

BS 7430:2011



BSI Standards Publication

# Code of practice for protective earthing of electrical installations

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#### Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 90, an inside back cover and a back cover.

## Foreword

### Publishing information

This British Standard is published by BSI and came into effect on 31 December 2011. It was prepared by Technical Committee GEL/600, *Earthing*. A list of organizations represented on this committee can be obtained on request to its secretary.

### Supersession

This British Standard supersedes BS 7430:1998, which is withdrawn.

### Relationship with other publications

This revision of BS 7430 takes into account changes in legislation (implementation of the Electricity Safety, Quality and Continuity Regulations 2002 as amended [1]) and changes in and publication of other relevant industry standards such as BS 7671:2008+A1, BS EN IEC 61936-1:2011 and BS EN 50522:2011.

### Legislation

In Great Britain earthing of an electricity supply system is governed by the Electricity Safety, Quality and Continuity Regulations 2002 as amended (ESQCR) [1] and the Electricity at Work Regulations 1989 [2]. In Northern Ireland, The Electricity Supply Regulations (Northern Ireland) 1988 as amended [3] apply.

### Presentational conventions

The provisions in this standard are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

*Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.*

The word "should" is used to express recommendations of this standard. The word "may" is used in the text to express permissibility, e.g. as an alternative to the primary recommendation of the clause. The word "can" is used to express possibility, e.g. a consequence of an action or an event.

Notes and commentaries are provided throughout the text of this standard. Notes give references and additional information that are important but do not form part of the recommendations. Commentaries give background information.

### Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

**Compliance with a British Standard cannot confer immunity from legal obligations.**

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## 1 Scope

This British Standard primarily provides recommendations and guidance on meeting the requirements for the earthing of electrical installations, including:

- a) protective earthing of low voltage installations to BS 7671:2008+A1;
- b) the interface between LV and HV substations of 11 000/400 V to BS EN IEC 61936-1:2011 within buildings; and
- c) protective earthing and changeover switch arrangements for generators supplying low voltage installations.

The earthing of a system or installation is generally provided for reasons of safety.

This British Standard applies only to land-based installations in and around buildings. It does not apply to:

- 1) ships, aircraft or offshore installations;
- 2) earthing of medical equipment [see BS EN 60601 (all parts)];
- 3) special problems encountered with solid state electronic components;
- 4) equipment sensitive to static electricity;
- 5) requirements for functional earthing;
- 6) earthing of overhead lines between electrical installations; or
- 7) the internal earthing of equipment.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS 215-2:1970, *Specification for aluminium conductors and aluminium conductors, steel-reinforced for overhead power transmission – Aluminium conductors, steel-reinforced* (withdrawn)

BS 951, *Electrical earthing – Clamps for earthing and bonding – Specification*

BS 1400, *Specification for copper alloy ingots and copper alloy and high conductivity copper castings* (withdrawn)

BS 1449:1991 (all parts), *Steel plate, sheet and strip* (withdrawn)

BS 1473:1972, *Specification for wrought aluminium and aluminium alloys for general engineering purposes – Rivet, bolt and screw stock*

BS 1474:1987, *Specification for wrought aluminium and aluminium alloys for general engineering purposes: bars, extruded round tubes and sections* (withdrawn)

BS 1561:1997, *Founding – Grey cast irons*

BS 1562:1997, *Founding – Malleable cast irons*

BS 1377-3, *Methods of test for soils for civil engineering purposes – Part 3: Chemical and electro-chemical tests*

BS 2754, *Memorandum – Construction of electrical equipment for protection against shock*

BS 2871-1:1971, *Specification for copper and copper alloys – Tubes – Part 1: Copper tubes for water, gas and sanitation* (withdrawn)

- BS 2871-2:1972, *Specification for copper and copper alloys – Tubes – Part 2: Tubes for general purposes* (withdrawn)
- BS 2871-3:1972, *Specification for copper and copper alloys – Tubes – Part 3: Tubes for heat exchangers* (withdrawn)
- BS 2873:1969, *Specification for copper and copper alloys – Wire* (withdrawn)
- BS 3288-1, *Insulator and conductor fittings for overhead power lines – Part 1: Performance and general requirements*
- BS 7375, *Distribution of electricity on construction and demolition sites – Code of practice*
- BS 7671:2008+A1:2011, *Requirements For Electrical Installations – IEE Wiring Regulations – Seventeenth edition*
- BS EN 485-2:2008, *Aluminium and aluminium alloys – Sheet, strip and plate – Part 2: Mechanical properties*
- BS EN 586-2:1994, *Aluminium and aluminium alloys – Forgings – Part 2: Mechanical properties and additional property requirements*
- BS EN 755-2:2008, *Aluminium and aluminium alloys – Extruded rod/bar, tube and profiles – Part 2: Mechanical properties*
- BS EN 1011-4, *Welding – Recommendations for welding of metallic materials – Part 4: Arc welding of aluminium and aluminium alloys*
- BS EN 1652:1998, *Copper and copper alloys – Plate, sheet, strip and circles for general purposes*
- BS EN 1780-1:2002, *Aluminium and aluminium alloys – Designation of alloyed aluminium ingots for remelting, master alloys and castings – Part 1: Numerical designation system*
- BS EN 1982:2008, *Copper and copper alloys – Ingots and castings*
- BS EN 10025-2:2004, *Hot rolled products of structural steels – Part 2: Technical delivery conditions for non-alloy structural steels*
- BS EN 10088-1:2005, *Stainless steels – List of stainless steels*
- BS EN 10263-4:2001, *Steel rod, bars and wire for cold heading and cold extrusion – Technical delivery conditions for steels for quenching and tempering*
- BS EN 12163:2011, *Copper and copper alloys – Rod for general purposes*
- BS EN 12165:2011, *Copper and copper alloys – Wrought and unwrought forging stock*
- BS EN 12167:2011, *Copper and copper alloys – Profiles and bars for general purposes*
- BS EN 12420:1999, *Copper and copper alloys – Forgings*
- BS EN 12449:1999, *Copper and copper alloys – Seamless, round tubes for general purposes*
- BS EN 12601, *Reciprocating internal combustion engine driven generating sets – Safety*
- BS EN 50122-1, *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 1: Protective provisions against electric shock*
- BS EN 50122-2, *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 2: Provisions against the effects of stray currents caused by d.c. traction systems*



- BS EN 50164-2, *Lightning protection components (LPC) – Part 2: Requirements for conductors and earth electrodes*
- BS EN 50522:2011, *Earthing of power installations exceeding 1 kV a.c.*
- BS EN 60228:2005, *Conductors of insulated cables*
- BS EN 60309/IEC 60309 (all parts), *Plugs, socket-outlets and couplers for industrial purposes*
- BS EN 60909-0/IEC 60909-0, *Short-circuit currents in three-phase a.c. systems – Part 0: Calculation of currents*
- BS EN 61008-1, *Specification for residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs) – Part 1: General rules*
- BS EN 61557/IEC 61557 (all parts), *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures*
- BS EN 61558-2-4/IEC 61558-2-4, *Safety power transformers, reactors, power supply units and similar products for supply – Part 2-4: Particular requirements and tests for isolating transformers and power supply units incorporating isolating transformers*
- BS EN 62305-1, *Protection against lightning – Part 1: General requirements*
- BS EN 62305-2, *Protection against lightning – Part 2: Risk management*
- BS EN 62305-3, *Protection against lightning – Part 3: Physical damage to structures and life hazard*
- BS EN 62035-4, *Protection against lightning – Part 4: Electrical and electronic systems within structures*
- BS IEC 60050-195, *International electrotechnical vocabulary – Part 195: Earthing and protection against electric shock*
- BS IEC 61000-5-2, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 2: Earthing and cabling*
- BS EN IEC 61936-1:2011, *Power installations exceeding 1 kV a.c. – Part 1: Common rules*
- DD IEC/TS 60479-1:2005, *Effects of current on human beings and livestock – Part 1: General aspects*
- ER G59, *Recommendations for the connection of embedded generating plant to the Regional Electricity Companies' distribution systems*
- ER G83, *Recommendations For The Connection Of Small-Scale Embedded Generators (Up To 16 A Per Phase) In Parallel With Public Low-Voltage Distribution Networks*
- ER G84, *Recommendations for the Connection of Mobile Generating Sets to Public Distribution Networks*
- ER S36-1, *Identification and Recording of "Hot Sites" – Joint Electricity Industry/BT Procedure*
- ISO/IEC Guide 51, *Safety aspects – Guidelines for their inclusion in standards*
- IEC Guide 104, *The preparation of safety publications and the use of basic safety publications and group safety publications*
- PD 970, *Wrought steels for mechanical and allied engineering purposes – Requirements for carbon, carbon manganese and alloy hot worked or cold finished steels*

### 3 Terms and definitions

For the purposes of this British Standard, the terms and definitions given in BS 7671:2008+A1 and BS IEC 60050-195, together with the following apply.

#### 3.1 earth grid

earth electrode in the form of two overlapping groups of buried, parallel, horizontal electrodes, usually laid approximately at right angles to each other, with the electrodes bonded at each intersection

#### 3.2 earth potential

electric potential with respect to the general mass of earth which occurs in, or on the surface of, the ground around an earth electrode when an electric current flows from the electrode to earth

#### 3.3 earth potential rise

voltage between an earthing system and reference earth  
[BS EN 50522:2011]

#### 3.4 earth resistance

resistance to earth of an earth electrode or earth grid

#### 3.5 earthing system

arrangement of connections and devices necessary to earth equipment or a system separately or jointly  
[IEV 604-04-02]

#### 3.6 global earthing system

equivalent earthing system created by the interconnection of local earthing systems that ensures, by the proximity of the earthing systems, that there are no dangerous touch voltages

*NOTE 1 Such systems permit the division of the earth fault current in a way that results in a reduction of the earth potential rise at the local earthing system. Such a system could be said to form a quasi equipotential surface.*

*NOTE 2 The existence of a global earthing system may be determined by sample measurements or calculation for typical systems. Typical examples of global earthing systems are in city centres; urban or industrial areas with distributed low- and high-voltage earthing.*

[BS EN 50522:2011]

#### 3.7 hot site

substation where the rise of earth potential, under the maximum earth fault condition, can exceed the value either 430 V or 650 V depending upon the fault clearance time

#### 3.8 potential gradient (at a point)

rate of change of voltage measured at that point in the direction in which it is a maximum

#### 3.9 transferred potential

potential rise of an earthing system caused by a current to earth transferred by means of a connected conductor (for example a metallic cable sheath, PEN conductor, pipeline, rail) into areas with low or no potential rise relative to reference earth resulting in a potential difference occurring between the conductor and its surroundings

*NOTE 1 The definition also applies where a conductor, which is connected to reference earth, leads into the area of the potential rise.*

*NOTE 2 Transferred potentials can result in electrocution paths through the human body other than the "touch voltage" path, e.g. hand to hand*

[BS EN 50522:2011]

### 3.10 (effective) touch potential

voltage between conductive parts when touched simultaneously

*NOTE The value of the effective touch voltage may be appreciably influenced by the impedance of the person in electric contact with these conductive parts.*

[IEV 195-05-11, modified]

### 3.11 prospective touch potential

voltage between simultaneously accessible conductive parts when those conductive parts are not being touched

[IEV 195-05-09, modified]

### 3.12 step voltage step potential

voltage between two points on the earth's surface that are 1 m distant from each other, which is considered to be the stride length of a person

[IEV 195-05-12]

### 3.13 Class I equipment

equipment with basic insulation as provision for basic protection and protective equipotential bonding as provision for fault protection

### 3.14 protective equipotential bonding

equipotential bonding for purposes of safety (e.g. protection against electric shock)

*NOTE 1 From IEV 195-01-15, modified.*

*NOTE 2 Functional equipotential bonding is defined in IEV 195-01-16.*

### 3.15 equipotential bonding

provision of electric connections between conductive parts, intended to achieve equipotentiality

*NOTE 1 From IEV 195-01-10.*

*NOTE 2 The effectiveness of the equipotential bonding may depend on the frequency of the current in the bonding.*

## 4 Earthing principles

### 4.1 Fundamental rule of protection against electric shock

BS EN 61140 gives fundamental principles and requirements which are common to electrical installations, systems and equipment or necessary for their co-ordination, for installations, systems and equipment without a voltage limit. BS EN 61140 states that the fundamental rule of protection against electric shock is that:

*...hazardous-live-parts shall not be accessible and accessible conductive parts shall not be hazardous live:*

- *either under normal conditions (operation in intended use, see ISO/IEC Guide 51, 3.13 and absence of a fault); or*

- under single-fault conditions (see also IEC Guide 104, 2.8).

The system and equipment standards are being amended to comply with BS EN 61140 so that the fundamental rule is met and to adopt the same terminology.

In order to achieve the principles within BS EN 61140 within electrical installations standards, BS 7671:2008+A1 makes certain requirements for the earthing of an installation and its sub-structure in order to achieve safety. With the exception of earth free locations, the main requirement under single fault conditions is for automatic disconnection of supply with selecting cable impedances in order to achieve certain touch voltages.

## 4.2 Supply system earthing

### 4.2.1 Legislation

In Great Britain the earthing of an electricity supply system is covered by the requirements of the Electricity Safety Quality and Continuity Regulations 2002 as amended (ESQCR) [1]. Part II, *Protection and Earthing* is particularly relevant to users of this standard. Guidance is given in DTI publication *Guidance on the Electricity Safety, Quality and Continuity Regulations* [4].

In Northern Ireland, regulations made by the Ministry of Commerce for Northern Ireland apply. The general provisions in the ESQCR [1] apply to both overhead and underground systems of supply.

The regulations require that every network at whatever voltage be connected with Earth and that the connection is maintained under fault conditions [Regulation 8(1)]. This requirement is designed primarily to preserve the security of the system by ensuring that the potential on each conductor is restricted to such a value as is consistent with the level of insulation applied. Every supply neutral conductor (of LV networks) is required to be connected with earth generally at the source of voltage [Regulation 8 (3(b))].

The regulations include a particular requirement where the neutral and protective conductors are combined that is in protective multiply earthed (PME) systems (see Regulation 9). This is the most common system adopted, see Figure 7.

### 4.2.2 High voltage (HV) power supply systems

*NOTE* Requirements for earthing HV installations are given in BS EN IEC 61936-1:2011 and BS EN 50522:2011. See also Clause 5.

### 4.2.3 Classification of low voltage systems

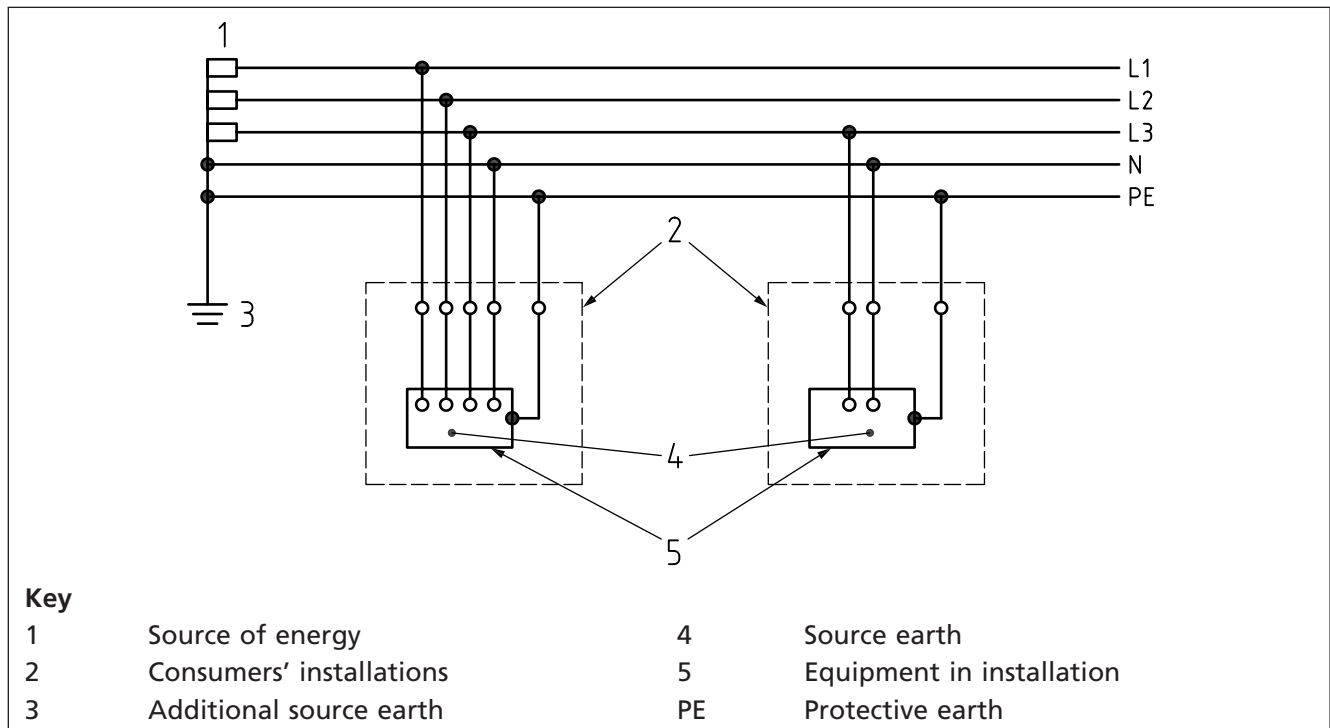
#### 4.2.3.1 General

For the purpose of this standard the following earthing systems are defined: TN-S, TN-C, TN-C-S, TT and IT.

#### 4.2.3.2 TN-S system

In a TN-S (Figure 1) the Neutral and Protective conductors should be kept separate throughout the system and the source is solidly earthed.

Figure 1 TN-S system

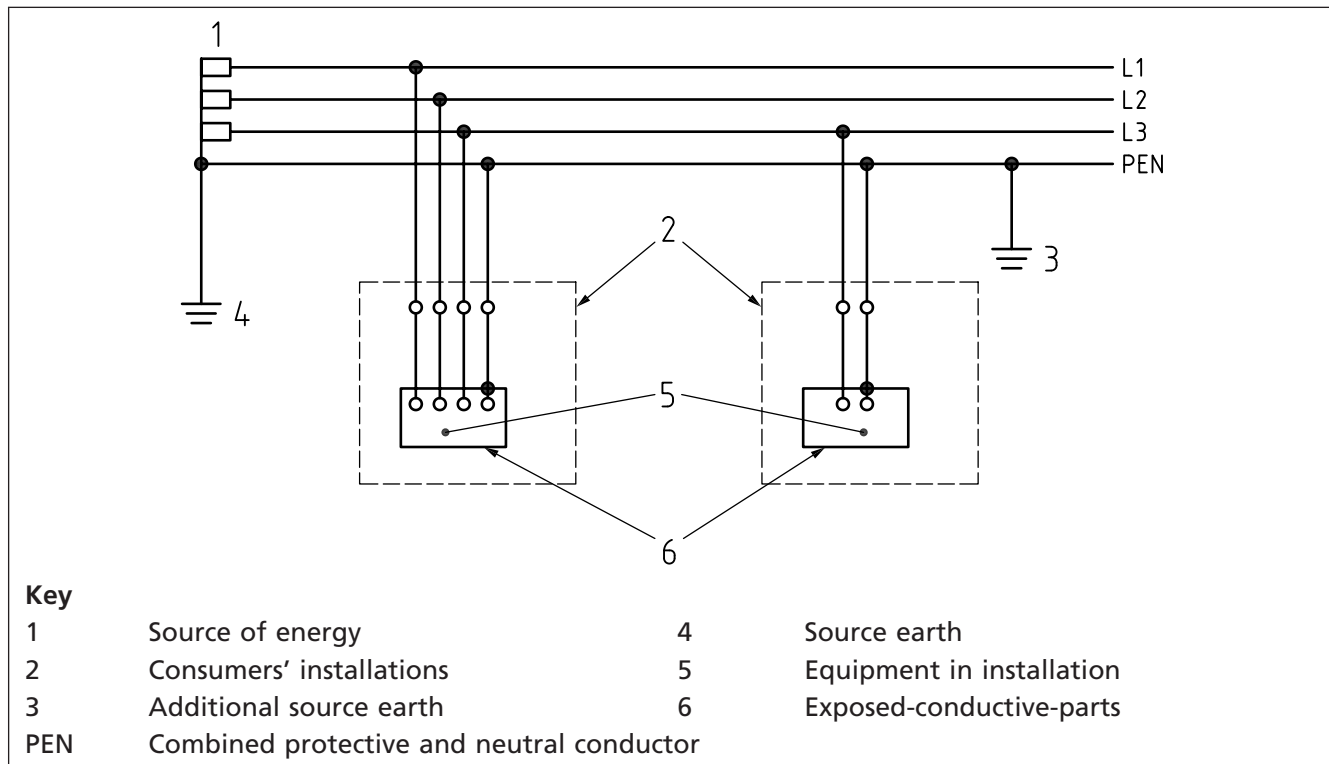
**COMMENTARY ON 4.2.3.2**

*A TN-S system has a particular disadvantage that in the event that the protective conductor becomes open circuit, there is no indication that a fault has occurred and installations can unknowingly be left without an earth. In the event of an earth fault all of the exposed-conductive-parts within a consumer installation may be raised to a hazardous potential. Earth fault protection devices will not operate as there will be no flow of current to earth.*

**4.2.3.3 TN-C system**

In a TN-C system (Figure 2) the neutral and protective functions should be combined in a single conductor (PEN) throughout the entire system. Multiple connections to earth are recommended along the PEN conductor and the source is solidly earthed.

Figure 2 TN-C system

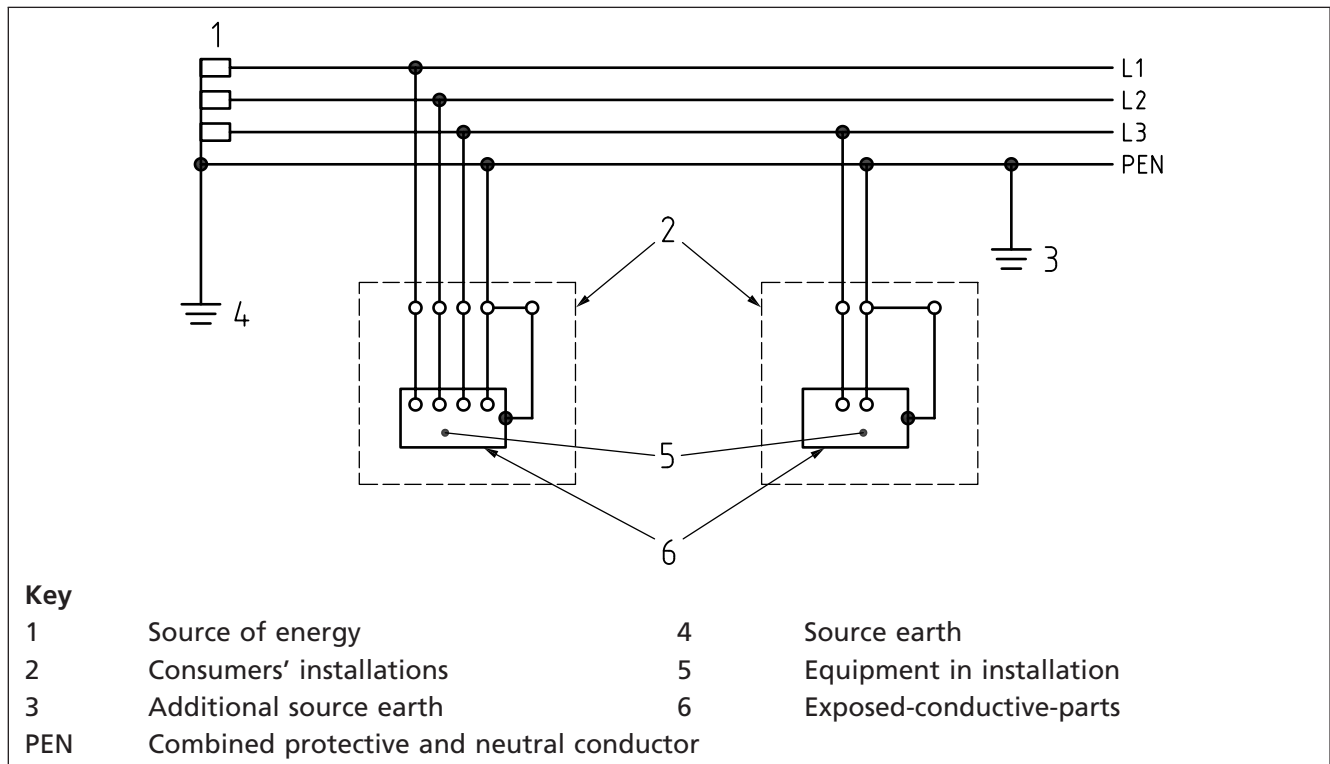
**COMMENTARY ON 4.2.3.3**

*The need for multiple earth connections is because if the neutral becomes open-circuit for any reason, the exposed-conductive-parts will rise to line to earth voltage in the case of single-phase connections and a value up to line to earth voltage in the case of three-phase connections, depending on the degree to which the load is unbalanced.*

**4.2.3.4 TN-C-S system**

In a TN-C-S system, (Figure 3) the neutral and protective functions should be combined in a single conductor (PEN) from the source (solidly earthed) up to the consumers intake. Multiple connections to earth are recommended along the PEN conductor. Within the consumer's installation the neutral and protective conductors should be kept separate.

Figure 3 TN-C-S system

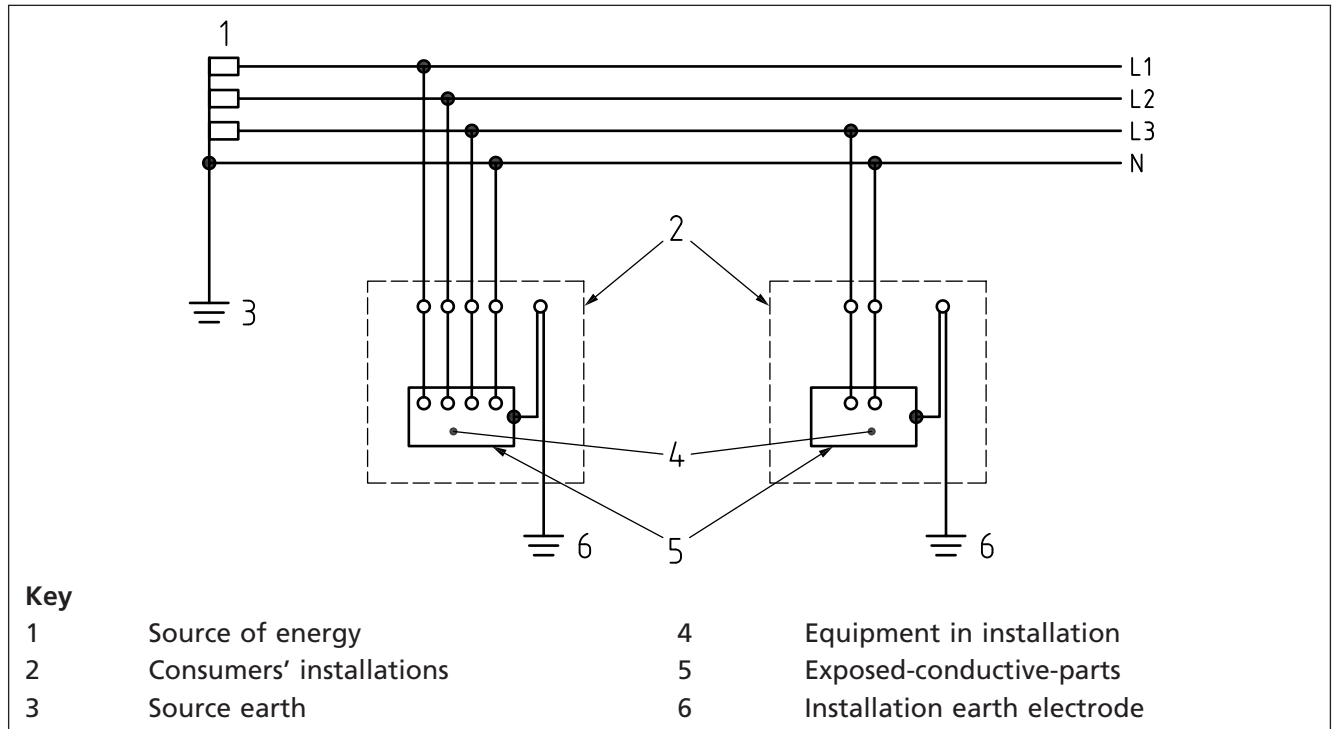
**COMMENTARY ON 4.2.3.4**

The TN-C-S system is also known as a "protective multiple earthed" (PME) system. The PEN conductor, which is referred to as a combined neutral and earth (CNE) conductor, is earthed at the source and extremities of the distribution mains and points in-between; hence the reference to multiple earthing. Multiple earthing of the CNE conductor ensures that if the conductor becomes open-circuit for any reason, exposed-conductive-parts remain connected to earth; under such conditions the supply voltage between the installation line and neutral conductors is substantially reduced and consumers will experience unacceptable voltage variations.

**4.2.3.5 TT installation**

A TT system (Figure 4) has a solidly earthed source; the exposed-conductive-parts of the consumer's installation are earthed through an installation earth electrode which is electrically independent of the source earth.

Figure 4 TT system

**COMMENTARY ON 4.2.3.6**

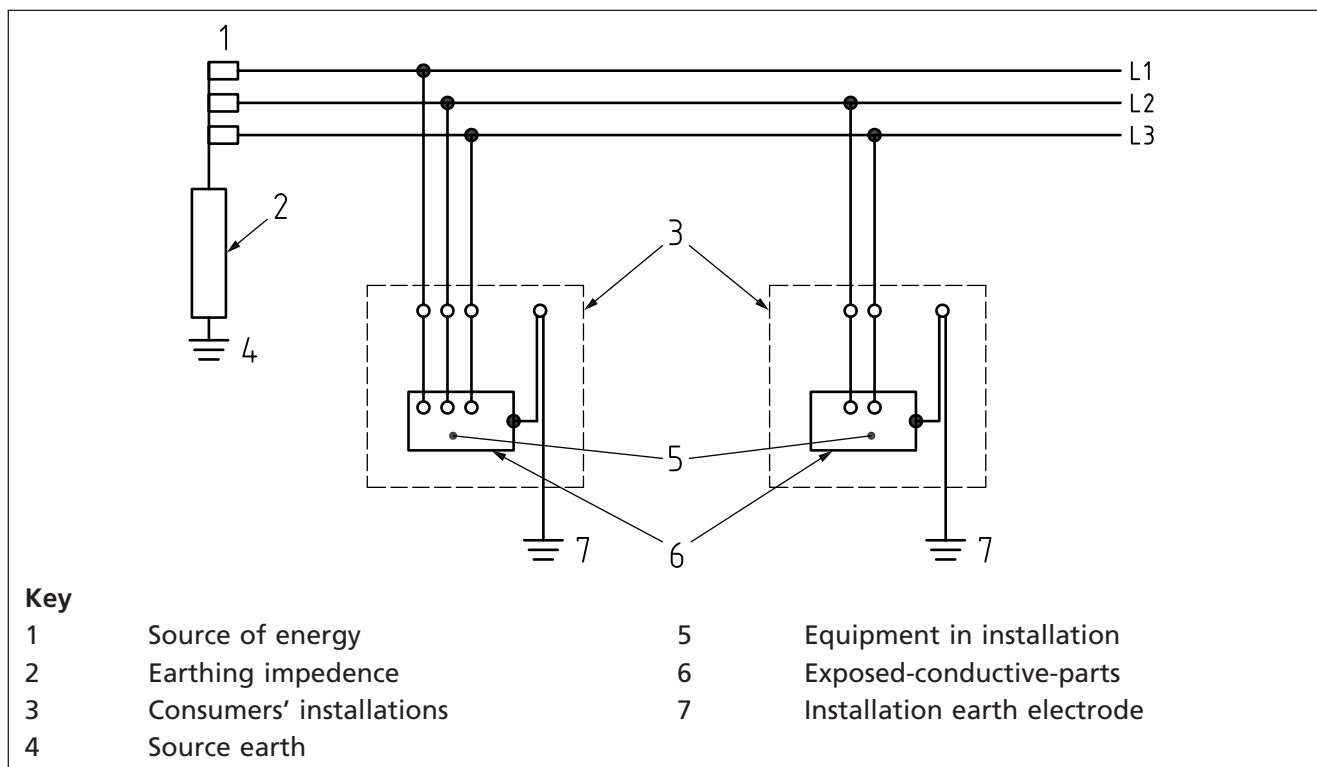
*In the TT system the earth fault loop impedance is generally high as the fault path includes the earth electrode resistance of the supply and the earth electrode resistance of the consumer's installation.*

**4.2.3.6 IT system**

An IT system (Figure 5) has the source either connected to earth through an earthing impedance or is isolated (Insulated) from the earth. All of the exposed-conductive parts of an installation are connected to an earth electrode in a similar manner to a TT arrangement.



Figure 5 IT system

**COMMENTARY ON 4.2.3.7**

Generally an IT system would be chosen in locations such as medical centres and mines where the supply has to be maintained even in the event of a fault, and where the connection with earth is difficult (for example a mobile generator).

**4.3 Installation earthing – Low-voltage (LV) installation earthing**

The purpose of earthing the non-current carrying metalwork of plant and equipment of a low-voltage installation is to:

- a) provide for a low earth fault loop impedance to facilitate automatic disconnection of supply in the event of a fault to exposed-conductive-parts; and
- b) limit the rise of potential under earth-fault conditions of non-current carrying metalwork with respect to earth to increase the safety of persons and animals in proximity to such metalwork.

Extending the earthing arrangement of an installation within a building by use of protective equipotential bonding of exposed-conductive-parts and extraneous-conductive-parts increases the safety of persons and animals by reducing touch voltages between such parts and it can also eliminate dangerous sparking.

The performance requirements for earthing of LV installations (e.g. disconnection times, conductor sizes) are specified in BS 7671:2008+A1.

Note that BS 7671:2008+A1, Regulation 411.3.2.6 has a relaxation:

**411.3.2.6** Where automatic disconnection according to Regulation 411.3.2.1 cannot be achieved in the time required by Regulation 411.3.2.2, 411.3.2.3 or 411.3.2.4, as appropriate, supplementary equipotential bonding shall be provided in accordance with Regulation 415.2. Also, Regulation 411.4.9 permits RCD protection to be used to satisfy the requirements of these regulations and maximum values of earth fault loop impedance are now provided in Table 41.5 within this standard.

#### 4.4 Current-using equipment

The purpose of earthing current-using equipment is similar to that for earthing electrical installations. However, for certain standards, e.g. those in the BS EN 60335 series, automatic disconnection of supply is not required in the event of a fault to accessible conductive parts (see BS EN 60335-1:2002+A14, Clause 27).

##### 27 Provision for earthing

**27.1** Accessible metal parts of class 0I appliances and class I appliances that may become live in the event of an insulation fault, shall be permanently and reliably connected to an earthing terminal within the appliance or to the earthing contact of the appliance inlet. Earthing terminals and earthing contacts shall not be connected to the neutral terminal.

The fuse in the BS 1363 plug fitted to appliances in the UK is not required by the relevant part of BS EN 60335; its rating is selected to provide protection to the flexible cable supplying the appliance.

In the remainder of Europe, plug fuses are not required.

## 5 HV/LV interface

Specific requirements that should be followed for high voltage installations including substations are found in BS EN IEC 61936-1:2011 and BS EN 50522:2011. Requirements that should be followed for the protection of LV installations against temporary overvoltages due to earth faults in an HV supply system are given in BS 7671:2008+A1, Section 442.

*NOTE Further guidance on the interface between LV and HV subsystems, including examples of earthing layouts, is given in Annex A.*

## 6 Low voltage installations

*NOTE The earthing requirements for low-voltage installations are specified in BS 7671:2008+A1. In BS 7671:2008+A1, Chapter 44, requirements for protection of low voltage installations against temporary overvoltages due to earth faults in the high voltage system and due to faults in the low voltage system are detailed. This is considered in Clause 5.*

### 6.1 Automatic disconnection

#### COMMENTARY ON 6.1

*When an earth fault occurs within an installation, dangerous voltages can appear between conductive parts, and if these parts are simultaneously accessible they might constitute a shock hazard. The severity of any shock experienced by a person at risk depends on, among other factors, the type of current (i.e. a.c. or d.c.), the magnitude of the voltages and the amount of time which the earth fault is allowed to persist.*

*The earth fault current can also be of such magnitude and duration as to cause an excessive temperature rise in the conductors through which it flows, thereby creating a fire hazard.*

*BS 7671:2008+A1 includes a number of protective measures which can be applied for protection against earth faults. However, this standard only considers the protective measure known as automatic disconnection of supply. This is the most commonly utilised of the protective measures contained in BS 7671:2008+A1. Furthermore, the others do not depend on earthing and have very limited applications.*

*<<NP>>ADS is a protective measure in which:*

- a) *basic protection is provided by basic insulation of live parts or by barriers or enclosures; and*
- b) *fault protection is provided by protective earthing, protective equipotential bonding and automatic disconnection in case of a fault.*

*A brief summary of the requirements of BS 7671:2008+A1 for automatic disconnection of supply is given in 6.2 to 6.11.*

Where automatic disconnection of supply is applied, Class I and Class II equipment may be used.

In designing the protective system of any installation, due account should be taken of the need to ensure that periodic inspection, testing and maintenance can be readily and safely undertaken.

## 6.2 Earthing of installations

Most installations are part of either a TN system or a TT system, and in both types of installation the exposed-conductive-parts of all the electrical equipment of an installation should be connected by means of circuit protective conductors to the main earthing terminal. The earth fault loop impedance should be sufficiently low for the protective device (fuse, circuit breaker, RCD) to operate in the required time in the event of a fault to earth.

Class II equipment, whether metal encased or insulation encased, embodies in its construction not only basic insulation but also supplementary or reinforced insulation; exposed metalwork of such equipment should not be considered to become live under fault conditions, i.e. is not considered to be an exposed-conductive-part.

The various earthing systems are considered in 4.2.

## 6.3 Information to be provided on request

As necessary, the owner of an installation, the employer or a contractor should determine from the electricity distributor the relevant information as described in the ESQCR [1]. The owner or his agent should satisfy themselves that the characteristics of the earth fault current path, including any part of that path provided by a supply undertaking, are suitable for operation of the type of earth fault protection intended for use in the installation concerned.

### COMMENTARY ON 6.3

*When it is intended to install standby supplies to operate in parallel with the normal supply provided by a supply undertaking, the arrangements have to be agreed with the distributor {see regulation 22(1)(d) of the ESQCR [1]}.*

*Regulation 28 of the ESQCR [1] requires the distributor to provide certain information as follows:*

- 28.** A distributor shall provide, in respect of any existing or proposed consumer's installation which is connected or is to be connected to his network, to any person who can show a reasonable cause for requiring the information, a written statement of –
- (a) *the maximum prospective short circuit current at the supply terminals;*
  - (b) *for low voltage connections, the maximum earth loop impedance of the earth fault path outside the installation;*
  - (c) *the type and rating of the distributor's protective device or devices nearest to the supply terminals;*
  - (d) *the type of earthing system applicable to the connection; and*
  - (e) *the information specified in regulation 27(1),*
- which apply, or will apply, to that installation.*

The main bonding to other services, considered in 6.4, might require permission of the undertakings responsible for those services, and such bonding to telephone and telegraphic circuits should not be undertaken unless authorized by those undertakings; guidance is contained in relevant Telecoms industry standards such as BS 7671:2008+A1 and BS EN 50173 (all parts).

#### 6.4 Protective equipotential bonding

*NOTE 1 The protective measure automatic disconnection of supply, requires:*

- a) *automatic disconnection in the event of a fault to earth;*
- b) *protective earthing (to facilitate this); and*
- c) *protective equipotential bonding to reduce touch voltages.*

Where the automatic disconnection of supply is adopted, protective equipotential bonding is recommended (see Figure 6), whatever the type of supply system. Bonding, by means of main equipotential bonding conductors, of extraneous-conductive-parts to the main earthing terminal of the installation is recommended; these extraneous-conductive-parts include:

- a) water installation pipes;
- b) gas installation pipes;
- c) other installation pipework and ducting;
- d) central heating and air conditioning systems;
- e) exposed metallic structural parts of the building structure; and
- f) other metallic parts such as cable trays and cable ladder racks.

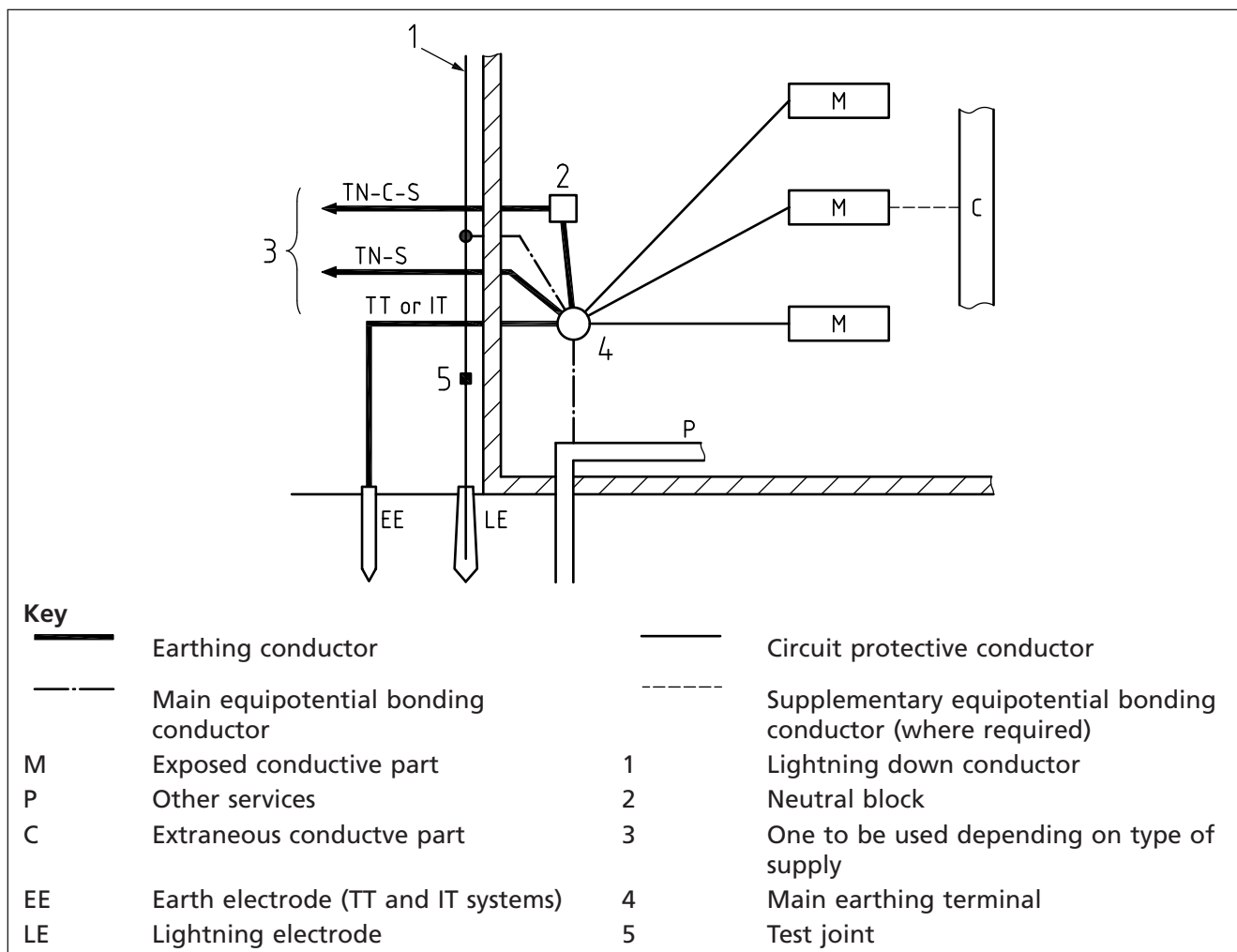
Connection of a lightning protection system to the protective equipotential bonding should be made in accordance with BS EN 62305-4.

*NOTE 2 BS EN 62305-4 requires that a bond is made between the lightning protecting system and the installation equipotential bonding system. The responsibility for specifying and installing this bond is that of the organization responsible for the lightning protection system.*

Where both main gas pipes and main water pipes enter a location, a common bonding conductor may be used, but in such cases that conductor should be continuous or should be permanently jointed (by soldering or crimping) in order to preserve continuity. Such a bonding conductor may also be used in association with other extraneous-conductive-parts.

The main equipotential bonding connections to the water and gas pipes should be made as near as practicable to their point of entry into the premises. If there is an insulating section or insert at that point, the bonding connection should be made to the metallic pipes on the consumer's side of the section or insert and before branch pipework. Where practicable, the connection should be made within 600 mm of the meter outlet union or at any point of entry to the building if the meter is external (see BS 7671:2008+A1, Regulation 544.1.2).

Figure 6 Earthing arrangement and protective conductors for consumers' installations



## 6.5 Main earthing terminal

A consumer's LV installation supplied from TN distribution networks should have a main earthing terminal (MET) that is connected to the protective conductor of the source and via this to earth electrodes installed in the electricity distribution supply system.

Where the installation provides electricity supplies to a number of consumers, an independent earth electrode should also be connected to the MET if the main supply has a combined neutral and protective conductor.

In the case of TT and IT systems the MET should be earthed by an independent earth electrode only.

### COMMENTARY ON 6.5

*The function of the MET is to provide a reference point for the installation. It consists of a terminal or bar provided for the connection of protective conductors, including protective bonding conductors, and conductors for functional earthing.*

*Although the MET is connected to Earth it is seldom at zero potential because of the potential difference caused by leakage and other currents flowing to Earth.*

*See also BS 7671:2008+A1, 411.4.2.*

## 6.6 Protective conductors

The generic term "protective conductor" embraces the specific types shown in Figure 6; in any particular case, the function intended should be correctly identified, because this determines which of the numerous requirements prescribed in BS 7671:2008+A1 are applicable.

### COMMENTARY ON 6.6

*BS 7671:2008+A1 requires that all protective conductors are suitably protected against mechanical and chemical deterioration and electrodynamic effects.*

*Two methods are given for determining the cross-sectional area required for a protective conductor. In the first the cross-sectional area is related empirically to that of the associated line conductor (see BS 7671:2008+A1, Table 54.7) and in the second method it is calculated using the "adiabatic equation" of BS 7671:2008+A1, Regulation 543.1.3:*

**543.1.3** *The cross-sectional area, where calculated, shall be not less than the value determined by the following formula or shall be obtained by reference to BS 7454.*

$$S \geq I\sqrt{t}/k$$

**NOTE** *This equation is an adiabatic equation and is applicable for disconnection times not exceeding 5 s.*

*where:*

*S is the nominal cross-sectional area of the conductor in mm<sup>2</sup>*

*I is the value in amperes (rms for a.c.) of fault current for a fault of negligible impedance, which can flow through the associated protective device, due account being taken of the current limiting effect of the circuit impedances and the limiting capability ( $I^2t$ ) of that protective device*

*t is the operating time of the disconnecting device in seconds corresponding to the fault current I amperes*

*k is a factor taking account of the resistivity, temperature coefficient and heat capacity of the conductor material, and the appropriate initial and final temperatures.*

*Values of k for protective conductors in various use or service are as given in Tables 54.2 to 54.6. The values are based on the initial and final temperatures indicated in each table.*

*Where the application of the formula produces a non-standard size, a conductor having the nearest larger standard cross-sectional area shall be used.*

*The advantage of the adiabatic calculation is that it will frequently permit the use of smaller conductor cross-sectional areas but it is not applicable to protective bonding conductors.*

*For disconnection times exceeding 5 s refer, to BS 7454.*

## 6.7 Earthing conductors

Earthing conductors are protective conductors and should be sized in the same way as other protective conductors (see 6.6), but with specified minimum cross-sectional areas when buried in the ground specified in BS 7671:2008+A1, Table 54.1.

**NOTE 1** *Uncoated buried copper is electro-positive to uncoated buried steel and when interconnected by a current-carrying conductor, these metals form an electrochemical cell that can cause accelerated corrosion of steel (see BS 7361-1). As a rough guide, a direct current of 1 A leaving a buried steel structure can remove nearly 9 kg of metal in 1 year.*

Aluminium or copper-clad aluminium conductors should not be used for final connections to earth electrodes. Where a copper conductor is to be joined to aluminium the procedure described in 9.9.4.3 should be followed.

The connection of the earthing conductor to the earth electrode or other means of earthing should be soundly made by the use of compound filled, encapsulated or substantial clamps of non-ferrous material. Where the earthing conductor is to be connected to the metal sheath and armour of a cable, the sheath and armour should be bonded together and the principal connection between the cable and the earthing conductor should be to the metal sheath and should be plumbed.

Alternatively, if a clamp is used for this connection it should be so designed and installed as to provide reliable connection without damage to the cable. Earthing and bonding clamps should conform to BS 951.

*NOTE 2 Whilst the connection referred to might be in a link box underground and therefore not readily accessible, BS 7671:2008+A1 stipulates that provision is made in an accessible position for disconnecting the main earthing terminal of an installation from the means of earthing to facilitate measurement of the resistance of the earthing arrangements.*

## 6.8 Circuit protective conductors

When the metallic sheath of a cable is used as a circuit protective conductor, every joint in that sheath should be so made that its current-carrying capacity is not less than that of the sheath and, where non-metallic joint boxes are used, means such as a metal strip having the same effective current-carrying capacity as the largest cable entering the box should be provided to maintain continuity.

When using the metallic sheath or armour, attention should also be paid to the ability of the cable glands and connections to carry prospective earth fault currents and it might be necessary to seek advice from the manufacturers on this aspect. Special precautions may be considered necessary with metal parts of the assembly, particularly gland plates where abrasion resistant finishes, e.g. powder coatings, are used.

Metallic enclosures for cables, such as conduit, ducting and trunking, may be used as circuit protective conductors but where flexible or pliable conduit is used separate protective conductors should be included inside the conduit to maintain the integrity of the earth path. Where conduit and trunking are used, a high standard of workmanship in installation is essential. Joints should be so made such that their current-carrying capacity is not less than that of the conduit itself. Joints should also have the same properties, as regards insulation, mechanical strength and protection, as those of the wiring system or conduit of which they are part. Slackness in joints can result in deterioration in, and even complete loss of, continuity; plain slip or pin-grip sockets should not be used. In the case of unscrewed conduit, the use of lug-grip fitting is recommended, but for outdoor installations and where otherwise subjected to atmospheric corrosion, screwed conduit should always be used, suitably protected against corrosion. In screwed-conduit installations the use of locknuts is recommended. Joints in all conduit systems should be painted overall after assembly.

These precautions ought to be adequate, but periodical tests should be made to verify that electrical continuity is satisfactorily maintained.

*NOTE Electrolytic corrosion is liable to occur under damp conditions at contacts between dissimilar metals. Copper and alloys having a high copper content are particularly liable to cause corrosion under these conditions when in contact with aluminium alloys.*

When dissimilar metals form part of an electrical circuit, the joints should be clean and assembled free of moisture, and then immediately treated with a suitable medium against the ingress of moisture.



Where damp conditions prevail, the fittings, fixing screws and saddles used to secure aluminium-based alloy conductors should be made of aluminium alloy or suitably protected steel (zinc coated) and the surfaces which are in contact with a conductor should be painted before assembly.

## 6.9 Installations and locations of increased shock risk

For installations and locations of increased shock risk, additional measures may be considered necessary; these include:

- a) supplementary equipotential bonding;
- b) RCDs with a rated residual current of 30 mA or less; and
- c) protective extra-low voltage (PELV) and separated extra-low voltage (SELV) equipment.

When an installation supplies a number of buildings, main equipotential bonding is essential in each building, so that each has a reference point to which are connected the conductive parts referred to in 6.4. In order to reduce the voltages occurring in the event of an earth fault still further, it is sometimes necessary to install supplementary local equipotential bonding.

## 6.10 Supplementary bonding – Circuits where disconnection times cannot be met

### COMMENTARY ON 6.10

Where the disconnection times of BS 7671:2008+A1, Chapter 41, cannot be met (typically 0.4 s and 5 s for 230 V TN systems) Regulation 411.3.2.6 requires supplementary bonding in accordance with Regulation 415.2.2:

**415.2.2** Where doubt exists regarding the effectiveness of supplementary equipotential bonding, it shall be confirmed that the resistance  $R$  between simultaneously accessible exposed-conductive-parts and extraneous-conductive-parts fulfils the following condition:

$$R \leq 50 V/I_a \text{ in a.c. systems}$$

$$R \leq 120 V/I_a \text{ in d.c. systems}$$

where  $I_a$  is the operating current in amperes of the protective device –

for RCDs,  $I_{\Delta n}$ .

for overcurrent devices, the current causing automatic operation in 5 s.

These formulae allow relatively long lengths and are unlikely to require other than standard conductor cross-sectional areas.

## 6.11 Industrial and commercial installations

### 6.11.1 General

Many industrial installations take their electrical power from a public distribution network operator at a voltage which might be above 1 000 V a.c.; fault capacities might also be greater than those encountered in domestic premises and great care should be exercised in the design of all protective conductors and their terminations.

Equally important is the consideration that should be given to the effect that earthing might have on the processes employed in some factories.

Where problems related to flammable liquids and gases are concerned, or if there is a need for detailed knowledge of protective earthing that is not directly related to electrical safety, reference should be made to the relevant British Standards.



*NOTE Further information is obtainable from the Health and Safety Executive concerning statutes, codes and standards that apply to particular processes.*

Where instrumentation and data circuits are involved, particular care should be exercised when interconnecting earthing systems. The designer should also consider transients or circulating currents in the earthing system that might introduce unwanted voltages within electronic circuits by magnetic induction.

There might be occasions, which should be considered, when direct earthing of exposed metalwork could interfere with other systems that employ the general mass of earth as a current transmission path; typical examples are telephony and cathodic protection.

### 6.11.2 Earth fault loop impedance

As in the case of high voltage supplies, the use of low resistance paths for the return of earth fault current in low voltage industrial systems is necessary, and the total loop impedance should be sufficiently low as to allow the operation of a suitably chosen protective device, fuse, circuit-breaker or RCD within the time given in BS 7671:2008+A1.

### 6.11.3 Single-core cables

Where single-core cables are used in a low voltage installation it is generally preferable to bond and earth all metallic sheaths or armour at both ends of each run (solid bonding). Induced voltages in the sheaths or armour should be reduced to low values and the sheaths or armour may then be used as a protective conductor, in parallel if necessary with an additional conductor. Currents circulating in the armour or sheath reduce the current-carrying capacity of the cables; where this reduction is not acceptable, sheaths and armour may be bonded at one end of a run only (single-point bonding) and a separate protective conductor is then necessary.

*NOTE Consideration of the values of standing voltage which will appear at the open circuit ends of the sheaths or armour is covered in 9.12.2.*

## 7 Generators

### COMMENTARY ON CLAUSE 7

*Three main types of generating set are considered in this clause:*

- a) *small sets having ratings below 10 kW that are not earthed and not operated in parallel with the electricity supply;*
- b) *sets having ratings usually in excess of 10 kW that are normally 3-phase and require earthing; and*
- c) *small-scale embedded generators (up to 16 A/phase) for operation in parallel with public low-voltage distribution networks.*

### 7.1 Unearthed generating sets (ratings below 10 kW)

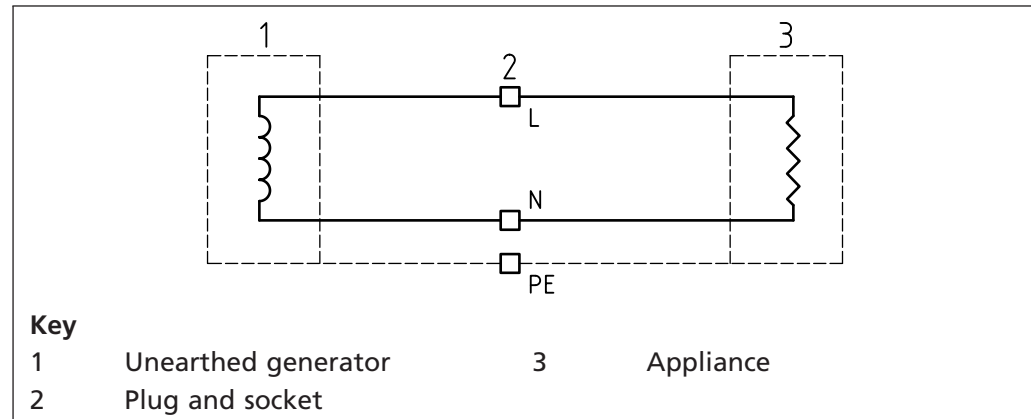
#### 7.1.1 General

*NOTE 1 Low-voltage, single-phase generating sets are generally mobile or transportable machines ranging in size from 0.2 kW to 10 kW.*

*NOTE 2 Winding connections are normally brought out to a socket-outlet in which the third or protective conductor is connected to the generator enclosure.*

Small single-phase generators are run as floating systems, i.e. without the winding connected to the frame or to earth, see Figure 7; the generator frame and enclosure should be bonded to all exposed-conductive-parts of the load equipment, using a correctly terminated protective conductor in the connecting cable.

Figure 7 Small low voltage single phase generator run as a floating system



Cables, plugs, socket-outlets and cable couplers should be suitable for their environmental exposure. Cables should be a flexible type which includes a metallic braid or screen suitable for use as a protective conductor.

*NOTE 3 The termination of braided cable in domestic type plugs can be difficult. For this reason it might be preferable to select plugs and sockets conforming to BS EN 60309 (all parts).*

If a cable without a metallic screen is used, it should be flexible with an extruded oversheath, capable of high abrasion resistance and should contain a separate protective conductor.

Cables, plugs and socket-outlets should be inspected frequently and if defective should be replaced, not repaired; equipment and cables that are in good condition are vital for the continued safety of an unearthed system and form the first line of protection against the risk of shock.

All cables should be as short as practicable and supply compactly located loads, since experience has shown that a compact installation is less likely to suffer insulation damage, causing earth faults, than an extensive one.

It should be noted that RCDs will not operate on a first fault and only on particular second faults.

### 7.1.2 Protective measure electrical separation

As required by BS 7671:2008+A1, Section 413, such an unearthed construction in conformity with 7.1.1 should be limited to one item of equipment unless under the supervision of a skilled or instructed person (see BS 7671:2008+A1, Regulation group 418.3).

### 7.1.3 Unearthed generators (rating below 10 kW) supplying a fixed installation

Where an unearthed generator is to supply a fixed installation (see Figure 8) it is recommended that automatic disconnection of supply is adopted as follows.

- One pole of a single phase generator should be connected to the installation main earthing terminal.
- The main earthing terminal should be connected to an earth electrode (see Figure 8).

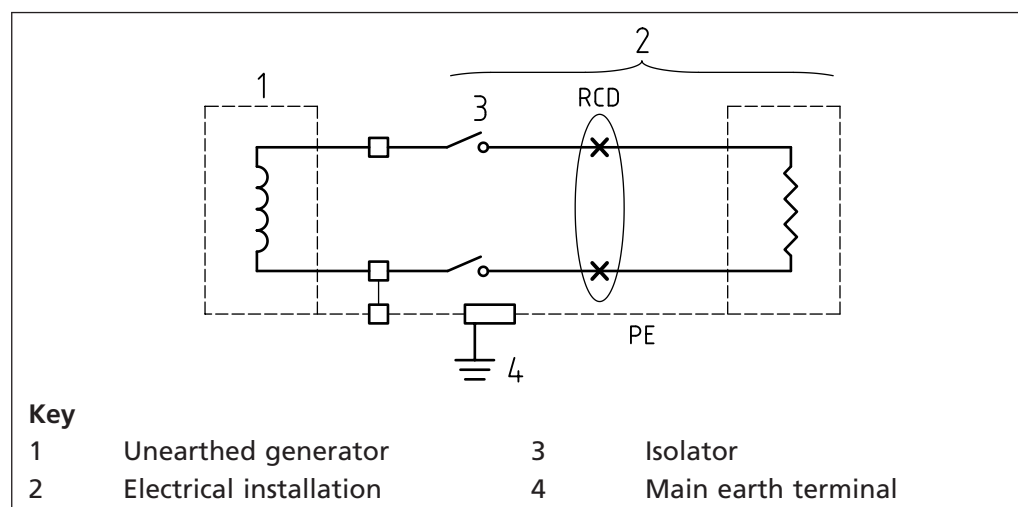
- c) The installation should conform to BS 7671:2008+A1, with all exposed-conductive-parts and all extraneous-conductive-parts connected to the main earthing terminal.
- d) The installation should be protected by RCDs.

The installation should conform to the requirements of BS 7671:2008+A1, including those for ADS.

The earth electrode should have a resistance to earth not exceeding 200  $\Omega$ , (see BS 7671:2008+A1, Table 41.5, Note 2).

The RCD will not provide protection for faults on the generator side of the RCD, and consequently precautions should be taken.

Figure 8 Small low voltage generator supplying a fixed installation



#### 7.1.4 Unearthed generators supplying a mobile or transportable unit

BS 7671:2008+A1, Section 717, and in particular Figure 717.2 should be consulted for constructions for supplying mobile and transportable units.

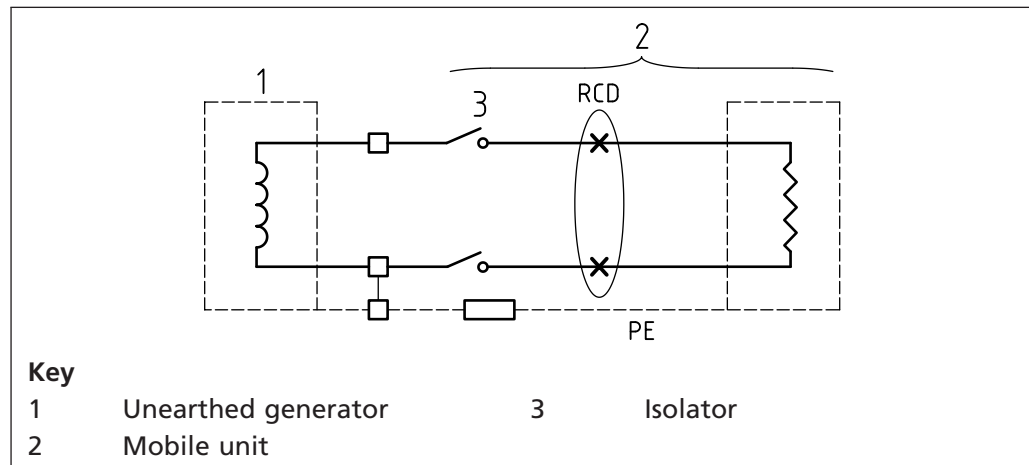
Where an unearthed generator is to supply a mobile installation it is recommended that the protective measure automatic disconnection of supply be adopted as follows (see Figure 9).

- a) One pole of a single phase generator should be connected to the installation main earthing terminal.
- b) The installation should conform to BS 7671:2008+A1, with all exposed-conductive-parts and all extraneous-conductive-parts connected to the main earthing terminal.
- c) The installation should be protected by RCDs.
- d) If the unit supplies equipment or socket outlets outside the unit these circuits should be protected by RCDs with a rated residual operating current not exceeding 30 mA and an operating time not exceeding 40 ms at a residual current of  $5I_{\Delta n}$ , see BS 7671:2008+A1, Section 717 and Regulation 551.4.4.

The installation should conform to the requirements of BS 7671:2008+A1, including those for automatic disconnection of supply.

If practicable, an earth electrode should be connected to the main earthing terminal of the unit with a resistance to earth sufficiently low to operate the RCDs. The RCD will not provide protection for faults on the generator side of the RCD, and consequently precautions should be taken.

Figure 9 Small unearthed generator supplying a mobile or transportable unit



## 7.2 Earthed generating sets

### 7.2.1 General

Generating sets may be earthed to limit the potential of line conductors with respect to the general mass of Earth particularly under fault or unbalanced conditions, and earthing is generally necessary as part of the protection against electric shock (see Figure 10 to Figure 12).

Generating sets should be protectively earthed by connecting the frame and the neutral point of the generating set, associated exposed-conductive-parts and extraneous-conductive-parts to a main earthing terminal. The earthing terminal or bar should be connected to an independent earth electrode. The earth loop impedance at any point of the installation should be low enough to ensure operation of the fault protection, and this should be taken into account if the earth electrode forms part of the earth fault loop, such as for a TT system (but not TN).

For independent earth electrodes associated with the local earthing of the star point of generating plant, the earth resistance should not exceed 20  $\Omega$ .

*NOTE 1* If the generating set is permanently installed, other earthing facilities associated with the installation might be necessary.

*NOTE 2* The earthing of the electrical system might require that the neutral point of the a.c. generator is connected to earth, either directly or via an impedance.

Where an installation is supplied by more than one source of energy (e.g. a supply from a distributor and a supply from a generating set), the earthing system of the installation should be designed so that each source that can operate independently of other sources and remain earthed if all the other sources are not connected.

*NOTE 3* There are many variations in system design and, for any particular application, the precise method of earthing of each energy source is subject to the recommendations of the equipment supplier and to the system parameters.

*NOTE 4* Public low voltage distribution networks have to be directly earthed in conformity to the current ESQCR (Regulations 7 to 10) [1]. Since an installation connected to a distributor's network might be expected to be designed accordingly, direct earthing is also normally adopted for any generating set which supplies such an installation.

Whenever it is intended that a private generating set be used to supply any part of a consumer's system normally supplied by a distributor, the distributor and supplier should be consulted.

*NOTE 5 The ESQCR (Regulation 22(1)(d)) [1] requires that, where operation in parallel with a distributors network is intended, the agreement of the distributor has to be obtained first, subject to (Regulation 22(2)) for generators rated up to a total of 16 A per phase.*

### 7.2.2 References

The following ENA Engineering Recommendations should be consulted where relevant:

- ER G59, *Recommendations for the connection of embedded generating plant to the Regional Electricity Companies' distribution systems;*
- ER G83, *Recommendations For The Connection Of Small-Scale Embedded Generators (Up To 16 A Per Phase) In Parallel With Public Low-Voltage Distribution Networks;*
- ER G84, *Recommendations for the Connection of Mobile Generating Sets to Public Distribution Networks.*

*NOTE ER G84 gives recommend working procedures for the connection of small portable generating sets and larger mobile generating sets for the purposes of providing a temporary supply to customers or for network support. It addresses direct connections to the low voltage network and connections via a step-up unit to the high voltage network.*

### 7.2.3 Generating sets having ratings above 10 kW

Generating sets with outputs above 10 kW are normally 3-phase; these types of set may be permanently installed in buildings, enclosed in weatherproof and sound attenuated enclosure, and vehicle or trolley mounted. It should not be assumed that they will be provided with the generator windings connected to a mounting frame.

An independent generator may be installed to supply construction sites (BS 7671:2008, Section **704**) or temporary electrical installations (BS 7671:2008, Section **740**) as an alternative to a distributor's supply which is as yet unavailable. Such installations though temporary should be robust and conform to the requirements of BS 7671:2008, with a main earthing terminal provided connected to earth, usually by an earth electrode.

### 7.2.4 Generators operating independently of the supply

In this mode of operation the generating plant should be the only source of supply to an installation. If there is only one machine, both protective and supply system earthing should be achieved by connecting the generator neutral, the generator frame and exposed-conductive-parts and extraneous-conductive-parts to a main earthing terminal and by the use of an independent earth electrode. Where two or more generators are operating in parallel, neutral/earth circulating currents should be dealt with by the methods described in **7.2.6**.

### 7.2.5 Generators providing a changeover supply

In this mode of operation the generating plant may be used to provide a full alternative supply to either the whole or part of an installation. Special attention should be given to the changeover arrangements so that operation in parallel with the incoming supply is not possible. Line and neutral isolation from the incoming supply should be provided.

Where there is only one generating set, the neutral point of its windings, the generator frame, all exposed-conductive-parts and extraneous-conductive-parts should be connected to the main earthing terminal. This earthing terminal should be connected to an independent earth electrode and, where appropriate, to the protective earth terminal provided by the distributor.

### 7.2.6 Two or more generators operating in parallel (providing a changeover supply)

When two or more generating sets, operating in parallel, are used to supply an installation, the protective earthing of the generator frames and associated metalwork should follow the same procedure as that described for only one generating set. However, the method of supply system earthing for the generator windings should be chosen considering the magnitude of the circulating currents, commonly third harmonic, which can flow in the neutral/earthing conductors.

To overcome such problems, one of the following arrangements should be selected:

- generating sets that have a.c. generators with low harmonic output (e.g. zigzag wound machines);
- star-point switching to connect the star point of only one generator to earth during parallel operation (a star point switching arrangement is shown in Figure 10); it is essential that electrical and mechanical interlocks on the star-point switches ensure the integrity of the neutral/earth connection at all times and under all possible operating conditions;
- a neutral earthing transformer connected between the line conductors and earth; this enables the neutral of the installation to be permanently earthed, with the generators connected to the busbars as three-wire machines (a neutral earthing transformer arrangement is shown in Figure 11); or
- a suitable reactor in the neutral connection of each generator which will attenuate higher frequency currents without offering significant impedance at mains frequency (an earthing arrangement for a single machine operating in changeover mode is given in Figure 12).

Figure 10 Low voltage standby generators with star-point switching

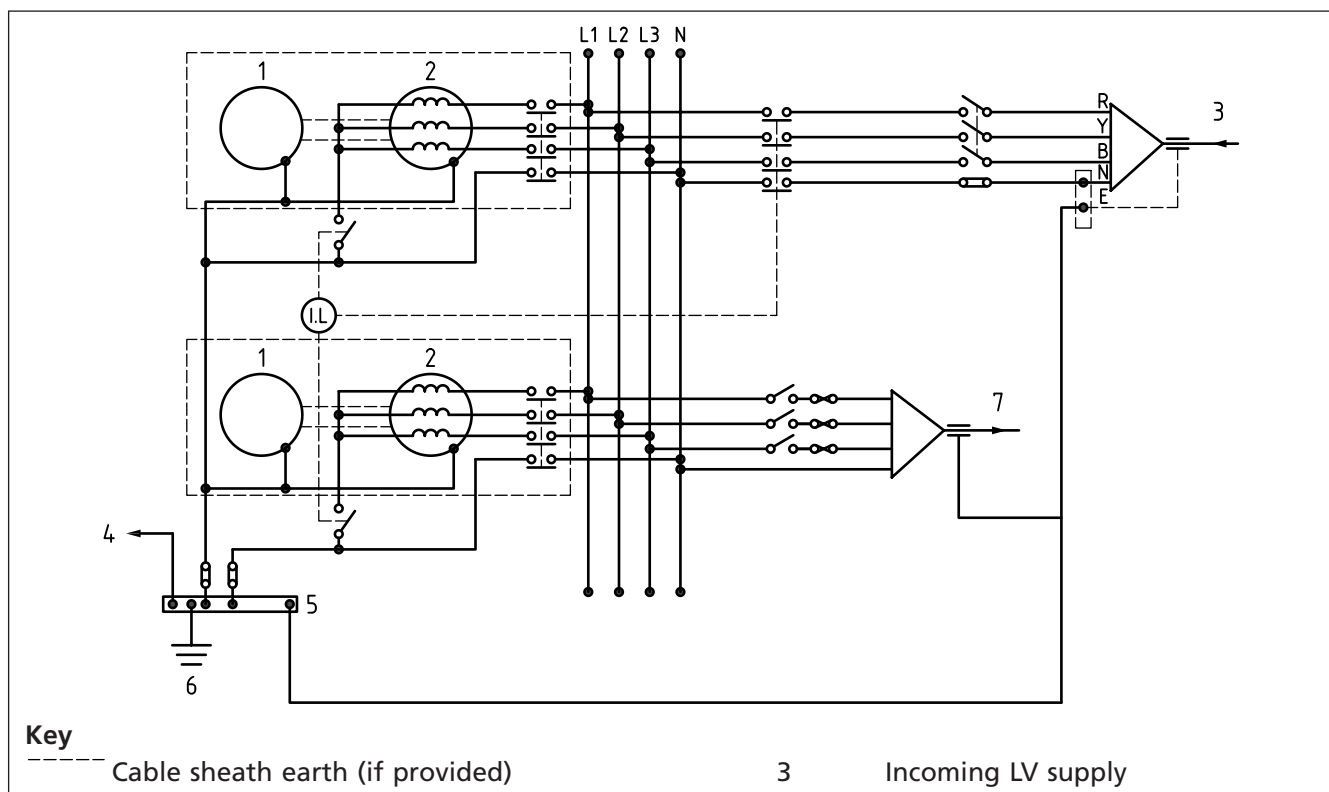


Figure 10 Low voltage standby generators with star-point switching



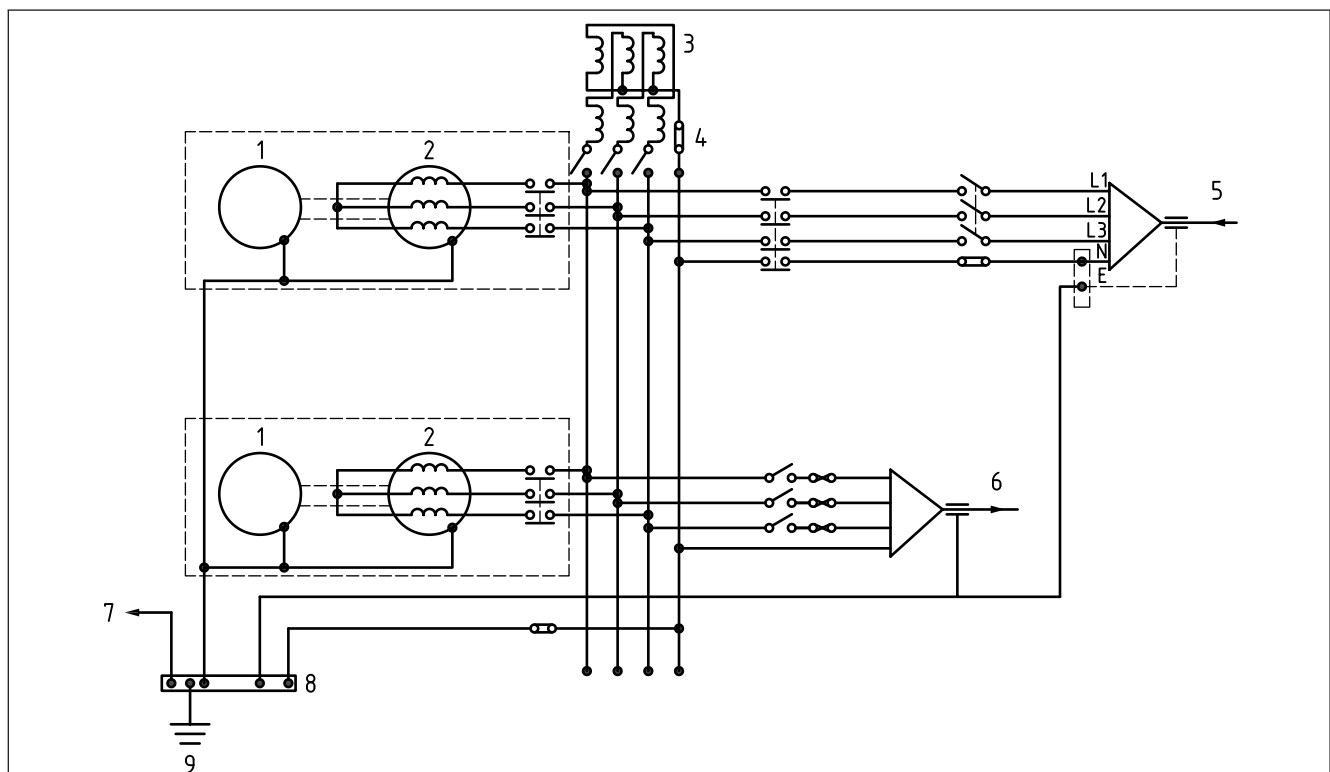
	Mechanical interlock to ensure that energy source	4	Extraneous-conductive-parts
	PME link (if provided)	5	Earthing bar
1	Prime mover	6	Independent earth electrode
2	Generator	7	Load

Figure 11 Low voltage standby generators with neutral earthing transformers



NOTE If a section switch is installed, a neutral earthing transformer will be needed on each section of a bucket.

Key



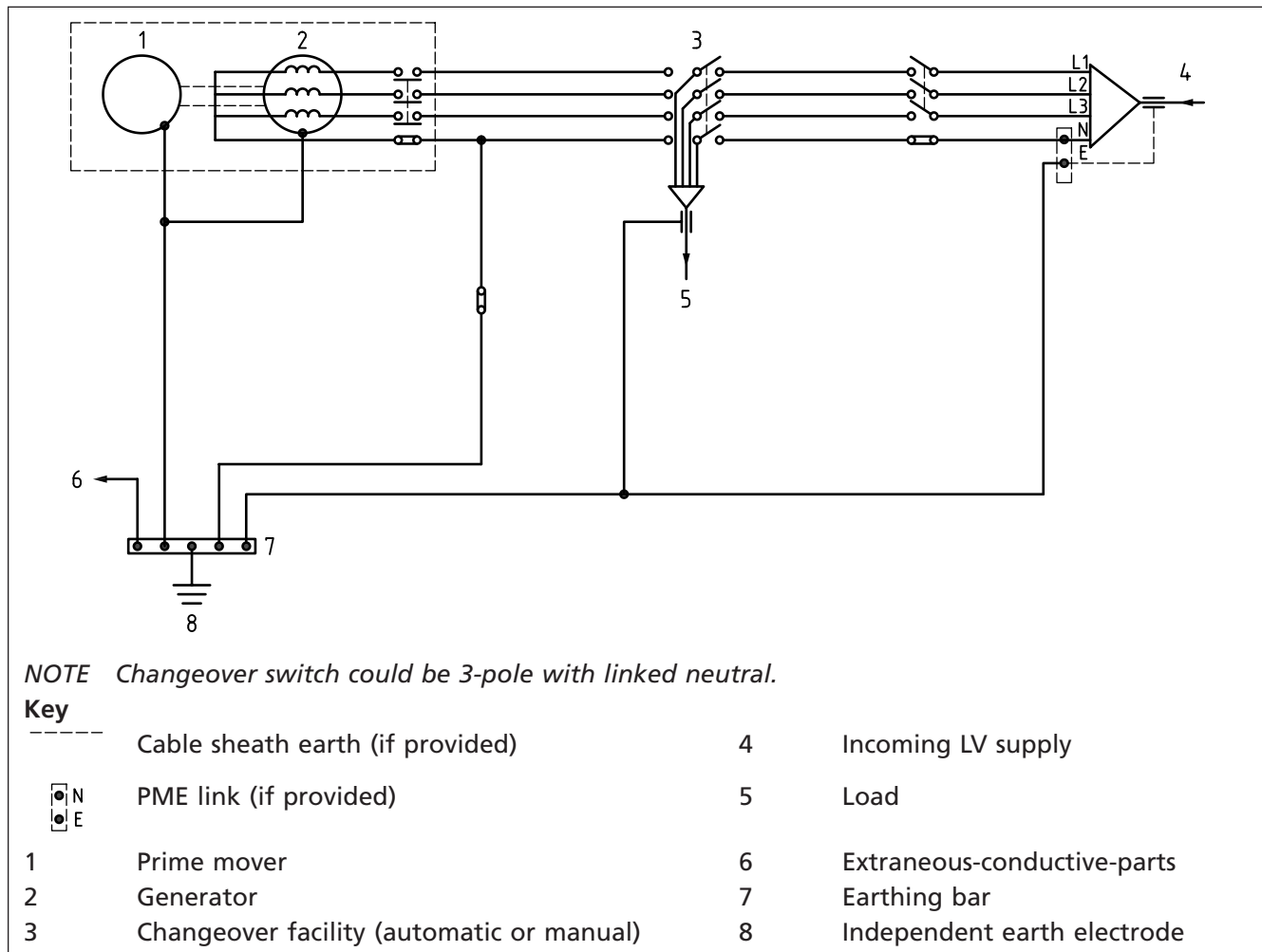
	Cable sheath earth (if provided)	5	Incoming LV supply
	PME link (if provided)	6	Load
1	Prime mover	7	Extraneous-conductive-parts
2	Generator	8	Earthing bar
3	Neutral earth transformer	9	Independent earth electrode
4	Non-automatic switch		

Figure 12 Single low voltage standby generator (without paralleling facility)



### 7.2.7 Generator operating in parallel with the electricity supply

The parallel operation of mains excited asynchronous or synchronous generators with an incoming mains supply provided by a distributor is generally permitted.

If there is a neutral point on the generator windings it should not be earthed. The machine framework, associated exposed-conductive-parts and extraneous-conductive-parts should be connected to the main earth terminal of the installation including the distributor's earth terminal if provided.

Synchronous and self-excited asynchronous generators may be operated in parallel with the supply if protection is provided to disconnect the incoming supply in the event of its loss or partial failure.

Problems of neutral/earth circulating currents arise when a generating set is operated in parallel with an incoming supply; where the magnitude of the circulating currents would be excessive or if the generating set is also required to operate in the changeover mode, the options described in 7.2.6 should be followed.

### 7.2.8 Mobile or transportable units

The generator, cables and load equipment for transportable generating sets should be installed in conformity with BS 7671:2008, including Regulation 551.4.4 and Section 717, that is requirements when the generator and the installation are not fixed.



These transportable units may be trailer, skid or vehicle mounted with outputs in excess of 10 kW (as supplied, the generator windings might not be connected to the machine frame). The three-phase terminals and the neutral connections should be brought out independently to the generator terminal box or, on smaller units, to a socket-outlet conforming to BS EN 60309 (all parts).

To limit the potential of the conductors to the metallic enclosures and to ensure correct operation of protective devices, the star point of the generator windings should be connected to a common reference point. The generator frame, all exposed metalwork, the under frame or vehicle chassis and all protective conductors should be connected to form this common reference point.

The terminal box or socket-outlet should make provision for five connections, i.e. there should be a separate connection for a protective conductor in addition to the usual four connections for the three lines and the neutral. Where connections for only four conductors are provided, the generator should be used to provide balanced three-phase loads only, the fourth connection being reserved for the protective conductor. The fourth connection and conductor should not be used for combined neutral/protective purposes, because of the risk which can arise if this conductor fails.

It is essential that separate neutral and protective conductors are used and that there is no connection between neutral and earth on the load side of the RCD.

### 7.2.9 Additional protection against electric shock

*NOTE 1 Some three-phase generators are supplied with a built-in RCD and the star point of the windings is internally bonded to the generator frame and the protective conductor terminal. Alternatively, it might be necessary to install a separate RCD and to make the appropriate connections externally.*

To provide protection against electric shock when in contact with a live part and the general mass of earth a 30 mA RCD in accordance with BS 7671:2008+A1, Regulation 411.3.3, should be provided and the common reference point/main earthing terminal connected to true earth.

*NOTE 2 Although, in the absence of a deliberate connection between the protective conductor and earth, fortuitous contact between metal cladding of equipment and earth can be such that any earth fault current likely to involve a risk of shock would be sufficient to cause the RCD to operate, it is better to ensure operation by making the earth connection wherever it is at all practicable.*

In conformity to BS 7671:2008+A1, the resistance of the earth electrode should be less than  $50/I_{\Delta n}$  where  $I_{\Delta n}$  is the rated operating current of the RCD.

*NOTE 3 For a 30 mA RCD at 230 V, this would allow a resistance to earth of 1667  $\Omega$ . However, a note to BS 7671:2008, Table 41.5 advises the resistance be as low as practicable and a value exceeding 200  $\Omega$  might not be stable.*

## 7.3 Uninterruptible power supplies (UPSs)

Fault protection of UPSs should conform to BS 7671:2008+A1, 551.4.3.3.

## 7.4 Other sources

Fault protection of any other sources should conform to BS 7671:2008+A1.

## 8 Special installations

### 8.1 Temporary scaffolding and similar metallic structures

#### 8.1.1 Metallic structures assembled by means of bolted joints or screw clamps

*NOTE 1* Where structures are assembled using bolted joints or screw clamps, a multiplicity of such connections is likely to provide several paths of relatively low resistance. Although such structures are not designed to be electrically continuous, it is reasonable to assume that they have a low value of electrical resistance.

Whatever type of structural fastenings or footings in contact with the ground are employed, and however a temporary structure may be fastened to a permanent structure, it should not be assumed that a temporary metallic structure is effectively earthed.

*NOTE 2* Most erections of metallic scaffolding are the subject of statutory regulations concerning construction work.

The distribution of electricity on construction sites should conform to BS 7375.

Except where it is necessary for lightning protection purposes (see 8.2), scaffolding external to a structure should not be connected to the means of earthing within the structure that is afforded by supply authorities.

Where scaffolding is erected against or around a structure which does not have electrical services, and electrical equipment is not likely to be used for construction work, electrical bonding for shock protection purposes may be omitted.

Where protective conductors are required, they should be of copper and protected against corrosion by a covering at least equivalent to the insulation of a single non-sheathed cable, and should be routed to avoid damage from work equipment and work activities. A conductor should be connected to scaffolding by a corrosion-resistant clamp conforming to BS 951, and which is suitably protected against mechanical damage.

For extensive scaffolding structures, where earthed, connections should be made at points not more than 20 m apart laterally.

#### 8.1.2 Structures forming part of precautions to avoid danger from live overhead electric lines

##### COMMENTARY ON 8.1.2

*The Health and Safety Executive publishes guidance on the dangers of live overhead power lines, see Guidance Note GS6 Avoidance of Danger from Overhead Electrical Lines [5].*

*Paragraph 20 b) of GS6 refers to the use of a tensioned wire fence as a high level barrier, and notes that the electricity distributor has to be consulted about the erection and earthing of the barrier.*

### 8.2 Lightning protection

If scaffolding is associated with an existing structure which has an external lightning protection system (LPS), it should be bonded to the earth termination network and the air termination network of the LPS. Lightning protection should otherwise be provided where indicated by risk assessment performed in accordance with BS EN 62305-2.

Other temporary tall metallic structures might require separate earthing electrodes to afford adequate lightning protection, which will depend on the construction of the temporary foundations and footings; BS EN 62305-3 should be consulted for further guidance and expert opinion should be obtained if necessary.

### 8.3 Other temporary structures

There are no recommendations for special earthing or bonding arrangements, i.e. structures that do not require lightning protection, which are not in the vicinity of electric overhead lines and which do not carry electrical circuits operating at a voltage in excess of 25 V a.c. to earth.

### 8.4 Telecommunication circuits and equipment

Recommendations for installing the cabling and earthing of telecommunication equipment, including equipment associated with high voltage stations, are given in ER S36-1.

Where the telecommunication equipment is associated with high-voltage generating, transmission or distribution equipment, special precautions should be taken to prevent the rise of voltage on the earthing system of the high voltage equipment being transferred to the telecommunication circuits.

### 8.5 Street furniture

#### 8.5.1 General

*NOTE Street furniture includes permanently sited lighting columns, traffic and pedestrian signals, illuminated traffic signs, bollards and other electrically supplied equipment.*

Reference should be made to the requirements for luminaires and lighting installations specified in BS 7671:2008+A1, Section 559.

Street furniture may be of:

- a) Class I construction, in which exposed-conductive-parts are connected to the earthing terminal within the equipment, as described in 8.5.2; or
- b) Class II construction, in which no provision is made for connection of exposed metallic parts of the street furniture to earth; with this form of construction, care should be taken to ensure that any protective or PEN conductor in the supply cable has an insulated termination preventing contact with or connection to the metallic parts of the street furniture.

The system of supply should be a TN-S system with separate line, neutral and protective conductors, a TN-C-S system where the source of supply is a concentric cable having a combined neutral and earth under a PME system, or a TT system where the source of supply consists of a line and neutral conductor only. The supply voltage should be extra-low (typically just less than 50 V), or low voltage (typically single-phase at 230 V or three-phase at 400 V).

Access panels, covers or doors of street furniture may be of non-metallic or metallic construction and may be hinged or may have to be removed to gain access. Access panels, covers or doors of street furniture should not be relied upon as a means of basic protection for contact with live parts within street furniture. Adequate enclosures or barriers should be provided within the street furniture to give the necessary level of protection (for further details, see BS 7671:2008+A1).

For street furniture of class II construction, no electrical connection should be made between metallic access panels, covers or doors and other metallic parts of the furniture.

For street furniture of class I construction, the characteristics of the supply system, the characteristics of the earthing system, including consumer earthing provisions, the material of the street furniture and any surface protection, and that of the access panels, covers or doors together with whether they are hinged or have to be lifted off to gain access should inform the designer's risk assessment as to whether they do or do not require any electrical connection.

In coming to a reasoned engineering judgement, note should be taken of the recorded instances and future possibility of reversed polarity of the supply or the loss of the neutral connection on the supply side of a TN-C-S system (for example, it would be reasonable for small isolated metal doors of non-conductive columns such as concrete columns, supplied from a PME distribution system that conform to the ESQCR [1], not to be earthed).

In all cases, the distributor should be consulted before design work on new street furniture is commenced to ascertain the type of system that will supply the new installation.

## **8.5.2 Supply systems for street furniture**

### **8.5.2.1 General**

Street furniture may normally be fed from TN-S or TN-C-S systems.

### **8.5.2.2 TN-S systems**

Street furniture may be fed from and protected by a TN-S system and in such arrangements a supply cable with separate line, neutral and protective conductors should be used. In Class I street furniture the wiring on the load side of the protective device in the unit should consist of separate line, neutral and circuit protective conductors. Exposed-conductive-parts of the item of street furniture being supplied should be earthed by connecting them to the earthing terminal within the equipment. The earthing terminal itself should be connected to the supply protective conductor.

If an installation is all Class II, no protective conductor is required and the wiring on the load side of the protective device should consist of line and neutral conductors only.

It is recommended that a circuit supplying one or more items of Class II equipment or a mixture of Class I and Class II should have a circuit protective conductor run to and appropriately terminated at each point in wiring and at each accessory.

### **8.5.2.3 TN-C-S systems**

An alternative method of supplying and protecting street furniture that may be used is by means of a TN-C-S system. In such cases a combined neutral and earth conductor cable may normally be used at the source of supply (for example to an individual lighting column or for larger installations a local supply authority PME supply into a feeder pillar, with cables using separate line, neutral and circuit protective conductors to feed individual items of street furniture as might be used on footpaths, or to feed items of street furniture in the carriageway).

In the case of circuits feeding more than one item of street furniture, e.g. by looping using a cable with separate line, neutral and protective conductors, an earth electrode should be installed preferably both at the point of supply and at the last or penultimate unit and this electrode should be such as to make the resistance to earth of the neutral at any point less than 20  $\Omega$  before the connection of any circuit protective or bonding conductors to the neutral terminal. If a single electrode produces a resistance of more than 20  $\Omega$ , other earth electrodes equally spaced along the circuit should be installed.

#### 8.5.2.4 TT systems

There is one further possibility that can arise, in which case the lighting authority should provide its own protective earthing electrode(s): that is where the electricity distributor does not provide an earth terminal (a TT system).

In this case, it is essential to ensure that both the initial and continuing impedance of the fault path is sufficiently low to ensure the operation of the protective device on the occurrence of a fault in the fixtures.

#### 8.5.3 Protection arrangements for street furniture

The neutral earth electrode at the supply transformer is an important part of the fault loop but its resistance to earth is not under the control of the lighting authority; in such circumstances consideration should be given to the use of RCDs to ensure disconnection of faulty equipment.

Metallic street light columns or the metal carcasses of feeder pillars or control units, etc., may be used as protective earth electrodes, providing appropriate calculations and subsequent measurements show that such use is suitable.

### 8.6 Railways and traction rails

#### 8.6.1 General

Railways and tramways are a case where there is a need to apply specific rules, depending upon the electrification and signalling systems in use. Most railways and tramways have their own detailed technical standards for earthing, bonding and ensuring the safety of adjacent electrical systems.

The following European Standards deal with the railway specific issues: BS EN 50122-1 and BS EN 50122-2.

For installations outside of the railway boundary, there is generally no need to apply specific rules.

For any installation that comes in to immediate contact with the electrical systems of the railway the designer should consult with the technical department of the railway or tramway company concerned.

No connections may be made to, or removed from, any part of a railway or tramway installation without the explicit agreement of their technical department.

#### 8.6.2 Non-electrified lines in private premises

The rails of non-electrified lines within private premises or electrical substations should be electrically separated from any adjoining railway, and connected to the premises' earthing system.

Suitable insulating rail joints should be included at the site boundary such that electrical separation is maintained from the adjacent railway system.

*NOTE In some cases two insulating rail joints might be needed to prevent the insulation being bridged by rolling stock.*

#### 8.6.3 Railway electrifications systems in use in the UK

##### 8.6.3.1 600 V to 750 V d.c. – Ground level contact systems (UK main line railways in London, Southern England and Liverpool; the London Underground; and the Docklands Light Railway)

Precautions need to be taken to limit stray currents from the railway, and care should be taken to avoid bonding equipment to the railway traction systems.

### 8.6.3.2 600 V to 750 V, 1 500 V d.c. – Overhead contact system (UK tramway and metro systems)

Precautions need to be taken to limit stray currents from the railway, and care should be taken to avoid bonding equipment to the railway traction systems.

### 8.6.3.3 Other systems

Some heritage or museum operations use other forms of electrification, and there might in future be newly installed railways, tramways or electric bus operations that use electrification systems that are new to the UK.

## 8.7 Uninterruptible power supplies (UPSs)

*NOTE* There are two kinds of UPS systems; both provide a continuous supply of electrical power in the event of failure of a distribution network operator's network. One type are static UPSs that utilize rechargeable storage batteries to provide the alternative form of input power and the output power is generated by static converters as specified by BS EN 62040-1-2. The other are rotary UPSs where the input power is provided by stored energy and/or internal combustion engine and the output power is provided by one or more rotating electrical machines as specified by BS EN 88528-11.

Earth fault protection of UPSs should conform to BS 7671:2008+A1, Chapter 55.

# 9 Earth electrode systems

## 9.1 General

Earthing of either a system or equipment involves the provision of a connection to the general mass of earth; this connection should have a resistance not greater than that required to operate safety mechanisms to isolate the electricity supply from a fault situation, and be capable of carrying the maximum expected fault current. The value of resistance required might not always be amenable to an automatically set value.

Therefore, the various factors which affect the resistance to earth and fault current capacity of the buried conductor, designated the earth electrode, should be considered. This should include the size and shape of the earth conductor, the resistivity of the soil in which it is buried and the connection of the system to it. It is also essential to consider the current density at the surface of the earth electrode and the ground potentials in its vicinity.

## 9.2 Nature of site

### 9.2.1 General

The basic nature and properties of soil in a given location cannot be changed without considerable expense, and careful consideration of the geology should be used to determine the best location for an earthing system.

Where there is an option, a site should be chosen in one of the following types of situations in the order of preference given:

- a) wet marshy ground;
- b) clay, loamy soil, arable land, clayey soil, clayey soil or loam mixed with small quantities of sand;
- c) clay and loam mixed with varying proportions of sand, gravel, and stones;
- d) damp and wet sand, peat.



Dry sand, gravel, chalk, limestone, whinstone, granite, any very stony ground, and all locations where virgin rock is very close to the surface should be avoided if possible. A site should be chosen where the moisture content is ideally continuously within the range of 15% to 20%. A waterlogged location is not essential unless the soil is sand or gravel. Care should be taken to avoid a site where water flows over it (e.g. the bed of a stream) for the beneficial salts can be entirely removed from the soil in such situations.

### 9.2.2 Soil treatment

In high resistivity locations or on rocky ground where long term performance is required, it may be considered necessary to utilize a conductive concrete to improve earth contact resistance around an earth rod or strip (tape) where applicable. There are commercially available materials to achieve this effectively, but care should be taken to understand how they work during installation to ensure that they remain in contact with the rod or strip and do not shrink or swell away after drying out.

Chemical treatment of soil has environmental implications and should not be considered as a long term solution in order to meet a specified level of resistance, apart from the risk of corrosion to the earthing system. Coke breeze should also not be used due to its highly corrosive nature.

### 9.3 Soil resistivity

*NOTE 1 The resistance to earth of a given electrode depends upon the electrical resistivity of the soil. Most first approximation formulae are related to homogenous soil, which is rarely the case in practice, where the different layers of strata will affect the distribution of current passing through the electrode.*

Table 1 gives examples of resistivity only; these figures are very general and should not be used to replace actual measurements made at the proposed site. They may be used to give an indication of the difficulties that one might face in preparing an adequate design at the chosen location. The effective resistivity is also controlled by the mineral salts in the ground and the level of moisture content, which is why it should be remembered that readings taken long after installation can vary considerably from the original test results.

Soil temperature has some effect on the upper layers of strata, but is only important under frosty conditions; therefore any part of an electrode system which is less than 0.5 m below ground level should not be considered to be effective.

*NOTE 2 Table 1 is only to be taken as a general guide. Earth resistivity is essentially electrolytic and affected by the moisture content and the soil's ability to retain moisture plus the chemical composition and concentration of beneficial salts dissolved in the water. Columns 2 and 3 relate to most of the British Isles, but column 5 is more specific to marshy flats around river estuaries*

Table 1 Examples of soil resistivity in  $\Omega\text{m}$ 

Type of soil	Climatic condition			
	Normal and high rainfall, i.e. > 500 mm/year		Low rainfall and desert conditions, i.e. < 250 mm/ year	Underground waters (saline)
	Probable value	Range of values encountered	Range of values encountered	Range of values encountered
<b>1</b>	<b>2</b>	<b>3</b>	<b>3</b>	<b>5</b>
Alluvium and lighter clays	5	A)	A)	1–5
Clays (except alluvium)	10	5–20	10–100	1–5
Marls (e.g. Keuper marl)	20	10–30	50–300	—
Porous limestone (e.g. chalk)	50	30–100	—	—
Porous sandstone (e.g. Keuper sandstone and clay shales)	100	30–300	—	—
Quartzite, compact and crystalline limestone (e.g. carboniferous sediments, marble, etc.)	300	100–1 000	—	—
Clay slates and slatey shales	1 000	300–3 000	1 000 upward	30–100
Granite	1 000	—	—	—
Fissile shales, schists, gneiss and igneous rocks	2 000	1 000 upward	—	—

A) Depends on water level of locality.

## 9.4 Measurement of soil resistivity

Soil resistivity may be measured in a similar manner to the establishment of the resistance of the earth electrode. It should be noted that these types of measurement are not always simple and can often result in a wide range of resistance values depending upon a number of factors such as those mentioned in 9.3.

Measurements of the soil resistivity for the pre-determination of the resistance to earth or the impedance to earth should be carried out using a four probe method (widely known as the Wenner method, see also 10.2.2) as follows.

- Drive four equally spaced test electrodes to a depth of not greater 5% of their spacing apart  $a$ . It is important to ensure that their resistance areas do not overlap (see Figure 13).
- Pass current between the two outer electrodes.
- Measure the earth potential between the two inner electrodes.

The resistance  $R$  should be taken as the ratio of the voltage between the inner electrodes and the current between the outer electrodes. In homogenous soil the average resistivity  $\rho$  in ohm metres ( $\Omega\text{m}$ ) may be taken as:

$$\rho = 2\pi aR$$

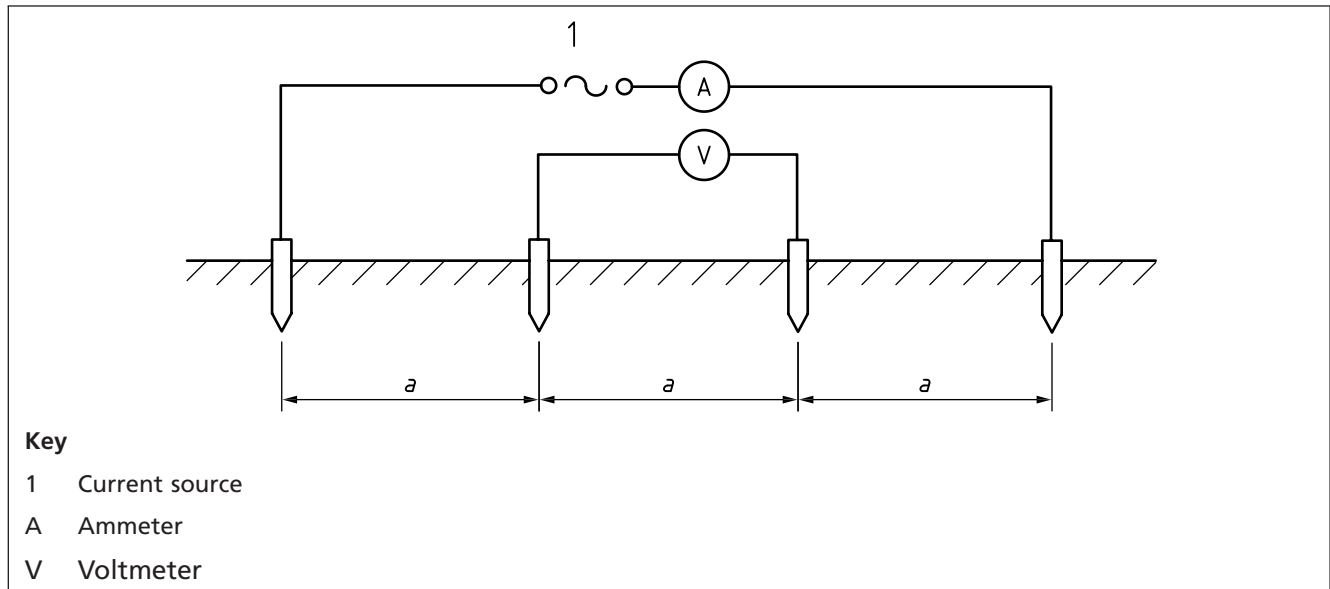
where:

- $a$  is the spacing between electrodes, in metres (m);
- $R$  is the resistance measured between the middle electrodes, in ohms ( $\Omega$ ).



The resistivity so determined applies to an electrode separation distance  $a$ , which is related to the depth of investigation. By repeating the measurement with increasing values of  $a$ , the apparent resistivity involving greater depths may be assessed. This may be taken as an indication of the possible gain from driving deeper rods, etc., into strata of a lower resistivity to get the required resistance.

Figure 13 Measurement of earth resistivity



## 9.5 Types of earth electrodes and their resistance calculation

### 9.5.1 General

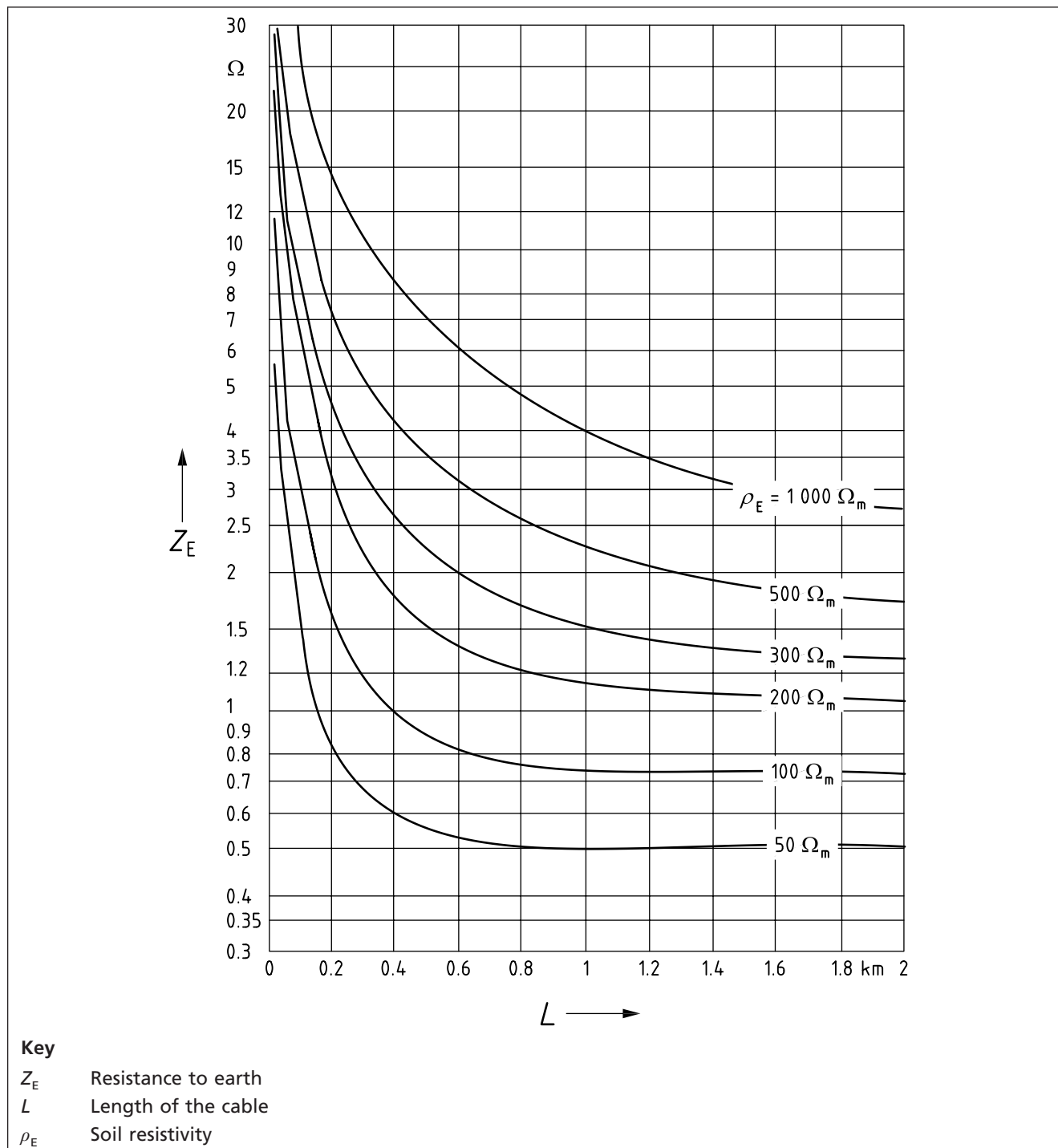
An earthing system should be of the highest integrity and of robust construction to ensure that it remains safe and will not endanger the health and safety of persons or their surroundings. The majority of the formulae presented in this subclause relate to low frequency currents and high frequency examples are not included; it is therefore important to recognize this issue if a long horizontal tape or bare cable is being considered for producing a low earth resistance, even though the impedance will ultimately be limited to a final value (see Figure 14).

Earthing systems should consist of copper conductors, copper clad or austenitic steel rods of appropriate dimensions (see 9.8 for more detail), cast iron plates, or steel piles used individually or connected together in combination to form a single local earth electrode system.

The formulae which follow are all based on homogeneous soil conditions, so in most practical situations only give a reasonable idea of the problems (within 15% accuracy) that might exist if the strata is such that the resistivity changes at different levels. It may be considered necessary to apply numerical methods which are more complex than the formulae given below and software is available to carry out the more detailed calculations. The results from the formulae below are within 10% to 15% accuracy and may be assumed to be sufficient for guidance on what might be the outcome of a given design. However, onsite resistivity testing should always be carried out prior to carrying out an earth system design and installation.

The effect of shape on an electrode resistance is related to the current density around the particular electrode considered. To obtain a low overall resistance the current density should be as low as possible in the medium surrounding the electrode. This may be achieved by making the dimensions in one direction large by comparison to the other two; thus a pipe rod or strip has a much lower resistance than a plate of equal surface area.

Figure 14 Impedance to earth of horizontal earth electrodes buried in homogeneous soil



### 9.5.2 Plates

The approximate resistance to earth of a plate  $R$  in ohms ( $\Omega$ ) may be calculated from:

$$R = \frac{\rho}{4} \sqrt{\left(\frac{\pi}{A}\right)}$$

where:

- $\rho$  is the resistivity of the soil (assumed uniform), in ohm metres ( $\Omega\text{m}$ );
- $A$  is the area of one face of the plate, in square metres ( $\text{m}^2$ ).

Plates, if used, should be installed as small units of not greater than 1.2 m  $\times$  1.2 m connected in parallel vertically and at least 2 m apart. The minimum ground cover should not be less than 600 mm and ideally the surrounding soil should be damp. Connections to the plate should be by copper conductor, welded, riveted or otherwise attached with material that will not cause corrosion at the joint. The finished joint should be covered with a heavy coat of bitumen. The connecting strip to the above ground disconnection point should be fully insulated to avoid electrolytic action

Where the plate is placed in a cut out slot, e.g. in a chalk bed near the surface, the slot should be big enough to allow at least 300 mm thickness of soil or other conducting low resistivity medium cover around the whole plate. This requires careful assembly during installation to ensure that the bottom of the plate is resting in the medium used and not on the chalk or high resistivity substrata.

*NOTE For conventional sizes, the resistance is approximately inversely proportional to the linear dimensions, not to the surface area, i.e. a 0.9 m  $\times$  0.9 m plate has a resistance approximately 25% higher than a 1.2 m  $\times$  1.2 m plate.*

### 9.5.3 Rod electrode

The resistance of a rod  $R_r$  in ohms ( $\Omega$ ) may be calculated from:

$$R_r = \frac{\rho}{2\pi L} \left[ \log_e \left( \frac{8L}{d} \right) - 1 \right]$$

where:

- $\rho$  is the resistivity of soil, in ohm metres ( $\Omega\text{m}$ );
- $L$  is the length of the electrode, in metres (m);
- $d$  is the diameter of the rod, in metres (m).

*NOTE Change of diameter has little effect on the overall value of resistance, and the size is more governed by the mechanical strength of the rod to withstand being mechanically driven when deep earth rods are required e.g. to depths of 20 m or more.*

### 9.5.4 Parallel connection of aligned rods

The resistance  $R_t$  in ohms ( $\Omega$ ) of  $n$  vertically driven rods set  $s$  metres apart may be calculated from:

$$R_t = \frac{1}{n} \frac{\rho}{2\pi L} \left[ \log_e \left( \frac{8L}{d} \right) - 1 + \frac{L}{s} \log_e \left( \frac{1.78n}{2.718} \right) \right]$$

where:

- $\rho$  is the resistivity of soil, in ohm metres ( $\Omega\text{m}$ );
- $L$  is the length of the electrode, in metres (m);

- $n$  is the number of rods;  
 $s$  is the spacing between the rods, in metres (m).

*NOTE This is based on work carried out by Heppe R.J in 1998 dealing with the computational approach to the potential at the surface face of rods, etc. and gives a slightly more optimistic answer than might be expected. This model is more closely aligned to the basic theory behind the electrostatic behaviour of an earthing system component, in effect stating more clearly the interactive effect of the value of  $s$  which for practical purposes has long been set as being not less than twice the depth of the rod. This is related to the hemispherical radius of the rod and that has avoided the effects of using less than the two-times constraint in design thinking. This affects the interference characteristics of multiple rod/tape, etc. systems when the spacing is reduced below the two-times value.*

### 9.5.5 Strip or round conductor electrodes

*NOTE This subclause deals only with a straight run of conductor. For other shapes see 9.5.6 to 9.5.8.*

The resistance  $R_{ta}$  in ohms ( $\Omega$ ) of a strip or round conductor may be calculated from:

$$R_{ta} = \frac{\rho}{2\pi L} \log_e \left( \frac{L^2}{1.85hd} \right)$$

where:

- $\rho$  is the resistivity of soil, in ohm metres ( $\Omega\text{m}$ );  
 $L$  is the length of the strip or conductor, in metres (m);  
 $h$  is the depth of the electrode, in metres (m);  
 $d$  is the diameter of the round conductor or diameter of the equivalent cross sectional area of the strip, in metres (m).

When two or more strips in straight lengths, each of length  $L$  in metres (m) and a separation distance  $s$  metres are laid parallel to each other and connected together at one end only the combined resistance may be calculated from the following equation:

$$R_n = FR_1$$

where:

- $R_n$  is the resistance of  $n$  conductors in parallel, in ohms ( $\Omega$ )  
 $R_1$  is the resistance of a single strip of length  $L$ , calculated from the preceding  $R_{ta}$  equation, in ohms ( $\Omega$ ).

$F$  has the following value:

For two lengths,  $F = 0.5 + [0.078(s/L)]^{-0.307}$

For three lengths,  $F = 0.33 + [0.071(s/L)]^{-0.408}$

For four lengths,  $F = 0.25 + [0.067(s/L)]^{-0.451}$

Provided that  $0.02 < (s/L) < 0.3$ .

### 9.5.6 Mesh

The resistance of a mesh (grid)  $R_m$  ohms ( $\Omega$ ) may be calculated from:

$$R_m = 0.443 \frac{\rho}{\sqrt{A}} + \frac{\rho}{L}$$

where:

- $\rho$  is the resistivity of soil, in ohm metres ( $\Omega\text{m}$ );  
 $A$  is the actual area covered by the mesh, in square metres ( $\text{m}^2$ );  
 $L$  is the total length of strip used in the mesh, in metres (m).

### 9.5.7 Resistance of an electrode encased in low resistivity material, e.g. conducting concrete

The resistance of a backfilled electrode  $R_b$  in ohms ( $\Omega$ ) may be calculated from:

$$R_b = \frac{1}{2\pi L} \left\{ (\rho - \rho_c) \left[ \log_e \left( \frac{8L}{d} \right) - 1 \right] + \rho_c \left[ \log_e \left( \frac{8L}{d} \right) - 1 \right] \right\}$$

where:

- $\rho$  is the resistivity of soil, in ohm metres ( $\Omega\text{m}$ );  
 $\rho_c$  is the resistivity of the conducting material used for the backfill, in ohm metres ( $\Omega\text{m}$ );  
 $L$  is the length of rod, in metres (m);  
 $d$  is the diameter of the rod, in metres (m).

### 9.5.8 Miscellaneous electrodes

*NOTE* There are many configurations that can be set out under this heading, but a few of those which one is most likely to try first in order to achieve the required value are included especially when dealing with deep reinforced piles, etc.

#### 9.5.8.1 Three rods at the vertices of an equilateral triangle

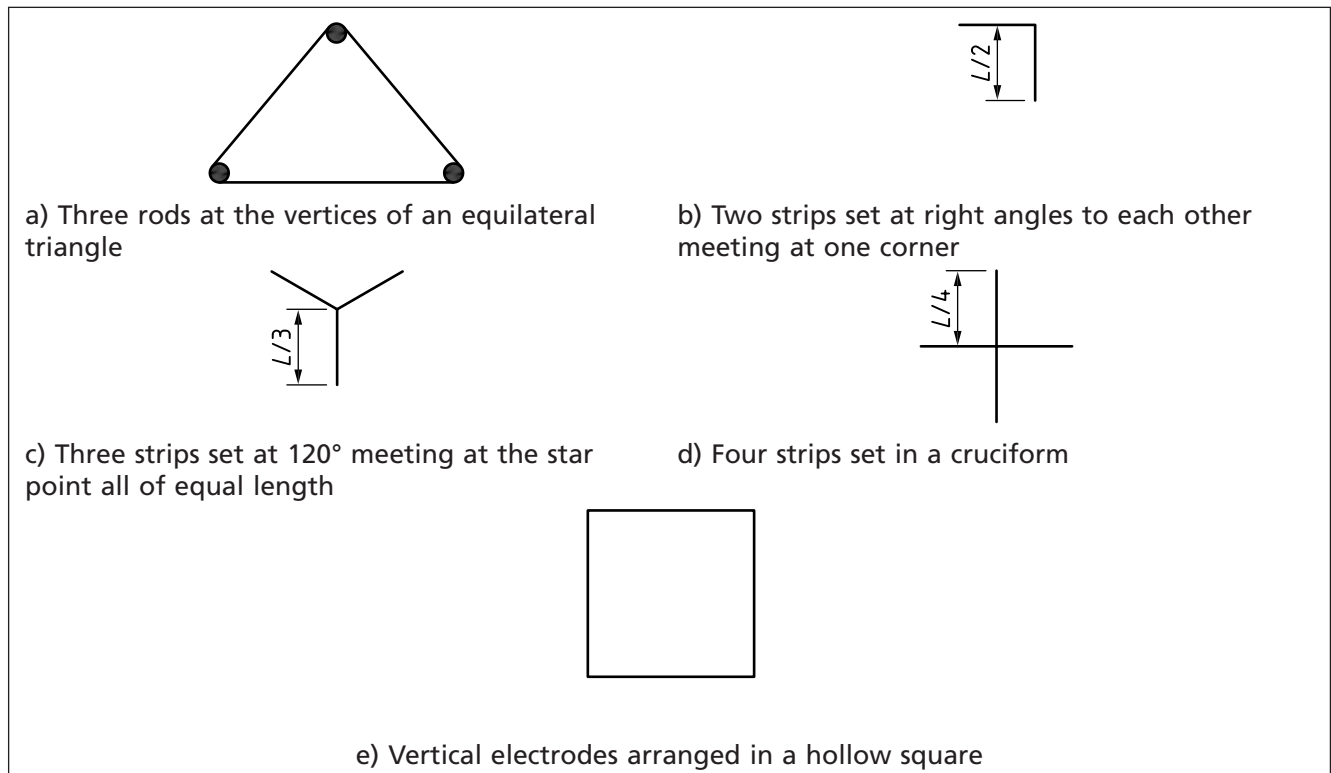
The resistance  $R_e$  in ohms ( $\Omega$ ) of three interconnected rods set out at the vertices of an equilateral triangle [see Figure 15a)] of side  $s$  metres length may be calculated from:

$$R_e = \frac{1}{3} \left\{ 2 \left[ \log_e \left( \frac{8L}{d} \right) - 1 \right] - 1 + 2Ls \right\}$$

where:

- $\rho$  is the resistivity of soil, in ohm metres ( $\Omega\text{m}$ );  
 $L$  is the length of rod, in metres (m);  
 $d$  is the diameter of rod, in metres (m);  
 $s$  is the length of one side of the equilateral triangle, in metres (m).

Figure 15 Miscellaneous electrode configurations



### 9.5.8.2 Two strips set at right angles to each other meeting at one corner

The resistance  $R_L$  in ohms ( $\Omega$ ) of two strips of equal length set at  $90^\circ$  with one corner touching [see Figure 15b)] may be calculated from:

$$R_L = \frac{\rho}{2\pi L} \log_e \left( \frac{L^2}{1.27hd} \right)$$

where:

- $\rho$  is the resistivity of soil, in ohm metres ( $\Omega\text{m}$ );
- $L$  is the total length of strip in metres (m);
- $h$  is the depth of burial in metres (m);
- $d$  is the diameter of the round conductor or diameter of the equivalent cross sectional area of the strip in metres (m).

### 9.5.8.3 Three strips set at $120^\circ$ meeting at the star point all of equal length

The resistance  $R_S$  in ohms ( $\Omega$ ) of a star arranged strip [see Figure 15c)] may be calculated from:

$$R_S = \frac{\rho}{2\pi L} \log_e \left( \frac{L^2}{0.767hd} \right)$$

where:

- $\rho$  is the resistivity of soil, in ohm metres ( $\Omega\text{m}$ );
- $L$  is the total length of strip in metres (m);
- $h$  is the depth of burial in metres (m);
- $d$  is the diameter of the round conductor or diameter of the equivalent cross sectional area of the strip in metres (m).

#### 9.5.8.4 Four strips set in a cruciform

The resistance  $R_{cr}$  in ohms ( $\Omega$ ) of four strips set out in a cruciform [see Figure 15d)] may be calculated from:

$$R_{cr} = \frac{\rho}{2\pi L} \log_e \left( \frac{L^2}{0.21767hd} \right)$$

where:

- $\rho$  is the resistivity of soil, in ohm metres ( $\Omega\text{m}$ );
- $L$  is the total length of strip in metres (m);
- $h$  is the depth of burial in metres (m);
- $d$  is the diameter of the round conductor or diameter of the equivalent cross sectional area of the strip in metres (m).

#### 9.5.8.5 Structural steelwork

Foundation metalwork in concrete may be used as a ready made and effective earth electrode. The total electrode area formed by the underground metalwork of large structure may often be used to provide an earth resistance lower than that obtainable by other methods; overall values well below 1  $\Omega$  are obtainable.

It is important that consideration is given to the possibility of corrosion of the metalwork reinforcement; the products of corrosion occupy a greater volume than the original metal and cracking might occur. In particular, continuous earth currents should be given attention; a possible source of such current might be incompatibility with other buried metalwork, including other types of earth electrode to which foundation metalwork may be bonded (see 9.6).

*NOTE 1 It might be necessary to consider the need for cathodic protection.*

Alternating current should not be expected to cause corrosion, but, rectification sufficient to produce a very small proportion of direct current might take place. Wherever significant continuous earth leakage current is expected, it is recommended that a main electrode of the types described in previous subclauses be provided to which the foundation electrodes can be bonded to provide auxiliary electrodes, thus giving assistance to high fault currents. Corrosion of concrete encased steelwork, subject to a.c. fault currents within its carrying capability, may be assumed to be negligible.

*NOTE 2 Damage to the concrete in the form of cracking, due to arcing or the rapid evaporation of moisture, can occur where the long-term duration earth fault currents exceed the carrying capability of the electrode. This situation is unlikely to arise if the electrode has a resistance sufficiently low to avoid dangerous voltages to earth.*

The resistance to earth of concrete encased steelwork or of concrete reinforcing bars varies according to the type of soil, its moisture content, and the design of the foundation. Concrete is hygroscopic and, except in dry locations, when buried in soil, it may be expected to have a resistivity of about 30  $\Omega\text{m}$  to 90  $\Omega\text{m}$ , at normal temperatures; this is lower than some types of soil.

It is essential to measure the resistance to earth of any metalwork it is intended to use as an electrode, and to monitor its value at regular intervals afterwards, in order to confirm that it continues to provide an adequate connection to earth (see Clause 10).

Ideally confirmation of the combined resistance of all the electrodes should be obtained, but the earth resistance of a structure covering a large area might be quite low and an accurate measurement on a completed structure might be difficult or impossible to achieve. Where the structure is supported on many similar footings, it may be considered feasible and more satisfactory to measure the resistance of one footing before it is electrically connected to others, and before there are any other electrically paralleled footings close by. If possible, it is advantageous and recommended to measure the resistance of several such footings to gain an indication of the likely variation of resistance. On the assumption that a representative value of footing resistance can be obtained, the combined effect of all similar footings  $R_{TOT}$  in ohms ( $\Omega$ ), assumed to be arranged in an approximately rectangular plan, may be determined from the following:

$$R_{TOT} = R_1 \frac{1 + \lambda \rho / 2\pi R_1 s}{n}$$

where

- $R_1$  is the resistance of one footing, in ohms ( $\Omega$ );
- $\lambda$  is the factor from Table 2;
- $\rho$  is the resistivity of soil, in ohm metres ( $\Omega\text{m}$ );
- $s$  is the spacing of footings, in metres (m);
- $n$  is the number of footings used as electrodes (see the note to Table 2).

*NOTE 3 This equation is based on the assumption that the spacing between adjacent electrodes is such that the ratio  $\rho/2\pi R_1 s$  is less than approximately 0.2.*

Table 2 Factors for vertical electrodes arranged in a hollow square

Number of electrodes ( $n$ ) along the side of the square	Factor $\lambda$	Number of electrodes ( $n$ ) along the side of the square	Factor $\lambda$
2	2.71	9	7.65
3	4.51	10	7.90
4	5.46	12	8.22
5	6.14	14	8.67
6	6.63	16	8.95
7	7.03	18	9.22
8	7.30	20	9.40

*NOTE* The number of electrodes around the square is  $4(n - 1)$ .

*NOTE 4 The large proportion of the resistance is due to the concrete to earth is immediately around the metalwork and is dependent on its moisture content. After construction and with the passage of time this moisture content will approach equilibrium with that of the soil, and will usually be dryer than when first laid.*

Allowance should be made for the consequent increase in electrode resistance due to changes in moisture content when using measurements made during the installation of a structure.

It is important to ensure electrical continuity between all metalwork considered to be part of the electrode. In the case of contacts between metalwork within concrete or below ground, such as reinforcing bars, this may best be effected by welding; above ground and at anchor bolts it may generally be done by attaching a bond conductor to bypass each structural joint. This applies particularly to surfaces which might have been primed before assembly.



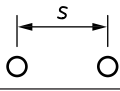
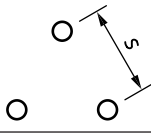
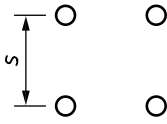
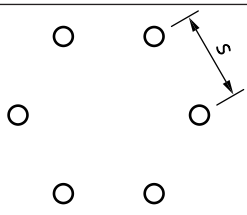
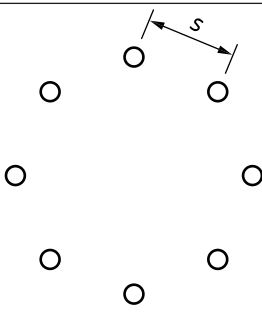
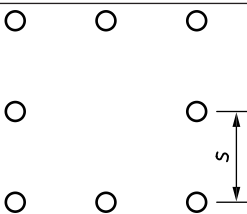
The resistance to earth of a reinforced concrete foundation  $R_r$  in ohms ( $\Omega$ ) may be estimated by assuming that only the vertical reinforcing rods are bonded to the building structure or to the earthing system. The effect of other reinforcement which might be attached by wire ties only, may be neglected. It may be assumed that the rods are equally spaced in a symmetrical pattern (see Table 3).

$$R_r = \frac{1}{2\pi L} \left[ (\rho_c - \rho) \log_e \left( 1 + \frac{\delta}{z} \right) + \rho \log_e \left( \frac{2L}{z} \right) \right]$$

where

- $\rho$  is the resistivity of soil, in ohm metres ( $\Omega\text{m}$ );
- $\rho_c$  is the resistivity of concrete, in ohm metres ( $\Omega\text{m}$ );
- $L$  is the length of reinforcing rod below ground level, in metres (m);
- $\delta$  is the thickness of concrete between rods and soil, in metres (m);
- $z$  is the geometric mean distance of rod cluster, in metres (m).

Table 3 Geometric mean distance  $z$  for closely spaced reinforcing rods in a symmetrical pattern

Number of rods	Arrangement of rods	$z$ m
2		$\sqrt{2as}$
3		$\sqrt[3]{as^2}$
4		$\sqrt[4]{2as^3}$
6		$\sqrt[6]{6as^5}$
8		$\sqrt[8]{52as^7}$
8		$\sqrt[8]{23as^7}$

**Key**

$a$  is the radius of a reinforcing rod, in metres (m)

$s$  is the distance between adjacent rods, in metres (m)

$z$  is the geometric mean distance, in metres (m)

**9.5.8.6 Sheet steel piling**

In consultation with the engineer in charge of works, it is often possible and permissible to secure an effective earth electrode by providing a suitable means of connection to steel reinforcement in concrete piles or to sheet steel piling.

**9.5.8.7 Mains water supplies and water pipe work generally**

The use of water mains for earthing purposes is not recommended. In older systems where a still existing metallic pipe was used for an earth connection, an alternative means of earthing should be installed. In many cases discussion with the electricity supplier should help to deal with this issue.

### 9.5.8.8 Service pipes

In general, metallic pipes, e.g. for gas, oil, compressed air, or drainage, should only be bonded to the protective conductors but not used for the sole means of earthing. Where, in an existing installation, a service pipe has been used as the sole earth electrode, an alternative means of earthing should be provided.

## 9.6 Potential gradient around earth electrodes

### 9.6.1 General

Under fault conditions an earth electrode is raised to a potential with respect to the general mass of Earth that may be calculated from the prospective fault current and the earth resistance of the electrode; this results in the existence of potential differences in the ground around the electrode that might be damaging to telephone and pilot cables, whose cores are substantially at earth potential. Such a risk should be considered mainly in connection with large electrode systems, as at power stations and substations. The potential gradient over the surface of the ground should also be considered because personnel or livestock can be in contact with two points sufficiently far apart that the potential difference constitutes a danger to life; cattle are most at risk.

Figure 16 may be used to predict the ground surface potential gradient around an isolated 3 m rod electrode. The high potential gradient within the first few centimetres of the rod is clearly seen and, depending on the electrode voltage, a barrier to prevent contact by personnel or livestock may be advisable out to a radius of 1 m or 2 m.

*NOTE Further recommendations on reducing this gradient by placing the top of the electrode below ground level are made later in this clause.*

The potential gradient on a perpendicular to a line of three electrodes may be taken from Figure 16; this shows that, for a given electrode voltage, although the initial gradient within about 2 m of the rods is slightly reduced, the general effect at greater distances is to increase both the ground potential and the gradient. However, for a given fault current the multiple electrode arrangement may be used for a lower resistance compared to a single electrode and results in considerably smaller ground potentials and gradients than those of a single electrode.

The distribution of ground surface potential in the vicinity of a horizontal electrode (wire or strip) may be assumed to have gradients much smaller than those of a vertical electrode, the highest gradient occurring at a distance from the electrode equal to its depth. Likewise, the potential gradients between horizontal electrodes may be assumed to be smaller. Depth of laying, within the range normally used, may be assumed to have little effect on ground surface potential.

It should be borne in mind that the ground potential contours associated with installations of more than one electrode consist of isolated areas around each electrode where the potential and its gradient are high and possibly dangerous; between these areas there are troughs of minimum potential which can nevertheless have a value which presents a danger to a person or animal touching conducting items in contact with either the electrode or the mass of earth at a more remote location, e.g. a metallic fence.

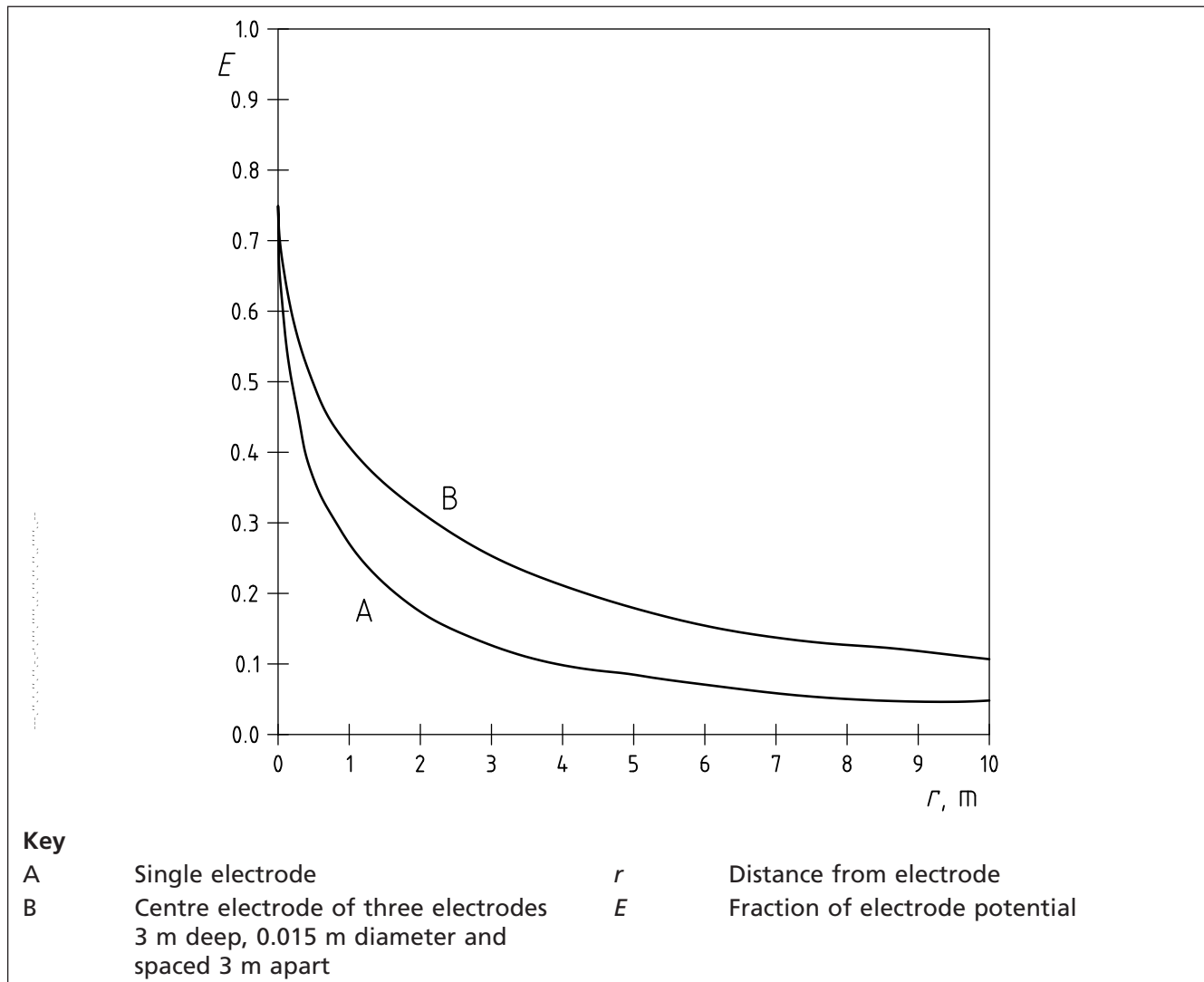
Such variations in ground potential within and close to an installation may be considered unacceptable and measures to reduce them might be necessary. These measures may be more conveniently implemented by the use of additional electrodes in the form of buried horizontal strip or wire, possibly 0.25 m to 0.6 m below the surface (see Clause 5 for further comment on the laying of such electrodes).

The large fraction of the electrode potential developed over the few centimetres of soil next to the electrode indicates how important it is to consider the resistivity of the material in this region. In high resistivity soils, for cases where the use of additional rods is not practicable and it is desired to reduce the electrode resistance by soil treatment or by replacement with concrete, only the soil in this region should be considered. Since soil conductivity is affected by soil density (except for very wet soils), good compaction, or lack of disturbance, of soil in contact with the electrode is important.

Earth electrodes should not be installed close to a metal fence, unless they are used for earthing that fence; this is to avoid the possibility of the fence becoming live and thus dangerous at points remote from the substation, or alternatively giving rise to danger within the resistance area of the electrode by introducing a good connection with the general mass of the earth.

In rural areas, danger to animals in the vicinity of earthed poles may be minimized by the use of insulated earthing connections and by having no earth electrode less than 0.6 m below the surface of the ground.

Figure 16 Ground surface potentials around a single rod and three rods in line



## 9.6.2 Calculation of ground surface potentials

### 9.6.2.1 Vertical electrodes

For vertical electrodes, the fraction  $E$  of the potential arising on the electrode(s) which appears at a point P on the ground surface may be estimated approximately by the following equation:

$$E = \frac{\sum_{i=1}^n \log_e(v_i + \sqrt{v_i^2 + 1})}{(1 + \lambda\beta) \log_e\left(\frac{4L}{d}\right)}$$

where:

$$v_i = L/r_i;$$

$n$  is the number of electrodes;

$L$  is the buried length of an electrode, in metres (m);

$r_i$  is the distance of point P on the ground surface to the  $i^{\text{th}}$  electrode, in metres (m) ( $r_i$  is greater than the radius of an electrode);

$\lambda$  is the grouping factor given in Table 4;

$$\beta = \frac{L}{s \log_e\left(\frac{4L}{d}\right)}$$

where:

$d$  is the diameter of the electrode(s), in metres (m);

$s$  is the spacing between the electrodes, in metres (m) (it is assumed that the electrodes are evenly spaced).

*NOTE* It is assumed that spacing between electrodes is not less than two-thirds of the electrode length and that electrode currents are equal.

For a single electrode, it may be assumed that  $n = 1$ ,  $\lambda = 0$  and  $E$  is the fraction of the electrode potential for an equipotential at a radius  $r$  around the electrode.

Table 4 Factors for vertical parallel electrodes arranged in a line

Number of electrodes $n$	Factor $\lambda$	Number of electrodes $n$	Factor $\lambda$
2	1.00	7	3.15
3	1.66	8	3.39
4	2.15	9	3.61
5	2.54	10	3.81
6	2.87		

### 9.6.2.2 Horizontal electrodes

For horizontal electrodes, the fraction  $E$  of the electrode potential, at a point P on a line perpendicular to the line of the electrodes, may be obtained from the following equation:

$$E = \frac{\sum_{i=1}^n 2 \log_e (v_i + \sqrt{v_i^2 + 1})}{F \log_e \left( \frac{L^2}{hd} \right)}$$

where:

$n$  is the number of electrodes;

$$v_i = \frac{L}{2\sqrt{h^2 + r_i^2}}$$

where:

$h$  is the depth of electrodes from the ground surface, in metres (m);

$r_i$  is the distance along the ground surface from point P to a point vertically above the  $i^{\text{th}}$  electrode, in metres (m);

$L$  is the length of each electrode, in metres (m);

$F$  is the group factor given in 9.5.5;

$d$  is the diameter of each electrode, in metres (m).

For a strip electrode,  $d$  may be obtained from:

$$d = \frac{2w}{\pi}$$

where:

$w$  is the width of a strip electrode, in metres (m).

Where there is one electrode, i.e.  $n = 1$ , the group factor may be assumed to be unity, i.e.  $F = 1$ .

*NOTE* These equations assume that electrode depth is small compared with its length and that electrode currents are equal.

## 9.7 Selection of an earthing conductor and connection to an electrode

Selection of the material for an earthing conductor should take into account compatibility with the material of the earth electrode and, for a conductor installed in the ground, the corrosive effect of the soil. Information provided in 9.10 for electrodes is also relevant to bare earthing conductors.

Aluminium or copper-clad aluminium conductors should not be used in contact with soil or in damp situations and in any case should not be used to make the final connection to an earth electrode.

The cross-sectional area of an earthing conductor and the type of support should be chosen so as to carry without danger the greatest earth fault currents and leakage currents likely to occur having regard to thermal and electromechanical stresses. It should be sufficiently robust to withstand mechanical damage and corrosion.

Table 5 gives recommendations for maximum likely fault current temperatures for bare earthing conductors, according to the environmental conditions and the type of connections used. For a conductor covered to provide corrosion or mechanical protection, or an insulated conductor, it should be borne in mind that the maximum temperature might be limited by the covering or insulating material.

The current densities  $k$  in r.m.s. amperes per square millimetre, for a 1 s duration, are given in Table 5 for copper, aluminium and steel conductors assuming an initial temperature of 30 °C. The corresponding conductor cross-sectional area  $S$  in square millimetres is given by:

$$S = \frac{I\sqrt{t}}{k}$$

where:

$I$  is the average fault current, in A r.m.s.;

$t$  is the fault current duration, in s.

recommended fault current capacities, for 1 s and 3 s durations, for a selection of standard sizes of copper and aluminium strips are given in Table 6 and Table 7.

For other durations the fault current capacity  $I$  in amperes r.m.s. may be calculated from one of the following equations:

$$I = I_1\sqrt{t} \text{ or } I = kS\sqrt{t}$$

where:

$I_1$  is the fault current for 1 s duration, in A r.m.s. (given in Table 6 and Table 7);

$S$  is the conductor cross-sectional area, in mm<sup>2</sup>;

$k$  is the r.m.s. current density, in A/mm<sup>2</sup> (given in Table 5).

For other initial and final temperatures the current density  $k$  for a 1 s duration may be obtained from the following equation:

$$k = K \sqrt{\log_e \left( \frac{T_2 + \beta}{T_1 + \beta} \right)}$$

where:

$T_1$  is the initial temperature, in °C;

$T_2$  is the final temperature, in °C;

$K$  and  $\beta$  have the values given in Table 8.

Where there are continuous earth leakage currents it should be confirmed that the conductor has a current-carrying capacity adequate for such currents without exceeding a temperature appropriate to its insulation or supports or, if it is bare and exposed to touch, that its temperature should not exceed 70 °C. Such continuous earth currents might increase the value of the initial temperature that should be considered when selecting the conductor size to carry earth fault currents.

In addition to conforming to the thermal constraints described above, the earthing conductor should have a cross-sectional area of not less than 4 mm<sup>2</sup> where protection against corrosion only is provided or 2.5 mm<sup>2</sup> where mechanical protection is also provided.

Where an earthing conductor is installed in the ground and is protected against corrosion, but has no mechanical protection, a size not less than 16 mm<sup>2</sup> for copper or coated steel should be used. If corrosion protection is not provided the size should be not less than 25 mm<sup>2</sup> for copper and not less than 50 mm<sup>2</sup> for steel.

Unprotected strip conductors should be not less than 3 mm thick.

The materials used for making connections should be compatible with the materials of the earth electrode and of the earthing conductor so that galvanic corrosion is minimized. Where copper alloy connectors are used they should not contain more than 15% zinc.

Connectors should be mechanically strong and securely fastened. All earth clamps should be inherently corrosion resistant. Where bolted connections are used, the bolts should withstand a torque of at least 20 Nm.

*NOTE 1 For large earthing installations, such as at major substations, it is common to make provision for the testing of earth electrodes. This is achieved by connecting a group of rod driven electrodes to the main earth grid through a bolted link adjacent to the electrodes in a sunken concrete box. Simpler disconnecting arrangements may be acceptable for small earthing installations.*

*NOTE 2 Further details are given in Clause 6 for installations within the scope of BS 7671:2008+A1.*

Table 5 Earth fault current densities for 1 s duration for earthing conductors with initial conductor temperature of 30 °C

Type of joint <sup>A)</sup>				Maximum temperature <sup>B)</sup> °Cs	U	R.M.S. current density, k			
Welded	Braze	Bolted	Soft soldered			Copper	Aluminium	Steel	
						0391	A/mm <sup>2</sup>	A/mm <sup>2</sup>	
✓				700			254	—	91
✓				600			252	—	87
✓				500		C)	228	—	82
✓	✓			450			220	—	79
✓	✓			400			211	—	76
✓	✓			350			201	—	73
✓	✓			300			190	125 <sup>D)</sup>	69
✓	✓	✓		250			176	116	64
✓	✓	✓		200		E)	159	105	58
✓	✓	✓	✓	150		F)	138	91	50
✓	✓	✓	✓	100			—	—	—

A) A tick (✓) indicates that the type of joint is suitable for use at temperatures up to and including the value indicated.

B) It should be verified that a material likely to be in the same location as the conductor will not be damaged or present a fire risk at the temperature selected.

C) At temperatures in excess of 200 °C the conductor should be visible throughout its length, have ceramic or metallic supports (or an equivalent) and there should be no risk of organic materials being in contact with or adjacent to the conductor. Temperatures higher than 500 °C are not recommended.

D) The mechanical strength of conducting quality aluminium is seriously reduced at higher temperatures.

E) For normal conditions where the conductor is not visible throughout its length.

F) Certain building materials likely to be adjacent to the conductor may present a fire risk if 150 °C is exceeded.

*NOTE Please refer to BS 7671:2008+A1 for maximum temperatures.*



Table 6 Earth fault currents (in kA) for copper strip earthing conductors

<b>a) 1 s duration</b>					
Size of conductor mm x mm	Maximum conductor temperature				
	150 °C	200 °C	250 °C	450 °C	500 °C
20 x 3	8.3	9.5	10.6	13.2	13.7
25 x 3	10.4	11.9	13.2	16.5	17.1
25 x 4	13.8	15.9	17.6	22	22.8
25 x 6	20.7	23.9	26.4	33	34.2
31 x 3	12.8	14.8	16.4	20.5	21.2
31 x 6	25.7	29.6	32.7	40.9	42.4
38 x 3	15.7	18.1	20.1	25.1	26
38 x 5	26.2	30.2	33.4	41.8	43.3
38 x 6	31.5	36.3	40.1	50.2	52
50 x 3	20.7	23.9	26.4	33	34.2
50 x 4	27.6	31.8	35.2	44	45.6
50 x 6	41.4	47.7	52.8	66	68.4
<b>a) 3 s duration</b>					
Size of conductor mm x mm	Maximum conductor temperature				
	150 °C	200 °C	250 °C	450 °C	500 °C
20 x 3	4.8	5.5	6.1	7.6	7.9
25 x 3	6	6.9	7.6	9.5	9.9
25 x 4	8	9.2	10.2	12.7	13.2
25 x 6	12	13.8	15.2	19.1	19.7
31 x 3	7.4	8.5	9.5	11.8	12.2
31 x 6	14.8	17.1	18.9	23.6	24.5
38 x 3	9.1	10.5	11.6	14.5	15
38 x 5	15.1	17.4	19.3	24.1	25
38 x 6	18.2	20.9	23.2	29	30
50 x 3	12	13.8	15.2	19.1	19.7
50 x 4	15.9	18.4	20.3	25.4	26.3
50 x 6	23.9	27.5	30.5	38.1	39.5

Table 7 Earth fault currents (in kA) for aluminium strip earthing conductors

a) 1 s duration				
Size of conductor mm × mm	Maximum conductor temperature			
	150 °C	200 °C	250 °C	300 °C
20 × 3	5.5	6.3	7	7.5
25 × 3	6.8	7.9	8.7	9.4
25 × 6	13.7	15.8	17.4	18.8
50 × 6	27.3	31.5	34.8	37.5
60 × 6	32.8	37.8	41.8	45
80 × 6	43.7	50.4	55.7	60
a) 3 s duration				
Size of conductor mm × mm	Maximum conductor temperature			
	150 °C	200 °C	250 °C	300 °C
20 × 3	3.2	3.6	4	4.3
25 × 3	3.9	4.5	5	5.4
25 × 6	7.9	9.1	10	10.8
50 × 6	15.8	18.2	20.1	21.7
60 × 6	18.9	21.8	24.1	26
80 × 6	25.2	29.1	32.1	34.6

Table 8 Values of  $K$  and  $\beta$ 

Metal	$K$	$\beta$
	A/mm <sup>2</sup> (r.m.s.)	°C
Copper	226	254
Aluminium	148	228
Steel	78	202

## 9.8 Current density at the surface of an earth electrode

An earth electrode should be designed to have a loading capacity adequate for the system of which it forms a part, i.e. it should be capable of dissipating the electrical energy in the earth path at the point at which it is installed under any condition of operation on the system.

*NOTE 1 Failure of an electrode to meet its purpose is fundamentally due to excessive temperature rise at the surface of the electrode and is thus a function of current density and duration as well as electrical and thermal properties of the soil.*

*NOTE 2 In general, soils have a negative temperature coefficient of resistance so that sustained current loading results in an initial decrease in electrode resistance and a consequent rise in the earth fault current for a given applied voltage. However, as soil moisture is driven away from the soil-electrode interface, the resistance increases and will ultimately become infinite if the temperature rise is sufficient. For short-duration loading this occurs in the region of 100 °C and results in complete failure of the electrode.*

Three conditions of operation should be considered, i.e. long-duration loading, as with normal system operation, short-time overloading, as under fault conditions in directly earthed systems, and long-time overloading, as under fault conditions in systems protected by arc-suppression coils.

### COMMENTARY ON 9.8

*The little experimental work which has been done on this subject has been confined to model tests with spherical electrodes in clay or loam of low resistivity and has led to the following conclusions.*

*Long-duration loading due to normal unbalance of the system will not cause failure of earth electrodes provided that the current density at the electrode surface does not exceed 40 A/m<sup>2</sup>. Limitation to values below this would generally be imposed by the necessity to secure a low-resistance earth.*

*Time to failure on short-time overload is inversely proportional to the specific loading, which is given by  $J^2\rho$  where  $J$  is the current density at the electrode surface and  $\rho$  the resistivity of the soil. For the soils investigated the maximum permissible current density  $J$ , in amperes per square metre (A/m<sup>2</sup>), is given by the following equation:*

$$J = 10^3 \sqrt{\frac{57.7}{\rho t}}$$

where:

$t$  is the duration of the earth fault, in seconds (s);

$\rho$  is the resistivity of the soil, in ohm metres ( $\Omega$ m).

*Experience indicates that this equation is also appropriate for plate electrodes.*

## 9.9 Earthing conductors for substations and industrial installations operating at similar voltages

### 9.9.1 Disposition

#### 9.9.1.1 General

It is necessary to provide permanent and substantial connections between all equipment and the earth electrodes so as to afford a low resistance path for fault currents both to earth and between items of equipment. The most efficient disposition of earthing conductors depends on the layout of equipment, but the following may be taken as a guide.

Where the current-carrying capacity of a main aluminium or steel member or welded sections forming a structure is at least equal to that of the required earthing conductor, the structure may form part of the connection and there is no need to fix an earth conductor along this section.

Where, in structures made of bolted sections, the electrical continuity of the structural joints cannot be relied upon to form permanent and reliable earth bonds it is necessary to install loops bonding across these joints.

#### 9.9.1.2 Indoor equipment

Main earth conductors, which may be in the form of a ring, should be provided and connected to the metalwork of each piece of equipment and to the earth electrodes. Except for the smallest installations there should be a connection to the earth electrodes at each end of the earth conductor or, if the conductors form a ring, at several points. These connections may, depending on the layout, be buried cables having a rating adequate for the short circuit current. Where the structure of a switchboard is extensive or occupies more than one floor, a further parallel main earth conductor may be included, which should be connected to the main earth conductor at one or more points in each section of the switchboard.

The main earth conductors should be so placed that metallic cable sheaths can be reliably and readily connected to it by bonds made off to the cable gland. Where the cable incorporates metallic armouring this should be clamped to the cable gland.

Earthing conductors should be accessible for the connection of any detachable earthing devices used with the electrical equipment.

Branch connections from the main earth conductor should be provided to all ancillary equipment, such as control and relay panels, constructional steelwork and fire-extinguishing installations.

Where phase to earth busbar protection is effected at switchboards by frame leakage devices, two earth conductors should be provided. The frame bar interconnecting the framework of the switch units should be connected to the main earth bar through a current transformer or other protective device and through bolted links for test purposes. The main earth conductor should be run separately from the frame earth bar in a convenient position for the connection of cable sheaths and earthing devices. Where it is mounted on the switch enclosure it should be insulated therefrom by insulation capable of withstanding a test voltage of 4 kV r.m.s. 50 Hz for 1 min. Care should be taken to avoid parallel paths for earth currents which might adversely affect the operation of the protection. Insulated cable glands should be of a kind that can be tested without breaking the main earth connections. Such glands should consist of two sections of insulation separated by a metal island layer, which is joined to the main switchgear metalwork by a link connection, thus enabling the insulation between the metal layer and the cable sheath and between the metal layer and the switchgear metalwork to be tested by opening the link.

### 9.9.1.3 Outdoor equipment (excluding pole mounted transformers)

A main earth bar should be provided, so disposed as to allow the shortest subsidiary connections to all major equipment, such as transformers or circuit breakers. Wherever possible, this should be arranged to form a ring round the station. The main earth bar (or ring) should be connected where required to earth electrodes. For larger stations the ring should be reinforced by one or more cross-connections.

From the main earth bar, branch connections should be taken to each item of apparatus, and where several such items lie together, a subsidiary ring with short branches is preferable to a number of longer individual branches from the main bar. The aim should be to provide a mesh system wherever this can be contrived with reasonable economy.

The operating mechanisms for outdoor disconnectors and earth switches and circuit breaker control kiosks, etc. not integral with the circuit breaker should be connected to the main earth grid by a branch earth connection entirely separate from that employed for earthing the disconnector or earth switch base, or the circuit breaker structure.

Where the earth wire of an incoming line ends at the terminal supports and is not connected to a point on the substation structures, a subsidiary earth connection should be provided between the substation earth system and the base of the support. If the latter lies outside the substation fence, the earth connection should be buried where it passes under the fence and should be kept well clear of the latter.

Earth connections to surge arrestors should be of ample cross-section and should be as direct and straight as possible; they should not pass through iron pipes or other steel or iron parts which would increase the surge impedance of the connection. The earth connections of the arrestors should be connected with the main earth system since, for the effective protection of the substation equipment, it is essential that there is a connection of low impedance between the equipment and the arrestors.

## 9.9.2 Size

### 9.9.2.1 Conductors installed above ground

Earthing conductors for power stations and substations should normally be selected from unsheathed copper or aluminium sections adequately rated in size to carry the designed earth fault or three-phase fault current for the appropriate designed maximum duration without attaining an excessive temperature rise. Conformity to this recommendation ensures satisfactory bonding without excessive voltage difference along any conductor. In some cases it may be possible to utilize galvanized steel structures as earthing conductors.

The minimum cross-sectional area of the earthing conductor should be determined by the choice of conductor material and the maximum duration of the fault current. The generally accepted durations that should be used for design purposes are 1 s for 400 kV and 275 kV systems and 3 s for systems of lower voltage.

### 9.9.2.2 Conductors buried as electrodes

Conductors buried to form earth electrodes should be more generously rated to restrict the temperature rise under fault conditions in order to ensure that the conductor remains an effective electrode. In this application the temperature rise may be assumed to be a function of both the heating effect of the current flowing in the conductor and the heating effect of the current dissipating from the surface of the conductor to the general mass of earth (see 9.8).

## 9.9.3 Construction

### 9.9.3.1 General

It is essential for the safety of personnel and plant that an earth system should remain effective throughout the life of the plant. It is difficult in many cases to make a check of continuity after installation; the system should therefore be robust and protected from mechanical damage and corrosion where necessary. Any joints should be capable of retaining low resistance after many passages of fault current.

### 9.9.3.2 Laying conductors

A buried bare copper or steel conductor forming part of the earthing system should be at about 600 mm deep, which in addition to giving protection to the conductor and connections will ensure that it will normally be below the frost line. In general an aluminium conductor should be used only above ground and the connections to earth electrodes should be made above ground with bimetallic connectors. Aluminium should be used below ground only if protected or sheathed against contact with soil and moisture.

Where an adequate earthing installation is provided, subsidiary conductors connecting the main earth grid to equipment may be laid at a depth and by routes most appropriate to site conditions. For convenience in connecting to equipment they may be laid at a depth of the order of 250 mm, and as they are therefore in ground more subject to seasonal or progressive changes of resistivity, it should be assumed that they make negligible contribution towards reducing station earth resistance. On the other hand subsidiary connectors may be assumed to serve to reduce ground surface voltage gradients within the station site. Conversely where these conductors are intended to reduce the value of the earth resistance of a station, their minimum depth should be 600 mm. These recommendations apply mainly with stations on normal sites. Where ground conditions restrict the installation depth or where the soil resistivity is excessive, additional measures may be needed to achieve acceptable ground surface potential gradients. Where a bare metal conductor is buried under metal fencing, and the fencing is independently earthed, the conductor should be insulated by threading through a non-metallic pipe extending for at least 2 m each side of the fence, or by using an insulated conductor.

When laying stranded conductor for earthing purposes, care should be taken to avoid "birdcaging" of the strands.

### 9.9.3.3 Fixing conductors

Aluminium or copper conductors should not be drilled for fixing to structures. Clips should be used that prevent contact between conductor and structure and which are of suitable material so that there is no electrolytic action between clip and conductor. Fixings should be spaced not more than 1 m apart.

Earth conductors in trenches containing power and/or multi-core cables should be fixed to the walls near the top (e.g. 100 mm from the top).

Copper earth strip supported from or in contact with galvanized steel should be tinned to prevent electrolytic action.

If sharp bends are required in aluminium strip they should be formed by the use of a bending machine to avoid stress concentration.

Aluminium is prone to corrosion when in contact with Portland cement and mortar mixes; contact of aluminium conductors with such materials should, therefore, be avoided by the use of stand-off fixings.

Unless it is protected, an aluminium earthing conductor should not be installed within 250 mm of ground level.

## 9.9.4 Jointing conductors

### 9.9.4.1 General

All crossings of conductors in the main earth grid should be jointed. Compression type joints may be used for stranded conductors and when compressed firmly onto its associated conductor the joint should conform to BS 3288-1.

No conductor strip should be drilled for a bolt having a diameter greater than one-third of the width of the strip. If this diameter would be exceeded then a flat should be jointed to the strip.

### 9.9.4.2 Aluminium to aluminium

When possible, joints on strip conductors should be arc welded using either the inert-gas tungsten-arc (TIG) or inert-gas metal-arc (MIG) techniques in accordance with BS EN 1011-4. Oxy-acetylene gas welding brazing or cold pressure welding may also be used.

Ranges of compression fittings and tools are available for circular conductors; circular conductors may also be flattened and punched with suitable tools to form a terminal.

Circular and rectangular conductors may be joined with bolted clamps.

Rectangular conductors may be joined or terminated by drilling and bolting. When making a bolted type joint, the surface of the aluminium should be cleaned thoroughly by wire brushing and an approved jointing compound applied immediately to both mating surfaces. Bolts should then be tightened and all excess grease or compound wiped off and discarded.

To ensure adequate contact pressure and avoid overstressing, torque spanners should be used. The conductor manufacturer's literature should be consulted for further details of the joints and procedures.

Cold pressure welding and explosive bonding may be used for jointing rectangular conductors. The appropriate manufacturer should be consulted for details of these procedures.

#### 9.9.4.3 Aluminium to copper

Joints between aluminium and copper should be bolted, cold pressure welded or friction welded and should be installed with mating faces in the vertical plane at a minimum distance of 250 mm above ground level. For bolted joints the aluminium mating surface should be cleaned thoroughly (e.g. by wire brushing) and a suitable grease or jointing compound applied; the copper surface should be hot tinned. After applying the correct torque to the bolt(s) the excess grease or compound should be wiped off. Where appropriate the protection of the joint from ingress of moisture may be achieved by the application of suitable mastic compound or irradiated polyethylene sleeve with mastic lining, over the complete joint. Alternatively, the joint may be protected by a bitumastic paint or a suitable protective wrapping.

Aluminium conductor connections to equipment should, where possible, be arranged so that joint faces are in the vertical plane. Surface preparation of the aluminium, joint fabrication and protection against moisture should be as previously described.

#### 9.9.4.4 Copper to copper

The following methods have been found to be satisfactory and may be used:

- a) brazing, using zinc-free brazing material with a melting point of at least 600 °C;
- b) bolting;
- c) thermic welding.

Earthing conductor connections to equipment should, as far as practicable, be arranged so that mating surfaces are vertical. In the case of painted metal, the paint should be carefully removed. Earthing conductors should be tinned when connected to galvanized steelwork.

No connection point should be less than 250 mm above ground level. In any installations where the finished joint is subject to corrosion, it should be protected by a bitumastic paint or a suitable protective wrapping.



#### 9.9.4.5 Loops for portable earths

Loops of aluminium or copper should be provided on the earth conductor at each location where portable earth leads might be applied. The loops should be of a length appropriate to the earthing devices which might be used, should be at a convenient height and should be separately formed, not by bending the earth strip itself. Loops should be jointed to the earth conductor using one of the methods given in 9.9.4.2 to 9.9.4.4.

### 9.10 Corrosion

#### 9.10.1 Type of soil

The factors associated with the corrosion of metals in contact with soil that should be considered are: the chemical nature of the soil, in particular acidity and salt content, differential aeration, and the presence of anaerobic bacteria.

A general picture of the aggressiveness of soils may be found in the following list, which places various types of soil in increasing order of aggressiveness:

- gravelly soils;
- sandy soils;
- silty soils (loam);
- clays;
- peat and other organic soils;
- made up soils containing cinders and other corrosive materials.

*NOTE Calcium carbonate in a soil will reduce the rate of corrosion. Non-cohesive soils, made from mixtures of the first three items above, are generally the least aggressive providing they are well drained and contain little or no dissolved salts. The least aggressive soils tend to be those having a high resistivity.*

Location of electrodes should be chosen to avoid the drainage of fertilizer and other materials into the area. Top soil should not be mixed with the backfill around an electrode.

More detail may be obtained by measuring the electrical resistivity of the soil, which provides an indication of corrosivity under aerated conditions, and the redox potential, which indicates the risk of corrosion due to the presence of anaerobic bacteria. These tests should be performed in compliance with BS 1377-3.

Guidance on the corrosivity of some electrode materials in relation to these soil parameters may be found in Table 9. Further information may be obtained from King, from which Table 9 has been summarized.

Copper is one of the better and commonly used materials for earth electrodes and underground conductors; solid copper is particularly suitable and recommended where high fault currents are expected. For other installations copper-covered steel (e.g. as earth rods) may be found effective and provides better mechanical strength in the smaller sections. However, the adverse effect of dissolved salts, organic acids and acid soils generally should be noted.

Steel in concrete foundation work is generally protected against corrosion by the concrete and may act as a satisfactory electrode, if provision is made to ensure electrical continuity and adequate conductivity. Steel in concrete has an electropotential similar to that of copper and may therefore be bonded to copper or copper-covered earth electrodes. Note, however, that galvanized steel is strongly electronegative to both copper and steel in concrete so that an earth electrode of bare galvanized steel should not be bonded to either of them.



Table 9 Corrosion resistance of some electrodes materials related to soil parameters

Soil parameter		Electrode materials			
		Copper	Galvanized steel	Austenitic steel	Mild steel
Resistivity, $\Omega\text{m}$	< 7	g	n	g	nn
	7 to 40	g	n	gg	n
	> 40	gg	gg	gg	gg
Redox potential, mV	< 200	n	nn	n	nn
	200 to 400	g	g	gg	g
	400	gg	gg	gg	gg
Moisture content, %	< 10	gg	gg	gg	gg
	10 to 80	g	n	g	n
	> 80	g	g	g	g
Dissolved: salts		n	n	g	n
	chlorides	n	n	g	n
pH	< 6	n	nn	g	n
	acidic	6 to 8	gg	gg	gg
	neutral	> 8	g	n	gg
	alkaline				g
Organic acids		nn	n	g	n

**Key**

gg indicates corrosion resistance generally unaffected

g indicates corrosion resistance only slightly reduced

n indicates corrosion resistance moderately reduced

nn indicates corrosion resistance considerably reduced

**9.10.2 Corrosion due to interconnection with another metallic item**

The possibility of damage to cables, other underground services and structural metalwork in the vicinity of earth electrodes, to which the earthing system is to be bonded, due to electrolytic action between dissimilar metals should not be overlooked; the rate of corrosion depends on the metals involved and to some extent on their relative surface areas. In some cases connection of neighbouring underground metalwork can also increase the rate of corrosion of earth electrode material; materials compatible with the neighbouring items should be selected or other precautions taken. Table 10 summarizes the situation for some construction and earthing materials.

Table 10 Suitability of materials for bonding together

Material assumed to have the larger surface area	Electrode material or item assumed to have the smaller surface area			
	Steel	Galvanized steel	Copper	Tinned copper
Galvanized steel	✓	✓	✓	✓
Steel in concrete	✗	✗	✓	✓
Galvanized steel in concrete	✓	✓ <sup>A)</sup>	✓	✓
Lead	✓	✓ <sup>A)</sup>	✓	✓

**Key**

✗ = not suitable for bonding

✓ = suitable for bonding

<sup>A)</sup> The galvanizing on the smaller surfaces might suffer.**9.10.3 Selection with respect to corrosion and mechanical strength**

Selection of the material for an earthing conductor should take into account compatibility with the material of the earth electrode and, for a conductor installed in the ground, the corrosive effect of the soil. Recommended materials for the manufacture of earthing components are listed in BS EN 50164-2.

There are two aspects which should be considered regarding the corrosion resistance of an earth electrode or an earthing conductor: compatibility with the soil itself and possible galvanic effects when it is connected electrically to neighbouring metalwork; the latter is most likely to come about when the earthing system is bonded to exposed metal structural components.

Electrodes, being directly in contact with the soil, should be of materials capable of withstanding corrosion (chemical or biological attack, oxidation, formation of an electrolytic couple, electrolysis, etc.). They should be able to resist the mechanical influences during their installation as well as those occurring during normal service. Steel embedded in concrete foundations and steel piles or other natural earth electrodes may be used as a part of the earthing system. Mechanical strength and corrosion considerations dictate the minimum recommended dimensions for earth electrodes given in Table 11 (from BS EN 50164-2).

Solid copper rods should be used in soft ground or ground which is highly corrosive (e.g. it has a high salt content), whereas electroplated steel may normally be used when mechanical driving is necessary due to the depth required or hardness of the ground.

Steel rods with a copper cable attached near to their points should be used when rods are required to be driven to depths of many metres in areas of high soil resistivity; eventually the steel rod will corrode away leaving the cable as the earth electrode.

Earthing and bonding conductors made of steel should be provided with appropriate and suitable protection against corrosion.

The calculation of the cross-section of the earthing conductors or earth electrodes should be calculated depending on the value and the duration of the fault current, see BS 7671:2008, Section 543 and 9.11 of this standard.

The final temperature should be chosen taking into account the material and the surroundings. Nevertheless, the minimum cross-sections stated in BS EN 50164-2 should be considered as listed in Table 11.

Table 11 Material, configuration and minimum cross-sectional area of air termination conductors, air termination rods, earth lead-in rods and down conductors

Material	Configuration	Minimum cross sectional area <sup>A)</sup>	Comments
Copper	Solid tape	50 mm <sup>2</sup>	2 mm min. thickness
	Solid round <sup>E)</sup>	50 mm <sup>2</sup>	8 mm diameter
	Stranded	50 mm <sup>2</sup>	1.7 mm min. diameter of each strand
	Solid round <sup>F,G)</sup>	200 mm <sup>2</sup>	16 mm diameter
Tin plated copper <sup>B)</sup>	Solid tape	50 mm <sup>2</sup>	2 mm min. thickness
	Solid round <sup>E)</sup>	50 mm <sup>2</sup>	8 mm diameter
	Stranded	50 mm <sup>2</sup>	1.7 mm min. diameter of each strand
	Solid round <sup>F,G)</sup>	200 mm <sup>2</sup>	16 mm diameter
Aluminium	Solid tape	70 mm <sup>2</sup>	3 mm min. thickness
	Solid round	50 mm <sup>2</sup>	8 mm diameter
	Stranded	50 mm <sup>2</sup>	1.7 mm min. diameter of each strand
Aluminium alloy	Solid tape	50 mm <sup>2</sup>	2.5 mm min. thickness
	Solid round	50 mm <sup>2</sup>	8 mm diameter
	Stranded	50 mm <sup>2</sup>	1.7 mm min. diameter of each strand
	Solid round <sup>F)</sup>	200 mm <sup>2</sup>	16 mm diameter
Galvanized steel <sup>C)</sup>	Solid tape	50 mm <sup>2</sup>	2.5 mm min. thickness
	Solid round	50 mm <sup>2</sup>	8 mm diameter
	Stranded	50 mm <sup>2</sup>	1.7 mm min. diameter of each strand
	Solid round <sup>F,G)</sup>	200 mm <sup>2</sup>	16 mm diameter
Stainless steel <sup>D)</sup>	Solid tape <sup>H)</sup>	50 mm <sup>2</sup>	2 mm min. thickness
	Solid round <sup>H)</sup>	50 mm <sup>2</sup>	8 mm diameter
	Stranded	70 mm <sup>2</sup>	1.7 mm min. diameter of each strand
	Solid round <sup>F,G)</sup>	200 mm <sup>2</sup>	16 mm diameter

A) Allowable tolerance: -3%.

B) Hot dipped or electroplated; minimum thickness coating of 1 µm.

C) The coating should be smooth continuous and free from flux stains with a minimum weight of 350 g/m<sup>2</sup> for solid round material and 500 g/m<sup>2</sup> for solid tape material. The coating can be measured in accordance with EN ISO 1460 with a sample length of approximately 200 mm. The coating can be measured also in accordance with EN ISO 1461:1999 with a sample length of approximately 200 mm.

D) Chromium ≥ 16%; Nickel ≥ 8%; Carbon ≤ 0.07%.

E) 50 mm<sup>2</sup> (8 mm diameter) may be reduced to 28 mm<sup>2</sup> (6 mm diameter) in certain applications where mechanical strength is not an essential requirement. Consideration should in this case, be given to reducing the spacing of the fasteners.

F) Applicable for air termination rods only. For applications where mechanical stress such as wind loading is not critical, a 10 mm diameter, 1 m long maximum air termination rod may be used.

G) Applicable for earth lead-in rods only.

H) If thermal and mechanical considerations are important then these values should be increased to 78 mm<sup>2</sup> (10 mm diameter) for solid round and 75 mm<sup>2</sup> (3 mm minimum thickness) for solid tape.

I) It is not necessary to detail any specific measuring techniques, as the dimensions of all conductors, plates, rods, etc. shown in the table are not critical.

The current carrying capability of the type of joints used (especially bolted joints) should also be taken into account. Reference should be made to BS EN 50164-2 for minimum earthing conductor and earth electrode dimensions.

### 9.11 Selection of a material for an earth electrode or a buried uninsulated earthing conductor

Although the material does not affect the earth resistance of an electrode, care should be taken to select a material that is resistant to corrosion in the type of soil in which it will be used. Some recommended materials for the manufacture of earthing components are listed in Table 12.

There are two aspects which should be considered regarding the corrosion resistance of an earth electrode or an earthing conductor: compatibility with the soil itself and possible galvanic effects when it is connected electrically to neighbouring metalwork; the latter is most likely to come about when the earthing system is bonded to exposed metal structural components.

Table 12 Recommended materials for the manufacture of earthing components (1 of 2)

Materials and processes	BS		BS EN	
	BS no.	Grade or type	BS EN no.	Designation
<b>Ingots for cast components</b>				
Leaded gunmetal			1982:2008	CB490K, CB491K
Aluminium silicon bronze	1400	AB3 [no equivalent in EN 1982]	1982:2008	CB331G,
Aluminium alloy			1780-1:2002	EN AB-44000, EN AB-42000
Cast iron			1561:1997	
Malleable iron			1562:1997	
<b>Forgings and stampings (hot and cold formed)</b>				
Copper			12165:1998, 12420:1999	CW004A, CW008A, CW024A
Aluminium			586-2:1994	EN AW-6082-T6
Steel	PD 970:2005	All grades	PD 970:2005 provides a guide to relevant ENs.	
<b>Pressings and fabrications (from strip, coil, foil and sheet)</b>				
Annealed copper			1652:1998	CW004A, CW006A, CW008A, CW024A
Aluminium			485-2:2007	EN AW-6082-T6
Stainless steel	1449-2:1991	316S11	10088-1:2005	1.4404
Steel (for galvanizing)	1449:1991 (all parts)	All relevant grades (see BS 1449-1.1:1991 for guidance).	10025-2:2004	S275
<b>Bars, rods and tubes (for machined components and fittings)</b>				
Copper, hard drawn or annealed	2871-1:1971, 2871-2:1972, 2874	C101, C102, C103	12449:1999, 12163:2011, 12167:2011	CW006A, CW023A, CW024A
Copper silicon			12163:2011	CW116C
Phosphor bronze			12163:2011	CW451K
Aluminium bronze	2871-3:1972	CA102	No equivalent	
Aluminium	1474:1987	6082-TF	755-2:1997	EN AW-6082-T6
Steel (for general use)	PD 970:2005	All grades	PD 970:2005 provides a guide to relevant ENs.	
Steel (for galvanizing)	PD 970:2005	All grades	PD 970:2005 provides a guide to relevant ENs.	
Stainless steel (general use)	PD 970:2005	325S31 316S11	10088-1:2005	1.4404

Table 12 Recommended materials for the manufacture of earthing components (2 of 2)

Materials and processes	BS		BS EN	
	BS no.	Grade or type	BS EN no.	Designation
Stainless steel (austenitic)	PD 970:2005	325S11 325S31	10088-1:2005	1.4301
<b>Nuts, bolts, washers, screws, rivet fixings and internal dowels in earth rods</b>				
For use on copper: Phosphor bronze Copper silicon			12163:2011	CW451K CW116C
For use on aluminium: Aluminium alloy Stainless steel Galvanized steel (see Note 2)	1473:1972	6082-T6	10263-4:2001	All grades
<b>Solid rounds, flats and stranded conductors</b>				
Copper Annealed copper Hard drawn copper Copper (stranded) Copper (flexible) Hard drawn copper strand Copper cadmium	2873:1969	C108	13601:2002 (insulated) 60228:2005	CW005A, CW008A Plain or metal-coated annealed, at permitted resistivities
Aluminium Aluminium strip/rod Aluminium Aluminium alloy Aluminium (steel reinforced)	215-2:1970	1350, 6101A Insulated As specified	485-2:2007 (insulated) 60228:2005	EN AW-6082-T6 All grades
Steel Galvanized steel (see Note 2) Galvanized strip (see Note 2)	1449 (all parts)	All relevant grades (see BS 1449-1.1 for guidance).	10025-2:2004	S275

**NOTE 1** Some of the BS standards and designations listed in this table are likely to be superseded by their European equivalents during the life of this British Standard. For current information please contact the Technical Information Group at BSI.

**NOTE 2** The recommended finish is galvanized in accordance with BS 729, which has to be done after manufacture or fabrication.

**NOTE 3** Stainless steel in contact with aluminium or aluminium alloys is likely to cause additional corrosion to the latter materials (see PD 6484). It is therefore important to take protective measures such as the use of inhibitors.

**NOTE 4** Copper alloys, other than those listed above, are permissible as long as they have a minimum copper content of 70% and similar tensile properties.

**NOTE 5** The use of hard drawn copper is advised for earthing applications.

## 9.12 Earthing of sheath and/or armour of cables

### 9.12.1 Three-core cables

A modern high voltage power cable is generally provided with a polymeric insulating oversheath; the sheath or armour of a solid type cable should be directly earthed at its terminations, and the cable sheaths should also be bonded across the joints. The earth connections of pressure type cables should generally be made via a removable link in a lockable box to permit periodic testing of the oversheath insulation. The joints should be insulated from earth and the sheaths should be bonded across the joints. The need to make such a test means that insulating glands should be provided at the cable termination boxes of transformers, switchgear, etc. and at cable sealing ends or joints.

### 9.12.2 Single-core cables

#### COMMENTARY ON 9.12.2

*A voltage is induced along the length of both the metallic sheath and the armour of a single-core cable carrying a.c. Except in the presence of ferromagnetic materials, the open-circuit value of this voltage does not depend upon the material (e.g. lead, aluminium, copper) since it arises from a single-turn inductive coupling with the cable live conductor. However, the differing conductivities of differing materials affects the current which flows if a complete circuit were available.*

*The more common situation is where the sheaths or armour of single-core cables are permanently connected to each other and to the circuit protective conductor at both ends of the run. Repeating such connections at intermediate points along a run does not affect the result. This is usually referred to as solid bonding. As a result, any voltage between the sheath or armour and earth along the run and at the ends is small and usually of negligible significance regarding safety. Such induced voltages, and the earth currents that result, are more important when there are significant harmonics in the line currents, and can be very important in respect of electromagnetic interference (e.m.i.). The principal adverse effect of solid bonding is the reduction in cable current carrying capacity, due to the circulating currents, and the consequential power losses in the sheaths or armour. A secondary and beneficial effect is a small reduction in circuit impedance and line voltage drop.*

Where it is important to achieve the best possible current carrying capacity, single point bonding may be used where the sheaths or armour at one end of the cable are left unbonded. Care should be exercised to avoid fortuitous connections at any other point. The penalty in using this method is that adequate and reliable sheath or armour insulation should be ensured, and the magnitudes of the sheath or armour voltages should be limited to safe values. In addition to the shock risk, the effect of corrosion should be considered. Except in very wet situations, an undamaged outer plastics sheath may usually be assumed to provide adequate protection against corrosion due to either sheath or armour voltages to ground. This longitudinal voltage may be calculated by reference to suitable text books, but the exercise is seldom justified for LV installations.

*NOTE A rule-of-thumb is that a longitudinal voltage with respect to single-point bonding of about 0.5 V is developed per 100 A per 100 m for cables in trefoil formation, and about 2.5 times this value for an outer cable in flat spaced formation. From this, it is clear that for LV cables there will seldom be any difficulty in meeting the BS 7671:2008+A1 requirement that sheath voltage to earth does not exceed 25 V at full load. Where a single-core LV circuit is designed to meet the voltage drop requirement of BS 7671:2008+A1, the sheath or armour voltage will always be at less than 25 V under full load conditions. It follows that low voltage single-core cables do not normally require any special sheath earthing arrangements.*

It is essential to avoid the use of both steel wire or tape armouring, and of ferrous ducts or conduits which enclose single cables. Non-ferrous gland plates are recommended at single-core cable terminations. Bonding and earthing at both ends of multiple runs of single-core cables are usually recommended.

Under fault conditions, longitudinal sheath or armour voltages are proportionately much higher, (perhaps 15 to 20 times), so it is essential that appropriate measures are taken to provide protection against electric shock, and the insulation at terminations should be adequate to avoid breakdown or flashover.

Different recommendations apply to HV single-core cables, since they can be considerably longer and the sheath to earth voltages on single-point bonded cables correspondingly higher. The reduction in current carrying capacity with solidly bonded sheaths or armour is often less acceptable and it may be considered necessary to resort to single-point bonding. For this to be effective, the cables should have insulating outer sheaths throughout their lengths if they are buried, or be secured in insulating cleats where they are open to the air. Consideration concerning possible deterioration may be necessary in respect of bitumen or hessian which have to serve for long periods.

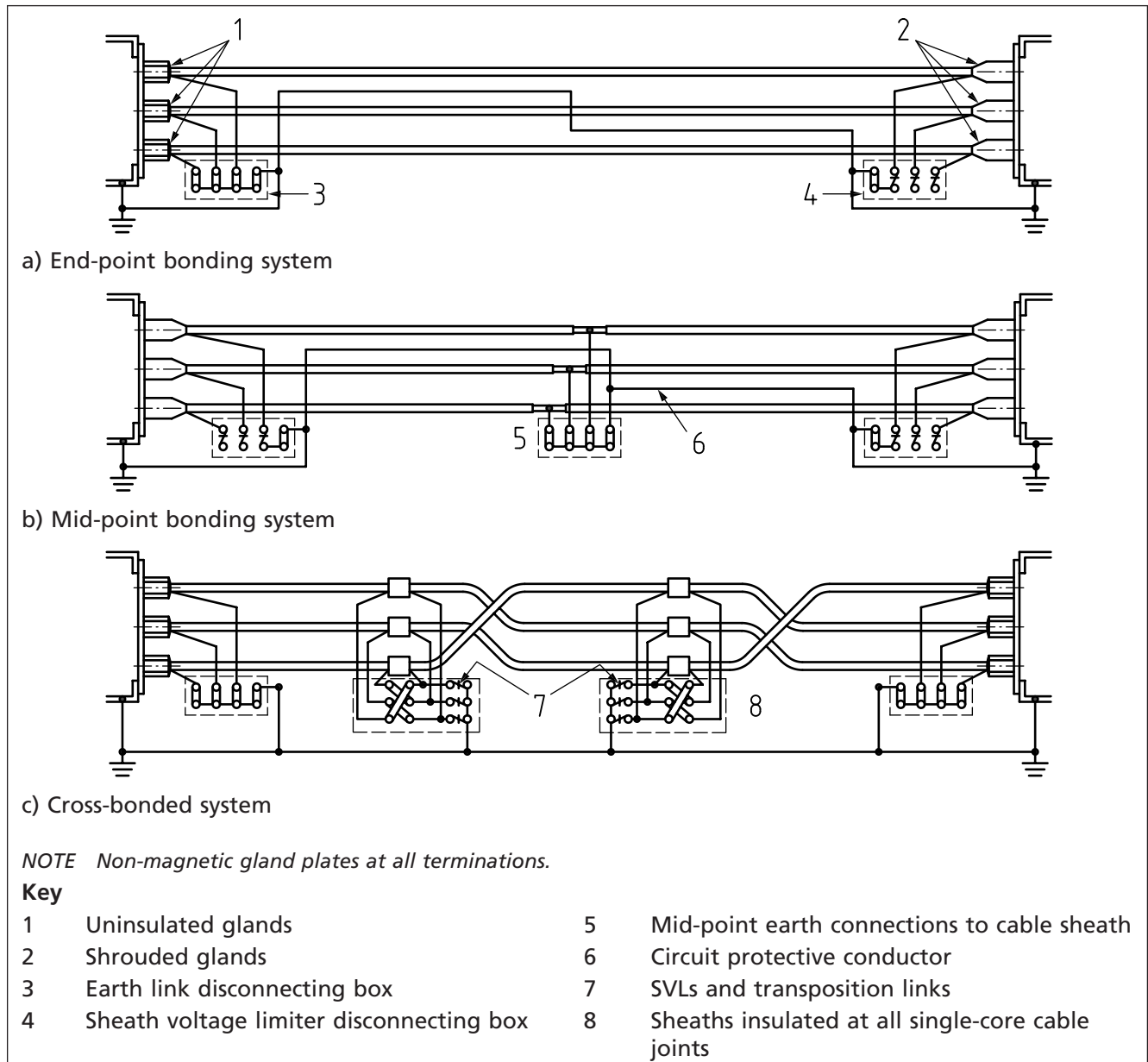
Although running cables in trefoil formation reduces the sheath to earth voltage, since the magnetic flux of the cores is to some extent self-cancelling, this formation may not be practicable for high voltage, high current circuits where the cables have to be spaced some distance apart to obtain adequate heat dissipation. This arrangement increases the sheath to earth voltage, and there are three methods of bonding that may be used for such installations, as follows.

- a) *End point bonding*, where all sheaths are bonded and earthed at one termination while at the other termination each sheath is insulated and connected to earth via a sheath voltage limiter (non-linear resistor) usually chosen to "conduct" at any voltage exceeding 65 V (which is the accepted maximum sheath to earth voltage for HV systems). Link disconnecting boxes are necessary to provide sheath insulation test facilities, and all metalwork not directly connected to earth has to be insulated. Since the standing voltage depends directly on the line current and the cable length, the maximum length should be approximately 500 m. Due to the discontinuity of the cable sheaths, an independent protective conductor is necessary between the circuit terminations. Its size will depend on the earth fault protection applied to the circuit. Figure 17 shows that in the event of a core to sheath insulation failure anywhere on the single-core cables, the fault path includes the test links [in Figure 17c)], also the transposition links] and the bonding connections from the cable glands to link boxes. The protective conductors and connections should be sized according to the proportion of prospective earth fault current that they are likely to carry under fault conditions.
- b) *Mid-point bonding* may be used, to double the permissible cable run, This is basically the same as end point bonding except that at both terminations the sheaths are insulated and connected to earth via test-link boxes and sheath voltage limiters. The earthing and bonding position for all sheaths is at the mid-point of the run. As with end point bonding, all metalwork not directly earthed at the mid-point has to be insulated and an independent protective conductor connected between the terminations [see Figure 17b)].
- c) For longer cable runs, cross-bonding has no restriction on permissible length between terminations. With this method, the sheaths at both terminations are connected via test-link boxes to earth, and the cable run is divided into multiples of three separate and equal lengths, each



up to 500 m. At the section joints, each cable sheath is insulated from its continuation, and the six insulated sheath connections are transposed in rotation, in pairs, so that on completion, there are three continuous earth connections via the sheaths between the terminations. Due to the transposition of the phases, the resultant sheath voltage to earth is minimal, and does not anywhere exceed 65 V. (The voltage is unlikely to be low because, due to deviations in the route, variations in cable spacing at joint bays, etc., there will not be complete symmetry and total cancellation will not result.) The design of such systems and their accessories is highly specialized and appropriate advice should be obtained.

Figure 17 Simplified illustration of single-core cable sheath bonding systems





## 10 Inspection and testing of the earthing system

### 10.1 Safety

Safety precautions should be taken whilst testing earthing arrangements. Making an installation (including substations) “dead” may not make the earthing system ‘dead’; voltages can be impressed from adjacent substation (via LV neutrals and cable sheaths, etc.) due to faults and switching operations.

Precautions that should be taken include:

- a) *Competence.* All work should be carried out under the control and direction of a competent person. All staff involved in the testing procedure should be instructed persons (particularly they should not touch leads or terminations during testing, except as instructed). Particular attention should be given to supervision of the test leads where they are laid across land accessible to the public or livestock.
- b) *Lightning.* Work should not start or continue if there is lightning activity (visible or audible) and if lightning risk warning has been issued, likely to affect the network connected to the earthing arrangements. Work should not take place if fault switching is in progress on associated networks; this makes it necessary for the competent person to contact the control to agree testing can take place.
- c) *Personal protective equipment.* Introducing earth electrodes (extraneous-conductive-parts) into an otherwise bonded earthing arrangement can result in high touch voltages. Consequently appropriate insulated footwear, fire-retardant clothing and insulated gloves (7.5 kV) should be worn during testing.
- d) *Test equipment.* To ensure operator safety and consistency of performance on earthing systems all test equipment should be selected to conform to EN 61010 Installation Category IV for safety and BS EN 61557 for performance. If other equipment is used it should provide no lesser degree of safety and performance. Insulated test leads should be suitably rated, and be of sufficient length and strength to pull out along the test route. Plug-in connectors on the leads should have shrouded contacts so as to prevent inadvertent contact with a remote earth (when unplugged). The voltage and current leads should be of different colour to prevent confusion when connecting to the test set. The continuity of all leads should be checked prior to use. An insulated mat large enough for the test equipment and operator should be available and used when testing.
- e) *Test route.* The test route should be selected to be as straight as possible, whilst minimizing any risks. Wherever possible, the route should not cross over busy roads or footpaths in frequent use, unless suitable precautions and appropriate signs, etc., are in place. Where test leads are required to pass through fields containing livestock, they should be continually supervised to avoid risk to the animals or damage to the leads. Where long test leads are supplied coiled they should, wherever possible, be unwound fully prior to tests commencing, so reducing the inductance of the lead and potential measurement errors. Test leads should preferably not be run parallel with, overhead power lines for any significant length. A record should be made of the test route and probe positions so that comparisons can be made in the future.
- f) *Communication.* The competent person should remain in constant communication with staff that are placing, connecting or disconnecting test leads remote from the testing point.
- g) *Testing for voltages on earth system.* Prior to any earth test, it is necessary to make sure that no significant stray voltages are present on the earth under test. An approved voltage detector is preferred. Some earth test

instruments incorporate a voltage test facility which may be used. However, in either case safe working practices are essential to prove the correct operation of the detector before use and to ensure no hazardous voltages prevail. On overhead poles an HV indicator such as an "Edgecomb" or equivalent tester should be used to confirm no voltages exist on the HV earth electrode. This test is important on overhead systems because if the earth is severed at the base of the pole any HV faults on the pole are unlikely to be cleared by the main protection and so could give rise to a significant voltage on the earth to be tested.

## 10.2 Measurement of soil resistivity

### 10.2.1 General

The resistance to the earth of any earth electrode may be determined by the resistivity of the surrounding soil.

*NOTE Resistivity depends upon the soil structure, strata, rock formation. The resistivity can change with:*

- a) depth;
- b) temperature;
- c) moisture content; and
- d) can vary from place to place.

The design of the earthing installation may be started with knowledge of the soil resistivity. For example, for a simple installation the type and number of earth electrodes may be estimated and the separation needed of HV and LV earths may be determined. For grid substations sample measurements should be taken at many locations around the site and at various electrode depths.

### 10.2.2 Soil resistivity – Wenner test

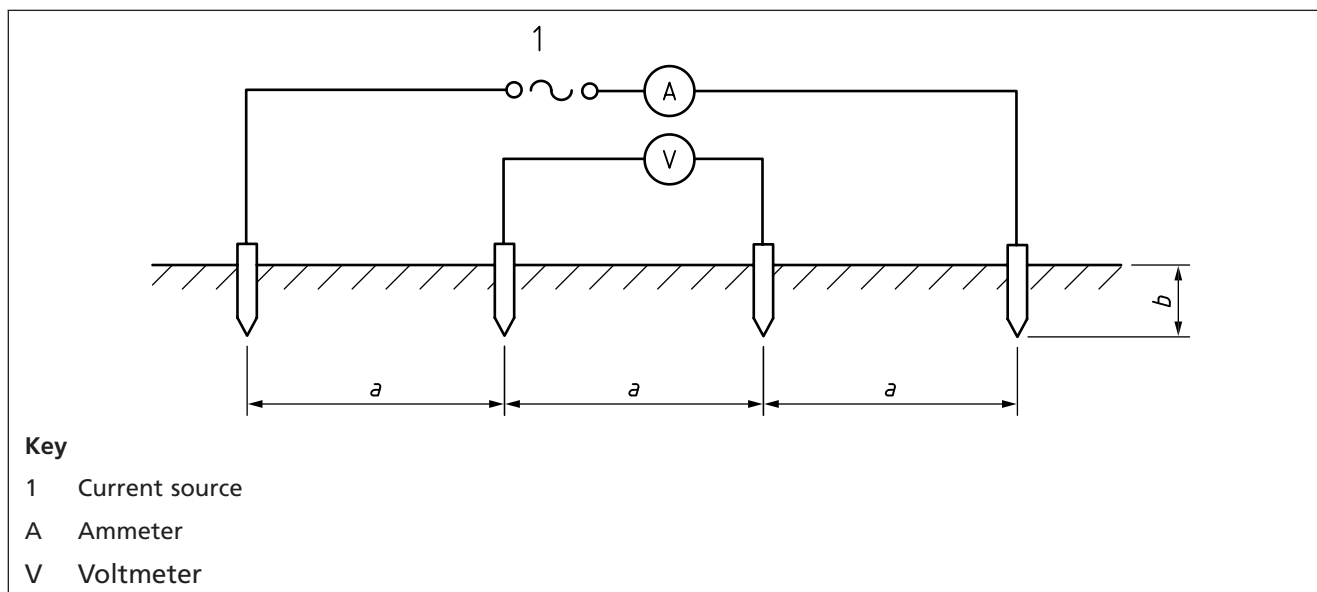
In a technique developed by Dr Frank Wenner of the U.S. Bureau of Standards (now NIST); it was demonstrated that provided the electrode depth  $B$  is small with respect to the spacing, the electrodes the average soil resistivity  $\rho$  to a depth  $a$  in  $\Omega\text{cm}$  may be found from:

$$\rho = 2\pi aR$$

where:

- $\pi$  is the constant 3.1416;
- $a$  is the distance between the electrodes in cm; and
- $R$  ( $V/A$ , see Figure 20) is the reading obtained from the Earth tester in ohms ( $\Omega$ ).

Figure 18 Measurement of earth resistivity



Four equally spaced test spikes should be driven to a depth of up to 1 m, the depth not exceeding 5% of their separation  $a$  (see Figure 18). It is important to ensure that their resistance areas do not overlap. Current should be passed between the two outer electrodes and the resistance  $R$  may be found as the ratio of the voltage between the inside electrodes to the current conducted through the outside electrodes.

The resistivity found applies to soil depth  $a$ , so by repeating the measurement with different values of  $a$ , the average resistivity to various depths may be found and the results indicates whether any advantage is to be gained by installing deeply driven electrodes in order to reach strata of a lower resistivity.

#### EXAMPLE

If the distance  $a$  between electrodes is 1 m the constant for the test setup is calculated as  $(2 \times 3.14 \times 100) \text{ cm} = 628 \text{ cm}$ .

If the instrument reads  $40 \Omega$  the earth resistivity is  $(40 \times 628) \Omega\text{cm} = 25\,120 \Omega\text{cm}$ .

It should be noted that environmental conditions such as temperature have an impact on earth resistivity with a corresponding decrease in resistivity as temperature rises.

### 10.2.3 Soil resistivity – One-rod test method

This is a simpler test than the full Wenner test described in 10.2.2 and may be used for distribution substations. The resistance of a single rod that is driven into the ground for a known depth should be measured. The resistance measurement and rod dimensions may then be used to calculate the average soil resistivity required to produce the measured resistance. The resistance measurement may be made by using the 61.8% method described in 10.3.3. The formula for calculating the resistance to earth  $R$  of a vertical rod given in 9.6.4 may be used:

$$R = \rho / 2\pi L [\log_e(8L/d) - 1] \text{ where:}$$

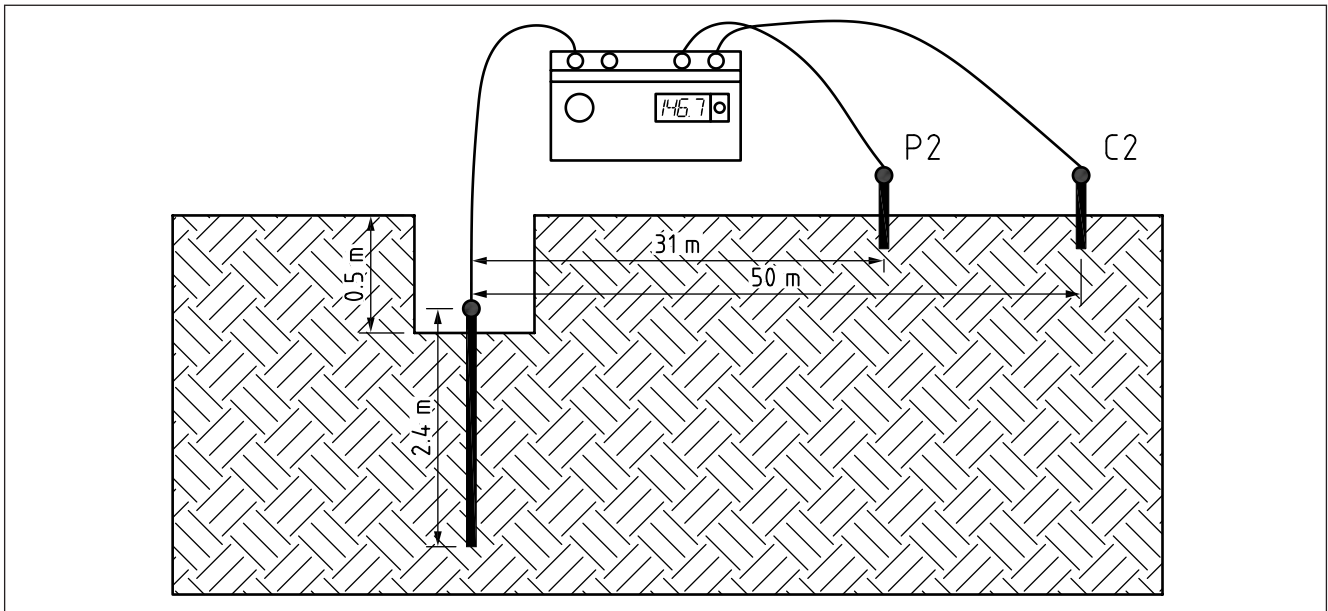
- $R$  is the resistance to earth of a vertical rod;
- $L$  is the length of the electrode, in metres (m);
- $d$  is the diameter, in metres (m);
- $\rho$  is the resistivity of the soil (assumed uniform), in ohm metres ( $\Omega\text{m}$ ).

Hence:

$$\rho = \frac{2\pi RL}{\left[ \log_e \left( \frac{8L}{d} \right) - 1 \right]}$$

For most distribution substations it is sufficient to drive the rod to a depth of 2.4 m and use this reading as the average soil resistivity value (see Figure 19).

Figure 19 One rod soil resistivity measurement



**NOTE** This method is particularly useful if HV and LV electrode systems are to be separated.

Once the average soil resistivity is known a separation distance between the HV and LV may be determined. The test rod may be incorporated into the final earthing arrangement.

### 10.3 Measurement of electrode system resistance to earth

#### 10.3.1 General

##### 10.3.1.1 Purpose

Electrode system resistance to earth should be measured in:

- a) *new installations* – to check that it is equal to or less than the design value; and
- b) *existing installations* – to check that it is equal to or less than the required value and has not substantially changed.

The resistance may be considered appropriate for:

- 1) protection to operated to disconnect the power source in the event of an earth fault; and
- 2) the duration and extent of the earth potential rise (EPR) during an earth fault to be within touch voltage limits.

### 10.3.1.2 Avoiding buried metal

For accurate results, the current flowing between the probe and the earth system being measured should return through the soil, not through any extraneous metalwork. It is important that the test electrode "line" avoids cables, metal pipes, buried structural steelwork and other earthing systems. The route may be surveyed with cable location equipment to attempt to locate buried metal. Where it is not possible to completely avoid buried metalwork, the current probe may be inserted so that current flowing back to the test electrode point is as near 90° as possible to any buried metal.

### 10.3.1.3 Accuracy

*NOTE Measurement of the resistance to earth of an earth electrode is not a simple matter. While certain fairly simple rules can be laid down, circumstances frequently arise which make it necessary to modify them. The resistance of an earth electrode is unique in that only the terminal provided by the electrode itself is definite, the other terminal of the resistance being theoretically at an infinite distance. There is no point in striving for a high degree of accuracy with such a measurement since, within the volume of such a resistance, there might be considerable non-uniformity in the soil and other disturbing features.*

An accuracy of 2% should be accepted, and accuracies of the order of 5% may usually be considered acceptable.

### 10.3.1.4 Selection of test method

A number of different test methods may be used to measure a site's overall resistance which are based on a fall of potential (FOP) technique. There are situations, typically in urban areas, where the earth electrode resistance may not be directly measured practicably. Alternative methods of assessing the earth resistance may include computer simulations carried out by earthing specialists. However, in general the following common test methods may be used.

#### a) *Fall of potential 61.8% test*

This test is suitable for simple earth electrode systems such as found in LV installations and in 11 kV distribution substations.

#### b) *Fall of potential 61.8% – Test using a clamp on CT*

This test procedure is similar to the standard 3 terminal FOP test and has the advantages that it may be used to measure the resistance of a system without disconnecting the earthing and can measure the resistance if an individual electrode (again without disconnecting).

#### c) *Fall of potential – Slope test*

This test is useful for large (i.e. > ??? KS to supply) earth electrode networks but may be used elsewhere if required.

## 10.3.2 Fall of potential technique

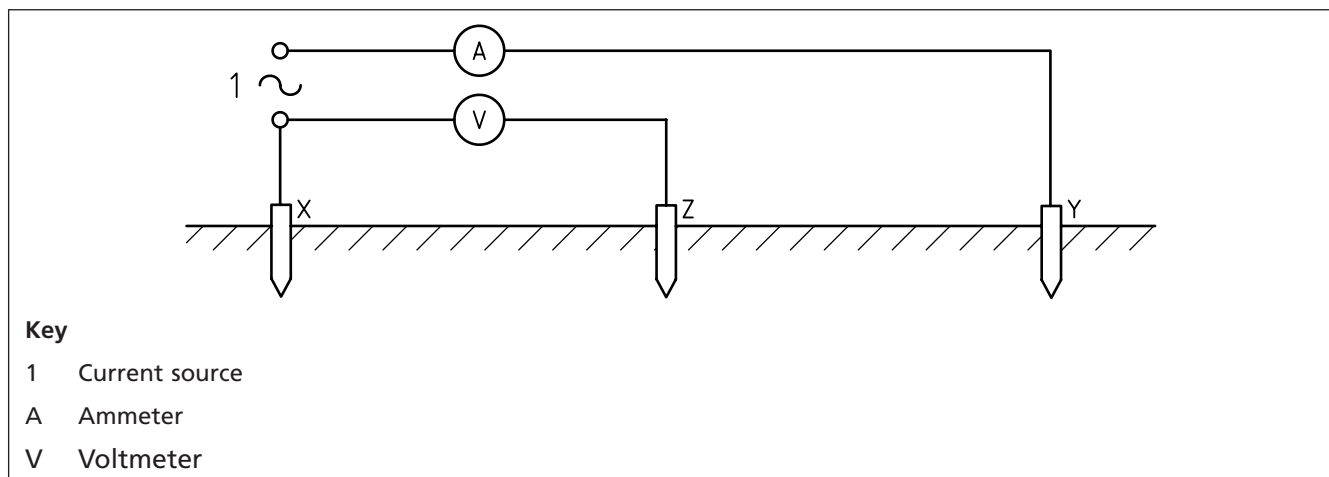
There are a number of different test methods that may be used to measure a site's overall resistance which are based on a fall of potential (FOP) technique.

*NOTE 1 In an earthing circuit, the current path is rapidly expanding with distance from the electrode. The net effect is that any significant resistance is concentrated in the area around the buried electrode. At a distance dependent upon the size and arrangement of the earth array, the rest of the earth offers little additional resistance such as to be of no practical consequence. A critical volume of soil surrounding the electrode determines its capabilities. In fairly standard environments, with moist, water-retentive soil, this volume is small (within six metres or so). However in difficult areas, with dry, sandy or rocky soil, the critical volume can extend for hundreds of metres. Rainfall contracts the field of influence and lowers resistance. Dry conditions and freezing expand and increase it.*

Either a three or a four terminal instrument may be used as shown in Figure 20. Three points of contact should be made with the soil: one is the connection to the electrode X under test; the other two are probes, one for supplying test current Y, and one Z for measuring potential at a given position in the soil. Current should be passed from Y to X through the soil.

The potential probe Z should be used to measure the voltage drop established by the test current against the local soil resistance. With current and voltage drop measured, Ohm's Law may be used to calculate the resistance.

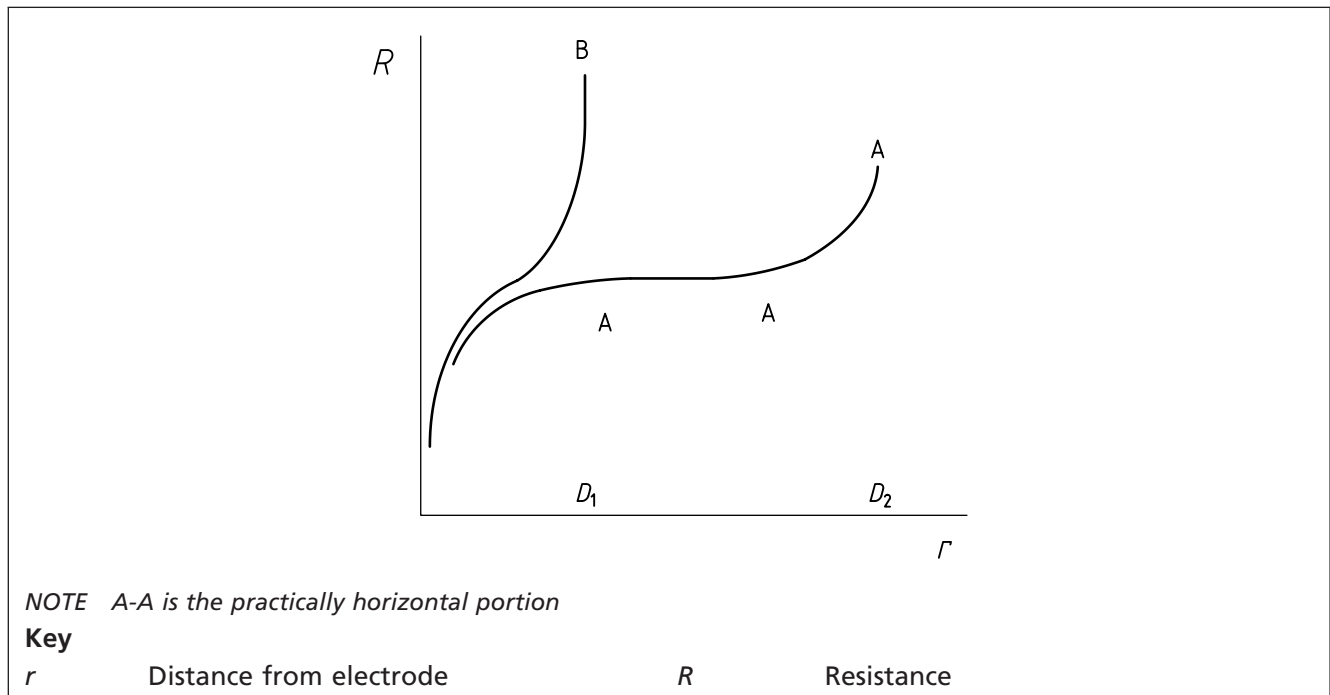
Figure 20 Measurement of earth electrode resist



*NOTE 2 To avoid polarization effects, commercially available testers commonly employ an alternating square wave current, at or near power frequency. A slight offset from multiples of the utility frequency enables the tester to base its reading on its own signal, without interference from utility harmonics.*

The potential probe Z should be moved at regular intervals, and a series of readings taken. These should be plotted and the result in homogeneous conditions is a rising curve where the probe is within the influence of the test electrode, followed by a levelling off; when approaching the influence of the current probe, an additional resistance is superimposed, so the curve rises again. The value recorded at the level point may be taken as the electrode/earthing system resistance (see curve A of Figure 21).

Figure 21 Earth resistance curves



*NOTE 3* If the current probe is not located at a sufficient distance, the two spheres of influence (test electrode and current probe) will coincide. Resistance will continue to rise, and there will be no way to tell from the graph how much resistance is associated with the test ground (see curve B).

If the characteristic shape of the graph is not achieved, the current probe should be moved farther out and the procedure repeated. In many instances space and time constraints make a level graph section impractical or difficult to achieve and alternative techniques such as the slope method (10.3.7) or the 61.8% (10.3.3) method may be used.

Tables are available relating current probe spacing to electrode dimensions but these should be regarded as a guide, not as a rule.

### 10.3.3 Fall of potential – 61.8% method

The 61.8% method is the recommended test procedure for small earth electrode systems where the electrical centre of the earth system is known, particularly ground mounted distribution substations and pole mounted transformers.

However, if the resistance of a particular electrode is required a CT clamp tester should be used (see 10.3.5) as any cables connected to the earth grid such will contribute to the connection with earth.

To obtain reliable readings the current probe and the voltage probe resistance areas should be sufficiently far apart to prevent the areas overlapping. The current and voltage probes should be in a straight line with the earth system under test.

A 90°/180° test should be carried out to check the results (see 10.3.4).

A 50 m separation between the earth grid and C2 probe may be used and is usually adequate for smaller earth systems and the resistance measured is equal to the true value when the voltage probe is positioned at 61.8% of the distance between the earth electrode and the current probe. If the earth electrode system is of medium size containing several rods, then these distances should be increased (see Table 13 for guidance).

Table 13 61.8% test probe spacing for various grid sizes

Maximum dimension of earth grid under test m	Distance to current electrode (C2) from centre of earth system m	50% distance m	61.8% distance to voltage electrode (P2) from centre of earth system m	70% distance m
Small or single electrode	50	25	31	37
5	100	50	62	70
10	150	75	93	105
20	200	100	124	140

To confirm the accuracy of the first reading the voltage probe P2 should be moved to the 50% and 70% positions and additional readings taken. If these readings are within  $\pm 5\%$  of the value from the 61.8% test then this first reading should be taken as the correct value (similar readings indicate that the measurements are being taken on the level part of the fall of potential curve, see curve A of Figure 21).

#### 10.3.4 90°/180° test

This technique should be used in conjunction with the slope (10.3.7) or 61.8% method (10.3.3) to verify the results obtained. The test equipment should be set up as shown in Figure 22.

The current probe C2 should be positioned as far as away from the earthing system under test as practicable and the voltage probe P2 should be positioned at an angle between 90°/180° to the current electrode route. A number of tests are carried out at say  $0.2 D_c$ ,  $0.4 D_c$  and  $0.6 D_c$ , where  $D_c$  is defined in 10.3.7. When the graph is drawn, it ought to level off, but never quite reach the true resistance value; by extrapolating, the true value may be estimated (see Figure 23).

*NOTE* Underground metallic objects or cables can produce a misshaped graph which might lead to false results.



Figure 22 90°/180° test

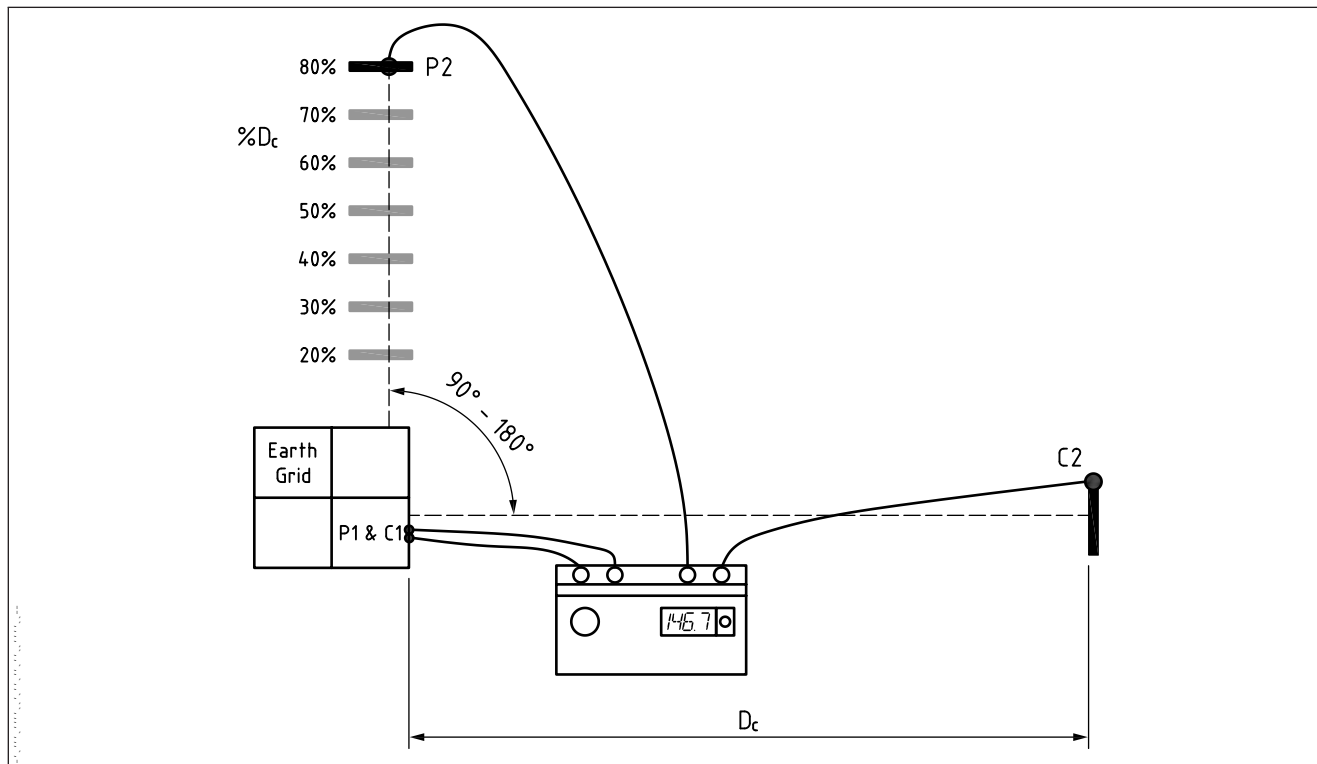
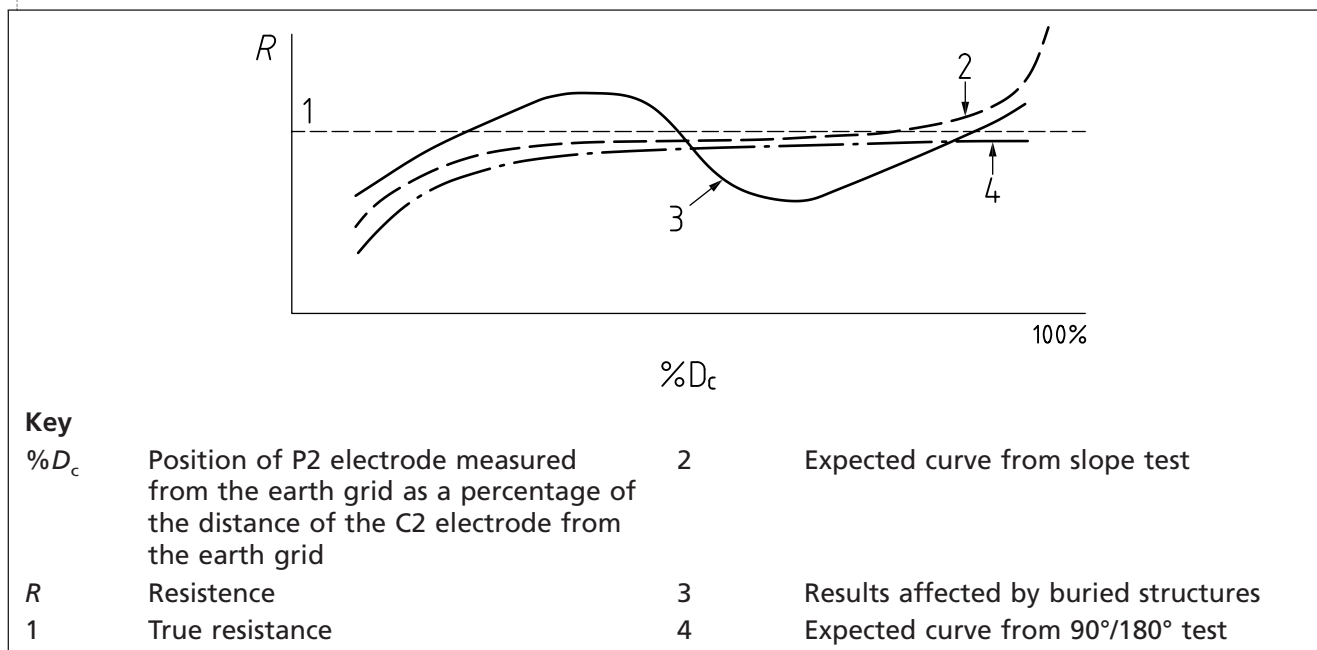


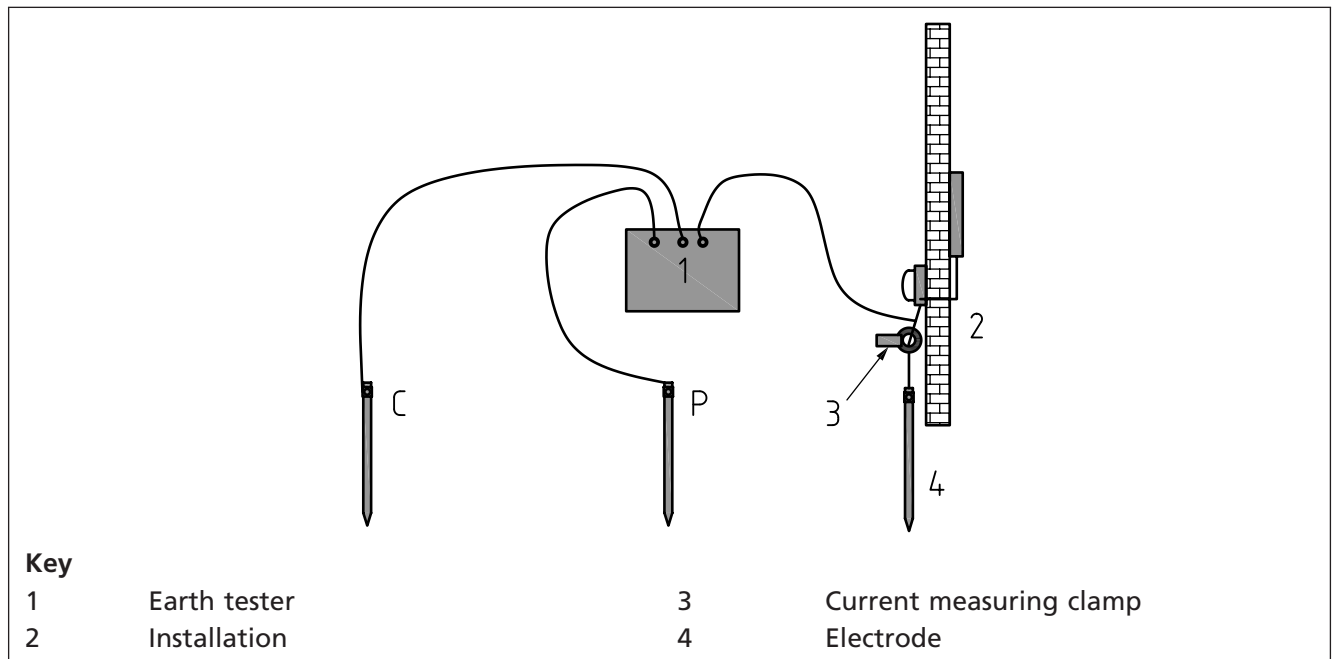
Figure 23 Typical 90°/180° test results



### 10.3.5 Fall of potential – 3-terminal tester and CT clamp

Certain test instruments that may be used incorporate a CT which clamps around the electrode to be tested (see Figure 24). The CT may be used to detect the test current returning via that specific electrode and allows the resistance of the electrode to be measured (using one of the standard fall-of-potential techniques) without disconnecting it from the rest of the earth system.

Figure 24 3-terminal tester with CT clamp



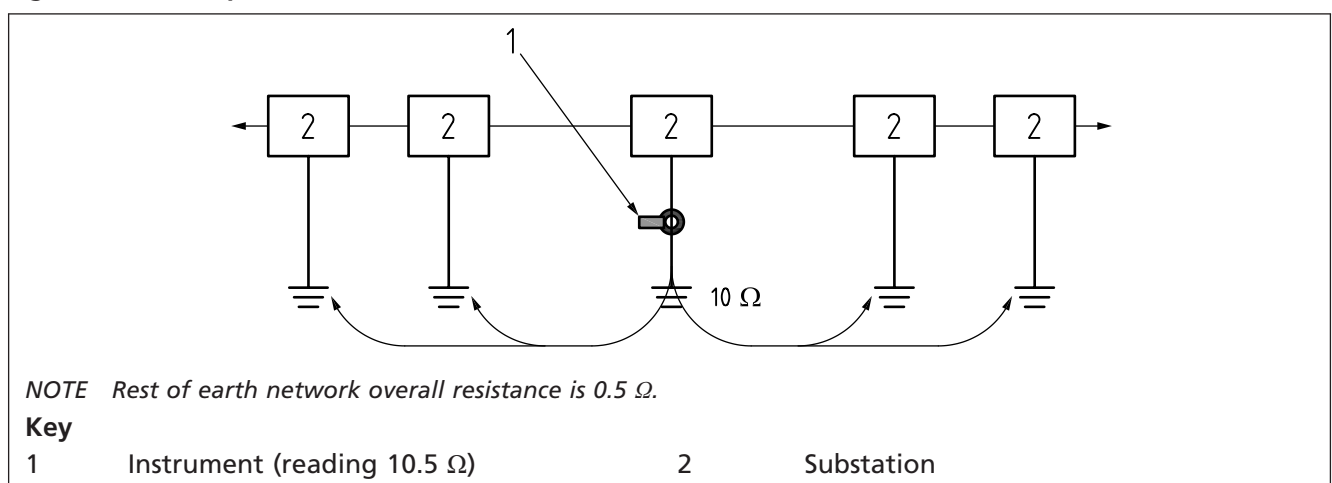
### 10.3.6 Hand-held clamp-on tester

This test may be used where an electrode is connected to an Earthing system with a much lower overall resistance than the electrode in question. In effect this test may be used to measure the loop impedance of the electrode under test and the rest of the earth system it is connected to.

This may be used to give an approximate resistance value for the electrode and when compared to previous results, gives an indication of any deterioration of the electrode. This test may also be used for measuring the resistance of deep high frequency earth rods when connected to a larger earth system.

*EXAMPLE* In Figure 25, if the electrode in question was actually  $10\ \Omega$  and the rest of the network was  $0.5\ \Omega$  then the reading given by the instrument would be  $10.5\ \Omega$ , which would be sufficiently accurate. However, if the electrode was  $1\ \Omega$  and the rest of the network also  $1\ \Omega$  then the reading would be  $2\ \Omega$  and hence the result is unreliable. This tester cannot be used on isolated electrodes as no alternative low resistance path exists to form the "loop".

Figure 25 Clamp-on tester



### 10.3.7 Fall of potential – Slope method

*NOTE* A large earthing grid, such as underlies a substation or encircles a transmission tower, has a commensurately large electrical field in the soil. Locating a current test probe beyond this influence can typically require several hundred feet, which might be quite impractical. Also the electrical centre of the earthing system (grid) cannot be known. If the current probe isn't far enough away, the plotted graph will show the rising resistance curve associated with the grid running directly into the curve from the test probe. The slope method permits an estimate of where the resistance of the electrode under test maximizes.

Critical data points should be measurements made with the potential probe placed at 0.2, 0.4, and 0.6 times the distance to the current probe, at points  $R_1$ ,  $R_2$ , and  $R_3$ , respectively. The current probe may be positioned somewhat arbitrarily, but it is best to obtain as much distance as the site will allow.

The slope coefficient  $\mu$  showing the rate of change of slope, may then be calculated from the formula:

$$\mu = \frac{R_3 - R_2}{R_2 - R_1}$$

A relationship may be derived between the slope coefficient  $\mu$ , the distance to the current probe  $D_c$  and the distance at which the potential probe would measure the true earth resistance  $D_{pt}$ . Equipment manufacturers provide tables from which the value of  $D_{pt}/D_c$  for various values of  $\mu$  may be taken. From this, using the known distance  $D_c$  to the current probe, the theoretical distance  $D_{pt}$  at which the potential probe should be placed may be calculated. The true resistance of the electrode may be taken from the graph (or by taking a reading at the distance  $D_{pt}$ ).

If the calculated  $\mu$  value is outside the range of the information provided by the manufacturers the current probe should be moved further out and the test repeated. Problems might arise from interference from buried cables, etc., in which case a different test "line" should be taken. If confirmation of test results is thought necessary a 90°/180° test (see 10.3.4) should be taken.

## 10.4 Maintenance/inspection of 11 kV substation earthing systems

### COMMENTARY ON 10.4

*The maintenance regime considered here comprises:*

- a) visual inspection carried out annually as part of the substation inspection; and
- b) routine maintenance as part of planned maintenance say every 5 years.

### 10.4.1 Visual inspection

The inspector should inspect above-ground earth conductors, connections, guards, etc., for evidence of corrosion, decay, signs of burning, vandalism or theft.

The inspector should visually check all earthing and bonding electrodes and connectors, particularly noting the condition of any bi-metallic connectors looking for corrosion damage and missing connections.

The inspection should include:

- a) the main HV earth electrode termination, normally connected either to the case of a transformer, HV switchgear or within the LV distribution board;
- b) the bonding connection between any plant items which are situated adjacent to each other;
- c) the LV earth termination, where this terminates at the substation;

- d) if the substation has separated HV/LV earthing, that the separation is maintained;
- e) the connection to any earth mats which are installed adjacent to 11 kV switchgear;
- f) the bonding connection to metallic fencing; and
- g) the bonding connection to any metal enclosure.

#### 10.4.2 Routine maintenance/examination

This should include visual inspection plus, where necessary, excavation to examine buried earth conductor, earth rods, and earth plates.

As part of the maintenance testing is carried out, the tests should include:

- a) resistance tests across joints using the micro-ohmmeter;
- b) checking the integrity of the bonding of all normally accessible metalwork (such as the tank of a transformer) to the substation earth or grid;
- c) measurement of the substation earth value (to be compared with the design specification); and
- d) for substations with segregated earthing, checking the integrity of the segregation.

Records of inspection/examination and testing should be taken and made available for subsequent maintenance visits.

The examination should be in four parts (a model inspection form is given in Table 15).

- 1) *Inspection.* The inspection under examination should cover the same items as listed in 10.4.1. However, at normal substation inspection, the inspector is only looking for obvious defects. Under inspection as part of the examination, the inspector should determine whether the conductor or connections are in a good enough state to last until the next examination. Where any real doubt exists, sections of the conductor and/or connections should be remade. The results of the inspection and any remedial work should be recorded.
- 2) *Joints.* A resistance measurement should be taken across all exposed accessible joints/connections using a micro-ohmmeter. The value should be compared with Table 14. Any joint where the resistance value is excessive should be broken down, cleaned and remade or replaced.

Table 14 Acceptable bonding readings within distribution substations

Equipment	Typical values expected	Max. acceptable values
Individual Joints (e.g. bolted connection to plant )	5 $\mu\Omega$ to 50 $\mu\Omega$	100 $\mu\Omega$
Between any two items of plant or equipment within 2 m of each other (i.e. touching distance apart)	200 $\mu\Omega$ to 2 500 $\mu\Omega$ (2.5 m $\Omega$ )	2 500 $\mu\Omega$ (2.5 m $\Omega$ )
Maximum resistance between any items within the whole substation	—	10 000 $\mu\Omega$ (10 m $\Omega$ )
Example resistance of 1 m length of 25 mm x 3 mm copper tape or 70 mm <sup>2</sup> copper conductor	200 $\mu\Omega$	—

**WARNING** The remaking or replacing of an existing joint can be a hazardous procedure even if the local plant has been made dead. Fault current can pass through the substation's earthing system from a remote earth fault. Approved procedures have to be used.

- 3) *Bonding checks.* The integrity of bonding of each item on site, as listed in 10.4.1 should be checked using a micro-ohmmeter and be compared with the values in Table 14.
- 4) *Substation earthing resistance.* On completion of all other testing the final check that should be carried out is the measurement of the substation earth values (HV and LV where appropriate). Where the HV and LV earths are separate then the resistance between the two earths should be measured as this gives an indication of the effective separation (see 5.8.3).

Table 15 Example of round mounted plant installation model inspection form

Items To Check	Damaged (Yes/No)	Corroded (Yes/No)	Missing (Yes/No)
Main H.V. earth termination			
Bonding connections between plant items			
LV neutral earth termination			
Earth mat connections			
Bonding connections metal enclosure			
Bonding connections to metallic fence			
Bonding connection to an associated customer's substation			
Inspector's name:			
Date of inspection:			

Annex A  
(informative)  
A.1

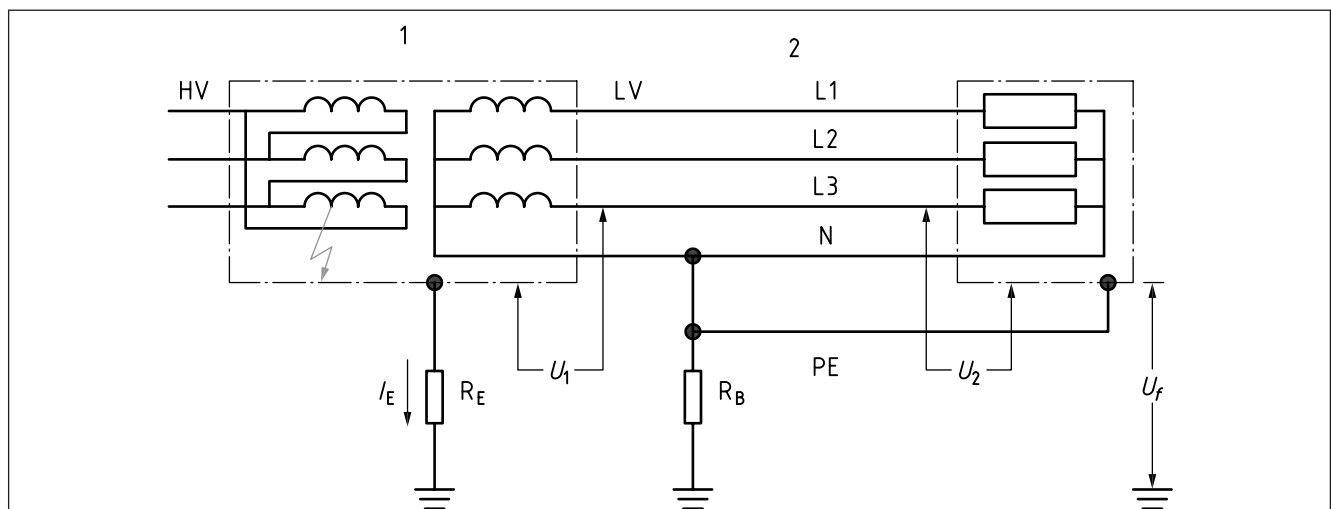
## Guidance on typical HV/LV interfaces

### Fault voltages and stress voltages

In the event of an HV fault to earth in a substation, the fault voltage and the stress voltages depend upon whether the HV equipment earth is separated from the LV neutral earth, see Figure A.1 and Figure A.2.

It can be seen that if HV equipment and LV neutral earths are common, a fault voltage  $U_f$  is imposed upon the LV installation between exposed-conductive-parts and Earth. If the earths are separated the fault voltage is zero. However, separating the earths requires open ground and is difficult other than in a rural environment.

Figure A.1 TN-S system with separate HV equipment and LV neutral earths



$$U_1 = R_E I_E + U_0, \quad U_2 = U_0, \quad \text{and} \quad U_f = 0$$

where:

- $I_E$  that part of the earth fault current in the high-voltage system that flows through the earthing arrangement of the transformer substation
- $R_E$  resistance of the earthing arrangement of the transformer substation
- $R_B$  resistance of the earthing arrangement of the low-voltage system neutral, for low-voltage systems in which the earthing arrangements of the transformer substation and of the low-voltage system neutral are electrically independent
- $U_0$  line-to-neutral voltage of the low-voltage system
- $U_f$  power frequency fault-voltage that appears in the low-voltage system between exposed-conductive-parts and earth for the duration of the fault
- $U_1$  power frequency stress-voltage between the line conductor and the exposed-conductive-parts of the low-voltage equipment of the transformer substation during the fault
- $U_2$  power frequency stress-voltage between the line conductor and the exposed-conductive-parts of the low-voltage equipment of the low voltage installation during the fault

**NOTE** The power frequency stress-voltage is the voltage that appears across the insulation of low-voltage equipment and across surge protective devices connected to the low-voltage system.

#### Key

1	Substation	2	LV installation
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#### A.4 Perimeter electrodes

Where possible, it is advisable to bury a perimeter electrode buried around the substation, immediately adjacent to the plinth. In some cases the perimeter electrode may be surface-mounted copper tape, fixed to the floor or at a low level around the internal wall. However, it is important to ensure a buried earth electrode passes in front of the switchgear to minimize touch potentials for the operator. If this cannot be achieved then the installation of metal earth mat gratings in front of the switchgear where the operator stands is advisable, with duplicate bonds to the main earth electrode.

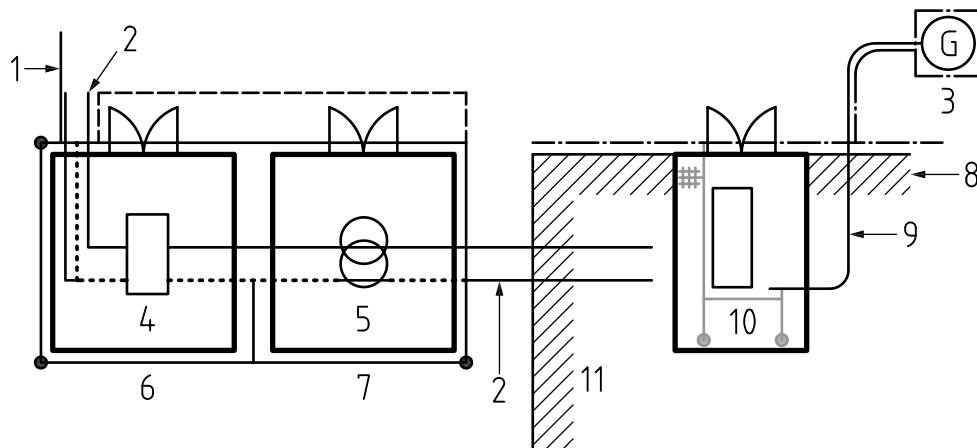
Within a building, the perimeter earth conductor may comprise surface mounted earth tape. It is advisable to bond the structural steelwork to the main earthing terminal.

#### A.5 Typical HV/LV earthing layouts

Figures A.3 to A.6 show typical earthing layouts for the HV/LV interface. These cannot be relied upon in the design of particular installations.



Figure A.3 Segregated HV and LV earthing

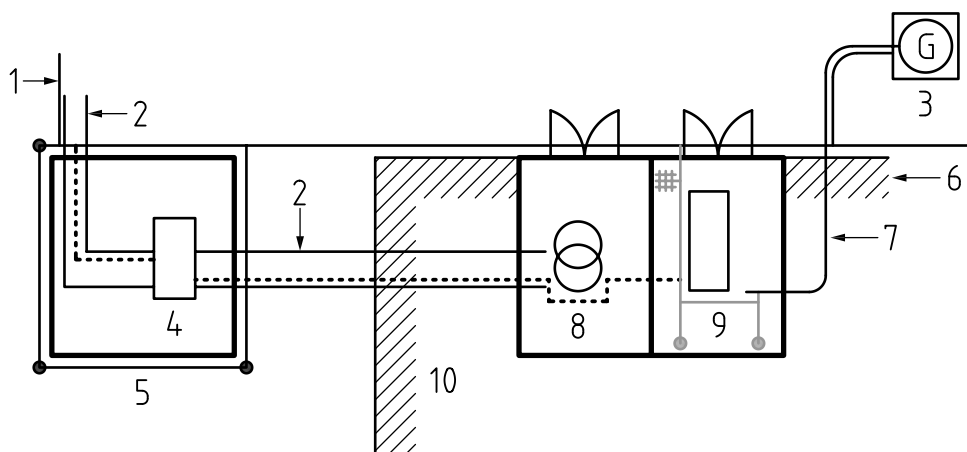


NOTE Typical switchroom layout with external HV supply. Supply companies' preferred method.

Key

#	Connection to rebar	—	HV earth (25 mm x 3 mm or 25 mm x 4 mm tape) at 0.6 m depth on edge of foundation distance increased to 0.5 m from foundation if enclosure is metal
---	LV earth (25 mm x 3 mm tape) buried at 0.6 m depth	---	Buried copper tape of 25 mm x 3 mm if doors are metal
—	Internal LV earth	●	3.6 m earth rods in pre-drilled holes through slab
-----	Copper tape for internal HV connections	●	2.4 m earth rods with test facilitation
1	HV earth in cable trench to provide required resistance	7	External Tx room
2	Trench or ducts	9	Rest of building
3	Generator located on roof or in basement	10	Cable from roof
4	HV switch	11	LV switch panel
5	Transformer	12	Main building
6	External HV switch		

Figure A.4 External HV switch supply



NOTE Typical substation layout with external HV switch. Supply companies' preferred method.

**Key**

#	Connection to rebar	—	HV earth (25 mm × 3 mm or 25 mm × 4 mm tape) at 0.6 m depth on edge of foundation distance increased to 0.5 m from foundation if enclosure is metal
—	Internal LV earth	●	3.6 m earth rods in pre-drilled holes through slab
- - - -	Copper tape for internal HV connections	●	2.4 m earth rods with test facilitation
1	HV electrode in trench (at appropriate length)	6	Rest of building
2	Trench or ducts	7	Cable from roof
3	Generator located on roof or in basement	8	Transformer
4	HV switch	9	LV switch panel
5	External HV switch	10	Main building

Figure A.5 Common external HV/LV interface to supply multiple buildings

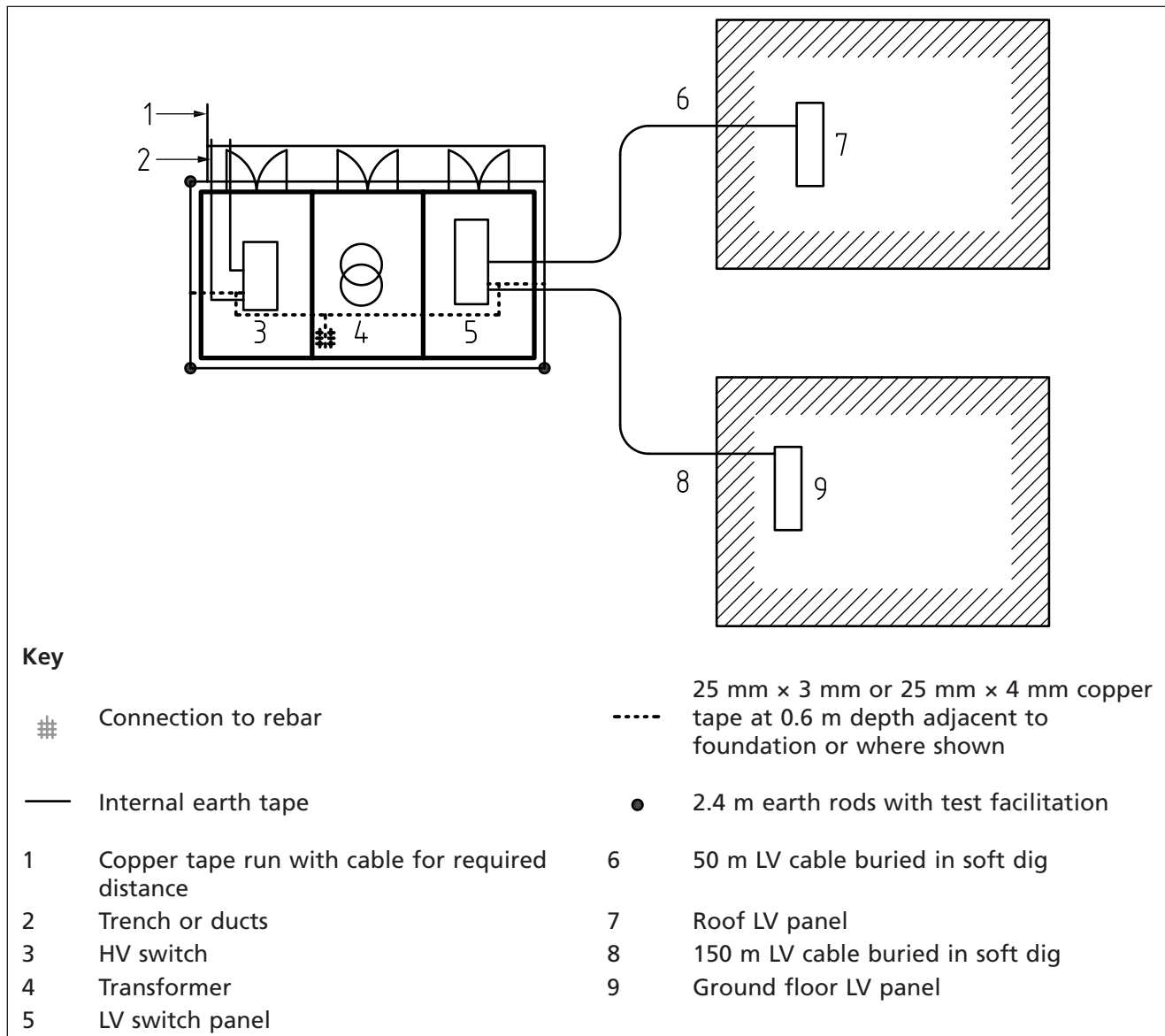
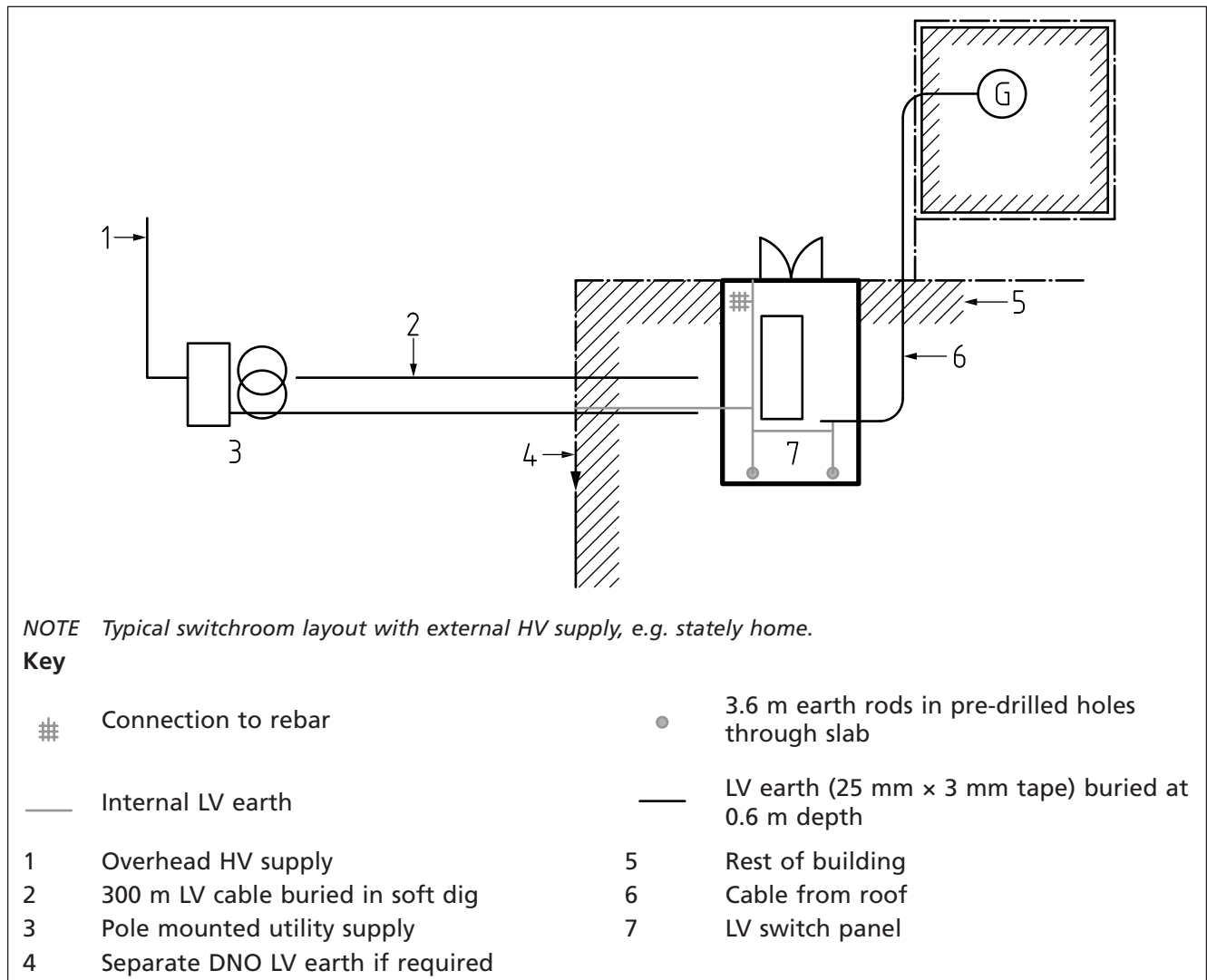


Figure A.6 External HV/LV interface and generator backup



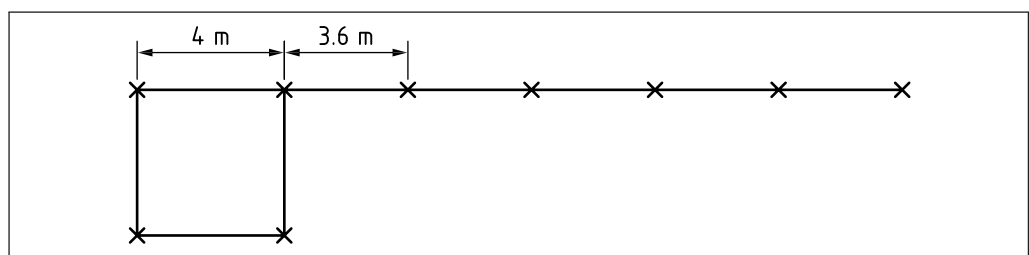
## Annex B (informative)

### Typical calculations for various types of earth electrodes for a small substation

**NOTE** See Clause 5 and Clause 9.

To estimate the resistance of an electrode system as Figure B.1 for a soil resistivity measured at  $400 \Omega\text{m}$ . If a layout as Table 2 is assumed: Table 2 advises that, for a soil resistivity of  $400 \Omega\text{m}$  that four 2.4 m basic earth rods plus five 2.4 m rods placed 3.6 m apart plus 18 m of horizontal electrode are used.

Figure B.1 Assumed electrode arrangement for a small substation with a soil resistivity of  $400 \Omega\text{m}$



Resistance of one vertical electrode is given by:

$$R = \frac{\rho}{2\pi L} \left[ \log_e \left( \frac{8L}{d} \right) - 1 \right]$$

where:

- R is the resistance of single rod or pipe, in ohms ( $\Omega$ );
- L is the length of rod, in metres (m);
- d is the diameter of rod or pipe, in metres (m);
- $\rho$  is the soil resistivity in ohm metres ( $\Omega\text{m}$ ).

If:

- $L = 2.4$  m;
- $d = 0.016$  m;
- $\rho = 100$   $\Omega\text{m}$ ;

$$R = 400 / 2\pi \times 2.4 [\log_e(8 \times 2.4 / 0.016) - 1] \Omega = 162 \Omega$$

Resistance of an hollow square, from Table 5, is given by:

$$R_n = R \left( \frac{1 + \lambda a}{n} \right)$$

where:

$$a = \frac{\rho}{2\pi R s}$$

where:

- R is the resistance of the rod in isolation, in  $\Omega$ ;
- s is the distance between adjacent rods, in m;
- $\rho$  is the resistivity of soil, in  $\Omega\text{m}$ ;
- $\lambda$  is a factor given in Table 4 or Table 5;
- n is the number of electrodes (as given in Table 4 or Table 5).

From Table 5:

$$\lambda = 2.71$$

then:

$$a = \frac{400}{2 \times \pi \times 162 \times 2.4} = 0.1637$$

and:

$$R_1 = 162 \left( \frac{1 + 3.61 \times 0.1637}{4} \right) \Omega = 64 \Omega$$

Resistance of a line of five electrodes, from Table 4, is given by:

$$\lambda = 2.54$$

then:

$$a = \frac{400}{2 \times \pi \times 162 \times 2.4} = 0.1637$$

and:

$$R_2 = 162 \left( \frac{1 + 2.54 \times 0.1637}{6} \right) \Omega = 38.2 \Omega$$

Resistance of a horizontal strip electrode is given by:

$$R = \frac{\rho}{P\pi L} \left[ \log_e \left( \frac{2L^2}{wh} \right) + Q \right]$$

where:

$L$  is the length of conductor, in metres (m);

$h$  is the depth of strip, in metres (m);

$w$  is the width of strip, in metres (m);

$\rho$  is the soil resistivity, in ohm metres ( $\Omega\text{m}$ );

$P$  and  $Q$  are the coefficients given in Table 6.

For the horizontal electrode in this example:

$L = 18$  m of conductor;

$h = 0.5$  m;

$w = 0.025$  m (25 mm  $\times$  3 mm);

$\rho = 400$   $\Omega\text{m}$ ;

$P = 2$  (Table 6);

$Q = -1$  (Table 6)

then:

$$R_3 = \frac{400}{2\pi 18} \left[ \log_e \left( \frac{2 \times 18^2}{0.025 \times 0.5} \right) + (-1) \right] \Omega = 38.2 \Omega$$

Resistance of two sides of the square perimeter electrode can also be found from the formula for the resistance of a horizontal strip electrode:

$$R = \frac{\rho}{P\pi L} \left[ \log_e \left( \frac{2L^2}{wh} \right) + Q \right]$$

In this example:

$L = 4$  m of conductor;

$h = 0.5$  m;

$w = 0.025$  m (25 mm  $\times$  3 mm);

$\rho = 400$   $\Omega\text{m}$ ;

$P = 4$  (Table 6);

$Q = 1.8$  (Table 6)

then:

$$R_4 = \frac{400}{4\pi 4} \left[ \log_e \left( \frac{2 \times 4^2}{0.025 \times 0.5} \right) + 1.8 \right] \Omega = 76.8 \Omega$$

The total resistance  $R_t$  is approximately given by:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{64} + \frac{1}{38.2} + \frac{1}{38.4} + \frac{1}{76.8} \Omega^{-1}$$

i.e.,  $R_t = 8.36 \Omega$ .

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