

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Low-voltage electrical installations –
Part 5-54: Selection and erection of electrical equipment – Earthing
arrangements and protective conductors**

**Installations électriques à basse tension –
Partie 5-54: Choix et mise en œuvre des matériels électriques – Installations
de mise à la terre et conducteurs de protection**



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**Low-voltage electrical installations –
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

LOW-VOLTAGE ELECTRICAL INSTALLATIONS –

Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors

FOREWORD

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This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC 60364-5-54 edition 3.1 contains the third edition (2011-03) [documents 64/1755/FDIS and 64/1766/RVD] and its amendment 1 (2021-04) [documents 64/2479/FDIS and 64/2481/RVD].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

International Standard IEC 60364-5-54 has been prepared by IEC technical committee 64: Electrical installations and protection against electric shock.

This third edition constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

- clarification of the definition of protective conductor;
- improved specification of mechanical characteristics of the earth electrode;
- introduction of earth electrode for protection against electric shock and lighting protection;
- annexes describing concrete-embedded foundation earth electrodes and soil-embedded earth electrode.

It has the status of a basic safety publication in accordance with IEC Guide 104.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The reader's attention is drawn to the fact that Annex E lists all of the "in-some-country" clauses on differing practices of a less permanent nature relating to the subject of this standard.

A list of all parts in the IEC 60364 series, under the general title: *Low-voltage electrical installations*, can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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INTRODUCTION

Clause numbering is sequential, preceded by the number of this Part. Numbering of figures and tables takes the number of this part followed by a sequential number, i.e. Table 54.1, 54.2, etc. Numbering of figures and tables in annexes takes the letter of the annex, followed by the number of the part, followed by a sequential number, e.g. A.54.1, A.54.2, etc.

To define a clear borderline between functional earthing and protective earthing the following explanations are given:

Functional earthing

- Functional earthing

If any connection of the functional earthing is interrupted, it does not impair any kind of protection or any kind of protective measure or protective provision provided for electrical safety. Therefore, its application mainly relates to:

- communication,
- measurement, and
- EMC as regards radiated disturbances and conducted high frequency disturbances.

- Protective earthing

If any connection of the protective earthing is interrupted, it impairs the protection or the function of a protective measure or protective provision provided for electrical safety.

Requirement for protective earthing are given in:

- IEC 60364-4-41 for protection against electric shock;
- IEC 60364-4-42 for protection against thermal effects;
- IEC 60364-4-44 for protection against conducted disturbances.

INTRODUCTION to Amendment 1

The main changes provided in this Amendment 1 are:

- clarification and necessary modifications to define a clear borderline between functional earthing and protective earthing (see INTRODUCTION);
- introduction of additional requirements for functional earthing and functional-equipotential-bonding for information technology systems and communication equipment (ICT).

LOW-VOLTAGE ELECTRICAL INSTALLATIONS –

Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors

541 General

541.1 Scope

This part of IEC 60364 addresses the earthing arrangements and protective conductors including protective bonding conductors in order to satisfy the safety of the electrical installation.

This document also includes requirements regarding earthing and equipotential bonding for information and communication technology (ICT) with the aim of:

- reducing the risk of electrical hazards for correct operation of these devices and the information and communication technology wiring;
- providing the telecommunication systems with a reliable signal reference plane that can improve resistance to electromagnetic interference (EMI) by reference to ISO/IEC 30129.

NOTE Examples of information and communication technology (ICT) include:

- DC supply networks (and systems) for supplying power to ICT equipment within a building;
- star-shaped private automatic branch exchanges (PABX) or their equipment;
- local area (communication) networks (LANs);
- fire and intruder alarms communication systems;
- building automation systems, e.g. direct digital control systems;
- systems for computer-aided manufacturing (CAM) and other computer-aided services;
- broadcast and communication technology.

541.2 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.

IEC 60364-4-41:2005, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock*

IEC 60364-4-44:2007, *Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*

IEC 60364-5-51:2005, *Electrical installations of buildings – Part 5-51: Selection and erection of electrical equipment – Common rules*

IEC 60417, *Graphical symbols for use on equipment* (available at <http://www.graphical-symbols.info/equipment>)

IEC 60439-2, *Low-voltage switchgear and controlgear assemblies – Part 2: Particular requirements for busbar trunking systems (busways)*

IEC 60445, *Basic and safety principles for man-machine interface, marking and identification – Identification of equipment terminals, conductor terminations and conductors*

IEC 61439-1, *Low-voltage switchgear and controlgear assemblies – Part 1: General rules*

IEC 61439-2, *Low-voltage switchgear and controlgear assemblies – Part 2: Power switchgear and controlgear assemblies*

IEC 60724, *Short-circuit temperature limits of electric cables with rated voltages of 1 kV ($U_m = 1,2$ kV) and 3 kV ($U_m = 3,6$ kV)*

IEC 60909-0, *Short-circuit currents in three-phase a.c. systems – Part 0: Calculation of currents*

IEC 60949, *Calculation of thermally permissible short-circuit currents, taking into account non-adiabatic heating effects*

IEC 61140:2001, *Protection against electric shock – Common aspects for installation and equipment*

IEC 61534-1, *Powertrack systems – Part 1: General requirements*

IEC 62305 (all parts) *Protection against lightning*

IEC 62305-3:2006/2010, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

541.3 Terms and definitions

For the purposes of this document, the terms and definitions of IEC 61140, together with the following definitions, apply.

Definitions used for earthing arrangements, protective conductors and protective bonding conductors are illustrated in Annex B and listed below:

541.3.1

exposed-conductive-part

conductive part of equipment which can be touched and which is not normally live, but which can become live when basic insulation fails

[IEC 60050-826:2004, 826-12-10]

541.3.2

extraneous-conductive-part

conductive part not forming part of the electrical installation and liable to introduce an electric potential, generally the electric potential of a local earth

[IEC 60050-825:2004, IEC 826-12-11]

541.3.3

earth electrode

conductive part, which may be embedded in the soil or in a specific conductive medium, e.g. concrete, in electrical contact with Earth

[IEC 60050-826:2004, 826-13-05, modified]

541.3.4

concrete-embedded foundation earth electrode

earth electrode embedded in concrete of a building foundation, generally in the form of a closed loop

[IEC 60050-826:2004, 826-13-08, modified]

541.3.5

soil-embedded foundation earth electrode

earth electrode buried in the soil under a building foundation, generally in the form of a closed loop

[IEC 60050-826:2004, 826-13-08, modified]

541.3.6

protective conductor

conductor provided for purposes of safety, for example protection against electric shock

[IEC 60050-826:2004, 826-13-22]

NOTE Examples of a protective conductor include a protective bonding conductor, a protective earthing conductor and an earthing conductor when used for protection against electric shock.

541.3.7

protective bonding conductor

protective conductor provided for protective-equipotential-bonding

[IEC 60050-826:2004, 826-13-24]

541.3.8

earthing conductor

conductor which provides a conductive path, or part of the conductive path, between a given point in a system or in an installation or in equipment and an earth-electrode network

[IEC 60050-826:2004, 826-13-12]

NOTE For the purposes of this part of IEC 60364, an earthing conductor is the conductor which connects the earth electrode to a point in the equipotential bonding system, usually the main earthing terminal.

541.3.9

main earthing terminal

main earthing busbar

terminal or busbar which is part of the earthing arrangement of an installation and enabling the electrical connection of a number of conductors for earthing purposes

[IEC 60050-826:2004, 826-13-15]

541.3.10

protective earthing conductor

protective conductor provided for protective earthing

[IEC 60050-826:2004, 826-13-23]

541.3.11

functional earthing

earthing a point or points in a system or in an installation or in equipment, for purposes other than electrical safety

[IEC 60050-826:2004, IEC 826-13-10]

541.3.12

earthing arrangement

all the electrical connections and devices involved in the earthing of a system, installation or an equipment

[IEC 60050-195:2004, 195-02-20]

541.3.13

functional earthing conductor

conductor provided for functional earthing

[SOURCE: IEC 60050-826:2004, 826-13-28, modified – In the definition, "earthing conductor" replaced with "conductor".]

541.3.14

main functional earthing terminal

main functional earthing busbar

MFET

terminal or busbar, which is part of the functional earthing arrangement of an electrical installation, enabling the electric connection of a number of conductors for functional earthing purposes

541.3.15

functional-equipotential-bonding

equipotential bonding for reasons other than electrical safety

[SOURCE: IEC 60050-826:2004, 826-13-21, modified – "operational reasons other than safety" replaced with "reasons other than electrical safety".]

541.3.16

protective-equipotential-bonding

equipotential bonding for the purposes of electrical safety

[SOURCE: IEC 60050-826:2004, 826-13-20, modified – "electrical" added.]

541.3.17

equipotential bonding

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

[SOURCE: IEC 60050-826:2004, 826-13-19]

541.3.18

protective earthing

earthing for purposes of electrical safety

[SOURCE: IEC 60050-826:2004, 826-13-09, modified – "a point or points in a system or in an installation or in equipment" deleted.]

541.3.19

functional bonding conductor

conductor provided for functional-equipotential-bonding

[SOURCE: IEC 60050-826:2004, 826-13-29]

542 Earthing arrangements

542.1 General requirements

542.1.1 The earthing arrangements may be used jointly or separately for protective and functional purposes according to the requirements of the electrical installation. The requirements for protective purposes shall always take precedence.

542.1.2 Where provided, earth electrodes within an installation shall be connected to the main earthing terminal using an earthing conductor.

~~NOTE—An installation does not need to have its own earth electrode.~~

542.1.3 Where the supply to an installation is at high voltage, requirements concerning the earthing arrangements of the high voltage supply and of the low-voltage installation shall also comply with Clause 442 of IEC 60364-4-44:2007.

542.1.4 The requirements for earthing arrangements are intended to provide a connection to earth which:

- is reliable and suitable for the protective requirements of the installation;
- can carry earth fault currents and protective conductor currents to earth without danger from thermal, thermo-mechanical and electromechanical stresses and from electric shock arising from these currents;
- if relevant, is also suitable for functional requirements;
- is suitable for the foreseeable external influences (see IEC 60364-5-51), e.g. mechanical stresses and corrosion.

542.1.5 Consideration shall be given to the earthing arrangements where currents with high frequencies are expected to flow (see Clause 444 of IEC 60364-4-44:2007).

542.1.6 Protection against electric shock, as stated in IEC 60364-4-41, shall not be adversely affected by any foreseeable change of the earth electrode resistance (e.g. due to corrosion, drying or freezing).

542.2 Earth electrodes

542.2.1 The type, materials and dimensions of earth electrodes shall be selected to withstand corrosion and to have adequate mechanical strength for the intended lifetime.

NOTE 1 For corrosion, the following parameters may be considered: the soil pH at the site, soil resistivity, soil moisture, stray and leakage a.c. and d.c. current, chemical contamination, and proximity of dissimilar materials.

For materials commonly used for earth electrodes, the minimum sizes, from the point of view of corrosion and mechanical strength, when embedded in the soil or in concrete, shall be as specified in Table 54.1.

NOTE 2 The minimum thickness of protective coating is greater for vertical earth electrodes than for horizontal earth electrodes because of their greater exposure to mechanical stresses while being embedded.

~~If a lightning protection system is required, 5.4 of IEC 62305-3:2006 applies.~~ Where a lightning protection system is required, IEC 62305-3:2010, 5.4 also applies.

Table 54.1 – Minimum size of commonly used earth electrodes, embedded in soil or concrete used to prevent corrosion and provide mechanical strength

Material and surface	Shape	Diameter mm	Cross-sectional area mm ²	Thickness mm	Weight of coating g/m ²	Thickness of coating/ sheathing μm
Steel embedded in concrete (bare, hot galvanized or stainless)	Round wire	10				
	Solid tape or strip		75	3		
Steel hot-dip galvanized ^c	Strip ^b or shaped strip/plate – Solid plate – Lattice plate		90	3	500	63
	Round rod installed vertically	16			350	45
	Round wire installed horizontally	10			350	45
	Pipe	25		2	350	45
	Stranded (embedded in concrete)		70			
	Cross profile installed vertically		(290)	3		
Steel copper-sheathed	Round rod installed vertically	(15)				2 000
Steel with electro-deposited copper coating	Round rod installed vertically	14				250 ^e
	Round wire installed horizontally	(8)				70
	Strip installed horizontally		90	3		70
Stainless steel ^a	Strip ^b or shaped strip/plate		90	3		
	Round rod installed vertically	16				
	Round wire installed horizontally	10				
	Pipe	25		2		
Copper	Strip		50	2		
	Round wire installed horizontally		(25) ^d 50			
	Solid round rod installed vertically	(12) 15				
	Stranded wire	1,7 for individual strands of wire	(25) ^d 50			
	Pipe	20		2		
	Solid plate			(1,5) 2		
	Lattice plate			2		

NOTE Values in brackets are applicable for protection against electric shock only, while values not in brackets are applicable for lightning protection and for protection against electric shock.

^a Chromium ≥16 %, Nickel ≥5 %, Molybdenum ≥2 %, Carbon ≤0,08 %.

^b As rolled strip or slit strip with rounded edges.

^c The coating shall be smooth, continuous and free from flux stains.

^d Where experience shows that the risk of corrosion and mechanical damage is extremely low, 16 mm² can be used.

^e This thickness is provided to withstand mechanical damage of copper coating during the installation process. It may be reduced to not less than 100 µm where special precautions to avoid mechanical damage of copper during the installation process (e.g. drilled holes or special protective tips) are taken according to the manufacturer's instructions.

542.2.2 The efficacy of any earth electrode depends on its configuration and upon local soil conditions. ~~One or more earth electrodes suitable for the soil conditions and the value of resistance to earth required shall be selected.~~ Earth electrode(s) shall be selected according to the soil conditions and the required value of resistance to earth.

Annex D gives methods of estimation of earth electrode resistance.

542.2.3 The following are examples of earth electrodes which may be used:

- concrete-embedded foundation earth electrode;
NOTE For more information see Annex C.
- soil-embedded foundation earth electrode;
- metallic electrode embedded directly in soil vertically or horizontally (e.g. rods, wires, tapes, pipes or plates);
- metal sheath and other metal coverings of cables according to local conditions or requirements;
- other suitable underground metalwork (e.g. pipes) according to local conditions or requirements;
- welded metal reinforcement of concrete (except pre-stressed concrete) embedded in the earth.

542.2.4 When selecting the type and embedded depth of an earth electrode, consideration shall be given to possible mechanical damage and to local conditions to minimize the effect of soil drying and freezing.

542.2.5 Consideration shall be given to electrolytic corrosion when using different materials in an earthing arrangement. For external conductors (e.g. earthing conductor) connected to a concrete-embedded foundation earth electrode, the connection made from hot-dip galvanized steel shall not be embedded in the soil.

542.2.6 The earthing arrangement shall not rely on a metallic pipe for flammable liquids or gases as the earth electrode and their buried length shall not be considered when dimensioning the earth electrode.

NOTE This requirement does not preclude the protective equipotential bonding via the main earthing terminal (541.3.9) of such pipes for compliance with IEC 60364-4-41.

Where cathodic protection is applied and the exposed-conductive-part of an item of electrical equipment supplied by a TT system is directly connected to the pipe, a metallic pipe for flammable liquids or gases may act as the sole earth electrode for this specific equipment.

542.2.7 Earth electrodes shall not be directly immersed in water of a stream, river, pond, lake or the like (see also 542.1.6).

542.2.8 Where an earth electrode consists of parts that must be connected together, the connection shall be by exothermic welding, pressure connectors, clamps or other suitable mechanical connectors.

NOTE Connections made by a wrapped iron wire only are not suitable for protection purposes.

542.3 Earthing conductors

542.3.1 Earthing conductors shall comply with 543.1.1 or 543.1.2. Their cross-sectional area shall be not less than 6 mm² for copper or 50 mm² for steel. Where a bare earthing conductor is buried in the soil, its dimensions and characteristics shall also be in accordance with Table 54.1.

Where no noticeable fault current is expected to flow through the earth electrode (e.g. in TN systems or IT systems), the earthing conductor may be dimensioned according to 544.1.

Aluminium conductors shall not be used as earthing conductors.

NOTE Where a lightning protection system is connected to the earth electrode, the cross-sectional area of the earthing conductor should be at least 16 mm² for copper (Cu) or 50 mm² for iron (Fe) (see the IEC 62305 series).

542.3.2 The connection of an earthing conductor to an earth electrode shall be soundly made and electrically satisfactory. The connection shall be by exothermic welding, pressure connectors, clamps or other suitable mechanical connectors. Mechanical connectors shall be installed in accordance with the manufacturer's instructions. Where a clamp is used, it shall not damage the electrode or the earthing conductor.

Connection devices or fittings that depend solely on solder shall not be used independently, as they do not reliably provide adequate mechanical strength.

NOTE Where vertical electrodes are installed, means may be provided to allow the inspection of the connection and the replacement of the vertical rod.

542.4 Main earthing terminal

542.4.1 In every installation where protective equipotential bonding is used, a main earthing terminal shall be provided and the following shall be connected to it:

- protective bonding conductors;
- earthing conductors;
- protective conductors;
- functional earthing conductors, if relevant.

NOTE 1 It is not intended to connect every individual protective conductor directly to the main earthing terminal where they are connected to this terminal by other protective conductors.

NOTE 2 The main earthing terminal of the building can generally be used for functional earthing purposes. For information technology purposes, it is then regarded as the connection point to the earth.

Where more than one earthing terminal is provided, they shall be interconnected.

542.4.2 Each conductor connected to the main earthing terminal shall be able to be disconnected individually. This connection shall be reliable and such that it can only be disconnected by means of a tool.

NOTE Disconnection means may conveniently be combined with the main earthing terminal, to permit measurement of the resistance of the earth electrode.

543 Protective conductors

NOTE Consideration should be given to requirements provided in Clause 516 of IEC 60364-5-51:2005.

543.1 Minimum cross-sectional areas

543.1.1 The cross-sectional area of every protective conductor shall satisfy the conditions for automatic disconnection of supply required in 411.3.2 of IEC 60364-4-41:2005 and be

capable of withstanding mechanical and thermal stresses caused by the prospective fault current during the disconnection time of the protective device.

The cross-sectional area of a protective conductor shall either be calculated in accordance with 543.1.2, or selected in accordance with Table 54.2. In either case, the requirements of 543.1.3 shall be taken into account.

Terminals for protective conductors shall be capable of accepting conductors of dimensions required by this subclause.

In TT systems, where the earth electrodes of the supply system and of the exposed-conductive- parts are electrically independent (see 312.2.2), the cross-sectional area of protective conductors need not exceed:

- 25 mm² copper,
- 35 mm² aluminium.

**Table 54.2 – Minimum cross-sectional area of protective conductors
(where not calculated in accordance with 543.1.2)**

Cross-sectional area of line conductor, S mm ² Cu	Minimum cross-sectional area of the corresponding protective conductor mm ² Cu	
	If the protective conductor is of the same material as the line conductor	If the protective conductor is not of the same material as the line conductor
$S \leq 16$	S	$\frac{k_1}{k_2} \times S$
$16 < S \leq 35$	16^a	$\frac{k_1}{k_2} \times 16$
$S > 35$	$\frac{S}{2}^a$	$\frac{k_1}{k_2} \times \frac{S}{2}$
where k_1 is the value of k for the line conductor derived from the formula in Annex A or selected from tables in IEC 60364-4-43, according to the materials of the conductor and insulation; k_2 is the value of k for the protective conductor, selected from Tables A.54.2 to A.54.6 as applicable. ^a For a PEN conductor, the reduction of the cross-sectional area is permitted only in accordance with the rules for sizing of the neutral conductor (see IEC 60364-5-52).		

543.1.2 The cross-sectional areas of protective conductors shall be not less than the value determined either:

- in accordance with IEC 60949; or
- by the following formula applicable only for disconnection times not exceeding 5 s:

$$S = \frac{\sqrt{I^2 t}}{k}$$

where

S is the cross-sectional area in mm²;

I is the r.m.s value expressed in amperes of prospective fault current, for a fault of negligible impedance, which can flow through the protective device (see IEC 60909-0);

t is the operating time in seconds of the protective device for automatic disconnection;

k is the factor dependent on the material of the protective conductor, the insulation and other parts and the initial and final temperatures (for calculation of k , see Annex A).

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

NOTE 1 Account should be taken of the current-limiting effect of the circuit impedances and the limitation of I^2t of the protective device.

NOTE 2 For limitations of temperatures for installations in potentially explosive atmospheres, see IEC 60079-0.

NOTE 3 As the metallic sheaths of mineral-insulated cables according to IEC 60702-1 have an earth fault capacity greater than that of the line conductors, it is not necessary to calculate the cross-sectional area of the metallic sheaths when used as protective conductors.

543.1.3 The cross-sectional area of every protective conductor which does not form part of a cable or which is not in a common enclosure with the line conductor shall be not less than

- 2,5 mm² Cu or 16 mm² Al if protection against mechanical damage is provided,
- 4 mm² Cu or 16 mm² Al if protection against mechanical damage is not provided.

NOTE The use of steel for a protective conductor is not excluded (see 543.1.2).

A protective conductor not forming part of a cable is considered to be mechanically protected if it is installed in a conduit, trunking or protected in a similar way.

543.1.4 Where a protective conductor is common to two or more circuits, its cross-sectional area shall be:

- calculated in accordance with 543.1.2 for the most onerous prospective fault current and operating time encountered in these circuits; or
- selected in accordance with Table 54.2 so as to correspond to the cross-sectional area of the largest line conductor of the circuits.

543.2 Types of protective conductors

543.2.1 Protective conductors may consist of one or more of the following:

- conductors in multicore cables;
- insulated or bare conductors in a common enclosure with live conductors;
- fixed installed bare or insulated conductors;
- metallic cable sheath, cable screen, cable armour, wirebraid, concentric conductor, metallic conduit, subject to the conditions stated in 543.2.2. a) and b).

NOTE See 543.8 for their arrangement.

543.2.2 Where the installation contains equipment having metal enclosures such as low-voltage switchgear and controlgear assemblies (see IEC 61439-1 and IEC 61439-2) or busbar trunking systems (see IEC 60439-2), their metal enclosures or frames may be used as protective conductors if they simultaneously satisfy the following three requirements:

- a) their electrical continuity shall be assured by construction or by suitable connection so as to ensure protection against mechanical, chemical or electrochemical deterioration;
- b) they comply with the requirements of 543.1;
- c) they shall permit the connection of other protective conductors at every predetermined tap-off point.

543.2.3 The following metal parts ~~are not permitted for use as protective conductors or as protective bonding conductors~~ shall not be used as protective conductors:

- metallic water pipes;

- metallic pipes containing potentially flammable materials such as gases, liquids, powder;

NOTE 1 For cathodic protection, see 542.2.6.

- constructional parts subject to mechanical stress in normal service;
- flexible or pliable metal conduits, unless designed for that purpose;
- flexible metal parts;
- support wires; cable trays and cable ladders.

~~NOTE 2 Examples of a protective conductor include a protective bonding conductor, a protective earthing conductor and an earthing conductor when used for protection against electric shock.~~

543.3 Electrical continuity of protective conductors

543.3.1 Protective conductors shall be suitably protected against mechanical damage, chemical or electrochemical deterioration, electrodynamic forces and thermodynamic forces.

Every connection (e.g. screwed connections, clamp connectors) between protective conductors or between a protective conductor and other equipment shall provide durable electrical continuity and adequate mechanical strength and protection. Screws for connecting protective conductors shall not serve any other purpose.

Joints shall not be made by soldering.

NOTE All electrical connections should have satisfactory thermal capacity and mechanical strength to withstand any combination of current/time which may occur in the conductor or in the cable/enclosure with the largest cross-sectional area.

543.3.2 Joints in protective conductors shall be accessible ~~for inspection and testing~~ except for

- compound-filled joints,
- ~~– encapsulated joints,~~
- connections within enclosures which can be opened only by destruction,
- joints in metal conduits, ducting and busbar trunking systems,
- joints forming part of equipment, complying with ~~equipment~~ the relevant standards, for example low-voltage switchgear and controlgear assemblies according to 543.2.2,
- joints made by welding or brazing,
- joints made by compression tool.

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

543.3.4 Where electrical monitoring of earthing is used, dedicated devices (e.g. operating sensors, coils, current transformers) shall not be connected in series in protective conductors.

543.3.5 Exposed-conductive-parts of electrical equipment shall not be used to form part of the protective conductor for other equipment except as allowed by 543.2.2.

543.4 PEN, PEL or PEM conductors

NOTE As these conductors serve two functions, as PE- and either as N-, L- or M-conductors, all applicable requirements for the relevant functions should be considered.

543.4.1 A PEN, PEL or PEM conductor may only be used in fixed electrical installations and, for mechanical reasons, shall have a cross-sectional area not less than 10 mm² copper or 16 mm² aluminium.

NOTE 1 For EMC reasons, the PEN conductor should not be installed downstream of the origin of the installation (see 444.4.3.2 of IEC 60364-4-44:2007).

NOTE 2 IEC 60079-14 does not permit the use of a PEN, PEL or PEM conductor in explosive atmospheres.

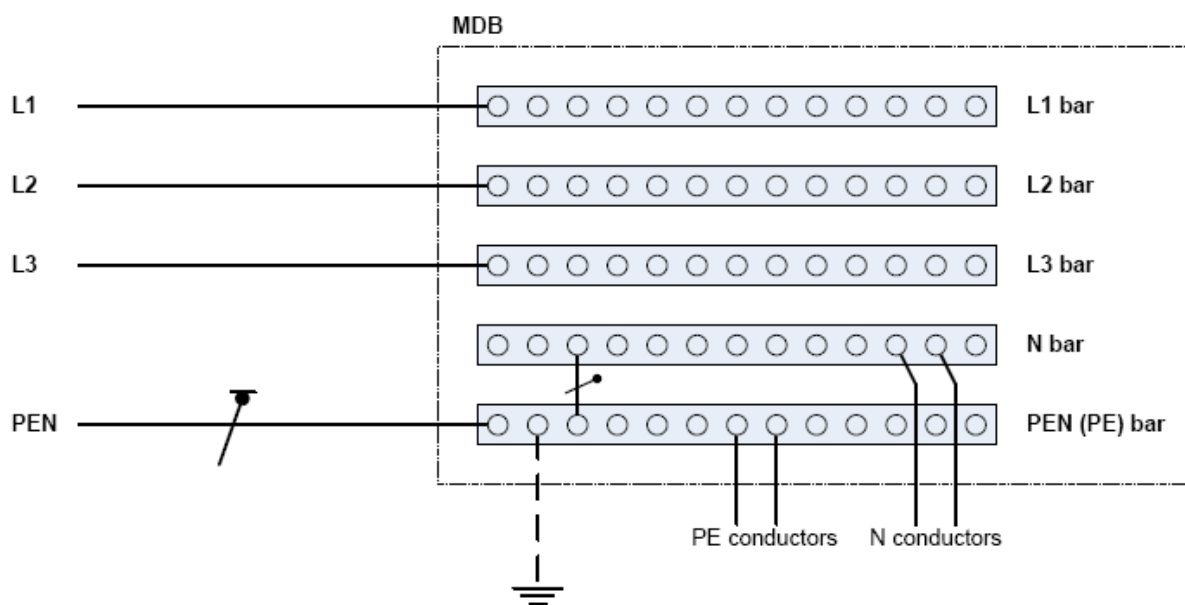
543.4.2 The PEN, PEL or PEM conductor shall be insulated for the rated voltage of the line conductor.

Metallic enclosures of wiring systems shall not be used as PEN, PEL or PEM conductors, except for busbar trunking systems complying with IEC 60439-2 and for powertrack systems complying with IEC 61534-1.

NOTE Product committees should consider the potential effect of EMI introduced into the equipment from a PEN, PEL or PEM conductor.

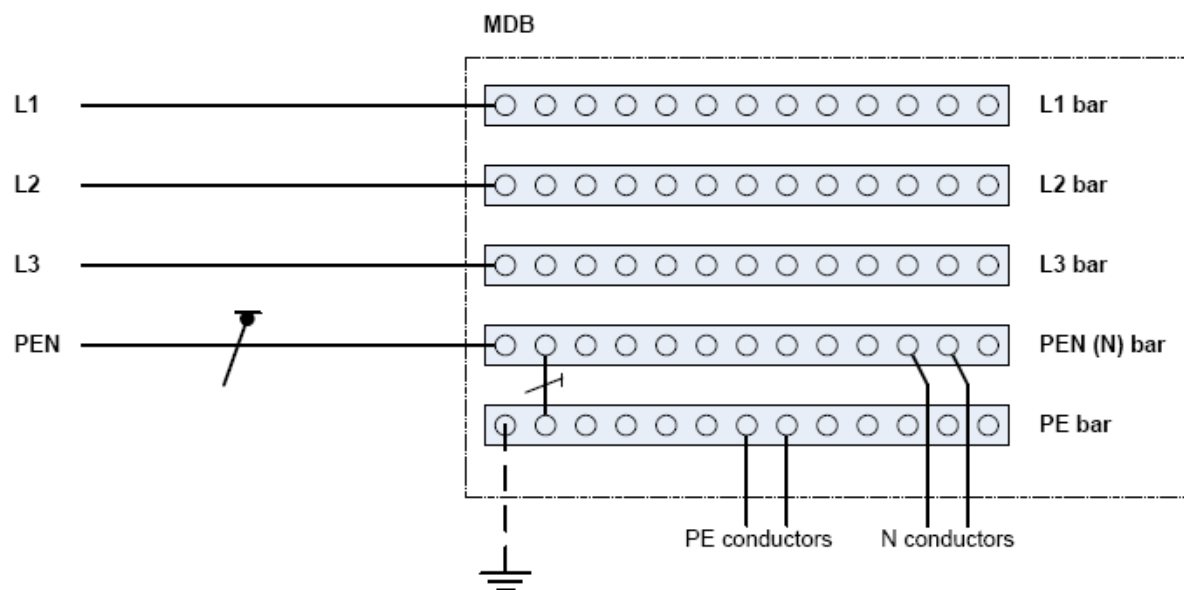
543.4.3 If, from any point of the installation, the neutral/mid-point/line and protective functions are provided by separate conductors, it is not permitted to connect the neutral/mid-point/line conductor to any other earthed part of the installation. However, it is permitted to form more than one neutral/mid-point/line conductor and more than one protective conductor from the PEN, PEL or PEM conductor respectively.

The PEN, PEL or PEM conductor shall be connected to the terminal or bar intended for the protective conductors (see Figure 54.1a), unless there is a specific terminal or bar intended for the connection of the PEN, PEL or PEM conductor (examples are given in Figures 54.1b and 54.1c).



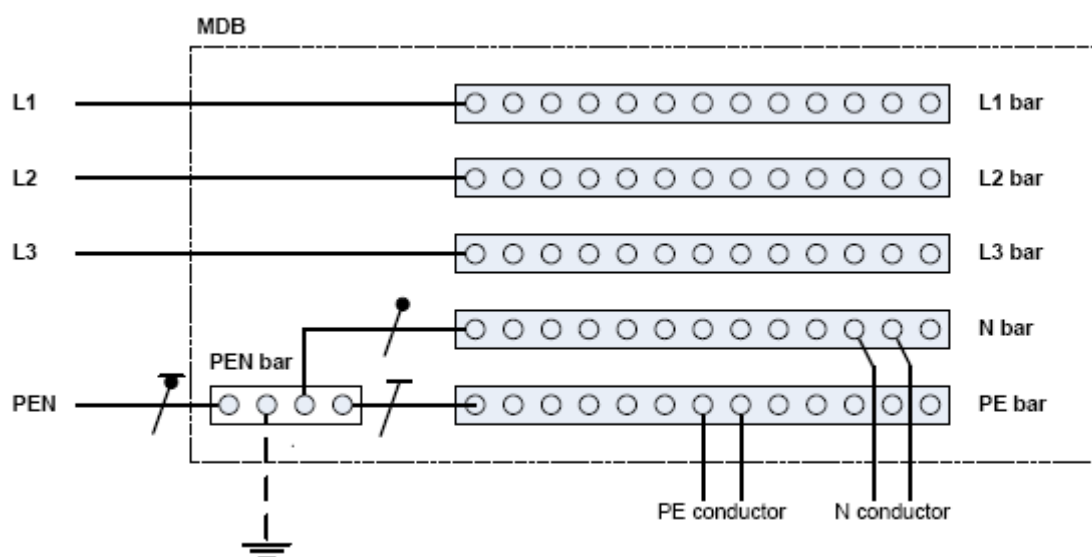
IEC 523/11

Figure 54.1a – Example 1



IEC 524/11

Figure 54.1b – Example 2



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Figure 54.1c – Example 3

Key

MDB main distribution board

Figure 54.1 – Examples of a PEN conductor connection

NOTE In systems supplied with SELV direct current, e.g. telecommunication systems, there is no PEL or PEM conductor.

543.4.4 Extraneous-conductive-parts shall not be used as PEN, PEL or PEM conductors.

543.5 Combined protective and functional earthing conductors

Where a combined protective and functional earthing conductor is used, it shall satisfy the requirements for a protective conductor. In addition, it shall also comply with the relevant functional requirements (see Clause 444 of IEC 60364-4-44:2007).

A d.c. return conductor PEL or PEM for an information technology power supply may also serve as a combined functional earthing and protective conductor.

NOTE For further information, see 7.5.3.1 of IEC 61140:2001.

543.6 Currents in protective earthing conductors

The protective earthing conductor should not be used as a conductive path for current under normal operating conditions (e.g. connection of filters for EMC-reasons), see also IEC 61140. Where the current exceeds 10 mA under normal operating conditions, a reinforced protective conductor shall be used (see 543.7).

NOTE Capacitive leakage currents, e.g. by cables or motors, should be reduced by the design of the installation and the equipment.

543.7 Reinforced protective earthing conductors for protective earthing conductor currents exceeding 10 mA

For current-using equipment intended for permanent connection and with a protective earthing conductor current exceeding 10 mA the following applies:

- where the current-using equipment has only one protective earthing terminal, the protective earthing conductor shall have a cross-sectional area of at least 10 mm² Cu or 16 mm² Al, through its total run;

NOTE 1 A PEN, PEL or PEM conductor in accordance with 543.4 complies with this requirement.

- where the current-using equipment has a separate terminal for a second protective earthing conductor a second protective earthing conductor of at least the same cross-sectional area as required for fault protection shall be run from a point where the protective earthing conductor has a cross-sectional area not less than 10 mm² Cu or 16 mm² Al.

NOTE 2 In TN-C systems where the neutral and protective conductors are combined in a single conductor (PEN conductor) up to the equipment terminals, protective conductor current may be treated as load current.

NOTE 3 Current-using equipment normally having high protective conductor current may not be compatible with installations incorporating residual current protective devices.

543.8 Arrangement of protective conductors

Where overcurrent protective devices are used for protection against electric shock, the protective conductor shall be incorporated in the same wiring system as the live conductors or be located in their immediate proximity.

544 Protective bonding conductors

544.1 Protective bonding conductors for connection to the main earthing terminal

Protective bonding conductors for connection to the main earthing terminal shall have a cross-sectional area not less than half the cross-sectional area of the largest protective earthing conductor within the installation and not less than:

- 6 mm² copper; or
- 16 mm² aluminium; or
- 50 mm² steel.

The cross-sectional area of protective bonding conductors for connection to the main earthing terminal need not exceed 25 mm² Cu or an equivalent cross-sectional area for other materials.

544.2 Protective bonding conductors for supplementary bonding

544.2.1 A protective bonding conductor connecting two exposed-conductive-parts shall have a conductance not less than that of the smaller protective conductor connected to the exposed-conductive-parts.

544.2.2 A protective bonding conductor connecting exposed-conductive-parts to extraneous-conductive-parts shall have a conductance not less than half that of the cross-sectional area of the corresponding protective conductor.

544.2.3 The minimum cross-sectional area of protective bonding conductors for supplementary bonding, and of bonding conductors between two extraneous-conductive-parts, shall be in accordance with 543.1.3.

545 Functional earthing and functional-equipotential-bonding for Information and communication technology equipment and systems (ICT)

545.1 Functional-equipotential-bonding for ICT

545.1.1 General

A functional-equipotential-bonding system may comprise

- functional earthing conductor(s),
- functional bonding conductor(s),
- a main functional earthing terminal.

Where the functional-equipotential-bonding system is not locally connected to the protective-equipotential-bonding system, the functional bonding conductors shall be

- insulated, and
- installed separately from the protective conductor, and
- connected to the main earthing terminal only once.

NOTE The functional-bonding-conductors are insulated because those conductors could under certain circumstances achieve a dangerous potential.

If there are multiple functional bonding conductors present in the electrical installation, a separate main functional earthing terminal (MFET) shall be installed for ease of connection for these conductors. The main functional earthing terminal shall be connected to the main earthing terminal only once.

The cross-sectional area of every functional bonding conductor or functional earthing conductor shall be capable of withstanding all mechanical and thermal stresses caused by the expected operational current. This current shall be determined in accordance with the manufacturer's instructions or by measurement taking into account the ICT equipment or system.

545.1.2 Minimum cross-sectional area

In the absence of requirements, for example stated by the equipment manufacturer, the following minimum cross-sectional area shall be applied for functional earthing conductors and functional bonding conductors:

- 2,5 mm² Cu or 16 mm² Al, if protection against mechanical damage is provided,
- 4 mm² Cu or 16 mm² Al, if protection against mechanical damage is not provided.

NOTE Larger cross-sectional areas can be specified for EMC reasons.

545.1.3 Identification

A functional earthing conductor shall be identified according to IEC 60445 by:

- the alphanumeric notation FE, or
- by the colour PINK at least applied at the terminations and points of connection, or
- by the symbol  (graphical symbol IEC 60417-5018:2011-07).

A functional bonding conductor shall be identified by:

- the alphanumeric notation FB, or
- by the symbol  (graphical symbol IEC 60417-5020:2002-10).

NOTE The alphanumeric notation and the colour marking are in accordance with IEC 60445.

The bi-colour combination GREEN-AND-YELLOW shall not be used to identify functional bonding conductors.

545.1.4 Electrical continuity of functional bonding conductors

The requirements of 543.3, except for 543.3.5, also apply for functional bonding.

If part of an item of equipment can be removed, the functional bonding conductor for the remaining part of the electrical installation shall not be disconnected.

545.1.5 Combined protective and functional bonding conductors

Where a combined protective and functional bonding conductor is used, it shall fulfil all requirements for a protective bonding conductor. The combined protective and functional bonding conductor shall be identified by the bi-colour combination GREEN-AND-YELLOW.

545.2 Main functional earthing terminal (MFET)

The following conductors shall be connected to the main functional earthing terminal (MFET), if any:

- functional earthing conductors;
- functional bonding conductors.

The main functional earthing terminal (MFET) and the main earthing terminal (MET) may be combined, as stated in 542.4.

545.3 Equipotential bonding ring conductors

The main earthing terminal (MET according to 542.4 and/or MFET according to 548.2) may be provided as a ring (closed loop) conductor to enable systems of information technology and communications equipment (ICT) to be incorporated into the equipotential bonding system using the shortest connection.

The equipotential bonding ring conductor shall be easily accessible wherever connections may be required.

The cross-sectional area of equipotential bonding ring conductors shall comply either with Clause 544 when used also for protective bonding, or:

- be at least 50 mm² hot-dip galvanized steel strip, or
- be at least 16 mm² copper, or

- be a cross-sectional area in another material, which provides at least a conductivity equivalent to 16 mm² copper.

Annex A (normative)

Method for deriving the factor k in 543.1.2 (see also IEC 60724 and IEC 60949)

The factor k is determined from the following formula:

$$k = \sqrt{\frac{Q_c(\beta + 20)}{\rho_{20}} \ln \left(\frac{\beta + \theta_f}{\beta + \theta_i} \right)}$$

where

- Q_c is the volumetric heat capacity of conductor material (J/K mm³) at 20 °C;
- β is the reciprocal of temperature coefficient of resistivity at 0 °C for the conductor (°C);
- ρ_{20} is the electrical resistivity of conductor material at 20 °C (Ωmm);
- θ_i initial temperature of conductor (°C);
- θ_f final temperature of conductor (°C).

Table A.54.1 – Value of parameters for different materials

Material	β^a °C	Q_c^a J/°Cmm ³	ρ_{20}^a Ωmm	$\sqrt{\frac{Q_c(\beta + 20)}{\rho_{20}}}$ A√s/mm ²
Copper	234,5	$3,45 \times 10^{-3}$	$17,241 \times 10^{-6}$	226
Aluminium	228	$2,5 \times 10^{-3}$	$28,264 \times 10^{-6}$	148
Steel	202	$3,8 \times 10^{-3}$	138×10^{-6}	78

^a Values taken from IEC 60949.

Table A.54.2 – Values of k for insulated protective conductors not incorporated in cables and not bunched with other cables

Conductor insulation	Temperature °C ^b		Material of conductor		
			Copper	Aluminium	Steel
	Initial	Final	Values for k ^c		
70 °C thermoplastic (PVC)	30	160/140 ^a	143/133 ^a	95/88 ^a	52/49 ^a
90 °C thermoplastic (PVC)	30	160/140 ^a	143/133 ^a	95/88 ^a	52/49 ^a
90 °C thermosetting (e.g. XLPE and EPR)	30	250	176	116	64
60 °C thermosetting (EPR rubber)	30	200	159	105	58
85 °C thermosetting (EPR rubber)	30	220	166	110	60
185 °C thermosetting (silicone rubber)	30	350	201	133	73

^a The lower value applies to thermoplastic (e.g. PVC) insulated conductors of cross-sectional area greater than 300 mm².

^b Temperature limits for various types of insulation are given in IEC 60724.

^c For the method of calculating k , see the formula at the beginning of this annex.

Table A.54.3 – Values of k for bare protective conductors in contact with cable covering but not bunched with other cables

Cable covering	Temperature °C ^a		Material of conductor		
			Copper	Aluminium	Steel
	Initial	Final	Values for k ^b		
Thermoplastic (PVC) polyethylene	30	200	159	105	58
	30	150	138	91	50
CSP ^c	30	220	166	110	60

^a Temperature limits for various types of insulation are given in IEC 60724.

^b For the method of calculating k , see the formula at the beginning of this annex.

^c CSP = Chloro-Sulphonated Polyethylene

Table A.54.4 – Values of k for protective conductors as a core incorporated in a cable or bunched with other cables or insulated conductors

Conductor insulation	Temperature °C ^b		Material of conductor		
			Copper	Aluminium	Steel
	Initial	Final	Values for k ^c		
70 °C thermoplastic (PVC)	70	160/140 ^a	115/103 ^a	76/68 ^a	42/37 ^a
90 °C thermoplastic (PVC)	90	160/140 ^a	100/86 ^a	66/57 ^a	36/31 ^a
90 °C thermosetting (e.g. XLPE and EPR)	90	250	143	94	52
60 °C thermosetting (rubber)	60	200	141	93	51
85 °C thermosetting (rubber)	85	220	134	89	48
185 °C thermosetting (silicone rubber)	180	350	132	87	47
^a The lower value applies to thermoplastic (e.g. PVC) insulated conductors of cross-sectional area greater than 300 mm ² . ^b Temperature limits for various types of insulation are given in IEC 60724. ^c For the method of calculating k , see the formula at the beginning of this annex					

Table A.54.5 – Values of k for protective conductors as a metallic layer of a cable, e.g. armour, metallic sheath, concentric conductor, etc.

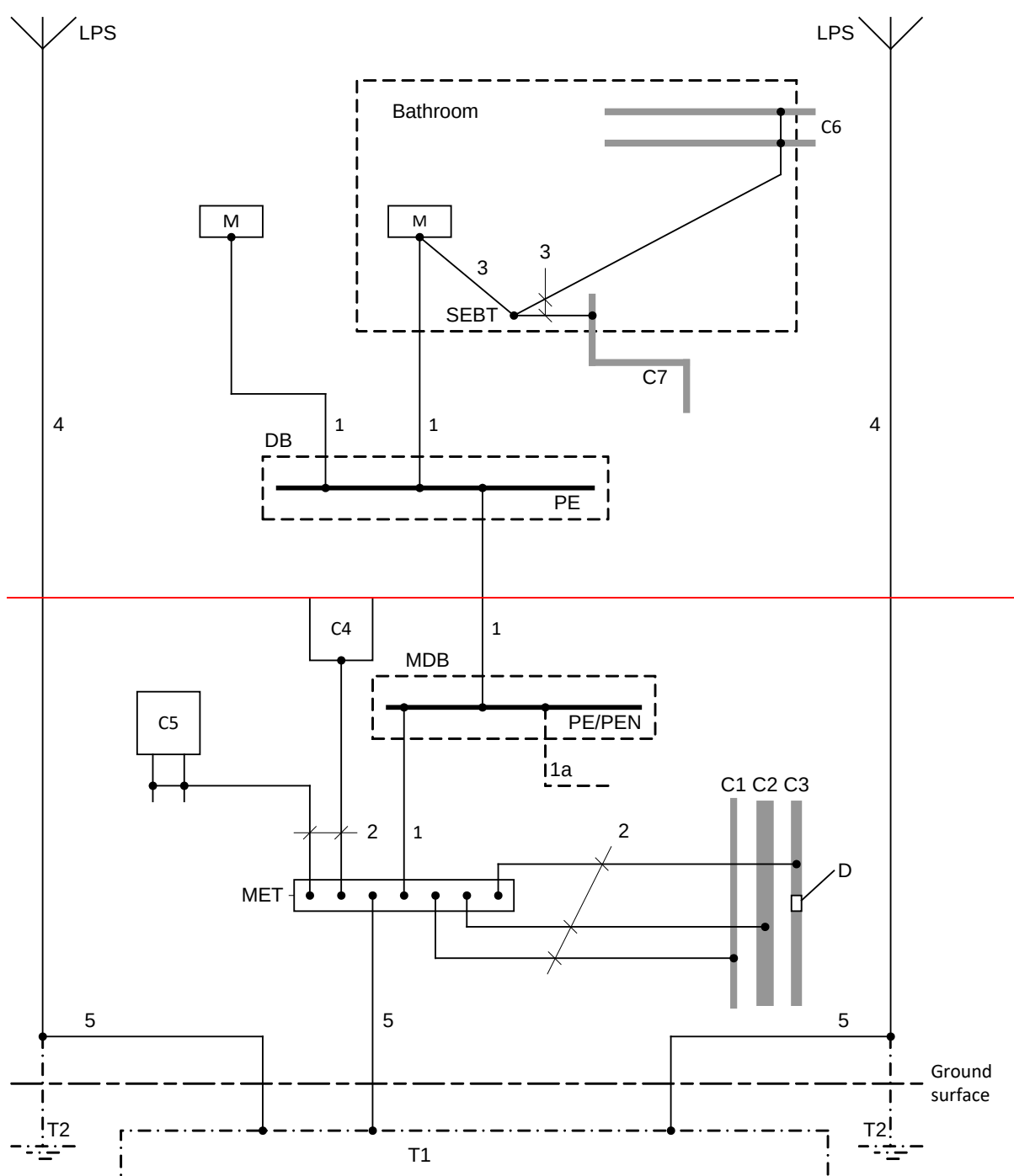
Conductor insulation	Temperature °C ^a		Material of conductor		
	Initial	Final	Copper	Aluminium	Steel
			Values for k ^c		
70 °C thermoplastic (PVC)	60	200	141	93	51
90 °C thermoplastic (PVC)	80	200	128	85	46
90 °C thermosetting (e.g. XLPE and EPR)	80	200	128	85	46
60 °C thermosetting (rubber)	55	200	144	95	52
85 °C thermosetting (rubber)	75	220	140	93	51
Mineral thermoplastic (PVC) covered ^b	70	200	135	–	–
Mineral bare sheath	105	250	135	–	–
^a Temperature limits for various types of insulation are given in IEC 60724. ^b This value shall also be used for bare conductors exposed to touch or in contact with combustible material. ^c For the method of calculating k , see the formula at the beginning of this annex.					

Table A.54.6 – Values of k for bare conductors where there is no risk of damage to any neighbouring material by the temperature indicated

Conditions	Initial temperature °C	Material of conductor					
		Copper		Aluminium		Steel	
		Maximum temperature (final temperature) °C	k value	Maximum temperature (final temperature) °C	k value	Maximum temperature (final temperature) °C	k value
Visible and in restricted area	30	500	228	300	125	500	82
Normal conditions	30	200	159	200	105	200	58
Fire risk	30	150	138	150	91	150	50

Annex B (informative)

Example of earthing arrangements and protective conductors



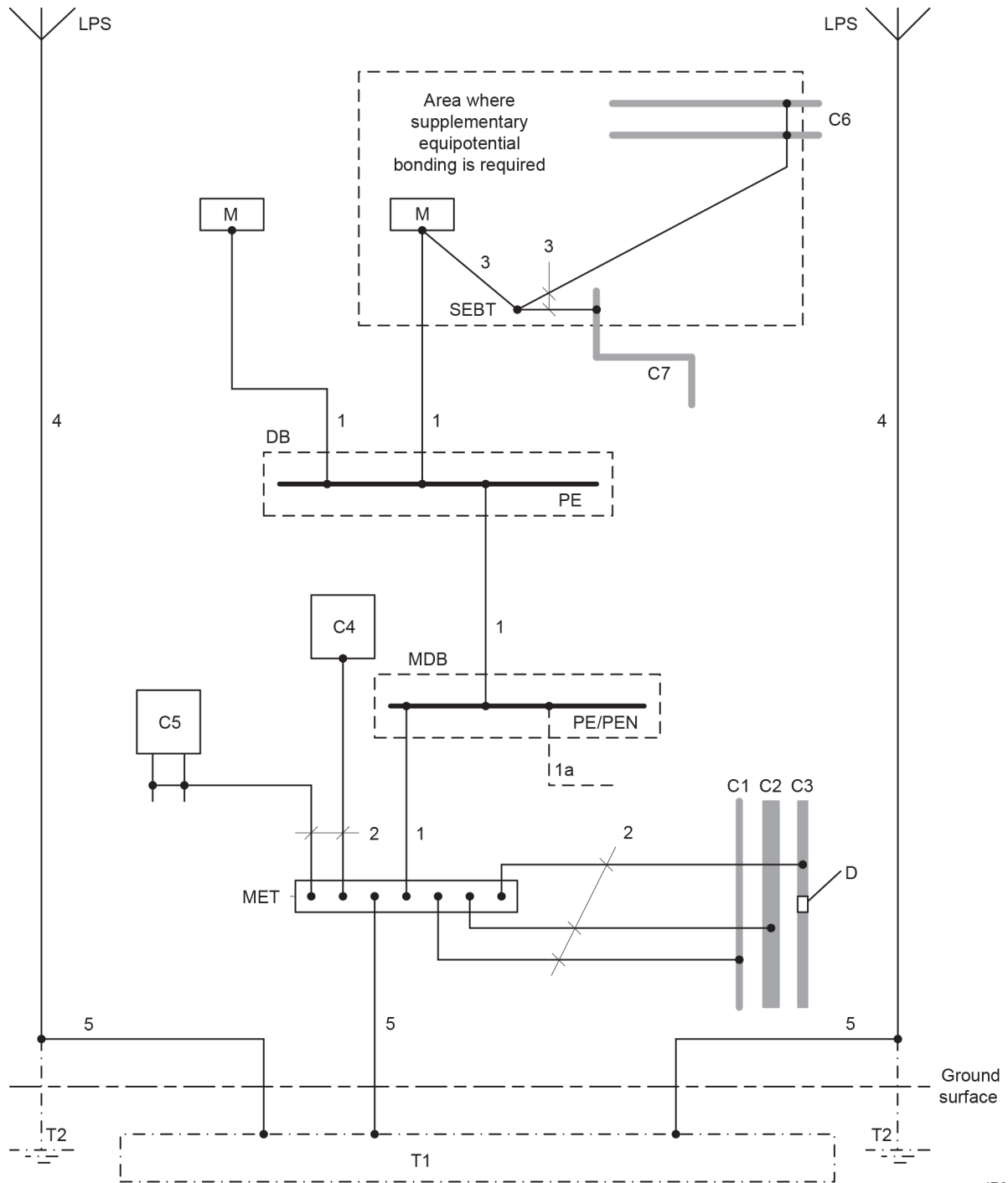
IEC 526/11

Key

Symbol	Name	Remark
~~C~~	~~Extraneous-conductive-part~~	
~~C1~~	~~Water-pipe, metal from outside~~	~~Or district heating-pipe~~
~~C2~~	~~Waste-water-pipe, metal from outside~~	
~~C3~~	~~Gas-pipe with insulating insert, metal from outside~~	
~~C4~~	~~Air-conditioning~~	
~~C5~~	~~Heating-system~~	
~~C6~~	~~Water-pipe, metal e.g. in a bathroom~~	~~See IEC 60364-7-701 701.415.2:2006~~
~~C7~~	~~Waste water pipe, metal e.g. in a bathroom~~	~~See IEC 60364-7-701 701.415.2 dated 2006~~
~~D~~	~~Insulating insert~~	
~~MDB~~	~~Main distribution-board~~	
~~DB~~	~~Distribution-board~~	~~Supplied from the main distribution board~~
~~MET~~	~~Main earthing-terminal~~	~~See 542.4~~
~~SEBT~~	~~Supplementary equipotential-bonding terminal~~	
~~T1~~	~~Concrete-embedded foundation earth-electrode or soil-embedded foundation earth-electrode~~	~~See 542.2~~
~~T2~~	~~Earth electrode for LPS if necessary~~	~~See 542.2~~
~~LPS~~	~~Lightning-protection-system (if any)~~	
~~PE~~	~~PE-terminal(s) in the distribution-board~~	
~~PE/PEN~~	~~PE/PEN-terminal(s) in the main distribution-board~~	
~~M~~	~~Exposed-conductive-part~~	
~~1~~	~~Protective earthing-conductor (PE)~~	~~See Clause 543~~ ~~Cross-sectional area see 543.1~~ ~~Type of protective conductor see 543.2~~ ~~Electrical continuity see 543.3~~
~~1a~~	~~Protective conductor, or PEN-conductor, if any, from supplying network~~	
~~2~~	~~Protective bonding-conductor for connection to the main earthing terminal~~	~~See 544.1~~
~~3~~	~~Protective bonding-conductor for supplementary bonding~~	~~See 544.2~~
~~4~~	~~Down-conductor of a lightning-protection-system (LPS) if any~~	
~~5~~	~~Earthing-conductor~~	~~See 542.3~~

Where a lightning protection system is installed, the additional requirements are given in Clause 6 of IEC 62305-3:2006, in particular those given in 6.1 and 6.2.

NOTE Functional earthing conductors are not shown in Figure B.54.1.



IEC

Key

Symbol	Name	Remark
C	Extraneous-conductive-part	
C1	Water pipe, metal from outside	Or district heating pipe
C2	Waste water pipe, metal from outside	
C3	Gas pipe with insulating insert, metal from outside	
C4	Air-conditioning	
C5	Heating system	
C6	Water pipe, metal e.g. in an area where supplementary equipotential bonding is required	See IEC 60364-7-701:2006, 701.415.2
C7	Waste water pipe, metal e.g. in an area where supplementary equipotential bonding is required	See IEC 60364-7-701:2006, 701.415.2
D	Insulating insert	
MDB	Main distribution board	
DB	Distribution board	Supplied from the main distribution board
MET	Main earthing terminal	See 542.4
SEBT	Supplementary equipotential bonding terminal	
T1	Concrete-embedded foundation earth electrode or soil-embedded foundation earth electrode	See 542.2
T2	Earth electrode for LPS if necessary	See 542.2
LPS	Lightning protection system (if any)	
PE	PE terminal(s) in the distribution board	
PE/PEN	PE/PEN terminal(s) in the main distribution board	
M	Exposed-conductive-part	
1	Protective earthing conductor (PE)	See Clause 543 Cross-sectional area see 543.1 Type of protective conductor see 543.2 Electrical continuity see 543.3
1a	Protective conductor, or PEN conductor, if any, from supplying network	
2	Protective bonding conductor for connection to the main earthing terminal	See 544.1
3	Protective bonding conductor for supplementary bonding	See 544.2
4	Down conductor of a lightning protection system (LPS) if any	
5	Earthing conductor	See 542.3

Where a lightning protection system is installed, the additional requirements are given in IEC 62305-3:2010, Clause 6, in particular those given in 6.1 and 6.2.

NOTE Functional earthing conductors are not shown in Figure B.54.1.

Figure B.54.1 – Examples of earthing arrangements for foundation earth electrode, protective conductors and protective bonding conductors

Annex C **(informative)**

Erection of concrete-embedded foundation earth electrodes

C.1 General

Concrete used for the foundations of buildings has a certain conductivity and generally a large contact area with the soil. Therefore bare metal electrodes completely embedded in concrete can be used for earthing purposes, unless the concrete is isolated from the soil by use of a special thermal insulation or other measures. Due to chemical and physical effects, bare or hot-dip galvanized steel and other metals embedded in concrete to a depth of more than 5 cm are highly protected against corrosion, normally for the whole life-time of the building. Wherever possible, the conductive effects of the reinforcement of the building should also be used.

The production of a concrete-embedded foundation earth electrode during the erection of the building may be an economical solution to obtain a good earth electrode of long standing because

- it does not necessitate additional excavation works,
- it is erected at a depth which is normally free from negative influences resulting from seasonal weather conditions,
- it provides a good contact with the soil,
- it extends over practically all of the building's foundation surface and results in the minimum earth electrode impedance which can be obtained with this surface,
- it provides an optimal earthing arrangement for lightning protection system purposes, and
- from the beginning of the erection of the building, it can be used as an earth electrode for the electrical installation of the construction site.

Besides its earthing effect, the concrete-embedded foundation earth electrode provides a good basis for the main protective bonding.

The following requirements and advice for the erection of a concrete-embedded foundation earth electrode apply.

C.2 Other considerations regarding the use of concrete-embedded foundation earth electrodes

If the building foundation is to be completely protected against loss of heat energy by insulating it using non-conductive materials, or if the foundation is to use certain insulating measures against water, e.g. using plastic sheets of more than 0,5 mm thickness, earthing using the foundation concrete is not viable. In such cases, the positive effect of metal reinforcement for protective bonding may be used, and for earthing purposes another earthing arrangement should be used, e.g. an additional concrete-embedded foundation earth electrode below the isolated foundation, or an earthing arrangement around the building or a soil-embedded foundation earth electrode.

C.3 Construction of concrete-embedded foundation earth electrodes

C.3.1 For concrete foundations without metal reinforcement, the concrete-embedded foundation earth electrodes must be coordinated with the type and dimensions of the

foundation. One or more closed ring(s) or rectangles with dimensions up to 20 m and mutually connected are preferred.

C.3.2 To avoid embedding of the electrodes in concrete at less than 5 cm depth, suitable means for the distance of the electrode wiring above the ground should be used. If strips are used as electrodes, they should be fixed set up on edge to avoid holes without concrete under the strip. If reinforcement is present, the wiring should be fixed to it at intervals of not more than 2 m. The connections should be made in accordance with 542.3.2. The use of keyed joints should be avoided.

C.3.3 The wiring of the concrete-embedded foundation earth electrode should have at least one terminal lug for connection to the electrical system of the building, either leaving the concrete inside the building to a suitable connection point (e.g. to the main earthing terminal) or ending at a special connection clamp embedded in concrete of a wall at its surface. At the point of connection, the terminal lug must be accessible for maintenance and measuring purposes.

For lightning protection and for buildings with special requirements concerning information technology, more than one terminal lug of the foundation earth electrode, e.g. for lightning protection system down-conductors, may be needed.

For connections needed outside the foundation concrete going through the soil, corrosion problems for steel wires need to be taken into account (see Clause C.4). For such connections, it is recommended that they should enter the concrete within the building, or outside at a suitable level above ground level.

C.3.4 For the minimum cross-sectional area of electrodes including terminal lugs, the values mentioned in Table 54.1 apply. Connections must be soundly made and electrically satisfactory (see 542.3.2).

C.3.5 Metal reinforcement of the foundations of the building may be used as an electrode provided it is soundly connected according to 542.3.2. For welded connections the permission of the responsible person for the structural design and analysis of the construction of the building is required. Connections made by a wrapped iron wire only are not suitable for protection purposes, but may be sufficient for EMC purposes for information technology. Pre-stressed reinforcement must not be used as an electrode.

If welded grids made from wires of smaller diameter are used for the reinforcement, it is possible to use them as electrodes provided they are soundly connected at more than one different point to the terminal lug or other parts of the electrode to provide at least the same cross-sectional area as required in Table 54.1. The minimum diameter of the single wires of such grids should be 5 mm with at least four connections between the terminal lug and the grid at several points of each grid.

C.3.6 The wiring of the electrodes should not go over joints between different parts of larger foundations. At such places, suitable malleable connectors should be installed outside the concrete to provide the necessary electrical connections.

C.3.7 Concrete-embedded foundation earth electrodes of single foundations (e.g. for the construction of large halls) should be connected to other parts of the concrete-embedded foundation earth electrode by using suitable earthing conductors. For embedding such connections in the soil see Clause C.4.

C.4 Possible corrosion problems for other earthed installations outside concrete-embedded foundation earth electrodes

Attention is drawn to the fact that ordinary steel (bare or hot-dip galvanized) embedded in concrete results in an electrochemical potential equal to that of copper embedded in the soil.

Consequently, there is a danger of electrochemical corrosion occurring to other earthing arrangements made from steel embedded in the soil near the foundation and being in connection with a concrete-embedded foundation earth electrode. This effect can also be found with reinforced foundations of large buildings.

Any steel electrode must not be installed directly from foundation concrete into the soil except for electrodes made from stainless steel or otherwise well protected by suitable prefabricated protection against humidity. Hot-dip galvanized covering or protection by painting or other similar materials later on is not sufficient for such purposes. Additional earthing arrangements around and near such buildings should be made from other than hot-dip galvanized steel so as to provide a sufficient life-time for this part of the earthing arrangement.

C.5 Completion of concrete-embedded foundation earth electrodes

C.5.1 After preparing the electrodes and/or the connected reinforcement, but before the concrete is poured, a survey and documented record of the arrangement should be made by a skilled person. The documentation should contain a description, plans and photos and should form a part of the whole documentation for the electrical installation (see IEC 60364-6).

C.5.2 Concrete used for the foundation should be made from at least 240 kg cement per m³ concrete. The concrete must have a suitable semi-liquid consistency to fill all holes below the electrodes.

Annex D (informative)

Erection of soil-embedded earth electrodes

D.1 General

Earth electrode resistance depends on its dimensions, its shape and on the soil resistivity in which it is embedded. This resistivity often varies from one place to another and in accordance with depth.

Resistivity of a soil is expressed in Ωm : numerically, it is the resistance in Ω of a cylinder of ground with a cross-sectional area of 1 m^2 a length of 1 m .

The aspect of surface and vegetation may give some indication of the more or less favourable characteristics of a soil for the implementation of an earth electrode. Where available results of measurements on earth electrodes installed in similar soil provides a better indication.

Soil resistivity depends on its humidity and on its temperature, both of which vary throughout the year. Humidity itself is influenced by the soil granulation and its porosity. In practice, the soil resistivity increases when humidity decreases.

Ground layers where water streams may go across, as found close to rivers, are rarely appropriate for the implementation of earth electrodes. In reality, these layers are composed of stony ground, are very permeable and become easily waterlogged by water itself purified by natural filtration and presenting high resistivity. Deep rods should be driven in order to reach deeper soils that may have better conductivity.

Frost considerably increases soil resistivity, which may reach several thousands of Ωm in the frozen layer. The thickness of this frozen layer may be 1 m or more in some areas.

Dryness also increases the soil resistivity. Drought effect can be found in some areas up to a depth of 2 m . Resistivity values in such circumstances can be of the same order as those occurring during times of frost.

D.2 Soil resistivity

Table D.54.1 gives information on resistivity values for certain types of soil.

Table D.54.2 indicates that resistivity may vary in large proportion, for the same type of soil.

Table D.54.1 – Resistivity for types of soil

Nature of ground	Resistivity Ωm
Marshy ground	From some units to 30
Alluvium	20 to 100
Humus	10 to 150
Damp peat	5 to 100
Malleable clay	50
Marl and compact clay	100 to 200
Jurassic marl	30 to 40
Clayey sand	50 to 500
Siliceous sand	200 to 3 000
Bare stony soil	1 500 to 3 000
Stony soil covered with lawn	300 to 500
Soft limestone	100 to 300
Compact limestone	1 000 to 5 000
Cracked limestone	500 to 1 000
Schist	50 to 300
Mica-schist	800
Granite and sandstone according to weathering	1 500 to 10 000
Granite and very altered sandstone	100 to 600

To enable a first approximation of the earth electrode resistance, a calculation may be made, using the average values indicated in Table D.54.2.

It is obvious that calculations made from these values only give a very approximate result of an earth electrode resistance. After having used the formula given in Clause D.3, the measurement of this resistance may allow an estimation of the average resistivity value of the ground. Such knowledge may be useful for further works done in similar conditions.

Table D.54.2 – Variation of the resistivity for different types of soil

Nature of soil	Average value of resistivity Ωm
Slimy arable soil, damp compact embankment	50
Poor arable ground, gravel, rough embankment	500
Bare stony ground, dry sand, impermeable rocks	3 000

D.3 Earth electrodes buried in the soil

D.3.1 Constituent parts

Earth electrodes may consist of buried elements of

- steel, hot-dip galvanized,
- steel copper-sheathed,
- steel with electro-deposited copper coating,

- stainless steel,
- bare copper.

Joints between metals of different nature shall not be in contact with the soil. Generally other metals and alloys should not be used.

Minimum thickness and diameters of the following parts consider usual risks of chemical and mechanical deterioration. However, these dimensions may not be sufficient in situations where significant risks of corrosion are present. Such risks may be encountered in soils where stray currents circulate, for instance return d.c. currents of electric traction or in the proximity of installations for cathodic protection. In such a case special precautions have to be taken.

Earth electrodes should be embedded, in the most humid parts of the available soil. They shall be kept away from garbage dumps where percolation of for example dung, liquid manure, chemical product, coke, etc. may corrode them and be erected, as far as possible, well away from busy locations.

D.3.2 Assessment of earth electrode resistance

a) Horizontally buried conductor

The earth electrode resistance (R) realized with a horizontally buried conductor (see 542.2.3 and Table 54.1), may be approximated from the formula:

$$R = 2 \frac{\rho}{L}$$

where ρ is the resistivity of the soil (in Ωm) and L is the length of the trench occupied by the conductors (in m).

It should be noted that the laying of conductor with a sinuous path in the trench does not noticeably improve the resistance of the earth electrode.

In practice, these conductors are laid down in two different ways:

- foundation earth electrode of the building: these earth electrodes are made of a foundation loop around the whole perimeter of the building. The length to be considered is the building perimeter;
- horizontal trenches: conductors are buried at a depth of about 1 m in trenches dug for this purpose.

Trenches should not be backfilled with stones, cinders or similar materials, but with earth liable to retain moisture.

b) Buried plates

To maintain good contact of the two surfaces with the soil, full plates should preferably be arranged vertically.

Plates should be buried in such a way that their top edge is situated at approximately 1 m depth.

The resistance (R) of a buried plate earth electrode at a sufficient depth is approximately equal to:

$$R = 0,8 \frac{\rho}{L}$$

where ρ is the resistivity of the soil (in Ωm) and L is the perimeter of the plate (in m).

c) Vertically buried electrodes

The resistance (R) of a vertically buried earth electrode (see 542.2.3 and Table 54.1) may be approximated from the formula:

$$R = \frac{\rho}{L}$$

where ρ is the resistivity of the soil (in Ωm) and L is the length of the rod or pipe (in m).

Where risk of frost or dryness exists the length of rods should be increased by 1 m or 2 m.

It is possible to reduce the value of the earth electrode resistance by driving several vertical rods connected in parallel, separated from each other by one rod length, in the case of two rods, and by more if there are more than two rods.

Attention is drawn to the fact that, where extra long rods can be driven, as the ground is rarely homogeneous such rods may reach ground layers with low or negligible resistivity.

D.4 Metallic pillar as earth electrodes

Metallic pillars interconnected by a metallic structure and buried at a certain depth in the ground, may be used as earth electrode.

The resistance (R) of a buried metallic pillar may be approximately calculated with the formula:

$$R = 0,366 \frac{\rho}{L} \log_{10} \frac{3L}{d}$$

where

L is the buried length of the pillar (in m);

d is the diameter of the cylinder circumscribed to the pillar (in m);

ρ is the ground resistivity (in Ωm).

A set of interconnected pillars located around a building has a resistance of the same order as that of a foundation earth electrode.

The eventual embedding of concrete does not prevent the use of pillars as earth electrodes and does not appreciably modify the earth electrode resistance.

Annex E (informative)

List of notes concerning certain countries

Country	Clause N°	Rationale (detailed justification for the requested country note)	Wording
US	541.1	In the USA, there are specific requirements in NFPA 70 applicable to earthing (grounding).	In the USA, requirements specific for earthing (grounding) arrangements, and related protective conductors are contained in NFPA 70, National Electrical Code.
BE	541.3.3, 541.3.4, 542	The wiring rules (Art. 69) do not permit the use of an earth electrode according to the definitions IEC 826-13-05 or IEC 826-13-08 (modified in 541.3.4 or 541.3.5). The definition given in the "Wording" column is consistent with the IEC definition 826-04-02:2004 or 604-04-03:1987	In Belgium, an earth electrode shall conform to the following definition: a conductive part or a group of conductive parts connected together which are buried in the soil and provide an electrical connection with earth.
DE	542.1.1		In Germany, there is an obligation to erect in every new building a foundation earth electrode according to National Standard DIN 18014.
IE	542.2.1		This note does not apply in Ireland
SI	542.2.1 542.3.1		In Slovenia the minimum cross-sectional area for steel solid tape or strip as earth electrode or earthing conductor is 100 mm ² .
CZ	542.2.1		In the Czech Republic, besides the steel electrodes which accord with Table 54.1, the minimum size steel earth electrodes whose corrosion and mechanical strength, when embedded in the soil, has a resistivity higher than 50 Ωm, are as shown in the following table:
Minimum size of steel earth electrodes in soil with resistivity higher than 50 Ω			
Type of earth electrode	Shape	Minimum dimensions	
		Zinc coated steel	Bare steel (without coating)
Strip or round wire earth electrode	Strip	According to Table 54.1	Cross-sectional area 150 mm ² , thickness 4 mm
	Steel wire	Ø 8 mm	Ø 10 mm
Rod with vertical extension	Round rod	Ø 8 mm	Ø 10 mm
	Pipe	Ø 15 mm, pipe wall thickness 3 mm	Ø 15 mm, pipe wall thickness 4 mm

Country	Clause N°	Rationale (detailed justification for the requested country note)	Wording			
				Steel angle, etc.	Cross-sectional area 100 mm ² angle wall thickness 3 mm	Cross-sectional area 150 mm ² angle wall thickness 4 mm
CZ	542.2.1		In the Czech Republic, metal plates are only used as earth electrodes in certain cases.			
US	542.2.1	The requirements in the US for the minimum size of earth electrode rods are different from those given in Table 54.1	In the US, the minimum diameter for earth electrodes of iron or steel is 15,87 mm (= 0,625 in), regardless of plating or coating. If certified for the use, stainless steel or nonferrous rods may be no less than 13 mm (0,519 in).			
NL	542.2.2		In the Netherlands, a single interruption in the earthing arrangement shall not lead to a touch voltage in the installation (connected to this earthing arrangement) that does not comply with Clause 411.			
NL	542.2.2		In the Netherlands, the earth electrodes and associated conductors shall be installed at a depth of at least 60 cm. The conductors of an earthing arrangement laid in a loop, or having a circular shape, shall be installed with a distance between them of at least 1 m.			
AT	542.2.3		In Austria, water pipes are not permitted as earth electrodes.			
BE	542.2.3		In Belgium, water pipes are not permitted as earth electrodes.			
CH	542.2.3		In Switzerland, water pipes are not permitted as earth electrodes.			
DE	542.2.3		In Germany, water pipes are not permitted as earth electrodes.			
FI	542.2.3		In Finland, water pipes are not permitted as earth electrodes.			
IE	542.2.3		In Ireland, water pipes are not permitted as earth electrodes.			
IS	542.2.3		In Iceland, water pipes are not permitted as earth electrodes.			
FR	542.2.3		In France, water pipes are not permitted as earth electrodes.			
SE	542.2.3		In Sweden, water pipes are not permitted as earth electrodes.			
UK	542.2.3		In the UK, a metallic pipe forming part of a water utility supply may not be used as an earth electrode.			
IT	542.2.3		In Italy, it is permitted to use a water pipe system, but only with the consent of the water distributor.			
PL	542.2.3		In Poland, it is permitted to use a water pipe system as earth electrodes, but only with the consent of the water distributor.			
KR	542.2.3		In South Korea, it is permitted to use a water pipe system, but only with the consent of the water distributor.			
NL	542.2.3		In the Netherlands, water pipes are not permitted as earth electrodes.			
SI	542.2.3		In Slovenia, water pipes are not permitted as earth electrodes.			
NO	542.2.3		In Norway, metallic pipelines are not permitted as earth electrodes.			

Country	Clause N°	Rationale (detailed justification for the requested country note)	Wording
DK	542.2.3		In Denmark, water pipes are not permitted as earth electrodes.
DE	542.2.5		In Germany, for external conductors (e.g. LPS down conductors) which are connected to the foundation earth, these connections made of hot galvanized steels shall not be buried in soil, except joints with plastic-cover or of stainless steel according No. 1.4571 are used for durable insulation (according to European certified reference material CRM 284-2 EN 10020).
CH	542.3.1		In Switzerland, the minimal cross-section of the earthing conductor shall be not less than 16 mm ² .
IE	542.3.1		In Ireland, the minimum cross-sectional area is 10 mm ² .
DK	542.3.1		In Denmark, earthing conductors buried in the soil shall be at a depth of at least 0,35 m.
NL	542.3.1		In the Netherlands, a single interruption in a protective conductor used for more than one installation shall not lead to a touch voltage that does not comply with Clause 411.
NO	542.3.1		In Norway, earthing conductors laid in the ground shall be at least 25 mm ² Cu or 50 mm ² corrosion protected Fe. Joints and/or connections shall be protected against corrosion.
CN	542.3.2		In China, joints in conduits are not permitted.
SI	542.3.2		In Slovenia the connection of an earthing conductor to an earth electrode shall be soundly made also with screws, not smaller than M10.
NL	542.3.2		In the Netherlands, earthing conductors embedded in the soil shall be installed at a depth of at least 60 cm.
DK	542.2.4		In Denmark, the earth electrode shall be installed at a depth of at least 2 m.
CZ	542.2.5 (after the 1 st para.)		In the Czech Republic, copper or copper-sheathed earth electrodes in densely inhabited regions are permitted, provided that the corrosive influence of the copper on steel, zinc coated steel, etc. is controlled and that sacrificial protection for the elimination of macro-cell is applied.
CZ	542.2.5 (at the end of the subclause)		In the Czech Republic, the contacts of steel earth electrodes and earthing conductors, and crossovers of steel earth electrodes and earthing conductors between two different medias, are protected no matter whether they are protected in a general sense (e.g. by zinc layer) or not. The crossovers are protected by passive protection (e.g. by asphalt sealing compound, pouring resin, anticorrosive band, etc.) up to these distances: – earthing conductors when crossing into the soil at least 30 cm below the surface and 20 cm above the surface; – earthing conductors from foundation earth electrodes; – on the crossing from concrete to the soil at least 30 cm in concrete and 100 cm in the soil; – on the crossing from concrete to the surface at least 10 cm in concrete and 20 cm above the surface; – at arching over the dilatation joints – arching waist in the joint and at least 20 cm in concrete on both sides of the joint.

Country	Clause N°	Rationale (detailed justification for the requested country note)	Wording
ES	542.2.6	The Spanish wiring rules, mandatory by R.D. 842/2002 prescribe different requirements.	In Spain, for safety reasons metallic pipe for flammable liquids or gases shall not be used as earthing arrangement.
IE	542.3.1		In Ireland, for circuits for lighting, the minimum cross-sectional area is 1,5 mm ² .
FI	542.3.1		In Finland, the minimum cross-sectional area for earthing conductors not protected against corrosion is 16 mm ² copper or 50 mm ² steel.
USA	543.1		In the USA, the minimum cross-sectional area for protective conductors is specified in document NFPA 70, National Electrical Code, Clause 250.
AT	543.1.1		In Austria replace the first and second paragraph by: The cross-sectional area of every protective conductor shall be capable of withstanding mechanical and thermal stresses caused by the prospective fault current for the expected duration. Where automatic disconnection of supply according to 411.3.2 is used, the cross-sectional area of the protective conductor shall be – either calculated in accordance with 543.1.2, – or selected in accordance with Table 54.2. For protective conductors protecting exposed conductive parts of sources (e.g. generators or transformers), a cross-sectional area of the half value of the line conductors could be not enough. In such special cases, it shall be ensured that the requirements of the first paragraph are met. In either case, the requirements of 543.1.3 shall be met.
AT	543.1.1 Table 54.2 Fifth line	Long term experiences	In Austria, for the time before relevant changing the standards for cables, it is allowed to use standardized cables with cross-sectional area of 150/70 mm ² and of 400/185 mm ² without calculation according to 543.1.2, nevertheless the cross-sectional area of the protective conductor is a little less than 0.5 times the cross-sectional area of the line conductor as here required within Table 54.2.
DK	543.1.1		In Denmark, for circuits protected by RCDs it is normally allowed to use copper protective conductors with a cross-sectional area of at least 2,5 mm ² , independent of the cross-sectional area of the line conductor and without calculation. Only when RCDs are used in TN-systems and the protective conductor is connected to the PEN conductor upstream of the RCD, with less cross-sectional area than the line conductor and shorter than 10 m is it necessary to calculate the cross-sectional area of the protective conductor from the formula.
NL	543.1.4		In the Netherlands, where an earthing arrangement is used for more than one installation, the earthing conductor shall be installed in such a way that a single interruption of the conductor does not impair the protective function of the arrangement.
CN	543.2.1		In China, cable trays and cable ladders are permitted as protective conductors in accordance with local or national regulations or standards.

Country	Clause N°	Rationale (detailed justification for the requested country note)	Wording
ES	543.2.1	The Spanish wiring rules, mandatory by R.D. 842/2002 prescribe different requirements.	In Spain, the use of conduits as protective conductors is forbidden.
ES	543.2.1	The Spanish wiring rules, mandatory by R.D. 842/2002 prescribe different requirements.	In Spain, for safety reasons metallic pipe for flammable liquids or gases shall not be used as earthing arrangement.
IT	543.2.1		In Italy, cable tray and cable ladder are permitted as protective conductors in accordance with local or national regulations or standards.
UK	543.2.1		In the UK, cable tray and cable ladder are permitted as protective conductors in accordance with local or national regulations or standards.
UK	543.2.1	In the UK, metallic trunking may also be used as a protective conductor	In the UK, extraneous-conductive-parts may be used as a protective conductor.
US	543.2.1		In the US, cable tray and cable ladder are permitted as protective conductors in accordance with local or national regulations or standards.
UK	543.2.3		In the UK cable tray and cable ladder are permitted as protective conductors in accordance with local or national regulations or standards.
CH	543.2.3		In Switzerland, metallic water pipes may be used as equipotential bonding conductors.
UK	543.4	In the UK, Regulation 8(4) of "Electricity Safety, Quality and Continuity Regulations 2002" states that a consumer shall not combine the neutral and protective functions in a single conductor in the consumer's installation.	In the UK, a consumer shall not combine the neutral and protective functions in a single conductor in the consumer's installation.
DE	544.1		In Germany, replace the first paragraph as follows: The protective bonding conductor for the connection to the main earthing terminal shall have a cross-sectional area not less than :
UK	544.1		In the UK, particular requirements exist regarding the minimum acceptable cross-sectional areas for protective bonding conductors where Protective Multiple Earthing (PME) conditions apply.
CZ	543.4.1		In the Czech Republic, the use of PEN conductors in parts of installations which are not metered, is permitted provided that: – the cross-sectional areas of all conductors of branches to electrometers, and from electrometers to the point of separation, are identical and not lower than 6 mm² Cu or 10 mm² Al; – separation of the PEN conductor into the neutral conductor N and protective conductor PE is carried out at the closest suitable point in the wiring system behind the electrometer (e.g. in the dwelling switchboard) and in compliance with the rest of the requirements of this subclause.

Country	Clause N°	Rationale (detailed justification for the requested country note)	Wording
SE	543.4.3 b)		In Sweden the example in item b) is not permitted.
DE	544.1		In Germany, replace the first paragraph as follows: The protective bonding conductor for the connection to the main earthing terminal shall have a cross-sectional area not less than:
CH	544.1.1	Swiss law requires a cross-sectional area of at least 10 mm ² for buildings provided with lightning protection.	In Switzerland, if used in conjunction with installations for lightning protection, the minimum cross-sectional area of the main protective bonding conductor shall be 10 mm ² .
IE	544.1 1st dash		In Ireland, the minimum value is 10 mm ² . In addition, a permanent label inscribed "Safety Electrical Connection- do not remove" shall be permanently affixed at each main bonding connection.
IE	544.1 2nd paragraph		In Ireland, the value for main bonding conductors need not exceed 70 mm ² .
IE	544.2.3		In Ireland, the minimum cross-sectional area for supplementary bonding conductors is 2,5 mm ² where mechanical protection is provided, and 4 mm ² where mechanical protection is not provided. In addition, a permanent label inscribed "Safety Electrical Connection- do not remove" shall be permanently affixed at the bonding connection to a pipe.

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