.

Signalling and control circuits are subject to a minimum csa of 0.5 mm^2 for copper cables and insulated conductors and to 4 mm^2 if the conductors are bare, except that if the circuit is for signalling control for electronic equipment and if a multicore flexible cable of seven or more cores is used then the minimum csa is 0.1 mm^2. The requirements relate more to mechanical strength than to current-carrying capacity.

Flexible final connections to specific appliances must be copper of minimum csa as specified in the appropriate Standard. For other appliances the minimum csa is 0.5 mm^2 copper. The minimum sizes needed to meet the requirements of Section 524 will of course be overridden where consideration of the current-carrying capacity of the conductor demands a larger csa.

Regulations 524–02–01 to 524–02–03 lay down the requirements for the minimum csa of neutral conductors and call for the neutral conductor in a circuit feeding discharge lighting to have a csa of not less than that of the associated phase conductor(s). Except for discharge lighting circuits, a reduced csa for the neutral is permitted, by Regulation 524–02–02, in a polyphase circuit (e.g. three-phase), provided the circuit is not significantly imbalanced. Imbalance may be due, for example, to phases with loads of different power factor and harmonics. Where a reduced csa is considered, the normal neutral current should of course be taken into account and the conductor sized accordingly. Regulation 524–02–02 allows multicore cables incorporating a reduced csa neutral to be used where there are unlikely to be serious imbalances. Such cables must have phase and neutral conductor cross-sectional areas in accordance with the appropriate Standard. Serious imbalances can be expected where low-order harmonics are generated by, for example, information technology switch-mode power supplies. These supplies typically employ rectifiers with the d.c. output connected to capacitors which then operate a switch-mode regulator. In three-phase circuits supplying such equipment the low-order harmonic currents generated can produce a neutral current exceeding those in the associated phase conductors. It is known that a neutral current up to 1.73 times ($\sqrt{3}$) of that of the phase conductors can exist. When contemplating the installation of such equipment, it is advisable to obtain from the manufacturers the necessary information relating to load current in terms of rms (root-mean-square) and its harmonic components. It is important to recognise that third-order harmonics add arithmetically in the neutral conductor (in three-phase circuits).

Some motors, other inductive loads and electronic equipment are prone to large inrush currents and this should be taken into account when considering current-carrying capacities. Particular care is required evaluating an intermittent load subject to frequent starting and stopping and where there may be substantial cumulative effects of these currents. The designer would be well advised to consult the manufacturer of such equipment and obtain a load profile and other characteristics.

10.4.3 Voltage drop

The requirements concerning voltage drop, set out in Regulations 525–01–01 and 525–01–02, relate only to the safety issues of electrical equipment performance. They do not address the other operational requirements which may include, for example, efficiency. It may be that compliance with BS 7671 in this respect is not the only consideration in assessing voltage drop; some equipment may operate at less than its optimum efficiency at voltages permitted by BS 7671. For example, some forms of lighting sources may have considerably reduced lifespan and/or efficiency at voltages other than those prescribed by the manufacturer. In some cases, the operational considerations may place more stringent limits on voltage drop than the specified requirements. Some cases have been reported where a reduction of 5% of nominal voltage reduces the efficiency of particular lamps by as much as 20%. When one considers that a supplier is permitted a tolerance of +6%/–10% of the nominal declared voltage, it can be seen that the designer may find difficulty in providing supplies to such circuits if optimum efficiency is to be achieved.

From the safety standpoint, the basic requirement, embodied in Regulation 525–01–01, is that the voltage supplied to the current-using equipment provides for safe operation. This may be ascertained by reference to the relevant Standard where that Standard has addressed the safe functioning requirements (e.g. BS 3456, BS 5784). Regulation 525–01–02 provides a 'deemed to comply' status provided the voltage drop from the origin of the installation (supply point) to the terminals of all the current-using equipment or to socket-outlets is not greater than 4% of the nominal voltage. This applies where the supply is derived from a service complying with the Electricity Supply Regulations. At this limit the voltage at the current-using equipment may be 90% of the nominal voltage (e.g. 230 V – (6 + 4)% = 207 V).

A greater voltage drop than prescribed may be permitted in the case of motors under starting conditions and other current-using equipment having high inrush current. However the designer will need to confirm that such voltage drops as may occur will not impair the *safe functioning* of the equipment and that the delivered voltages are within the limits set out in the appropriate Standard and/or the manufacturer's recommendations.

The 4% 'deemed to comply' limit of voltage drop from the origin to the current-using equipment may at first sight appear to be a relaxation of the previous 'deemed to comply' limit of $2\frac{1}{2}$% on final circuits. This may well be the case in some installations with, say, one or two distribution boards. However, on the larger installation with distribution circuits (sub-mains and sub-sub-mains), the requirements may well turn out to be more onerous.

Table 10.16 gives the values of 4% voltage drop relating to some of the more common nominal voltages and the lower limit of voltage at the terminals of the current-using equipment at this voltage drop.

Table 10.16: Limiting values of voltage drop (at 4%) for some common nominal voltages

Ref	Nominal Voltage, U_n(1) (Volts)	4% of U_n(2) (Volts)	U_n – 4% of U_n(3) (Volts)	6% of U_n(4) (Volts)	10% of U_4(4) (Volts)	Voltage range at terminals –10% to +10% of nominal voltage(5)
A	12	0.48	11.52	0.72	1.20	10.80 to 13.20
B	24	0.96	23.04	1.44	2.40	21.60 to 26.40
C	50	2.00	48.00	3.00	5.00	45.00 to 55.00
D	55	2.20	52.80	3.30	5.50	49.50 to 60.50
E	110	4.40	105.60	6.60	11.00	99.00 to 121.00
F	230	9.20	220.80	13.80	23.00	207.00 to 253.00
G	400	16.00	384.00	24.00	40.00	360.00 to 444.00

Notes:
(1) The nominal voltage,U_n, is the declared voltage of the supply.
(2) The 4% voltage drop between the origin and the current-using equipment is the 'deemed to comply' value permitted by Regulation 525–01–02.
(3) This value is the nominal voltage, U_n, less the 4% voltage drop.
(4) This value is 10% of the nominal voltage, U_n, (+10% permitted on supplies given in accordance with the Electricity Supply Regulations 1988, as amended).
(5) This range represents the voltage at the terminals of current-using equipment at both extremes (i.e. U_n less 4+6% to U_n plus 10%).

Although the actual voltage of the supply at the origin may not vary much from its nominal value, the designer should consider this as a bonus and not rely on it staying at a particular value. The public supply network must be regarded as dynamic, continually under change and development. Because of this the supply may be connected to different points on the network during the lifetime of the installation. The supply voltages may change from time to time though the nominal voltage remains the same. The designer should assume the philosophy of '*plan for the worst and hope for the best*'. For the purpose of calculating the voltage at the terminals of the current-using equipment, the voltage at the origin should be taken as the nominal voltage less 6% in the case of supplies derived from the public network.

The tabulated figures of voltage drop given in Appendix 4 of BS 7671 relate to the voltage dropped per metre per ampere of load current and assume that the conductors are at their maximum permitted operating temperature, t_p. They apply only to frequencies in the range 49 to 61 Hz. Where higher frequencies are involved, the values of voltage drop are increased and allowance should be made in this respect. For cables of csa of 16 mm^2 or less, the inductive reactance component of impedance may be ignored. For cables of greater csa than 16 mm^2, this component becomes more significant and cannot be neglected. Where values are tabulated for single-core armoured cables the tables in BS 7671 assume that the armour is bonded to Earth at *both* ends of the run. Where this is not the case, further consideration in this respect is required.

The method of assessing voltage drop where conductors are at their maximum permitted normal operating temperature, t_p, is given in Equation (10.9).

$$V_\mathrm{d} = \frac{mV\ per\ metre\ (\text{tabulated}) \times I_\mathrm{b}\ (A) \times length\ (\mathrm{m})}{1000}(\mathrm{V}) \qquad (10.9)$$

Values given in Appendix 4 of BS 7671 for three-phase circuits assume balanced conditions and refer to line voltage. Where values are given for cables of csa greater than 16 mm^2 they are presented in terms of their resistive component $(\mathrm{mV/A/m})_\mathrm{r}$ and their reactive component $(\mathrm{mV/A/m})_\mathrm{x}$. The voltage drop per metre is therefore as given in Equation (10.10).

$$V_\mathrm{d}\ per\ metre = I_\mathrm{b}\ \sqrt{}(V^2_{\mathrm{d(r)}} + V^2_{\mathrm{d(x)}})\ (\mathrm{V}) \qquad (10.10)$$

where I_b = design current (A)
$V_{\mathrm{d(r)}}$ = resistive component of voltage drop per metre (V)
$V_{\mathrm{d(x)}}$ = reactive component of voltage drop per metre (V)

When using the tables giving the voltage drop values without further consideration of the actual cable operating temperature and using only the assumed maximum permitted operating temperature, t_p, the resulting calculated voltage drops may be pessimistically high. Cables will operate at less than their maximum permitted normal operating temperature, where the actual load current is less than the current-carrying capacity of the cable, as so often is the case. Equation (10.11) may be used where the protective device is other than a BS 3036 semi enclosed (rewirable) fuse, to establish the correction factor for the operating temperature of the conductor, C_t. Hence a more accurate assessment of voltage drop may be made. It can be used only where the ambient temperature is not less than 30°C.

$$C_\mathrm{t} = \frac{(230 + t_\mathrm{p}) - [(t_\mathrm{p} - 30)(C^2_\mathrm{a} + C^2_\mathrm{g} - I^2_\mathrm{b}/I^2_\mathrm{t}]}{(230 + t_\mathrm{p})} \qquad (10.11)$$

where C_t = correction factor for the operating temperature of the conductor
t_p = maximum permitted operating temperature (°C)
C_a = correction factor for ambient temperature
C_g = correction factor for grouping
I_b = design current (A)
I_t = current tabulated in Appendix 4 of BS 7671 for single circuits for a particular installation method in an ambient temperature of 30°C (A).

Having established a value for C_t this is then applied as a multiplying factor only to the tabulated resistive components of the tabulated voltage drops, $(mV/A/m)_r$, because the reactive component is unaffected by temperature. For the larger conductor where the ratio of reactance to resistance is more than 3:1, this correction factor, C_t, is not worth considering for all practical purposes. Where there is no correction required for both ambient temperature and grouping, Equation (10.11) is simplified to that given in Equation (10.12) for PVC insulated cables (with a maximum permitted operating temperature of 70°C) and to that given in Equation (10.13) for 90°C cables.

$$C_t = \frac{13}{15} + \frac{2}{15}\left(\frac{I_b}{I_t}\right)^2 \qquad (10.12)$$

$$C_t = \frac{13}{16} + \frac{3}{16}\left(\frac{I_b}{I_t}\right)^2 \qquad (10.13)$$

A further correction is possible for power factor in that multiplying the tabulated $(mV/A/m)_r$ by cos ϕ (power factor) and the tabulated $(mV/A/m)_x$ by sin ϕ gives a more accurate voltage drop figure.

10.4.4 Grouping

The question of correction factors for grouping is one which has vexed the industry for more than a decade. The basic theory underlying the derating of current-carrying capacities of grouped cables is that the dissipation of heat generated in the cable when current flows (I^2R losses) is inhibited or retarded when other cables are in close proximity and possibly generating heat themselves.

Correction factors (C_g) for groups of circuits of single-core cables and one or more multicore cables are given in Table 4B1 of Appendix 4 of BS 7671. All factors are less than unity and are to be applied to the tabulated current-carrying capacity of single circuit cables given in the following tables of Appendix 4 (Tables 4D1 to 4D4, 4E1 to 4E4, 4F1 and 4F2, 4J1, 4K1 to 4K4 and 4L1 to 4L4). Where appropriate, different values are given depending on whether the cables are touching or spaced apart by one cable diameter. Table 4B2 of Appendix 4 gives similar data for MICC cables and correction factors here again depend on whether the cables are touching, spaced (by 1 or 2 cable diameters) or separated in trefoil.

The Appendix 4 tables assume that the cables so grouped are all the same size which is seldom the case in practice. Where circuits are known to carry up to only 30% of their corrected current-carrying capacity (i.e. $0.3CgI_t$), they may be overlooked when assessing the correction factor for the remainder of the grouped circuits. For example, if a circuit cable had an 'un-grouped' current-carrying capacity (I_t) of, say, 10 A and the appropriate grouping correction factor (C_g) was 0.60 and consequently the effective current-carrying capacity was 6 A, and the actual load current was known not to exceed 1.8 A, this circuit could be ignored from the point of view of contributing to the number of grouped circuits. This example may apply, for instance, where the csa of conductors of a long run has been determined from voltage drop considerations rather than current-carrying capacity.

Cables with different conductor operating temperatures must be assessed on the basis of the lower or lowest temperature as required by Regulation 521–07–03.

Correction factors need not be considered where cables are separated horizontally by twice the cable diameter. For convenience, Table 10.17 gives the correction factors for grouping (C_g) of circuits (not conductors). Row A gives values for PVC/PVC insulated and sheathed cables clipped direct to a non-metallic surface (installation method 1). Row B gives those relating to similar cables clipped direct in single layer formation. Row C provides figures for non-sheathed single-core cables in conduit and Row D gives data for similar cables in trunking. These values are from Table 4B1 of Appendix 4 of BS 7671. Where no data are provided it has to be assumed that such grouping factors have not been evaluated. In any event, grouping circuits in large numbers can often prove to be uneconomic because of the high degree of derating, and the designer would, in these circumstances, wish to avoid the problem by increasing the number of separate runs of circuits.

10.4.5 Cables in enclosed trenches

The current-carrying capacities of cables installed vertically and/or horizontally on cleats, brackets or ladders (as for reference methods 12 and 13) in enclosed trenches (as reference method 18, 19 or 20) must be corrected in accordance with Table 4B3 of Appendix 4 of BS 7671. The factors given in that table relate to the number of conductors and to their cross-sectional area. Again, cables with different conductor operating temperatures must be assessed on the basis of the lower or lowest temperature as required by Regulation 521–07–03.

10.5 Resistances of copper conductors

Table 10.18 gives the resistance values of copper conductors at 20°C and the values ($R_1 + R_2$) with and without the multiplying factors relevant to the type of insulation (making allowance for the higher temperature of the conductor under fault conditions). These data have been developed from the IEE Guidance Note *Selection and erection* which also gives values of resistance for aluminium conductors.

10.6 Electrical connections

Section 526 of BS 7671 deals with electrical connections between conductors and equipment and with their accessibility. Electrical connections

Table 10.17: Correction factors (C_g) for grouping for PVC/PVC cables and PVC insulated cables enclosed in conduit and trunking

Ref	Wiring system	Installation method and spacing		Number of circuits(3)													
		Method(1)	T or S(2)	2	3	4	5	6	7	8	9	10	12	14	16	18	20
A	PVC/PVC cables bunched and clipped direct to non-metallic surface.	1	—	0.80	0.70	0.65	0.60	0.57	0.54	0.52	0.50	0.48	0.45	0.43	0.41	0.39	0.38
B	PVC/PVC cables clipped direct to non-metallic surface-single layer.	1	T	0.85	0.79	0.75	0.73	0.72	0.72	0.71	0.70	—	—	—	—	—	—
			S	0.94	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
C	PVC cables in metallic and non-metallic conduit.	3 and 4	—	0.80	0.70	0.65	0.60	0.57	0.54	0.52	0.50	0.48	0.45	0.43	0.41	0.39	0.38
D	PVC cables in metallic and non-metallic trunking.	3 and 4	—	0.80	0.70	0.65	0.60	0.57	0.54	0.52	0.50	0.48	0.45	0.43	0.41	0.39	0.38

Notes: (1) Installation method of BS 7671 Appendix 4.
(2) T means cables touching, S means cables spaced by at least one cable diameter.
(3) Number of circuits or multicore cables.

Table 10.18: Resistances of copper conductors

Ref	**Conductor resistances at 20°C**					**70°C PVC**		**85°C rubber**		**90°C thermosetting**	
						cpc as core of cable (Table 54C)	**cpc *not as* core of cable (Table 54B)**	**cpc as core of cable (Table 54C)**	**cpc *not as* core of cable (Table 54B)**	**cpc as core of cable (Table 54C)**	**cpc *not as* core of cable (Table 54B)**
	Phase conductor		**cpc**		$R_1 + R_2$	**1.38 times** $(R_1 + R_2)$	**1.30 times** $(R_1 + R_2)$	**1.53 times** $(R_1 + R_2)$	**1.42 times** $(R_1 + R_2)$	**1.60 times** $(R_1 + R_2)$	**1.48 times** $(R_1 + R_2)$
	mm²	**mΩ/m**	**mm²**	**mΩ/m**	**mΩ/m**	**mΩ/m**	**mΩ/m**	**mΩ/m**	**mΩ/m**	**mΩ/m**	**mΩ/m**
A	1.0	18.100	1.0	18.100	36.200	49.956	47.060	55.386	51.404	57.920	53.576
B	1.5	12.100	1.0	18.100	30.200	41.676	39.260	46.206	42.884	48.320	44.696
C	1.5	12.100	1.5	12.100	24.200	33.396	31.460	37.026	34.364	38.720	35.816
D	2.5	7.410	1.0	18.100	25.510	35.204	33.163	39.030	36.224	40.816	37.755
E	2.5	7.410	1.5	12.100	19.510	26.924	25.363	29.850	27.704	31.216	28.875
F	2.5	7.410	2.5	7.410	14.820	20.452	19.266	22.675	21.044	23.712	21.934
G	4.0	4.610	1.5	12.100	16.710	23.060	21.723	25.566	23.728	26.736	24.731
H	4.0	4.610	2.5	7.410	12.020	16.588	15.626	18.391	17.068	19.232	17.790
I	4.0	4.610	4.0	4.610	9.220	12.724	11.986	14.107	13.092	14.752	13.646
J	6.0	3.080	2.5	7.410	10.490	14.476	13.637	16.050	14.896	16.784	15.525
K	6.0	3.080	4.0	4.610	7.690	10.612	9.997	11.766	10.920	12.304	11.381
L	6.0	3.080	6.0	3.080	6.160	8.501	8.008	9.425	8.747	9.856	9.117
M	10.0	1.830	4.0	4.610	6.440	8.887	8.372	9.853	9.145	10.304	9.531
N	10.0	1.830	6.0	3.080	4.910	6.776	6.383	7.512	6.972	7.856	7.267
O	10.0	1.830	10.0	1.830	3.660	5.051	4.758	5.600	5.197	5.856	5.417
P	16.0	1.150	6.0	3.080	4.230	5.837	5.499	6.472	6.007	6.768	6.260
Q	16.0	1.150	10.0	1.830	2.980	4.112	3.874	4.560	4.232	4.768	4.410
R	16.0	1.150	16.0	1.150	2.300	3.174	2.990	3.519	3.266	3.680	3.404
S	25.0	0.727	10.0	1.830	2.557	3.528	3.324	3.912	3.631	4.091	3.784
T	25.0	0.727	16.0	1.150	1.877	2.590	2.440	2.872	2.665	3.003	2.778
U	25.0	0.727	25.0	0.727	1.454	2.007	1.890	2.225	2.065	2.326	2.152
V	35.0	0.524	16.0	1.150	1.674	2.310	2.176	2.561	2.377	2.678	2.478
W	35.0	0.524	25.0	0.727	1.251	1.726	1.626	1.914	1.776	2.002	1.851
X	35.0	0.524	35.0	0.524	1.048	1.446	1.362	1.603	1.488	1.677	1.551

Note: The appropriate temperature corrected values of (R_1 and R_2) should always be used in design calculations.

wherever they occur must be selected and installed so that they perform their function throughout the lifetime of the installation. Account should be taken of the environment in which the connections are located. Particular care is needed to avoid corrosion by external influences and by electrolytic action of dissimilar metals in close contact, especially in damp conditions. It goes without saying that all connections must provide durable and reliable electrical continuity and be sufficiently mechanically robust to cope with all the likely external influences (e.g. vibration). Good workmanship is always an essential part of effecting sound connections. Floating connectors in enclosures are best avoided and the use of fixed connector blocks provides for a much tidier, well-ordered job and stands a better chance of being maintained properly in the future. Connections which are not properly made are the cause initially of high resistance joints leading, through continual expansion and contraction due to varying load conditions, to loose joints and eventually to the risk of fire. Great care is needed in selecting connections where they interface with conductors of the higher normal operating temperature (e.g. 90°C and 105°C), which are in increased usage nowadays. Connections should be selected so that they are able to cope with these higher temperatures without any adverse effects either on the connection or the conductor insulation.

Where enclosures and boxes are used for making connections, they should be selected so as to afford ample space for the connections and the conductors, and the designer should not forget the practical difficulties of terminating the larger conductors, especially solid aluminium cores. At terminations of MICC, the correct sleeving and other-sleeving should always be used to match the temperature rating of the seal.

Termination glands for rubber and plastic insulated cables must comply with BS 6121. Where the armouring forms part or all of the circuit protective conductor it is inadvisable to rely on detachable plates of equipment as a permanent and reliable path for earth fault current. Detachable plates are often covered with ‘non-conductive’ finishes and are usually secured by a few very small screws which are unlikely to sustain earth fault current adequately. In such circumstances, it should be considered essential to make the protective conductor connection via a gland tag, nut, bolt and washers with a crimped protective conductor connecting the tag to the earthing terminal in the equipment repeating the procedure for the outgoing cable (see Figure 10.15).

Regulations 526–01–01, 526–02–01, 526–03–01 to 526–03–03 and 526–04–01 set out the requirements for such connections and their accessibility and these are summarised in Table 10.19.

10.7 Cable supports and cable management systems

10.7.1 General

The regulatory requirements for cable supports are embodied in Section 522 of BS 7671 and in particular Regulation 522–08–05 which calls for supports to cables so that there is no undue mechanical strain on con-

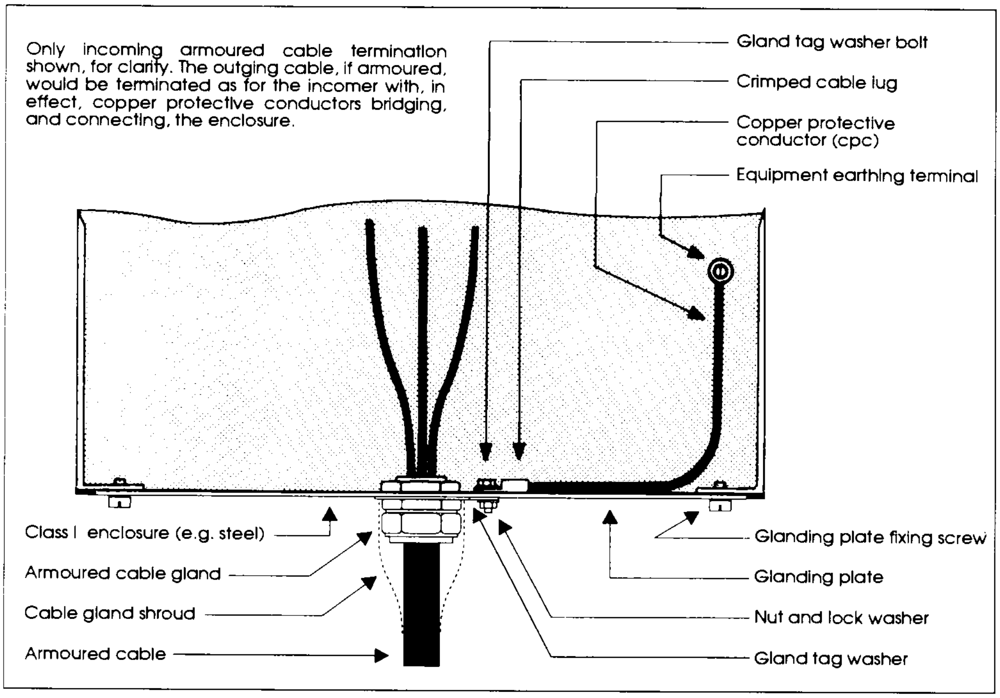


Figure 10.15: Termination of armoured cables

ductors including those at termination points. The spacings of such supports will be a matter of judgement and will depend on the location and whether cables will eventually be seen or hidden (e.g. in an intermediate floor space).

BS 7671 really only considers the safety aspects of support systems and very often additional supports will be needed to make the finished installation look aesthetically pleasing. Where installations are subjected to vibration at medium or high severity and/or higher risk of mechanical impact, additional supports and mechanical protection will be needed, as necessary. With all the many cable management systems available on the market there is now no excuse for untidy or unsafe cable installations.

10.7.2 Maximum cable support spacings

Table 10.20 gives suggested maximum distances between supports for accessible and inaccessible cables for general application for both vertical and horizontal runs (dimensions are given in both metric and imperial for those still reluctantly 'going metric inch-by-inch'); these distances will need modification for special installations and circumstances.

Table 10.19: Electrical connections and their accessibility

Ref	Regulation	Requirement	Comment
A	526-01-01	Durable electrical continuity.	
B	526-01-01	Adequate mechanical strength and connection locking arrangements, where necessary.	Adequate mechanical strength against, for example, impact and vibration. Use of locking nuts on threaded connectors may be necessary where subject to vibration and/or thermal cycling.
C	526-02-01	Suitable for the conductor material.	Avoid metals where there is likely to be electrolytic action.
D	526-02-01	Suitable for the conductor insulating material.	Consider the temperatures of the connection under all conditions and that of the insulating material.
E	526-02-01	Suitable for the conductor csa and shape and the number of conductor strands.	Care must be exercised with connections of multi-strand and shaped conductors.
F	526-02-01	Suitable for the number of conductors to be connected together.	Connector must be capable of accepting all conductors without modification of the conductors (no cutting out strands).
G	526-02-01	If soldered connections are used they must be capable of withstanding the temperature attained under normal and fault conditions.	Assess the temperature reached under the conditions stated and select suitable jointing material.
H	526-02-01	If soldered connections are used they must be selected taking account of creep, mechanical stresses and temperature rise in service.	
I	526-03-01	Connections in enclosures must have adequate mechanical protection against all the likely external influences.	External influences include water, temperature, dust, corrosive substances, impact, vibration, flora and fauna, and solar radiation.
J	526-03-02	Connections of live and PEN conductors must be in enclosures consisting of one or more of the following: ☐ accessories complying with the appropriate Standard, ☐ equipment enclosure complying with the appropriate Standard, ☐ enclosure material complying with the fire-glow test of BS 6458, Section 2.1, ☐ an enclosure formed partly by building material which when tested to BS 476, Part 4 can be considered to be non-combustible, ☐ an enclosure formed partly by building structure which has the ignitibility characteristic 'P' of BS 476, Part 5.	Enclosures to BS 4662 and BS 5733 are also suitable for this purpose.
K	526-03-03	Sheathed cables from which the sheath has been removed and unsheathed cables where they emerge from conduit, trunking and ducting, must be terminated in one of the above enclosures (Ref J).	Cores of sheathed cables which have a portion of their sheath removed for termination must be contained in the enclosure, i.e. sheath must go right into enclosure and leave no core exposed.

Continued on facing page

Table 10.19 continued: Electrical connections and their accessibility

Ref	Regulation	Requirement	Comment
L	526-04-01	Except as stated below (Ref M), all connections and joints must be accessible for maintenance, inspection and testing.	
M	526-04-01	Connections and joints which need not be accessible are: ☐ encapsulated joints; ☐ compound filled joints; ☐ cold tail connection of a heating system (e.g. pipe-tracing elements, ceiling and floor embedded elements); ☐ welded joint; ☐ soldered joint; ☐ brazed joint; ☐ mechanical joint by compression tool.	Compression joints to be certified as complying with BS 4579 and the manufacturer's instructions to be adhered to particularly in the use of suitable tools and methods.

10.7.3 Overhead cables between buildings

Table 10.21 gives suggested minimum heights and maximum spans for overhead cables linking buildings on a site. They should only be applied to the general case and not to special cases, including agricultural and horticultural locations, yacht marinas and the like. These will need individual consideration and the cables may need to be much higher above the ground. The amount of sag depends on the cable weight and the tension to which it is subjected and, of course, the distance between supports. The point at which the maximum sag occurs will be at the centre of the run if the suspension points are at the same height but will be off centre towards the lower suspension point if the heights are different.

10.7.4 Supports for conduits

Supports for conduit come in a number of different types and are suitable for different environments. Table 10.22 gives suggested maximum spacing for fixing of conduit but in many circumstances further supports will be necessary to enhance the appearance, especially on surface installations. Figure 10.16 gives some examples of the types of conduit support systems available.

10.7.5 Minimum bending radii of cables

For compliance with Regulation 522–08–03, it is important when installing cables that the radius of bends is such as not to cause damage either at installation stage or indeed subsequently. Table 10.23 gives the minimum bending radii for some common types of cables. The radius dimension relates to the internal cable surface and is given in terms of the cable overall diameter.

Table 10.20: Maximum cable support spacings for armoured, non-armoured and MICC cables

Ref	Cable diameter, ϕ_c(1)		Example(3)	Vertical(4)		Horizontal(5)	
	mm	inch(2)		mm	inch(2)	mm	inch(2)
			Non-armoured cables				
A	up to 9	up to 0.35	1 to 10 mm^2 BS 6004 (6181Y) PVC/PVC 1-core. 1 mm^2 BS 6004 6242Y PVC/PVC 2-core/cpc.	400	16	250	10
B	9 to 14	0.39 to 0.55	16 to 35 mm^2 BS 6004 (6181Y) PVC/PVC 1-core. 1.5 to 4 mm^2 BS 6004 (6242Y) PVC/PVC 2-core/cpc. 1 and 1.5 mm^2 BS 6004 (6243Y) PVC/PVC 3-core/cpc.	400	16	300	12
C	15 to 19	0.59 to 0.75	6 to 10 mm^2 BS 6004 (6242Y) PVC/PVC 2-core/cpc. 2.5 and 4 mm^2 BS 6004 (6243Y) PVC/PVC 3-core/cpc.	450	18	350	14
D	20 to 40	0.79 to 1.57	16 mm^2 6242Y PVC/PVC 2-core/cpc. 6 to16 mm^2 BS 6004 (6243Y) PVC/PVC 3-core/cpc.	550	22	400	16
			Armoured cables				
E	9 to 14	0.39 to 0.55	1.5 and 2.5 mm^2 PVC BS 6346 SWA 2-core. 1.55 mm^2 PVC BS 6346 SWA 3-core. 1.5 mm^2 PVC BS 6346 SWA 4-core.	450	18	350	14
F	15 to 19	0.59 to 0.75	4 and 6 mm^2 PVC BS 6346 SWA 2-core. 2.5 and 6 mm^2 PVC BS 6346 SWA 3-core. 2.5 to 4 mm^2 PVC BS 6346 SWA 4-core.	550	22	400	16
G	20 to 40	0.79 to 1.57	10 and 16 mm^2 PVC BS 6346 SWA 2-core. 10 and 16 mm^2 PVC BS 6346 SWA 3-core. 6 to 16 mm^2 PVC BS 6346 SWA 4-core.	600	24	450	18
			Mineral insulated copper sheathed cables				
H	up to 9	up to 0.35	E.g. Light duty 500 V – 4 core 2.5 mm^2 – 4L1 (not served).	800	32	600	24
I	9 to 14	0.39 to 0.55	E.g. Light duty 500 V – 7 core 2.5 mm^2 – 7L2.5 (not served). E.g. Heavy duty 750 V – 2 core 10 mm^2 – 2H10 (not served).	1200	48	900	36
J	15 to 19	0.59 to 0.75	E.g. Heavy duty 750 V – 2 core 25 mm^2 – 2H25 (not served). E.g. Heavy duty 750 V – 4 core 16 mm^2 – 4H16 (not served).	2000	80	1500	60

Notes:
(1) Where the cable is of the flat type, the major axis is taken as the cable diameter. For larger cable diameters, consult the manufacturer.
(2) Dimensions in inches are approximate.
(3) Examples cited, in terms of popular BCMC's references, are not comprehensive and serve only to provide comparison.
(4) Vertical spacings relate to runs up to 30° from the vertical axis.
(5) Horizontal spacings relate to runs up to 60° from the horizontal axis.

Table 10.21: Minimum heights and maximum spans of cables linking buildings

Ref	Type of wiring system	Minimum cable height above ground level(2)						Maximum span(2)	
		Where accessible to vehicle traffic		At vehicle crossing		Where inaccessible to vehicle traffic			
		m	ft(1)	m	ft(1)	m	ft(1)	m	ft(1)
A	Plastics sheathed cables without intermediate support.	5.20	17.10	5.80	19.10	3.50	11.50	3.00	9.80
B	Plastics sheathed cables enclosed in galvanised conduit of diameter not less than 20 mm and not jointed in span.	5.20	17.10	5.80	19.10	3.00	9.90	3.00	9.80
C	Plastics sheathed cables with separate catenary wire.	5.20	17.10	5.80	19.10	3.50	11.50	No limit	
D	Oil resisting, flame retardant (hofr) without intermediate support.	5.20	17.10	5.80	19.10	3.50	11.50	3.00	9.80
E	Oil resisting, flame retardant (hofr) enclosed in galvanised conduit of diameter not less than 20 mm and not jointed in span.	5.20	17.10	5.80	19.10	3.00	9.90	3.00	9.80
F	Oil resisting, flame retardant (hofr) with separate catenary wire.	5.20	17.10	5.80	19.10	3.50	11.50	No limit	
G	Covered or bare overhead lines supported only at the ends of the span.	5.20	17.10	5.80	19.10	3.50	11.50	30.00	98.00
H	Overhead cable with integral catenary wire.	5.20	17.10	5.80	19.10	3.50	11.50	Not exceeding manufacturer's guidance.	
I	Covered or bare overhead lines meeting the requirements of the Electricity Supply Regulations 1988, as amended.	5.20	17.10	5.80	19.10	3.50	11.50	No limit.	

Notes: (1) Dimensions in feet are approximate.
(2) Suspension point heights must be chosen to allow for the inevitable sag between supports.

10.7.6 Maximum cable trunking support spacings

Table 10.24 gives maximum support spacings for cable trunking in terms of trunking csa and material for both vertical and horizontal runs. Additional supports may be required at changes of direction and other bends or indeed where the trunking is likely to be subjected to mechanical impact and vibration. The figures in the table do not apply to supports for busbar and lighting trunking which should be carried out in accordance with the manufacturer's recommendations.

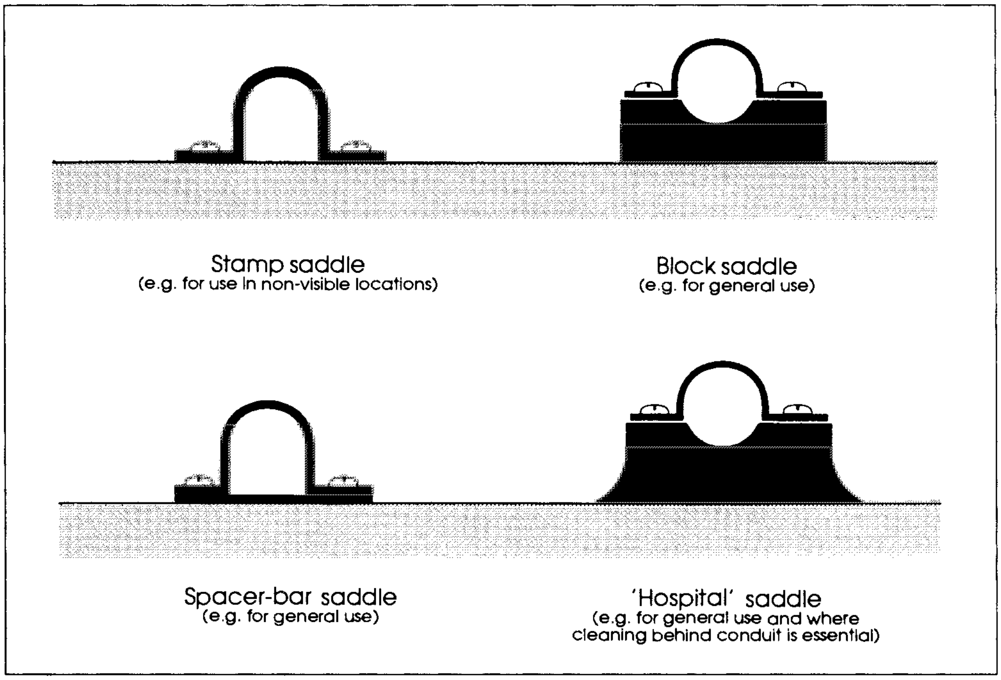
10.7.7 Other cable management systems

There are many other cable management systems available to the designer and consideration should be given to their use for specific applications. Metallic and non-metallic cable trays and ladders lend themselves to industrial installations and underfloor systems, floor and dado trunking are

Table 10.22: Maximum spacing for supports for conduits

Ref	Conduit outside diameter mm	Maximum distance between supports					
		Steel conduit		Rigid non-metallic		Flexible conduit	
		m	ft-in(1)	m	ft-in(1)	m	ft-in(1)
Horizontal runs							
A	16	0.75	2′ 5½″	0.75	2′ 5½″	0.30	0′ 11¾″
B	20	1.75	5′ 9″	1.50	4′ 11″	0.40	1′ 3¾″
C	25	1.75	5′ 9¾″	1.50	4′ 11″	0.40	1′ 3¾″
D	32	2.00	6′ 6¾″	1.75	5′ 9¾″	0.60	1′ 11½″
E	38	2.00	6′ 6¾″	1.75	5′ 9¾″	0.60	1′ 11½″
F	50	2.25	7′ 4½″	2.00	6′ 6¾″	0.80	2′ 7½″
Vertical runs							
G	16	1.00	3′ 3¼″	1.00	3′ 3¼″	0.50	1′ 7½″
H	20	2.00	6′ 6¾″	1.75	5′ 9¾″	0.60	1′ 11½″
I	25	2.00	6′ 6¾″	1.75	5′ 9¾″	0.60	1′ 11½″
J	32	2.25	7′ 4½″	2.00	6′ 6¾″	0.80	2′ 7½″
K	38	2.25	7′ 4½″	2.00	6′ 6¾″	0.80	2′ 7½″
L	50	2.50	8′ 2¼″	2.00	6′ 6¾″	1.00	3′ 3¼″

Note: (1) Imperial dimensions are approximate.



Stamp saddle
(e.g. for use in non-visible locations)

Block saddle
(e.g. for general use)

Spacer-bar saddle
(e.g. for general use)

'Hospital' saddle
(e.g. for general use and where cleaning behind conduit is essential)

Figure 10.16: Typical conduit support systems

Table 10.23: Internal minimum bending radii for common wiring systems

Ref	**Cable type**	**Conductor construction and material**	**Cable diameter, $\phi^{(1)}$ (mm)**	**Minimum internal radii factor, *n*, (radius = *n* times ϕ)**	
				Single-strand conductor (solid)	**Multi-strand conductor**
Non-armoured					
A	Rubber PVC XPLE	Copper and aluminium circular and circular stranded conductors.	$\phi \leq 10$	3	2
B			$10 < \phi \leq 25$	4	3
C			$25 < \phi$	6	6
D		Copper shaped conductors and solid aluminium conductors.	All	8	8
Armoured					
E	Rubber PVC XPLE	Copper and aluminium circular and circular stranded conductors.	All	6	
F		Copper shaped conductors and solid aluminium conductors.	All	8	
MICC					
G	MICC – bare	Copper.	All	6 but 3 if bend is not re-worked	
H	MICC – with covering	Copper.	All	6 but $3^{(2)}$ if bend is not re-worked	

Notes: (1) Where the cable is of the flat type, the major axis is the cable diameter.
(2) MICC cable diameter to be taken as overall diameter with covering.

often used in the commercial environment. Cornice and skirting trunking frequently have a place in the domestic installation particularly for rewiring of solid-floor buildings. In all cases where these cable management systems are used the requirements of BS 7671 should be observed and in particular those relating to grouping of cables, supports and segregation of different systems (e.g. power, computer data lines, fire alarms, etc.) Additionally, the recommendations of the manufacturers of such systems should be observed.

10.8 Minimising the risk of fire

Section 527 deals with the sealing of wiring system penetrations so as to prevent or retard the spread of fire. It calls for all such penetrations through walls, floors, roofs, ceilings, partitions and cavity barriers to be sealed so that the fire resistance stipulated for the element penetrated is met. In other words, the fire barrier properties of the structure holed by wiring systems should be maintained as if there had been no penetration. Where a wiring

Table 10.24: Maximum spacings for cable trunking supports

Ref	**Trunking csa**	**Examples of trunking sizes(1)**		**Vertical**		**Horizontal**	
	mm^2	**mm**	**inch(2)**	**m**	**ft-in(2)**	**m**	**ft-in(2)**
				Metallic trunking			
A	csa ≤ 700	25 x 25	1 x 1	1.00	3′ 3″	0.75	2′ 5″
B	700 < csa ≤ 1500	38 x 38	1½ x 1½	1.50	4′ 11″	1.25	4′ 1″
C	1500 < csa ≤ 2500	50 x 50	2 x 2	2.00	6′ 6″	1.75	5′ 8″
D	2500 < csa ≤ 5000	100 x 50	4 x 2	3.00	9′ 10″	3.00	9′ 10″
E	5000 < csa	100 x 75	4 x 3	3.00	9′ 10″	3.00	9′ 10″
				Non-metallic trunking			
F	csa ≤ 700	25 x 25	1 x 1	0.50	1′ 7″	0.50	1′ 7″
G	700 < csa ≤ 1500	38 x 38	1½ x 1½	0.50	1′ 7″	0.50	1′ 7″
H	1500 < csa ≤ 2500	50 x 50	2 x 2	1.25	4′ 1″	1.25	4′ 1″
I	2500 < csa ≤ 5000	100 x 50	4 x 2	2.00	6′ 6″	1.50	4′ 11″
J	5000 < csa	100 x 75	4 x 3	2.00	6′ 6″	1.75	5′ 8″

Notes: (1) The examples are given in common sizes.
(2) Imperial dimensions are approximate.

system has an internal cross-sectional area of not greater than 710 mm^2 (e.g. 32 mm conduit and 25 × 25 mm trunking) and is of the non-flame propagating type, no further internal sealing is required though, of course, external sealing is still required (see Figure 10.17). The sealing arrangement must be tested by the method specified in BS 476 Part 23 for fire resistance up to one hour but where a long resistance is required the sealing should be the subject of special testing. The sealing material must be compatible with the wiring system with which it is in contact so that there is no deterioration of either.

The sealing material must also be resilient to all potential external influences (e.g. water, corrosive materials, mechanical stresses, etc.). It should allow for expansion and contraction due to the thermal effects of the wiring systems and changes in ambient temperature and should, in so doing, maintain its sealing characteristics intact. It should also be removable for future extensions to the wiring system and the removal and replacement of the sealing material must not damage the wiring system.

Every sealing arrangement must be verified as complying with the manufacturer's instructions by visual inspection both in the erection stage and on completion and a record issued to confirm compliance. Where sealing arrangements have been dismantled during alteration work, those arrangements should be resealed as soon as practicable so as to restore the fire resistance capabilities of the structure concerned. The designer should consider the use of wiring systems which have lower fire propagation characteristics (see item 10.1.2) meeting the standard of performance set out in BS 4066: Part 3.

Figure 10.18 illustrates a typical arrangement of trunking penetrating a wall and a structural floor, which is intended to provide a fire barrier. Consultation with the person responsible for fire containment and with the

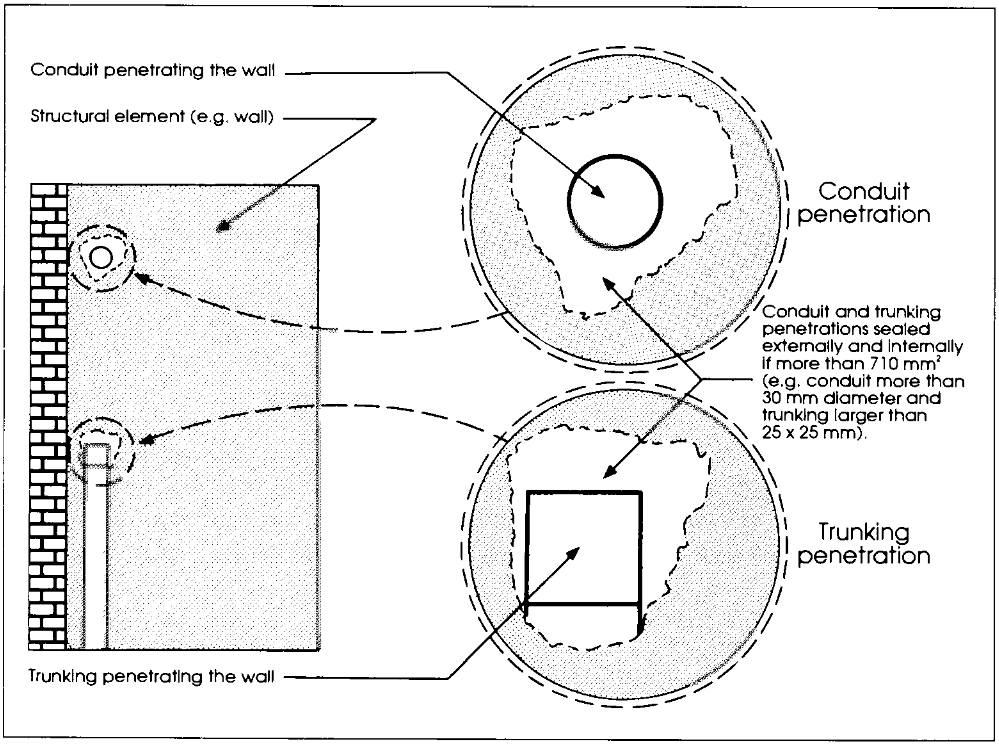


Figure 10.17: Sealing of wiring system penetrations

structural engineer will almost certainly be inevitable for most installation designs.

Cables which do not comply with the flame propagation requirements of BS EN 50265–1 must be limited to the short length of connection of appliances to the fixed wiring. Such cable must not pass between fire-segregated compartments.

10.9 Electromagnetic and electromechanical effects

Electromagnetic effects of a.c. current are of principal concern where single-core cables with steel wire or tape armouring are used and Regulation 521–02–01 precludes the use of such cables for a.c. This regulation goes on to call for a.c. conductors enclosed in ferromagnetic materials (e.g. steel conduit and trunking) to have all phase(s), neutral, if any, and the circuit protective conductor of a circuit to be contained within the enclosure. Conductors arranged in this manner will minimise the electromagnetic effects of current during both normal load conditions and fault conditions. Where the steel conduit or trunking serves as the circuit protective conductor and is adequate, there is no further requirement in this respect regarding an additional cpc to be run in the conduit or trunking.

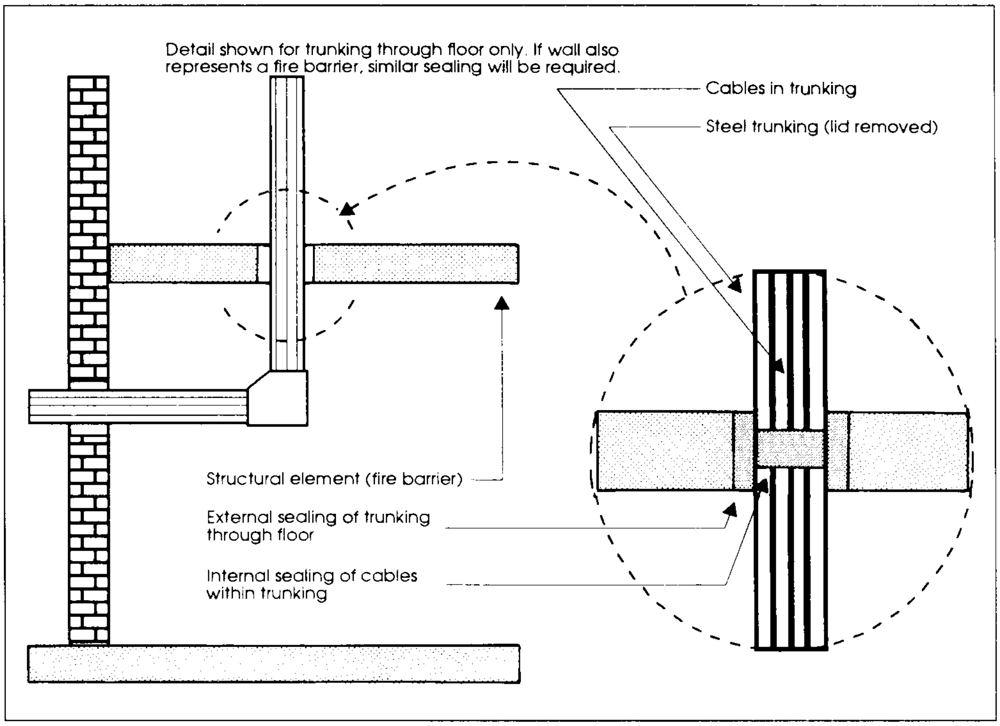


Figure 10.18: Trunking penetrating a structural floor and a wall

Conductors entering metal enclosures must not be separated by ferromagnetic material (e.g. steel) unless other precautions are taken to minimise the effects of eddy currents circulating in the steel producing small currents to flow in the phase(s) and neutral conductors. This may lead to an audible acoustic noise (induction hum) in extreme cases. Figure 10.19 graphically shows the eddy current effect.

Regulation 523–05–01 requires that the metallic sheaths of single-core cables, irrespective of whether the armouring is magnetic or not, be electrically bonded at both extreme ends of the run, sometimes known as solid bonding. Alternatively, for conductors of more than 50 mm^2 the armouring may be bonded at one end only provided the armouring is covered with a non-conducting sheath. When this ‘single-point bonding’ is employed, care must be taken to establish that the induced voltage in the armouring does not exceed 25 V with respect to the point at which the bonding has been effected. Other precautions may also be necessary to prevent corrosion by, for example, electrolytic action and damage to property particularly when the conductors are subjected to fault conditions. Figure 10.20 illustrates the transformer effect of solid bonding.

Regulation 521–03–01 calls for every conductor to be of adequate strength to cope with electromechanical stresses. Conductors will tend to be subjected to mechanical forces during load conditions owing to expansion and contraction of conductors due to temperature changes. Changes in

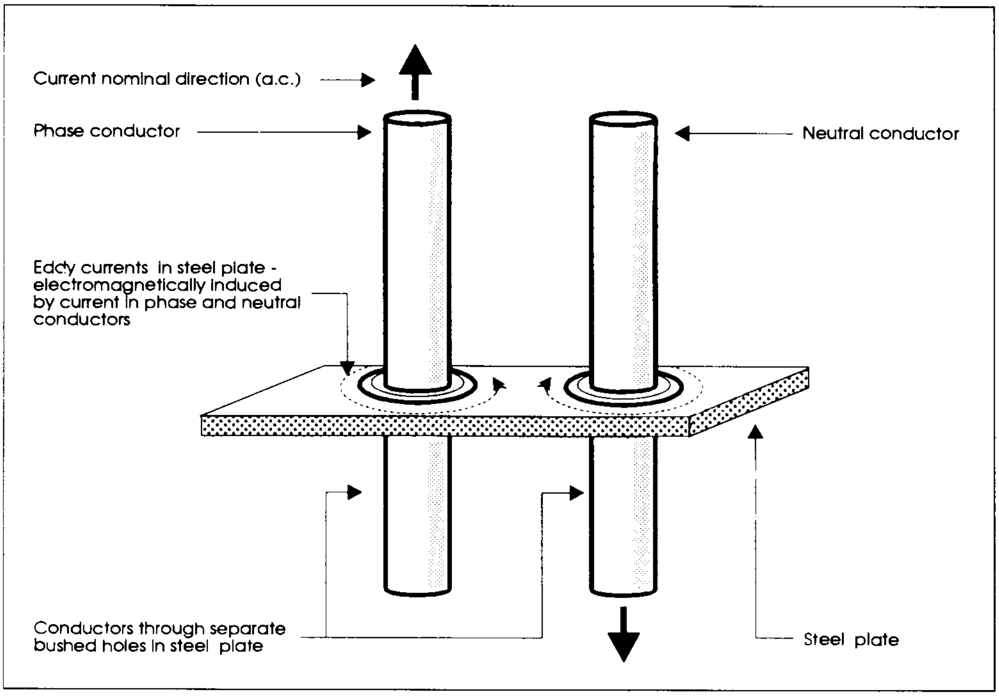


Figure 10.19: The eddy-current effect

temperature may be associated with the ambient conditions and/or variations in load current. Stresses will occur by virtue of the difference in the coefficients of expansion of the conductors and that of the material with which it is in contact. Under fault conditions, where currents may be of the order of magnitude of a 100 times the load current, serious distorting effects can occur on the cable. It is important for this reason, if no other, that wiring systems are supported in accordance with BS 7671.

10.10 Conduit and trunking cable capacities

10.10.1 Conduit capacities

BS 7671 itself is not specific about the number of cables that are permitted to be installed in conduit systems but there is a general requirement under Regulation 522–08 for cables to be installed so that they are not subjected to undue mechanical stresses.

The IEE Guidance Note *Selection and erection* gives, in its Appendix A, a method of determining the maximum number of cables permitted to be drawn into a conduit. Obviously, there are several factors which influence this number including:

- the length of conduit run,
- the number of bends in the run,

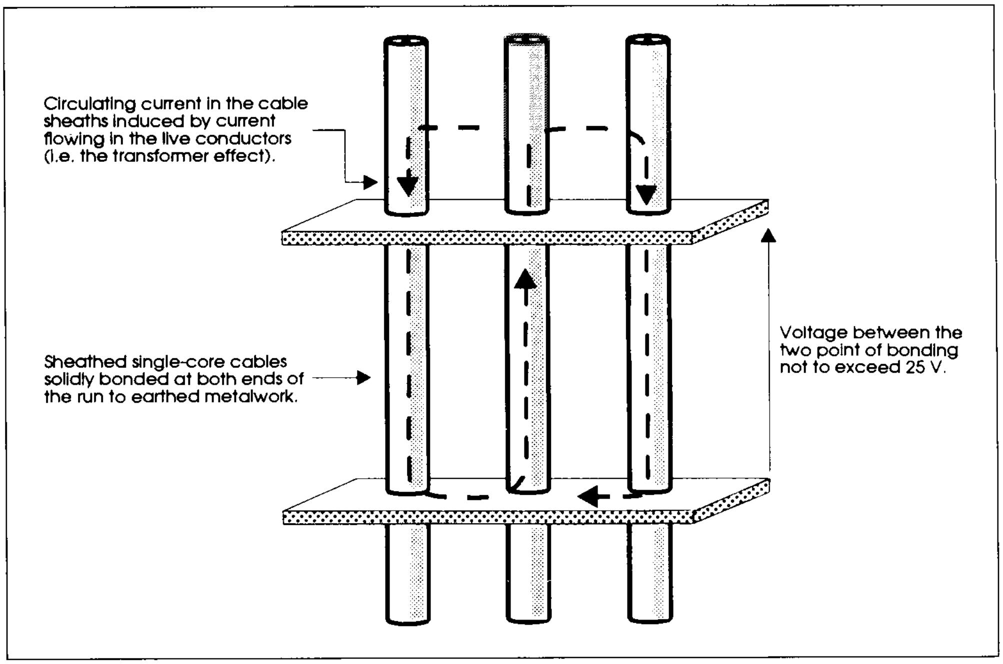


Figure 10.20: The transformer effect of 'solid bonding'

- the radius of bends,
- accessibility points (adequate space for drawing in cables),
- proper fabrication of conduit system (e.g. conduit ends properly reamed),
- the construction of the cables (e.g. solid-single strand and multi-strand),
- insulation rating (thickness),
- tolerance of conduit dimensions,
- conductor material (e.g. copper and aluminium),
- space for future extensions.

All these factors influence the number of cables which may be drawn into a conduit system. The method devised in Appendix A of the IEE Guidance Note is an attempt to provide useful advice to the designer in assessing the conduit sizes required for a particular number of cables (and circuits). In this method, PVC/copper cables have been allocated a term dependent on their cross-sectional area and the nature of the conduit run.

Cable and conduit terms for straight runs not exceeding 3 m are given Appendix A. Table A1 and Table A2 of the IEE Guidance Note *Selection and erection* respectively and those for longer runs with and without bends are given in Tables A3 and A4. For convenience these terms are summarised in Tables 10.25 and 10.26.

To use Tables 10.15 and 10.26, the designer first needs to assess the number and cross-sectional area of the PVC conductors and whether he

Table 10.25: Terms for PVC/copper cables

Ref	**Conduit runs**	**Conductor configuration**	**Conductor csa (mm²)**							
			1	**1.5**	**2.5**	**4**	**6**	**10**	**16**	**25**
A	Straight runs up to 3 m.	Solid	22	27	39	—	—	—	—	—
B		Stranded	—	31	43	58	88	146	202	385
C	Straight runs over 3 m with and without bends	Solid	16	22	30	—	—	—	—	—
D		Stranded	—	22	30	43	58	105	145	217

intends to use solid or stranded conductors (if there is an option for the particular sizes envisaged). The cable terms from Table 10.15 can then be identified and where there are a number of different sizes, Equation (10.14) may be used to ascertain the sum of the cable terms.

$$T_t = (t_1 \times n_1) + (t_2 \times n_2) + (t_3 \times n_3) + \ldots + (t_n \times n_n) \qquad (10.14)$$

where t_1 = the cable term for size n_1
t_2 = the cable term for size n_2
t_3 = the cable term for size n_3
t_n = the cable term for size n_n
n_1 = quantity of cables of size 1
n_2 = quantity of cables of size 2
n_3 = quantity of cables of size 3
n_n = quantity of cables of size n
T_t = the sum of all the cable terms.

To take a practical example, we have size 2.5 mm^2 (solid), twelve 1.5 mm^2 (stranded), four 6 mm^2 cables to run 2.3 m in a conduit with three right-angled bends. Substituting cable term values obtained from Table 10.15 (Rows reference A and B) for cable terms into Equation (10.14) we get the sum of terms for all the cables to be 958, as given in Equation (10.15).

$$T_t = (39 \times 6) + (31 \times 12) + (88 \times 4) = 958 \qquad (10.15)$$

We now know that the sum of terms for the cables is 958 and we need a value of conduit terms not less than this. From Table 10.16 we look for values in the row N3 which relates to a run of 2 to 2.5 m with three bends. We see for a 38 mm conduit the term is 900 which is less than we require. Therefore, the minimum conduit size that will be required is 50 mm with a conduit term of 1671.

It may be, in some cases, more economical to run the cables in more than one conduit and in the foregoing example had two conduits been used (instead of the one 50 mm conduit) and each contained three 2.5 mm^2 (solid), six 1.5 mm^2 (stranded), two 6 mm^2 cables (assuming they can be divided in this way), we could have used two 32 mm conduits. This option

Table 10.26: Terms for conduit

Ref	**Length of conduit run, R (m)**	**Conduit term**						
		16mm	**20mm**	**25mm**	**32mm**	**38mm**	**50mm**	**63mm**
		Straight runs with no bends						
A	$R \le 3.0$	290	460	800	1400	1900	3500	5600
B	$3.0 < R \le 3.5$	179	290	521	911	1275	2368	3826
C	$3.5 < R \le 4.0$	177	286	514	900	1260	2340	3780
D	$4.0 < R \le 4.5$	174	282	507	889	1244	2311	3733
E	$4.5 < R \le 5.0$	171	278	500	878	1229	2282	3687
F	$5.0 < R \le 6.0$	167	270	487	857	1199	2228	3599
G	$6.0 < R \le 7.0$	162	263	475	837	1171	2176	3515
H	$7.0 < R \le 8.0$	158	256	463	818	1145	2126	3435
I	$8.0 < R \le 9.0$	154	250	452	800	1120	2080	3360
J	$9.0 < R \le 10.0$	150	244	442	783	1096	2035	3288
		Runs with one bend						
K1	$R \le 1.0$	188	303	543	947	1325	2462	3977
L1	$1.0 < R \le 1.5$	182	294	528	923	1292	2399	3876
M1	$1.5 < R \le 2.0$	177	286	514	900	1264	2340	3780
N1	$2.0 < R \le 2.5$	171	278	500	878	1229	2282	3687
O1	$2.5 < R \le 3.0$	167	270	487	857	1199	2228	3599
P1	$3.0 < R \le 3.5$	162	263	475	837	1171	2176	3515
Q1	$3.5 < R \le 4.0$	158	256	463	818	1145	2126	3435
R1	$4.0 < R \le 4.5$	154	250	452	800	1120	2080	3360
S1	$4.5 < R \le 5.0$	150	244	442	783	1096	2035	3288
T1	$5.0 < R \le 6.0$	143	233	422	750	1050	1950	3150
U1	$6.0 < R \le 7.0$	136	222	404	720	1008	1872	3024
V1	$7.0 < R \le 8.0$	130	213	388	692	968	1799	2906
W1	$8.0 < R \le 9.0$	125	204	373	667	933	1734	2801
X1	$9.0 < R \le 10.0$	120	196	358	643	900	1671	2700
		Runs with two bends						
K2	$R \le 1.0$	177	286	514	900	1260	2340	3780
L2	$1.0 < R \le 1.5$	167	270	487	857	1199	2228	3599
M2	$1.5 < R \le 2.0$	158	256	463	818	1145	2126	3435
N2	$2.0 < R \le 2.5$	150	244	442	783	1096	2035	3288
O2	$2.5 < R \le 3.0$	143	233	422	750	1050	1950	3150
P2	$3.0 < R \le 3.5$	136	222	404	720	1008	1872	3024
Q2	$3.5 < R \le 4.0$	130	213	388	692	968	1799	2906
R2	$4.0 < R \le 4.5$	125	204	373	667	933	1734	2801
S2	$4.5 < R \le 5.0$	120	196	358	643	900	1671	2700
T2	$5.0 < R \le 6.0$	111	182	333	600	840	1560	2520
U2	$6.0 < R \le 7.0$	103	169	311	563	788	1463	2364
V2	$7.0 < R \le 8.0$	97	159	292	529	740	1375	2221
W2	$8.0 < R \le 9.0$	91	149	275	500	700	1300	2100
X2	$9.0 < R \le 10.0$	86	141	260	474	663	1232	1990
		Runs with three bends						
K3	$R \le 1.0$	158	256	463	818	1145	2126	3435
L3	$1.0 < R \le 1.5$	143	233	422	750	1050	1950	3150
M3	$1.5 < R \le 2.0$	130	213	388	692	968	1799	2906
N3	$2.0 < R \le 2.5$	120	196	358	643	900	1671	2700
O3	$2.5 < R \le 3.0$	111	182	333	600	840	1560	2520
P3	$3.0 < R \le 3.5$	103	169	311	563	788	1463	2364
Q3	$3.5 < R \le 4.0$	97	159	292	529	740	1375	2221
R3	$4.0 < R \le 4.5$	91	149	275	500	700	1300	2100
S3	$4.5 < R \le 5.0$	86	141	260	474	663	1232	1990

Continued on facing page

Table 10.26 continued: Terms for conduit

Ref	Length of conduit run, R (m)	Conduit term						
		16mm	20mm	25mm	32mm	38mm	50mm	63mm
		Runs with four bends						
K4	$R \leq 1.0$	130	213	388	692	968	1799	2906
L4	$1.0 < R \leq 1.5$	111	182	333	600	840	1560	2520
M4	$1.5 < R \leq 2.0$	97	159	292	529	740	1375	2221
N4	$2.0 < R \leq 2.5$	86	141	260	474	663	1232	1990

may be easier to install and the cable current-carrying 'capacities' would need less correction because of grouping.

10.10.2 *Trunking capacities*

In designing cable trunking systems it is important for the designer to select a size that will provide an adequate space factor and make an allowance for future extensions to the installation. The space factor is defined as the ratio of the sum of the cross-sectional areas of all the cables enclosed in the trunking to the effective internal cross-sectional area of the trunking. Where cables are not of circular section, their diameter is taken as the distance across their major axis.

As with cables in conduit, it is first necessary to assess the number and cross-sectional areas of cables which need enclosure in trunking and determine their corresponding cable terms from Table 10.27 either from Row A or Row C dependent on whether trunking terms from Table 10.28 or Table 10.29 are to be used. Note that the cable terms for trunking are different from those where the cables are to be enclosed in conduit.

To take the practical example that we used for cables in conduit, we have six 2.5 mm^2 (solid), twelve 1.5 mm^2 (stranded), four 6 mm^2 cables to run 2.3 m in trunking. The sum of the csa cable terms, T_s, from the individual terms in Table 10.27 (Row A) is give by Equation (10.16).

$$T_s = (10.2 \times 6) + (8.1 \times 12) + (22.9 \times 4) = 250 \tag{10.16}$$

Table 10.27: Cable terms when installing in trunking

Ref	Cables marked 'S' are solid conductors	Cable terms for trunking															
		1.5	1.5S	2.5	2.5S	4	6	10	16	25	35	50	70	95	120	150	240
A	CSA term(1)	8.1	7.1	11.4	10.2	15.2	22.9	36.3	—	—	—	—	—	—	—	—	—
B	BESA diameter(2)	3.2	3.0	3.8	3.6	4.4	5.4	6.8	8.0	—	—	—	—	—	—	—	—
C	BESA term(3)	9.6	8.6	13.9	11.9	18.1	22.9	36.3	50.3	75.4	95.0	132.7	176.7	227	284	346	552

Notes: (1) CSA term to be used only with Table 10.28 data.
(2) British Electrical Systems Association (BESA) outside diameter of cable.
(3) BESA term to be used with Table 10.29 only.

Table 10.28: Trunking terms for use with csa terms

Ref		Trunking dimensions (mm)										
A	Height	50	50	75	75	75	75	100	100	100	100	100
B	Depth	37.5	50	25	37.5	50	75	25	37.5	50	75	100
C	Terms(1 & 2)	767	1037	738	1146	1555	2371	993	1542	2091	3189	4252

Notes: (1) Terms only to be used with csa cable terms from Table 10.27 Row A.
(2) Terms allow for 45% space factor and take into account the gauge of the trunking.

Table 10.29: Trunking terms for use with BESA terms

Ref		Dimensions and BESA terms for trunking sizes 50 x 38 mm to 200 x 50 mm																		
A	Height	50	50	75	75	75	75	100	100	100	100	100	150	150	150	150	150	200	200	
B	Depth	38	50	25	38	50	75	25	38	50	75	100	38	50	75	100	150	38	50	
C	Gauge	1.0	1.0	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.4	1.6	1.6	1.2	1.2	1.6	1.6	1.6	
D	BESA term	767	1037	738	1146	1555	2371	993	1542	2091	3189	4252	2999	3091	4743	6394	9697	3082	4145	
		Dimensions and BESA terms for trunking sizes 200 x 75 mm to 300 x 300 mm																		
E	Height	200	200	200	200	225	225	225	225	225	225	225	300	300	300	300	300	300	300	300
F	Depth	75	100	150	200	38	50	75	100	150	200	225	38	50	75	100	150	200	225	300
G	Gauge	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	2.0
H	BESA term	6359	8572	13001	17429	3474	4671	7167	9662	14652	19643	22138	4648	6251	9590	12929	19607	26285	29624	39428

Having established the sum of all the cable csa terms to be 250, we now have to find a trunking with a term not less than 250. We find, from Table 10.28, Row C, that 50 × 37.5 mm trunking provides a term of 767 which is more than adequate for enclosing the cables we proposed.

To take another example, we have eight 120 mm^2, twelve 95 mm^2 and four 150 mm^2 cables to enclose in trunking. From Table 10.27, Row C, we find the cable BESA terms are 284, 227 and 346 respectively, which gives the sum of cable terms as 6380. To find a trunking size that will be adequate to enclose these cables we look to Table 10.29, Rows D and H and find that the minimum size will be 150 × 100 mm with a trunking term of 6394.

It must be remembered that these terms provide for the necessary space factor of 45% but do not make any allowance for the inevitable future extensions to the wiring system. Neither do they take account of the bending radii of cables (see Table 10.23) which may well demand a larger size than that necessary to meet the space factor considerations. In making provision for additional future cables to be contained within the trunking, the designer should not overlook the need to allow for the added grouping in his assessment of the correction factors for the circuits considered initially. It may well be more attractive economically to have a number of trunking runs in order to reduce the effects of derating from grouping.

Where PVC cables are sheathed, a reduction in the number of cables will be necessary to allow for the increased cable overall diameter. Where cables of other types and construction are used the manufacturer's advice relating to containment should be obtained.

Where the trunking is metal, irrespective of whether or not it is used as a circuit protective conductor, all joints between lengths of trunking and between trunking and bends should be soundly made and be adequate to take the largest earth fault current reliably. Riveted joints should not be relied upon to cope with such fault currents and copper links across joints with soundly bolted connections or other equally acceptable method should be used. Most trunking manufacturers can provide such links.

10.11 Maintainability

Section 529 of BS 7671 deals with the aspect of maintainability of an installation and calls for provision to be made for safe and adequate access to all equipment including wiring systems. Regulation 300–01–01 requires that the person who will be responsible for maintenance should be consulted. His or her capabilities will influence the designer's decisions relating to the selection and erection of equipment for the installation, in this respect. Appendix 5 of BS 7671 categorises capabilities of persons as: BA1 – Ordinary, BA2 – Children, BA3 – Handicapped, BA4 – Instructed and BA5 – Skilled. Dependent on the use of the building, the designer will need to decide what measures are required for maintenance to be carried out safely by the maintenance personnel involved.

Ideally, switchrooms should have adequate and safe access to all equipment from floor level and use of the room for other purposes (e.g. storage, particularly of combustible materials) should be actively discouraged. Distribution boards, consumer's units and the controlgear enclosures should be readily accessible from floor level and live parts must be protected against inadvertent, unintentional or accidental contact. Care should be taken that all conductors are identified and located in an easily recognised sequence and that points of isolation of the equipment are indicated. Where there are live parts which cannot easily be isolated they should be shrouded in insulating material and access denied. Overcurrent and other protective devices should be of the type which makes replacement by other types or rating difficult and their functions and related information should be readily available.

Again ideally, luminaires which need removal for cleaning and the like should be fitted with luminaire supporting couplers and be so constructed to allow lamp replacement and cleaning to be carried out by unskilled personnel without potential danger. Where luminaires are at high level, consideration should be given to providing self-hoisting facilities to allow maintenance to be carried out at ground level.

An Operations and Maintenance Manual should be provided to the maintenance personnel and guidance is given in this respect in BS 5940 *Recommendations for the presentation of technical information about products and services in the construction industry* and Section 6 of The Health and Safety at Work etc. Act 1974. Such a manual may, for example, include:

- the installation design;
- the installation as-fixed drawings, including circuit, protective devices and conductor identification;
- the Electrical Installation Certificate;
- the recommended installation re-inspection intervals (including all different installations and where necessary different parts of installations);
- a schedule of maintenance intervals for all installed equipment;
- competence level required of personnel for each and every maintenance operation;
- the number of persons required for each and every maintenance operation;
- a schedule of life expectancy of installed equipment;
- manufacturers' technical specifications (includes, for example, accessories, luminaires, fire alarm and emergency lighting equipment);
- manufacturers' recommended maintenance procedures and intervals;
- isolation procedures;
- safe working procedures;
- all special instructions as to use and maintenance of equipment.

Chapter 11

Switchgear, Protective Devices and other Equipment

11.1 Switchgear and protective devices – general

As Regulation 511-01–01 clearly states, switchgear including protective devices must comply with the appropriate British Standard or Euronorm. Where this is not possible and the proposed switchgear does not meet the requirements of an appropriate British or CENELEC Standard, the onus is on the designer to determine that the equipment selected will provide a degree of safety not less than that inherent in similar equipment which does comply with an appropriate British Standard or Euronorm. In this respect it may be necessary to employ the services of a third party certification body to assess the equipment and certify its degree of safety. Table 11.1 lists some common LV switchgear including protective devices together with their Standard. The list should not be regarded as being exhaustive.

11.2 Switchgear and controlgear

11.2.1 Switchgear and controlgear – general

Chapter 53 deals in some detail with the regulatory requirements of switchgear for protection, isolation and for switching. Section 530 addresses the common rules and in Regulation 530–01–02 calls for no fuse, unlinked switch and unlinked circuit-breaker to be inserted in the neutral conductor of both TN systems and TT systems. This does not however preclude a *linked* switch or *linked* circuit-breaker interrupting the neutral conductor where the associated phase conductor(s) are also interrupted at substantially the same time. In such cases the device must be of the type which does not break the neutral conductor before the break occurs in the associated phase conductor(s) and does not make the phase conductor(s) before the neutral (Regulation 530–01–01).

The nominal current ratings of switchgear should be carefully assessed by checking that they match the characteristics of the load. It should not be assumed, for example, that the equipment will take its rated current continuously. If there is doubt the designer should confirm with the manufacturer and/or standard the actual circumstances under which the rating was assigned. In particular, the designer should bear in mind that consumer's units complying with BS 5486: Part 13 are not usually designed to

Table 11.1: Common LV switchgear including protective devices together with their Standards

Ref	Equipment	Standard	Requirements/Comments
	Switchboards, distribution boards and consumers units		
A	Low voltage switchgear and controlgear assemblies.	BS 5486 Part 1 # BS EN 60 439-1 ≠ IEC 439-1	Requirements for type-tested assemblies (TTA) and partially type-tested assemblies (PTTA).
B	Low-voltage switchgear and control-gear: Switches, disconnectors, switch-disconnectors, and fuse combination units.	BS EN 60 947-3	Requirements for defined switchgear.
C	Busbar trunking systems.	BS 5486 Part 2 ≠ IEC 439-1	Requirements for busbar trunking systems. To be read in conjunction with BS 5486 Part 1.
D	Fuseboards.	BS 5486 Part 11	Requirements for fuseboards. To be read in conjunction with BS 5486 Part 1.
E	Circuit-breaker boards.	BS 5486 Part 12	Requirements for circuit-breaker boards. To be read in conjunction with BS 5486 Part 1.
F	Consumer's units.	BS 5486 Part 13	Requirements for consumer's units. To be read in conjunction with BS 5486 Part 1.
G	Distribution assemblies for construction and building sites.	BS 4363 BS EN 60 439-4	Requirements for six types of LV distribution assemblies. Requirements for LV assemblies.
H	LV switchgear and controlgear: switches, disconnectors, switch-disconnectors and fuse combination units.	BS EN 60 439	Specification for LV switchgear and controlgear.
	Fuses and circuit-breakers		
I	HBC cartridge fuses.	BS 1361 ≠ IEC 269-1	General requirements.
J	HBC cartridge fuses.	BS 1362 ≠ IEC 269-1	General requirements.
K	Semi-enclosed (rewirable) fuses.	BS 3036	General requirements.
L	Miniature Circuit-Breaker (MCB).	BS 3871: Part 1 BS EN 60 898	General requirements.
M	Moulded Case Circuit-Breaker (MCCB).	BS EN 60 947-2	General requirements.
	Residual current devices		
N	Residual Current Device (RCD).	BS EN 61008 ≠ IEC 755	General requirements.
O	Time-delayed residual Current Device.	BS EN 61009	General requirements.
P	Portable Residual Current Device (PRCD).	BS 7071	General requirements.
Q	Socket-outlets incorporating Residual Current Device (SRCD).	BS 7288	General requirements.

Notes: (1) This listing is not exhaustive and serves only as a guide to the more commonly used equipment.
(2) The symbols # and ≠ signify an identical Standard and a differing Standard respectively.

take their fully rated current continuously or for long periods. Where so employed they may be subjected to excessive temperature rise which may result in premature operation of protective devices (e.g. MCBs). It may be more appropriate to use a distribution board complying with BS 5486 Part 11 with separate isolating device if required.

11.2.2 Switchgear and controlgear – forms of assembly

British Standard BS 5486: Part 1; 1990 (BS EN 60 439–1: 1990) addresses the specification for LV switchgear and controlgear assemblies. Its requirements include constructional considerations and allow for four distinct forms of physical separation of circuits which are shown graphically in Figure 11.1 and summarised in Table 11.2.

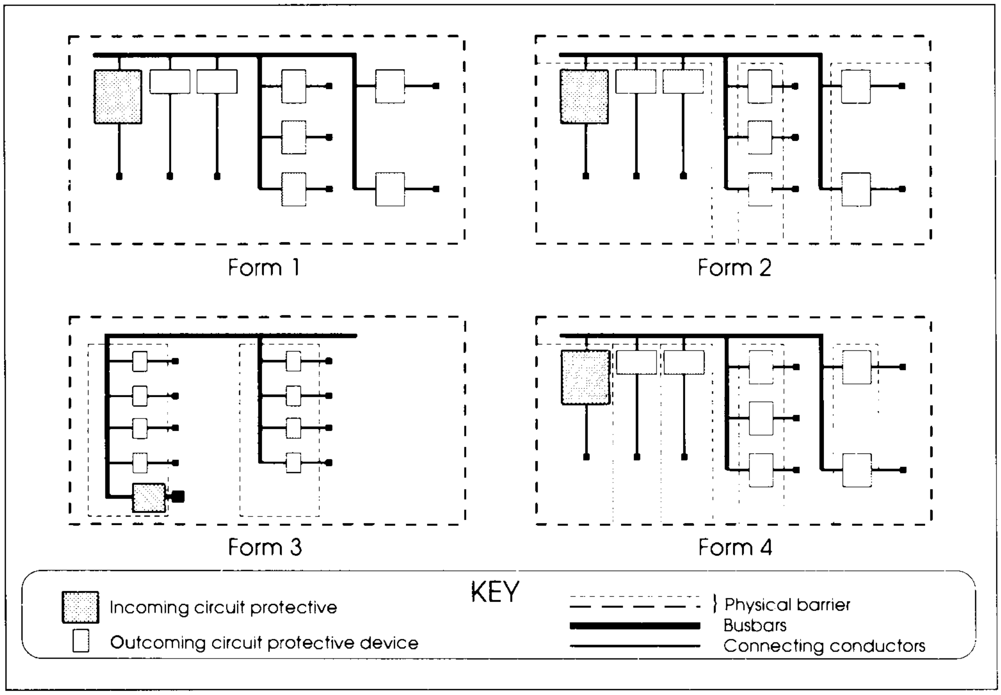


Figure 11.1: Forms of assembly of switchgear and controlgear

Depending on the circumstances all four forms of assembly may be employed. Very careful consideration is essential to establish the methods of operation and of maintenance of the equipment with particular regard to personnel who will be required to do such work. Form 4 offers the highest level of safety and will usually be used where it is necessary for access to be gained without the need to isolate the whole assembly. The use of the other three forms would require additional precautionary measures to be taken for compliance with the Electricity at Work Regulations 1989.

11.3 Selection of devices for overload and fault current protection – general

Regulation 533–02–01 demands that in the selection of devices for protection against overload the nominal current of the protective device, I_n,

Table 11.2: LV switchgear and controlgear assemblies form of assembly

Form	**Internal separation**			**Restrictions**	**Comment**
	Between busbars and outgoing protective devices	**Between circuits**	**Between busbars and outgoing circuit terminals**		
1	None.	None.	None.	For use where assemblies can be isolated before gaining access and/or situated in areas restricted to authorised persons.	Assemblies may have exposed live parts when outer barriers removed (e.g. door opened).
2	Yes.	None.	Yes.		Similar to Form 1 but separation of circuits minimises the spread of the effects of faults.
3	Yes.	Yes.	None.		Similar to Forms 1 and 2 except that circuits are separated from each other and from busbars.
4	Yes.	Yes.	Yes.	Live parts to be isolated before gaining access to them, or equipped with additional internal barriers preventing unintentional contact.	Form 4 affords internal separation of busbars from circuits, circuits from each other and outgoing terminals from busbars.

must be chosen in accordance with the relationship given in Equations (11.1) and (11.2) (see Regulations 433–02–01 to 433–02–03).

$$I_{\mathrm{n}} \leqslant I_{\mathrm{b}} \leqslant I_{\mathrm{z}} \qquad (11.1)$$

$$I_2 \leqslant 1.45\, I_{\mathrm{z}} \qquad (11.2)$$

where I_{b} = circuit design current
I_{z} = continuous service current-carrying capacity under the declared installation conditions
I_{n} = nominal rated current of the overcurrent protective device
I_2 = current that will indicate the protective device to disconnect on overload

In every case the peak load of the circuit must be taken into consideration. Assessment of the current-carrying capacity of conductors and the selection of the nominal current rating of the protective devices must be made on the basis of the peak load. This regulation affords cyclic loads special consideration inasmuch as the designer is entitled to treat such loads on the basis of a thermally equivalent load. In the absence of more precise information, one approach to establishing the relationship between a thermally equivalent load and a cyclic load is illustrated in Figure 11.2.

As can be seen in Figure 11.2, an example of a cyclic load is shown

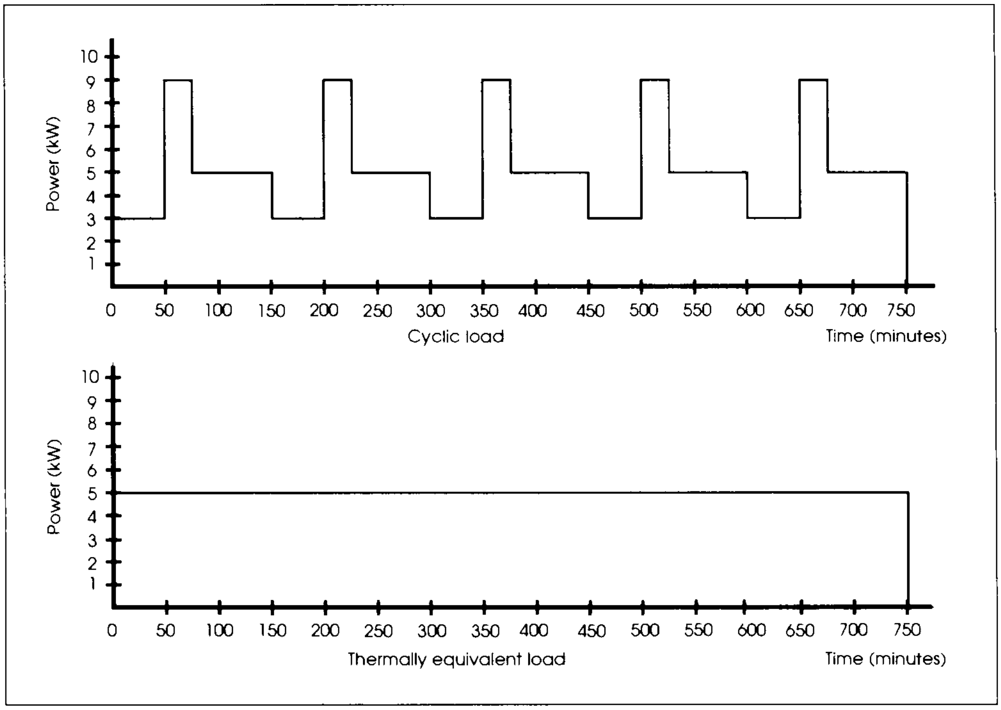


Figure 11.2: An example of a cyclic load and its thermally equivalent load

together with a thermally equivalent load based on energy (power × time) losses in the current-using equipment and circuit conductors, the areas under the 'curve' being equal. However, this is only one approach and others may be more appropriate depending on the circumstances. In any event, it is necessary for the designer to establish that the overload protective devices will not operate unintentionally (i.e. prematurely) and to provide the necessary protection against overload.

In the case of a normal motor circuit the overload protective device often forms part of the starter controlgear and it is often positioned near to the motor. This is permitted by Regulation 473–01–02 where the stated conditions are met. In such cases it is not necessary to duplicate overload protection at the circuit origin and the overcurrent protective device at this point may be selected on the basis of fault current protection only.

In fact, its nominal rating may be more that the circuit design current and indeed the current-carrying capacity of the wiring system. Figure 11.3 shows typical motor starting and running load profiles together with motor starter overload relay characteristic. The back-up fuse providing fault current protection only is also shown. It is worth noting that motor starting currents are much higher than steady state-conditions (running) and the initial inrush current may last for up to ten seconds when direct-on-line starting methods are used depending on the motor type and characteristics.

Regulation 533–03–01 demands that in the consideration of fault current protective devices, the maximum and minimum fault currents are taken

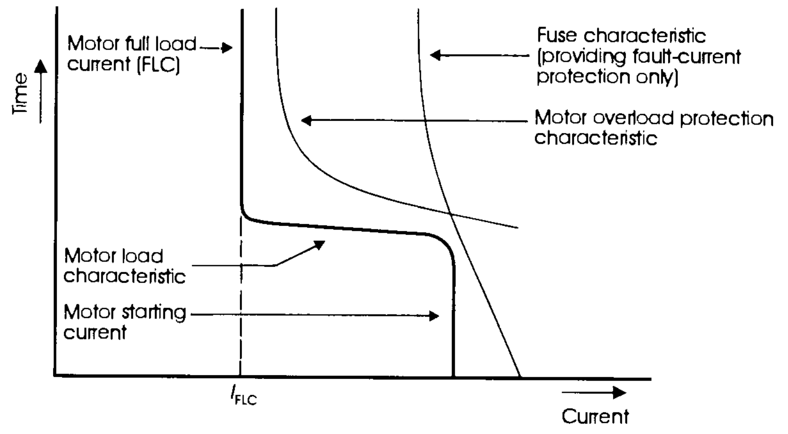


Figure 11.3: Typical characteristics of a motor load and associated protective devices

into account. Generally speaking, the three-phase fault current (under no-load conditions) may be assumed to be the maximum fault current. However, it is important to recognise that earth fault currents may exceed phase-to-phase short-circuit currents (by up to approximately 5% in some cases). It is also vital to appreciate that the prospective fault current is attenuated (reduced) as the distance of the fault from the source is increased. Where circuits are of some considerable length the fault levels will be significantly reduced at the remote end of the circuit. Selection of the overcurrent protective device would require these factors to be taken into consideration, particularly regarding disconnection time and the thermal capacity of the wiring system (S^2k^2).

11.4 Overcurrent protective devices

Regulation 530–01–03 recognises that a protective device may fulfil more than one function (e.g. protection against indirect contact, protection against overcurrent and, thirdly, isolation). Where it does provide for more than one function it must meet *all* the requirements relating to every function. Table 11.3 provides a summary of protective devices and the functions they are commonly called upon to provide.

The choice of protective devices will depend on many factors including the system type and earthing arrangements, initial and maintenance costs and, not least, the designer's own preference. Table 11.4 summarises the relative merits of the more common devices and lists, where appropriate, the main advantages and disadvantages. Table 11.5 details the short-circuit capacities of the more common devices.

Where, in TN and TT systems, overcurrent devices are also used to

Table 11.3: Common protection devices and the functions they are frequently called upon to perform

Ref	Protective device	Standard	Protective functions						Comments
			Overcurrent	Protection against electric shock		Isolation and switching		Fire	
				Direct contact	Indirect contact	Isolation	Switching		
A	MCB Type 1.	BS 3871 and BS EN 60 898	✓	×	✓	✓	✓	×	See Notes 1, 2, 3 and 4.
B	MCB Type 2.		✓	×	✓	✓	✓	×	See Notes 1, 2, 3 and 4.
C	MCB Type B.		✓	×	✓	✓	✓	×	See Notes 1, 2, 3 and 4.
D	MCB Type 3.		✓	×	✓	✓	✓	×	See Notes 1, 2, 3 and 4.
E	MCB Type C.		✓	×	✓	✓	✓	×	See Notes 1, 2, 3 and 4.
F	MCB Type D.		✓	×	✓	✓	✓	×	See Notes 1, 2, 3 and 4. Limited scope for overcurrent and indirect contact protection.
G	MCB Type 4.		✓	×	✓	✓	✓	×	See Notes 1, 2, 3 and 4. Limited scope for overcurrent and indirect contact protection.
H	MCCB.	BS EN 60 947-2	✓	×	✓	✓	✓	×	See Notes 1, 2, 3 and 4.
I	HBC cartridge fuse.	BS 88	✓	×	✓	✓	×	×	—
J	HBC cartridge fuse.	BS 1361	✓	×	✓	✓	×	×	—
K	Cartridge fuse.	BS 1362	✓	×	✓	✓	×	×	—
L	Semi-enclosed fuse (rewirable).	BS 3036	✓	×	✓	✓	×	×	—
M	RCD ($I_{\Delta n} \leq 30$ mA).	BS 4293	×	✓	✓	✓	✓	✓	Some measure of protection against fire. See Note 5.
N	RCD ($I_{\Delta n} \geq 30$ mA).	BS 4293	×	×	✓	✓	✓	✓	Some measure of protection against fire.
L	RCD ($I_{\Delta n} = 500$ mA).	BS 4293	×	×	✓	✓	✓	✓	Some measure of protection against fire.

Notes:
(1) Suitable for isolation purposes provided the device affords the necessary contact separation and provides a reliable indication.
(2) If device is used as a remote isolating device it must be capable of securing in the open position.
(3) Device may be used for switching operations provided manufacturer agrees that it can be used for this purpose.
(4) Although device can provide overcurrent protection, it cannot directly protect the against fire hazard.
(5) Can provide supplementary protection against direct contact but not the sole means of this protection.

KEY:
× = Not commonly used or not permitted.
✓ = Commonly used.

provide protection against electric shock (indirect contact), Regulation 531–01–01 calls for the co-ordination of the characteristics of the devices and the phase-earth loop impedance. In addition to providing automatic disconnection within the prescribed time limits, the fault current must not cause the phase conductor and the cpc to exceed their respective maximum permissible final temperature. The regulation also requires that the touch voltage between conductive parts (exposed and extraneous) during an earth fault does not exceed the safe limits in terms of both magnitude and duration. In assessing maximum temperatures, the designer need only consider whether the adiabatic equation (given in Equation (11.3)) is satisfied for both phase conductor and cpc (see 434–03–03 for live conductors and 543–01–03 for protective conductors). The adiabatic equation featured in these two regulations is stated differently; for short-circuit considerations the subject of the equation is time, *t*, (the maximum duration permitted in order that the conductor limiting temperature is not exceeded) and for earth fault analysis the minimum protective conductor cross-sectional area, *S*, is the subject. Equation (11.3) is in the form for calculating the time permitted to disconnect a short-circuit current.

$$t = \frac{k^2 \, S^2}{I^2} \tag{11.3}$$

where S = the cross-sectional area of the conductor, (mm^2)
I = fault-current, (A)
t = duration of the fault (from occurrence to disconnection), (s)
k = a factor for the conductor based on its resistivity, temperature coefficient and heat capacity.

Table 11.4: The relative merits of common overcurrent protective devices

Ref	Protective device	Standard	Initial cost	Maintenance costs	Advantages	Disadvantages
A	Semi-enclosed (rewirable) fuse.	BS 3036	Low	Low	None other than costs.	Low short-circuit breaking capacity. Cable current-carrying capacities usually need to be increased (C_d). Prone to misuse particularly on replacement of fuse element. Tend to deteriorate with time. A possibility exists of fuse insertion on to a faulty circuit.
B	Cartridge fuse.	BS 1362	Low	Low		Low short-circuit breaking capacity. A possibility exists of fuse insertion on to a faulty circuit.

Continued on facing page

Table 11.4 continued: The relative merits of common overcurrent protective devices

Ref	Protective device	Standard	Initial cost	Maintenance costs	Advantages	Disadvantages
C	HBC fuse.	BS 88 Part 2	Medium	Medium	High short-circuit capacities capable of dealing with most fault levels encountered in practice. Less prone to misuse than semi-enclosed fuses.	A possibility exists of fuse insertion on to a faulty circuit.
D		BS 88 Part 6	Medium	Medium		
E		BS 1361 Type I	Medium	Medium	Fairly high short-circuit capacities capable of dealing with most fault levels encountered in practice. Less prone to misuse than semi-enclosed fuses.	
F		BS 1361 Type II	Medium	Medium	High short-circuit capacities capable of dealing with most fault levels encountered in practice. Less prone to misuse than semi-enclosed fuses.	
G	MCB.	BS 3871 and BS EN 60 898	Medium to high	Low	Generally provides for quicker disconnection. Short-circuit capacities available to deal with most fault levels up to 16 kA. Less prone to misuse. The two Types afford easy selection of various load characteristics.	The need to maintain, and have ready, the necessary spares
H	MCCB.	BS EN 60 947-2	High	Low	Generally provides for quicker disconnection. Short-circuit capacities available to deal with most fault levels. Adjustable overcurrent settings.	

Table 11.5: Common overcurrent protective devices and their short-circuit capacities

Ref	Protective device	Standard	Short-circuit capacities	Nominal ratings	At nominal power factor	Comments
A	Semi-enclosed (rewirable) fuse.	BS 3036	S1 – 1 kA	All ratings except 100 A	—	Short-circuit capacities marked on device.
B			S2 – 2 kA	All ratings except 100 A		
C			S4 – 4 kA	30 A to 100 A		
B	Cartridge fuse.	BS 1362	6.0 kA	All	—	—
D	HRC fuse.	BS 88 Part 2	80 kA 40 kA	All All	— —	For a.c. of 4.5 V or more. For d.c. not exceeding 500 V.
E		BS 88 Part 6	—	—	—	Seek manufacturer's advice.
F		BS 1361 Type I	16.5 kA	All	0.3	—
G		BS 1361 Type II	33.0 kA	All	0.3	—
H	MCB.	BS 3871 and BS EN 60 898	M1 – 1 kA	All	0.85 to 0.90	Short-circuit capacities marked on device.
I			M1.5 – 1.5 kA	All	0.80 to 0.85	
J			M2 – 2 kA	All	0.75 to 0.80	
K			M3 – 3 kA	All	0.75 to 0.80	
L			M4 – 4 kA	All	0.75 to 0.80	
M			M6 - 6 kA	All	0.75 to 0.80	
N			M9 – 9 kA	All	0.55 to 0.60	
O			M16 – 16 kA	All		
P	MCCB.	BS EN 60 947-2	—	—	—	Short-circuit capacities marked on device.
Q	Switchgear and controlgear assemblies.	BS 5486	—	—	—	Seek manufacturer's advice.

In an IT system, the requirements in the event of a second fault where exposed-conductive-parts are connected together and the overcurrent device is used to provide protection against electric shock, the requirements relating to TN and TT systems in this respect must also be met (see Regulations 531–01–02).

There are three varieties of overcurrent protective devices which are commonly used in LV installations, namely fuses, MCBs and MCCBs. These devices are also often used to provide protection against electric shock (indirect contact) and for isolation and switching (see Table 11.3).

The time/current characteristics are given in Appendix 3 of BS 7671 together with accompanying tables to provide data on the magnitude of the fault current required to cause disconnection within the various time limits (e.g. 0.2 s and 0.4 s). It should be borne in mind that, as mentioned earlier, it is the magnitude of the fault current that is the crucial factor and that the limiting circuit impedance is dependent on the nominal voltage. Table 11.6 summarises the fault current magnitudes required to effect automatic disconnection within 0.1, 0.2, 0.4 and 5 s (the common maximum permissible disconnection times).

Overcurrent devices and their associated switchgear are commonly referred to by the number of poles in terms of switching and overcurrent detection in a.c. systems and these are summarised in Figure 11.4. Note that overcurrent detection is normally provided in each phase (Ph) conductor but not in the neutral conductors, except where it is necessarily required (as shown in the DP device).

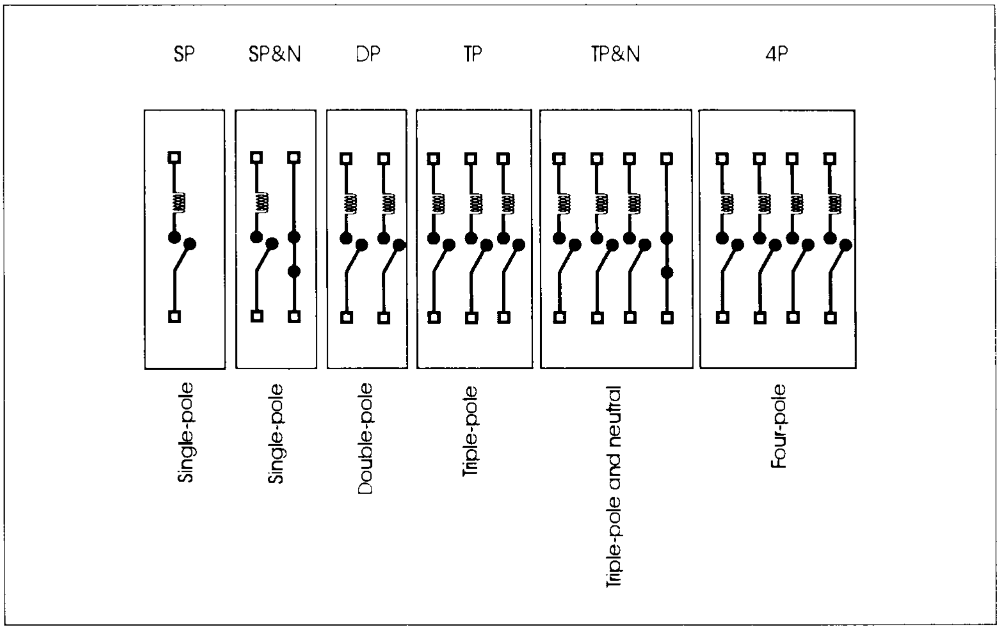


Figure 11.4: Identification of overcurrent switchgear in the terms of number of poles

11.4.1 Fuses – general

There are principally four types of fuses in common usage in LV installations, namely the semi-enclosed (rewirable) fuses to BS 3036, High Breaking Capacity (HBC) fuses to BS 88 and BS 1361 (commonly used in PES's cut outs) and the cartridge fuses to BS 1362 (commonly used in plug tops and fused connection units). All have their advantages and disadvantages as summarised in Table 11.4 and for compliance with Regulation 533–01–01 an indication of their nominal rating must be provided on or adjacent to the protective device. This regulation goes on to require that, where replacement is likely to be carried out by a person other than a skilled or an instructed person, fuses are to be of a type which cannot be replaced inadvertently by one of higher nominal rating.

Table 11.6: Minimum fault current magnitudes (amperes) required for automatic disconnection within stated time limits for common overcurrent protective devices

Ref	Nominal rating (A)		Fuses to BS 88 gG Parts 2 and 6				Fuses to BS 1361				Fuses to BS 3036				Fuses to BS1362		MCBS to BS 3871 and BS EN 60 898					
																	Type 1	Type 2	Type B	Types 3 and C	Type D	Type 4
		Times(s)	0.1	0.2	0.4	5	0.1	0.2	0.4	5	0.1	0.2	0.4	5	0.4	5	0.1s and 5 s					
A	5		—	—	—	—	30	25	22	14	45	32	24	13	—	—	20	35	25	50	100	250
B	6		36	31	27	17	—	—	—	—	—	—	—	—	—	—	24	42	30	60	120	300
C	10		60	51	45	31	—	—	—	—	—	—	—	—	—	—	40	70	50	100	200	500
D	13		—	—	—	—	—	—	—	—	—	—	—	—	95	60	—	—	—	—	—	—
E	15		—	—	—	—	97	80	70	46	180	125	90	43	—	—	60	105	75	150	300	750
F	16		120	95	85	55	—	—	—	—	—	—	—	—	—	—	64	112	80	160	320	800
G	20		175	150	130	79	180	155	135	82	260	180	130	60	—	—	80	140	100	200	400	1000
H	25		220	180	160	100	—	—	—	—	—	—	—	—	—	—	100	175	125	250	500	1250
I	30		—	—	—	—	280	240	200	125	450	300	210	87	—	—	120	210	150	300	600	1500
J	32		320	260	220	125	—	—	—	—	—	—	—	—	—	—	128	224	160	320	640	1600
K	40		400	340	280	170	—	—	—	—	—	—	—	—	—	—	160	280	200	400	800	2000
L	45		—	—	—	—	550	470	400	240	900	580	390	145	—	—	—	—	—	—	—	—
M	50		540	450	380	220	—	—	—	—	—	—	—	—	—	—	200	350	250	500	1000	2500
N	60		—	—	—	—	880	720	600	330	1300	800	550	205	—	—	—	—	—	—	—	—
O	63		710	590	500	280	—	—	—	—	—	—	—	—	—	—	252	441	315	630	1260	3150
P	80		1100	890	740	400	1100	950	800	460	—	—	—	—	—	—	320	560	400	800	1600	4000
Q	100		1400	1150	980	550	1800	1400	1200	630	2800	1800	1200	430	—	—	400	700	500	1000	2000	5000
R	125		1800	1500	1300	690	—	—	—	—	—	—	—	—	—	—	—	—	623	1263	2667	—
S	160		2400	2000	1700	900	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
T	200		3000	2500	2200	1200	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
U	315		—	—	—	1960	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
V	400		—	—	—	3000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
W	450		—	—	—	3340	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	500		—	—	—	3980	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Y	560		—	—	—	4430	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Z	630		—	—	—	5100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A1	710		—	—	—	6090	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B1	800		—	—	—	7530	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Note: The current magnitudes given relate to devices manufactured to take full allowance of the operating range specified. Where manufacturers state that devices have been designed to operate within a narrower range, the current magnitudes may be modified appropriately. The entries denoted by — indicate that devices are not normally available or their use is impracticable. From the values of fault current data given, the appropriate Z_s may be calculated by application of the formula $Z_s = U_o/I_F$.

11.4.2 Semi-enclosed fuses to BS 3036

The semi-enclosed fuse, more commonly known as a rewirable fuse, has enjoyed a long history of service in the United Kingdom. Despite its disadvantages, it is the most inexpensive device for overcurrent protection. Whilst most manufacturers have designed these fuses so that a fuse carrier of higher nominal rating cannot be inserted in the shielded circuit connection barrier, there is the real danger of inadvertent (and deliberate) replacement of the fuse element with a higher rating rendering the circuit unprotected against overload. As called for by Regulation 533–01–04 the preference is for cartridge type fuse-links but where semi-enclosed fuses are used the fuse element wire must be selected to meet the sizes set out in Table 53A of BS 7671. A major disadvantage of the semi-enclosed fuse is its low short-circuit capacity (1 kA to 4 kA – see Table 11.5 of this Guide) which restricts its use to locations where the fault level does not exceed these values or where back-up protection is provided by an upstream device that can break the prospective fault current. Another not inconsiderable drawback is the application of the correction factor C_d (0.725) to be applied as a multiplier to the tabulated current-carrying capacities of conductors resulting in an increase in conductor cross-sectional area of at least 38% and, in some cases, more.

11.4.3 High breaking capacity fuses to BS 88

High Breaking Capacity (HBC) fuses to BS 88 are extensively used in industrial and commercial installations and, to a lesser extent, in the domestic field. Their high short-circuit capabilities make them suitable for most installations and make life much easier for the designer when considering fault levels throughout the installation. The principal variations are the BS 88: Part 2 'gG' fuses for use by authorised persons and the BS 88: Part 6 for use in 230/400 V industrial and commercial installations. Fuses are further identified as follows:

- 'gG' – (general purpose) fuse with full short-circuit capacities for general application;
- 'gM' – fuse with full short-circuit capacities for motor circuit protection application;
- 'aM' – fuse with partial-range short-circuit capacities for motor circuit protection application.

Important considerations in design of circuits protected by these fuse-links, particularly in regard to discrimination, are the pre-arcing energy ($I^2t_{[pa]}$) and the total operating energy let-through ($I^2t_{[t]}$); these data, and the operating characteristics, are readily available from the manufacturers.

Figure 11.5 shows graphically the cut-off and energy let-through of current limiting overcurrent devices. The point A is where disconnection commences and the darkly shaded area $0At_1$ represents the pre-arcing energy, $I^2t_{[pa]}$ and the sum of both shaded areas, $0At_2$ portrays the total energy let-through $I^2t_{[t]}$ (units: A^2 s).

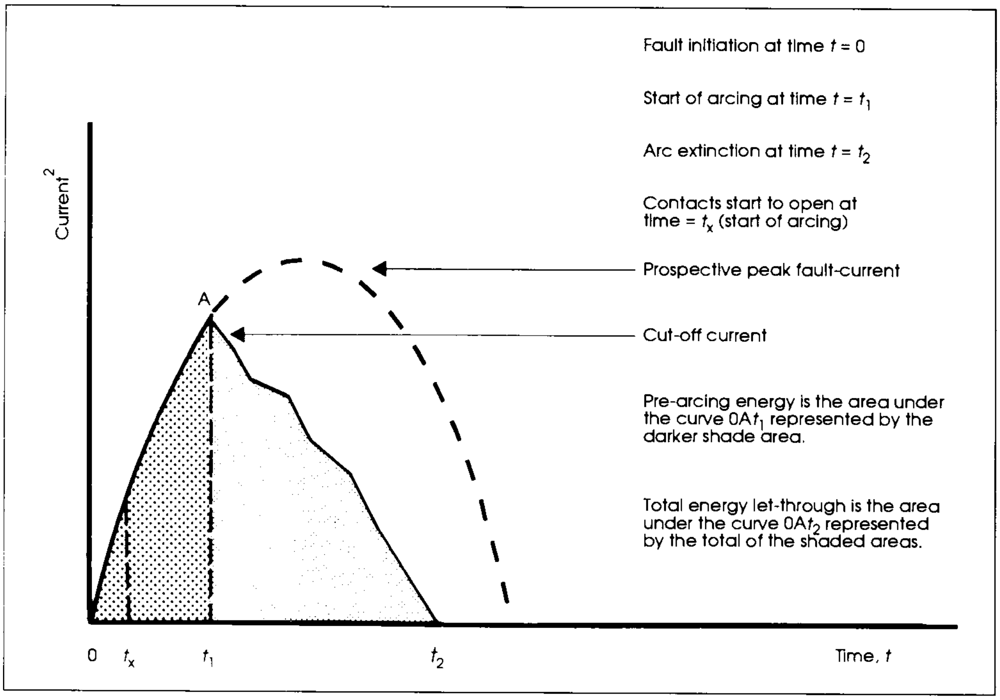


Figure 11.5: Cut-off current and energy let-through of a current-limiting overcurrent device

Figure 11.6 illustrates typical I^2t characteristics for a range of fuse-links (rms symmetrical current 33 kA) on which the $I^2t_{[pa]}$ and the total energy let-through $I^2t_{[t]}$ are shown. Figures 11.7 and 11.8 show the typical cut-off characteristics for a range of HBC fuses and typical cut-off currents again for HBC fuses (for a particular prospective current), respectively.

11.4.4 High breaking capacity fuses to BS 1361

Fuses to BS 1361 are more commonly used in circuits for installations in domestic and similar premises and EDs make extensive use of them in their household service cut-outs. They are of lower short-circuit capacity than BS 88 fuses but at 16.5 kA are adequate for most domestic applications. As with BS 88 fuses, operating data are freely available from the manufacturers.

11.4.5 Cartridge fuses to BS 1362

Cartridge fuses to BS 1362 are for general use primarily in the BS 1363 13 A fused plug and 13 A fused connection units. With a short-circuit capacity of 6 kA they are capable of coping with fault levels available on final circuits in most cases although this should be always be checked.

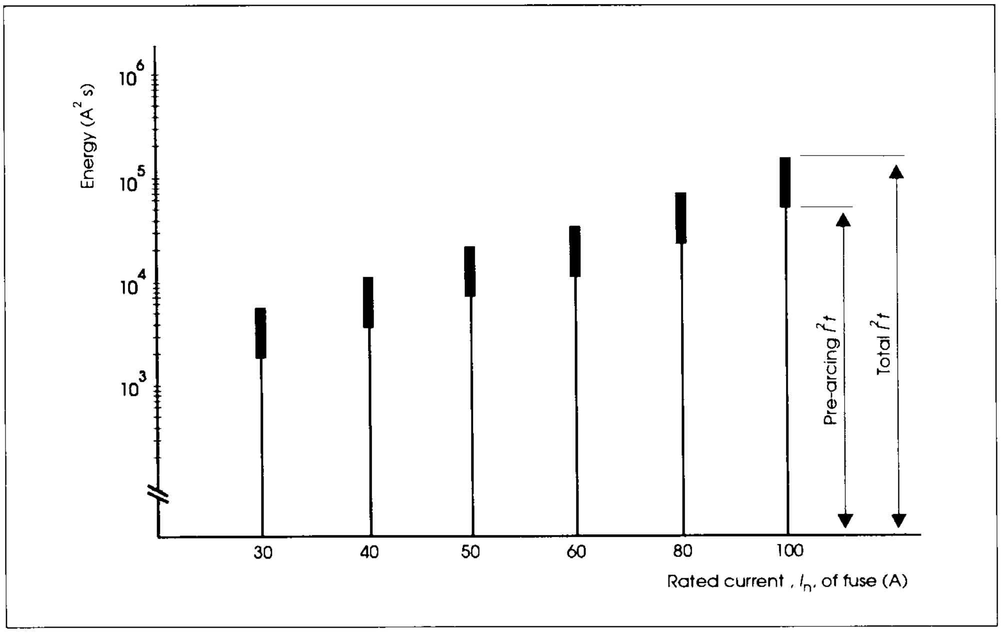


Figure 11.6: Typical I^2t characteristics of a range of fuses

11.4.6 Miniature circuit-breakers to BS 3871 and BS EN 60 898

There are three important parameters to consider when selecting an MCB:

- the nominal rating,
- the Type,
- the short-circuit capacity.

The nominal rating is easily identified as the nearest available rating in amperes equal to, or more than, the design current, I_b. The short-circuit capacity, marked on the device (e.g. as M1, . . . , M16) must be not less than the prospective fault current (short-circuit and earth fault current) unless a back-up device is employed upstream.

As illustrated in Figure 11.9, there are seven Types of MCBs currently in use in the industry, though BS 3871 has now been replaced by BS EN 60898. They vary in their operating characteristics so that different current magnitudes are required to operate the devices instantaneously (defined as within 100 ms) although, within small variations, their overload characteristics are the same in all cases. The constructional Standard (BS EN 60 898) permits instantaneous operation to occur between gates (within a range) and this is defined for each Type in terms of the nominal rated current, I_n. Figure 11.10 illustrates a typical operating characteristic of an MCB and Table 11.7 details the main features of the various Types and the uses to which they are commonly put. When considering discrimination the

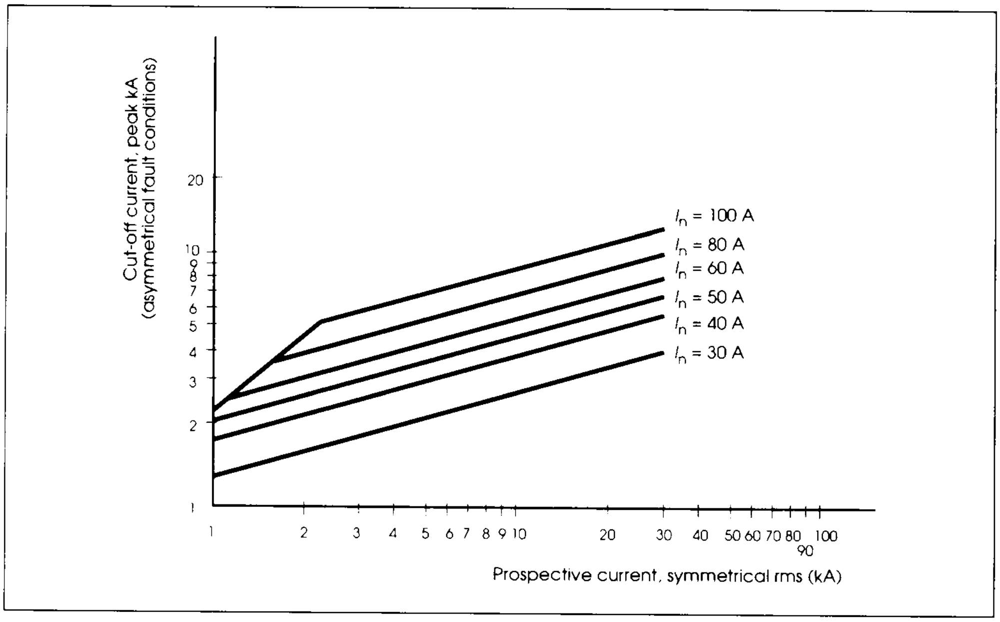


Figure 11.7: Typical cut-off characteristics of a range of MCB fuses

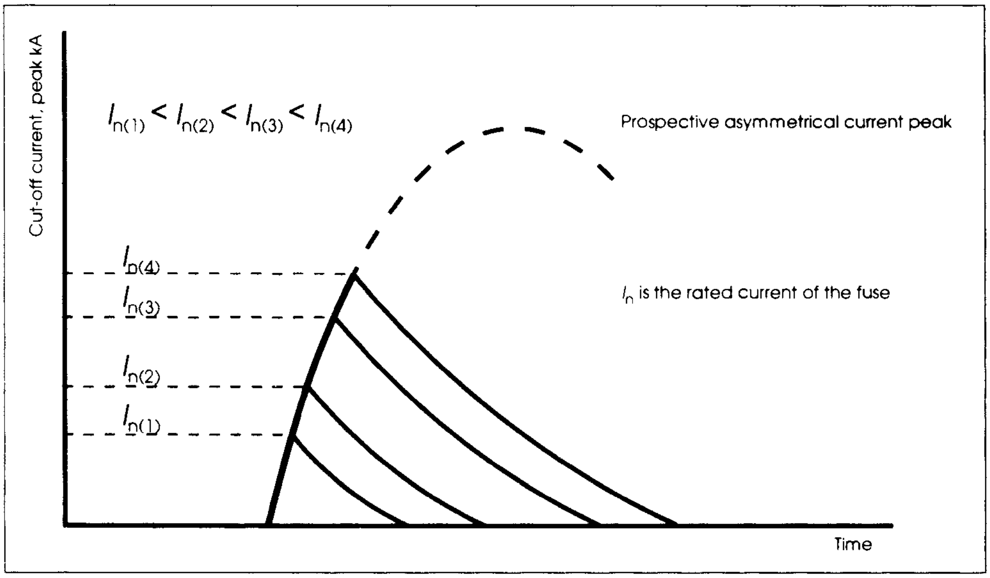
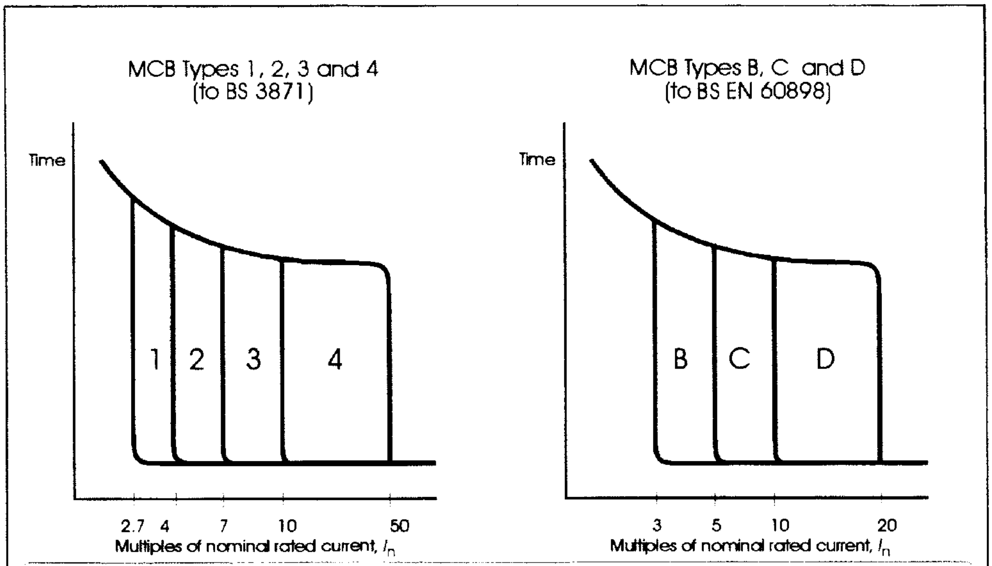


Figure 11.8: Typical cut-off currents for a range of HBC fuses, for a particular prospective current

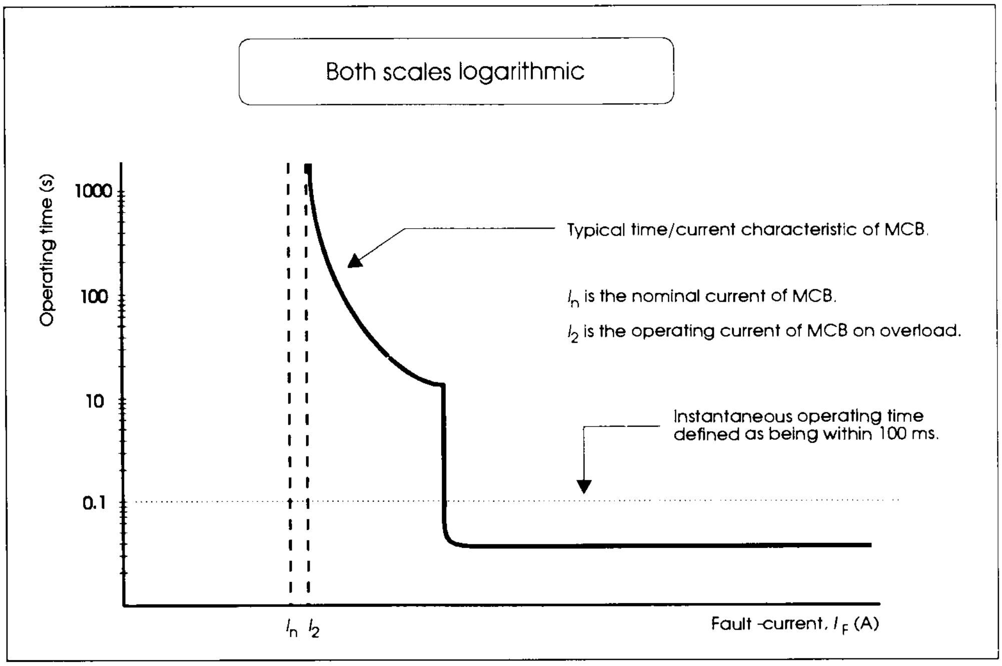
whole range for fault current operation needs to be taken into account whereas for protection against indirect contact the worst case value is all that it is necessary to consider. Limiting values of Z_s are based on these 'worst case' values.



Instantaneous disconnection (within 100 ms) occurs within a range of currents expressed as multiples of nominal rated current, I_n.

For example, a Type C, 32 A MCB will disconnect (in100 ms) with currents in the range 160 A to 320 A (5 to 10 I_n).

Figure 11.9: MCB characteristics



Both scales logarithmic

Typical time/current characteristic of MCB.

I_n is the nominal current of MCB.

I_2 is the operating current of MCB on overload.

Instantaneous operating time defined as being within 100 ms.

Figure 11.10: Typical operating characteristics of an MCB

Table 11.7: Miniature circuit-breakers to BS 3871(2) and BS EN 60 898 – main features

Ref	Type	Nominal rating, I_n (A)	Overload characteristic(1)	Current band causing instantaneous operation, I_{inst}	Current necessary for instantaneous operation	Common utilisation
(i)	1	$I_n \le 10$ $I_n > 10$	1.50 I_n 1.35 I_n	2.7 I_n to 4.0 I_n	4 I_n	General circuits where load does not exhibit high inrush characteristics. Tungsten lighting loads.
(ii)	B	All	1.45 I_n	3 I_n to 5 I_n	5 I_n	
(iii)	2	$I_n \le 10$ $I_n > 10$	1.50 I_n 1.35 I_n	4 I_n to 7 I_n	7 I_n	General circuits where load only exhibits moderate inrush characteristics. Large tungsten and fluorescent lighting loads.
(iv)	C	All	1.45 I_n	5 I_n to 10 I_n	10 I_n	General circuits where load exhibits moderate to high inrush characteristics. E.g. motor loads, air conditioning plant, etc.
(v)	3	$I_n \le 10$ $I_n > 10$	1.50 I_n 1.35 I_n	7 I_n to 10 I_n	10 I_n	
(vi)	D	All	1.45 I_n	10 I_n to 20I_n	20 I_n	General circuits where load exhibits high to harsh inrush characteristics. E.g. X-ray equipment, welding equipment, DOL motors, circuits with transformers, etc.
(vii)	4	$I_n \le 10$ $I_n > 10$	1.50 I_n 1.35 I_n	10 I_n to 50 I_n	50 I_n	

Notes (1) Current required for overload operation within 'conventional time' at reference temperature. Conventional time for Types 1, 2, 3 and 4 and for Types B, C and D up to $I_n \le 63$ A is 1 h. For Types B, C and D of $I_n > 63$ A the conventional time is 2 h.

(2) BS 3871 was withdrawn on 1 July 1994.

11.4.7 Moulded case circuit-breakers to BS EN 60 947–2

Moulded case circuit-breakers (MCCBs) are commonly used as an alternative to HBC fuses for protecting circuits rated at 100 A or more. They are used extensively to protect against fault current and in some cases against overload. Their initial cost is high compared with switchgear incorporating HBC fuses but they are often preferred in areas under the control of skilled persons where breakers with adjustable thermal-magnetic trip mechanisms may be used (on the higher nominally rated units) which can aid discrimination. BS EN 60947 permits these devices to be calibrated at 20°C or 40°C so it is important to know the temperature to which the device has been calibrated before making a selection.

Where devices with adjustable settings are employed in areas accessible only to authorised personnel it will be beneficial if a notice, recording the settings, is affixed to or near the device. Adjustable fault current settings are often of the form of two distinct calibrated and marked levels (e.g. 2000 A and 4000 A).

The short-circuit capacities of MCCBs can be high (e.g. 150 kA) which, in circumstances of circuits with high fault levels, make them attractive to the designer. The time/current characteristics of such devices are published by the manufacturers and the designer should consult with them in matching the device with the particular load and other relevant factors.

11.5 Residual current devices

11.5.1 Residual current devices – general

Residual Current Devices (RCDs) is the generic term for a range of devices including those that have previously been known as Residual Current Circuit-Breakers (RCCBs). Also included in this term are the Residual Current Breaker with Overcurrent device (RCBO), which incorporates an MCB with the RCD, the socket-outlet with Residual Current Device (SRCD) and the Portable Residual Current Device (PRCD).

There are two principal types of operating characteristics of RCDs, namely, the basic type and the polarised type which are dealt with to some extent later. There are also RCDs with a time-delay operation which are particularly useful in the pursuit of discrimination.

Regulations 531–02–01 to 531–02–09 set out the requirements for RCDs generally and Regulations 531–03–01, 531–04–01 and 531–05–01 call for the additional requirements as they relate to TN, TT and IT systems respectively. Table 11.8 summarises these various considerations.

In a fixed installation there are a number of instances where it is essential to employ an RCD and these are summarised in Table 11.9.

RCDs in general should be capable of withstanding the prospective fault current at the point of insertion into the circuit (see Regulation 434–03–01) unless they have back-up protection in which the energy-withstand of the device must more than match the energy let-through of the upstream device. It should also be borne in mind that when an RCD forms part of a consumer's unit to BS 5486 Part 13, which itself has a 'conditional rating', the device may be used for prospective fault currents up to 16 kA.

Where RCDs meet all the prerequisites for an isolating device they may be used for isolation purposes. Where remote from the current-using device they serve they must be securable in the open (OFF) position for compliance with Regulation 476–02–02. It is vital to appreciate that RCDs are *not* devices suitable for providing protection against overcurrent.

In a domestic installation fed from a TT source and with 'front end' protection provided by an RCD (also serving as a main switch, where suitable), it should be recognised that the RCD will only protect equipment that is downstream of it. For this reason, it is advisable to use a consumer's unit of insulated construction with a wiring system which

Table 11.8: Regulatory requirements for RCDs

Ref	Regulation	Essential requirements
A	531-02-01	RCD must disconnect all phase conductors of the protected circuit at substantially the same time.
B	531-02-02	All live conductors (phase[s] and neutral) must pass through the transformer magnetic circuit (but not the protective conductor).
C	531-02-03	The residual operating current must be appropriate to the type of earthing system as required by Section 413 (indirect contact).
D	531-02-04	Account must be taken of earth leakage currents (which are not fault currents) so that the device selected is not prone to unwanted and/or unnecessary tripping. (Accumulative effects of leakage current need to be assessed as do the effects of capacitors connected between live conductors and Earth.)
E	531-02-05	Where a circuit normally requiring a protective conductor is not so equipped, the RCD must not be considered to provide protection against indirect contact (even if $I_{\Delta n} \leq 30$ mA).
F	531-02-06	Where an RCD is energised or de-energised from an auxiliary source, it must be supervised, inspected and tested by a skilled or instructed person or such protection must fail to safety (i.e. protection is maintained even in the event of power failure to auxiliary source).
G	531-02-07	The RCD must be located so that it is not adversely affected by the presence of magnetic fields generated by other equipment. (Magnetic fields may have serious consequences on the transformer magnetic circuit of the RCD and may cause malfunction and may not fail to safety.)
H	531-02-08	When used for protection against indirect contact in conjunction with, but separate from, an overcurrent device, it must be ascertained that the RCD is capable of withstanding without impairment all mechanical stresses arising from a fault on the downstream circuit(s).
I	531-02-09	Where two or more RCDs are connected in series, effective discrimination to prevent danger must be provided.
J	531-03-01	In TN systems where the requirements of Regulation 413-02-08 ($Z_s \leq U_o/I_a$) cannot be met, an RCD may be used for indirect contact. When so used the exposed-conductive-parts must be connected to the MET or separate earth electrode. When a separate earth electrode is used, the RCD protected circuit must be treated as part of a TT system and subjected to the requirements of Regulations 413-02-18 to 413-02-20.
K	531-04-01	In an installation forming part of a TT system and a sole RCD is used, this device must be positioned at the origin (front end) unless the equipment between the RCD and the origin is of Class II construction or equivalent insulation. See also Figure 11.11.
L	531-05-01	In IT systems where disconnection of a first fault is not contemplated, the non-operating residual current must not be less than the first fault circulating current.

does not employ exposed-conductive-parts between it and the ED's meter. Where a metalclad consumer's unit is used, care should be taken to determine that the possibility of an earth fault occurring on the upstream side of the RCD is minimised or eliminated. One option is by the use of suitable protection of the incoming 'tails' as shown in Figure 11.11. It should not be forgotten that an earth fault developing on a metalclad consumer's unit would produce a touch voltage, with respect to 'true earth' on the consumer's unit and all other conductive parts. This touch voltage would persist until the supplier's fuse operated and in some cases may remain indefinitely. Incoming supply cables to the metalclad unit should be insulated and sheathed, enter via an insulated bush and cable clamp, and should be kept as short possible within the enclosure so as to minimise the possibility of an earth fault.

Table 11.9: Instances where RCDs will be needed, if appropriate

Ref	**Locations**	**System type**	**Regulation**	**Requirement qualifications**
A	Generally.	TT	413-02-18 to 413-02-20	Where the phase-earth loop impedance is too high to effect protection against indirect contact by use of an overcurrent protective device (e.g. MCB). Regulation 413-02-19 expresses a preference for RCDs in TT systems.
B		TT	471-08-06	For every LV socket-outlet in a TT system. See also Regulation 413-02-16 ($Z_s\ I_{\Delta n} \leq 50\,\text{V}$).
C		All	412-06-01 and 412-06-02	Where it is necessary to provide supplementary protection against direct contact ($I_{\Delta n} \leq 30\,\text{mA}$).
D		All	471-16-02	Where a socket-outlet rated at 32 A or less may be expected to supply portable equipment outdoors.
E		All	471-16-01	Where a circuit, rated at 32 A or less, feeds other than via a plug and socket-outlet to supply portable equipment outdoors.
F		All	413-02-04	Where disconnection times cannot be achieved using an overcurrent protective device and where supplementary bonding has not been effected.
G	Swimming pools	All	602-07-01 and 602-07-02	As specifically required by these regulations.
H	Construction sites.	All	604-04-07	Where protection against electric shock cannot be provided by an overcurrent device.
I	Agricultural and horticultural premises.	All	605-03-01	For circuits supplying socket-outlets ($I_{\Delta n} \leq 30\,\text{mA}$).
J		All	605-10-01	For protection against fire as specified ($I_{\Delta n} \leq 500\,\text{mA}$).
K	Restrictive conductive locations.	All	606-04-01	Where Class II equipment is used ($I_{\Delta n} \leq 30\,\text{mA}$).
L	Caravans and motor caravans.	All	608-03-02	Where EEBADS method of protection against indirect contact is used (the usual method). RCD required to be double pole.
M	Caravan parks.	All	608-13-05	As required by Regulation 608-13-05 ($I_{\Delta n} \leq 30\,\text{mA}$)

11.5.2 Residual current devices – principles of operation

Figure 11.12 illustrates, in schematic single-phase form, the normal core-balancing RCD main components. The load is shown in fault condition with current allowed to pass via the protective conductor and earth electrode (e.g. separate electrode to the star/neutral of the supply transformer. In a normal healthy circuit, the phase and neutral currents would be of the same magnitude and would produce equal and opposing magnetic flux in the common transformer core of the RCD, through which the conductors pass. When a fault occurs on the downstream phase conductor, the fault current flows down the protective conductor. There is, therefore, an imbalance between the phase and neutral conductors and hence the resultant magnetic

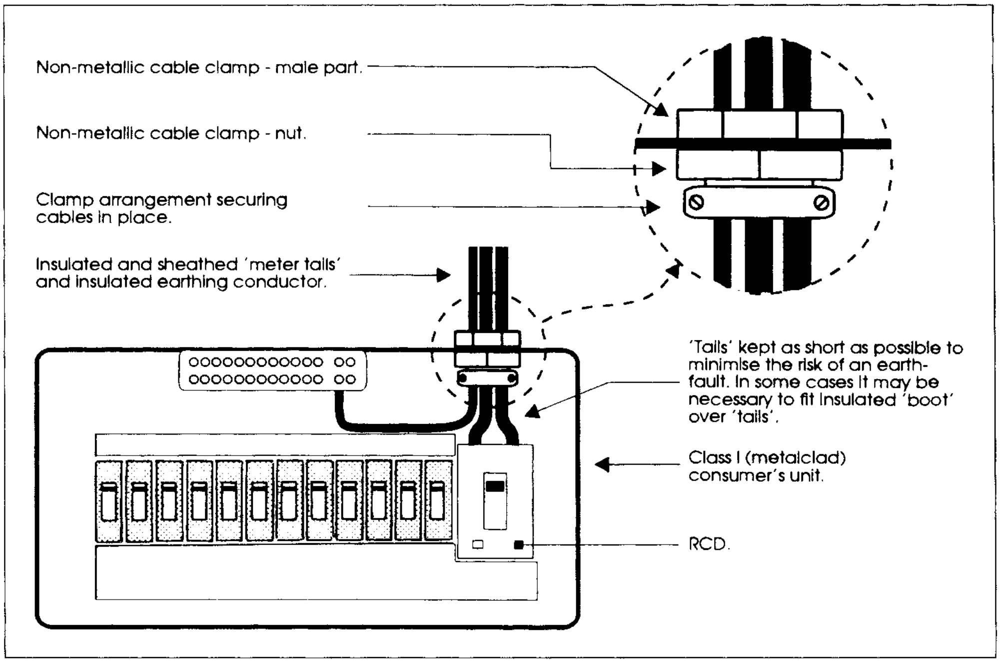


Figure 11.11: Class I consumer's unit on a TT system

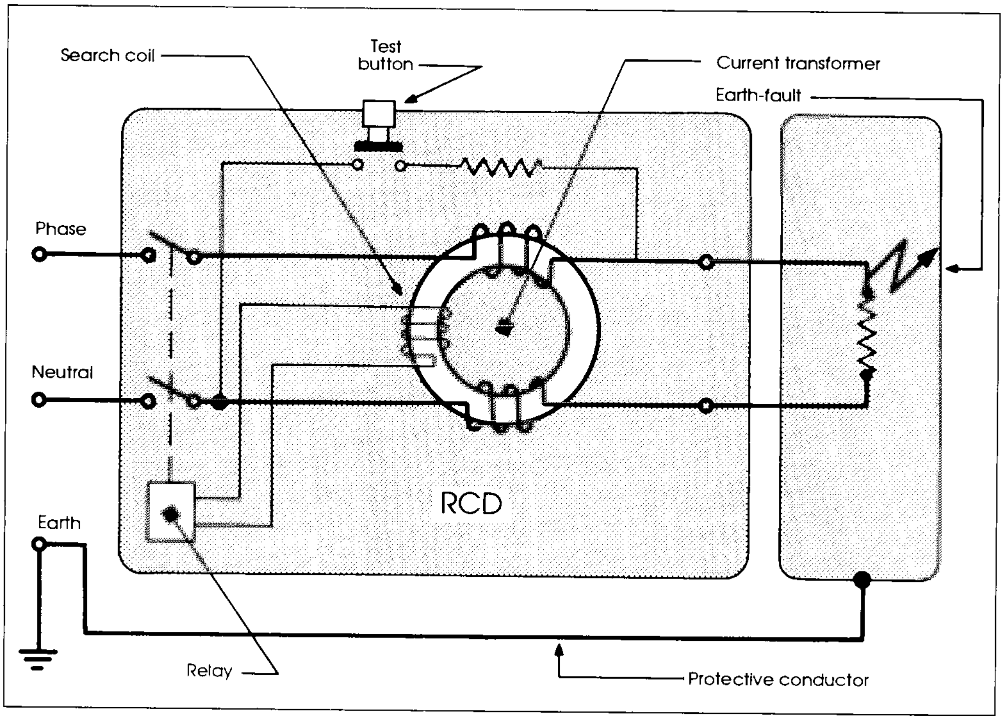


Figure 11.12: Principal components of an RCD

flux operates the relay and disconnects the circuit. In many cases the search coil produces insufficient power to operate the tripping mechanism and some means of amplification will be necessary. This may be achieved in a number of ways including the search coil output fed into an solid state amplifier.

It should be noted that the test button, when depressed, allows current to flow from the phase conductor on the downstream side of the current transformer to the neutral on the upstream side thereby creating an imbalance in the transformer and causing the device to operate. This test therefore only serves to confirm or otherwise that the device itself performs satisfactorily. It does *not* indicate that the means of protection against electric shock is adequate and effective because the protective conductor(s) and the means of earthing are not included in the test.

Another method of amplification is to employ the polarised relay principle (illustrated in Figure 11.13) in which a permanent magnet is employed. The weak magnetic field set up by the magnet retains the armature (and tripping mechanism) under normal conditions. Under fault conditions the output from the search coil 'de-energises' the magnet sufficiently for the armature to be released (powered by the operating spring) and thus disconnection is effected.

Although Figures 11.12 and 11.13 show the single phase system, the principle holds good for both three-phase three-wire and three-phase four-wire systems. This is because the phasor sum of currents in the live con-

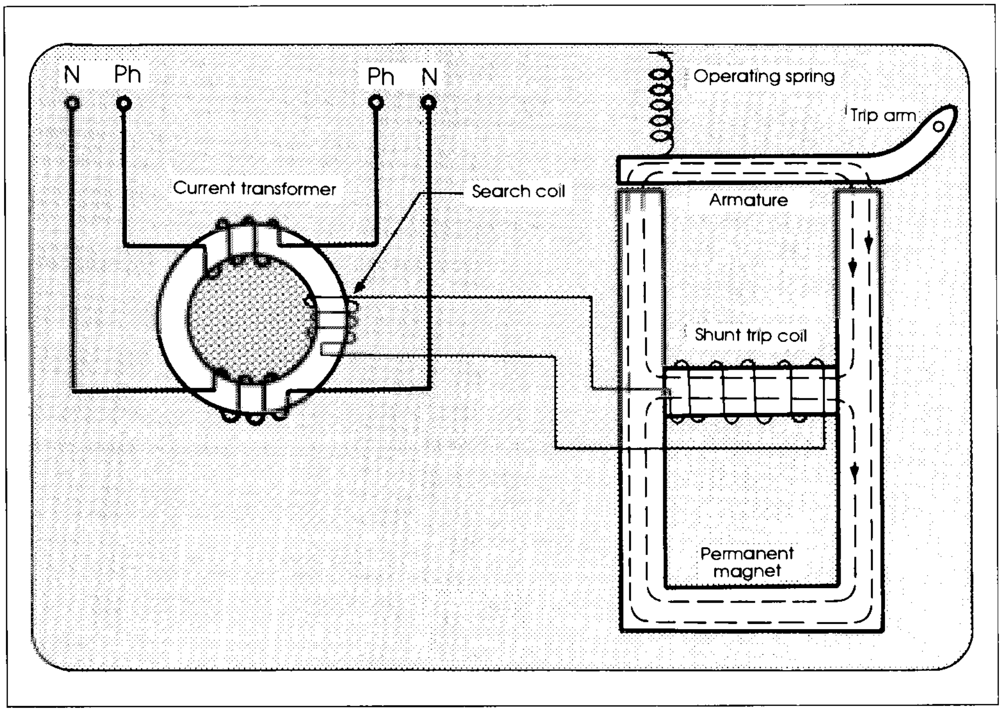


Figure 11.13: RCD polarised relay mechanism

ductors always equals zero in a healthy circuit and only departs from zero when fault current flows elsewhere (e.g. a protective conductor or through a human body) to Earth.

As Table 11.1 shows, BS EN 61008 covers the constructional specification for RCDs which are identified in three groups or types of delay:

- 'O' type – Ordinary device with no in-built type delay;
- 'S' type – Selectable in-built time delay;
- 'G' type – General very small in-built time delay for the purpose of preventing unwarranted tripping.

The 'S' type is useful in achieving discrimination with a downstream RCD in series. The 'G' type provides for a very small time-delay and may be particularly useful in circumstances where the circuit supply is prone to high frequency 'spikes'.

It has to be borne in mind that RCDs to BS 4293 permit the device to operate above 0.5 $I_{\Delta n}$ and that for an RCD of 30 mA sensitivity it may operate (trip) at a residual current above 15 mA. Using such a device at the 'front end' of an installation is generally undesirable because the cumulative effects of leakage currents of the variously connected appliances may exceed this value. This arrangement is unlikely to afford compliance with Regulations 314–01–02 and 531–02–04.

The safety requirements embodied in the appropriate British Standard set out the limits for permitted earth leakage and these are normally expressed in mA per kVA for stated conditions (e.g. temperature and humidity). For some items of equipment these limits are quite generous and for others no limit is set. This makes it important for the designer to check with the appropriate Standard(s) in order to evaluate the cumulative effects of earth leakage.

Many installations now incorporate loads which are used for control and monitoring and for information technology (IT) and these often include electronic solid-state components. This phenomenon has increased the possibility that, in the event of an earth fault, the fault current may be of a non-sinusoidal waveform. In such circumstances, the designer should consider using RCDs which include pulsating d.c. current protection. Such waveforms may be of the rectified half-wave or chopped rectified half-wave forms as illustrated in Figure 11.14.

Every RCD must be equipped with a manual test button to simulate earth fault conditions. This should be operated by the installation user at intervals not exceeding three months. It is imperative therefore that the user is advised of this requirement in the Operations and Maintenance Manual and further have their attention drawn to the need for testing by an affixed notice in compliance with Regulation 514–12–02.

11.6 Identification of overcurrent protective devices

Identification of equipment has to some extent been dealt with earlier in Chapter 9 of this Guide. Section 533 of BS 7671 makes further demands for identification relating to overcurrent devices.

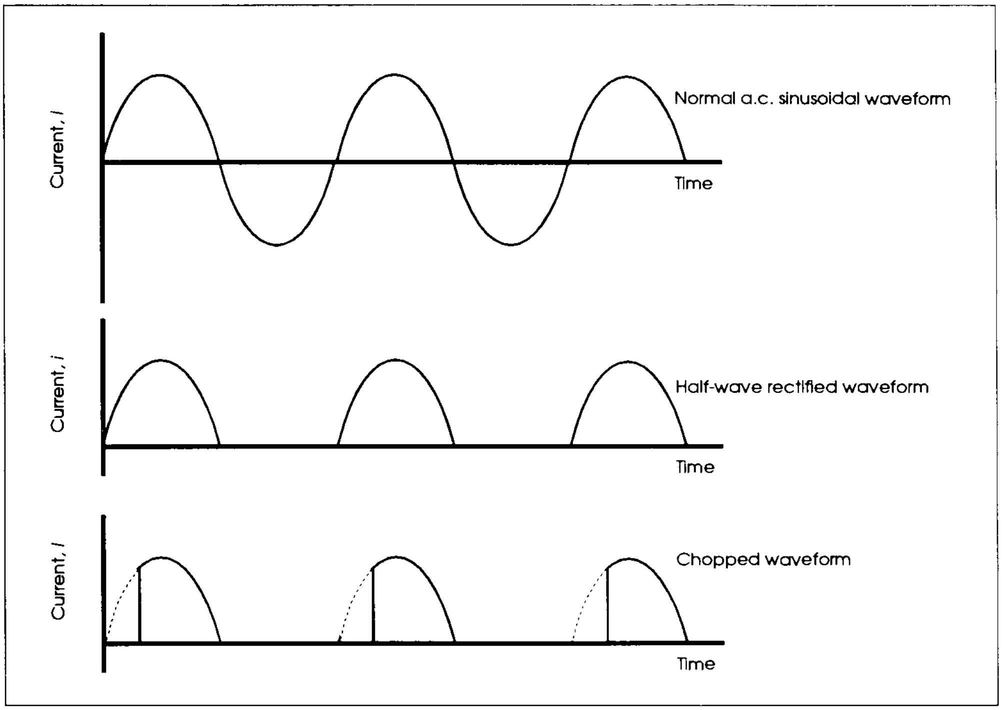


Figure 11.14: Examples of pulsating d.c. waveforms

For *all* overcurrent devices (fuses and circuit-breakers), Regulation 533–01–01 demands that there must be an indication on (or adjacent to) the device of the nominal current rating of the circuit it protects. Normally this is achieved by the nominal rating signified on the device itself but, in some cases, it may be necessary to provide further notices.

Where semi-enclosed (rewirable) fuses are employed the nominal current and the size of the tinned copper fusewire need to be matched as given in Table 53A of BS 7671. It is not difficult to envisage that these devices might be prone to abuse and misuse. This regulation (533–01–01) demands that where they are likely to be replaced by other than skilled or instructed person (i.e. in nearly all practical situations), they must be of a type which cannot be inadvertently replaced by one of higher rating. This is normally achieved by the use of fuses and their associated carriers and shields being manufactured in discrete sizes. For example, a 30 A fuse cannot be inserted into a 5 A shield. This does not, of course, prevent these fuses being fitted with incorrectly sized tinned copper fusewire either inadvertently or indeed intentionally. Additionally, Regulation 533–01–02 calls for fuses, where they are likely to be replaced by other than skilled or instructed persons, to be marked or an indication provided near the device with the relevant type (e.g. British Standard Number and any further necessary qualifications) or be of a type that cannot be replaced by a fuse of similar rating but of a higher fusing factor. In any event, the designer may consider it necessary to provide a comprehensive indication of the device's fault current capacity nominal rating, type and Standard specification reference.

As required by Regulation 533–01–03, where a fuse is intended to be capable of withdrawal and insertion whilst it is energised, it is required to be of a type which permits such operations to be carried out without the risk of danger. Where such facility is envisaged the designer would need to establish that no danger could result from, for example, current arcs and molten metal in motion when breaking a circuit under load conditions or replacing a device under load or fault conditions.

As mentioned earlier in this chapter, where a circuit-breaker is equipped with adjustable fault current protection (and not subject to operation by other than a skilled or instructed person), a notice indicating the appropriate settings should be affixed on or near the device. These circuit-breakers must not be used where a person other than a skilled or instructed person may operate the device unless the settings can only be modified by means of a key or tool (to satisfy Regulation 533–01–05). Furthermore the settings, if adjustable, must be visually indicated, but access to this information may involve the opening of the enclosure.

11.7 Discrimination

11.7.1 Discrimination – general

Regulation 533–01–06 demands that where it is necessary to prevent danger by discrimination, the characteristics and settings of protective devices be such that discrimination is achieved. Whilst it is true that discrimination is only necessary where danger might otherwise occur, the designer would wish to apply the principle to all circuits in order to reduce and minimise shut-down of circuits. In terms of convenience and operational considerations, the consequences of faults should be restricted to the circuit concerned.

Discrimination relates to all faults whether they be short-circuits (faults between live conductors) or phase-earth faults. Consideration must be given to overcurrent devices and, where employed, residual current devices where two or more such devices are configured in series. In simple terms, discrimination is achieved when a circuit under fault conditions causes only the protective device of the affected circuit to disconnect. Upstream protective devices remain unaffected so that only the faulty circuit is disconnected from the supply. In order to carry out an analysis of discrimination it is necessary in many cases to know the fault levels (i.e. the prospective fault currents) at the various points of insertion of all the overcurrent protective devices. It is necessary to establish fault levels and the margins by which they are likely to change. For example, changes may occur because of modifications to the supply network. Discrimination should be designed to take account of this range.

Whilst it is not possible to consider all the possible combinations of protective devices in series, an attempt is made here to address the more common ones. In all cases the designer should obtain the necessary operating characteristics from the manufacturers.

11.7.2 Discrimination – HBC/HBC fuses

In effecting discrimination between fuses in series, the principal factor is to establish that the total energy let-through, $I^2_{(t)}$, of the major fuse (the upstream device) does not exceed the pre-arcing energy, $I^2t_{(pa)}$, of the minor fuse (downstream device) (see Figure 11.6). It should be borne in mind that at low fault levels the difference between $I^2t_{(t)}$ and $I^2t_{(pa)}$ is very small and can be ignored for this purpose.

Two methods exist in determining whether or not discrimination will be achieved, namely that of comparing pre-arcing times of the devices or by visually correlating their time/current characteristics. For this technique, it is important to establish the fault level at the various points in order to establish the approximate pre-arcing times and in particular whether they are more than or less than 20 ms. Where pre-arcing times exceed 20 ms an assessment may be made using the time/current characteristics but otherwise this should be made by assessing the I^2t characteristics.

Most manufacturers publish data on their fuses including pre-arcing energy and total energy let-through (A^2 s) from which discrimination can be assessed. In many cases, a table of fuse data is provided, for convenience, showing where discrimination will be achieved using various nominal ratings. Fuses complying with BS 88 Parts 2 and 6, for example, are deemed to discriminate with each other at fault currents up to 80 kA providing that a ratio of 1.6:1 (nominal current ratings) between the major and minor fuse-links is maintained.

Take a hypothetical small three-phase distribution example shown schematically in Figure 11.15 (in single-line form). All overcurrent protective devices are fuses to BS 88: Part 2 having the nominal ratings shown on the figure. Consider a fault occurring at each of the four points marked A, B, C and D in turn. Using the discrimination ratio of 1.6:1, the results are given in Table 11.10.

It can be seen from the above simplistic example that the designer needs to address discrimination and not just the loading in the selection of protective devices in order to provide a safe installation. In the two cases shown in Table 11.10 where the ratios are less than 1.6:1, it may be that in practice discrimination may be achieved at certain fault levels. To be sure, it would be necessary to consider altering the ratio by, for example, replacing fuses No 3 and No 13 with fuses of nominal ratings 100 A and 35 A respectively assuming, of course, that the circuit loading will permit.

11.7.3 Discrimination – MCBs/MCBs

Figure 11.16 illustrates a common occurrence of two MCBs in series. Both devices are Type 2 and the upstream unit, the major device, has been designated A and the minor device is shown as B. Since both devices are Type

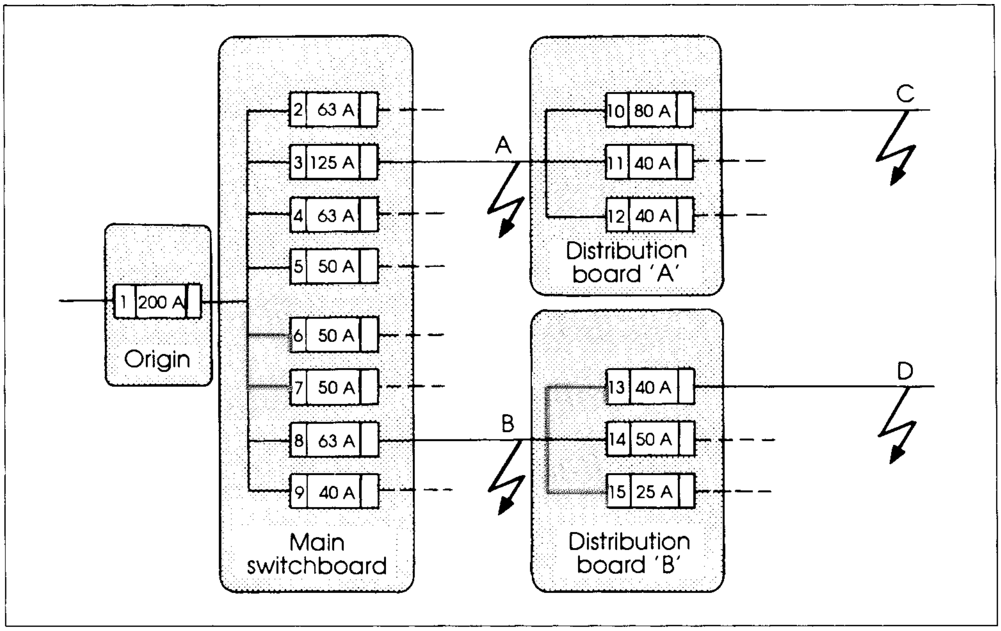


Figure 11.15: Small distribution layout using HBC fuses

Table 11.10: Discrimination (see Figure 11.16)

Fault location	Major fuse		Minor fuse		Ratio⁽¹⁾	Discrimination assured	Comments
	Ref No	Nominal rating (A)	Ref No	Nominal rating (A)			
A	1	200	3	125	1.60:1	Yes.	Within the ratio limits.
B	1	200	8	63	3.17:1	Yes.	Within the ratio limits.
C	1 3	200 125	3 10	125 80	1.60:1 1.56:1	Yes. No⁽²⁾.	Within the ratio limits. Not within the ratio limits.
D	1 8	200 63	8 13	63 40	3.17:1 1.57:1	Yes. No⁽²⁾.	Within the ratio limits. Not within the ratio limits.

Notes: (1) Ratios given are approximate.
(2) By consideration of the I^2t characteristics of the devices, it may be possible to show that discrimination can be achieved.

2 the instantaneous operation (tripping) will occur between four and seven times their nominal rating. When evaluating protection against indirect contact we need only consider the 'worst case' instantaneous operating current (i.e. 7 × I_n), but in addressing discrimination we need to have regard to the range (4 –7 times I_n) within which instantaneous tripping occurs.

It is apparent from Figure 11.16 that there will be discrimination between the two MCBs under overload conditions occurring downstream of MCB 'B'. Under fault conditions (both short-circuit and earth fault) it is

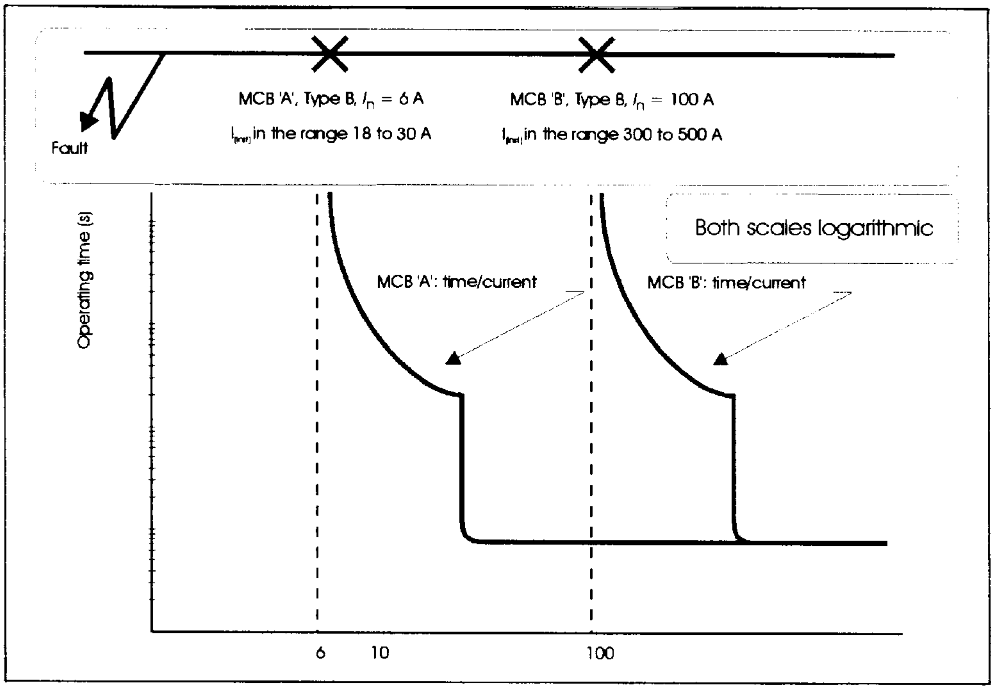


Figure 11.16: Discrimination between MCBs

necessary to know the prospective short-circuit current and the prospective earth fault current in order to determine whether or not discrimination is achieved.

By way of a practical example, let MCB 'A' have a nominal rating of 100 A and MCB 'B' be rated at 6 A, the latter feeding a 230 V lighting circuit. Taking three cases, let us first consider the case with a prospective short-circuit current of 230 A ($Z_{p\text{–}n} = 1.0\ \Omega$) and prospective earth fault current of 209 A ($Z_s \simeq 1.1\ \Omega$). Clearly we should take the higher value of prospective fault current represented here by the short-circuit fault current 230 A. It is easy to see that discrimination will be achieved because the prospective short-circuit fault current is less than three times the nominal rating (representing the lower end of the instantaneous tripping range) of MCB 'A'.

For the second case, consider a circuit with the same components but where the prospective earth fault current is 750 A ($Z_s \simeq 0.31\ \Omega$). It is obvious that both MCBs will trip at this fault level and therefore discrimination will not be obtained with the consequence of losing power to all circuits fed by MCB 'A'. For the third and final case, let us attribute a prospective earth fault current of 328 A ($Z_s \simeq 0.7\ \Omega$) where it will be evident that discrimination may be achieved (depending on the particular devices in question) but the designer could not claim discrimination with any degree of certainty and would wish to reconsider the distribution layout and amend it by, for example, inserting an intermediate device.

11.7.4 Discrimination – MCBs/fuse

MCBs and fuses are often used in series and Figure 11.17 shows typical time/current characteristics of an MCB and a fuse. If selected correctly these devices will present little difficulty in achieving discrimination under overload conditions. However, it can be readily seen from the characteristic curves that discrimination will depend to a large extent on the prospective fault current magnitude. The figure illustrates that discrimination may be achieved for fault currents approaching $I_{F(m)}$. For fault currents at that value discrimination will be doubtful and for fault currents exceeding that value there will be no discrimination.

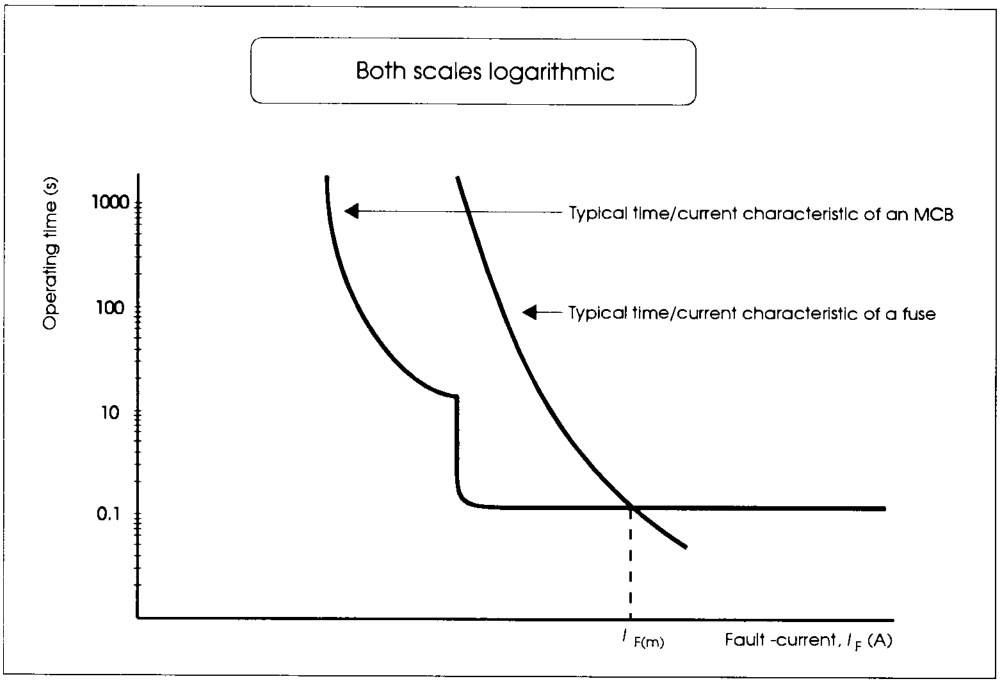


Figure 11.17: Typical time/current characteristics of an MCB and a fuse-link

Figure 11.18 shows the time/current characteristics of MCBs rated at 16 A, 20 A and 32 A together with that of a 13 A BS 1362 fuse (commonly used in 13 A plug tops to BS 1363 and fused connection units). Again we can see that discrimination will depend on the prospective fault current. Taking the 32 A MCB and the fuse characteristic curves to illustrate the point, we can see that at fault levels above point X (about 120 A) discrimination will not be achieved. It may be that in the case of final ring circuits protected by a 32 A MCB the lack of discrimination with the BS 1363 plug top fuse will not be an important consideration from the safety standpoint and the designer may feel that such a situation could be tolerated.

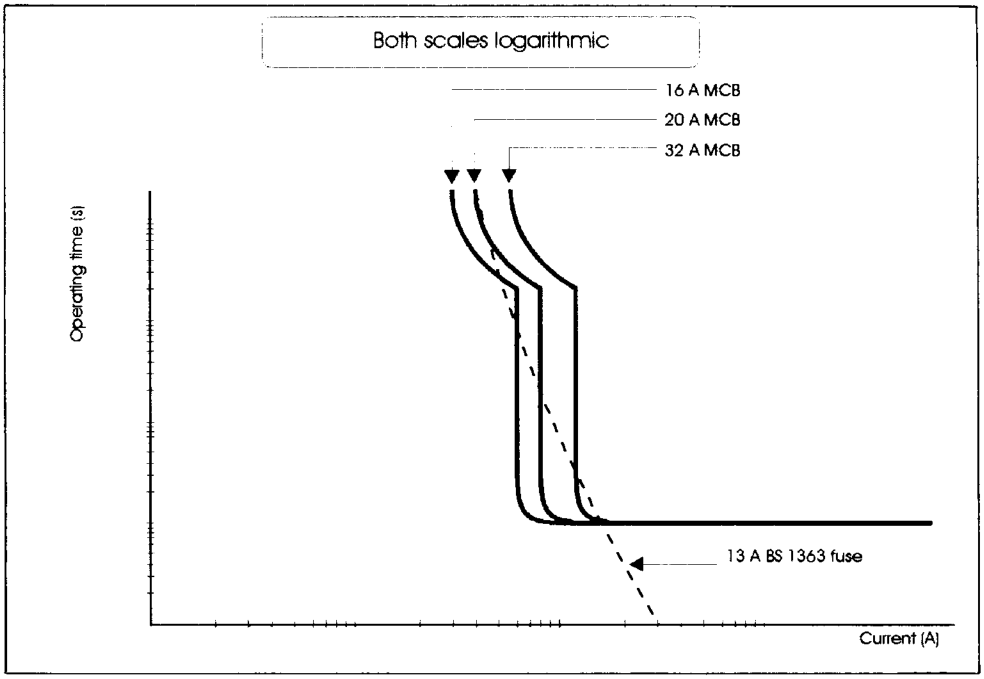


Figure 11.18: Time/current characteristics of MCBs (16 A, 20 A, and 32 A) and a BS 1363 fuse-link

11.7.5 Discrimination – RCDs

Where RCDs are used to protect against electric shock (indirect contact). Regulation 531–02–09 calls for discrimination between two or more such devices in series. The first fundamentally important point to recognise is that RCDs *do not* limit the earth fault current, I_F. For example, an RCD with rated residual operating (tripping) current, $I_{\Delta n}$, of 100 mA does not limit the fault current to 100 mA. Earth fault current is a function of the nominal voltage to earth, U_o, and the phase-earth loop impedance, Z_s, such that $I_F = U_o \div Z_s$. For a fault current of 100 mA on a 230 V circuit, the impedance Z_s would be 2300 Ω ($230 \div 100 \times 10^{-3}$). Even on a TT system it is unlikely that such a high phase-earth loop impedance would be encountered and for this reason attempting to discriminate on the basis of fault current magnitude is not a practical option. Figure 11.19 represents a circuit, in a TT system, under earth fault conditions.

Referring to Figure 11.19, the total phase-earth loop impedance, Z_s, is given in Equation (11.4).

$$Z_s = Z_T + Z_p + Z_1 + Z_2 + R_A + R_T \qquad (11.4)$$

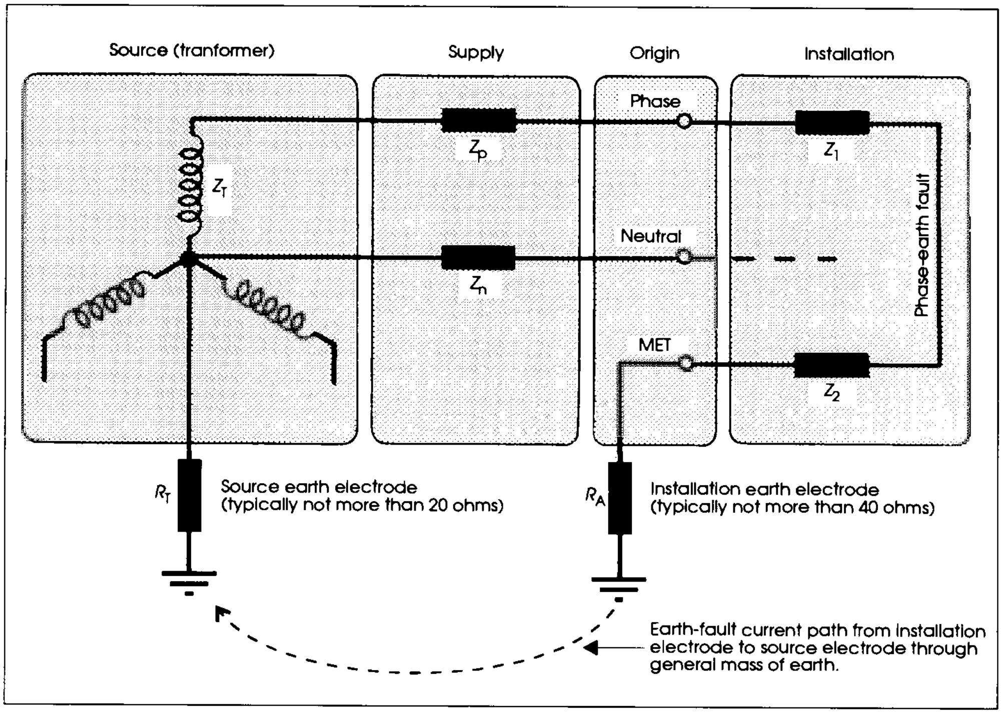


Figure 11.19: TT system circuit under earth fault conditions

where Z_s = total phase-earth loop impedance
Z_T = transformer impedance
Z_p = supply phase cable impedance
Z_1 = installation phase cable impedance
Z_2 = installation circuit protective conductor impedance
R_A = installation earth electrode and connecting protective conductor impedance
R_T = source earth electrode and connecting protective conductor impedance.

The total phase-earth loop impedance, Z_s, on a TT system is usually of the order of between 10 and 30 Ω but in extreme cases may be up to 200 Ω. The source earth electrode resistance can be up to 20 Ω and that of the installation electrodes is typically about 5 to 10 Ω. A phase-earth loop impedance value of 23 Ω would produce a fault current of 10 A on a 230 V circuit (230 ÷ 23).

Discrimination between RCDs can only really be accomplished using the time parameter. This can be achieved by the introduction of a time delay on the upstream RCD. In order to achieve discrimination between a time delayed RCD upstream and a non-time delayed (or shorter time delayed) RCD downstream, it is essential that the downstream device operates (trips) before the time delay on the upstream device has expired. The operating times will depend to some extent on the earth fault current magnitude but in practice it is normal to allow the time delay to be in excess of that which is strictly necessary to effect discrimination. BS 4293 does not currently include in its scope the specifications for RCDs with time delayed operation but these devices are readily available from leading manufacturers and are the subject of development of an CENELEC Standard.

In a domestic situation on a TT system, it is normally necessary to protect socket-outlets likely to supply equipment outdoors (and equipment supplied other than through a socket-outlet by an RCD ($I_{\Delta n} \leqslant 30$ mA) for compliance with Regulations 471–16–01 and 471–16–02 (see also Regulation 412–06–02). It would be undesirable to provide the 30 mA RCD protection at the 'front end' since it is likely that the cumulative effects of earth leakage currents of the various connected appliances and other factors would produce unwanted tripping, leaving the whole installation without power. A much more effective approach (but somewhat more expensive) would be to use, say, a 100 mA time delayed RCD at the 'front end' with a 30 mA non-time delay RCD to protect final circuits which require such protection. The arrangement is shown in Figure 11.20 and is currently available in the form of a 'split-load' consumer's unit. A similar arrangement for a 'split load' consumer's unit for use on TN systems is illustrated in Figure 11.21.

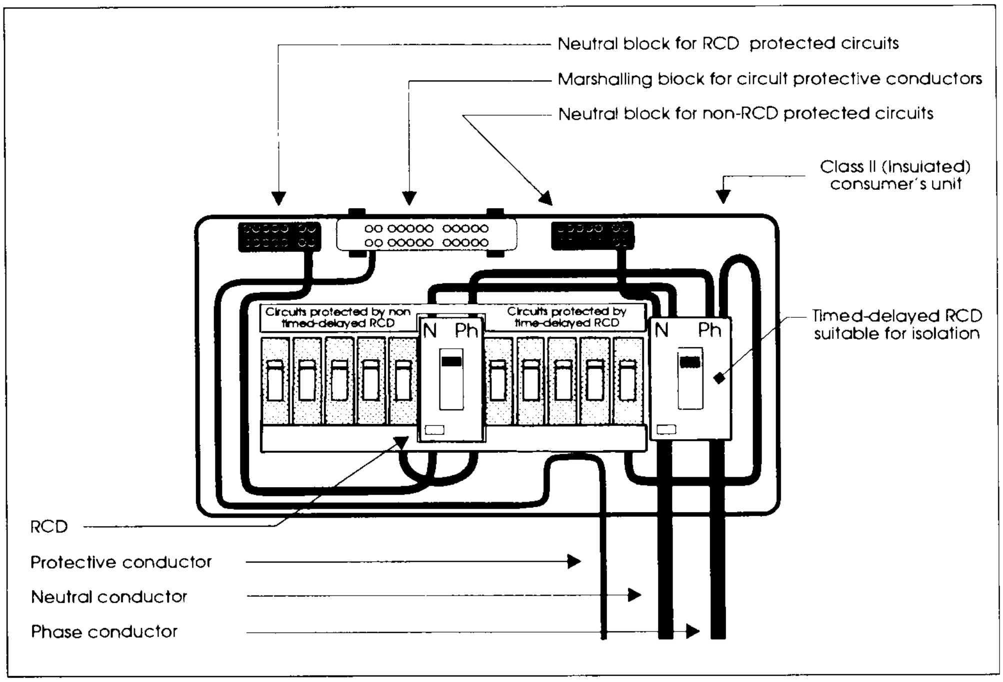


Figure 11.20: Split-load consumer's unit (TT systems)

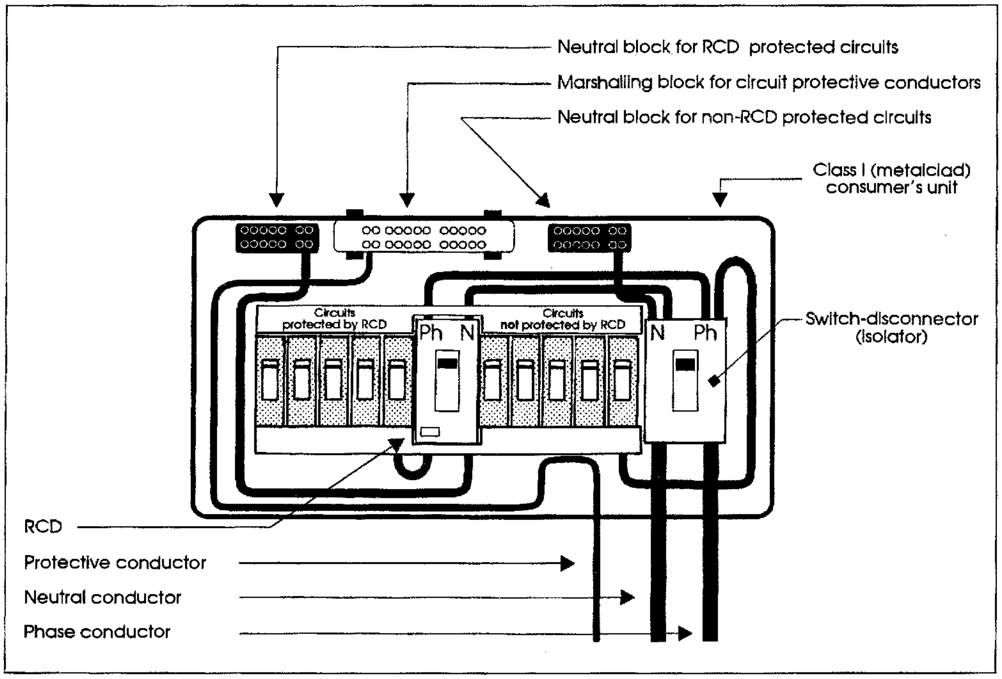


Figure 11.21: Split-load consumer's unit (TN-S and TN-C-S systems)

11.8 Other equipment

11.8.1 Accessories

Chapter 55 of BS 7671 makes demands on the selection of accessories not included elsewhere in BS 7671 and these are summarised in Table 11.11.

11.8.2 Luminaires and lighting points

The regulatory requirements embodied in Chapter 55 of BS 7671 relating to lighting points, luminaires and their connection are summarised in Table 11.12. Of particular interest is that Regulation 553–04–01 sets out the requirements for the connection of luminaires – see Ref. N in Table 11.12. Ceiling roses (pendants) and batten-holders have their limited uses but Luminaire Supporting Couplers (LSCs) will increasingly become commonplace providing as they do an aesthetically pleasing and sound final connection with the added facility of enabling disconnection of the luminaire for cleaning purposes etc. without disturbing the fixed installation. Decorative and domestic luminaire manufacturers should be encouraged to supply luminaires with a fitted integral LSC 'plug' (as some already do) so that it becomes standard practice for the fixed wiring installer to terminate with a LSC 'socket'. Another significant requirement of this regulation is that every luminaire must be controlled by a switch or by an automatic control system, which where necessary must be suitable for discharge lighting.

Table 11.11: Requirements relating to selection of plugs, socket-outlets and cable couplers

Ref	Accessory	British Standard	Requirements/Comments	Regulation
A	Plugs and socket-outlets, except SELV.		Must not be possible for any pin of a plug to make contact with a live part of its associated socket-outlet whilst any other pin is completely exposed nor with other types of socket-outlet within the same installation.	553-01-01
B			Except for SELV and special circuits (see Row M) every plug and socket-outlet must be the non-reversible type.	533-01-02
C			Socket-outlets for household or similar use must be of the shuttered type, preferably the 13 A to BS 1363.	553-01-04
D		BS 1363	For 13 A fused two-pole and earth plug and socket-outlets (with BS 1362 fuses).	553-01-03
E		BS 546	For 2, 5, 15 and 30 A fused and non-fused two-pole and earth plug and socket-outlets (with BS 646 fuses).	
F		BS 196	For 5, 15 and 30 A fused and non-fused two-pole and earth plug and socket-outlets.	
G		BS EN 60 309-2 (BS 4343)	For 16, 32, 63 and 125 A industrial type plug and socket-outlets.	
H			Wall mounted socket-outlets must be mounted at a sufficient height above finished floor or work surface to prevent mechanical damage to plug top flex by insertion of plug – usually taken as at least 150 mm above floor or work surface.	553-01-06
I			Where for use with portable equipment, socket-outlets to be positioned for equipment to be fed from adjacent socket-outlet taking into account the normal length of flexible cord provided on the equipment (usually taken as not more than 2 m).	553-01-07
J	Clock connector sockets.		The connection of electric clocks may be other than plugs and socket-outlets listed above but must incorporate a fuse not exceeding 3 A to BS 646 or BS 1362. Nominal voltage not to exceed 250 V.	553-01-05
K	Shaver sockets.	BS 3535	In bathrooms shaver sockets must comply with this Standard. Nominal voltage not to exceed 250 V.	
L		BS 4573	In locations other than bathrooms shaver socket must comply with this Standard or BS 3535. Nominal voltage not to exceed 250 V.	
M	Special circuit socket-outlets.		In a circuit having special characteristics where danger may otherwise occur or where it is necessary to distinguish it from other circuits in order to prevent danger, then it is permissible to use socket-outlets to Standards not mentioned above. Nominal voltage not to exceed 250 V.	
N	Cable couplers, except for SELV and a Class II circuit.	BS 196 BS EN 60 309-2 (BS 4343) BS 4491 BS 6991	Cable couplers to comply with one of these British Standards and must be of the non-reversible type and have provision for connection of a protective conductor.	553-02-01
O			The cable coupler connector (not the plug) is connected to the cable from the supply.	553-02-02

Table 11.12: Requirements relating to selection and erection of lighting points, luminaires and their connection

Ref	Accessory/ aspect		British Standard	Requirements	Regulation
		CAP			
A	Lampholders	SCB	BS 5042 or BS EN 61 184	Type B15 lampholder with overcurrent protective device rating not to exceed 6 A unless lampholder is enclosed in earthed metal or insulating material with characteristic ‘P’ (BS 476 Part 5). Lampholders must have temperature rating ‘T2’.	553-03-01 and 553-03-03
B		BC		Type B22 lampholder with overcurrent protective device rating not to exceed 16 A unless lampholder is enclosed in earthed metal or insulating material with characteristic ‘P’ (BS 476 Part 5). Lampholders must have temperature rating ‘T2’.	
C		SES	BS EN 60 238 (BS 6776)	Type E14 lampholder with overcurrent protective device rating not to exceed 6 A unless lampholder is enclosed in earthed metal or insulating material with characteristic ‘P’ (BS 476 Part 5). Outer contact connected to the neutral conductor in TN and TT systems.	553-03-01 and 553-03-04
D		ES		Type E27 lampholder with overcurrent protective device rating not to exceed 16 A unless lampholder is enclosed in earthed metal or insulating material with characteristic ‘P’ (BS 476 Part 5). Outer contact connected to the neutral conductor in TN and TT systems.	
E		GES		Type E40 lampholder with overcurrent protective device rating not to exceed 16 A unless lampholder is enclosed in earthed metal or insulating material with characteristic ‘P’ (BS 476 Part 5). Outer contact connected to the neutral conductor in TN and TT systems (except E14 and E27 lampholders).	
F		All		Lampholder for filament lamps not to be installed in circuit operating at a voltage exceeding 250 V.	553-03-01
G		All	BS EN 60 400	Lampholder for tubular fluorescent lamps and starterholders to comply with this Standard.	553-03-01
H	Lighting track.		BS 4533 Section 102.57	Outer contact connected to the neutral conductor in TN and TT systems.	553-03-04
I	Ceiling roses.		BS 67	Ceiling roses to comply with the British Standard and must not be installed in a circuit operating at a voltage exceeding 250 V.	553-04-01 and 553-04-03
J			—	Unless specially designed for multiple pendants, ceiling roses must only be used for single pendants.	553-04-03

Continued on facing page

Table 11.12 continued: Requirements relating to selection and erection of lighting points, luminaires and their connection

Ref	Accessory/ aspect	British Standard	Requirements	Regulation
K	Luminaire supporting couplers.	BS 6972 BS 7001	LSCs to comply with one of the British Standards.	553-04-01
L			LSCs not to be used for connection of equipment other than luminaires.	553-04-04
M	Batten lampholders.	BS 5042 BS EN 60 238 (BS 6776) or BS EN 61 184	Batten lampholders to comply with one of the British Standards.	553-04-01
N	Lighting points.	—	Connection to luminaires at fixed lighting points to be by ceiling rose, LSC, batten lampholder or directly connected to luminaire where luminaire has been specifically designed for that purpose. Points to be controlled by lighting switches.	553-04-01
O	Lighting switches.	BS 3676 BS 5518	Lighting switches to comply with one or both of the British Standards.	553-04-01
P	Luminaires generally.	BS 4533 BS EN 60 598	Luminaires generally to comply with the relevant Parts of the Standard unless meeting another appropriate Standard.	511-01-01
Q	Pendant luminaires.	BS 67 plus BS 5042 or BS EN 60 238 (BS 6776)	Must be suitable for the mass suspended (see Regulation 522-08-06).	554-01-01
R	ELV luminaires.	BS 4533 BS EN 60 598	Unless incorporating a provision of protective conductor contact an ELV luminaire must only be used within a SELV system.	554-01-02
S	HV discharge lighting luminaires.	BS 559	HV discharge lighting luminaires to comply with the British Standard and associated control switches must be suitable for this duty.	554-02-01 and 553-04-01

11.8.3 Heaters for liquids and other substances including water

As with all equipment, water heaters must comply with the relevant British Standard or Euronorm. Regulations 554–03–01 to 554–03–07 deal with electrode water heaters and boilers whilst Regulation 554–04–01 specifically relates to heaters with immersed elements. Regulations 554–05–01 to 554–05–04 make demands in relation to water heaters having immersed and un-insulated elements. The requirements are summarised in Table 11.13. It is crucially important that the manufacturer's instructions and recommendations are followed when installing water heaters particularly in the case of electrode heaters and boilers.

11.8.4 Heating conductors and electric surface heating systems

Regulations 554–06–01 to 554–06–04 set out the requirements relating to heating conductors and cables and Regulation 554–07–01 deals with electric surface heating systems all of which are summarised in Table 11.14.

Table 11.13: Requirements relating to heaters for liquids and other substances including water

Ref	Regulation	Requirements
Electrode water heaters and boilers		
A	554-03-01	To be used on a.c. systems only. Not for use on d.c.
B	554-03-02	Supply to be controlled by a linked circuit-breaker with overcurrent protection on each conductor connected to an electrode.
C	554-03-03	Earthing generally in accordance with Chapter 54 of BS 7671.
D	554-03-03	Heater or boiler shell to be connected to metallic armouring or sheath, if any, on supply cable.
E	554-03-03	Protective conductor to be connected to shell and must meet the requirements of the adiabatic equation or Table 54G of BS 7671.
F	554-03-04	RCD protection required for boilers and heaters operating on, and directly connected to, HV. RCD normally set at 10% of load and may incorporate a short time delay mechanism to overcome imbalances of short duration.
G	554-03-05	If three-phase LV, neutral must be connected to the shell in addition to protective conductor. Neutral current-carrying capacity no less than that of the largest phase conductor.
H	554-03-06	If single-phase LV, neutral must be connected to the shell in addition to protective conductor and to the supply neutral and earthing conductor.
I	554-03-07	For heaters and boilers not piped to a water supply and not in contact with Earth, and where the electrodes are shielded in insulating material so they cannot be touched whilst alive, the linked circuit breaker may be replaced by a phase conductor fuse and there is no need to connect the shell to the neutral.
Heaters having immersed heating elements		
J	554-04-01	Automatic device required for preventing a dangerous rise in temperature.
Water heaters with immersed and uninsulated elements		
K	554-05-01	Calls for requirements of the following Regulations to be met but excludes electrode boilers and heaters.
L	554-05-02	Metal parts in contact with water (excluding current-carrying parts but including metal taps, and covers) to be connected to the metallic water supply pipe to heater. This in turns needs connecting to the MET by means of an *independent* protective conductor.
M	554-05-03	Permanent connection to supply required. DP linked switch required either separate from heater and within easy reach or incorporated in heater. Plugs and socket-outlets not permitted for final connection. Where installed in a special location (e.g. bathroom) the requirements relating to the location must also be met.
N	554-05-04	Installer to check that no single-pole device is fitted in the neutral conductor in any part of circuit between the heater and the installation origin.

11.8.5 Transformers

There are only three Regulations (555–01–01 to 555–01–03) relating to transformers as items of equipment though of course their installation is subject to the generality of BS 7671. The first is concerned with autotransformers and requires that where such a transformer is employed and is connected to a circuit with a neutral conductor that conductor must be connected to the common terminal of the winding. Regulation 555–01–02 precludes the connection of *step-up* autotransformers to an IT system. In all cases where a step-up transformer is used, Regulation 555–01–03 calls for a linked switch to disconnect all live conductors (phases and neutral) simultaneously from the supply.

Table 11.14: Requirements relating to heating conductors and cables and electric surface heating systems

Ref	Regulation	Requirements
A	554-06-01	Heating conductors and cables passing through or in close proximity to material representing a fire hazard must be enclosed with material having ignitability characteristics 'P' as laid down in BS 476, Part 5. Additionally suitable and adequate mechanical protection must be provided.
B	554-06-02	Cables laid direct in soil or in the building fabric must be capable of withstanding mechanical damage likely to be encountered.
C	554-06-02	Cables laid direct in soil or in the building fabric must be of such construction as to be resistant to damage from moisture.
D	554-06-02	Cables laid direct in soil or in the building fabric must be of such construction as to be resistant to damage from corrosion.
E	554-06-03	Heating cables directly laid in soil, a road or in the building fabric must be completely embedded.
F	554-06-03	Heating cables directly laid in soil, a road or in the building fabric must not suffer damage from normal relative movement.
G	554-06-03	Heating cables directly laid in soil, a road or in the building fabric must comply fully with the manufacturer's instructions and recommendations.
H	554-06-04	Maximum conductor operating temperatures not to exceed temperatures specified in Table 55C of BS 7671. Full consideration must also be given to other component parts including seal and coverings and adjacent materials.
I	554-07-01	Electric surface heating systems to comply with BS 6351 in respect of system design, installation and testing.

11.8.6 Rotating machines

Regulation 552–01–01 requires that all equipment associated with rotating machine circuits which carry starting, accelerating, braking and load currents must be suitable for such currents and rated at not less than that given in the relevant British Standard or Euronorm. The effects of frequent starting and stopping have also to be taken into consideration as do the consequential effects on the supply and the temperature rise on equipment including conductors.

The supplier (ED or others) should always be consulted where fairly large motors are concerned in order to establish the effects of such loads on the supply. The supplier will be able to advise on the maximum 'voltage dip' which can be tolerated and this will affect the method of starting rotating machines. Direct-on-line starting is commonly used for small motors and, where acceptable, provides for the most inexpensive method of starting. Other methods include star-delta starting for three-phase motors and the 'soft-start' thyristor starting techniques. These need to be considered together with the type of mechanical load characteristics and the supplier's requirements. Lack of proper design co-ordination in this respect may result in 'voltage dips' on the supply which are unacceptable to the supplier and to other users on the network.

Regulation 552–01–02 calls for motors of rating exceeding 370 W to be provided with overload protection. This requirement does not apply to equipment incorporating a motor which itself, as a whole, complies with the relevant British Standard. Unless there is a danger from so doing, Regulation 552–01–03 demands that every motor be provided with ‘no-volt’ release which prevents the motor restarting on restoration of full supply voltage after stopping as a result of a reduction of supply voltage or a failure of the supply. This requirement does not preclude the use of automatic starting systems (e.g. on a process line) where adequate alternative measures have been taken to prevent danger from unexpected starting. Regulation 552–01–04 requires that, where a motor is equipped with reverse-current braking, precautions must be taken to prevent the motor running in the opposite direction after braking has been completed, if there is a possibility of danger resulting from reverse running. Additionally, Regulation 552–01–05 requires that, where safety depends on the direction of rotation, provision must be made to prevent reverse operation due to any cause, including the loss of one phase on a multi-phase motor.

Chapter 12

Protective Conductors, Earthing and Equipotential Bonding

12.1 Protective conductors

12.1.1 Protective conductors – general

The requirements for protective conductors are embodied in Chapter 54 which sets out constraints in terms of minimum cross-sectional areas and acceptability of certain material and types and Figure 12.1 lays out the various sections of Chapter 54 of BS 7671.

It is important to recognise that the term ‘protective conductor’ is generic and embraces the following particular protective conductors:

- earthing conductor,
- main equipotential bonding conductor,
- supplementary equipotential bonding conductor,
- additional equipotential bonding conductor,
- circuit protective conductor,
- combined protective and functional conductor,
- ‘clean earth’ (low noise) protective conductor.

The sizing requirements may differ depending on the function of the protective conductor. In all cases where the conductor has a covering that covering must be coloured yellow/green (70/30% or 30/70%) to meet the requirements of Regulation 514-03-01. Any other colour (including green alone – Regulation 514–06–02) must not be used except for functional earthing conductors for telecommunication equipment (see BS 6701: Part 1) where the colour cream must be used. Additionally, Regulation 514–06–01 requires every conductor to be identified at least at its terminations, though preference is expressed that it should be identified throughout its length. Where bare protective conductors are used, they should be identified by green/yellow paint, tape disc or sleeving (514–06–03). Flexible cords must have every core identified throughout their lengths (514–07–01).

Protective conductors may serve more than one function (e.g. main equipotential bonding conductor and circuit protective conductor). They may serve the function of circuit protective conductor to a number of circuits as in the case of steel conduit, enclosing a number of circuits. When so used the protective conductor must fulfil the requirements relating to the most onerous for all the function and/or circuits it is used to protect.

Where protection against indirect contact is provided by an overcurrent

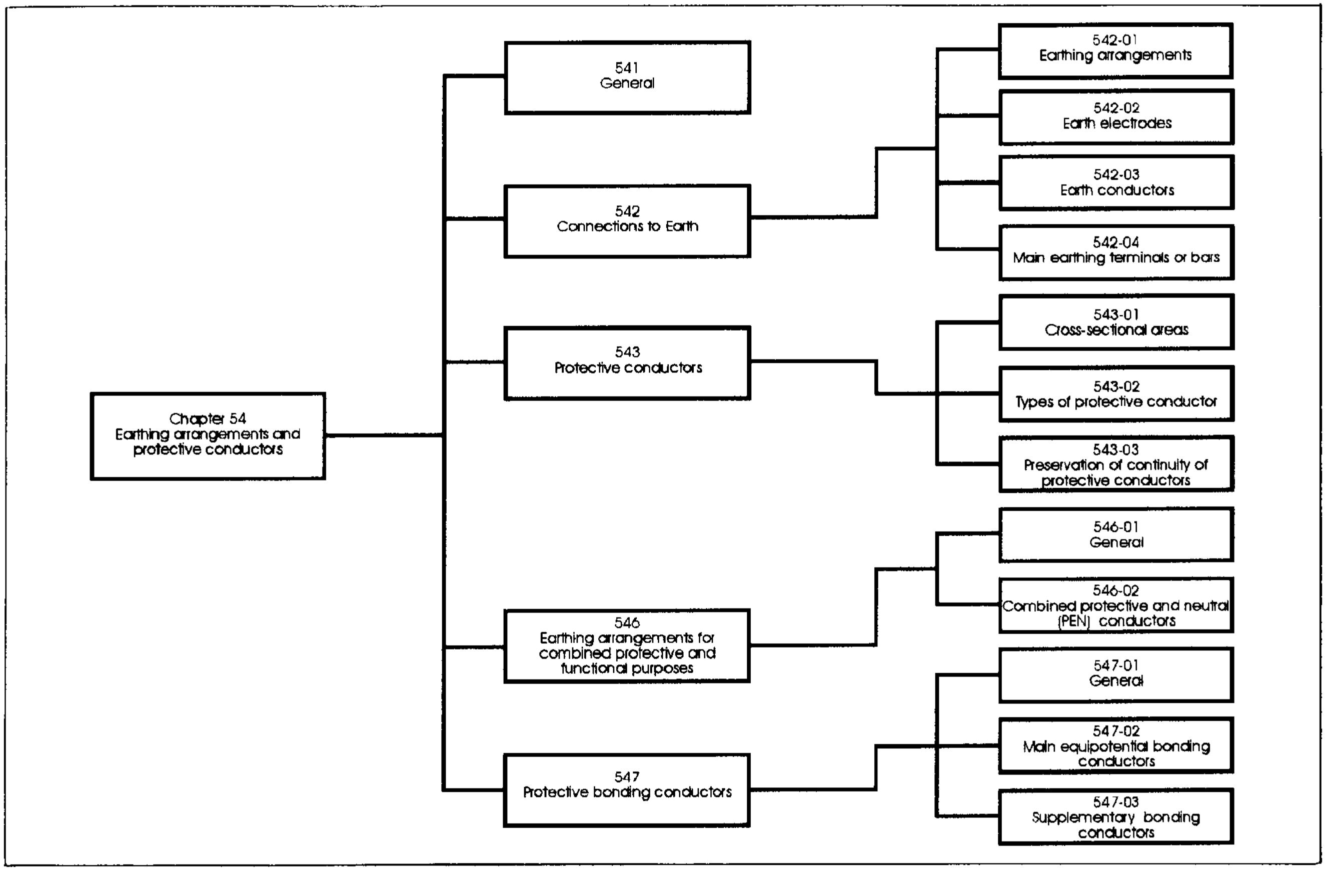


Figure 12.1: Arrangement of Chapter 54 – earthing arrangements and protective conductors

protective device, Regulation 544–01–01, introduced with Amendment No 1 to BS 7671, calls for the protective conductor to be incorporated in the same wiring system as associated live conductors, or at least in the immediate proximity of those live conductors.

12.1.2 Protective conductors – types

Section 543 of BS 7671 identifies the various types of protective conductors which are acceptable and those that are not. These requirements are summarised in Table 12.1.

12.1.3 Protective conductors – thermal withstand

As with live conductors, the designer needs to consider the effects of earth fault current on protective conductors. It is important to recognise that the energy withstand (S^2k^2) of the protective conductor must not be less than the energy let-through (I^2t) of the protective device(s). This is satisfied if the adiabatic equation is met (see Equation (12.3)) or the csa of the protective conductor is related to the phase conductor csa in accordance with Table 54G of BS 7671.

One could easily be forgiven for thinking that the csa of the protective conductor is proportional to the fault current magnitude, i.e. the higher the fault current, the larger the cross-sectional area. This is not so and it can be shown that in many circumstances a lesser csa will be acceptable with the increasing earth fault current. To illustrate by way of example, take a 100 A BS 88 Part 2 HBC fuse and consider disconnection times of 0.1, 0.2, 0.4 and 5 s:

Fault current I_f (A)	Disconnection time (s)	Energy let-through, I^2t (A^2s)	Minimum csa, S, of conductor (with $k = 143$) (mm^2)
1400	0.2	196 000	3.1
1150	0.2	264 500	3.6
980	0.4	384 160	4.3
550	5.0	1 512 500	8.6

The example only serves to illustrate the point made and should not be taken to mean it is suggested that designing protective conductors to such close tolerances is advocated. Figure 12.2 shows graphically the relationship between fault current and the minimum conductor csa from the viewpoint of thermal protection where protection is provided by fuses. Where MCBs are employed the curve is a horizontal straight line.

In determining the earth fault current for application of the adiabatic equation, due account must be taken of the effects of temperature rise of protective conductors under earth fault conditions and the consequential rise in the resistive component of impedance. This can be done by application of the appropriate multiplication factor to the resistance of the

Table 12.1: Acceptable and unacceptable types of protective conductor

Ref	**Regulation**	**Type of protective conductor**	**Acceptable**	**Restrictions, if any/comments**
A	543-02-02 543-02-03	Conductor in a cable.	Yes.	If csa does not exceed 10 mm^2, to be copper.
B		Single-core cable.	Yes.	
C		Insulated or un-insulated conductor in a common enclosure with live conductors.	Yes.	
D		Fixed insulated or un-insulated conductor.	Yes.	
E		Metal cable sheath, armouring or screen.	Yes.	See also Regulations 543-02-04 and 543-02-05.
F		Metal conduit	Yes.	Subject to a minimum csa of 10 mm^2. See also Regulation 543-02-04.
G		Metal enclosure (e.g. trunking).	Yes.	Subject to a minimum csa of 10 mm^2. See also Regulation 543-02-04.
H		Electrically continuous conductor support system.	Yes.	Subject to a minimum csa of 10 mm^2. See also Regulation 543-02-04.
I	543-02-02 543-02-06	Extraneous-conductive-part.	Yes.	Excepting gas and oil pipe lines, an extraneous-conductive-part may be used as a protective conductor. Subject to a minimum csa of 10 mm^2. Must be protected against mechanical, chemical and electromagnetic deterioration. Electrical continuity must be assured. The csa must meet the adiabatic equation (Regulation 543-01-03) or be verified by test to BS 5486 Part 1 provided always that precautions are taken against its removal and that the part has been considered for such use.
J	543-02-01	Gas pipes.	No.	Must never be used.
K	543-02-01	Oil pipes.	No.	Must never be used.
L	543-02-01	Flexible and pliable conduit.	No.	Must never be used.
M	543-02-04	Metal enclosure of switchgear and control gear.	Yes.	Must be protected against mechanical, chemical and electromagnetic deterioration. Electrical continuity must be assured. The csa must meet the adiabatic equation (Regulation 543-01-03) or be verified by test to BS 5486 Part 1. The arrangement must provide for connection of other protective conductors at every predetermined point.
N	543-02-04	Busbar trunking systems.	Yes.	
O	543-02-05	Cable sheaths and other cable metal coverings including armouring, copper sheaths (MICC) and conduit.	Yes.	To be used as a protective conductor for the associated circuit. Must be protected against mechanical, chemical and electromagnetic deterioration. Electrical continuity must be assured. The csa must meet the adiabatic equation (Regulation 543-01-03) or be verified by test to BS 5486 Part 1.

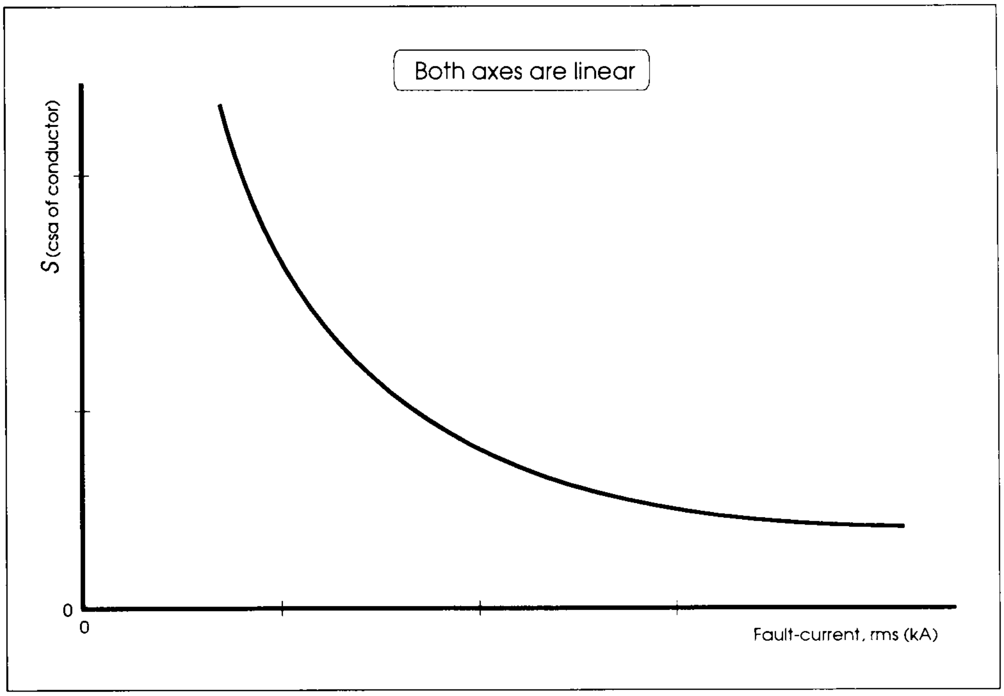


Figure 12.2: Relationship between fault current and the minimum protective conductor csa for fuses

protective conductor when one is given by the manufacturer or available elsewhere. When no such data are available the designer needs to calculate the average temperature of the conductor under fault conditions and this is done in cases where the protective conductor is incorporated in cable or bunched with cables (see Table 54C of BS 7671) using Equation (12.1).

$$\text{Average temperature} = \frac{\textit{max normal operating temp} + \textit{max final temp}}{2} \qquad (12.1)$$

To take the example of a copper/PVC insulated protective conductor (installed in trunking with other cables operating at 70°C) with normal maximum operating temperature 70°C and a final maximum operating temperature of 160°C with the average temperature of 115°C [(70 + 160) ÷ 2]. This average temperature represents an increase of 45°C on the initial temperature and this together with the temperature coefficient of resistance for copper (0.004/°C) gives an increase in resistance of 18%. Had all the cables been operating at 50°C (because they were lightly loaded), the average temperature would have been 105°C, a temperature difference of 55°C and an increase in resistance of 22%. Again, had the protective conductor not been installed with other cables it could be argued that the initial temperature could be taken as ambient, say 30°C, making the average temperature of 65°C with a consequential increase in resistance of 14%.

12.1.4 Protective conductors – sizes

The sizing of all protective conductors, except equipotential bonding conductors, relates primarily to thermal withstand consideration of the conductor such that the insulating and/or adjacent materials do not exceed their final permissible temperatures under earth fault conditions. From such considerations, the sizing obtained should be regarded as the minimum. There may be cases where the csa may need to be increased to reduce the protective conductor's contribution to the total phase-earth loop impedance.

As stated in Regulation 543–01–01, the minimum csa can be obtained in one of two ways; first, by reference to Table 54G of BS 7671 or, secondly, by application of the adiabatic equation in Regulation 543–01–03. For most designers reference to Table 54G will be the easier of the two approaches involving little calculation where the protective conductor is of the same material as the associated phase conductor. Where this is not the case, the simple application of a multiplying factor of ($k_1 \div k_2$) to the csa of the phase conductor (S) is all that is required.

The k factor takes account of the resistivity, temperature coefficient and heat capacity of the conductor together with the initial and final temperatures; k_1, the factor for the phase conductor is obtained from reference to Table 43A of BS 7671 and k_2, the factor for the protective conductor from Tables 54B, 54C, 54D, 54E or 54F depending on the particular protective conductor's constructional aspects. By way of example, take a phase conductor of 16 mm^2 copper and a steel protective conductor in the form of armouring of a 90°C thermosetting cable. From Table 43A we get k_1 as 143 and from Table 54D we get a k_2 of 46 from which we can deduce the minimum csa of the steel protective conductor as 50 mm^2 as shown in Equation (12.2).

$$S_\mathrm{p} = S \times \frac{2k_1}{k_2} = 16 \times \frac{143}{46} = 50\ \mathrm{mm}^2 \qquad (12.2)$$

where S = csa of phase conductor (copper) (mm^2)
S_p = csa of protective conductor (steel) (mm^2)
k_1 = the factor for the phase conductor (copper)
k_2 = the factor for the protective conductor (steel).

The alternative method of obtaining the csa of protective conductors by calculation very often results in smaller sizes than those given in Table 54G but takes more of the designer's time unless computer facilities are used. The basic equation for such calculations is given in Regulation 543–01–03 and is as set out in Equation (12.3).

$$S_\mathrm{p} = I_\mathrm{F}\frac{\sqrt{t}}{k}\mathrm{mm}^2 \qquad (12.3)$$

where I_F = earth-fault rms current (with fault of negligible impedance) taking account of current limiting capabilities of the protective device, if any (A)

t = operating time of protective device associated with the particular fault current magnitude (s)

S_p = minimum csa of protective conductor (mm^2)

If we transpose Equation (12.3) we can see the energy withstand ($S_p^2k^2$) of the protective conductor must not be less than the energy let-through (I^2t) of the protective device as indicated in Equation (12.4).

$$S_pk \geqslant I_F\sqrt{t} \equiv S_p^2k^2 \geqslant I_F^2t \tag{12.4}$$

Taking a practical example, an 80 A BS 88 Part 2 protects a 230 V circuit with live conductors of 25 mm^2 csa where it is anticipated that the maximum total earth loop impedance, Z_s, will be 0.6 Ω and the protective conductor will be a separate copper conductor with 70°C insulation and not bunched with other cables ($k = 143$ from Table 54B). From this we can deduce that the fault current will be about 383 A (230 V ÷ 0.6 Ω) and from the time/characteristics for this device, we can see that the device will operate within 5 s. The minimum csa of the protective conductor, S_p, will be 6.25 mm^2 as shown in Equation (12.5).

$$S_p = \frac{I_F\sqrt{t}}{k} = 383\frac{\sqrt{5}}{143} = 6.0\ \text{mm}^2 \tag{12.5}$$

Where the application of the adiabatic equation results in a non-standard size, the csa of the next larger standard size must be chosen as 'clearly' to choose the next lower size would render the protective conductor thermally unprotected.

Table 12.2 rearranges the data given for *k* factors in Tables 54B, 54C, 54D, 54E and 54F of BS 7671.

12.1.5 Protective conductors – for combined protective and functional purposes

Where an earthing arrangement provides the means of protection against indirect contact and is also used for functional purposes, Regulations 542–01–06 and 546–01–01 demand that the requirements relating to the protective function must take precedence.

Combined Protective and Neutral (PEN), conductors providing both functions, may only be used (Regulation 546–02–01) if one of the four conditions is met:

- the supply is obtained from a privately owned generating plant, or
- the supply is obtained from a privately owned transformer arranged so that there is, excepting the earthing connection, no metallic connection between the installation and the public supply, or

Table 12.2: Protective conductors – *k* factors

Ref	Protective conductor arrangement	Insulation/ covering	Appx.4 Table	Temp. (°C)		csa (mm^2)	Copper	Aluminium	Steel	Lead
				Initial	Final					
	Protective conductors with insulation or covering									
A	Insulated conductor not part of cable not bunched with other cables. Separate bare conductor in contact with cable covering but not bunched (assumed initial temperature 30°C).	PVC – 70°C.	54B	30	160	≤ 300	143	95	52	—
B		PVC – 70°C.		30	140	> 300	133	88	52	—
C		PVC – 85°C.		30	160	≤ 300	143	95	52	—
D		PVC – 85°C.		30	140	> 300	133	88	52	—
E		Rubber – 85°C.		30	220	All	166	110	60	—
F		Thermosetting – 90°C.		30	250	All	176	116	64	—
G	Insulated and non-insulated protective conductor incorporated in a cable or bunched with cables (assumed initial temperature 70°C).	PVC – 70°C.	54C	70	160	≤ 300	115	76	—	—
H		PVC – 70°C.		70	140	> 300	103	68	—	—
I		PVC – 85°C.		85	160	≤ 300	104	69	—	—
J		PVC – 85°C.		85	160	> 300	90	60	—	—
K		Rubber – 85°C.		85	220	All	134	89	—	—
L		Thermosetting – 90°C.		90	250	All	143	94	—	—
M	Cable sheath or cable armouring protective conductor.	PVC – 70°C.	54D	60	200	All	—	93	51	26
N		PVC – 85°C.		75	200	All	—	87	48	24
O		Rubber – 85°C.		75	220	All	—	93	51	26
P		Thermosetting – 90°C.		80	200	All	—	85	46	23
Q	Protective conductor formed by steel conduit, steel ducting and/or steel trunking enclosing cables listed. Where enclosed cables consist of different temperature ratings, the *k* values attributed to the lowest or lower temperatures must be used.	PVC – 70°C.	54E	50	160	All	—	—	47	—
R		PVC – 85°C.		58	160	All	—	—	45	—
S		Rubber – 85°C.		58	220	All	—	—	54	—
T		Thermosetting – 90°C.		60	250	All	—	—	58	—

Table 12.2 continued : Protective conductors – *k* factors

Ref	**Protective conductor arrangement**	**Insulation/ covering**	**Appx.4 Table**	**Temp. (°C)**		**csa (mm²)**	**Copper**	**Aluminium**	**Steel**	**Lead**
				Initial	**Final**					
Bare protective conductors										
U	Visible conductors in restricted areas.	Copper.	54F	30	500	All	—	—	82	—
V		Aluminium.		30	300	All	—	125	—	—
W		Steel.		30	500	All	228	—	—	—
X	Normal installation conditions.	Copper.		30	200	All	159	—	—	—
Y		Aluminium.		30	200	All	—	105	—	—
Z		Steel.		30	200	All	—	—	58	—
A1	Where risk of fire exists.	Copper.		30	150	All	138	—	—	—
B1		Aluminium.		30	150	All	—	91	—	—
C1		Steel.		30	150	All	—	—	50	—

- the supply is obtained from a privately owned convertor arranged so that there is, excepting the earthing connection, no metallic connection between the installation and the public supply, or
- the supply is obtained from a supplier with his express agreement and authorisation for such a system to operate and the installation complies with all the prerequisite conditions for use with PEN conductors.

BS 7671 makes further demands relating to the conductor (summarised in Table 12.3) and requires that where the functions of neutral conductor and protective conductor are separated they must not be rejoined further downstream (see Figure 12.3).

Table 12.3: Requirements for conductors for combined protective and neutral conductors

Ref	Regulation	Requirements
A	546-02-06 460-01-03	No means of isolation or switching permitted in the outer conductor of concentric cable.
B	546-02-03	The outer conductor of a concentric cable only to be used as a conductor (protective and neutral) for that circuit and for no others. This does not preclude the use of multicore cables where, for example, additional cores are used for switching and control provided they are all associated with the same final circuit.
C	546-02-05	Where joints are made in the outer PEN conductor of a cable, the continuity of that joint must be reinforced by a separate conductor linking the PEN conductor. The additional conductor must be of conductance required by Regulation 546-02-04. The additional conductor serves to supplement the continuity afforded by the normal sealing and clamping of the joint.
D	546-02-07	Every joint in a PEN conductor, except as stated in Row E, must be insulated or have a covering suitable for the highest voltage.
E	546-02-07	For cables complying with BS 6207 (MICC) and installed to meet the manufacturer's instructions, there are no additional regulatory requirements relating to insulation of joints.
F	546-02-04	The conductance (measured at 20°C) of a single-core cable (outer conductor) must not be less than that of the internal conductor.
G	546-02-04	The conductance (measured at 20°C) of the outer conductor of a multi-core cable, excepting cables to BS 5593, must not be less than that of one of the internal conductors.
H	546-02-04	The conductance (measured at 20°C) of the outer conductor of a multi-core cable, excepting cables to BS 5593, using parallelled internal conductors must not be less than that of the parallel internal conductors.
I	546-02-04	For cables complying with BS 5593 (CONSAC) there are no further regulatory requirements relating to conductance.
J	546-02-02	For the fixed installation and where there is no flexing, a copper conductor may be used as a PEN conductor provided it is of a csa not less than 10 mm^2 and it is not supplied via an RCD.
K	546-02-02	For the fixed installation and where there is no flexing, an aluminium conductor may be used as a PEN conductor provided it is of a csa not less than 16 mm^2 and it is not supplied via an RCD.
L	546-02-02	For cables complying with the relevant British Standard the minimum csa of the PEN conductor is 4 mm^2 but may need to be larger for compliance with Regulations 546-02-03 to 546-02-08 (provided it is not supplied via an RCD).
M	546-02-08	Where the protective and neutral functions are separated, the split conductors must be provided with separated terminals (or bars) for protective and neutral conductors with the PEN conductor connecting both terminals with a link of conductance satisfying Regulation 546-02-04. Once separated the protective and neutral conductors must not be reconnected together (see Figure 12.3).

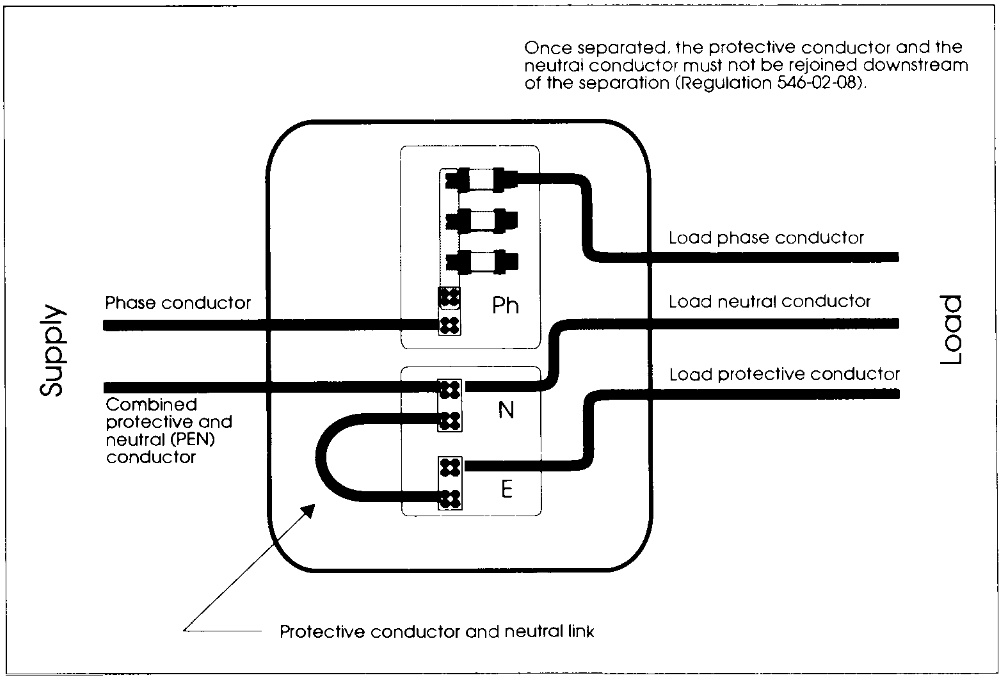


Figure 12.3: The separation of protective and neutral conductors

12.1.6 Protective conductors – electrical continuity

As stated in Regulation 543–03–01, all protective conductors must be protected against mechanical external influences such as impact and vibration and similarly protected against chemical reactions (e.g. between dissimilar metals). Additionally, account must be taken of electrodynamic effects. These effects may be severe where a high earth fault current flows and may put unacceptable mechanical forces on the protective conductor support system if it is less than adequate.

Unless the protective conductor is in the form of steel conduit or trunking or contained within a multi-core cable, Regulation 543–03–02 calls for all conductors of csa up to and including 6 mm^2 to have a covering (similar to the insulation provided on non-sheathed cables to BS 6004 and BS 7211). Where the protective conductor is contained in a sheathed cable (e.g. PVC/PVC to BS 6004) and where the sheath is removed for termination purposes, insulated sleeving compliant with BS 2848 must be used to sleeve the otherwise bare protective conductor (Regulation 543–03–02).

Generally speaking, no switching device is permitted to be installed in a protective conductor (Regulation 543–03–04) although mechanical joints with disconnectable links (removable only by use of a tool) are permitted for test purposes. However there are exceptions to this rule in that multi-pole linked switching and plug-in devices are permitted provided the protective conductor is not interrupted before the associated live conductors and is made before the live conductors are re-established. Another important exemption relates to generator earthing and where parallel operation with other generators or with other sources is involved. A protective conductor linking the neutral point of a generator may be broken, if this is required for operational reasons, provided the switching arrangement is linked to the interruption of live conductors in the same manner as previously mentioned.

Where steel conduit and metallic sheathed cables forming the protective conductor are terminated into an insulated enclosure, care must be taken to preserve the continuity of the conductor through the enclosure by, for example, the fitting of gland tag rings on the incoming and outgoing wiring system and providing an adequate conductor between the two. Of no less importance is the adequacy of metal enclosures to provide a reliable conductive path for earth fault current. Often cables and conduits are terminated into switchgear via a steel plate bolted to the main enclosure by a few small bolts. With the application of paint and other non-conductive finishes to enclosures and plates, too much reliance must not be placed on the effectiveness of such connections and it is far better to preserve the earth fault path through the enclosure by means of gland tags and separate conductors.

12.1.7 Protective conductors – formed by steel conduit, trunking, etc.

Whether or not steel conduit is used for the protective conductor, joints in that conduit must be mechanically sound and electrically continuous and this is possible only with fully tightened screwed couplers (sockets) and socket and bush unions. Slip conduit and conduit relying on pin grip sockets are not acceptable (Regulation 543–03–06) since these joints cannot be relied upon to provide permanent and reliable connections either for the provision of a protective conductor or for the earthing of the steel conduit. As Regulation 543–03–03 requires, all joints in conduit, trunking, ducting and their support systems must meet the requirements of Regulation 526–04–01 which calls for joints (with certain exceptions) to be accessible.

Trunking should not be regarded as an effective cpc for circuits of nominal current exceeding 100 A unless it can be shown that it is capable of providing a permanent and reliable fault path for the prospective earth fault current.

Modern accessory and switchgear metal enclosures are often applied with paint or other non-conductive finishes which are not conducive to good electrical continuity between joints. These coatings must be removed where they are likely to affect the protective conductor or earthing continuity.

Where metal conduit and metal trunking are used as protective conductors (i.e. no separate cpc provided), it is necessary to equip the accessories with a protective conductor ‘tail’ to connect the earthing terminal of the accessory with the conduit or trunking system (Regulation 543–02–07). Although strictly not necessary for compliance with the Wiring Regulations, an earth ‘tail’ is considered good practice irrespective of whether the conduit provides the protective conductor or not. This good practice of providing an earth ‘tail’ from the accessory box (particularly, where flush) to the accessory itself holds good for installations employing PVC/PVC cables (to BS 6004) although again not strictly necessary.

A separate enclosure for cables (as opposed to a composite cable) must not be used as a PEN (Protective Earthing and Neutral) conductor (Regulation 543–02–10) in a TN-C installation and an exposed-conductive-part of equipment must not be used as a protective conductor for other circuits not associated with it unless fully compliant with Regulations 543–02–02 to 543–02–05.

12.1.8 Protective conductors – mineral insulated cables

Mineral insulated cables to BS 6207 present little problem when considering the energy withstand of the copper sheath and its use as a circuit protective conductor. For multi-core 500 V and 750 V grades of MICC cable the effective sheath areas are in excess of their associated phase conductor csa. For single-core the picture is different with only 6 mm^2 and 35 mm^2 meeting the csa requirements of Table 54G of the regulations. However, other sizes, not meeting the requirements of Table 54G, may satisfy the adiabatic equation (of Regulations 543–01–03) depending on the particular fault levels.

Difficulty can sometimes be experienced in effecting and maintaining continuity of the protective conductor at the terminations of MICC cable into thin-walled accessories and other equipment. The use of ‘earth-tail’ pots is a useful way of achieving better continuity as is the use of a zinc-plated lock-washer between the brass male bush and the enclosure. Additionally, internally threaded glands are available which allow the male bush to be screwed directly into the gland dispensing with the conduit socket and make a much more aesthetically pleasing installation finish on surface work.

12.1.9 Protective conductors – of ring circuits

In order to secure some added integrity of the circuit protective conductor of ring circuits including ring final circuits, Regulation 543–02–09 calls for the protective conductor to be of the form of a ring with each ‘leg’ connected to the earthing terminal at the position from which it is supplied. This requirement does not apply, for obvious reasons, where a steel conduit or steel trunking or ducting wiring system provides the only circuit protective conductor.

12.1.10 Protective conductors – armouring

When considering the use of cable armouring as a circuit protective conductor the designer has two principal aspects to consider. First, the contribution that the armouring makes to the total phase-earth loop impedance and, second, whether the protective conductor will be thermally protected. Where the contribution of impedance made by the armouring is too great to be acceptable, the designer may consider it necessary to provide a separate conductor connected in parallel (but not run in close proximity) with the armouring in order to reduce that contribution. Again this may be a solution to the case where the armouring is not thermally protected (i.e. does not meet the adiabatic equation of Regulation 543–01–03). An alternative solution would involve the selection of a larger cable than would be dictated by current-carrying capacity considerations. However, the designer will find that in most practical situations steel armouring will be adequate for use as a circuit protective conductor but checks must, of course, be made to verify this.

The story is different when considering the use of the armouring as a main bonding conductor (as well as a cpc) and by application of the adiabatic equation or Table 54G it is unlikely that the armouring will provide an adequate csa for use as a main bonding conductor. It is important to recognise that the resistivity of aluminium is about 1.6 times that of copper and that of steel is of the order of 8 times that of copper.

Cable manufacturers publish constructional and electrical data for all cables they produce and Tables 12.4 and 12.5 summarise some of the information in the form of the csa of round wire armouring of cables with stranded live conductors of both copper and aluminium to the specifications of BS 6346 (PVC), BS 5467 (XPLE) and BS 6724 (LSHF). Table 12.6 sets out the cross-sectional areas of steel conduit and steel trunking for some common sizes. Table 12.7 gives a correlation between the copper live conductors of armoured cables to BS 6346 and the equivalent copper (in

Table 12.4: Cross-sectional areas of armour (round wires) of PVC cables to BS 6346 (all cables with stranded conductors)

Ref	**Nominal csa of live conductors (mm²)**		**Copper live conductors**											**Aluminium live conductors**		
			Power cables			**Auxiliary cables**								**Power cables**		
		Cores	**2**	**3**	**4**	**5**	**7**	**10**	**12**	**19**	**27**	**37**	**48**	**2**	**3**	**4**
			Cross-sectional areas of armour (mm²)													
A	1.5		15	16	17	19	20	36	38	44	70	76	88	—	—	—
B	2.5		17	19	20	22	24	44	45	70	82	92	135	—	—	—
C	4		21	23	35	39	42	72	74	86	131	—	—	—	—	—
D	6		24	36	40	—	—	—	—	—	—	—	—	—	—	—
E	10		41	44	49	—	—	—	—	—	—	—	—	—	—	—
F	16		46	50	72	—	—	—	—	—	—	—	—	42	46	66
G	25		60	66	76	—	—	—	—	—	—	—	—	54	62	70
H	35		66	74	84	—	—	—	—	—	—	—	—	58	68	78
I	50		74	84	122	—	—	—	—	—	—	—	—	66	78	113
J	70		84	119	138	—	—	—	—	—	—	—	—	74	113	128
K	95		122	138	160	—	—	—	—	—	—	—	—	109	128	147
L	120		131	150	220	—	—	—	—	—	—	—	—	—	138	201
M	150		144	211	240	—	—	—	—	—	—	—	—	—	191	220
N	185		201	230	265	—	—	—	—	—	—	—	—	—	215	245
O	240		225	260	299	—	—	—	—	—	—	—	—	—	240	274
P	300		250	289	333	—	—	—	—	—	—	—	—	—	265	304
Q	400		279	319	467	—	—	—	—	—	—	—	—	—	—	—

Table 12.5: Cross-sectional areas of armour (round wires) of XLPE cables to BS 5467 and BS 6724 (LSHF)

Ref	**Nominal csa of live conductors (mm^2)**		**Power cables with stranded conductors**					
			Copper live conductors			**Aluminium live conductors**		
		Cores	**2**	**3**	**4**	**2**	**3**	**4**
			Cross-sectional areas of armour (mm^2)					
A	1.5		16	17	18	—	—	—
B	2.5		17	19	20	—	—	—
C	4		19	21	23	—	—	—
D	6		22	23	36	—	—	—
E	10		26	39	43	—	—	—
F	16		41	44	49	40	42	46
G	25		42	62	70	38	58	66
H	35		62	70	80	54	64	72
I	50		68	78	90	60	72	82
J	70		80	90	131	70	84	122
K	95		113	128	147	100	119	135
L	120		125	141	206	—	131	191
M	150		138	201	230	—	181	211
N	185		191	220	255	—	206	235
O	240		215	250	289	—	230	265
P	300		235	269	319	—	250	289

Table 12.6: Cross-sectional areas of steel conduit and steel trunking

Steel conduit			**Steel trunking**	
Nominal outside diameter (mm)	**Cross-sectional area (mm^2)**		**Size (mm)**	**Cross-sectional area (mm^2)**
	Light gauge	**Heavy gauge**		
16	47	72	50 x 36.5	125
20	59	92	50 x 50	150
25	89	131	75 x 50	225
32	116	170	75 x 75	285
See also BS 5468 for further information relating to steel conduit and BS 4678 for steel trunking.			100 x 50	260
			100 x 75	320
			100 x 100	440
			150 x 50	380
			150 x 75	450
			150 x 100	520
			150 x 150	750

terms of conductance) of the armouring to the nearest standard csa below that calculated.

Table 12.8 summarises the relationship between the protective conductor and the phase conductor referred to in Regulation 543–01–04 (Table 54G) where they are of different metals. By referring back to Table 12.4 it can be seen that for copper/PVC cables to BS 6346 all two-core cables up to 95 mm^2, all three-core cables up to 185 mm^2 and all four-core up to 240 mm^2 will have armouring of adequate energy withstand. Likewise, all 1.5, 2.5 and

Table 12.7: Equivalent copper csa of armouring for cables to BS 6346

Ref	**Nominal csa of live conductors (mm^2)**	**Nominal csa of copper conductor providing equivalent conductance to that of the armouring (mm^2)**		
		2-core	**3-core**	**4-core**
A	1.5	1.5	1.5	1.5
B	2.5	1.5	1.5	1.5
C	4	2.5	2.5	4
D	6	2.5	4	4
E	10	4	4	4
F	16	4	4	6
G	25	6	6	6
H	35	6	6	6
I	50	6	6	10
J	70	6	10	10
K	95	10	10	16
L	120	10	16 (Cu), 10 (Al)	25 (Cu), 16 (Al)
M	150	16	16	25
N	185	16	25 (Cu), 16 (Al)	25
O	240	25	25	35 (Cu), 25(Al)
P	300	25	25	35
Q	400	25	35	50

Note: Unless otherwise stated the data relate to cables having copper live conductors.

Table 12.8: Sheath or armour of a cable used as a protective conductor – minimum csa of S_p

Phase conductor csa	**Armour**			
	Copper	**Steel**	**Aluminium**	**Lead**
S (mm^2)	**S_p (mm^2)**			
$S \leq 16$	S	2.26 S	1.24 S	4.4 S
$16 < S \leq 35$	16	36	20	71
$S > 35$	0.5 S	1.13 S	0.62 S	2.2 S

4 mm^2 five-core to forty eight-core auxiliary cable to this Standard will satisfy the armouring energy withstand requirement. This table may be used in a similar manner to determine the energy withstand capabilities of cables to the other Standards listed.

As stated in Regulation 521–02–01, single-core armoured cables with steel armouring must not be used for a.c. circuits. Aluminium armoured cables on the other hand may be so used but care is needed when the cables' protective conductors are connected to switchgear and the like to minimise the circulating currents.

Armoured cables always require correctly terminating to the equipment they serve irrespective of the constructional specification (i.e. Class I or Class II) of that equipment not least in order to maintain the mechanical protection properties of the armoured cable. Type C glands to BS 6121 *Mechanical cable glands* should always be used together with gland earth tag washer, nut, bolt and washers. If there is any doubt about the equipment enclosure being reliable as a protective conductor a connection (e.g. in a copper conductor) should be made between the bolt and the earthing terminal of the equipment. The use of BS 951 earthing and bonding clamps directly to the armouring should never be contemplated as a means of connection of the protective conductor as an alternative to proper glanding off. Such a method is unlikely to effect a reliable connection and deterioration can be expected over time as the armour wires are compressed into the insulating bedding leaving the joint less than tight thus providing a high resistance joint.

12.1.11 Protective conductors – 'clean' earths

The term 'clean' earth means different things to different people and it is important to establish the precise specification for such a facility. To this end the manufacturers of equipment for which a 'clean' earth is required should be consulted at an early stage. It is difficult to imagine a truly 'clean' earth since all conductors are subject to electrical noise imported either from the supply or from adjacent electromagnetic fields and the designer should obtain from the manufacturer the levels of noise which can and cannot be tolerated. Such an earth may be provided by a separate (usually a copper) cable from the equipment which utilises it to the main earthing terminal of the installation. Alternatively, an additional core of a multi-core cable may be used but again the manufacturer should be consulted with regard to induced voltages generated from the other cores of the cable.

Often a 'clean' earth will provide the dual purpose of protective and functional conductor to the equipment concerned but sometimes it only serves the functional objectives. In all cases the designer would need to consider the fault voltages that may arise between equipment connected to the 'clean' earth and other equipment and extraneous-conductive-parts connected to the normal ('un-clean') protective conductors.

12.1.12 Protective conductors – proving and monitoring

There may be occasions where consideration of the integrity of the protective conductor may warrant earth fault monitoring and protective conductor monitoring (e.g. where flexible trailing leads supply mobile apparatus). When using such equipment it is important to confirm that the operating coil is connected in the pilot conductor and not the protective conductor (Regulation 543–03–05). Where such protection is provided, the installation of such equipment should comply with BS 4444 *Guide to electrical earth monitoring and protective conductor proving*. This Code of Practice addresses the principles of design, construction and application of such equipment. It includes earth monitoring units and earth proving units, and units with combined functions. When designing and installing such protection reference to BS 4444 is essential. Figure 12.4 shows the basic circuit for a combined earthing proving and earth monitoring unit. The key to the symbols used in the figure is as follows:

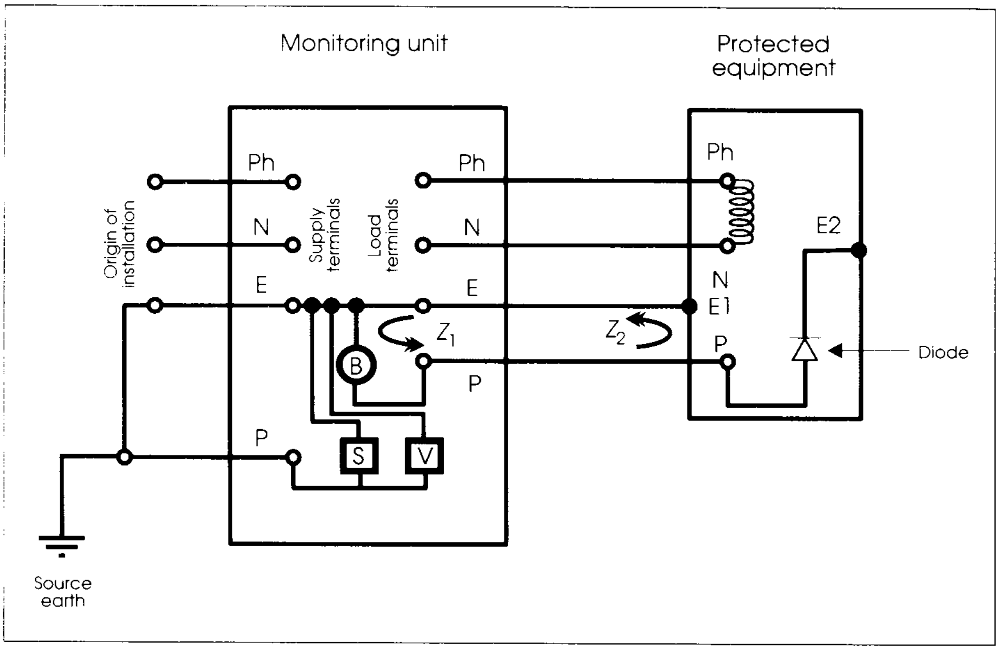


Figure 12.4: Outline circuit for a combined earth proving and earth monitoring unit

Ph = Phase conductor
N = Neutral conductor
E = Earthing/protective conductor
E_2 = Pilot conductor earthing terminal
Z_1 = Source phase earth-loop impedance
V = ELV source
B = Balancing sensing network
P = Pilot conductor terminal
E_1 = Equipment protective conductor terminal
S = Sensing device
Z_2 = Impedance of loop (cpc and pilot conductor).

12.2 Earthing

12.2.1 Earthing – general

Earthing is defined as the act of connecting the exposed-conductive-parts of an installation to the MET of that installation. It should *not* be confused with equipotential bonding which is different in concept in that it connects the extraneous-conductive-parts of the premises in which the installation is located to the MET thus creating a local equipotential zone.

Earthing serves two basic purposes:

- to limit the potential on current-carrying conductors with respect to the general mass of the Earth, and

- to limit the potential on non-current-carrying conductors with respect to the general mass of the Earth.

In other words, the limiting of the potential on current-carrying conductors with respect to the general mass of the Earth effectively 'ties down' the live conductors to Earth or, if you prefer, to reference them to Earth potential. This is essential for the proper functioning, particularly under unbalanced load conditions, of the electrical system and is commonly referred to as 'system earthing'. Limiting the potential on normally non-current-carrying conductors with respect to the general mass of the Earth on the other hand relates to safety protective measures used, in the majority of cases, to protect humans and livestock against hazards (e.g. electric shock) and this is commonly known as 'equipment earthing'. Chapter 54 of BS 7671 deals with the earthing arrangements as they relate to installations and BS 7430 addresses earthing in the form of a Code of Practice (formerly BS CP 1013).

Regulations 541–01–01 and 541–01–02 call for the means of earthing (and every protective conductor) to be selected and installed to afford compliance with BS 7671 and in particular with Chapter 54 and where the installation is subdivided each part is required to comply.

12.2.2 Earthing – responsibilities

It is the consumer who is responsible for providing facilities for the earthing of his installation and not the supplier (e.g. ED). In practice this responsibility is delegated to the electrical contractor engaged to carry out the installation work. There is no duty upon a ED to provide earthing facilities though, of course, many do offer such a facility when their network is such that it can be readily supplied. When offered, it is for the consumer (or his electrical contractor) to assess the nature of the facility and determine whether it is suitable for his purpose (e.g. a PME supply may not be acceptable in some cases). On existing installations the means of earthing needs regular testing to confirm its continuing effectiveness and reliability. On rewires, where the supply is already installed, it would be foolish to assume that an earthing facility is available even where there is some evidence to suggest there has been a connection in the past. Under no circumstances should a consumer or his electrical contractor make a connection to an PES's supply cable. In all cases the supplier should be requested, in writing at an early stage, to provide confirmation of whether or not a means of earthing can be provided.

12.2.3 Earthing – connection to Earth and system arrangements

Section 542 of BS 7671 deals with the requirements relating to the connection of the installation with Earth. Regulations 542–01–01 to 542–01–05 set out the requirements relating to the connection of the installation MET to the means of earthing depending on the system type. Figure 12.5 illustrates the connection arrangements for the TN-C-S, TN-S and TT system

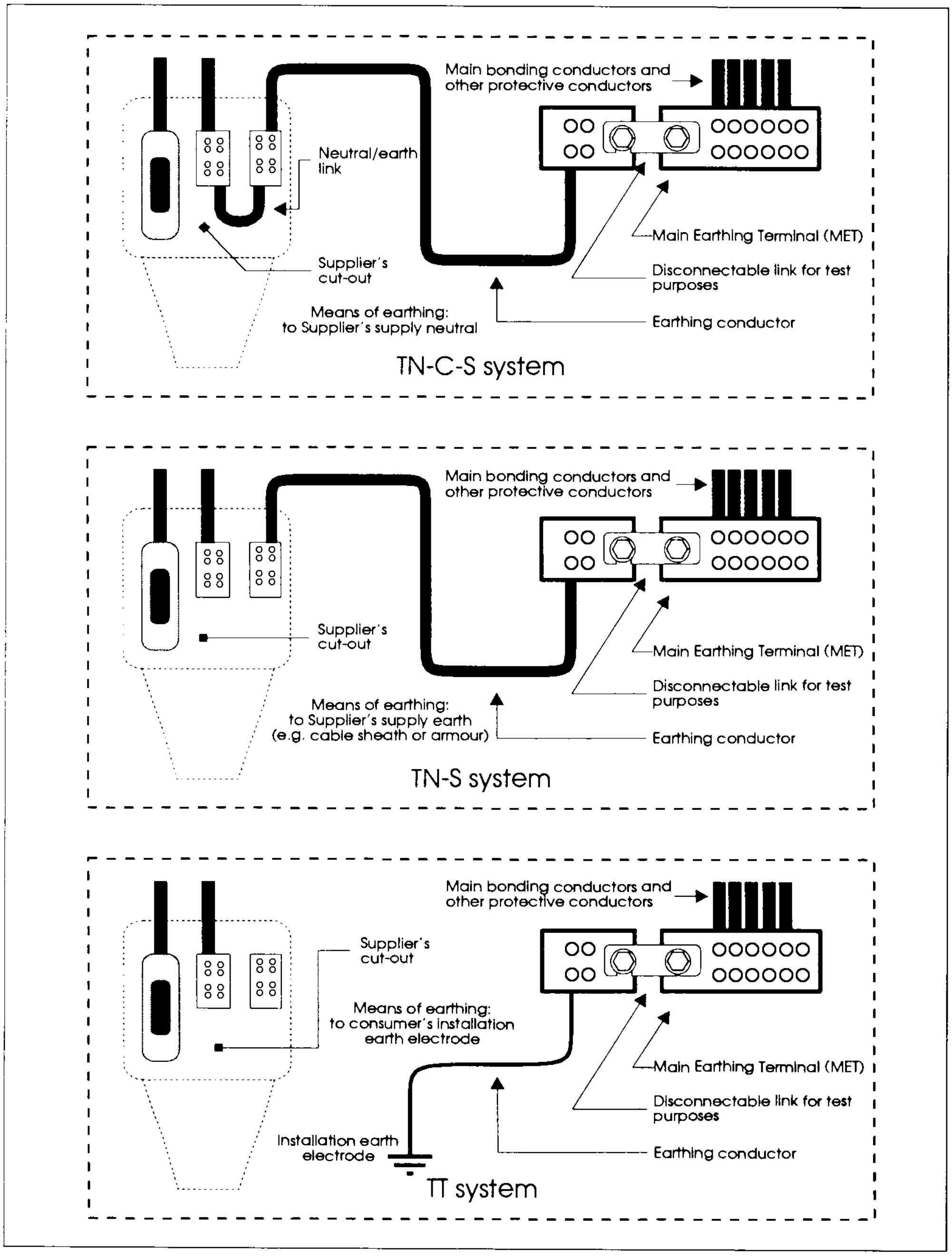


Figure 12.5: Connection arrangements depending on system type

types. The link between the neutral and earthing terminal on TN-C-S systems is made by the supplier and kept under seal as is the bonding conductor terminal in certain cases.

On domestic supplies, a growing trend is for EDs to terminate their supplies in an isolator fed from their service cut-out via the meter and leave this for connection of the installation by the consumer (or his electrical contractor). In some cases, the isolator takes the form of a double-pole device with only the phase conductor capable of being isolated. The other pole is used, where required, for a second tariff supply with the neutral solidly connected in a 'Henley' block. When such a device is used by the PES it should not be regarded as satisfying the requirements of Regulation 460–01–02 which demands a double-pole main switch for single-phase supplies. When this method of supply termination is used, it is customary for the PES to attach instructive notices adjacent to the supply point to aid the consumer to make the necessary connection.

As demanded by Regulation 542–01–07, in every case the earthing arrangements must be such as to be considered permanent and reliable and be protected against thermal, thermo-mechanical and electro-mechanical stresses and all other external influences. Precautions need to be taken to avoid the risk of damage to other metallic parts (e.g. water and gas pipework) from electrolysis as required by Regulation 542–01–08 which may involve the use of sacrificial cathodic electrodes (see BS 7361). Where a number of installations share protective conductors the designer will need to consider the effects of fault current sharing and, as called for in Regulation 542–01–09, any common protective conductor must be capable of carrying the highest fault current available from any of the installations making use of the common protective conductor. Alternatively, the installations should be separated electrically by, for example, making use of the TT system arrangement.

12.2.4 Earthing conductors

As can be seen in Figure 12.6, and as defined in BS 7671, the earthing conductor is the conductor connecting the MET of the installation to the means of earthing. The means of earthing can be an earthing facility provided by the PES in the form of cable sheath or armouring earth (TN-S) or a neutral/earthing terminal on a protective multiple earthing of a TN-C-S system. It can also be a single or multiple earth electrode system (TT and IT systems) which might consist of driven rods and/or buried copper tape. On many TT systems, the installation earthing conductor is mechanically protected by conduit and this allows for much smaller conductors to be used than would otherwise be dictated.

As Regulation 542–03–01 points out, earthing conductors are one form of protective conductor and must meet all the relevant requirements for those conductors. A new requirement in the 2001 version of BS 7671 calls for the minimum cross-sectional area of the earthing conductor to be not less than that required for main equipotential bonding conductors given in Regulation 547–02–01. Additionally, for buried earthing conductors, the minimum cross-sectional areas must meet the requirements of Table 54A. For tape and strip conductors, this regulation refers out to BS 7430 (formerly BS CP 1013) the Code of Practice for earthing. It also calls for the thickness of the conductor to be such as to withstand mechanical damage and corrosion.

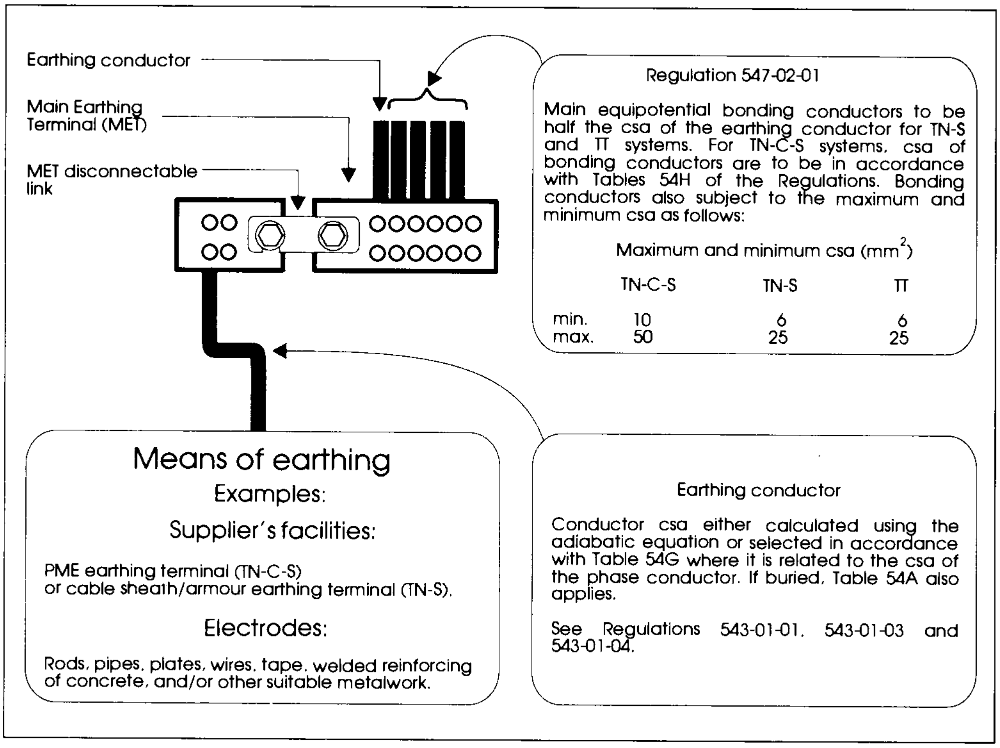


Figure 12.6: Earthing and other protective conductors

The sizes given for such conductors (in Table 54A) depend on the conductor metal and whether or not additional protection is provided against mechanical damage (mainly impact and vibration) and corrosion (water and chemical).

Where no mechanical or corrosion protection (no protective covering) is provided the minimum csa is 25 mm^2 for copper and 50 mm^2 for steel. In cases of earthing conductors with a protective covering and with mechanical protection the minimum csa is calculated from the adiabatic equation given in Regulation 543–01–03 or taken from Table 54G of Regulation 543–01–04 but if no further mechanical protection is afforded, then the minimum is 16 mm^2 copper or 16 mm^2 *coated* steel. The values given are *minimum* csa and it should be noted that there may be instances where these will be insufficient to meet the requirement relating to protective conductors (e.g. compliance with Table 54G of BS 7671).

As called for in Regulation 543–03–03, all connections to the means of earthing, including electrodes, must be protected against corrosion and be mechanically and electrical sound in order to provide a satisfactory and reliable connection. As with all connections of protective conductors a label, reading '**Safety Electrical Connection – Do not remove**' must be provided in a visible position on or near the connection (see Figure 9.9).

12.2.5 Earthing electrodes

Regulations 542–02–01 to 542–02–05 deal with the particular requirements relating to earth electrodes and identify suitable and acceptable types, as follows:

- earth rods and pipes, or
- earth tapes or earth wires, or
- earth plates, or
- underground structural metalwork embedded in the foundations, or
- welded metal reinforcing of concrete embedded in the Earth (but not pre-stressed concrete), or
- cable lead sheaths (or other metal coverings of cables, e.g. armouring) provided that the cable owner's consent has been obtained *and* the sheath is in effective contact with Earth *and* arrangements have been made for the owner of the installation to be warned of any proposed changes to the cable which might affect the suitability of the sheath as an electrode, or
- any other *suitable* underground metalwork.

Whatever type of electrode is chosen, the design and construction must take account of all the external influences (e.g. corrosion, water table, mechanical impact and vibration) and, as called for in Regulation 542–02–03, allowances must be made for a possible increase in electrode resistance due to the effects of corrosion. Regulation 542–02–04 makes clear that the metalwork of gas and water services must not, in any circumstances, be used as an earth electrode for protection against indirect contact but must of course be connected to the MET to effect main equipotential bonding.

Regulation 542–02–02 draws attention to the need to establish the effects on the electrode resistance of the soil drying or freezing. Where the designer has any options he should choose wet, preferably permanently wet, locations for electrodes. Obvious areas to be avoided if possible are dry sand, gravel limestone and anywhere where rocks are near to the surface. For this reason, it may be necessary to locate an electrode at some distance from the building foundations, the trenches of which are often infilled with rubble.

There are many factors which affect the resistance of an earth electrode including the size and shape of the electrode, the soil resistivity, the current density at the electrode surface and the step voltages in the ground around the electrode. The designer will find that reference to BS 7430 *Code of practice for earthing* (formerly BS CP 1013) will be invaluable in the design of effective and safe earthing systems and this publication should be consulted in all but the simplest of earthing systems. The Standard gives information, *inter alia*, on the relationship between rod diameter and rod length to resistance. It will be seen that increasing the rod diameter has less effect on resistance than does increasing the number of rods or extending their length. Where multiple rods are required, information is provided relating to overlapping resistance areas and gives recommendations for spacing. Mechanical, chemical and electrolytic properties of materials are also addressed.

According to BS 7430, for the driven rod or similar electrode the resistance to Earth is given in Equation (12.6).

$$R = \frac{1}{2\pi L}(\rho - \rho_c)\ [\log_e \frac{8L}{D} - 1] + \frac{\rho_c}{2\pi L}[\log_e \frac{8L}{d}] \tag{12.6}$$

where ρ = resistivity of the soil (Ω m)
ρ_c = resistivity of the infill material (Ω m)
d = diameter of the electrode (m)
D = diameter of the infill (m)
L = driven length of the electrode (m).

It can be readily seen from equation (12.6) that where the infill material is the same as the surrounding material the first term goes to zero leaving only the second term. This may, for example, apply to earth electrodes associated with TT and IT systems where the electrode is driven directly in the ground. In this case Equation (12.7) would apply.

$$R = \frac{\rho_c}{2\pi L}[\log_e \frac{8L}{D}] \tag{12.7}$$

As with all electrical equipment, it is essential that the earthing electrode, particularly when in the form of a single separate rod, is protected against mechanical, chemical and electrolytic damage. Figure 12.7 gives such an example of mechanical protection of a rod electrode although a purpose made concrete or brick housing with removable slab cover would also be acceptable as would a suitable steel box type enclosure. Where multiple rods are required it is recommended that the distance between rods should not be less than the effective depth of the rod.

12.2.6 Main Earthing Terminals (METs)

As called for in Regulations 542–04–01 and 542–04–02, a MET is required for every installation. The MET must have provision for connecting separately the circuit protective conductors, the main bonding conductors, any functional earthing conductors and the main bonding conductor to the lightning protection system where used. One of the principal purposes of the MET is to provide for disconnection of the earthing conductor from circuit protective conductors and bonding conductors so that the external phase-earth loop impedance, Z_e, can be measured. For this reason, the earthing conductor and other protective conductors should be clearly identifiable. The means of disconnection must involve the use of a tool (e.g. spanner or screwdriver) and is best provided with a disconnectable link (see Figure 12.6). It goes without saying that METs must be mechanically robust and capable of providing long-term reliability and continuity.

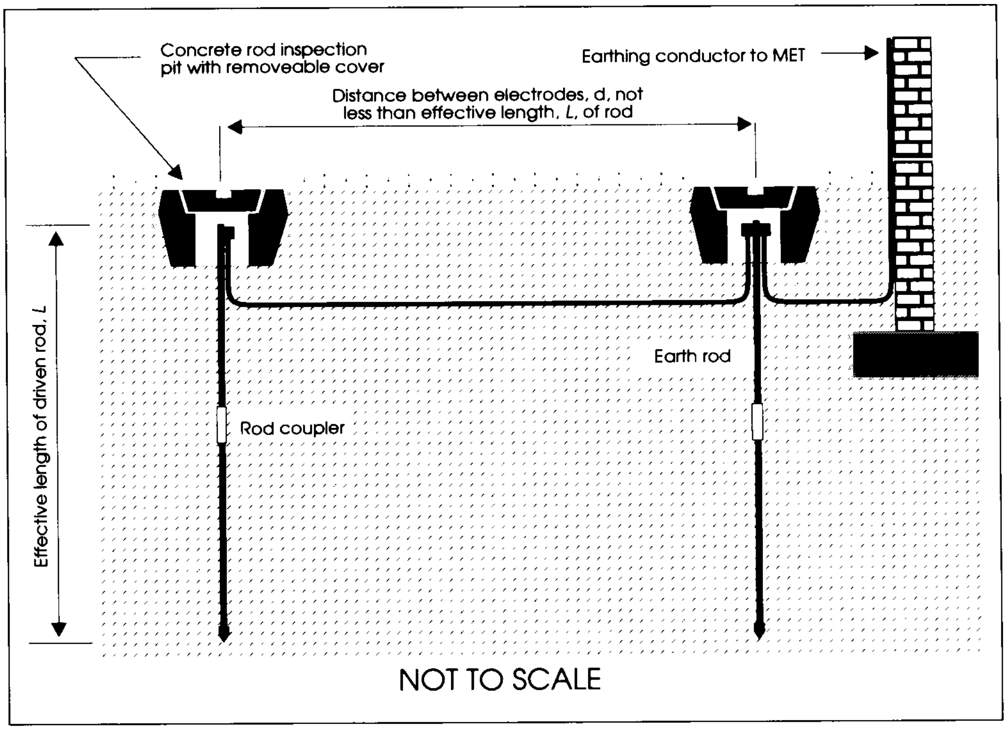


Figure 12.7: Electrodes with inspection pits

Testing of Z_e must only be carried out by skilled and competent persons and the disconnectable link of the MET must never be removed whilst the installation is energised since any earth fault current, however minor, could cause a voltage (up to U_o) between the disconnected parts of the MET. The designer may consider it prudent to affixed a notice adjacent to the MET warning of the dangers of disconnecting the link.

Where an installation is contained in more than one separate building, Regulations 413–02–02 calls for a MET (and equipotential bonding) for each building. Figure 12.8 shows such an typical arrangement for three such separate buildings each with its own MET and equipotential zone. Building A is supplied with a PME service from the public network and houses the main distribution switchboard. Building B makes use of the TN–C–S earthing facility and the main bonding conductors here are of the same csa as the Building A. The supply earthing is not utilised in Building C which is treated as an installation which is part of a TT system and equipped with its own earth electrode.

12.2.7 Earthing – accessories and other equipment

As with all exposed-conductive-parts on installations where EEBADS (Earthed Equipotential Bonding and Automatic Disconnection of Supply) is used, accessories require earthing via the circuit protective

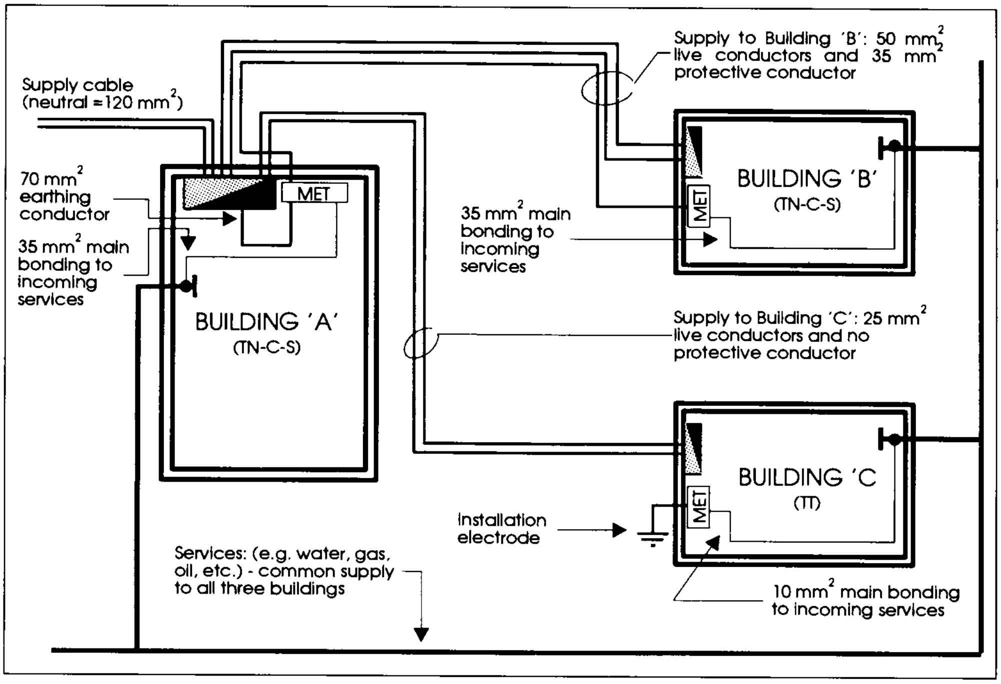


Figure 12.8: Typical arrangement for one installation spanning three separate buildings

conductor to the MET for compliance with Regulation 413–02–06 in TN systems or Regulation 413–02–18 in TT systems. This is also true for any metal boxes which house the accessory including those installed flush with the wall and which are also deemed to be exposed-conductive-parts. Where the cpc(s) are separate it is preferable to terminate them directly into the accessory and then earth the box by means of a 'fly-lead' from the earthing terminal of the accessory to the terminal in the box. Where the cpc is provided by steel conduit or steel trunking, all that is required is the 'fly-lead'. Reliance of the contact between the accessory and a flush box for earthing purpose should not be regarded as providing a permanent and reliable connection owing to uneven surfaces and the possibility of corrosion over time.

The operating mechanism (if metal) of time switches needs earthing. It is not always recognised that, when such a mechanism is supplied with a conduit box enclosure, an earthing connection between the two is often not provided. Again, all that is required (provided the box is adequately earthed) is a 'fly-lead' between the box and the time switch mechanism.

Metal cable-trays, cable-ladders and other cable-supporting exposed-conductive-parts must be earthed (Regulations 413–02–06 or 413–02–18) and this can be effected, in the case of sheathed cables, by providing a separate conductor. If the cables being supported are of the metal sheathed or exposed-armoured type this may be achieved by the use of metal clips and bolts to the support system.

12.3 Equipotential bonding

Equipotential bonding will always be required where protection against electric shock (indirect contact) is provided by EEBADS. There are essentially three forms of bonding (which should not be confused with earthing):

- main equipotential bonding (applicable to all installations where EEBADS is employed),
- supplementary equipotential bonding (applicable to some special locations and installations and other special circumstance installations where EEBADS is employed),
- additional equipotential bonding (applicable to where EEBADS is employed and disconnection times for distribution circuits cannot be met and where circuits with differing disconnection times emanate from a common distribution board).

Equipotential bonding should only be considered where conductive parts including those of non-electrical services fall within the definition of extraneous-conductive-parts, i.e. *conductive parts liable to introduce a potential*. Bonding of conductive parts which are not liable to introduce a potential, far from providing a measure of safety, can indeed, under certain circumstances, create a hazard that was not present hitherto.

12.3.1 Main equipotential bonding

The principal purpose of providing main equipotential bonding is to protect against dangers resulting from earth faults on the supply so that any fault voltage on the MET and all exposed-conductive-parts connected to it are substantially at the same potential (under these conditions) to extraneous-conductive-parts such as water pipes, etc.

Section 547 of BS 7671 deals with requirements for main equipotential bonding conductors but it should not be forgotten that other relevant parts of BS 7671 are no less applicable to these conductors than to current-carrying conductors. In particular, precautionary measures need to be taken in relation to external influences (e.g. mechanical stress and the need for proper supports, and corrosion). If the conductor metal is other than copper the conductance of that material must not be less than that of copper of csa appropriate to the particular installation.

The minimum csa of main bonding conductors is related to the csa of the earthing conductor (the conductor connecting the MET to the means of earthing) which itself is related to the phase conductor csa in all cases except where the supply is obtained from a network which uses protective multiple earthing (PME). For installations supplied by a PME source (a TN-C-S system) the csa of the main bonding conductors is related to the csa of the neutral of the supply. In all the cases the csa of the bonding conductor is subject to a minimum of 6 mm^2 (Regulation 547–02–01). For TN-C-S installations Table 54H of BS 7671 gives data for selecting the csa of these bonding conductors. Table 12.9 of this Guide summarises the required csa for main equipotential bonding conductors for both PME and non-PME supplies.

Where the protective measure of EEBADS is used, a main equipotential bonding conductor is required from the MET to each and every extraneous-conductive-part which enters the equipotential zone. Regulation 413–02–02 cites a number of examples of such parts but the list should not be regarded as exhaustive and there may be other conductive parts entering the zone which will require main bonding (e.g. oil pipe lines and compressed air lines). As previously mentioned, bonding conductor connections at the MET should be easily identifiable.

Figure 12.9 shows a typical installation with the main bonding connections. These connections should be made as near as practicable to the point (ideally within 600 mm) where the services enter the zone as called for in Regulation 547–02–02. This regulation goes on to require that where insulated parts are inserted into service pipes etc. the bonding conductor termination should be made on the consumer's side of that insert. Where there is a significant length of pipework from the point of entry to an insulated insert it may be necessary to apply insulating material to that section of pipework.

It may not always be necessary or economical to take separate bonding conductors to the various extraneous-conductive-parts (incoming services) entering the zone. It may sometimes be appropriate for one conductor to connect a number of parts (possibly all) but when so doing it is advisable that the conductor is left continuous and is looped-terminated at every point but the last on the run.

As called for in Regulation 413–02–02, and again in Regulation 541–01–03, a main equipotential bonding conductor is required to connect the MET with the lightning protection system (see Figure 12.9). The csa of such a bonding conductor must be related to the earthing conductor and would normally be the same csa (if of the same metal) as other main bonding conductors (see Table 12.9). BS 6651 which deals with lightning protection systems has long called for such a conductor and requires the connection to the lightning protection system to be made above the test joint of the down conductors. Where, as in most cases, there are a number of down conductors, each will require effective bonding but this would not preclude the lightning protection conductors also serving as bonding conductors provided they were of adequate conductance. Additional cross-bonding may be required where exposed and extraneous-conductive-parts are located within flash-over distance of the lightning protection system conductors.

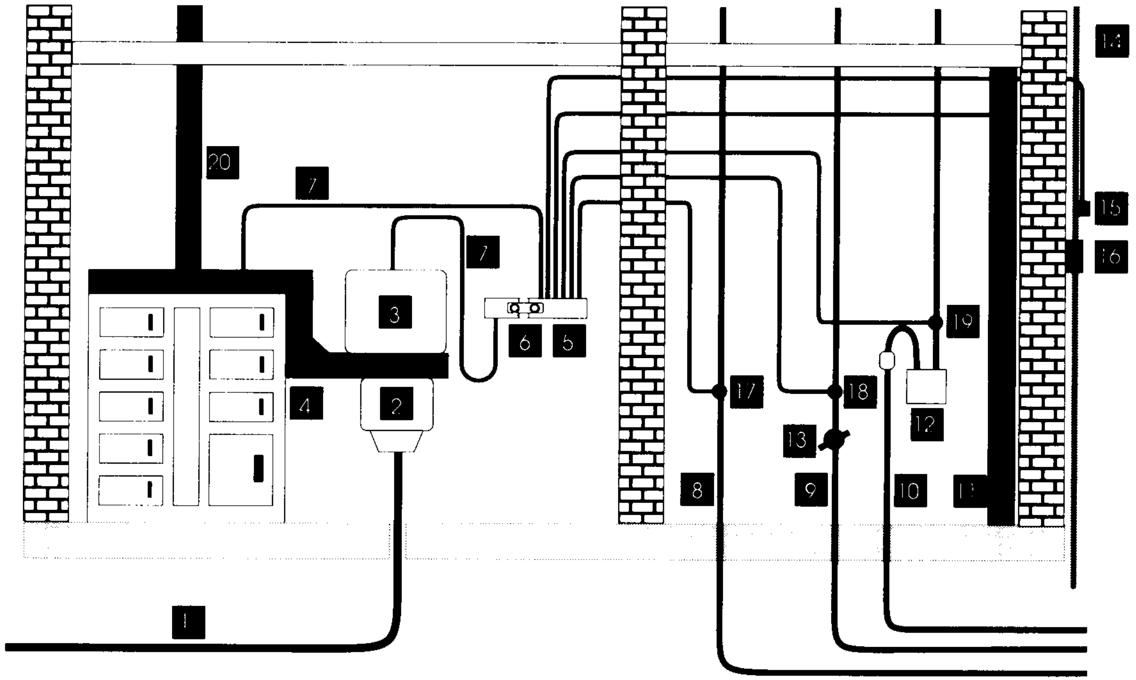
12.3.2 Additional equipotential bonding

Additional equipotential bonding is similar to supplementary bonding except in respect of sizing and the csa of these conductors should be selected as if for main equipotential bonding. Regulation 413–02–12 refers to additional bonding for circuits supplying socket-outlets and other portable equipment and Regulation 413–02–13 makes specific requirements

Table 12.9: Cross-sectional areas of main equipotential bonding conductors (nearest standard sizes)

Ref	System supply	Phase conductor csa (mm²)	Neutral conductor csa (mm²)	Earthing conductor csa (mm²)	Non-PME supplies (mm²)	PME supplies (mm²)	Comments
A	Non-PME	6	—	6	6	—	Minimum csa applies. See Table 54G and Regulation 547-02-01.
B	PME	—	6	6	—	10	See Table 54H.
C	Non-PME	10	—	10	6	—	See Table 54G and Regulation 547-02-01.
D	PME	—	10	10	—	10	See Table 54H.
E	Non-PME	16	—	16	10	—	See Table 54G and Regulation 547-02-01.
F	PME	—	16	16	—	10	See Table 54H.
G	Non-PME	25	—	16	10	—	See Table 54G and Regulation 547-02-01.
H	PME	—	25	16	—	10	See Table 54H.
I	Non-PME	35	—	16	10	—	See Table 54G and Regulation 547-02-01.
J	PME	—	35	16	—	10	See Table 54H.
K	Non-PME	50	—	25	16	—	See Table 54G and Regulation 547-02-01.
L	PME	—	50	25	—	16	See Table 54H.
M	Non-PME	70	—	35	25	—	See Table 54G and Regulation 547-02-01.
N	PME	—	70	35	—	25	See Table 54H.
O	Non-PME	95	—	50	25	—	See Table 54G and Regulation 547-02-01.
P	PME	—	95	50	—	25	See Table 54H.
Q	Non-PME	120	—	75	25	—	See Table 54G and Regulation 547-02-01.
R	PME	—	120	75	—	35	See Table 54H.
S	Non-PME	150	—	75	25	—	See Table 54G and Regulation 547-02-01.
T	PME	—	150	75	—	35	See Table 54H.
U	Non-PME	185	—	120	25	—	See Table 54G and Regulation 547-02-01.
V	PME	—	185	120	—	50	See Table 54H.

Notes: (1) The csa attributed to earthing conductors on installations supplied by a PME source assumes that the phase conductor csa equals that of the neutral conductor.



1 Electricity service supply cable
2 Supplier's cut-out
3 Supplier's metering equipment
4 Main switchboard
5 Main Earthing Terminal (MET)
6 MET disconnectable link
7 Earthing conductor
8 Other service pipe (e.g. oil pipe)
9 Water incoming service
10 Gas incoming service
11 Structural steel
12 Gas meter
13 Water stopcock
14 Lightning protection down conductor
15 Main bonding to down conductor
16 Down conductor test point
17 Main bonding to other service pipework
18 Main bonding to water service
19 Main bonding to gas service
20 Distribution cable containment system

Figure 12.9: Typical main bonding connections

for distribution circuits. Again such bonding would of necessity be required to connect all extraneous-conductive-parts together with exposed-conductive-parts. These cases are discussed in Chapter 5 of this Guide.

12.3.3 Supplementary equipotential bonding

Other than special locations or installations (embraced by Part 6 of BS 7671) there is generally little need for supplementary bonding except where circuit disconnection times cannot be met and where the use of an RCD is undesirable (Regulation 413–02–04). However, there may be a need to provide supplementary bonding (Regulation 471–08–01) where the fault voltage magnitude and duration are such that there may be a danger, particularly where the more susceptible members of our society (old or physically disabled persons) are the users of an installation. Supplementary bonding for special locations and installations is discussed in Chapter 16 under the relevant headings.

As called for in Regulation 547–03–01, supplementary bonding conductors between two or more exposed-conductive-parts must have equivalent conductance to that of the smaller or smallest cpc. Where the bonding conductor is not sheathed or otherwise protected against mechanical damage, it is subject to the minimum csa of 4 mm^2. Bonding conductors between exposed-conductive-parts and extraneous-conductive-parts must, according to Regulation 547–03–02, be not less than half the csa of the cpc of the circuit concerned, but again the minimum csa of 4 mm^2 applies if mechanical protection is not provided. Regulation 473–03–03 calls for the bonding connection between two or more extraneous-conductive-parts to be a minimum of 2.5 mm^2 if sheathed or otherwise mechanically protected or 4 mm^2 if mechanical protection is not provided. For most practical situations a minimum csa of 4 mm^2 would apply to all supplementary bonding conductors.

Regulation 547–03–04 acknowledges that the bonding conductors may take the form of separate conductors or conductive parts which provide a permanent and reliable conductive path or a combination of both. This would include metallic pipework (e.g. copper water pipes). Where it is necessary to effect a supplementary bonding connection to a item of Class I equipment (e.g. electric towel rail), Regulation 547–03–05 permits the cpc of the flexible cord making the final connection to the appliance to be also used as a bonding connection thereby obviating the need for a separate conductor and separate termination. This dispensation is only applicable where the final connection is short (e.g. 150 to 200 mm).

As mentioned earlier, Regulations 413–02–27 and 413–02–28 reinforce the requirements contained in Chapter 54 relating to supplementary bonding and additionally call for the resistance, R, of the supplementary bonding conductor between conductive parts to meet Equation (12.8) for the general situation.

$$R \leqslant \frac{50}{I_a} \Omega \tag{12.8}$$

where I_a is the operating (tripping) current (in amperes) of the protective device which if an RCD is $I_{\Delta n}$ or, if an overcurrent device, is the minimum current which causes disconnection within 5 s.

Transposing Equation (12.7) it will be seen that (RI_a) must not exceed 50 V for the general case (i.e. normal dry conditions) but, as can be seen later, this limit of touch voltage will need reducing for special installations and locations. Where there are a number of final circuits with exposed-conductive-parts requiring supplementary bonding, the operating current, I_a, to be used in Equation (12.7) will be the worst case value. By way of example, if exposed-conductive-parts of three final circuits need supplementary bonding, the designer would find the worst case value of earth fault current from the time/current characteristics of the protective devices and insert it into the equation. Taking three circuits protected by Type 2 MCBs with nominal rating of 6 A, 20 A and 32 A respectively (for disconnection within 0.1 s and 5 s) it can be determined from the time/current characteristics that the respective operating currents, I_a, are 42 A, 140 A, 224 A respectively. Clearly the I_a of 224 A would be used to determine the supplementary bonding conductor resistance, R, in this case limited to 0.22 Ω (50 ÷ 224).

12.3.4 Bonding clamps

Equipotential bonding connections must be made to extraneous-conductive-parts (e.g. water pipes) using clamps manufactured to comply with BS 951 *Specifications for clamps for earthing and bonding purposes*. Clamps are available for securing to pipework, etc. of diameter of 6 mm or greater and for conductor sizes from 2.5 mm^2 to 70 mm^2 (identified by the letters A, B, C, D, E, F, G and H for conductor of csa 2.5, 4, 6, 10, 16, 25, 35 and 70 mm^2 respectively).

Wherever such clamps are used they must be accompanied by a suitable label to meet the requirements of Regulation 514–13–01 in the case of protection by EEBADS and to meet the requirements of Regulation 514–13–02 where the protective measure of earth-free equipotential bonding is employed (see Figures 9.9 and 9.10). Most commercially available clamps are acquired with a label attached (to meet Regulation 514–13–01) and are commonly of the form of a thin twin-slotted or twin-hold aluminium embossed strip attached, for convenience of packing, to the strap of the clamp. Because of the risk of corrosion and electrolytic action between dissimilar metals (e.g. copper and aluminium) the label should be removed from the strap and attached either to the bonding conductor itself or below the locking nut of the clamp taking care that the label cannot come into contact with the copper pipework.

Applying such clamps to lead sheathed cables should be avoided because the inevitable expansion and contraction of the cable (under varying load conditions) is likely, in time, to make the clamp joint become loose and lose its effectiveness. Soldered joints should not be used under such circumstances. Regulation 547–02–02 demands that such bonding connections be made to the hard metal pipework of incoming services and this would preclude a connection being made directly with a lead gas or water pipe and lead-sheathed cable.

Some manufacturers of BS 951 earthing clamps use a method of colour coding to indicate the suitability of the item for dry conditions and for wet or damp environments. The accepted code is red for dry conditions and blue for wet or damp conditions.

Chapter 13

Specialised Installations

13.1 General

It is not the intention here to provide a detailed specification for the specialised installations addressed but rather to identify specific points which are worthy of note. An attempt is therefore made to distinguish some of the issues which, from experience, need consideration prior to carrying out the design. Where guidance on the subject is made in other publications, these are identified and their careful perusal is recommended.

13.2 Emergency lighting

The first point to make is that the designer of an emergency lighting installation should consult with other interested parties before commencing the detailed design. Interested parties would include, for example, the architect, the lighting engineer, the owner of the premises, the electricity supplier and the licensing and enforcing authority (e.g. Fire Authority, Local Authority, Health Board, etc.). Some aspects which would be the subject of consultation are:

- number and position of fire alarm call points; and
- location of fire-fighting equipment (e.g. hose reels); and
- location of lifts, elevators, walkways, toilets, control room, accommodation, etc.; and
- location of plant rooms and car parks and the siting of the generator, where required; and
- designation of escape route(s) including an assessment of fire risks; and
- assessment of potential risks along escape route; and
- requirements for external escape lighting.

An emergency lighting installation is required to comply both with BS 7671 and BS 5266 *Emergency lighting* (see Regulation 110–01–01). The last revision to the Standard in 1999 identified a number of changes including an increase in the number of definitions. Additionally, the Standard now requires an Operational and Maintenance Manual to be provided as well as the installation drawings. Detailed guidance for emergency lighting installations is beyond the scope of this Guide. For those engaged in this type of work, BS 5266 Parts 1 and 7 are considered to be essential reading and explain in detail all the necessary requirements. Further advice on luminaire specifications is obtainable from the Industry Committee for Emergency Lighting (ICEL) and the Lighting Industry Federation. ICEL, in conjunction with the Assessment Department of BSI, have a certification scheme for emergency lighting luminaires and ICEL labels are affixed to certified products (Product Standard ICEL-1001).

Regulation 528–01–04 and the Standard call for emergency lighting circuits to be segregated from all other cables including those of fire detection and alarm systems. This requirement does not apply to the case of the circuit supplying self-contained luminaires with integral batteries which is considered to be a normal LV circuit. Luminaires, like other equipment, need a means of interrupting the supply and this can be done by a local 'key' switch either mounted adjacent to the luminaire or at a local gridswitch (suitably labelled). This switch can also provide the means for testing and discharging batteries. Devices for the control, isolation and operation of the system must be clearly identified and marked accordingly by, for example, labelling, as appropriate, '**Standby lighting**', '**Escape lighting**' or '**Emergency lighting**'.

Circuits which supply emergency lighting luminaires, including self-contained units fed from a general lighting circuit, need to be identified at their distribution board and distribution circuit feeder (if any), in the normal way.

On completion of such an installation, inspection, testing and certification must be completed and the necessary documentation handed to the building occupier. Testing for illuminance will involve the use of a suitable meter with an appropriate scale (lux). Records, including initial certification, must be kept in the form of a log book, detailing subsequent events and listing the checks that are made and the particulars of periodic inspection and testing.

13.3 Fire detection and alarm systems

A fire detection and alarm system installation is required to comply both with BS 7671 and BS 5839 Part 1 *Code of practice for system design, installation and servicing* (see Regulation 110–01–01). Other parts of this Standard relate to equipment specifications:

- Part 2 *Specification for manual call points*,
- Part 3 *Specification for automatic release mechanisms for certain fire protection equipment*,
- Part 4 *Specification for control and indicating equipment*,
- Part 5 *Specification for optical beam smoke detectors*,
- Part 6 *Code of practice for the design and installation of fire detection and alarm systems in dwellings*,
- Part 8 *Code of practice for the design, installation and servicing of voice alarm systems*.

British Standards Institution's publication PD 6531 *Queries and interpretations on BS 5839: Parts 1 and 4 (as amended)* will be essential reading for the system and installation designer. Some other BSI Standards relevant to this subject are:

- BS 5306 *Fire extinguishing installations and equipment on premises*,
- BS 5445 *Components of automatic fire detection systems*,
- BS 5446 *Components of automatic fire alarm systems for residential premises*,
- BS 5588 *Fire precautions in the design, construction and use of buildings*,
- BS 6266 *Code of practice for fire protection of electronic data processing installations*.

Where these systems are installed to satisfy statutory requirements imposed, for example by the Fire Precautions Act 1971, the enforcing authority would normally require compliance with BS 5839. It is recommended that consultations with all interested parties, including the licensing and enforcing authority, take place prior to commencing detailed design work. Other interested parties who should be consulted include the building fire insurer, the architect, HSE, communications link provider etc. Detailed consideration of such issues as the purpose of the system, occupants' escape time, fire brigade response time, the relationship with other building occupants and servicing and maintenance procedures, are required at an early stage. System operational requirements, planning of escape routes and sound levels of the alarm sounders, in the context of the ambient noise and occupancy patterns, will also need to be established at an early stage. Generally, a number of small sounders are usually more effective in terms of audibility levels (see Clause 9.4.1 of the Standard) than a lesser number of larger units. Verification of installations and their periodic testing will necessarily involve testing of the sounder(s) and a suitable meter (dB) will be required. Particular attention needs to be paid to sound level attenuation caused by, for example, curtains, doors, carpeting and furniture.

There are two basic types of protection; the protection of life and the protection of property. The design approach for one system differs from the other and Table 13.1 summarises the principal features of the systems and their variations.

Clause 17.3, of BS 5839: Part 1, makes recommendations as to the acceptable types of wiring system and Clause 17.6 states that other cables may be used subject to certain conditions. Table 13.2 summarises this information.

Fire alarm systems come in many different types and the installation planning and techniques will depend to a large extent on the particular type chosen. Open circuit operation is used on many conventional systems but has the disadvantage that it cannot differentiate between a circuit fault condition and a genuine fire signal whereas the initiation circuit which is monitored can make this distinction. Many addressable and Time-Division-

Table 13.1: Principal features of the systems for the protection of life and the protection of property

Protection required	**Type**	**Description of type**	**Basic features**	**Possible additional features**
Protection against property.	P1	Covering all parts of the premises.	A control and indicating panel, external and internal sounders, manual call points, automatic detectors.	Fixed extinguishing system, additional sounders, repeat indicator panels, a manned centre link.
	P2	Covering only those parts of the premises having a high fire risk.		
Protection against life.	L1	Covering all parts of the premises.	A control and indicating panel, alarm sounders, manual call points.	Fixed extinguishing system, additional sounders, repeat indicator panels, a manned centre link, automatic detectors, automatic door release relay unit
	L2	Covering only those parts of the premises where there is a high risk to life if there is a fire anywhere in the building.		
	L3	Covering only areas critical to free movement along escape routes.		
	M	Provides only for manual initiation and relies on the presence of persons at all times.		

Multiplexing (TDM) systems can allow all devices to be wired on the same ring circuit and others permit the trigger devices to be so wired with other power circuits to sounders wired through appropriate triggering relays. Generally, sounders are wired on radial circuits with more than one circuit per system. Where a single two-wire ring circuit is employed it is normally necessary to fit each device with short-circuit ‘isolators’ (one each side of the device) so that a faulted unit will not prevent the rest of the system from operating.

It is generally necessary to split a building up into zones if for no other reason than to be able to identify the location of a particular fire condition signal. In the consideration of these zones it would be necessary to decide on whether sounders should sound in all zones or groups of zones bearing in mind the risk to occupants and their escape routes. In other words, zoning is vitally important from the fire protection planning viewpoint and it will be closely related to the ‘fire compartments’ or areas contained in fire resisting material of, say, 30 minutes’ resistance. As a rule of thumb, zones would not normally exceed 2000 m^2 and a person should not need to travel more than 30 m to identify the position of a fire visually. The use of remote indicating lamps repeating the signal of a detector device or group of devices, can assist in this respect. Stairwells, lift shafts and the like should be treated as separate zones and one zone would not normally cover more than one storey unless the whole building has a floor area of less than 300 m^2 . For multi-occupancy buildings, the zones should coincide with the occupancy boundaries and whilst it is acceptable for a zone to extend over a number of fire compartments it is not considered admissible to have zones overlapping.

Table 13.2: Preferred wiring systems

Ref	BS No	Cable type	Suitable for application requiring prolonged operation	Additional mechanical/ electrical protection
		(See BS 5839: Part 1: Clause 17.3)	**(See BS 5839: Part 1: Clause 17.4)**	**(See BS 5839: Part 1: Clause 17.5)**
A	6207	Mineral insulated copper-sheathed cables (with or without overall PVC or LSHF covering).	Yes.	Requires surge protection. No further mechanical protection required.
B	6387	Cables required to maintain circuit integrity under fire conditions (Categories AWS or SWX or above).	Yes.	See BS 5839.
C	6387	Cables required to maintain circuit integrity under fire conditions (Categories A or S or above).	Requires additional protection against exposure to fire – see BS 5839.	See BS 5839.
D	6004	PVC/PVC insulated and sheathed.		See BS 5839.
E	6004	PVC insulated.		See BS 5839.
F	6007	Rubber insulated, textile-braided and compounded.		See BS 5839.
G	6231	PVC insulated, type 'BK', 'BR' and 'BU'.		See BS 5839.
H	6346	PVC/PVC insulated and sheathed with steel-wire armour.		No.
I	5467	Cross-linked polyethylene or hard ethylene propylene rubber insulated, sheathed, with steel-wire armour.		No.
J		Polyethylene-insulated PVC sheathed coaxial cable. Centre conductor of $\Phi \geq 2$ mm/16-strand but otherwise complying with BS 2316: Part 3 for Uniradio Sheet M210.	No but see BS 5839.	$U_n \leq 50$ V.
K		Cables designed for detection of heat.	No but see BS 5839.	See BS 5839.
L		Other cables permitted by Clause 17.6 of BS 5839: Part 1.	No but see BS 5839.	See BS 5839.

Note: (1) Because PVC/PVC insulated and sheathed cables installed without additional mechanical protection are required by Clause 17.10 to be separated from other circuit wiring (by 300 mm) and the requirement for marking or labelling every 2 m, there is limited scope for its use.

Figure 13.1 shows a simple fire alarm system in which each zone has its own two-core circuit for sounders and triggering devices and it can be seen that this configuration has the advantage of limiting the effects of a faulted circuit to devices on that circuit. Figure 13.2 shows a typical fire alarm system supply schematic layout in which the fire alarm system supply is derived from the upstream side of the general installation main switch. The Standard also permits the supply to be taken from the downstream side of the main switch – see Clause 16.2. In any event, warning notice labels are required as follows:

- FA system supply connected to the upstream side of the main switch: **'Warning: this supply remains when the main switch is turned off'**. Notice to be affixed to FA system switchfuse.

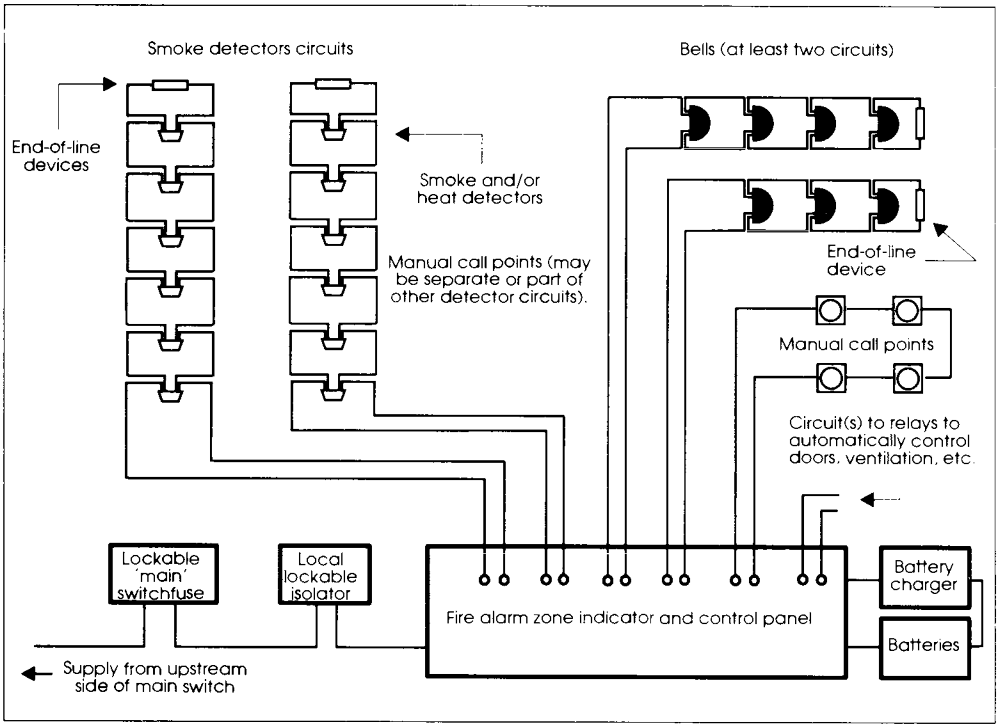


Figure 13.1: A schematic representation of a simple fire alarm system

- FA system supply connected to the downstream side of the main switch: **'Warning: this switch also controls the supply to the fire alarm system'**. Notice to be affixed to general installation main switch.

Generally, protection against indirect contact by means of an RCD should be avoided if possible for fire alarm systems. Where RCD protection cannot be avoided (e.g. on TT systems), the device should be dedicated to the system and not also protect general purpose circuits. Additionally, the use of the more sensitive RCDs ($I_{\Delta n} \leqslant 100$ mA) should be avoided wherever possible.

Clause 6.6.3 of BS 5839: Part 1 calls for at least one sounder to continue to operate in the event of a fault condition occurring on others. In practice this means that for a simple system with radially wired sounder circuits at least two such circuits will be required. For the more complex systems (e.g. TDM) wired on a single ring circuit, each sounder device will need to be fitted with a short-circuit isolator on both 'legs' of the ring.

Recently introduced legislation both on the UK mainland and in Northern Ireland, amending the Building Regulations, requires for the first time provision of a smoke detection and alarm on each floor of newly-built houses and dwellings converted from a building previously used for other purposes. This provision may be by means of a system complying with BS 5839: Part 1 to at least 'L3' standard (covering areas critical to free

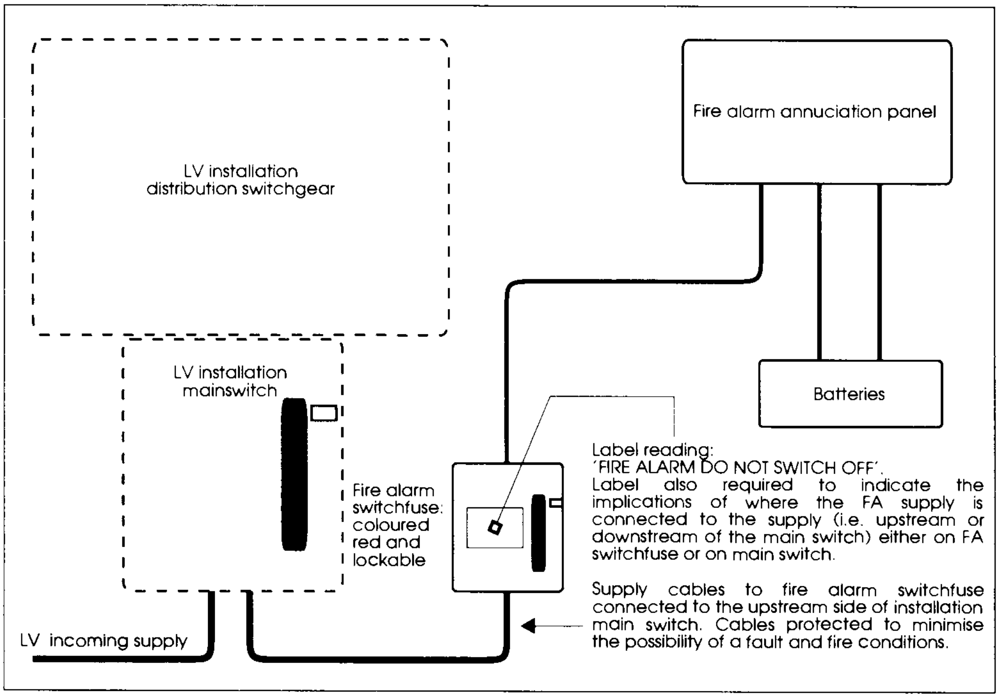


Figure 13.2: Fire alarm system supply schematic layout

movement along escape routes) or by appropriately sited self-contained smoke alarms. Smoke alarms must be either wholly mains operated or mains supplied with secondary back-up batteries. Units with primary batteries are not acceptable. For the larger dwellings the self-contained smoke alarms are not usually adequate and a full fire alarm and detection system should be used. In sheltered and warden-controlled housing the warden's apartment should be equipped with a central monitoring annunciation panel to enable the warden to identify the location of the fire signal. Whilst the Statutory Regulations must be studied in depth the following points, relating to the legislation in Northern Ireland, may be useful as a general guide to self-contained smoke alarm installations:

- not less than one self-contained smoke alarm sited in an appropriate place on each storey;
- where the distance, via the shortest route, from any point in any room to the furthest point in any other room on the same storey is more than 30 m, self-contained smoke alarms are not regarded as suitable and a full alarm and detection system must be used;
- where a dwelling is contained within a building which contains other rooms and where a full detection and alarm system is installed to protect the whole building, a detector capable of detecting a fire in the circulation routes of the dwelling is required and the system alarm must be adequately audible in *all* rooms of the dwelling;

- where a dwelling comprises more than one storey, the self-contained smoke detectors on each storey must be interconnected so as to provide an audible alarm on every device in the event of a fire signal on any unit;
- self-contained smoke alarms must be permanently wired to a circuit which is separately fused at the distribution board;
- the circuit used for self-contained smoke alarms must not be used to supply any other equipment;
- where it is essential to employ an RCD (e.g. on TT systems) to protect the circuit supplying self-contained smoke alarms, the RCD must not provide protection for, or control of, any other circuit or equipment;
- self-contained smoke alarms should be sited on circulation routes avoiding, where possible, kitchens, bathrooms and other rooms where fumes or steam are generated under normal conditions;
- self-contained smoke alarms must be sited within 3 m from every bedroom door and within 7 m from every living room door;
- self-contained smoke alarms must be sited at no greater distance than 15 m apart on the same storey;
- self-contained smoke alarms must be sited either on the ceiling not less than 300 mm from the wall or luminaire, or on a wall between 150 mm and 300 mm from the ceiling. In any event the minimum distance from a heater or air conditioning ventilator must not be less than 300 mm and the unit mounted on a surface where the temperature does normally not exceed ambient temperature;
- every self-contained smoke alarm must be sited so that it is easily and safely accessible;
- every installation of smoke alarms should be not regarded as complete until the necessary instructions relating to the operation and maintenance of the system are issued to the user (or his/her agent).

13.4 Petrol filling stations and liquid petroleum gas (LPG) stations

Petrol filling stations are an obvious case of increased risk and require additional care in the design and installation of electrical equipment. There is no point in reiterating the excellent advice given in the publication *Guidance for the design, construction, modification and maintenance of petrol filling stations*, published jointly by the Association of Petroleum Explosives Administration (APEA) and the Institute of Petroleum (IP). A 'competent person' is defined as a person with enough practical experience and theoretical knowledge and actual experience to carry out a particular task safely and effectively. Persons who are not competent should not be engaged in this work. The publication identifies the hazardous zones and determination of the extent of the zones should only be undertaken by a competent and responsible person, normally employed by the licensing and enforcing authority.

13.5 Installations in dusty environments

Regulation 522–04–02 requires, where there is a presence of dust and other substances (external influence AE4, AE5 or AE6), that additional precautions are taken to prevent the ingress of this dust. If equipment can be placed outside dust-laden atmospheres then this obviously is the best solution. However, where this is not possible, equipment should have at least the degree of protection IP5X. Where equipment installation in dusty atmospheres is contemplated the equipment manufacturers should be consulted in order to clarify that the equipment satisfies the test requirements for the appropriate degree of ingress protection (IP5X) and that, by virtue of dust deposits forming on the enclosures, the temperature rise will not be such as to cause ignition of the collected dust. Further guidance is included in various British Standards and CENELEC including:

- BS EN 50281 *Electrical apparatus for use in the presence of combustible dust*,
- BS 5501 *Electrical apparatus for potentially explosive atmospheres* (9 parts),
- BS 6467 *Electrical apparatus with protection by enclosure for use in the presence of combustible dusts*,
- BS 6713 *Explosion protection systems* (4 parts),
- BS 7527 *Classification of environmental conditions* (3 parts).

13.6 Installations in underground and multi-storey car parks etc.

Underground car parks and multi-storey car parks are not generally regarded as hazardous areas though many should be so regarded. Although petrol is not dispensed in such locations, the accumulative quantity of petrol ‘stored’ in car petrol tanks warrants further consideration. One leaking tank together with an ignitive source can spell disaster. Zone classification will depend to a great extent on the ventilation and other provisions but it is not unusual for the whole of the volume occupied by parked cars to be classified as Zone 2 and the lower section of that volume, say from floor level up to a height of 225 mm, to be designated Zone 1. These matters need to be discussed with the Local Authority Fire Prevention Officer and the Petroleum Licensing Officer before carrying out detailed design work.

13.7 Installations in multi-occupancy blocks of flats

Generally speaking multi-occupancy blocks of flats may be regarded as a single equipotential zone with main equipotential bonding carried out from the MET at the main supply intake position in the normal way. However, where the PES provides distribution within the block of flats, main equipotential bonding may be required to individual flats treating each flat as an equipotential zone with its own MET. Bonding conductors are required to have not less than half the csa of the supply phase conductor, subject to a maximum of 25 mm^2, in the case of non-PME supplies and not less than that given in Table 54H for PME supplies (see Regulation 547–02–01) where the csa is related to that of the supply neutral conductor.

Where the distribution of supply in the block of flats is by a lateral circuit provided with separate neutral and protective conductors, individual main bonding from every flat back to the main intake position is not generally required. Where the supply is PME and the main distribution within the block is carried out using a PEN conductor (combining the functions of neutral and protective conductors), main bonding in every flat is normally required. In this case the csa of all the main bonding conductors is usually related to the whole block incoming supply neutral. Figure 13.3 illustrates main bonding requirements where PEN distribution is employed. In all cases, the designer should consult, at an early stage, with the supplier to ascertain the precise requirements.

Wiring systems for the flats, within the block, should be separate and, wherever possible, be contained within each flat in order to minimise the legal problems of entry when carrying out maintenance work in the years to come.

13.8 Installations in ‘Section 20’ buildings

The phrase ‘Section 20 buildings’ is well known to designers working on projects within London but may be less familiar to others who may from time to time be involved with such work. The reference is to Section 20 of the London Building Acts (Amendment) Act 1939 as amended by the Building (Inner London) Regulations 1985. The primary concern is with the danger from fire within certain classes of buildings owing to their use, height and/or cubic volume. Formerly administered by the Greater London Council, the implementation of the Regulations is now the responsibility of the Inner London Boroughs who may impose conditions on fire and life-safety systems. Installation of some equipment will warrant special consideration and these may include:

- vehicle and parking areas at ground level and in basements, and
- cellulose spraying rooms, and
- heating plant in excess of 220 kW, and
- generators in excess of 44 kW, and
- HV equipment containing more than 250 litres of oil, and
- areas containing flammable and/or combustible materials in such quantities likely to constitute a fire hazard.

The above listing should not be regarded as exhaustive and the relevant London Borough Council’s Building Regulations Engineering Group should be consulted at the earliest stage of the electrical installation design.

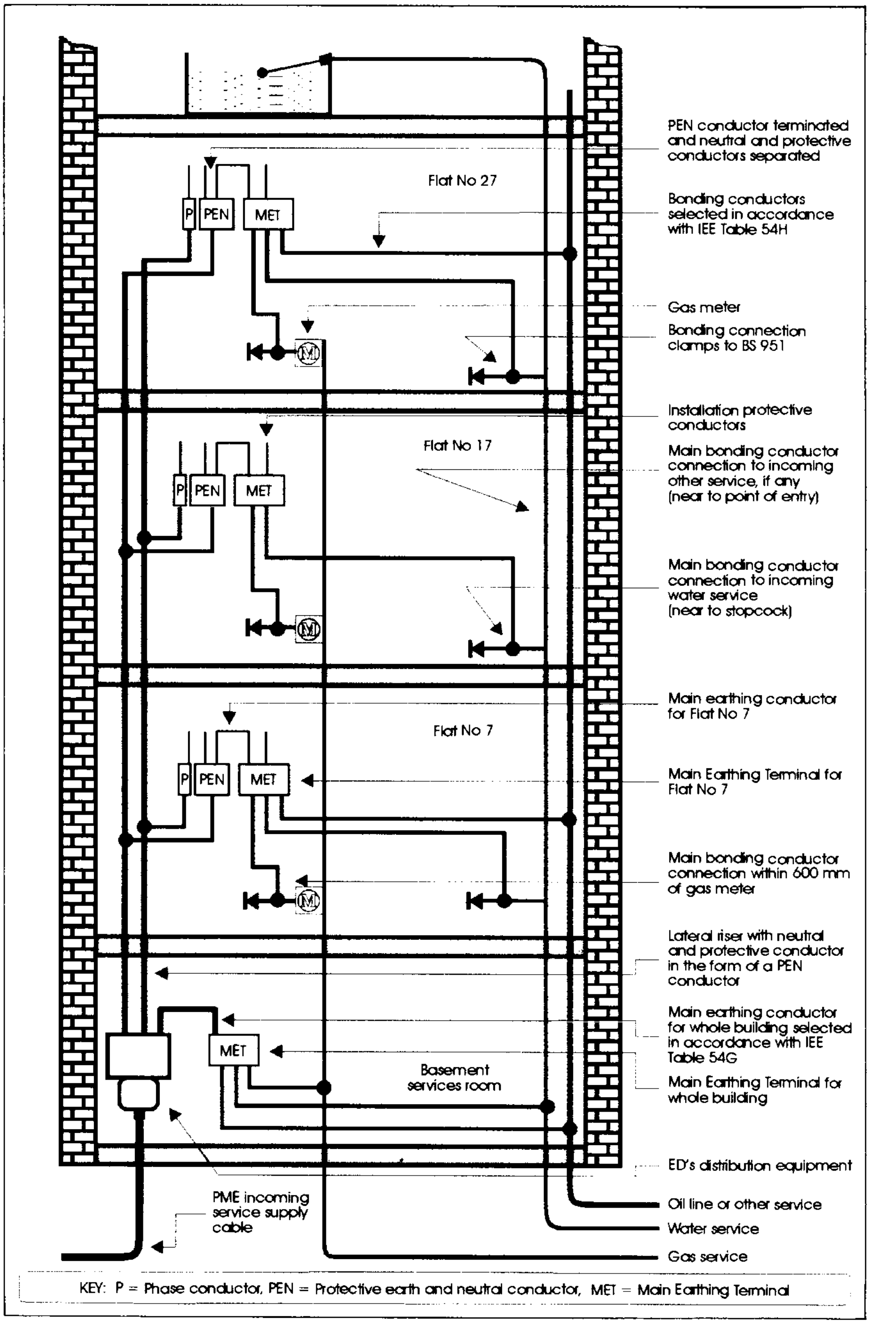


Figure 13.3: Main equipotential bonding in a multi-occupancy block of flats with ED's lateral riser incorporating a PEN conductor (PME supply)

Particular attention to the choice of wiring system is essential and in some cases this may be restricted to cables enclosed in screwed steel conduit, metal trunking and/or mineral insulated cables. Further guidance can be obtained from the London District Surveyors' Association's (PO Box 15, London SW6 3TU) published document entitled *Fire safety Guide No 1 – Fire safety in Section 20 buildings*.

13.9 Installations in churches

Electrical installations in churches are addressed in quite some detail in *Lighting and Wiring of Churches* published by Church House Publishing (ISBN 0 7151 7553 X). The designers of such installations are recommended to consult this publication before commencing the detailed design. The aspects covered are comprehensive and include, for example, power and lighting requirements, wiring systems, external flood lighting, supply arrangements and motor circuits. In many cases, lightning protection systems will also be desirable particularly for high protruding features such as spires (see BS 6651).

13.10 Installations in thatched properties

Installations in thatched properties pose problems unique to the type of construction and in particular pose additional fire risks. Wiring systems running in spaces adjacent to the thatch, for example in the loft, need special consideration. Screwed steel conduit or mineral insulated cables are no doubt a much safer option in these areas but where other wiring systems are used, special attention to scaling of enclosures is required. Mechanical protection from the thatcher's fixings for all wiring systems except steel conduit is required (see Figure 13.4) in vulnerable areas. Joint boxes should be avoided in these areas (straw dust can penetrate the box and present a fire hazard) and cables should not, under any circumstances, be allowed to pass immediately under, through or over the thatch. This applies not only to the normal power and lighting circuits, but also to television and radio aerial down-leads and other communications cables. Where the thatch has wire-netting applied, the wiring system should be installed not closer than 300 mm to the netting.

A fire detection and alarm system would be an obvious advantage in such properties as would an adequate number of fire extinguishers and fire blankets. For the larger buildings, a sprinkler system may also be worth considering. Smoke detectors in high risk areas such as the loft will provide some measure of reassurance.

Overhead wiring systems that pass over or near the thatch should be avoided and consideration should also he given to providing a facility to switch off non-essential circuits at night and during periods when the building is unoccupied. Luminaires installed in roof spaces should be the totally enclosed type and mounted at sufficient distance from the thatch so

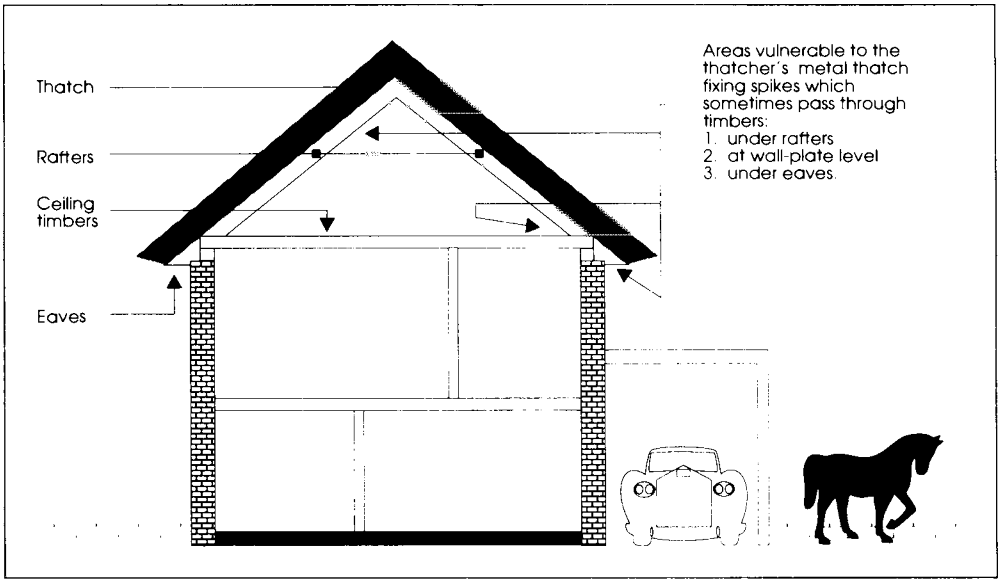


Figure 13.4: Mechanical protection in lofts of thatched properties

as not to cause ignition of the thatch. Ideally, such luminaires should have some form of remote indication (e.g. indicator lamp near loft access) to indicate whether the they are 'ON' or 'OFF'.

The designer will find it advantageous to consult with the Local Authority's Fire Prevention Officer and the building insurer prior to carrying out the initial installation design. The intervals between periodic inspection and testing may be significantly reduced for thatched properties.

13.11 Extra-low voltage lighting

There one or two points worthy of mention concerning the installation of extra-low voltage lighting. It must be recognised that at these lower voltages ($U_n \leqslant 50V$) currents are much higher for lamps of a similar power rating. Protection against electric shock, overcurrent and thermal effects are just as important on these systems as on LV circuits. In particular, proper consideration must be given to shock risks (direct and indirect contact), fire hazards and thermal effects.

Basically there are two systems which can be used. Functional extra-low voltage is one option where the source is a 'normal' transformer and the secondary circuit to the lighting is treated as an extension to the primary circuit. All the associated protective measures including the earthing of all exposed-conductive-parts of the secondary circuit are essential. The other possibility is the use of a SELV system which utilises a safety source (e.g. safety isolating transformer to BS 3535) and where metalwork associated with the secondary ELV circuit is *not* earthed, either deliberately or fortuitously (see Regulations 411–02–07 and 411–02–08).

It is important too to consider the temperature of the luminaires with respect to the adjacent building fabric. The method of fixing should take account of the requirements of Regulation 422–01–02 and, in particular, provision must be made for the safe dissipation of heat with the luminaires mounted at a safe distance from adjacent material. Significantly, Regulation 422–01–04 requires that every termination of live conductors (see Figure 13.5) must be contained within an enclosure, irrespective of the nominal voltage; this requirement relates to protection against thermal effects and not necessarily to protection against electric shock.

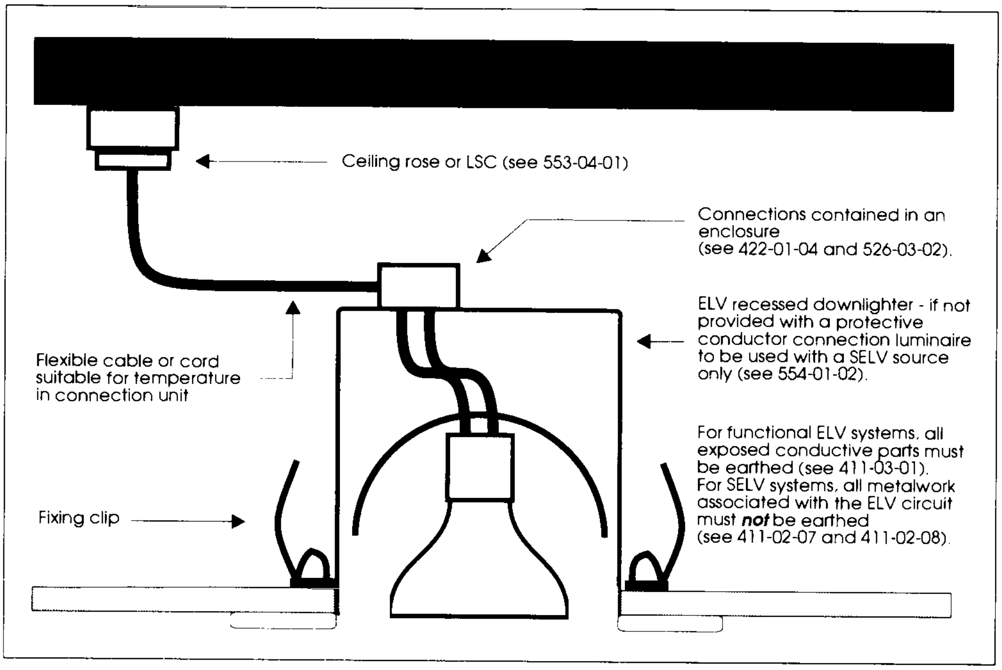


Figure 13.5: Typical final connection to ELV luminaire

Since much of this type of lighting equipment is used for decorative purposes and commonly installed in suspended ceilings, the proper mounting of transformers is important. Depending on the size, this type of transformer commonly weighs between 2 and 8 kg (for, say, a 50 V A and a 300 V A, respectively) and secure fixings are always necessary. Many transformers, too, can be a major heat source (copper losses – I^2R) and the effects on adjacent material must also be considered carefully. Overcurrent protection is required on both the primary and secondary circuits of the transformer.

This form of lighting is particularly sensitive to voltage variations and lamp life is considerably shortened if lamps are energised outside their normal operating voltage tolerances. Voltages above and below the nominal voltage will have adverse effects on lamp life and when designing such a system it is important to recognise the manufacturer's stated voltage variations which can be tolerated. The use of luminaires with their own integral transformer is probably the best way to avoid the effects of voltage regulation, but quite an expensive solution. Alternatively, a number of luminaires may be supplied by a common transformer of adequate rating. In designing this system, account should be taken of the voltage drop with all lamps functioning and the voltage rise when one or more lamps fail.

Many extra-low voltage lighting systems actually operate on 12 V a.c. and many luminaires incorporate 50 W SBC halogen lamps. To illustrate some of the problems, Figure 13.6 shows an a typical ELV lighting layout operating as a SELV system with six 50 W 12 V lamps supplied by a single 300 VA transformer. The secondary circuit full load current, I_{sec} is 25 A, as given in Equation (13.1).

$$I_{\mathrm{sec}} = \frac{\textit{total power demand}}{\textit{nominal voltage}} = \frac{6 \times 50}{12} = 25 \text{ A} \tag{13.1}$$

If the wiring system used was PVC cables enclosed in non-metallic conduit (reference method 3) a minimum csa of 4 mm^2 would be required with a corresponding 11 mV per A, per m volt drop. This volt drop together with the transformer voltage regulation needs to be taken into account. For

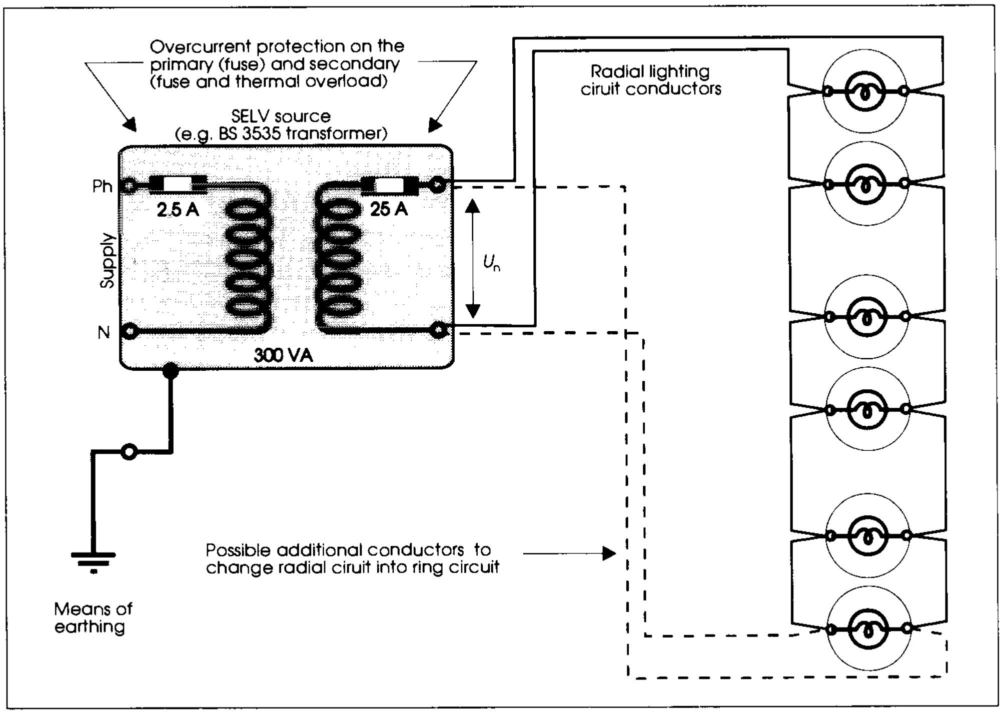


Figure 13.6: A problematic solution to ELV lighting

example, many 12 V halogen lamps normally have an acceptable voltage range of 11.7 V to 12.3 V. This implies that the luminaire furthest from the transformer must have a voltage of at least 11.7 V and that the voltage at any luminaire at any time, including occasions when other lamps fall, is not more than 12.3 V. The transformer output voltage should not therefore be above 12.3 V and this means a transformer voltage regulation not exceeding 2.5%, as given in Equation (13.2).

$$\text{Maximum voltage regulation} = \frac{V_{\text{NL}} - V_{\text{FL}}}{V_{\text{NL}}} \tag{13.2}$$

$$= \frac{12.3 - 12.0}{12.0} = 0.025 = 2.5\%$$

where V_{NL} = secondary no-load output voltage
V_{FL} = secondary full-load output voltage.

Similarly the secondary circuit voltage drop should not exceed 0.3 V and using the 4 mm^2 with a volt drop of 11 mV per ampere per metre, this would limit the circuit length, L, to 1.09 m as given in Equation (13.3).

$$L = \frac{\textit{volt-drop limit}}{I_{\text{sec}} \times \textit{tabulated } mV/A/m \times 10^3} \tag{13.3}$$

$$= \frac{0.30}{25 \times 11 \times 10^{-3}} = 1.09 \text{ m}$$

Clearly, this is impractical due to the unrealistically short maximum length permitted by using 4 mm^2 and increasing the csa of the conductor would present difficulties in effecting terminations, particularly into ceiling roses and LSCs. Forming the secondary circuit into a ring would improve matters but not much. Wiring each luminaire on a radial circuit from the transformer and increasing the conductor csa would again present difficulties in terminating conductors. Figure 13.7 shows an alternative approach where luminaires are radially wired individually with smaller csa conductors and each radial circuit individually fused near the transformer secondary output. The required design current for a 50 W luminaire is 4.2 A and, if the radial circuit is protected by a 5 A fuse, the csa could be little as 1 mm^2 for a 1.6 m run, or 1.5 mm^2 for a 2.4 m length or 2.5 mm^2 for a 3.9 m circuit.

13.12 Security lighting

In recent years there has been a much increased use of security lighting both in the industrial and commercial fields and in the domestic market. Generally these installations involve the use of a Passive Infra-red Sensor (PIR) to detect movement by sensing heat and an integral or separate time-switch and/or photoelectric sensing device and are often connected with a

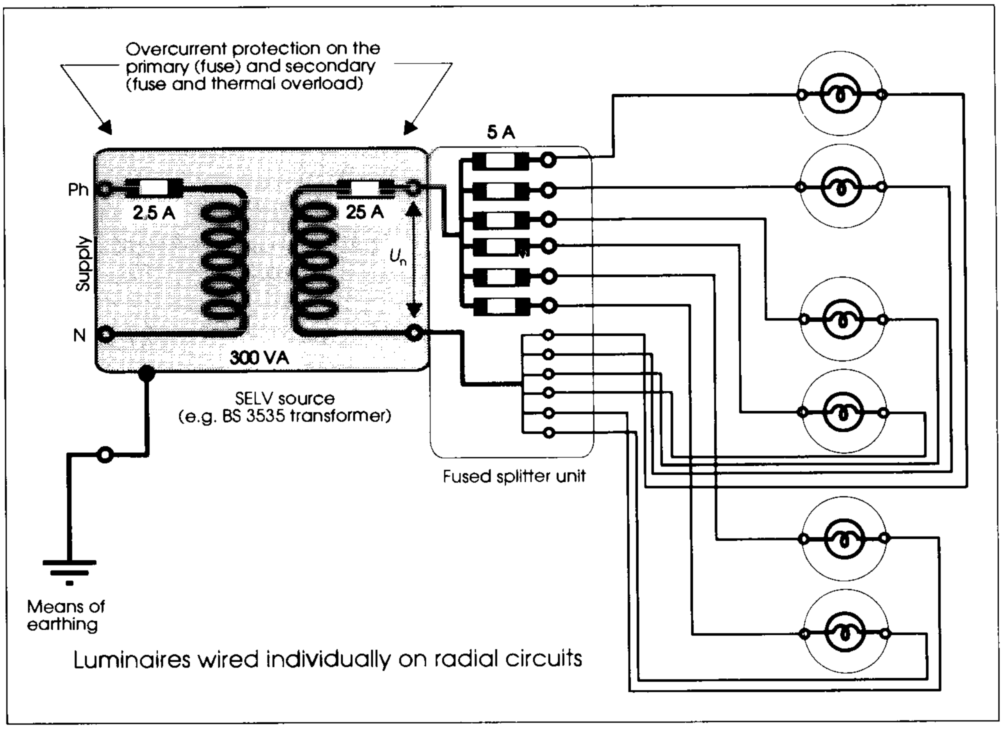


Figure 13.7: A practical solution to ELV lighting

manual over-ride switch. Regulation 553–04–01 calls for each lighting accessory and luminaire to be controlled by a switch complying with BS 3676 and/or BS 5518. It is necessary therefore that in addition to the above mentioned devices a circuit lighting switch is required as well as a means of isolation and a means for switching off for mechanical maintenance in order to, for example, change a lamp safely. All three functions may be combined in one device, suitably labelled, located in some convenient place within the confines of the secure area. If necessary, the switch may be labelled to indicate that the switch should only be switched off for electrical and non-electrical maintenance work be carried out. A suitable form of words may be **'Security lighting – Switch off only for maintenance'**.

13.13 Welding equipment

Electric welding can often cause problems with the general electrical installation and, in particular, with protective conductors not associated with the circuit supplying the welding apparatus. Stray currents from the welder can find their way back to the supply transformer via a number of parallel paths including those provided by other circuits. The problem can arise from poor equipment not properly maintained and from unsatisfactory working practices. Poor insulation on the welder return path conductor, poor connections, not placing the return lead as close as possible to the work being undertaken and incorrect earthing of the welding circuit are all major contributors to the problem. Cases have come to light where such stray currents have been sufficient to 'burn out' protective conductors of other circuits. Clearly, where welding apparatus is used on a day-to-day basis, regular cheeks on the continuity of protective conductors will be essential. The HSE guidance document PM64 addresses the use of welding apparatus.

13.14 Entertainers' equipment

Whilst strictly not specifically called for in BS 7671, socket-outlets for entertainer's equipment should be protected by an RCD with a residual operating current, $I_{\Delta n}$, of not more than 30 mA. We have all seen examples of musical amplification equipment with wrongly connected plugs, loose terminals, frayed flexes, mismating of flex connectors and earthed protective conductors deliberately disconnected to prevent feedback on the audio system.

Even with RCD protection it is essential that such installations are routinely maintained and regularly inspected and tested and the licensing authority would normally require such procedures. Care must be taken in selecting RCDs where there are also electronic dimmers in circuit controlling, for example, lighting effects. Some RCDs are affected by such electronic devices and in extreme cases can be rendered ineffective. Manual testing of RCDs is generally required quarterly but in such locations consideration should be given to this test being carried out before every 'performance'. Those involved in design and maintenance of this type of installation should become familiar with HSE publications Guidance Note GS 50 *Electrical safety at places of entertainment* and booklet IND(G)102L *Electrical safety for entertainers*.

13.15 Generator sets

Amendment No 2, issued in December 1997, to BS 7671 : 1992 introduced particular requirements for generator sets. For the experienced installation designer the new requirements will not represent anything new, as the requirements would have had to be met before the introduction of the new requirements. The scope of the new section is given in Table 3.3. It does not apply to self-contained ELV source and load for which a specific product exists that includes electrical safety requirements.

Regulation 551–02–01 calls for the means of excitation and commutation to be appropriate for the intended use and such as not to impair the safe functioning of other sources. Regulation 551–02–02 demands that the prospective fault current be assessed for every independent source (or combination of sources), and also requires that the short-circuit capacity of protective devices be suitable for all the sources, or combination of a number of sources, likely to be used to supply the installation.

Table 13.3: Section 551-01: scope – LV and ELV generator sets

Aspect	Regulation	Application embraced in the scope
Scope – general	551–01–01	Generating sets supplying installations which are not supplied by the public supply. Generating sets supplying installations as an alternative to being supplied by the public supply. Generating sets supplying installations in parallel to the public supply. Any appropriate combination of the above. The final paragraph of this regulation states that the requirements of the electricity supplier must be ascertained before a generator set is installed in an installation connected to the public supply.
Scope – types of power sources	551–01–02	Combustion engines. Turbines. Electric motors. Photovoltaic cells. Electrochemical sources. Other suitable sources.
Scope – electrical characteristics	551–01–03	Mains-excited and separately-excited synchronous generators. Mains-excited and self-excited asynchronous generators. Mains-commuted and self-commuted static inverters with or without bypass facilities.
Scope – utilisation of generators	551–01–04	Supplies to permanent installations. Supplies to temporary installations. Supplies to portable equipment which is not connected to a permanent fixed installation.

Where a generating set supplies an installation, either as a sole source or as a standby, Regulation 551–02–03 requires that the capacity and operating characteristics must be such as not to be a danger or cause damage on connection or disconnection of the load. Means of load-shedding must be provided where loading is beyond the generator capacity.

Extra-low voltage systems may be supplied from more than one source and where this is so, Regulation 551–03–01 requires that either all sources must be SELV or, alternatively, all sources must to be PELV, and that the requirements of Regulation 411–02–02 (acceptable SELV sources) must be met for the sources. Where one of the sources does not comply with Regulations 411–02–01 to 411–02–04 (SELV sources), then the requirements relating FELV must be applied (Regulation 413–03–01 – protection against direct and indirect contact must be provided as specified in Regulations 471–14–01 to 471–14–06).

Regulation 551–03–02 stipulates that where it is necessary to maintain a supply to an ELV system when one or more parallel sources fail, it is essential that the remaining source is capable of supplying the load on its own. Additionally, provision must be made so that, on the loss of the LV supply to the ELV system, no danger or damage to other ELV systems can result.

With regard to protection against indirect contact, Regulation 551–04–01, stating the obvious, calls for protection against indirect contact to be provided in respect of each source that may be run independently. This means, for example, that an installation fed by standby generator must have suitable protective devices for automatic disconnection of supply bearing in mind the likely reduced fault level compared to that available on the public network supply.

Regulation 551–04–02 demands that protection against indirect contact must be provided by EEBAD in accordance with Regulation Group 413–02, except as modified by Regulation 551–04–03, 551–04–04 or 551–04–06.

Generators for standby systems must not rely on the public supply means of earthing, as indicated in Regulation 551–04–03. A suitable independent earth electrode must be provided.

Where installations incorporate static inverters, Regulation 551–04–04 stipulates that in the case of protection against indirect contact which relies on automatic closure of a bypass switch and the protective devices on the supply side does not disconnect within the time limits, supplementary bonding must be carried out on the load side of the inverter (as per Regulations 413–02–27 and 413–02–28), and the following equation must be met:

$$R \leqslant \frac{50}{I_a}$$

where: R = resistance of the supplementary bonding conductor
I_a = is the maximum fault current which can be supplied by the static inverter alone, for a period up to 5 s.

For parallel operation with the public supply, Regulations Group 551–07 also applies.

Regulation 551–04–05 calls for precautions to be taken so that the correct operation of protective devices is not impaired by d.c. currents generated by a static inverter, or by associated filters. Alternatively, selection of devices must take account of such d.c. currents.

Additional requirements for protection by automatic disconnection apply where the installation and generating sets are not permanently fixed. Regulation 551–04–06 demands that where a generating set which is not fixed is portable or is intended to be moved, protective conductors between separate items of equipment must be selected in accordance with Table 54G or incorporated in suitable cord or cable. Additionally, irrespective of the system type, an RCD (30 mA or less) must be employed for protection against indirect contact.

For protection against overcurrent, Regulation 551–05–01 simply calls for the means of detecting overcurrent in the generating set, as opposed to the conductors, to be located as near as practicable to the generator terminals.

As set out in Regulation 551–05–02, for a generating set operating in parallel, either with the public supply or with another generating set, the circulating harmonic currents must be limited to the thermal rating of the conductors. There are five options for limiting the circulating harmonic currents:

- generating sets with compensation windings,
- provision of suitable impedance in connection of the generator star points,
- provision of interlocking switches to interrupt the circulatory circuit, but which do not impair protection against indirect contact,
- provision of filters,
- other suitable means.

There are additional requirements for installations where the generating set provides a supply as a switched alternative to the public supply (standby systems). Regulation 551–06–01 requires precautions to be taken to prevent the generating set operating in parallel with the public supply by one or more of the options available, which include, mechanical interlock with one key, electrical-controlled changeover device, three-position break-before-make changeover switch, or other means providing equivalent security.

For TN systems, where the neutral is not distributed, any RCD must be positioned so that malfunction due to any parallel neutral earth path is avoided, as indicated in Regulation 551–06–02.

Additional requirements apply for installations where the generating set may operate in parallel with the public supply. As called for in Regulation 551–07–01, where a generating set is to run in parallel with the public supply, care is necessary to avoid the adverse effects, to the public supply and other installations, in consideration of :

- power factor,
- voltage changes,
- harmonic distortion,
- unbalance,
- starting,
- synchronising,
- voltage variation.

The use of automatic synchronising systems which consider frequency, phase and voltage is preferred.

In the event of loss of public supply, or deviation in voltage or frequency of supply, protection must be provided to disconnect the generating set from the supply, as required by Regulation 551–07–02. It goes without saying that such protection must be agreed with the public supplier.

Regulation 551–07–03 requires means to be provided to prevent connection of the generating set to the public supply if the generator voltage or frequency is on excursion outside the normal limits of the public supply.

Means of isolation, accessible to the public supplier at all times, must be provided for the generating set, as called for in Regulation 551–07–04. Regulation 551–07–05 goes on to call for, in the case of where the generator set is also to serve as standby set, the requirements of Regulation Group 551–06 to also apply.

Chapter 14

Supplies for Safety Services

14.1 Safety services – general

BS 7671 does not in itself call for safety services to be provided but does, where such services are installed, state additional requirements relating to the supplies, equipment and circuits for these services. The general requirements in Regulations 561–01–01 to 561–01–04 call for safety service supplies to be selected so that a supply of adequate duration is maintained. Where the service is required to operate under fire conditions, all equipment must be capable, by construction or by erection, of providing fire resistance for an adequate duration. In other words, the equipment must withstand the fire conditions for sufficient time for the safety service to perform its intended function. The penultimate of these four regulations states a preference that the protective measure against indirect contact does not automatically disconnect on first fault condition and where an IT system is used it must be provided with continuous insulation monitoring with provision for audible and visual indications of a first fault condition. As ever, it is important to arrange equipment so as to accommodate inspection, testing and maintenance (561–01–04).

Whilst BS 7671 does not stipulate where and for what purpose safety services may be required, there may be, in fact, a statutory requirement for a particular safety service to be provided. The Fire Precautions Act 1971, for example, requires, in certain circumstances, a means of giving warning in the case of fire. Hospitals, schools, colleges, public places of entertainment, hotels, boarding houses, offices, factories and shops are all examples where a safety service may be needed to afford compliance with statutory requirements.

This chapter only addresses the additional regulatory requirements relating to these services and reference to the appropriate British Standard Code of Practice will be necessary to identify *all* the essential requirements relating to a particular safety service. Examples of safety services include:

- fire detection and alarm systems in buildings (BS 5839),
- emergency lighting (BS 5266),
- sprinkler systems (BS 5306),
- fire extinguishing systems (gas, foam, powders, etc.) (BS 5306),
- fire hydrant pumps,
- automatic door closing mechanisms (BS 5839).

The designer will find it advantageous, and in some cases obligatory, to discuss the design proposals with the local fire authority, the Health and Safety Executive and the building insurers. Any input to the design proposals by others should be welcomed but not be regarded as being the total design requirements.

14.2 Common sources

Regulations 562–01–01 to 562–01–06 lay down the requirements for safety service sources and give details of where and how the equipment is to be erected. The four acceptable sources are listed as a primary cell(s), a storage battery, a generator capable of independent operation and an independent separate feeder (see Figure 14.1). Where a separate feeder is employed, it must be confirmed that both sources are unlikely to fall at the same time or the separate feeder to fall due to additional loading brought about by the failure of the main feeder.

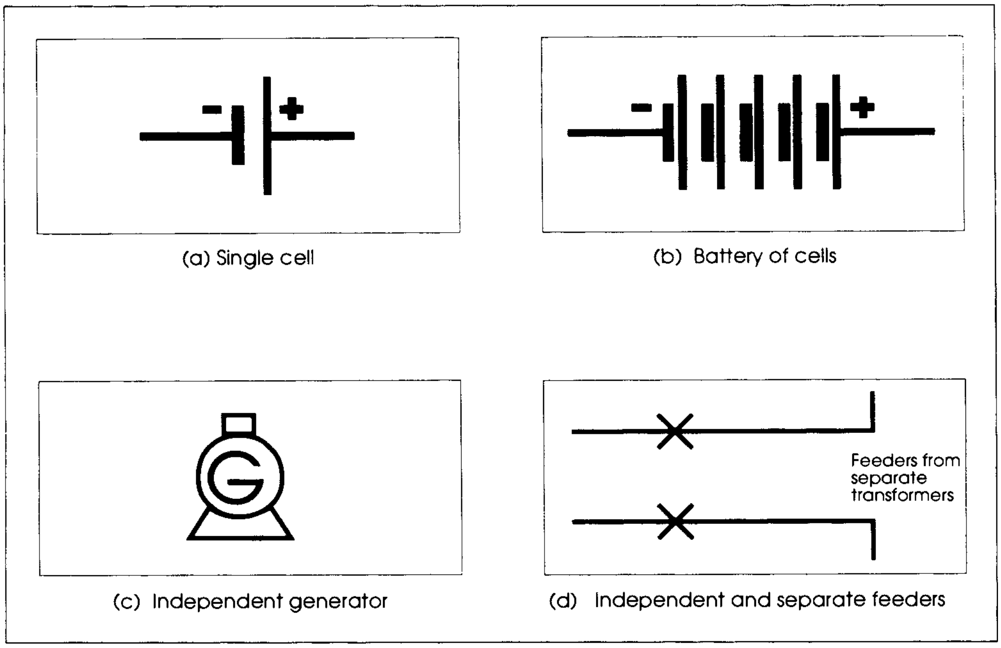


Figure 14.1: Suitable safety sources

The source must always be fixed in position and located in a suitable location accessible to skilled and instructed persons only. Installation of the source must be such that failure of the normal supply does not affect the safety source. As given in Regulation 562–01–05, these conditions do not apply to equipment individually supplied by an integral self-contained battery as would be the case, for example, of a self-contained emergency lighting luminaire. Safety sources must not be used to supply equipment other than that directly associated with the safety service. Where more than one source is available (e.g. public supply and generator) they may supply standby systems provided that, in the event of failure of one, the energy available from the other is sufficient to start and maintain operation of the safety service(s). Where necessary, non-essential load-shedding will be required in order to reduce loading to a level within the capability of the remaining source. Figure 14.2 shows a typical arrangement for two sources and the load-shedding technique. It is essential that sources are adequately ventilated so as to prevent smoke, fumes and other exhaust gases, as required by Regulation 562–01–06.

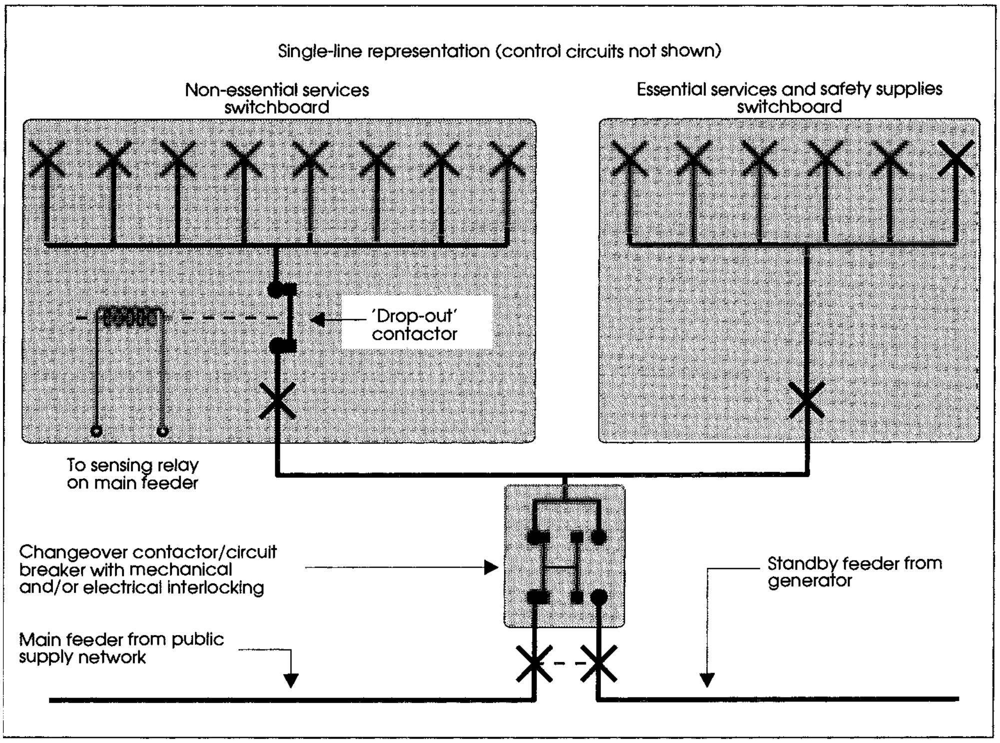
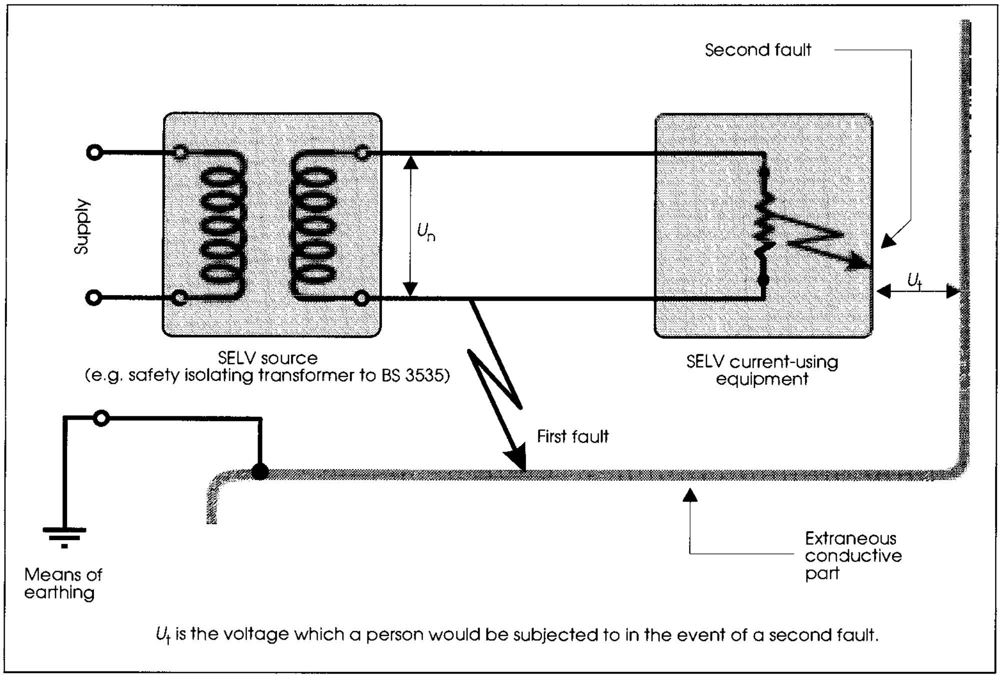


Figure 14.2: Typical standby arrangements

Although there is no maximum time delay stated in BS 7671 for the standby supply to take over from the failed main feeder supply, this obviously needs to be as short as possible. Where, for example, emergency lighting is supplied, British Standard 5266 requires that the emergency lighting should reach the required level of illuminance within 5 s or where the building is only likely to be occupied by persons familiar with the building layout then this time limit may be increased to 15 s with the agreement of the appropriate enforcing authority. With modern equipment and techniques very short changeover times can be achieved.

As mentioned earlier, BS 7671 expresses a preference for the safety service source to be such that automatic disconnection does not occur on first fault. One obvious solution would be the use of a SELV source (e.g. safety isolating transformer to BS 3535). As shown in Figure 14.3, the development of a first fault between a secondary live conductor and an extraneous-conductive-part, itself connected to Earth, would effectively make the SELV circuit a localised TN system with the faulted secondary live conductor earthed. Only on the occasion of a second fault condition, between the load equipment metal case (not earthed, deliberately) and the extraneous-conductive-part, would a touch voltage, U_t, appear between these conductive parts and this could be, at worst, the secondary no-load voltage (e.g. 50 V). Other than for special installations and locations, this touch voltage (up to 50 V) could, from the viewpoint of the shock hazard, be tolerated indefinitely, at least in theory. For locations of increased shock risk the nominal voltage, U_n, would need to be reduced accordingly.



U_t is the voltage which a person would be subjected to in the event of a second fault.

Figure 14.3: SELV circuit

14.3 Parallel and non-parallel sources

Regulation 565–01–01 calls for safety service sources not capable of parallel operation to be effectively interlocked by mechanical and/or electrical means to ensure that not more than one source is connected to the installation served at any one time. Regulation 566–01–01 does however recognise that sources may be connected in parallel where that is the designer's intention. Particular care is needed, in the selection of sources to operate in parallel, to establish their compatibility (e.g. voltage, frequency, rated current, and impedance). The general requirements relating to protection against overcurrent and indirect contact must be met in all cases although where a source is used solely for a safety service, protection against overload may be omitted, as indicated in Regulation 563–01–03.

The general requirements for isolation and switching apply and particular care is required to ensure that total isolation of the safety service from its sources can be achieved. Where more than one device is necessary to effect isolation an appropriately worded notice is required (by Regulation 461–01–05) to be affixed on or near every isolating device, identifying devices and warning personnel of the correct isolation procedure.

In circumstances where there may be circulating currents (e.g. third harmonics and other triplens) in the connection between neutral points of sources, precautions need to be taken to obviate harmful effects.

14.4 Circuit and equipment requirements

A safety service circuit must be independent of any other circuit (Regulation 563–01–01) and be arranged so that a fault developing in any other circuit, including that of another safety service, should not be capable of adversely affecting the intended function of the circuit. Similarly, modifications or interventions to another circuit must not impair the correct functioning of the safety service circuit. Safety service circuit conductors must have adequate fire resistance appropriate for the locations through which they pass, as indicated in Regulation 563–01–02.

Overcurrent protective devices must be selected and installed so that an overcurrent in one circuit does not affect other circuits (Regulation 563–01–04). To this end, adequate circuits will need to be provided together with generous allowances for design current in the selection of protective devices and circuit conductors in order to avoid unwanted automatic disconnection. As called for in Regulations 563–01–05 and 563–01–06, switchgear and controlgear must be located in areas accessible only to skilled and instructed persons and must be clearly identified as to purpose. Similarly, alarms, controlling devices and indication equipment must also be clearly identified.

Where an item of equipment is supplied by two different circuits (e.g. normal supply and standby source), Regulation 564–01–01 requires that should a fault occur in one circuit the protection against electric shock must not be impaired nor the correct functioning of the other circuit affected in any way.

14.5 Protection against overcurrent and indirect contact

As indicated in Regulations 565–01–02 and 566–01–01 the general requirements relating to protection against indirect contact and fault current apply to safety service circuits. Care is needed, particularly in the case of standby generator supplies, that the fault levels from all sources are adequate to operate protective devices. For example, the fault level of a standby generator may be much lower than that of a supply from the public network and, additionally, the generator prospective fault current may reduce rapidly. The designer would wish to consider these matters very carefully and consultation with the generator manufacturer at an early stage will be advantageous. Similarly, a rigorous analysis of fault levels is essential where more than one source can simultaneously feed a fault.

Chapter 15

The Smaller Installation

15.1 Scope

The guidance given in this chapter is limited in scope to the 100 A single-phase installation supplied from an ED's low voltage network and includes supplies forming part of TN-S, TN-C-S or TT systems. Consideration of special installations or locations is not addressed here but Chapter 16 deals in some depth with these special requirements.

The general principle that every circuit and every item of equipment is required to be designed holds good for the smaller installation. Circuit design for the smaller installation may utilise those given in the *IEE On-Site Guide* which if implemented will produce a circuit design which is deemed to comply with BS 7671 but may not produce the most economic solution.

15.2 The IEE On-Site Guide

The IEE have published the *On-Site Guide* for competent electricians. The guide is limited in scope to domestic and small industrial and commercial installations where circuit distribution is from distribution board(s) located near the PES's cut-out. Except for rooms containing a bath tub or shower and temporary buildings, the *On-Site Guide* does not include within its scope the requirements for special installations or locations. Conventional circuits are introduced which are a legacy of the 15th Edition of the Wiring Regulations Appendix 5 'standard' circuits. Where the designer makes use of the *On-Site Guide* for a small installation, the design in its entirety should meet the requirements of that Guide.

15.3 User's requirements

The first task for the designer is to ascertain the user's requirements and he/she is commonly called upon to assist in formulating and identifying what the customer actually wants. As a guide, Table 15.1 sets out some of the technical points which need to be clarified at an early stage. The table should not be regarded as exhaustive as there may well be other points which need addressing depending on the particular circumstances.

Table 15.1: User requirements – points of clarification

Ref	Clarification required for:	Some common possible items to consider
A	Type of wiring system(s).	PVC insulated and sheathed cables. PVC insulated cables in steel conduit. PVC insulated cables in non-metallic conduit. PVC/PVC insulated and sheathed cables with non-metallic conduit switch-drops. PVC insulated cables in steel trunking. PVC insulated cables in non-metallic trunking. Armoured cables. Mineral insulated cables. Cable management system(s).
B	Installation methods.	Flush wiring system(s). Surface run wiring system(s). Other environmental conditions.
C	External influences.	Identification of the required degrees of ingress protection (e.g. of water, dust, etc.). Identification of the ambient temperature, heat sources, and corrosive and polluting substances. Identification of impact, vibration and other mechanical stresses. Identification of the presence of flora and mould growth. Identification of the exposure to solar radiation. Identification of structure stability.
D	Loadings.	Load assessment of fixed current-using equipment together with all anticipated portable appliances. Load assessment based on the rated supply.
E	Luminaires.	Identification of all lighting and switching requirements.
F	Other fixed electrical equipment.	Identification of all fixed electrical equipment in terms of loadings and siting. Equipment may, for example, include: cooking equipment, immersion heater, boiler, waste-disposal unit, water heaters, space heating. Information technology equipment, shower unit, shaver sockets, intruder alarms, fire alarms, emergency lighting, etc.
G	Socket-outlets.	Number, siting and rating of socket-outlets. Finished colour of socket-outlets. Mounting height from finished floor level.
H	Switches.	Number, siting and rating of switches. Finished colour of switches. Mounting height from finished floor level.
I	Other accessories.	Number, siting and rating of accessories. Finished colour of accessories. Mounting height from finished floor level.
J	Main distribution.	Type and siting required. Preferred type of protective devices (fuses, circuit-breakers and RCDs).
K	Special concerns.	User's capabilities (e.g. disabled, infirm, elderly, etc.).

15.4 Wiring systems

The selection of the wiring system will depend to a large extent on the type of premises in which the installation is located and whether the building exists or is in the process of construction. For the small installation in domestic premises, PVC insulated and sheathed cables are likely to be the first choice because of the cost implications, whereas for small commercial premises PVC insulated cables in conduit and/or trunking may be a more appropriate solution. Often a number of different types of wiring systems will be employed in a building, each with its own advantages and disadvantages. Chapter 10 of this Guide gives further information with regard to wiring systems.

15.5 Supplier's requirements

As with all installations supplied from the public supply network, the Electricity Distributor (ED) will require the installation to be constructed to such a standard as to allow them to meet their statutory obligations under the Electricity Supply Regulations 1988, as amended. The ED would be particularly interested in loading, earthing and equipotential bonding conductors and 'meter tails'.

15.6 Assessment of supply characteristics

As addressed in Chapter 4 of this Guide, an assessment of the general characteristics of the supply is necessary for all installation design. In addition to the nominal voltage, frequency and number of phases, the prospective fault current and external phase-earth loop impedance are also required to be assessed together with the current rating of the service. This information is available from the ED and the designer should obtain this at an early stage. An assessment of maximum demand will also be a necessary task and it is essential that the supply is adequate for this demand, taking into account any allowable diversity. The most commonly used overcurrent protective device in the ED's cut-out is a BS 1361 Type II fuse. Cartridge fuses used may be 60 A, 80 A or 100 A but if not identified the highest rating must be assumed when considering overcurrent protection.

The prospective fault current (short-circuit and earth fault) for supplies up to 100 A may be taken as 16 kA generally but the Electricity Association's Engineering Recommendation P25 provides a method for calculating the fault-level attenuation. Except for supplies provided in London, fault-level attenuation can be correlated to the length of service cable from the public highway to the intake position (i.e. the origin of the installation). The length of service cable from the pavement (or roadway) to the ED's cut-out and the prospective fault current attenuation are related as follows.

Length of service cable (m)	**Up to 25 mm^2 Al and 16 mm^2 Cu (kA)**	**35 mm^2 Al and 25 mm^2 Cu (kA)**
5	10.8	12.0
10	7.8	9.3
15	6.0	7.0
20	4.9	6.2
25	4.1	5.3
30	3.5	4.6
35	3.1	4.0
40	2.7	3.6
45	2.5	3.3
50	2.2	3.0

It is important to note that the lengths given above relate only to the final service cable. No part of the roadway cable should be included since the PES may, from time to time, alter the network.

15.7 'Meter tails'

The only overcurrent protection afforded to the 'meter tails' is that provided by the ED's cut-out fuse. In every case the designer should check with the ED for their requirements for the csa of the 'meter tails' and the maximum length of 'tails' which they will accept – commonly not more than three metres. As a guide, the minimum copper csa of these conductors (to BS 6004) for reference method 1 (clipped direct), assuming no correction factors for ambient temperature, thermal insulation or grouping are given below:

Overcurrent protective device	**Single-phase**	**Three-phase**
60 A BS 1361 Type II rated	10 mm^2	16 mm^2
80 A BS 1361 Type II rated	16 mm^2	16 mm^2
100 A BS 1361 Type II rated	25 mm^2	25 mm^2

In all circumstances, the designer should check with the ED to confirm that the above quoted cross-sectional areas meet with their particular needs which may exceed the regulatory requirements.

In cases where the current rating of the cut-out fuse is unknown, the highest value should be assumed and it is generally considered good practice to install 'meter tails' for the highest value in any case to allow for any fuse replacement errors. The csa areas given above may need to be increased where the 'meter tails' are run in close proximity to other load carrying conductors and an appropriate grouping factor applied (see Table 4B1 of Appendix 4 of BS 7671). It should be noted in this respect that direct-reading electricity meters (i.e. those not employing current transformers) will not normally accept cables of csa greater than 35 mm^2.

Mechanical protection of 'meter tails' is important as is adequate support. Generally, PVC insulated and PVC sheathed cables will be used and care must be taken to terminate these into equipment so that the sheath is not removed excessively, leaving exposed PVC insulation only. It is sometimes necessary or desirable to enclose 'tails' in trunking using PVC insulated cables only. Where this method is adopted, care must be taken to ensure that mechanical damage does not result from un-smooth edges of trunking and that the trunking system completely encloses the 'tails'. Additionally, where trunking is metal it must be earthed and protected against indirect contact and this can only be effected by making use of the ED's cut-out fuse. The ED's express agreement must be obtained prior to adopting this method of protection of the 'tails' against mechanical damage. Metal trunking for the purpose of containing 'meter tails' is generally not an option for TT systems because the phase-earth loop impedance is normally too high to effect protection against indirect contact (for the trunking).

It is important to note that no consumer's equipment, such as a main switch, should be fixed to the ED's meter board or within their meter cabinet.

15.8 System earthing arrangements

System earthing arrangement is addressed in Chapter 12 of this Guide but the following information will serve as a reminder for those contemplating the design of the smaller installation. Only TN-C-S, TN-S and TT systems are considered here as TN-C is unlikely to be encountered on the smaller installation and IT systems are not available on the public supply network.

Figure 15.1 shows a typical arrangement for a TN-C-S system single-phase supply cut-out, 'meter tails', earthing and main equipotential bonding connections. Figures 15.2 and 15.3 indicate similar arrangements for TN-S and TT systems respectively. A supply forming part of a TN-C-S system (e.g. PME supply) will normally have a maximum external phase-earth loop impedance of 0.35 Ω as compared with 0.80 Ω for a TN-S (e.g. cable sheath means of earthing).

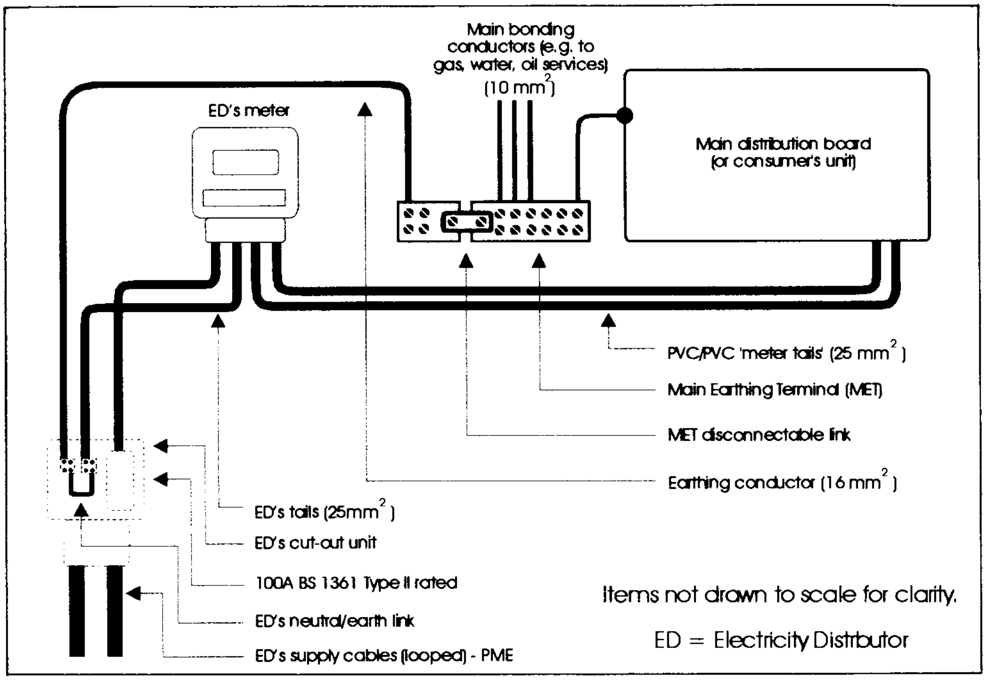


Figure 15.1: Typical arrangement for connection of a smaller installation on a TN-C-S system

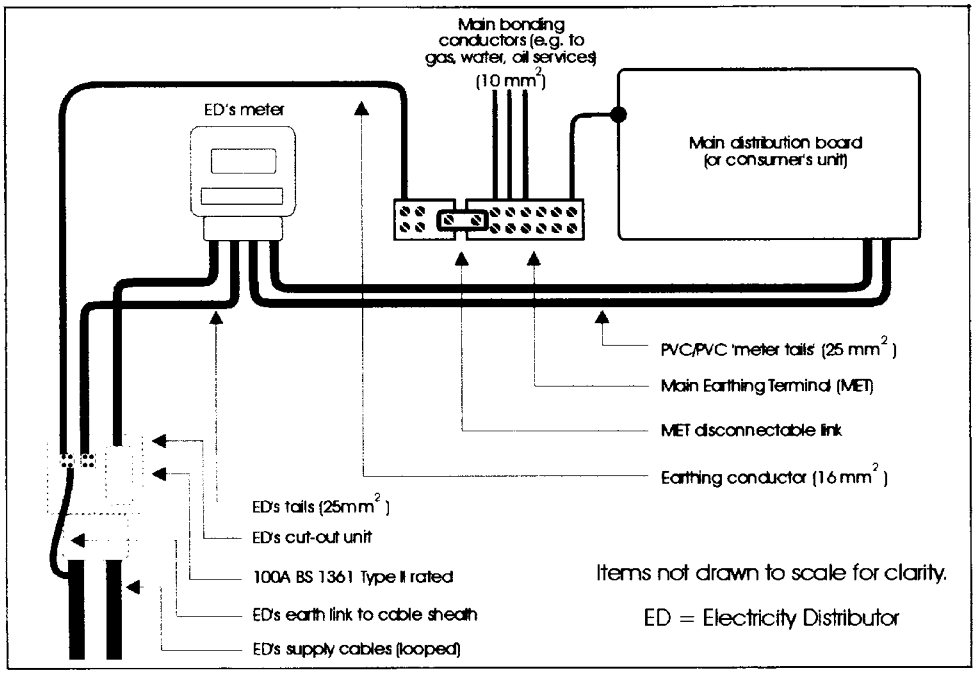


Figure 15.2: Typical arrangement for connection of a smaller installation on a TN-S system

Irrespective of system type and earthing arrangements, the csa of the earthing conductor must either be calculated using the adiabatic equation given in Regulation 543–01–03 or selected to meet the requirements of Table 54G of BS 7671. Since the length of such a conductor is generally relatively short, the favoured method of selection is by the use of the table. For a 100 A supply with phase conductor(s) csa (copper) of 25 mm^2 or 35 mm^2 an earthing conductor csa of 16 mm^2 (copper) will be required. This csa will also afford compliance with Table 54A for buried earthing conductors where protection against corrosion has been provided. In the case of TT systems, Regulation 413–02–20 requires that Equation (15.1) is met.

$$R_A I_a \leqslant 50 \text{ V} \tag{15.1}$$

where: R_A = sum of the resistances of the earth electrode and the protective conductor(s) connecting the exposed-conductive-parts to the electrode

I_a = current causing automatic operation of the protective device within 5 s (where an RCD is employed, as is usually the case, I_a is $I_{\Delta n}$).

In practice, Equation (15.1) is not difficult to meet. Generally, the resistance of the electrode is typically of the order of 30 to 150 Ω and

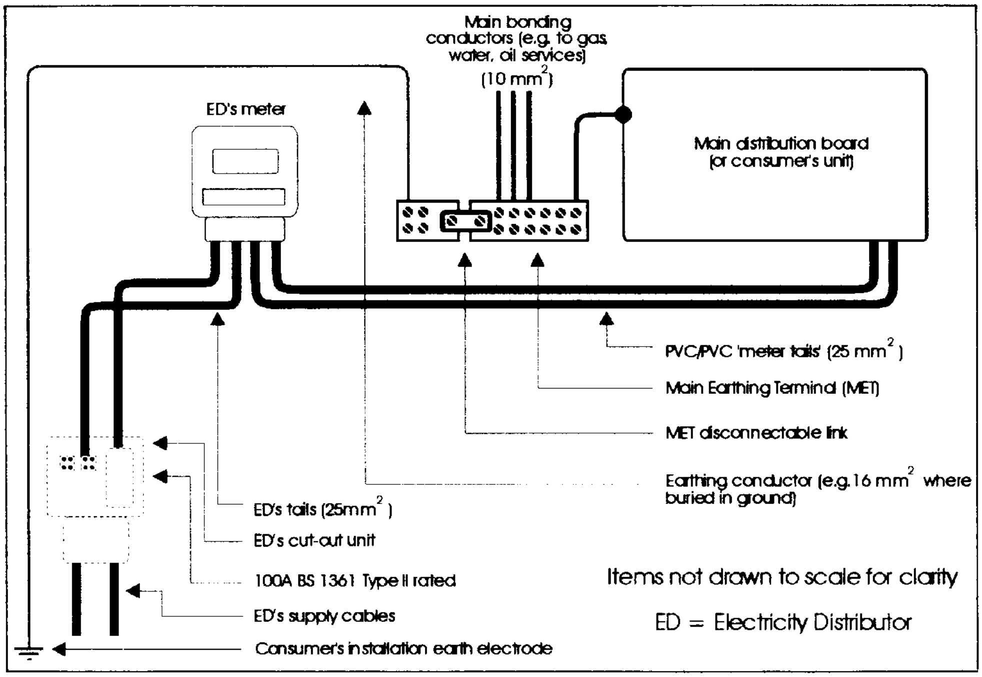


Figure 15.3: Typical arrangement for connection of a smaller installation on a TT system

constitutes the major contribution to R_A. To illustrate the point by example, take an electrode resistance of 149 Ω and a resistance of 1 Ω for the protective conductors. So that the touch voltage does not exceed 50 V the rated residual operating (tripping) current of the RCD would need not to exceed 0.33 A to meet Equation (15.1). Clearly, selecting a 300 mA RCD, at the front end, will more than satisfy this requirement.

It is important to recognise that an ED is not obliged to offer a means of earthing and in some cases it may not be able to provide such a service. In other cases the ED may refuse to provide an earthing facility where, for example, they cannot be satisfied that statutory requirements relating to PME (contained in the Electricity Supply Regulations, as amended) will be met. It is essential therefore that liaison with the ED is instigated at an early stage of the design to establish whether or not a means of earthing can be provided. When offered an earthing facility by the ED, it is the designer's responsibility to ensure that such a facility is suitable for the particular installation.

15.9 Main equipotential bonding

The general requirements for main equipotential bonding are discussed in Chapter 12 of this Guide and the smaller installation has no dispensations in this respect. All incoming services such as gas, water, oil, etc. will need to be main bonded to the MET. These bonding conductors, if not copper, must have the equivalent conductance to that of copper and must be selected to meet the requirements of Regulation 547–02–01. For TN-S and TT systems (i.e. non-PME supplies), the conductor csa is subject to a minimum of 6 mm^2 and a maximum of 25 mm^2 and it must not be less than 50% of the csa of the installation earthing conductor. For a 100 A rated supply with an earthing conductor of 16 mm^2 the main bonding conductor csa would need to be not less than 8 mm^2 and therefore a 10 mm^2 conductor will be required.

Where the installation forms part of a TN-C-S system (i.e. PME supply), the main bonding conductor csa is related to the supply neutral as detailed in Table 54H of BS 7671 which stipulates a minimum of 10 mm^2 and a maximum of 50 mm^2. For a 100 A supply, a 10 mm^2 main bonding conductor will generally be adequate but a check with the ED is always desirable to ensure that any particular requirements which it may have are met.

The connection of the bonding conductors to the incoming services must be made using BS 951 earthing/bonding clamps at a point as near as practicable to the entry of the service into the equipotential zone. For a water service this point is generally immediately after the stopcock and for the gas service within 600 mm of the meter if it is located within the zone, or at the point of entry if external. Other services should be treated in a similar way.

Where convenient and desirable, it is permissible to loop the main equipotential bonding conductors so that one conductor connects a number of incoming services. When this method is adopted the conductor should be continuous and not cut at each connection. This is necessary to avoid any disconnection of any bonding connection (e.g. gas bond by gas fitter) affecting the connection of other services.

Further data for earthing and main equipotential conductor cross-sectional areas for supplies other than 100 A are given in item 15.10 and Table 15.2 of this chapter.

15.10 Minimum csa of earthing and main equipotential bonding conductors

There are a number of regulations which place constraints on the csa of earthing and main equipotential bonding conductors. Regulation 542–03–01 relates to earthing conductors buried in the ground and for most practical purposes only applies to TT and IT systems since for TN-C-S and TN-S systems the means of earthing is provided by the supplier. Regulations 543–01–01 to 543–01–04 give the requirements for protective conductors generally and Regulations 547–02–01 and 547–02–02 make additional demands for main equipotential bonding conductors. In the case of TT systems a further constraint is made on the earthing conductor in that the product of the sum of the resistances of the earth electrode and connecting protective conductors and the minimum current causing automatic disconnection of

Table 15.2: Earthing and main equipotential bonding conductors – minimum cross-sectional areas

Phase (or neutral) csa (mm^2)	**Minimum conductor csa (copper or copper equivalent) (mm^2)**								
	Earthing conductor	**Main equipotential bonding conductor csa(2)**		**Earthing conductor**	**Main equipotential bonding conductor csa(2)**		**Earthing conductor**	**Main equipotential bonding conductor csa(2)**	
	Non-separate conductor and separate conductor not buried or buried with corrosion and mechanical protection(1)(3)			**Separate buried earthing conductor with protection against corrosion but no additional mechanical protection(1)(3)**			**Separate buried earthing conductor with no additional corrosion protection(1)(3)**		
		for non-PME(3)	**for PME**		**for non-PME(3)**	**for PME**		**for non-PME(3)**	**for PME**
4	_*4 (10)_	6	10	16	10	10	25	16	10
6	_*6 (10)_	6	10	16	10	10	25	16	10
10	_10_	6	10	16	10	10	25	16	10
16	_16_	_10_	10	16	10	10	25	16	10
25	_16_	_10_	10	16	10	10	25	16	10
35	_16_	_10_	10	16	10	10	25	16	10
50	_25_	_16_	16	_25_	_16_	16	25	16	16

Notes: (1) Earthing conductor csa taking account of Regulation 542-03-01 (Table 54A) and Regulation 543-01-04 (Table 54G).

(2) Main equipotential bonding conductor csa taking account of Regulation 547-02-01 (and Table 54H).

(3) Data given in italics indicate that by use of the adiabatic equation given in Regulation 543-01-03 a smaller csa may be achieved.

(4) Where TN-S and TT systems are employed, the data given for 'non-PME' should be used but where the system is TN-C-S, the larger value given in the two columns 'non-PME' and 'PME' should be used.

* Regulation 542-03-01 requires the earthing conductor csa to be not less than the main bonding conductor csa for installations with a PME supply.

the protective device is limited to 50 V. This is not generally the overriding constraint and, for most practical purposes, other constraints will take precedence. Table 15.2 summarises the requirements and provides data for these conductors related to the supply phase conductor for non-PME supplies and to the neutral conductors in the case of PME services.

It should be noted that where the supply is derived from the public supply network most EDs will stipulate the minimum phase(s) and neutral 'meter tails' that they require (generally not less than 6 mm^2) which will be related to the fault current protection afforded by their cut-out fuse. The smaller sizes of these conductors given in Table 15.2 are for use with connections to fire alarm systems and the like and would not generally be applicable to the installation main 'meter tails'.

15.11 Supplementary equipotential bonding

Supplementary equipotential bonding is addressed in Chapter 12 and, for special installations or locations, in Chapter 16. Generally, supplementary bonding will only be necessary in areas of increased risk of electric shock such as bathrooms and swimming pools. In such locations both extraneous-conductive-parts and exposed-conductive-parts are required to be bonded together to form an equipotential zone so that in the event of a fault no substantial voltage exists between these conductive parts. Generally, a conductor of 4 mm^2 is sufficient for most circumstances but, in any event, the bonding conductor csa must not be less than that of the smaller cpc of any two circuits having exposed-conductive-parts requiring mutual connection. Where a bonding conductor is to connect an extraneous-conductive-part with an exposed-conductive-part the csa must not be less than half the circuit protective conductor's csa to the exposed-conductive-part.

Supplementary bonding conductors may be formed in part by a conductive part not forming a component of the electrical installation. For example, copper or iron pipework, provided that it is considered to be permanent and reliable, may be so used as a supplementary bonding conductor. Notwithstanding the minimum csa of bonding conductors given above, a further constraint is placed on such conductors for some special locations and installations in that their resistance is limited so that the touch voltage between conductive parts does not exceed 50 V.

15.12 Devices for protection against overcurrent and indirect contact

General guidance relating to protection against overcurrent is given in Chapter 7 of this Guide and for protection against indirect contact in Chapter 5. More often than not a single device provides for both functions and when so used must satisfy all the relevant requirements.

Many smaller installations are served with a consumer's unit to BS 5486: Part 13. This standard introduces the term 'conditional rating' which implies that such a unit will be protected against the effect of fault current, under certain conditions, when backed by a BS 1361: Part II, 100 A fuse provided by an ED. The pertinent conditions include connection through a single-rate meter and specified lengths of connection cables including meter tails'.

Having established the prospective fault current at the origin, the designer will need to establish that the protective devices and main switch are intended to be capable of withstanding this current. It should be noted that BS 5486: Part 13 requires the consumer unit manufacturer to provide, in the form of installation instructions, all the necessary guidance and conditions relating to the conditional rating.

Provided that the overcurrent protective devices in the consumer's unit have adequate short-circuit capacity for the prospective fault current at the origin then no further consideration of downstream devices is necessary in this respect.

In the smaller installation there will normally be a need to provide RCD(s) for either protection against indirect contact or for supplementary protection against direct contact. With regard to the latter, an RCD, with a rated residual operating current of not more than 30 mA, will be required to protect all socket-outlets (Regulation 471–16–01) (except SELV, reduced low-voltage and electrically separated circuits) which may be reasonably expected to be used outdoors. This will normally involve protecting all ground-floor socket-outlets in this way and may, depending on the precise circumstances, be necessary for socket-outlets at other levels. Additionally, Regulation 471–16–02 calls for portable equipment for use outdoors to be similarly protected. Where the installation forms part of a TT system, all socket-outlets must be protected by an RCD (preferably $I_{\Delta n} \leqslant 30$ mA) in order to comply with Regulation 471–08–06. Generally, the whole of the installation forming part of a TT system will need to be protected by an RCD but it is undesirable to protect the whole installation with one having $I_{\Delta n} \leqslant 30$ mA since this is likely to be prone to unwanted tripping. Normally, it is necessary to provide a time-delayed RCD (say, $I_{\Delta n} = 200$ mA) at the 'front-end' and 30 mA RCD(s) for the socket-outlets thus providing discrimination. Equipment prone to high earth-leakage (e.g. washing machine) and vulnerable items (e.g. freezers) should preferably be wired on their own dedicated circuit and for the latter the more sensitive RCD protection should be avoided wherever possible.

Where the installation forms part of a TT system the prospective earth fault current will be relatively low owing to the high phase-earth fault loop impedance with a value of the order of 10 to 200 Ω not being uncommon, see Figure 15.4. The high impedance is due to a number of factors including the fairly high resistance of the source earth electrode (e.g. 21 Ω), and that of the installation earth electrode typically 30 to 150 Ω).

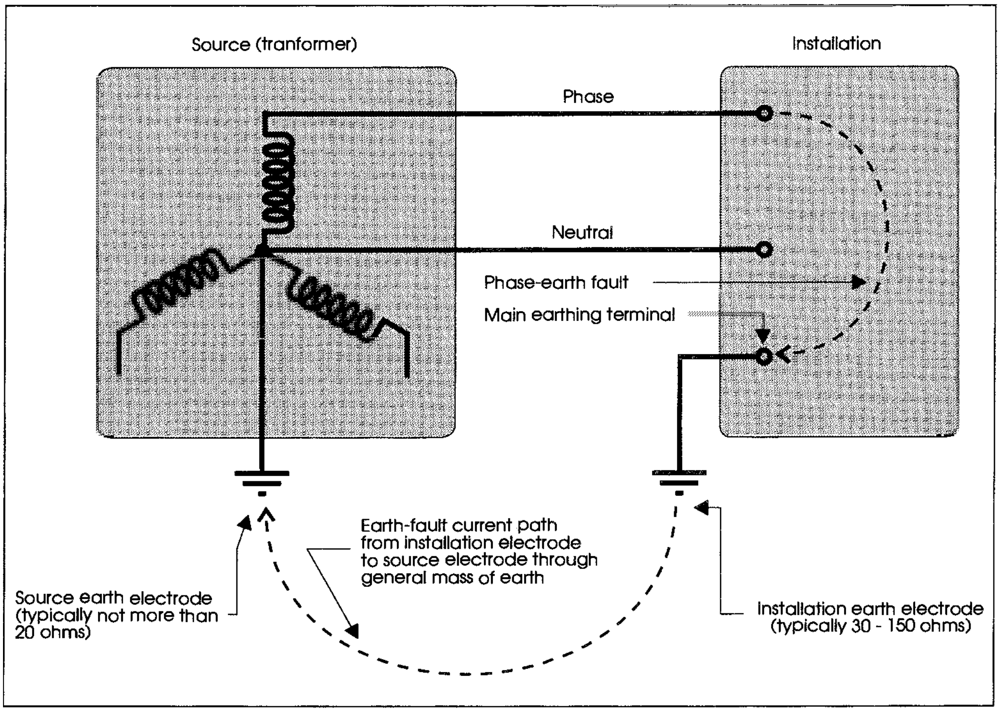


Figure 15.4: TT system earth fault path

15.13 Devices for isolation and switching

Guidance in connection with isolation and switching is given in Chapter 8 of this Guide and there are no dispensations for the smaller installation. Regulation 460–01–02 calls for a main linked switch or circuit-breaker to be provided for every installation. In the smaller installation the consumer's unit main switch will provide this function as will a main circuit-breaker and, provided it is designed to meet the isolation requirements, an RCD.

15.14 Final circuit design

As mentioned earlier, every circuit has to be designed. It may be that the designer may choose to adopt the designs in the *IEE On-Site Guide* which will provide for a safe design if not the most economical. A number of conventional circuits, both radial and ring, are given in that guide which need no further explanation.

Amendments to BS 7671 introduced a number of significant changes which affected circuit design mainly in two ways. Firstly, the nominal voltages for low voltage supplies complying with the Electricity Supply Regulations 1988, as amended, changed from 240 V to 230 V, and hence calculation for load current was marginally modified. Secondly, the revision to Regulation 413–02–05 means that there is no further consideration of the increase in conductor resistances as a result of the elevated conductor temperatures which occur during the clearance of a fault, provided overcurrent protective devices are selected from those given in Appendix 3 of BS 7671 (and the associated circuits comply with the loop impedance values given in Tables 41B1, 41B2 and 41D of BS 7671). Finally, the 'deemed to comply' voltage drop limit of 4%, although unchanged in percentage terms, reduces the ohmic value of the limit of voltage drop to 9.2 V from 9.6 V.

It is generally recognised that the change to the nominal voltage will have little or no effect on the actual voltages supplied from the public network (though it is acknowledged that the new regime allows more latitude for suppliers). Bearing this in mind and the fact that the data given in Tables 41B1, 41B2 and 41D of BS 7671 remain unchanged from that data previously given for 240 V circuits, it has been decided that the calculations in this section (15.14) remain unaltered but the reader should recognise that applying the new development in BS 7671 will render different design solutions. Additionally, although the resistance/temperature correction factor strictly need not be applied in the cited examples (in other words the factor should be reset to '1'), it has been decided to leave it in to show how such a factor used to be applied and how it would be applied for circuits where the overcurrent protective device is one which is not embraced by Appendix 3 of BS 7671. For consistency, Tables 15.3(a), 15.3(b), 15.4(a), 15.4(b), 15.5 of this Guide remain unaltered and still refer to 240 V rather than 230 V.

By way of additional guidance, Tables 15.3(a) and 15.3(b) provide data for maximum circuit lengths for installations forming part of a TN-S system,

Table 15.3(a): Maximum conductor lengths for PVC/PVC cables to BS 6004 for TN-S systems where $Z_e = 0.80\ \Omega$ and $U_o = 240$ V

Ref	**Conductor csa (mm²)**		**Circuit type**	**Installation reference method(s)**	**I_n and I_b**	**Maximum length of circuit conductors (m)(1)**											
						Protective device											
	Live	**cpc**				**BS 88 fuse Parts 2 and 6**		**BS1361 fuse**		**BS 3036 fuse**		**MCBs BS 3871 and BS EN 60 898**					
						Maximum disconnection times						**Disconnection times within 100 ms**					
					A	**5 s**	**0.4 s**	**5 s**	**0.4 s**	**5 s**	**0.4 s**	**1**	**B**	**2**	**3 and C**	**D**	**4**
A	16	6	Radial	1 and 3	63	*10*	*0*	—	—	—	—	54	*0*	*0*	*0*	*0*	*0*
B			Radial	1	60	—	—	*0*	*0*	57	*0*	—	—	—	—	—	—
C			Radial	1 and 3	60	—	—	*0*	*0*	—	—	—	—	—	—	—	—
D			Radial	1, 3 and 4	50	*49*	*0*	—	—	—	—	68	*27*	*0*	*0*	*0*	*0*
E			Radial	1 and 3	45	—	—	*34*	*0*	76	*0*	76	*46*	*0*	*0*	*0*	*0*
F			Radial	1, 3 and 4	45	—	—	*34*	*0*	—	—	76	*46*	*0*	*0*	*0*	*0*
G			Radial	1, 3 and 4	40	85	*10*	—	—	—	—	85	*68*	*10*	*0*	*0*	*0*
H	10	4	Radial	1 and 3	50	*32*	*0*	—	—	—	—	43	*18*	*0*	*0*	*0*	*0*
I			Radial	1	45	—	—	*22*	*0*	48	*0*	48	*30*	*0*	*0*	*0*	*0*
J			Radial	1 and 3	45	—	—	*22*	0	—	—	48	*30*	*0*	*0*	*0*	*0*
K			Radial	1, 3 and 4	40	54	*6*	—	—	—	—	54	*45*	*6*	*0*	*0*	*0*
L			Radial	1, 3 and 4	32	68	*32*	—	—	—	—	68	68	*30*	*0*	*0*	*0*
M			Radial	1, 3 and 4	30	—	—	72	*45*	72	*38*	72	—	*38*	*0*	*0*	*0*
N			Radial	1, 3 and 4	25	87	*78*	—	—	—	—	—	—	—	—	—	—
O	6	2.5	Radial	1	45	—	—	*13*	*0*	—	—	29	*18*	*0*	*0*	*0*	*0*
P			Radial	1	40	32	*4*	—	—	—	—	32	*27*	*4*	*0*	*0*	*0*
Q			Radial	1, 3 and 4	32	41	*20*	—	—	—	—	41	41	*18*	*0*	*0*	*0*
R			Ring	1, 3 and 4	32	—	*80*	—	—	—	—	164	164	*74*	*0*	*0*	*0*
S			Radial	1	30	—	—	43	*27*	43	*23*	43	—	*23*	*0*	*0*	*0*
T			Radial	1, 3 and 4	30	—	—	43	*27*	—	—	43	—	*23*	*0*	*0*	*0*
U			Ring	1, 3 and 4	30	—	—	—	*110*	—	*93*	175	—	*93*	*0*	*0*	*0*
V			Radial	1, 3 and 4	25	52	*48*	—	—	—	—	—	—	—	—	—	—
W			Radial	1, 3 and 4	20	65	65	65	65	65	65	65	65	*62*	*27*	*0*	*0*
X			Radial	1, 3 and 4	16	82	82	—	—	—	—	82	82	82	*48*	*0*	*0*
Y			Radial	1, 3 and 4	15	—	—	87	87	87	87	87	—	87	*55*	*0*	*0*

Notes: (1) Lengths shown in normal font indicate that volt-drop is the limiting factor whereas those shown in italics signify that Z_s is the limiting factor.

(2) Table only to be used after establishing that the particular csa has adequate current-carrying capacity for the particular circumstances, taking into account all the appropriate correction factors.

(3) Entries denoted by — mean that either the current-carrying capacity for the csa given is inadequate for the given protective device or the protective device is otherwise unsuitable or unavailable.

Table 15.3(b): Maximum conductor lengths for PVC/PVC cables to BS 6004 for TN-S systems where $Z_e = 0.80\ \Omega$ and $U_o = 240$ V

Ref	**Conductor csa (mm²)**		**Circuit type**	**Installation reference method(s)**	I_n **and** I_b	**Maximum length of circuit conductors (m)**[1]											
						Protective device											
	Live	**cpc**				**BS 88 fuse Parts 2 and 6**		**BS1361 fuse**		**BS 3036 fuse**		**MCBs BS 3871 and BS EN 60 898**					
						Maximum disconnection times						**Disconnection times within 100 ms**					
					A	**5 s**	**0.4 s**	**5 s**	**0.4 s**	**5 s**	**0.4 s**	**1**	**B**	**2**	**3 and C**	**D**	**4**
A	4	1.5	Radial	1	32	27	*12*	—	—	—	—	27	27	*11*	*0*	*0*	*0*
B			Ring	1, 3 and 4	32	—	*50*	—	—	—	—	109	109	*46*	*0*	*0*	*0*
C			Radial	1 and 3	30	—	—	29	*17*	—	—	29	—	*14*	*0*	*0*	*0*
D			Ring	1 and 3	30	—	—	—	*69*	—	*58*	116	—	58	*0*	*0*	*0*
E			Radial	1, 3 and 4	25	34	*30*	—	—	—	—	—	—	—	—	—	—
F			Radial	1 and 3	20	43	43	43	*42*	43	43	43	43	*39*	*17*	*0*	*0*
G			Radial	1, 3 and 4	20	43	43	43	*42*	—	—	43	43	*39*	*17*	*0*	*0*
H			Radial	1, 3 and 4	16	54	54	—	—	—	—	54	54	54	*30*	*0*	*0*
I			Radial	1, 3 and 4	15	—	—	58	58	58	58	58	—	58	*34*	*0*	*0*
J			Radial	1, 3 and 4	10	87	87	—	—	—	—	87	87	87	*69*	*17*	*0*
K	2.5	1.5	Ring	1 and 3	32	—	*43*	—	—	—	—	66	66	*40*	*0*	*0*	*0*
L			Ring	1 and 3	30	—	—	—	*59*	—	—	71	—	*50*	*0*	*0*	*0*
M			Radial	1	25	21	21	—	—	—	—	—	—	—	—	—	—
N			Radial	1 and 3	20	26	26	26	26	—	—	26	26	26	*14*	*0*	*0*
O			Radial	1, 3 and 4	16	33	33	—	—	—	—	33	33	33	*25*	*0*	*0*
P			Radial	1	15	—	—	35	35	35	35	35	—	35	*29*	*0*	*0*
Q			Radial	1, 3 and 4	15	—	—	35	35	—	—	35	—	35	*29*	*0*	*0*
R			Radial	1, 3 and 4	10	53	53	—	—	—	—	53	53	53	53	*14*	*0*
S			Radial	1, 3 and 4	6	88	88	—	—	—	—	88	88	88	88	*44*	*0*
T			Radial	1, 3 and 4	5	—	—	106	106	106	106	106	—	106	106	*59*	*5*

Table 15.3(b) continued: Maximum conductor lengths for PVC/PVC cables to BS 6004 for TN-S systems where $Z_e = 0.80\ \Omega$ and $U_o = 240$ V

Ref	Conductor csa (mm²)		Circuit type	Installation reference method(s)	I_n and I_b	Maximum length of circuit conductors (m)[1]											
	Live	cpc				Protective device											
						BS 88 fuse Parts 2 and 6		BS1361 fuse		BS 3036 fuse		MCBs BS 3871 and BS EN 60 898					
						Maximum disconnection times						Disconnection times within 100 ms					
					A	5 s	0.4 s	5 s	0.4 s	5 s	0.4 s	1	B	2	3 and C	D	4
U			Radial	1 and 3	16	20	20	—	—	—	—	20	20	20	*16*	*0*	*0*
V			Radial	1 and 3	15	—	—	22	22	—	—	22	—	22	*19*	*0*	*0*
W	1.5	1	Radial	1, 3 and 4	10	33	33	—	—	—	—	33	33	33	33	*9*	*0*
X			Radial	1, 3 and 4	6	55	55	—	—	—	—	55	55	55	55	*28*	*0*
Y			Radial	1,3 and 4	5	—	—	66	66	66	66	66	—	66	66	*38*	*3*
Z			Radial	1	15	—	—	14	14	—	—	14	—	14	14	*0*	*0*
Z1	1	1	Radial	1, 3 and 4	10	21	21	—	—	—	—	21	21	21	21	*8*	*0*
Z2			Radial	1, 3 and 4	6	36	36	—	—	—	—	36	36	36	36	*24*	*0*
Z3			Radial	1, 3 and 4	5	—	—	43	43	43	43	43	—	43	43	*32*	*3*

Notes: (1) Lengths shown in normal font indicate that volt-drop is the limiting factor whereas those shown in italics signify that Z_s is the limiting factor.
(2) Table only to be used after establishing that the particular csa has adequate current-carrying capacity for the particular circumstances, taking into account all the appropriate correction factors.
(3) Entries denoted by — mean that either the current-carrying capacity for the csa given is inadequate for the given protective device or the protective device is otherwise unsuitable or unavailable.

Table 15.4(a): Maximum conductor lengths for PVC/PVC cables to BS 6004 for TN-C-S systems where $Z_e = 0.35\ \Omega$ and $U_o = 240$ V

Ref	Conductor csa (mm²)		Circuit type	Installation reference method(s)	I_n and I_b	Maximum length of circuit conductors (m)[1]											
						Protective device											
	Live	cpc				BS 88 fuse Parts 2 and 6		BS1361 fuse		BS 3036 fuse		MCBs BS 3871 and BS EN 60 898					
						Maximum disconnection times						Disconnection times within 100 ms					
					A	5 s	0.4 s	5 s	0.4 s	5 s	0.4 s	1	B	2	3 and C	D	4
A	16	6	Radial	1 and 3	63	54	*22*	—	—	—	—	54	54	*32*	*5*	*0*	*0*
B			Radial	1	60	—	—	57	*8*	57	*14*	—	—	—	—	—	—
C			Radial	1 and 3	60	—	—	57	*8*	—	—	—	—	—	—	—	—
D			Radial	1, 3 and 4	50	68	*47*	—	—	—	—	68	68	*58*	*22*	*0*	*0*
E			Radial	1 and 3	45	—	—	76	42	76	46	76	76	*70*	*30*	*0*	*0*
F			Radial	1, 3 and 4	45	—	—	76	42	—	—	76	76	*70*	*30*	*0*	*0*
G			Radial	1, 3 and 4	40	85	85	—	—	—	—	85	85	85	*42*	*0*	*0*
H	10	4	Radial	1 and 3	50	43	*31*	—	—	—	—	43	43	*38*	*14*	*0*	*0*
I			Radial	1	45	—	—	48	*28*	48	*30*	48	48	*46*	*20*	*0*	*0*
J			Radial	1 and 3	45	—	—	48	*28*	—	—	48	48	*46*	*20*	*0*	*0*
K			Radial	1, 3 and 4	40	54	54	—	—	—	—	54	54	54	*28*	*0*	*0*
L			Radial	1, 3 and 4	32	68	68	—	—	—	—	68	68	68	*45*	*2*	*0*
M			Radial	1, 3 and 4	30	—	—	72	72	72	72	72	—	72	*50*	*5*	*0*
N			Radial	1, 3 and 4	25	87	87	—	—	—	—	—	—	—	—	—	—
O	6	2.5	Radial	1	45	—	—	29	*17*	—	—	*29*	*29*	*28*	*12*	*0*	*0*
P			Radial	1	40	*32*	*32*	—	—	—	—	*32*	*32*	*32*	*17*	*0*	*0*
Q			Radial	1, 3 and 4	32	41	41	—	—	—	—	41	41	41	*27*	*1*	*0*
R			Ring	1, 3 and 4	32	—	164	—	—	—	—	164	164	164	*110*	*6*	*0*
S			Radial	1	30	—	—	43	43	43	43	43	—	43	*31*	*3*	*0*
T			Radial	1, 3 and 4	30	—	—	43	43	—	—	43	—	43	*31*	*3*	*0*
U			Ring	1, 3 and 4	30	—	—	—	175	—	175	175	—	175	*124*	*13*	*0*
V			Radial	1, 3 and 4	25	87	*79*	—	—	—	—	—	—	—	—	—	—
W			Radial	1, 3 and 4	20	65	65	65	65	65	65	65	65	65	*58*	*17*	*0*
X			Radial	1, 3 and 4	16	82	82	—	—	—	—	82	82	82	*79*	*27*	*0*
Y			Radial	1, 3 and 4	15	—	—	87	87	87	87	87	—	87	*86*	*31*	*0*

Notes: (1) Lengths shown in normal font indicate that volt-drop is the limiting factor whereas those shown in italics signify that Z_s is the limiting factor.

(2) Table only to be used after establishing that the particular csa has adequate current-carrying capacity for the particular circumstances, taking into account all the appropriate correction factors.

(3) Entries denoted by — indicate that either the current-carrying capacity for the csa given is inadequate for the given protective device or the protective device is otherwise unsuitable or unavailable.

considering the limitations imposed by phase-earth fault loop impedance, Z_s, and volt-drop (4%). Similarly, Tables 15.4(a) and 15.4(b) give data for installations forming part of a TN-C-S system and Table 15.5 provides data for installations forming part of a TT system, where protection against indirect contact is provided by an RCD, considering only the volt-drop constraint. All the tables serve only as guidance and the designer will need to check that all the requirements relating to, for example, indirect contact, overcurrent and volt-drop are fully met. These tables should only be used where the distribution board is adjacent to the origin of the installation.

As with all circuitry, it is important to observe the requirements of Section 413 *Installation circuit arrangement* and in particular Regulation 314–01–04. Every circuit must be electrically separate to facilitate safety in operation, inspection, testing and maintenance; implicitly, the phase and neutral of each and every circuit must be separately connected in an easily identifiable sequence in the distribution board or consumer's unit. Though strictly not called for in this regulation, it is considered to be good practice to follow the same sequential identification of circuit protective conductors where these are separate and dedicated conductors (e.g. not MICC sheath or conduit or a cpc common to a number of circuits). Additionally, a neutral from one circuit must not be 'borrowed' for any other circuit.

To explain the use of Tables 15.4(a) and 15.4(b), Figure 15.5 shows a typical distribution layout for a smaller installation with a consumer's unit with 12 outgoing ways, one of which is a spare way. The design of some of the circuits is undertaken here to show the necessary procedures including reference to the aforementioned tables. The supply with the installation forms a TN-S system where the maximum prospective fault current is, say, 5.7 kA and the maximum external loop impedance, Z_e, is 0.8 Ω.

Circuit 1: Radial circuit feeding a 240 V, 26.4 kW electric cooker (hob and oven) with cooker-control incorporating a 13 A socket-outlet. Cable (PVC insulated and sheathed to BS 6004) run through thermal insulation on part (for 100 mm) of the cable run which in total is 46 m. Ambient temperature is 30°C throughout and there is no grouping correction factor necessary.

The total rated (full-load) current is 110 A (26 400 W ÷ 240 V) and applying diversity (see Appendix J of IEE Guidance Note No 1) gives a design current, I_b, of 45 A as shown in Equation (15.2).

$$\begin{aligned} I_b &= 10 + 0.3\,(\textit{rated current} - 10) + 5 \text{ (A)} \qquad (15.2)\\ &= 15 + 0.3\,(110 - 10) \text{ (A)}\\ &= 45 \text{ A} \end{aligned}$$

The next step is to choose the protective device. The fault level of 5.7 kA is outside the capabilities of a semi-enclosed (rewirable) fuse had the circuit distribution been a distribution board. However, in the example shown a consumer's unit has been chosen and we could have used semi-enclosed

Table 15.4(b): Maximum conductor lengths for PVC/PVC cables to BS 6004 for TN-C-S systems where $Z_e = 0.35\ \Omega$ and $U_o = 240$ V

Ref	**Conductor csa (mm²)**		**Circuit type**	**Installation reference method(s)**	I_n **and** I_b	**Maximum length of circuit conductors (m)**[1]											
						Protective device											
	Live	**cpc**				**BS 88 fuse Parts 2 and 6**		**BS1361 fuse**		**BS 3036 fuse**		**MCBs BS 3871 and BS EN 60 898**					
						Maximum disconnection times						**Disconnection times within 100 ms**					
					A	**5 s**	**0.4 s**	**5 s**	**0.4 s**	**5 s**	**0.4 s**	**1**	**B**	**2**	**3 and C**	**D**	**4**
A	4	1.5	Radial	1	32	27	27	—	—	—	—	27	27	*27*	*17*	*1*	*0*
B			Ring	1, 3 and 4	32	—	109	—	—	—	—	109	109	109	*69*	*4*	*0*
C			Radial	1 and 3	30	—	—	29	29	—	—	29	—	29	*19*	*2*	*0*
D			Ring	1 and 3	30	—	—	—	116	—	116	116	—	116	*78*	*8*	*0*
E			Radial	1, 3 and 4	25	34	34	—	—	—	—	—	—	—	—	—	—
F			Radial	1 and 3	20	43	43	43	43	43	43	43	43	43	*36*	*10*	*0*
G			Radial	1, 3 and 4	20	43	43	43	43	—	—	43	43	43	*36*	*10*	*0*
H			Radial	1, 3 and 4	16	54	54	—	—	—	—	54	54	54	*49*	*17*	*0*
I			Radial	1, 3 and 4	15	—	—	58	58	58	58	58	—	58	*54*	*19*	*0*
J			Radial	1, 3 and 4	10	87	87	—	—	—	—	87	87	87	*87*	*36*	*5*
K	2.5	1.5	Ring	1 and 3	32	—	66	—	—	—	—	66	66	66	*59*	*3*	*0*
L			Ring	1 and 3	30	—	—	—	71	—	—	71	—	71	*66*	*7*	*0*
M			Radial	1	25	21	21	—	—	—	—	—	—	—	—	—	—
N			Radial	1 and 3	20	26	26	26	26	—	—	26	26	26	26	*9*	*0*
O			Radial	1, 3 and 4	16	33	33	—	—	—	—	33	33	33	33	*14*	*0*
P			Radial	1	15	—	—	35	35	35	35	35	—	35	35	*16*	*0*
Q			Radial	1, 3 and 4	15	—	—	35	35	—	—	35	—	35	35	*16*	*0*
R			Radial	1, 3 and 4	10	53	53	—	—	—	—	53	53	53	53	*31*	*4*
S			Radial	1, 3 and 4	6	88	88	—	—	—	—	88	88	88	88	*61*	*16*
T			Radial	1, 3 and 4	5	—	—	106	106	106	106	106	—	106	106	*76*	*22*

Table 15.4(b) continued: Maximum conductor lengths for PVC/PVC cables to BS 6004 for TN-C-S systems where $Z_e = 0.35\ \Omega$ and $U_o = 240$ V

Ref	Conductor csa (mm²)		Circuit type	Installation reference method(s)	I_n and I_b	Maximum length of circuit conductors (m)[1]											
						Protective device											
	Live	cpc				BS 88 fuse Parts 2 and 6		BS1361 fuse		BS 3036 fuse		MCBs BS 3871 and BS EN 60 898					
						Maximum disconnection times						Disconnection times within 100 ms					
					A	5 s	0.4 s	5 s	0.4 s	5 s	0.4 s	1	B	2	3 and C	D	4
U	1.5	1	Radial	1 and 3	16	20	20	—	—	—	—	20	20	20	20	*9*	*0*
V			Radial	1 and 3	15	—	—	22	22	—	—	22	—	22	22	*10*	*0*
W			Radial	1, 3 and 4	10	33	33	—	—	—	—	33	33	33	33	*20*	*3*
X			Radial	1, 3 and 4	6	55	55	—	—	—	—	55	55	55	55	*39*	*10*
Y			Radial	1, 3 and 4	5	—	—	66	66	66	66	66	—	66	66	*49*	*14*
Z	1	1	Radial	1	15	—	—	14	14	—	—	14	—	14	14	*9*	*0*
Z1			Radial	1, 3 and 4	10	21	21	—	—	—	—	21	21	21	21	*17*	*2*
Z2			Radial	1, 3 and 4	6	36	36	—	—	—	—	36	36	36	36	*33*	*9*
Z3			Radial	1, 3 and 4	5	—	—	43	43	43	43	43	—	43	43	*41*	*12*

Notes: (1) Lengths shown in normal font indicate that volt-drop is the limiting factor whereas those shown in italics signify that Z_s is the limiting factor.

(2 Table only to be used after establishing that the particular csa has adequate current-carrying capacity for the particular circumstances, taking into account all the appropriate correction factors.

(3) Entries denoted by — mean that either the current-carrying capacity for the csa given is inadequate for the given protective device or the protective device is otherwise unsuitable or unavailable.

Table 15.5: Maximum conductor lengths, considering a maximum volt-drop of 4%, for cables to BS 6004 supplying single-phase circuits for TT systems where U_0 = 230 V.

Ref	Live conductor csa (mm²)	Circuit type	I_b A	Maximum length of circuit conductors
A	16	Radial	63	54
B		Radial	60	57
C		Radial	50	68
D		Radial	45	76
E		Radial	40	85
F	10	Radial	50	43
G		Radial	45	48
H		Radial	40	54
I		Radial	32	68
J		Radial	30	72
K		Radial	25	87
L	6	Radial	45	29
M		Radial	40	32
N		Radial	32	41
O		Ring	32	164
P		Radial	30	43
Q		Ring	30	175
R		Radial	25	52
S		Radial	20	65
T		Radial	16	82
U		Radial	15	87
A1	4	Radial	32	27
B1		Ring	32	109
C1		Radial	30	29
D1		Ring	30	116
E1		Radial	25	34
F1		Radial	20	43
G1		Radial	16	54
H1		Radial	15	58
I1		Radial	10	87
J1	2.5	Ring	32	66
K1		Ring	30	71
L1		Radial	25	21
M1		Radial	20	26
N1		Radial	16	33
O1		Radial	15	35
P1		Radial	10	53
Q1		Radial	6	88
R1		Radial	5	106
S1	1.5	Radial	16	20
T1		Radial	15	22
U1		Radial	10	33
V1		Radial	6	55
W1		Radial	5	66
X1	1	Radial	15	14
Z1		Radial	10	21
Z2		Radial	6	36
Z3		Radial	5	43

Note: The above tabulated data relate only to volt-drop considerations. Current-carrying capacity, thermal constraints and protection against indirect contact must be considered separately.

fuses because of the conditional rating of such units. For the purposes of this exercise we shall choose an MCB with nominal current rating of 45 A. The MCB will need at least an M6 short-circuit capacity (6 000 A) if we are to avoid tiresome calculations of energy let-through of the upstream protective device. Cookers are not notorious for high in-rush currents so we could choose a Type 1 MCB but for the purposes of this exercise we shall choose Type 2. The cooking equipment is fixed and would normally require disconnection within 5 s but, because the cooker-control incorporates a socket-outlet, automatic disconnection for protection against indirect contact must occur within 0.4 s. From Table 41B2 of BS 7671 (for 0.4 s disconnection), we see that the limiting value for Z_s for a 45 A Type 2 MCB is 0.76 Ω (the values for 5 s and 0.4 s disconnection are the same for an MCB owing to its time/current characteristic). We can immediately see that this protective device is unsuitable as the limiting Z_s (0.76 Ω) is less than Z_s (0.8 Ω). For this circuit it will obviously be necessary to select a 'more sensitive' MCB Type. Let us consider a Type B MCB which, according to Table 41B2, has a limiting Z_s of 1.07 Ω.

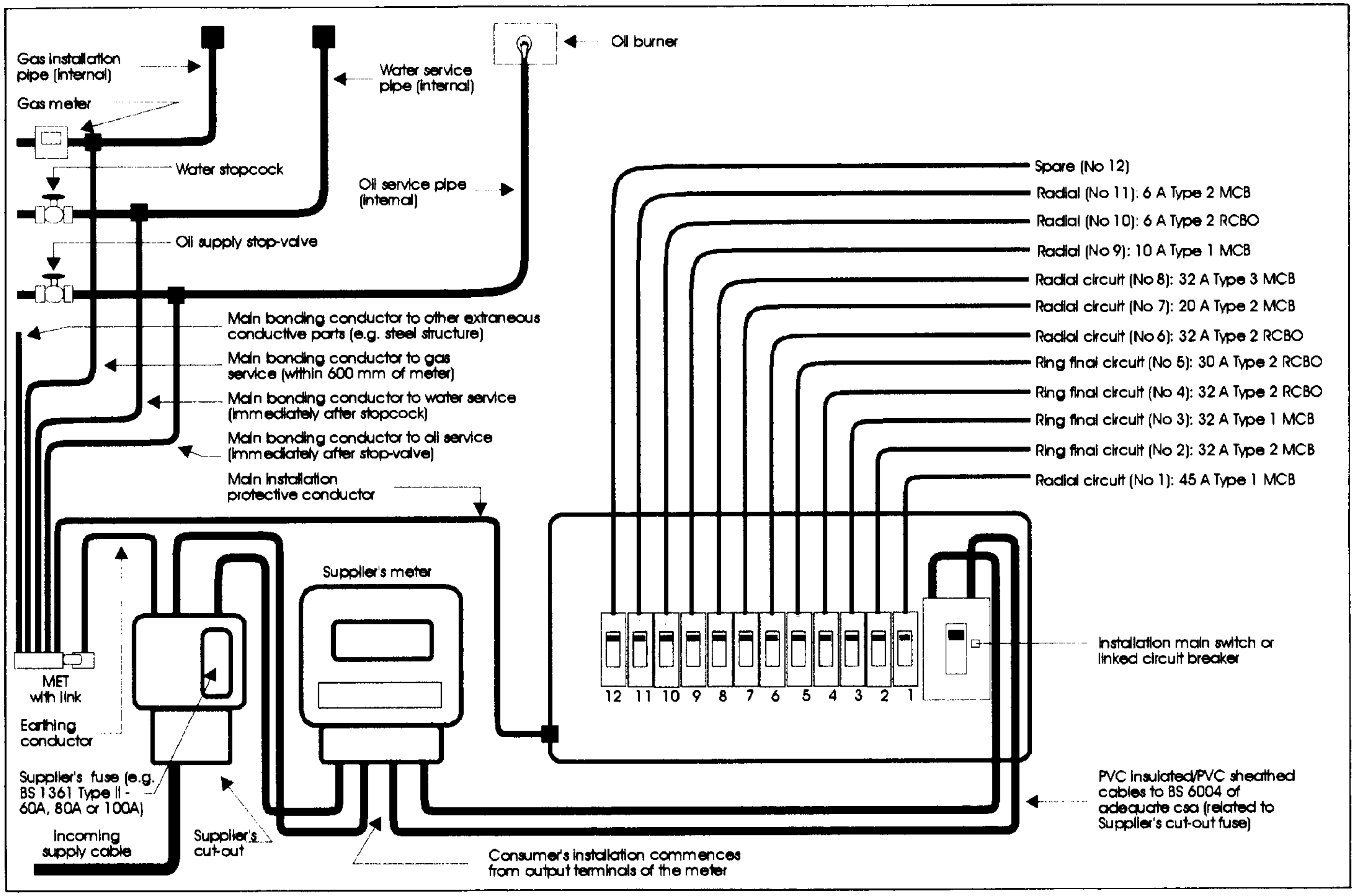


Figure 15.5: Typical small installation layout – TN-S system

The next step is to select the cable cross-sectional area. From Table 4A of Appendix 4 of BS 7671 we see that the installation method for sheathed cables embedded in plaster is reference method 1 but, because the cable runs through 100 mm of thermal insulation, is subject to a thermal insulation correction factor, C_i, of 0.81 (see Table 52A of Regulation 523–04–01). The minimum tabulated current rating, $I_{t(min)}$ is given by Equation (15.3).

$$I_{t(min)} = \frac{I_n}{C_a \times C_g \times C_i} = \frac{45}{1 \times 1 \times 0.81} = 55.6 \text{ A} \tag{15.3}$$

From Table 4D2A of Appendix 4 of BS 7671 we find that we require a 10 mm^2 csa which gives a tabulated current-carrying capacity, I_t, of 63 A for reference method 1 (clipped direct) and this in service provides for an effective current-carrying capacity, I_z, of 51 A (63 × 0.81).

We next have to look at the limiting Z_s for the Type B MCB which, as previously mentioned, is 1.07 Ω. To find the limit on circuit length, L, we need to divide (Z_s – Z_e) by the (R_1 + R_2) per metre (corrected for temperature rise under earth fault conditions), as given in Equation (15.4). The data for corrected (R_1 + R$_2$) per metre values are given in Table 10.18 of this Guide and for 10/4 mm^2 with cpc as a core within a composite cable is given, in Row M, as 8.887 mΩ/m (i.e. 6.44 × 1.38).

$$L = \frac{Z_{s(Max)} - Z_e}{(R_1 + R_2) \times 10^{-3} \times \textit{resistance/temperature correction factor}} \text{(m)}$$

$$= \frac{1.07 - 0.8}{6.44 \times 1.38 \times 10^{-3}} = 30.3 \text{ m} \tag{15.4}$$

From Equation (15.4) we can see that, in the consideration of the limiting Z_s, the maximum length permitted is 30.3 m and therefore we cannot use a Type B MCB because the length of circuit run is 46 m. We could, of course, increase the cable csa so that the calculated Z_s would be reduced but for the purposes of this exercise we do not. Our next step is to select a Type 1 MCB which, from Table 41B2 of BS 7671, has an associated maximum Z_s of 1.33 Ω. Using again the above equation we determine the maximum length of 59.6 m as given in Equation (15.5).

$$L = \frac{Z_{s(Max)} - Z_e}{(R_1 + R_2) \times 10^{-3} \times \textit{resistance/temperature correction factor}} \text{(m)}$$

$$= \frac{1.33 - 0.8}{6.44 \times 1.38 \times 10^{-3}} = 59.6 \text{ m} \tag{15.5}$$

Having established the maximum length from a Z_s point of view, we now have to determine the length that can be tolerated considering volt-drop. In the absence of more precise information, we shall take the 'deemed to comply' value of 4% which, by application of Equation (15.6), gives a limit on length of 48.48 m. The value of 4.4 mV/I/m is obtained from Table 4D2B of Appendix 4 of BS 7671.

$$L = \frac{0.04 \times 240}{I_b \times (mV/A/m) \times 10^{-3}}$$

$$= \frac{9.6}{45 \times 4.4 \times 10^{-3}} = 48.48 \text{ m} \tag{15.6}$$

So we now have a limit on circuit length of 48 m for volt-drop and 59 m for Z_s. Obviously, we have to take the lower figure which imposes the limit of 48 m on cable run. As the actual run for this circuit is 46 m this cable would appear to be satisfactory. There is however one further check to be made and that relates to the thermal constraint on the reduced csa of the cpc. For this calculation we first need to know the magnitude of the earth fault current, I_F, which is determined by application of Equation (15.7).

$$I_F = \frac{U_o}{Z_s} = \frac{U_o}{Z_e + L[(R_1 + R_2) \times 10^{-3} \times 1.38]} \tag{15.7}$$

$$= \frac{240}{0.8 + 46(6.44 \times 10^{-3} \times 1.38)} = 198.5 \text{ A}$$

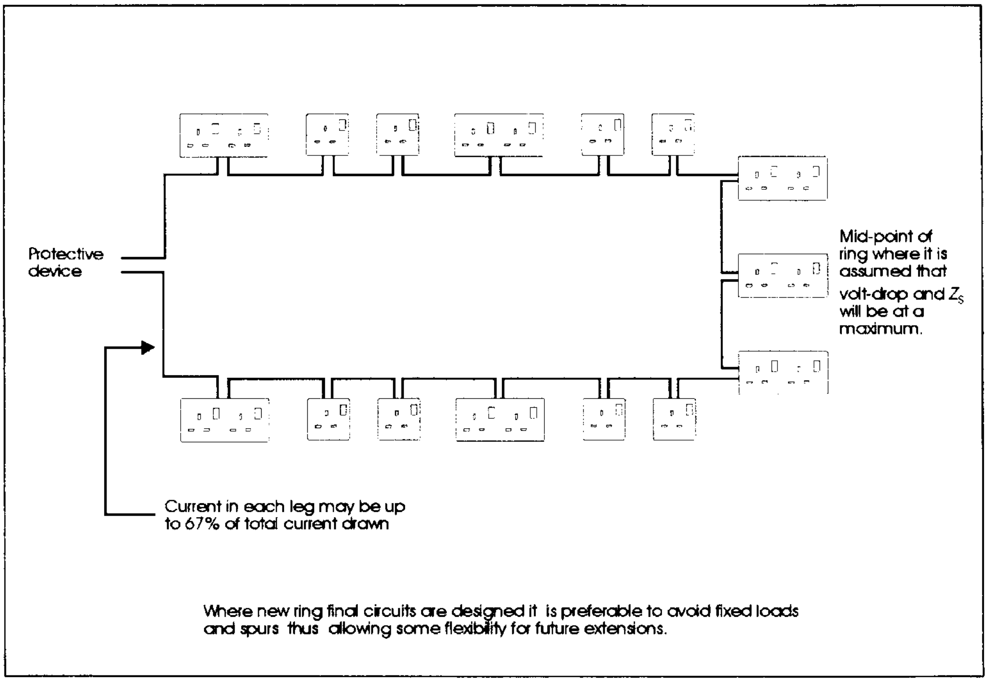
Now that we have determined the earth fault current we can proceed to establish the minimum csa of the cpc by application of the adiabatic equation given in Regulation 543–01–03. The factor k for the cable used is 115 (from Table 54C of BS 7671) and the disconnection time is 100 ms (because we are using an MCB). The minimum csa of the cpc, S, is 0.55 mm^2 as given in Equation (15.8).

$$S = \frac{I_F \sqrt{t}}{k} = \frac{198.5 \sqrt{0.1}}{115} = 0.55 \text{ mm}^2 \tag{15.8}$$

In the case of MCBs, satisfying the thermal constraints relating to the cpc is not difficult owing to the rapid disconnection times. However, where fuses are used to provide protection against indirect contact a check is always required particularly where disconnection times of 5 s are appropriate.

As an aid to the design process we could have used Table 15.3(a) of this Guide to obtain the maximum circuit length for this particular cable. Having checked the cable has adequate current-carrying capacity taking account of all the appropriate correction factors, we look to this table (for TN-S systems) and find, in Row 1, the limiting lengths for the various common protective devices. Data given in normal font indicate that the limiting factor is volt-drop whereas figures given in *italics* signify that Z_s is the overriding constraint. We can see at a glance from Row 1 that MCBs Types 2, 3, C, D and 4 are unsuitable and we can also see that Type B is limited to a 30 m circuit run. The limiting length for Type 1 is given, in normal font, as 48 m indicating that the volt-drop constraint is the limiting factor.

Circuit 2: A ring final circuit feeding BS 1363 13 A socket-outlets on a first-floor location over an area of 95 m^2. The circuit length is estimated to be 64 m and the ambient temperature along the whole run is not expected to exceed 30°C. No correction factors are applicable. Again PVC/PVC cables are to be used. See Figure 15.6 for typical ring final circuit.



Mid-point of ring where it is assumed that volt-drop and Z_s will be at a maximum.

Current in each leg may be up to 67% of total current drawn

Where new ring final circuits are designed it is preferable to avoid fixed loads and spurs thus allowing some flexibility for future extensions.

Figure 15.6: Typical ring final circuit

The first value to decide is the circuit design current. In the absence of better information this is normally taken as the nominal rating, I_n, of the overcurrent protective device. It is important that a check is made that the chosen I_n is adequate for the anticipated load of the circuit. Because the area served is less than 100 m^2 the number of socket-outlets is unlimited. For the purposes of this design let us select a 32 A MCB to provide overcurrent and indirect contact protection. It is generally accepted that in the case of ring final circuits the current-carrying capacity of each 'leg' of the ring is required to be two-thirds of that of the nominal current rating of the overcurrent protective device. In this case we would be looking for a current-carrying capacity of 21.3 A (32 × $\frac{2}{3}$). From Table 4D2A of BS 7671 we can see that for reference method 1 we have 2.5 mm^2 with a current-carrying capacity of 27 A which is more than adequate for this circuit.

Looking now to Table 15.3(b) of this Guide we can see, in Row K, that for the circuit length of 64 m we cannot use MCBs Types 2, 3, C, D and 4 because of Z_s considerations. We could however use either Type 1 or Type B which both give a maximum length of 66 m owing to volt-drop limitations. It is assumed in this exercise that the first-floor socket-outlets will not reasonably be expected to be used for portable appliances outdoors.

Circuit 3: A ring final circuit feeding BS 1363 13 A socket-outlets on a first-floor location over an area of 80 m^2. The circuit length is estimated to be 86 m and the ambient temperature along the whole run is not expected to exceed 30°C. No correction factors are applicable. Again PVC/PVC cables are to be used.

Similar consideration, with regard to design current, is required to that given to Circuit 2. Selecting a 32 A MCB we can see from Table 15.3(b), again Row K, that if we used 2.5 mm^2 PVC/PVC cable for this ring final circuit we are limited to 66 m for MCBs Types 1 and B and to 40 m if we were to use a Type 2. As these limiting lengths are less than the estimated run, we clearly cannot use 2.5 mm^2 and have to look to the next larger csa, namely 4 mm^2.

In Row B of Table 15.3(b) we see that by using 4/1.5 mm^2 PVC/PVC cable we are allowed a run of 46 m if using an MCB Type 2 (unsatisfactory for this circuit) or 109 m for Types 1 and B, the length being limited by the volt-drop constraint. It is assumed in this exercise that the first-floor socket-outlets will not reasonably be expected to be used for portable appliances outdoors.

Circuit 4: A ring final circuit feeding BS 1363 13 A socket-outlets on a ground-floor location over an area of 90 m^2. The circuit length is estimated to be 39 m and the ambient temperature along the whole run is not expected to exceed 30°C. The circuit cables run through thermal insulation for 100 mm.

Similar consideration, with regard to design current, is required to that given to Circuits 2 and 3. Because the circuit cables run through 100 mm of thermal insulation we have to apply a correction factor, C_i, of 0.81 (see Table 52A of BS 7671), so we are now looking to Table 4D2A of BS 7671 for a cable with a current-carrying capacity of not less than 26.3 A, assuming that we again use a 32 A MCB. For installation reference method 1 we get 2.5 mm^2 with a tabulated current-carrying capacity of 27 A which is adequate for our needs. Again from Row K of Table 15.3(b) we see that we can use a Type 1, Type B or a Type 2 MCB for the circuit length of 39 m.

Because this circuit feeds socket-outlets on the ground-floor, a combined MCB/RCD or RCBO will be chosen in order to satisfy Regulations 471–08–04 and 471–16–01. The MCB component of this combined device should be Type 2 and the RCD should have a rated residual current not exceeding 30 mA.

Circuit 5: A ring final circuit feeding BS 1363 13 A socket-outlets on a ground-floor location over an area of 94 m^2 . The circuit length is estimated to be 68 m and the ambient temperature along the whole run is not expected to exceed 30°C. The circuit cables run through thermal insulation for 100 mm.

We can see immediately from Row K of Table 15.3(b) that the length of 68 m is too long to use a 32 A MCB (of any Type) if we intend to use 2.5/1.5 mm^2 PVC/PVC cables. We now have the choice of using 4/1.5 mm^2 or replacing the 32 A MCB with one rated at 30 A which will allow a circuit length of 71 m for a Type 1 device. Because this circuit feeds socket-outlets on the ground-floor, a combined MCB/RCD or RCBO will be chosen in order to satisfy Regulation 471–16–01. The MCB component of this combined device will be 30 A Type 1 and the RCD have a rated residual current of 30 mA.

Circuits 6 to 8: All these circuits are radial and maximum length of runs, assuming checks are made on current-carrying capacity and the thermal constraints of the reduced cpcs have been made, can easily be determined from Table 15.3.

Circuits 9 to 10: These circuits are for lighting and a similar approach should be made in the circuit design. It is generally considered necessary to provide at least two lighting circuits in order to avoid the entire premises being plunged into darkness as a result of a fault on a solitary lighting circuit.

Circuit 11: This circuit is dedicated to supplying the fire detection and alarm system which in the case of new housing would probably consist of at least two mains-operated smoke alarms. Circuit design should be similar to that of any other circuit.

Where the supply and installation is a TN-C system, Tables 15.4(a) and 15.4(b) should be used and, for TT systems, Table 15.5. It should be noted that for TN-C-S systems, more limiting lengths are dictated by the volt-drop considerations than is the case for TN-S systems. For TT systems, with protection against indirect contact provided by an RCD, the limiting factor is always the volt-drop. In all cases a check on current-carrying capacity and the thermal constraint on the reduced cpc should be made in conjunction with the tables.

15.15 Remote buildings

Where installations are supplied from a PME supply it is often impracticable to extend the earthed equipotential zone to remote buildings because of the intervening ground which exhibits a ‘true earth’ potential. This potential will be negative with respect to the PME earth (at least when some load is being supplied) and for this reason extending the zone would be undesirable. A solution to this problem is to make the remote building installation part of a TT system. The PME earthing would be discarded either at the main building or at the remote building. Where the former method is adopted, the outgoing distribution circuit (if it incorporates a cpc) must be protected by an RCD with its own electrode at the main building. Another possible solution, illustrated in Figure 15.7, is for the remote building supply cable to be terminated in an ‘all-insulated’ adaptable box at which point the PME earthing is ‘lost’. The upstream overcurrent protective device will still protect against indirect contact up to the adaptable box so that if, for example, an earth fault developed on the supply cable (say, SWA) between the buildings the main building device would operate. The remote building earthing would be by means of its own RCD and associated earth electrode and circuits emanating from the remote building ‘all-insulated’ distribution board would be protected against indirect contact by the local RCD. In the circumstances where an upstream series RCD was used this would need to be time-delayed to provide for discrimination.

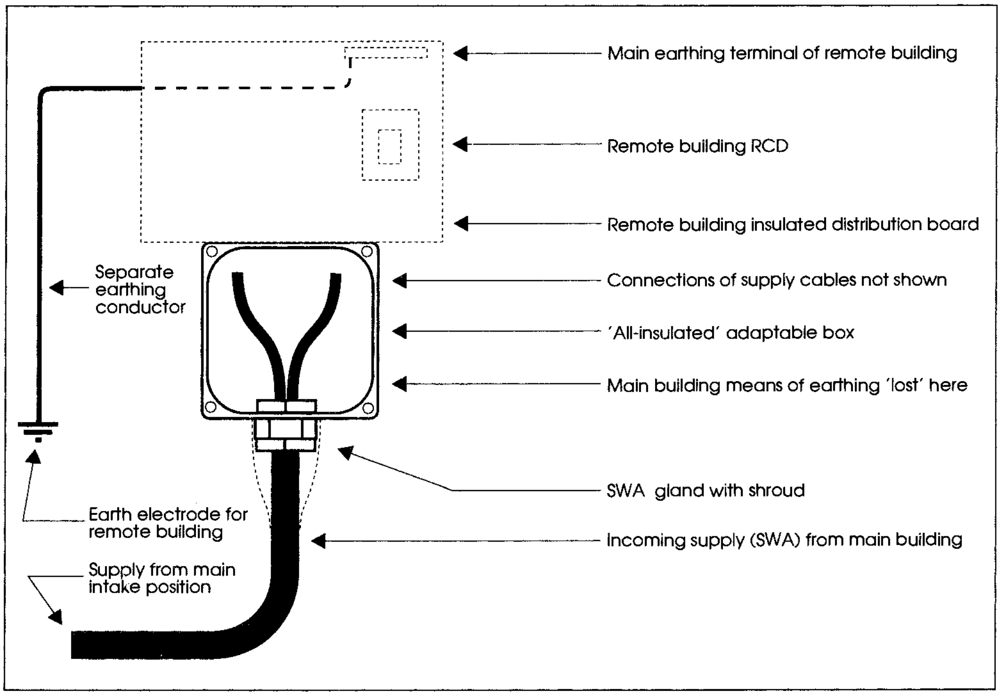


Figure 15.7: A method for earthing detached, remote buildings

15.16 Minimum number of socket-outlets in domestic premises

Regulation 553–01–07 calls for adequate provision for the connection of portable equipment wherever such items are likely to be used bearing in mind the length of flexible cord normally fitted to portable appliances and portable luminaires. Some portable appliances are supplied with flexible cords as short as 2 m. In practically all cases the designer will not know precisely what equipment is to be used when the installation is put into use still less what the future may hold. Generally, the decision on the number of

Table 15.6: Minimum number of socket-outlets in homes – recommendations

Room type	**Source**					
	This Guide[6] **(1994)**	**NHBC**[1] **(1992)**	**EIILC**[2] **(1977)**	**Consumers' Association**[3] **(1974)**	**DoE**[4] **(1971)**	**Parker Morris**[5] **(1961)**
Living room.	4	4	6	6	3	3
Dining room.	3	2	3	4	2	1
Kitchen.	5	6	4	6	4	4
Utility.	3	—	—	—	—	—
Main double bedroom.	3	3	4	4	2	2
Double bedroom.	2	2	4	4	2	2
Main single bedroom.	2	3	3	4 or less	2	2
Single bedroom.	2	2	3	4 or more	—	2
Study.	2	—			—	
Single bed/ Sitting room.	4	—	4	—	—	—
Landing/Stairs.	1	1	—	—	—	—
Hall.	1	1	1	1 or 2	1	1
Store/ Workroom.	1	—	1	—	1	1
Garage.	1	—	2	1 or 2	1	1

Notes: (1) NHBC is the National House-Building Council. Twin outlets count as two but where used will result in a diminution of socket-outlet distribution.

(2) EIILC is the Electrical Installation Industry Liaison Committee.

(3) The recommendations published by the Consumers' Association are their most recent guidance.

(4) DoE is the Department of the Environment which published recommendations in the form of a leaflet. Each outlet recommended should be regarded as a twin outlet.

(5) Parker Morris Report states that a twin socket-outlet should be regarded as two outlets with respect to recommendations made.

(6) The recommended number of socket-outlets of this Guide relate to twin outlets in every case.

(7) All recommendations relate to socket-outlets for use with portable equipment. Fixed equipment will require additional supply points such as switched and unswitched connection units.

socket-outlets is dictated by budgetary considerations but it should be appreciated that one can never have too many. Table 15.6 brings together recommendations by a number of bodies published since the early 1960s.

15.17 Modifications to existing installations

Additions and alterations to existing installations need careful consideration. Essentially, any alteration or addition must not impair the safe functioning of the existing installation. Additionally, if any parts of the existing installation are utilised to provide any protective measures for the alteration or addition then it is for the designer and the installer to check that those existing parts are both satisfactory and reliable. For example, where a new circuit is installed using EEBADS as indirect contact protection it will be essential to determine that the earthing of the existing installation is adequate and that acceptable equipotential bonding is in place.

Generally, inspecting, testing, verification and certification are required for alterations and additions however small. Direct replacement of equipment (e.g. lampholders, switches etc.) involving no installation work does not warrant certification but a certain amount of testing (e.g. polarity, Z_s) will inevitably be necessary.

15.18 Inspection, testing, verification and certification of the smaller installation

The procedures for inspection, testing, verification and certification for the smaller installation do not differ from those of any other installation and must be completed fully. Chapter 17 of this Guide gives guidance in this important aspect of electrical installation work.

Chapter 16

Special Installations and Locations

16.1 General

Regulations 600–1 and 600–02 make clear that the particular requirements set out in the various sections of Part 6, supplement or modify the general requirements in the remainder of BS 7671. It is important to appreciate that though a design may meet all the requirements laid down in a particular section for a particular special installation or location, it will not comply with BS 7671 unless all the other requirements embodied elsewhere are also met.

The practical guidance given here assumes that the reader recognises the full implications of the preceding paragraph, and the advice given for a particular location or installation is additional to guidance given elsewhere in this Guide.

16.2 Locations containing a bath tub or shower basin

16.2.1 General

A location containing a bath, a shower or a cabinet containing a shower and/or bath is considered to be a location where there is an increased risk of electric shock due to a reduction in body resistance caused either by bodily immersion or wet skin, and likely contact between substantial areas of the body and earth potential.

The requirements of Section 601 apply to a location containing a bath, or a shower or a cabinet containing a shower and/or a bath, and the surrounding zones. The requirements do not apply to showers and similar decontamination facilities for emergencies in industrial areas and laboratories, as given in Regulation 601–01-01. Special requirements beyond those of BS 7671 may apply to a location containing bath and shower for medical treatment or for disabled people. The requirements for such installations must be determined by the designer of the installation in consultation with the customer and/or the manufacturer of the equipment concerned.

Whirlpool baths (e.g. Jacuzzis) should be treated as ordinary baths and the general requirements and those contained in Section 601 of BS 7671 are applicable to installations incorporating this type of bath.

Table 16.1 sets out in tabular form descriptions and demarcation dimensions of the zonal system and Table 16.2 similarly sets out the degrees of ingress protection (IP) for the particular zones. Table 16.3 details switchgear and current-using equipment permitted in the various zones. Figure 16.1 illustrates a typical bathroom layout and the equipment often found in such a location.

Table 16.1: Zonal descriptions and demarcation dimensions

Zone	Zone description	Dimensional information
Zone 0	Interior of the bath tub or shower basin	For location containing a shower without a basin, zone 0 is the three-dimensional space limited by the floor, the horizontal plane 0.05 m above the floor and the vertical plane at a radius of 1.2 m horizontally from the water outlet at the wall if the shower head is demountable and able to be moved in use, or 0.6 m horizontally from the shower head if the shower is not demountable.
Zone 1	Three-dimensional space above and below zone 0	Zone 1 is the three-dimensional space limited by the upper plane of zone 0, the horizontal plane 2.25 m above the floor and the vertical plane circumscribing the bath tub or shower basin For a shower without a basin, the limiting vertical plane of zone 1 is at a radius of 1.2 m horizontally from the water outlet at the wall if the shower head is demountable and able to be moved in use, or 0.6 m horizontally from the shower head if the shower is not demountable. Zone 1 includes the space below the bath tub or shower basin where that space is accessible without the use of a tool. Spaces under the bath, accessible only with the use of a tool, are outside the zones.
Zone 2	Three-dimensional space above and adjacent to zones 0 and 1	Zone 2 is the three-dimensional space limited by the floor, the horizontal plane 2.25 m above the floor, the vertical plane forming the outer limit to zone 1 and a parallel vertical plane 0.6 m external to it. In addition, where the ceiling height exceeds 2.25 m above the floor, the space above zone 1 up to the ceiling or a height of 3.0 m above the floor, whichever is the lower, is also zone 2.
Zone 3	Three-dimensional space above and adjacent to zone 2	Zone 3 is the three-dimensional space limited by the floor, the horizontal plane 2.25 m above the floor, the vertical plane forming the outer limit to zone 2 and a parallel vertical plane 2.4 m external to it. In addition, where the ceiling height exceeds 2.25 m above the floor, the space above zone 2 up to the ceiling or a height of 3.0 m above the floor, whichever is the lower, is also zone 3.

Note: These zones are determined taking account of walls, doors, fixed partitions, ceilings and floors, where these effectively limit the extent of a zone.

Table 16.2: Minimum degree of ingress protection

Zone	Particular conditions, if any	Minimum degree of protection	
		IP code	Symbol code*
Zone 0		IPX7	💧💧
Zones 1 and 2	(see note 1)	IPX4	⚠
	Where water jets are likely to be used for cleaning purposes in communal baths or communal showers.	IPX5	⚠⚠
Zone 3		General rules (see note 2)	
	Where water jets are likely to be used for cleaning purposes in communal baths or communal showers.	IPX5	⚠⚠
Outside zones 0, 1, 2 and 3		General rules (see note 2)	

Notes: (1) Shaver supply units to BS EN 60742, Chapter 2, Section 1 may be installed in zone 2 provided they are located where direct spray from a shower is unlikely.
(2) Equipment to be suitable for the conditions likely to occur at the particular point of installation.

* Although the symbol code has now been superseded by the IP code, some items of equipment may still use this form of labelling. The two systems are not entirely comparable.

16.2.2 Zonal arrangements

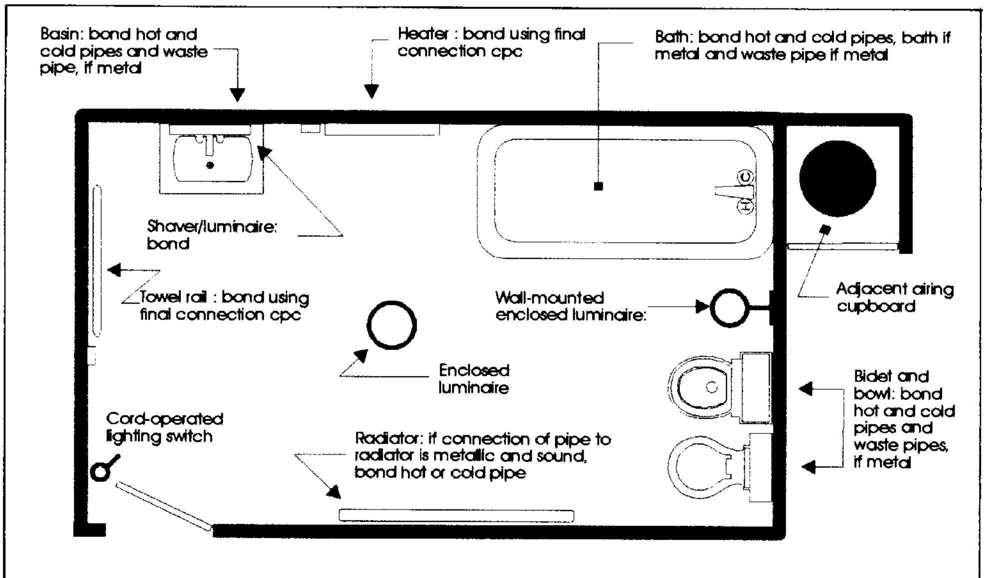
The zonal arrangements, previously introduced in Amendment No 3 (April 2000) to BS 7671: 1992, have now to be applied for all locations containing a bath or shower. It should be noted that BS 7671: 2001 incorporates minor amendments to those requirements given in Amendment No 3.

The requirements for safety of a location containing a bath or shower are based on the application of a zonal concept similar to that used for swimming pools, the requirements for each zone and beyond being based on the perceived degree of risk of electric shock.

The demarcation dimensions for the various zones are given in Table 16.1. The zones are limited by walls, doors, fixed partitions, ceilings and floors where these effectively limit the extent of a zone.

16.2.3 Degrees of ingress protection (IP)

For rooms containing a bath or shower, or cabinet containing a shower, the general requirements of Regulation Group 512–06 for degrees of protection against external influences are supplemented by Regulation 601–06–01, which are summarised in Table 16.2. Such influences are likely to include steam and condensation, falling drops of water and sprays and/or jets from shower nozzles.



Note: Where pipework forms a reliable conductive part it may be used as a supplementary bonding conductor. If the airing cupboard is in close proximity to the bathroom, much of the supplementary bonding may be carried out in the cupboard For zonal definitions and dimensions, see Regulation 601-012-01 and Figures 601A and 601B of BS 7671.

Figure 16.1: Supplementary equipotential bonding in a typical bathroom

16.2.4 Equipment permitted in and outside the various zones

The equipment sanctioned by Regulations 601–08–01 and 601–09–01 to 601–09–03 for installation in and outside the various zones is given in Table 16.3.

All the equipment listed in Table 16.3 should comply with the relevant requirements of the applicable Standard (British or Harmonized) appropriate to the intended use of the equipment. Where equipment is not to a British or Harmonized Standard, the designer or person responsible for specifying the installation is to verify that safety is not compromised.

Switches and controls, such as immersion heater switches in airing cupboards, which fall within a particular zone would be required to meet the zonal requirements. However, the general requirements of BS 7671 are applicable to a location containing a bath or shower and Regulation 512–06–01 calls for every item of equipment to be of a design appropriate to the situation in which it is to be used, or its mode of installation shall take account of the conditions likely to be encountered. Normal wall-mounted light switches and similar accessories may not have a degree of Ingress Protection (IP) appropriate for installation in zone 3 and would therefore not satisfy the requirements of BS 7671.

Table 16.3: Switchgear and fixed current-using equipment permitted in zones

Zone	Equipment	Permitted equipment
Zone 0	Switchgear	Switches and controls incorporated in fixed current-using equipment suitable for use in the zone.
	Fixed current-using equipment	Equipment suitable for the conditions of the zone and which can reasonably only be located in zone 0.
Zone 1	Switchgear	Switches and controls incorporated in fixed current-using equipment suitable for use in the zone. Switches of SELV circuits supplied at a nominal voltage not exceeding 12 V a.c. rms or 30 V ripple-free d.c., the safety source being installed outside of zones 0, 1 and 2.
	Fixed current-using equipment	The following fixed current-using equipment provided it is suitable for the conditions of the zone: water heater, shower pump, other fixed current-using equipment which can reasonably only be located in zone 1, providing the supply circuit is protected by a residual current protective device having a rated operating current, $I_{Ćn}$, not exceeding 30 mA in accordance with Regulation 412–06, SELV current-using equipment
Zone 2	Switchgear	Switches and controls incorporated in fixed current-using equipment suitable for use in the zone. Shaver supply units to BS EN 60742, Chapter 2, Section 1 may be installed in zone 2 provided they are located where direct spray from a shower is unlikely. Switches of SELV circuits, the safety source being installed outside of zones 0, 1 and 2.
	Fixed current-using equipment	The following fixed equipment provided it is suitable for the conditions of the zone: water heater, shower pump, luminaire, fan, heating appliance, unit for a whirlpool bath, other fixed current-using equipment which can reasonably only be located in zone 2, SELV current-using equipment.
Zone 3	All equipment	The general requirements of BS 7671 apply. Current-using equipment other than fixed equipment (such as a washing machine) may be installed provided it is protected by an RCD with an $I_{Ćn}$ of not more than 30 mA (see Regulation 601–09–03).
Outside all zones	All equipment	The general requirements of BS 7671 apply.

Note: Except in zone 0, the insulating pull cords of cord-operated switches, complying with BS 3676, are permitted in all zones and beyond.

16.2.5 Electric shock

Protection by obstacles (Regulation Group 412–04) and protection by placing out of reach (Regulation Group 412–05), for protection against direct contact is not permitted by Regulation 601–05–02, even where such measures could be contemplated as potentially applicable. Similarly, protection by non-conducting location (Regulation Group 413–04) and protection by earth-free local equipotential bonding (Regulation Group

413–05), for protection against indirect contact is precluded by Regulation 601–05–03.

SELV and PELV

The only protective measure against electric shock permitted in zone 0 is SELV at a nominal voltage not exceeding 12 V a.c. rms or 30 V ripple-free d.c. with the safety source being located outside of zones 0, 1 and 2 (Regulation 601–05–01). The protective measure PELV may be used in a location containing a bath or shower outside zone 0. The pre-conditions for both SELV and PELV are summarised in Table 16.4.

Table 16.4: Pre-conditions for SELV or PELV circuits

Protective measure	**Regulations**	
SELV	601–05–01 601–08–01	Safety source must be installed outside zones 0, 1 and 2.
	601–03–02	Protection against direct contact must be provided by barriers or enclosures affording a degree of protection of at least IP2X or IPXXB, or insulation capable of withstanding a type test voltage of 500 V a.c. rms for 1 minute.
	601–05–01	The nominal voltage of a SELV circuit in zone 0 must not exceed 12 V a.c. rms or 30 V ripple-free d.c.
	601–08–01	The nominal voltage of a SELV circuit with switches installed in zone 1 must not exceed 12 V a.c. rms or 30 V ripple-free d.c.
PELV	601–05–01	Safety source must be installed outside zones 0, 1 and 2, as for SELV.
	601–03–02	Protection against direct contact must be provided by barriers or enclosures affording a degree of protection of at least IP2X or IPXXB, or insulation capable of withstanding a type-test voltage of 500 V a.c. rms for 1 minute.

Note: Regulation 601–05–01 does not specifically call for the PELV safety source to be outside zones 0, 1 and 2 but the safety considerations in this respect are the same as for a SELV source.

16.2.6 Supplementary equipotential bonding

Where protection against indirect contact is by earthed equipotential bonding and automatic disconnection of supply (EEBAD), Regulation 601–04–01 requires the protective conductor terminals of each circuit supplying Class I and Class II electrical equipment in zones 1, 2 or 3, and extraneous-conductive-parts in these zones (for example metallic pipework services, baths and shower basins), all to be connected together by local supplementary equipotential bonding conductors complying with Regulation Group 547–03.

The requirements for supplementary equipotential bonding in a location containing a bath or shower now apply irrespective of whether or not the exposed-conductive-parts and extraneous-conductive-parts are simultaneously accessible. Exposed-conductive-parts of SELV circuits are excluded from the supplementary bonding requirements and must not be connected to such bonding (Regulation 411–02–07).

Metallic door architraves, window frames and similar parts are not considered to be extraneous-conductive-parts unless they are electrically connected to metallic parts of the building, and are not therefore required to be bonded. Normal accessible metallic structural parts of the building are required to be bonded (see Regulation 6001–04–01).

In a room, other than a bathroom or shower room, where a cabinet containing a shower and/or bath is installed, the supplementary bonding requirements of Regulation 601–04–01 apply only to zones 1 and 2 (see Regulation 601–04–02).

The supplementary bonding must be carried out in the location containing the bath or shower or in close proximity, such as in an adjoining roof void or an airing cupboard opening into, or adjoining, the room (see Regulation 601–04–01).

A supplementary bonding connection, as with all electrical connections or joints, is required by Regulation 526–04–01 to be accessible for inspection, testing and maintenance (apart from connections or joints made in one of the ways exempted by that Regulation, such as joints made by welding, brazing or a compression tool).

By virtue of Regulation 543–02–02, certain extraneous-conductive-parts in the special location, may, at least in part, be used as supplementary bonding conductors. This is subject to the extraneous-conductive-parts satisfying all the requirements given in Regulation 543–02–06. Thus, for example, the supplementary bonding conductors in a particular bathroom could comprise a combination of permanent-and-reliable metal pipework (perhaps of the central heating and water supply services) and green-yellow insulated copper cables.

The supplementary bonding connections to a fixed electrical appliance, such as a metallic electric towel rail, may be provided by the circuit protective conductor within a short length of flexible cord connecting the appliance to an accessory having a flex outlet (Regulation 547–03–05). (Note that supplementary bonding must be provided to the accessory in the normal way.)

BS 7671 does not require a protective conductor to link the supplementary equipotential bonding in a bathroom or shower room with the main earthing terminal (MET) of the installation.

The purpose of such bonding is to ensure that the voltages appearing on exposed and extraneous-conductive-parts under fault conditions are at an acceptable magnitude in respect of other conductive parts; in other words, the bathroom becomes an equipotential zone, within the main equipotential zone of the premises, where touch voltages are maintained at acceptable levels. All the supplementary equipotential bonding is to be effected in the location and it is generally not necessary to take a protective (bonding) conductor to the main earthing terminal.

Exposed-conductive-parts may include metallic accessory plates, shaver socket cpc, and stationary heating equipment, towel rails etc., and floor heating element sheath.

Extraneous-conductive-parts may include metallic baths, metallic hot and cold pipework, metallic waste pipework, and central heating radiators and associated pipework, and floor heating grid, and central heating tank and other pipework in the location, and any other conductive part entering the bathroom zone.

The csa of supplementary equipotential bonding conductors is determined by a number of factors:

- Regulation 547–03–01 calls for the minimum conductance of a conductor connecting exposed-conductive-parts together to be not less than the conductance of the smaller cpc of the circuits concerned and, in any event, to be not less than 4 mm^2 where mechanical protection is not provided, and
- Regulation 547–03–02 calls for a conductor connecting exposed-conductive-parts together with extraneous-conductive-parts to be not less than half the conductance of the cpc of the exposed-conductive-part (the largest) and to be not less than 4 mm^2 where mechanical protection is not provided, and
- Regulation 547–03–03 calls for a conductor to be not less than 2.5 mm^2 if sheathed, and to be not less than 4 mm^2 where mechanical protection is not provided.

In most practical situations, the option of mechanical protection will not be feasible for the whole length, and the minimum cross-sectional area will therefore be 4 mm^2. However, this may need to be increased because of the requirements of Regulations 547–03–1 and 547–03–02 where, for example, in rare cases a cpc of csa greater than 4 mm^2 is employed. Copper and other suitably conductive pipes and associated fittings, which represent permanent and reliable conductors, may be used as supplementary equipotential bonding conductors (or part conductors). Regulation 547–03–05 permits supplementary bonding to fixed equipment, such as electric towel rails, to be effected by the cpc in a short (say, 150 mm) length of flexible cord used as the final connection to that appliance, so that ugly bonding clamps affixed to such equipment may be avoided. However, this ‘relaxation’ does not mean that the need to supplementary bond such equipment is obviated.

16.2.7 Shaver supply units and socket-outlets

In a location containing a bath or shower, shaver supply units complying with BS EN 60742 Chapter 2, Section 1 are permitted in other than zones 0 and 1 (see Regulation 601–08–01). Such a shaver supply unit is not normally regarded as ‘splash-proof’, and it cannot therefore simply be positioned anywhere in the location. Regulation 601–08–01 permits its installation outside zones 0 and 1. However, it should be positioned well away from a bath or a shower, and normal lighting switch height will usually safeguard against splashing from a wash basin.

In a bathroom or shower room, Regulation 601–08–01 restricts the type of shaver supply unit to one complying with BS EN 60742 Chapter 2, Section 1. Such shaver supply units incorporate a safety isolating transformer affording protection against indirect contact by electrical separation.

Where a cubicle containing a shower and/or bath is installed, shaver socket-outlets complying with BS 4573 Specification for 2-pin reversible plugs and shaver socket-outlets, may also be used outside zones 0, 1, 2 and 3 but only if protected by a residual current protective device having a rated residual operating current $I_{\acute{C}n}$, not exceeding 30 mA (Regulation 601–08–02).

The long-established rule of disallowing LV socket-outlet in such locations is maintained in BS 7671: 2001. However, socket-outlets supplied by a SELV circuit are permitted in a location containing a bath, a shower, or a cabinet containing a shower and/or bath but must be installed outside of zones 0 and 1 (see Regulation 601–08–01).

Where a cubicle containing a shower and/or bath is installed, socket-outlets, other than above-mentioned shaver supply units and SELV circuits, may be installed outside zones 0, 1, 2 and 3, but are required to be protected by a residual current protective device having a rated residual operating current, $I_{\acute{C}n}$, not exceeding 30 mA (see Regulation 601–08–02).

16.2.8 Portable and non-fixed equipment

Regulation 601–08–01 precludes the provision for connecting portable equipment such as a hair-drier by any means in zone 3 and, by inference, in zones 0 and 1. However, it is acceptable to make provisions in zone 3 for the connection of non-fixed current-using equipment other than portable equipment such as a washing machine, provided it is protected by a residual current protective device having a rated residual operating current, $I_{\acute{C}n}$, not exceeding 30 mA (see Regulation 601–09–03).

Even where all the relevant electrical installation requirements of BS 7671 can be met, and in the absence of the equipment manufacturer's installation and/or user instructions for the appliance giving permission for such use, the express agreement of the manufacturer of a non-portable appliance should be sought as to the suitability of the appliance for use in a bathroom or shower room. In extreme cases, a manufacturer's agent may not be prepared to carry out a service on an appliance in a bathroom until it is moved to what might be considered a 'safer' location.

The provision for connecting portable and other non-fixed equipment by means other than through a socket-outlet is not forbidden outside zones 0, 1, 2 and 3. The general requirements for such equipment, such as suitability for external influences, should as always be applied.

16.2.9 Electric heating embedded in the floor

An electric heating unit embedded in the floor below any zone for heating the floor of the location is permitted by Regulation 601–09–04, provided it is either covered by an earthed metallic grid or has an earthed metallic sheath connected to the local supplementary equipotential bonding.

16.2.10 Routeing of wiring systems

For surface wiring systems, or for wiring systems embedded in walls at a depth not exceeding 50 mm which do not comply with Regulation 522–06–07, wiring in zones 0, 1 and 2 is restricted to circuits supplying fixed electrical equipment in the particular zone, or fixed electrical equipment in other zones where the risk of electric shock is greater. For example, the only wiring systems permitted in zone 2 are those supplying fixed electrical equipment in zone 2, zone 1 or zone 0 (see Regulation 601–07–02). Similarly, the only wiring systems permitted in zone 1 are those supplying fixed electrical equipment in zone 1 or zone 0.

16.2.11 Special-purpose and medical baths

Regulation 601–01–01 draws attention to the need to give special attention to baths used for medical purposes and in this respect consideration should be given to the special needs of likely occupants and to their vulnerability to the effects of electric shock. The designer may well consider, bearing in mind the special needs and vulnerability of the uses, that disconnection times need to be reduced further (from 400 ms) and that limits on touch voltage between conductive parts are reduced from the 50 V (see Regulations 413–02–08 for TN systems and 413–02–20 for TT systems) to, say, 25 V.

Each and every application needs careful consideration of all the options available including the use of SELV (at, for example, a nominal voltage not exceeding 12 V), other electrical separation methods, Class II equipment or selection of equipment designed specifically for the purpose.

Whirlpool and other health baths for use in the normal domestic environment have similar inherent risks as ordinary baths and, generally speaking, should be treated in the same way. However, special further measures may need to be taken where the user is particularly vulnerable to the risks associated with the use of such equipment.

16.2.12 Other equipment

Other equipment, not readily associated with the fixed electrical installation, is sometimes considered for use in a bathroom and care should be taken to avoid the use of potentially dangerous items in such a location. It has been known for telephones to be installed and if this is contemplated it should be borne in mind that this type of installation is covered by BS 7671 (see Regulation 110–01–01). Compliance with BS 6701: Part 1 is also required for any installation subject to the Telecommunications Act 1984. Modern telephone systems typically operate at 50 V d.c. and, when the telephone rings, the voltage is likely to exceed 80 V d.c. and where corded telephones are used it would obviously be desirable to prevent the telephone being accessible to the person using a bath even with the cord extended; in the typical UK bathroom, the installation of this type of telephone would be highly undesirable.

16.3 Swimming pools

16.3.1 General

Regulation 602–01–01 sets out the scope of Section 602 and states that the particular requirements relate to basins of swimming pools and paddling pools and their surrounding zones. Attention is drawn to the fact that this is a location in which there is an increased risk of electric shock by virtue of a reduction in body resistance (due mainly to the lower contact resistance associated with wet surfaces) and because of contact with Earth potential. This regulation also recognises that swimming pools for medical treatment may need further special consideration. The requirements for initial inspection, testing and certification of installations in this location are no different from the general requirements.

Regulation 602–02 defines three Zones (A, B and C) in terms of linear dimensions and it is important to recognise that the zones are volume zones and the dimensions apply on the horizontal and vertical axes. Figure 16.2 illustrates the zones in section and plan views and gives a representation of the zones for a typical, small swimming pool. Considerations of shock protection and selection and erection of equipment need to take account of the particular requirements peculiar to the three zones and one should not lose sight of the need to comply also with the general requirements of BS 7671.

16.3.2 Additional requirements relating to electric shock

Table 16.5 sets out in tabular form the particular requirements in terms of protection against electric shock. As required by Regulation 602–03–02, local supplementary equipotential bonding is required in all three zones to connect together all conductive parts, irrespective of whether or not the parts are simultaneously accessible. Where there are solid floors in Zones B and C, incorporating a grid, it must be connected to other conductive parts. Where required, the grid may, for example, be formed by factory-made welded steel (plain or deformed wires) complying with BS 4483 *Specification for steel fabric for the reinforcement of concrete*. Maximum disconnection times and related limiting loop impedance values for particular nominal voltages are as for the general installation.

Figure 16.3 gives an example of the connection of the supplementary equipotential bonding conductor to the floor grid though there are many other ways of achieving this link.

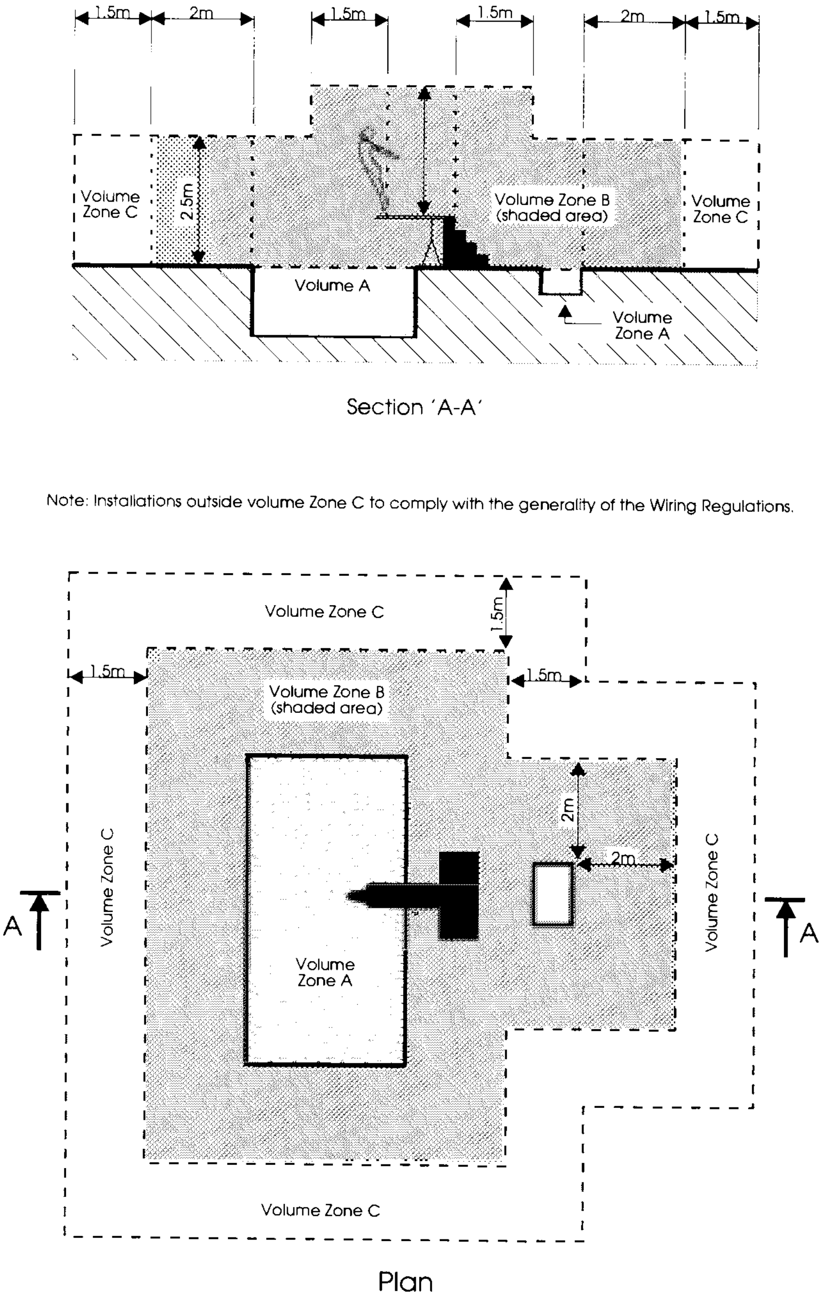


Figure 16.2: Swimming pool zones – section and plan

Table 16.5: Particular requirements for swimming pools – protection against electric shock

Aspect	**Regulation**	**Particular requirements**	**Comments**
General	602–01–01	Scope defined.	
	602–02	Assessment of general characteristics.	
Electric shock	602–03-01	At least IP2X or IPXXB barriers or enclosures or insulation capable of withstanding a 500 V 60 s test.	Applies equally to SELV as to any voltage.
	602–03–02	Local supplementary equipotential bonding required to connect all conductive parts (except SELV equipment) in all three zones together. Where Zones B and C have solid floors, an equipotential grid must be provided and connected to the supplementary equipotential bonding in general.	
	602–04–01	In Zones A and B only SELV at a nominal voltage not exceeding 12 V a.c. rms or 30 V d.c. to be used as the protective measure against electric shock. The exceptions to this rule are: – floodlights may be supplied by individual transformers (or individual windings of a multi-secondary transformer) providing the open circuit voltage does not exceed 18 V, and – socket-outlets, to BS EN 60 309-2 (BS 4343), may be protected with an RCD with $I_{\Delta n} \leqslant 30$ mA, provided any socket-outlet in Zone B is not less than 1.25 m from Zone A and not less than 300 mm from finished floor level, and – In Zone C a BS EN 60 309–2 (BS 4343), socket-outlet, switch or accessory is permitted provided it is protected by electrical separation (individually), SELV or by a RCD with $I_{\Delta n} \leqslant 30$ mA, and – in Zone C shaver sockets to BS 3535 are permitted.	SELV safety source to be located outside Zones A, B and C.
	602–04–02	These protective measures are precluded: – obstacles, and – placing out of reach, and – non-conducting location, and – earth-free equipotential bonding.	These protective measures are inappropriate and/or impracticable.

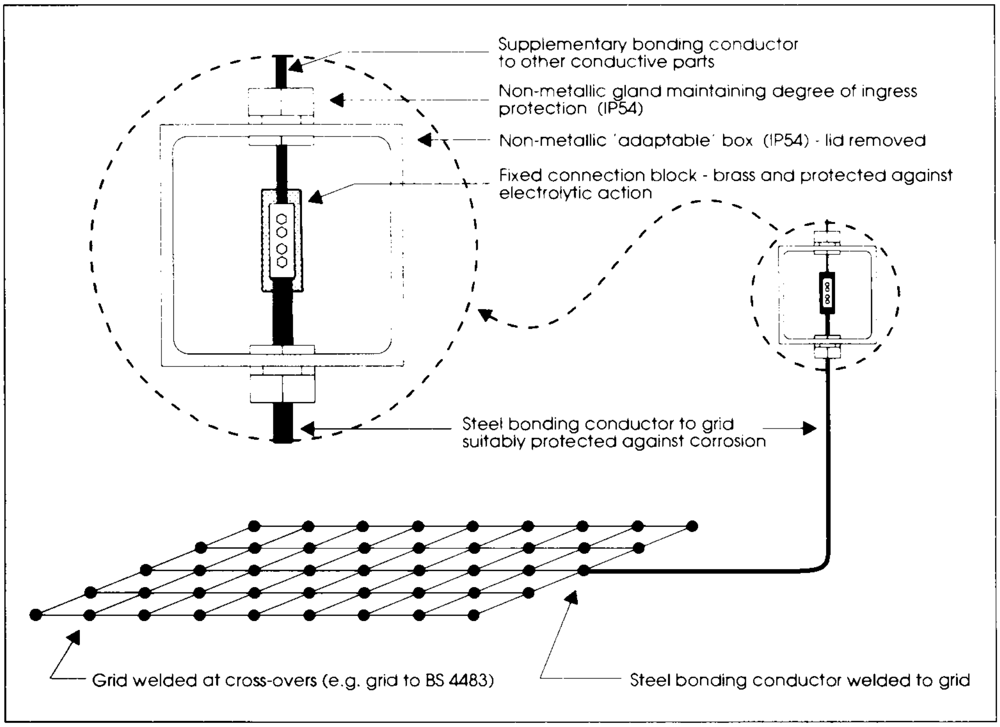


Figure 16.3: Typical method of connection of equipotentially bonded grid in Zones B and C

16.3.3 Additional requirements relating to selection and erection of equipment

Table 16.6 identifies the additional requirements relating to selection and erection of equipment. Table 16.7 details the degrees of protection required in terms of the three zones.

16.4 Hot air saunas

16.4.1 General

Regulation 603–01–01 sets out the scope of Section 603 and states that the particular requirements apply to locations in which hot air sauna heating equipment (to BS EN 60 335–2–53) is installed. As with swimming pools the concept of zones is adopted for this location but this time the zones relate to temperature and there are four such zones (A, B, C and D). The requirements for initial inspection, testing and certification of installations in this location are no different from the general requirements.

Figure 16.4 gives a sectional view and plan of a typical layout respectively and Table 16.8 sets out the particular requirements in terms of protection against electric shock and selection and erection of equipment.

Table 16.6: Particular requirements for swimming pools – equipment

Aspect	**Regulation**	**Particular requirements**
Wiring systems.	602–06–01	In Zones A and B surface wiring systems not to utilise metallic conduit, metallic trunking, or exposed (bare) cable sheath, exposed (bare) earthing or bonding conductors. Does not apply to flush wiring systems.
	602–06–02	Wiring systems in Zones A and B only permitted if supplying equipment in these Zones. Wiring for equipment to Zone C and to outside of all zones not to be taken through Zones A and B.
	602–06–03	Accessible metal junction boxes are not permitted in Zones A and B.
Switchgear, controlgear and accessories.	602–07–01	Switchgear, controlgear and accessories are not generally permitted in Zones A and B. Exceptions are: – BS EN 60 309-2 (BS 4343) socket-outlets are permitted if, and only if, it is impossible to locate outside Zone B and they are positioned at not less than 1.25 m from edge of Zone A and at least 300 mm above floor level and protected by an RCD with $I_{\Delta n} \leqslant 30$ mA or by electrical separation with safety isolating transformer outside all zones.
	602–07–02	Socket-outlets, switches and accessories are permitted in Zone C if, and only if, they are protected by: – individual electrical separation, or – SELV, or – RCD with $I_{\Delta n} \leqslant 30$ mA. Shaver sockets complying with BS 3535 are permitted in Zone C as are insulated cords of cord-operated switches complying with BS 3676.
Socket-outlets.	602–08–01 602–07–02	Socket-outlets generally to comply with BS EN 60 309-2 (BS 4343). Socket-outlets, switches and accessories are permitted in Zone C if, and only if, they are protected by: – individual electrical separation, or – SELV, or – RCD with $I_{\Delta n} \leqslant 30$ mA.
Water heaters.	602–08–05	Permitted in Zones B and C.
Electric floor heating.	602–08–04	Electric heating embedded in the floor of Zones B and C to incorporate a metallic sheath which is to be connected to the local supplementary equipotential bonding or must also be covered by a metallic grid also bonded as required by Regulation 602–03–02.
Instantaneous water heaters.	602–08–03	Instantaneous water heaters, complying with the relevant requirements of an appropriate British Standard are permitted in Zone C but not Zones A and B (see Regulation 602–08–02).
Other equipment.	602–08–02	Only current-using equipment specifically intended for use in swimming pools to be located in Zones A and B.
	602–08–03	Equipment generally in Zone C to be protected by: – individual electrical separation, or – SELV, or – RCD with $I_{\Delta n} \leqslant 30$ mA.

16.5 Construction site installations

16.5.1 General

As with all special installations or locations the general requirements apply to construction and building sites unless supplemented or modified by the particular requirements of Section 604 of BS 7671. Additionally, the

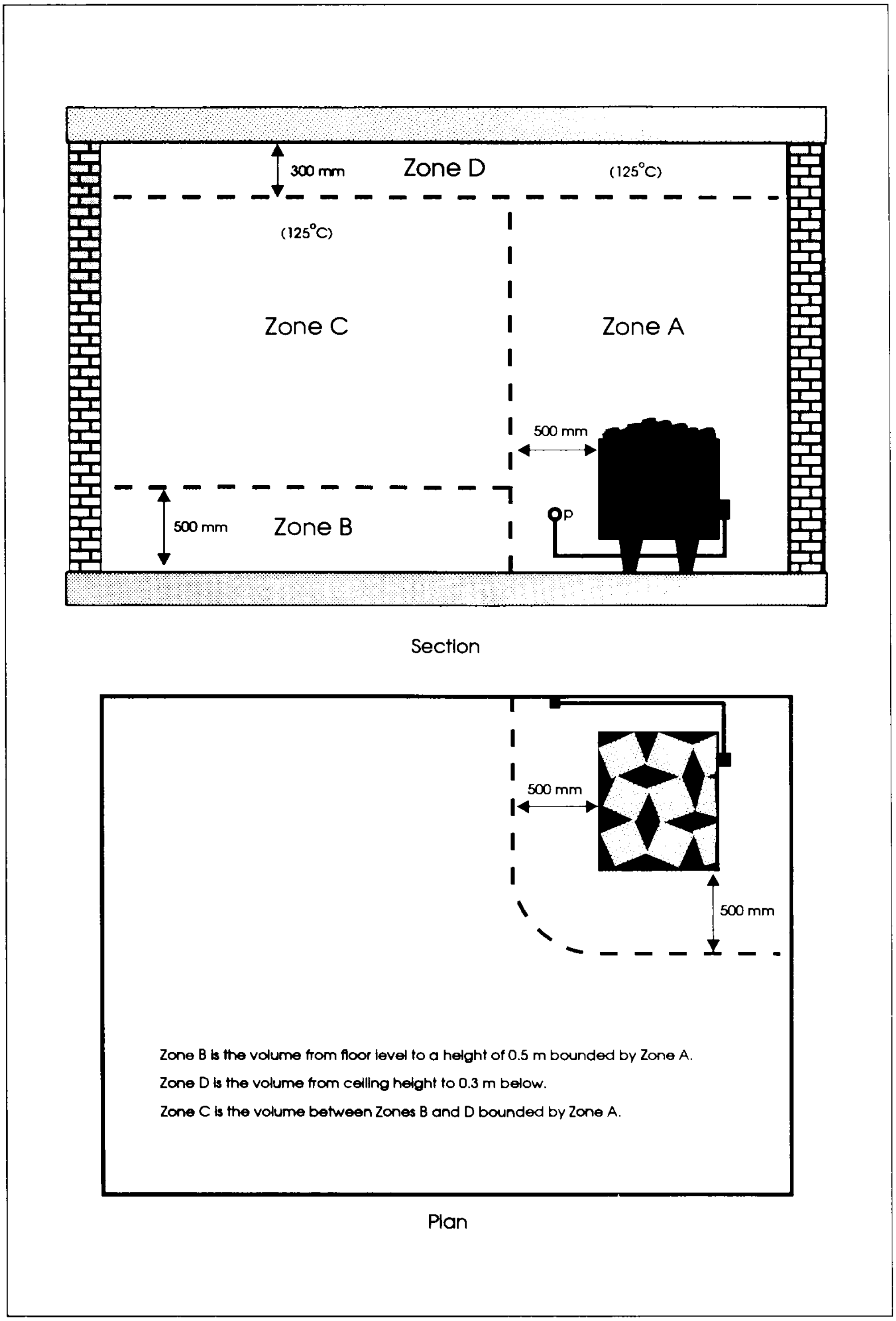
Table 16.7: Particular requirements for swimming pools – IP degrees of protection (Regulation 602-05-01)

Circumstances	Zone A	Zone B	Zone C
Swimming pool where water jets are likely to be used.	IPX8	IPX5	IPX5
Swimming pool where water jets are not likely to be used – indoor pools.	IPX8	IPX4	IPX2
Swimming pool where water jets are not likely to be used – outdoor pools.	IPX8	IPX4	IPX4

Aide-mémoire (see BS EN 60 529 for full definitions of degrees of protection):
IPX2 – protected against drops of water falling at up to 15° from the vertical,
IPX4 – protected against projections of water from all directions,
IPX5 – protected against jets of water from all directions,
IPX8 – protected against prolonged effects of immersion under pressure.

Table 16.8: Particular requirements for locations containing hot air sauna heating equipment according to IEC publication 335–2–53

Aspect	Regulation	Particular requirements
Electric shock.	603–03–01	Irrespective of nominal voltage (0 V to 50 V), where SELV is used direct contact protection must be provided by insulation (capable of withstanding 500 V a.c. rms type-test for 60 s) and/or barriers or enclosures to at least IP24 or IPX4B.
	603–04–01	Direct contact protection not permitted by means of: – obstacles, and/or – placing out of reach.
	603–05–01	Indirect contact protection not permitted by means of: – non-conducting location, and/or – earth-free local equipotential bonding.
Wiring systems.	603–07–01	Only 180°C thermosetting rubber flexible cords are permitted and must be protected mechanically with material providing Class II or equivalent insulation (see Regulation 413–03–01).
	603–06–02	In Zone D, only wiring associated with luminaires in that zone permitted.
Switchgear, controlgear, and accessories.	603–08–01	Switchgear not built into the sauna heater unit is not permitted in any zones except that a thermostat and a thermal cut-out are permitted.
	603–08–02	No accessories permitted in all zones except: – a thermostat and a thermal cut-out, and – in Zone A, the sauna heater and directly associated equipment, and – in Zone D, luminaires and their control devices suitable for an ambient temperature of 125°C.
	603–06–01	Equipment to have at least IP24 degree of protection.
	603–06–02	In Zone A, the sauna heater and directly associated equipment.
	603–06–02	In Zone B, no special degree of heat resilience required.
	603–06–02	In Zone C, equipment must be suitable for an ambient temperature of 125°C.
Luminaires.	603–06–01	Equipment to have at least IP24 degree of protection.
	603–06–02	Luminaires must be suitable for an ambient temperature of 125°C.
	603–09–01	Luminaires must be mounted to prevent overheating.



Zone B is the volume from floor level to a height of 0.5 m bounded by Zone A.

Zone D is the volume from ceiling height to 0.3 m below.

Zone C is the volume between Zones B and D bounded by Zone A.

Figure 16.4: Hot air sauna – section and plan views

regulations covered under 476–15 *Automatic disconnection and reduced low voltage systems* will be of particular interest to the designer of such installations as will the recommendations contained in BS 7375 *Code of Practice for distribution of electricity on construction and building sites*, for the installation. Site distribution equipment is addressed in BS 4363 *Specification for distribution assemblies for electricity supplies for construction and building sites* and the equipment generally must also comply with BS 5486: Part 4.

Regulation Group 604–01 outlines the scope of this section and states that Section 604 relates to installations for supplies for carrying out construction work on new buildings, constructional extensions to buildings, building demolition and all building alteration work including home extensions, loft conversions and office refurbishment. Also included in the scope are engineering construction, earthworks and similar works; this would therefore include all works of the type where supplies are required for lighting, power tools and other equipment.

Fixed installations associated with site works are not required to meet the particular requirements of this section but would, of course, need to comply with the general requirements. Such fixed installations may include site offices, canteens, toilets, sleeping dormitories and meeting rooms, etc. where there is no requirement for temporary supplies (see Regulation 604–02–03).

For the construction site installation, the fixed part of the installation is considered to be only the assembly of main switchgear together with the main protective devices. All equipment downstream (on the load side) is considered to be the temporary installation unless designed and installed in accordance with Chapter 52 (as if for a fixed installation).

Regulation 604–02–02 calls for equipment used on a particular supply to be identified with that supply and, of course, be compatible. Where more than one such supply unit exists on a site, marking of the equipment will be necessary and care must be taken that there are no interconnections between the supply units except for necessary control and signalling circuits, where required.

The requirements for initial inspection, testing and certification of installations in this location are no different from the general requirements.

16.5.2 Voltages

Regulation 604–02–02 stipulates the maximum nominal voltages for the various equipment usage on such sites and these are summarised in Table 16.9.

16.5.3 Protection against electric shock – general

Unless no other system is available, IT systems (those with the supply source not earthed or earthed through a high impedance) must not be used. In circumstances where an IT system is the only available option, the system must be continuously monitored for earth faults by permanent earth fault

Table 16.9: Construction site installation equipment maximum voltages

Equipment	Restrictions	Maximum voltage	Comments
Fixed equipment.	Above 3.75 kW. Up to 3.75 kW.	400 V, 3Φ 110 V, 1Φ	— —
Fixed floodlighting.	None.	230 V, 1Φ	Floodlighting fixed to structure.
Local lighting.	Up to 2 kW.	110 V,1Φ*	*Centre point earthed – reduced low voltage.
Portable handlamps.	For general use.	110 V, 1Φ*	*Centre point earthed – reduced low voltage.
	In damp and confined locations.	25 V, 1Φ SELV 50 V, 1Φ*	Fed via a safety source (e.g. transformer to BS 3535). *Centre point earthed.
Portable hand-held tools.	None.	110 V, 1Φ*	*Centre point earthed – reduced low voltage. Hand-held tools and portable equipment which may be held or touched by hand in operating.
Large equipment.	Where necessary for functional reasons.	HV	Probably only applicable for the very large site.

monitoring equipment (see BS 4444) and the general requirements relating to this system type must be applied. Such monitoring need not be applied in the case of portable generator sets (see Regulation 604–03–01)

16.5.4 Protection against electric shock – TN systems

Many, if not most, site 'short-term' installations will take their supply off the public supply network through an Electricity Distributor (ED). Most distributors will not be willing to provide earthing facilities, particularly PME, and this will usually necessitate the use of RCDs to provide protection against indirect contact shock. Where an RCD is employed, the device will need a connection to Earth. It is important to establish that this connection is made with a permanent and reliable earth electrode which is suitable protected against any mechanical damage to which it may be subjected, bearing in mind the more onerous conditions prevailing on such sites and the robust work methods of site-workers.

Maximum disconnection times for the fixed low voltage permanent installations and for reduced low voltage are given in Table 41A of BS 7671 and Regulation 471–15–06 respectively. For circuits supplying temporary site and moveable installations or equipment at any nominal voltage (not exceeding low voltage), the disconnection times are given in Table 604A of BS 7671. The maximum disconnection times for all circuits supplying moveable equipment or installations (Regulations 604–04–01 and 604–04–02), irrespective of whether or not supplied via a socket-outlet, on construction sites are summarised in Table 16.10. Where disconnection times *simply cannot be guaranteed* by the use of an overcurrent protective device, further measures, such as RCD protection, may be required.

Table 16.10: Maximum disconnection times on construction sites with respect to U_o

System voltage to neutral, U_o and restrictions (V)	**Maximum disconnection times (ms)**
580	20
480	50
400	50
230	200
120	350
63.5 (reduced low voltage three-phase, star pointed earthed)	5000
55 (reduced low voltage single-phase, centre pointed earthed)	5000

As Table 16.10 indicates, where the circuit nominal voltage is 230 V and feeds moveable equipment, the maximum disconnection time is 200 ms, and the limiting earth-loop impedances are given in Regulations 604–04–03 and 604–04–04 and summarised in Table 16.11 of this Guide. Regulation 604–04–06 permits 230 V circuits feeding the fixed installation to have 5 s disconnection time and the corresponding limiting earth-loop impedances are given in Tables 41B2 and 41D of BS 7671.

Table 16.11: Limiting impedances for common protective devices used on construction sites for 200 millisecond disconnection for 230 V circuits (Ω)

I_n	**BS 88 HRC fuse**	**BS 1361 HRC fuse**	**Type 1 MCB**	**Type B MCB**	**Type 2 MCB**	**Type 3 and Type C MCB**
5	—	9.60	12.00	—	6.86	4.80
6	7.74	—	10.00	8.00	5.71	4.00
10	4.71	—	6.00	4.80	3.43	2.40
15	—	3.00	4.00	—	2.29	1.60
16	2.53	—	3.75	3.00	2.14	1.50
20	1.60	1.55	3.00	2.40	1.71	1.20
25	1.33	—	—	—	—	—
30	—	1.00	2.00	—	1.14	0.80
32	0.92	—	1.88	1.50	1.07	0.75
40	0.71	—	1.50	1.20	0.86	0.60
45	—	0.51	1.33	1.07	0.76	0.53
50	0.53	—	1.20	0.96	0.69	0.48
60	—	0.33	—	—	—	—
63	—	—	0.95	0.76	0.54	0.38

Notes: (1) Data for BS 88 (gG) fuses to Parts 2 and 6.
(2) Circuit-Breakers to BS EN 60 898 or BS 3871.
(3) Entries denoted by – mean that the rating is either unavailable or inappropriate.

Regulation 604–04–05 makes clear that the alternative method of providing indirect contact shock protection to socket-outlet circuits by increasing disconnection time from 400 ms to 5 s (provided limitations are applied to the final circuit cpc) is not an option for construction sites.

Table 16.12 provides a summary for limiting earth loop impedance for circuits operating on reduced low voltage of 55 V (110 V system – 55 V phase to centre-tapped earthed neutral) and 63.5 V (110 V system – 55 V phase to earthed neutral star point), for 5 s disconnection.

Table 16.12: Limiting impedances for common protective devices used on construction sites for 5 s disconnection for reduced low voltage at 55 V to earthed centre tap and 63.5 V to earthed star point neutral (Ω)

I_n	Phase voltage to Earth, U_0	BS 88 HRC fuse	Type 1 MCB	Type B MCB	Type 2 MCB	Type 3 and Type C MCB
5	55	—	2.76	2.20	1.58	1.10
5	63.5	—	3.18	2.54	1.82	1.28
6	55	3.20	2.30	1.83	1.32	0.92
6	63.5	3.70	2.65	2.12	1.52	1.07
10	55	1.77	1.38	1.10	0.79	0.55
10	63.5	2.05	1.59	1.27	0.91	0.64
15	55	—	0.92	0.73	0.53	0.37
15	63.5	—	1.06	0.85	0.61	0.43
16	55	1.00	0.86	0.69	0.49	0.34
16	63.5	1.15	0.99	0.79	0.57	0.40
20	55	0.69	0.69	0.55	0.40	0.28
20	63.5	0.80	0.80	0.64	0.46	0.32
25	55	0.55	0.55	0.44	0.32	0.22
25	63.5	0.63	0.64	0.51	0.36	0.26
30	55	—	0.46	0.37	0.26	0.18
30	63.5	—	0.53	0.42	0.30	0.21
32	55	0.44	0.43	0.34	0.25	0.17
32	63.5	0.51	0.50	0.40	0.28	0.20
40	55	0.32	0.35	0.28	0.20	0.14
40	63.5	0.37	0.40	0.32	0.23	0.16
50	55	0.25	0.28	0.22	0.16	0.11
50	63.5	0.29	0.32	0.25	0.18	0.13
63	55	0.20	0.22	0.17	0.13	0.09
63	63.5	0.23	0.25	0.20	0.14	0.10
80	55	0.14	0.17	0.14	0.10	0.07
80	63.5	0.16	0.20	0.16	0.11	0.08
100	55	0.10	0.14	0.11	0.08	0.05
100	63.5	0.12	0.16	0.13	0.09	0.06

Notes: (1) Data for BS 88 (gG) fuses to Parts 2 and 6.
(2) Circuit-Breakers to BS EN 60 898 or BS 3871.
(3) Entries denoted by – mean that the rating is either unavailable or inappropriate.

Where disconnection times cannot be met by the use of an overcurrent device, Regulation 604–04–07 calls for the circuit to be protected by an RCD; the option of local supplementary equipotential bonding given in Regulation 413–02–04 is not available for construction sites. Where an RCD is used the formula given in Regulation 413–02–16 is modified by Regulation 604–04–08 so that it becomes

$$Z_s I_{\Delta n} \leqslant 25 \text{ V} \qquad (16.1)$$

where Z_s = earth loop impedance of the whole circuit
$I_{\Delta n}$ = operating (rated tripping) current of the RCD.

Application of protective measures Regulations 471–08–02, 471–08–03, 471–08–04, and 471–08–05 are not applicable to construction sites and

Regulation 604–08–03 calls for every socket-outlet to be protected by at least one of the following measures:

- reduced low voltage and automatic disconnection,
- RCD with rated operating current of not more than 30 mA ($I_{\Delta n} \leqslant 30\,\text{mA}$),
- SELV,
- electrical separation (each socket-outlet supplied by a separate transformer (see Regulation 604–08–04).

Because of the shorter disconnection times applicable to these installations, Regulations 604–08–01 and 604–08–02 preclude the application of Regulations 471–08–02 and 471–08–03 relating to EEBADS.

16.5.5 Protection against electric shock – TT systems

The general TT system requirements apply for TT systems on construction sites and in particular Regulations 413–02–18 to 413–02–20 concerning protection by EEBADS. The general requirements are modified in one important way by Regulation 604–05–01; the formula given in Regulation 413–02–20 as $R_A I_a \leqslant 50$ V is modified to that given in Equation (16.2).

$$R_A I_a \leqslant 25 \text{ V} \tag{16.2}$$

where R_A = sum of the resistance of the earth electrode and all protective conductors connecting it to exposed-conductive-parts,
I_a = current causing automatic operation within 5 s or, in the case of an RCD, is the rated operating current (or rated tripping current), $I_{\Delta n}$.

16.5.6 Protection against electric shock – IT systems

The general IT system requirements apply to IT systems on construction sites (Regulations 413–02–21 to 413–02–26). Regulation 604–06–01 modifies the formula given in Regulation 413–02–23 to that given in Equation (16.3).

$$R_A I_d \leqslant 25 \text{ V} \tag{16.3}$$

where R_A = resistance of the earth electrode for exposed-conductive-parts
I_d = first fault current.

Disconnection times are also modified by Regulation 604–06–02 and Table 604E of BS 7671 gives the reduced disconnection times relating to IT systems on construction sites. Regulation 604–03–01 states that an IT system must not be used if there is an alternative system and where it is used permanent earth fault monitoring must be used (see BS 4444), except in the case of a portable generator where such monitoring may be omitted.

16.5.7 Protection against electric shock – supplementary equipotential bonding

Supplementary equipotential bonding, where required, will need to comply with the general requirements set out in Regulations 413–02–27 and 413–02–28, the formula given in the latter being modified by Regulation 604–07–01, as given in Equation (16.4).

$$R \leqslant \frac{25}{I_a}\,\Omega \tag{16.4}$$

where R = resistance of any bonding conductor
I_a = current causing automatic operation within 5 s or, in the case of an RCD, the rated operating current (or rated tripping current), $I_{\Delta n}$ (use ampere units in the above equation).

Where a number of protective devices are involved, Equation (16.4) will need to be satisfied for all such circuits, taking account of the worst case.

16.5.8 Selection of equipment

There are additional requirements for construction site installations in the selection and erection of equipment. These requirements, supplementing or modifying the general requirements, are summarised in Table 16.13.

Regulation 604–10–01 underscores the general requirements for the avoidance of strain on cable terminations and mindful of the rough treatment such cable can be subjected to on construction sites, it is advisable to cleat or otherwise support cables well at distribution units. Regulation 604–10–02 stresses the need to protect cables from mechanical damage particularly where they cross walkways and roadways where they may suffer major damage by hob-nail boots, spades, forks, etc, not to mention compression from heavy vehicles.

16.5.9 Isolation and switching

The general requirements of Chapter 46, Section 476 are applicable to construction sites but Regulations 604–11–01 to 604–11–06 make further demands for this location. An assembly housing the main switchgear and controlgear must be provided at the origin (see Figures 16.5 and 16.6). This assembly must include the means to switch and isolate the incoming supply and incorporate facilities to secure (lock off) all isolating devices in the OFF position. It is a requirement for all construction site temporary circuits to be fed from a distribution assembly enclosing the necessary overcurrent protective devices, devices for protection against indirect contact, isolating devices and, where required, socket-outlets to BS EN 60 309–2 (BS 4343).

Regulation 604–11–03 demands that where it may be necessary to remove a hazard, circuits must be provided with emergency switching facilities. This is particularly important where rotating machines are used, including hand-held portable tools.

Table 16.13: Construction site – additional requirements in terms of selection and erection of equipment

Aspect	Regulation	Particular requirements
Assemblies for supply distribution.	604-09-01	Assemblies for distribution of electricity to comply with BS 4363 and BS 5486: Part 4.
	604-11-1	Assemblies to comprise main controlgear and principal protective device(s).
	604-11-2	Assemblies to incorporate a means of switching and isolation of the incomer.
	604-11-05	Every outgoing circuit to be protected by devices against over-current and indirect contact.
	604-11-05	Socket-outlets, where required, to be incorporated into assembly.
Degree of protection.	604-09-02	All equipment to be at least to IP44, except assemblies complying with BS 4363 and BS 5486: Part 4.
Wiring systems.	604-10-02	Cables across roadways and walkways to be protected against mechanical damage.
	604-10-03	For reduced low voltage systems, low temperature 300/500 V thermoplastic (pvc) flexible cables (or equivalent) must be used. For low voltage systems, H07 RN-F type, or equivalent, flexible cables rated at 450/750 V, and resistant to abrasion and water penetration are to be used.
Couplers, socket-outlets and plugs.	604-13-01	Cables couplers to comply with BS EN 60 309-2 (BS 4343).
	604-12-03	Luminaire supporting couplers (LSCs) not to be used.
	604-12-02	Socket-outlets and plugs to comply with BS EN 60 309-2 (BS 4343).
	604-12-01	Socket-outlets to be part of a distribution assembly.
Circuit protection.	604-11-05	Every outgoing circuit to be protected by devices against over-current and indirect contact.
Safety and standby supplies.	604-11-06	Safety and standby supplies connected by devices arranged to prevent interconnection of different supplies.

16.6 Agricultural and horticultural premises

16.6.1 General

As with all special installations or locations, the general requirements apply unless supplemented or modified by the particular requirements. Regulation 605–01–01 defines in the scope that fixed installations, indoors and outdoors, in premises for agricultural and horticultural use where animals are kept are subject to the particular requirements of Section 605. Examples of where livestock are kept include stables, chicken-houses, piggeries, feed-processing locations, lofts and storage areas for hay, straw and fertilisers. Fixed installations in buildings intended solely for use by humans (farm-houses, farm offices, canteens, etc.) are not expected to meet these particular requirements though they do, of course, need to meet the general requirements.

This location is one in which there is an increased risk of electric shock by virtue of a reduction in body resistance (due mainly to the lower contact resistance associated with wet surfaces) and because of contact with Earth potential.

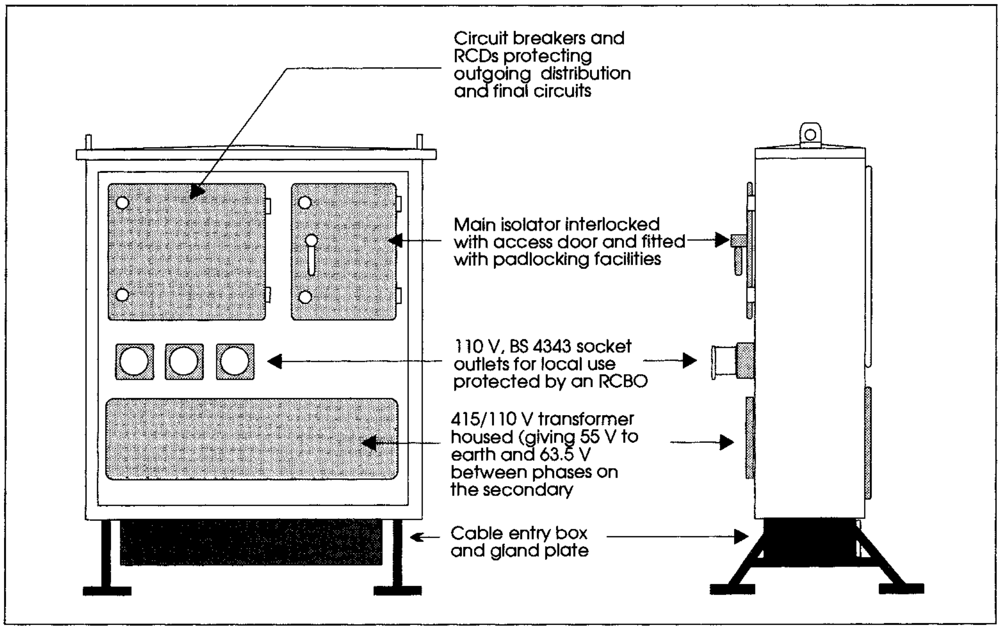


Figure 16.5: 200 A construction site distribution unit

16.6.2 Protection against electric shock – direct contact

As stated in Regulation 605–02–01, where equipment protected by SELV is located where livestock may gain access to it, the SELV voltage may need to be reduced from its normal limit of 50 V to some lesser limit appropriate to the type of livestock. In the absence of knowledge of the physiological effects of current on a particular type of livestock, the designer may well decide to limit the SELV voltage to 12 V. Irrespective of the nominal voltage of any SELV system, insulation, barriers and/or enclosures (not less than IP2X) are required to provide protection against the direct contact shock hazard. Every socket-outlet circuit, except those supplied by a SELV source, is required by Regulation 605–03–01 to be protected by an RCD with rated operating (tripping) current of not more than 30 mA ($I_{\Delta n} \leqslant 30\,\text{mA}$).

16.6.3 Protection against electric shock – indirect contact

Protection against the indirect contact shock hazard by the method of EEBADS depends on the various system types; other forms of protection are not changed by the particular requirements of Section 605 of BS 7671.

16.6.4 EEBADS – TN systems

Regulations 605–05–01 and 605–05–02 modify the disconnection times given in Table 41A of BS 7671 for the general requirements by the intro-

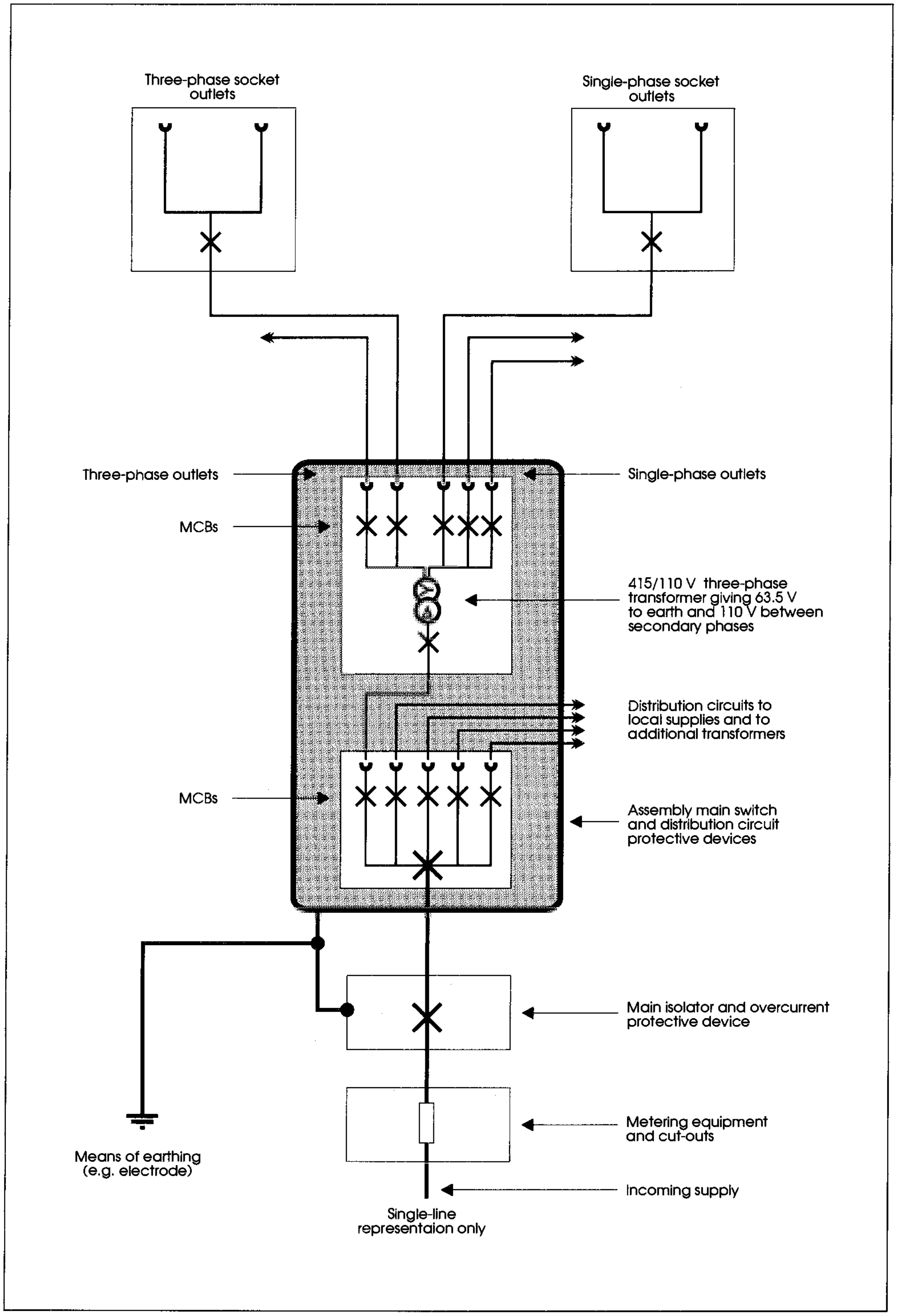


Figure 16.6: Typical construction site 415/110 V supplies

duction of Table 605 A. For nominal voltages of 230 V, the disconnection for these locations is 200 ms as opposed to 400 ms for the general installation. Table 16.9 gave the limiting earth loop impedances for circuits supplied at a nominal voltage of 230 V and where disconnection is required in 200 ms, it applies also to this location. Where disconnection times *simply cannot be guaranteed* further measures may be required such as supplementary equipotential bonding. Regulation 605–05–05 makes clear that the alternative method (see Regulation 413–02–12) of providing indirect contact shock protection for socket-outlet circuits by increasing disconnection time from 400 ms to 5 s (provided limitations are applied to the final circuit cpc) is not an option for these locations.

Regulation 605–05–06 modifies the requirements of Regulation 413–02–13 in that where circuits requiring different disconnection times (e.g. 200 ms and 5 s) emanate from a common distribution board, the limitation placed on the protective conductor of the distribution circuit supplying the distribution board is reduced as given in Equation (16.5).

$$Z_{\mathrm{dpc}} \frac{Z_{\mathrm{s}}}{U_{\mathrm{o}}} \Omega \tag{16.5}$$

where Z_{dpc} = impedance of the distribution circuit protective conductor
Z_{s} = phase-earth loop impedance corresponding to a disconnection time of 5 s
U_{o} = nominal voltage to Earth.

If the limitation in distribution circuit protective conductor impedance (Z_{dpc}) cannot be met, the alternative approach in these circumstances is to use supplementary equipotential bonding, sized as for main equipotential bonding, as allowed in the general requirements but modified by Regulation 605–08–01 as set out in Equation (16.6).

$$R \leqslant \frac{25}{I_{\mathrm{a}}} \Omega \tag{16.6}$$

where R = resistance of the supplementary bonding conductor
I_{a} = current causing automatic operation within 5 s or, in the case of an RCD, is the rated operating current (or rated tripping current), $I_{\Delta\mathrm{n}}$.

Where an RCD is used, the formula given in Regulation 413–02–16 is modified by Regulation 605–05–09 so that it becomes that given in Equation (16.7).

$$Z_{\mathrm{s}} I_{\mathrm{a}} \leqslant 25 \text{ V} \tag{16.7}$$

where Z_{s} = earth loop impedance of the whole circuit
$I_{\Delta\mathrm{n}}$ = operating (rating tripping) current of the RCD.

Regulation 605–09–01 makes clear that the limiting values for disconnection times are applicable only where such circuits and associated extraneous-conductive-parts are contained within the main earthed equipotential zone.

Regulation 605–09–03 states that where socket-outlets are used they must be protected by an RCD with a residual operating current ($I_{\Delta n}$) not exceeding 30 mA as indicated in Regulations 605–08–06 and 605–03–01 for TN and TT systems.

Regulations 605–05–03 and 605–05–04 provide data for the limiting values of Z_s for fuses and MCBs for 200 ms disconnection.

16.6.5 EEBADS – TT systems

In general, TT system requirements apply for TT systems on agricultural and horticultural premises and in particular Regulations 413–02–18 to 413–02–20 concerning protection by EEBADS. The general requirements are modified in one important way by Regulation 605–06–01; the formula given in Regulation 413–02–20 is modified to that given in Equation (16.8).

$$R_A I_a \leqslant 25 \text{ V} \tag{16.8}$$

where R_A = sum of the resistance of the earth electrode and all protective conductors connecting it to exposed-conductive-parts

I_a = current causing automatic operation within 5 s or, in the case of an RCD, is the rated operating current (or rated tripping current).

16.6.6 EEBADS – IT systems

The general IT system requirements apply to IT systems on agricultural and horticultural premises (Regulations 413–02–21 to 413–02–26). Regulation 605–07–01 modifies the formula given in Regulation 413–02–23 to that given in Equation (16.9).

$$R_A I_d \leqslant 25 \text{ V} \tag{16.9}$$

where R_A = resistance of the earth electrode for exposed-conductive-parts

I_d = first fault current.

Disconnection times are also modified by Regulation 605–07–02 and Table 604E of BS 7671 gives the reduced disconnection times relating to IT systems in this location.

16.6.7 Supplementary equipotential bonding

Supplementary equipotential bonding, where required, needs to comply with the general requirements set out in Regulations 413–02–27 and 413–

02–28 the formula of the latter being modified to that given in Equation (16.10).

$$R \leqslant \frac{25}{I_a}\Omega \tag{16.10}$$

where R = resistance of the bonding conductor
I_a = current causing automatic operation within 5 s or, in the case of an RCD, the rated operating current (or rated tripping current). Use ampere units in the above equation.

Where a number of protective devices are involved the equation will need to be satisfied for all such circuits.

Regulation 605–08–02 calls for supplementary bonding to connect all exposed-conductive-parts together and to all extraneous-conductive-parts in areas where such parts may be touched by the livestock and this requirement is to be applied to non-insulating floors. Metallic grids laid in the floor (of conducting floors) are required to be connected to the protective conductors of the installation by Regulation 605–08–03. The designer may conclude that a floor with a resistance to Earth of less than 500 kΩ is conductive and will consequently require a metallic floor grid for compliance with Regulations 605–08–01 and 605–08–02.

16.6.8 Fire and harmful thermal effects

Regulation 605–10–01 calls for all equipment to be protected with an RCD of rated operating current not exceeding 500 mA to protect against fire. An exception to this requirement is permitted if automatic disconnection by such an RCD causes the welfare of livestock to be put at risk. This may apply, for example, where livestock depend on motive power for ventilation but the designer would need to keep such circuits without RCDs (500 mA) to a minimum.

Careful siting of heating appliances is called for in Regulation 605–10–02 and such equipment needs to be located at a safe distance from livestock and combustible materials bearing in mind the likely temperatures that such equipment may attain. In the case of radiant heaters, the distance must be at least 500 mm or some greater distance specified by the manufacturer.

The general requirements relating to protection against thermal effects of Chapter 42 of BS 7671 and to the spread of fire contained in Regulations 527–02–01 to 527–02–03, 527–03–01, 527–03–02 and 527–04–01 also apply.

16.6.9 Selection of equipment

There are additional requirements for installations in agricultural and horticultural premises in the selection and erection of equipment. These requirements, supplementing or modifying the general requirements, are

Table 16.14: Agricultural and horticultural premises – additional requirements in terms of selection and erection of equipment

Aspect	**Regulation**	**Particular requirements**	**Comments**
External influences.	605–11–01	Equipment to be suitable for the external influences likely to be encountered, for example, dust, water, corrosion, stresses, flora, fauna, wind and solar radiation.	Careful selection of equipment is required in terms of construction methods and materials and degrees of protection (IP ratings).
Class II equipment.	605–11–01	Equipment to IP44 or higher.	
Emergency switching and emergency stopping devices.	605–13–01	All emergency devices to be placed so that they are inaccessible to livestock and where access to them is not impeded by livestock even in the event of livestock panic.	Emergency switching devices should be discriminatory.
Electric fence controllers.	605–14–01	Controller to comply with BS EN 61 011 (BS 6369).	Electric fence controller should be located away from livestock. Due account should be taken of induction from overhead power lines.
	605–14–02	Controller to be installed so that it is free from risk of mechanical damage and unauthorised interference.	
	605–14–03	Controller not to be fixed to pole of a power supply and telephone line except that where the supply to the controller is by an overhead insulated line, then it is permissible to affix is to a pole on that supply line.	
	605–14–04	Controller earth electrode to be located outside the resistance area of any other electrode and to be separate from any other earthing system.	
	605–14–05	Not more than one controller to each electric fence.	
	605–14–06	Electric fence to be installed so that it does not come into contact with any other equipment or conductor.	

summarised in Table 16.14. Generally speaking, the use of Class II equipment is recommended but careful selection of all equipment is necessary to establish, as far as is practicable, that the installation remains safe during its lifetime in what must be considered to be difficult environmental conditions. The choice of equipment with adequate IP rating is essential and particular care in installation is needed to guarantee that this rating is not impaired during installation. Wiring system entries to other equipment should be kept to a minimum and sealed as appropriate to maintain the necessary protection. Unused holes should similarly be blanked off and sealed.

Direct contact protection by placing out of reach is not precluded for this location but care should be exercised in the selection of overhead wiring systems taking account of vehicle and other machinery movements around the location. Height of cable runs generally are given in Chapter 10 of this Guide but may need modifying to suit the particular circumstances.

16.6.10 RCDs in series

It is inevitable that installations in this location will involve RCDs in series and the designer also needs to consider discrimination of these devices. Most locations will involve at least two RCDs, one for socket-outlets ($I_{\Delta n} \leqslant$ 30 mA) and one to protect against fire ($I_{\Delta n} \leqslant$ 500 mA). For compliance with Regulation 605–03–01 every circuit supplying socket-outlets will have its own RCD but more realistically an RCD will protect a number of circuits. The total number of circuits protected by a single RCD will depend on the likely equipment to be used. Bearing in mind that some equipment may be less than adequately maintained and subject to poor environmental conditions, the maximum number of circuits protected by an RCD, by 'rule of thumb', should ideally not exceed three. RCDs in series should be avoided wherever possible and it may be beneficial to employ combined MCB/RCDs (RCBOs) to protect individual circuits. Where RCDs have to be connected in series careful consideration is required so as to provide effective discrimination. Figure 16.7 shows a typical arrangement providing discrimination of RCDs by the use of devices with deliberate time delayed operation.

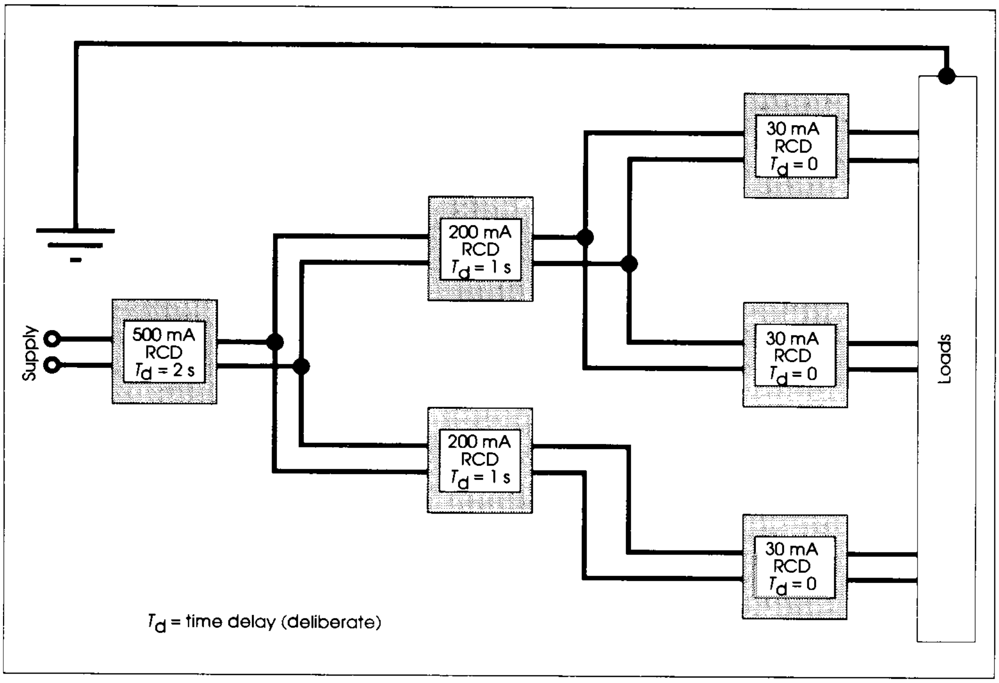


Figure 16.7: Typical arrangement providing discrimination of RCDs

16.7 Restrictive conductive locations

16.7.1 General

As with other special locations, the particular requirements of Section 606 of BS 7671 supplement or modify the general requirements. As indicated in Regulation 606–01–01, this Section applies to installation within, and intended to supply equipment and appliances for use in, such a location. The location is defined as one with metallic or conductive surrounding parts to which a person may have contact through a substantial part of their body. Examples of such locations would include large boilers, storage tanks, large pipework or any conductive locations which restrict the physical movement of a person working in it.

16.7.2 Protection against direct contact

Regardless of the nominal voltage, the only acceptable measures for protection against direct contact are barriers and enclosures to IP2X or IPXXB or insulation capable of withstanding a 500 V test voltage for 60 s, as given in Regulation 606–02–01. Where SELV and functional extra-low voltage are used, the upper limit on nominal voltage is 25 V a.c. (rms) or 60 V d.c. (ripple-free). Not surprisingly, Regulation 606–03–01 precludes the use of the protective measures of obstacles and placing out of reach as clearly they are unsuitable for such locations.

16.7.3 Protection against indirect contact

There are a number of options, given in Regulation 606–04–01, for protection against indirect contact. These are:

- SELV,
- automatic disconnection,
- electrical separation (each socket-outlet and each item of equipment connected to a separate winding of an isolating transformer),
- Class II equipment (with adequate IP rating, additionally protected by an RCD with $I_{\Delta n} \leqslant 30$ mA).

In cases where a functional earth is required, supplementary bonding conductors are required, to connect together the exposed-conductive-parts of the installation and the conductive parts of the location.

As indicated in Regulations 606–04–02 to 606–04–06, further demands are made on supplies to equipment within the location as summarised in Table 16.15.

Table 16.15: Summary of requirements relating to supplies to equipment within the restrictive conductive location

Ref	**Regulation**	**Equipment**	**Requirement**
A	606–04–06	Safety and isolating sources, except electrochemical sources (e.g. battery) and sources independent of a higher voltage circuit (e.g. engine driven generator).	To be located outside the location except where the source is a part of the fixed installation within a permanent restrictive conductive location.
B	606–04–05	Supplies to fixed equipment.	To be protected by one or more of the protective measures given in Regulation 606–04–01 (see item 16.7.3 above).
C	606–04–02	A supply or socket-outlet for headlamp.	Must be protected by SELV with an upper limit on nominal voltage of 25 V a.c. (rms) and 60 V d.c. (ripple-free).
D	606–04–04	A supply or socket-outlet for hand-held tool.	Must be protected by SELV with an upper limit on nominal voltage of 25 V a.c. (rms) and 60 V d.c. (ripple-free) or electrical separation with each item of equipment connected to a separate winding of an isolating transformer.
E	606–04–03	A supply or socket-outlet for equipment requiring a functional earth.	Supplementary bonding required.

16.8 Earthing requirements for the installation of equipment having high protective conductor currents

16.8.1 General

Section 607 of BS 7671: 2001 has been largely rewritten but many of the requirements remain unchanged. The term ‘earth leakage current’ has disappeared and been replaced by ‘protective conductor current’, the former term having been deleted from Part 2 Definitions.

The scope of the section has been more clearly defined as applying to:

- the part of the wiring between the current-using equipment and the final circuit, where the protective conductor current exceeds 3.5 mA in normal use, and
- circuits where the total protective conductor current may exceed 10 mA in normal use.

The scope of Section 607 now includes *all* equipment having a protective conductor current exceeding 3.5 mA including:

- information technology (IT) equipment complying with BS EN 60950,
- industrial and telecommunications equipment with radio-frequency interference suppression filtering, and
- heating elements.

The requirements of Section 607 of BS 7671 relate to the particular circumstances where equipment has higher currents which flow to Earth as a normal aspect of its functioning. All current-using equipment permits some protective conductor current but this is not generally a problem unless this current is high enough to have physiological effects on a person coming into contact with charged metalwork and Earth. Where such currents are higher than normal by design and are continuously in use, special precautions are required to minimise the risk of electric shock.

It will be appreciated that where such equipment is used in large numbers as would, for example, be the case in commercial office buildings, there are additional risks associated with the accumulative earth-leakage current 'generated' by the equipment in use. These protective conductor currents pose additional risks for the users and possible problems with malfunctioning. Additionally, problems can occur with earth-leakage detection devices, such as RCDs, where the leakage may operate the protective devices causing, for example, loss of data on computer controlled systems.

Protective conductor currents are often the result of imbalance caused by low-order harmonic currents in, for example, oscillators, inverters (sometimes operating in the order of MHz frequencies). Equipment containing sources of earth-leakage current will, generally, be the subject of BS EN 60 950 (BS 7002) *Specification for safety of information technology including electrical business equipment*. However, as indicated in Regulation 607–01–01, industrial type control equipment may also have such characteristics as may domestic 'white' goods and other appliances, such as those containing heating elements. In consideration of all equipment, the designer would need to check with the relevant British or CENELEC Standard to establish the maximum leakage current permitted by that Standard.

Notwithstanding the user's requirements, the requirements of this Section are paramount because they relate to the safety in use of equipment and in particular the earthing connection arrangements to prevent or minimise danger from electric shock. Of particular concern is the conduction of any remaining protective conductor currents to Earth after the supply and the protective conductor have been disconnected as might be the case where the plug to the equipment has been withdrawn.

16.8.2 Additional requirements for earthing of equipment in TN and TT systems

The requirements for system types other than IT systems are summarised in Table 16.16. The minimum csa of protective conductors of final and distribution circuits, where the total protective conductor current is likely to exceed 10 mA, is summarised in Table 16.17.

16.8.3 Minimum csa of protective conductors of final and distribution circuits

Regulation 607–02–04 gives a number of options for compliance in terms of cross-sectional areas of protective conductors, which are summarised in Table 16.17.

Table 16.16: Additional requirements for earthing of equipment in TN and TT systems

Ref	**Regulation No**	**Protective conductor current, I_L**	**Additional protective conductor connection requirements (alternatives)**
A	607-02-01	$I_L \leq 3.5\,\text{mA}$	No additional requirements
B	607-02-02	$3.5\,\text{mA} \geq I_L \leq 10\,\text{mA}$	Permanently connected to the fixed wiring of the installation
C			Connected by means of an industrial type plug and socket-outlet complying with BS EN 60309-2.
D	607-02-03	$I_L < 10\,\text{mA}$	Permanently connected to the fixed wiring of the installation, with a protective conductor complying with the particular cross-sectional area and other requirements. A flexible cable may be used for the permanent connection. (See Note 1)
E			Flexible cable with an industrial type plug and socket-outlet complying with BS EN 60309-2, providing the protective conductor meets specified cross-sectional area requirements. (See Note 2)
F			By a protective conductor complying with Section 543 (protective conductors) with an earth monitoring system to BS 4444.
G	607-02-04		The wiring of every final circuit and *distribution circuit* where the protective conductor current is likely to exceed 10 mA must have a high integrity protective connection. (See Note 3)
H			A high integrity protective conductor may now have a cross-sectional area of 4 mm^2, provided it is enclosed to provide additional protection, such as in a flexible conduit. (See Note 4)
I	607-02-05		Where two protective conductors are used to provide a high integrity protective connection, the ends of the conductors must be terminated independently at *all* points throughout the circuit, such as distribution boards, junction boxes and socket-outlets. (See Note 5)
J	607-03-01		Three examples of high integrity protective conductor arrangements for radial final circuits for socket-outlets: • the protective conductor may be connected as a ring, or • a separate protective conductor connection is provided at the final socket-outlet by connection to the metal conduit or ducting, or • where two or more similar radial circuits supply socket-outlet circuits in adjacent areas then a second protective conductor may be provided at the final socket-outlet on one circuit by connection to the protective conductor of the adjacent circuit. However, conditions apply to the two socket-outlet circuits in this example. They must be fed from the same distribution board, have identical means of short-circuit and fault current protection, and have circuit protective conductors of the same csa. (See Note 6)

Continued on facing page

Table 16.16 continued: Additional requirements for earthing of equipment in TN and TT systems

Ref	Regulation No	Protective conductor current, I_L	Additional protective conductor connection requirements (alternatives)
K	607-03-02	$I_L \geq 3.5\,\text{mA}$	Visible information, identifying circuits having high protective conductor currents, to be given at the distribution board.

Notes:

(1) Item D is the preferred method.

(2) The requirement for a duplicate protective conductor connection via a separate connection within the plug is no longer a requirement.

(3) It is important to note that the requirements for high integrity protective conductors now specifically apply to *distribution circuits*.

(4) The previous minimum csa was 10 mm^2.

(5) This requires accessories to be provided with two earthing terminals. Socket-outlets used in a ring final circuit where the protective conductor current is expected to exceed 10 mA are no longer restricted to the single type. However, as indicated above, all such socket-outlets will require two earthing terminals. Spurs are permitted in ring final circuits provided each spur includes a high integrity protective connection.

(6) A socket-outlet circuit other than a ring final circuit or one of the example types of radial circuit can be used, provided that the protective conductor arrangements meet the general requirements of Section 607.

Table 16.17: Minimum csa of protective conductors of final and distribution circuits, where the total protective conductor current is likely to exceed 10 mA

Ref	Regulation No	Protective conductor form	Minimum csa of protective conductors	Minimum csa of multi-core cable
A	607-02-04	Single protective conductor meeting the requirements of Regulation Groups 543-02 and 543-03.	10 mm^2	
B		Single copper protective conductor meeting the requirements of Regulation Groups 543-02 and 543-03 and enclosed to provide additional mechanical protection (e.g. within a flexible conduit).	4 mm^2	
C		Two separate protective conductors meeting the requirements of Section 543 incorporated in a single multi-core cable. One protective conductor may be sheath armour or wire-braid of cable meeting the requirements of Regulation 543-02-05.	—	10 mm^2
D	607-04-01	Additionally, the csa of all protective conductors must not be less than given by Regulation Group 543-01.		

Notes:

(1) Where earth monitoring complying with BS 4444 is employed which provides for automatic disconnection in the event of a loss of protective conductor continuity, no additional requirements related to protective conductor cross-sectional areas are stipulated in the Section.

(2) Where the supply is derived from a double-wound transformer or equivalent source, the protective conductors must comply with A, B or C above.

16.8.4 RCD compatibility

The requirement that the total protective conductor current must not exceed 25% of the rated residual operating current $I_{\acute{C}n}$ that was previously called for has been replaced with a new requirement that the residual current which may be expected to occur, including switch-on surges, must not operate the RCD (see Regulation 607-07-01). This applies to all circuits having a protective conductor current exceeding 3.5 mA.

This requirement will necessitate careful consideration of all current-using equipment in terms of start-up inrush currents as well as their normal protective conductor currents. Where it is not possible to meet this requirement, the current-using equipment must be supplied through a double-wound transformer or equivalent device.

16.8.5 Requirements for TT and IT systems

Direct connection of equipment having high protective conductor currents to an IT system is precluded by Regulation 607-06-01, though methods not involving direct connection are options available to the designer. In TT systems, the general requirements apply as for TN systems but Regulation 607-05-01 additionally constrains the protective conductor current to the limit given in Equation 16.11. Where it is not possible to meet this requirement, the current-using equipment must be supplied through a double-wound transformer or equivalent device.

$$I_L R_A \leq 25V \tag{16.11}$$

where I_L is the protective conductor current (A)
R_A is the sum of the resistances of the earth electrode and the protective conductor connecting it to the exposed-conductive-parts

16.9 Installations in caravans and motor caravans

16.9.1 General

As with all special locations or installations, the general requirements apply and are supplemented or modified by the particular requirements embodied in Section 608 Division I. As indicated in Regulation 608–01–01, the requirements relate to supplies and installation, on single-phase LV not exceeding 250/400 V, in caravans and motor caravans. Installations in residential park homes intended for permanent occupation are subject to the general requirements but not to the particular requirements of this Section. The scope of this Section specifically does not apply to mobile homes, fixed recreational vehicles, transportable sheds or other similar temporary structures and buildings.

The requirements do not apply to vehicle electrical systems employed to meet the requirements of Road Vehicle Lighting Regulations 1989 except in the sense that necessary segregation of the LV system from the vehicle

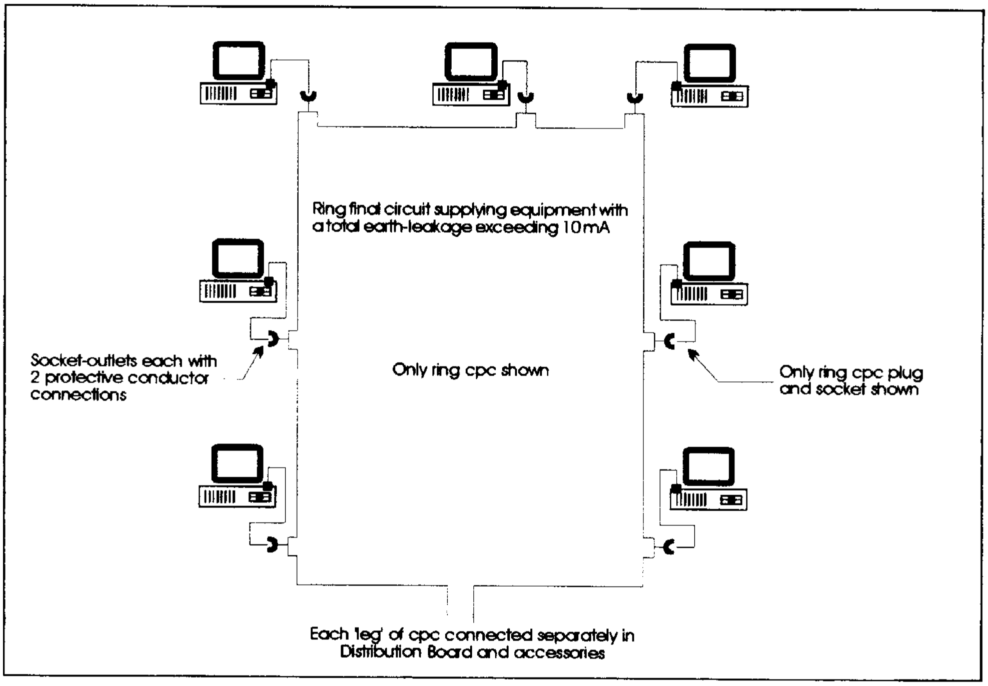


Figure 16.8: Final ring cpc feeding equipment having high earth-leakage

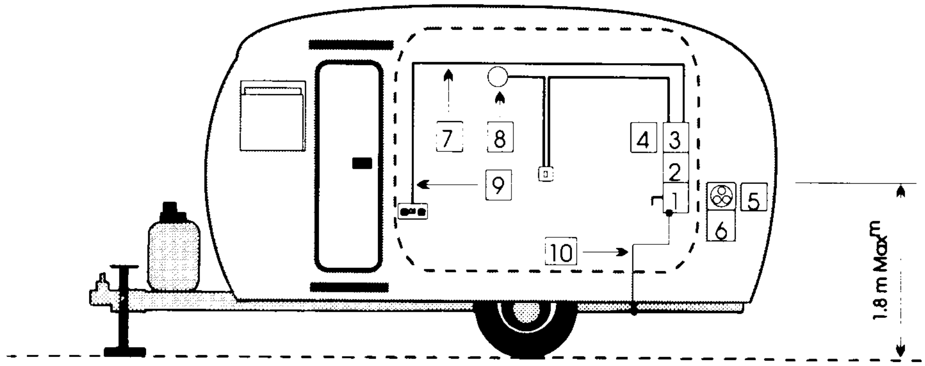
road lighting systems as required by Section 528 (proximity to other services) of BS 7671 and Regulation 608–06–04. Similarly not covered in the scope of Section 608 are installations covered by BS 6765 Part 3 *Specification for 12 V direct current extra-low voltage electrical installations*, except, again, to the extent of segregation. Where such accommodation includes a bath or a shower, the particular requirements of Section 601 also apply.

Initial inspection and testing and certification for caravans and motor caravans is essentially no different from general installations (see Chapter 17 of this Guide). As far as periodic inspection and testing are concerned, the intervals between inspections are largely a matter of judgement and would depend to a great extent on the extent of usage and the degree of maintenance. The generally accepted maximum interval would be three years (see Table 17.21).

16.9.2 Requirements for safety

The direct contact protective measures of obstacles and placing out of reach are, not surprisingly, precluded by Regulation 608–02–01 and, similarly, indirect contact measures of non-conducting location, earth-free equipotential bonding and electrical separation are precluded by Regulation 608–03–01.

Regulation 608–03–02 calls for an RCD, with $I_{\Delta n} \leqslant 30$ mA, (see Figure 16.9) where protection by automatic disconnection of supply is used (the normal method) with a protective conductor connecting the exposed-conductive-parts of the installation, including socket-outlet protective contacts, with the earthing contact of the caravan inlet plug. Where protective conductors are not incorporated in a composite cable, the minimum csa must be 4 mm^2, as indicated in Regulation 608–03–03.



1	DP main isolating switch	2	RCD (30 mA)
3	Overcurrent protective devices	4	Periodic inspection and test notice
5	Power inlet notice	6	Power inlet (16 A 2 pole and E)
7	Horizontal cable run to socket-outlet	8	Luminaire fixed to caravan wall
9	Vertical cable run to socket-outlet	10	Main bonding conductor to chassis

Figure 16.9: Installation in a typical caravan

Unless the accommodation is substantially made of insulating material and any isolated metallic parts are unlikely to become live, all extraneous-conductive-parts must be bonded with a protective conductor of csa 4mm^2, as called for in Regulation 608–03–04. Metal sheets forming the outside structure of the vehicle are not considered to be extraneous-conductive-parts for the purposes of this Section and all that will be required, in many cases, will be a ‘main’ bond on to the vehicle chassis and supplementary bonding in the bath/shower room (see Figure 16.9).

Regulation 608–04–01 calls for each final circuit to be protected by an overcurrent protective device which disconnects all live (phase and neutral) conductors (see Figure 16.9). This will of necessity involve the use of single pole and neutral (SP&N) or double pole (DP) circuit-breakers. DP devices will detect overcurrent in both phase and neutral and interrupt both on operation whereas SP&N devices detect only overcurrent in one pole (phase) but will disconnect both poles on operation.

Where more than one electrically independent installation are present, each will require its own independent inlet plug, as indicated in Regulation 608–05–01.

Any part of the caravan installation operating at ELV must comply with the requirements of Regulation 411–02 (SELV) and for d.c. be at one of the standard voltages (12 V, 24 V, 48 V). For a.c., permissible standard voltages are 12 V, 24 V, 42 V and 48 V.

16.9.3 Wiring systems

Regulations 608–06–01 to 608–06–06 supplement and modify the general requirements relating to wiring systems in caravans and motor caravans and these are summarised in Table 16.18.

Table 16.18: Additional requirements relating to wiring systems in caravans and motor caravans

Ref	**Regulation**	**Aspect**	**Requirements**
A	608–06–01	Type of wiring system.	Must be one of the following three types: – flexible single-core insulated conductors in non-metallic conduit or – stranded (7 or more) insulated conductors in non-metallic conduit, or – sheathed flexible cables (i.e. csa $\geqslant$ 4 mm^2). – pliable polyethylene conduits must not be used.
B	608–06–02	Minimum csa of live conductors.	1.5 mm^2.
C	608–03–03	Minimum csa of protective conductors.	4 mm^2 where not incorporated in cable.
D	608–06–03 543–03–02	Bare protective conductors.	All protective conductors must have a green/yellow covering regardless of csa.
E	608–06–04	Segregation.	LV cables must be run separately from extra-low voltage circuits (including road lighting circuits) so as to prevent physical contact between the different systems.
F	608–06–05	Cable supports.	Where cables are not contained within rigid conduit, to be supported at spacings not exceeding 400 mm for vertical runs and 250 mm for horizontal runs. (Note: designers may consider these spacings for safety are too generous to provide for an aesthetically pleasing surface installation.) See Figure 16.9.
G	608–06–06	Fuel storage.	No electrical equipment (including wiring systems) to be installed in any compartment intended for gas cylinder storage.
H	608–06–07	Mechanical protection of wiring.	All wiring to be protected, either by location or by additional protection, against mechanical damage, particularly where cables pass through metalwork.

16.9.4 Main isolating switch, caravan inlets and connection leads

Regulation 608–07–04 calls for the installation to be equipped with a DP main isolating switch which must be placed within the caravan and positioned for ready operation (see Figure 16.9). Isolators located in linen cupboards or under bed-box covers or blanket chests, and which need some effort to locate, are unlikely to meet the requirement for ready operation. Additionally, such devices may be the subject of adverse effects from the lack of proper ventilation and consequential temperature rise particularly where incorporated with overcurrent protective devices. In cases where there is only one circuit, the main isolating switch may be incorporated with the overcurrent protective device and where the latter also meets the requirements for isolation (e.g. adequate contact separation and visual indication of contacts) it may also serve as the main isolating switch. Similarly, an RCD with the necessary isolation characteristics may also serve the combined function.

The electrical inlet to the caravan must be a two pole plus earth appliance inlet (Regulation 608–07–01), of adequate rating for the caravan load, complying with BS EN 60 309–2 (BS 4343) with the key position at '6h'. The inlet must not be installed at a height exceeding 1.8 m from the ground (see Regulation 608–07–02 and Figure 16.9) and must be mounted on the exterior of the caravan and housed in an enclosure with a suitable cover. A legible and durable notice as required by Regulation 608–07–03 must be affixed on or near the inlet (see Figure 9.21 for example of label details) giving details of nominal voltage and frequency together with the installation rated current.

It is a requirement of Regulation 608–08–08 for the caravan installation to be equipped with a flexible cord or cable to connect the caravan inlet to the park pitch socket-outlet. The flexible link, to be complete with plug and connector both of two pole and earth with key position '6h', must not be longer than 25 m. Rubber insulated cables to HO7RN-F or HO5VV-F or equivalent are acceptable and should be sized according to the rating of the caravan installation:

- 16 A – 2.5 mm^2
- 25 A – 4 mm^2
- 32 A – 6 mm^2
- 63 A – 16 mm^2
- 100 A – 35 mm^2

Most, if not all, small touring caravans will not need a greater rating than 16 A.

16.9.5 Luminaires and accessories

There are additional requirements relating to accessories and luminaires in terms of selection and these are summarised in Table 16.19.

Figure 16.9 identifies in graphical representation some of the requirements relating to caravans and motor caravans.

Table 16.19: Additional requirements for luminaires and accessories in caravans and motor caravans

Ref	**Regulation**	**Equipment**	**Additional requirement**
A	608–08–01	Accessories – generally.	No accessible conductive parts (insulated type required).
B	608–08–04		Where accessories are exposed to moisture at least IP 55 degree of protection is required either for the accessory itself or by a suitable enclosure.
C	608–08–02	LV socket-outlets.	Unless supplied by an individual winding of an isolating transformer, to incorporate a protective contact.
D	608–08–03		All ELV socket-outlets to be clearly marked with nominal voltage.
E	608–08–03		LV and ELV socket-outlets to be incompatible.
F	608–08–05	Appliances – generally.	Electrical appliance connected other than by means of a plug and socket-outlet to be controlled by a switch, either near or incorporated within the appliance, to break all live conductors to the appliance.
G	608–08–06	Luminaires – generally.	Caravan luminaire preferably to be affixed directly to the structure or lining (see also Figure 16.9).
H	608–08–06		Where pendant luminaires are installed, provision for securing them in transit must be made.
I	608–08–06		Accessories for the suspension of luminaires must be suitable for the suspended mass.
J	608–08–07	Luminaires – dual voltage.	Separate lampholder required for each voltage present.
K	608–08–07		Lamp wattage and voltage clearly and legibly marked near each lampholder.
L	608–08–07		Be designed and constructed so that no damage is sustained if both lamps are energised simultaneously (mindful of the additional heat dissipation required).
M	608–08–07		Conductors of different voltages are separated by design and construction methods.
N	608–08–07		Designed so as to prevent the insertion into lampholder of lamps of other voltages.

16.10 Installations in caravan parks

16.10.1 General

As with all special locations or installations, the general requirements apply and are supplemented or modified by the particular requirements embodied in Section 608 Division II. As stated in Regulation 608–09–01, the additional requirements relate to electrical installations in caravan parks for the connection of caravans and motor caravans at nominal voltages not exceeding 250/440 V single-phase.

The detailed requirements are, of course, based on the same basic principles which relate to general installations but, additionally, take account of the particular additional hazards associated with connections made outside an equipotential zone.

Initial inspection and testing and certification for caravan parks is essentially no different from general installations (see Chapter 17 of this Guide). As far as periodic inspection and testing are concerned, the interval between inspections is largely a matter of judgement and would depend, to a great extent, on the degree of maintenance of the park installation. The generally accepted maximum interval would be twelve months and, where the park is subjected to licensing (see Table 17.21), the maximum period would be a mandatory condition.

16.10.2 Requirements for safety

The direct contact protective measures of obstacles and placing out of reach are, not surprisingly, precluded by Regulation 608–10–01 and, similarly, indirect contact measures of non-conducting location, earth-free equipotential bonding and electrical separation are precluded by Regulation 608–11–01.

16.10.3 Equipment – selection and erection

Section 608 makes additional demands relating to wiring systems (Regulations 608–12–01 to 608–12–03) and switchgear and controlgear (Regulations 608–13–06); Table 16.20 summarises these additional requirements.

16.10.4 Typical caravan park distribution layout

Figure 16.10 shows a typical park layout (one of the many possible) in which the supply is derived from a PME source. From a central switchroom distribution cables run underground, following routes which do not encroach on the pitches, to a number of pitch distribution pillars. Each pillar, serving four pitches, is constructed predominately of non-metallic material (with degree of protection IP54) and embodies a main isolating switch, four 16 A BS EN 60 309–2 (BS 4343) socket-outlets and six combined MCB/RCDs (RCBOs). Each socket-outlet is individually circuited and protected against overcurrent and the indirect contact shock hazard by an RCBO.

BS 7671 demands (608–13–05) that where a PME service is provided, the protective conductors for the socket-outlets must not be connected to the PME earthing terminal. Figure 16.11 illustrates one example of how armoured cables may be terminated into the gland plate of the pillar and how continuity may be maintained for the underground cables protective conductors (e.g. SWA). Providing there are no metallic parts within the pillar which need earthing, the PME earthing need not be brought further into the pillar and a local earth electrode will be used to protect all the socket-outlet circuits. The installation in the pillar would then form part of a TT system where Regulations 413–02–18 to 413–02–20 apply. This includes the requirement for the resistance of the earth electrode to meet the formula given in Equation (16.13).

$$R_A I_a \leqslant 50 \text{ V} \tag{16.13}$$

where R_A = sum of resistances of the earth electrode and protective conductor between the socket-outlet and the earth electrode,

I_a = rated operating current of the RCBO $I_{\Delta n}$).

Table 16.20: Additional requirements relating to equipment selection and erection in caravan parks

Ref	Regulation	Equipment	Additional requirement
A	608–12–01	Wiring systems.	Underground supply cables to be used wherever practicable.
B	608–12–02		Underground cables to be located outside caravan pitch or provided with additional mechanical protection.
C	608–12–03		Where it is impracticable to use underground cables, overhead lines must be insulated and suitably constructed for such use. Additionally, line runs must be not less than 2 m horizontally from the edge of the pitch and at least 6 m high in areas of vehicle access and 3.5 m elsewhere. Poles and other supports must be located, or otherwise protected, so that they are unlikely to be damaged by foreseeable vehicle activity.
D	608–13–01	Caravan pitch supply unit.	Supply point must not be more than 20 m from any position on the pitch intended for supply service.
E	608–13–02		
F	608–13–02		Socket-outlets to BS EN 60 309-2 (BS 4343) with key position '6h'.
G	608–13–02		Socket-outlets to have at least IPX4 degree of protection.
H	608–13–02		Socket-outlets to be mounted between 800 mm and 1500 mm from ground level.
I	608–13–02		Socket-outlets to be rated at not less than 16 A.
J	608–13–02		At least one socket-outlet to be provided for each pitch.
K			Where maximum demand exceeds 16 A, additional socket-outlet to be provided with adequate rating.
L	608–13–04		Each socket-outlet to be protected individually by an overcurrent protective device.
M	608–13–05		Each socket-outlet to be protected individually, or in a group of not more than three, by an RCD with $I_{\Delta n} \leqslant 30$ mA.
N	608–13–05		Where supplies are obtained from a TN-C-S (PME) source, the RCD's protective conductor is not to be connected to the PME earthing. In such cases the protective conductor of socket-outlet to be connected to an electrode.
O	608–13–06		Socket-outlets grouped together to be connected to the same phase.

Had the supply been a TN-S system, the underground cable protective conductor could have been used to connect the protective conductors of the socket-outlet circuits to Earth and the local electrodes would have been unnecessary. However, the designer will need to consider the potential risk associated with the loss of this underground protective conductor on the protective measures against indirect contact; the loss of protective conductors in the underground site distribution cables would render all RCBOs inoperative and an earth fault on any connected caravan would raise the potential on every caravan to Earth up to line voltage to Earth, U_o. For this reason the designer should consider the advantages of employing an earth-monitoring system at least for the site distribution circuits.

Park distribution may be single-phase or three-phase, depending on the availability of supply and park size in terms of loading, but grouped socket-outlets in the pillar must be on the same phase. Where three-phase is used, the load should be balanced as far as is possible and the necessary through connections provided in the pillars.

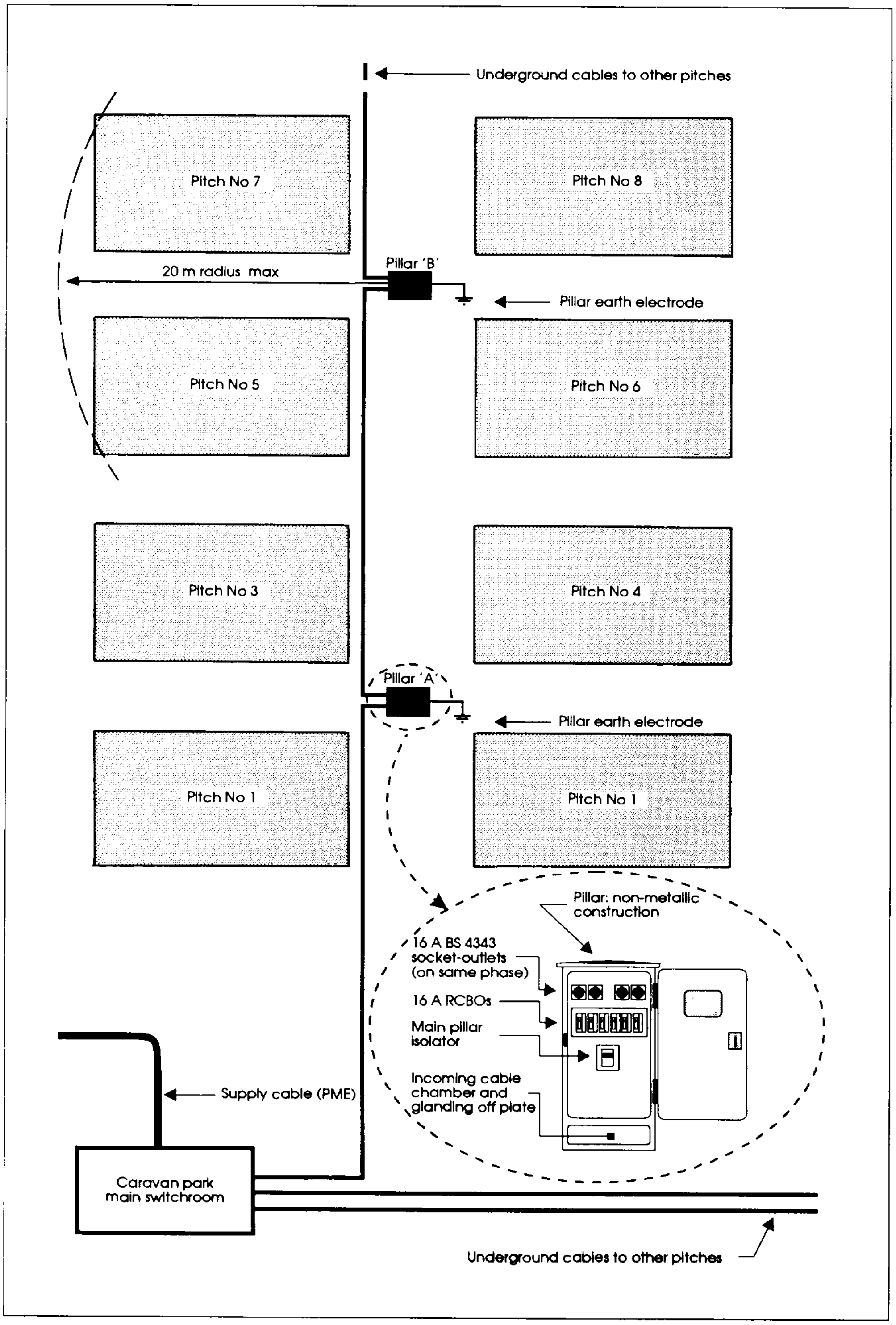


Figure 16.10: A typical caravan park installation layout

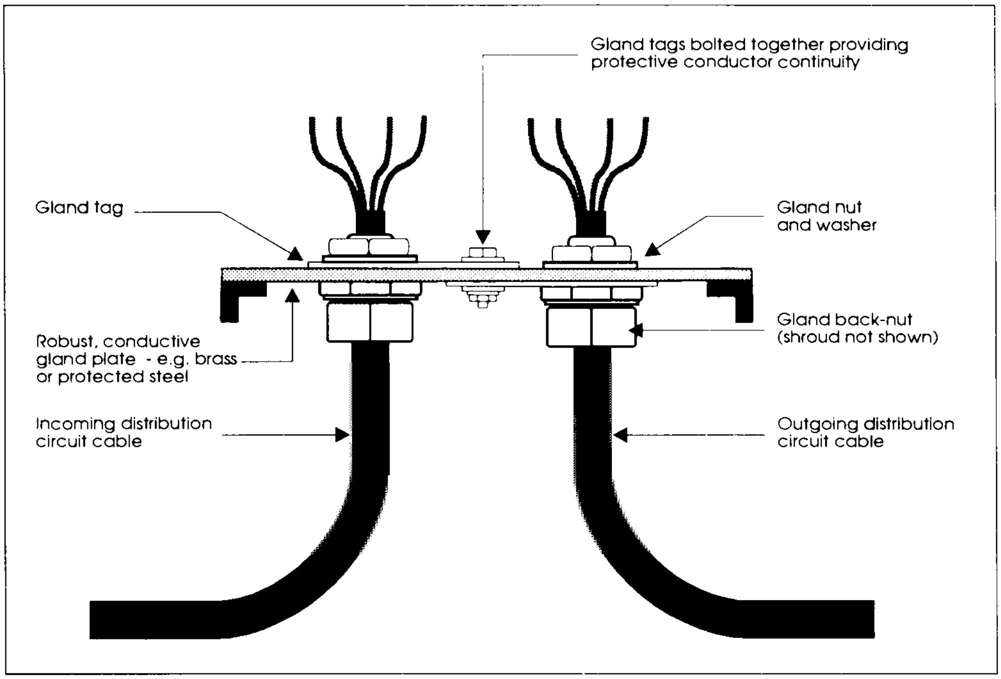


Figure 16.11: Pillar gland plate – typical arrangement

BS 7671 demands only that socket-outlets be protected by an RCD and allows up to three to be protected by a single device. Because the same Regulation (608–13–05) calls for the RCD to have a rated residual operating current of not more than 30 mA, it would be unwise to protect three socket-outlets together. Cumulative earth-leakage currents from three caravans would be likely to produce much unwanted tripping and the installation designer would wish to avoid this potential problem. It should not be overlooked that the Standard for RCDs allows a range for the operating current and it may be that the device will trip at a residual current much lower than the rated residual operating current. The pillar shown in Figure 16.10 shows six RCBOs, one each for the four socket-outlets, one perhaps for path and roadway lighting and one spare. Adopting this approach would avoid the situation of an earth fault occurring in one caravan affecting the supply to others.

There is also a problem with discrimination with the residual current device on the site with a similar device within the caravan, both units having rated residual operating current $I_{\Delta n} \leqslant 30$ mA. Having the caravan RCD rated at, say, 10 mA is not a practical solution to the discrimination problem and would probably lead to further unwanted tripping. Since RCDs of this residual operating current are not available with time delayed tripping mechanisms, the only practical solution, or part solution, is to protect each pillar socket-outlet with its own RCD. The discrimination aspect remains however with the caravan RCD and its pitch RCD but at least other caravan supplies should remain unaffected.

Initial inspection, testing, verification and certification are the same as that for general installations as are periodic inspection and testing (see Chapter 17 of this Guide).

16.11 Highway power supplies, street furniture and street located equipment

16.11.1 General

This special location, like others, is subject to the general requirements in addition to those given in Section 611. As indicated in Regulations 611–01–01 and 611–01–02, the additional requirements apply to installations comprising highway distribution circuits, street furniture and other street located equipment. They also apply to similar equipment in areas, not designated as a highway or part of a building, used by the public which would include, for example, hospital drive lighting and football stadia floodlighting. Supplier's works carried out in accordance with the requirements of the Electricity Supply Regulations 1988 as amended, fall outside the scope of this Section.

Designers involved in this type of installation will find reference to the Institute of Lighting Engineers' publications *Code of Practice for Electrical Safety in Public Lighting Operations* essential.

16.11.2 Protection against electric shock

The direct contact protective measures of obstacles and placing out of reach are precluded for general application by Regulation 611–02–01. However, the latter measure may be used where LV overhead lines are constructed to comply with the Electricity Supply Regulations 1988. Additionally, where maintenance work is restricted to skilled persons specially trained for the task and where LV overhead lines are placed beyond 1.5 m from street located equipment, the protective measure of placing out of reach may be employed.

The general requirement of Regulation 412–03–01 (requirements for barriers and enclosures) is not satisfied by the street equipment door. Regulation 611–02–02 goes on to call for an intermediate barrier (to IP2X) to be provided removable only by use of a tool. Additionally, doors located in such equipment at less than 2.5 m above ground level are to be locked with a key or secured by the use of a tool. Similarly, where a luminaire is located at less than 2.8 m above ground level, access to the light source must be possible only after removing a barrier or enclosure requiring the use of a tool.

Similarly, indirect contact measures of non-conducting location, earth-free equipotential bonding and electrical separation are precluded by Regulation 611–02–03. The acceptable measures are therefore EEBADS or by Class II (or equivalent insulation) equipment. Where the EEBADS method is used, Regulation 611–02–05 requires that metalwork, including structures, not connected to, or forming part of, the street furniture or equipment must *not* be bonded to the MET though in other locations such parts may be considered to be extraneous-conductive-parts. Where protection against indirect contact is by Class II equipment or equivalent insulation, Regulation 611–02–06 demands that no protective conductor be provided, and that no conductive parts of the lighting column, street furniture or street located equipment be intentionally connected to Earth.

As given in Regulation 611–02–04, the maximum disconnection time for circuits feeding fixed equipment is 5 s. However, where socket-outlets are provided in or on the street furniture for use, for example, by maintenance personnel, the disconnection time for a 230 V circuit would need to be within 0.4 s for compliance with Regulation 413–02–08 for TN systems. Generally, circuits feeding equipment located outside the earthed equipotential zones are required to be disconnected within 0.4 s but in the case of street furniture the relaxation to 5 s is permitted owing to the fact that the street furniture, if metallic, itself forms an earth electrode. Consequently, the magnitude of the touch voltages present during an earth fault are generally considered to be acceptable for a 5 s second-fault duration by virtue of the voltage gradient which occurs between the street furniture and, for want of a better term, true Earth.

16.11.3 Isolation and switching

Regulations 611–03–01 and 611–03–02 state that where the supplier's cut-out is used as a means of isolation for single items of equipment with distribution circuits up to 16 A (as shown in Figure 16.12) or up to the maximum nominal rating of the device, the supplier's express approval is first obtained before the cut-out fuse is used for such a purpose and operation must be restricted to skilled persons and instructed persons. Where more than one circuit emanates from the distribution board or higher loads are involved, a main linked switch or circuit-breaker must be installed for compliance with Regulation 460–01–02.

Some manufacturers market suitable cut-outs and double pole switchfuse units for street furniture and some units are available with built-in facilities for testing purposes and with lockable covers. One such unit has many features including live parts made 'dead' on removal of cover, fuse insertion under load conditions restricted, separate sealing chamber for incoming supply, robust design using insulating material and facilities for locking and testing of Z_e without the necessity of removing covers.

16.11.4 Cable installation and identification

Regulations 611–04–01 to 611–04–04 address the additional requirements for the installation of cables and their identification. Details of the installation, including cables, need to be properly recorded, in accordance with Regulation 514–09–01, and a copy attached to the Electrical Installation Certificate. It is important that records are kept and maintained and this is

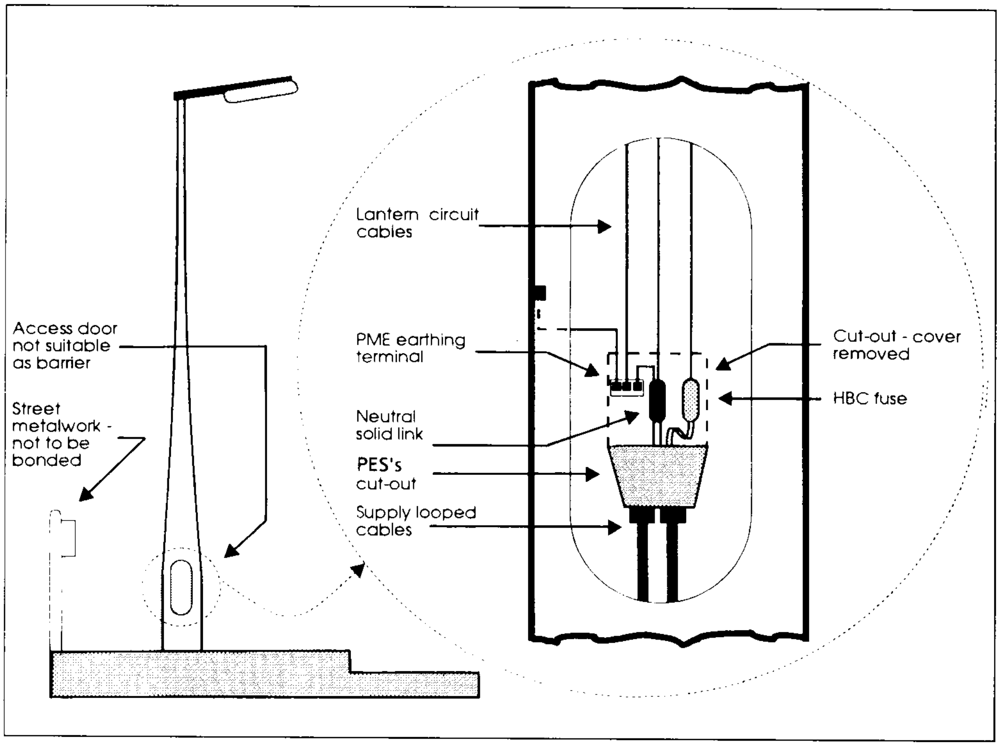


Figure 16.12: Street lighting column connections

crucial for cable networks in order to satisfy the statutory requirements of, *inter alia*, the Electricity at Work Regulations 1989.

Cable installation must be marked with ducting, cable tiles and/or marker tape and must meet the other requirements of Regulation 522–06–03. Where not installed in conduits or ducts, an equal degree of mechanical protection must be afforded as that obtained by such a method of enclosure (e.g. using SWA or insulated concentric type cables).

The general requirements for provision of a periodic inspection and testing and an RCD test notice (Regulations 514–12–01 and 514–12–02) are not essential provided the installation is subject to a planned programme of inspection and testing. The interval between periodic inspections is generally accepted to be between four and six years.

Cable identification must be distinct from the marking of other services and advice on colour coding may be obtained from the National Joint Utilities Group and the Institution of Lighting Engineers' publication *Code of Practice for Electrical Safety in Public Lighting Operations*.

16.11.5 Temporary supplies from street furniture

Where it is necessary to provide temporary supplies from street furniture (e.g. for festive decorations or temporary power supplies for tools), Regulations 611–06–01 and 611–06–02 call for the temporary installation not to impair the safety of the permanent installation. Additionally, a durable label is required, indicating the maximum sustained current required by the temporary installation, to be affixed on or near the temporary supply switchgear.

16.11.6 External influences

Regulation 611–05–02 requires all electrical equipment to have a degree of protection not less than IP33.

Chapter 17

Inspection, Testing, Certification and Reporting

17.1 Inspection, testing, certification and reporting – general

Part 7 of BS 7671 sets out the requirements relating to the inspection and testing of an electrical installation and identifies specific aspects as follows:

- initial verification,
- alterations and additions,
- periodic inspection and testing,
- certification and reporting.

Figure 17.1 identifies the various Chapters, Sections and Regulations of Part 7.

17.2 Test instruments

17.2.1 General

Although international standards exist for test instruments (see IEC 61010 and 61557), it will be the purchaser who will have to evaluate the relative merits of the instruments offered and make a decision on what is best for his/her particular circumstances.

As far as BS 7671 is concerned, some instruments are required to provide certain features but they do not demand a particular accuracy or regular calibration. However, the installation designer may consider it necessary to lay down certain limits in terms of accuracy and resolution. He may also wish to stipulate the requirements for calibration in terms of intervals between calibration and the traceability of the calibration (e.g. calibration traced back to a recognised standard).

Generally speaking, an accuracy, under ideal conditions, of 2% (of full scale deflection) in an analogue instrument and 3% of reading ± digits of a digital instrument is acceptable. However, under field conditions on site the accuracy is going to be much less. Errors can occur due to, for example, ambient temperature difference, operator's skill, high resistance connections (of test leads), low battery or incorrect generator speed, instrument orientation, circuit inductive and capacitive components, induced voltages from other systems, and electromagnetic and electrostatic fields. In all cases, test methods and procedures should be developed to minimise the errors in test results.

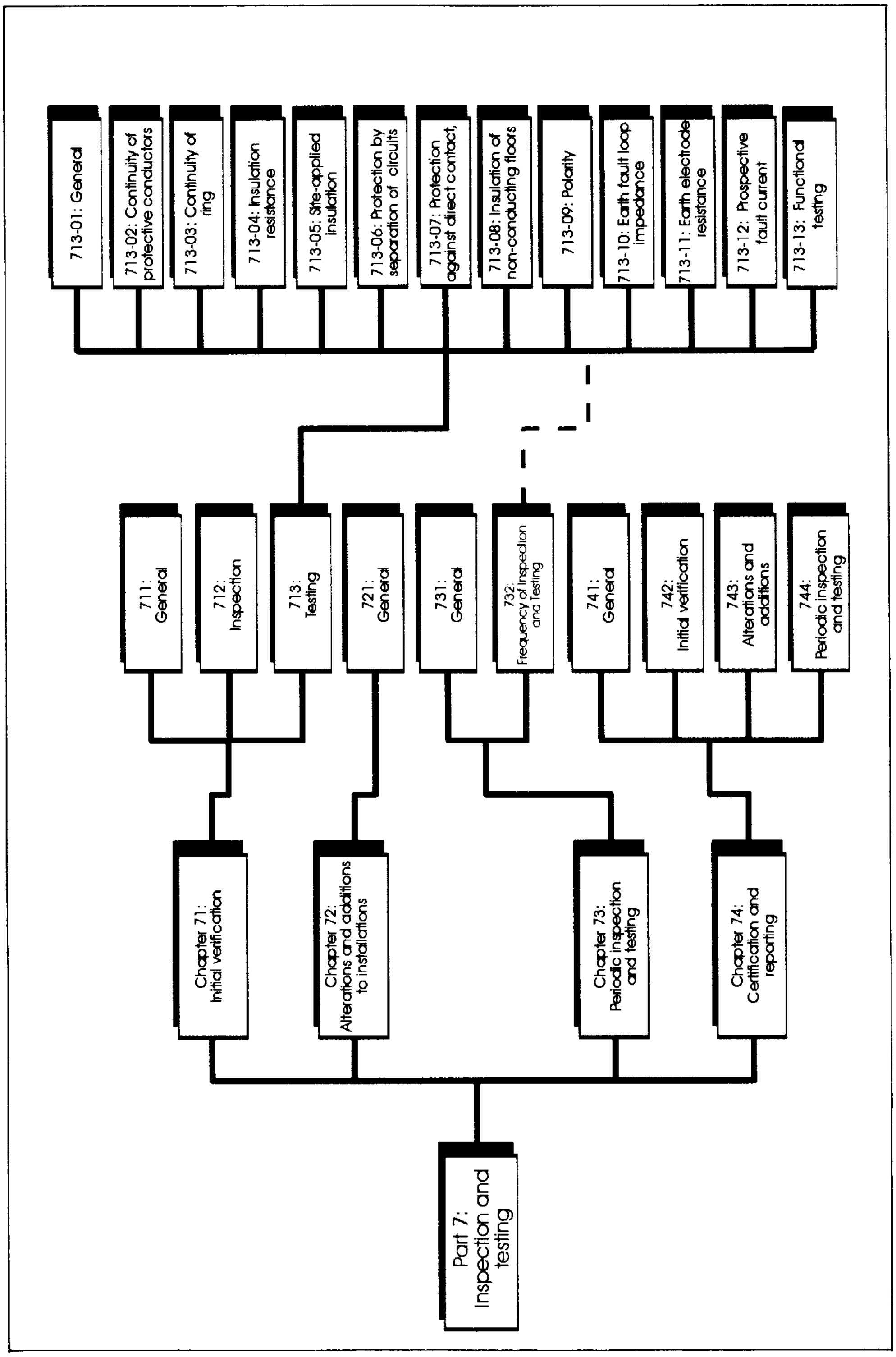


Figure 17.1: Part 7: Inspection and testing

It is essential for the test engineer to be fully versed in the capabilities and limitations of instruments and be aware when a test is likely to create a dangerous situation. As called for in Regulation 711–01–01, a test must not lead to danger to persons and livestock or damage to property and equipment even when the circuit being tested is faulty.

It is considered good practice that a record of test instruments is maintained showing the serial number and the dates of calibration. It can also be advantageous to record the particular instrument(s) used for making tests for certification purposes in order that, should a recorded reading be challenged or give cause for concern later, the particular instrument is traceable. Using such a procedure would also enable other tests (on other installations) undertaken using the same instrument(s) to be checked should there be any doubt about the test results.

17.2.2 Insulation test instruments

Regulation 713–04–02 demands that an instrument for testing insulation must have a d.c. test voltage and be capable of supplying that test voltage (1 kV, 500 V or 250 V, as appropriate to the circuit) when loaded at 1 mA. The latter requirement is to ensure that the test voltage will be delivered when loaded with the equivalent load corresponding to the minimum acceptable insulation resistance (e.g. a test voltage of 500 V applied to a load of 0.5 MΩ produces a current of 1 mA).

It should be noted that most circuits have capacitive components which are charged during the test and the instrument should ideally embody a facility for discharge at the end of the test. Instruments meeting the requirements of the German Standard VDE 01413 Part 1 will meet this criterion. Resolution for these instruments should present little problem with a 100 kΩ resolution being adequate for most applications.

17.2.3 Continuity test instruments

BS 7671 makes no explicit demands for the performance of low resistance test instruments. Normally, a resolution of 10 mΩ will be adequate and ideally the output voltage should be in the range of 3 V to 24 V and the output current should not be less than 20 mA. When testing circuit protective conductors for compliance with Table 41C of BS 7671 a higher resolution may be required depending on the nominal current rating and type of fuse. A four-terminal instrument with a resolution of 1 mΩ will normally be required for such purposes.

When testing protective conductors formed by a steel enclosure such as the metalwork of Class I equipment, steel conduit and trunking and the like, a higher test current is desirable and in such cases the test current should be a.c. so that the inductive reactances as well as the resistance will be measured.

17.2.4 Earth loop impedance test instruments

Again BS 7671 makes no explicit demands for performance of instruments for measuring loop impedances. Generally speaking, an instrument with a resolution of 10 mΩ should be sufficient. Most commercially available instruments make comparative measurements between the no-load voltage and a test circuit loaded with 10Ω and consequently operate with a test current of 20–25 A. The test is normally limited to a duration of approximately four half cycles (40 ms on 50 Hz). From a safety viewpoint the potential on the cpc could rise to dangerous levels (particularly where a defective circuit loop is involved where the potential could rise to phase voltage with respect to earthy parts) and for this reason the instrument would not normally require a test duration exceeding 40 ms.

17.2.5 Applied voltage test instruments

There are no specific regulatory requirements in terms of performance of applied voltage test instruments but the IEE Guidance Notes recommend that the instruments should be capable of steadily increasing the applied voltage and should have an accuracy of about 5%. Unless there is a need for higher test currents, the output current should be limited to 5 mA. The duration of the test should be at least 60 s and the maximum applied test voltage should be 4 kV to accommodate all tests stipulated in BS 7671. As with all testing, the methods and procedures of testing should be such that the risk of electric shock for test personnel and bystanders (and livestock) is kept to a minimum. This is particularly important when test currents exceeding 5 mA are used.

17.2.6 Earth electrode test instruments

BS 7671 itself makes few demands with regard to electrode test instruments. Generally speaking a proprietary make of instrument with a three or four terminal arrangement should be used in order that the resistance of the test leads and test electrode may be evaluated. Instruments may be hand-cranked or powered by batteries including rechargeable ones. Compliance with the German VDE specification is likely to provide all the necessary instrument facilities and safety requirements and ideally, instruments should conform to the requirements of German Standard VDE 0413 Part 7. Resistance ranges from 10 mΩ to 2 kΩ should meet most of the practical test circumstances. Reference to BS 7430 *Code of practice for earthing* will provide additional information relating to earthing electrodes and associated tests.

17.2.7 Residual current device test instruments

BS 4293 and Regulation 713–13–01 require RCD test instruments to test for proper RCD operation at the rated residual current, $I_{\Delta n}$ and at 150 mA, where applicable. Additionally, a test at 0.5 $I_{\Delta n}$ will be desirable. The in-service accuracy of displayed disconnection times should be within $\pm 10\%$ and will depend, to some extent, on supply voltage variations. Some contemporary test instruments have a facility for testing the ‘O’ type, the ‘S’ type and the ‘G’ type RCDs and also have a capability for test initiation at both the start of positive-going or negative-going cycles of the a.c. supply.

17.2.8 Voltage indication

Every test engineer will need some form of voltage indication for, if nothing else, proving a circuit dead. Indicators can be of the form of a voltmeter or other no less effective and reliable device (see also item 17.3 – Safety in electrical testing).

17.3 Safety in electrical testing

Perhaps the most important, and often overlooked, aspect of safety in electrical testing is that of the skill of the operator undertaking the testing. Testing is not a task for the unskilled person and persons engaged in such work must be skilled and have received proper and adequate training relating to procedures and test equipment utilised for the particular testing activity envisaged.

It is essential that test instruments and test leads are maintained in a safe condition and that the test methods do not create danger either for the operator or for other persons or livestock. An unsafe or unsuitable instrument is akin to handling a bomb and it is paramount that instruments are obtained from reputable manufacturers with a good instrument safety record. Test leads are of crucial relevance to safety and, when making voltage measurements on potentially live circuits, should always be fused or fitted with current-limiting devices. Such test lead fuses should be capable of breaking the prospective fault current and be inserted in both leads.

Where tests are required to circuits which have not to be energised, it is always necessary to prove that the circuit is *dead* before applying the test. The Electricity at Work Regulations 1989 preclude ‘live working’ wherever possible and tests involving live conductors should be restricted to those occasions where it is impossible to make the circuit dead or where it is necessary to have the circuit live to perform a test (e.g. earth loop impedance test). Testing generally should be the subject of a well thought out procedure and system of work in order to provide safety for the test engineer and others. HSE Guidance Note GS 38 *Electrical test equipment for use by electricians* provides additional information in this respect. Figure 17.2 indicates some of the safety features required for fused test probes. The International Standard IEC 1010–2–031 addresses the safety aspects of unfused test probes and should be consulted where such probes are being considered for use.

Some environments need special consideration relating to safety of testing. For example, in potentially explosive atmospheres, most generally available instruments will produce sufficient current to ignite potentially explosive gases and vapours. Where testing in such environments is envisaged, the test equipment and procedures are critically important and the test engineer should consult with the instrument manufacturer and the person responsible for safety at the site and indeed, where necessary, the Health and Safety Executive. With regard to petrol filling stations, *Guidance for the design, construction, modification and maintenance of petrol filling stations*, published jointly by the Association for Petroleum Explo-

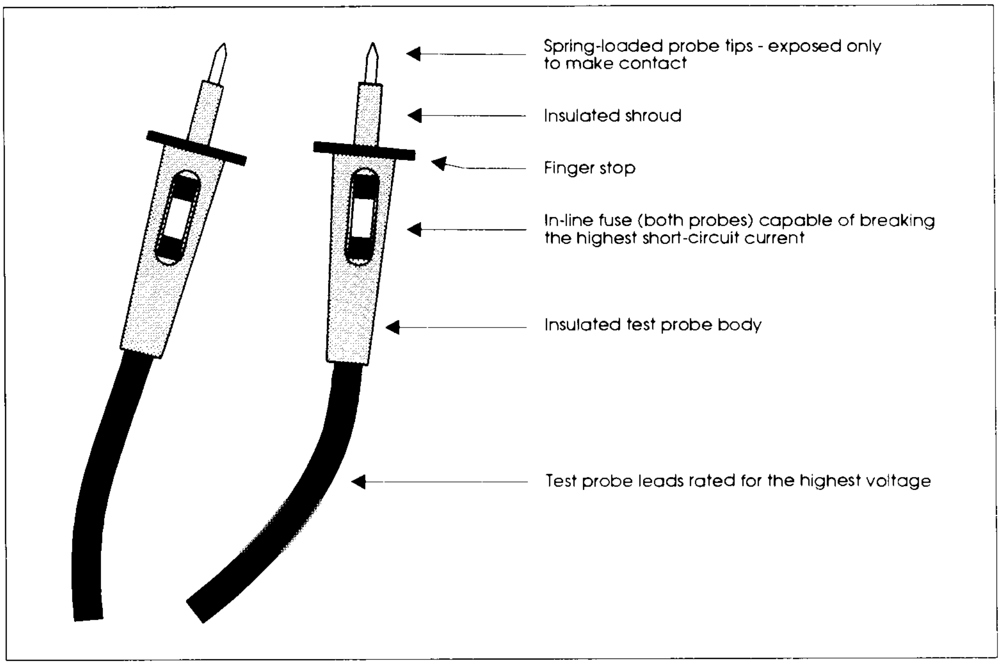


Figure 17.2: Safety features for fused test probes

sives Administration (APEA) and the Institute of Petroleum (IP), is essential reading for the designer, installer and testing engineer involved in such work. Part 14 of that publication deals with the electrical installation aspects including inspection and testing.

17.4 Test methods

17.4.1 General

It is essential that a certain sequence is followed in the testing procedures to minimise the risk of a defective circuit component creating a dangerous condition when a test is made and to ensure that the test results are valid. Most tests can be made without the need for the installation to be energised but some do require the installation to be connected to the supply. The sequences for initial and for periodic testing are different and are identified under the relevant items.

Testing should only be carried out after enquiries have revealed that there are no particular circumstances which could present a danger during such testing. For example, many organic materials, plastics and metal oxides may form explosive dust and some very serious cases of dust explosions have been reported. It is accepted that some dust clouds may be ignited with an electrical arc (spark) of an energy level of as little as 5 mJ. A typical energy level of, for example, a loop impedance test instrument is of the order of 5 J – a thousand times more than the energy level needed for ignition. Instruments are available which are claimed to be intrinsically safe; it should be recognised that this generally relates to arcing within the instrument itself and not to its use or test method.

17.4.2 Insulation tests

The principal purpose of testing the insulation is to verify that there are no inadvertent connections between live conductors and between live and Earth, before the installation is energised. Tests are required (Regulation 713–04–01) between live conductors (e.g. between phases and between phase(s) and neutral) and between all live conductors and Earth. In TN-C systems, the PEN conductor is considered to be part of the earth. Insulation testing does not require the installation, or the part of it under test, to be connected to the electricity supply and the test engineer must ensure that the circuit(s) under test and associated equipment are de-energised and proved to be 'dead' before carrying out any such testing.

As called for in Regulation 460–01–06, provision must be made for disconnecting the neutral conductor from the supply to facilitate the necessary insulation resistance testing between neutral and Earth, which is not possible without such disconnection. As regards testing between conductors, it will be necessary to remove any loads (e.g. lamps, capacitors, inductors, etc.) which are connected between conductors under test in order to avoid obtaining a distorted test value for insulation. As called for in Regulation 713–04–04, any equipment which is likely to be damaged by an insulation test should be disconnected and tested separately by a suitable method. Equipment that would be vulnerable to an insulation test may include, for example, electronic equipment and other solid-state devices, dimmer switches, electronic starters and the like. Regulation 514–09–01 requires vulnerable equipment and circuits to be identified precisely for this purpose. Where vulnerable equipment disconnected for this test is constructed such that it contains exposed-conductive-parts (e.g. metalwork of Class I equipment), Regulation 713–04–04 requires that it is subjected to an insulation test between live parts connected together to protective earth.

The minimum insulation resistances that are acceptable are given in Regulation 713–04–03 and Table 71A of BS 7671 and are summarised, albeit in a somewhat different format, in Table 17.1. Testing of SELV circuits is addressed in item 17.4.8 of this Guide. The normal insulation tests for low voltage systems apply equally to functional extra-low voltage systems.

Where feasible, installations should be tested for insulation resistance as a whole but where this is not possible or desirable the installation should be divided into convenient sections. In any event, tests should be carried out with the upstream supply isolation device in the open position (OFF) with all downstream protective devices (e.g. fuses, MCBs, etc.) in the closed position (ON). It should be remembered that notwithstanding the values given in BS 7671 for minimum insulation resistances, the designer may consider a much higher value is desirable and indeed such low values may

Table 17.1: Minimum insulation resistance values as they relate to circuit nominal voltages

Ref	Type of circuit (or parameter)	Nominal voltage, U_n (V)	Test instrument output voltage (V)	Minimum resistance (MΩ)
A	LV circuit.	$500 < U_n \leqslant 1000$	1000 d.c.	1.00
B	LV circuit (except ELV).	$0 < U_n \leqslant 500$	500 d.c.	0.50
C	SELV and PELV circuits.	$0 < U_n \leqslant 50$	250 d.c.	0.25
D	Functional ELV.	$0 < U_n \leqslant 50$	500 d.c.	0.50

suggest some impending latent defect. Generally speaking, most designers would consider a value of less than 100 MΩ on a final circuit and 10 MΩ on a distribution circuit to be unacceptably low and requiring further investigation.

Referring to Figure 17.3, the sequence of testing the insulation resistance of a three-phase circuit (or group of circuits) may, for example, be

(1) test between red phase and yellow phase,
(2) test between red phase and blue phase,
(3) test between red phase and neutral,
(4) test between red phase and protective conductor,
(5) test between yellow phase and blue phase,
(6) test between yellow phase and neutral,
(7) test between yellow phase and protective conductor,
(8) test between blue phase and neutral,

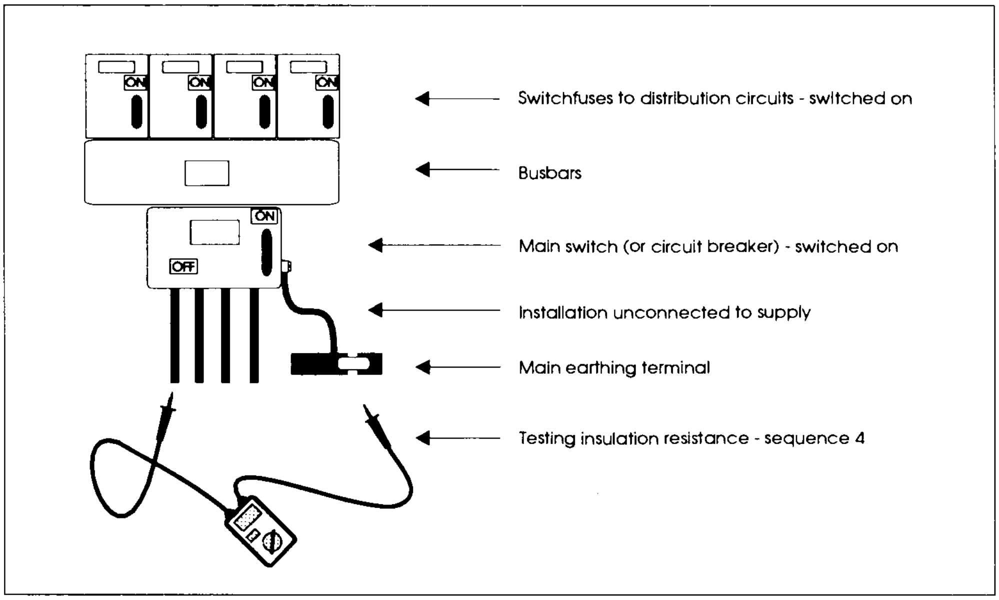


Figure 17.3: Testing insulation

(9) test between blue phase and protective conductor.
(10) test between neutral and protective conductor.

Alternatively, phase conductors may be grouped together for testing insulation to neutral and to protective conductor. For single phase circuits the tests are much simplified and only tests 3, 4 and 10 apply. Where the circuit incorporates two-way or multiple position switching, separate tests are required for each and every switch position (i.e. one test for each location of a switching device with a different switch operated between tests).

17.4.3 Barriers and enclosures

For barriers and enclosures to be effective in providing protection against direct contact they must provide at least the degree of protection IP2X or IPXXB (see Regulation 412–03–01). Additionally, the top horizontal surface of such enclosures and barriers must afford at least IP4X (see Regulation 412–03–02). It goes without saying that all these barriers and enclosure must be properly affixed and secured in place (see Regulation 412–03–03). Regulation 713–07–01 requires a test to be carried out to verify that the necessary degree of protection is provided. This text is applicable only where barriers or enclosures are provided during erection.

Where equipment is the subject of an appropriate British and/or CENELEC Standard and has been subjected to type-testing or partial-type-testing, compliance with the relevant requirements for barriers and enclosures will be assured providing the equipment has been properly installed in accordance with the manufacturer's recommendations. However, where enclosures and barriers have been purposely fabricated and fitted on site, a test is required to determine that these degrees of protection have been met. The test involves the use of the standard finger (see BS EN 60 529 and Figure 17.7). The IP2X degree of protection relates approximately to prevention of insertion of a finger or similar object not exceeding 80 mm long. For IP4X this relates to wires and strips of thickness more than 1 mm and solid objects greater than 1 mm diameter.

In establishing that a barrier or enclosure affords the IP2X or IPXXB protection it is necessary to insert the metallic test finger through the aperture and, in doing so, the finger may be bent through 90° to the axis of the finger with both of the two joints bent in the same direction. This test should use only normal force (not exceeding 10 N) and when it enters the aperture it should be placed in every conceivable position and orientation. An extra low voltage supply of between 40 and 50 V is connected between the live parts of the equipment and the test finger. It is essential that before carrying such a test the supply to the equipment under test is isolated and that the live parts are proved to be dead. Where live conductors have had varnishes, paint or other covering applied to their surfaces, a metallic foil should be applied to such parts before carrying out this test. The protection can only be considered acceptable if the test lamp does not light up during testing in all the positions and on completion the lamp itself must be tested to ensure that it is still in working order.

The test for IP4X is made with a straight rigid steel wire, free of burrs, of between 1.05 and 1.00 mm diameter applied with a force of 1 N ± 10%. The equipment affords the degree of protection if the wire is prevented from entering.

17.4.4 Non-conducting location tests

Protection by non-conducting location is a little-used protective measure which may provide protection against indirect contact under conditions where constant trained supervision can ensure that earthed metalwork is not inadvertently introduced into the location. When so used, Regulation 713–08–01 calls for the resistance of the insulating floors and insulated walls to be tested. The test involves measurements to be taken at not less than three points on each surface, one of which is within 1.0 to 1.2 m from any extraneous-conductive-parts (e.g. pipes) in the location. Figure 17.4 illustrates the test point arrangements.

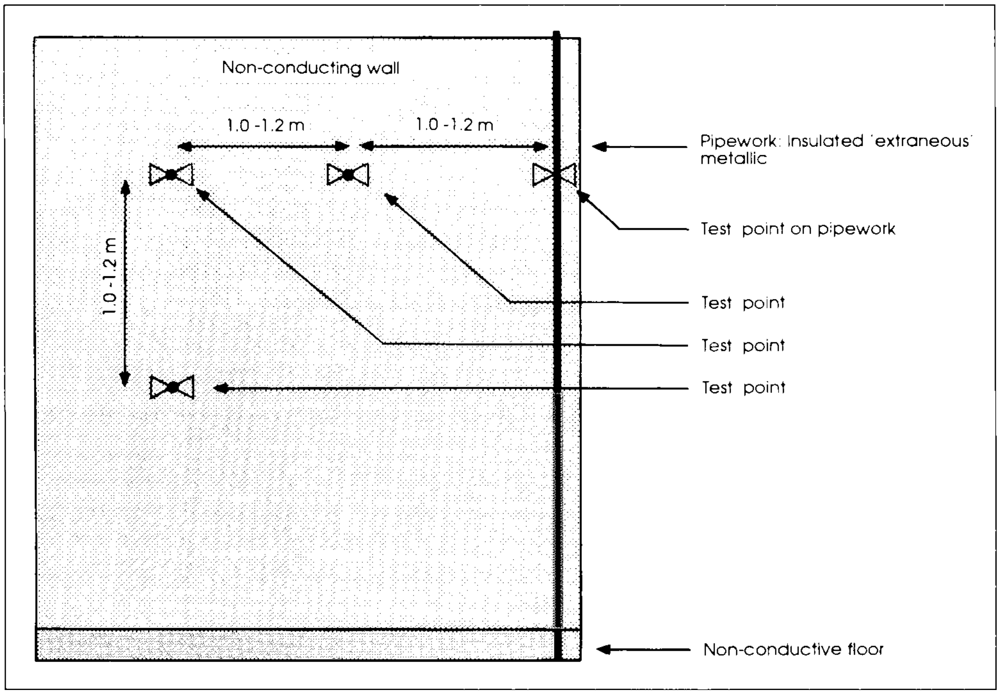


Figure 17.4: Non-conducting wall – example of test point positions

As stipulated in Regulation 413–04–04 the acceptable lower limit for resistances of walls and floors is 50 kΩ for installations operating on voltages not exceeding 500 V and 100 kΩ for operating voltages exceeding 500 V. As called for in Regulation 713–08–02, a resistance value of 500 kΩ for extraneous-conductive-parts is the minimum that is acceptable when tested at 500 V d.c. Where these resistance values are not met, the parts tested (e.g.

walls and floors) must be considered to be conductive and this particular protective measure would be rendered invalid. Where any part, which would otherwise be an extraneous-conductive-part, is insulated an applied voltage test of 2 kV rms a.c. (output current limited to 1 mA) is required. If no flashover is experienced and a further insulation test at 500 V produces a 500 kΩ (minimum) reading the insulation may be considered satisfactory. HV test procedures are similar to those given for site-applied insulation testing.

17.4.5 Polarity tests

Regulation 713–09–01 calls for a polarity test to be carried out to establish that every fuse and every single-pole device (e.g. MCB, switch, etc.) is located in the phase conductor only. Additionally, tests are required to confirm that the polarity of socket-outlets, other accessories and points of utilisation (e.g. luminaires) is correct. Additionally, a check is required to ensure that the centre contacts of Edison Screw (ES) lampholders are connected to the phase conductor though Regulation 713–09–01 exempts E14 and E27 Edison Screw lampholders from this test as there is no safety issue involved for these specific lampholders. Polarity testing must be carried with the supply isolated from the installation or the part of it under test.

There are a number of ways in which polarity can be tested, one of which can be the use of a continuity test instrument (e.g. a low resistance ohmmeter) connected to the outgoing way (at the distribution board) of the circuit under test with a long extension test lead connected to the test instrument and the other test lead probe used to test the various points of the circuit (e.g. switches, luminaires, etc.). Another method would involve the bridging out of the outgoing way in the distribution board and the cpc marshalling terminal block and then making tests between the phase conductor and the earthing terminal of all the points of the circuit (see Figure 17.5 showing the link). There may be instances where testing of polarity can be incorporated in tests relating to other parameters.

17.4.6 Continuity tests

The continuity of every protective conductor must be tested, as called for in Regulation 713–02–01, to verify that it is electrically sound and correctly connected. For protective conductors of 35 mm^2 or less their inductive reactance can be ignored and therefore it is acceptable to test with an instrument with a d.c. output. For protective conductors of greater than 35 mm^2 the inductive reactance becomes significant (i.e. the X:R ratio is much greater) and for these conductors a test instrument with an a.c. output (frequency as that of the installation supply being preferable) is desirable. All such tests are required to be made with supplementary bonding (if any) disconnected from the protective conductor under test.

There are a number of ways in which tests may be carried out, one of which involves the strapping of the earthing terminal block in the distribution board (or consumer's unit) with the outgoing phase conductor of the circuit under test as shown in Figure 17.5. The instrument's test leads

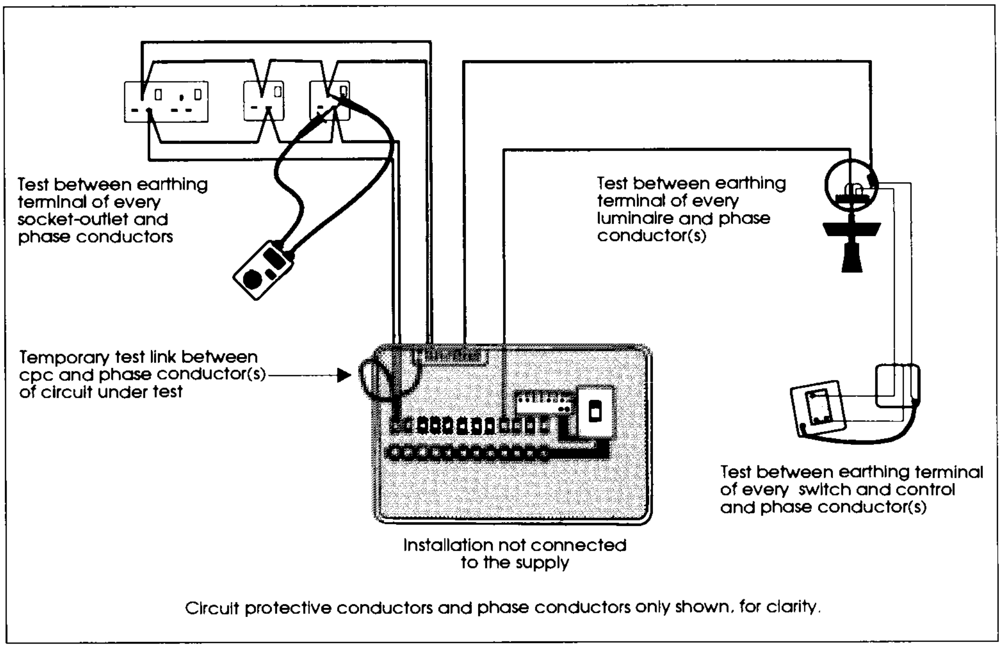


Figure 17.5: Testing protective conductor continuity

should then be applied at points along the circuit including switches, socket-outlets and points of utilisation. The measurement at the extreme end of the circuit will provide the value for (R_1 + R_2) and this should be recorded to verify compliance with BS 7671.

Another equally acceptable method of testing protective conductor continuity is by connecting one test lead to the distribution board's earth terminal and the other to various points along the circuit including the extreme end. This invariably involves the use of an extension lead on one test lead, the resistance of which should be subtracted before the measurement is recorded. This method does not, of course, permit a value to be obtained for (R_1 + R_2) and is more appropriate, for example, for testing equipotential bonding conductors.

For ring final circuits, Regulation 713–03–01 calls for the continuity of each live conductor and the protective conductor to be verified. This is particularly important as even with properly marked cables it is possible to connect, for example, the phase conductors of two different ring final circuits into one outgoing way of a distribution board leaving the two circuits without adequate overcurrent and indirect contact protection. Additionally, it is not unheard of for one or more socket-outlet to be 'lost', for example during plastering, again leading to a potentially dangerous situation through inadequate protection. To test the circuit, phase conductors should be split at the distribution board and the test applied to the ends of the ring. This should then be repeated for the neutral and protective conductor. Any open circuit condition should be investigated further. The (R_1 + R_2) value to the mid-point of the ring may be taken as a quarter of the sum of the values measured for the phase conductor and for the protective conductor.

It must be borne in mind that testing of ring final circuits as described above will not reveal the situation where a ring has been 'bridged' by the connection of a cable between outlets other than from one outlet to the next. The $(R_1 + R_2)$ value obtained by measurement of such a bridged ring circuit would be grossly inaccurate and over-optimistic.

Where a protective conductor is formed by metal conduit, metal trunking, MICC, SWA or other conductive enclosure, continuity tests become extremely difficult because of the fortuitous parallel paths. For this reason the test described above becomes impracticable. This would also apply to the situation where exposed-conductive-parts of equipment (e.g. luminaires) are affixed to parts of the building which themselves provide conductive paths back to the earthing terminal (e.g. steel girders, ceiling tile frames, etc.). Where luminaires are connected by LSC, disconnection for test purposes is fairly easy. Where this is not possible, tests are required to be undertaken before final connection of the luminaires. To test conductive enclosures (e.g. steel conduit) it is necessary to first apply a standard continuity test followed by a careful examination of the earth fault current path back to the earthing terminal of the distribution board. When satisfied that such a path is going to provide a permanent and reliable path, the test engineer may then use a standard phase-earth loop impedance test instrument to the protective conductor with one test lead connected to the phase conductor of the circuit for which the protective conductor is provided and the other test lead applied to the protective conductor. In cases where there is any doubt, a further test will be necessary using an a.c. instrument with output voltage not exceeding 50 V and a test current of 1.5 times the design current (I_b) or 25 A, whichever is the less. It is worth remembering that no test has yet been developed to predict the performance of a fault current path under actual fault conditions. A single strand of flexible cord making a connection between otherwise separated parts of an fault current path would undoubtedly produce good results under a continuity test (low-current test) but would obviously not withstand fault currents which may be of the order of many kA.

An assessment of the circuit lengths of radial circuits may be made from the measured values of R_1 or $(R_1 + R_2)$ using one of the following methods and utilising data given in Table 10.18 of this Guide. First, taking the measured resistance value for a phase (R_1) and dividing by the value given for the particular csa given in Table 10.18, the length in metres may be obtained. Similarly, the same procedure will give the length when the measured value is that of $(R_1 + R_2)$ when the appropriate tabulated value is used. Take a simple example, the $(R_1 + R_2)$ value of a 10/4 mm^2 cable has been measured as 0.4 Ω. From Table 10.18 (Row M) it will be seen that this cable has a $(R_1 + R_2)$ per metre of 6.44 mΩ/m. The circuit length is therefore 62 m ($0.4 \div 0.00644$). These assessments are only valid where the conductor temperature is about 20°C.

Every protective conductor (including equipotential bonding conductors, both main and supplementary) needs testing (Regulation 713–02–01) for continuity. It is important to recognise that the impedance of a conductor is made up of two constituent parts, namely, resistance and inductive reactance. For conductors of csa of 35 mm^2 or less the inductance is small compared with the resistive component (i.e. the ratio X:R is small) and in most cases can be ignored. Conversely, for conductors of csa greater than 35 mm^2 the inductance cannot be ignored as it represents a significant contribution to the impedance. It must also be remembered that resistance, unlike inductive reactance, is a function of temperature.

Where the inductance of a conductor can be neglected, continuity of protective conductors may be carried out using a d.c. test instrument. Where the inductance cannot be ignored an a.c. instrument must be used.

17.4.7 Earth loop impedance and prospective fault current tests

Regulation 713–11–01 calls for a full knowledge of the earth fault path where the protective measure of EEBADS is employed. By implication, this makes a demand for testing loop impedances. Furthermore, where disconnection times of circuits are extended from 0.4 s to 5 s in compliance with Regulation 413–02–12 and where Regulation 413–02–13 is applicable, the impedance of the protective conductors is also required to be measured to confirm compliance with Table 41C of BS 7671.

Tests of the earth loop impedance must be carried out at the most remote end of the circuit (i.e. the longest cable length from the circuit overcurrent protective device). The phase-earth fault loop path is as shown in Figure 17.6. For testing of socket-outlet circuits it is more convenient to use a test

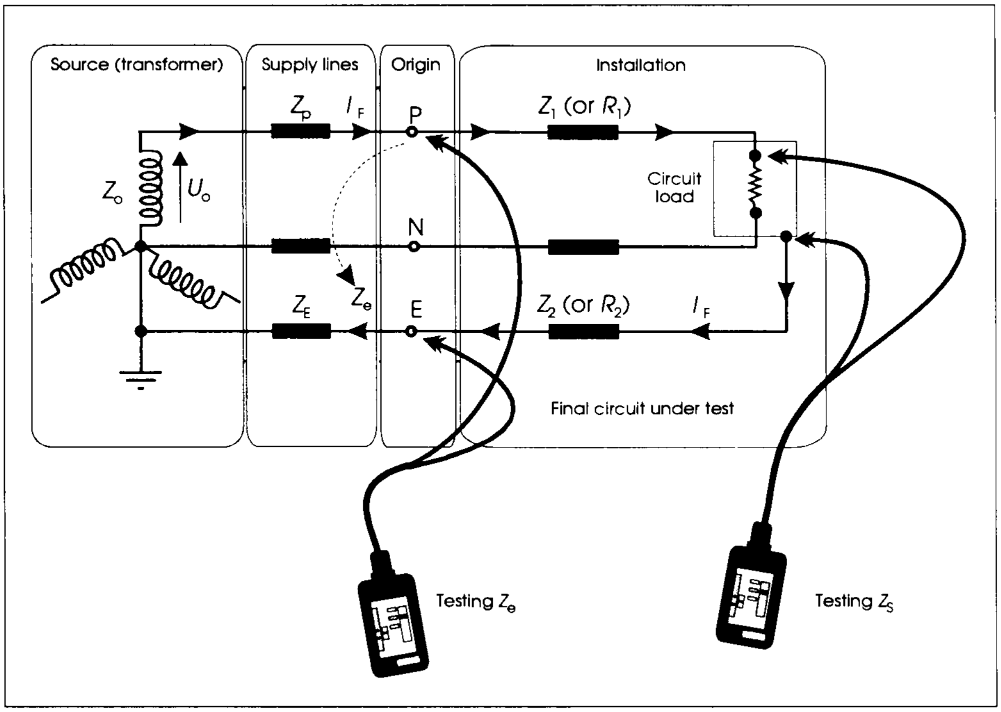


Figure 17.6: Testing earth loop impedance on a TN-S system

lead with an appropriate plug top fitted and it is considered good practice, in addition to the prerequisite tests for continuity of conductors, for every socket-outlet to be tested. For lighting circuits again it is a good idea to test every luminaire and switch in addition to the most remote point of the circuit. For fixed equipment if is often desirable to make a test at the terminals of the load (rather than, say, the local functional or safety switch or control) to ensure that the loop impedance at the actual load will permit disconnection within the prescribed time limits should an earth fault occur on or near the current-using equipment.

It can be seen from Figure 17.6 that measuring the external phase-earth loop impedance, Z_e, involves the partial loop comprising the transformer impedance (Z_o), the impedance of the phase supply line conductor (Z_p) and that of the supply earthing conductor (Z_E) in the TN-S system shown. For a TN-C-S the supply earthing conductor impedance, Z_E, is replaced by that of the neutral. The total loop impedance (Z_s) of a TN-S system is represented by Equation 17.1 and the resultant earth fault current, I_F is given in Equation (17.2) where U_o is the nominal circuit voltage to Earth.

$$Z_s = Z_o + Z_p + Z_1 + Z_2 + Z_E \ (\Omega) \tag{17.1}$$

$$I_F = \frac{U_o}{Z_o + Z_p + Z_1 + Z_2 + Z_E} \text{(A)} \tag{17.2}$$

It should be recognised that the measured value of total earth loop impedance (Z_s) is likely to be less than that which would pertain under fault conditions. The conductors of the loop when tested are going to be at some temperature not exceeding their maximum operating temperature but more likely to be at ambient temperature. In any event the temperature at testing is going to be much less than the maximum final temperature of the conductors under fault conditions. Because the resistance component of impedance is a function of temperature, some correction needs to be made to the values obtained from testing so that a realistic evaluation of Z_s for comparison with Tables 41B1, 41B2 and 41D of BS 7671 (limiting values of Z_s) may be made. The correcting factor will depend to some extent on the relative contributions to the total loop impedance that each part of the whole circuit makes. For example, the fault current will have more effect on the final circuit conductors than on the supply conductors and the distribution circuit (sub-main), if any, though the final circuit conductor impedances may make a minor contribution to the loop impedance. However, the impedance of the final circuit will, in most cases, be a significant contributor to the total loop impedance.

To obviate this potential problem it often makes sense to measure the loop (or more accurately, the partial loop) at the distribution board end of the final circuit where, for most practical situations, this part may be ignored from the aspect of temperature related increase in resistance. This measured value can then be subtracted from the value measured for Z_s with the resultant value representing $Z_1 + Z_2$ which can then be corrected accordingly. For conductors of csa not exceeding 35 mm^2 the inductive reactance may be ignored and ($Z_1 + Z_2$) becomes ($R_1 + R_2$) and can be corrected by applying a correction factor relating to the temperature at which tests are carried out and a correction factor relating to the conductor insulation (see Table 10.18). The temperature correction factor is based on the resistance-temperature coefficient of copper and aluminium conductors taken as 0.004/°C (approximately) taking 20°C as the datum. So for tests carried out at 5°C the correction factor is 1.06 derived as 1 + [(20 – 5) × 0.0004/°C]. Similarly for testing temperatures of 10°C, 15°C, 25°C, and 30°C the correction factors are 1.04, 1.02, 0.98 and 0.96 respectively.

To illustrate by example, take a final circuit of PVC insulated cables (of live conductor csa of 4 mm^2) where, at the circuit overcurrent protective device position, the phase-earth loop impedance has been measured as 0.3 Ω and Z_s (at the load end of the circuit) has been tested as 0.7 Ω. This indicates that the uncorrected value of $(R_1 + R_2)$ is 0.4 Ω (0.7 – 0.3). Had the test been taken at an ambient temperature of 10°C a correcting factor of 1.04 must be applied to the 0.4 Ω previously derived giving $(R_1 + R_2)$ as 0.416 Ω (0.4 × 1.04). Additionally the factor relating to the particular conductor insulating material also needs applying and in this case it is 1.30 (for PVC cable where the cpc does not form part of a composite cable – see Table 10.18). The real value of $(R_1 + R_2)$ under earth fault conditions now becomes 0.54 Ω (0.416 × 1.30) giving a corrected value for Z_s under fault conditions as 0.84 Ω, representing an increase of 20% on the originally tested value.

In many cases where more detailed investigation is unwarranted a rough guide can be used and this may be taken as the measured value of Z_s which represents two thirds (67%) of the true value under fault conditions. In other words, the measured value should be multiplied by 1.5 and then compared with values given in Tables 41B1, 41B2 and 41D of BS 7671 for the appropriate overcurrent protective device. As a guide only, Table 17.2 lists the values of Z_s adjusted to 67% of those given in BS 7671 for comparison with test results. This table should be used with much caution and it should be borne in mind that it is intended as a rough guide only.

It is not unheard of when testing lighting circuits and the like for the earth loop impedance for the test probes to be applied across the phase conductor of a convenient socket-outlet and exposed-conductive-parts of a lighting circuit (e.g. metalwork of a Class I luminaire). Such a test does not measure the phase-earth loop impedance since the loop under test comprises the phase conductor of the socket-outlet circuit and the protective conductor of the lighting circuit. Such a test serves no useful purpose and should not be undertaken because of the obvious risks to safety and the inherent inaccuracies.

Where an installation or a circuit incorporates an RCD it is still necessary to evaluate the phase-earth loop impedance, Z_s, at the remote end of the circuit in order to confirm that the requirements of Regulation 413–02–16 have been met. Equation (17.3) sets out the requirement.

$$Z_s \times I_{\Delta n} \leqslant 50\ \text{V} \tag{17.3}$$

Many loop impedance test instruments will operate (trip) the RCD on phase-earth loop testing before a measurement of Z_s can be taken.

Table 17.2: Anticipated values of earth-loop impedances (Ω) for common circuit protective devices, for indirect contact operating on 230 V under test conditions (67% of limiting values)

Ref	Nominal rating (A)	Fuses								Miniature Circuit-Breakers to BS EN 60 898 or BS 3871					
		BS 88 'gG' Parts 2 and 6		BS 1361		BS 3036		BS 1362(3)		Type 1	Type 2	Type B	Types 3 and C	Type D	Type 4
		0.4 s	5 s	0.4 s	5 s	0.4 s	5 s	0.4 s	5 s	0.1 s and 5 s					
A	5	—	—	7.3	11.4	6.7	12.3	1.7	2.6	8.0	4.6	—	3.8	1.6	0.6
B	6	5.9	9.4	—	—	—	—	—	—	6.7	3.8	5.3	2.6	1.3	0.5
C	10	3.5	5.1	—	—	—	—	—	—	4.0	2.3	3.2	1.6	0.8	0.3
D	13	—	—	—	—	—	—	1.7	2.6	—	—	—	—	—	—
E	15	—	—	2.3	3.5	1.7	3.7	—	—	2.6	1.5	—	1.0	0.5	0.2
F	16	1.8	2.9	—	—	—	—	—	—	2.5	1.4	2.0	1.0	0.5	0.2
G	20	1.2	2.0	1.2	1.9	1.2	2.6	—	—	2.0	1.1	1.6	0.8	0.4	0.1
H	25	1.0	1.6	—	—	—	—	—	—	—	—	—	—	—	—
I	30	—	—	0.8	1.2	0.7	1.8	—	—	1.3	0.7	—	0.5	0.2	0.1
J	32	0.7	1.2	—	—	—	—	—	—	1.2	0.7	1.0	0.5	0.2	0.1
K	40	0.5	0.9	—	—	—	—	—	—	1.0	0.5	0.8	0.4	0.2	0.0
L	45	—	—	0.4	0.6	0.4	1.1	—	—	0.8	0.5	0.7	0.3	0.1	0.0
M	50	0.4	0.7	—	—	—	—	—	—	0.8	0.4	0.6	0.3	0.1	0.0
N	60	—	—	0.2	0.4	—	0.7	—	—	—	—	—	—	—	—
O	63	—	0.5	—	—	—	—	—	—	0.6	0.3	0.5	0.2	0.1	—
P	80	—	0.4	—	0.3	—	—	—	—	0.5	0.2	0.4	0.2	0.1	—
Q	100	—	0.3	—	0.2	—	0.3	—	—	0.4	0.2	0.3	0.1	0.0	—
R	125	—	0.2	—	—	—	—	—	—	—	—	—	—	—	—
S	160	—	0.1	—	—	—	—	—	—	—	—	—	—	—	—
T	200	—	0.1	—	—	—	—	—	—	—	—	—	—	—	—

Notes: (1 The entries denoted by — represent either that the device is not commonly available or that by virtue of its characteristics it is not appropriate for protection against indirect contact.

(2) The impedance values are based on the 'worst case' limits allowed by the relevant Standard and in certain cases where the manufacturer can claim closer limits than the Standard permits the values may be accordingly modified.

(3) The values given for 5 A BS 1362 fuses are those for 13 A fuses because of the ease of replacement by electrically unskilled persons.

However, one can measure the phase-earth loop impedance upstream of the RCD and add the $(Z_1 + Z_2)$ values to this giving a resultant value for Z_s. Where the downstream conductors are of 35 mm^2 or less $(Z_1 + Z_2)$ becomes $(R_1 + R_2)$. In any event there should be no difficulty in meeting this requirement since, for example, even with an RCD with $I_{\Delta n} = 500$ mA, the maximum permitted value of Z_s is 100 Ω.

Appearing for the first time in BS 7671: 2001 is a requirement to measure, or otherwise determine, the prospective short-circuit current and the prospective earth fault current (see Regulation 713–12–01). Often those measurements are beneficially taken at the same time as tests of earth fault loop impedances.

17.4.8 Applied voltage tests

Regulations 713–05–01 and 713–05–02 require that where site applied insulation has been used for protection against direct contact and where protection against indirect contact is provided by supplementary insulation, applied voltage tests must be carried out. For site applied insulation intended to provide protection against direct contact an applied voltage test is required to demonstrate that there is no flashover or breakdown when the equipment is subjected to a test voltage and duration described in the British Standard for similar type-tested equipment. Where there is no applicable British Standard or there are no laid-down test procedures, the applied voltage test must be at 3.75 kV, at the supply frequency, and the test duration should be 60 s. This test is also required where supplementary insulation has been provided for indirect contact protection unless it can be established by use of the BS standard test finger (see BS 3042) that such insulation and or enclosure provides at least the degree of protection IP2X (see BS EN 60 529).

Figure 17.7 shows the British Standard test finger (not to scale) and Figure 17.8 shows some typical applied voltage testing. It should be noted that the test voltage is applied between the live conductors temporarily connected together and a metallic foil closely wrapped around the insulation.

Although not directly concerning the installation designer, it is interesting to note that where protection against indirect contact is provided by separation of circuits, an HV test is required at manufacturing stage, to determine the electric strength capabilities. For example, for a BS 3535 transformer of a rating of 1 kV A the test voltage is applied for 2 s, initially at half full voltage and rapidly rising to full test voltage.

Where SELV is employed a check that the source complies with BS 7671 (e.g. a safety isolating transformer to BS 3535) is necessary before any tests are made. Insulation tests are required between the primary and secondary of the source in order to verify electrical separation. The first test involves the strapping together of the SELV (secondary) conductors and an insulation test, at 500 V, between these conductors and those of the higher voltage conductors (primary) similarly strapped together. The insulation resistance, taken after a period of one minute of applied voltage, should not be less than 5 MΩ for compliance with Table 71A of BS 7671. A second test is now required and this involves applying a test voltage of 3.75 kV for one

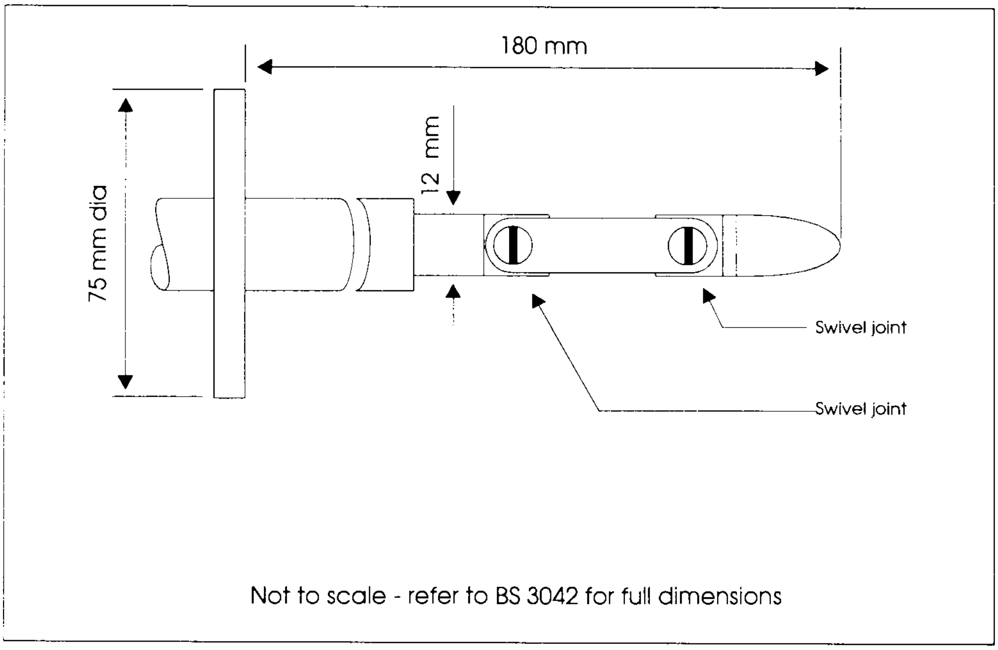


Figure 17.7: British Standard test finger

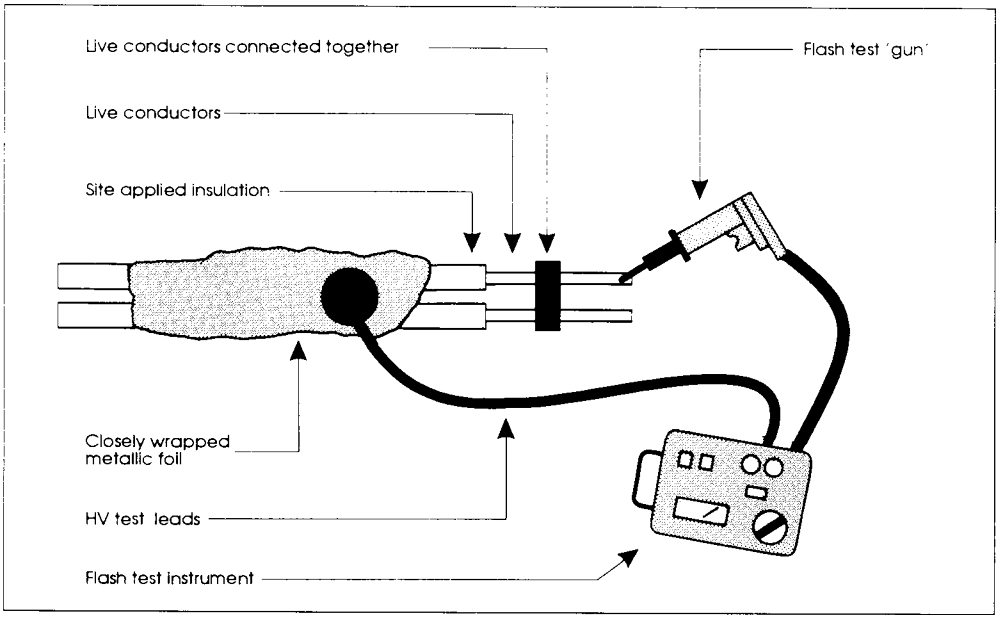


Figure 17.8: Applied voltage testing

minute between the same conductors. A satisfactory outcome is achieved if no flashover or breakdown of insulation occurs during the test. Finally, a further insulation resistance test at 500 V is required, as previously described, and where the resistance is not less than 5 MΩ the electrical separation may be considered satisfactory. These three tests must now be repeated to test the insulation resistance between the SELV conductors and the protective conductor of the higher voltage (primary) circuit.

17.4.9 Earth electrode tests

Testing of earth electrodes is required by Regulation 713–10–01 where the protective measures employed to protect against indirect contact (e.g. in TT and IT systems) dictate a knowledge of that resistance. In practice, this generally applies to installations which form part of a TT system or parts of an installation which employ separate electrodes. The electrode is, in such cases, a critically important constituent part of the protective measure and the designer would need to be satisfied that it is going to provide a permanent and reliable connection to Earth and maintain a sufficiently low resistance during its required lifetime (see Chapter 12 of this Guide).

One method of testing involves the use a four-terminal instrument together with two additional test spikes and is shown in Figure 17.9. The test instrument terminals C1 and P1 are connected to the electrode under test and these connections should be made independently to exclude the

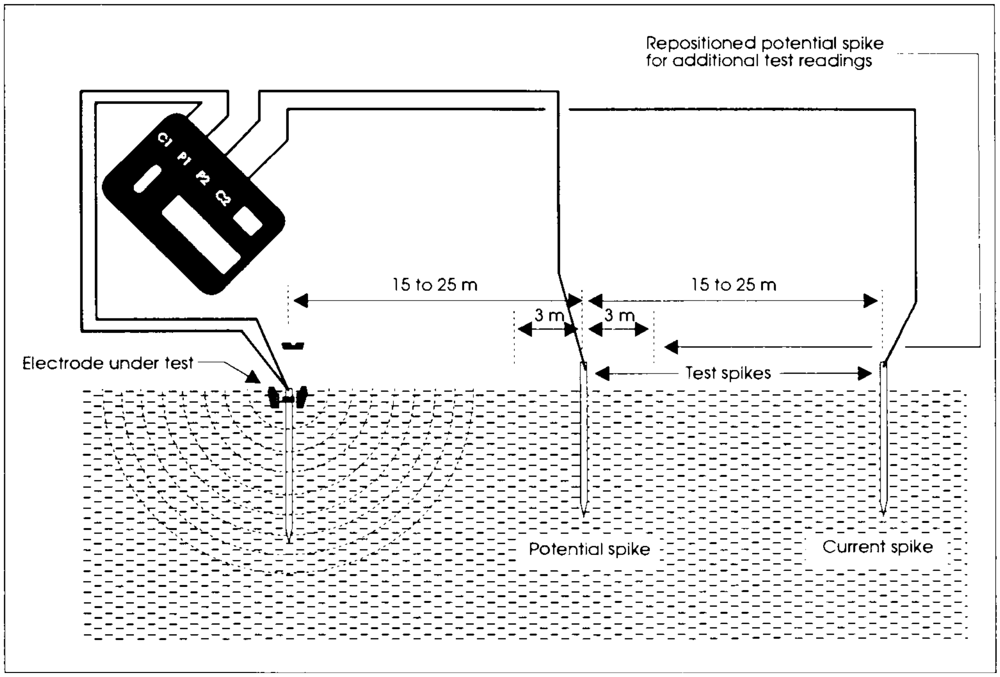


Figure 17.9: Earth electrode testing

resistance of the test leads. Where test lead resistance is insignificant, it is permissible to connect together the terminals (C1 and P1) at the instrument. Terminals C2 and P2 of the instrument are connected to the *potential* spike and the *current* spike respectively. A three-terminal instrument can also be used for this purpose. The output voltage for such instruments is commonly 50 V on open circuit and 25 V applied voltage to the measured loop and at a frequency of 128 Hz. Some instruments operate on reversed d.c. which assists in overcoming problems with electrolytic effects and some instruments incorporate phase-sensitive detectors which minimise the effects of stray currents. Most instruments employ a facility to check the resistance of test spikes. In the interest of safety and reliability of results, it is important when using test equipment to follow the methods and procedures recommended by the instrument manufacturer. Further information is contained in BS 7430 *Code of practice on earthing*.

It is important to position the test spikes so that the effects of overlapping of resistance areas are minimised. Normally this would require the distance between the test spike and the electrode being tested to be not less than ten times the major dimension of the electrode. For example, for a 15 mm diameter 1.2 m deep electrode, the separating distance would be not less than 12 m. However, as a general rule the distances shown on Figure 17.9 should be used where possible in order for the test engineer to have confidence that the test results are reliable.

It is necessary for the three following readings to be taken.

- A measurement is taken with the *potential* spike midway (i.e. 50% of distance) between the electrode under test and the *current* spike giving electrode resistance reading R_1.
- A measurement is taken with the *potential* spike 40% of the distance between the electrode under test and the *current* spike giving electrode resistance reading R_2.
- A measurement is taken with the *potential* spike 60% of the distance between the electrode under test and the *current* spike giving electrode resistance reading R_3.

Provided reliable readings are taken, the resistance of the electrode, R_A, may be taken as the average as given in Equation (17.4).

$$R_\mathrm{A} \simeq R_{\mathrm{A(av)}} = \frac{R_1 + R_2 + R_3}{3} \tag{17.4}$$

where $R_{\mathrm{A(av)}}$ is the average of the three measured resistance values, R_1, R_2 and R_3.

Before finally accepting the resistance value obtained by using Equation (17.4), a check needs to made on the percentage deviation of all the three readings by applying Equation (17.5).

$$\text{Percentage deviation} = \frac{\textit{electrode reading} - R_{\mathrm{A(av)}}}{R_{\mathrm{A(av)}}} \times 100 \tag{17.5}$$

If the deviation in any of the three readings from the average is less than 5% the readings may be regarded as reliable. If not, the tests should be repeated with a greater separation between the electrode under test and the current spike until a more reliable measurement is made.

As an alternative method where an installation forms part of a TT system and employs RCDs for protection for the whole of the installation (which is normally the case), it is permissible (as stated in the IEE Guidance Note No 3) to use an earth-loop impedance test instrument to measure the total phase-earth loop impedance, Z_s. As the resistance of the earth electrode, R_A, is much greater than that of other constituent parts of the loop, the measured Z_s may be taken as being equal to R_A. It is necessary for the supply to be energised for this test which involves a measurement using the test probes of the loop impedance test instrument between the supply side of the main switch and the MET which is connected to the electrode by the earthing conductor. Before a test is made the test engineer must ensure that the supply to the installation is OFF and the main equipotential bonding conductors are disconnected from the MET. The measured value multiplied by the residual operating current, $I_{\Delta n}$, of the RCD should not exceed 50 V (see Table 5.10). On completion of testing, the equipotential bonding conductors must be reconnected to the MET *before* the installation is energised.

In practice, in most locations in the UK the necessary earth electrode resistance will be met with ease. However, where values of 200 Ω or more are found, further efforts should be made to reduce this value by the use of additional rods and/or longer rods or the possibility of using plates should be considered. Electrodes with resistance exceeding this value should be considered unreliable and prone to instability.

17.4.10 Residual current device tests

Where RCDs form part of the installation whether they be for the protection against indirect contact or for supplementary protection against direct contact or both, it is a requirement of Regulation 713–13–01 that such devices must be tested. This test is in addition to the test carried out by the use of the manual test button incorporated within the RCD which, as previously mentioned, only tests the mechanism which does not include external parts such as protective conductors and earth electrode. Before RCD testing is contemplated, other prerequisite testing must have been carried out and any connected loads either disconnected or switched off.

Using an RCD test instrument (as previously referred to), the test is made using the instrument's probes connected to the phase conductor on the load side of the RCD and the associated protective conductor again on the load side, as shown in Figure 17.10 or by using the test instrument fitted with a test lead plug and inserted into a convenient socket-outlet. The test results should meet those laid down in BS 4293 and other Standards which are summarised in Table 17.3.

17.4.11 Separation of circuits

Where the protective measure of SELV is employed, Regulation 713–06–01 requires that compliance with Regulations 411–02–05 to 411–02–11 and 'application' Regulation 471–02–01 is verified by inspection and test. It must

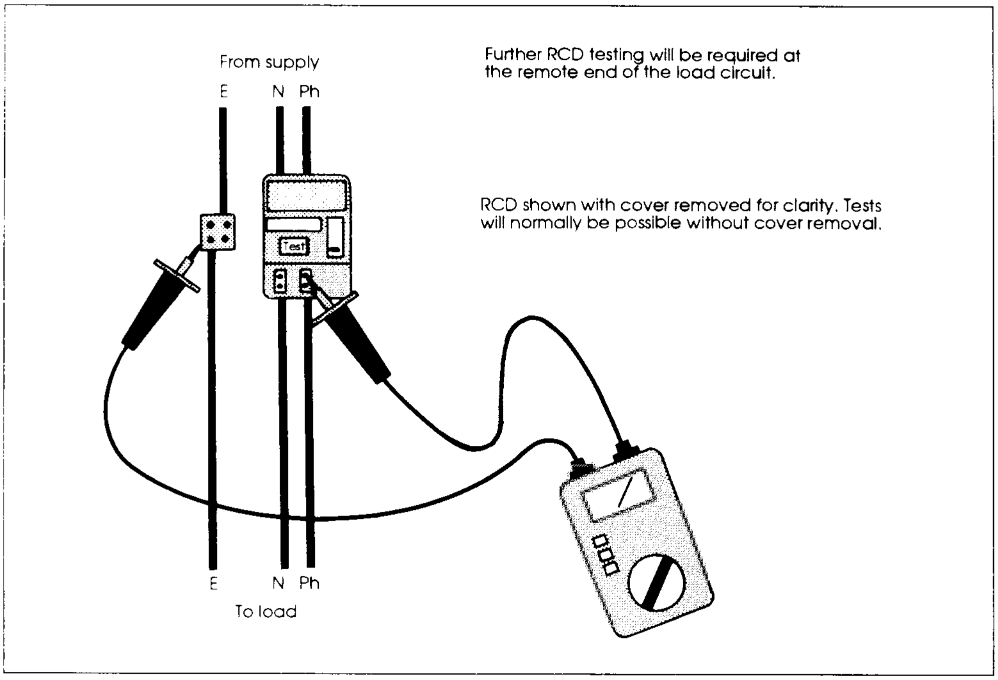


Figure 17.10: RCD testing

be confirmed that the nominal voltage concerned does not exceed extra low voltage (50 V a.c. or 120 V ripple-free d.c.) and that the source complies with Regulation 411–02–02 (e.g. a safety isolating transformer to BS 3535). All the remaining requirements embodied in these Regulations need to be confirmed as being met (see item 5.2.2 of this Guide). As with SELV, Regulation 713–06–02 makes similar requirements with regard to circuits which use electrical separation (see items 5.4.10 and 17.4.8 of this Guide).

17.5 Initial verification

17.5.1 General

As required by Regulation 711–01–01 every installation must be inspected and tested during erection and on completion before it is put into service and verified as being compliant with all the relevant requirements of BS 7671. In order that the person may carry out such verification it is necessary for him to have available all the initial design data relating to the assessment of general characteristics which is summarised in Table 17.4.

17.5.2 Inspection

It is essential that a detailed inspection is carried out prior to testing with the installation (or any part of it being inspected) isolated from the supply to meet the requirements of Regulation 712–01–01. Tables 17.5 to 17.19

Table 17.4: Information required by the person carrying out the initial verification

Ref	Regulations		Information required
A	711-01-02	311-01-01	Maximum demand of the installation.
B	711-01-02	312-02-01	The number and type of live conductors.
C	711-01-02	312-03-01	Type of earthing arrangement.
D	711-01-02	313-01-01	Nominal voltage(s).
E	711-01-02	313-01-01	The nature of current and frequency.
F	711-01-02	313-01-01	The prospective fault current at the origin (short-circuit and earth fault currents).
G	711-01-02	313-01-01	The external phase-earth loop impedance, Z_e.
H	711-01-02	313-01-01	The suitability of the supply for the particular installation.
I	711-01-02	313-01-01	The type and nominal rating of the overcurrent protective device at the origin.
J	711-01-02	514-09-01	A diagram, chart or table providing adequate information relating to the type and composition of each and every circuit including points of utilisation, number and size of circuit conductors and type(s) of wiring system.
K	711-01-02	514-09-01	Information relating to the identification of every device and their location, providing protection and isolation and switching.
L	711-01-02	514-09-01	Information and identification of any circuit and/or any equipment liable to damage by a typical test.
M	711-01-02	514-09-01	Identification of the method used for, and means of, compliance with Regulation 413-02-04 (protection against indirect contact)

—Notes:
(1) Maximum test duration.
(2) Maximum time permitted for operation of RDC under type-test conditions.
(3) Necessary where RCD provides supplementary protection against direct contact (see Regulation 412–06–02).
(4) Where time-delayed RCDs are used the operating time should not normally exceed 2 s.

Table 17.4: Information required by the person carrying out the initial verification

Ref	Regulations		Information required
A	711-01-02	311-01-01	Maximum demand of the installation.
B	711-01-02	312-02-01	The number and type of live conductors.
C	711-01-02	312-03-01	Type of earthing arrangement.
D	711-01-02	313-01-01	Nominal voltage(s).
E	711-01-02	313-01-01	The nature of current and frequency.
F	711-01-02	313-01-01	The prospective fault current at the origin (short-circuit and earth fault currents).
G	711-01-02	313-01-01	The external phase-earth loop impedance, Z_e.
H	711-01-02	313-01-01	The suitability of the supply for the particular installation.
I	711-01-02	313-01-01	The type and nominal rating of the overcurrent protective device at the origin.
J	711-01-02	514-09-01	A diagram, chart or table providing adequate information relating to the type and composition of each and every circuit including points of utilisation, number and size of circuit conductors and type(s) of wiring system.
K	711-01-02	514-09-01	Information relating to the identification of every device and their location, providing protection and isolation and switching.
L	711-01-02	514-09-01	Information and identification of any circuit and/or any equipment liable to damage by a typical test.
M	711-01-02	514-09-01	Identification of the method used for, and means of, compliance with Regulation 413-02-04 (protection against indirect contact)

Table 17.5: Examples of installation items requiring inspection (see Regulation 712-01-03)

Ref	Item	See Section$^{(1)}$	Comment
A	Connection of conductors.	526	Applicable to all installations.
B	Identification of conductors.	514	Applicable to all installations.
C	Cables routed through 'safe' zones or mechanically protected.	522	Applicable to all installations.
D	Conductors suitable for current-carrying capacity.	433	Applicable to all installations.
E	Conductors suitable for voltage drop.	525	Applicable to all installations.
F	Connection of single-pole switching devices (including fuses) in phase conductor only (unless linked).	530	Applicable to all installations.
G	Connection of socket-outlets (including polarity).	General	Applicable to all installations.
H	Connection of ES lampholders (including polarity).	553	Applicable to all installations.
I	Connection of track lighting (including polarity).	553	Applicable to all installations.
J	Presence of fire barriers and suitable seals.	527	Applicable to all installations.
K	Protection against thermal effects.	422	Applicable to all installations.
L	Direct contact protection by insulation of live parts.	412	Applicable to all installations.
M	Direct contact protection by barriers and enclosures.	412	Applicable to all installations.
N	Direct contact protection by obstacles, where applicable.	412	Applicable only to installations where this measure has been employed.
O	Direct contact protection by placing out of reach, where applicable.	412	Applicable only to installations where this measure has been employed.
P	Indirect contact protection – presence of earthing conductor.	542	Applicable only to installations where EEBADS has been employed.
Q	Indirect contact protection – presence of protective conductors.	543	Applicable only to installations where EEBADS has been employed.
R	Indirect contact protection – presence of main equipotential bonding conductors.	547	Generally applicable to installations where EEBADS has been employed, but also see electrical separation (Regulation 413-06).
S	Indirect contact protection – presence of supplementary equipotential bonding conductors.	547	Generally applicable only to installations where EEBADS has been employed, but see also earth-free equipotential bonding (Regulation 413-05).
T	Indirect contact protection – presence of suitable combined functional and protective conductors.	546	Applicable only to installations where EEBADS has been employed.
U	Indirect contact protection – proper use of Class II equipment.	413	Applicable only to installations where this measure has been employed.
V	Indirect contact protection – proper use of non-conducting location.	413	Applicable only to installations where this measure has been employed.
W	Indirect contact protection – proper use of earth-free equipotential bonding.	413	Applicable only to installations where this measure has been employed.
X	Indirect contact protection – proper use of electrical separation.	413	Applicable only to installations where this measure has been employed.
Y	Prevention of mutual detrimental influences.	515	Applicable to all installations.
Z	Suitable devices for isolation and switching.	537	Applicable to all installations.

Continued on facing page

Table 17.5 continued: Examples of installation items requiring inspection (see Regulation 712-01-03)

Ref	Item	See Section$^{(1)}$	Comment
A1	Suitable devices for undervoltage protection.	451	Applicable to all installations.
B1	Suitable rated (or setting) of overcurrent protective and monitoring devices.	533	Applicable to all installations.
C1	Suitable rated (or setting) of protective devices for protection against indirect contact.	531	Applicable to all installations.
D1	Adequate access to equipment and switchgear.	513	Applicable to all installations.
E1	Equipment suitable for external influences.	522	Applicable to all installations.
F1	Protective measures suitable for external influences.	522	Applicable to all installations.
G1	Suitable equipment erection methods.	510	Applicable to all installations.
H1	Proper identification of switchgear.	514	Applicable to all installations.
I1	Proper identification of circuits, fuses, switches and terminals.	514	Applicable to all installations.
J1	Presence of voltage warning notices.	514	Applicable to all installations.
K1	Presence of isolation and danger notices.	514	Applicable to all installations.
L1	Presence of diagrams and instructions.	514	Applicable to all installations.

Note: (1) Reference to BS 7671 sections includes only the most appropriate; reference to the particular Regulation will also be necessary.

summarise some of the many facets of inspections which are demanded by Regulations 712–01–02 and 712–01–03. Whilst it is not possible to list all aspects for inspection on every installation, the tables may serve as a useful *aide mémoire* for the inspector who should appreciate that the listings are not exhaustive and should be supplemented with additional items where appropriate. Inspections should of course be made on completion but, under close supervision, these can be done, in part at least, as the work progresses provided detailed records are maintained. Table 17.5 sets out the items mentioned in Regulation 712–01–03 which need to be included for inspection. Not all the items will apply to every installation and in some cases additional items may need to be included.

Tables 17.6 to 17.19 relate to specific aspects of the typical installation, where the method of protection against indirect contact is EEBADS, as follows:

- Table 17.6 General check list for equipment,
- Table 17.7 Check list for switchgear,
- Table 17.8 General check list for cables and conductors,
- Table 17.9 Check list for flexible cables and cords,
- Table 17.10 Check list for protective devices,
- Table 17.11 Check list for conduit systems,
- Table 17.12 Check list for trunking systems,
- Table 17.13 Check list for lighting points of utilisation,
- Table 17.14 General check list for accessories,
- Table 17.15 Check list for lighting switches,
- Table 17.16 Check list for socket-outlets,
- Table 17.17 Check list for joint boxes
- Table 17.18 Check list for cooker control units and fused connection units,
- Table 17.19 Check list for protective conductors.

Table 17.6: General check list for items of equipment that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	511-01-01	Equipment correctly selected and affords compliance with the relevant British Standard or harmonised European Standard.
B	511-01-01	Equipment correctly selected for atmospheric and temperature conditions (see BS 5345).
C	130-01-01	Equipment correctly selected for environmental conditions (including external influences). See BS EN 60 529 for IP requirements.
D	130-01-01	Equipment not been damaged or is not otherwise defective.
E	130-01-01	Equipment installed in a good workmanlike manner.
F	Section 412	All necessary provisions for protection against direct contact have been effected.
G	513-01-01	Equipment accessible for operation, inspection and maintenance.
H	527-02-01 to 527-02-03	Equipment provided with fire barriers, as necessary.
I	Chapter 42	Equipment protected from thermal effects.
J	515-01	Equipment protected against mutual detrimental influences.
K	130-02-02	Equipment correctly selected in terms of rated current - see BS 5486 and BS EN 60 439 - and is suitable for the ambient temperature.
L	413-02-06 413-02-18	Equipment properly earthed (see also Chapter 54 of BS 7671).
M	130-01-01	Equipment properly fixed and is secure.
N	461-01 476-02	Adequate means of isolation.
O	462-01	Adequate means of switching off for mechanical maintenance.
P	463-01 476-03	Adequate means of emergency switching.
Q	510-01-01	Equipment voltages properly identified.
R	514-01-01	Equipment properly identified as to purpose.
S	512-01-01	Equipment suitable for voltages present.
T	514-11-01	Equipment properly identified for isolation purposes where isolation is required by more than one device.
U	514-12-01	Periodic test notice affixed.
V	514-12-02	RCD test notice affixed, where appropriate.
W	521-02-01	Due consideration paid to electromagnetic effects.
X	521-03-01	Due consideration paid to electromechanical stresses.
Y	515-01-01 515-01-02	Circuits segregated as required to prevent mutual detrimental influences.
Z	528-01-01 to 528-01-07	Circuits segregated from other electrical services as required.
Z1	528-02-01 to 528-02-06	Circuits segregated from non-electrical services as required.
Z2	515-01-01 515-01-02	There are no mutual detrimental influences between electrical and non-electrical services (see also Section 528 of BS 7671).

The detailed inspection envisaged by Regulation 712–01–02 is threefold in purpose. First, the inspection must determine that the equipment complies with Section 511 of BS 7671 in that it conforms to the relevant Standard confirmed by suitable marking or certificate provided by the equipment manufacturer or installer. Secondly, the inspection must confirm that the equipment has been correctly selected and installed in such a manner as to provide conformity with the requirements of BS 7671. Finally, the inspection is intended to identify equipment which has been damaged

Table 17.7: Check list for items of switchgear that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	Chapter 53	Switchgear correctly selected and installed.
B	130-01-01	Switchgear meets the appropriate Standard(s) (see BS 4752, BS 5486, BS 5345 and BS EN 60 439).
C	130-02-02	Switchgear correctly selected in terms of rated current – see BS 5486 and BS EN 60 439 – and is suitable for the ambient temperature.
D	Chapter 46 Section 476	Isolation, switching for mechanical maintenance and emergency switching requirements met as necessary.
E	413-02-06 413-02-18	Switchgear properly earthed (see also Chapter 54 of BS 7671).
F	130-01-01	Switchgear properly fixed and is secure.
G	412-01-01	Adequate protection against direct contact with live parts.
H	471-06-01	Where protection against direct contact is provided by obstacles, restriction to skilled and/or instructed persons is evident.
I	471-07-01	Where protection against direct contact is provided by placing out of reach, restriction to skilled and/or instructed persons is evident.
J	530-01-02	Single pole devices in phase conductor only.
K	522-08-01	No sharp edges to damage cable insulation etc.
L	531-01-01	Protective devices correctly selected and installed.
M	513-01-01	Switchgear accessible for operation, maintenance and testing.
N	514-01-01	Switchgear properly identified as to purpose.
O	514-10-01	Switchgear properly selected as to voltages present.
P	601-08-01	Switchgear not accessible to a person using a bath or shower.
Q	412-03-01 412-03-02 Section 522	Degree of protection (IP) is appropriate.
R	461-01 476-02	Adequate means of isolation.
S	462-01	Adequate means of switching off for mechanical maintenance.
T	463-01 476-03	Adequate means of emergency switching.
U	537-04-06	Fireman's switch installed where required.
V	537-04-04	Emergency switches suitably colour identified.
W	514-11-01	Switchgear properly identified for isolation purposes where isolation is required by more than one device.
X	514-08-01 514-09-01	Adequate diagrams, instructions for circuit and protective device identification.
Y	514-09-01	Vulnerable equipment and circuits identified.
Z	514-12-01	Periodic inspection and testing notice has been affixed on or near main switchgear.
Z1	130-01-01	Where applicable, check cable glands and gland plates have been correctly selected and installed (see BS 6121).
Z2	543-02-05	Where switchgear, trunking, conduit and cable sheaths or armouring have been used as a protective conductor, the requirements of Regulation 543-02-04 have been satisfied.

or is otherwise defective so as to compromise safety.

Certain specialised installations are not only subject to the requirements of BS 7671 but also those contained within the relevant British Standard or Code of Practice, which are listed in Table 17.20.

17.5.3 Testing

Initial testing of an electrical installation is essential not least to enable the verifying engineer to sign the Electrical Installation Certificate with

Table 17.8: General check list for cables and conductors that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	511-01-01 521-01-01	Cables have been correctly selected for the particular circumstances and that they are compliant with the relevant Standard.
B	512-06-01 512-06-02	Suitable for all external influences, e.g. temperature, water, corrosive substances, mechanical stresses, flora and fauna, solar radiation and building structural design.
C	523-01-01	Correctly current rated.
D	525-01-01	Voltage drop not excessive.
E	311-01-01	Diversity correctly applied.
F	526-03	All connection enclosed.
G	527-02	All necessary sealing of wiring system penetrations has been effected.
H	522-06	All cables either run in 'safe' zones or suitably mechanically protected.
I	523-04-01	Where run in thermal insulation, suitably derated.
J	523-01-01	Conductor operating temperature not exceeding that given in Table 52B of the Wiring Regulations.
K	524-01-01	Conductor cross-sectional area is not less than that given in Table 52C of the Wiring Regulations.
L	522-06-01 522-08-01	Protected against mechanical damage including abrasion and suitable for location.
M	522-08-05	Cables adequately supported.
N	130-01-01	Cable glands correctly selected and fitted.
O	522-01-01	Suitable for the highest and lowest temperatures.
P	521-07-03	Non-sheathed cables enclosed in conduit, trunking, etc.
Q	514-03-01	Core colour identification of protective conductors (green/yellow).
R	514-06-02	The single colour green has not been used.
S	514-06-01	Core colour identification of live non-flexible cables and conductors (see also Table 51A of BS 7671).
T	514-07-02	The single colour green or single colour yellow or any bi-colour other than green/yellow has not been used as a protective conductor in a flexible cable or flexible cord.
U	130-01-01	Where applicable, cable glands and gland plates have been correctly selected and installed (see BS 6121).
V	521-01-01	Correct selection and installation of cables (see Appendix 4 of BS 7671).
W	543-02-05	Where required, MICC earth-tail pots have been correctly fitted.
X	314-01-04	Check that circuits are separate, e.g. no 'borrowed' neutrals.
Y	522-11-01	Where exposed to direct sunlight, of suitable type.
Z	522-03-01	Where exposed to water, of suitable type.
A1	528-02-06	Unless forming part of the lift installation complying with BS 5655, cables not run in lift shaft.
B1	Deleted	Deleted.
C1	546-02	Earthed concentric wiring used only as permitted.
D1	514-06-01 Table 51A	Fixed wiring phase conductors identified red, neutral conductors black and switched phase conductors (switchwires) red and protective conductors green/yellow.
E1	543-03-02	Bare protective conductors of composite cables covered with green/yellow sleeving, to BS 6004 or BS 7211, at terminations.
F1	543-02-07	Where protective conductor formed by conduit, trunking, etc., a 'fly lead' linking the wiring system protective conductor to the earthing terminal of the accessory is provided.
G1	526-03-03	Unsheathed cores of cables contained within enclosure.
H1	522-08-05	Where applicable, cord grips properly utilised.
I1	526-01-01	All conductor terminations tight.
J1	526-01-02	All strands of conductor properly terminated.
K1	Appendix 4	Cables correctly installed to appropriate installation method and having sufficient current-carrying capacity and within voltage drop constraints.

Table 17.9: Check list for flexible cables and cords that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	514-07-01	Core identification of flexible cords and flexible cables with Table 51B.
B	514-07-01	Cores of flexible cords and flexible cables are identified through their length.
C	514-07-02	The single colour green or single colour yellow or any bi-colour other than green/yellow has not been used.
D	130-01-01	Where applicable, cable glands and gland plates have been correctly selected and installed (see BS 6121).
E	514-07-01 Table 52A	Flexible cables and cords phase conductors identified brown, neutral conductors blue (or black in 4 and 5 cores) and protective conductors green/yellow. All identified throughout their length.
F	526-03-03	Unsheathed cores of cables and cords contained within enclosure.
G	522-08-05	Where applicable, cord grips properly utilised.
H	526-01-01	All conductor terminations tight.
I	526-01-02	All strands of conductor properly terminated.
J	554-01-01	When used to suspend luminaires, suitable for the suspended mass.

Table 17.10: Check list for protective devices that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	511-01-01 432-01-01	Protective devices correctly selected and are compliant with the relevant Standard.
B	432-03-01	Protective devices have adequate short circuit capacity (e.g. 'M' or 'S' rating).
C	433-02-01	Protective devices correctly selected with regard to load current and current-carrying capacity of connected conductors.
D	413-02-11	Where MCBs, the correct type.
E	432-03-01	Overload protection is afforded, where applicable.
F	432-04-01	Fault current protection is afforded, where applicable.
G	413-02-04	Protection against electric shock (indirect contact) is afforded, where applicable.
H	413-02-08	Disconnection times are likely to be met.
I	533-01-06	There is discrimination between overcurrent devices in series.
J	531-02-09	There is discrimination between RCDs in series.
K	412-06-02	RCDs have been installed where they are necessary – supplementary protection against direct contact.
L	413-02-07	RCDs have been installed where they are necessary – TN systems.
M	413-02-19	RCDs have been installed where they are necessary – TT systems.
N	413-02-22	RCDs have been installed where they are necessary – IT systems.
O	471-16-01 471-16-02	RCDs have been installed where they are necessary – supplies for portable equipment outdoors.
P	608-03-02	RCDs have been installed where they are necessary – caravans.
Q	608-13-05	RCDs have been installed where they are necessary – caravan parks.
R	314-01-01	Neutral conductors and circuit protective conductors are in an easily identifiable sequence related to the associated phase conductor(s).
S	514-09-01	Identification of protective devices is adequate.
T	526-01-01 526-02-01	Conductor connections are tight and connect all conductor strands.

Table 17.11: Check list for conduit systems that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
Conduits generally		
A	511-01-01 521-04-01	Complies with the relevant Standard (BS 31, BS 4568, BS 4607, BS 6099 Part 1 or Part 2 Section 2.2).
B	514-02-01	Where required to be distinguishable from other services, identified in accordance with BS 1710.
C	522-08-02	Adequate means of access (drawing-in boxes) and, if sunken, complete before circuit cables are installed.
D	522-08-05	Fixings made securely and spacings between fixings not excessive (see Chapter 10 of this Guide).
E	522-06-01	Protected against impact.
F	522-07-01	Protected against vibration.
G	522-08-01	Protected against other mechanical stresses.
H	522-05-01	Corrosive resistant in damp locations.
I	522-08-03	Adequate radii of bends.
J	522-02	Protected against other external influences including ambient and working temperatures.
K	522-06-01 522-08-01	Conduit ends properly reamed and cleaned out and bushed.
L	522-08-01 522-08-03	Solid elbows and 'tees' used only where permitted.
M	522-08-02 513-01-01	Conduit boxes and other inspection points to be accessible.
N	522-03-02	Conduit system provided with adequate drainage points, where necessary.
O	528-02-01 to 528-02-06	Conduit system does not contain non-electrical services (pipes etc.).
P	Deleted	Deleted
Q	Deleted	Deleted
R	521-07-03	Conduit ends blanked-off where unused.
S	527-02-02	Fitted with fire barriers to prevent the spread of fire.
T	522-08-01	Conduits not filled excessively with cables.
Rigid metallic conduits		
U	543-02-04	Electrically continuous.
V	413-02-06 413-02-18	Earthed.
W	713-02-01	Continuity satisfactory.
X	543-01-03	Adequacy for use as a circuit protective conductor where so used.
Y	Deleted	Deleted.
Z	522-05	Adequate protection for conduits in damp and/or corrosive environment.
A1	522-08-04	Where used as overhead link, span not excessive (see Chapter 10 of this Guide).
B1	521-02-01	Phase(s) and neutral conductors of a circuit to be enclosed by the same conduit.
C1	601-07-01	Not used as surface wiring system in locations containing a bath or shower.
Flexible metallic conduits		
D1	543-02-01	Flexible metal conduit not used as a protective conductor.
E1	522-08-04	Flexible conduits adequately supported.
F1	130-01-01	Appropriate conduit gland-adaptors are used.
Rigid non-metallic conduits		
G1	522-01-01	Suitable for highest and lowest temperatures.
H1	522-08-01	Adequate provision for expansion and contraction.
I1	554-01-01	Conduit boxes suitable for the mass of suspended luminaires where so used.

Table 17.12: Check list for trunking wiring systems that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	511-01-01 521-05-01	Complies with BS 4678 or having characteristic 'P' of BS 476 Part 5.
B	522-08-05	Fixings made securely and spacings between fixings not excessive (see Chapter 10 of this Guide).
C	522-06-01	Protected against impact.
D	522-07-01	Protected against vibration.
E	522-08-01	Protected against other mechanical stresses.
F	522-05-01	Corrosive resistant in damp locations.
G	522-08-03	Adequate radii of bends.
H	522-02	Protected against other external influences including ambient and working temperatures.
I	543-02-04	Where metallic, electrically continuous.
J	413-02-06 413-02-18	Where metallic, earthed.
K	713-02-01	Where metallic, continuity satisfactory.
L	543-02-04	Where metallic, joints electrically and mechanically sound.
M	543-01-03	Adequacy for use as a circuit protective conductor where so used.
N	Deleted	Deleted.
O	522-05	Adequate protection for trunking in damp and/or corrosive environment.
P	522-06-01 522-08-01	Trunking ends properly de-burred and cleaned out and bushed.
Q	521-02-01	Phase(s) and neutral conductors of a circuit to be enclosed by the same trunking, if metallic.
R	601-07-01	If metallic not used as surface wiring system in locations containing a bath or shower.
S	522-03-02	Trunking system provided with adequate drainage points, where necessary.
T	528-02-01 to 528-02-07	Trunking system does not contain non-electrical services (pipes etc.).
U	Deleted	Deleted.
V	528-01-02	Band I and Band II circuits segregated or appropriately insulated.
W	Deleted	Deleted.
X	522-08-01	Trunking not filled excessively with cables.
Y	527-02-02	Fitted with fire barriers to prevent the spread of fire.
Z	528-01-07	Trunking accessories boxes and common outlets for Band I and Band II circuits provided with barriers or partitions.

confidence that the installation meets all the requirements of BS 7671. On any except a very small installation it will be necessary for some testing to be carried out during the course of construction but a record of such test results needs to be kept so that duplication does not occur. Even so, some tests will need to be repeated on final completion to ensure that essential features have not changed.

As called for in Regulation 713–01–01, tests must be carried out in a logical sequence and the results compared with the relevant criteria, such as loop impedance limits and those associated with insulation resistance. Where a particular test indicates that the item tested does not comply, that failure is required to be remedied and the test, and those preceding it, need repeating until a satisfactory condition is obtained. Figure 17.11 summarises that sequence.

Table 17.13: Check list for lighting points of utilisation that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	533-04-01	Luminaires controlled by a lighting switch compliant with BS 3676 and/or BS 5518.
B	553-04-01	Connection to luminaires by means of a ceiling rose, luminaire supporting coupler, batten lampholder or direct to luminaires which have been specifically designed for direct connection to the wiring system.
C	553-04-01	Ceiling roses comply with BS 67.
D	553-04-02	Ceiling roses not installed in any circuit operating at normal voltages exceeding 250 V.
E	553-04-04	Ceiling roses not connecting more than one flexible cord unless specifically so designed.
F	522-08-01	Ceiling rose's flex support utilised.
G	554-01-01	Ceiling roses suitable for the suspended mass.
H	527-02-01	Wiring system penetration through building fabric and ceiling rose made good to minimise the spread of fire.
I	553-04-04	Luminaire supporting couplers not used for connection of equipment other than luminaires.
J	604-13-01	Luminaire supporting couplers not used on construction sites.
K	553-04-01 553-04-04	Luminaire supporting couplers comply with BS 6972 or BS 7001.
L	553-04-01	Batten lampholders comply with BS 5042 or BS EN 60 238 (BS 6776).
M	553-03-03	BC lampholders comply with temperature rating 'T2'.
N	553-03-02	Lampholders not used in circuits operating at a voltage exceeding 250 V.
O	553-03-03	Bayonet cap lampholders (B15 and B22) comply with BS 5042.
P	553-03-02	Filament lamp lampholders not connected in a circuit operating at a voltage exceeding 250 V.
Q	553-03-04	ES lampholders (and track mounted systems) with outer contact connected to neutral in TN and TT systems.
R	511-01-01	Luminaires compliant with the relevant Sections of BS 4533.
S	511-01-01	Lighting track compliant with BS 4533 Section 102.57.
T	554-02-01	HV electric sign and HV luminous discharge tube installation complying with BS 559.

17.5.4 *Initial certification – general*

Regulation 741–01–01 calls for an Electrical Installation Certificate to be completed for every installation and handed to the person ordering the work, who may be an agent of the consumer (e.g. Architect or Consulting Engineer). This Regulation also embodies a requirement to record details of the inspections undertaken and the test results on a schedule. Regulation 741–01–02 requires the schedule of test results to also identify every circuit and its protective device(s). The certificate must be in the form as set out in Appendix 6 of BS 7671 and must be signed by a competent person each for the design, the construction and the inspection, testing and verification of the installation. The three required signatories may in fact be one and the same person where, for example, an installation has been designed, constructed, inspected, tested and verified by an electrical contractor who has been responsible for all three aspects. Conversely, the three elements may have been the responsibility of three or more persons where, for instance, the design has been undertaken jointly by a consulting engineer and an electrical contractor, the construction by an electrical contractor and the inspection, testing and verification by a third-party

Table 17.14: General check list for accessories that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	512-06-01 512-06-02	Suitable for all external influences, e.g. temperature, water, corrosive substances, mechanical stresses, flora and fauna, solar radiation and building structural design.
B	130-02-02 512-02-01	Suitable current ratings. Every item suitable for design and fault currents.
C	130-01-01 713-09-01	Polarity correct.
D	513-01-01	Readily accessible.
E	511-01-01	Accessories compliant with BS 5733 or other relevant Standard.
F	130-01-01	Box and/or enclosures securely fixed.
G	413-02-06 413-02-18	Metallic enclosures, metallic front plates and grids properly earthed.
H	527-02-01 526-03-02	Sunken boxes flush with finished building fabric (e.g. plaster).
I	522-08-01	No evidence of sharp edges within enclosure including those caused by the use of countersunk screws instead of round heads.
J	514-06-01 Table 51A	Fixed wiring phase conductors identified red, neutral conductors black and switched phase conductors (switchwires) red and protective conductors green/yellow.
K	514-07-01 Table 52A	Flexible cables and cords phase conductors identified brown, neutral conductors blue (or black in 4 and 5 cores) and protective conductors green/yellow. All identified throughout their length.
L	543-03-02	Bare protective conductors of composite cables covered with green/yellow sleeving to BS 6004 or BS 7211.
M	543-02-07	Where protective conductor is formed by conduit, trunking, etc., a 'fly lead' linking the wiring system protective conductor to the earthing terminal of the accessory.
N	526-03-03	Unsheathed cores of cables contained within enclosure.
O	522-08-05	Where applicable, cord grips properly utilised.
P	526-01-01	All conductor terminations tight.
Q	526-01-02	All strands of conductor properly terminated.
R	528-01-08	Accessories boxes and common outlets for Category 1, 2 and 3 provided with barriers or partitions.

engaged only for that purpose. There are, of course, many other possibilities and combinations of various personnel who might be involved in an installation, but in all cases a minimum of three signatures are required from the competent person(s).

An electrical contractor would wish to establish at the outset who is going to carry out the design before contracts are signed and sealed. He should also establish precisely the designer(s) responsible and obtain his signature certifying the design before installation work commences. Certification without the three signatures is considered invalid.

Competency of persons is difficult, if not impossible, to define except in general terms. A competent person will have suitable technical and professional qualifications in addition to a sound knowledge, and relevant experience, of the particular aspect of the installation in which he is involved (including the technical standards demanded by BS 7671). He or she will, for the verification, be fully versed in inspection and testing and be equipped with adequate test equipment. Regulations 742–01–01 and 742–01–04 confirm the obvious by stating that the inspection must be in accordance

Table 17.15: Check list for lighting switches that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	553-04-01 511-01-01	Lighting switches compliant with BS 3676 and/or BS 5518.
B	553-04-01	Lighting switches controlling discharge lighting circuits and other inductive loads to be suitably rated.
C	413-02-06 413-02-18	Switch box, grid and plate adequately earthed.
D	530-01-02	Single pole switches in phase conductor only.
E	601-08-01	Switches inaccessible to person using a bath or shower.
F	471-08-08 471-09-02	Where insulated enclosures and boxes are used, cpc connected to an earth terminal.
G	514-06-01 Table 51A	Fixed wiring phase conductors identified red, neutral conductors black and switched phase conductors (switchwires) red and protective conductors green/yellow.
H	514-10-01	Where switch unit is connected to more than one phase, label indicating presence of voltages above 250 V gives warning to skilled personnel.
I	514-01-01	Where not obvious, a designation label indicating the function of the switch.

Table 17.16: Check list for socket-outlets that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	553-01-03	Socket-outlets complies with BS 1363, BS 546, BS 196 or BS EN 60 309-2 (BS 4343) (see Table 54A of BS 7671).
B	553-01-04	Socket-outlets for household or similar use are of the shuttered type.
C	413-02-06 413-02-18	Box and plate adequately earthed.
D	130-01-01	Polarity visually correct.
E	537-05-02	Controlled by a switch when supplied by d.c.
F	543-02-09	Where cpc is formed by other than conduit or trunking etc., it is of a ring if the circuit is also in the form of a ring.
G	543-02-07	Where metal conduit serves as cpc, a 'fly lead' connection to box from socket, otherwise cpc terminated directly into socket-outlet earthing terminal.
H	553-01-06	Mounted at sufficient height above floor or working surface.
I	554-05-03	Not used to supply water heater with immersed elements.
J	601-10-02	Not located in room containing a bath (except SELV).
K	601-10-03	Not located within 2.5 m of a shower unit.
L	553-02-01	Excepting SELV and Class II, non-reversible couplers to be to BS 196, BS EN 60 309-2 (BS 4343), BS 4491, BS 6991 with provision for protective conductor connection.
M	553-02-02	The coupler of cable coupler fitted to the end remote from the supply.

with Chapter 71 and any defects made good prior to the issuing of a Certificate, and that the certificate signatories must be competent persons.

Here in the United Kingdom we have traditionally accepted self-certification (first-party certification), and by and large this has worked well and, compared to third-party certification, has been relatively inexpensive. It is important for this reason, if for no other, that installations are properly and thoroughly inspected, tested, verified and certified, so that the pressure for third-party certification is kept at bay, which from many points of view

Table 17.17: Check list for joint boxes that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	512-06-01 512-06-02	Suitable for all external influences, e.g. temperature, water, corrosive substances, mechanical stresses, flora and fauna, solar radiation and building structural design.
B	130-02-02 512-02-01	Suitable current ratings.
C	513-01-01	Readily accessible.
D	526-03-01	Joints mechanically protected.
E	526-03-03	Unsheathed cores of cables contained within enclosure.
F	543-01-01	If protective conductor is located outside joint box enclosure, to be not less than 2.5 mm^2.
G	526-01-01	All conductor terminations tight.
H	526-01-02	All strands of conductor properly terminated.
I	602-06-03	No joint boxes in Zones A and B of a swimming pool.

Table 17.18: Check list for cooker control units and fused connection units that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	512-06-01 512-06-02	Suitable for all external influences, e.g. temperature, water, corrosive substances, mechanical stresses, flora and fauna, solar radiation and building structural design.
B	130-02-02 512-02-01	Suitable current ratings.
C	433-02-01 434-01-01	Suitably fused, where appropriate.
D	476-03-04	Cooker control unit positioned so that operator is not put in danger.
E	476-03-04 513-01-01	Readily accessible.
F	526-03-03	Unsheathed cores of cables contained within enclosure.
G	526-01-01	All conductor terminations tight.
H	526-01-02	All strands of conductor properly terminated.
I	530-01-02	Single-pole fused connection unit switches in phase conductor only.
J	514-01-01	Where not obvious, a designation label indicating the function of the unit is affixed.

would be highly desirable but would in all probability lead to more expense for the consumer.

Figure 17.12 is a reproduction of a suitable Electrical Installation Certificate (by kind permission of the NICEIC – for use by Approved Contractors) of the form based on the model given in Appendix 6 of BS 7671. THe NICEIC also publish 'green' versions of many of these forms of certification for use by electrical contractors not enrolled with the NICEIC. A Domestic Electrical Installation is also available from the NICEIC.

For competent engineers, compiling the Electrical Installation Certificate will present few difficulties. However, for those less familiar with the necessary form compilation the following guidance will hopefully assist.

Table 17.19: Check list for protective conductors that require visual inspection prior to carrying out testing

Ref	Regulation references	Facet to inspect
A	542-01	Earthing arrangements properly assessed.
B	542-04-01	Main earthing terminal provided.
C	542-04-02	Main earthing terminal facility for disconnection of the earthing conductor for test purposes provided.
D	511-01-01 521-01-01	Conductors have been correctly selected for the particular circumstances and that they are compliant with the relevant Standard.
E	512-06-01 512-06-02	Suitable for all external influences, e.g. temperature, water, corrosive substances, mechanical stresses, flora and fauna, solar radiation and building structural design.
F	543-02-01 543-02-02	Protective conductor of suitable type.
G	543-02-03	Protective conductors of 10 mm^2 or less of copper.
H	543-03-01	Protective conductors protected against mechanical, chemical and electro-dynamic effects.
I	543-02-04	Where protective conductor formed by metal enclosure, electrical continuity assured.
J	542-03	Earthing conductors of suitable material, size and adequately protected.
K	542-03-02	Aluminium and copperclad aluminium not used as underground earthing conductors.
L	542-02	Earth electrodes correctly selected and installed.
M	542-03-03	Earth electrodes correctly protected against corrosion and mechanical damage.
N	543-02-05	Cable sheaths and/or armouring are thermally protected.
O	543-01-03 543-01-04	Protective conductors of adequate cross-sectional area (see Tables 54A, 54B, 54C, 54D, 54E, 54F, 54G and 54H of BS 7671).
P	543-03-02	Copper conductors of 6 mm^2 or less, other than strip, covered by insulation/covering.
Q	547-01-01	Aluminium and copperclad aluminium not used as bonding conductors.
R	543-02-01	Gas and oil pipe lines not used as a protective conductor.
S	524-01-01	Conductor cross-sectional area not less than that given in Table 52 C of BS 7671.
T	413-02-02	Main bonding correctly carried out and connects all extraneous-conductive-parts entering the zone.
U	547-02	Main equipotential bonding conductors correctly sized.
V	547-03	Supplementary bonding conductors correctly sized.
W	471-08-01	Supplementary bonding carried out where necessary.
X	601-04-02	Supplementary bonding carried out in bathrooms
Y	602-03-02	Supplementary bonding carried out in swimming pools
Z	605-08-02	Supplementary bonding carried out in locations where livestock is kept.
A1	543-03	Electrical continuity preserved throughout.
B1	546-01	Combined protective and neutral (PEN) correctly used and sized.
C1	522-06-01 522-08-01	Protected against mechanical damage including abrasion and suitable for location.
D1	522-08-05	Cables adequately supported.
E1	522-01-01	Suitable for the highest and lowest temperatures.
F1	514-13-01 514-13-02	Protective conductor connection appropriately labelled.
G1	514-03-01	Colour identification of protective conductors (green/yellow).
H1	514-06-02	The single colour green has not been used.
I1	543-02-01	Flexible conduit not used as a sole cpc.

Details of the Client (Figure 17.12(a)) This section is self-explanatory and needs no further illustration, requiring as it does the name and address of the client for whom the work has been carried out.

Table 17.20: Specialised installations subject also to the requirements of a British Standard and Code of Practice

Ref	BS/CP reference	Type of installation
A	BS EN 60079 and BS EN 50014	Installations in potentially explosive atmospheres.
B	BS 5266	Emergency lighting.
C	BS 5839	Fire detection and alarm systems in buildings.
D	BS 559	Electric signs and high voltage discharge tube installations.
E	BS 6701	Part 1: Installations subject to the Telecommunications Act 1984.
F	BS 6351	Electric surface heating systems.
G	BS EN 50281	Installations for use in the presence of combustible dust

Details of the Installation (Figure 17.12(a)) The address of the installation together with all relevant information relating to the extent of the installation should fully identify the scope and nature of the electrical installation work which is the subject of the Certificate. The installation should also be declared *new, an addition* and/or *an alteration*, as appropriate.

Design, Construction, Inspection and Testing Boxes (Figure 17.2(a)) Each of the three elements of the installation work, namely *Design, Construction* and *Inspection and Testing* must be certified in the boxes provided for this purpose. In cases where the design element has been shared between two bodies, both bodies responsible must certify that the design meets the requirements of BS 7671. In addition to the necessary signatures, the competent person's name and date of signature are also required. Where the design, construction and inspection and testing have been the responsibility of one person, the composite box towards the bottom of the page may be used instead of the three separate boxes.

Where the use of new materials or inventions leads to departures from BS 7671, details of these departures are to be recorded in the data-entry box provided in the *Design* section of the certificate (Regulation 120–02–01), and repeated in the data-entry boxes provided in the *Construction* and the *Inspection and Testing* sections to confirm the designer(s)' intent. Where no departures have been sanctioned by the designer(s), the data-entry boxes should be completed by entering 'None'.

In each of the four boxes, provision has been made to insert the date of the latest amendment to BS 7671 to which the Certificate relates. It is important that this data is inserted in order to obviate disputes over amended regulatory requirements.

Particulars of the Organisation(s) Responsible for the Electrical Installation (Figure 17.12(b)) These details will identify to the recipient the organisation(s) responsible for the work certified by their representatives on page 1. The organisations, addresses and postcodes must be given, together with their NICEIC Enrolment Number and Branch Number, where appropriate. Where an Approved Contractor has been responsible

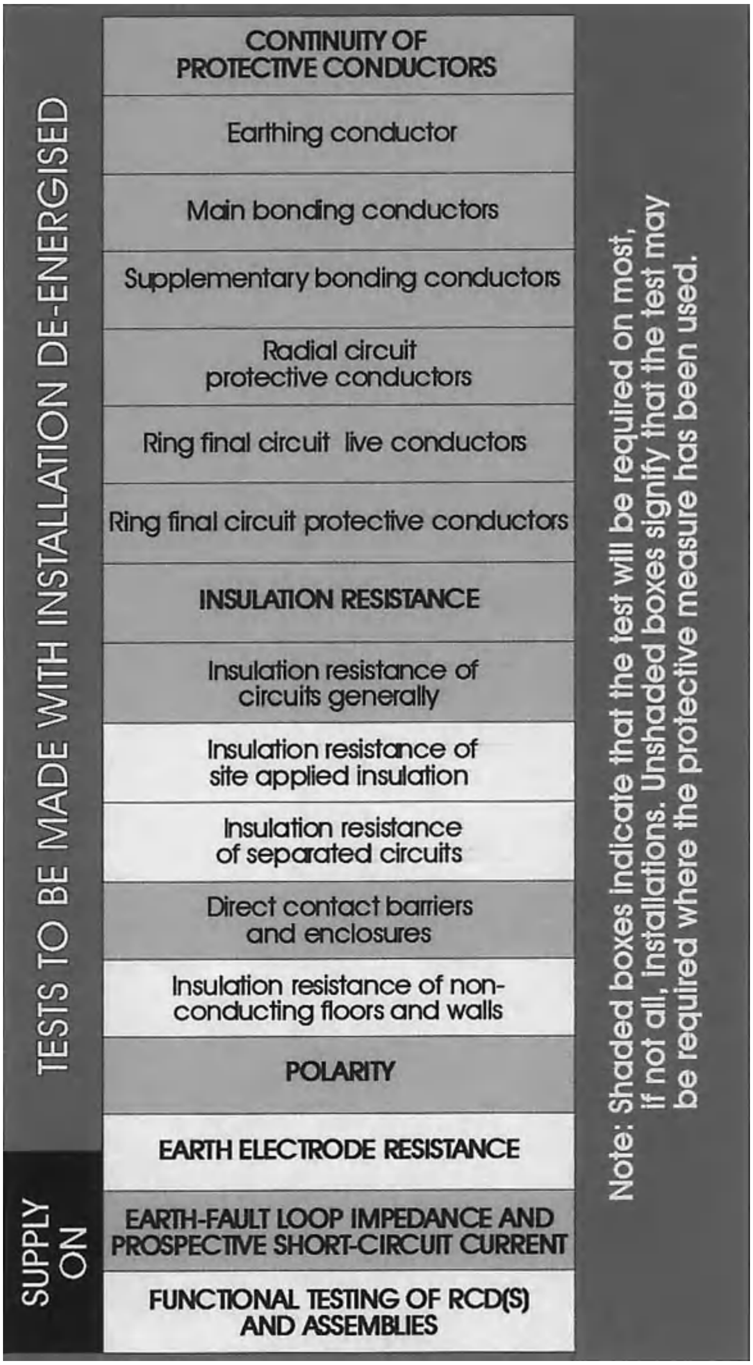
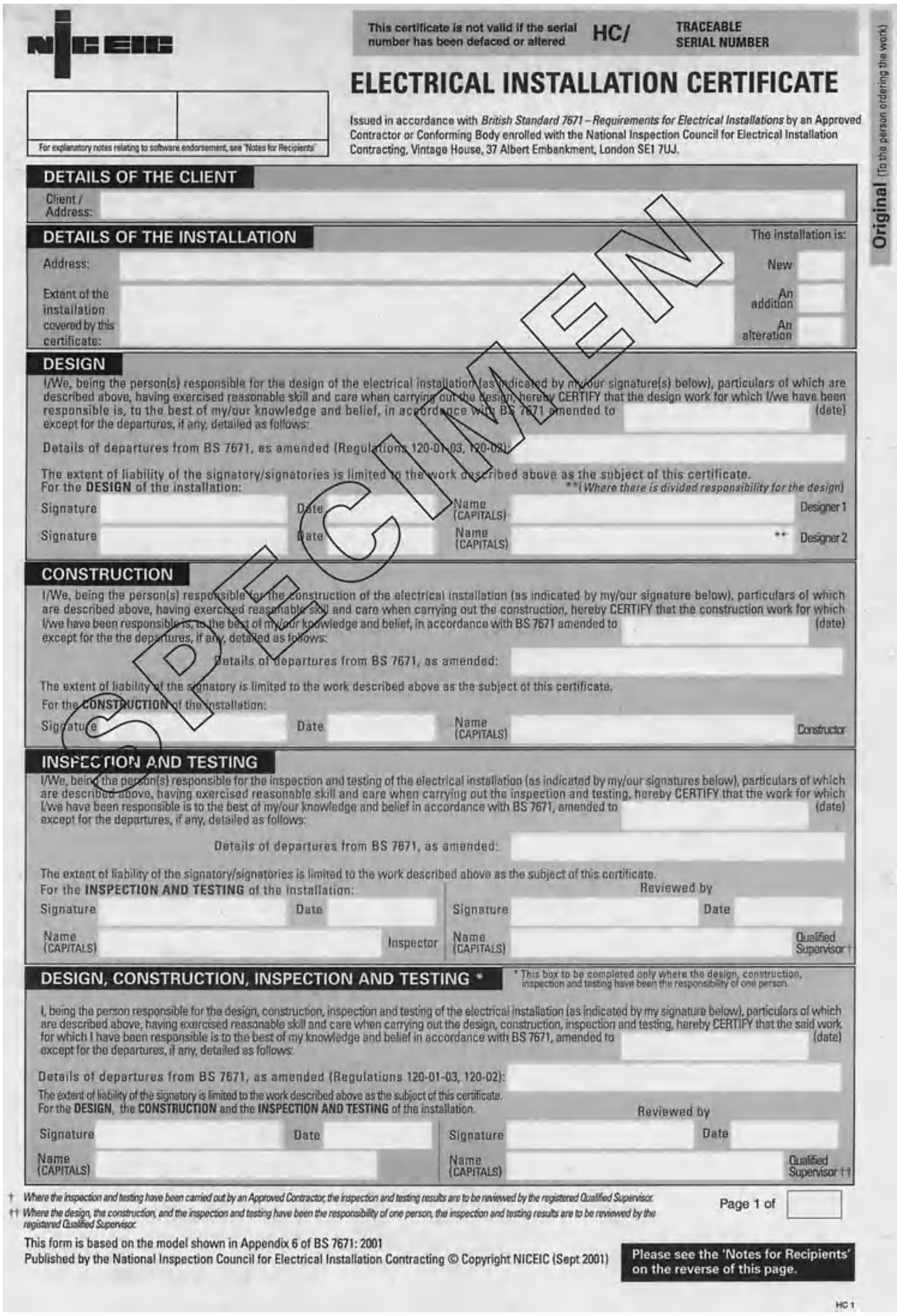


Figure 17.11: Sequence of tests for initial testing



This certificate is not valid if the serial number has been defaced or altered **HC/** TRACEABLE SERIAL NUMBER

Original (To the person ordering the work)

ELECTRICAL INSTALLATION CERTIFICATE

For explanatory notes relating to software endorsement, see 'Notes for Recipients'

Issued in accordance with *British Standard 7671 – Requirements for Electrical Installations* by an Approved Contractor or Conforming Body enrolled with the National Inspection Council for Electrical Installation Contracting, Vintage House, 37 Albert Embankment, London SE1 7UJ.

DETAILS OF THE CLIENT

Client / Address:

DETAILS OF THE INSTALLATION

The installation is:

Address:

New ☐

Extent of the installation covered by this certificate:

An addition ☐

An alteration ☐

DESIGN

I/We, being the person(s) responsible for the design of the electrical installation (as indicated by my/our signature(s) below), particulars of which are described above, having exercised reasonable skill and care when carrying out the design, hereby CERTIFY that the design work for which I/we have been responsible is, to the best of my/our knowledge and belief, in accordance with BS 7671 amended to (date) except for the departures, if any, detailed as follows:

Details of departures from BS 7671, as amended (Regulations 120-01-03, 120-02):

The extent of liability of the signatory/signatories is limited to the work described above as the subject of this certificate.
For the **DESIGN** of the installation: **(*Where there is divided responsibility for the design*)

Signature Date Name (CAPITALS) Designer 1

Signature Date Name (CAPITALS) ** Designer 2

CONSTRUCTION

I/We, being the person(s) responsible for the construction of the electrical installation (as indicated by my/our signature below), particulars of which are described above, having exercised reasonable skill and care when carrying out the construction, hereby CERTIFY that the construction work for which I/we have been responsible is, to the best of my/our knowledge and belief, in accordance with BS 7671 amended to (date) except for the the departures, if any, detailed as follows:

Details of departures from BS 7671, as amended:

The extent of liability of the signatory is limited to the work described above as the subject of this certificate.
For the **CONSTRUCTION** of the installation:

Signature Date Name (CAPITALS) Constructor

INSPECTION AND TESTING

I/We, being the person(s) responsible for the inspection and testing of the electrical installation (as indicated by my/our signatures below), particulars of which are described above, having exercised reasonable skill and care when carrying out the inspection and testing, hereby CERTIFY that the work for which I/we have been responsible is to the best of my/our knowledge and belief in accordance with BS 7671, amended to (date) except for the departures, if any, detailed as follows:

Details of departures from BS 7671, as amended:

The extent of liability of the signatory/signatories is limited to the work described above as the subject of this certificate.
For the **INSPECTION AND TESTING** of the installation:

Signature Date

Name (CAPITALS) Inspector

Reviewed by

Signature Date

Name (CAPITALS) Qualified Supervisor †

DESIGN, CONSTRUCTION, INSPECTION AND TESTING *

* This box to be completed only where the design, construction, inspection and testing have been the responsibility of one person.

I, being the person responsible for the design, construction, inspection and testing of the electrical installation (as indicated by my signature below), particulars of which are described above, having exercised reasonable skill and care when carrying out the design, construction, inspection and testing, hereby CERTIFY that the said work for which I have been responsible is to the best of my knowledge and belief in accordance with BS 7671, amended to (date) except for the departures, if any, detailed as follows:

Details of departures from BS 7671, as amended (Regulations 120-01-03, 120-02):

The extent of liability of the signatory is limited to the work described above as the subject of this certificate.
For the **DESIGN**, the **CONSTRUCTION** and the **INSPECTION AND TESTING** of the installation.

Signature Date

Name (CAPITALS)

Reviewed by

Signature Date

Name (CAPITALS) Qualified Supervisor ††

† *Where the inspection and testing have been carried out by an Approved Contractor, the inspection and testing results are to be reviewed by the registered Qualified Supervisor.*

†† *Where the design, the construction, and the inspection and testing have been the responsibility of one person, the inspection and testing results are to be reviewed by the registered Qualified Supervisor.*

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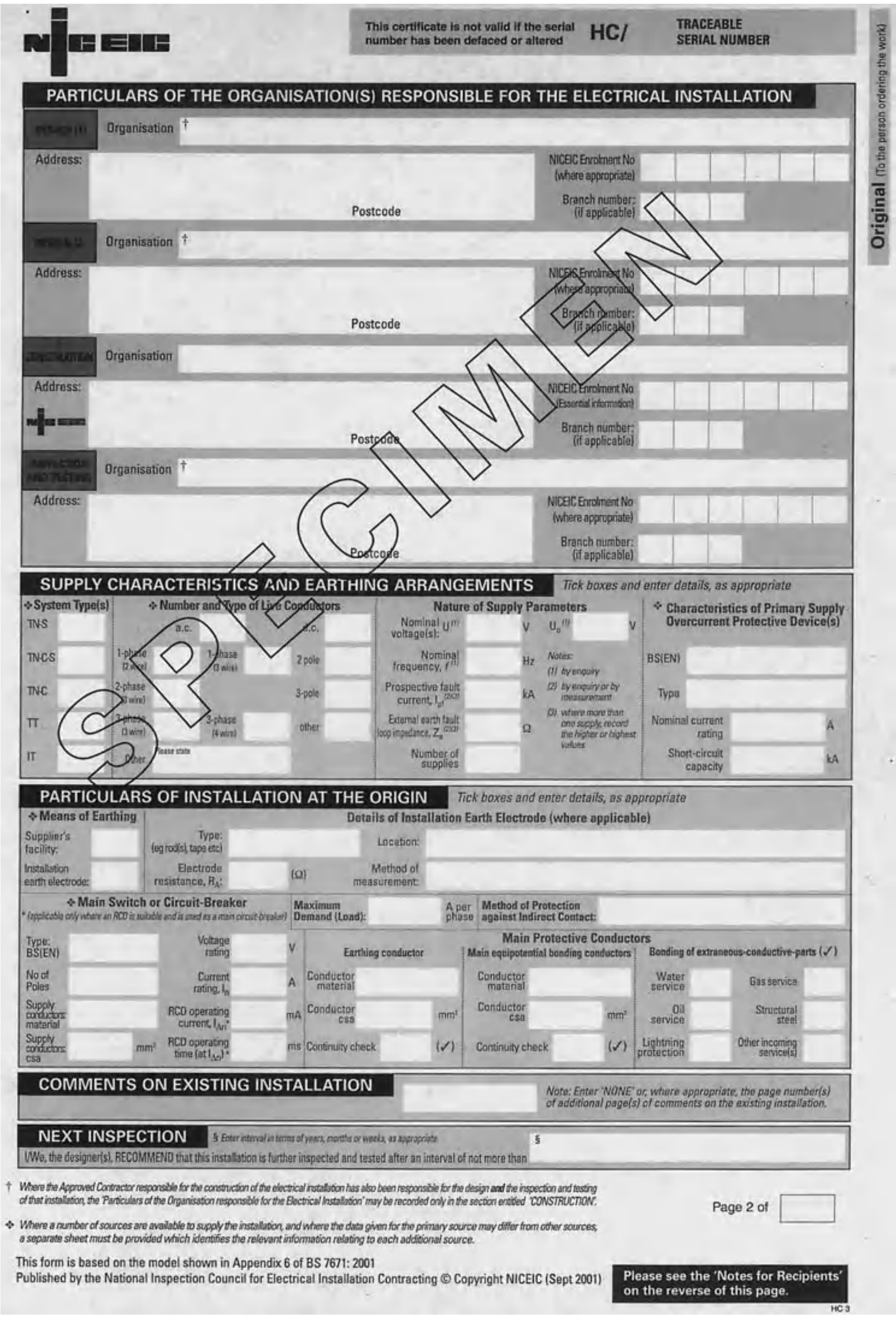
Please see the 'Notes for Recipients' on the reverse of this page.

HC 1

Figure 17.12 (a): Electrical Installation Certificate – page 1



NICEIC

This certificate is not valid if the serial number has been defaced or altered **HC/** TRACEABLE SERIAL NUMBER

Original (To the person ordering the work)

PARTICULARS OF THE ORGANISATION(S) RESPONSIBLE FOR THE ELECTRICAL INSTALLATION

Organisation †
Address:
Postcode
NICEIC Enrolment No (where appropriate)
Branch number: (if applicable)

Organisation †
Address:
Postcode
NICEIC Enrolment No (where appropriate)
Branch number: (if applicable)

Organisation
Address:
Postcode
NICEIC Enrolment No (Essential information)
Branch number: (if applicable)

Organisation †
Address:
Postcode
NICEIC Enrolment No (where appropriate)
Branch number: (if applicable)

SUPPLY CHARACTERISTICS AND EARTHING ARRANGEMENTS

Tick boxes and enter details, as appropriate

❖ System Type(s)
TN-S
TN-C-S
TN-C
TT
IT

❖ Number and Type of Live Conductors
a.c.
1-phase (2 wire)
1-phase (3 wire)
2-phase (3 wire)
3-phase (3 wire)
3-phase (4 wire)
Other Please state
d.c.
2 pole
3-pole
other

Nature of Supply Parameters
Nominal voltage(s): $U^{(1)}$ V $U_o^{(1)}$ V
Nominal frequency, $f^{(1)}$ Hz
Prospective fault current, $I_{pf}^{(2)(3)}$ kA
External earth fault loop impedance, $Z_e^{(2)(3)}$ Ω
Number of supplies

Notes:
(1) by enquiry
(2) by enquiry or by measurement
(3) where more than one supply, record the higher or highest values

❖ Characteristics of Primary Supply Overcurrent Protective Device(s)
BS(EN)
Type
Nominal current rating A
Short-circuit capacity kA

PARTICULARS OF INSTALLATION AT THE ORIGIN

Tick boxes and enter details, as appropriate

❖ Means of Earthing
Supplier's facility:
Installation earth electrode:

Details of Installation Earth Electrode (where applicable)
Type: (eg rod(s), tape etc)
Location:
Electrode resistance, R_A: (Ω)
Method of measurement:

❖ Main Switch or Circuit-Breaker
* *(applicable only where an RCD is suitable and is used as a main circuit-breaker)*
Type: BS(EN)
No of Poles
Supply conductors: material
Supply conductors: csa mm²
Voltage rating V
Current rating, I_n A
RCD operating current, $I_{\Delta n}$* mA
RCD operating time (at $I_{\Delta n}$)* ms

Maximum Demand (Load): A per phase

Method of Protection against Indirect Contact:

Main Protective Conductors

Earthing conductor
Conductor material
Conductor csa mm²
Continuity check (✓)

Main equipotential bonding conductors
Conductor material
Conductor csa mm²
Continuity check (✓)

Bonding of extraneous-conductive-parts (✓)
Water service
Gas service
Oil service
Structural steel
Lightning protection
Other incoming service(s)

COMMENTS ON EXISTING INSTALLATION

Note: Enter 'NONE' or, where appropriate, the page number(s) of additional page(s) of comments on the existing installation.

NEXT INSPECTION

§ Enter interval in terms of years, months or weeks, as appropriate

I/We, the designer(s), RECOMMEND that this installation is further inspected and tested after an interval of not more than §

† *Where the Approved Contractor responsible for the construction of the electrical installation has also been responsible for the design* ***and*** *the inspection and testing of that installation, the 'Particulars of the Organisation responsible for the Electrical Installation' may be recorded only in the section entitled 'CONSTRUCTION'.*

❖ *Where a number of sources are available to supply the installation, and where the data given for the primary source may differ from other sources, a separate sheet must be provided which identifies the relevant information relating to each additional source.*

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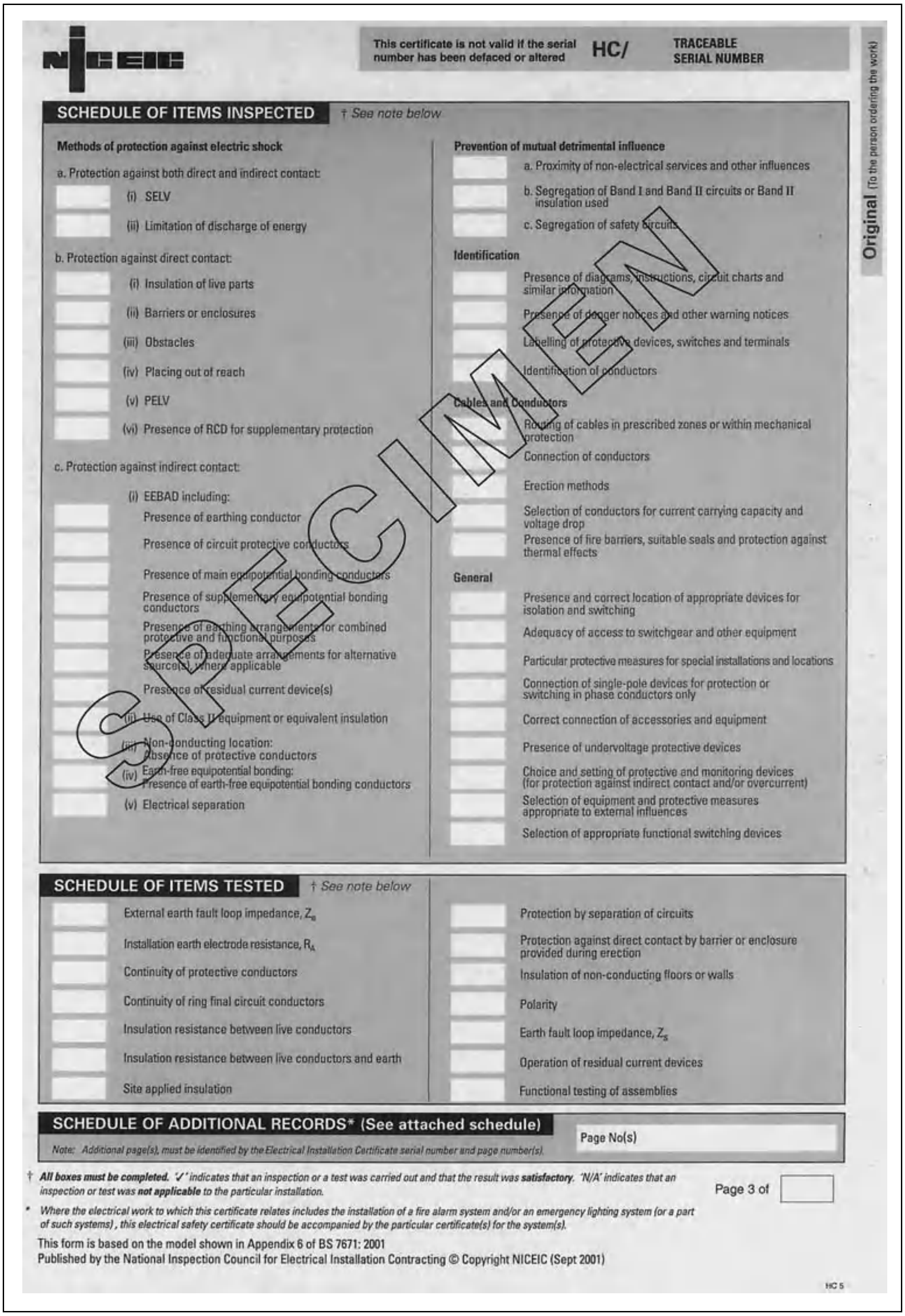
Please see the 'Notes for Recipients' on the reverse of this page.

HC 3

Figure 17.12 (b): Electrical Installation Certificate – page 2



This certificate is not valid if the serial number has been defaced or altered **HC/** TRACEABLE SERIAL NUMBER

Original (To the person ordering the work)

SCHEDULE OF ITEMS INSPECTED

† See note below

Methods of protection against electric shock

a. Protection against both direct and indirect contact:

- ☐ (i) SELV
- ☐ (ii) Limitation of discharge of energy

b. Protection against direct contact:

- ☐ (i) Insulation of live parts
- ☐ (ii) Barriers or enclosures
- ☐ (iii) Obstacles
- ☐ (iv) Placing out of reach
- ☐ (v) PELV
- ☐ (vi) Presence of RCD for supplementary protection

c. Protection against indirect contact:

(i) EEBAD including:

- ☐ Presence of earthing conductor
- ☐ Presence of circuit protective conductors
- ☐ Presence of main equipotential bonding conductors
- ☐ Presence of supplementary equipotential bonding conductors
- ☐ Presence of earthing arrangements for combined protective and functional purposes
- ☐ Presence of adequate arrangements for alternative source(s), where applicable
- ☐ Presence of residual current device(s)
- ☐ (ii) Use of Class II equipment or equivalent insulation
- ☐ (iii) Non-conducting location: Absence of protective conductors
- ☐ (iv) Earth-free equipotential bonding: Presence of earth-free equipotential bonding conductors
- ☐ (v) Electrical separation

Prevention of mutual detrimental influence

- ☐ a. Proximity of non-electrical services and other influences
- ☐ b. Segregation of Band I and Band II circuits or Band II insulation used
- ☐ c. Segregation of safety circuits

Identification

- ☐ Presence of diagrams, instructions, circuit charts and similar information
- ☐ Presence of danger notices and other warning notices
- ☐ Labelling of protective devices, switches and terminals
- ☐ Identification of conductors

Cables and Conductors

- ☐ Routing of cables in prescribed zones or within mechanical protection
- ☐ Connection of conductors
- ☐ Erection methods
- ☐ Selection of conductors for current carrying capacity and voltage drop
- ☐ Presence of fire barriers, suitable seals and protection against thermal effects

General

- ☐ Presence and correct location of appropriate devices for isolation and switching
- ☐ Adequacy of access to switchgear and other equipment
- ☐ Particular protective measures for special installations and locations
- ☐ Connection of single-pole devices for protection or switching in phase conductors only
- ☐ Correct connection of accessories and equipment
- ☐ Presence of undervoltage protective devices
- ☐ Choice and setting of protective and monitoring devices (for protection against indirect contact and/or overcurrent)
- ☐ Selection of equipment and protective measures appropriate to external influences
- ☐ Selection of appropriate functional switching devices

SCHEDULE OF ITEMS TESTED

† See note below

- ☐ External earth fault loop impedance, Z_e
- ☐ Installation earth electrode resistance, R_A
- ☐ Continuity of protective conductors
- ☐ Continuity of ring final circuit conductors
- ☐ Insulation resistance between live conductors
- ☐ Insulation resistance between live conductors and earth
- ☐ Site applied insulation
- ☐ Protection by separation of circuits
- ☐ Protection against direct contact by barrier or enclosure provided during erection
- ☐ Insulation of non-conducting floors or walls
- ☐ Polarity
- ☐ Earth fault loop impedance, Z_s
- ☐ Operation of residual current devices
- ☐ Functional testing of assemblies

SCHEDULE OF ADDITIONAL RECORDS* (See attached schedule)

Note: Additional page(s), must be identified by the Electrical Installation Certificate serial number and page number(s).

Page No(s)

† ***All boxes must be completed.*** *'✓' indicates that an inspection or a test was carried out and that the result was* ***satisfactory****. 'N/A' indicates that an inspection or test was* ***not applicable*** *to the particular installation.*

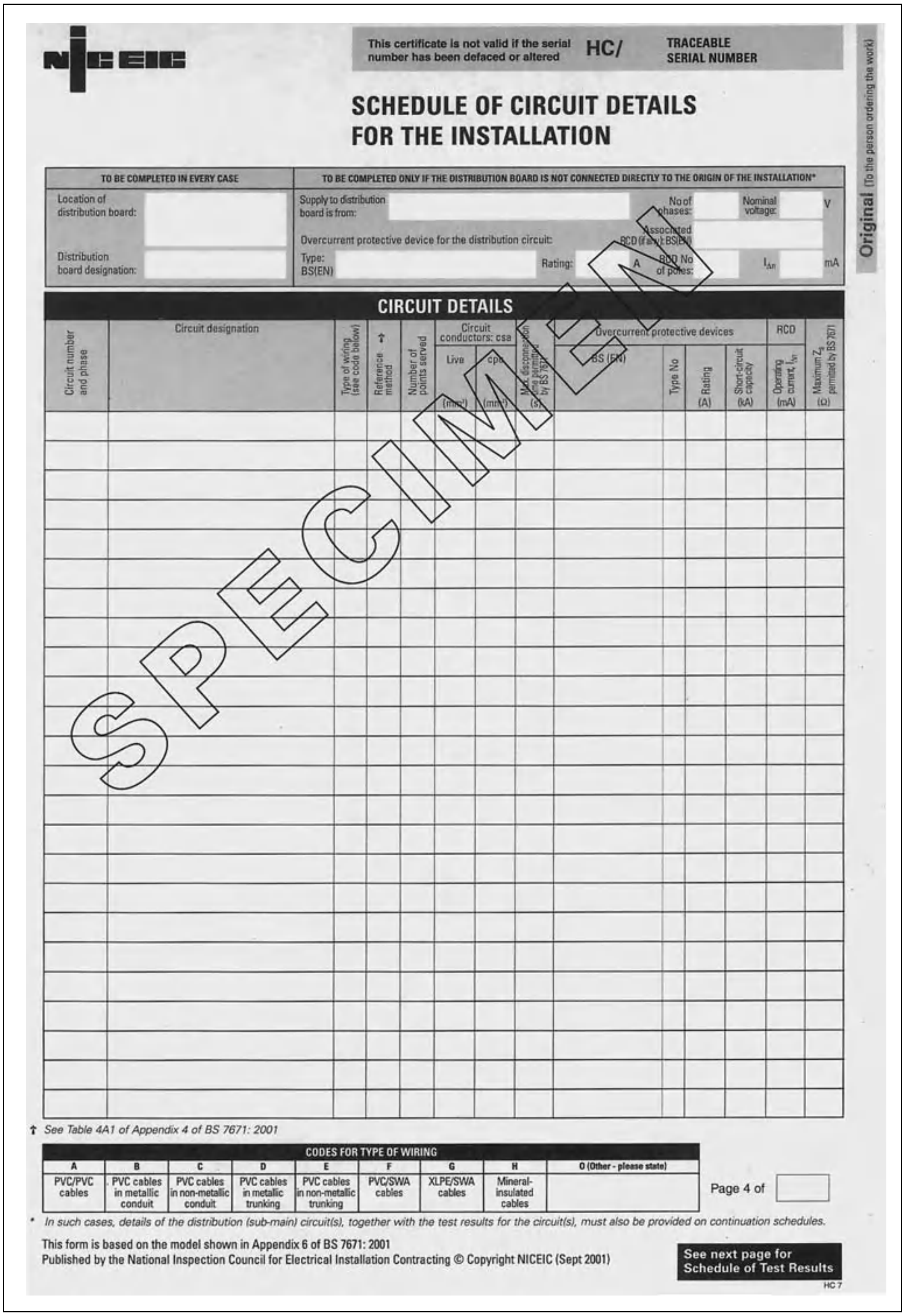
Page 3 of ☐

* *Where the electrical work to which this certificate relates includes the installation of a fire alarm system and/or an emergency lighting system (or a part of such systems), this electrical safety certificate should be accompanied by the particular certificate(s) for the system(s).*

This form is based on the model shown in Appendix 6 of BS 7671: 2001

HC 5

Figure 17.12 (c): Electrical Installation Certificate – page 3



NICEIC

This certificate is not valid if the serial number has been defaced or altered HC/ TRACEABLE SERIAL NUMBER

Original (To the person ordering the work)

SCHEDULE OF CIRCUIT DETAILS FOR THE INSTALLATION

TO BE COMPLETED IN EVERY CASE

Location of distribution board:

Distribution board designation:

TO BE COMPLETED ONLY IF THE DISTRIBUTION BOARD IS NOT CONNECTED DIRECTLY TO THE ORIGIN OF THE INSTALLATION*

Supply to distribution board is from: No of phases: Nominal voltage: V

Overcurrent protective device for the distribution circuit: Associated RCD (if any): BS(EN)

Type: BS(EN) Rating: A RCD No of poles: $I_{\Delta n}$ mA

CIRCUIT DETAILS

Circuit number and phase	Circuit designation	Type of wiring (see code below)	† Reference method	Number of points served	Circuit conductors: csa		Max. disconnection time permitted by BS 7671 (s)	Overcurrent protective devices				RCD	Maximum Z_s permitted by BS 7671 (Ω)
					Live (mm²)	cpc (mm²)		BS (EN)	Type No	Rating (A)	Short-circuit capacity (kA)	Operating current, $I_{\Delta n}$ (mA)	

† *See Table 4A1 of Appendix 4 of BS 7671: 2001*

CODES FOR TYPE OF WIRING

A	B	C	D	E	F	G	H	O (Other - please state)
PVC/PVC cables	PVC cables in metallic conduit	PVC cables in non-metallic conduit	PVC cables in metallic trunking	PVC cables in non-metallic trunking	PVC/SWA cables	XLPE/SWA cables	Mineral-insulated cables	

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* *In such cases, details of the distribution (sub-main) circuit(s), together with the test results for the circuit(s), must also be provided on continuation schedules.*

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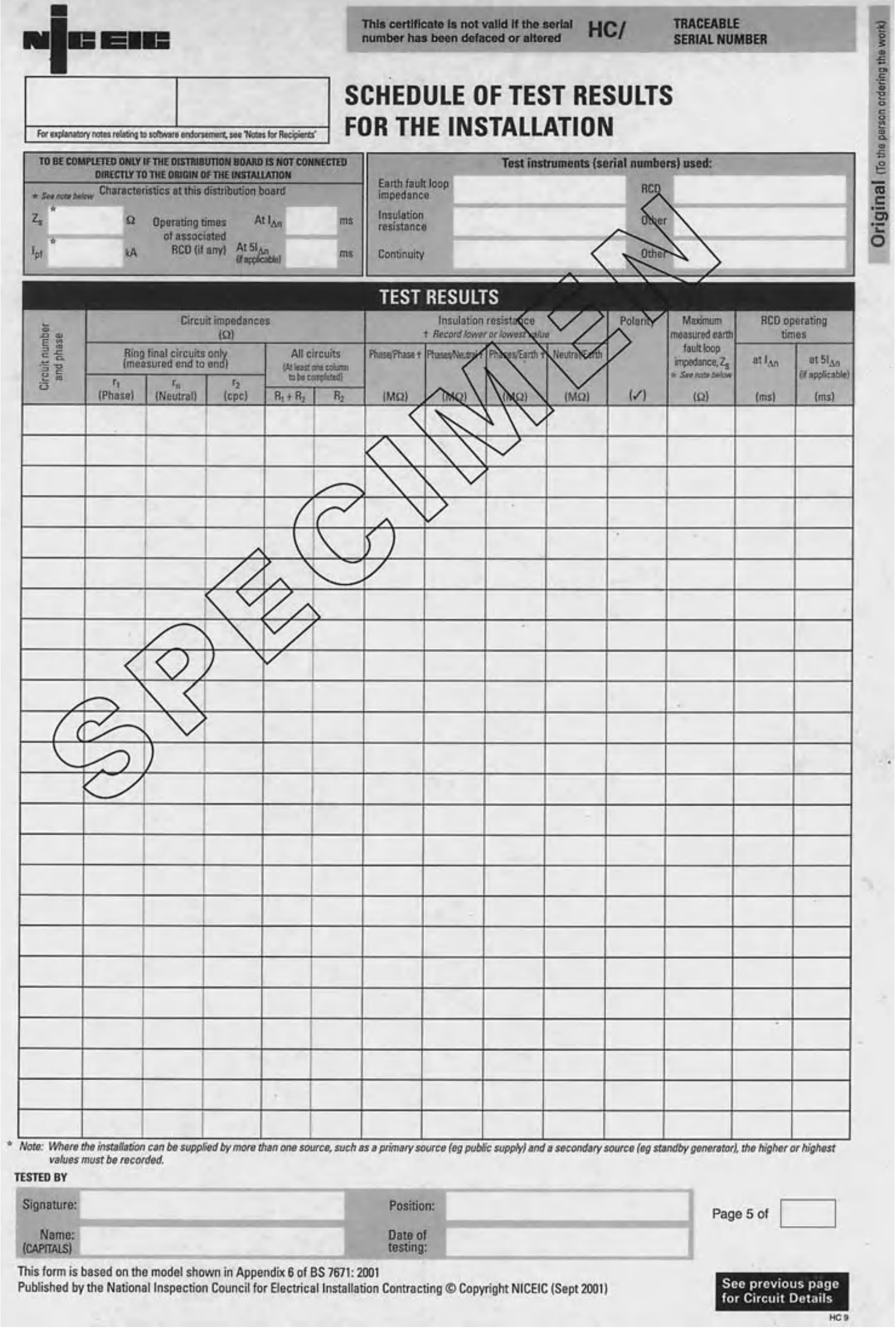
See next page for Schedule of Test Results

HC 7

Figure 17.12 (d): Electrical Installation Certificate – page 4



This certificate is not valid if the serial number has been defaced or altered HC/ TRACEABLE SERIAL NUMBER

For explanatory notes relating to software endorsement, see 'Notes for Recipients'

SCHEDULE OF TEST RESULTS FOR THE INSTALLATION

Original (To the person ordering the work)

TO BE COMPLETED ONLY IF THE DISTRIBUTION BOARD IS NOT CONNECTED DIRECTLY TO THE ORIGIN OF THE INSTALLATION

* See note below Characteristics at this distribution board

Z_s * Ω Operating times of associated RCD (if any) At $I_{\Delta n}$ ms

I_{pf} * kA At $5I_{\Delta n}$ (if applicable) ms

Test instruments (serial numbers) used:

Earth fault loop impedance

Insulation resistance

Continuity

RCD

Other

Other

TEST RESULTS

Circuit number and phase	Circuit impedances (Ω)					Insulation resistance † Record lower or lowest value				Polarity	Maximum measured earth fault loop impedance, Z_s * See note below	RCD operating times	
	Ring final circuits only (measured end to end)			All circuits (At least one column to be completed)		Phase/Phase †	Phases/Neutral †	Phases/Earth †	Neutral/Earth			at $I_{\Delta n}$	at $5I_{\Delta n}$ (if applicable)
	r_1 (Phase)	r_n (Neutral)	r_2 (cpc)	$R_1 + R_2$	R_2	(MΩ)	(MΩ)	(MΩ)	(MΩ)	(✓)	(Ω)	(ms)	(ms)

* *Note: Where the installation can be supplied by more than one source, such as a primary source (eg public supply) and a secondary source (eg standby generator), the higher or highest values must be recorded.*

TESTED BY

Signature:

Name: (CAPITALS)

Position:

Date of testing:

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See previous page for Circuit Details

HC 9

Figure 17.12 (e): Electrical Installation Certificate – page 5 for elements of the work in addition to construction, repetition of the *Particulars of the organisation(s) responsible for the electrical installation* is unnecessary and, in such cases, the words ‘Details as given for Construction’ may be inserted, where appropriate.

Supply Characteristics and Earthing Arrangements (Figure 17.12(b)) The *System Type* must be identified in terms of TN-S, TN-C-S, TN-C, TT or IT. There may be circumstances where more than one system type is involved, such as TN-C-S and TT, in which case a positive indication should be made in each of the relevant data-entry boxes.

The *Number and type of live conductors* is self-explanatory, but it is also necessary to identify the supply current in terms of a.c. or d.c. The number of phase(s) will usually be one (two-wire) or three (four-wire) or, on rare occasions, a supply with two phases (three-wire) may be encountered. However, other combinations of a.c. supplies are possible and provision is made on the form for most a.c. and d.c. system supplies.

The details of the *Nature of the supply parameters* will have been determined already by the designer(s) in consultation with the electricity distributor, and all such data should be readily available. The nominal voltage, U_o, will be the voltage between phase and Earth and, if the supply is derived from the public supply network, this will normally be 230 V in England, Wales and Scotland and in Northern Ireland. Similarly, the nominal voltage U is that between unearthed live conductors and for many supplies this will simple be $\sqrt{3}U_o$ (400 V). Both these nominal voltages can only be ascertained from enquiry to the electricity distributor – measured values are not nominal values. The frequency in the United Kingdom will normally be 50 Hz for a.c. supplies.

Prospective fault-current, I_{pf}, relates to the maximum current that would flow if a fault of negligible impedance (both short-circuit and earth-fault prospective currents) occurred at the origin of the installation. These values are needed to ensure that protective devices have adequate short-circuit capacity to interrupt the fault current without sustaining damage or causing a hazard to its surroundings or to persons.

The *External phase-earth loop impedance,* Z_e, at the origin is the impedance of the part of the loop external to the installation (i.e. the supply source and the supply lines coming into the installation upstream of the origin).

Both these parameters (I_{pf} and Z_e) have to be determined by measurement or equiry, although for design purposes the often higher values quoted by the electricity distributor should have been used for the design. Where supplies are derived from the public supply network both parameters are obtainable upon request from the supplier and this will often be the preferred method. Whilst calculation is given as an option in BS 7671, such a procedure is often impractical because all the necessary data relating to upstream impedances are not known. Measurements produce a value only for the particular time of measurement and, as we all know, the network must be considered liable to change (within the normal range) without notice being given to the consumer. The technique of calculation should only be used where the designer has at his disposal all the relevant characteristics of the supply and is confident that these will remain unchanged. However, confirmation by measurement will always be necessary to ensure that means of earthing is adequate and reliable.

The *Number of supplies* must be identified in the data-entry box even where there is only one. Where the installation can be supplied by more than one source, such as the public supply and a standby generator, the higher or highest values of prospective fault current, I_{pf}, and external earth fault loop impedance, Z_e, must be recorded in the data-entry boxes provided for this purpose. Where a number of sources are available to supply the installation, and where the data given for the primary source may differ from other sources, an additional page must be included in the certificate which gives the relevant information relating to each additional source.

The *Characteristics of the primary supply overcurrent protective device(s)* are required to be identified in terms of BS or BS EN number (e.g. BS 1361), type (e.g. Type II), nominal current rating (e.g. 100 A) and short-circuit capacity (e.g. 16.5 kA) to be recorded. It is important to be assured that the nominal current rating is not less than the maximum demand and that the short-circuit capacity is not less that the highest prospective fault current, I_{pf}, at the origin.

Particulars of the Installation at the Origin (Figure 17.12(b)) The *Means of earthing* will have already been determined by the designer in consultation with the electricity distributor. There are two options for providing a means of earthing, namely, an installation earth electrode (for TT and IT systems – no earthing facility provided by the supplier), or an earthing facility made available by the distributor. The most common means of earthing which might be provided by the supplier will be those associated with TN-C-S (e.g. PME supply) or TN-S (separate supply earth provided usually in the form of cable sheath or separate protective conductor).

Details of the earth electrode are normally only applicable to TT and IT systems. Where so used, the details of the type of electrode (e.g. rod(s), tape and/or plate(s), etc.) and its location(s) are required to be recorded, as is the resistance of the electrode, R_A, and the method of measurement of that parameter (see item 17.4.9 of this Guide).

A main linked switch or main linked circuit-breaker, as demanded by Regulation 460–01–02, is required for every installation and its details, in terms of its BS or BS EN number, voltage rating, the number of poles (e.g. 2-, 4-pole) and current rating must be recorded on the Certificate. Additionally, provision has been made on the form to identify the supply conductors to the main switch (often the meter tails) in terms of conductor material (e.g. copper) and cross-sectional area. Where an RCD, meeting all the necessary requirements for isolation, has been employed as a main switch, the rated residual operating current, $I_{\Delta n}$, must also be recorded together with the operating time (in ms) when subjected to a test current equal to the rated residual operating current, $I_{\Delta n}$.

Maximum demand, in terms of amperes per phase, will be that which the designer has assessed from his design calculations, taking into account allowable diversity, and will depend to a large extent on the size of the installation and any load management measures adopted to limit peak loads.

The *Method of protection against indirect contact* is that method which has been used for protection (against indirect contact) for the majority of the installation, although other methods may have been used on certain parts of the installation (e.g. Class II luminaire). By far the most common form of protection against indirect contact is Earthed Equipotential Bonding and Automatic Disconnection of Supply (EEBADS). It is important to recognise that automatic disconnection of supply on its own is not an option. However, there are alternative methods of providing this protection (e.g. earth-free local equipotential bonding) but these are much less extensively employed.

Provision has been made under *Main protective conductors* to record the particulars of the earthing conductor in terms of conductor material (e.g. copper) and cross-sectional area, together with a facility to record that a continuity check has been carried out on this conductor. Similar provision has to be made for the *Main equipotential bonding conductors*. Additionally, the various services to which main equipotential bonding conductors are connected are to be identified in this section.

Comments on Existing Installations (Figure 17.12(b)) Such comments are applicable only where an existing installation has been altered or has had an addition made to it. As mentioned in Regulation 721–01–02, it is imperative that an alteration and/or addition to an installation complies in full with BS 7671. Where, for example, a new circuit makes use of any protective measures within the existing installation (e.g. an existing fuse for protection against overcurrent and indirect contact), the person carrying out such an addition would need to be assured that all the requirements relating to that protection are adequate (e.g. main equipotential bonding). Additionally, any alteration and addition must not adversely affect the safety of the existing installation. This part of the Certificate gives the compiler the opportunity to draw the consumer's attention to any aspects of unrelated parts of the existing installation which require attention. The entry here should be 'None' or the additional page number(s) on which the comments are set out.

Next Inspection (Figure 17.12(b)) The recommendation for the interval to the next inspection is for the designer(s) to complete. The entry should be an appropriate interval, in terms of weeks, months or years, bearing in mind all the relevant circumstances relating to the installation.

Schedule of Items Inspected (Figure 17.12(c)) This schedule identifies most of the items that need inspection prior to testing, and data-entry boxes are provided so that necessary actions (that of inspections) may be recorded. All data-entry boxes are to be completed, as appropriate for the particular installation, by inserting a 'Yes' or a '✓' indicating that the inspections have been undertaken on all applicable parts of the installation and that the result of inspection was satisfactory. It is unlikely that all items will apply, and the range of applicable inspections will depend on the particular installation covered by the Certificate. If an inspection is not applicable, 'N/A', meaning 'Not Applicable', should be recorded in the box. No boxes should remain blank.

Schedule of Items Tested (Figure 17.12 (c)) Again, this schedule identifies most of the items that need testing and data-entry boxes are provided so that necessary actions (that of testing) may be recorded. All data-entry boxes are to be completed, as appropriate for the particular installation, by inserting a 'Yes' or a '✓' indicating that the tests have been undertaken on all applicable parts of the installation and the results are satisfactory. It is unlikely that all items will apply, and the range of applicable tests will depend on the particular installation covered by the Certificate. If a test is not applicable, 'N/A', meaning 'Not Applicable', should be recorded in the box. No boxes should remain blank.

Schedule of Additional Records (Figure 17.12(c)) Where additional records, such as as-fitted drawings, are to be submitted as part of the Certificate, these are required to be identified in the *Schedule of additional records* section near the bottom of the page, by entering the additional page (or sheet) numbers of these records.

Schedule of Circuit Details for the Installation (Figure 17.12 (d)) This schedule begins with *Location of distribution board* and *Distribution board designation*. Information required here is self-explanatory and needs to be completed for every installation, irrespective of where the distribution board is located. Where the distribution board is located at a position other than at the origin, the requested information should be recorded which includes:

- Supply to distribution board is from:
- No of phases:
- Nominal voltage:
- Overcurrent protective device for the distribution circuit: Type BS (EN):
- Overcurrent protective device for the distribution circuit: Rating:
- Associated RCD (if any): BS (EN):
- RCD No of poles:
- $I_{\Delta n}$:

A separate *Schedule of circuit details for the installation* will be required for each and every distribution board, which should be identified using the same designation identification as used on the distribution board itself.

Moving on to the *Circuit details* section, the entry for *circuit number and phase(s)* needs no explanation nor does the *circuit designation*, except to say that identification should be succinct and unambiguous in order to avoid confusion later (e.g. at subsequent periodic inspections).

The *type of wiring* should be identified in accordance with the code at the bottom of the form. For ease of reference the code is repeated here:

A: PVC/PVC cables.
B: PVC cables in metallic conduit.
C: PVC cables in non-metallic conduit.
D: PVC cables in metallic trunking.
E: PVC cables in non-metallic trunking.
F: PVC/SWA cables.
G: XLPE/SWA cables.
H: Mineral-insulated cables.
O: Other.

The *reference method* is that which is appropriate to the particular installation method, both of which are given in Table 4A of Appendix 4 of BS 7671.

The *number of points* served is self-explanatory and refers to the number of points such as socket-outlets and/or items of current-using equipment (e.g. luminaires).

Provision is made to record the cross-sectional area of *circuit conductors* both for live conductors (phase(s) and neutral) and circuit protective conductors.

A record of the *maximum disconnection time permitted by BS 7671* is required for every circuit. Such disconnection times will of course depend on the type of circuit as well as the location of equipment served.

Details of the *overcurrent protective devices* are required in terms of their BS (EN) specification reference (e.g. BS EN 60 898), type (e.g. Type C), rating (e.g. 32 A), and short-circuit capacity (e.g. 6 kA).

Where an RCD is employed, the residual operating current, $I_{\Delta n}$, must be recorded for each circuit. Likewise, provision is made for recording the *maximum* Z_s *permitted by BS 7671*, which completes the *Schedule of circuit details for the installation*.

Schedule of Test Results for the Installation (Figure 17.12 (e)) This schedule begins with provision for recording parameters at the distribution board where it is located at other than the origin. Information required here is self-explanatory and needs to be completed for every installation where the distribution board is located at a position remote from the origin. The requested information which should be recorded includes:

- Earth fault loop impedance, Z_s, at the distribution board.
- Prospective fault current, I_{pf}, at the distribution board.
- Operating time of RCD when subjected to a test current equal to $I_{\Delta n}$.
- Operating time of RCD when subjected to a test current 150 mA, if applicable.

Where the installation can be supplied by more than one source, such as a primary source (e.g. public supply) and a secondary source (e.g. standby generator), the higher or highest value earth fault loop impedance, Z_s, and prospective fault current, I_{pf}, at the distribution board must be entered.

Provision has been made to make the essential record of the test instruments used for such testing. This is an important aspect since inaccuracies may be revealed later which necessitates the tracing of the test instruments used.

A separate schedule will be required for each and every distribution board which should be identified using the same designation identification as used on the distribution board itself. Generally, where entry to a column is not relevant the data-entry box should be marked 'N/A', meaning 'Not Applicable'.

Moving on to the *Test results* section, the entry for *circuit number and phase(s)* needs no explanation and will be identifical to that given on the *Schedule of circuit details for the installation*.

Five columns are provided for recording *circuit impedances*, which for most final circuits will only warrant recording the resistance component of impedance. The three columns headed 'r_1', 'r_n', 'r_2' relate to the end-to-end resistances of the phase conductor, the neutral conductor and the circuit protective conductor of a ring final circuit, respectively. Where the circuit is not a ring final circuit, the columns should be marked 'N/A', meaning 'Not Applicable'. The two following columns headed '$R_1 + R_2$' and 'R_2' apply to all circuits but it is essential only to complete one or the other.

Four columns are provided for *insulation resistance* and are all self-explanatory, except to note that where multi-phase systems are employed the higher or highest values must be recorded. A record that *polarity* has been checked must be acknowledged by ticking the data-entry box.

The *maximum measured earth fault loop impedance,* Z_s, must be recorded. Where the installation can be supplied by more than one source, such as a primary source (e.g. public supply) and a secondary source (e.g. standby generator), the higher or highest value must be entered. It should be acknowledged that the measured value of earth fault loop impedance should normally be less than that allowed by BS 7671 in recognition of the likely lower temperature of the circuit conductors under test conditions than when operating under full load. It is generally accepted that, where the earth fault loop impedance values do not exceed 80% of the limits given for the overcurrent protective device in Tables 41B1, 41B2 and 41D (and their derivatives elsewhere) of BS 7671, the earth fault loop impedance of the circuits will be acceptable under all conditions, including when fully loaded. Circuits where values exceed 80% will need closer examination to be confident that the circuit complies in this respect.

To complete this schedule, provision is made to record the operating times of RCDs, when subjected to a test current of $I_{\Delta n}$ and, if applicable, at 150 mA.

17.5.5 Initial certification – caravans

The NICEIC in consultation with the National Caravan Council have devised a Certificate, for use by approved contractors, solely for the purposes of certification of new caravans. This certificate is reproduced, by kind permission of the NICEIC, in Figure 17.13 and is self-explanatory. At the time of publication of this revised guide (2002) the NICEIC Certificate had not been updated though it is anticipated that this will be carried out in the not too distant future.

17.5.6 Initial certification – minor works

The NICEIC has revised their Minor Electrical Installation Works Certificate, shown in Figure 17.14, for the very small alteration work and/or small additions to an electrical installation. The scope of the certificate is limited to small alterations and additions that do not extend to the introduction of a new circuit. Its use should therefore be restricted to the very small jobs and full certification will be required for all other installation work. This form of certification for alterations and additions which do not extend to a new circuit is recognised in Regulations 743–01–02 to 741–01–03.

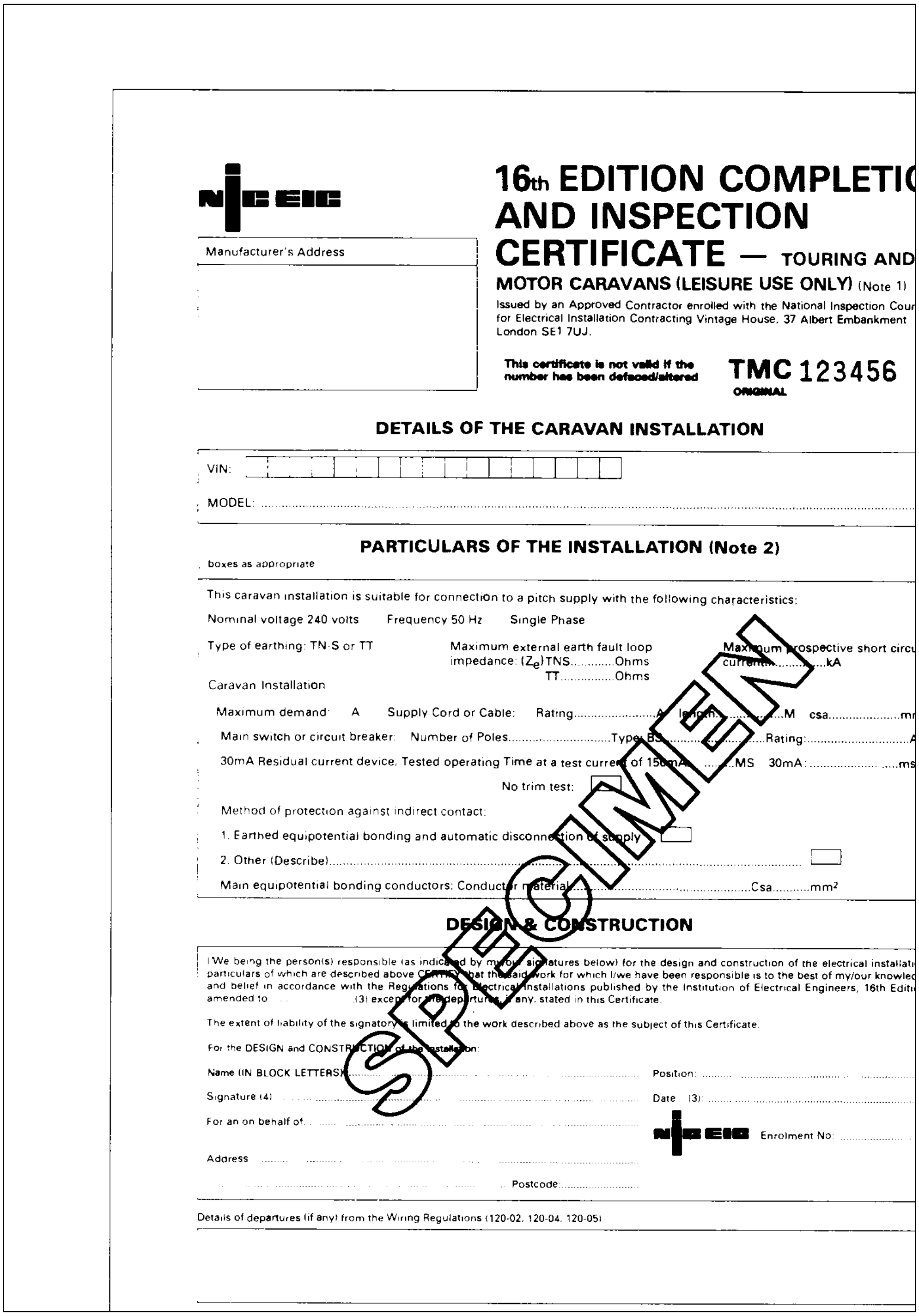
17.6 Periodic inspection and testing

17.6.1 General

As set out in Regulations 731–01–01 to 731–01–05 the periodic inspection and testing of every installation must be carried out in accordance with Chapter 73 of BS 7671 and involve careful scrutiny without dismantling, or with partial dismantling, and accompanying inspection and testing to determine, as far as is reasonably practicable, whether the installation is in a satisfactory condition for continued service. Additionally, safety risks relating to damage to property from fire and heat must be identified as must any damage or deterioration of installation equipment which may impair safety. Finally, any defect or non-compliance with BS 7671 which may give rise to danger must be identified.

It is the responsibility of the person certifying the initial verification of an installation to make a recommendation for the subsequent inspection and testing and this would be based on the whole circumstances relating to the particular installation. Regulations 741–01–02 and 744–01–01 call for a report to be issued to the person ordering such an inspection. The report must draw the attention of the consumer (or his agent) to any dangerous conditions which are observed and must also state the scope and limitations of such an inspection. In the absence of any stated limitations it would be fair for the consumer to assume that every part of the installation had been inspected and tested including, for example, cables concealed within the building inter-floor spaces. A suitable report form is reproduced (by kind permission of the NICEIC – for use by approved contractors) in Figure 17.16.

Any Periodic Inspection Report of an installation which has been carried out to an earlier Edition of the Wiring Regulations should only refer to departures (if any) from the current Edition (BS 7671) and not to the



16th EDITION COMPLETI
AND INSPECTION
CERTIFICATE — TOURING AND
MOTOR CARAVANS (LEISURE USE ONLY) (Note 1)

Issued by an Approved Contractor enrolled with the National Inspection Cou
for Electrical Installation Contracting Vintage House, 37 Albert Embankment
London SE1 7UJ.

Manufacturer's Address

This certificate is not valid if the number has been defaced/altered

TMC 123456
ORIGINAL

DETAILS OF THE CARAVAN INSTALLATION

VIN: ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

MODEL: ....

PARTICULARS OF THE INSTALLATION (Note 2)

boxes as appropriate

This caravan installation is suitable for connection to a pitch supply with the following characteristics:

Nominal voltage 240 volts Frequency 50 Hz Single Phase

Type of earthing: TN-S or TT Maximum external earth fault loop impedance: (Z_e) TNS............Ohms TT...............Ohms Maximum prospective short circu current...............kA

Caravan Installation

Maximum demand: A Supply Cord or Cable: Rating........................A length..............M csa.....................mr

Main switch or circuit breaker: Number of Poles.............................Type: BS..........................Rating:.............................A

30mA Residual current device, Tested operating Time at a test current of 150mA...........MS 30mA:..................... .....ms

No trim test: ☐

Method of protection against indirect contact:

1. Earthed equipotential bonding and automatic disconnection of supply ☐

2. Other (Describe)... ☐

Main equipotential bonding conductors: Conductor material..Csa...........mm²

DESIGN & CONSTRUCTION

I/We being the person(s) responsible (as indicated by my/our signatures below) for the design and construction of the electrical installati particulars of which are described above CERTIFY that the said work for which I/we have been responsible is to the best of my/our knowled and belief in accordance with the Regulations for Electrical Installations published by the Institution of Electrical Engineers, 16th Editi amended to ....(3) except for the departures, if any, stated in this Certificate.

The extent of liability of the signatory is limited to the work described above as the subject of this Certificate.

For the DESIGN and CONSTRUCTION of the installation:

Name (IN BLOCK LETTERS).. Position: ....

Signature (4) .... Date (3): ....

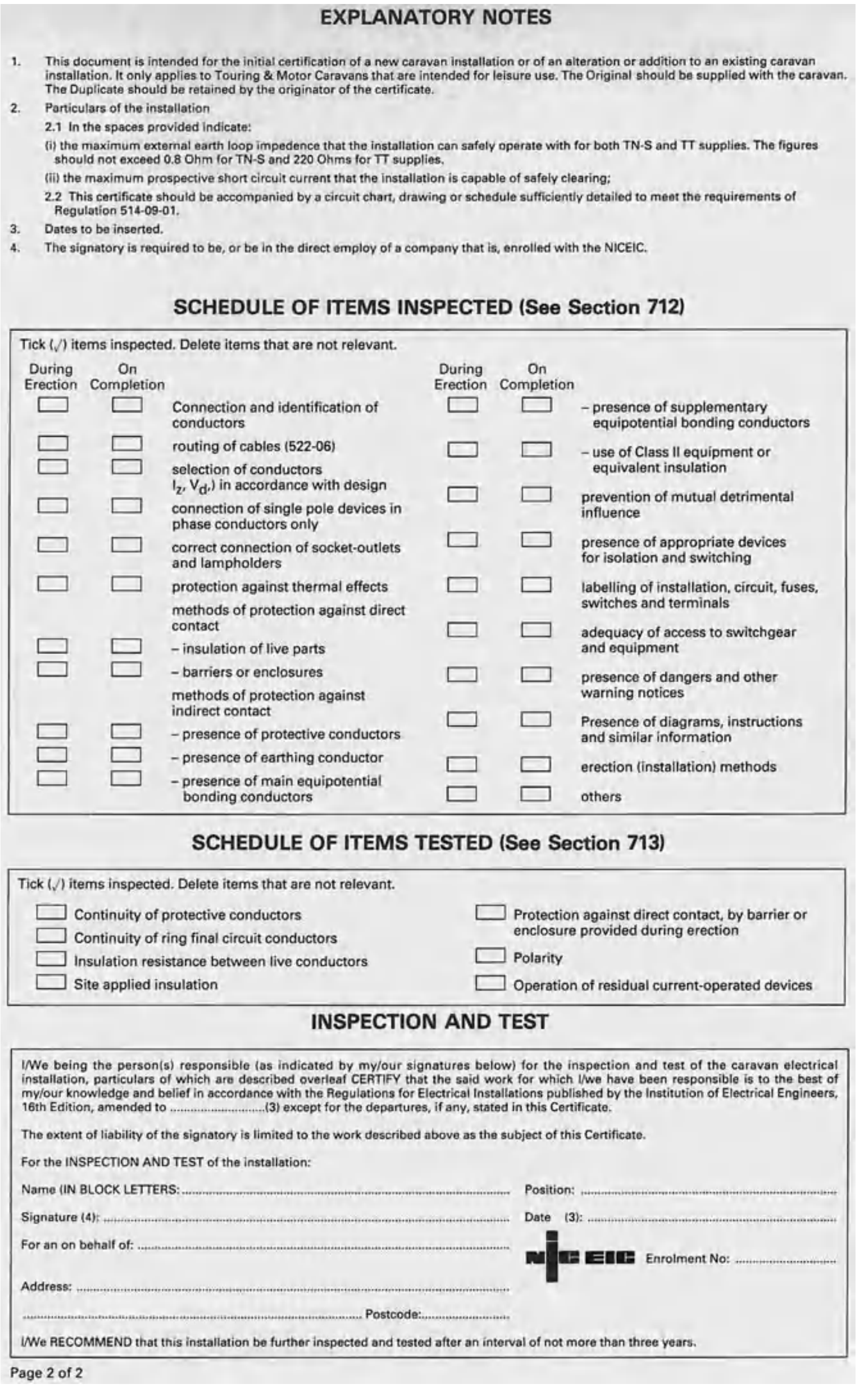
For an on behalf of... Enrolment No: ....

Address ....

.... Postcode:..........................

Details of departures (if any) from the Wiring Regulations (120-02, 120-04, 120-05)

Figure 17.13 (a): Certificate (Touring and Motor Caravans) – page 1



EXPLANATORY NOTES

1. This document is intended for the initial certification of a new caravan installation or of an alteration or addition to an existing caravan installation. It only applies to Touring & Motor Caravans that are intended for leisure use. The Original should be supplied with the caravan. The Duplicate should be retained by the originator of the certificate.
2. Particulars of the installation
   - 2.1 In the spaces provided indicate:
   - (i) the maximum external earth loop impedence that the installation can safely operate with for both TN-S and TT supplies. The figures should not exceed 0.8 Ohm for TN-S and 220 Ohms for TT supplies.
   - (ii) the maximum prospective short circuit current that the installation is capable of safely clearing;
   - 2.2 This certificate should be accompanied by a circuit chart, drawing or schedule sufficiently detailed to meet the requirements of Regulation 514-09-01.
3. Dates to be inserted.
4. The signatory is required to be, or be in the direct employ of a company that is, enrolled with the NICEIC.

SCHEDULE OF ITEMS INSPECTED (See Section 712)

Tick (✓) items inspected. Delete items that are not relevant.

During Erection	On Completion	
☐	☐	Connection and identification of conductors
☐	☐	routing of cables (522-06)
☐	☐	selection of conductors (I_z, V_d,) in accordance with design
☐	☐	connection of single pole devices in phase conductors only
☐	☐	correct connection of socket-outlets and lampholders
☐	☐	protection against thermal effects
		methods of protection against direct contact
☐	☐	– insulation of live parts
☐	☐	– barriers or enclosures
		methods of protection against indirect contact
☐	☐	– presence of protective conductors
☐	☐	– presence of earthing conductor
☐	☐	– presence of main equipotential bonding conductors

During Erection	On Completion	
☐	☐	– presence of supplementary equipotential bonding conductors
☐	☐	– use of Class II equipment or equivalent insulation
☐	☐	prevention of mutual detrimental influence
☐	☐	presence of appropriate devices for isolation and switching
☐	☐	labelling of installation, circuit, fuses, switches and terminals
☐	☐	adequacy of access to switchgear and equipment
☐	☐	presence of dangers and other warning notices
☐	☐	Presence of diagrams, instructions and similar information
☐	☐	erection (installation) methods
☐	☐	others

SCHEDULE OF ITEMS TESTED (See Section 713)

Tick (✓) items inspected. Delete items that are not relevant.

☐ Continuity of protective conductors
☐ Continuity of ring final circuit conductors
☐ Insulation resistance between live conductors
☐ Site applied insulation
☐ Protection against direct contact, by barrier or enclosure provided during erection
☐ Polarity
☐ Operation of residual current-operated devices

INSPECTION AND TEST

I/We being the person(s) responsible (as indicated by my/our signatures below) for the inspection and test of the caravan electrical installation, particulars of which are described overleaf CERTIFY that the said work for which I/we have been responsible is to the best of my/our knowledge and belief in accordance with the Regulations for Electrical Installations published by the Institution of Electrical Engineers, 16th Edition, amended to ....(3) except for the departures, if any, stated in this Certificate.

The extent of liability of the signatory is limited to the work described above as the subject of this Certificate.

For the INSPECTION AND TEST of the installation:

Name (IN BLOCK LETTERS: .... Position: ....

Signature (4): .... Date (3): ....

For an on behalf of: .... NICEIC Enrolment No: ....

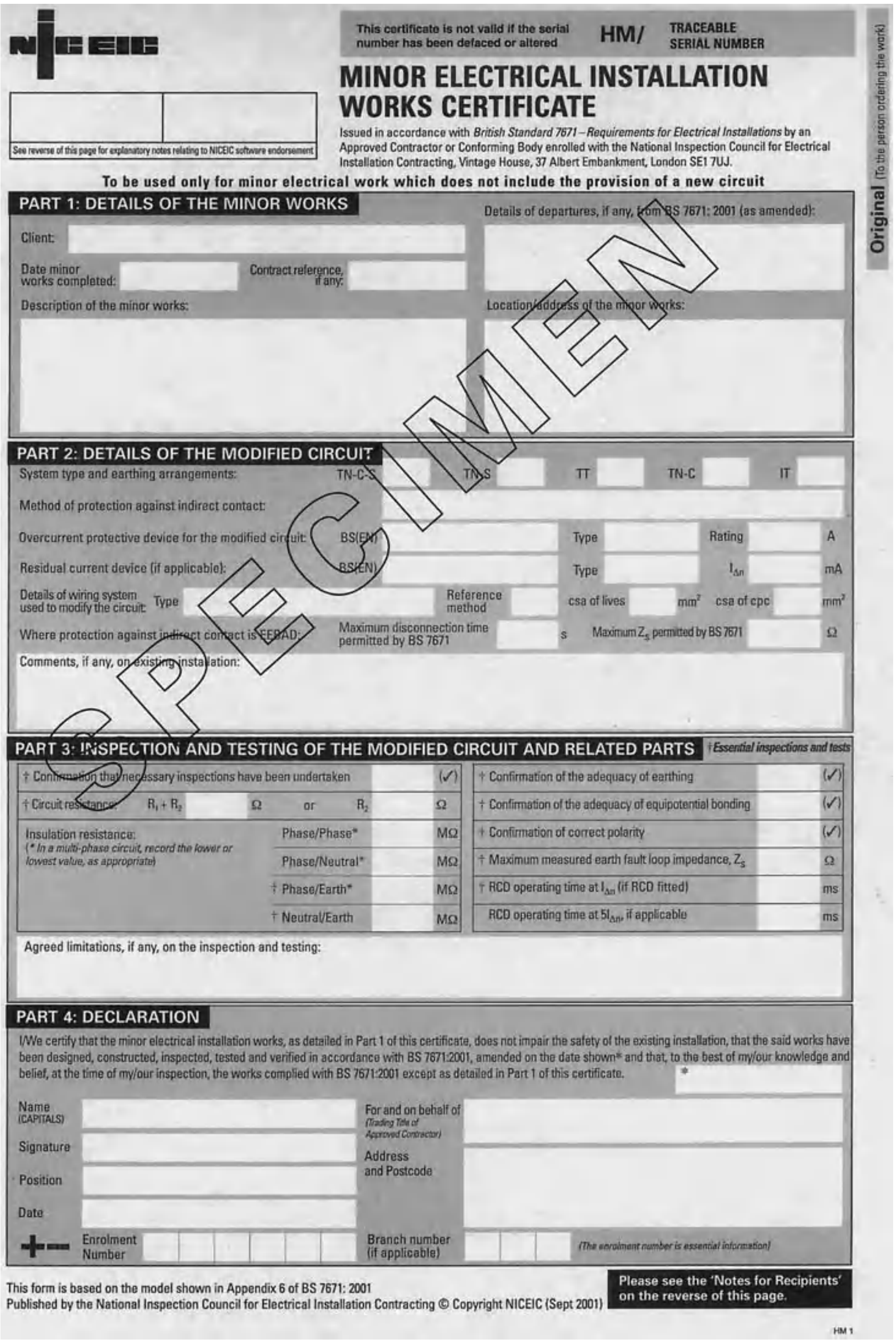
Address: ....

.... Postcode:..........................

I/We RECOMMEND that this installation be further inspected and tested after an interval of not more than three years.

Page 2 of 2

Figure 17.13 (b): Certificate (Touring and Motor Caravans) – page 2



This certificate is not valid if the serial number has been defaced or altered HM/ TRACEABLE SERIAL NUMBER

Original (To the person ordering the work)

MINOR ELECTRICAL INSTALLATION WORKS CERTIFICATE

See reverse of this page for explanatory notes relating to NICEIC software endorsement

Issued in accordance with *British Standard 7671 – Requirements for Electrical Installations* by an Approved Contractor or Conforming Body enrolled with the National Inspection Council for Electrical Installation Contracting, Vintage House, 37 Albert Embankment, London SE1 7UJ.

To be used only for minor electrical work which does not include the provision of a new circuit

PART 1: DETAILS OF THE MINOR WORKS

Client:

Date minor works completed:

Contract reference, if any:

Description of the minor works:

Details of departures, if any, from BS 7671: 2001 (as amended):

Location/address of the minor works:

PART 2: DETAILS OF THE MODIFIED CIRCUIT

System type and earthing arrangements: TN-C-S ☐ TN-S ☐ TT ☐ TN-C ☐ IT ☐

Method of protection against indirect contact:

Overcurrent protective device for the modified circuit: BS(EN) Type Rating A

Residual current device (if applicable): BS(EN) Type $I_{\Delta n}$ mA

Details of wiring system used to modify the circuit: Type Reference method csa of lives mm² csa of cpc mm²

Where protection against indirect contact is EEBAD: Maximum disconnection time permitted by BS 7671 s Maximum Z_S permitted by BS 7671 Ω

Comments, if any, on existing installation:

PART 3: INSPECTION AND TESTING OF THE MODIFIED CIRCUIT AND RELATED PARTS

†*Essential inspections and tests*

† Confirmation that necessary inspections have been undertaken		(✓)	† Confirmation of the adequacy of earthing		(✓)
† Circuit resistance: $R_1 + R_2$ Ω or R_2		Ω	† Confirmation of the adequacy of equipotential bonding		(✓)
Insulation resistance: (* *In a multi-phase circuit, record the lower or lowest value, as appropriate*) Phase/Phase*		MΩ	† Confirmation of correct polarity		(✓)
Phase/Neutral*		MΩ	† Maximum measured earth fault loop impedance, Z_S		Ω
† Phase/Earth*		MΩ	† RCD operating time at $I_{\Delta n}$ (if RCD fitted)		ms
† Neutral/Earth		MΩ	RCD operating time at $5I_{\Delta n}$, if applicable		ms

Agreed limitations, if any, on the inspection and testing:

PART 4: DECLARATION

I/We certify that the minor electrical installation works, as detailed in Part 1 of this certificate, does not impair the safety of the existing installation, that the said works have been designed, constructed, inspected, tested and verified in accordance with BS 7671:2001, amended on the date shown* and that, to the best of my/our knowledge and belief, at the time of my/our inspection, the works complied with BS 7671:2001 except as detailed in Part 1 of this certificate. *

Name (CAPITALS)

Signature

Position

Date

For and on behalf of (*Trading Title of Approved Contractor*)

Address and Postcode

Enrolment Number

Branch number (if applicable)

(*The enrolment number is essential information*)

This form is based on the model shown in Appendix 6 of BS 7671: 2001

Published by the National Inspection Council for Electrical Installation Contracting © Copyright NICEIC (Sept 2001)

Please see the 'Notes for Recipients' on the reverse of this page.

HM 1

Figure 17.14: Minor Electrical Installation Works Certificate

Edition to which it was constructed. Should an inspection reveal deficiencies in the installation which present an immediate danger, the consumer (or his agent) should be advised immediately (verbally initially and preferably in writing subsequently) of the safety risks and detail any corrective action required.

It is self evident that all installations should be regularly inspected and tested periodically. However, BS 7671 cannot impose such a requirement on the consumer who may, if so disposed, ignore completely the recommendations of the initial verifier and this may be particularly true of domestic consumers some of whom are unable to see any benefit of such inspections. In the case of installations in places of work the situation is somewhat different as under the Electricity at Work Regulations 1989 the duty holder responsible for the maintenance of the installation is required to maintain all electrical systems so as to prevent danger. It should also be noted that in some cases there is a statutory requirement for periodic inspections (e.g. cinemas, petrol filling stations, public houses, church and village halls, bingo rooms, school assembly halls used for public concerts).

17.6.2 Intervals between periodic inspection and testing

All installations should be regularly inspected and tested in order that the person responsible for the safety of the installation can be reassured that it continues to give satisfactory and safe service. On completion of the initial verification of an installation it is the verifier who makes the recommendation as to when the first periodic inspection and testing should be made. The recommendation for a subsequent periodic inspection then rests with the test engineer carrying out the first periodic inspection and so on. It is reasonable to expect the intervals to become progressively shorter as the installation ages, suffering as it surely must from normal wear and tear. Much will depend on the type of installation, its usage and its environment and the person responsible for making recommendations will need to take all these factors into consideration.

Regulation 732–01–01 states that the frequency of periodic inspection will depend on the type of installation and the type of premises and the use and operation of the installation. Table 17.21 seeks to provide a listing of suggested intervals between inspections but should only be used as a guide since all the relevant factors relating to the installation must be taken into account. Furthermore, where premises are required to be licensed, the licensing authority may seek to impose shorter time spans between inspections particularly for those installations nearing the end of their useful service life. The table identifies the type of premises that are likely to be the subject of licensing conditions, or where there are implicit requirements in legislation, by the code ‘M’ and those that are not by the code ‘R’.

Regulation 732–01–02 recognises that where an installation is under effective supervision in normal use, a regime of continuous monitoring may obviate the need for periodic inspection and testing, providing adequate records are maintained.

17.6.3 Approximate age of an installation

Most experienced installation engineers will have no difficulty in dating an installation within five to ten years. Though perhaps unconsciously, features will be seen which will identify the period to within a decade or so and a combination of features will reduce the period even further. In Table 17.22 an attempt has been made to collate some of the many installation features which will, hopefully, be an aid to making a more accurate assessment of the age of an installation. The dates given are necessarily very approximate.

It is difficult to predict the life, or remaining life, of an installation, much depending on the level of maintenance it has received in the past and what it is likely to receive in the future. Furthermore, the usage to which the installation has, and will be, subjected is very important in the estimation of its life expectancy as is the consideration of the environmental conditions. Most installations carried out more than 30 years ago must be nearing the end of their life or existing on borrowed time and installations of greater vintage must be highly suspect in providing continuing service and safety.

17.6.4 Periodic inspection and testing

In an ideal world the documentation (diagrams, circuit charts and design details) dealing with the initial verification of the electrical installation will be available to the person carrying out subsequent periodic inspections. The inspector should take particular note of any change in circumstances which may, for example, include environmental conditions, alterations and additions to the building structure and electrical installation and any changes in loadings. As called for in Regulation 731–01–03, the inspection should be carried out with careful scrutiny and without wholesale dismantling of the installation. Partial dismantling will, of course, be necessary to establish, for example, that wiring systems are generally in a good serviceable condition. It is important that an assessment is made to evaluate the general condition and whether it is safe to conduct tests without creating danger to persons and livestock. The inspector should take particular note of the suitability and condition of equipment in terms of safety, age, wear and tear, physical damage, corrosion, loading and overloading and any change of external influences (e.g. by, for example, a change of use of the premises).

Protective devices must be checked for their suitability, their ratings, in terms of short-circuit capacity and nominal current rating, their accessibility and identification. Isolating and switching devices, including emergency switching arrangements must also be checked for their suitability, accessibility, identification and performance.

Switchgear and enclosures generally should be checked for their suitability, condition and performance and that the intended degree of ingress protection (IP) is maintained. A check of the colour coding of conductors should also be made together with a check of correct connection and an assessment of whether overloading is evident and that the

Table 17.21: Intervals between inspections

Ref	Type of premises	Interval (years)	Code[2]	Other references[1]
General installations				
A	Private housing.	10	R	—
B	Offices and other commercial premises.	5	R	See also the Electricity at Work Regulations 1989.
C	Schools and other educational establishments.	5	R	See also the Electricity at Work Regulations 1989.
D	Hospitals and other medical establishments.	5	R	See also the Electricity at Work Regulations 1989.
E	Factories and other industrial premises.	3	M	See also the Electricity at Work Regulations 1989.
Public building installations				
F	Churches and other places of worship with installations completed in the preceding 5 years.	2	R	See also the Electricity at Work Regulations 1989. See Lighting and Wiring of Churches 1981.
G	Churches and other places of worship with installations completed over 5 years ago.	1	R	See also the Electricity at Work Regulations 1989. See Lighting and Wiring of Churches 1981.
H	Theatres.	1	M	See also the Electricity at Work Regulations 1989. See Conditions of Licence imposed by the Licensing Authority.
I	Cinemas.	1	M	See also the Electricity at Work Regulations 1989. See clause 17 of The Cinematograph (Safety) Regulations 1955.
J	Places of public entertainment.	1	M	See also the Electricity at Work Regulations 1989. See Conditions of Licence imposed by the Licensing Authority.
K	School halls, church halls etc. used for public concerts.	1	M	See also the Electricity at Work Regulations 1989. See Conditions of Licence imposed by the Licensing Authority.
L	Hotels.	1	M	See also the Electricity at Work Regulations 1989. See Conditions of Licence imposed by the Licensing Authority.
M	Restaurants.	1	M	See also the Electricity at Work Regulations 1989. See Conditions of Licence imposed by the Licensing Authority.
N	Sports and leisure centres.	1	M	See also the Electricity at Work Regulations 1989. See Conditions of Licence imposed by the Licensing Authority.

Continued on facing page

Table 17.21 continued: Intervals between inspections

Ref	Type of premises	Interval (years)	Code$^{(2)}$	Other references$^{(1)}$
Special locations				
O	Farms and other agricultural premises.	3	R	See also the Electricity at Work Regulations 1989.
P	Garden centres and other horticultural premises.	3	R	See also the Electricity at Work Regulations 1989.
Q	Caravan parks.	1	M	See also the Electricity at Work Regulations 1989. See Conditions of Licence imposed by the Licensing Authority.
R	Caravans.	3	R	—
S	Construction and building sites and other temporary installations.	0.25	R	See also the Electricity at Work Regulations 1989.
T	Highway power supply and street lighting etc.	6	M	See also the Electricity at Work Regulations 1989. See Conditions of Licence imposed by the Licensing Authority.
Specialised installations				
U	Fire detection and alarm systems in buildings.	1	M	See also the Electricity at Work Regulations 1989. See BS 5839. See Conditions of Licence imposed by the Licensing Authority.
V	Emergency lighting systems.	3	M	See also the Electricity at Work Regulations 1989. See BS 5266. See Conditions of Licence imposed by the Licensing Authority. Batteries and safety supply generators need further consideration.
W	Laundries and launderettes.	1	M	See also the Electricity at Work Regulations 1989.
X	Petrol filling stations.	1	M	See also the Electricity at Work Regulations 1989. See Conditions of Licence imposed by the Licensing Authority.

Notes: (1) Where electricity supplies are obtained from the public supply network, the PES will wish to ensure that the requirements of the Electricity Supply Regulations 1988, as amended are met.
(2) The code signifies: 'R', recommended and 'M', mandatory.

insulation remains in a good serviceable condition. Where metallic sheathed and/or armoured cables have been used a check on the termination of their glands should be made to establish that a sound mechanical and electrical connection is evident. Conductors, including protective conductors, should be checked for correct sizing and protection against overcurrent and, where applicable, provide sufficient protection against direct contact.

A check must also be made of the protective measures employed for direct contact and a note of, for example, any absent barriers should subsequently be made on the report. Particular attention should be paid to provision of safety features intended to prevent danger to persons and

Table 17.22: Approximate age of an installation

Ref	Feature	Approximate dates
A	Lead sheathed cables.	pre 1948
B	Tough Rubber Sheathed cables (TRS).	1945 – 1962
C	'Capothene' and 'Ashothene' sheathed cables.	1952 – 1960
D	PVC/PVC cables without cpc used on lighting circuits.	1955 – 1966
E	PVC cables of imperial sizes.	1955 – 1971
F	2.5 mm^2 PVC/PVC sheathed cables with 1 mm^2 cpc.	1971 – 1981
G	Black earthing conductors.	pre 1966
H	Absence of main equipotential bonding conductors.	pre 1966
I	Green protective conductor oversleeving.	pre 1966
J	2.5 mm^2 main equipotential bonding conductors – small installations.	1971 – 1972
K	6 mm^2 main equipotential bonding conductors – small installations.	1966 – 1983
L	10 mm^2 main equipotential bonding conductors – small installations.	post 1983
M	Twin-twisted flexible cords.	pre 1977
N	Fault voltage operated circuit-breakers.	pre 1981
O	Accessories mounted on wooden blocks.	pre 1966
P	Non 13 A socket-outlets.	pre 1955
Q	Double-pole fused switchgear on a.c. installations.	pre 1955

Note: Dates given should be treated with extreme caution.

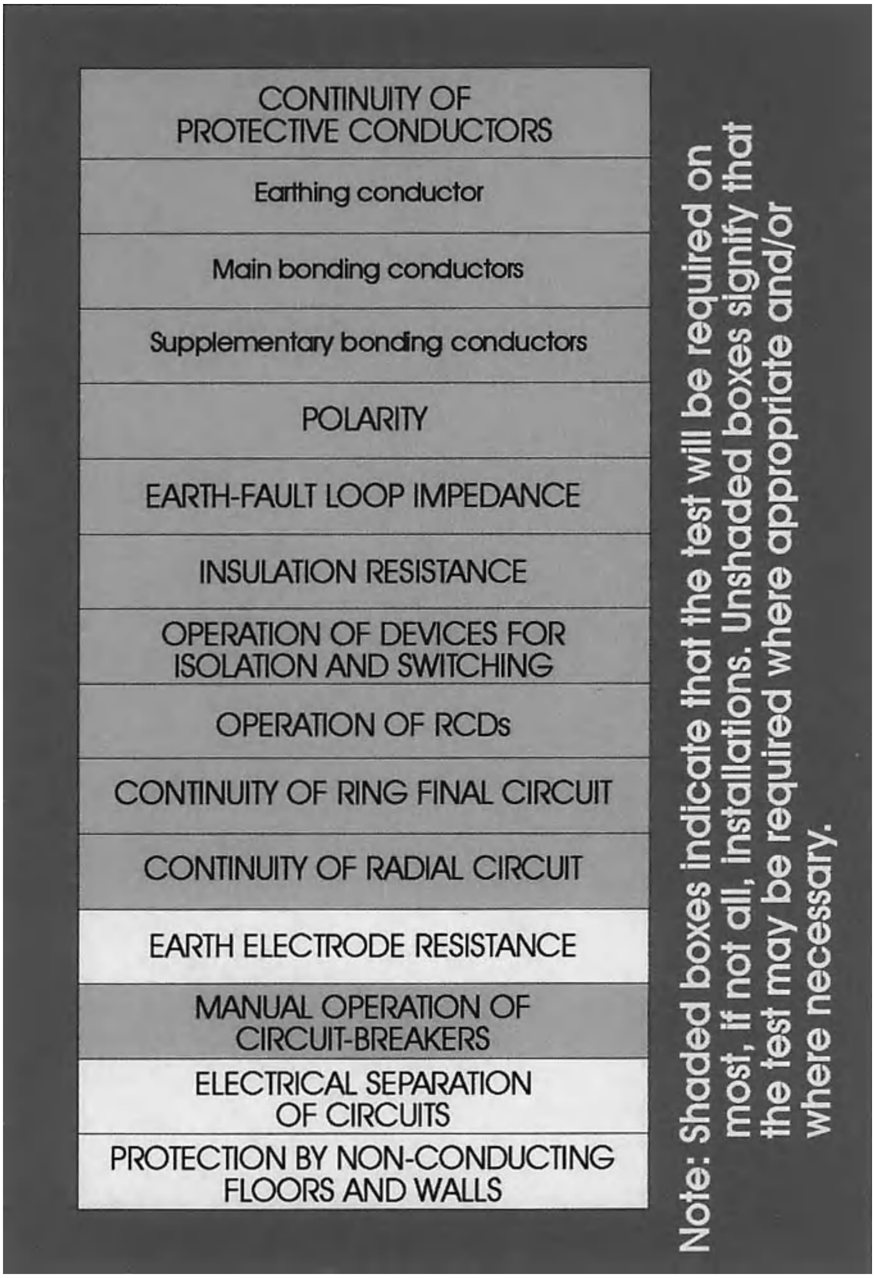
livestock (from shock, fire, burns and injury from mechanical movement) and damage to property; where deficiencies are evident, these matters should be noted on the report.

The marking and labelling of an installation is an important feature and special attention should be paid to this aspect. Warning notices and labelling should be as set out in Chapter 51 of BS 7671 and addressed in Chapter 9 of this Guide. Again, any deficiencies should be reported.

As previously mentioned, testing must not commence before the inspector has satisfied himself that tests can be made without danger (Regulation 732–01–05) and this can only be done after a careful visual inspection of all equipment that can reasonably be assessed.

The sequence of testing for periodic testing is different from that of initial testing and must be made in accordance with Figure 17.15. Particular care is needed to identify equipment and circuits vulnerable to a particular test and these should be disconnected (after prior arrangement with the consumer) before tests are made and other means should be used to establish their safety.

Tests of the continuity of the protective conductors cannot be carried out without first isolating the installation from the supply source. It is important to recognise that a dangerous potential can exist between the MET and disconnected protective conductors under installation normal conditions (e.g. if the means of earthing provides functional earthing requirements) and under installation earth fault conditions. A potential can also exist between these parts under earth fault conditions of supply equipment. Main bonding conductors should therefore only be disconnected from the MET for testing after taking the precaution of isolating the installation *and* ensuring that simultaneous contact between the bonding conductors and the MET is prevented.



Note: Shaded boxes indicate that the test will be required on most, if not all, installations. Unshaded boxes signify that the test may be required where appropriate and/or where necessary.

Figure 17.15: Sequence of tests for periodic testing

Polarity tests can now follow, again starting at the origin and working downstream through distribution boards and on to final circuits. Particular attention must be paid to ensure that single-pole devices (fuses, circuit-breakers, switches) are in the phase conductors only. Socket-outlets, fused connection units, ES lampholders, lighting track systems must also be checked for correct polarity. Any alterations and/or additions to the installation since the previous inspection should rate very close scrutiny.

Having established that the earthing and main equipotential bonding are satisfactory and also that polarity is correct, it is then necessary to carry out earth loop impedance tests in order to establish that the integrity of all the protective conductors is intact. Testing would normally start with a measurement of the external earth fault loop-impedance, Z_e, and then progressing on to distribution circuits (sub-mains). From the results of these tests it can then be confirmed that all protective conductors, including circuit protective conductors, are satisfactory and that, where Z_s influences the operation of protective devices for indirect contact protection, disconnection times are within permitted limits. More extensive earth fault loop impedance tests can now follow for final circuits including all socket-outlets, lighting circuits and other radial circuits with exposed-conductive-parts.

Insulation testing at the main switch (with the installation isolated) may be all that is required provided that the required value of insulation resistance is obtained (500 kΩ for circuits up to 500 V). This must be done with all the fuse links in place and with circuit-breakers in the closed position and with lighting luminaires switched on and lamps removed. Before testing, care should be taken to disconnect any vulnerable circuits (e.g. electronic equipment) before applying the test voltage in order to avoid damage to such equipment and costly replacements. The value of insulation resistance should be compared with the reading taken on the previous occasion of testing. Where there is a significant difference, further investigation may be necessary. Any vulnerable equipment disconnected for test purposes should, if it contains exposed-conductive-parts, be tested separately by a suitable instrument in order to ensure that it complies with the safety requirements laid down in the British Standard for that equipment or, in the absence of a specified insulation value, to have an insulation resistance of not less than 500 kΩ.

Where the necessary insulation resistance is not obtained at the main switch, further insulation tests will be necessary to identify the problem circuit(s) and to remedy the reasons for the poor insulation. It is worth remembering that overall insulation resistance is related to the individual circuit insulation resistances as given in Equation (17.6):

$$\frac{1}{R_o} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_n} \tag{17.6}$$

where R_o = insulation resistance overall
R_1 = insulation resistance of circuit 1
R_2 = insulation resistance of circuit 2
R_3 = insulation resistance of circuit 3
R_n = insulation resistance of n.

By way of example to illustrate the point, take three circuits with insulation resistance to Earth of 6 MΩ, 5 MΩ and 4 MΩ respectively. By inserting these values into Equation (17.7), the reciprocal of resistance is obtained:

$$\frac{1}{R_o} = \frac{1}{6} + \frac{1}{5} + \frac{1}{4} = \frac{10 + 12 + 15}{60} = \frac{37}{60} \qquad (17.7)$$

From which the overall insulation resistance R_o is 1.62 MΩ (60/37 MΩ).

According to Regulation 713–04–02 and Table 71A of Regulation 713–04–05, the minimum acceptable insulation resistance for the whole installation is 0.5 MΩ and this relates to a leakage current on an installation, operating on 240 V to Earth, of 0.48 mA. On the larger installation this limiting value of insulation resistance may be applied to each distribution circuit.

Devices for switching and isolation must be checked for correct operation. Such devices include isolators, disconnectors, switch-disconnectors, devices for switching off for mechanical maintenance and emergency switches. The devices should be verified as being capable of providing their allocated function and where a visual indication is a requirement the indicators should also be checked. A voltage indicator should be used to ensure that the device cuts off the equipment served from the supply and devices used for safety purposes such as emergency switches should all be verified as being capable of satisfactory service by operating the device in the intended manner. Where the isolating or other device is remote from the equipment it serves and where interlocking arrangements have not been used, locking devices, removable handles, etc. should be checked and the interchangeability of the locking mechanisms should be verified as being satisfactory.

All RCDs should be tested by simulating earth fault conditions in accordance with the requirements laid down in BS 4293 which are summarised in Table 17.3 (see also item 17.4.10 of this Guide) together with the requirements for time-delay RCDs. Where RCDs have been installed to provide supplementary protection against direct contact (e.g. for equipment located outside the equipotential zone), these must also be checked to ensure that their residual operating current, $I_{\Delta n}$, does not exceed 30 mA.

It is not possible to test the effectiveness of overcurrent protective devices (e.g. MCBs and MCCBs) *in situ* because of the dangers that would be created by allowing high currents which would flow in order to check satisfactorily the overload protection and much higher currents for fault current operation. However, such devices should be checked by operating the devices by hand and by observing that they open and close as intended. The inspector would also note that the device had originally been correctly selected and installed. Where there is doubt regarding the suitability of the device, or it has suffered damage or deterioration, it should be replaced.

IEE Guidance Note No 3 on inspection and testing recognises that it may be appropriate to use a sampling technique for testing of polarity and earth fault loop impedance where installations have not been the subject of additions and alterations since previously inspected. For polarity, other than for socket-outlets which should be individually checked (100%), a sample of 10% is suggested but where this reveals any incorrect polarities this sampling should be increased to 25% for the particular distribution board concerned and if further discrepancies are found this must be increased to 100%. Earth fault loop impedance tests must be carried out at the origin, at each distribution board, at all fixed equipment and socket-outlets and at the most remote point of each-radial circuit. Similarly, any circuit feeding equipment, which is obviously exposed to damage and deterioration or presents a special risk, must also be tested. A 10% sampling method is permitted for luminaires for each circuit provided the most remote point is tested. Where a sampling technique is used the points tested should be recorded so that at the next inspection the sampling method can again be applied but this time to a different series of points.

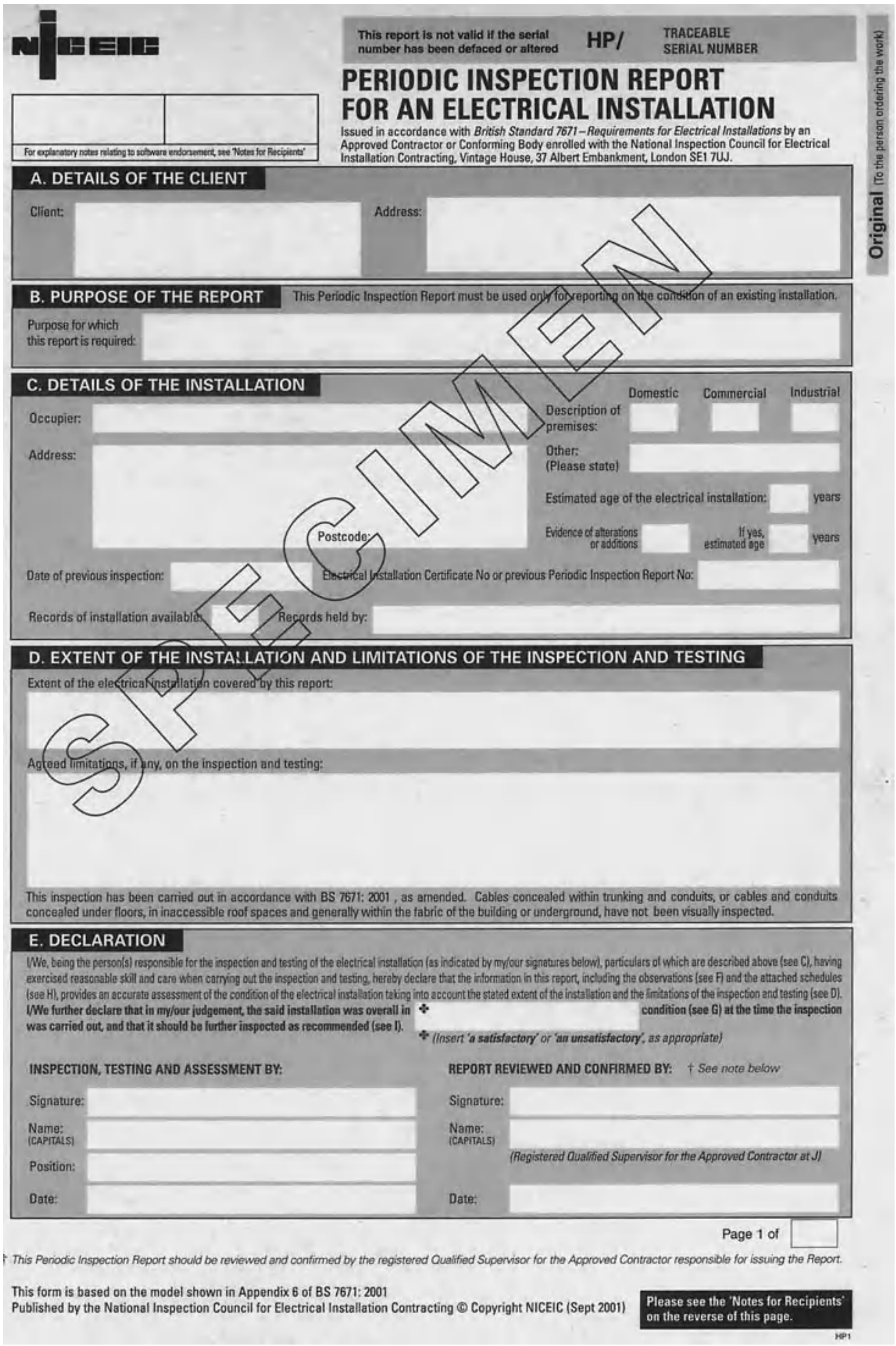
17.6.5 Reporting

Regulation 744–01–01 calls for the results of the periodic inspection to be recorded on a Report by the person carrying out the inspection, or a person acting on his behalf, and given to the person ordering such an inspection. Explicitly, Regulation 744–01–02 calls for the Report to contain information relating to any damage, deterioration, defects and dangerous conditions, and non-compliances with BS 7671 which may give rise to danger, and to identify the scope and limitations of the inspection. Any dangerous conditions should be reported to the duty-holder, or other person responsible for the installation, immediately by word of mouth followed by written confirmation and, ideally, the defect remedied without delay. Suitable Report forms should be developed and tailored to the particular type of installation and, for electrical contractors enrolled by the NICEIC, such forms are readily available for their use. Figure 17.16 reproduces the NICEIC Periodic Inspection Report (by kind permission of the NICEIC for use by Approved Contractors).

The compilation of the Periodic Inspection Report form is fairly straightforward and the experienced inspector will have no difficulty in completing the form. However, for the benefit of the less-experienced, the following guidance related to the form sections ‘A’ to ‘L’ and the necessary attachment schedules (see Figures 17.21 (a) to 17.21(f)), may provide assistance.

It is important to note that the Periodic Inspection Report form is to be used only for reporting on the condition of an existing installation. It must not be used instead of an Electrical Installation Certificate for certifying a new electrical installation, or as a substitute for a Minor Electrical Installation Works Certificate for certifying an addition or an alteration to an existing circuit.

Section A: Details of client (Figure 17.16 (a)) This section provides space for such client details in terms of name of person or organisation and the associated address.



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Original (To the person ordering the work)

For explanatory notes relating to software endorsement, see 'Notes for Recipients'

PERIODIC INSPECTION REPORT FOR AN ELECTRICAL INSTALLATION

Issued in accordance with *British Standard 7671 – Requirements for Electrical Installations* by an Approved Contractor or Conforming Body enrolled with the National Inspection Council for Electrical Installation Contracting, Vintage House, 37 Albert Embankment, London SE1 7UJ.

A. DETAILS OF THE CLIENT

Client:

Address:

B. PURPOSE OF THE REPORT

This Periodic Inspection Report must be used only for reporting on the condition of an existing installation.

Purpose for which this report is required:

C. DETAILS OF THE INSTALLATION

Occupier:

Address:

Postcode:

Description of premises: Domestic ☐ Commercial ☐ Industrial ☐

Other: (Please state)

Estimated age of the electrical installation: years

Evidence of alterations or additions ☐ If yes, estimated age years

Date of previous inspection:

Electrical Installation Certificate No or previous Periodic Inspection Report No:

Records of installation available: ☐

Records held by:

D. EXTENT OF THE INSTALLATION AND LIMITATIONS OF THE INSPECTION AND TESTING

Extent of the electrical installation covered by this report:

Agreed limitations, if any, on the inspection and testing:

This inspection has been carried out in accordance with BS 7671: 2001 , as amended. Cables concealed within trunking and conduits, or cables and conduits concealed under floors, in inaccessible roof spaces and generally within the fabric of the building or underground, have not been visually inspected.

E. DECLARATION

I/We, being the person(s) responsible for the inspection and testing of the electrical installation (as indicated by my/our signatures below), particulars of which are described above (see C), having exercised reasonable skill and care when carrying out the inspection and testing, hereby declare that the information in this report, including the observations (see F) and the attached schedules (see H), provides an accurate assessment of the condition of the electrical installation taking into account the stated extent of the installation and the limitations of the inspection and testing (see D). **I/We further declare that in my/our judgement, the said installation was overall in ✤ condition (see G) at the time the inspection was carried out, and that it should be further inspected as recommended (see I).**

✤ *(Insert **'a satisfactory'** or **'an unsatisfactory'**, as appropriate)*

INSPECTION, TESTING AND ASSESSMENT BY:

Signature:

Name: (CAPITALS)

Position:

Date:

REPORT REVIEWED AND CONFIRMED BY: † *See note below*

Signature:

Name: (CAPITALS)

(Registered Qualified Supervisor for the Approved Contractor at J)

Date:

Page 1 of

† *This Periodic Inspection Report should be reviewed and confirmed by the registered Qualified Supervisor for the Approved Contractor responsible for issuing the Report.*

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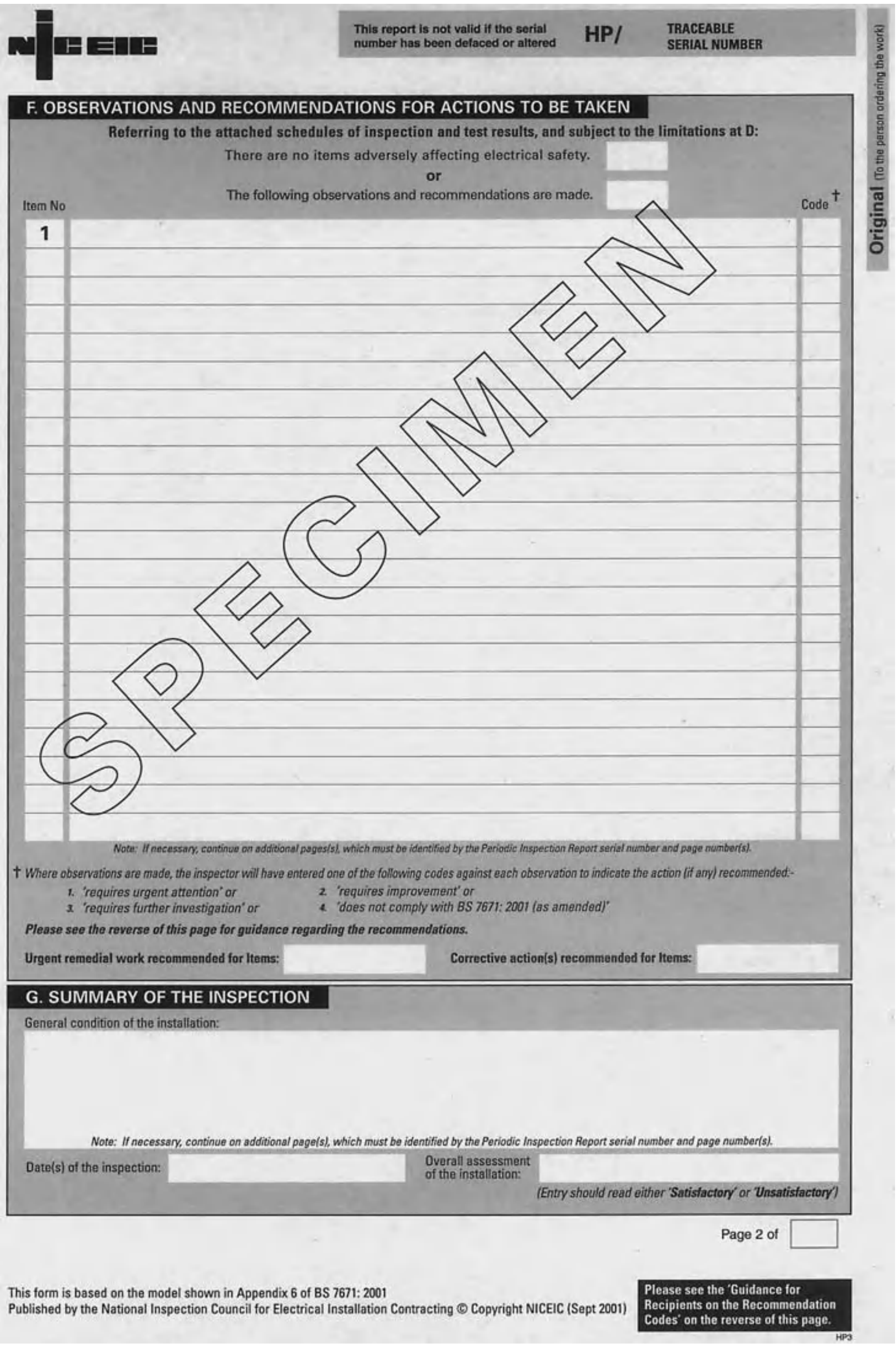
Please see the 'Notes for Recipients' on the reverse of this page.

HP1

Figure 17.16 (a): Periodic Inspection Report – page 1



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F. OBSERVATIONS AND RECOMMENDATIONS FOR ACTIONS TO BE TAKEN

Referring to the attached schedules of inspection and test results, and subject to the limitations at D:

There are no items adversely affecting electrical safety. ☐

or

The following observations and recommendations are made. ☐

Item No		Code †
1		

Note: If necessary, continue on additional pages(s), which must be identified by the Periodic Inspection Report serial number and page number(s).

† *Where observations are made, the inspector will have entered one of the following codes against each observation to indicate the action (if any) recommended:-*

1. 'requires urgent attention' or
2. 'requires improvement' or
3. 'requires further investigation' or
4. 'does not comply with BS 7671: 2001 (as amended)'

Please see the reverse of this page for guidance regarding the recommendations.

Urgent remedial work recommended for Items:

Corrective action(s) recommended for Items:

G. SUMMARY OF THE INSPECTION

General condition of the installation:

Note: If necessary, continue on additional page(s), which must be identified by the Periodic Inspection Report serial number and page number(s).

Date(s) of the inspection:

Overall assessment of the installation:

*(Entry should read either **'Satisfactory'** or **'Unsatisfactory'**)*

Page 2 of ☐

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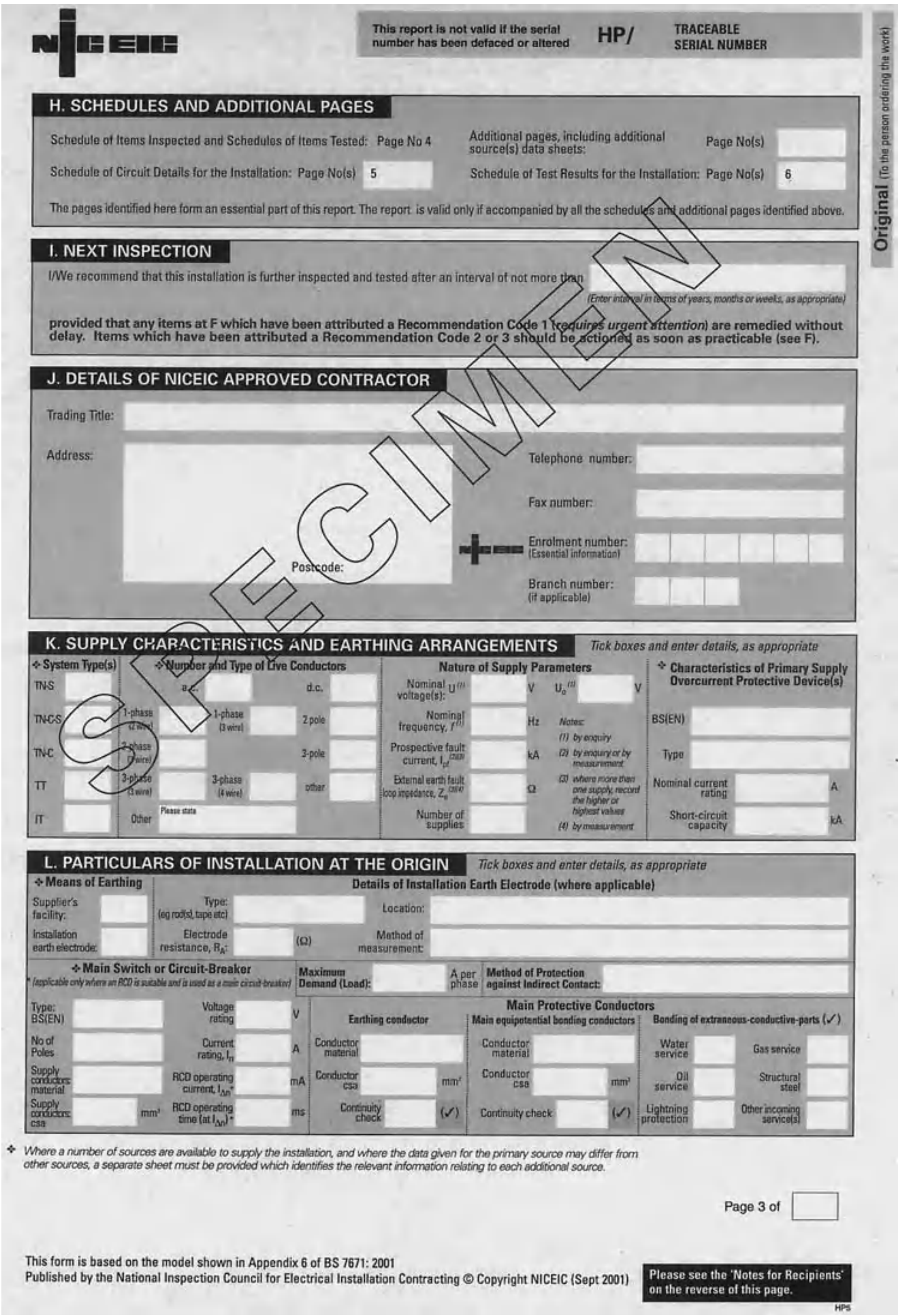
Please see the 'Guidance for Recipients on the Recommendation Codes' on the reverse of this page.

HP3

Figure 17.16 (b): Periodic Inspection Report – page 2



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H. SCHEDULES AND ADDITIONAL PAGES

Schedule of Items Inspected and Schedules of Items Tested: Page No 4

Additional pages, including additional source(s) data sheets: Page No(s)

Schedule of Circuit Details for the Installation: Page No(s) 5

Schedule of Test Results for the Installation: Page No(s) 6

The pages identified here form an essential part of this report. The report is valid only if accompanied by all the schedules and additional pages identified above.

I. NEXT INSPECTION

I/We recommend that this installation is further inspected and tested after an interval of not more than

(Enter interval in terms of years, months or weeks, as appropriate)

provided that any items at F which have been attributed a Recommendation Code 1 (*requires urgent attention*) are remedied without delay. Items which have been attributed a Recommendation Code 2 or 3 should be actioned as soon as practicable (see F).

J. DETAILS OF NICEIC APPROVED CONTRACTOR

Trading Title:

Address:

Postcode:

Telephone number:

Fax number:

Enrolment number: (Essential information)

Branch number: (if applicable)

K. SUPPLY CHARACTERISTICS AND EARTHING ARRANGEMENTS

Tick boxes and enter details, as appropriate

✣ System Type(s)

TN-S ☐
TN-C-S ☐
TN-C ☐
TT ☐
IT ☐

✣ Number and Type of Live Conductors

	a.c.			d.c.	
1-phase (2 wire)	☐	1-phase (3 wire)	☐	2 pole	☐
2-phase (3 wire)	☐			3-pole	☐
3-phase (3 wire)	☐	3-phase (4 wire)	☐	other	☐
Other	Please state				

Nature of Supply Parameters

Nominal voltage(s): $U^{(1)}$ V $U_o^{(1)}$ V

Nominal frequency, $f^{(1)}$ Hz

Prospective fault current, $I_{pf}^{(2)(3)}$ kA

External earth fault loop impedance, $Z_e^{(2)(4)}$ Ω

Number of supplies

Notes:
(1) by enquiry
(2) by enquiry or by measurement
(3) where more than one supply, record the higher or highest values
(4) by measurement

✣ Characteristics of Primary Supply Overcurrent Protective Device(s)

BS(EN)

Type

Nominal current rating A

Short-circuit capacity kA

L. PARTICULARS OF INSTALLATION AT THE ORIGIN

Tick boxes and enter details, as appropriate

✣ Means of Earthing

Supplier's facility: ☐
Installation earth electrode: ☐

Details of Installation Earth Electrode (where applicable)

Type: (eg rod(s), tape etc)

Location:

Electrode resistance, R_A: (Ω)

Method of measurement:

✣ Main Switch or Circuit-Breaker

* *(applicable only where an RCD is suitable and is used as a main circuit-breaker)*

Type: BS(EN)

No of Poles

Supply conductors: material

Supply conductors: csa mm²

Voltage rating V

Current rating, I_n A

RCD operating current, $I_{\Delta n}$* mA

RCD operating time (at $I_{\Delta n}$)* ms

Maximum Demand (Load): A per phase

Method of Protection against Indirect Contact:

Main Protective Conductors

Earthing conductor

Conductor material

Conductor csa mm²

Continuity check (✓)

Main equipotential bonding conductors

Conductor material

Conductor csa mm²

Continuity check (✓)

Bonding of extraneous-conductive-parts (✓)

Water service ☐
Oil service ☐
Lightning protection ☐
Gas service ☐
Structural steel ☐
Other incoming service(s) ☐

✣ *Where a number of sources are available to supply the installation, and where the data given for the primary source may differ from other sources, a separate sheet must be provided which identifies the relevant information relating to each additional source.*

Page 3 of ☐

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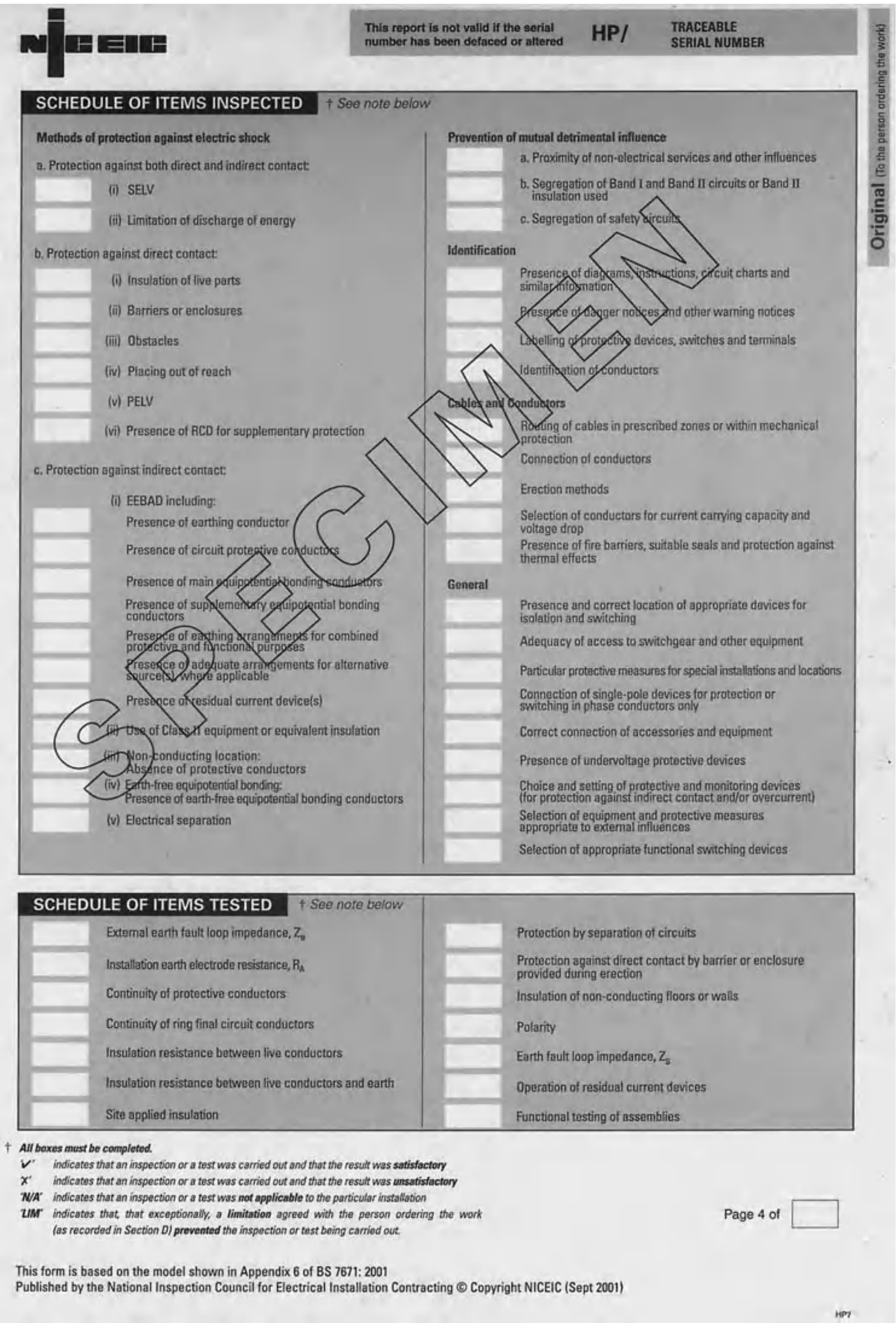
HPS

Figure 17.16 (c): Periodic Inspection Report – page 3



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SCHEDULE OF ITEMS INSPECTED

† See note below

Methods of protection against electric shock

a. Protection against both direct and indirect contact:

- ☐ (i) SELV
- ☐ (ii) Limitation of discharge of energy

b. Protection against direct contact:

- ☐ (i) Insulation of live parts
- ☐ (ii) Barriers or enclosures
- ☐ (iii) Obstacles
- ☐ (iv) Placing out of reach
- ☐ (v) PELV
- ☐ (vi) Presence of RCD for supplementary protection

c. Protection against indirect contact:

(i) EEBAD including:

- ☐ Presence of earthing conductor
- ☐ Presence of circuit protective conductors
- ☐ Presence of main equipotential bonding conductors
- ☐ Presence of supplementary equipotential bonding conductors
- ☐ Presence of earthing arrangements for combined protective and functional purposes
- ☐ Presence of adequate arrangements for alternative source(s), where applicable
- ☐ Presence of residual current device(s)
- ☐ (ii) Use of Class II equipment or equivalent insulation
- ☐ (iii) Non-conducting location: Absence of protective conductors
- ☐ (iv) Earth-free equipotential bonding: Presence of earth-free equipotential bonding conductors
- ☐ (v) Electrical separation

Prevention of mutual detrimental influence

- ☐ a. Proximity of non-electrical services and other influences
- ☐ b. Segregation of Band I and Band II circuits or Band II insulation used
- ☐ c. Segregation of safety circuits

Identification

- ☐ Presence of diagrams, instructions, circuit charts and similar information
- ☐ Presence of danger notices and other warning notices
- ☐ Labelling of protective devices, switches and terminals
- ☐ Identification of conductors

Cables and Conductors

- ☐ Routing of cables in prescribed zones or within mechanical protection
- ☐ Connection of conductors
- ☐ Erection methods
- ☐ Selection of conductors for current carrying capacity and voltage drop
- ☐ Presence of fire barriers, suitable seals and protection against thermal effects

General

- ☐ Presence and correct location of appropriate devices for isolation and switching
- ☐ Adequacy of access to switchgear and other equipment
- ☐ Particular protective measures for special installations and locations
- ☐ Connection of single-pole devices for protection or switching in phase conductors only
- ☐ Correct connection of accessories and equipment
- ☐ Presence of undervoltage protective devices
- ☐ Choice and setting of protective and monitoring devices (for protection against indirect contact and/or overcurrent)
- ☐ Selection of equipment and protective measures appropriate to external influences
- ☐ Selection of appropriate functional switching devices

SCHEDULE OF ITEMS TESTED

† See note below

- ☐ External earth fault loop impedance, Z_e
- ☐ Installation earth electrode resistance, R_A
- ☐ Continuity of protective conductors
- ☐ Continuity of ring final circuit conductors
- ☐ Insulation resistance between live conductors
- ☐ Insulation resistance between live conductors and earth
- ☐ Site applied insulation
- ☐ Protection by separation of circuits
- ☐ Protection against direct contact by barrier or enclosure provided during erection
- ☐ Insulation of non-conducting floors or walls
- ☐ Polarity
- ☐ Earth fault loop impedance, Z_s
- ☐ Operation of residual current devices
- ☐ Functional testing of assemblies

† ***All boxes must be completed.***

'✓' indicates that an inspection or a test was carried out and that the result was ***satisfactory***

'✗' indicates that an inspection or a test was carried out and that the result was ***unsatisfactory***

'N/A' indicates that an inspection or a test was ***not applicable*** *to the particular installation*

'LIM' indicates that, that exceptionally, a ***limitation*** *agreed with the person ordering the work (as recorded in Section D)* ***prevented*** *the inspection or test being carried out.*

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HP7

Figure 17.16 (d): Periodic Inspection Report – page 4

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SCHEDULE OF CIRCUIT DETAILS FOR THE INSTALLATION

TO BE COMPLETED IN EVERY CASE	TO BE COMPLETED ONLY IF THE DISTRIBUTION BOARD IS NOT CONNECTED DIRECTLY TO THE ORIGIN OF THE INSTALLATION*
Location of distribution board:	Supply to distribution board is from: No of phases: Nominal voltage: V
	Overcurrent protective device for the distribution circuit: Associated RCD (if any): BS(EN)
Distribution board designation:	Type: BS(EN) Rating: A RCD No of poles: $I_{\Delta n}$ mA

CIRCUIT DETAILS

Circuit number and phase	Circuit designation	Type of wiring (see code below)	† Reference method	Number of points served	Circuit conductors: csa		Max. disconnection time permitted by BS 7671 (s)	Overcurrent protective devices				RCD	Maximum Z_s permitted by BS 7671 (Ω)
					Live (mm²)	cpc (mm²)		BS (EN)	Type No	Rating (A)	Short-circuit capacity (kA)	Operating current, $I_{\Delta n}$ (mA)	

† *See Table 4A1 of Appendix 4 of BS 7671: 2001*

CODES FOR TYPE OF WIRING

A	B	C	D	E	F	G	H	O (Other - please state)
PVC/PVC cables	PVC cables in metallic conduit	PVC cables in non-metallic conduit	PVC cables in metallic trunking	PVC cables in non-metallic trunking	PVC/SWA cables	XLPE/SWA cables	Mineral-insulated cables	

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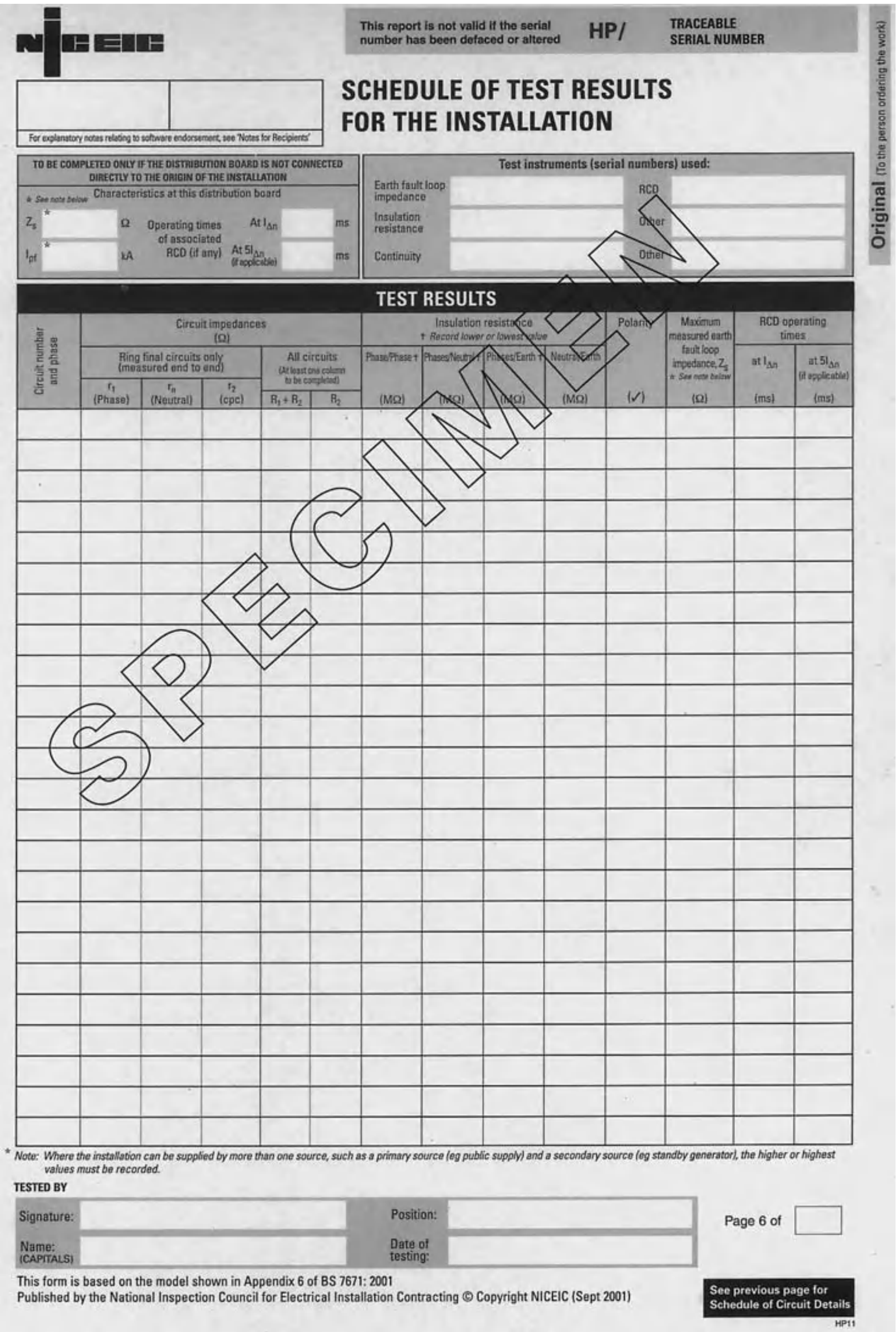
* *In such cases, details of the distribution (sub-main) circuit(s), together with the test results for the circuit(s), must also be provided.*

This form is based on the model shown in Appendix 6 of BS 7671: 2001

See next page for Schedule of Test Results

HP9

Figure 17.16 (e): Periodic Inspection Report – page 5



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SCHEDULE OF TEST RESULTS FOR THE INSTALLATION

TO BE COMPLETED ONLY IF THE DISTRIBUTION BOARD IS NOT CONNECTED DIRECTLY TO THE ORIGIN OF THE INSTALLATION

* See note below Characteristics at this distribution board

Z_s * Ω Operating times of associated RCD (if any) At $I_{\Delta n}$ ms

I_{pf} * kA At $5I_{\Delta n}$ (if applicable) ms

Test instruments (serial numbers) used:

Earth fault loop impedance

Insulation resistance

Continuity

RCD

Other

Other

TEST RESULTS

Circuit number and phase	Circuit impedances (Ω)					Insulation resistance † Record lower or lowest value				Polarity	Maximum measured earth fault loop impedance, Z_s * See note below	RCD operating times	
	Ring final circuits only (measured end to end)			All circuits (At least one column to be completed)		Phase/Phase †	Phases/Neutral †	Phases/Earth †	Neutral/Earth			at $I_{\Delta n}$	at $5I_{\Delta n}$ (if applicable)
	r_1 (Phase)	r_n (Neutral)	r_2 (cpc)	$R_1 + R_2$	R_2	(MΩ)	(MΩ)	(MΩ)	(MΩ)	(✓)	(Ω)	(ms)	(ms)

* *Note: Where the installation can be supplied by more than one source, such as a primary source (eg public supply) and a secondary source (eg standby generator), the higher or highest values must be recorded.*

TESTED BY

Signature:

Position:

Name: (CAPITALS)

Date of testing:

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See previous page for Schedule of Circuit Details

HP11

Figure 17.16 (f): Periodic Inspection Report – page 6

Section B: Purpose of the Report (Figure 17.16(a)) This section is to enable the purpose of the report to be clearly identified and recorded. There are many reasons why a Report may be required; for example, the normal periodic monitoring of an installation to confirm its continuing safety and serviceability, a Report to support a Building Society mortgage application, or a Report to satisfy the building duty-holder that the installation remains compliant with the relevant aspects of the Electricity at Work Regulations, 1989 and other statutory requirements.

This Report form is not intended for the specialised installations such as Fire Detection and Alarm Systems, Emergency Lighting and installations in Petrol Filling Stations all of which are dealt with later in this Guide.

Section C: Details of the Installation (Figure 17.16(a)) Again this section is straightforward, with the occupier, occupier's address and the description of the premises requiring no further explanation. The estimation of the age of the installation and that of any alterations and additions will present no complication if proper records of the installation have been maintained and are available. However, should these records not be available, reference to Table 17.22 may assist the inspector to date the installation within a period of about five years. Of course, the older the installation the less is the need to accurately establish its age. Where records are available, it will be rudimentary to determine the date of the previous inspections, and to identify any subsequent alterations and additions to the installation and, for the record, the person responsible for maintaining the documentation.

Section D: Extent and Limitations of the Inspection and Limitations of the Inspection and Testing (Figure 17.16(a)) This section must fully identify the extent of the installation covered by the report and any agreed limitations on the inspection and testing. This section is crucially important for both the author and recipient of the Report. The scope, or extent, of the installation (possibly only part of the whole installation) which is the subject of the inspection and Report needs to be clearly and unambiguously defined, as do the limitations of the periodic inspection and testing by virtue of the constraints laid down by the installation owner and by any physical restrictions imposed by the nature of the installation or its use. For example, for many commercial and domestic premises much of the wiring systems will be permanently concealed within the building fabric and it would, in most cases, be unreasonable to extract cables etc. to determine their condition. Experience has shown that wiring systems are more likely to deteriorate at their terminations (especially at heat sources like tungsten-lamped luminaires) and these points will be the most productive to inspect. The owner or occupier of the premises may place restrictions on the extent to which he is agreeable in the dismantling of equipment and/or testing which must be recorded on the Report. Similarly, if procedures involve a sampling technique, the basis of such a strategy must be recorded. There may, of course, be other limitations but it is important that these are mutually agreed before carrying out the periodic inspection and testing and that an entry is made in this section. The absence of any stated limitations would, justifiably, lead the recipient to assume that all parts and aspects of the installation had been included. **The contractor should have agreed all such aspects with the client and other interested parties (licensing authority, insurance company, building society) before carrying out the inspection and testing**.

Section E: Declaration (Figure 17.16(a)) This section requires the signature of the person carrying out the periodic inspection and testing and assessment of the overall condition of the installation. This declaration of the overall condition of the installation must reiterate that given in Section G which should summarise the observations and recommendations made in Section F. The inspection, testing and assessment by the inspector must be reviewed and confirmed by the NICEIC registered Qualifying Manager. The signatures are to be those of the competent person undertaking the inspection of the installation and of the Qualified Supervisor of the NICEIC Approved Contractor or Conforming Body, who should review each report. Where the Qualified Supervisor carries out the inspection personally, he or she should sign in both places.

A list of observations and recommendations for urgent remedial work and for corrective actions necessary to maintain the installation in a safe working order should be given in Section F, where appropriate.

Section F: Recommendations and Recommendations for Actions to be taken (Figure 17.16(b)) This section includes two data-entry boxes at the top in which the report compiler is required to confirm that ‘there are no items adversely affecting electrical safety’ **or** that ‘the following observations and recommendations are made’, as appropriate. In the latter case, the observations and recommendations are to be listed with a Code 1, 2, 3 or 4 (see below). At the bottom of the section, two data-entry boxes are provided for recording the deficiencies which, in the opinion of the report’s compiler, need urgent remedial work and those items requiring corrective actions, respectively.

Where an Approved Contractor classifies a recommendation as ‘requires urgent attention’ the client is to be advised immediately, in writing, to satisfy the duties imposed by the Electricity at Work Regulations 1989. It should be noted that, where an existing or a potential danger is observed that may put the safety of those using the installation at risk, Recommendation Code 1 (requires urgent attention) must be used. If the space available on the form for recording recommendations is insufficient, additional numbered pages are to be provided as necessary.

The codes for ranking the items are:

- 1 – Requires urgent attention,
- 2 – Requires improvement,
- 3 – Requires further attention,
- 4 – Does not comply with BS 7671 : 1992 (as amended).

Defects which represent an immediate safety hazard would necessarily warrant a code 1 and would include, for example, bare live parts exposed to touch or ineffective protective devices. A code 2 would include such items that do not represent an instant danger but would benefit from an improvement embracing, for example, deteriorated enclosure covers. Where, because of limitations placed on the inspection or because some unforeseen difficulty arises, full diagnosis of some malfunction or apparent fault condition is not possible, this fact must be reported in this section in order that the person responsible for the installation is made aware that further investigation is needed by attributing a code 3. Items that do not comply with BS 7671 also need to be recorded. Some deficiencies may necessarily warrant more than one code; for example, live parts with missing barriers demand a code of 4 (contravention of Regulation 412–01–01) and a code 1 signifying that urgent attention is required. However, only one code should be attributed to any one item, this being the code which is more or most appropriate in the circumstances.

Section G: Summary of Inspection (Figure 17.16(b)) This section must be completed with an accurate description of the general condition of the installation, together with the date(s) of the inspection and a succinct assessment of the condition of the installation, in terms of *a satisfactory condition* or *an unsatisfactory condition* entry. The entry for the date(s) of the inspection would, of course, be the actual date(s) on which the site inspection was carried out and may, in certain circumstances be a number of dates and not necessarily consecutive days. The condition of the installation needs to be an overview of the overall state of the installation and should summarise the main findings of the inspection and testing. Evidence of wear and tear of the installation generally and, in particular, that of accessories, wiring systems and switchgear should be noted here, as would any change of use of the premises (which may render the installation unsuitable for the new environmental conditions). Any misuse and abuse of the installation together with evidence of added loads (which may have resulted in overloading) should also be chronicled. The attention of the Report reader should be drawn to a summary of any damage, deterioration, defects and dangerous conditions and entered in Section G together with an estimate of the remaining life expectancy of the installation.

Section H: Schedules and Additional Pages (Figure 17.16(c)) This section is intended to identify the page numbers of all the various schedules and additional pages which form part of the Periodic Inspection Report. The *Schedule of items inspected* and the *Schedule of Items Tested* will always be page 4. The *Schedule of Circuit Details for the Installation* and the *Schedule of Test Results for the Installation* will always be pages 5 and 6 respectively, but where there is a need to use more of these schedules, space has been provided to record their page numbers. Space has also be provided to identify any additional pages which form part of the Report, such as an additional page of observations and recommendations (see Section F). All pages forming part of the Periodic Inspection Report must be numbered together with a reference to the total number of pages (e.g. 7 of 10).

Section I: Next Inspection (Figure 17.16(c)) This section calls for the appropriate time interval before re-inspection of the installation to be inserted. IEE Guidance Note 3 gives guidance on the maximum recommended intervals for various types of premises, but due account must be taken of the present condition of the installation. The recommendation for the interval to the next inspection is to be conditional on all deficiencies which have attracted a recommendation code 1 in Section F being remedied without delay. Additionally, the recommendation for the interval to the next inspection is also to be conditional on all deficiencies which have attracted recommendation codes 2 or 3 being remedied as soon as practicable. The Report compiler would need to exercise his professional judgement in deciding the date for the next inspection. In exercising his judgement, account should be taken of the condition of the installation, the level of maintenance received in the past and that expected in the future, and any factors which may materially affect the interval. In some cases (e.g. places of public entertainment) the maximum interval may be the subject of licensing conditions and the recommended re-inspection interval would need to take this into account (see Table 17.21).

Section J: Details of NICEIC Approved Electrical Contractor (Figure 17.16(c)) This section is self-explanatory, but it should be noted that these forms are for use by NICEIC approved contractors only who must identify their trading title, enrolment number and branch number, where appropriate, in the spaces provided.

Section K: Supply Characteristics and Earthing Arrangements (Figure 17.17(c)) The compilation of this section is straightforward and needs no explanation, except as regards the *number of supplies* which must be identified in the data-entry box even where there is only one. Where the installation can be supplied from more than one source, such as the public supply and a standby generator, the higher or highest value of prospective fault current, I_{pf}, and external earth fault loop impedance, Z_e, must be recorded in the data-entry boxes provided for this purpose. Where a number of sources are available to supply the installation, and where the data given for the primary source may differ from the other sources, an additional page must be provided which gives the relevant information relating to each source.

This section is almost identical to the similarly titled section in the Electrical Installation Certificate where more detailed guidance is given.

Section L: Particulars of the Installation at the Origin (Figure 17.16(c)) The compilation of this section is again straightforward and self-explanatory, except that where a number of sources are available to supply the installation. Where the data given for the *Means of earthing* and the

Main switch or circuit-breaker relating to the primary source may differ from that of other sources, the relevant information must be recorded for each additional source.

This section is identical to the similarly titled section in the Electrical Installation Certificate where more detailed guidance is given.

The Schedule of Items Inspected of the Installation (Figure 17.16(d)) Except for the unique numbering prefix, this section is identical to the similarly titled section in the Electrical Installation Certificate where more detailed guidance is given. All data-entry boxes on this schedule are to be completed, as appropriate for the particular installation, by inserting a 'Yes' or a '✓' indicating that the installation inspection or test has been undertaken with satisfactory results. Where an inspection has revealed an unsatisfactory result, the entry of an 'X' should be made. It is unlikely that all items will apply, and the range of applicable inspections will depend on the particular installation covered by the Report. If an inspection is not applicable, 'N/A' should be recorded in the box. Exceptionally, where a limitation on a particular inspection or test has been agreed, and has been recorded in Section D, the appropriate data-entry box(es) must be completed by inserting 'LIM', indicating that an agreed limitation has prevented the inspection of test being carried out.

The Schedule of Items Tested of the Installation (Figure 17.16 (d)) Except for the unique numbering prefix, this section is identical to the similarly titled section in the Electrical Installation Certificate where more detailed guidance is given. All data-entry boxes on this schedule are to be completed, as appropriate for the particular installation, by inserting a 'Yes' or a '✓' indicating that the test has been undertaken with satisfactory results. Where the test result is unsatisfactory, this should be recorded by inserting an 'X'. It is unlikely that all items will apply, and the range of applicable tests will depend on the particular installation covered by the report. If a test is not applicable, 'N/A' should be recorded in the box. Exceptionally, where a limitation on a particular test has been agreed, and has been recorded in Section D, the appropriate data-entry box(es) must be completed by inserting 'LIM', indicating that an agreed limitation has prevented the inspection of test being carried out.

The Schedule of Circuit Details of the Installation (Figure 17.16(e)) Except for the unique numbering prefix, this schedule is identical to the similarly titled section in the Electrical Installation Certificate where more detailed guidance is given.

The Schedule of Test Results of the Installation (Figure 17.16(f)) Except for the unique numbering prefix, this schedule is identical to the similarly titled section in the Electrical Installation Certificate where more detailed guidance is given.

17.7 Alterations and additions

17.7.1 General

As indicated in Regulation 743–01–01, the inspection, testing and certification requirements apply equally to alterations and additions to an electrical installation. It is essential that any addition or alteration does not have an adverse effect on the safety of the existing installation and that any protective measures embodied in the existing installation and used to protect the addition or alteration are satisfactory and effective. For example, if the EEBADS method of protection against the indirect contact shock risk is used and a new circuit made use of an existing MCB for this purpose, it would be necessary to ensure that earthing and equipotential bonding were adequate and that the MCB was of the correct type and nominal rating to provide adequate protection for the new circuit. Normally, the designer/installer of an alteration and/or addition would need to ensure that the supply to the installation was adequate for the additional load. He would also need to ensure that the short-circuit capacity of protective devices etc. was adequate and this would be particularly important where there was a need to reinforce the supply. A check on MET, the earthing conductor and equipotential bonding conductors would be a matter of course as would a check of phase-earth loop impedances Z_e and Z_s. In all cases a systematic approach is required to ensure that any newly installed circuit(s) and alterations will operate safely under normal and fault conditions and that the newly installed work will not adversely affect the safety of the existing installation.

It is important to recognise that whilst installations constructed to an earlier Edition of the Wiring Regulations may well have deviations from the current Edition (BS 7671), these may or may not represent an unsafe condition and it will be a matter of judgement of how the inspector treats such deviations (e.g. reports as unsafe, undesirable, or replacement needed in due course).

17.7.2 Inspection

The inspection required for an alteration and addition would be similar to that entailed in a completely new installation (restricted to the alteration and addition) and, as mentioned earlier, would also include inspection of any protective measures of the existing installation used to protect the new work (e.g. earthing and bonding and protective devices).

17.7.3 Testing

Testing of alterations and additions is essentially no different from that required for a whole installation but would be restricted to the extent of the new work and/or alteration except that any existing installation protective measures used to protect the new work would also need testing as if for initial verification.

17.7.4 Certification

The requirements for the certification of alterations and additions are the same as for any new installation and the procedure is as for initial inspection and testing of an installation (see item 17.5 of this Guide). Defects observed in the existing installation will need to be included in certification form.

17.8 Inspection, testing and certification of specialised installations

17.8.1 Fire detection and alarm systems in buildings

The installation of fire detection and alarm systems in buildings is required to comply with the BS 7671 and the British Standard Code of Practice BS 5839: Part 1. The installation of such a system will, of course, be the subject of an Electrical Installation Certificate as detailed in section 17.5.4, as well as the form of certification required by the Code of Practice.

17.8.2 Emergency lighting

The installation of the emergency lighting systems in buildings is required to comply with the BS 7671 *and* British Standard Code of Practice BS 5266: Parts 1 and 7. The installation of such a system will, of course, be the subject of an Electrical Installation Certificate as detailed in section 17.5.4, as well as the form of certification required by the Code of Practice.

17.8.3 Petrol filling stations

In terms of initial inspection and testing of an installation in petrol filling stations, the requirements and practice for inspection and testing and certification are not too dissimilar to those relating to other installations providing the testing is carried out before the stations are fuelled up. However, as soon as petrol is delivered to the station testing becomes more difficult and potentially dangerous because of the risks of igniting the fuel in its gaseous form. For this reason any periodic testing can be extremely dangerous and such work needs to be carried out by an engineer fully versed in the inspection and testing procedures relating to such installations.

Familiarisation with *Guidance for the design, construction, modification and maintenance of petrol filling stations*, published jointly by the Association for Petroleum and Explosives Administration (APEA) and the Institute of Petroleum (IP), is a necessary prerequisite to carrying out any installation work at a petrol filling station. Additionally, all persons undertaking such work would of necessity be experienced and thoroughly versed in the risks and hazards associated with these special environments. They should also be conversant with the Petrol (Regulations) Act 1928 and 1936 and the Health and Safety at Work etc. Act 1974 (including the Electricity at Work Regulations 1989). Furthermore, persons should be aware of, and have had practical experience of, the relevant parts of BS EN 60079 *Electrical Apparatus for Explosives Gas Atmospheres*: Parts 10, 14 and 17.

The model Inventory and Certificate given in *Guidance for the design, construction, modification and maintenance of petrol filling stations* is complex but adequate guidance is contained therein to aid compilation by competent persons. In addition to the issue of the above forms, initial certification of a petrol filling station must be completed by the issue of a ‘normal’ Electrical Installation Certificate (see Fig. 17.12).

Petrol filling stations are the subject of licensing (by local authorities) and are required to be periodically inspected and tested annually. The model forms may be used for both initial and periodic verification.

Appendix

Standards to which reference has been made

National Standards (British Standards)

BS 31	Specification. Steel conduit and fittings for electrical wiring.
BS 67	Specification for ceiling roses.
BS 88	Cartridge fuses for voltages up to and including 1000 V a.c. and 1500 V d.c.
BS 196	Specification for protected-type non-reversible plugs, socket-outlets, cable couplers and appliance-couplers with earthing contacts for single phase a.c. circuits up to 240 volts.
BS 415	Specification for safety requirements for mains-operated electronic and related apparatus for household and similar general use.
BS 476	Fire tests on building materials and structures.
BS 546	Specification. Two-pole and earthing-pin plugs, socket-outlets and socket-outlet adaptors.
BS 559	Specification for electric signs and high voltage luminous-discharge-tube installations.
BS 646	Specification. Cartridge fuse-links (rated up to 5 amperes) for a.c. and d.c. service.
BS 731	Flexible steel conduit for cable protection and flexible steel tubing to enclose flexible drives.
BS 951	Specification for clamps for earthing and bonding purposes.
BS 1361	Specification for cartridge fuses for a.c. circuits in domestic and similar premises.
BS 1362	Specification for general purpose fuse links for domestic and similar purposes (primarily for use in plugs).
BS 1363	13 A plugs, socket-outlets, connection units and adaptors.
BS 1710	Specification for the identification of pipelines and services.
BS 2632	See BS EN 61 011.
BS 2754	Memorandum. Construction of electrical equipment for protection against electric shock.
BS 2848	Specification for flexible insulating sleeving for electrical purposes.
BS 3036	Specification. Semi-enclosed electric fuses (ratings up to 100 amperes and 240 volts to earth).
BS 3042	Test probes to verify protection by enclosures.
BS 3456	Specification for safety of household and similar electrical appliances.

BS 3535	Isolating transformers and safety isolating transformers.
BS 3676	Switches for household and similar fixed electrical installations.
BS 3858	Specification for binding and identification sleeves for use on electric cables and wires.
BS 3871	Specification for miniature and moulded case circuit-breakers.
BS 4066	Tests on electric cables under fire conditions.
BS 4099	Colours of indicator lights, push-buttons, annunciators and digital readouts.
BS 4293	Specification for residual current-operated circuit-breakers. (See also BS EN 61 008–1 and BS EN 61 009–1.)
BS 4343	See BS EN 60 309–2.
BS 4363	Specification for distribution assemblies for electricity supplies for construction and building sites.
BS 4444	Guide to electrical earth monitoring and protective conductor proving.
BS 4483	Specification for steel fabric for the reinforcement of concrete.
BS 4491	Appliance couplers for household and similar general purposes.
BS 4533	Luminaires.
BS 4568	Specification for steel conduit and fittings with metric threads of ISO form for electrical installations.
BS 4573	Specification for 2-pin reversible plugs and shaver socket-outlets.
BS 4579	Specification for performance of mechanical and compression joints in electric cable and wire connectors.
BS 4607	Non-metallic conduits and fittings for electrical installations.
BS 4662	Specification for boxes for the enclosure of electrical accessories.
BS 4678	Cable trunking.
BS 4737	Intruder alarm systems.
BS 4752	See BS EN 60 947.
BS 4884	Technical manuals.
BS 4940	Recommendation for the presentation of technical information about products and services in the construction industry.
BS 4941	See BS EN 60 947–4–1.
BS 5042	Specification for bayonet lampholders.
BS 5266	Emergency lighting.
BS 5306	Fire extinguishing installations and equipment on premises.
BS 5445	Components of automatic fire detection systems.
BS 5446	Components of automatic fire alarm systems for residential premises.
BS 5467	Specification for cables with thermosetting insulation for electricity supply for rates voltages of up to and including 600/1000 V and up to and including 1900/3300 V.
BS 5468	See BS 6469 and BS 6899.
BS 5486	Low-voltage switchgear and controlgear assemblies (see also BS EN 60 439).
BS 5490	See BS EN 60 529.
BS 5501	Electrical apparatus for potentially explosive atmospheres.
BS 5518	Specification for electronic variable control switches (dimmer switches) for tungsten filament lighting.

BS 5588	Fire precautions in the design, construction and use of buildings.
BS 5593	Specification for impregnated paper-insulated cables with aluminium sheath/neutral conductor and three shaped solid aluminium phase conductors (CONSAC), 600/1000 V, for electricity supply.
BS 5655	Lifts and service lifts.
BS 5733	Specification for general requirements for electrical accessories.
BS 5784	Safety of electrical commercial catering equipment.
BS 5839	Fire detection and alarm systems in buildings.
BS 6004	Specification for PVC-insulated cables (non-armoured) for electric power and lighting.
BS 6007	Specification for rubber-insulated cables for electric power and lighting.
BS 6053	Specification for outside diameters of conduits for electrical installations and threads for conduits and fittings. (See also BS EN 60 423.)
BS 6081	Specification for terminations for mineral-insulated cables.
BS 6099	Conduits for electrical installations. (See also BS EN 50 086–1.)
BS 6121	Mechanical cable glands.
BS 6141	Specification for insulated cables and flexible cords for use in high temperature zones.
BS 6207	Specification for mineral-insulated cables with a rated voltage not exceeding 750 V.
BS 6231	Specification for PVC-insulated cables for switchgear and controlgear.
BS 6266	Code of practice for fire protection for electronic data processing installations.
BS 6346	Specification for PVC-insulated cables for electricity supply.
BS 6351	Electric surface heating.
BS 6360	Specification for conductors in insulated cables and cords.
BS 6369	BS EN 61 011–1
BS 6458	Fire hazard testing for electrotechnical products.
BS 6467	Electrical apparatus with protection by enclosure for use in the presence of combustible dusts.
BS 6469	Insulating and sheathing materials of electric cables.
BS 6480	Specification for impregnated paper-insulated lead or lead alloy sheathed electric cables of rated voltages up to and including 33 000 V.
BS 6500	Specification for insulated flexible cords and cables.
BS 6651	Code of practice for protection of structures against lightning.
BS 6701	Code of practice for installation of apparatus intended for connection to certain telecommunication systems.
BS 6702	See BS EN 60 400.
BS 6708	Specification for flexible cables for use at mines and quarries.
BS 6713	Explosion protection systems.
BS 6724	Specification for armoured cables for electricity supply having thermosetting insulation with low emission of smoke and corrosive gases when affected by fire.

BS 6726	Specification for festoon and temporary lighting cables and cords.
BS 6739	Code of practice for instrumentation in process control systems: installation design and practice.
BS 6746	Specification for PVC insulation and sheath of electric cables.
BS 6765	Leisure accommodation vehicles: caravans.
BS 6776	See BS EN 60 238.
BS 6840	Sound system equipment.
BS 6883	Specification for elastomer insulated cables for fixed wiring in ships and in mobile and fixed offshore units.
BS 6899	Specification for rubber insulation and sheath of electric cables.
BS 6972	Specification for general requirements for luminaire supporting couplers for domestic, light industrial and commercial use.
BS 6977	Specification for insulated flexible cables for lifts and for other flexible connections.
BS 6991	Specification for 6/10 A, two-pole weather-resistant couplers for household, commercial and light industrial equipment.
BS 7001	Specification for interchangeability and safety of a luminaire supporting coupler.
BS 7002	See BS EN 60 950.
BS 7071	Specification for portable residual current devices.
BS 7211	Specification for thermosetting insulated cables (non-armoured) for electric power and lighting with low emission of smoke and corrosive gases when affected by fire.
BS 7288	Specification for socket-outlets incorporating residual current devices.
BS 7361	Cathodic protection.
BS 7375	Code of practice for distribution of electricity on construction and building sites.
BS 7430	Code of practice for earthing.
BS 7454	Method of calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects.
BS 7527	Classification of environmental conditions.
BS 7629	Thermosetting insulated cables with limited circuit integrity when affected by fire.
BS 7671	Requirements for electrical installations. IEE Wiring Regulations. Sixteenth Edition.
PD 6531	Queries and interpretations on BS 5839: Parts 1 and 4 (as amended).
PD 6519	Effect of current passing through the human body.

European Standards (CENELEC Standards)

BS EN 50 014	Electrical apparatus for potentially explosive atmospheres
BS EN 50 081	Electromagnetic compatibility. Generic emission standard.
BS EN 50 082	Electromagnetic compatibility. Generic immunity standard.
BS EN 50 085–1	Specification for cable trunking and ducting systems for electrical installations.
BS EN 50 086–1	Specifications for conduit systems for electrical installations (Part 1. General requirements).
BS EN 60 079	Electrical apparatus for explosive gas atmospheres
BS EN 60 238	Specification for edison screw lampholders.
BS EN 60 269–1	Low voltage fuses (Part 1. General requirements – also numbered BS 88: Part 1: 1988).
BS EN 60 309	Plugs, socket-outlets and couplers for industrial purposes.
BS EN 60 309–1	Plugs, socket-outlets and couplers for industrial purposes (Part 1. General requirements – also numbered BS 4343: 1968).
BS EN 60 309–2	Plugs, socket-outlets and couplers for industrial purposes (Part 2: Dimensional interchangeability requirements for pin and contact tube accessories of harmonised configurations).
BS EN 60 400	Specification for lampholders for tubular fluorescent lamps and starter-holders.
BS EN 60 423	Conduits for electronic purposes. Outside diameters of conduits for electrical installations and threads for conduits and fittings (see BS 6053).
BS EN 60 439	Specification for low-voltage switchgear and controlgear assemblies.
BS EN 60 439–1	See BS 5486: Part 1.
BS EN 60 439–4	Particular requirements for assemblies for construction sites (ACS).
BS EN 60 529	Specification for degrees of protection provided by enclosures (IP Code).
BS EN 60 598	Luminaires.
BS EN 60 598–1	See BS 4533: Part 101.
BS EN 60 598–2–22	See BS 4533: Section 102.22.
BS EN 60 617	Graphical symbols for diagrams. (Replaces BS 3939.)
BS EN 60 742	See BS 3535: Part 1.
BS EN 60 898	Specification for circuit-breakers for overcurrent protection for household and similar installations.
BS EN 60 900	Specification for safety of information technology equipment, including electrical business equipment.

BS EN 60 947	Specification for low-voltage switchgear and controlgear.
BS EN 60 947–1	General rules.
BS EN 60 947–2	Circuit-breakers.
BS EN 60 947–3	Switches, disconnectors, switch-disconnectors and fuse-combination units.
BS EN 60 947–4	Contactors and motor-starters.
BS EN 60 947–4–1	Electromechanical contactors and motor-starters.
BS EN 60 950	Specification for safety of information technology equipment, including electrical business equipment.
BS EN 61 008	Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs) (Part 1. General rules).
BS EN 61 009	Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBOs).
BS EN 61 011	Electric fence energisers safety requirements.
BS EN 61 011–1	Electric fence energisers safety requirements for battery-operated electric fence energisers suitable for connection to the supply mains.
BS EN 61 184	Bayonet lampholders.

International Standards (IEC Standards)

IEC 269–1	Low-voltage fuse. Part 1: General requirements.
IEC 364	Electrical installations in buildings.
IEC 439–1	Low-voltage switchgear and controlgear assemblies; Part 1: Type-tested and partially type-tested assemblies.
IEC 755	General requirements for residual current operated protective devices.
IEC 909	Short circuit calculation in three-phase a.c. systems.
IEC 947–2	Low-voltage switchgear and controlgear. Part 2: Circuit-breakers.
IEC 949	Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects.
IEC 1008	Residual current operated circuit-breakers without integral overcurrent protection for household or similar use (RCCBs).
IEC 1010–2–031	Safety requirements for electrical equipment for measurement, control, and laboratory use; particular requirements for hand-held probe assemblies for electrical measurement and test.
IEC 335–2–53	Safety of household and similar electrical appliances; electric sauna heating appliances.

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Note: Reference is by section number; figure and table numbers are given in *italics*. See also check lists in Tables 17.5–9.

Index of Tables

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Subject Index

The numbers listed here for each entry are section numbers rather than page numbers. Italic numbering refers to figure and table numbers.