BRITISH STANDARD

BS 6907-2:
1988

Electrical installations for open-cast mines and quarries —

Part 2: General recommendations for protection against direct contact and electric shock

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Committees responsible for this British Standard

The preparation of this British Standard was entrusted by the Mining and Quarrying Requisites Standards Committee (MQE/-) to Technical Committee MQE/23, upon which the following bodies were represented:

Associated Offices Technical Committee
British Coal
China Clay Association
Electric Cable Makers' Confederation
Electrical Contractors' Association
Engineering Equipment and Materials Users' Association
Federation of Civil Engineering Contractors
Federation of Manufacturers of Construction Equipment and Cranes
Health and Safety Executive
Independent Engineering Insurers' Committee
Institution of Mining and Metallurgy

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Contents

Foreword

This Part of BS 6907 has been prepared under the direction of the Mining and Quarrying Requisites Standards Committee.

BS 6907 is based on the International Electrotechnical Commission's publication IEC 621 *"Electrical installations for outdoor sites under heavy conditions (including open-cast mines and quarries)"* and, like that publication, is published in Parts as follows.

— *Part 1: Glossary;*

— *Part 2: General recommendations for protection against direct contact and electric shock;*

— *Part 3: Recommendations for equipment and ancillaries;*

— *Part 4: Recommendations for winning, stacking and processing machinery, pumps and low signal level and communications systems;*

— *Part 5: Recommendations for operation.*

BS 6907 sets out the guiding principles for the installation and operation of electrical equipment so as to ensure safety of persons, livestock, property and the proper functioning of the plant.

It applies to the installation and operation of electrical apparatus and systems associated with outdoor sites under heavy conditions, including open-cast mines, quarries, stockpiles, etc. It applies particularly to electrical apparatus and systems used for the following:

a) winning, stacking and primary processing machinery;

b) secondary processing machinery;

c) conveyor systems;

d) pumping and water supply systems;

e) movable railway systems;

f) control, signal, supervisory and communication systems.

BS 6907 does not cover temporary and provisional places of work in the open, such as building sites and earth-moving sites, unless the equipment used is similar to that used in surface mining applications.

It takes account of British practice, electrical regulations and law and thereby differs in several respects from the IEC publication. Both cover a subject not previously the subject of an International Standard or a British Standard.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 18, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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Section 1. General

1 Scope

This Part of BS 6907 gives recommendations for protection against direct contact and electric shock for all installations in normal service, and in cases of fault, overcurrent and fault current.

For winning, stacking and processing machinery, pumps and low signal level and communications systems, exemptions from these recommendations and supplementary recommendations are given in BS 6907-4, which should, therefore, be read in conjunction with this Part.

The recommendations given for low voltage installations are essentially from the IEE "Regulations for Electrical Installations" (the Wiring Regulations), as applicable.

NOTE 1 A glossary of terms used in this standard is given in BS 6907-1.

NOTE 2 The titles of the publications referred to in this standard are listed on the inside back cover.

Section 2. Protection against electric shock in normal service

2 Protection against direct contact by limitation of voltage

Protection against direct contact is deemed to be ensured where the system is not more than 25 V a.c. or 60 V d.c. or where, as a protective measure, safety extra-low voltage or functional extra-low voltage is used.

3 Complete protection by means of barriers or enclosures

3.1 Protection from live parts

All live parts should be contained inside enclosures or behind barriers providing at least the following degrees of protection in accordance with BS 5490.

Low voltage	Complete protection IP2X or IP4X for top surfaces or barriers or enclosures which are readily accessible. This applies in particular to those parts of enclosures which might serve as a standing surface.
Above 1 000 V	Complete protection IP5X within arm's reach.
	Partial protection IP2X beyond arm's reach.

3.2 Strength and stability of barriers and enclosures

Barriers and enclosures should be firmly secured in place. Taking into account their nature, size and arrangement, they should have sufficient stability and durability to resist the strains and stresses likely to occur in normal service.

3.3 Access to installation

Where it is necessary to make provision for the removal of barriers, the opening of enclosures, or the withdrawal of parts of enclosures (doors, casings, lids, covers, etc.), this should be accomplished by one of the following.

a) *Key or tool.* Removal, opening or withdrawal should necessitate the use of a key or tool.

b) *Interlocking device.* An interlocking device should be provided so that removal, opening or withdrawal without the use of a key or tool necessitates previous switching off of all live parts behind the barrier or enclosure which might be touched accidentally. Restoration of supply should be possible only after replacement or reclosure of the barriers or enclosures.

Provision should be made for the discharge of stored energy in capacitors or cable systems where they are likely to give rise to the risk of electric shock.

c) *Automatic disconnection.* Removal, opening or withdrawal without use of a key or tool should initiate automatic switching off before live parts behind the barrier or enclosure can be touched accidentally. Restoration of supply should be possible only after replacement or reclosure of the barriers or enclosures.

d) *Internal interposing screen.* An internal interposing screen should be so positioned that none of the live parts can be touched while the barrier or enclosure is removed. The screen should be either firmly secured in place or slid into place at the moment the barrier or enclosure is removed except where used as a second barrier [see item e)]. It should not be removable except by means of a tool or key.

Such a screen may be a protective shutter which, in the case of a disconnectable assembly, slides into place in front of the feed line contacts.

e) *Access to control circuit components.* Where any parts within an enclosure need occasional handling (such as the replacement of a lamp or of a fuse-link, instrument settings or adjustment of electronic controls) removal, opening or withdrawal without the use of a key or tool and without switching off should be possible only if the following conditions are simultaneously fulfilled.

1) A second barrier suitably labelled is provided within the enclosure so as to prevent persons from coming accidentally into contact with live parts.

It should not be possible to remove the second barrier except through the use of a key or tool.

2) The voltage of all live parts behind the second barrier does not exceed 660 V.

3.4 Additional protection for cable conductors

All cables external to the equipment should be fully insulated for the system voltage and, where this exceeds 125 V a.c. or 250 V d.c., provided with suitable metallic covering.

4 Protection from contact with overhead line conductors

4.1 Where use of overhead lines is essential, they have to be constructed and maintained in accordance with the overhead lines regulations[1]. However, the maximum height of vehicles likely to be used may require ground/lowest conductor clearances greater than those specified in the regulations.

4.2 Where an existing overhead line is within the quarry curtilage, special care should be exercised to prevent the possibility of contact of cranes, excavators, or other high vehicles, e.g. dump trucks and tipping lorries.

Reference should also be made to BS 6907-5.

[1] "Avoidance of danger from overhead lines", HSE Guidance note GS6 "Overhead lines regulations for securing the safety of the public" — Factories Act 1961. Electricity Regulations.

Section 3. Protection against electric shock in case of a fault

5 General

5.1 The protective measures recommended in this section are intended to prevent a touch voltage from persisting for such a length of time after the occurrence of a fault that danger to persons or livestock could arise. The measures have been developed from experience and consideration of the probability of persons or livestock being in indirect contact and of the nature of the plant involved in the fault situation.

Protection should be afforded in the case of an earth fault by either automatic disconnection of supply within specified conditions of voltage and time, or limitation of indirect contact voltage below the conventional voltage limit at which disconnection of the supply is not required.

In this section, the protective measures against indirect contact with a protective conductor for all installations with voltages up to and including 1 000 V and those above 1 000 V are described.

NOTE The recommendations for installations for voltages up to and including 1 000 V are taken from the IEE "Regulations for Electrical Installations" (the Wiring Regulations).

5.2 It is essential that exposed conductive parts be connected to a protective conductor.

The earthable point of the power system and protective conductor should be connected to an earth electrode near the respective power transformer or generator.

If good earthing facilities or points are available, the protective conductor should be connected to them at as many places as possible.

NOTE Multiple earthing at points distributed as evenly as possible may be necessary in order to ensure that the potential of the protective conductor remains as close as possible to the earth potential in case of fault. This protective conductor may be a bare conductor, that is, without a covering of insulating material.

5.3 A protective device should automatically disconnect the supply to that part of the electrical installation protected by the device, if, following a fault in that part, the touch voltage cannot be maintained at any point of the installation at a value equal to or less than the conventional touch voltage limit U_L, where $U_L = \sim 50$ V r.m.s. For evaluation of touch voltage the operating current and/or the characteristics of the protective device should be used.

NOTE 1 In certain configurations of IT systems, automatic disconnection may not be required on the occurrence of the first fault.

NOTE 2 For nominal voltage to earth of 240 V a.c., disconnection may be achieved by compliance with regulation 413-5 of the IEE "Regulations for Electrical Installations" (the Wiring Regulations).

NOTE 3 It may be necessary to specify lower values than 50 V for certain applications or locations, for example wet and conductive environments.

5.4 In particular installations (for example, systems supplying motors) up to and including 1 000 V where a clear and permanent distinction can be made between

a) those parts of the installation which supply only fixed apparatus, and

b) those parts intended to supply portable and mobile apparatus having exposed conductive parts likely to be held in the hand,

then the disconnection time under fault condition for the fixed installation should be as short as practical but not exceeding 5 s.

NOTE "Clear and permanent distinction" means that a fault in a fixed installation does not impair the safety of portable or mobile apparatus.

5.5 It should be recognized that, in systems above 1 000 V, a finite time is required to disconnect under a fault condition, and that during this time under some special situations, higher prospective touch voltages may exist during the disconnection process. In such situations, it is essential that disconnection takes place in the shortest practical time.

5.6 The protective measures necessitate co-ordination of:

a) the power system type in relation to earthing (see clause **6**); and

b) the characteristics of the protective devices.

6 Power systems

The power systems given in a) to c) are recommended. Where the characteristics of the system of earthing of the supply to the electrical installation are not known, they should be ascertained from the power supplier.

a) TN-S systems (see Figure 1). The protective conductor (PE) is the metallic covering of the cable supplying the installation or a separate conductor. All exposed conductive parts of an installation are connected to this protective conductor via the main earthing terminal of the installation.

NOTE This is the system normally used by the Electricity Boards in the UK for supplies made to open-cast mines and quarries.

b) TT systems (see Figure 2). All exposed conductive parts of an installation are connected to an earth electrode which is electrically independent of the source earth.

c) IT systems (see Figure 3, Figure 4 and Figure 5). The earthable point is not connected to earth, or is connected to earth through an impedance (resistor or reactor); but the exposed conductive parts of the installation are connected to earth electrodes which may be the same as those used for the earthing resistor or reactor. Figure 5 shows power systems deriving supply from other systems (TT or TN) through a three-phase reactor (zero sequence reactor) offering a high impedance to earth fault (zero sequence) currents with neutral displacement (see **9.3**).

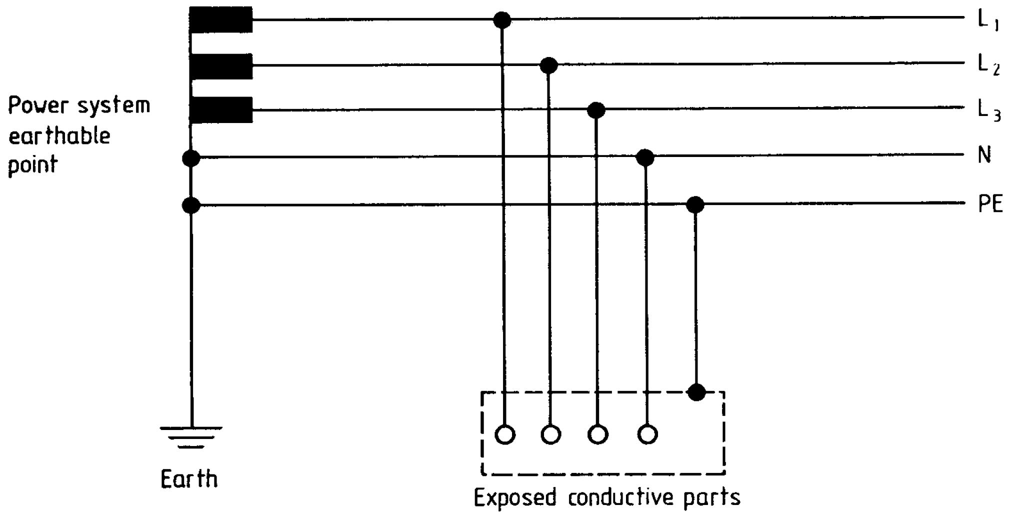


Figure 1 — TN-S system with separate neutral and protective conductors throughout the system

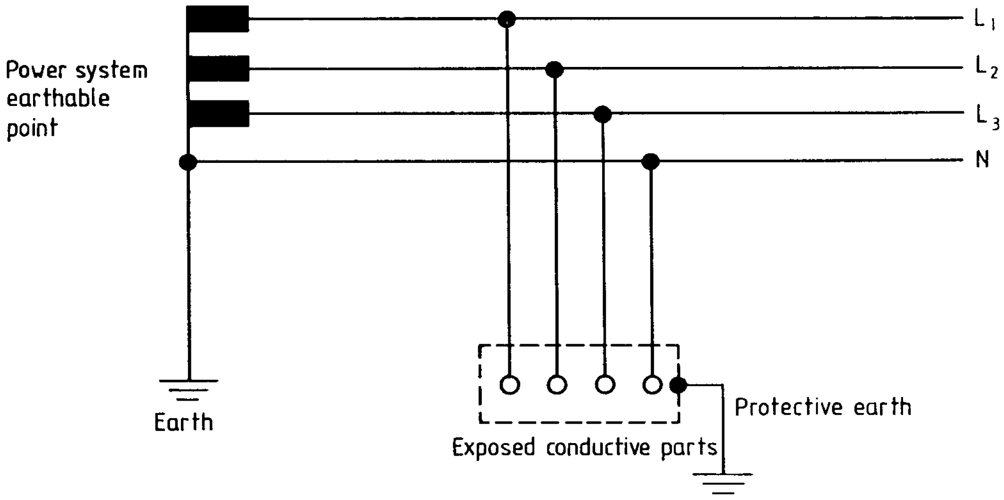


Figure 2 — TT system

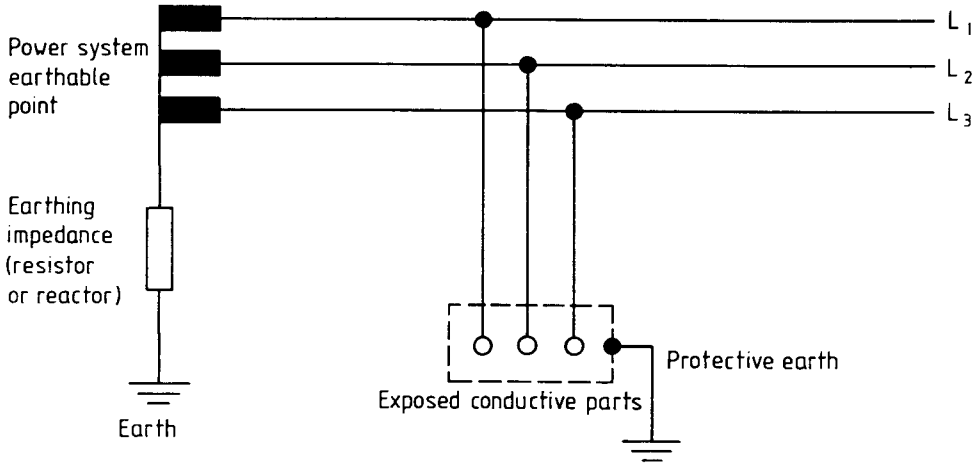


Figure 3 — IT system with independent earth electodes

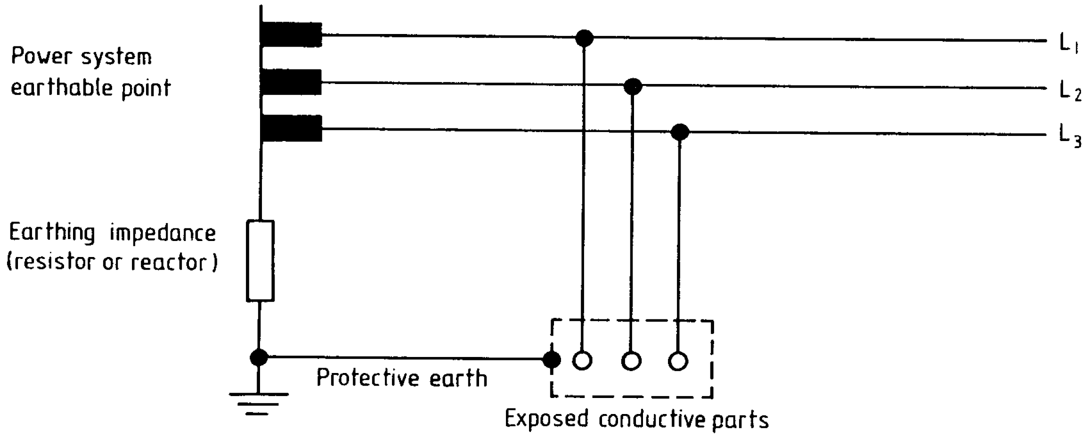


Figure 4 — IT system with common earth electrode

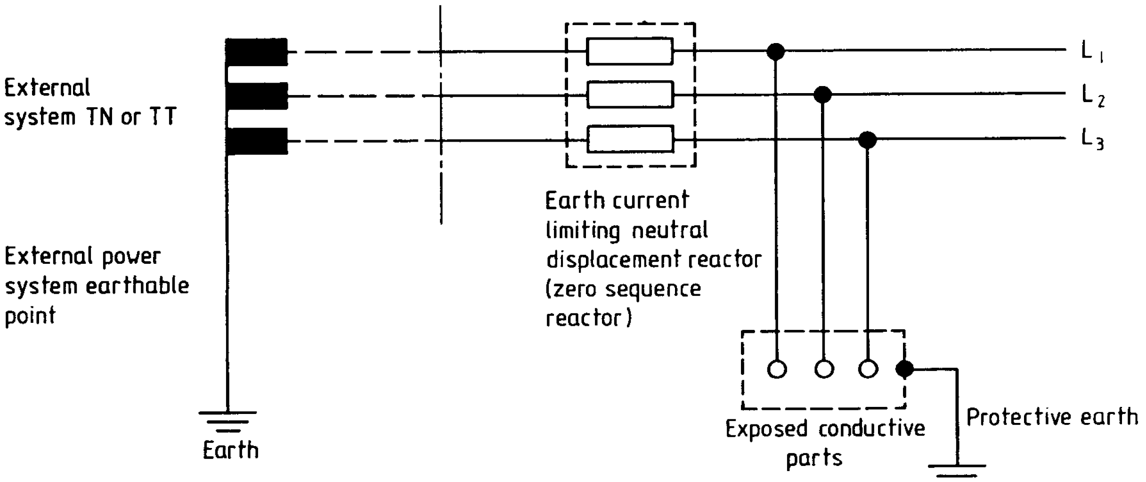


Figure 5 — IT system using external TT or TN system as a source

7 Protective measures for TN-S systems

7.1 General

In TN-S systems the earthable point (in three-phase systems commonly the neutral point of the power system) and exposed conductive parts are interconnected by a protective conductor. In the case of an earth fault of negligible impedance between a phase conductor and the protective conductor or exposed conductive parts, the resultant fault current initiates, through a protective device, disconnection of the supply to the defective equipment.

7.2 Bonding of exposed conductive parts

All exposed conductive parts of the electrical installation should be connected to the earthable point of the power system by protective conductors.

7.3 Disconnection following fault

The protective devices and the cross-sectional area of the conductors should be chosen in such a way that, if an earth fault occurs at any point between a phase conductor and the protective conductor or any exposed conductive part connected to it, disconnection will be effected in accordance with clause **5**.

The conditions to ensure disconnection in accordance with clause **5** will be dependent upon the combined impedances of the phase conductor, the protective conductor and the source. In practice these conditions will generally be met by providing a protective conductor with a conductance of not less than 50 % of the conductance of the phase conductor of the circuit. If this condition cannot be fulfilled, then supplementary bonding in accordance with **11.7.2** should be provided.

7.4 Interruption of protective conductor

The protective conductor should not be interrupted in service.

7.5 Neutral conductor insulation and installation

The neutral conductor, if any, should be insulated and installed in the same manner as a phase conductor.

7.6 Protective devices

The use of the following protective devices is recommended:

a) overcurrent-operated protective devices;

b) residual-current-operated protective devices.

7.7 Overhead lines

In certain cases on TN-S systems a direct fault between a phase conductor and earth can occur. In such cases, the total resistance of the protective conductor and its associated earthing electrode(s) has to be maintained at a level that ensures the touch voltage of the protective conductor, or any parts connected thereto, is limited in accordance with clause **5**.

The following protective measures are recommended:

a) a cradle (connected to the protective conductor) erected below the overhead line conductors; and

b) connection of the structural parts of the overhead line supports to the protective conductor.

8 Protective measures for TT systems

8.1 General

In TT systems, the earthable point (neutral point) is directly connected to an earth electrode with no impedance (other than the impedance of the protective conductor) being inserted between the earthable point and the earth electrode.

The exposed conductive parts are connected, either individually, in groups, or as a whole, to one or several earth electrodes independent of the earth electrode of the earthable point.

For systems wholly contained within movable or mobile apparatus, the earthable point and all exposed conductive parts should be connected to the metallic structure.

In the event of a fault between a phase conductor and an exposed conductive part, the touch voltage should be limited in accordance with clause **5**.

8.2 Neutral conductor insulation and installation

The neutral conductor, if any, should be insulated and installed in the same manner as a phase conductor.

8.3 Bonding of exposed and extraneous conductive parts

All exposed conductive parts of electrical equipment protected by a common protective device should be interconnected and connected by a protective conductor to a common earth electrode.

Exposed conductive parts which are simultaneously accessible should be connected to a common earth electrode.

In the event of a fault, if the conditions of clause **5** cannot be met, then supplementary equipotential bonding in accordance with **11.7.2** should be installed.

8.4 Protective devices

The use of the following protective devices is recommended:

a) residual-current operated protective devices;

b) overcurrent operated protective devices.

9 Protective measures for IT systems

9.1 General

In IT systems the earthable point of the power system will be earthed through a resistor or reactor and the exposed conductive parts connected to one or several earth electrodes either individually, in groups, or as a whole.

In the event of a single fault, where the fault current to exposed conductive parts is of sufficiently low value that the touch voltage limit is not exceeded, disconnection of the source of supply may not be required. Measures should be taken to avoid danger in the case of two simultaneous earth faults (phase to earth to phase).

A system in which supply is taken from a TN or TT power system through an earth fault current limiting neutral displacement reactor (zero sequence reactor) (see Figure 5) restricts the earth fault current to a low value and accords with the definition of an IT system.

Where neutral displacement is to be achieved through the application of an earth fault current limiting device, such a device should be in accordance with clause **10**.

9.2 Earthing of the power system earthable point

The earthable point (the neutral point in this case) should be earthed through a resistor or reactor.

9.3 Neutral conductor

The neutral point should not be used for the connection of loads as, under phase to earth fault conditions, it may be raised to a potential above earth which approaches a valve of $\sqrt{3} \times$ the system phase voltage.

9.4 Bonding of exposed conductive parts

All exposed conductive parts should be earthed individually, in groups or as a whole and may be connected directly to the common system earth electrode(s).

The total earthing resistance of all exposed conductive parts connected by the protective conductor to an earth electrode should be such as to ensure that the touch voltage of the protective conductor or any parts connected thereto is limited in accordance with clause **5**.

9.5 Operation of the protective devices under fault condition

On the occurrence of a first fault; where the prospective touch voltage (see **9.4**) exceeds the safe limit as described in clause **5**, the protective device should disconnect the supply to the circuit.

NOTE Where the prospective touch voltage (see **9.4**) does not exceed the safe limit as described in clause **5**, operation may be continued subject to protection being provided to disconnect the supply in the event of a second fault (phase to earth to phase).

9.6 Protective devices

The use of the following protective devices is recommended:

a) insulation monitoring devices;

b) overcurrent-operated protective devices;

c) residual-current-operated protective devices;

d) residual-voltage-operated protective devices (only for applications where the preferred residual-current-operated protective devices are impractical).

10 Earth fault current limitation devices

10.1 In IT systems where earth fault current limitation devices affording system neutral displacement are used, the value of earth current limitation should be co-ordinated with the operating values of the protective devices used on the system.

NOTE The ratio between maximum prospective earth fault current and protection settings is known as the "tripping ratio". In practice it has been found that, in order to take account of voltage depressions occurring when a short circuit coincides with an earth fault, the tripping ratio should be set to at least 5 : 1.

The rated insulation voltage of these devices should be the phase to phase voltage of the system and consideration should be given to the cyclic-duty and any other rating requirements.

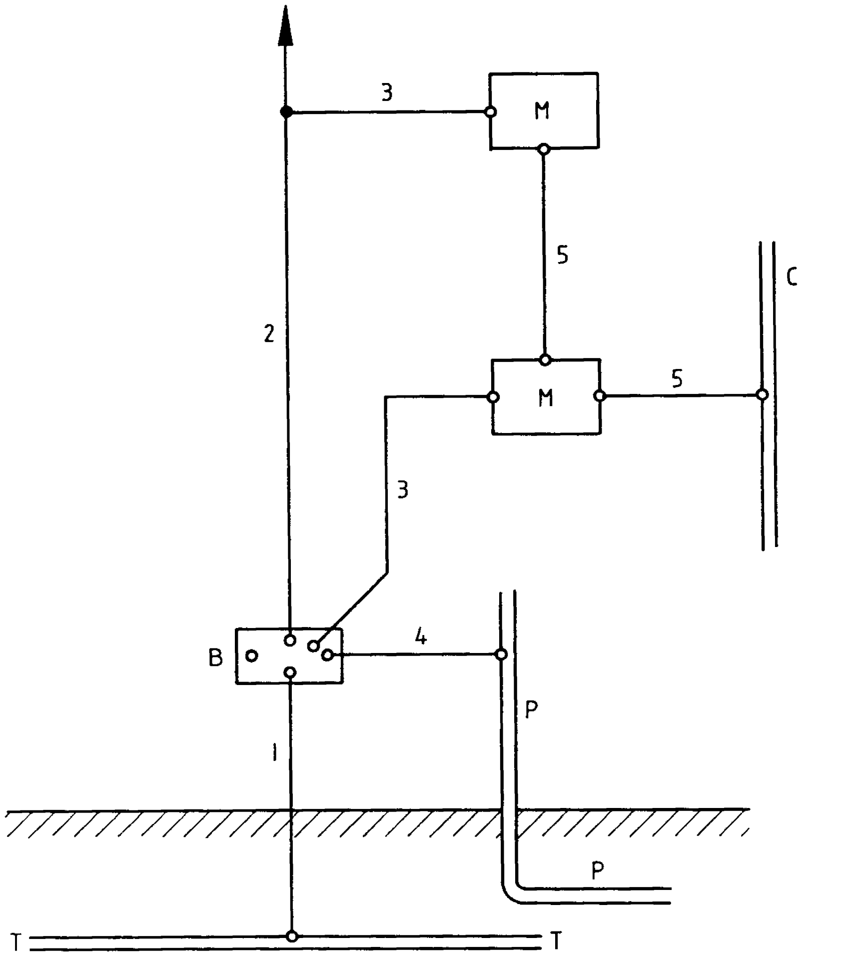
10.2 Earth fault current limitation devices may take the form of:

a) neutral earthing resistors;

b) neutral earthing reactors;

c) three-phase earth fault current limiting neutral displacement reactors (zero sequence reactors).

NOTE Earth fault current limiting neutral displacement reactors are intended for use in series with a three-phase system, the earthable point (the neutral point in this case) being earthed (see Figure 5). The device provides low impedance to load current but high impedance to zero sequence currents in order to limit to a specified value the current which would occur under conditions of a single phase to earth fault.
Normally reactors of this type are used on systems above 1 000 V and may be used in lieu of an isolating transformer for the purpose of restricting earth fault currents.



Key

1 Earthing conductor
2 Main protective conductor
3 Protective conductor
4 Main equipotential bonding conductor
5 Supplementary equipotential bonding conductor

T Earth electrode
B Main earthing terminal
M Exposed conductive part
C Extraneous conductive part
P Main metallic water pipe

Figure 6 — Illustration of the elements of a typical earthing arrangement

11 Earthing arrangements and protective conductors

11.1 General

11.1.1 The performance of the earthing arrangements should satisfy the safety and functional requirements of the electrical installation and the equipment of that installation. The earthing arrangements may be used jointly or separately for protective or functional purposes according to the requirements of the installation.

11.1.2 The earthing arrangements should include earth electrode(s) and protective conductor(s). However, the provision of separate earthing arrangements or conductors is not necessary where protection can be achieved by other means.

NOTE An illustration of the elements of a typical earthing arrangement is provided in Figure 6. Not all of the elements illustrated need be present in every earthing arrangement, additional elements may be required in some installations, and some elements may have a combined function.

11.1.3 The design, selection and installation of the earthing arrangement should be such that:

a) protection against indirect contact is provided in accordance with section 2;

b) the conditions for proper functioning of protective devices are satisfied;

c) the earth electode(s) and protective conductor(s) are designed and installed so that the protective and functional requirements are met under the expected conditions;

d) earth fault currents (including currents resulting from phase-earth-phase faults in the case of IT systems) and earth-leakage currents can be carried without danger, particularly from thermal, thermo-mechanical and electro-mechanical stresses;

e) it is adequately robust or has additional mechanical protection appropriate to the assessed conditions of external influence;

f) the value of earth electrode resistance is in accordance with the protective and functional requirements of the installation and is expected to be continuously effective.

11.1.4 Precautions should be taken to minimize damage to other metallic parts through electrolysis.

11.2 Earth electrodes

11.2.1 The following types of earth electrode may be used:

a) rod or pipe;

b) tape or wire;

c) plate or mat;

d) other underground structures suitable for use as electrodes.

One or more earth electrodes suitable for the soil conditions and value of earth electrode resistance required should be selected.

Movable or mobile equipment should have the earthable point of the self-contained power supply connected to the metallic structure of that equipment. Protection against leakage to exposed or extraneous conductive parts should be provided by residual current earth fault protection connected as close as possible to the source of the supply.

NOTE 1 The effectiveness of any earth electrode depends on local soil conditions. Where conditions preclude satisfactory electrical contact the use of techniques such as blasting and/or the addition of chemical fillers may be advantageous.

NOTE 2 In some cases separate earth electrode arrangements may be required.

11.2.2 The material and total cross-sectional area of the earth electrode(s) should be such as to provide a conductance of not less than that of the earthing conductor (see also **11.3.1**).

11.2.3 The type and embedded depth of earth electodes should be such that soil drying and freezing will not increase the earth resistance above the required value.

11.2.4 The design of the electrodes should take into consideration the type, temperature and moisture content of the soil as well as the magnitude and duration of expected current flow so as to prevent soil dryness in the vicinity of the electrodes.

11.2.5 The design, selection of materials and construction of earth electrodes should take into consideration the possible deterioration and increase of resistance due to corrosion over the expected period of use of the installation.

11.2.6 The earth resistance should be measured when the electrode is initially installed and should be periodically checked thereafter.

11.2.7 Metallic pipe systems for water or other services (e.g. flammable liquids or gases, heating systems) should not be used as earth electrodes for protective or functional purposes.

NOTE This recommendation does not preclude connections to metallic pipe systems for equipotential bonding.

11.2.8 Lead sheaths and other metallic coverings of cables should not be used as earth electrodes for protective or functional purposes.

11.3 Earthing conductors

11.3.1 Every earthing conductor should have a cross-sectional area of not less than that determined in accordance with **11.5.2**, but the cross-sectional area should in no case be less than the appropriate value prescribed in Table 1.

Table 1 — Minimum size of earthing conductors

Conductor	Minimum cross-sectional area	
	Mechanically protected	Mechanically unprotected
Protected against corrosion	As determined by **11.5.2**	16 mm^2 for copper and ferrous materials
Not protected against corrosion	25 mm^2 for copper 50 mm^2 for ferrous materials	

11.3.2 The connection of an earthing conductor to an earth electrode should be soundly made and provide satisfactory electrical continuity. Where a clamp is used it should not damage the electrode or the earthing conductor.

Connections between earthing conductors and earth electrodes should be protected against mechanical damage and corrosion.

NOTE In certain installations it may be necessary to use more than one electrode and in these circumstances it is desirable for the points of connection to the electrodes to be accessible for testing purposes.

11.4 Main earthing terminals or bars

11.4.1 One or more main earthing terminals or bars should be provided for the interconnection of:

a) protective conductors;

b) main equipotential bonding conductors; and

c) functional earthing conductors, if required, and for their connection to the earthing conductors.

11.4.2 To permit measurement of the resistance of the earth electrodes, means should be provided in an accessible position for disconnecting the earthing conductor. This joint should be mechanically strong to ensure the maintenance of electrical continuity. Disconnection should only be possible by means of a tool and should only take place with the supply isolated, or the system connected to an alternative earth electrode.

11.5 Protective conductors

11.5.1 *Types of protective conductor.* Protective conductors may be:

a) conductors in multicore cables;

b) insulated or bare conductors in a common enclosure with phase conductors;

c) separate bare or insulated conductors;

d) metal coverings for conductors or cables, for example, sheaths, screens or armouring;

e) suitable metallic enclosures for conductors.

11.5.2 ***Minimum cross-sectional area***

11.5.2.1 *General.* The cross-sectional area of the protective conductor should be selected to ensure:

a) that it will withstand the thermal conditions which may be experienced in the case of a fault (see **11.5.2.2**); and

b) that it has adequate mechanical strength to ensure the integrity of the conductor under the expected conditions (see **11.5.2.3**).

In addition, the protective conductor, as an element of the earthing arrangement, should, either alone or in conjunction with other elements of the earthing arrangement, be in accordance with section two, for protection against indirect contact and for the proper operation of protective devices.

11.5.2.2 *Minimum cross-sectional area based on thermal considerations.* The cross-sectional area of the protective conductor should be either calculated or selected in accordance with a) or b) below, as applicable.

a) *Calculation.* The cross-sectional area S_p (in mm^2) should be not less than the value determined by using the following expression (applicable only for disconnection times less than 5 s):

$$\frac{k_1 \sqrt{(l^2 t)}}{k}$$

where

l is the value (a.c., r.m.s.) of fault current for a fault of negligible impedance, which can flow through the protective conductor (in A);

t is the operating time of the disconnecting device (in s);

k is a factor having a value dependent on the material of the protective conductor and the initial and the final temperatures;

k_1 is a factor which takes into account the effect of asymmetrical fault currents for short disconnecting times. It is recommended that a factor of 1 be used for operating times of 0.2 s but not exceeding 5 s and 1.3 for operating times of less than 0.2 s.

Account should be taken of the current limiting effect of the circuit impedance and l^2t limiting capability of the protective device.

The value of k for the calculation should be selected in accordance with Appendix A.

If application of the expression produces a size not readily available, a conductor of the next larger available cross-sectional area should be used.

b) *Selection.* The cross-sectional area of the protective conductor should be not less than the appropriate value shown in Table 2. If the application of this table produces a size not readily available, a conductor having the next larger available cross-sectional area should be used.

Where the cross-sectional area of the protective conductor is selected from Table 2, checking by calculation in accordance with a) is not necessary.

The values in Table 2 are valid only if the protective conductor is made of the same metal as the phase conductors. If this is not so, the cross-sectional area of the protective conductor should be determined in a manner which produces a conductance equivalent to that which results from the application of Table 2.

Table 2 — Selection of minimum cross-sectional area for protective conductors

Cross-sectional area of phase conductors (S) of the installation	Minimum cross-sectional area of the corresponding protective conductor (S_p)
mm^2	mm^2
$S \leqslant 16$	S
$16 < S \leqslant 35$	16
$S > 35$	$S/2$

11.5.2.3 *Minimum cross-sectional area based on mechanical strength considerations.* Notwithstanding the size of protective conductor determined in accordance with **11.5.2.2**, the cross-sectional area should be not less than the appropriate value given in a) to d) inclusive. The cross-sectional areas given are based on the use of copper conductors; when other conductor materials are used, equivalent mechanical strength should be provided.

a) *Separately installed protective conductors.* The cross-sectional area of every protective conductor which does not form part of the cable or cable enclosure should be not less than:

1) 2.5 mm^2 if mechanical protection is provided;

2) 4.0 mm^2 if mechanical protection is not provided.

b) *Protective conductors installed with the phase conductors.* Where the protective conductor is installed in the same cable, conduit, sheathing or other protective covering as phase conductors of size not greater than 2.5 mm^2, the protective conductor should have the same cross-sectional area as the phase conductors.

c) *Protective conductors of high voltage installations.* Where the phase conductors are at a voltage greater than 1 000 V, the cross-sectional area of the associated protective conductor should be not less than 16 mm^2.

d) *Aerial and suspended protective conductors.* Aerial and suspended protective conductors should be not less than the relevant cross-sectional area given in Table 3. Conductors of larger cross-sectional area may be required for severe icing or wind conditions.

Table 3 — Minimum cross-sectional area of aerial and suspended protective conductors

Type of protective conductor	Span	Minimum cross-sectional area
	m	mm^2
Weatherproof rubber-insulated or thermoplastic-insulated cables with annealed conductors	$\leqslant 10$	4
Bare or covered hard-drawn conductors	$\leqslant 25$	4
	$> 25 \leqslant 50$	6
	$> 50 \leqslant 75$	16

11.5.3 ***Preservation of electrical continuity of protective conductors***

11.5.3.1 Protective conductors should be suitably protected against mechanical and chemical deterioration and electrodynamic effects.

11.5.3.2 Connections of protective conductors should be accessible for inspection and testing except in the case of compound filled or encapsulated joints.

11.5.3.3 No switching device should be inserted in the protective conductor, but joints which can be disconnected by use of a tool may be provided for test purposes.

11.5.3.4 Where electrical monitoring of earth-continuity is used, the sensing elements should not be inserted in series with the protective conductors.

11.5.3.5 Where protective conductors are liable to be broken or rendered ineffective in spite of the safeguards adopted, protective conductor monitoring and protection should be employed.

11.5.3.6 Exposed conductive parts of apparatus should not be used to form part of the protective conductor of other equipment.

11.6 Earthing arrangements for protective conductors used with overcurrent-operated protective devices

When overcurrent-operated protective devices are used for protection against indirect contact in alternating current systems, the protective conductors should preferably follow the same magnetic path as the phase conductors.

11.7 Equipotential bonding

11.7.1 *Main equipotential bonding.* Wherever practicable a main equipotential bonding conductor should be installed to connect extraneous conductive parts which are embedded in the earth (e.g. main metallic water pipes, metallic structures, metallic reinforcement of foundations) to the main earthing terminal or equivalent point (see Figure 6).

The main equipotential bonding conductor(s) should have a current carrying capacity of not less than that of the main protective conductor of the installation. However, for IT systems of up to and including 1 000 V, the cross-sectional area of the conductor need not exceed 25 mm^2 if made of copper or a cross-sectional area affording equivalent current carrying capacity if made of another metal.

11.7.2 ***Supplementary equipotential bonding***

11.7.2.1 If, in an installation or part of an installation, the conditions for protection against indirect contact in the event of a fault cannot be fulfilled, then local bonding, known as supplementary equipotential bonding, should be provided. This may be achieved by the use of additional conductors, additional structural parts, or both. Supplementary equipotential bonding may involve the entire installation, a part of the installation, or an item of apparatus. In addition, the bonding of metallic parts may be necessary in hazardous locations (e.g. fuel storage areas) to minimize the risk of explosion.

11.7.2.2 Supplementary equipotential bonding should connect:

a) simultaneously accessible exposed conductive parts, e.g. frames of equipment, covers, exposed cable armour;

b) exposed conductive parts simultaneously accessible to extraneous conductive parts, e.g. ladders, walkways.

11.7.2.3 The cross-sectional area of supplementary equipotential bonding conductors should be in accordance with either a) or b), as appropriate, but should be not less than the relevant value given in Table 4.

a) Conductors connecting two exposed conductive parts should have a cross-sectional area not less than that of the smaller protective conductor connected to the exposed conductive parts.

b) Conductors connecting exposed conductive parts to extraneous conductive parts should have a cross-sectional area not less than half the cross-sectional area of the corresponding protective conductor.

Table 4 — Minimum cross-sectional area of supplementary equipotential bonding conductors

Rated operating voltage U	Minimum cross-sectional area[a]	
	Mechanically protected	Mechanically unprotected
V	mm^2	mm^2
$0 < U \leqslant 1\ 000$	2.5	4
$U > 1\ 000$	10	10

[a] The minimum cross-sectional areas apply to copper conductors. Where other conductor materials are used a cross-sectional area affording the equivalent current carrying capacity will need to be provided.

11.7.2.4 Where doubt exists regarding the effectiveness of supplementary equipotential bonding, it should be confirmed that the impedance between simultaneously accessible conductive parts and extraneous conductive parts is such that the touch voltage limit in accordance with clause **5** is not exceeded.

Where supplementary equipotential bonding is installed between exposed conductive parts of apparatus which are connected to separate supplies, confirmation should be obtained for each of the supplies involved.

Section 4. Protection against overcurrent and fault current

12 General

12.1 This section gives the minimum conditions for the protection against overcurrent in respect of overload protection and short-circuit protection, together with the co-ordination of overload and short-circuit protection and the co-ordination of this protection with the conductors and apparatus.

12.2 Electrical apparatus and live conductors should be protected by one or more devices for automatic interruption of the supply in the event of overcurrent due to overload and short-circuits except where otherwise allowed by clauses **14** and **15**.

Protection against overload and against short-circuits should be co-ordinated in accordance with clause **16**.

13 Types of protective device

The protective devices should be chosen from the following.

a) Devices ensuring protection against both overload current and short-circuit current. They should be suitable for the voltage and be capable of breaking any overcurrent up to and including the prospective short-circuit current at the point where the device is installed.

NOTE A device having a breaking capacity below the value of the prospective short-circuit at its place of installation may also be used in accordance with **15.3.1** a).

b) Devices ensuring protection against overload current only. They generally have a breaking capacity below the value of the prospective short-circuit and generally have inverse time lag characteristics.

c) Devices ensuring protection against short-circuit current only. They should be suitable for the voltage and be capable of breaking any short-circuit current up to and including the prospective short-circuit current.

14 Automatic interruption: protection against overcurrent due to overload

14.1 Conditions of application

14.1.1 *Live conductors.* Protective devices should be provided to break any overcurrent flowing in the conductors before such a current can cause a temperature rise detrimental to insulation, joints, terminations or to the surroundings of the conductors, except as provided in **14.1.2.2**.

14.1.2 ***Electrical apparatus***

14.1.2.1 Any electrical apparatus which may cause over-current due to overload should be provided with an overcurrent protective device to interrupt automatically the supply to the apparatus.

14.1.2.2 Overcurrent protective devices should not be installed in conductors supplying electrical apparatus where the unexpected interruption of supply could subject persons to danger or cause greater hazard to mechanical or electrical apparatus. Such cases may include but not be limited to:

a) excitation circuits for d.c. and a.c. (synchronous) motors;

b) supply circuits of lifting magnets;

c) current transformer secondary circuits;

d) fire service pumps and certain drainage pump installations.

14.1.2.3 Where overcurrent protective devices do not inhibit circuit operation alarm facilities should be provided to identify the overload condition.

NOTE For some types of electrical apparatus, it may not be practicable to provide an overcurrent protective device, for example motors subjected to periodic or cyclic loading. In such cases protection against overload may also be fulfilled by the limitation of the overcurrent to a safe value and duration, for example by means of design.

14.1.3 *Electrical apparatus and live conductors.* The use of a single overload protective device for both electrical apparatus and the associated circuit conductors is permitted.

14.2 Co-ordination between protective devices and conductors

14.2.1 *Nominal current* (l_n) *of the protective device.* The current setting of the protective device should not exceed the current-carrying capacity (l_z) of the conductors.

14.2.2 *Protection of conductors in parallel.* Where several conductors are in parallel to provide a supply to one item of electrical equipment and are protected by the same protective device, the combined current rating should be taken as the sum of the permissible current in each of those conductors. This provision is acceptable only if the conductors have the same electrical characteristics (conductor material, method of installation, length, cross-section) and do not have any branches along their run.

14.3 Arrangement of the overload protective device

14.3.1 *Electrical apparatus and five conductors.* Any over-load protective device provided in accordance with **14.1.3** to protect both electrical apparatus and the associated circuit conductors should be installed in accordance with **14.3.2**.

14.3.2 *Live conductors.* An overload protective device should be provided where the current-carrying capacity is reduced except as follows:

a) under the condition given in **14.1.2.1**;

b) where the overload protective device for the conductor with the higher current-carrying capacity adequately protects the conductor with the lower current-carrying capacity.

Alternatively, the overload protective device may be fitted at any point on the conductor run for which it is providing such protection, provided that the part of the conductor run between the point at which the current carrying capacity is reduced and the protective device fulfils one of the following conditions:

1) the conductor is protected against short-circuit in accordance with clause **15** and there are no branch circuits along the conductor;

2) the length of the part of the conductor run does not exceed 3 m and there are no branch circuits along it, and the conductor

i) is constructed in such a way as to minimize, under the conditions of use expected, the risk of overload due to a fault,

ii) is not located in the vicinity of any ignitable materials, and

iii) is not likely to cause harmful effects to persons.

15 Automatic interruption: protection against short-circuits

15.1 Conditions of application

A protective device should be provided to break a current flowing in circuit conductors resulting from a short-circuit in either the conductors or the connected electrical apparatus before that current can give rise to danger due to thermal and mechanical effects produced in the conductors, connections or electrical apparatus.

15.2 Determination of prospective short-circuit currents

Short-circuit currents may be determined:

a) by an appropriate calculating method;

b) by means of a network analyser;

c) by measurements in the installation.

NOTE Where the protective device is installed at the feeding point of a consumer's installation, information on the prospective short-circuit current at that point may be obtained from the distribution authority or supplier.

15.3 Operating conditions for short-circuit protection

15.3.1 *Characteristics of short-circuit protective devices.* Each short-circuit protective device should meet both of the following conditions.

a) The breaking or interrupting current capacity should take into consideration the system voltage and the prospective short-circuit current at the point of installation.

A lower breaking capacity is permitted if another protective device having the necessary breaking capacity is installed on the supply side. In that case, the characteristics of the devices need to be co-ordinated so that the energy let through by the device on the supply side does not exceed that which can be withstood without damage by the device on the load side and the conductors protected by these devices.

b) All currents caused by a short-circuit occurring at any point of the circuit should be interrupted in a time not exceeding that given in **15.3.2**.

15.3.2 *Temperature of conductors.* With regard to the insulation, the permissible temperature limits for a short-circuit duration from 0.2 s up to 5 s based on the specification for conductors and cables, are:

a) 160 °C for PVC, conductor size up to and including 300 mm^2;

b) 140 °C for PVC, conductor sizes greater than 300 mm^2;

c) 200 °C for general purpose (GP) rubber;

d) 160 °C for paper;

e) 220 °C for butyl rubber;

f) 250 °C for cross-linked polyethylene and ethylene-propylene rubber.

Reference should be made to the cable manufacturer's published information to determine the time required for short-circuit currents to produce cable limiting temperatures.

With regard to the termination of conductors, whether soldered, brazed, welded, mechanically clamped or compression socketed, consideration should be given to the effects of temperature upon the bonding medium and to the materials surrounding the termination under fault conditions.

NOTE Certain solder alloys soften below 160 °C, resulting in the loss of mechanical strength.

15.4 Arrangement of devices for short-circuit protection only

A device affording protection against short-circuits should be installed at the point where a reduction of the cross-section of the conductor or any other change causes a modification of the characteristics according to **15.3.1**.

NOTE Protective devices against short-circuits may be omitted in the following cases:

a) conductors of a length not exceeding 3 m laid in a short-circuit proof manner;

b) current transformer secondary circuits.

16 Co-ordination of overcurrent and short-circuit protection

16.1 Protection afforded by one device

If an overload protective device in accordance with **14.2** has a breaking capacity at the system voltage equal to or greater than the value of the prospective short-circuit current at its point of installation, it is also considered to protect the conductor on the load-side of that point against short-circuits. The device should then be placed as indicated in **14.3.1** and **15.4**.

16.2 Protection afforded by separate devices

The characteristics of overload and short-circuit protective devices
(see clauses **14** and **15** respectively) need to be co-ordinated so that the energy let through by the short-circuit device does not exceed that which can be with-stood without damage by the overload protective device.

17 Limitation of overcurrent by nature of the source

Protection against overload and short-circuit current is considered to be afforded in the case of conductors supplied from a source incapable of supplying a current exceeding the current-carrying capacity of the conductors (for example, certain types of bell transformer, welding transformer, thermo-electric generating set).

Appendix A Selection of factor *k* for calculating the minimum cross-sectional area of protective conductors

The value of *k* for the calculation in **11.5.2.2** a) is selected from Table 5 to Table 8 according to the type of conductor material and the initial and final temperatures of the protective conductor.

The values of *k* given in Table 5 to Table 8 have been derived using the following expression. The expression may also be used to calculate values of *k* for other initial and final temperatures.

$$k = D\sqrt{\log_e \frac{(B + T_2)}{(B + T_1)}}$$

where

D is a constant having the following values:

for copper	226
for aluminium	148
for lead	41
for steel	78

B is the reciprocal of temperature coefficient of resistance of the protective conductor at 0 °C:

for copper	234.5
for aluminium	228
for lead	230
for steel	202

T_1 is the assumed initial temperature of protective conductor (in °C);

T_2 is the limiting final temperature of protective conductor (in °C).

Table 5 — Values of *k* for insulated protective conductors not incorporated in cables and not bunched with cables or for bare protective conductors in contact with cable covering

Conductor		Insulation material or cable coverings											
		PVC[a] and paper			PVC[b]			85 °C rubber			90 °C thermosetting rubber		
Temperatures (in ° C)	T_1	20	30	40	20	30	40	20	30	40	20	30	40
	T_2	160	160	160	140	140	140	220	220	220	250	250	250
Copper		150	143	136	140	133	126	172	166	160	181	176	170
Aluminium		99	95	90	93	88	83	114	110	106	120	116	113
Steel		55	52	49	51	49	46	63	60	58	66	64	62

NOTE T_1 is the ambient temperature for the installation. T_2 is the maximum permissible temperature for earth fault conditions of duration not exceeding 5 s, as appropriate to the type of conductor insulation.

[a] Up to and including 300 mm^2.

[b] Above 300 mm^2.

Table 6 — Values of *k* for protective conductor as a core in a cable or bunched with cables

Conductor		Insulation material			
		PVC[a] and paper	PVC[b]	85 °C rubber	90 °C thermosetting rubber
Temperatures (in ° C)	T_1	70	70	85	90
	T_2	160	140	220	250
Copper		115	103	134	143
Aluminium		76	68	89	94

NOTE T_1 is the maximum steady-state temperature for normal operation of the associated current-carrying conductors. T_2 is the maximum permissible temperature for earth fault conditions of duration not exceeding 5 s, as appropriate to the type of conductor insulation.

[a] Up to and including 300 mm^2.

[b] Above 300 mm^2.

Table 7 — Values of *k* for protective conductor as a sheath or armour of a cable

Conductor		Insulation material			
		PVC[a] and paper	PVC[b]	85 °C rubber	90 °C thermosetting rubber
Temperatures (in °C)	T_1	60	60	75	80
	T_2	160	140	220	250
Steel		44	40	51	54
Aluminium		81	73	93	98
Lead		22	20	26	27

NOTE T_1 is a temperature 10 °C lower than the maximum steady state temperature given in Table 6, as appropriate to the type of conductor insulation. T_2 is the maximum permissible temperature for earth fault conditions of duration not exceeding 5 s, as appropriate to the type of conductor insulation.

[a] Up to and including 300 mm^2.

[b] Above 300 mm^2.

Table 8 — Values of *k* for bare protective conductors where there is no risk of damage to any neighbouring material by the temperatures indicated

Conductor		Conditions								
		Visible and in restricted areas			Not visible and in normal area			Not visible and in areas of increased fire risk		
Temperature (in °C)	T_1	20	30	40	20	30	40	20	30	40
	T_2 Copper	500			200			150		
	T_2 Aluminium	300			200			150		
	T_2 Steel	500			200			150		
Copper		233	228	224	165	159	153	145	138	131
Aluminium		129	125	122	109	105	101	96	91	87
Steel		84	82	80	60	58	56	53	50	48

NOTE T_1 is the ambient temperature for the installation. T_2 is the maximum permissible temperature for earth fault conditions of duration not exceeding 5 s, as appropriate to the conductor material, assuming that it is bare and not touching any material which would be damaged by the maximum temperature allocated.

Publications referred to

BS 5490, *Specification for classification of degrees of protection provided by enclosures*.

BS 6907, *Electrical installations for open-cast mines and quarries*.

BS 6907-1, *Glossary*.

BS 6907-3, *Recommendations for equipment and ancillaries*[2].

BS 6907-4, *Recommendations for winning, stacking and processing machinery, pumps and low signal level and communications systems*.

BS 6907-5, *Recommendations for operation*.

IEC 621, *Electrical installations for outdoor sites under heavy conditions (including open-cast mines and quarries)*[2].

IEE Regulations for Electrical Installations (the Wiring Regulations)[3].

[2] Referred to in the foreword only.

[3] Obtainable from IEE Publications Sales Department, Station House, Nightingale Road, Hitchin, Hertfordshire SG5 1RJ.

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