BUREAU OF INDIAN STANDARDS

DRAFT FOR COMMENTS ONLY

Preliminary Draft Indian Standard

CODE OF PRACTICE FOR EARTHING

(Third Revision)

(ICS 91.140.50)

Electrical Installations Sectional Committee, ETD 20 — **Last date for Comments – 05-January -2025**

FOREWORD

(Formal clause will be added later)

The Indian Electricity Act, 2003, together with the Central Electricity Authority (Measures Relating to Safety and Electric Supply) Regulations, 2023, made compliance to IS standards including IS3043 a mandatory requirement for safety, to govern the electrical installation work in generating stations, substations, industrial locations, buildings, etc, in the country. The code of practice for earthing was formulated with the intention to serve as a consolidated guide to all those who are concerned with the design, installation, verification and maintenance of electrical systems and apparatus.

This standard was first published in 1966 and revised in 1987 and 2018. The Central Electricity Authority (Measures Relating to Safety and Electric Supply) Regulations, 2023 made several changes in the regulation, subsequently, National Electrical Code was revised in 2023. Also, the Code of Practice of Electrical Wiring Installation (IS 732) has been revised in 2019 and IS/IEC 61936-1 published in 2021, demand improvements in earthing arrangement. Therefore, the revision of this standard was undertaken to align with the latest practices and the requirements of regulation.

The terms earth and earthing have been used in this Code irrespective of reliance being placed on the earth itself as a low impedance return path of the fault current. As a matter of fact, the earth now rarely serves as a part of the return circuit but is being used mainly for fixing the voltage of electrical energy system.

The object of an earthing system is to provide as nearly as possible a surface under and around a station which shall be at a uniform potential. In general, all parts of apparatus other than live parts, shall be at equal potential and avoid touch/step potentials during fault. The recommendations in this Code are made in order that these objects may be carried out.

In this Code, the terms ‘earth' is used as a verb as defined in IEV 195-01-08. In many places, the noun form of ‘earth’ is mentioned as ‘ground’.

The Code includes comprehensive guidelines on earth fault protection in consumer's premises. The rules given in the Code should be read in conjunction IS 732 & IS/IEC 61936-1. Guidance on achieving fault protection by protective equipotential bonding and automatic disconnection of supply is covered in this Code. Other fault protective measures are subject of IS732.

The revision of the Code aims at consolidating in one volume all the essential guidelines needed for preparing a good earthing arrangement and equipotential bonding in an electrical installation.

The major changes in this revision from the previous standard are as follows:

a) Updating of requirements based on Central Electricity Authority (Measures Relating to Safety and Electric Supply) Regulations, 2023;
b) Detailed explanations about various statutory requirements of earthing are included in clause 4;
c) Aligning the disconnection times, touch/step voltages and TOV’s as per IS 732, IS/IEC 61936-1;
d) New colour figures for easy understanding;
e) Mis concepts of earthing explained in IEC 61000-5-2 and IS732 in clause 6.3;
f) Explanation of protective earthing from majorly used product standards in clause 7.1;
g) Different type of earth electrodes (see 8.2.1 and Table 24), its installation and limiting the usage of earth enhancing compounds (see 8.1.7),
h) Global Earthing System and modern methods of Substation earthing and GIS (see 10)
i) Earthing of specific applications such as industrial and commercial (see 11.1) medical establishments (see 11.2) Solar PV (see 11.3);
j) Measurement of touch / step voltages (see 13.5) and continuity resistance measurement (see 13.7);
k) Earthing of multiple sources in modern and upcoming applications as an informative annex (see Annex A);
l) Earthing and Bonding for EMC in buildings (see Annex B);
m) Portable earthing and short circuiting devices for live working (see Annex C);
n) Maximum allowed continuity resistance of conductors used in protective equipotential bonding (see Annex D);
o) Calculation of Earth Fault Loop Impedance (see Annex E);
p) Earthing and shared protective earthing conductors (Annex F).

In the preparation of the Code, assistance has been taken from the following:

IEC Pub 60364 (all Parts) Electrical installations in buildings. International Electrotechnical Commission.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2: 1960 ‘Rules for rounding off numerical values (revised)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

CONTENTS

CODE OF PRACTICE FOR EARTHING
(THIRD REVISION)

1 SCOPE

1.1 This Code of practice provides recommendations and guidance on meeting the requirements for the earthing of electrical installation for the purpose of:

a) Protective earthing to limit the potential of non-current carrying metal work associated with equipment, apparatus and appliance connected to the system with respect to the general mass of earth during an earth fault,
b) Protective equipotential bonding to protect living beings from electric shock due to touch and step potentials,
c) Electrical Systems (called as system earthing) to limit the potential of current carrying conductor with respect to general mass of earth,
d) Earthing and changeover arrangement of multiple sources.

The earthing of an electrical system or installation is generally provided for reasons of safety and functionality.

1.2 This Code applies only to land-based installations.

It does not apply to:

a) ships, aircrafts, off shore installations;
b) equipment sensitive to static electricity; and
c) the internal earthing of the equipment (see 7.1.2 for some examples).
d) the design of earth electrode stations for high-voltage direct current (HVDC) links.
e) Measures for Telecommunication systems in or in the vicinity of MV/HV/EHV earthing systems.
f) Traction application of Railways

2 REFERENCES

2.1 The standards listed below contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. In case the standards are to be referred in this clause they are to be listed as follows:

Standard Number	Title
IS 732: 2019	Code of practice for electrical wiring installations (fourth revision)

IS 9409: 2023	Protection Against Electric Shock - Common Aspects for Installation and Equipment (First Revision).
IS/IEC 61936-1: 2021	Power installations exceeding 1 kV a.c. - Part 1 Common Rules
SP 30: 2023	National Electrical Code of India 2023 (SP 30)
IS 13234 / Part 3 : 2017 / IEC 60909-3 : 2009	Short - Circuit Currents in Three-Phase a.c. Systems Part 3 Current During Two Separate Simultaneous Line-to-Earth Short Circuits and Partial Short-Circuit Currents Flowing Through Earth
IS 11353: 2023	Basic and Safety Principles for Man-Machine Interface Marking and Identification - Identification of Equipment Terminals Conductor Terminations and Conductors (First Revision).
IS 13252 (Part 1): 2010	Information technology equipment - Safety: Part 1 General requirements
IS/IEC 60479 (Part 1): 2018 (Part 2): 2019 (Part 3): 1998 (Part 4): 2004 (Part 5): 2007	Effects of current on human beings and livestock: General aspects Special aspects Effects of currents passing through the body of livestock Effects of lightning strokes on human beings and livestock Touch voltage threshold values for physiological effects
IS/IEC 60898-1: 2015	Electrical accessories — Circuit breakers for over current protection for household and similar installations: Part 1 Circuit-breakers for ac operation
IEEE 80	IEEE Guide for Safety in AC Substation Grounding

3 TERMINOLOGY

For the purpose of this standard, the following definitions shall apply.

3.1 Arc-Suppression Coil (Peterson Coil) - a single-phase neutral earthing reactor intended for compensating the capacitive line-to-earth current due to a single-phase earth fault.

3.2 Bonding Conductor (protective bonding conductor) - A protective conductor providing equipotential bonding.

3.3 Class I Equipment - Equipment in which protection against electric shock does not rely on basic insulation only, but which includes means for the connection of exposed conductive parts to a protective earthing conductor in the fixed wiring of the installation.

3.4 Class II equipment - Electrical equipment where basic protection and fault protection are provided by double insulation or reinforced insulation.

NOTE - For information on classification of equipment with regard to means provided for protection against electric shock (see IS 9409).

3.5 Current to earth (I_E) - current flowing to earth via the impedance to earth

3.6 Dead - The term used to describe a device or circuit to indicate that a voltage is not applied.

3.7 DISCOM: Licensee or supplier who supply electricity.

3.8 Double Insulation - Insulation comprising both basic and supplementary insulation.

3.9 Earth (verb) - to make an electric connection between a conductive part and a local earth.

Note:

1. The connection to local earth can be intentional, or unintentional or accidental and can be permanent or temporary.
2. The noun form of "earth" is mentioned as "ground" also in this document.

3.10 Earth Electrode - Conductive part that is in electric contact with local earth, directly or through an intermediate conductive medium.

3.11 Earth Electrode Resistance - The resistance of an earth electrode or earth grid to earth.

3.12 Earth fault - Occurrence of an accidental conductive path between a live part and the Earth

Note: The conductive path can consist of faulty insulation, structures (e.g. poles, scaffoldings, cranes, ladders), or vegetation (e.g. trees, bushes) and can have a significant impedance.

3.13 Earth fault current (I_F) - current which flows from the main circuit to earth or earthed parts at the fault location (earth fault location)

3.14 Earth Fault Loop Impedance - The impedance of the earth fault current loop (phase-to-earth loop) starting and ending at the point of earth fault. This impedance is denoted by the symbol Z. The earth fault loop comprises the following, starting at the point of fault:

a) the circuit protective conductor;
b) the consumer’s earthing terminal and earthing conductor, and for TN systems, the metallic return path;
c) for TT and IT systems, the earth return path;
d) the path through the earth neutral point of the transformer;
e) the transformer winding; and
f) the line conductor from the transformer to the point of fault.

3.15 Earth Grid - A system of interconnected earth electrodes arranged in a pattern over a specified area and buried below the surface of the earth embedded in soil or concrete.

3.16 Earth Leakage Current - A current which flows to earth or to extraneous conductive parts in a circuit which is electrically sound.

NOTE — This current may have a capacitive component including that resulting from the deliberate use of capacitors.

3.17 Earth Potential - Electric potential with respect to general mass of earth which occurs in, or on the surface of the earth around an earth electrode when an electric current flows from the electrode to earth.

3.18 Earth Potential Rise (U_E) - voltage between an earthing system and reference earth.

3.19 Earthed Concentric Wiring - A wiring system in which one or more insulated conductors are completely surrounded throughout their length by a conductor, for example, a sheath which acts as PE/PEN conductor.

3.20 Earthed Conductor - Protective conductor provided by the supplier for protective earthing of consumer electrical installation. (eg. Protective Earth conductor in a TN-S system)

Note: Earthed conductors originate from the earthed point of the source and runs along with Live conductors.

3.21 Earthed Neutral Conductor - Combined Neutral and protective conductor (eg. PEN conductor in a TN-C-S system)

3.22 Earthed Terminal - A terminal which is solidly connected to the earthed conductor or earthed neutral conductor of an incoming service line. (eg. PEN conductor in a TN-C-S system or PE conductor in a TN-S system)

3.23 Earthing - Electric connections between conductive parts and local earth.

Note:

1. The CEA regulations 2023 define earthing as Connection of the exposed conductive and extraneous parts of an installation to the MET of that installation or connection of neutral of transformer or generator to general mass of earth or to earth bonding bar of that installation
2. The IS 732 defines earthing as Connection of the exposed conductive parts of an installation to the MET of that installation.

3.24 Earthing Arrangement - all the electric connections and devices involved in the earthing of a system, an installation or equipment.

3.25 Earthing Conductor - conductor forming a conductive path between a conductive part and an earth electrode.

3.26 Equipment - Single apparatus or set of devices or apparatuses, or the set of main devices of an installation, or all devices necessary to perform a specific task.

Note – Examples of equipment are a power transformer, the equipment of a substation, measuring equipment.

3.27 Equipotential Bonding - set of electric connections intended to achieve equipotentiality between conductive parts

NOTE — In a building installation, equipotential bonding conductors shall interconnect the extraneous conductive parts to the MET:

3.28 Exposed Conductive Part - A conductive part of equipment which can be touched and which is not a live part but which may become live under fault conditions.

3.29 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.

3.30 Final Circuit - electric circuit incorporating current using equipment and/or socket outlets

3.31 Functional Earthing - Connection to earth necessary for proper functioning of electrical equipment.

3.32 Global Earthing System - Equivalent earthing System created by the interconnection of local earthing system that ensures, by the proximity of the earthing system, that there is no dangerous touch voltage.

NOTES

1) Such a system 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.
2) The existence of global earthing system may be determined by simple measurement or calculation for typical system. Typical examples of global earthing systems are in city centre, urban or industrial areas with distributed low and high voltage earthing.

3.33 Independent Earth Electrodes - earth electrode located at such a distance from other earth electrodes that its electric potential is not significantly affected by electric currents between Earth and other earth electrodes.

3.34 Impedance to earth (Z_E) - Impedance at a given frequency between a specified point in a system or in an installation or in equipment and reference earth

Note: Impedance to earth is composed of the resistance to earth of the substation and connected parallel impedances such as overhead earth wires and cable sheaths.

3.35 Live Part - Conductive part intended to be energized under normal operating conditions, including the neutral conductor and mid-point conductor, but excluding the PEN conductor, PEM conductor and PEL conductor.

3.36 Local earth - Part of the Earth that is in electric contact with an earth electrode and that has an electric potential not necessarily equal to zero.

3.37 Main Earthing Terminal (MET) - Terminal or busbar that is part of the earthing arrangement of an installation and enabling the electric connection of a number of conductors used for earthing or bonding purposes.

NOTE — Main Earthing Terminal is also called as Main Earthing Busbar.

3.38 Neutral Conductor - A conductor connected to the neutral point of a system and capable of contributing to the distribution of electrical energy.

3.39 Origin of the electrical installation - point at which electric energy is delivered to the electrical installation.

3.40 PEN Conductor - A PEN conductor is a conductor where the function of a protective earthing conductor is combined with the function of a neutral conductor. By definition, the PEN is not a live conductor but a conductor carrying an operating current.

NOTE

1) In case of a single-phase 2-wire arrangement which is derived from a three-phase 4-wire arrangement, the two conductors are either two line conductors or a line conductor and a neutral conductor or a line conductor and a PEN conductor.
2) PEN conductor is also called as Earthed Neutral Conductor in CEA regulations.

3.41 PEL conductors - A PEL conductor is a conductor where the function of a protective earthing conductor is combined with the function of a line conductor. By definition, the PEL is not a live conductor but a conductor carrying an operating current.

3.42 PEM conductors - A PEM conductor is a conductor where the function of a protective earthing conductor is combined with the function of a mid-point conductor. By definition, the PEM is not a live conductor but a conductor carrying an operating current.

3.43 Permanently connected equipment - Equipment that can only be connected to or disconnected from the electric power system by the use of a tool.

3.44 Permissible touch voltage (U_{Tp}) - limit value of touch voltage U_T

3.45 Pluggable equipment type A - Equipment that is intended for connection to the mains via a non-industrial plug and socket-outlet or via a non-industrial appliance coupler, or both.

Note: For non-industrial plug and socket-outlets, see IS 1293. For non-industrial appliance couplers, see IEC 60320-1.

3.46 Pluggable equipment type B - Equipment that is intended for connection to the mains via an industrial plug and socket-outlet or via an industrial appliance coupler, or both.

Note: For industrial plug and socket-outlets, see IS/IEC 60309-1. For industrial appliance couplers, see IEC 60309-1.

3.47 Portable Equipment - Equipment which is moved while in operation or which can easily be moved from one place to another while connected to the supply.

Note: Portable equipment carried by a person during its operation is sometimes referred to as hand-held equipment.

3.48 Potential grading - control of the earth potential, especially the earth surface potential, by means of earth electrodes.

Note

1) In the case of high-voltage installations and equipment, potential grading shall prevent persons or livestock from hazardous step and touch voltages under normal conditions by providing a potential grading earth electrode.
2) Potential grading may be used by installation of additional earth electrodes to reduce the touch voltage and step voltage which appear in the case of a fault.

3) Earth electrodes are usually buried at a horizontal distance of 1 m from the equipment or any conductive part, at a depth of 0.5 m below ground level and are connected to the earthing arrangement.

3.49 Protective Conductor - Conductor provided for purposes of electrical safety.

Note: Protective conductor is used for connecting any of the following parts:

a) Exposed conductive parts,
b) Extraneous conductive parts,
c) Main earthing terminal (MET), and
d) Earthed point of the source or an artificial neutral.

3.50 Protective earthing - Earthing for purposes of electrical safety

3.51 Protective earthing conductor (PE conductor) - Protective conductor provided for protective earthing.

3.52 Prospective Touch Voltage (U_{vT}) - Voltage between simultaneously accessible conductive parts when those conductive parts are not touched simultaneously by a person.

3.53 Prospective permissible touch voltage U_{vTp} - limit value of prospective touch voltage U_{vT}.

3.54 Reference Earth - Part of the Earth considered as conductive, the electric potential of which is conventionally taken as zero, being outside the zone of influence of any earthing arrangement.

3.55 Reinforced Insulation - Insulation that provides a degree of protection against electric shock equivalent to double insulation.

NOTE - Reinforced insulation can comprise several layers that cannot be tested singly as basic insulation or supplementary insulation.

3.56 Residual Current Device - Mechanical switching device or association of devices designed to make, carry and break currents under normal service conditions and to cause the opening of the contacts when the residual current attains a given value under specified conditions.

3.57 Residual Operating Current - Value of residual current which causes the residual current device to operate under specified conditions.

3.58 Resistance Area (for an Earth Electrode only) - The surface area of ground (around an earth electrode) on which a significant voltage gradient may exist.

3.59 Resistance Earthed System - A system earthed through a high resistance to limits the earth fault current.

3.60 Simultaneously Accessible Parts - Conductors or conductive parts which can be touched simultaneously by a person or, where applicable, by livestock.

NOTES

1. In the context of protection against direct contacts a live part may be accessible with:
   a) another live part, or
   b) an exposed conductive part, or
   c) an extraneous conductive part, or
   d) a protective conductor.
2. The following may constitute simultaneously accessible parts in the context of protection against indirect contacts:
   a) Exposed conductive parts,
   b) Extraneous conductive parts, and
   c) Protective conductors.
3. It should be noted that the word touched signifies any contact with any part of the body (hand, foot, head, etc).

3.61 Supplementary Insulation - Independent insulation applied in addition to basic insulation, in order to provide protection against electric shock in the event of a failure of basic insulation.

3.62 Switchgear - An assembly of main and auxiliary switching apparatus for operation, regulation, protection or other control of electrical installations.

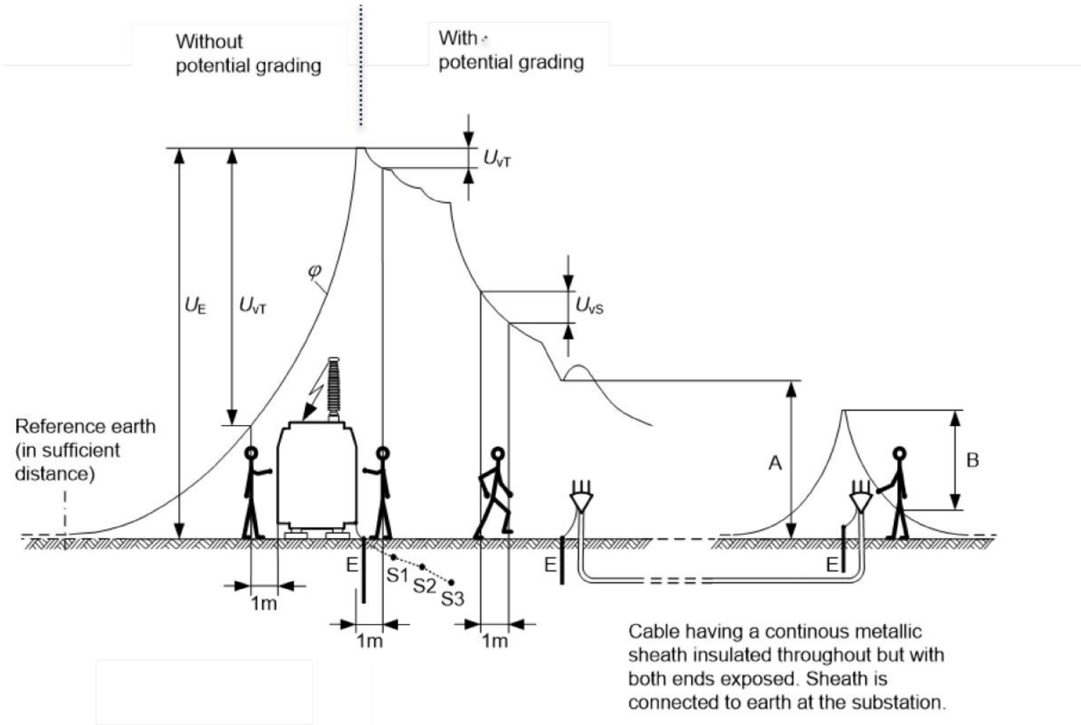
NOTE - A more comprehensive definition of the term ‘Switchgear’ can be had from IS 1885 (Part 17).

3.63 System-referencing-conductor (SRC) - A system-referencing-conductor is a conductor between a live part and an earthing arrangement for enabling the live part to be substantially at the potential of the earthing arrangement.

Note: Where it is considered necessary, a system-referencing-conductor may be provided with protective provisions to ensure its effectiveness throughout the lifetime of the system. It shall be ensured that those provisions will not have a detrimental effect on the characteristic behaviour of the system.

3.64 Solidly earthed system - System in which at least one live part is earthed directly.

3.65 Step Voltage - The voltage between two points on the Earth's surface that are 1 m distant from each other (see Fig. 1).



Key

E	Earth electrode
S1, S2, S3	Potential grading earth electrodes (e.g. ring earth electrodes), connected to the earth electrode E
U_E	Earth potential rise
U_{vS}	Prospective step voltage
U_{vT}	Prospective touch voltage
A	Prospective touch voltage resulting from transferred potential in case of single side cable sheath earthing
B	Prospective touch voltage resulting from transferred potential in case of cable sheath earthed on both sides
φ	Earth surface potential

FIGURE 1 EXAMPLE FOR THE SURFACE POTENTIAL PROFILE DURING AN EARTH FAULT IN MV/HV AND EHV SYSTEM, THE RESULTING STEP AND TOUCH VOLTAGES

3.66 Touch Voltage - Voltage between conductive parts when touched simultaneously.

NOTES

1) Voltage between conductive parts when touched simultaneously that is the potential difference between an exposed conductive part and a point on a extraneous conductive part liable to transmit a potential including earth potential and not forming part of the electrical installation or a point on earth’s surface separated by a distance equal to the maximum normal reach (hand to hand or hand to foot) approximately one metre (see Fig. 1).
2) The value of the effective touch voltage is influenced by the impedance of the person in electrical contact with these conductive parts.

3.67 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 related to reference earth resulting in a potential difference occurring between the conductor and its surroundings.

NOTES

1) The definition also applies where a conductor which is connected to reference earth, leads into the area of the potential rise.
2) Transferred potential can result in electrocution path through the human body other than the ‘touch voltage’ path that is hand to hand.

3.68 Voltage Nominal (U_n)— Voltage by which an installation (or part of an installation) is designated and identified

3.68.1	Voltage, Extra Low (ELV)	A system with a nominal voltage $U_n \leq 50$ V a.c. or ≤ 120 V d.c.
3.68.2	Voltage, Low (LV)	A system with a nominal voltage $U_n \leq 1\ 000$ V a.c. and $\leq 1\ 500$ V d.c.
3.68.3	Voltage, Medium (MV)	A system with a nominal rms voltage is 1 kV $< U_n \leq 33$ kV.
3.68.4	Voltage, High (HV)	A system with a nominal rms voltage is $33 < U_n \leq 150$ kV.
3.68.5	Voltage, Extra High (EHV)	A system with a nominal rms voltage is > 150 kV.

Note: ELV is a subcategory under LV, hence minimum value is not considered.

3.69 Symbols and Numbering used in Earthing and Bonding and purpose and their definition.

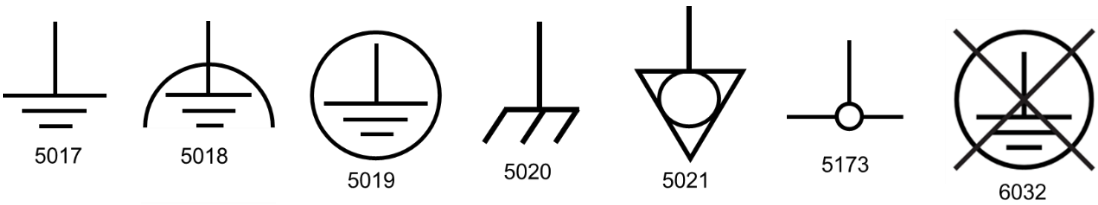


FIGURE 2 SYMBOLS/NUMBERING USED IN EARTHING

No. 5017 Earth: To identify an earth terminal in cases where neither the symbol 5018 nor 5019 is explicitly stated.

No. 5018 Functional Earth: To identify a noiseless (clean) earth terminal, of an equipment. These terminals are to be connected to specially designed functional earthing arrangement to avoid causing malfunction of the equipment.

No. 5019 Protective Earth: To identify any terminal which is intended for connection to an external conductor for protection against electrical shock in case of a fault.

No. 5020 Frame or chassis (also called as functional bonding): To identify a frame or chassis terminal. (e.g. measure to enhance the immunity of the equipment against conducted and radiated RF disturbance - connection of sensitive electrical circuits to the chassis).

No. 5021 Frame or chassis Equipotentiality: To identify the terminals when connected, bring the various parts of an equipment or of a system to the same potential, not necessarily being the earth potential, e.g. for local bonding.

No 5173 Signal low terminal: To indicate the signal terminal the potential of which is closest to the earth or chassis potential.

No 6032: Do not connect to protective earth.

4 STATUTORY PROVISIONS FOR EARTHING

4.1 REQUIREMENTS FROM CEA SAFETY REGULATION

4.1.1 Earthing and electrical safety shall be carried out in accordance with the requirements of Central Electricity Authority (Measures Relating to Safety and Electric Supply) Regulations, 2023, as amended from time-to-time. Important regulations related to earthing in the 2023 regulation are 14-21, 25, 28, 31, 33, 35, 37, 38, 43, 44, 50, 62, 73 and 74. Regulation 14 (2) and (3) need compliance to NEC and IS standards.

Note:

1. Regulation 14 (2): Save as otherwise provided in these regulations, the relevant standards including National Electrical Code and National Building Code shall be followed to carry out the purpose of these regulations and where relevant Indian standards are not available, international standards shall be followed and in the event of any inconsistency, the provisions of these regulations shall prevail.
2. Regulation 14 (3): The material and apparatus used shall conform to the relevant standards.
3. When the earthing of a consumer’s installation is being planned, prior consultation should take place between the consultant or contractor and the supply authority. Where necessary, precaution will be taken in order to avoid any interference with the telecommunication system.
4. The regulations made by CEA required that every electrical network at whatever voltage be connected with earth and that the connection is maintained under fault conditions in a sound manner. This requirement is 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.

4.2 EARTHING AT ORIGIN OF INSTALLATION FOR LOW VOLTAGE CONSUMER PREMISE

Note: see requirement from CEA Safety regulation 16, 17,18, 43 & 74 for Public distribution system.

4.2.1 Where the neutral and protective conductors (earthed conductors) of electricity supply system upto 1000 V a.c of electrical supply undertaking are combined, it is called as TN-C-S system. The PEN conductor, which is referred to as a combined neutral and earth conductor, is earthed at the source and extremities of the distribution mains and point in between. This is also called as protective multiple earthing (PME), which is the recommended system in the regulations to be adopted by the Electrical supply undertakings.

4.2.2 Multiple earthing of the PEN conductor ensures that if this conductor becomes open circuit for any reason (probably cut or snapped at the distribution), exposed-conductor parts remain connected to earth; under such conditions the supply voltage between the installation line and neutral conductor is substantially reduced (see 4.2.3).

4.2.3 In a TN-C-S system, where the supply is TN-C and the arrangement in the installations is TN-S, the changeover from TN-C to TN-S shall happen at the origin of installation, through a link suitable for disconnection (e.g. disconnection required during insulation resistance test).

Note: See IS732:2019 clause 5.4.3.4.3, and Fig. 61 and IS8061:2024.

4.2.4 All equipment of voltages of 250 V to 650 V shall be earthed by two separate and distinct connections with earthing arrangement. How ever the number of connections should be restricted to one, if only one provision is provided by the equipment manufacturer, and the equipment confirm the relevant Indian/IEC standard.

4.2.5 Every building shall have protective equipotential bonding by interconnecting the exposed and extraneous conductive parts as per this code of practice.

4.2.6 All earthing systems shall, consist of protective equipotential bonding capable of carrying the prospective earth fault current without exceeding the allowable temperature limits as per this code in order to maintain all noncurrent carrying metal works reasonably at earth potential and to avoid dangerous contact potentials being developed on such metal works;

4.2.7 All earthing system shall have earth fault loop impedance sufficiently low to permit adequate fault current for the operation of protective device within the time stipulated in Table 1 (also see cluses 7.4.1.8 to 7.4.1.12).

4.2.8 Where multiple sources are used (e.g. DG), the requirement of sufficiently low earth fault loop impedance is applicable for every source.

TABLE 1 MAXIMUM DISCONNECTION TIMES.

System	50 V < UO ≤ 120 V s		120 V < UO ≤ 230 V s		230 V < UO ≤ 400 V s		UO >400 V s	
	a.c	d.c	a.c	d.c	a.c	d.c	a.c	d.c
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
TN	0.8	Note 1	0.4	5	0.2	0.4	0.1	0.1
TT	0.3	Note 1	0.2	0.4	0.07	0.2	0.04	0.1

Maximum disconnection times as per this table are applicable, where fault protection is achieved by protective earthing, protective equipotential bonding and automatic disconnection of supply as per clause 4.2.11.3 of IS732. In locations where protective equipotential bonding does not exist, the maximum allowed disconnection time shall be 0.2 s. The existence of protective equipotential bonding shall be proved by a touch voltage test.

Where in TT systems the disconnection is achieved by an over current protective device and the protective equipotential bonding is connected with all extraneous-conductive-parts within the installation, the maximum disconnection times applicable to TN systems may be used.

*U*o is the nominal a.c. or d.c. line to earth voltage. Clause 7.4.1.8 to 7.4.1.12 applies along with this table on disconnection time.
NOTES: Disconnection may be required for reasons other than protection against electric shock.

4.2.9 Be mechanically strong, withstand corrosion and retain electrical continuity during the life of the installation and all earthing systems shall be tested to ensure effective bonding before the electric supply lines or apparatus are energised.

4.2.10 Each earthing arrangement shall be so devised that the testing of protective conductors is possible.

NOTE - Continuity of protective conductors and efficiency of automatic disconnection shall be tested as per clause 6 of IS 732 or part 1 section 17 of NEC 2023 (SP 30).

4.2.11 It is recommended that a drawing showing the main earthing arrangement be prepared for each installation.

4.2.12 No addition to the current-carrying system, either temporary or permanent, shall be made which will increase the maximum available earth fault current or its duration until it has been ascertained that the existing earthing arrangement are capable of carrying the new value of earth fault current which may be obtained by this addition.

4.2.13 No cut-out, link, switch or circuit breaker other than a linked switch arranged to operate simultaneously on the earthed or earthed neutral conductor and live conductors shall be inserted or remain inserted in any earthed or earthed neutral conductor of a two wire-system or in any earthed or earthed neutral conductor of a multi-wire system or in any conductor connected thereto: This, however, does not include the case of a switch for use in controlling a generator or a transformer or a link for test purposes.

4.2.14 As far as possible, all earth connections shall be visible for inspection.

4.2.15 In cases where direct earthing such as TN/TT system may prove harmful effect rather than provide safety (for example, power supply to Operation Theatre in hospitals / Instrumentation system / Building Management and security system), IT system may be used.

4.2.16 Earthing arrangements at origin of installation for PEN, PEL or PEM conductors.

PEN, PEL or PEM conductors serve two functions, as PE and either as N, L or M conductors, all applicable requirements for the relevant functions should be considered.

Note: N – Neutral conductor, L – Line conductor & M – Midpoint conductor. See 4.1.5.8 of IS732:2019.

- PEN conductor should not be installed downstream of the origin of the installation.
- PEN, PEL or PEM conductor are not permitted in explosive atmospheres.
- For mechanical reasons, PEN, PEL or PEM conductor shall have a cross-sectional area not less than 10 mm^2 copper or 16 mm^2 aluminium.

– PEN, PEL or PEM conductors are not permitted downstream origin of installation. The neutral/mid-point/line and protective functions are provided by separate conductors downstream origin of installation. It is not permitted to connect the neutral/midpoint/ line conductor to any other earthed part of the installation.
– The PEN, PEL or PEM conductor shall be insulated for the rated voltage of the line conductor or made inaccessible.
– Metallic enclosures of wiring systems shall not be used as PEN, PEL or PEM conductors, except for busbar trunking systems complying with IS 8623 (Part 2) and for power track systems complying with IEC 61534-1.
– The PEN, PEL or PEM conductor shall be connected to the terminal or bar intended for the protective conductors (see IS 732, Fig. 61 a), unless there is a specific terminal or bar intended for the connection of the PEN, PEL or PEM conductor (see IS 732, Fig. 61 b and c).
– Extraneous-conductive-parts shall not be used as PEN, PEL or PEM conductors.
– Earthed Neutral conductor from the supplier can be connected to earthed terminal as per the Fig. 61 (a to c) of IS732.

4.2.17: Protection against earth fault and additional protection

4.2.17.1 The CEA safety regulation 44 require RCD for certain application and not for every application.

Note: Regulation 44 Residual Current Device as below.

a. The use of electricity to electrical installation, shall be controlled by a residual current device to disconnect the supply having rated residual current and duration as per the relevant standards:
b. Provided that in domestic installation, residual current device having residual operating current not exceeding 30 milliampere shall be used:
c. Provided further that such protective device shall not be required for supply lines having protective devices which are effectively bonded to the neutral of supply transformers and conforming to regulation 76.

4.2.17.2 The regulation 43 (xi) and (xii) need automatic disconnection of fault by testing and ensuring low earth fault loop impedance. However, in TT system earth fault loop impedance may not be sufficiently low to disconnect an OCPD, hence an RCD may be required as an earth fault protective measure to disconnect the supply within the time specified in Table 1.

4.2.17.3 Regulation 44 (para 2) Every domestic installation RCD having $I_{\Delta n}$ 30 mA shall be used. Providing 30 mA RCD at origin of installation may not be practical due to higher leakage current inherent in the installation. In such cases RCD with $I_{\Delta n} \leq 30$ mA should be used in circuits.

4.2.17.4 Regulation 44 (para 3) relaxes the use of RCD in locations where OCPD installed in compliance to regulation 43(xi) and (xii) ensure earth fault protection. (see 7.5.3 to 7.5.4). Such installation may require RCD with $I_{\Delta n} \leq 30$ mA as an additional protection (see 7.5.5).

4.2.17.5 RCD's are classified into Type AC, Type A, Type F and Type B. Appropriate types shall be used in a given application (see 7.5.7)

4.3 EARTHING AT ORIGIN OF INSTALLATION FOR HIGH VOLTAGE CONSUMER PREMISE

Note: See requirement from CEA Safety regulation 16, 17,18, 50 & 74 for public distribution system. –

4.3.1 Requirements from Regulation 50.

(1) The entire switchyard or substation equipment and buildings including all non-current carrying metal parts associated with an installation shall be effectively earthed to an earthing system or mat which shall, –

(ii) limit the earth potential rise to tolerable values as per relevant standards, so as to prevent danger due to transfer of potential through ground, earth wires, cable sheath, fences, pipelines or other such equipment; and

(iii) maintain the resistance of the earth connection to such a value as to make operation of the protective device effective.

4.3.2 In the case of high and extra high voltages, the neutral points shall be earthed by not less than two separate and distinct connections with earthing arrangement. If necessary, the neutral may be earthed through suitable impedance.

4.3.3 In cases where direct earthing may prove harmful rather than provide safety (for example, high frequency and mains frequency coreless induction furnaces), relaxation may be obtained from the competent authority.

4.3.4 Earthing arrangement shall be provided at generating stations, substations and consumer premises in accordance with the requirements of this Code. (see clause 7, 10 and 11).

Note: See fig. 4 for Permissible touch voltage limits U_{Tp} and 5.1 and 5.2 for calculated touch voltage.

4.4 EARTHING ASSOCIATED WITH OVERHEAD POWER LINES.

4.4.1 Type of Support

Any consideration of whether metalwork associated with overhead power lines should be earthed and/or bonded has to take account of the type of support. Some overhead lines are supported by lattice towers of metallic construction, others by poles, which may be of steel, wood, concrete or of fabricated construction, for example, glass-reinforced plastics; brackets attached to buildings are also used to support conductors.

4.4.2 Insulation Failure

Following an insulation failure, a voltage may exist between any supporting metalwork and earth. The public are generally protected if no metalwork within 3 m of the earth is liable to become live on failure of insulation. If the supports are close to buildings, etc, the particular circumstances have to be considered.

4.4.3 Lattice Steel Structures

There will often be satisfactory earthing of lattice steel structures, poles of metallic construction and reinforced concrete poles through their contact with the earth. In areas of high earth resistivity, special earthing arrangements may be necessary; an overhead protective conductor attached at each support and connected to the neutral of the supply and of the line may be the most economical solution. This conductor if positioned above the live conductors will also provide a measure of lightning protection.

4.4.4 Poles of Non-conducting Material

4.4.4.1 General

Where a pole is of non-conducting material, for example wood or glass-reinforced plastics, the pole will act against the flow of leakage current and can be expected to prevent danger near ground level due to leakage across or failure of any insulator supporting a line conductor, except where there is intervening equipment or metalwork that is or may become live.

For the reasons given in 4.4.4.2 to 4.4.4.4, there are advantages in not earthing the pole-top metalwork of such poles and in not making bonding connections to it.

Note :- This does not omit the usage of continuous earth wire required under various Regulations.

4.4.4.2 Omission of Bonding

Where insulators are attached to a pole or to non-conducting cross-arms, etc, attached to the pole, omission of bonding of pole-top metalwork gives a greater impulse withstand voltage, so there is less risk of faults due to phase-to-phase flashover. To reduce risk of fire, where wooden cross-arms are used, care should be taken to make close, fire contact between the cross-arm and the insulator pipe.

4.4.4.3 Omission of Earthing

If pole top metalwork is not earthed, transient faults due to birds, flying branches, etc, bridging the clearance between line conductors and the metalwork are greatly reduced.

4.4.4.4 Transformers, Rod-operated Switchgear and Cable Terminations

In cases where equipment, such as transformers, rod-operated switchgear or cable terminations are mounted on a wooden or reinforced plastics pole, the impulse flashover value of the additional insulation provided by the pole is impaired, and all the metal work on the pole needs to be bonded and earthed.

4.4.5 Stays

To prevent stay corrosion that would otherwise occur due to passage of small leakage currents occurring even in normal operation, stay insulators should be fitted in stay wires on poles.

No part of the stay insulator should be less than 3 m above ground; it should be fitted as high up the stay as possible, but the stay insulator should be so positioned that there can be no contact below the stay insulator between the stay wire and any phase conductor (including a jumper connection), should either of them break or become loose.

4.4.6 Metal Brackets Attached to Buildings

A metal bracket attached to or adjacent to any metalwork on or joining part of any building or structure and supporting a phase conductor needs to be earthed unless the conductor is both insulated and supported by an insulator, each form of insulation being suitable for the conditions under which it will be required to operate in the event of failure of the other.

4.4.7 Earth Wires and Earth Connection

Any connection between metalwork and earth has to be of low resistivity, both to provide for prompt operation of protective equipment and to minimize inductive interference with communications circuits in the event of a flow of fault current. Electromagnetic interference is reduced if the resistance of the earth return path is small compared with its reactance. At 50 Hz, inductive interference may be caused by the use of a high-resistivity wire (for example, steel wire) even if it is perfectly earthed. A single low-resistivity earth wire made of copper, aluminium etc, should be used and it should avoid passing close to conductors or cables belonging to other circuits. It should be protected against mechanical damage for a distance of 3 m above ground level.

4.4.8 Lightning Protection

A lightning conductor attached to a structure and earthed at its lower end acts to reduce the likelihood of an arching during a lightning strike. An over-running aerial earth-wire on overhead power line, besides forming part, of the earth return path, also gives a degree of lightning protection. The lower the impedance between aerial earth-wire and earth, the better is the protection since this reduces the possibility of a back flashover from the earthed metalwork to line conductors on the occasion of a direct strike to the earth wire.

NOTE: The conductors of fundamental earthing may be connected to the main earthing terminal (which is equipotential bonding conductor) only if the same is recommended by original electrical equipment manufacturer.

4.5 PROTECTIVE BONDING AND CONDUCTORS

4.5.1 For several applications, two distinct and separate earth connections are recommended (called as double earthing), to ensure redundancy in protective earthing. However modern, indoor/outdoor equipment may not have provision for double earthing. In such case modifying the equipment outside the equipment manufacturers premise for making additional provision for second protective earth connection may damage the equipment, under such condition duplicate connection may be avoided. A typical schematic of earthing and protective conductors for Low Voltage electrical installation in a building is given in Fig. 3.

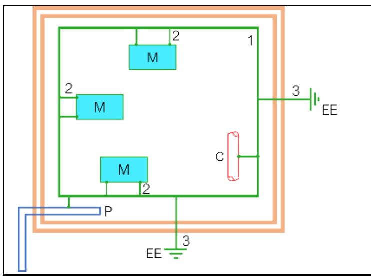
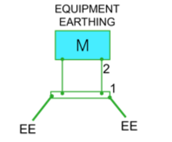
		*M* = Exposed conductive parts of class 1 equipment *P* = Incoming metallic service *C* = Extraneous conductive parts *EE* = Earth electrode 1 = MET (Equipotential bonding conductor) 2 = Protective earthing conductor (in duplicate) 3 = Earthing conductor

FIGURE 3 TYPICAL SCHEMATIC OF EARTHING AND PROTECTIVE CONDUCTORS

4.5.1.1 Protective earthing conductor (sl no 2 in Fig. 3) connects exposed conductive part to MET. Protective earthing conductor shown in duplicate (meaning two connection / conventionally called as double earthing) can be made if the class 1 equipment have provision for duplicate connection.

4.5.1.2 The number of PE conductor connections to MET can be restricted to one, if only one provision is available in the equipment, provided the equipment confirms the relevant IS/IEC standard.

4.5.2 Duplicate connection of PE conductor shall be required in cases where reinforced protective earthing conductors as per clause 5.4.3.7 of IS732:2019 is necessary.

4.5.3 If industrial sockets as per IS/IEC 60309 are used, the PE conductor shall be a part of multi core cable (e.g. 3 core cable for 1 phase and 5 core cable for 3 phase applications). In such a condition, duplicate connection may be avoided.

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

– calculated in accordance with 7.3.2.1 for the most onerous prospective fault current and operating time encountered in these circuits; or

– selected in accordance with Table 10 so as to correspond to the cross-sectional area of the largest line conductor of the circuits.

4.5.5 The incorporation of the protective conductor in the same wiring system as the live conductors or in their immediate proximity is strongly recommended to avoid creation of large loops, which may create EMI and electromechanical forces during an over current.

4.5.5.1 EMI produced due to large loops may affect the performance of electronic equipment.

4.5.5.2 Complete electrical installation including cables installed in cable trays / ladders and wiring inside switchgear and controlgear assemblies should be protected against electromechanical forces.

4.5.6 For large industrial and commercial installations, where multiple runs of cables run through trench / trays / ladders, at least one run of shared PE conductor (or equipotential bonding conductor as shown (1) in Fig. 3) is recommended. The armoring of cables may be used as additional PE conductor, provided the armoring is bonded to earthing arrangement by materials which satisfy the requirement of 7.3.2.1 or table 10.

4.5.7 For larger buildings, it is recommended to repeat the equipotential bonding at every 20 meter.

5. GENERAL INFORMATION

5.1 CALCULATION OF EARTH FAULT CURRENTS

5.1.1 The magnitude of the current that will flow in the event of a line-to-earth fault on an earthed system is determined by the impedance from the source to the fault plus the impedance of the earth return path, including the impedances of earthing transformers, resistors and reactors (see IS 13234). For interconnected systems, the calculation of the current may be complicated.

5.1.2 When a single line-to-earth fault occurs on a resistance earthed system, a voltage appears across the resistor nearly equal to the normal line-to-neutral voltage of the system.

5.1.3 In solidly earthed systems, the current is approximately equal to the line-to-neutral voltage divided by the impedance of the loop in ohms (Ω). This simple method is only suitable when the earth fault current is small compared to 3-phase fault current. The fault current can be computed from:

$$I_F = \frac{3E}{X_1 + X_2 + X_0 + 3X_{GP}}$$

5.1.4 In a resistance earthed system with a single line-to-earth fault, the earth fault current may be computed from:

$$I_F = \frac{3E}{X_1 + X_2 + X_0 + 3(X_n + X_{GP})}$$

where

I_F = earth fault current in A,

X_1 = system + ve sequence reactance in Ω /phase including the sub transient reactance of the rotating machines,

X_2 = –ve sequence reactance as for X1,

X_0 = zero sequence reactance as for X1,

X_n = reactance of neutral earthing reactor,

X_{GP} = reactance of earth return circuits, and

E = line-to-earth voltage in V.

In most industrial and commercial systems without in plant generator X2 = X1.

Note:

1. Cl 10.2.3.6, also can be referred for calculating earth fault current.
2. The current to earth electrodes I_E shall be calculated from the fault current I_F. (See10.2.3.6 and 10.5.2).

5.1.5 For Low voltage applications, the following formula shall be followed to determine the earth fault current, considering the increase of resistance of the conductors with the increase of temperature due to faults.

$$Z_s(m) \leq \frac{2}{3} \times \frac{U_0}{I_a}$$

where

Z_S(m) = the measured impedance of the fault current loop starting and ending at the point of fault (measured in Ω);
U_O = the line conductor to earthed neutral voltage (V); and
I_a = the fault current causing the automatic operation of the protective device within the allowed disconnection time.

5.2 TOLERABLE VALUES OF TOUCH VOLTAGE

Note

1. IS/IEC 60479 – (part 1 to 5) Effects of current on human beings and livestock.
2. Refer IS 9409: Protection against electric shock – Common aspects for installations and equipment.
3. IS/IEC 61936 – 1 Power installations exceeding 1 kV AC and 1,5 kV DC Part 1: AC
4. IS/IEC 61936 – 2 Power installations exceeding 1 kV AC and 1,5 kV DC Part 1: DC
5. See Fig. 4 for Permissible Touch Voltage.

***5.2.1**. Permissible touch voltage*

The equation to calculate the permissible touch voltage in AC system is as follows.

$$U_{Tp} = I_B(t_f) \times \frac{1}{HF} \times Z_T(U_T) \times BF$$

Where,

U_T	is touch voltage
U_{Tp}	is permissible touch voltage
t_f	is fault duration
$I_B(t_f)$	is body current limit $c2$ in Fig. 20 and Table 11 of IS/IEC 60479-1:2018,where probability of ventricular fibrillation is less than 5 %. I_B depends on fault duration
H_F	is heart current factor Table 12 of IS/IEC 60479-1:2018, i.e. 1,0 for left hand to feet, 0,8 for right hand to feet, 0,4 for hand to hand
$Z_T(U_T)$	is body impedance Table 1 and Fig. 3 of IS/IEC 60479-1:2018, Z_T not exceeded by 50 % of the population, Z_T depends on touch voltage. Therefore, first calculation has to start with assumed level
BF	is body factor Fig. 3 of IS/IEC 60479-1:2018, i.e. 0,75 for hand to both feet, 0,5 for both hands to feet

NOTE 1 Different touch voltage conditions, e.g. left hand to feet, hand to hand, lead to different tolerable touch voltages. Fig. 4 of this code is based on a weighted average taken from four different touch voltage configurations. Touch voltage left hand to feet (weighted 1,0), touch voltage right hand to feet (weighted 1,0), touch voltage both hands to feet (weighted 1,0) and touch voltage hand to hand (weighted 0,7).

5.2.2 *Prospective permissible touch voltage*

For specific consideration of additional resistances, the formula to determine prospective permissible touch voltage becomes:

$$U_{vTp} = I_B(t_f) \times \frac{1}{HF} \times (Z_T(U_T) \times BF + R_H + R_F)$$

Where,

U_{vTp}	is prospective permissible touch voltage,
R_H	is additional hand resistance,
R_F	is additional foot resistance.

NOTE: For calculation of permissible Touch voltage U_{Tp} in dc systems, refer IS/IEC 61936-2.

5.2.3 *Permissible step voltages*

Touch and step voltages shall always to be considered. As a general rule, the touch voltage requirements satisfy the step voltage requirements, because the tolerable step voltage limits are much higher than the touch voltage limits due to the different current path through the body (heart current factor HF = 0,04).

In special cases with high U_E (earth potential rise) step voltage limits shall be considered. In this case the permissible step voltage is derived similar to the method in 5.2.1 and taking into account Formula (5.2.1) with the following factors, but without weighing.

Step voltage should be considered at the boundaries of the earthing system when e.g. U_E > 20 x U_{Tp} depending on fault duration.

Body current limit	$I_B(t_f)$	c2 in IS/IEC 60479-1, c and Table 11 where probability of ventricular fibrillation is less than 5 %,
Heart current factor	H_F	IS/IEC 60479-1, Table 12 i.e. 0,04 for left foot to the right foot,
Body impedance	$Z_T(U_T)$	IS/IEC 60479-1, Table 1 and Fig. 3, Z_T not exceeded by 50 % of the population
Body factor	B_F	IS/IEC 60479-1, Fig. 3, i.e. 1 for left foot to right foot.

5.2.4 *Permissible values*

The limit value of the touch voltage (U_T) is the permissible touch voltage (U_{Tp}) and is given in Fig. 4, representing the limit values of permissible touch voltage U_{Tp} depending on the fault duration.

Step voltage limits can be derived according to 5.2.3, but are only needed in exceptional cases.

Any voltage over the human body (bare skin to bare skin) due to the simultaneous touching of two conductive parts shall be lower than or equal to the values of the curve in Fig. 4.

Fig. 4 is based only on bare hand to hand or hand to feet contact (direct skin contact). It is allowable to use the calculations given in 5.2.1 to take account of additional resistances e.g. footwear, gloves and surface materials of higher resistivity.

Every earth fault will be disconnected automatically or manually. Thus, touch voltages of very long or indefinite duration do not appear as a consequence of earth faults.

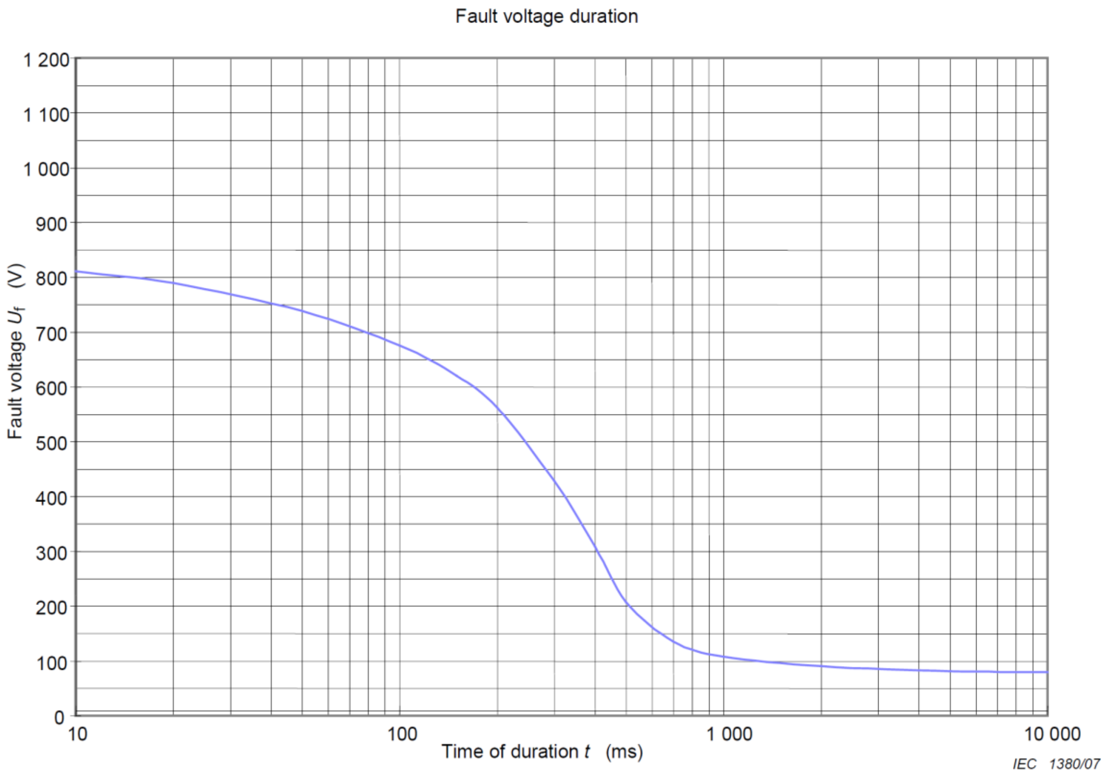


FIGURE 4 PERMISSIBLE TOUCH VOLTAGE. (TOLERABLE FAULT VOLTAGE DUE TO AN EARTH-FAULT IN THE HV SYSTEM)

NOTE: The curve shown in Fig. 4 is from IS/IEC 61936-1. On the basis of probabilistic and statistical evidence this curve represents a low level of risk for the simple worst case where the low voltage system neutral conductor is earthed only at the transformer substation earthing arrangements. Guidance is provided in IS/IEC 61936-1 concerning other situations.

5.3 TEMPORARY OVER VOLTAGE AT LV INSTALLATION DURING FAULTS IN THE HV SYSTEM AND MITIGATION

5.3.1 The rules of this clause provide requirements for the safety of low-voltage TN/TT installation in the event of a fault between the high-voltage system and earth in the transformer substation that supplies the low-voltage installation,

Note: See IS732 clause 4.5.2.2 for IT systems.

Note: See 10 for earthing arrangement at power stations and 11.1 for transformer substation in industrial premises.

5.3.2 This clause gives rules for the designer and installer of the substation. It is necessary to have the following information concerning the high-voltage system:

- quality of the system earthing;
- maximum level of earth fault current;
- resistance of the earthing arrangement.

The following symbols are used for further explanation.

I_E 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_A resistance of the earthing arrangement of the exposed-conductive-parts of the equipment of the low-voltage installation.

R_B is the resistance of the earthing arrangement of the low-voltage system neutral, in which the earthing arrangements of the transformer substation and of the low-voltage system neutral are electrically independent.

U_o in TN- and TT-systems: nominal a.c. r.m.s. line voltage to earth

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
1: The power-frequency stress voltage (U_1 and U_2) is the voltage that appears across the insulation of low voltage equipment and across surge protective devices connected to the low-voltage system.
2: An earthing arrangement may be considered electrically independent of another earthing arrangement if a rise of potential with respect to earth in one earthing arrangement does not cause an unacceptable rise of potential with respect to earth in the other earthing arrangement. *See* IS/IEC 61936-1.

5.3.3 In case of a fault to earth on the HV-side of the substation including faults created due to failure of HV surge arresters, the following types of overvoltage may affect the LV-installation:

- power frequency fault-voltage (U_f);
- power frequency stress-voltages (U_1 and U_2).

Table 2 explains the methods of calculation for the different types of overvoltages.

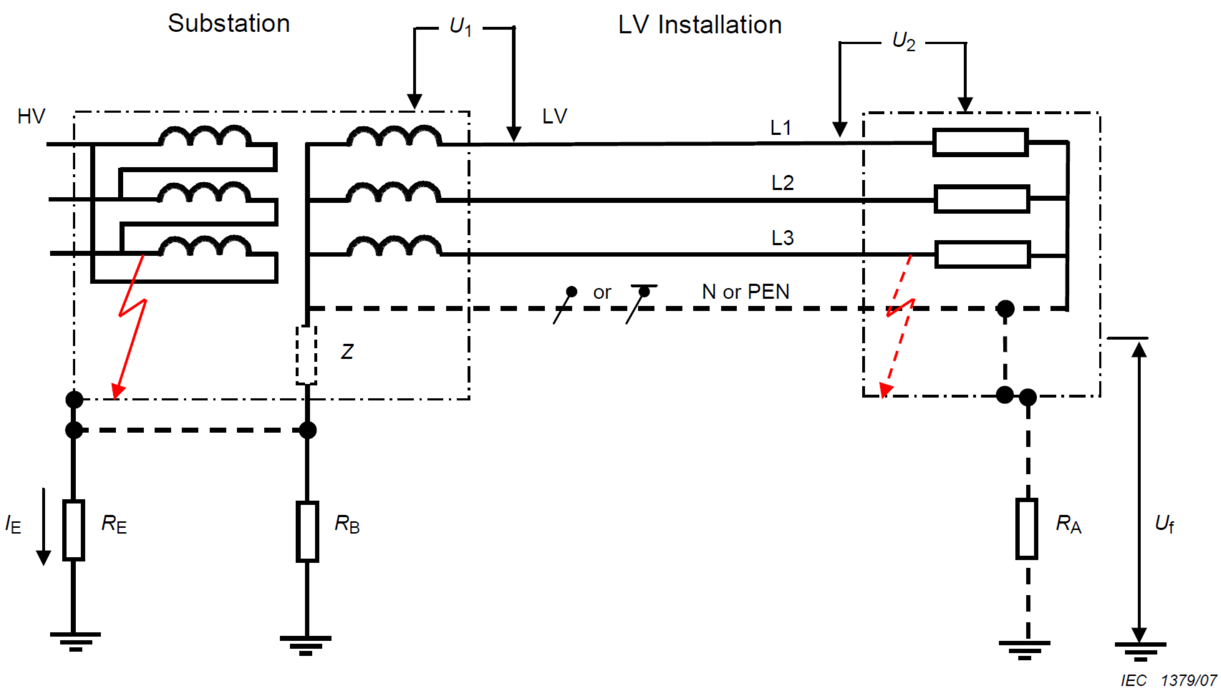


FIGURE 5 REPRESENTATIVE SCHEMATIC SKETCH FOR POSSIBLE CONNECTIONS TO EARTH IN SUBSTATION AND LV-INSTALLATION AND OCCURRING OVERVOLTAGES IN CASE OF FAULTS.

Where high- and low-voltage earthing systems exist in proximity to each other, two practices are presently used:

– interconnection of all high-voltage (R_E) and low-voltage (R_B) earthing systems;
– separation of high-voltage (R_E) from low-voltage (R_B) earthing systems.

The general method used is interconnection. The high- and low-voltage earthing systems shall be interconnected if the low-voltage system is totally confined within the area covered by the high-voltage earthing system (*see* IS/IEC 61936-1).

TABLE 2 POWER-FREQUENCY STRESS VOLTAGES AND POWER-FREQUENCY FAULT VOLTAGE IN LOW-VOLTAGE TN/TT SYSTEM.

Type of system earthing	Type of earth connections	U_1	U_2	U_f
TT	R_E and R_B connected	U_o *)	$(R_E \times I_E) + U_o$	0*)
	R_E and R_B separate	$(R_E \times I_E) + U_o$	U_o *)	0*)
TN	R_E and R_B connected	U_o *)	U_o *)	$R_E \times I_E$ **
	R_E and R_B separate	$(R_E \times I_E) + U_o$	U_o *)	0ˣˣ

★)	– NO consideration necessary
★★	- refer clause 5.3.4 second para

NOTE

1. The requirements for U_1 and U_2 are derived from design criteria for insulation of low-voltage equipment with regard to temporary power-frequency overvoltage (*see* also Table 3).
2. In a system whose neutral is connected to the earthing arrangement of the transformer substation, such temporary power-frequency overvoltage is also to be expected across insulation which is not in an earthed enclosure when the equipment is outside a building.
3. In TT- and TN-systems the statement "connected" and "separated" refers to the electrical connection between R_E and R_B.

5.3.4 Magnitude and duration of power-frequency fault voltage

The magnitude and the duration of the fault voltage U_f (as calculated as per Table 2) which appears in the LV installation between exposed-conductive-parts and earth, shall not exceed the values given for U_f by the curve of Fig. 4 for the duration of the fault.

Normally, the PEN conductor in a TN-C-S system is connected to earth at more than one point at the distribution. In this case, the total resistance is reduced. For these multiple earthed PEN conductors, U_f can be calculated as:

$$U_f = 0.5\, R_E \times I_E$$

5.3.5 Magnitude and duration of power-frequency stress voltages

The magnitude and the duration of the power-frequency stress voltage (U_1 and U_2) as calculated as per Table 2 of the low-voltage equipment in the low-voltage installation due to an earth fault in the high-voltage system shall not exceed the values given in Table 3.

TABLE 3 PERMISSIBLE POWER-FREQUENCY STRESS VOLTAGE.

Duration of the earth fault in the HV system t	**Permissible power-frequency stress voltage on equipment in LV installations** (U_1 & U_2) U
> 5 s	U_o + 250 V
≤ 5 s	U_o + 1200 V
In systems without a neutral conductor, U_o shall be the line-to-line voltage.	
NOTES 1. The first line of the Table relates to high-voltage systems having long disconnection times, for example, isolated neutral and resonant earthed high-voltage systems. The second line relates to high-voltage systems having short disconnection times, for example low-impedance earthed high-voltage systems. Both lines together are relevant design criteria for insulation of low-voltage	

equipment with regard to temporary power frequency overvoltage, see IEC 60664-1.

2. In a system whose neutral is connected to the earthing arrangement of the transformer substation, such temporary power-frequency overvoltage is also to be expected across insulation which is not in an earthed enclosure when the equipment is outside a building.

5.3.6 Requirements for calculation of limits

The permissible power-frequency stress voltage calculated based on Table 2, shall not exceed the value given in Table 3.

The permissible power-frequency fault voltage shall not exceed the value given in Fig. 4.

The requirements of **5.3.4** and **5.3.5** are to be fulfilled by the supplier for installations with a low-voltage supply from a public electricity distribution system.

For HV supply from supplier, to fulfil the above requirements, coordination between the HV-system and the LV system is necessary. Compliance with the above requirements mainly falls into the responsibility of the substation designer/installer/owner/operator who needs also to fulfil requirements provided by IS/IEC 61936-1.

Possible measures to fulfil the above requirements are e.g.

– separation or interconnection of earthing arrangement between HV and LV;
– change of LV system earthing;
– reduction of earth resistance R_E.

5.4 SAFETY IN EARTHING

5.4.1 General

In principle, a protective earthing has the following two objectives:

a) to provide means to carry electric currents into the earthed point of electrical system under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting continuity of service.
b) to reduce the risk of a person or livestock from electric shock.

5.4.2 Condition of Danger in High Voltage Substations (66 kV and above)

During an earth fault, the flow of current to earth electrodes will produce potential gradients within and around a substation.

Unless proper precautions are taken in design, the maximum potential gradients along the earth’s surface in HV and EHV substations may be of sufficient magnitude during earth fault conditions to endanger a person in the area. Moreover, dangerous voltages may develop between earthed structures or equipment frames and the nearby earth.

In HV and EHV system, the circumstances that make electric shock accidents possible can include the following:

a) relatively high fault current to earth in relation to the area of earthed system and its resistance to remote earth;
b) soil resistivity and distribution of earth currents such that high potential gradients may occur at points at the earth's surface;
c) presence of an individual at such a point, time, and position that the body is bridging two points of high potential difference;
d) absence of sufficient contact resistance or other series resistance to limit current through the body to a safe value under circumstances (a) through (c); and
e) duration of the fault and body contact, and hence, of the flow of current through a human body for a sufficient time to cause harm at the given current intensity.

The relative low frequency of accidents in HV and EHV system is due largely to the low probability of coincidence of all the unfavourable conditions listed above.

Note: See 7.4 and 7.5 for Earth fault protection in LV system.

6. SYSTEM EARTHING FOR A.C AND D.C

6.1 FACTORS INFLUENCING THE CHOICE OF EARTHED OR UNEARTHED SYSTEM

6.1.1 Service Continuity

A number of industrial plant systems have been operated unearthed at one or more voltage levels. This is basically guided by the thought of gaining an additional degree of service continuity varying in its importance depending on the type of plant. Earthed systems are in most cases designed so that circuit protective devices will remove the faulty circuit from the system regardless of the type of fault. However, experience has shown that in a number of systems, greater service continuity may be obtained with earthed-neutral than with unearthed neutral systems.

6.1.2 Multiple Faults to Earth

While an earth fault on one phase of an unearthed system generally does not cause a service interruption, the occurrence of a second earth fault on a different phase before the first fault is cleared, does result in an outage. The longer an earth fault is allowed to remain on an unearthed system, greater is the likelihood of a second one occurring in another phase and repairs are required to restore service. With an unearthed system, an organized maintenance programme is therefore extremely important so that faults are located and removed soon after detection.

Experience has shown that multiple earth faults are rare, if ever, experienced on earthed neutral systems.

6.1.3 Arcing Fault Burndowns

In typical cases, an arcing fault becomes established between two or more phase conductors in an unearthed system or between phase and earth in a solidly earthed-neutral system. This would result in severe damage or destruction to equipment.

However, arcing fault current levels may be so low that phase over current protective devices do not operate to remove the fault quickly. Such faults are characteristic of open or covered fuses, particularly in switchgear or metal-enclosed switching and motor control equipment. It is generally recognized that protection under such circumstances is possible by fast and sensitive detection of the arcing fault current and interruption within 10-20 cycles. In solidly earthed-neutral systems, this is possible as an arcing fault would produce a current in the earth path, thereby providing an easy means of detection and tripping against phase-to- earth arcing fault breakdowns.

6.1.4 Location of Faults

On an unearthed system, an earth fault does not open the circuit. Some means of detecting the presence of an earth fault requires to be installed. In earthed system, an accidental earth fault is both indicated at least partially located by an automatic interruption of the accidentally earthed circuit or piece of equipment.

6.1.5 Safety

Whether or not a system is earthed, protection of personnel and property from hazards require thorough earthing of equipment and structures. Proper earthing results in less likelihood of accidents to personnel. Other hazards of shock and fire may result from inadequate earthing of equipment in unearthed and earthed systems. However, relatively high fault currents associated with solidly earthed system may present a hazard to workers from exposure to hot arc products and flying molten metal. This hazard is, however, reduced because of use of metal-enclosed equipment.

6.1.6 Abnormal Voltage Hazards

6.1.6.1 The possible over-voltages on the unearthed system may cause more frequent failures of equipment than the earthed system. A fault on one phase of an unearthed or impedance-earthed system places a sustained increased voltage on the insulation of unearthed phases in a 3-phase system. This voltage is about 1.73 times the normal voltage on the insulation. This or other sustained over-voltages on the unearthed system may not immediately cause failure of insulation but may tend to reduce the life of the insulation. Some of the more common sources of over-voltages on a power system are the following:

a) Lightning,
b) Switching surges,
c) Static,
d) Contact with a high voltage system,
e) Earth fault,
f) Resonant conditions, and
g) Restriking earth faults.

6.1.6.2 Surge protection devices are recommended for protection from lightning and switching surges. System earthing is not likely to reduce the total magnitude of over-voltage produced by lightning or switching surges. It can, however, distribute the voltage between phases and reduce the possibility of excessive voltage stress on the phase-to-earth insulation of a particular phase. A system earth connection even of relatively high resistance can effectively prevent static voltage build-up. Even under conditions of an HV line breaking and falling on an LV system, an effectively earthed LV system will hold the system neutral close to the earth potential thus limiting the over-voltage. An unearthed system will be subjected to resonant over-voltages. Field experience and theoretical studies have shown the world over that arcing, restriking or vibrating earth faults on unearthed systems can, under certain conditions, produce surge voltages as high as 6 times the normal voltage. Neutral earthing is effective in reducing transient build up by reducing the neutral displacement from earth potential and the destructiveness of any high frequency voltage oscillations following each arc initiation or restrike.

6.1.7 Cost

The cost differential between earthed and unearthed neutral system will vary, depending on the method of earthing, the degree of protection desired, and whether a new or an existing system is to be earthed.

6.2 ELECTRICAL SYSTEM (SYSTEM EARTHING)

6.2.1 General

6.2.1.1 Earthing of electrical system 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. From the point of view of safety, it is equally important that earthing should ensure efficient and fast operation of protective gear in the case of earth faults. Most high voltage public supply systems are earthed. Unearthed overhead line systems are also in use, but limited to 11 kV systems derived from 33 kV mains, where the capacitive earth current is less than 4 A and circumstances are such that the system will not be appreciably extended.

6.2.1.2 The limitation of earthing to one point on each system is designed to prevent the passage of current through the earth under normal conditions, and thus to avoid the risks of electrolysis and interference with communication circuits. With a suitably designed system, properly operated and maintained, earthing at several points may be permitted. This method of earthing becomes economically essential in systems at 200 kV and above.

6.2.1.3 In the case of overhead-line systems protected by over current protection only, there may be difficulty in arranging that the value of the system earth fault loop impedance is such that a conductor falling and making good contact with the earth results in operation of the protection. A low system-earth resistance is required even in the cases where an arc-suppression coil is installed, as its operation may be influenced by too high earth-electrode resistance.

6.2.1.4 Earthing may not give protection against faults that are not essentially earth faults. For example, if a phase conductor on an overhead spur line breaks, and the part remote from the supply falls to the earth, it is unlikely that any protective gear relying on earthing, other than current balance protection at the substation, will operate since the earth-fault current circuit includes the impedance of the load that would be high relative to the rest of the circuit.

6.2.2 Classification of Systems Based on Type of Electrical System

6.2.2.1 For the purposes of this Code of practice, it is convenient to consider a system as comprising a source of energy, a distribution, and an installation;

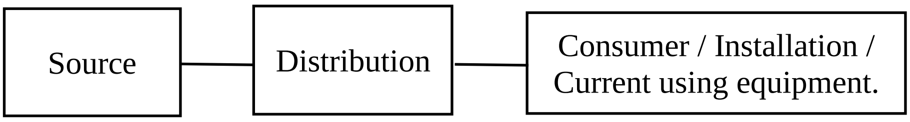


FIGURE 6 PRINCIPLE OF AN ELECTRIC SYSTEM

6.2.2.2 The electrical systems (system earthing) are classified as TN System, TT System and IT System. They are:

a) TN System — has one or more points of the source of energy directly earthed, and the exposed and extraneous conductive parts of the installation are connected by means of protective conductors to the earthed point(s) of the source, that is, there is a metallic path for earth fault currents to flow from the installation to the earthed point(s) of the source. TN systems are further sub-divided into TN-C, TN-S and TN-C-S systems.
b) TT System — has one or more points of the source of energy directly earthed and the exposed and extraneous conductive parts of the installation are connected to a local earth electrode or electrodes that are electrically independent of the source earth(s).
c) IT System — has the source either unearthed or earthed through a high impedance and the exposed conductive parts of the installation are connected to electrically independent earth electrodes.

Electrical Systems are described according to the following:
First letter – Indicates how live parts of the electric system are related to earth:

T = one live part is directly connected to earth;

I = all live parts are isolated from earth, or one live part is connected to earth through a high impedance

Second letter – Indicates how exposed-conductive-parts are earthed:

T = exposed-conductive-parts are connected to earth, independent of the earthing of the live parts of the electric system;

N = exposed-conductive-parts are connected to the earthed point where the live parts are connected to earth.

Subsequent letter(s) (if any) – Arrangement of live conductors and protective earthing conductors:

S = live conductors and protective earthing conductors are separated from each other.

C = the function of a live conductor is combined with the function of a protective earthing conductor to form a single PEN, PEM, or PEL conductor.

Table 4 describes the types of electric systems considered for AC installations, and Table 5 describes the types of electric systems considered for DC installations. Table 6 shows the symbols used to indicate conductor functions.

TABLE 4 TYPES OF ELECTRIC SYSTEMS CONSIDERED FOR a.c INSTALLATIONS

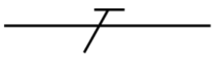
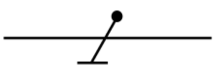
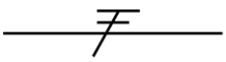
Electrical System		Live parts relationship to Earth.	Arrangement of live conductors and protective earthing conductors.	Earthing of exposed-conductive-parts of the installation.
TN	TN-C	The neutral point or a line conductor is connected to Earth.	The neutral conductor or a line conductor is combined with the protective earthing conductor combined in one common PEN, PEM or PEL conductor.	Exposed-conductive-parts are connected to the PEN/ PEM/ PEL conductor that provides a conductive path to the earthed point where the live parts are connected to earth.
	TN-C-S		The neutral conductor or a line conductor is combined with the protective earthing conductor in one common PEN, PEM or PEL conductor in parts of the system but are kept separate within the installation	Exposed-conductive-parts are connected to the PE/ PEN/ PEM/ PEL conductor that provides a conductive path to the earthed point where the live parts are connected to earth
	TN-S		Live conductors and protective earthing-conductor are kept separate throughout the system.	Exposed-conductive-parts are connected to the PE conductor that provides a conductive path to the earthed point where the live parts are connected to earth
TT		The neutral point or a line conductor is connected to Earth, preferably near the source.	Live conductors and protective earthing conductors are kept separate throughout the system.	Exposed-conductive-parts are connected to earth, independent of the earthing of the live parts of the electrical system.
IT		The live conductors are isolated from earth, or one point connected to Earth through a high impedance.	Live conductors and protective earthing conductors are kept separate throughout the system.	Exposed-conductive-parts are connected to earth, independent of the earthing of the live parts of the electrical system.

TABLE 5 TYPES OF ELECTRIC SYSTEMS CONSIDERED FOR d.c INSTALLATIONS

Electrical System		Live parts relationship to Earth	Arrangement of live conductors and protective earthing conductors	Earthing of exposed-conductive-parts of the installation
TN	TN-C	The mid-point or a line conductor is connected to Earth, preferably near the source.	The mid-point conductor or a line conductor is combined with the protective earthing conductor combined in one common PEM conductor or PEL conductor.	Exposed-conductive-parts are connected to the PEM /PEL conductor that provides a conductive path to the earthed point where the live parts are connected to earth.
	TN-C-S		The mid-point conductor or a line conductor is combined with the	Exposed-conductive-parts are connected to the PE/ PEM/ PEL

			protective earthing conductor in one common PEM conductor or PEL conductor in parts of the system but are kept separate within the installation.	conductor that provides a conductive path to the earthed point where the live parts are connected to earth.
	TN-S		Live conductors and protective earthing conductors are kept separate throughout the system.	Exposed-conductive-parts are connected to the PE conductor that provides a conductive path to the earthed point where the live parts are connected to earth.
TT		The mid-point or a line conductor is connected to Earth, preferably near the source.	Midpoint conductor and protective earthing-conductors are kept separate throughout the system. Protective earthing conductors are not connected to the earthing point at the source. Protective earthing conductors are not supplied from the source.	Exposed-conductive-parts are connected to earth, independent of the earthing of the live parts of the electrical system.
IT		The live conductors are isolated from Earth or one point connected to Earth through a high impedance.	Live conductors and protective earthing-conductors are kept separate throughout the system.	Exposed-conductive-parts are connected to earth, independent of the earthing of the live parts of the electrical system.

TABLE 6 SYMBOLS INDICATING THE CONDUCTOR FUNCTION

Symbols for indication of conductor in accordance with IEC 60617	
	Neutral conductor (N); mid-point conductor (M)
	Protective conductor (PE)
	PEN conductor PEM conductor
	System-referencing conductor (SRC)
	PEL conductor

6.2.2.3 Fig. 7 to Fig. 11 show examples of commonly used three-phase a.c systems. The sources illustrated show the secondary side of a transformer. Fig. 12 to Fig. 21 show examples of commonly used d.c systems. The sources illustrated show a power electronic converter with electrical separation.

6.2.3 Types of electric systems for AC

6.2.3.1 TN-systems

6.2.3.1.1 General

One live part shall be directly connected by a system-referencing-conductor to the earthing arrangement, preferably near the source. Where exposed-conductive-parts of the electrical installation need to be connected to the earthing arrangement, protective earthing conductors shall be provided to connect the exposed-conductive-parts to the earthed point of the source, where the live parts are connected to earth.

The neutral conductors or the earthed line conductors and the protective earthing conductors shall be arranged as follows:

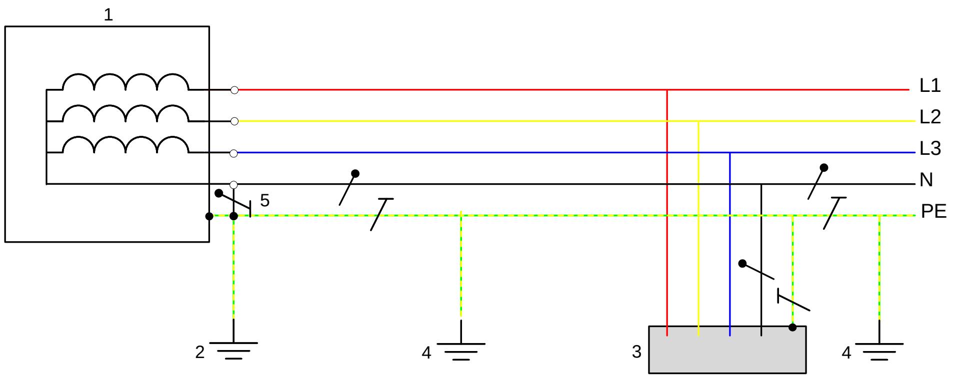
- The neutral conductors and protective earthing conductors shall be separated throughout the system, (see Fig. 7 and Fig. 9 called as TN-S) or

- The neutral conductor or the earthed line conductor shall be combined with the function of protective earthing conductor in one single conductor in parts of the system, (see Fig. 8, called as TN-C-S) or

- The neutral conductor or the earthed line conductor shall be combined with the function of protective earthing conductor in one single conductor throughout the system (called as TN-C).

Additional earthing of the protective earthing conductor may be provided.

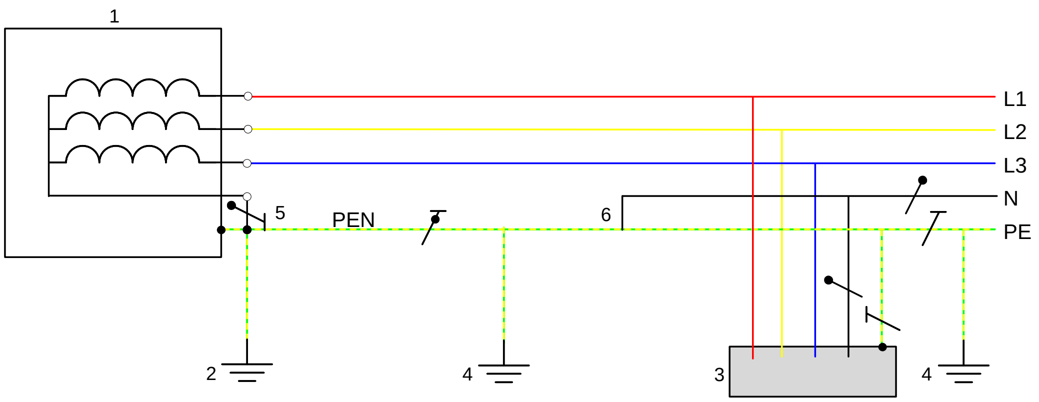
6.2.3.1.2 System with a single source



Key

1) Source
2) Earth electrode for earthing of the system at the source
3) Electrical equipment with exposed-conductive-part
4) Additional earthing which may be provided throughout the system
5) System-referencing-conductor

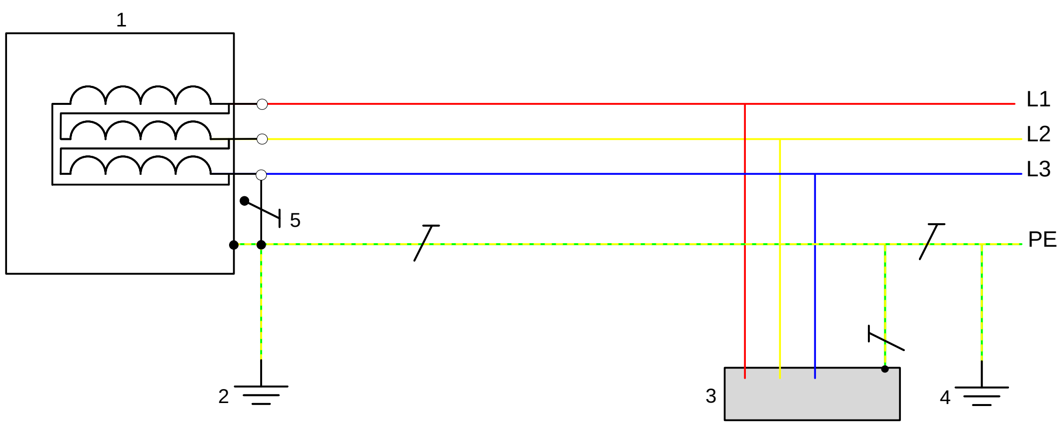
FIGURE 7 EXAMPLE OF AN a.c TN-S SYSTEM WITH SEPARATE NEUTRAL CONDUCTOR AND PROTECTIVE EARTHING CONDUCTOR THROUGHOUT THE SYSTEM.



Key

1) Source
2) Earth electrode for earthing of the system at the source
3) Electrical equipment with exposed-conductive-part
4) Additional earthing which may be provided throughout the system
5) system-referencing-conductor
6) separation of neutral conductor from an upstream PEN conductor

FIGURE 8 EXAMPLE OF AN a.c TN-C-S SYSTEM WITH A PEN CONDUCTOR SEPARATED INTO A PROTECTIVE EARTHING CONDUCTOR AND A NEUTRAL CONDUCTOR.



Key

1) Source
2) Earth electrode for earthing of the system at the source
3) Electrical equipment with exposed-conductive-part
4) Additional earthing which may be provided throughout the system
5) System-referencing-conductor

FIGURE 9 EXAMPLE OF AN a.c TN -S SYSTEM WITH AN EARTHED LINE CONDUCTOR AND SEPERATE PE CONDUCTOR.

6.2.3.1.3 System with more than one source (See IS732)

6.2.3.2 TT-systems

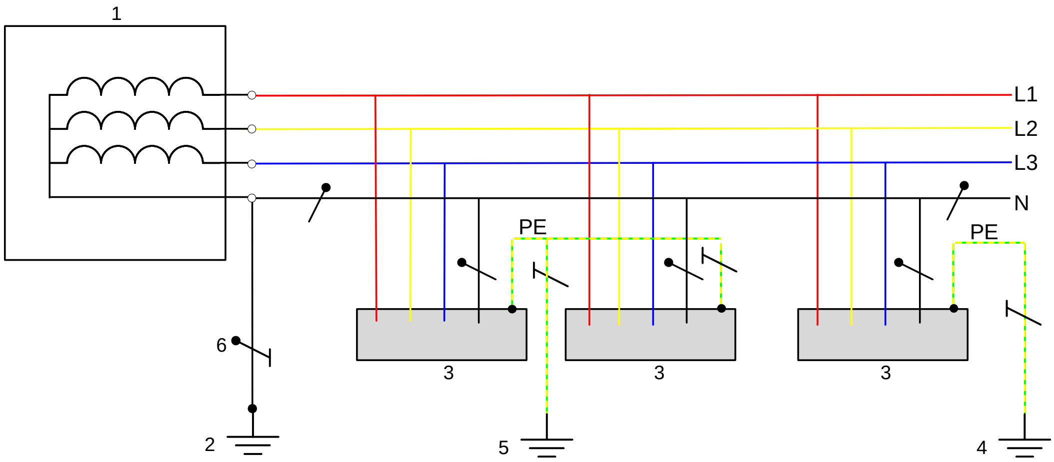
11.1.3.2.1 General

One live part shall be directly connected by a system-referencing-conductor to the earthing arrangement, preferably near the source. Where exposed-conductive-parts of the electrical installation need to be connected to an earthing arrangement, this earthing arrangement should be electrically independent of the earthing arrangement of the source, to which the system-referencing-conductor is connected.

The neutral conductors or the earthed line conductors and the protective earthing conductors shall be separated throughout the installation.

Additional earthing of the protective earthing conductors may be possible, provided this earthing is electrically independent from the earthing arrangement to which the system-referencing conductor is connected.

6.2.3.2.2 System with single source



Key

1) Source
2) Earth electrode for earthing of the system at the source
3) Electrical equipment with exposed-conductive-part
4) Individual protective earthing of an exposed-conductive-part in the installation
5) Grouped protective earthing of exposed-conductive-parts in the installation
6) System-referencing-conductor

FIGURE 10 EXAMPLE OF AN a.c TT SYSTEM

6.2.3.2.3 System with more than one source refer IS732

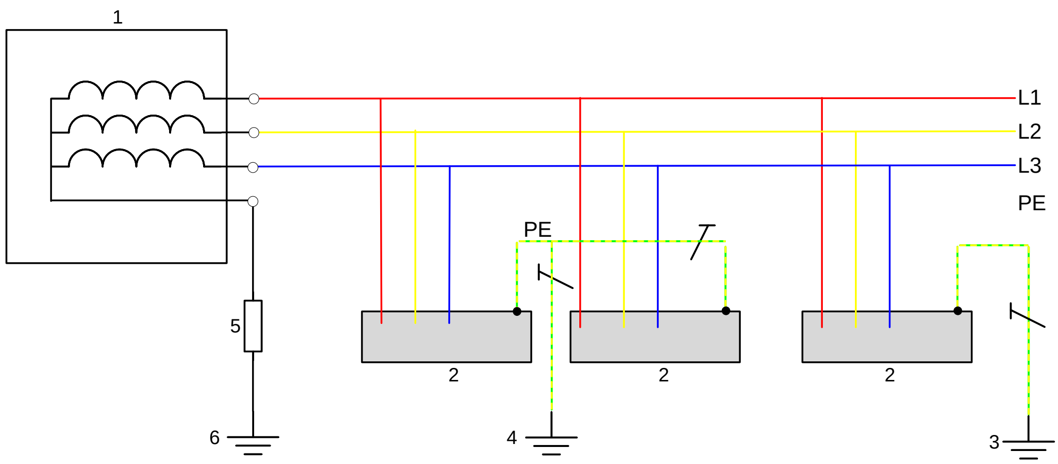
6.2.3.3 IT system

6.2.3.3.1 General

All live parts shall be insulated from the earthing arrangement, or one live part shall be connected through a high impedance to an earth electrode, preferably near the source.

Where the live parts are connected to earth by an impedance, this impedance shall be sufficiently high as to ensure that the protective measures specified for the IT system is not undermined by the presence of the impedance. Where protective earthing of the exposed-conductive-parts of the electrical installation is required, an earthing arrangement shall be provided in the installation.

Note: The maximum steady-state voltage to be applied is the line-to-line voltage.



Key

1) Source
2) Electrical equipment with exposed-conductive-part
3) Individual protective earthing of an exposed-conductive-part
4) Grouped protective earthing of exposed-conductive-parts
5) Earthing impedance at the source, if present
6) Earthing of the impedance at the source

FIGURE 11 EXAMPLE OF AN a.c IT SYSTEM WITH EXPOSED-CONDUCTIVE-PARTS EARTHED INDIVIDUALLY OR IN GROUPS BY PROTECTIVE EARTHING CONDUCTORS.

6.2.3.3.2 System with more than one source

In IT systems with more than one source and where high impedance earthing is used, consideration shall be given to maintain the effectiveness of the high impedance in all operational modes.

6.2.4 Types of electric systems for d.c

6.2.4.1 General

Where a live part in a d.c system is to be earthed, the decision whether to earth the positive line, the negative line or the mid-point should be based on operational conditions or other considerations (e.g. corrosion).

Where multiple sources are used, consideration should be given to minimize operating currents in the protective earthing conductors.

This section considered a d.c. system independent or electrically separated from other system.

6.2.4.2 TN systems

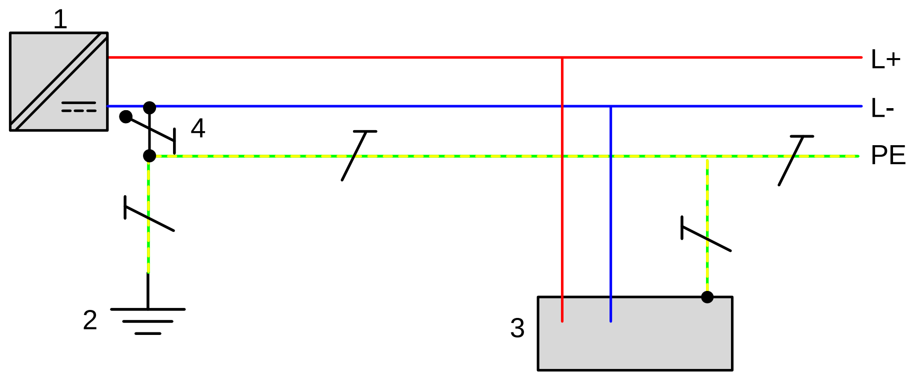
One live conductor shall be directly connected by a system-referencing-conductor to the earthing arrangement. Where exposed-conductive-parts of the electrical installation need to be connected to the earthing arrangement, protective conductors shall be provided to connect the exposed conductive parts to the earthed point where the live parts are connected to earth.

The mid-point conductor or the earthed line conductor and the protective conductor shall be arranged as follows:

- The earthed line or the mid-point conductor and the PE conductors shall be separated throughout the system, (see Fig. 12 and Fig. 13) or
- The mid-point conductor or the earthed line conductor are combined with the protective conductor function in one single conductor throughout the system (Fig. 14 and Fig. 15).
- The mid-point conductor or the earthed line conductor are combined with the protective conductor function in one single conductor in parts of the system, (see Fig. 16, Fig. 17,).

A live conductor shall not be provided with more than one connection to a conductor having a protective earthing function at any given time.

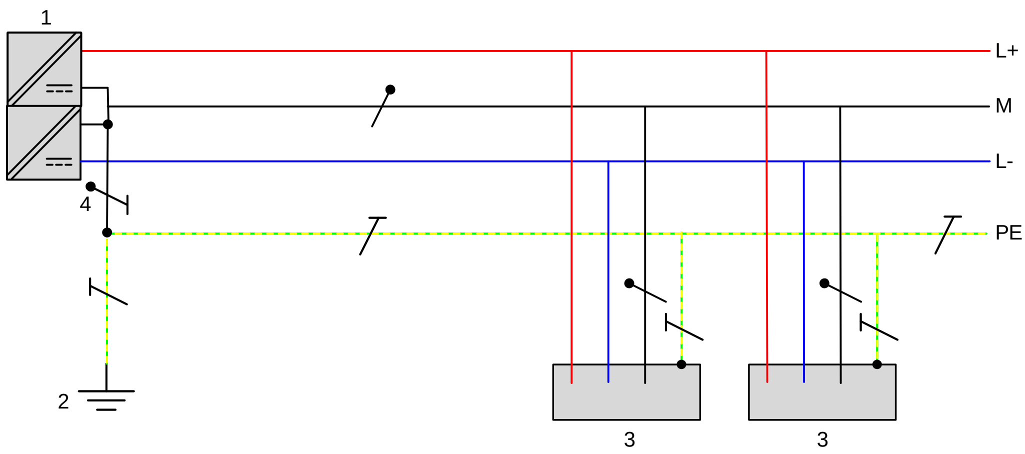
Additional earthing of the protective conductors in the installation may be provided.



Key

1) Source
2) Earth electrode for the earthing of the System
3) Electrical equipment with exposed-conductive-part
4) System-referencing-conductor

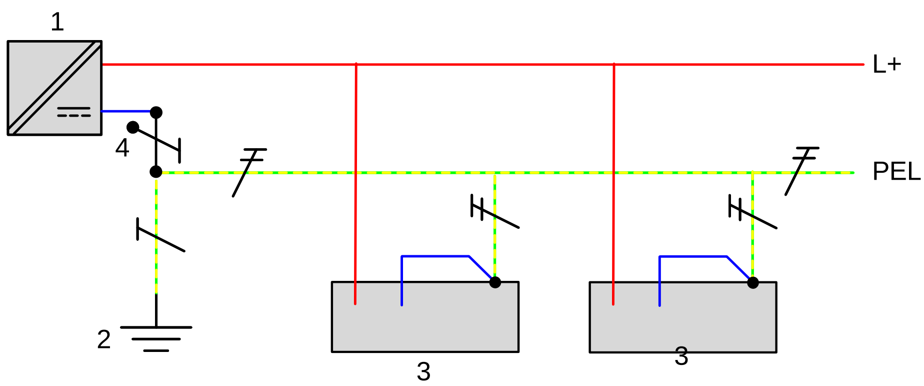
FIGURE 12 EXAMPLE OF A d.c TN-S SYSTEM WITHOUT MID-POINT



Key

1) Source
2) earth electrode for earthing of the system
3) Electrical equipment with exposed-conductive-part
4) System-referencing-conductor

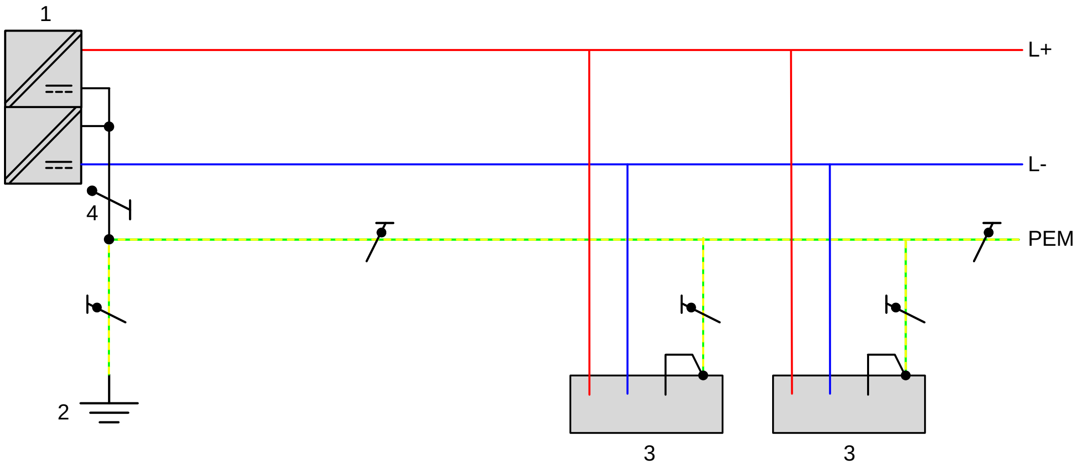
FIGURE 13 EXAMPLE OF A d.c TN-S SYSTEM WITH MID-POINT



Key

1) Source
2) earth electrode for earthing of the system
3) Electrical equipment with exposed-conductive-part
4) System-referencing-conductor

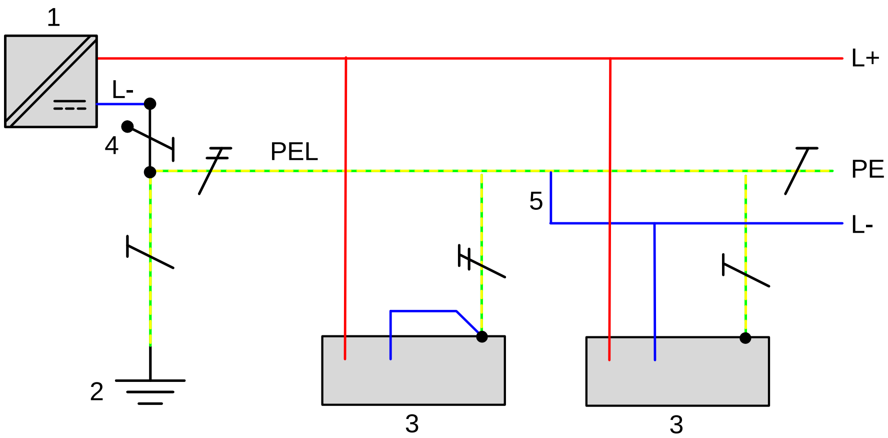
FIGURE 14 EXAMPLE OF A d.c TN-C SYSTEM WITHOUT MID-POINT



Key

1) Source
2) System earthing at the source
3) Electrical equipment with exposed-conductive-part
4) System-referencing-conductor

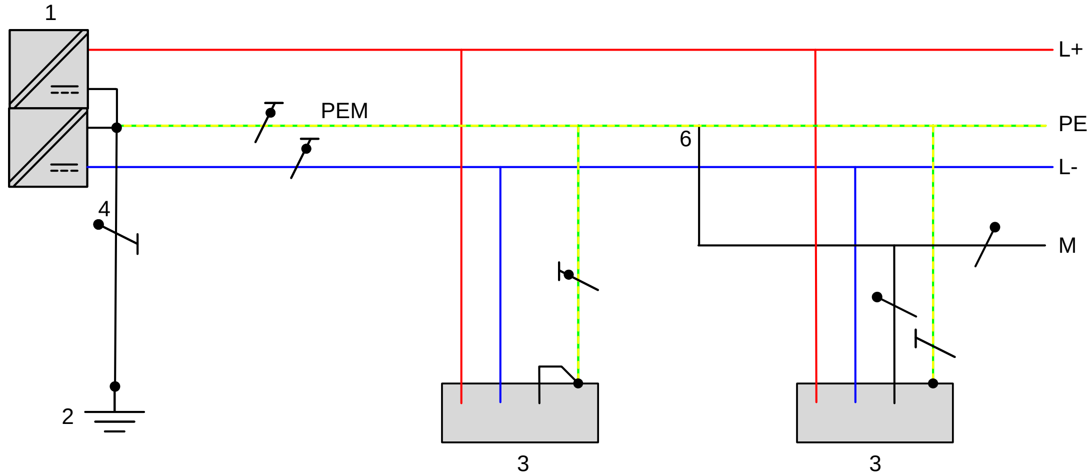
FIGURE 15 EXAMPLE OF A d.c TN-C SYSTEM WITH MID-POINT



Key

1) Source
2) System earthing at the source
3) Electrical equipment with exposed-conductive-part
4) System-referencing-conductor
5) Separation of a line conductor from a PEL conductor

FIGURE 16 EXAMPLE OF A d.c TN-C-S SYSTEM WITHOUT MID-POINT



Key

1) Source
2) System earthing at the source
3) Electrical equipment with exposed-conductive-part
4) System-referencing-conductor
6) Separation of the mid-point-conductor from a PEM conductor

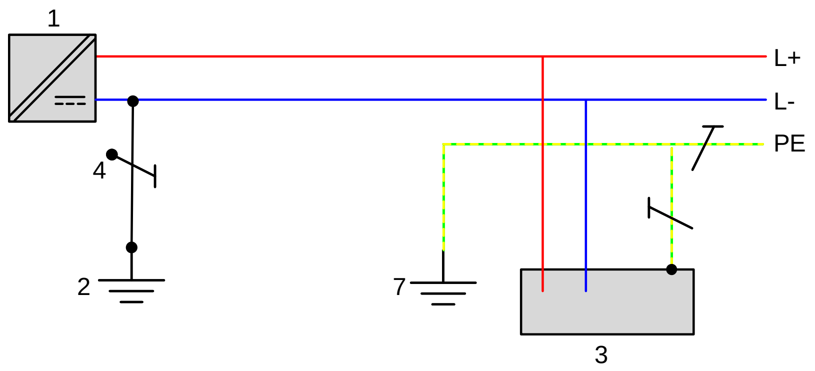
FIGURE 17 EXAMPLE OF A d.c TN-C-S SYSTEM WITH MID-POINT

6.2.4.3 TT-system

One live part shall be directly connected by a system-referencing-conductor to the earthing arrangement, preferably near the source. Where exposed-conductive-parts of the electrical installation need to be connected to an earthing arrangement, this earthing arrangement should be electrically independent of the earthing arrangement to which the system-referencing-conductor is connected.

The mid-point conductors or the earthed line conductors and the protective conductors shall be separated throughout the installation.

Additional earthing of the PE conductor in the installation may be possible, provided this earthing is electrically independent from the earthing arrangement to which the system-referencing conductor is connected.



Key
1) Source
2) System earthing at the source
3) Electrical equipment with exposed-conductive-part
4) System-referencing-conductor
7) Protective earthing of exposed-conductive-parts

FIGURE 18 EXAMPLE OF A d.c TT SYSTEM WITHOUT MID-POINT

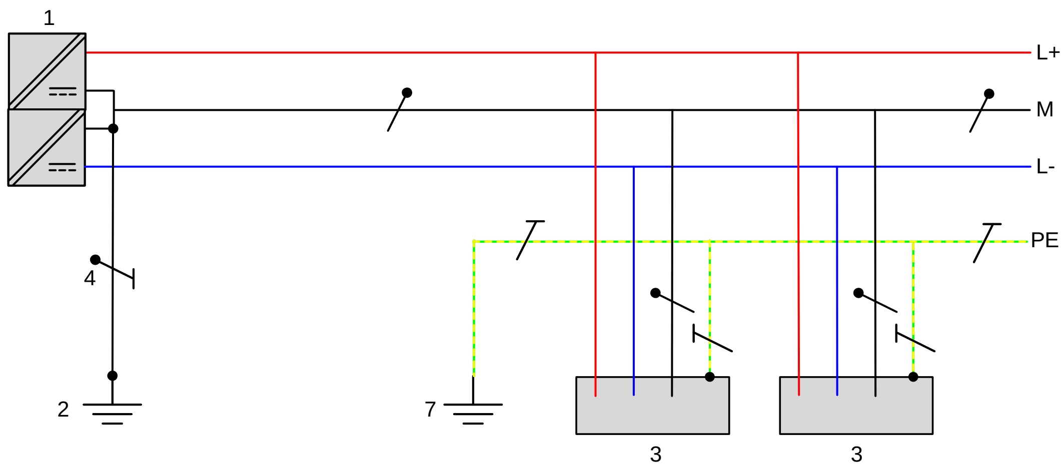


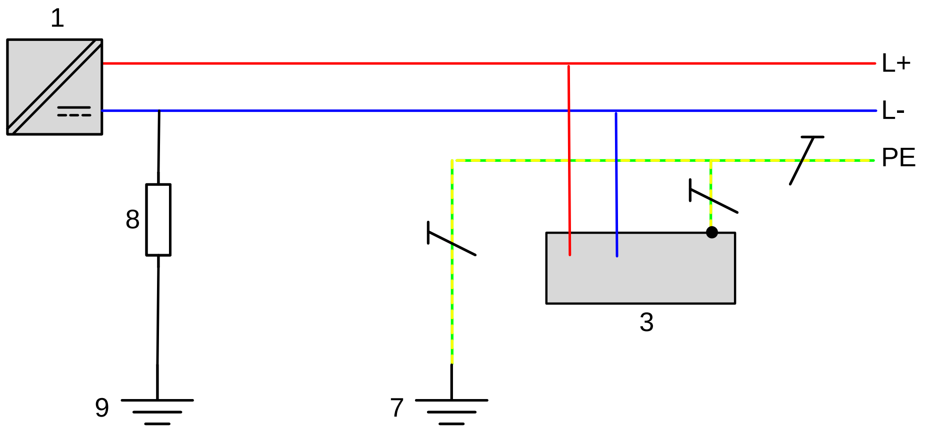
FIGURE 19 EXAMPLE OF A d.c TT SYSTEM WITH MID-POINT

Key
- 1) Source
- 2) System earthing at the source
- 3) Electrical equipment with exposed-conductive-part
- 4) System-referencing-conductor
- 7) Protective earthing of exposed-conductive-parts

6.2.4.4 IT-system

All live parts shall be insulated from the earthing arrangement, or one live part shall be connected through a high impedance to the earthing arrangement, preferably near the source.

Where the exposed-conductive-parts of the electrical installation need to be connected to an earthing arrangement, this earthing arrangement shall be provided in the installation.



Key

1) Source
3) Electrical equipment with exposed-conductive-part
7) Protective earthing of exposed-conductive-parts
8) Earthing impedance at the source, if present
9) Earthing of the impedance at the source

FIGURE 20 EXAMPLE OF A d.c IT SYSTEM WITHOUT MID-POINT

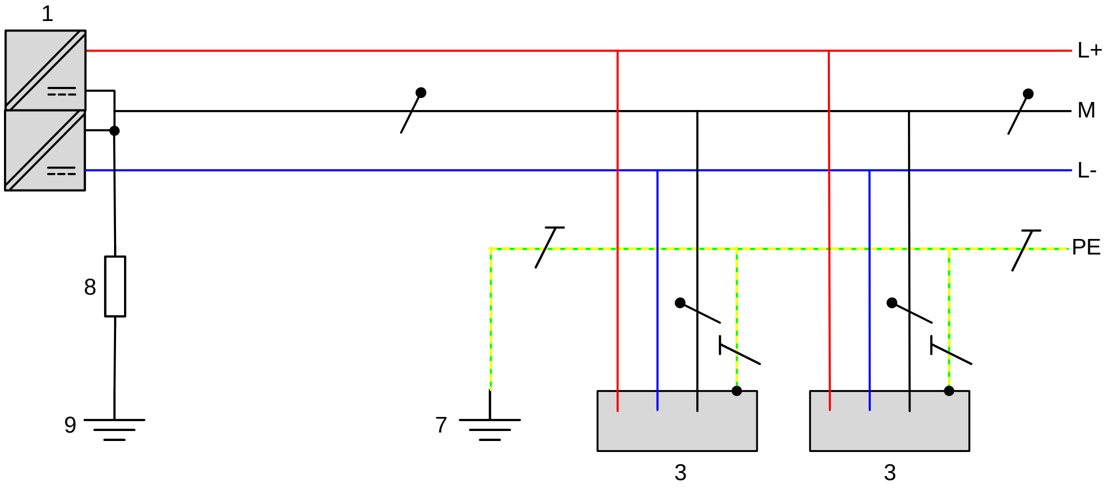


FIGURE 21 EXAMPLE OF A d.c IT SYSTEM WITH MID-POINT

Key
1) Source
3) Electrical equipment with exposed-conductive-part
7) Protective earthing of exposed-conductive-parts
8) Earthing impedance at the source, if present

9) Earthing of the impedance at the source

6.3 MISCONCEPTS IN EARTHING AND THE CORRECT METHOD.

6.3.1 The nonstandard methods explained in 6.3.1.1 to 6.3.1.4 are misconceptions and shall not be followed.

6.3.1.1 The use of independent, "isolated" earth electrodes for safety of a system or functionality of computer or electronic systems (Fig. 22 to Fig. 24) is prohibited. There are always links by the soil or by parasitic elements (capacitances and mutual inductances) in the installation. In case of lightning or power system fault, dangerous transient voltages (for personnel safety and for EMC) can occur between this isolated earthing system and other parts of the installation.

6.3.1.2 The misconception of "earthing" to "earth electrodes" lead to connection of multiple points of one electrical installation to different earth electrodes, often called as dedicated earth electrodes. This approach is a safety hazard and not suitable for EMC, hence this is prohibited.

Note: example of such misconceptions are two separate earth electrodes for each transformer / DG Neutral and two separate earth electrodes for each transformer / DG body, separate earth electrodes for distribution boards, lifts, UPS, electronics etc used widely in Residential, Industrial and Commercial premises.

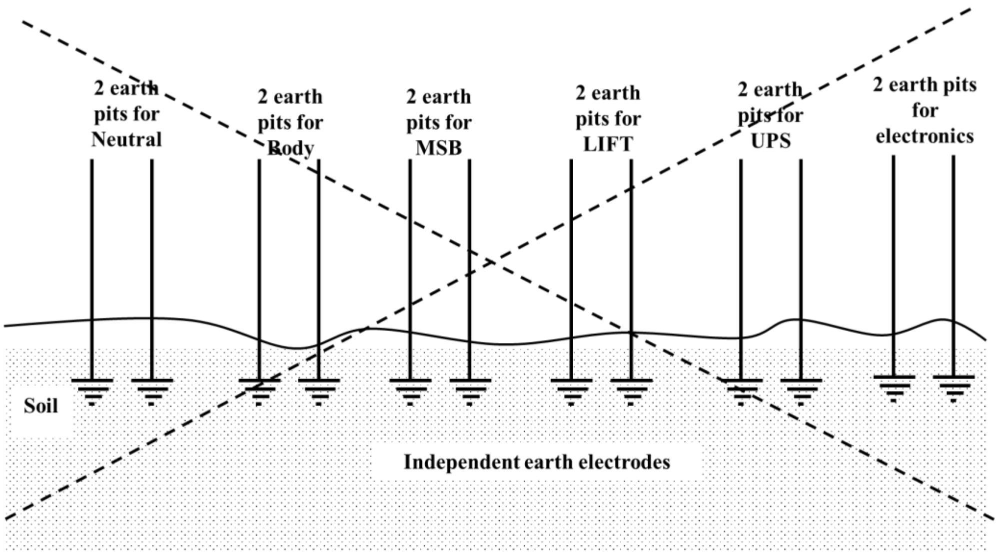


FIGURE 22 MISCONCEPTION OF SEPARATE EARTH ELECTRODES.

6.3.1.3 In an attempt to obtain a "clean" earthing network, for example to be used as a reference for signals, the earth electrodes have not been bonded. This approach is a safety hazard and not suitable for EMC, hence this is prohibited.

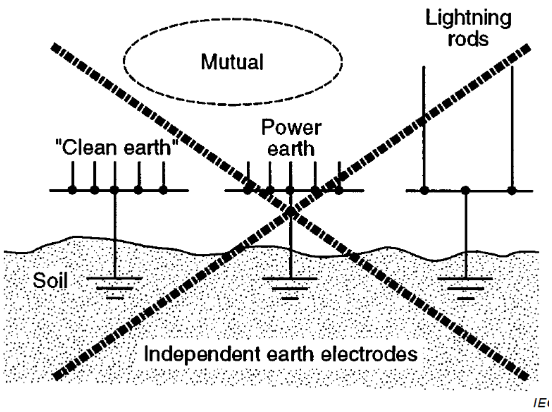


FIGURE 23 MISCONCEPTION OF "DEDICATED", "INDEPENDENT", OR "ISOLATED" EARTH ELECTRODES.

6.3.1.4 In an attempt to obtain a so-called "clean" or "instrument" earthing network, for example to be used as a reference for signals, the earthing network is separated into a signal and a power earthing network. When properly installed and the topology maintained, this approach may be found satisfactory, but it is not recommended for general use. It may be suitable for safety at power frequencies in small installations, but a safety hazard in large installations; it is generally not suitable for high-frequency EMC concerns.

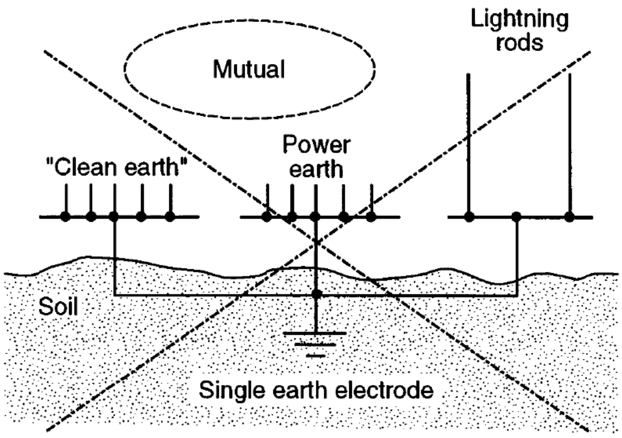


FIGURE 24 THE MIS CONCEPT OF A SINGLE EARTH GRID

6.3.2 Recommended method of earthing in a building for safety and functionality.

This two-dimensional conceptual representation, in Fig.25B, is actually a three-dimensional network, as shown in Fig. 66A. It is the recommended approach in the general case, for safety as well as for EMC.

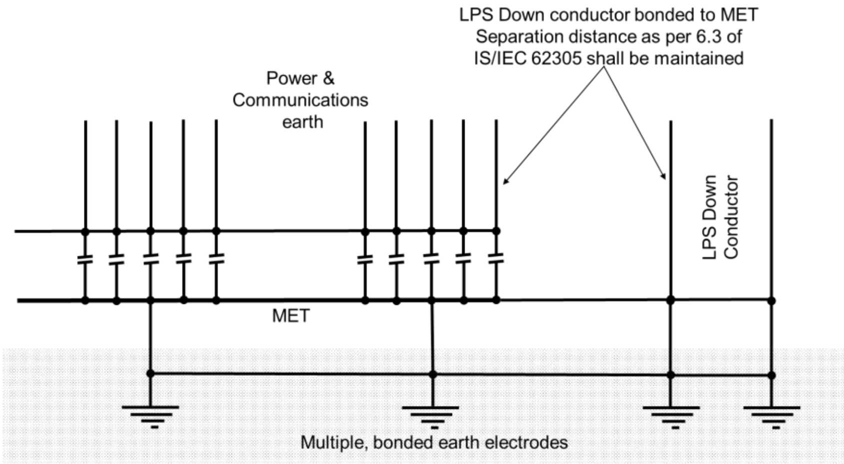


FIGURE 25A RECOMMENDED CONFIGURATION FOR THE EARTH ELECTRODES, EARTHING NETWORK AND AN ELECTRICALLY INSULATED LPS.

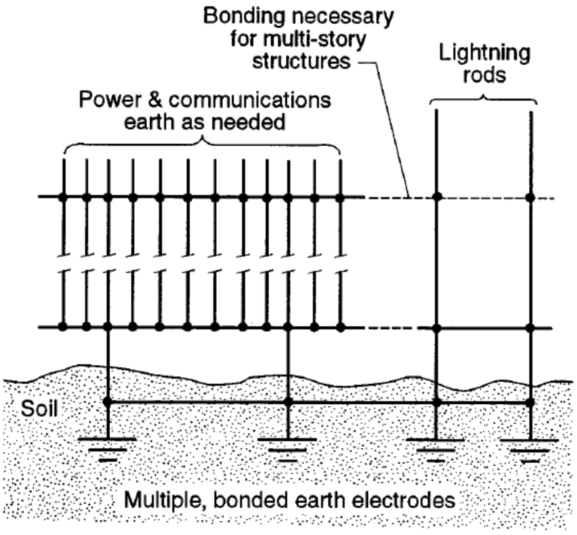


FIGURE 26B RECOMMENDED CONFIGURATION FOR THE EARTH ELECTRODES, EARTHING NETWORK AND ATTACHED LPS

7. EARTHING AT LOW VOLTAGE CONSUMER PREMISE

7.1 EQUIPMENT EARTHING

7.1.1 Equipment Using Current

7.1.1.1 Classification of equipment w.r.t fault protection is provided in Table 7 and w.r.t condition of connection of the equipment to the installation is provided in Table 8. (see IS732 Table 7 condition BC: contact of person with earth potential)

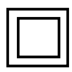
Note

1) Equipment and appliances are different in their definition. Appliances are for domestic or similar use. They are classified into class 0, class 0I, class II, class III. Sale of class 0 and class 0I appliances are banned in India.
2) IS732:2019 permits the use of class 0 equipment in BC 1 and BC 2 locations (earth free environment). However, the use of class 0 equipment is discouraged.

TABLE 7 CLASSIFICATION OF EQUIPMENT

	Class 0	Class I	Class II	Class III
Principal characteristics of equipment	No means of protective earthing	Protective earthing means provided	Additional insulation and no means for protective earthing	Designed for supply at safety extra low voltage
Precautions for safety	Earth free environment	Connection to the protective earthing	None necessary	Connection to safety extra low voltage

TABLE 8 CONDITION OF CONNECTION OF THE EQUIPMENT OR APPLIANCE TO THE INSTALLATION

Type of Appliance / equipment	Equipment marking or instructions	Symbol	Equipment marking or instructions
Class 0	Only Basic Protection NO Fault protection		Class 0 appliances are not allowed in India
Class 01	Appliance having at least basic insulation throughout and incorporating an earthing terminal but having a supply cord without earthing conductor and a plug without earthing contact.		Class 01 construction is not allowed in India for safety reason
Class 1	Marking of the protective bonding terminal with graphical symbol 5019 (IEC 60417), or letters PE, or colour combination green-yellow.		Connect this terminal to the protective equipotential bonding system of the installation
Class II	Marking with the graphical symbol 5172 (IEC 60417) (double square)		No reliance on installation protective measures
Class III	Marking with the graphical symbol 5180 (IEC 60417) (roman numeral III in a diamond)		Connect only to SELV or PELV systems

Note: For more information on application of class 0 and class 01 equipment, See IS732:2019, Table 7, code BC.

Accessible metal parts of Class I appliances/equipment 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 terminal and earthing contact shall not be connected to the neutral terminal. The continuity resistance between the earth terminal and accessible metal parts of such equipment shall meet the requirements of product standard. (e.g. IEC 61439-1: Low voltage switchgear and controlgear assemblies part 1, General rules, need 0.1 Ω for this application).

However, Class II equipment, in which double insulation (insulation comprising both basic and supplementary insulation) or reinforced insulation are provided, may not have provision for connection of exposed metal work of the equipment to a protective conductor and no reliance upon precautions to be taken in the fixed location of installation.

7.1.2 Examples of Provisions for protective earthing in class 1 electrical equipment.

7.1.2.1 Low-voltage switchgear and controlgear assemblies

All Switchgear and controlgear assemblies shall satisfy these requirements (See IS/IEC 61439-1).

When a TT earthing system is being used in the electrical network, one of the following protective measures shall be applied in the assembly:

a) double or reinforced insulation of all conductors (incoming cables, extension terminals, etc.) up to the supply side of the first RCD(s) in the system (this is not a requirement when a Class II assembly is used); or
b) residual current device (RCD) protecting the incoming circuit.

Note: In case of fault protection by RCD, the fault loop impedance and the residual current of the protective device shall be selected based on Table 19.

In all cases, effective earth continuity between the exposed-conductive-parts of the class I assembly and the protective equipotential bonding of the installation shall be ensured. It shall be verified that the different exposed-conductive-parts of the assembly are effectively connected to the terminal for the incoming external protective conductor.

a) To ensure protection against the consequences of earth faults within the class I assembly, all exposed-conductive-parts of the assembly shall be interconnected together to a protective earthing terminal / busbar, which is connected to the incoming external protective conductor of the supply to the earthing arrangement. The resistance between protective earthing terminal to exposed conductive parts shall not exceed 0.1 Ω.

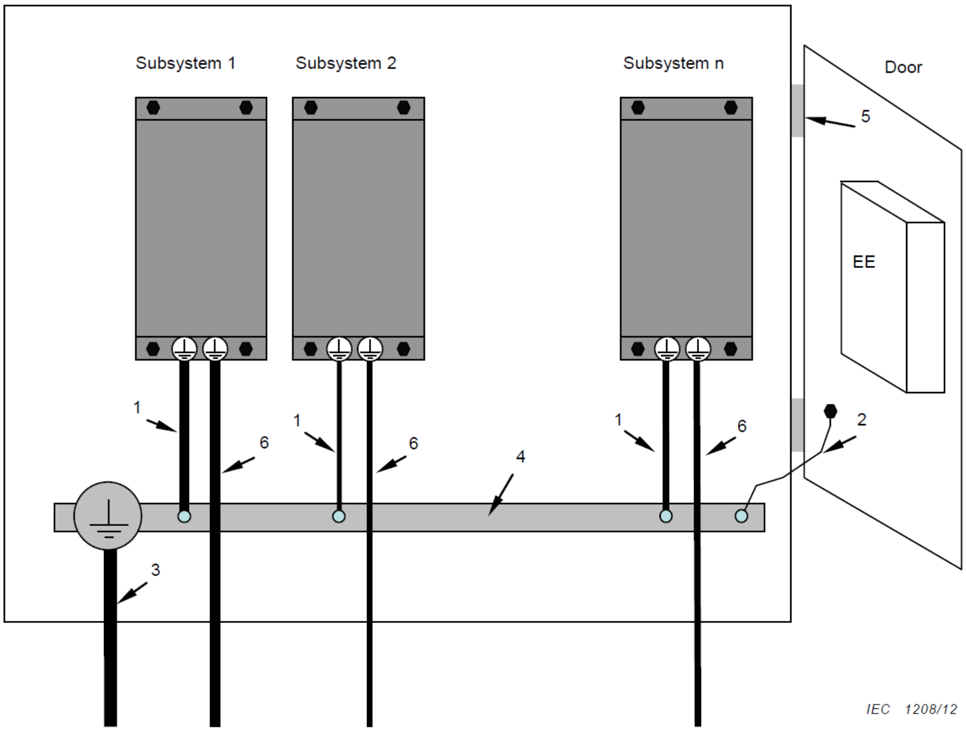
b) To ensure protection against the consequences of earth faults in external circuits supplied through the class I and class II assembly, the protective conductor ensuring continuity shall be designed so that it can withstand the highest thermal and dynamic stresses arising from earth fault currents in external circuits supplied through the assembly in its installed location In the case of a class II assembly, the protective conductor may or may not be incorporated within the assembly: it is permissible for it to pass the assembly externally.

c) Continuity resistance and measurement: Every switchgear and control gear assemblies shall be verified for the effectiveness of protective bonding by measuring the resistance between the exposed-conductive-parts of the assembly to the protective earth terminal or busbar of the assembly using a resistance-measuring instrument that is capable of driving a current of at least 10 A (AC or DC). The current is passed between each exposed conductive-part and the protective earthing terminal of the assembly. The resistance shall not exceed 0.1 Ω. It is recommended to limit the duration of the test where low-current equipment is used to avoid adverse effect of the test.

7.1.2.2 Uninterrupted power Supplies

Fig. 26 shows examples of UPS assembly and its associated protective equipotential bonding.

Note: for more information refer IS 16242 (all parts)



key:

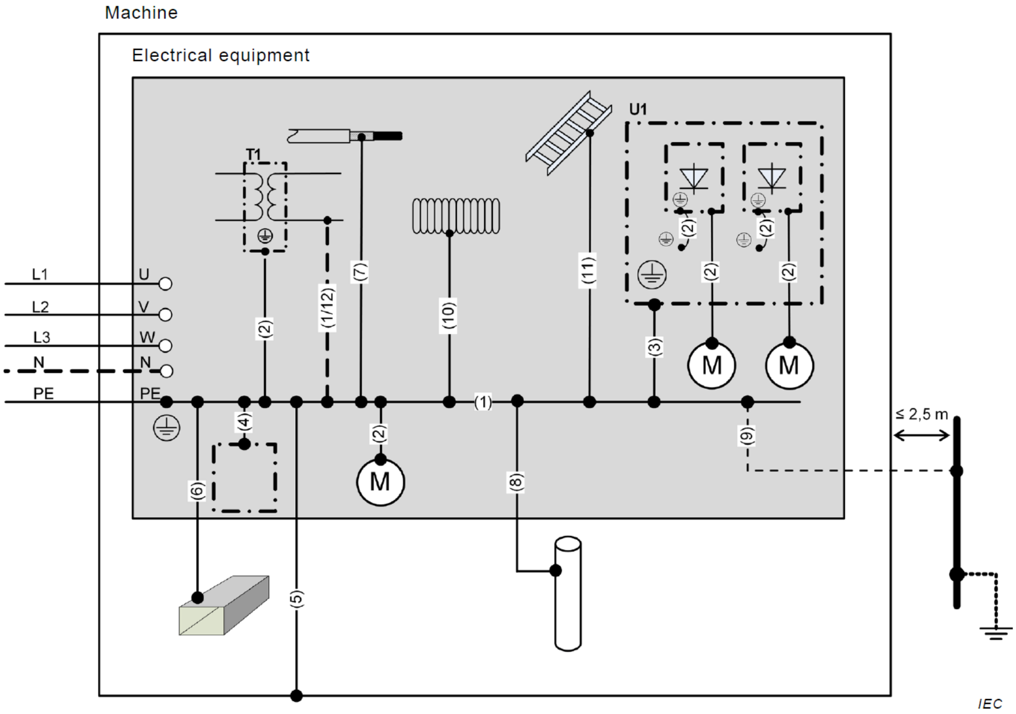
1. Protective equipotential bonding of subsystem
2. Protective Bonding conductor
3. PE conductor from MET.
4. MET (Protective Earthing Terminal or Earth Bar).
5. Hinge
6. PE conductor to load

EE: Other electrical equipment (bonded as relevant for that equipment)

FIGURE 27 EXAMPLE OF UPS ASSEMBLY AND ITS ASSOCIATED PROTECTIVE EQUIPOTENTIAL BONDING.

7.1.2.3 Earthing of machinery

Effectiveness of fault protection in machineries shall be ensured by verifying the conditions for protection by automatic disconnection of supply. Verification of the continuity of the protective bonding circuit and efficiency of automatic disconnection are necessary in all cases. (See IS/IEC 60204-1).



Protective bonding circuit:	
(1)	Interconnection of protective conductor(s) and the PE terminal
(2)	Connection of exposed conductive parts
(3)	Protective conductor connected to an electrical equipment mounting plate used as a protective conductor
(4)	Connection of conductive structural parts of the electrical equipment
(5)	Conductive structural parts of the machine
Parts connected to the protective bonding circuit which are not to be used as protective conductor:	
(6)	Metal ducts of flexible or rigid construction
(7)	Metallic cable sheaths or armouring
(8)	Metallic pipes containing flammable materials
(9)	Extraneous-conductive-parts, if earthed independently from the power supply of the machine and liable to introduce a potential, generally the earth potential, (see 17.2 d)), e.g.: metallic pipes, fences, ladders, handrails.
(10)	Flexible or pliable metal conduits
(11)	Protective bonding of support wires, cables tray and cable ladders
Connections to the protective bonding circuit for functional reasons:	
(12)	Functional bonding
Legend to reference designations:	
T1	Auxiliary transformer
U1	Mounting plate of electrical equipment

FIGURE 28 EXAMPLE OF EQUIPOTENTIAL BONDING FOR ELECTRICAL EQUIPMENT OF A MACHINES

7.1.2.4 Earthing of Lifts

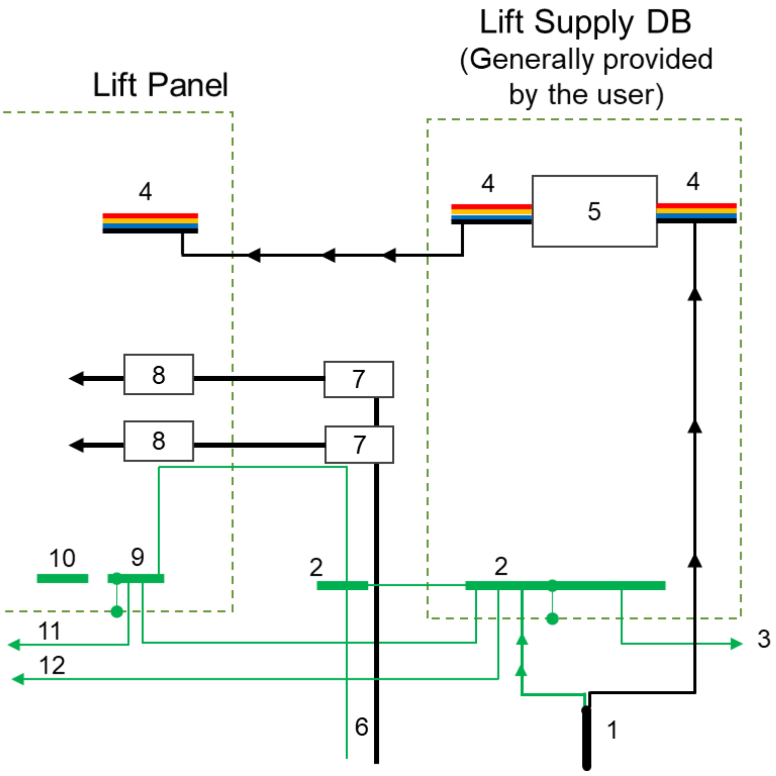
Protective Earthing of Lift shall be achieved by connecting the protective earth terminal of lift panel to the MET of the location as shown in Fig. 28 satisfying the requirements of system earthing (see 6.2 and 7.4.2 to 7.4.4). Minimum Cross-Sectional Area of Protective Earthing conductor shall satisfy 7.3.2. The local equipotential bonding at the lift room reduces touch voltages.

Fault protection shall be achieved either by OCPD or by RCD (see 7.5.3 and 7.5.4)

Uunwanted tripping of RCD’s due to higher leakage current shall be avoided by achieving fault protection by OCPD and by reinforced protective conductor.

Note:

1. IS17900-1: 2022, Clause 5.10.9 needs protective earthing of lift as per clause 4.2.11.3.1.1 of IS732.
2. IS17900-1: 2022, Clause 6.3.2 d) needs verification of the effectiveness of the measures for fault protection by automatic disconnection of supply according to 6.2.3.6 and 6.2.3.7 of IS732.
3. IS17900-1 need additional protection by 30 mA RCD in clause 5.10.1.2.3 as an additional protection against electric shock. Requirements for fault protection and additional protection are different.
4. Where the PE conductor current exceeds 10 mA under normal operating conditions, a reinforced protective conductor shall be used (see 5.4.3.7 of IS732:2019).



1. Incoming supply (preferably 5 core cable. (R,Y,B,N & PE))
2. MET of Lift room (can be called as Protective Earth Terminal or PE terminal)
3. Connection to extraneous conductive parts in lift room.
4. Live parts (R, Y, B, N)
5. OCPD or RCD for fault protection [a].
6. Single phase supply (L+N+PE, 3 wire) to car light and shaft light.
7. OCPD for single phase supply (lift car and lift shaft).
8. 30 mA RCCB/RCBO for single phase supply as additional protection against shock for safety of passengers [c]. This is mandatory and be a part of lift panel. TYPE A RCCB is recommended for LED lights.
9. PE terminal in lift panel for protective equipotential bonding [c].
10. Additional PE terminal for reinforced protection [b] [c].
11. PE conductor to other parts of Lift [c].
12. Bonding conductor to elevator guide rails. (separate connection preferred for each rail)

a) OCPD such as MCB or MCCB's can be provided for protection against over current and earth fault, provided the fault loop impedance is low enough to enable automatic disconnection during an earth fault. In case of higher fault loop impedance, an RCCB shall be installed for fault protection. $I_{\Delta n}$ of RCCB can be selected based on the available fault loop impedance and expected protective conductor current of VFD's used in Lift. Type B RCCB shall be used if the lift contains 3 phase VFD.

b) Required in case of PE conductor current higher than 10 mA. The manufacturer shall decide the method of reinforced protective measure for this terminal, which is not a part of this picture.

c) Part of Lift.

FIGURE 29 EXAMPLE OF PROTECTIVE EARTHING, FAULT PROTECTION AND ADDITIONAL PROTECITON OF LIFT

7.1.2.5 Earthing and safety in electric vehicle charging stations

Each socket-outlet for electric vehicle shall have an earthing contact connected to the protective conductor (PE) of the installation. RCDs protecting each connecting point shall comply at least with the requirements of an RCD type A and shall have a rated residual operating current not exceeding 30 mA.

Where the EV charging station is equipped with a socket-outlet or vehicle connector complying with IS 17017/IEC 62196 (all parts), protective measures against d.c. fault current shall be taken, except where provided by the EV charging station. The appropriate measures, for each connection point, shall be as follows:

a) the use of an RCD type B;
b) the use of an RCD type A in conjunction with a residual direct current detecting device (RDC-DD) complying with IEC 62955; or
c) the use of an RCD type F in conjunction with a residual direct current detecting device (RDC-DD) complying with IEC 62955.

RCDs shall comply with one of the following standards: IS 12640 (Part 1), IS 12640 (Part 2), IS/IEC 609472 or IEC 62423.

NOTE

1. For charging stations in residential premises, where protection against d.c fault may not be available. In such case RCD type B is required.
2. RCD is not applicable in case the connecting point is protected by other protective measures against electric shock such as SELV or electric separation.

7.2 EARTHING ARRANGEMENT

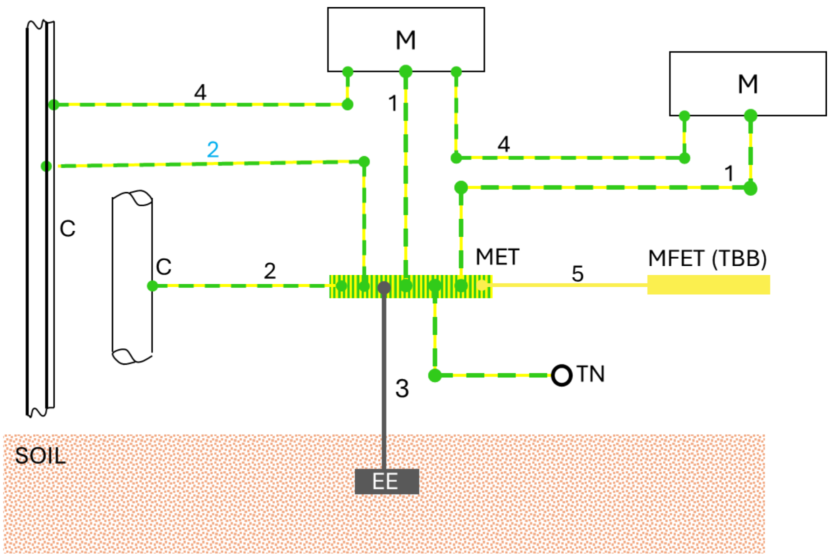
7.2.1 General

7.2.1.1 Earthing arrangement: Earthing arrangement in a consumer premise consists of protective earthing, main and supplementary protective equipotential bonding, functional earthing, functional bonding etc as shown in Fig. 29, depending upon the availability of exposed, extraneous conductive parts, functional requirement of electronics and system earthing.

7.2.1.2 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.

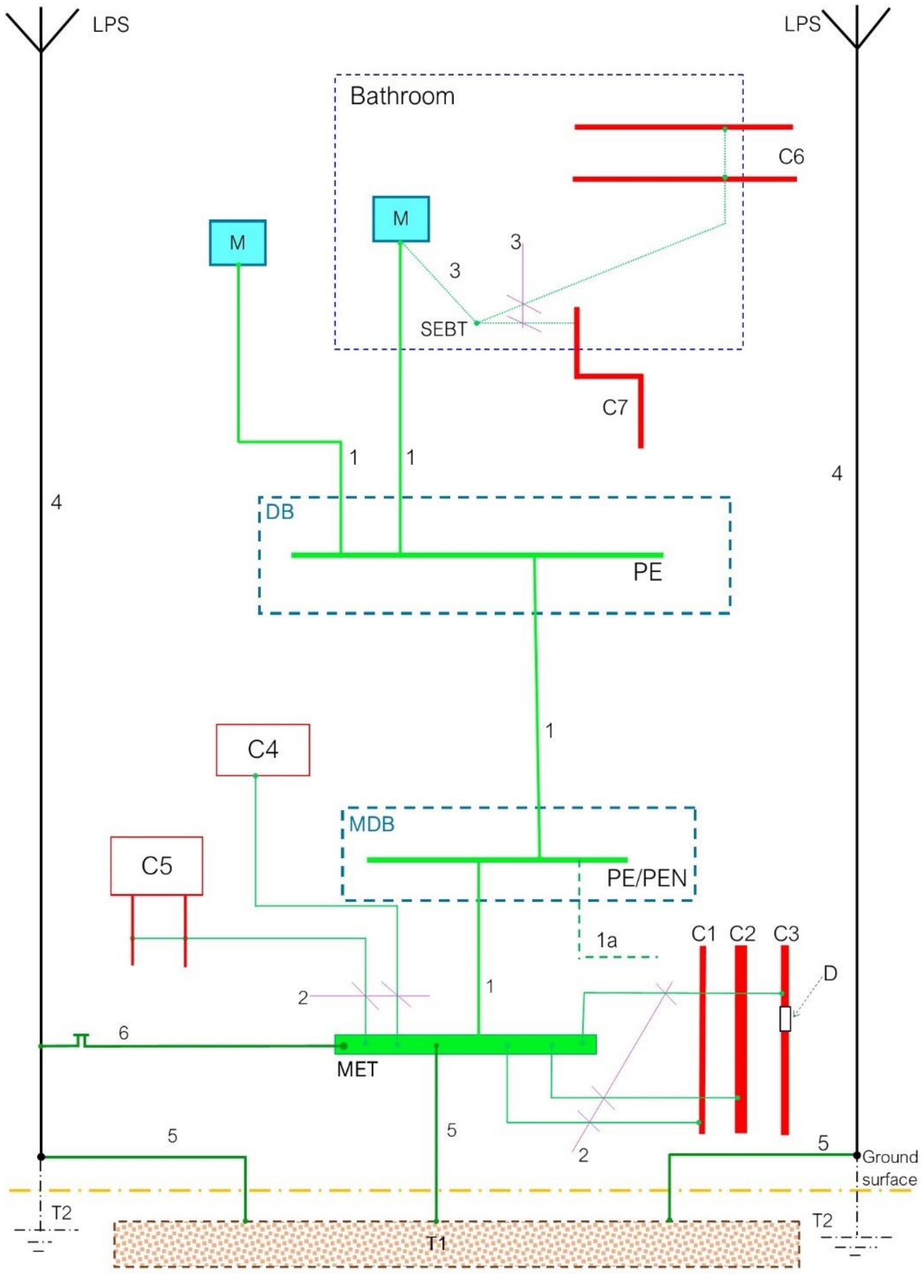
7.2.1.3 Where provided, earth electrodes within an installation shall be connected to the main earthing terminal using an earthing conductor.

NOTE - An installation does not need to have its own earth electrode for safety measures covered in IS732:2019 (See clause 5.4.2.1.2 of IS732:2019).



Key
M – Exposed Conductive Part.
MET - Main Earthing Terminal.
MFET – Main Functional Earth Terminal (Also called as Telecommunication bonding bar (TBB)).
C – Extraneous Conductive Part (structural steel, metallic pipes, down conductor of LPS etc).
EE - earth electrode in a TT or IT system.
TN - other means of earthing in a TN system eg. connection to earthed point of the power system.
1 – Protective Earth Conductor (PE conductor).
2 - Main protective bonding conductor.
3 - Earthing conductor (Conductor connecting other buried metal parts to MET are also considered as earthing conductor).
4 - Supplementary protective bonding conductors (if required).
5 – Telecommunication Bonding Conductor (TBC).

FIGURE 29A - ILLUSTRATION EARTHING ARRANGEMENT CONSISTING OF PROTECTIVE EQUIPOTENTIAL BONDING, PROTECTIVE AND FUNCTIONAL CONDUCTORS.



Key	**Symbol Name Remark**
C	Extraneous conductive part
C1	Water pipe, metal from outside
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
C7	Waste water pipe, metal e.g. in a bathroom
D	Insulating insert
MDB	Main distribution board

DB	Distribution board supplied from the main distribution board
MET	Main earthing terminal
SEBT	Supplementary equipotential bonding terminal
T1	Concrete-embedded foundation earth electrode or soil-embedded foundation earth electrode
T2	Earth electrode for LPS (if necessary)
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)
1a	Protective conductor, or PEN conductor, if any, from public distribution
2	Main bonding conductor (connection to the MET)
3	Supplementary bonding conductor
4	Down conductor of a lightning protection system (LPS) if any (separation distance shall be considered)
5	Earthing conductor
6	Bonding of MET to down conductor through a link (if necessary). (See IS/IEC 62305-3, clause 6)

FIGURE 30B EXAMPLE OF EARTHING ARRANGEMENT, FOUNDATION EARTH ELECTRODE, PROTECTIVE EARTH CONDUCTORS AND PROTECTIVE BONDING CONDUCTORS IN A RESIDENTIAL BUILDING.

7.2.1.4 When an installation supplies number of buildings, main equipotential bonding is essential in each building, so that each has a reference point as an MET to which the conductor parts referred in 7.2.1.1 are connected.

7.2.1.5 Protective and functional bonding conductors shall be connected individually to the MET in such a way that if one conductor becomes disconnected the connections of all the other conductors remain secured.

7.2.1.5 For larger buildings, it is recommended to repeat the equipotential bonding at every 20 meter.

7.2.1.6 Simultaneously accessible exposed conductive parts shall be connected to the same earthing system individually, in groups or collectively.

7.2.1.7 If part of a protective bonding is temporarily removed, (e.g. for the purpose of addition or maintenance) the bonding for the remaining part of the electrical installation shall not be disconnected.

7.2.2 Description of conductors used in an Earthing Arrangement

7.2.2.1 Main Earthing Terminal (MET) or Main Earthing Busbar: Terminal or busbar of an installation, enabling the electric connection to a number of conductors used for earthing or bonding purposes.

7.2.2.2 Protective Earthing Conductors: Conductors to connect exposed conductive parts to MET in an installation and MET to the means of earthing in a TN system. They are also called as PE conductor. The PE conductor in final circuits is also called as circuit protective conductors (CPC).

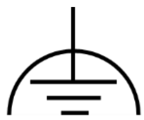
7.2.2.3 Protective Bonding Conductor: Conductors used to connect extraneous conductive parts to MET. They are used in main equipotential bonding and supplementary equipotential bonding.

7.2.2.4 Earthing conductor: Conductors used to connect MET to earth electrodes and to other buried metal parts. Earthing conductors may be used in air and in soil.

7.2.3 Marking of Earthing/Protective Conductor

7.2.3.1 The earthing and protective conductor shall be marked as given in Table 9 (see IS 11353).

TABLE 9 MARKING OF CONDUCTORS

Designation of conductors	Identification by		Colour
	Alphanumeric notation	Graphical symbol	
(1)	(2)	(3)	(4)
Earthing Conductor	E		No colour
Protective bonding conductor			Green and yellow
Protective earthing conductor	PE		Green and yellow
Functional earthing	FE		Cream (NEC 2023). Note: Internationally purple is used.

7.2.3.2 Use of Bi-Colour Combination - Green and Yellow

The bi-colour combination, green and yellow (green/yellow), shall be used for identifying the protective bonding/protective earthing conductor and for no other purpose. This is the only colour code recognized for identifying these protective conductors.

Bare conductors or bus bars, used as protective conductors, shall be coloured by equally broad green and yellow stripes, each 15 mm up to 100 mm wide, close together, either throughout the length of each conductor or in each compartment or unit or at each accessible position. If adhesive tape is used, only bi-coloured tape shall be applied.

For insulated conductors, the combination of the colours, green and yellow, shall be such that, on any 15 mm length of insulated conductor, one of these colours covers at least 30 percent and not more than 70 percent of the surface of the conductor, the other colour covering the remainder of that surface.

NOTE — Where the protective conductor can be easily identified from its shape, construction or position, for example, a concentric conductor, then colour coding throughout its length is not necessary but the ends or accessible positions should be clearly identified by a symbol or the bi-colour combination, green and yellow.

7.2.3.3 The materials used for making connections have to be compatible so that galvanic corrosion is minimized. In all cases, the connections have to be mechanically strong.

7.2.3.4 The incorporation of the protective conductor in the same wiring system as the live conductors or in their immediate proximity is strongly recommended (see 4.5.5).

7.3 MINIMUM CROSS-SECTIONAL AREA

7.3.1 General

7.3.1.1 The cross-sectional area of every protective conductor shall satisfy the conditions for automatic disconnection of supply and be capable of withstanding mechanical and thermal stresses caused by the prospective fault current during the disconnection time of the protective device.

7.3.1.2 The cross-sectional area of a protective conductor shall either be calculated in accordance with 7.3.2.1, or selected in accordance with Table 10. In either case, the requirements of 7.3.2.3 shall be taken into account.

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

7.3.1.4 In TT systems, where the earth electrodes of the supply system and of the exposed conductive parts are electrically independent, the cross-sectional area of protective conductors need not exceed 25 mm^2 copper (or 35 mm^2 aluminium or equivalent steel).

7.3.2 Minimum Cross-Sectional Area: Protective Earthing conductor

7.3.2.1 The cross-sectional areas of protective earthing conductors shall be not less than the value determined 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 mm^2;
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
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 7.3.2.7).

7.3.2.2 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.
2) For limitations of temperatures for installations in potentially explosive atmospheres, see IEC 60079-0.

(where not calculated in accordance with 7.3.2.1)

TABLE 10 MINIMUM CROSS-SECTIONAL AREA OF PROTECTIVE CONDUCTORS

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 ≤16	S	$\frac{k_1}{k_2} \times S$
16 < S ≤35	16	$\frac{k_1}{k_2} \times 16$
S >35	$\frac{S}{2}$	$\frac{k_1}{k_2} \times \frac{S}{2}$
where k_1 is the value of k for the line conductor derived from the formula in 7.3.2.7 or selected from Tables 12, according to the materials of the conductor and insulation;		
k^2 is the value of k for the protective conductor, selected from Table 13 to Table 17 as applicable.		

7.3.2.3 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 mm^2 Cu or 16 mm^2 Al if protection against mechanical damage is provided, or 4 mm^2 Cu or 16 mm^2 Al if protection against mechanical damage is not provided.

7.3.2.4 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.

7.3.2.5 The use of steel for a protective conductor is also allowed based on the selection as per Table 13 to Table 17.

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

- calculated in accordance with 7.3.2.1 for the most onerous prospective fault current and operating time encountered in these circuits; or
- selected in accordance with Table 10 so as to correspond to the cross-sectional area of the largest line conductor of the circuits.

7.3.2.7 Method for deriving the factor *k*

(see 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 mm^3) at 20 °C;
β is the reciprocal of temperature coefficient of resistivity at 0 °C for the conductor (°C);
ρ20 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 11 VALUE OF PARAMETERS FOR DIFFERENT MATERIALS

Material	β^a °C	Q_c^a J/°Cmm^3	$\rho 20^a$ Ωmm	$\sqrt{\frac{Qc(\beta + 20)}{\rho_{20}}}$ $A\sqrt{S}/mm^2$
Copper	234.5	3.45×10^{-3}	17.241×10^{-6}	226
Aluminium	228	2.5×10^{-3}	28.264×10^{-6}	148
Steel	202	3.8×10^{-3}	138×10^{-6}	78
a Values taken from IEC 60949.				

TABLE 12 VALUE OF K FOR CONDUCTORS

Property/ Condition	**Type of Conductor Insulation**									
	PVC Thermoplastic		PVC Thermoplastic 90°C		EPR XLPE Thermosetting		Rubber 60 °C Thermosetting		Mineral	
									PVC sheathed	Bare unsheathed
Conductor cross-sectional area mm^2	≤300	> 300	≤ 300	> 300						
Initial temperature °C	70		90		90		60		70	105

Final temperature °C	160	140	160	140	250		200		160	250
Conductor material:										
Copper	115	103	100	86	143		141		115	135-115[(1)]
Aluminium	76	68	66	57	94		93		-	-
Tin-soldered joints in copper conductors	115	-	-	-	-	-	-	-	-	-
[(1)] This value shall be used for bare cables exposed to touch										
NOTE **1** Other values of k are under consideration for:										
– small conductors (particularly for cross-sectional areas less than 10 mm²); – other types of joints in conductors; – bare conductors. **2** The nominal current of the short-circuit protective device may be greater than the current-carrying capacity of the cable. **3** The above factors are based on IEC 60724.										

TABLE 13 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 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 14 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	30	200	159	105	58
(PVC) polyethylene	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 15 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	220	134	89	48

85 °C thermosetting (rubber)					
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 301 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 16 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		
			Copper	Aluminium	Steel
	Initial	Final	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
85 °C thermosetting (rubber)	75	220	140	93	51
Mineral thermoplastic (PVC) covered [b]	70	200	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 17 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

7.3.3 Minimum Cross-Sectional Area: Earthing Conductor

7.3.3.1 Earthing conductors shall comply with 7.3.1.1 to 7.3.1.3. Their cross-sectional area shall be not less than 6 mm^2 for copper or 50 mm^2 for steel. Where a bare earthing conductor is buried in the soil, its dimensions and characteristics shall also be in accordance with Table 24.

7.3.3.2 Where no noticeable fault current is expected to flow through the earth electrode the earthing conductor may be dimensioned according to 7.3.4.1.

7.3.3.3 Where a lightning protection system is connected to the earth electrode, the cross-sectional area of the earthing conductor should be at least 16 mm^2 for copper (Cu) or 50 mm^2 for iron (Fe).

7.3.3.4 Aluminium shall not be used as earthing conductors.

7.3.3.5 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. The connections shall be capable of withstanding the expected fault current with a maximum temperature of 200 deg C in normal conditions. Higher temperatures are allowed only in visible and restricted areas (see Table 16).

7.3.3.6 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.

7.3.3.7 While the connector referred to might be in a link box underground and therefore not readily accessible, provision is made in an accessible portion for disconnecting the MET of an installation from the means of earthing to facilitate measurement of the resistance of the earthing arrangements.

7.3.3.8 For MV/HV/EHV applications (e.g. above 1000 V a.c / 1500 V d.c.) due to mechanical strength and stability against corrosion minimum cross-sections are:

- copper: 16 mm^2
- aluminium: 35 mm^2
- steel: 50 mm^2

7.3.4 Minimum Cross-Sectional Area: Protective bonding conductors

7.3.4.1 Protective bonding conductors for connection to the MET

1) Protective bonding conductors for connection to the MET 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 mm^2 copper; or
   - 16 mm^2 aluminium; or
   - 50 mm^2 steel.
2) The cross-sectional area of protective bonding conductors for connection to the MET need not exceed 25 mm^2 Copper or an equivalent cross-sectional area for other materials.

7.3.4.2 Protective bonding conductors for supplementary bonding

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.
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.
3) The minimum cross-sectional area of protective bonding conductors for supplementary bonding, and of bonding conductors between two extraneous-conductive parts, 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 mm^2 Cu or 16 mm^2 Al if protection against mechanical damage is provided, or 4 mm^2 Cu or 16 mm^2 Al if protection against mechanical damage is not provided.

7.3.4.3 For MV/HV/EHV applications (e.g. above 1000 V a.c / 1500 V d.c.) Protective bonding conductors shall satisfy 7.3.3.8.

7.3.5 Main Earthing Terminals or Main Earth Bus Bar (MET)

7.3.5.1 A consumer’s electrical installation below 1000 V a.c. shall have a main earthing terminal (MET). In TN system, the MET is connected to the earthed point of the source. In the case of TT and IT system, the MET shall be earthed to an independent earth electrode. Functional earthing conductors should be connected to MET (see IS732)

7.3.5.2 The function of MET is to provide a reference and equipotential point for the installation, it consists of a terminal or bar provided for the connection of protective conductors and conductors for functional earthing.

7.3.5.3 Although the MET is connected to Earth, it is seldom at zero potential because of the potential difference caused by leakage and other current flowing to earth.

7.3.5.4 An independent earth electrode should also be connected to the MET if the main supply has a combined neutral and protective conductor.

7.3.5.5 Each conductor connected to the MET 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.

7.3.5.6 MET shall have a conductance not less than the conductance of Protective Earthing Conductor (see 7.3.2).

Note: In case of confusion in double earthing, two nos of MET may be used, both interconnected at every 5 meters.

7.3.6 Types of Protective Earthing Conductors

7.3.6.1 Protective Earthing conductors may comprise:

a) Conductors in multicore cables;
b) Insulated or bare conductors in a common enclosure with live conductors;
c) Fixed conductor, bare or insulated;
d) Metallic cable sheath, cable screen, cable armour, wirebraid, concentric conductor, metallic conduit, subject to the conditions stated in 7.3.6.2 a) and b).

7.3.6.2 Where the installation contains equipment having metal enclosures such as low voltage switchgear and controlgear assemblies as per IS/IEC 61439-1 and IS/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 minimum cross sectional area of protective earthing conductor as per 7.3.2,
c) they shall permit the connection of other protective conductors at every predetermined tap-off point.

7.3.6.3 When the metallic sheath of a cable is used as a Protective Earthing conductor, every joint in that sheath should be 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 metal strip having the same effective current-carrying capacity as the largest cable entering the box should be provided to maintain continuity. However this is not permitted in cables $\leq$ 16 mm^2. For cables up to 16 mm^2, protective earth conductor as a core in multicore cables should be used (e.g. 3 core cable for 1 Line + N application and 5 core cable for 3 Line + N application)

Note: For industrial application using protective conductor as a part of cable suitably sized according to clause 7.3.2 or table 10 read with table 15 is recommended.

7.3.6.4 When using the metal sheath or armour, attention should also be paid to the ability of the cable glands and connections and the armouring to withstand the fault current without damaging the cable. Special precautions may be considered necessary with the metal parts of the assembly, particularly gland plates where abrasion resistant function for example, powder coating, are used.

7.3.6.5 Metallic enclosures for cable, such as conduit, ducting and trunking, may be used as Protective Earth conductors but where flexible conduit is used, separate protective earth 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, as those of the wiring system or conduit of which they are part. Slackness in joints can result in deterioration and even complete loss of continuity; plain slip or pin-grip sockets should not be used. In case of unscrewed conduit, the use of lug-grip fitting is recommended, but for outdoor installation where the conduits are subjected to corrosion, screwed type conduits shall always be used. Painting is to be done on all conduit systems after the assembly. The complete construction shall withstand fault current with out damaging the cable and surrounding.

7.3.6.6 Electrolytic corrosion is liable to occur under damp condition at contacts between dissimilar metals. Copper and its alloys having high copper content are particularly liable to cause corrosion under these condition when in contact with aluminium alloys. Bi-metallic strips/contacts shall be used when dissimilar metal form part of an electrical circuit, the joints should be clean and assembled free of moisture, and then immediately treated with suitable coating or cover to protect from moisture.

7.3.6.7 Extraneous conductive parts may be used as a protective conductor if they satisfy the following four requirements, provided the leakage current in the installation are within the limits

a) their electrical continuity shall be assured either by construction or by suitable connections in such a way as to be protective against mechanical, chemical or electrochemical deterioration;
b) their conductance shall be at least equal to that of minimum cross sectional area of protective earthing conductor as per 7.3.2;
c) unless compensatory measures are provided precautions shall be taken against their removal; and
d) they have been considered for such a use and, if necessary, suitably adapted.

The use of metallic water pipes is permitted, as a protective conductor provided the consent of a person or body responsible for the water system is obtained. Gas pipes shall not be used as protective conductors. However equipotential bonding of these pipes are mandatory unless they are sufficiently insulated

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

7.3.7 Electrical continuity of protective conductors

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

7.3.7.2 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.

7.3.7.3 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.

7.3.7.4 Joints in protective conductors shall be accessible except for

- compound-filled 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 the relevant standards, for example low voltage switchgear and controlgear assemblies according to 7.3.6.2,
- joints made by welding or brazing,
- joints made by compression tool.

7.3.7.5 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.

7.3.7.6 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.

7.3.7.7 Exposed-conductive-parts of electrical equipment shall not be used to form part of the protective conductor for other equipment except as allowed by 7.3.6.2.

7.3.7.8 Periodical tests to verify the electrical continuity should be undertaken. (See NEC 2023 Part 1, section 17, Annex E for periodicity)

7.4 EARTH FAULT PROTECTION IN INSTALLATIONS

7.4.1 Basic Philosophy of Earth Fault Protection

7.4.1.1 The rules given in this clause are applicable to installation below 1000 V a.c. and 1500 V d.c.

7.4.1.2 Amongst other things, fault protection (protection against shock in case of a fault / indirect contact) is provided by protective equipotential bonding and automatic disconnection of supply. This protective measure necessitates coordination of the types of electrical system earthing and the characteristics of the protective devices. Clause 7.4 discusses the basic criteria for achieving this protection.

7.4.1.3 Protection against electric shock both in normal service (Basic protection, also called as protection against direct contact) and in case of fault (fault protection also called as protection against indirect contact) can be achieved by several measures. Details of achieving protection through the choice of an appropriate protective measure is the subject of IS 732. One of such measures is protection by automatic disconnection of supply.

7.4.1.4 Automatic disconnection is intended to prevent a touch voltage persisting for such time that a danger could arise. This method necessitates co-ordination of (a) the type of system earthing, and (b) characteristics of protective devices.

7.4.1.5 Protective measure by automatic disconnection of supply relies on the association of two conditions given below:

a) The existence of a conducting path (fault loop) to provide for circulation of fault current; and
b) The disconnection of this current by an appropriate device in a given time.

The determination of this time depends on various parameters, such as probability of fault, probability of a person touching the equipment during the fault and the touch voltage to which a person might thereby be subjected.

7.4.1.6 The study of the electrical impedance of the human body as a function of touch voltage and magnitude of current flow in the body as a function of its duration likely to produce a given effect are two components which help in establishing a relationship between prospective touch voltage and its duration which will not result in harmful physiological effects for any person. Limits of touch voltage are based on studies on the effects of current on human body (see IS/IEC 60479).

7.4.1.7 Permissible touch voltage U_{Tp} as shown in Fig. 4 calculated based on 5.2.1 and 5.2.2 can be used alternatively.

7.4.1.8 The maximum disconnection time stated in Table 1 shall be applied to final circuits with a rated current not exceeding,

- 63 A with one or more socket-outlets, and
- 32 A supplying only fixed connected current-using equipment.

7.4.1.9 In TN systems, a disconnection time not exceeding 5 s is permitted for distribution circuits, and for circuits not covered by 7.4.1.8.

7.4.1.10 In TT systems, a disconnection time not exceeding 1 s is permitted for distribution circuits and for circuits not covered by 7.4.1.8.

7.4.1.11 Where it is not feasible for an over current protective device to interrupt the supply or the use of an RCD for this purpose is not appropriate, following measures shall be followed.

7.4.1.11.1 Where automatic disconnection is not feasible in circumstances where,

- electronic equipment with limited short-circuit current is installed, or
- the required disconnection times cannot be achieved by a protective device,

the following provisions are applicable.

7.4.1.11.2 For installations with power electronic converters with nominal voltage U_O greater than 50 V a.c. or 120 V d.c. and where automatic disconnection is not feasible, the output voltage of the source shall be reduced to 50 V a.c. or 120 V d.c. or less in the event of a fault between a live conductor and the protective conductor or earth in a time as given in 7.4.1.8, 7.4.1.9 and 7.4.1.10, as appropriate (see IEC 62477-1).

The power electronic converter shall be one for which the manufacturer gives adequate methods for the initial and periodic verification of the installation.

7.4.1.11.3 Except where 7.4.1.11.1 applies, if automatic disconnection cannot be achieved in the time required by 7.4.1.8, 7.4.1.9 and 7.4.1.10 an appropriate, supplementary protective equipotential bonding shall be provided in accordance 7.4.5 and the voltage between simultaneously accessible conductive parts shall not exceed 50 V a.c. or 120 V d.c.

7.4.1.11.4 However, disconnection may be required for reasons other than protection against electric shock.

7.4.1.12 If automatic disconnection cannot be achieved with in the recommended time supplementary protective equipotential bonding shall be provided in accordance with 7.4.5.

7.4.2 TN Systems

7.4.2.1 All exposed conductive parts shall be connected to the earthed point of the supply system by protective conductors. The protective conductors shall be earthed near each power transformer or generator of the installation.

The characteristics of the protective devices and the cross-sectional area of conductors shall be so chosen that if a fault of negligible impedance occurs anywhere between a phase conductor and a protective conductor or exposed conductive part, automatic disconnection of the supply will occur within the minimum possible safe time.

7.4.2.2 In TN systems the integrity of the earthing of the installation depends on the reliable and effective connection of the PEN or PE conductors to earthed point of source. Where the earthing is provided from a public or other supply system, compliance with the necessary conditions external to the installation is the responsibility of the supply network operator.

NOTE: PEN is not allowed downstream the origin of installation.

Examples of conditions include the PEN is connected to earth at a number of points at the distribution and is installed in such a way as to minimize the risk arising from a break in the PEN conductor;

$$R_B/R_E \leq 50/(U_0 - 50)$$

where

R_B is the earth electrode resistance, in ohms, of all earth electrodes in parallel;
R_E is the minimum contact resistance with earth, in ohms, of extraneous-conductive-parts not connected to a protective conductor, through which a fault between line and earth may occur;
U_0 is the nominal a.c. r.m.s. voltage to earth, in volts.

7.4.2.3: The neutral point or the midpoint of the power supply system shall be earthed. If a neutral point or midpoint is not available or not accessible, a line conductor shall be earthed.

Exposed-conductive-parts of the installation shall be connected by a protective conductor to the main earthing terminal of the installation which shall be connected to the earthed point of the power supply system.

If other effective earth connections exist, it is recommended that the protective conductors also be connected to such points wherever possible. Earthing at additional points, distributed as evenly as possible, may be necessary to ensure that the potentials of protective conductors remain, in case of a fault, as near as possible to that of earth.

It is recommended that protective conductors (PE and PEN) should be earthed where they enter any buildings or premises taking account of any diverted neutral currents of multiple earthed PEN conductors.

7.4.2.4 In fixed installations, a single conductor serving both as a protective conductor and as a neutral conductor is allowed only upstream the origin of installation.

7.4.2.5 The characteristics of the protective devices (see 7.4.2.6) and the circuit impedances shall fulfil the following requirement:

$$Z_S \times I_a \leq U_O$$

where

Z_S is the impedance in ohms (Ω) of the fault loop comprising

- the source,
- the line conductor up to the point of the fault, and
- the protective conductor between the point of the fault and the source;

I_a is the current in amperes (A) causing the automatic operation of the disconnecting device within the time specified in 7.4.1.8, or 7.4.1.9. When a residual current protective device (RCD) is used this current is the residual operating current providing disconnection in the time specified in 7.4.1.8, or 7.4.1.9;

U_O is the nominal a.c. or d.c. line to earth voltage in volts (V).

NOTE In TN systems the residual fault currents are significantly higher than $5 \times I_{\Delta n}$. Therefore, the disconnection times in accordance with Table 1 are fulfilled where residual current protective devices (RCDs) are installed. Circuit-breakers providing residual current protection (CBR) and MRCDs can be used, provided the time delay is adjusted to afford compliance with Table 1.

7.4.2.6 In TN systems, the following protective devices may be used for fault protection,

- over current protective devices (OCPDs);
- residual current devices (RCDs).

NOTE

1. The incorporation of the protective conductor in the same wiring system as the live conductors or in their immediate proximity is strongly recommended (see 4.5.5).
2. Where an RCD is used for fault protection the circuit should also be protected by an over current protective device.

A residual current protective device (RCD) shall not be used in TN-C systems.

Where an RCD is used in a TN-C-S system, a PEN conductor shall not be used on the load side. The connection of the protective conductor to the PEN conductor shall be made on the source side of the RCD.

7.4.2.7 In order that the devices will give thermal protection to the protective conductor & considering the tolerance requirement in IS 732, the condition of automatic disconnection is met if the fault loop impedance satisfies,

$$z_S(m) \leq \frac{2}{3} \times \frac{U_0}{I_a}$$

Where,

$Z_s(m)$ = the measured impedance of the fault current loop starting and ending at the point of fault (measured in Ω);
U_o = the line conductor to earthed neutral voltage (V); and
I_a = the current causing the automatic operation of the protective device within the stipulated disconnection time.

Where the measured value of the fault loop impedance exceeds 2 U_o / 3 I_a, a supplementary bonding may be necessary.

7.4.2.8 Recommended Maximum Earth Fault Loop Impedance Values for MCB's - Z_s(m) (see Table 18)

Note: Maximum earth fault loop impedance values for MCBs conforming to IS/IEC 60898-1 are given in Table 18. For other OCPDs, refer to manufacturer's data.

TABLE 18 MAXIMUM ALLOWED EARTH FAULT LOOP IMPEDANCE ZS FOR MCB'S

MCB I_n in Amps	6	10	16	20	25	32	40	50	63	80	100	125
Type of MCB	Maximum allowed fault loop impedance for different type of MCB's											
Type B	5.11	3.07	1.92	1.53	1.23	0.96	0.77	0.61	0.49	0.38	0.31	0.25
Type C	2.56	1.53	0.96	0.77	0.61	0.48	0.38	0.31	0.24	0.19	0.15	0.12
Type D	1.28	0.77	0.48	0.38	0.31	0.24	0.19	0.15	0.12	0.10	0.08	0.06

If this condition cannot be fulfilled, supplementary bonding in accordance with 7.4.5 may be necessary.

7.4.3 TT Systems

7.4.3.1 All exposed conductive parts collectively protected by the same protective device shall be interconnected by protective conductors with an earth electrode common to all those parts. Where several protective devices are used in series, this requirement applies separately to all the exposed conductive parts protected by each device.

The neutral point or the mid-point of the power supply system shall be earthed. If a neutral point or mid-point is not available or not accessible, a line conductor shall be earthed.

Generally in TT systems, RCDs should be used for fault protection. Alternatively, over current protective devices may be used for fault protection provided a suitably low value of Z_s is permanently and reliably assured.

7.4.3.2 For compliance the following shall be fulfilled:

7.4.3.2.1Where a residual current protective device (RCD) is used for fault protection, the following conditions shall be fulfilled

- the disconnection time as required by 7.4.1.8 or 7.4.1.10, and
- $R_A \times I_{\Delta n} \leq 50$ V

Where,
R_A is the sum of the resistance in ohms (Ω) of the earth electrode and the protective conductor for the exposed conductive-parts,
$I_{\Delta n}$ is the rated residual operating current of the RCD.

NOTES

1. Fault protection is provided in this case also if the fault impedance is not negligible.
2. Where discrimination between RCDs is necessary, see IS 732:5.3.6.3.
3. Where R_A is not known, it may be replaced by Z_S.
4. The disconnection times in accordance with Table 1 relate to prospective residual fault currents significantly higher than the rated residual operating current of the RCD (typically 5 $I_{\Delta n}$).

7.4.3.2.2 Where an over current protective device is used the following condition shall be fulfilled:

$$Z_s \times I_a \leq U_o$$

where

Z_s is the impedance in ohms (Ω) of the fault loop comprising,

- the source,

- the line conductor up to the point of the fault,
- the protective conductor of the exposed-conductive-parts,
- the earthing conductor,
- the earth electrode of the installation and
- the earth electrode of the source,

I_a is the current in A causing the automatic operation of the disconnecting device within the time specified in 7.4.1.8 or 7.4.1.10.
U_o is the nominal a.c. or d.c. line to earth voltage.

7.4.4 IT Systems

7.4.4.1 In IT systems live parts shall be insulated from earth or connected to earth through a sufficiently high impedance. This connection may be made either at the neutral point or midpoint of the system or at an artificial neutral point. The latter may be connected directly to earth if the resulting impedance to earth is sufficiently high at the system frequency. Where no neutral point or mid-point exists, a line conductor may be connected to earth through a high impedance.

The fault current is then low in the event of a single fault to an exposed-conductive-part or to earth and automatic disconnection in accordance with 7.4.1.8 is not imperative provided the condition in 7.4.4.2 is fulfilled. Provisions shall be taken, however, to avoid risk of harmful pathophysiological effects on a person in contact with simultaneously accessible exposed conductive parts in the event of two faults existing simultaneously.

NOTE 1 To reduce overvoltage or to damp voltage oscillation, it may be necessary to provide earthing through impedances or artificial neutral points, and the characteristics of these should be appropriate to the requirements of the installation.

The impedance of the power system earth shall be such that on the occurrence of a single fault to exposed conductive parts or to earth, the fault current is of low value. Disconnection of the supply is not essential on the occurrence of the first fault. Protective measures must, however, prevent danger on the occurrence of two simultaneous faults involving different live conductors.

7.4.4.2 Exposed-conductive-parts shall be earthed individually, in groups, or collectively.

The following condition shall be fulfilled:

In a.c. systems the following condition shall be fulfilled to limit the touch voltage to:

$$R_A \times I_d \leq 50 \text{ V}$$

where

R_A is the sum of the resistance in ohms (Ω) of the earth electrode and protective conductor for the exposed-conductive-parts;
I_d is the fault current in A of the first fault of negligible impedance between a line conductor and an exposed-conductive-part. The value of I_d takes account of leakage currents and the total earthing impedance of the electrical installation.

7.4.4.3 In IT systems the following monitoring devices and protective devices may be used:

– insulation monitoring devices (IMDs);
– residual current monitoring devices (RCMs)
– insulation fault location systems (IFLS);
– over current protective devices;
– residual current protective devices (RCDs).

NOTE

1. Where a residual current protective device (RCD) is used, tripping of the RCD in the event of a first fault cannot be excluded due to capacitive leakage currents.
2. In case of faults in two different items of class I current-using equipment supplied by different line conductors, the operation of a residual current protective device (RCD) is only likely to be achieved if every single item of current using equipment is protected by an individual residual protective device (RCD). The use of over current protective devices to provide fault protection is also suitable.

7.4.4.4 Where an IT system is designed not to disconnect in the event of first fault, the occurrence of the first fault shall be indicated by either:

− an insulation monitoring device (IMD), which may be combined with an insulation fault location system (IFLS), or
− a residual current monitor (RCM), provided the residual current is sufficiently high to be detected.

NOTE: RCMs are not able to detect symmetrical insulation faults.

This device shall initiate an audible and/or visual signal which shall continue as long as the fault persists. The signal can be initiated via a relay contact output, an electronic switching output or a communication protocol.

A visual and/or an audible alarm system shall be arranged at a suitable place, so that it is perceived by responsible persons.

If there are both audible and visible signals, it is permissible for the audible signal to be cancelled.

It is recommended that a first fault be eliminated with the shortest practicable delay.

In addition, an insulation fault location system (IFLS) according to IEC 61557-9 may be provided to indicate the location of a first fault from a live part to exposed-conductive-parts or earth or another reference point.

7.4.4.5 After the occurrence of a first fault, conditions for automatic disconnection of supply in the event of a second fault occurring on a different live conductor shall be as follows:

a) Where exposed-conductive-parts are interconnected by a protective conductor collectively earthed to the same earthing system, the conditions similar to a TN system apply and the following conditions shall be fulfilled where the neutral conductor is not distributed in a.c. systems and in d.c. systems where the mid-point conductor is not distributed:

$$2I_aZ_S \leq U$$

or where the neutral conductor or mid-point conductor respectively is distributed:

$$2I_aZ'_S \leq U_O$$

where

U_O is the nominal a.c. or d.c. voltage, in V, between line conductor and neutral conductor or mid-point conductor, as appropriate,
U is the nominal a.c. or d.c. voltage in V between line conductors,

Z_s is the impedance in ohms (Ω) of the fault loop comprising the line conductor and the protective conductor of the circuit,

Z'_s is the impedance in ohms (Ω) of the fault loop comprising the neutral conductor and the protective conductor of the circuit,
I_a is the current in A causing operation of the protective device within the time required in 7.4.1.8 for TN systems or 7.4.1.9.

NOTE

1. The time stated in Table 1 of 7.4.1.8 for the TN system is applicable to IT systems with a distributed or non-distributed neutral conductor or mid-point conductor.
2. The factor 2 in both formulas takes into account that in the event of the simultaneous occurrence of two faults, the faults may exist in different circuits.
3. For fault loop impedance, the most severe case should be taken into account, e.g. a fault on the line conductor at the source and simultaneously another fault on the neutral conductor of a current-using equipment of the circuit considered.

b) Where the exposed-conductive-parts are earthed in groups or individually, the following condition applies:

$$R_A \times I_a \leq 50 \text{ V}$$

where

R_A is the sum of the resistances of the earth electrode and the protective conductor to the exposed-conductive-parts,
I_a is the current causing automatic disconnection of the disconnection device in a time complying to that for TT systems in Table 1 of 7.4.1.8 or in a time complying to 7.4.1.10.

NOTE

If compliance to the requirements of b) is provided by a residual current protective device (RCD) compliance with the disconnection times required for TT systems in Table 1 may require residual currents significantly higher than the rated residual operating current $I_{\Delta n}$ of the RCD applied (typically 5 $I_{\Delta n}$)

7.4.5 Supplementary Equipotential Bonding

If the conditions specified in 7.4.2 to 7.4.4 cannot be fulfilled for automatic disconnection of supply, it is necessary to provide supplementary equipotential bonding. This applies to entire installation or a part thereof, an item of apparatus or a location. The protective conductors for supplementary bonding shall also confirm to 7.3.4.2.

NOTE

1. Supplementary protective equipotential bonding is considered as an addition to fault protection.
2. The use of supplementary protective bonding does not exclude the need to disconnect the supply for other reasons, for example protection against fire, thermal stresses in equipment, etc.
3. Additional requirements may be necessary for special locations, (e.g. Group 1 and group 2 Medical locations), or for other reasons.

7.4.5.1 Supplementary protective equipotential bonding shall include all simultaneously accessible exposed-conductive-parts of fixed equipment and extraneous-conductive-parts including where practicable the main metallic reinforcement of constructional reinforced concrete. The equipotential bonding system shall be connected to the protective conductors of all equipment including those of socket-outlets.

7.4.5.2 The resistance *R* between simultaneously accessible exposed-conductive-parts and extraneous-conductive-parts shall fulfil the following condition:

$$R \leq \frac{50V}{I_a} \text{ in ac system}$$

$$R \leq \frac{120V}{I_a} \text{ in dc system}$$

where
I_a is the operating current in A of the protective device

– for residual current protective devices (RCDs), $I_{\Delta n}$
– for over current protective devices, the 5 s operating current.

7.4.6 Installation and Location of Increased Shock Risk

For installation and location of increased shock risk, additional measures may be considered if necessary, these include:

a) RCD with rated residual current of 30 mA, and
b) Protective extra-low voltage (PELV) and separated extra-low voltage (SELV) equipment.

7.4.7 Basic Purpose of Earth Fault Protection

The occurrence of an earth fault in an installation creates two possible hazards. Firstly, voltage appear between exposed conductive parts and extraneous conductive parts, and if these parts are simultaneously accessible, this voltage constitute a shock hazard, this condition being known as indirect contact.

Secondly, the fault current that flows in the phase and protective conductors of the circuit feeding the faulty equipment (the earth fault may, of course, occur in the fixed wiring of the circuit itself) may be of such a magnitude as to cause an excessive temperature rise in those conductors, thereby creating a fire hazard.

The protective measure known as 'protective equipotential bonding and automatic disconnection of the supply' is intended to give a high degree of protection against both hazards. The choice of protective device used to give disconnection is influenced by the type of system of which the installation is part, because either:

a. the earth fault loop impedance has to be low enough to allow adequate earth fault current flow to cause an over current protective device (for example, a fuse or circuit breaker) in the faulty circuit to operate in a sufficiently short time; or
b. where it is not possible to achieve a low enough earth fault loop impedance, disconnection may be initiated by fitting a residual current device (RCD). The rated residual current $I_{\Delta n}$ shall fulfil 7.4.3. Alternatively rated residual current $I_{\Delta n}$ and the corresponding Fault loop impedance shall be as per Table 19.

Note: RCD's should be required as an additional protection (See 7.5.5).

7.4.8 Earthing of Installations

Most installations are part of either a TN system or a TT system and in both type of installation the exposed conductive parts of all electrical equipment of an installation should be connected by means of protective earth conductor to the main earthing terminal (MET).

Class II equipment, whether metal enclosed or insulation enclosed, embodied in its construction not only basic insulation but also supplementary or reinforced insulation, exposed metal work of such equipment should not be considered to become live under fault condition and are not considered to be an exposed-conductive part.

Various earthing systems are considered in 6.2

7.4.8.1 Fault Protection (Protection Against Indirect Contact / Electric Shock)

Protection against indirect contact is achieved by the adoption of one of the following protective measures:

a. Safety extra low voltage;
b. The use of Class II equipment or by equivalent insulation;
c. A non-conducting location;
d. Earth free local equipotential bonding;
e. Electrical separation; and
f. Earthed equipotential bonding and automatic disconnection of the supply.

NOTES

1. The primary concern of this Code is (d) and (f) while other methods of protection against indirect contact are covered in IS732.
2. Item (a) requires that the nominal voltage of the circuit concerned does not exceed extra low voltage that the source has a high degree of isolation from higher voltage circuits (for example, a Class II safety isolation transformer) and that live parts also have a similar degree

of isolation or separation from those circuits. The most important requirement, however, is that live parts and exposed conductive parts of a safety extra low voltage circuit should not be connected to earth, protective conductors or exposed conductive parts of another circuit. Where these general requirements are not met but the nominal voltage still does not exceed extra low voltage, the circuit is described as a functional extra low voltage circuit and one part of it may be connected to earth.

3. Item (b) is generally applicable and covers the selection and use of equipment complying with either insulation encased Class II equipment ('all-insulated') or metal cased Class II equipment. In some cases, such as factory built assemblies of switchgear and control gear, the equivalent term used is 'total insulation'. Item (b) can also be achieved by the application of suitable supplementary or reinforced insulation to equipment on site. Earthing of the equipment is not required. In fact, by definition there will be no facility for earthing provided in Class II equipment.
4. Items (c), (d) and (e) are of limited interest as they can be applied only in special situations and used under effective supervision. They all include a high degree of isolation from earth.
5. In this Clause, detailed consideration is limited to protective equipotential bonding and automatic disconnection of the supply.

7.4.8.2 Protective Equipotential Bonding and Automatic Disconnection of the Supply

The two aims of this protective measure are to:

a) ensure that when an earth fault occurs, the voltages appearing between exposed conductive parts and extraneous conductive parts in the location served by the installation concerned are minimized; and
b) ensure rapid disconnection of the circuit in which that earth fault occurs.

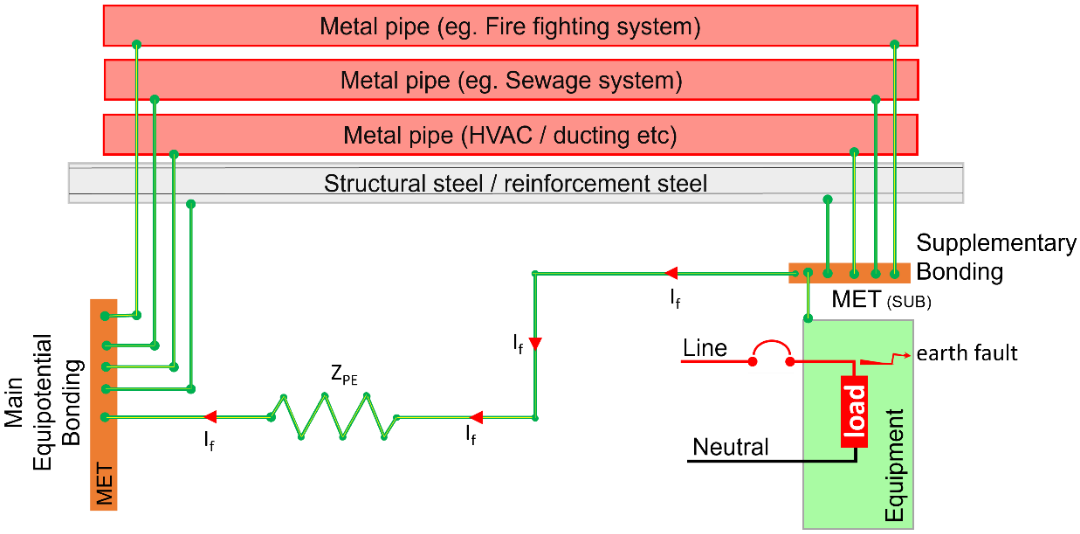
In order to meet (a), a zone is created by first connecting all extraneous conductive parts by means of protective bonding conductors to the main earthing terminal of the installation.

The zone is completed by the connection of all exposed conductive parts of the circuits in the installation and of current-using equipment fed from those circuits to the main earthing terminal using protective earth conductors.

Whilst such a zone is called an equipotential zone, the fault voltages will still exist between the exposed conductive parts of perfectly sound equipment and between such parts and extraneous conductive parts, but the application of bonding minimizes these voltages in each case.

An installation may consist of a number of zones; for instance, when an installation supplies a number of buildings, equipotential bonding is necessary in each building so that each constitutes a zone having a reference point to which the exposed conductive parts of the circuits and current-using equipment in that building are connected.

The second aim of this protective measure is met by limiting the upper value of the earth fault loop impedance of each circuit to a value determined by the type and current rating of the protective device concerned such that, on the occurrence of an earth fault (assumed to be of negligible impedance), disconnection will occur before the prospective touch voltage reaches a harmful value.



I_f: Fault current
Z_{PE}: Impedance of the protective earth conductor

FIGURE 31 MAIN AND SUPPLEMENTARY EQUIPOTENTIAL BONDING

7.4.8.3 Protective equipotential bonding

Note: Central Electricity Authority (Measures relating to Safety and Electric Supply) Regulations, 2023, Regulation No 43 (v) every building shall have protective equipotential bonding by interconnecting the exposed and extraneous conductive parts as per the relevant standards. IS 3043, IS732 and NEC 2023 are the relevant standards;

The protective measure of automatic disconnection in the event of a fault to earth requires:

a) Automatic disconnection in the event of a fault to earth,
b) Protective earthing to facilitate above, and
c) Protective equipotential bonding to reduce touch voltage.

Bonding, by means of main equipotential bonding conductors, of extraneous-conductive parts to the main earthing terminal of the installations is a mandatory safety requirement in CEA safety regulations 2023 (see 7.2.1 and Fig. 29A).

Where such conductive parts originate outside the building, they shall be bonded as close as practicable to their point of entry within the building.

Supplementary equipotential bonding shall ensure that the fault voltage downstream the main equipotential bonding is kept below the tolerable fault voltage.

Note: Example of tolerable voltages are 50 V in general locations and lesser voltage in special locations (e.g 25 V in medical locations).

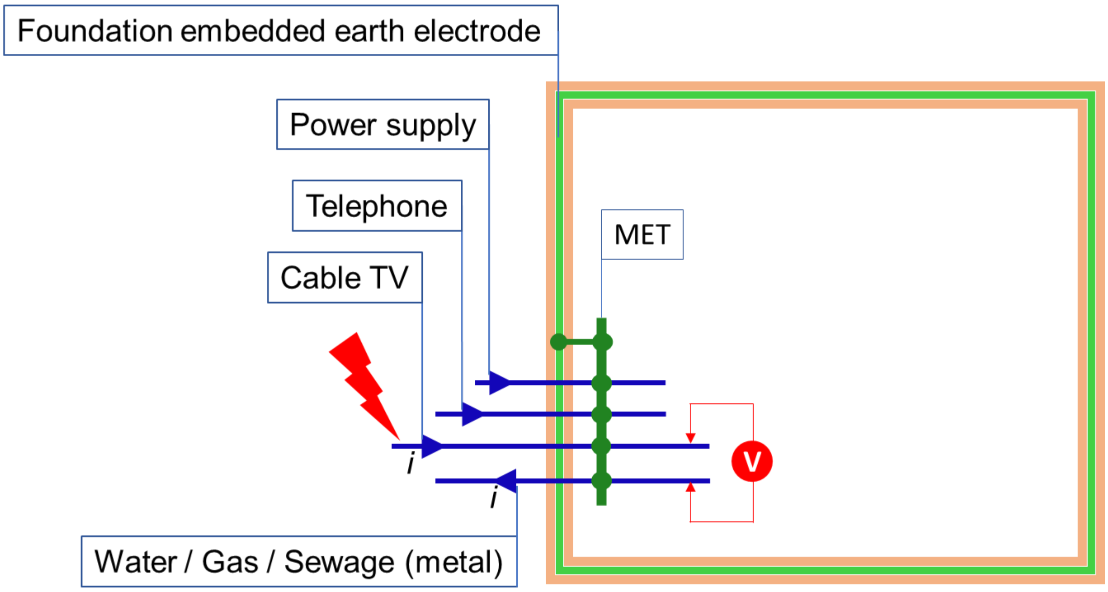


FIGURE 32 BONDING OF INCOMING METALLIC SERVICES INCLUDING ARMOURING OF CABLES ENTERING THE BUILDING

7.4.8.4 Extraneous Conductive Parts:

The extraneous conductive parts that are required to be bonded to the MET of the installation include:

a) gas pipes,
b) other service pipes and ducting,
c) risers and pipes of fire protection equipment,
d) structural extraneous conductive parts, if accessible in normal condition,
e) metallic reinforcements of constructional reinforced concrete, if reasonably practicable. and
f) conductors of lightning protection system.

NOTE — Connections pipes, ducting and exposed metallic parts of building structure should be considered most carefully. In some types of earthing systems, especially TN-C or TN-C-S systems effectively connect extraneous conducting metalwork to the supply system neutral and could cause continuously circulating currents and standing voltages that might result in electrochemical corrosion or random spark hazards in potentially flammable atmospheres.

7.4.8.5 Exposed Conductive Parts

Exposed conductive parts that are required to be connected by means of protective earthing conductors to the MET of the installation are as follows:

a) All metalwork associated with wiring system (other than current-carrying parts) including cable sheaths and armour, conduit, ducting, trunking, boxes and catenary wires.
b) The exposed metalwork of all Class I fixed and portable current-using equipment.
c) The exposed metalwork of transformers used in the installation other than those that are an integral part of equipment. The secondary windings of transformers should be earthed depending upon the system earthing.

Simultaneously accessible exposed conductive parts shall be connected to the same earthing system individually, in groups or collectively.

All fixed wiring accessories and circuits concerned such as wires in conduits, sockets etc should incorporate a protective earthing conductor that is connected to the MET of the installation. At the time of the erection of the installation the connected equipment may be of Class II construction or its equivalent, but there is a possibility that in the life of the installation the equipment may be replaced by Class I equipment.

Exposed conductive parts that (because of their small dimensions or disposition) cannot be gripped or contacted by a major surface of the human body (that is, a human body surface not exceeding 50 mm × 50 mm) need not be earthed if the connection of those parts to a protective conductor cannot readily be made and reliably maintained. Typical examples of such parts are screws and nameplate, cable clips and lamp caps. Fixing screws for non-metallic accessories need not be earthed provided there is no appreciable risk of the screws coming into contact with live parts.

Other exposed conductive parts not required to be earthed are:

a) Overhead line insulator brackets and metal parts connected to them if such parts are not within arm's reach; and
b) Short lengths of metal conduit or other metal enclosures used to give mechanical protection for equipment of Class II or equivalent construction.

7.5 SELECTION OF DEVICES FOR AUTOMATIC DISCONNECTION OF SUPPLY

7.5.1 Protective Measure: Automatic Disconnection of Supply

Automatic disconnection of supply 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 requirement for automatic disconnection of supply is given in clauses 7.4.

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

7.5.2 Device for Automatic Disconnection

In general, every circuit is provided with a means of over current protection. Where earth fault loop impedance is low enough to cause these devices to operate within the specified times (that is, sufficient current can flow during an earth fault), such devices may be relied upon for automatic disconnection of supply. If the earth fault loop impedance does not permit the over current protective devices to give automatic disconnection of the supply under earth fault conditions, the first option is to reduce that impedance. It may be permissible for this to be achieved by the use of protective multiple earthing or by additional earth electrodes such as a horizontal earth continuity conductor. There are practical limitations to both approaches.

An alternate approach is to use residual current devices with appropriate settings (see Table 19) to clear the faults within the permissible time. This method is equally applicable where earth loop impedances cannot be improved.

7.5.3 Use of Over current Protective Devices for fault protection by automatic disconnection of supply

7.5.3.1 Where over current protective devices are used to facilitate automatic disconnection of supply in case of earth fault, conditions mentioned in clause 7.4 shall be fulfilled. Details of the maximum permissible earth loop impedance for the thermal protection of cables by over current protective devices can also be computed (see 7.4 / Table 18).

7.5.3.2 The incorporation of the protective conductor in the same wiring system as the live conductors or in their immediate proximity is strongly recommended (see 4.5.5).

7.5.3.3 Where multiple sources (such as Transformer and DG) are used, automatic disconnection of earth fault by over current protective devices shall be ensured for all sources.

7.5.4 Use of Residual Current Devices for fault protection by automatic disconnection of Supply.

In installations where the earth fault loop impedance is not sufficiently low to facilitate automatic disconnection in case of a fault by use of an over current protective device, residual current devices shall be used. Table 19 provides maximum value of rated residual operating current of RCD's as a function of earth loop impedance.

TABLE 19 MAXIMUM VALUE OF RATED RESIDUAL OPERATING CURRENT OF RCD AS A FUNCTION OF EARTH LOOP IMPEDANCE

Rated residual operating current of RCD	Measured Maximum Earth Loop Impedance
10 A	5 Ω
5 A	10 Ω
3 A	20 Ω
1 A	50 Ω
500 mA	100 Ω
300 mA	100 Ω
100 mA	200 Ω
30 mA	200 Ω

7.5.5 Additional Protection by RCD:

In a.c., TN or TT system, additional protection by means of an RCD with $I_{\Delta n} \leq 30$ mA shall be provided for:

a) Socket-outlets with a rated current not exceeding 32 A that are liable to be used by ordinary persons and are intended for general use; and
b) Mobile equipment for use outdoors with a rated current not exceeding 32 A.
c) Luminaires in domestic and similar premises.
d) Equipment and installation which are frequently used / touched by people (e.g. street furniture, Metal distribution boards in streets and public places).

Note: The CEA regulations 2023 (regulation 44, para 2) require a Residual Current Device having a rated residual operating current not exceeding 30 mA for every domestic installation. This requirement can be met by providing an RCD with $I_{\Delta n} \leq 30$ mA as an additional protection in final circuits.

7.5.6 Protection against fire due to insulation faults.

Electrical installations in locations with the external influence BE2 (see IS 732), supplied by TN and TT systems, final circuits and current-using equipment shall be protected against earth faults by the use of RCDs with a rated residual operating current $I_{\Delta n} \leq 300$ mA. Where resistive faults may cause a fire, e.g. for overhead heating with heating film elements, the rated residual operating current shall be $I_{\Delta n} \leq 30$ mA.

7.5.7 Selection of Residual Current Devices in relation to the nature of residual current.

IEC 60755 recognises four types of RCDs, intended to be used on AC supply systems. They are Type AC, Type A, Type F and Type B.

Note: RCD's include RCCB's, RCBO's, CBR's & MRCD.

RCDs shall be selected on the basis of connected electrical equipment and their characteristics:

– Residual Current Devices of Type AC shall only be used to serve fixed equipment, where it is known that the load current contains no d.c component.

Note: Type AC RCD shall not be used for applications where LED lights and SMPS power suppliers (e.g. Computers, modern electronics etc) are used.

– Residual Current Devices of Type A shall be used where load may produce residual current with DC components.

NOTE: An example application for RCDs of type A is socket-outlet circuit for the use of portable electronic equipment. Type A RCD is a minimum requirement if used in locations where LED lights and SMPS power supplies are used.

– Residual Current Devices of Type F shall be used where loads may produce residual current containing DC components and chopping frequency currents

Note: An example is a single phase class 1 equipment containing a motor controlled by a variable speed drive air conditioner.

– Residual Current Devices of Type B shall be used where loads contain multi-phase frequency converters or where loads may produce smooth DC residual current.

NOTE: An example of loads containing multi-phase frequency converters is a three-phase, class 1 equipment containing a motor controlled by a variable speed drive. Examples of loads which may produce smooth DC residual current are solar PV and electric vehicle supply equipment. Type B RCD shall also be used in the AC side of grid connected solar PV system, where there is no simple separation.

7.5.8 Selection of Residual Current Devices in relation to time delay

RCDs with a time delay shall not be used for additional protection.

RCDs intended to be operated by ordinary persons which have a time-delay are known as type S. The tripping of such devices is delayed, and they are able to withstand a residual current during a specified time, without tripping. Type S residual current device can withstand 2 times $I_{\Delta n}$ for 60 ms without tripping.

RCD of $I_{\Delta n}$ ≤30 mA shall be used for shock protection.

RCDs with an adjustable time delay are only to be installed where accessible to instructed persons (BA4) or skilled persons (BA5).

RCD of $I_{\Delta n}$ ≤300 mA shall be used for protection against fire in building due to leakage current.

NOTE: See IS 732 for the classification of external influences, such as BA4 and BA5.

7.6 EARTHING REQUIREMENTS FOR INSTALLATIONS HAVING HIGHER PROTECTIVE CONDCUTOR CURRENT

7.6.1 General

7.6.1.1 This clause covers the special requirements for the connection of equipment to the electrical power installation of buildings, where the protective earthing conductor current exceeds the limit specified in IS 732 / IS9409 (for a.c and d.c). These requirements are intended to ensure the safety of personal in the presence of such leakage current.

High Frequency interference suppression filters fitted to power electronics and data processing equipment may produce high earth leakage current. In such cases, failure of continuity in the protective earth connection may cause a dangerous touch voltage.

The requirements of this clause apply where equipment having high leakage current is connected to any type of power system. Additional requirements are given for TT and IT systems in 7.6.6 and 7.6.7.

NOTES

1. On TN-C Systems, where the neutral and protective conductors are contained in a single conductor (PEN conductor) up to the equipment terminals, leakage current may be treated as load current.
2. Equipment normally having high earth leakage current may not be compatible with installations incorporating residual current protective devices, as well as the standing residual current due to leakage current. The possibility of nuisance tripping due to capacitor charging currents at switch-on shall be considered.

7.6.1.2 Equipment considered.

The equipment shall be:

a) Stationary, and
b) Either permanently connected to the building wiring installation or connected via industrial plugs and sockets.

Note: Industrial plugs and sockets are examples of suitable plugs and sockets. Plugs and sockets for general use are not suitable.

7.6.1.3 It is particularly important for equipment with high leakage current that earth continuity should be checked at the time it is installed and after any modification to the installation. It is also recommended that earth continuity be checked thereafter at regular intervals.

7.6.1.4 Additionally, where leakage current measured in accordance with IS 13252 exceeds 10 mA (for a.c system), equipment shall be connected in accordance with one of the requirements detailed in 7.6.2 to 7.6.4.

Note: Leakage current measurements prescribed by IS 13252 include likely undetected fault conditions within the equipment.

7.6.2 High integrity earth connections

NOTE: The aim of the requirements detailed below is to provide high integrity earth connections by using robust or duplicate conductors in association with permanent connections or robust connectors.

Protective earthing conductors shall comply with the following:

a. 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 mm^2 Cu or 16 mm^2 Al, through its total run;
b. 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 mm^2 Cu or 16 mm^2 Al.
c. Each protective earthing conductor specified in (a) and (b) shall meet the requirements of 7.3.2.

7.6.3 Earth integrity monitoring

A protective device shall be provided which will disconnect the equipment, in the event of a discontinuity occurring in the earth conductor, within the voltage/time limits prescribed by relevant standards.

Note: The aim of the requirements detailed above is to monitor the continuity of the protective earth connection and provided means of automatic supply disconnection in case of failure.

7.6.4 Use of electrical separation

Equipment shall be connected to the supply via a double wound transformer of other units in which the input and output circuits are electrically separated(see 7.6.9).

The secondary circuit should preferably be connected as a TN-S System but an IT System may be used where required for the specific application.

Note: The aim of the requirements above is to localize the path of the leakage current, and minimize the possibility of a break in continuity in this path.

7.6.5 Additional requirements for RCD's:

The leakage in normal operation of all equipment protected by one and the same protective device is less than 30 % of the rated disconnection current of the RCD or half of the minimum required current to operate the RCD.

If the above requirements cannot be met, the requirements of 7.6.4 (electrical separation) shall apply.

7.6.6 Additional requirements for TT System

The requirements below ensure that the leakage in normal operation of all equipment protected by one and the same protective device is less than half of that required to operate earth fault protective devices for the installation circuit.

a) The total leakage current I_1 (in amperes), the resistance of the earth electrode R_A (in ohms) and the nominal operating residual current of the protective device $I_{\Delta n}$ (in amperes) shall be related as follows:

$$I_1 \frac{I\Delta n}{2} \leq \frac{U_L}{2R_A}$$

b) If the requirements of (a) cannot be met, the requirements of 7.6.4 shall apply.

7.6.7 Additional Requirements for IT-Systems

7.6.7.1 It is preferred that equipment with high leakage current is not connected directly to IT systems because of the difficulty of satisfying touch voltage requirements on a first fault.

Where possible, the equipment is supplied by a TN-S system derived from the mains supply by means of electrical separation.

Where it is possible, the equipment may be connected directly to the IT system. This may be facilitated by connecting all protective earth connections for equipment using the IT system directly to the local earth electrode.

7.6.7.2 Before making direct connection to an IT system, installers shall ensure that equipment is suitable for connection to IT systems according to the declaration of the manufacturer.

7.6.8 Safety Requirement for Low Noise Earthing Connections

Note: It may be found that the large leakage currents on the protective earthing system of building installations cause an unacceptable incidence of malfunction on data processing equipment connected to it.

7.6.8.1 Whatever measures are taken to provide a low noise earthing connection, it is required that exposed conductive parts of data processing shall be connected to the MET. The use of separate earth electrodes for simultaneously accessible exposed conductive parts is not permitted.

This requirement shall also apply to metallic enclosures of Class II and Class III equipment, and to FELV circuits when these are earthed for functional reasons.

Conductors, which serve functional purposes only, need not comply with 7.3. (See ISO/IEC 30129)

7.6.8.2 Other Special Methods

In extreme cases, if the safety requirements of 7.6.8.1 are fulfilled, but electrical noise on the MET of the installation cannot be reduced to an acceptable level, the installation has to be treated as a special case.

The earthing arrangement has to provide the same level of protection as is generally provided by these requirements and particular attention should be given to ensure that the arrangement:

a) provides adequate protection against over current;
b) prevents excessive touch voltages on the equipment and ensures equipotential between the equipment and adjacent metal work or other electrical equipment, under normal and fault conditions; and
c) meets the requirements relating to excessive earth leakage current, if appropriate, and does not invalidate them.

7.6.9 Example of the use of transformers for electrical separation.

7.6.9.1 Transformer Incorporated in or Attached to Unit.

The transformer shall be connected in accordance with Fig. 31 in order to confine the earth leakage current in conductors within the unit.

NOTE — No further special installation measures are necessary.

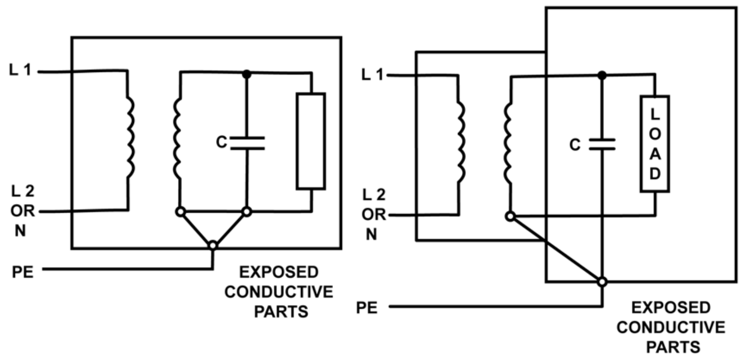


FIGURE 33 METHODS OF CONNECTING DOUBLE-WOUND TRANSFORMERS SITUATED WITHIN OR ATTACHED TO SINGLE UNITS

- Single phase system depicted for ease. System may be 3-phase.

- Protection and control arrangements are not shown.
- C is the filter capacitance.
- L1 and L2 or N are connections to the incoming supply and PE is the connection from accessible parts of the equipment to the MET of installation for both protective conductors of Class I equipment and functional earthing conductors for Class II/Class III equipment.

7.6.9.2 Method of Connecting Transformers Physically Separate from Units

The neutral point for the secondary circuit shall be connected to earth at the transformer and the earth connections between the equipment and the transformer shall comply with the requirements of **7.6.2** or **7.6.3**.

Connections shall be as shown in Fig. 32.

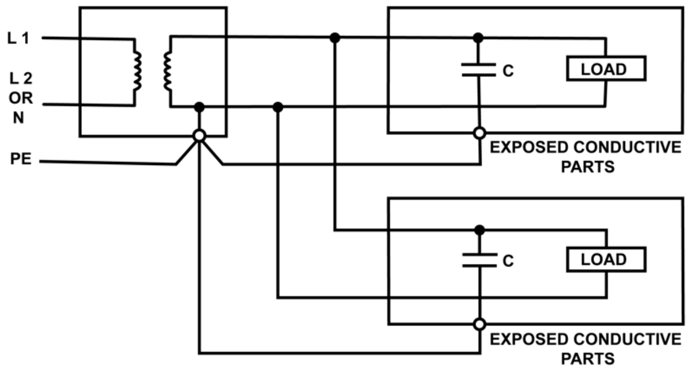


FIGURE 34 METHOD OF CONNECTING PHYSICALLY SEPARATED TRANSFORMERS

- Single-phase system depicted for ease. System may be 3-phase.
- Primary and secondary circuits must have means of control and protection. These are not shown.
- C is the filter capacitance.
- L1 and L2 or N are connections to the incoming supply and PE is the connection from accessible parts of the equipment to the MET of the installation for both protective conductors of Class I equipment and functional earthing conductors of Class II/Class III equipment.

7.7 INFORMATION TECHNOLOGY: TELECOMMUNICATIONS BONDING NETWORKS FOR BUILDINGS AND OTHER STRUCTURES

7.7.1 General

In addition to protective earthing which may be required in accordance with this Code, information technology (IT) and, more generally, telecommunications equipment and systems may require functional earths for any or all of the following purposes:

a) minimise the risk to the correct function of that equipment and interconnecting cabling from electrical hazards,

b) provide the telecommunications installation with a reliable signal reference – which may improve immunity from electromagnetic interference (EMI).

If equipment requires both a protective earth and a functional earth connection, it is preferred that the two earths should be separated within the equipment so that power system fault currents cannot flow in the functional earthing conductors. The manufacturer shall provide separate protective and functional earthing terminals in the equipment, suitably marked as defined in 3.69 (Symbols and Numbering). The functional earthing system and conductors can then be designed solely in accordance with the requirements of the telecommunication system. Alternatively, the protective and functional earth may be connected together within the equipment but in this case the functional earth system and conductors should be suitable for the current they may carry under power system fault conditions.

Note: For more information refer ISO/IEC 30129 / IEC 61000-5-2.

7.7.2 Earthing arrangements for functional purposes

7.7.2.1 General

Earthing arrangements for functional purposes shall be provided to ensure correct operation of equipment or to permit reliable and proper functioning of installations.

7.7.2.2 Functional-equipotential-bonding for ICT

A functional equipotential bonding system may comprise

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

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 MET only once.

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 MET 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.

7.7.3 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 mm^2 Cu or 16 mm^2 Al, if protection against mechanical damage is provided,
– 4 mm^2 Cu or 16 mm^2 Al, if protection against mechanical damage is not provided.

NOTE Larger cross-sectional areas should be required for EMC reasons. (See ISO/IEC 30129).

7.7.4 Identification

A functional earthing conductor shall be identified by:

– the alphanumeric notation FE, or
– by the colour cream at least applied at the terminations and points of connection, or
– by the symbol  (graphical symbol 5018).

Note: The recommended colour of functional conductors is cream. Internationally they are identified by the colour PINK.

A functional bonding conductor shall be identified by:

– the alphanumeric notation FB, or
– by the symbol  (graphical symbol 5020).

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.

7.7.5 Electrical continuity of functional bonding conductors

The requirements of 7.3.7. except for 7.3.7.7, 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.

Note: Certain application need a d.c. contact resistance of ≤ 0.1 mΩ. Bonding connectors, the fasteners and processes used to connect them shall be designed to provide and maintain low resistance joints (see ISO/IEC 30219).

7.7.6 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.

Note: Certain application need a d.c. contact resistance of ≤ 0.1 mΩ. Bonding connectors, the fasteners and processes used to connect them shall be designed to provide and maintain low resistance joints (see ISO/IEC 30129).

7.7.7 Equipotential bonding ring conductors

The main earthing terminal (MET and/or MFET) 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 7.3.4 when used also for protective bonding, or:

– be at least 50 mm^2 hot-dip galvanized steel strip, or
– be at least 16 mm^2 copper, or
– be a cross-sectional area in another material, which provides at least a conductivity equivalent to 16 mm^2 copper.

Note

1. See 4.5.4.5 of IS732 for more information.
2. See IEC 30129 for detailed information on Information technology – Telecommunications bonding networks for buildings and other structures.

7.8 EARTH FREE EQUIPOTENTIAL BONDING

Precautions shall be taken to ensure that persons entering the equipotential location cannot be exposed to a dangerous potential difference, in particular, where a conductive floor insulated from earth is connected to the earth-free equipotential bonding system.

8. RESISTANCE TO EARTH (GROUND) AND EARTH ELECTRODES

8.0 GENERAL

An earth electrode system is generally composed of several horizontal, vertical or inclined electrodes, buried or driven into the soil by force.

The use of chemicals to reduce soil resistivity is not recommended (see 8.1.7).

Horizontal earth electrodes are preferably buried at a depth of 0.5 m to 1 m below ground level. This gives sufficient mechanical protection.

In the case of vertical driven rods, the top of each rod will usually be situated below ground level. Vertical or inclined driven rods are particularly advantageous when the soil resistivity decreases with depth.

Metal frameworks, which forms a part of construction, may be used as an earthing conductor to earth parts which are directly fixed to this framework. Consequently, the whole framework shall have a sufficiently conductive cross-section and the joints shall be conductively and mechanically reliable. Precautions shall be taken to avoid part of the framework becoming disconnected from the earthing system when temporary dismantling takes place. Large frameworks shall be connected to the earthing system in a sufficient number of points.

8.1 RESISTANCE TO EARTH (GROUND)

8.1.1 Nature of Earthing Resistance

The earthing resistance of an electrode is made up of:

a. resistance of the (metal) electrode,
b. contact resistance between the electrode and the soil, and
c. resistivity of the soil from the electrode surface outward in the geometry set up for the flow of current outward from the electrode to infinite earth.

The first two factors are very small fractions of an ohm and can be neglected for all practical purposes. The factor of soil resistivity is discussed in 13.1.

8.1.2 Application of earth electrodes and its resistance to earth (Ground)

a. For low voltage electrical installation an earth electrode may be required, however no minimum value of earth electrode resistance is necessary.
b. For high voltage application earth electrodes as a combination of horizontal electrodes, vertical electrodes and electrodes embedded in concrete shall reduce touch and step potentials.
c. Where lightning protection of structures is required, two types of earth electrodes (Type A and Type B) are specified in IS/IEC 62305 – 3. For type A earth electrode if the minimum length of horizontal and/or vertical earth electrodes as mentioned in 5.4.2.2 of IS/IEC 62305 – 3 can be disregarded, if the earthing resistance of the earth termination system is less than 10 Ω.

Note on c): Earth termination system means all earth electrodes and down conductors interconnected.

8.1.3 Soil Resistivity

8.1.3.1 The resistance to earth of a given electrode depends upon the electrical resistivity of the soil in which it is installed. This factor is, therefore, important in deciding which of many protective systems to adopt. The type of soil largely determines its resistivity. Table 20 and Table 21 gives information on resistivity values for certain types of soil.

TABLE 20 RESISTIVITY OF SOIL (GROUND).

Nature of ground	Resistivity Ωm
Marshy ground	From some units to 30

Alluvium Humus Damp peat	20 to 100 10 to 150 5 to 100
Malleable clay Marl and compact clay Jurassic marl	50 100 to 200 30 to 40
Clayey sand Siliceous sand Bare stony soil Stony soil covered with lawn	50 to 500 200 to 3000 1 500 to 3 000 300 to500
Soft limestone Compact limestone Cracked limestone Schist Mica-schist	100 to 300 1 000 to 5 000 500 to 1 000 50 to 300 800
Granite and sandstone according to weathering Granite and very altered sandstone	1 500 to 10 000 100 to 600

TABLE 21 VARIATION OF RESISTIVITY FOR DIFFERENT TYPES OF SOIL.

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

8.1.4 Effect of Moisture Content on Earth Resistivity

Moisture content is one of the controlling factors in earth resistivity. Fig. 34 shows the variation of resistivity of red clay soil with percentage of moisture. The moisture content is expressed in percent by weight of the dry soil. Dry earth weighs about 1440 $kg/m^3$and thus 10 percent moisture content is equivalent to 144 kg of water per cubic metre of dry soil. It will be seen from Fig. 34 that above about 20 percent moisture, the resistivity is very little affected, while below 20 percent the resistivity increases very abruptly with the decrease in moisture content. A difference of a few percent moisture will therefore, make a very marked difference in the effectiveness of earth connection if the moisture content falls below 20 percent. The normal moisture content of soils ranges from 10 percent in dry seasons to 35 percent in wet seasons, and an approximate average may be perhaps 16 to 18 percent.

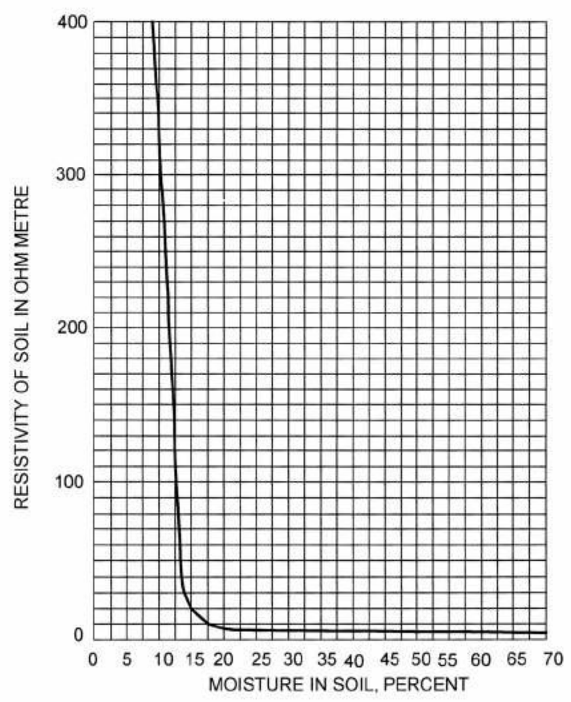


FIGURE 35 VARIATION OF SOIL RESISTIVITY WITH MOISTURE CONTENT

It should be recognized, however, that moisture alone is not the predominant factor in the low resistivity of soils; for example, earth electrodes driven directly in the beds of rivers or mountain streams may present very high resistance to earth. If the water is relatively pure, it will be high resistivity and unless the soil contains sufficient natural elements to form a conducting electrolyte, the abundance of water will not provide the soil with adequate conductivity. The value of high moisture content in soils is advantageous in increasing the solubility of existing natural elements in the soil, and in providing for the solubility of ingredients which may be artificially introduced to improve the soil conductivity.

8.1.5 Corrosion Allowance and Conditions of Corrosion

8.1.5.1 Corrosion Allowance

On an average, steel corrodes about six times as fast as copper when placed in soil. The extent of corrosion depends upon the properties of soil. The generally accepted correlation between the electrical resistivity of soil and its corrosivity is as indicated in Table 22.

TABLE 22 SOIL RESISTIVITY AND CORROSION

Sl No.	Range of Soil Resistivity (Ω.m)	Class of Soil
(1)	(2)	(3)
i)	Less than 25	Severely corrosive
ii)	25-50	Moderately corrosive
iii)	50-100	Mildly corrosive
iv)	Above 100	Very mildly corrosive

The following methods can be adopted to safeguard conductor against excessive corrosion:

a. Use material those are resistant to corrosion. E.g. copper, stainless steel, copper coated steel.
b. Concrete embedded foundation earth electrode.
c. Use of cathodic protection;
d. Use steel conductor including galvanised steel conductor with large cross-section having allowance for corrosion.

Based on the results of the field studies on rates of corrosion, the following allowances in cross- sectional area of the earthing conductor and earth electrode are recommended to take the effect of corrosion into account (see Table 23).

(Clause 13.4)

TABLE 23 ALLOWANCES IN CROSS-SECTIONAL AREA OF BARE OR GALVANISED STEEL EARTHING CONDUCTOR AND EARTH ELECTRODE TO TAKE THE EFFECT OF CORROSION INTO ACCOUNT.

Sl No.	Type of Laying of the Earth Conductor	Allowances to be Considered in Sizing
i)	Conductors laid in soils having resistivity greater than 100 ohm-meters	0 (No allowance)
ii)	Conductors laid in soils having resistivity from 25 to 100 ohm-meters	15 percent
iii)	Conductors laid in soils having resistivity lower than 25 ohm-meters or where treatment of soil around electrode is carried out	30 percent

For the purpose of determining the allowance to be made for corrosion, the minimum resistivity of the soil of the location of earth electrodes to be considered. The resistivity will be the minimum in wet weather.

Note: Minimum size of commonly used earth electrodes, embedded in soil or concrete used to prevent corrosion and provide mechanical strength are provided in Table 24.

8.1.5.2 Conditions of Corrosion: Electrochemical corrosion due to galvanic currents:

Steel in concrete has approximately the same galvanic potential in the electrochemical series as copper in soil. Therefore, when steel in concrete is connected to steel in soil, a driving galvanic voltage (of approximately 1 V) causes a corrosion current to flow and dissolve steel in soil.

Earth electrodes in soil should use copper, copper bonded steel or stainless steel where these are connected to steel in concrete.

Any electrode embedded in concrete must not be connected directly from foundation concrete into the soil except for electrodes made from stainless steel, copper or copper bonded steel. 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 bare/galvanized steel so as to provide a sufficient life-time for this part of the earthing arrangement.

Earthing conductors and earth electrodes embedded in soil, in locations where soil resistivity is severely or moderately corrosive shall use Copper, Stainless steel or Copper bonded steel.

The behaviour of a galvanized layer on steel in concrete is very complicated, particularly in concrete with chlorides, where zinc will corrode quickly on contact with the reinforcement and can under certain conditions cause damage to the concrete. Galvanized steel should therefore not be used in coastal areas and where there can be salt in the ground water. As the use of galvanized steel in concrete requires evaluation of many external factors, this material should be used only after careful analysis. With this in mind, the use of the other mentioned materials in Table 24 is preferred over the use of bare/galvanized steel.

8.1.6 Effect of Temperature on Earth Resistance

The temperature coefficient of resistivity for soil is negative but is negligible for temperatures above freezing point. At about 20°C, the resistivity change is about 9 percent per °C. Below 0°C the water in the soil begins to freeze and introduces a tremendous increase in the temperature coefficient, so that as the temperature becomes lower the resistivity rises enormously. It is, therefore, recommended that in areas where the temperature is expected to be quite low, the earth electrodes should be installed well below the frost line. Where winter seasons are severe, this may be about 2 m below the surface, whereas in mild climates the frost may penetrate only a few centimetres or perhaps the ground may not freeze at all. Earth electrodes which are not driven below the first depth may have a very great variation in resistance throughout the seasons of the year. Even when driven below the frost line, there is some variation, because the upper soil, when frozen, presents a decided increase in soil resistivity and has the effect of shortening the active length of electrode in contact with soil of normal resistivity.

8.1.7 Artificial Treatment of Soil

Multiple rods, even in large number, may sometime fail to produce an adequately low resistance to earth. This condition arises in installations involving soils of resistivity above 3000 Ωm. Treatment of soil by using earth enhancing compounds can be one solution. Soil treatment to improve earth electrode contact resistance may be applied in locations where the soil resistivity is higher than 3000 Ωm.

In soil with resistivity lesser than 200 Ωm compounds used for artificial treatment of soil are not effective, hence shall not be used. In soil with low resistivity increased corrosion of the earth electrode and other buried steel materials in and around the area also should be considered where these compounds are used.

Earth enhancing compound shall comply to IEC 62561-part 7

8.2 EARTH ELECTRODES

8.2. 1 The following are examples of earth electrodes which may be used:

- Concrete-embedded foundation earth electrode,
- 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,
- Embedded conductor bonded to metal reinforcement of concrete (except pre-stressed concrete).

8.2. 2 Minimum size of commonly used earth electrodes shall be as per Table 24.

(clause 8.2.2 also refer IS732, Table 13)

TABLE 24 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 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 with electro-deposited copper coating	Round rod installed vertically	14				250[e]
	Round wire installed horizontally	(8)	50			70
	Strip[b] 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			
	Round rod installed vertically	(12) 15				
	Stranded wire	1.7 for individual strands of wire	(25)[d] 50			
	Pipe[e]	20		2		
	Solid plate			(1.5) 2		
	Lattice plate			2		

Note

1. Values in bracket are applicable for protection against electric shock only, while values not in brackets are applicable for lightning protection and for protection against electric shock.
2. Metals inserted inside pipe (e.g. pipe in pipe) have no influence in reducing the final earth resistance value.
3. Unprotected ferrous materials are not recommended due to high corrosion. (see 8.1.5)
4. Stranded conductors are more vulnerable to corrosion than solid conductors. Stranded conductors are also vulnerable where they enter or exit concrete positions. This is the reason why stranded galvanized steel is not recommended in earth.
5. Galvanized steel can be corroded in clay soil or moist soil.
6. Galvanized steel in concrete should not extend into the soil due to possible corrosion of the steel just outside the concrete.
7. Galvanized steel in contact with reinforcement steel in concrete should not be used in coastal areas where there can be salt in the ground water (see 8.1.5.2).
8. Underground connections in soil which require removal of conductor coatings is not recommended without adequate post corrosion protection.

9.	Metals inserted inside pipe Will not influence in the final earth resistance value.
a.	Chromium ≥ 16 %, Nickel ≥ 5 %, Molybdenum ≥ 2 %, carbon ≤ 0.08 %
b.	As rolled strip or slit strip with round edges.
c.	The coating must be smooth, continuous and free from flux stains.
d.	Where experience shows that the risk of corrosion and mechanical damage is extremely low, 16 mm^2 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 (eg drilling holes or special protective tips) are taken according to the manufacturers instruction.

8.2.3 Resistance and Common Types of Earth electrodes

8.2.3.1 Erection of soil-embedded earth electrodes

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.

8.2.3.2 Earth electrodes buried in the soil

To enable a first approximation of the earth electrode resistance, a calculation may be made, using the average values resistivity for different types of soil indicated in Table 21.

It is obvious that calculations made from these values only give an approximate result of an earth electrode resistance. After having used the formula given in 8.2.3.3, 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.

Earth electrodes may consist of buried elements of

- steel, hot-dip galvanized,
- 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 earth electrodes in Table 24 considered 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.

8.2.3.3 Assessment of earth electrode resistance

8.2.3.3.1 Buried Plates

To maintain good contact of the two surfaces with the soil, full plates should preferably be arranged vertically. Plate electrodes shall be buried such that its top edge is at a depth not less than 1 m from the surface of the ground.

The approximate resistance to earth of a plate can be calculated from:

$$R = 0.8\frac{\rho}{L}$$

Where, ρ: resistivity of the soil (assumed uniform) (in Ω.m), and L: perimeter of the plate. (in m).

8.2.3.3.2 Vertically buried electrodes (Pipes or Rods)

The resistance (R) of a vertically buried earth electrode 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).

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.

8.2.3.3.3 Horizontally buried conductor (Strip or Conductor Electrodes)

The earth electrode resistance (R) realized with a horizontally buried conductor 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 horizontally buried conductor in soil (in m).

It should be noted that the laying of conductor with a sinuous path in the soil 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 in buried 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.

8.2.3.3.4 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 resistivity of the soil (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.

At power stations and large substations, it is often possible to secure an effective earth-electrode by making use of the reinforcement in concrete piles. The earth strap should be bonded to a minimum of four piles and all the piles between the bonds should be bonded together. Each set of four piles should be connected to the main earthing-strap of the substation.

8.2.3.4 Concrete embedded earth electrodes

8.2.3.4.1 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, 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.

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

If the building foundation is to be completely protected with insulating measures against water e.g. using plastic sheets of more than 0.5 mm thickness (or against loss of energy by thermal insulation), 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.

8.2.3.4.3 Construction of concrete-embedded foundation earth electrodes

8.2.3.4.3.1 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.

8.2.3.4.3.2 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 bonding should be fixed to it at intervals of not more than 2 m. The connections should be made in accordance with 7.3.3.5. The use of keyed joints should be avoided.

8.2.3.4.3.3 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 MET) 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. For such connections, it is recommended that they should enter the concrete within the building, or outside at a suitable level above ground level.

8.2.3.4.3.4 For the minimum cross-sectional area of electrodes including terminal lugs, the values mentioned in Table 24 apply. Connections must be soundly made and electrically satisfactory (see 7.3.3.5).

8.2.3.4.3.5 Metal reinforcement of the foundations of the building may be used as an electrode provided it is soundly connected according to 7.3.3.5. 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. Prestressed 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 24. 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.

8.2.3.4.3.6 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.

8.2.3.4.3.7 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 8.2.3.4.4.

8.2.3.4.4 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.

8.2.3.4.5 Completion of concrete-embedded foundation earth electrodes

8.2.3.4.5.1 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 IS732-6).

8.2.3.4.5.2 Concrete used for the foundation should be made from at least 240 kg cement per m^3 concrete. The concrete must have a suitable semi-liquid consistency to fill all holes below the electrodes.

8.2.4 Selection of materials for earth-electrodes

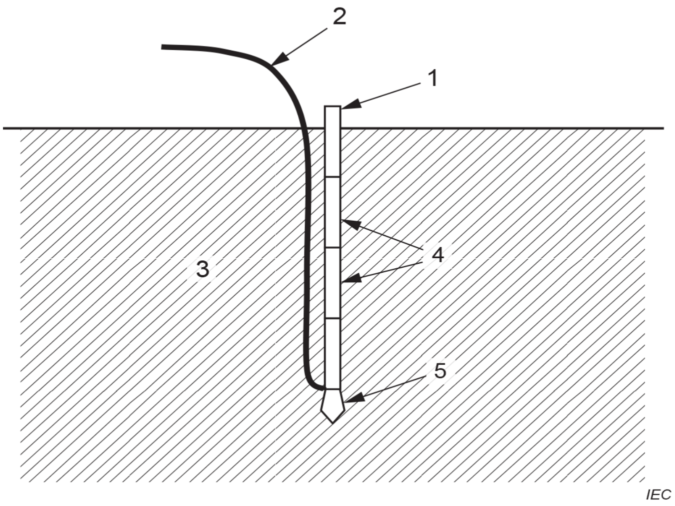
Although electrode material does not affect initial earth resistance, care should be taken to select a material that is resistant to corrosion in the type of soil in which it will be used. The possibility on damage to cables and other underground services and structural metalwork in the vicinity of earth-electrode due to electrolytic action between dissimilar materials should not be overlooked when the material for earth-electrodes is selected. Materials compatible with other metal structures in the vicinity should be selected or other remedial action taken.

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. Aluminium or copper clad aluminium conductors should not be used for final connection to earth electrode. Where a copper conductor is to be joined to Aluminium the proper procedure for joining conductors of Aluminium to copper 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 metal. Where the earthing conductor is to be connected to the metal sheath and armoured 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 clamp should conform to relevant IS standards.

It may be essential to use materials of types other than those mentioned earlier in special circumstances, when cathodically protected structures such as pipelines are encountered.

8.2.5 Installation of earth electrodes and conductors

Typical example of installing vertically earth electrode, plate earth electrode, and combined foundation earth electrode is shown in Fig. 35 and Fig. 39.



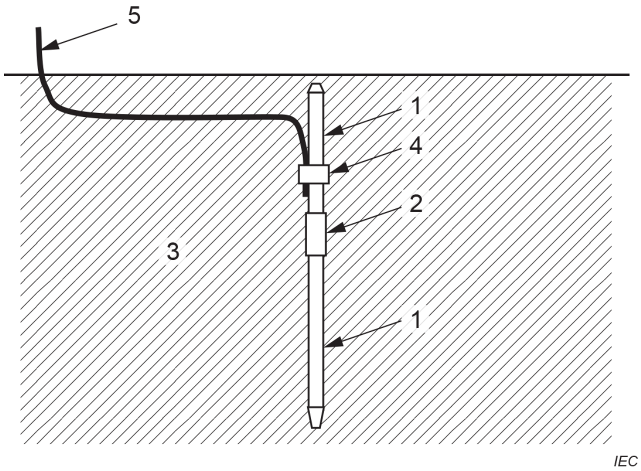
Key

1 short upper-most driving rod
2 earth lead-in conductor
3 soil
4 short driving rods
5 driving steel dart

Note

1. A continuous wire conductor is driven into the soil by means of short driving rods. The electrical continuity of the earth electrode conductor is of great advantage; using this technique, no joints are introduced into the earth electrode conductor. Short driving rod segments are also easy to handle.
2. The short upper-most driving rod can be removed.
3. The uppermost part of the earth lead-in conductor can have an insulating jacket.

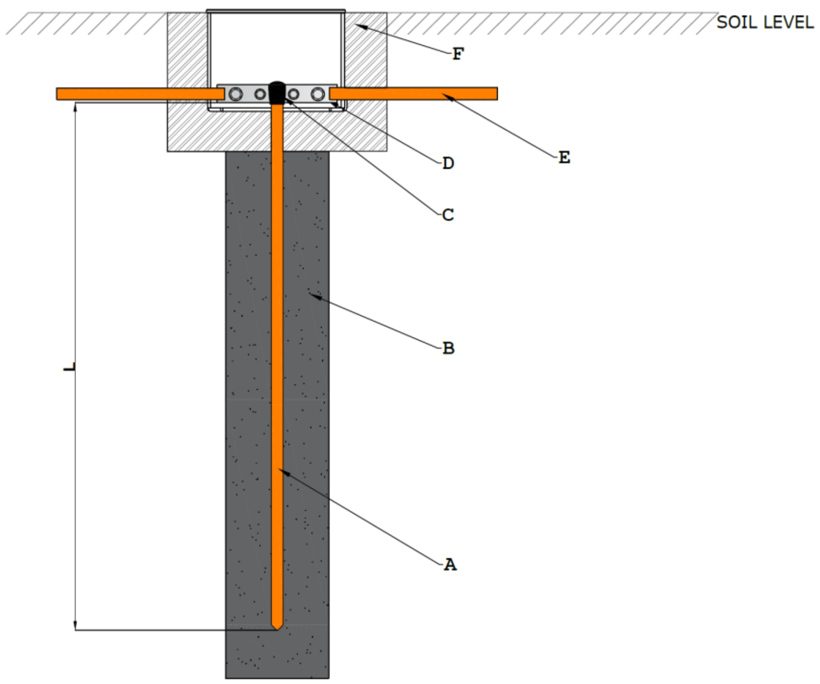
FIGURE 36 EXAMPLE OF A VERTICAL DRIVEN ROD WITH EARTH LEAD IN CONDUCTOR.



Key

1	extensible earth rod
2	rod coupling
3	soil
4	conductor to rod clamp
5	earth lead-in conductor

FIGURE 37 EXAMPLE OF AN EARTHING ARRANGEMENT WITH A VERTICAL DRIVEN ROD TYPE ELECTRODE

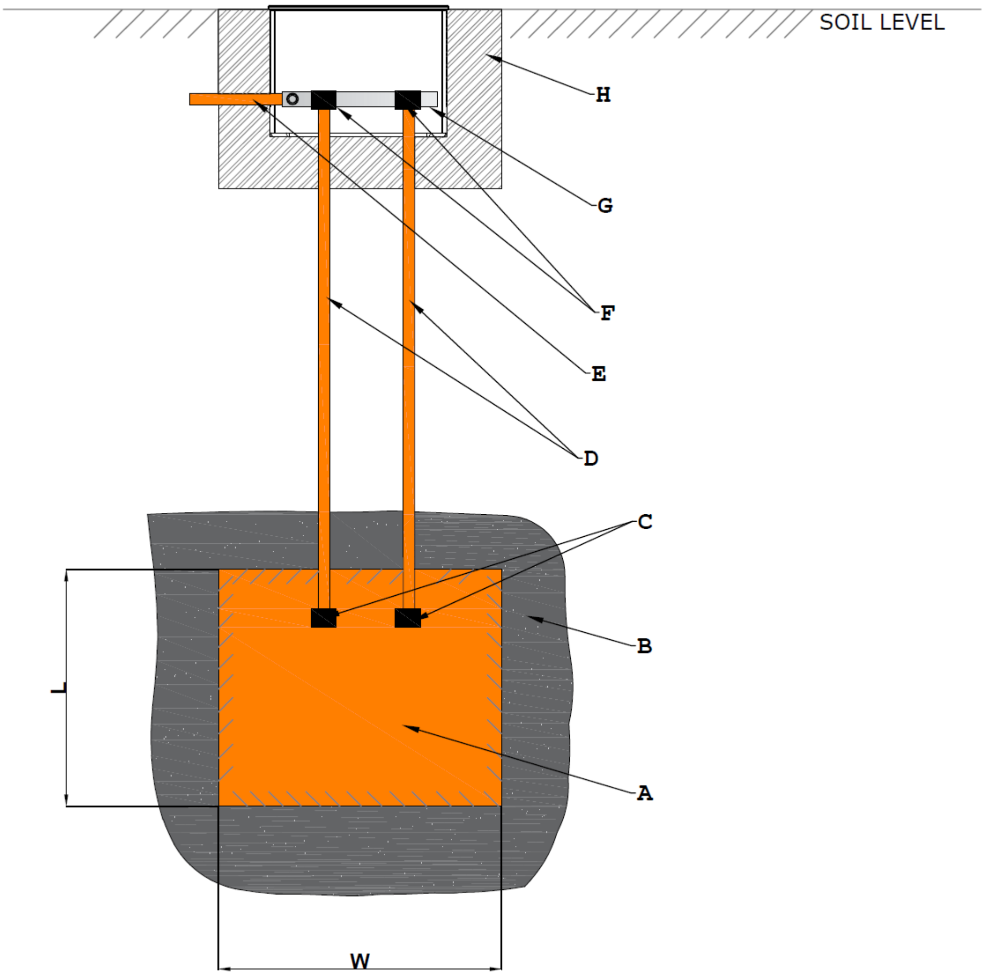


Key

A. Vertical earth electrode (ref Table 24 for material and minimum sizes)
B. Backfill soil. (Earth Enhancement compound confirming to IS/IEC 62561-7 is recommended only in locations where the soil resistivity is higher than 3000Ωm).
C. Joint/Connector/Exothermic Welding
D. Busbar with provisions for connection
E. Earthing conductor
F. Inspection Chamber with Lid / cover (e.g. 300 mm * 300 mm) tested according to IEC 62561 – 5
L. Length of the vertical electrode (e.g. 2000 to 4000 mm)

All dimensions are in mm. The dimensions are shown as typical example.

FIGURE 38 TYPICAL ARRANGEMENT OF VERTICAL EARTH ELECTRODE INSTALLED IN AUGURED HOLE.

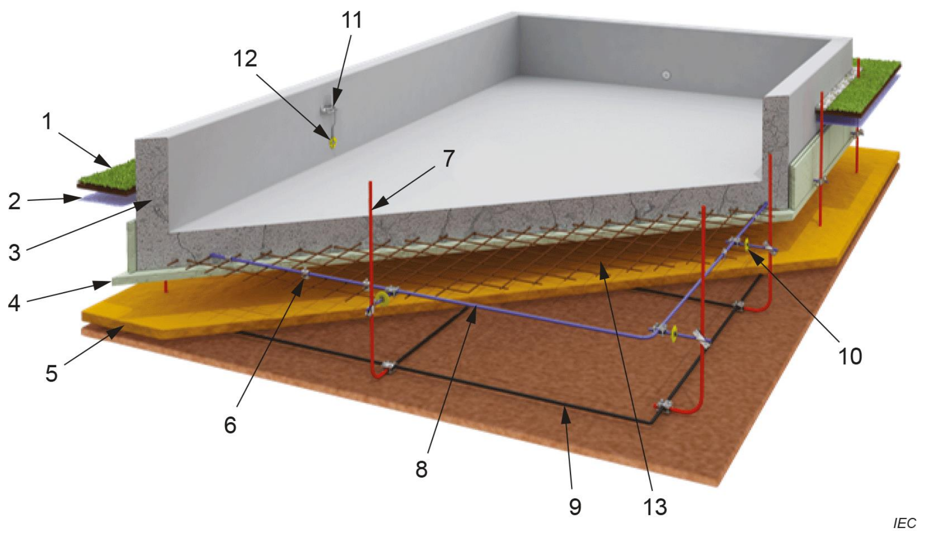


Key

A. Plate Electrode (ref Table 24 for more information)
B. Backfill soil. (Earth Enhancement compound confirming to IS/IEC 62561-7 is recommended only in locations where the soil resistivity is higher than 3000Ωm)
C. Joint/Connector/Exothermic Welding/Brazing
D. Earthing Conductor to electrode
E. Earthing Conductor from MET
F. Joint/Connector/Exothermic Welding
G. Busbar with provisions for connection.
H. Inspection Chamber with Lid / cover (e.g. 300 mm * 300 mm) tested according to IEC 62561-5

All dimensions are in mm. The dimensions are shown (L & W) as typical example. The L or W can be between 600 mm to 1200 mm.

FIGURE 39 TYPICAL ARRANGEMENT OF PLATE EARTHING



Key

1	Floor surface	7	LPS down conductor
2	Highest ground water level	8	Foundation earth electrode
3	Waterproof foundation slab	9	Ring earth electrode
4	Insulator e.g. waterproof membrane (if applicable)	10	Pressure-water-tight wall bushing
5	PCC layer	11	Equipotential busbar
6	Connection to the reinforcement	12	Provision to connect RCC
		13	Steel reinforcement in concrete

FIGURE 40 FOUNDATION EARTH ELECTRODE

8.2.6 Typical method for jointing of conductors

All joints of protective conductors shall confirm 7.3.3.5 to 7.3.3.7.

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

8.2.7 Current density at the surface of an earth electrode

Note: This clause may be useful for HV system (e.g. HVDC MONOPOLR System) for continuous loading or HV substations for fault currents (see IS 17860:2022). For LV 8.2.7.4 applies.

8.2.7.1 An earth electrode should be designed to have a loading capacity adequate for the system of which it forms a part, that is, it should be capable of dissipating without failure the energy in the earth path at the point at which it is installed under any condition of operation on the system. Failure 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.

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. As soil moisture is driven away from the soil-electrode interface, however, the resistance increases and will ultimately become infinite if the temperature-rise is sufficient.

8.2.7.2 Three conditions of operation require consideration, that is, long-duration loading as with normal system operation; short-time overloading as under fault conditions in directly earthed systems.

8.2.7.3 The little experimental work which has been done on this subject by experts at the international level has been confined to model tests with spherical electrodes in clay or loam of low resistivity and has led to the following conclusions:

a. Long-duration loading shall be made as per IS 17860:2022.
b. Time to failure on short-time overload is inversely proportional to the specific loading, which is given by i^2, where i is the current density at the electrode surface. For the soils investigated, the maximum permissible current density, i is given by:

$$i = \frac{7.57 \times 10^3}{\sqrt{\rho t}} A/m^2$$

where
t = duration of the earth fault (in s); and
ρ = resistivity of the soil (in Ω.m).

Experience indicates that this formula is appropriate for plate electrodes, hence shall not be used for other forms of earth electrodes. Further information for other forms of earth electrodes are under consideration.

The amount of fault current dissipated through earth electrode depends on the availability of metallic fault return current (e.g. armouring of cable, shield wire in transmission lines). The current will be low in High Voltage systems where there is a metallic fault return path.

8.2.7.4 For Low Voltage application the following apply,

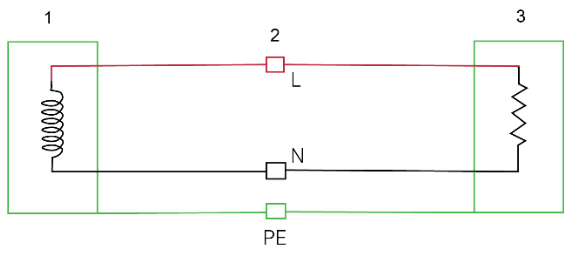
a) In TN-S system the above calculation is not required as majority of the fault current returns through protective conductor.
b) In TT system, the amount of fault current will be of the order for few amps to few 100 amps, hence this calculation is not required.

9. EARTHING IN LV & HV GENERATING PLANTS

9.1 LV PORTABLE GENERATORS

9.1.1 Unearthed Generating sets (Rating below 10 kW)

Small single-phase generators are run as floating systems, that is without the winding connected to the frame or to earth (see Fig. 40) 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.



Key
1 — Unearthed Generator
2 — Plug and Socket
3 — Appliance
NOTES

1. Low-voltage, single phase generating sets are generally mobile or transportable machines ranging in size from 0.2 kW to 10 kW.
2. Winding connection are normally brought out to a socket-outlet in which the third or protective conductor is connected to the generator enclosure.

FIGURE 41 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, screen or armour suitable for use as a protective conductor.

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

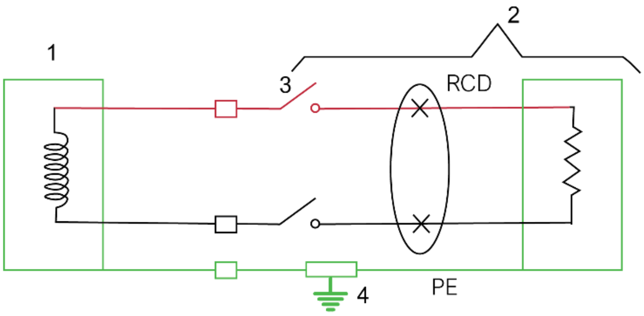
It should be noted that RCDs will not operate on a first fault and only on particular second faults.

9.1.2 Earthed Generators (Rating Below 10 kW) Supplying a Fixed Installation

Where an earthed generator is to supply a fixed installation (see Fig. 41) it is recommended that automatic disconnection of supply is adopted as follows:

a. One pole of a single phase generator should be connected to the installation MET.
b. The MET should be connected to an earthing arrangement or earth electrode (see Fig. 41)
c. The installation should conform to standards with all exposed-conductive parts and all extraneous-conductive-parts connected to the MET.
d. The installation should be protected by RCDs.

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



Key
1 — Unearthed Generator   3 — Isolator
2 — Electrical Installation   4 — Main Earth Terminal

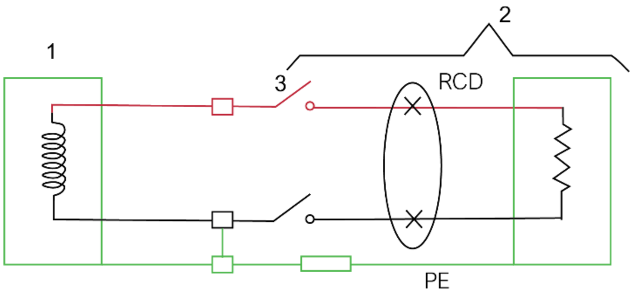
FIGURE 42 SMALL LV GENERATOR SUPPLYING A FIXED INSTALLATION

9.1.3 Earthed Generators Supplying a Mobile or Transportable Unit

Where an earthed generator is to supply a mobile installation (see Fig. 42 and Fig. 43), it is recommended that the protective measure automatic disconnection of supply be adopted as follows.

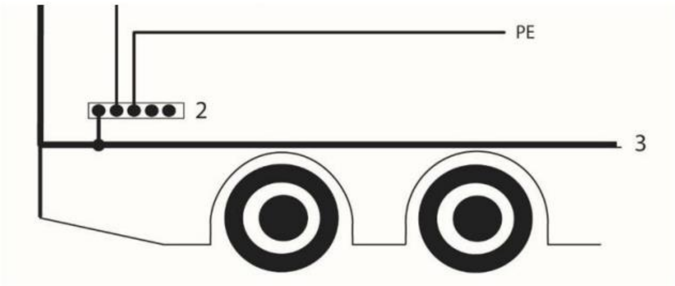
a. One pole of a single phase generator should be connected to the installation MET.
b. The installation should conform to standards with all exposed-conductive parts and all extraneous-conductive-parts connected to the MET.
c. The installation should be protected by RCDs.
d. If the unit supplies equipment or socket outlets outside the unit these circuits should be protected by RCDs with a rated residual operating current not exceeding 30 mA.

If practicable, an earth electrode should be connected to the MET of the unit. The RCD will not provide protection for faults on the generator side of the RCD, and consequently precautions should be taken.



Key
1 — Unearthed Generator   3 — Isolator
2 — Mobile Unit

FIGURE 43 SMALL UNEARTHED GENERATOR SUPPLYING A MOBILE OR TRANSPORTABLE UNIT



Key
2. Main Earthing Terminal (MET)
3. Metallic frame of enclosure of the unit

FIGURE 44 EXAMPLE OF EARTH CONNECTION TO THE CHASSIS

Where a supply is taken from a mobile generator, the following recommendations, shall apply:

a. The generator neutral should be connected to the vehicle chassis;
b. The earth terminal at each outlet on the generator vehicle should be connected separately to the alternator neutral where the latter is bonded to the vehicle chassis; and
c. Where a protective earth terminal or exposed structural metalwork is present, it should be connected to the earthing conductor on the mobile generator.

9.2 STANDBY GENERATING PLANTS (INCLUDING PORTABLE AND MOBILE GENERATORS).

9.2.1 General

Note: The contents of this clause are related to Synchronous Machines only. Other kind of Generating stations such as SOLAR PV, Wind etc, are included in Annex A.

The earthing of standby and other private generating plant is necessary to protect against indirect contact that may result in electric shock. The objective is to create a equipotential bonding zone in which voltage between exposed conductive parts and extraneous conductive parts are minimized in the event of an earth fault.

In this clause the requirement is met by connecting the generating set frame(s), metallic cable sheaths and armouring, and all exposed conductive parts to an earthing arrangement, and by connecting the electric system (Neutral of the Generator) to the same earthing arrangement (normally at one point only).

Except in some special applications, there is, in every case, need for an independent earth electrode (no 5020 – Chassis earth) for energy source earthing at the premises (Suppliers' protective earth terminal at the premises should also be connected to the independent earth electrode).

There are many variations in system design and for any particular application, the precise method of energy source earthing is subject to the recommendations of the machine manufacturers (based on this code), the system parameters and, where mains supplies are also involved, the agreement of the concerned supply authority.

It may, however, be noted that the guidance included in this clause, applies to shock protection as well as protection of equipment.

9.2.2 Low Voltage (Up to 1000 V) Generators

9.2.2.1 Single Low Voltage Generator Earthing (Synchronous Machines)

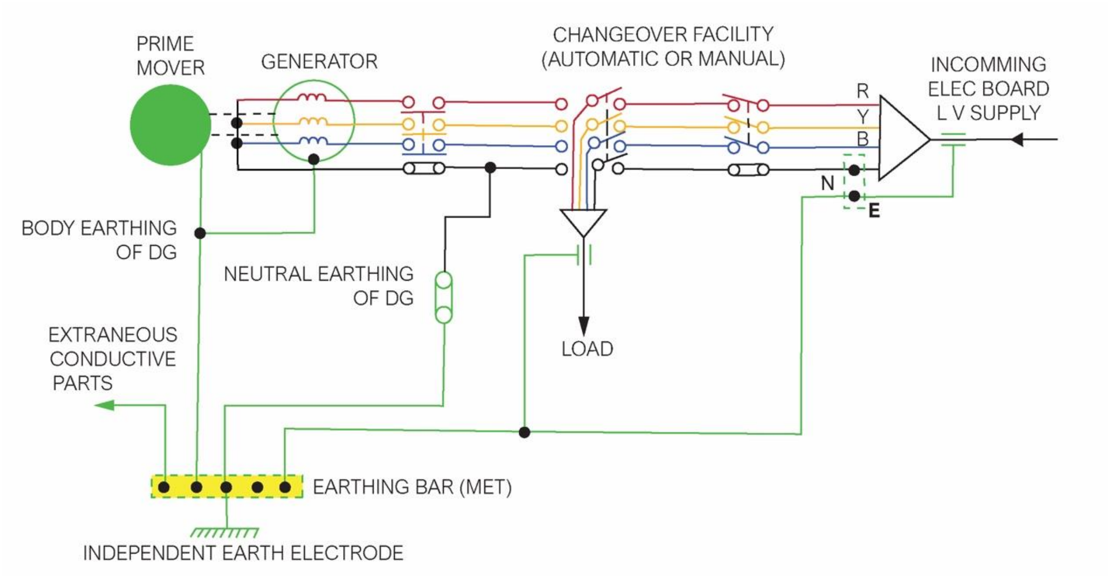
9.2.2.1.1 Generator operating in isolation (from the mains or other supplies)

In this basic arrangement, the generator neutral point should be connected to the neutral of the low voltage switchgear which itself is connected through a bolted link (for test purposes) to an earthing arrangement (See Fig. 44 without incoming LV discom supply).

9.2.2.1.2 Standby generator (without paralleling facility)

In addition to the earthing requirements stated for a generator operating in isolation from other supplies, special attention needs to be given to the change-over arrangement for standby set, which has to ensure that there can be no inadvertent parallel connection (see Fig. 44).

In general, four-pole changeover switching between the mains and standby, supplies should be used to provide isolation of the generator and electricity board neutral earths. However, in the case of a low voltage TN-C-S supply with protective multiple earthing (PME), three-or four-pole switching may be used.



NOTES
1 Cable sheath as protective earth shown in the figure. See 7.3.6 for actual use;
2 PE to N link of incoming supply shown considering TN-C-S with PME**;**
3 Changeover switch could be 3-pole with linked neutral.

FIGURE 45 SINGLE LOW VOLTAGE STANDBY GENERATOR (WITHOUT PARELLELING FACILITY)

9.2.2.1.3 Standby generator (capable of parallel operation with incoming mains supply)

DISCOM’s will not generally permit continuous parallel operation of a synchronous machine with the low voltage mains supply, unless there are no other consumers on the network. However, short-term parallel operation for no-break load transfer or testing may be permitted. Also, if a synchronous machine output is rectified and connected through mains modulated static inverter continuous parallel operation will usually be permitted. In the latter case, the generator neutral terminal should be connected to the earthing arrangement with independent earth electrode and to any Discom earthed or earthed neutral conductor.

9.2.2.2 Multiple Low Voltage Generator Earthing (Synchronous Machines)

9.2.2.2.1 Generator operating in isolation from other supplies.

When low voltage generating sets are operated in parallel, the electric source earthing method is influenced by the magnitude of the circulating currents, particularly third harmonic, which can arise when generators are connected as four-wire machines. If the magnitude of the circulating current due to the nature of the load or the design of the generators is excessive when the neutrals are connected, then a neutral earthing transformer or star-point earthing switches are required.

In the case of an inappropriate design of an installation forming part of a TN system with more than one source some of the operating current can flow through unintended paths. These currents can cause

– fire;

- corrosion;
- electromagnetic interference

Hence, three alternative neutral earthing arrangements are possible for parallel operation as follows:

a. All generator neutrals connected — With this arrangement, the neutral busbar in the main low voltage switchgear (Main Distribution board) is connected through a bolted link to an earthing arrangement.
b. Neutral earthing transformer — By providing a neutral earthing transformer solidly connected to the busbars, the system neutral can remain earthed at all times whilst any number of generators can be connected to the busbars as three-wire machines.
c. Generator star point switching — When this arrangement is adopted, it is necessary before the first generator is started for its star-point/neutral earthing switch to be closed. When subsequent sets are started, their star-point earthing switches remain open. This avoids the circulating current problem, but it is essential that electrical and mechanical interlocks on the starpoint/earth switches ensure the integrity of the energy source neutral earth connection at all times and under all possible operating conditions.

9.2.2.2.2 Standby generators (without mains paralleling facility)

The alternative neutral earthing arrangements for standby generators are as set out in 9.2.2.2.1 for generators operated in isolation from an electricity board supply. The earthing arrangements are shown in the following drawings:

a. All generator neutrals connected (see Fig.45);
b. Neutral earthing transformer (see Fig. 46); and
c. Alternator star-point switching (see Fig. 47).

For standby generators with no mains paralleling facility, the changeover arrangement has to prevent inadvertent connection of the generator outputs and DISCOM supply.

In general, four-pole changeover switching between the DISCOM supply and the standby supply should be used to provide isolation of the neutral. However, in the case of a low voltage TN-C-S supply with protective multiple earthing (PME), three-or four-pole switching may be used.

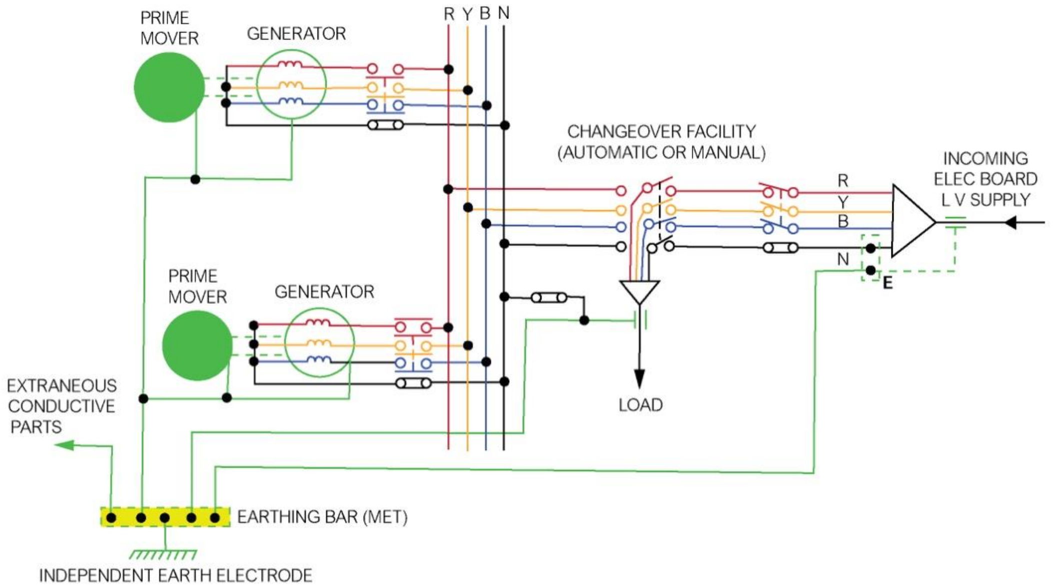
9.2.2.2.3 Standby generators (capable of parallel operation with the incoming mains supply)

The conditions for which parallel operation of multiple generating set installations with the mains supply may be permitted by the DISCOM are the same as apply for single generators (see 29.2.1.3).

The possible alternative energy source earthing arrangements are as listed in 29.2.3.2.

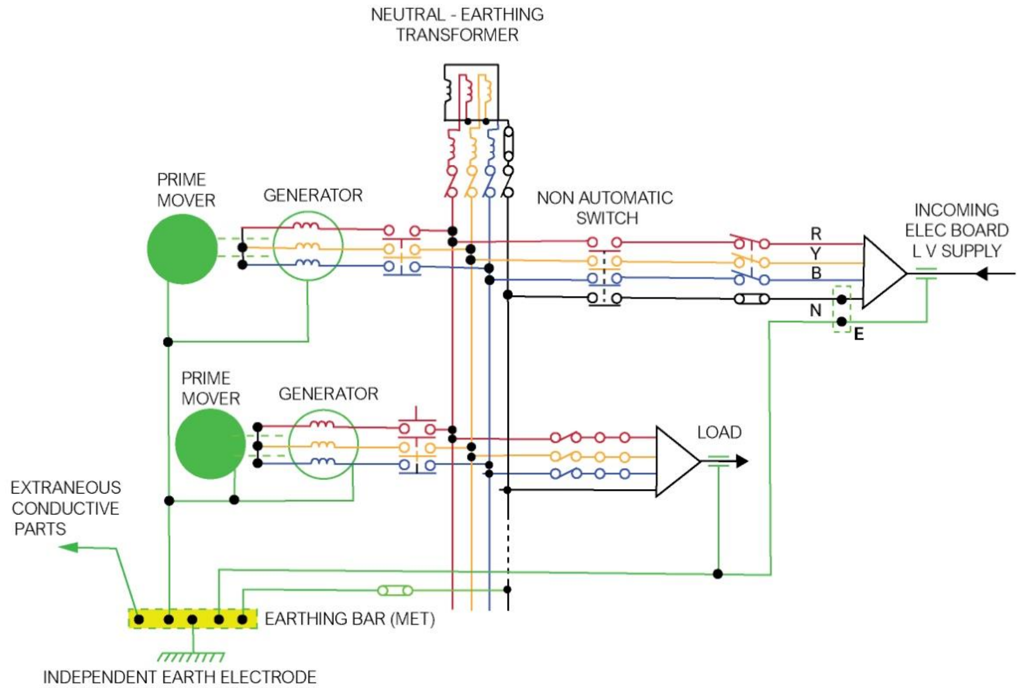
9.2.2.3 Single and Multiple Generator Earthing (Synchronous Machines)

The parallel operation of synchronous machines is generally permitted; such machines are normally provided where the prime mover is driven by wind, water or biochemical plant, but may be provided with any prime mover. Any neutral point of such machine windings should be earthed, but the machine framework and any other extraneous metalwork should be connected to the DISCOMS earth terminal, if provided.



NOTES
1 Cable sheath as protective earth shown in the figure. See 7.3.6 for actual use.
2 PE to N link of incoming supply shown considering TN-C-S with PME
3 Changeover switch could be 3-pole with linked neutral.

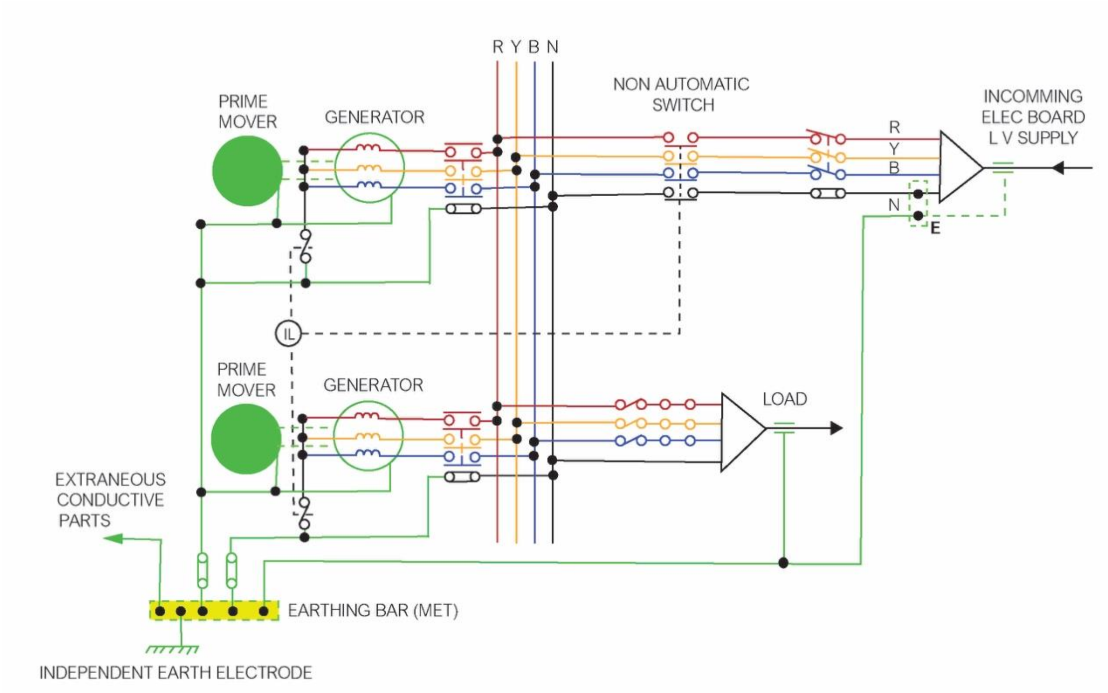
FIGURE 46 LOW VOLTAGE STANDBY GENERATORS WITH NEUTRALS CONNECTED



NOTES

1 Cable sheath as protective earth shown in the figure. See 7.3.6 for actual use.
2 PE to N link of incoming supply shown considering TN-C-S with PME
3 If a bus section switch is installed a neutral earthing transformer will be required on each section of busbar.

FIGURE 47 LOW VOLTAGE STANDBY GENERATORS WITH NEUTRAL EARTHING TRANSFORMERS



NOTES
1 Cable sheath as protective earth shown in the figure. See 7.3.6 for actual use.
2 PE to N link of incoming supply shown considering TN-C-S with PME
3 Mechanical interlock to ensure that energy source neutral it always earthed but at one point only.

FIGURE 48 LOW VOLTAGE STANDBY GENERATORS WITH STAR POINT SWITCHING

9.3 HIGH VOLTAGE GENERATORS

9.3.1 Earthing Resistors

Where a resistor is used for earthing the star-point of a high voltage generator, it is normally designed to limit the earth fault current to the same order of magnitude as the machine’s full load current.

9.3.2 Single High Voltage Generator Earthing (Synchronous Machines with Star Connected Alternators)

9.3.2.1 Generator operating in isolation (from mains or other suppliers)

The star-point of the generator should be connected (via a resistor, if necessary) and through a bolted link for test purposes to an earthing arrangement.

9.3.2.2 Standby generator (without paralleling facility)

In addition to the earthing requirements described for a set operating in isolation from other supplies, the presence of an incoming DISCOM supply makes necessary the interlocking of the standby supply circuit breakers to prevent inadvertent connection (see Fig. 48).

9.3.2.3 Standby generator (capable of parallel operation with an incoming supply)

The operation of a private generator (or generators) in parallel with an DISCOM high voltage system is subject to the technical agreement with the DISCOM.

In most cases where parallel operation with an incoming DISCOM supply is required, an earthing contactor is necessary between the generator star-point and the bolted test link (see Fig. 49). The contactor should be interlocked with the incoming supply circuit breaker so that it is open during periods of parallel operation but closes at all times. In the event of the DISCOM supply being lost during a period of parallel operation, the earthing contactor should be arranged to close automatically. The form of generator earthing (direct or resistance) is dependent upon the system parameters and the machine manufacturer's recommendations.

9.3.3 Multiple High Voltage Generator Earthing

9.3.3.1 Generators operating in isolation from other supplies

When it is required to operate two or more generators in parallel and the method of electric supply system earthing is direct or resistance earthing, then earthing contactors should be installed between each generator star-point and the earthing arrangement. The contactors need to be interlocked so that only one can be closed to maintain a single energy source earth.

If a neutral earthing transformer is to be used for electric supply system earthing, it should be connected as shown in Fig. 50 except that in the case of an isolated generating system, the earthing contactors is not required.

9.3.3.2 Standby generators (without mains parallel facility)

When the generating sets are not to be operated in parallel with the mains supply, and have direct or resistance earthing, the standby generator circuit-breakers and mains circuit-breaker need to be interlocked.

If a neutral earthing transformer is used the requirements are the same as described for a single standby generator in 9.3.2.2; as shown in Fig. 51, but without the earthing contactor.

9.3.3.3 Standby generators (capable of parallel operation with an incoming mains supply)

When the generating sets have direct or resistance earthing and are used as standby to the mains, earthing contactors are needed if parallel running is a requirement. These should be interlocked with the incoming mains supply circuit-breaker so that they are open during parallel operation of the set with the mains, but one is closed at all other times (see Fig. 49).

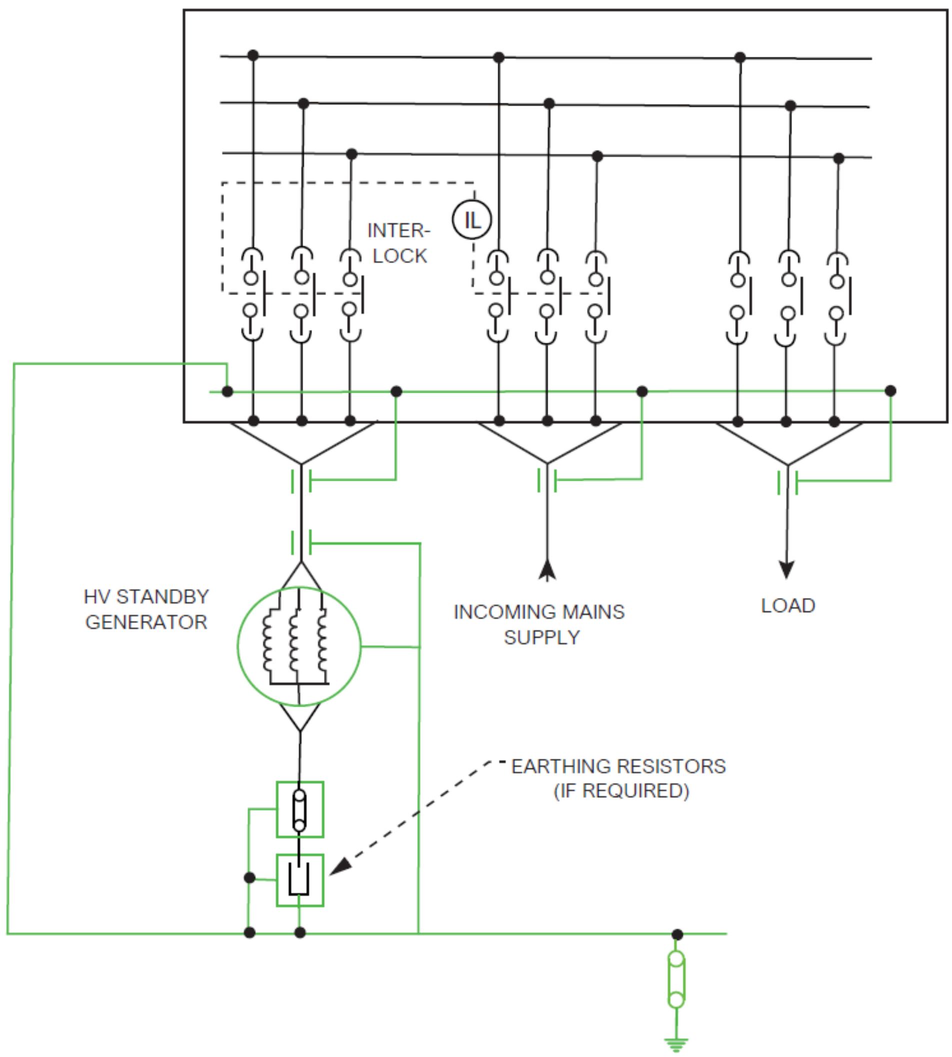


FIGURE 49 SINGLE HIGH VOLTAGE STANDBY GENERATING SET NOT SUITABLE FOR PARALLEL OPERATION

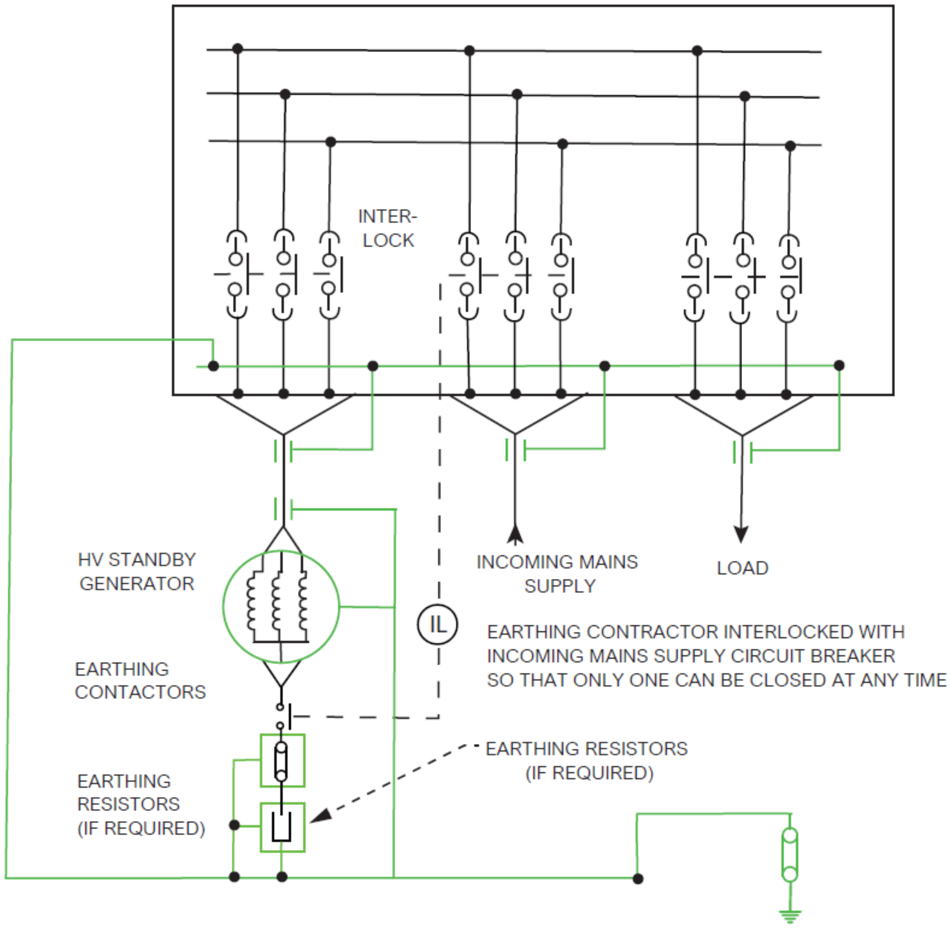
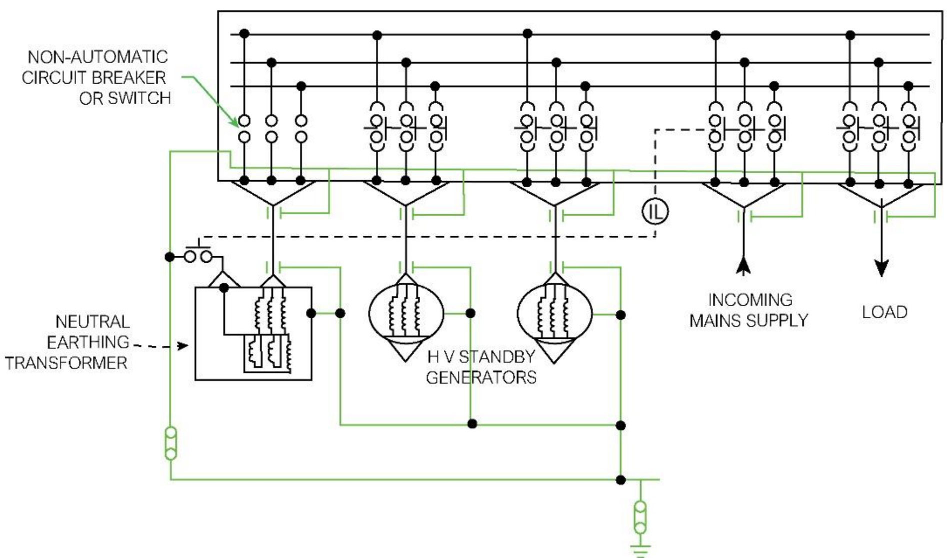


FIGURE 50 SINGLE HIGH VOLTAGE STANDBY GENERATING SET SUITABLE FOR PARALLEL OPERATION WITH INCOMING MAINS SUPPLY



Note: Earthing contactor interlocked so that the contactor cannot be closed during parallel operation with the incoming mains supply.

FIGURE 51 MULTIPLE HIGH VOLTAGE STANDBY GENERATING SETS WITH NEUTRAL EARTHING TRANSFORMER SUITABLE FOR PARALLEL OPERATION WITH EACH OTHER AND WITH THE INCOMING MAINS SUPPLY

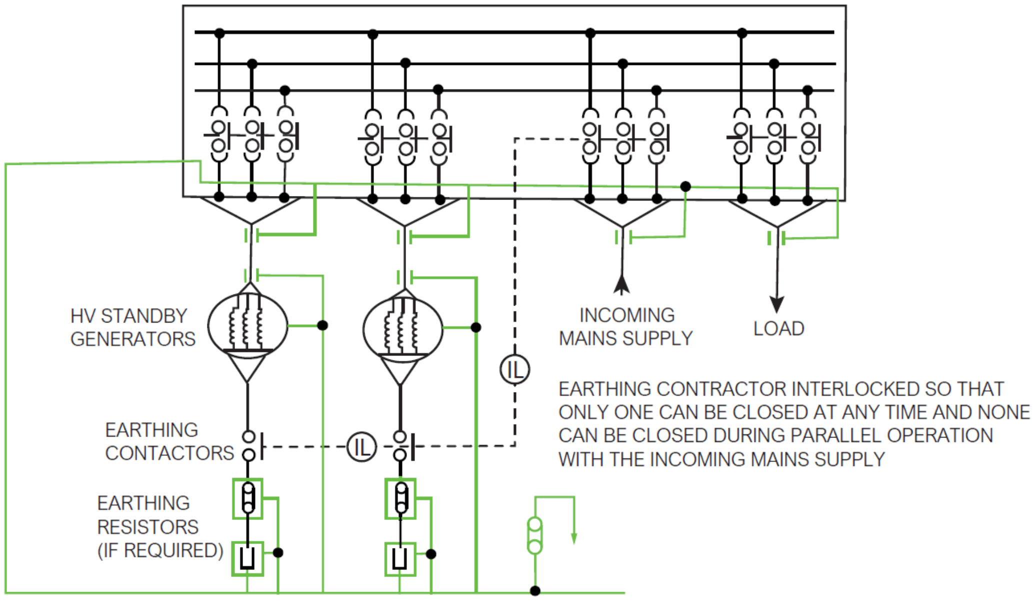


FIGURE 52 MULTIPLE HIGH VOLTAGE STANDBY GENERATING SETS SUITABLE FOR PARALLEL OPERATION WITH EACH OTHER AND WITH THE INCOMING MAINS SUPPLY

10. EARTHING IN POWER STATIONS AND SUBSTATIONS

10.1 GENERAL SAFETY

In general earthing installations will be required at power stations and substations for:

a. The neutral points of each separate electricity system which has to be earthed at the power station or substation;
b. Apparatus framework or cladding or other non-current carrying metalwork associated with each system, for example, transformer tanks, instrument transformer tank, Surge Arresters, power cable sheaths; and
c. Extraneous metalwork not associated with the power systems, for example boundary fences, mast, sheaths of control or communication cables.

In all cases, the safety measures mentioned in IS/IEC 61936-1 for a.c. system and IS/IEC 61936-2 for d.c. system shall be achieved.

For safety, the objective of earthing is to ensure that, in normal or abnormal conditions, any voltage appearing on equipment to which there is access should be below a dangerous level. It is not practicable to ensure that metal parts are earthed and remain near true earth potential during the passage of earth fault currents, particularly on high voltage systems with directly earthed neutrals. The objective should, therefore, be to provide effective bonding of low impedance and adequate current-carrying capacity between parts with which anyone may be in simultaneous contact, and to arrange, as far as possible, that large fault currents do not flow between such points.

10.2 FUNDAMENTAL REQUIREMENTS

10.2.1 Safety criteria

The hazard to human beings is that a current will flow through the region of the heart which is sufficient to cause ventricular fibrillation. The current limit, for power-frequency purposes is derived from the appropriate curve in IS/IEC 60479-1. This body current limit is translated into voltage limits for comparison with the calculated step and touch voltages taking into account the following factors:

- proportion of current flowing through the region of the heart;
- body impedance along the current path;
- resistance between the body contact points and, for example, metal structure to hand including glove, feet to remote ground including shoes or gravel;
- fault duration.

It shall also be recognized that fault occurrence, fault current magnitude, fault duration and presence of human beings are probabilistic in nature.

The earthing design parameters (relevant fundamental requirements, e.g. fault current, fault duration) shall be agreed between the supplier and user.

For electrical power installation design, the curve shown in Fig. 4 is calculated according to the method defined in 5.2.

NOTE The curve is based on data extracted from IS/IEC 60479-1 as below:

1) body impedance from Table 1 of IS/IEC 60479-1, (not exceeded by 50 % of the population);
2) permissible body current corresponding to the c2 curve in Figure 20 and Table 11 of IS/IEC 60479-1 (probability of ventricular fibrillation is less than 5 %);
3) heart-current factor according to Table 12 of IS/IEC 60479-1.

The curve in Fig. 4, which gives the permissible touch voltage, should be used.

As a general rule, meeting the touch voltage requirements satisfies the step voltage requirements, because the tolerable step voltage limits are much higher than touch voltage limits due to the different current path through the body.

For electrical power installations where high-voltage electrical equipment is not located in closed electrical operating areas, e.g. in an industrial environment, a global earthing system should be applied to prevent intolerable touch voltages.

10.2.2 Functional requirements

The earthing system, its components and bonding conductors shall be capable of distributing and discharging the fault current without exceeding thermal and mechanical design limits based on backup protection operating time.

The earthing system shall maintain its integrity for the expected electrical power installation lifetime with due allowance for corrosion and mechanical constraints.

Earthing system performance shall avoid damage to equipment due to excessive potential rise, potential differences within the earthing system and due to excessive currents flowing in auxiliary paths not intended for carrying parts of the fault current.

The earthing system, in combination with appropriate measures (e.g. potential control, local isolation) shall maintain step, touch and transferred potentials within the voltage limits based on normal operating time of protection relays and breakers.

The earthing system performance shall contribute to ensuring electromagnetic compatibility (EMC) among electrical and electronic apparatus of the high-voltage system in accordance with IEC TR 61000-5-2 .

10.2.3 High and low voltage earthing systems

10.2.3.1 General

Where high- and low-voltage earthing systems exist in proximity to each other and do not form a global earthing system, part of the EPR from the HV system can be applied on the LV system. Two practices are presently used:

a) interconnection of all HV with LV earthing systems;
b) separation of HV from LV earthing systems.

In either case, the relevant requirements concerning step, touch and transfer potentials specified below shall be complied with within a substation and at an LV installation supplied from that substation.

Interconnection is preferred when practicable.

10.2.3.2 LV supply only within an electrical power installation

Where the LV system is totally confined within the area covered by the HV earthing system, both earthing systems shall be interconnected even if there is no global earthing system.

10.2.3.3 LV supply incoming to or outgoing from an electrical power installation

Full compliance is ensured if the earthing system of the electrical power installation is part of a global earthing system or connected to a multi-earthed HV neutral conductor in a balanced system. If there is no global earthing system, the minimum requirements of Table 25 shall be used to identify those situations where interconnection of earthing systems with low-voltage supply outside the high-voltage installation is feasible.

If high-voltage and low-voltage earthing systems are separate, the method of separating earth electrodes shall be chosen such that no danger to persons or electrical equipment can occur in the low-voltage installation. This means that step, touch and transfer potentials and stress voltage in the LV installation caused by a high-voltage fault are within the appropriate limits.

10.2.3.4 LV in the proximity of an electrical power installation

Special consideration shall be given to LV systems which are located in the zone of influence of the earthing system of the electrical power installation.

For industrial and commercial installations, a common earthing system can be used. Due to the close proximity of equipment, it is not possible to separate earthing systems.

TABLE 25 MINIMUM REQUIREMENTS FOR INTERCONNECTION OF LOW-VOLTAGE AND HIGH-VOLTAGE EARTHING SYSTEMS BASED ON EPR LIMITS

<table>
<tr><th colspan="2" rowspan="3">Type of LV system [a]</th><th colspan="3">EPR requirements</th></tr>
<tr><th rowspan="2">Touch voltage</th><th colspan="2">Stress voltage [b]</th></tr>
<tr><th>Fault duration $t_f \leq 5$ s</th><th>Fault duration $t_f > 5$ s</th></tr>
<tr><td colspan="2">TT</td><td>Not applicable</td><td>EPR ≤ 1 200 V</td><td>EPR ≤ 250 V</td></tr>
<tr><td colspan="2">TN</td><td>EPR ≤ $F \times U_{Tp}$ [c, d]</td><td>EPR ≤ 1 200 V</td><td>EPR ≤ 250 V</td></tr>
<tr><td rowspan="2">IT</td><td>Distributed protective earth conductor</td><td>As per TN system</td><td>EPR ≤ 1 200 V</td><td>EPR ≤ 250 V</td></tr>
<tr><td>Protective earth conductor not distributed</td><td>Not applicable</td><td>EPR ≤ 1 200 V</td><td>EPR ≤ 250 V</td></tr>
</table>

a For telecommunication equipment, the ITU recommendations should be used.

b Limit may be increased if appropriate LV equipment is installed or EPR may be replaced by local potential differences based on measurements or calculations.

c	The typical value for *F* is 2, indicating the touch voltage is 50 % of EPR. Higher values of F (up to 5) may be applied where there are additional connections of the PEN conductor to earth which therefore may reduce the touch voltage as a percentage of EPR. For certain soil structures, caution is necessary in soils with high contrast of top layer resistivity and underlying lower resistivity. In this case F is closer to 1 as the touch voltage can exceed 50 % of the EPR. If the PEN or neutral conductor of the low-voltage system is connected to earth only at the HV earthing system, the value of F shall be 1.
d	U_{Tp} is derived from Fig. 4.

10.2.3.5 Global Earthing System

Note: See 5.2 and Fig. 4 for limits of tolerable touch voltage.

Global earthing system is the 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.

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.

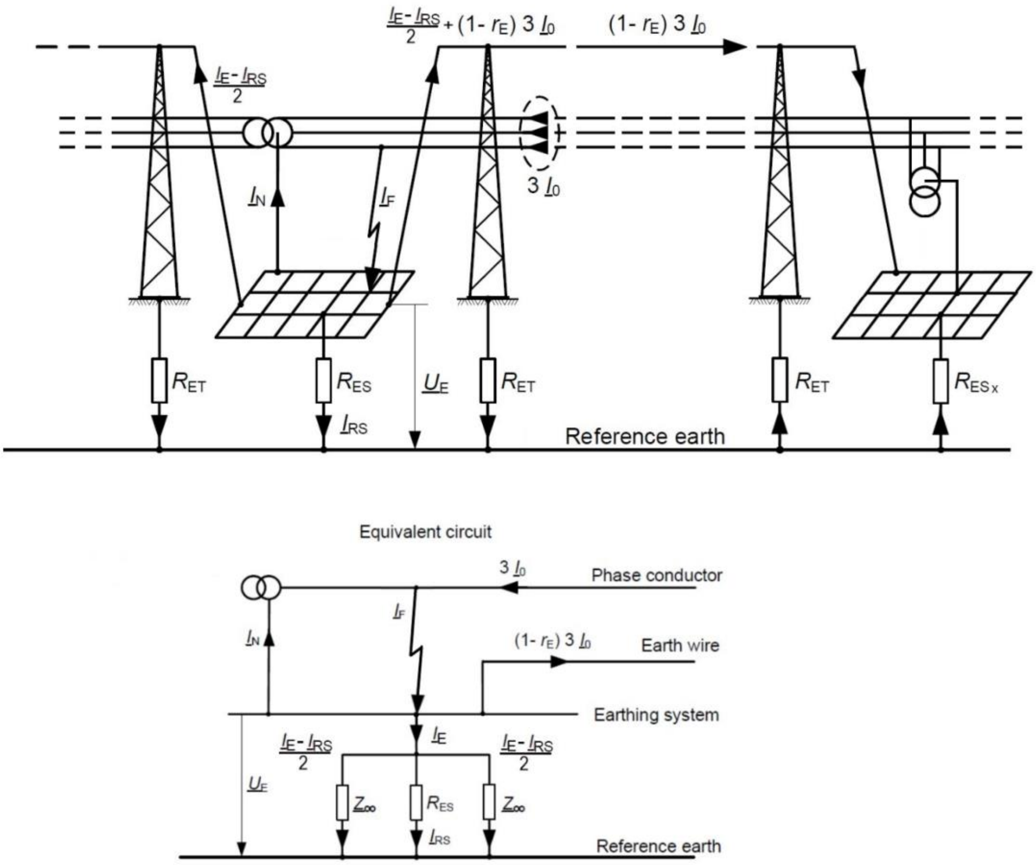
The existence of a global earthing system may be determined by sample measurements or calculation for typical systems.

Typical cases where a global earthing system exists could be:

- substation is surrounded by buildings with foundation earth electrodes and the earthing systems are interconnected e.g. by cable sheath, low voltage protective earth conductors or PEN conductors;
- substation is feeding city centre or densely built-up areas;
- substation is feeding area with many distributed earth electrodes interconnected by protective earth conductors or PEN conductors of low voltage system;
- substation with given number of nearby substations;
- substation with given number and length of outgoing earth electrodes;
- substation connected via cables with earth electrode effect;
- substation is feeding extended industrial area;
- substations are part of system with multi earthed high voltage neutral conductor.

An earthing system design flow chart is included in Fig. 58 and Fig. 59.

10.2.3.6 Earth fault current under different conditions of neutral earthing.



$I_F = 3I_0 + I_N$

$I_E = r_E \times (I_F - I_N)$

$U_E = I_E \times Z_E$

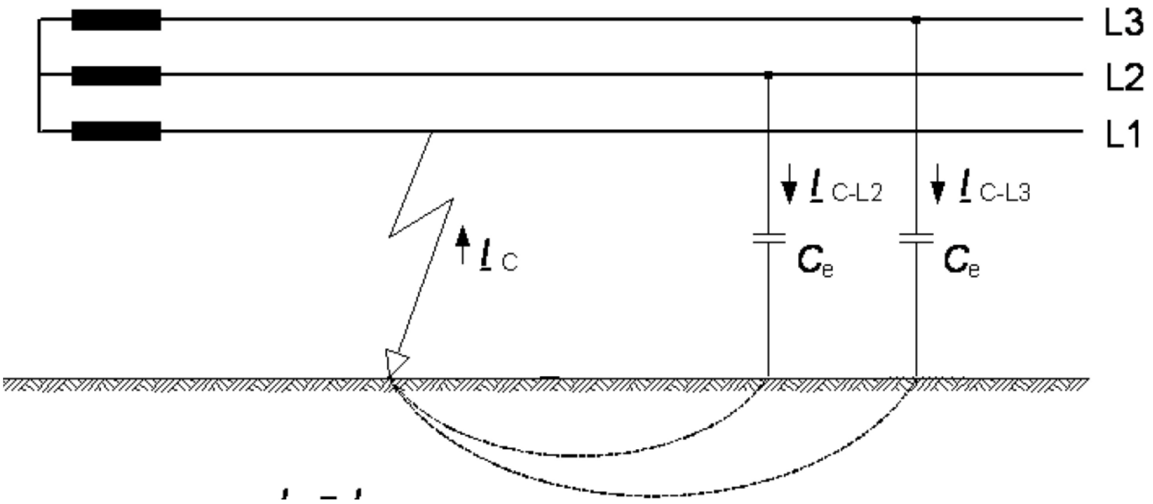
$$Z_E = \frac{1}{\frac{1}{R_{ES}} + n\frac{1}{Z_\infty}}$$

For equal earth wire tower footing impedances of the overhead lines

Key

$3\ I_0$	Three times zero sequence current of the line
I_N	Current via neutral earthing of the transformer
I_F	Earth fault current
I_E	Current to earth (cannot be measured directly)
I_{RS}	Current via the resistance to earth of the mesh earth electrode
r_E	Reduction factor of the overhead line
R_{ES}, R_{ESx}	Resistance to earth of the mesh earth electrode
R_{ET}	Resistance to earth of the tower
$Z\infty$	Chain impedance (several number of towers with resistance to earth, RET) represents a value of the overhead line assumed to be infinite
Z_E	Impedance to earth
U_E	Earth potential rise
n	Number of overhead lines leaving the substation (here: n = 2)

FIGURE 53 EXAMPLE FOR CURRENTS, VOLTAGES AND RESISTANCES FOR AN EARTH FAULT IN A TRANSFORMER SUBSTATION WITH LOW IMPEDANCE NEUTRAL EARTHING

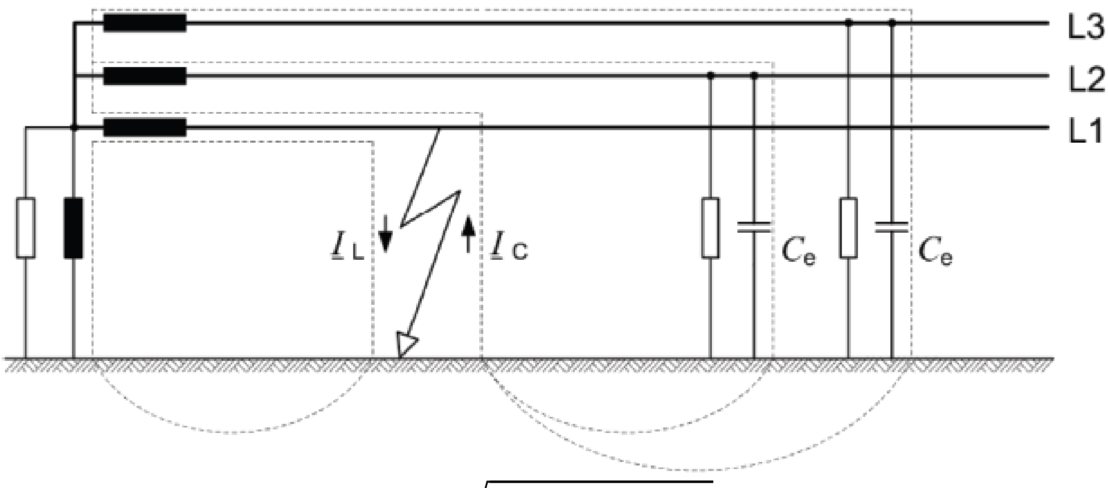


$$I_F = I_C$$

Key

I_F	Earth fault current
I_C	Capacitive earth fault current (complex value, including ohmic component)
Note	I_C may include ohmic component.

FIGURE 54 EARTH FAULT CURRENT IN A SYSTEM WITH ISOLATED NEUTRAL

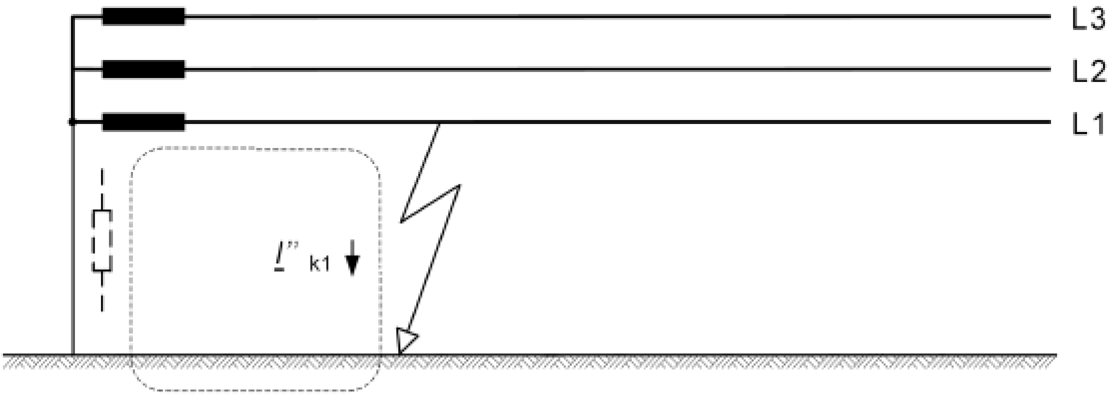


$$|I_F| = |I_{RES}| = \sqrt{|I_c + I_L|^2 + |I_H|^2}$$

Key

I_F	Earth fault current
I_C	Capacitive earth fault current (complex value, including ohmic component)
I_L	Sum of the currents of the parallel arc-suppression coils (complex value, including ohmic component)
I_H	Harmonic current (different frequencies)
I_{RES}	Earth fault residual current
Note	I_R is the ohmic part of the complex value of (I_C + I_L).

FIGURE 55 EARTH FAULT CURRENT IN A SYSTEM WITH RESONANT EARTHING

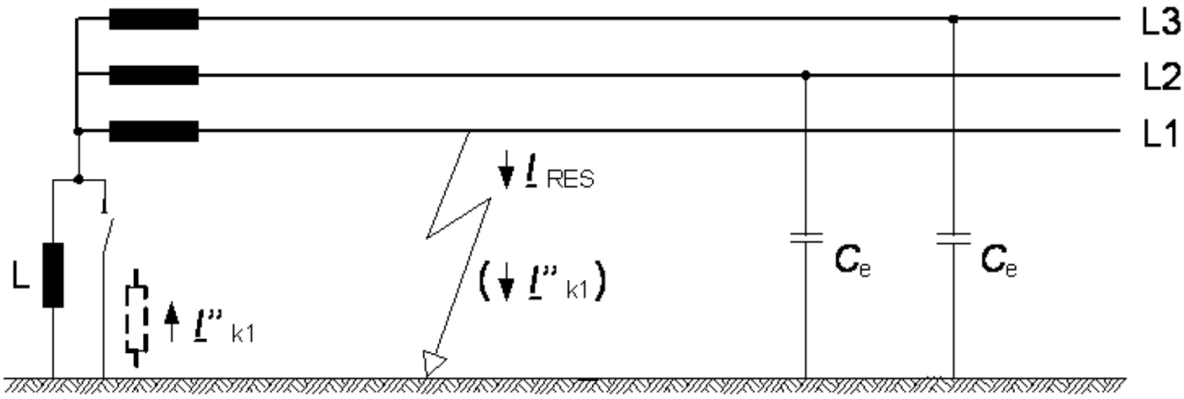


$$I_F = I''_{k_1}$$

Key

I_F	Earth fault current
I''_{k1}	Initial symmetrical short-circuit current for a line-to-earth short circuit
Note	If I_C is in the same order as I''_{k1} this current shall be considered additionally.

FIGURE 56 EARTH FAULT CURRENT IN A SYSTEM WITH LOW IMPEDANCE NEUTRAL EARTHING

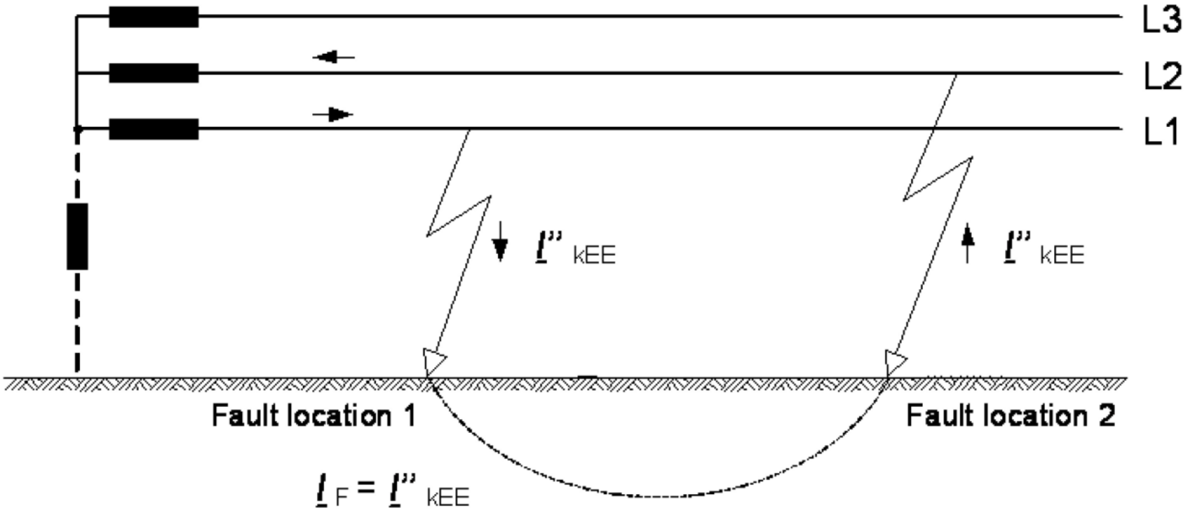


$I_F = I_{RES}$ after a short time I''_{k1}

Key

I_F	Earth fault current
I_{RES}	Earth fault residual current
I''_{k1}	Initial symmetrical short-circuit current for a line-to-earth short circuit

FIGURE 57 EARTH FAULT CURRENT IN A SYSTEM WITH RESONANT EARTHING AND TEMPORARY LOW IMPEDANCE NEUTRAL EARTHING



$$I_F = I''_{kEE}$$

Key

I_F	Earth fault current
I''_{kEE}	Double earth fault current

FIGURE 58 DOUBLE EARTH FAULT CURRENT IN A SYSTEM WITH ISOLATED NEUTRAL OR RESONANT EARTHING

10.3 DESIGN OF EARTHING SYSTEMS

Design of an earthing system can be accomplished as follows:

a) data collection, e.g. earth fault current, fault duration and layout;
b) initial design of the earthing system based on the functional requirements;
c) determine if it is part of a global earthing system;
d) if not, determine soil characteristics e.g. of layers with different specific electric resistivity of soil;
e) determine the current flowing into earth (I_E) from the earthing system, based on earth fault current (I_F);
f) determine the overall impedance to earth, based on the layout, soil characteristics, and parallel earthing systems;
g) determine earth potential rise, U_E, (see Fig. 1 & 10.5.2)
h) determine the permissible touch voltage value from Fig. 4 for the relevant fault duration;
i) if the earth potential rise is below the permissible touch voltage and the requirements of Table 25 are met, the design is complete;
Note:
The design is also complete if U_E is less than 2 U_{Tp} according to 10.4 and the requirements of Table 25 are met.
The design is also complete if U_E is less than 4 U_{Tp} according to 10.4 with specified measures M (see 10.6 and Table 27) applied and the requirements of Table 25 are met
j) if not, determine if touch voltages inside and in the vicinity of the earthing system are below the tolerable limits;
k) determine if transferred potentials present a hazard outside or inside the electrical power installation; if yes, proceed with mitigation at exposed location;

l) determine if low-voltage equipment is exposed to excessive stress voltage; if yes, proceed with mitigation measures which can include separation of HV and LV earthing systems;

Table 25 shall be taken into account regarding transferred potentials to low voltage systems.

Once the above criteria have been met, the design can be refined, if necessary, by repeating the above steps. Detailed design is necessary to ensure that all exposed-conductive-parts, are earthed. Extraneous-conductive-parts shall be earthed, if appropriate.

A flowchart of this design process is given in Fig. 58 and Fig. 59.

A structural earth electrode, if any, shall be bonded and form part of the earthing system. If not bonded, verification is necessary to ensure that all safety requirements are met.

Metallic structures with cathodic protection may be separated from the earthing system. Precautions, such as labelling, shall be taken to ensure that when such measures are taken, maintenance work or modifications will not inadvertently nullify them.

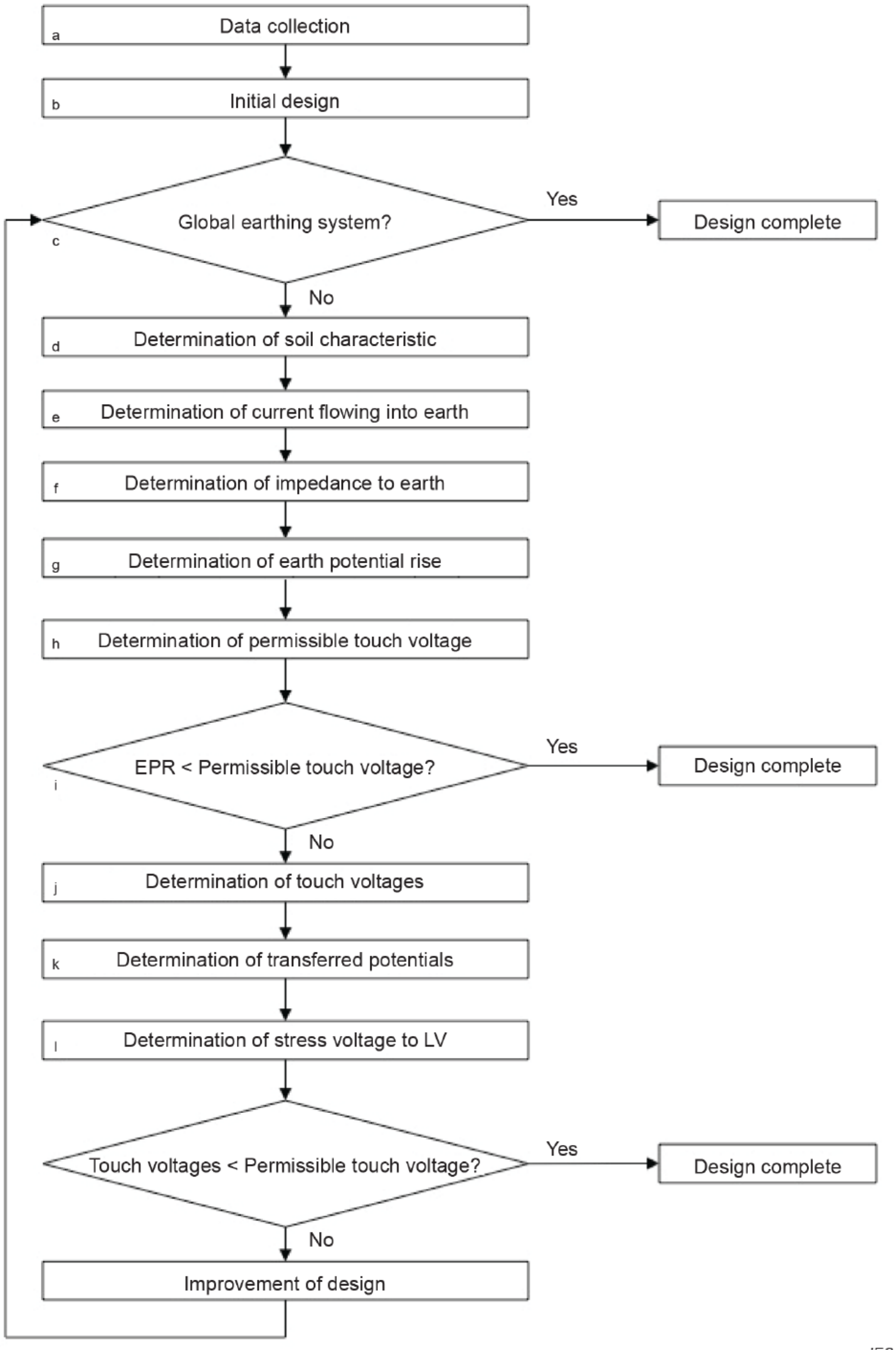
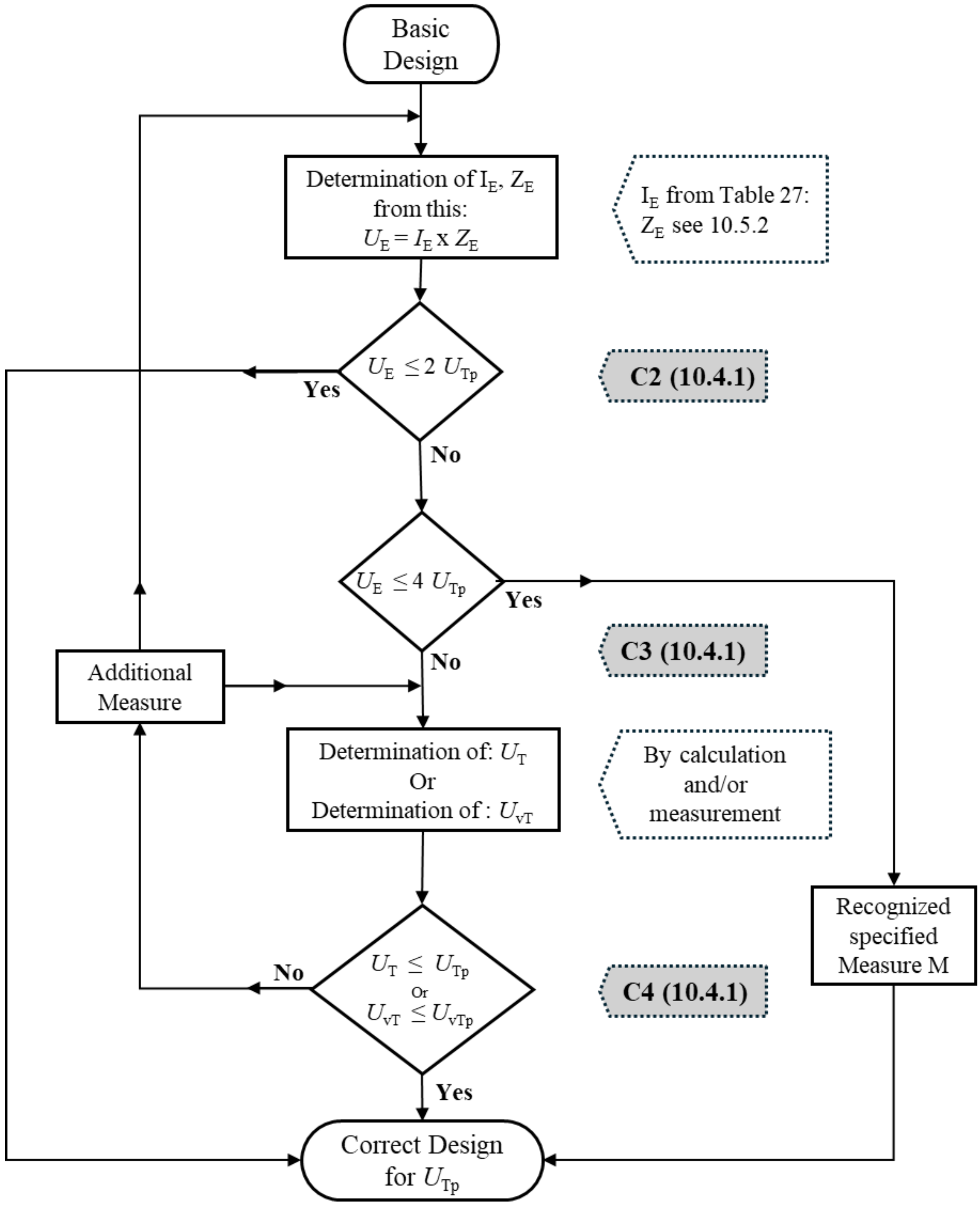


FIGURE 59 AN EARTHING SYSTEM DESIGN FLOW CHART



Note: The design is based on permissible touch voltage U_{Tp} by checking the earth potential rise U_E or the touch voltage U_T and without consideration of transferred potential.

FIGURE 60 DESIGN OF EARTHING SYSTEMS, WHICH IS NOT A PART OF GLOBAL EARTHING SYSTEM

10.4 SAFETY MEASURES TO OBSERVANCE THE PERMISSIBLE TOUCH VOLTAGES

10.4.1 Permissible Touch Voltage

Application of the fundamental requirements will give the basic design of the earthing system. This design shall be checked with respect to touch voltages and could then be considered as a type design for similar situations.

For the values of the permissible touch voltages U_{Tp} Fig. 4 shall be used. These permissible values are considered to be satisfied,

a) C1: if the relevant installation becomes a part of a global earthing system.
b) C2: C1 is not satisfied and the earth potential rise, determined by measurement or calculation does not exceed double the value of the permissible touch voltage U_{Tp} in accordance with Fig. 4.
c) C3: if C2 is not satisfied and the earth potential rise, determined by measurement or calculation does not exceed four times the value of the permissible touch voltage in accordance with Fig. 4 and the relevant recognized specified measures M are carried out in accordance with the magnitude of the earth potential rise and the fault duration, see10.6.
d) C4: if C3 is not satisfied the criteria for the permissible touch voltage (U_{Tp}) of Fig. 4 shall be proved by calculation and/or measurement of touch voltage (U_T). Additional resistances may be taken into account to determine the prospective permissible touch voltage (U_{vTp}) according to 5.2 and proved by calculation and/or measurement of U_{vT}. Generally, the verification of the criteria of permissible voltages (U_{Tp} or U_{vTp}) is done by measurements. If the criteria for U_T or U_{vT} are still not satisfied, the design shall be improved and steps C2 to C4 shall be reconsidered.

A flowchart of the design process from C2 to C4 is given in Fig. 59.

Alternatively, any type of designs may be used that ensures the requirements in 5.2 are fully met.

NOTE

1. Examples of high earth potential rise where step voltages could be necessary to be considered at the boundaries of the earthing system are e.g. when $U_E > 20 \times U_{Tp}$
2. As an alternative to using one of the conditions M1 to M4, the values of the touch voltages can be checked by field measurements.

Transferred potentials are always to be checked separately.

The earth potential rise and touch voltages of an earthing system may be calculated from available data (soil resistivity, impedance to earth of existing earthing systems, see 8 and 10.5). For the calculation all earth electrodes and other earthing systems, which are reliably connected to the relevant earthing system with sufficient current carrying capacity, may be considered. In particular, this applies to connected overhead earth wires, wires buried in earth and cables with earth electrode effect. This also applies to earthing systems, which are conductively connected to the relevant earthing system via sheaths or screens of cables, PEN-conductors or in another way.

For the determination of the earth potential rise and touch voltages the currents of Table 26 are relevant.

For proof by measurement, see 13.5.

TABLE 26 RELEVANT CURRENTS FOR THE DESIGN OF EARTHING SYSTEMS

Type of high voltage system	Relevant for thermal loading [a e]		Relevant for earth potential rise and touch voltages
	Earth electrode	Earthing conductor	
Systems with isolated neutral			
	I''_{kEE}	I''_{kEE}	$I_E = r \cdot I_C$ [b]
System with resonant earthing **Includes short time earthing for detection**			
Substations without arc-suppression coils [f]	I''_{kEE}	I''_{kEE}	$I_E = r \cdot I_{RES}$ [b]
Substations with arc-suppression coils	I''_{kEE}	I''_{kEE} [c]	$I_E = r \sqrt{I_L^2 + I_{Res}^2}$ [b h]
Systems with low-impedance neutral earthing **Includes short time earthing for tripping [g]**			
Substation without neutral earthing	I''_{kEE}	I''_{kEE}	$I_E = r \cdot I''_{k1}$
Substation with neutral earthing	I''_{kEE}	I''_{kEE}	$I_E = r \cdot (K''_{k1} - I_N)$ [d]

Legend:

I_C Calculated or measured capacitive earth fault current.

I_{RES} Earth fault residual current.
If the exact value is not available, 10 % of I_C may be assumed.

I_L Sum of the rated currents of the parallel arc-suppression coils in the relevant substation.

I''_{kEE} Double earth fault current calculated in accordance with the IS 13234.
For I''_{kEE} 85 % of the initial symmetrical short-circuit current may be used as a maximum value.

I''_{k1} Initial symmetrical short-circuit current for a line-to-earth short-circuit, calculated in accordance with the IS 13234.

I_E Current to earth.

I_N Current via neutral earthing of the transformer.

r Reduction factor (see IS13234-3 clause 7 and 8).

If the lines and cables leaving the substation have different reduction factors, the relevant current shall be determined.

[a] If several current paths are possible a split up may be considered.

[b] If there is no automatic disconnection of earth faults, the need to consider double earth faults depends on operational experience.

[c] The earthing conductor of the Petersen coil shall be sized according to the maximum coil current.

[d] It shall be checked if external fault may be decisive.

e	The minimum cross-sections of Annex C are to be considered.
f	In case of not well compensated system the general approach of 10 % I_C cannot be applied. The reactive/capacitive component of residual current shall be considered additionally.
g	Short-term earthing of system with resonant earthing starts automatically within 5 s after earth fault detection.
h	In case of a fault in the substation the capacitive earth fault current I_C shall be considered. In case of further coils external to the substation they may be considered

10.4.2 Power system faults

The objective is to determine the worst case fault scenario for every relevant aspect of the functional requirements, as these may differ. The following types of fault shall be examined at each voltage level present in the electrical power installation:

a) three phases to earth;
b) two phases to earth;
c) single phase to earth;
d) if applicable: phase to phase via earth (cross-country earth fault).

Faults within and outside the electrical power installation site shall be examined to determine the worst fault location.

10.4.3 Lightning and transient overvoltages

Lightning and switching operations are sources of high- and low-frequency currents and voltages. Surges typically occur when switching long cable sections, operating GIS disconnectors or carrying out back-to-back capacitor switching. Successful attenuation requires sufficient electrode density at injection points to the earthing system to deal with high-frequency currents, together with an earthing system of sufficient extent to deal with low-frequency currents. The HV earthing system shall form part of the lightning protection system and additional earthing conductors may be required at connection points between the lightning protection system and the earthing system.

Relevant electromagnetic compatibility and lightning standards shall be used to address specific aspects related to the transient performance of the earthing system and its components.

When an industrial or commercial electrical power installation includes more than one building or location, the earthing system of each shall be interconnected. Since during surges such as lightning strokes, there will be a large difference in potential between the earthing systems of each building and location in spite of the interconnection, measures shall be taken to prevent damage to sensitive electrical equipment connected between different buildings or locations. Where possible, non-metallic media, such as fibre optic cable, should be used for the exchange of low-level signals between such locations.

10.4.4 Construction work on earthing systems

Where construction work involves an existing earthing system, protective measures shall be taken to ensure the safety of persons during fault conditions.

10.4.5 Measurements

Measurements shall be carried out after construction, where necessary, to verify the adequacy of the design. Measurements may include the earthing system impedance, prospective touch and step voltages at relevant locations and transferred potential, if appropriate. When measuring touch and step voltages under test conditions, e.g current injection test, two choices are possible. Either measure the prospective touch and step voltages using a high impedance voltmeter or measure the effective touch and step voltages appearing across an appropriate resistance which represents the human body.

10.4.6 Maintainability

10.4.6.1 Inspections

The construction of the earthing system shall be carried out in a way that the condition of the earthing system can be examined periodically by inspection at least once in two years. Excavating at selective locations and visual inspection are appropriate means which shall be considered.

10.4.6.2 Measurements

Design and installation of the earthing system shall allow measurements to be carried out periodically or following major changes affecting fundamental requirements, or even for continuity tests.

10.5 SIMPLIFIED CALCULATIONS

10.5.1 calculation of earth resistance

Estimation of the total impedance to remote earth is one of the first steps in determining the size and basic layout of an earthing system. The resistance depends primarily on the area to be occupied by the earthing system, which is usually known in the early design stage. As a first approximation, a minimum value of the substation earthing system resistance in uniform soil can be estimated by means of the formula of a circular metal plate at zero depth.

$$Z_E = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} \qquad \text{.....(1)}$$

where
Z_E is the substation earth impedance in Ω.
ρ is the soil resistivity in Ωm
A is the area occupied by the earth grid in m^2

In the case of a grid-rod combination in uniform soil, a combined length of horizontal conductors and earth rods will yield a slightly conservative estimate of L_T, because earth rods usually are more effective on a per unit length basis

$$Z_E = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} + \frac{\rho}{L_T} \qquad \text{….. (2)}$$

where
L_T is the total buried length of conductors in m

The resistance of any actual grounding system that consists of a number of conductors is higher than that of a solid metallic plat. The difference will decrease with the increasing length of buried conductors and will approach 0 for infinite L_T, when the condition of a solid plate is reached.

For grids without ground rods, the following formula may be used,

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right]$$

where
h is the depth of the grid in m

Note:

1. The prevailing fault current I_F shall be obtained from the supplier. The designer may add a safety margin of 25 % in the fault current if future growth to be considered.
2. If the supplier is not aware of earth fault current and provide Line to Line Short circuit fault current, the earth fault current shall be calculated. See 5.1
3. From the calculated / available I_F, current through the earth electrode I_E shall be calculated.

10.5.2 Determination of the earth potential rise.

The earth potential rise U_E is given by:

$$U_E = Z_E \times I_E \qquad \text{(see 13.4, Fig. 85)}$$

Where,

Z_E is the impedance to earth (for example from the measurement in accordance with 13.4b) or from the calculation in accordance with 13.4c),
I_E is the current to earth.

The current to earth during measurement is given by:

$$I_{EM} = r \times I_M$$

The impedance to earth is given by:

$$Z_E = \frac{U_{EM}}{I_{EM}}$$

The earth potential rise in case of fault is given by:

$$U_E = I_E \times Z_E = U_{EM} \times \frac{I_E}{r \times I_M}$$

For an earth fault in a three-phase system and for a similar earth wire reduction factor of all overhead lines leaving the substation, the current to earth can be determined by:

$$I_E = r \times \sum 3\, I_0$$

Where,

r is the earth wire reduction factor,
$\sum 3\, I_0$ is the vector sum of the currents of all phase conductors of this system flowing to the substation.

For a fault in the substation $\sum 3\, I_0$ is the difference between the earth fault current and the transformer neutral current.

If the earth wire reduction factors of the lines A, B, C ... leaving the substations are different, the current to earth is given by:

$$I_E = r_A \times 3I_{0A} + r_B \times 3I_{0B} + r_C \times 3I_{0C} + \cdots$$

Where,

I_{0A} is the zero-sequence current of a phase conductor (for example phase L1) of the line A, I_{0B} accordingly of the line B, etc,
r_A is the earth wire reduction factor of the line A, r_B of the line B, etc.

NOTE This equivalent circuit includes the chain impedance Z_∞ of the tower foot resistances and earth wire of the outgoing overhead lines. In practise the chain impedance is almost achieved after a few spans. For overhead lines longer than a few spans the effect of magnetic coupling results in an earth wire current, which is considered by the reduction factor.

For a cable leaving the substation, instead of the earth wire reduction factor the cable sheath reduction factor shall be used in the equation above for I_E.

For cables with insulated sheath which lead fault current to the substation the cable sheath reduction factor is the primary effect. In addition, the chain impedance (cable sheath/neighbouring earth grids) can be considered if the cable is significantly longer than the sections forming the chain impedance.

10.6 RECOGNIZED SPECIFIED MEASURES M

(see Fig. 4)

TABLE 27 CONDITIONS FOR THE USE OF RECOGNIZED SPECIFIED MEASURES M TO ENSURE PERMISSIBLE TOUCH VOLTAGES UTP

Fault duration t_f	Earth Potential rise U_E	On outer walls and fences around installations	Inside the installation	
			Indoor installation	Outdoor installation

$t_f > 5s$	$U_E \leq 4 \times U_{Tp}$	M1 or M2	M3	M4.1 or M4.2
	$U_E > 4 \times U_{Tp}$	Proof $U_T \leq U_{Tp}$		
$t_f \leq 5s$	$U_E \leq 4 \times U_{Tp}$	M1 or M2	M3	M4.2
	$U_E > 4 \times U_{Tp}$	Proof $U_T \leq U_{Tp}$		

M 1	Recognized specified measures for the outer walls of buildings with indoor installations. One of the recognized specified measures M 1.1 to M 1.3 may be applied as protection against external touch voltage.
M 1.1	Use of non-conductive material for the outer walls (for example masonry or wood) and avoidance of earthed metal parts which can be touched from outside.
M 1.2	Potential grading by a horizontal earth electrode which is connected to the earthing system, at a distance of approximately 1 m outside the outer wall and not deeper than 0,5 m with a recommended depth of 0,2 m to 0,3 m.
M 1.3	Insulation of the operating location: The layers of insulating material shall be of sufficient size, so that it is impossible to touch the earthed conductive parts with the hand from a location outside the insulating layer. If touching is possible only in lateral direction, an insulating layer width of 1.25 m is sufficient. The insulation of the operating location is considered to be sufficient in the following cases: − a layer of gravel or crushed stones with a thickness of at least 100 mm, − a layer of asphalt with adequate base (for example asphalt on gravel basement), − an insulating mat with a minimum area of 1 000 mm x 1 000 mm and a thickness of at least 2,5 mm or a measure ensuring equivalent insulation.
M 2	Recognized specified measures for external fences at outdoor installations. One of the recognized specified measures M 2.1 to M 2.3 may be applied as protection against external touch voltage; at gates in external fences recognized specified measure M 2.4 shall also be considered.
M 2.1	Use of fences of non-conductive material or of plastic-covered material e.g. wire mesh with appropriate non-conductive links.
M 2.2	When using fences of conductive material, potential grading by a horizontal earth electrode, which is connected to the fence, at a distance of approximately 1 m outside the fence and at a maximum depth of 0.5 m. The connection of the fence to the earthing system is optional and in accordance to options described in 10.7.1. (however, see recognized specified measure M 2.4).

M 2.3	Insulation of the operating location in accordance with recognized specified measure M 1.3 and earthing of the fence either in accordance with 10.7.1 or by connection with the earthing system.
M 2.4	If gates in external fences are connected directly to the earthing system or via protective conductors or metal sheaths of cables for staff locator systems etc., then at the opening area of the gates a potential grading or insulation of the operating location in accordance with recognized specified measure M 1.3 shall be applied. When the gates in a separately earthed conductive fence are to be connected to the main earthing system, the gates shall be isolated from the conductive parts of the fence in a way that establishes an electrical separation of at least 2.5 m. This may be achieved by using a fence section of non-conductive material or by using conductive fencing with insulated inserts at the end. Care shall be taken to ensure the electrical separation is maintained when the gates are fully opened.
M 3:	Recognized specified measures in indoor installations. Within indoor installations one of the recognized specified measures M 3.1 to M 3.3 may be applied.
M 3.1	Equipotential grading by embedding grid-type electrodes in the building foundations (for example of a minimum cross-section of 50 mm^2 and maximum mesh widths of 10 m or structural steel mats) and connection to the earthing system at a minimum of two separate locations. If concrete steel reinforcement is also used for dissipating the fault current, the capability of the steel reinforcement shall be checked by calculation. If structural steel mats are used, then the adjacent mats shall be interconnected at least once and all the mats together shall be connected to the earthing system at a minimum of two locations. At existing buildings, a horizontal earth electrode may be used, which shall be buried in the soil near the outside walls and connected to the earthing system.
M 3.2	Construction of the operating locations from metal (for example a metal grid or metal plate) and connection to any metal parts which shall be earthed and which can be touched from the operating location.
M 3.3	Insulation of the operating locations for the earth potential rise in accordance with recognized specified measure M 1.3. For equipotential bonding the metal parts which shall be earthed and which can be simultaneously touched from the operating location, shall be interconnected.
M 4:	Recognized specified measures in outdoor installations.
M 4.1	At operating locations (only applicable for fault duration t_f > 5 s): Potential grading by a horizontal earth electrode at a depth of approximately 0.2 m and a distance of approximately 1 m from the equipment to be operated. This horizontal earth electrode shall be

	connected to all metal parts which shall be earthed and which can be touched from the operating location. or Construction of the operating locations from metal (for example metal grid or metal plate) and connection to the metal parts which shall be earthed and which can be touched from the operating location. or Insulation of the location in accordance with recognized specified measure M 1.3. For equipotential bonding the metal parts which shall be earthed and which can be simultaneously touched from the operating location, shall be interconnected.
M 4.2	Burying a horizontal earth electrode surrounding the earthing system in the form of a closed ring. Inside this ring, a meshed earth grid shall be buried, whose individual meshes have a maximum size of 10 m x 50 m. At individual parts of the installation, which are situated outside of the ring and which are connected to the earthing system, a grading earth electrode at a distance of approximately 1 m and a depth of approximately 0.2 m shall be provided (for example lightning masts, which are connected to the earthing system via protective conductors).

10.7 DETAILED MEASURES FOR EARTHING OF EQUIPMENT AND INSTALLATIONS

10.7.1 Fences around substation installations

Bare metallic fences shall be earthed. A number of earth points shall be used, for example at each corner. In accordance with local conditions (fence inside or outside the earthing system) the earth connection should be made either to the high voltage earthing system or to separate earth electrodes. Fig. 60 is illustrating the principle together with the information in 10.6, item M 2.2.

Bare metallic parts of the fence coated with insulating material need not be earthed.

All physical breaks in the fencing surrounding a substation installation, for example the gates, shall be bonded in such a way as to ensure that dangerous potentials do not arise between the parts of the fence.

For remote metallic fences not connected to the earthing system, natural grounding of the fence posts with local bonding or establishing a potential grading earth electrode, may be sufficient as illustrated in Fig. 61

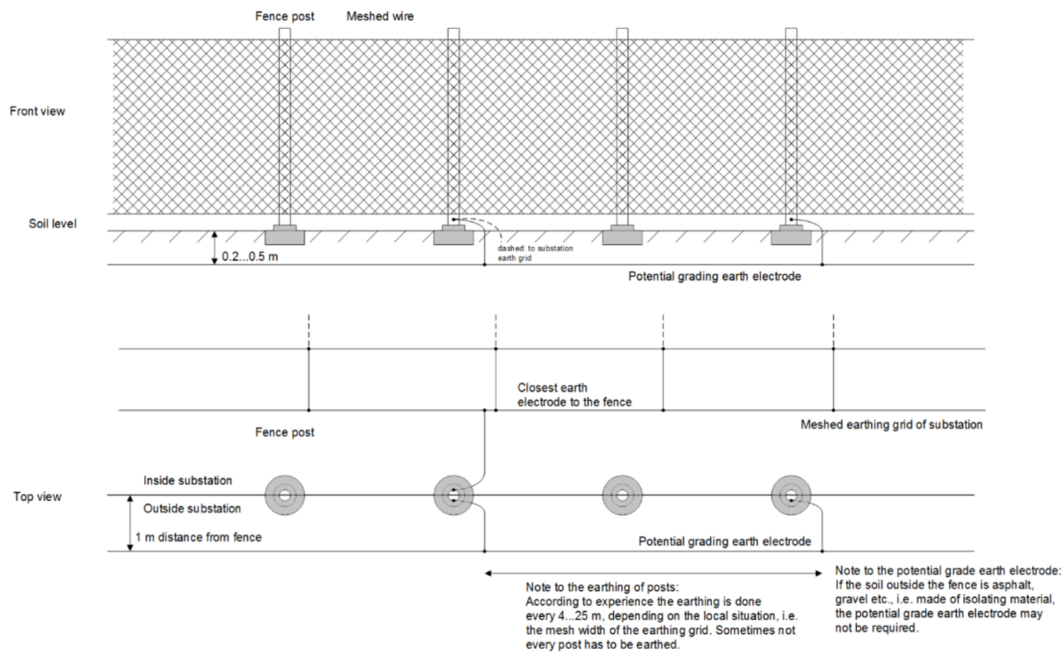


FIGURE 61 EARTHING PRINCIPLE OF METALLIC FENCE, INTERCONNECTED TO EARTHING GRID OF SUBSTATION

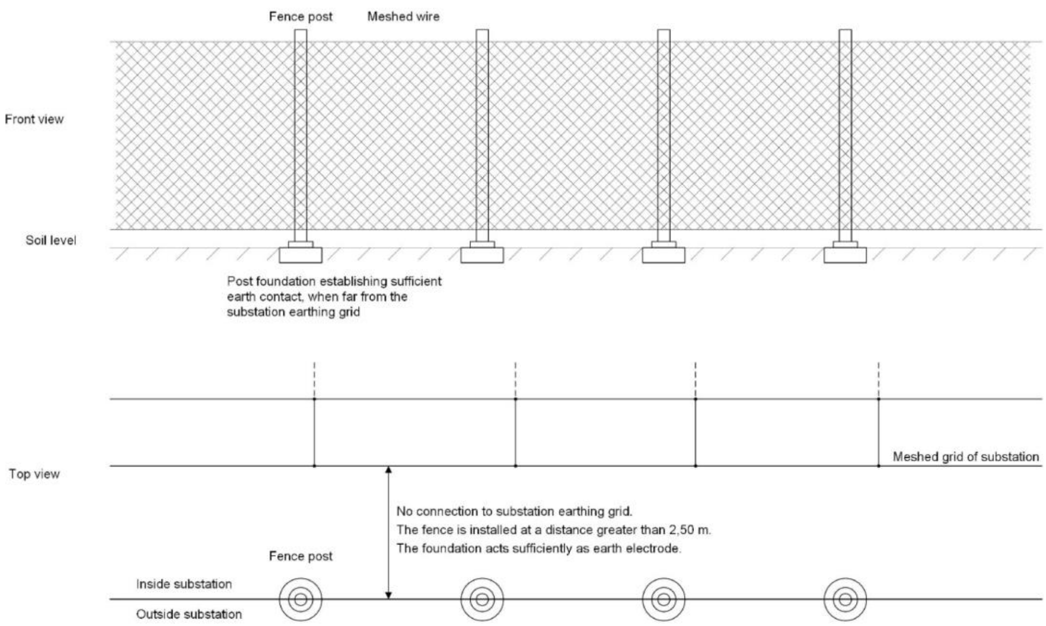


FIGURE 62 EARTHING PRINCIPLE OF REMOTE METALLIC FENCE, EARTHED INDEPENDENTLY

10.7.2 Pipes

Metallic pipes within the substation site should be connected to the substation earthing system.

The use of metallic pipes, for example water supplies, from outside the substation perimeter, should be avoided and non-metallic materials or isolating joints should be used instead.

10.7.3 Traction rails

The rails of non-electric tracks that cross into the substation site shall be connected to the substation earthing system.

Suitable insulating rail joints should be included at the boundary of the substation site such that the electrical separation is maintained to the remaining parts of the traction system. In some cases, two insulating rail joints could be required to prevent short-circuiting by the traction unit. Special attention shall be paid at traction operating locations. For the determination of measures, the owner of the railway system shall be consulted and Transferred potentials to telecommunication and other systems should be taken into account.

10.7.4 Pole mounted transforming and/or switching installations

In general, all pole mounted transforming equipment combined with switching equipment, or not, shall be earthed.

In cases, where at the pole only a transformer is situated, a minimum earthing system (e.g. an earth rod or a ring earth electrode or the footing of a conductive pole) fulfils the earthing requirements of the transformer.

In general, switching equipment mounted on poles made of steel or other conductive material or made of reinforced concrete shall be earthed. At the operating position the permissible touch voltage according to 5.2 shall be met. This can be accomplished by, e.g.:

- the design of the earthing system, or
- an equipotential bonding by means of an earth mat, or earth ring electrode, or
- using insulation of operating location, or
- using insulating equipment (e.g. insulating tools, gloves or mat) when the switching operation is done, or
- by a combination of the measures described.

Switching equipment mounted on poles made of non-conductive material need not be earthed. If it is not earthed, mechanically reliable insulators (for example unsplit core insulators) shall be installed in operating linkages outside the normal arm's reach. These shall be designed for the nominal voltage of the system. The part of the actuator which can be touched from the ground shall be earthed to dissipate possible leakage currents. An earth rod of at least 1 m length or a horizontal earth electrode around the pole at a distance of approximately 1 m is sufficient. Earth electrodes and earthing conductors shall satisfy the minimum cross sections (see 7.3).

10.7.5 Secondary circuits of instrument transformers

The secondary circuits of all instrument transformers shall be earthed as close as possible to the instrument transformer's secondary terminals.

The minimum cross-section are does not apply to this type of equipment. A minimum cross-section of 2.5 mm^2 copper is required; if the earthing conductor is mechanically unprotected then 4.0 mm^2 copper is necessary.

If, however, it is necessary to earth at some other points, then there shall be no possibility of the earth being inadvertently disconnected.

10.8 TYPICAL EARTHING ARRANGEMENT

A typical earthing arrangement for an outdoor switchyard is shown in Fig. 62. A typical earthing arrangement for connecting the reinforcement of foundations of substation building and switchyard RCC masts is shown in Fig. 63.

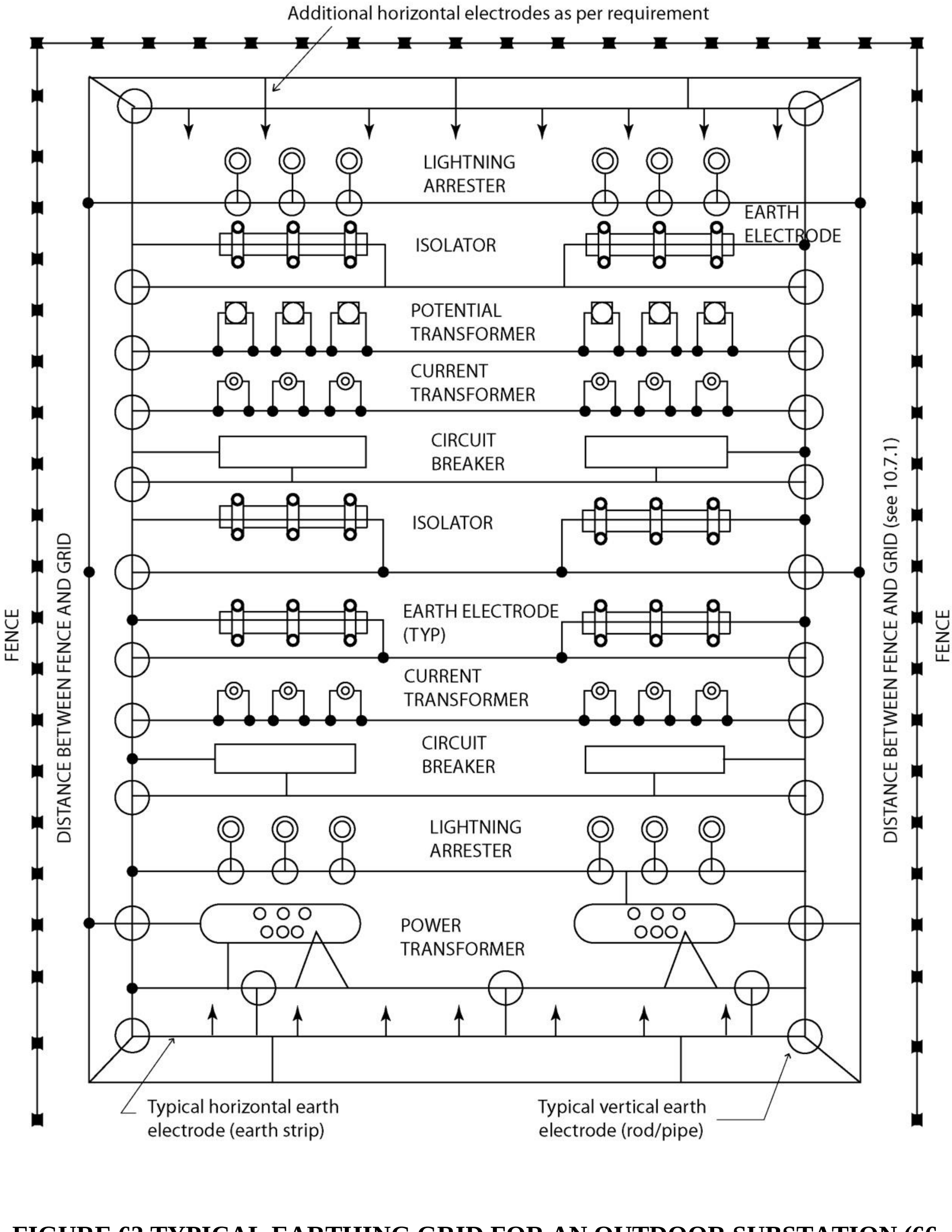
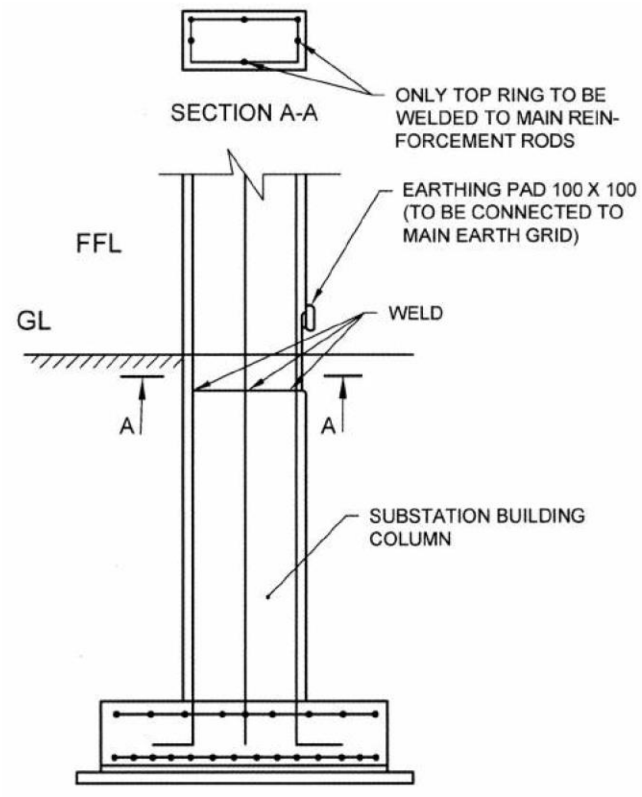


FIGURE 63 TYPICAL EARTHING GRID FOR AN OUTDOOR SUBSTATION (66 KV AND ABOVE)



NOTES

1. Top ring should be half the size of main vertical reinforcement rod.
2. Minimum of two extreme columns should be earthed like this in each substation.
3. This is also applicable to RCC masts and equipment supports in OD switchyard.
4. Inserts other than earthing pads may or may not be welded to reinforcement.

FIGURE 64 EARTHING AND FOUNDATION REINFORCEMENT (CONCRETE ENCASED EARTH ELECTRODE)

The perimeter fence may need to be earthed separately from the main station earth electrode system (see 10.7.1).

The tertiary winding of a power transformer should be connected to the transformer tank by a connection of sufficient cross-sectional area to carry the primary short-circuit current.

In the case of pole mounted transformers on overhead line systems, temporary over voltage at LV installation during faults in the HV system and mitigation recommendation in 5.3 shall be considered.

In the case of pole mounted transformers on overhead line systems, difficulties may arise in areas of high soil resistivity. Here, if the pole carries also isolating switchgear with low level operating handle, up to three separately earthed electrode systems may be required. The neutral of the low voltage system is usually earthed one pole span away from other earth electrodes. The high voltage metalwork (transformer tank, switch framework, support metal work), consists of one earth electrode at or near the pole. In addition, an earth mat should be provided, near the ground surface, in the position taken up by a person operating the switch handle. This mat should be connected to the switch handle. The mat should be electrically separated from the main electrode. This is considered to be achieved by spacing the nearest element of that electrode at least 1 m from the periphery of the mat. The top of the main electrodes should be at least 250 mm and preferably 750 mm below the ground. The earthing wire to the main electrode of outdoor type rubber or PVC-insulated cable up to a point 2 m above ground level shall be insulated. This cable, between the bottom of the pole and the electrode should be laid in a 50 mm diameter earthenware duct filled solid with bitumen.

10.9 GENERAL EARTHING ARRANGEMENTS AT POWER STATIONS OF PUBLIC ELECTRICITY SUPPLIES

10.9.1 Neutral Earthing of Generator Circuits

At large power stations for electricity supply the generation circuits generally comprise a star-connected stator circuit with an operating voltage up to about 32 kV, directly connected to a step-up delta/star transformer, the higher voltage winding generally operating at 132 kV, 275 kV or 400 kV, with the transmission system neutral point directly earthed.

The following three methods have been used for earthing the neutral of the generator windings:

a. Earthing through the primary winding of a matching transformer, with resistor connected across the secondary winding,
b. earthing through a resistor, and
c. earthing through the primary winding of a voltage transformer.

Method (a) — is current practice, the design being such that the maximum sustained earth fault current in the generator circuit is restricted to 10 to 15 A, thus limiting the damage at the point of fault. The neutral and earthing connections, however, are of adequate capacity to withstand for 3 s the earth fault current that would flow in the event of the matching transformer terminals flashing over during an earth fault. The resistor used for the arrangement is of the metallic grid-non inductive type.

Method (b) — can be used to achieve the same degree of fault-current limitation, by design of a suitable high-current resistor, but is not preferred on the grounds of its less robust construction than that of the equipment used in method (a). It was earlier practice, however, to individually earth each generator at power stations by liquid earthing resistors designed to limit the earth-fault current to about 300 A.

Method (c) — is now historic, but had the advantage that minimal damage resulted at an earth fault. If desired, the generator could remain in circuit while operational arrangements were made to permit its withdrawal. However, this imposed a higher voltage stress on the stator windings and plant on the un-faulted phases, and the machine design usually imposed limitations on this. The output from the secondary winding of the voltage transformer could be arranged to activate an alarm or trip the generator circuit as desired. In designing the neutral and earthing connections to the voltage transformer, the earth-fault current used was that resulting by flashover of the voltage transformer during an earth-fault.

Some old power stations have generators connected directly to distribution system busbars. In general, the neutral terminals of such generators have been earthed via liquid neutral earthing resistors of such a value that the maximum sustained earth fault current is of the order of full load current of the generator. Installations of neutral point switchboards with switching of neutral points and earthing resistors have been abandoned in favour of individual unswitched earthing resistors.

10.9.2 Earthing of Power Station Auxiliary Systems

There are, in common use, three methods of earthing the neutral point in power station auxiliary systems:

a. Solidly earthed;
b. Earthing through a voltage transformer (or voltage relay) with a surge diverter (but not a fuse) shunting the primary winding (or the relay); and
c. Resistance earthing.

Methods (a) and (c) involve the automatic disconnection of the individual fault circuit.

With method (b), an alarm can be arranged to be operated from the secondary of the voltage transformer and the scheme enables all auxiliaries to be kept in service until it is convenient to make the auxiliary switchboard dead.

Method (a) is normally used in power stations with smaller generating sets and method (c) used in the larger power stations. Method (b) has certain disadvantages, such as the complication in arranging for speedy identification of the individual faulty circuit and the possible difficulties arising from functioning of the surge diverter. How ever with the availability of Insulation monitoring system and insulation fault locating system up to 1000 A a.c., could make the method (b) reliable for auxiliary power system.

Note: See 10.2.3.6 or 5.1 for earth fault current calculations.

10.10 EQUIPMENT EARTHING AT POWER STATIONS

Practice in equipment earthing at power stations is identical to that for large substations not giving external low voltage supplies (see 10.2.3). A common earth is used for the neutral earthing of generators and power station auxiliaries, and for all equipment framework, cladding, power cables sheaths and extraneous metalwork not associated with the power systems, other than the perimeter fence (see 10.7.1).

10.11 POWER STATION AND SUBSTATION EARTH ELECTRODES

10.11.1 General

The required characteristics of earth electrode system are:

a) a stable resistance, under all variations due to climatic conditions, for the fault currents envisaged capable of reducing the touch and step potentials below the tolerable value;
b) current carrying capability for all currents and durations that may arise in normal operating conditions or during fault or surge discharge conditions, without undue increase in resistance;

c) suitable location in the vicinity of any lightning discharge devices such that earthing conductors from such devices are as short and straight as possible to minimize surge impedance; and
d) earth electrode installations should be durable and of such material and design to avoid corrosions.

Where the soil of a site is hostile by virtue of alkalinity or acidity it may be necessary to embed earth electrodes in rammed neutral soil or in concrete to avoid corrosion.

Earth electrode systems can also represent some hazard to adjacent underground services or structural steelwork through electrolytic action between dissimilar metals (see 7.3.6.6). Where this danger cannot be avoided by selection of compatible metals, the adoption of cathodic protection or other remedial action may be necessary.

At power stations and substations, the steel reinforcement in foundations and piles can be used to provide an effective electrode system, without necessity to provide further buried electrodes. Where piles are used they should be bonded securely (see 7.3.3.5) and connected to earth bonding bars at least four points.

Where no substantial adventitious earths exist or where they are in adequate, it is necessary to install electrodes (see 8).

All cladding or steel work at a station should be bonded to the earthing system as should all structural steel work, but attention is drawn to precautions against undue reliance on the latter as an electrode.

10.11.2 Choice and Design

Where electrodes of large surface area are necessary to provide the requisite current carrying capacity (applicable above 66 kV), earth plates are recommended (see Table 24). Pipes with large diameter also serves the purpose.

Note: For this application material in cast-iron are also allowed.

For lower current rating requirements, driven rods are preferred, usually, of the Steel with electro- deposited copper coating. They are generally driven in groups, preferably with a spacing of not less than their length, although this is not always achievable. Closer spacing reduces their effectiveness. The use of driven rods is advantageous where the deeper strata of a site have a lower resistivity than the upper strata but they may not be suitable if the site is stony or has rock sub-strata.

Note: the driven rods shall be of sufficient size (e.g. ≥ 20 mm dia.) to withstand the driving force.

At large substation compounds, it is usual to lay a mesh of underground earth strips to which system neutral terminals and the earthing conductors from above-ground structures are connected. In addition to providing an approximately equipotential surface over the substation, the earth strip mesh frequently suffices to provide an electrode of suitable resistance and current carrying capacity without augmentation.

10.12 EARTHING CONDUCTORS FOR POWER STATIONS AND SUBSTATIONS

10.12.1 Disposition

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. In addition, all other metal plant in or about the station should be connected to the main station earthing system. The most efficient disposition of earthing conductors required will depend on the layout of equipment and the following may be taken as a guide:

10.12.1.1 Indoor Equipment

An main earth bar (MET) should be provided and connected to the framework of each item and to the nearest earth raisers. There should be a connection to the earth electrodes system at each end of the earth bar or, if this is in the form of a ring, at several points on the ring. These connections may, depending on the layout be buried cables of a size 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 bar (MET) may be required which should be cross connected to its companion bar at one point at least in each section of the switchboard. The indoor equipment should be provided with adequate size pad / stud having proper surface contact with earth bar / raisers.

The main earth bar should be so placed that cable sheaths can be readily connected to it. When cables are so connected, the bonds should be made to the cable gland on which the lead sheath should be bonded, and the armouring clamped. The main earth bar should be accessible for the connection of any detachable earthing devices provided with the switchgear.

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

Where busbar protection is effected at switchboards by frame leakage, two main earth bars are required. The frame bar interconnecting the framework of the switch units will be connected to the true earth bar through a current transformer and bolted links for test purposes. The true earth bar should be run separately from the frame earth bar in convenient position for the connection of cable sheaths and earthing devices. Where it is mounted on the switch units, it should be insulated therefrom by insulation capable of withstanding a test voltage of 4 kV rms a.c. for 1 min.

Where insulated cable glands are used, it is recommended that ‘island’ insulation should be provided to facilitate testing.

10.12.1.2 Outdoor Equipment (Excluding Pole Mounted Transformers)

A main earth bar should be provided, so disposed as to allow of the shortest 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 electrode system. 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 possible.

The operating mechanisms for outdoor air break switch 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 air-break switch-disconnector or earth switch base, or the circuit-breaker structure. The further contribution to safety given by an insulated insert in the mechanism drive is less compared with that obtained from such a branch earth connection and, therefore, insulated inserts are not recommended in operating mechanisms of apparatus installed in substations. While sites covered with hard core and stone chippings will constitute a surface layer with a relatively high specific resistance, in the interests of safety, a metal grid can be provided at the operating points to give a level standing area and an earth connection made from this grid to the operating handle.

Where it can be proved by visual inspection and continuity resistance measurement that the current carrying capacity of a main aluminium or steel member or welded sections forming a structure are at least equal to that of the required size of earth conductor, the structure may form part of the connection and there is no need to fix an earth conductor along this section. A structure made up of bolted sections should not be relied upon to form an efficient earth bond between equipment and the main earth grid, and loops bonding across structural joints are required.

Connections to metal cladding, steel structure and metal door frames and windows or any other metallic panels should be made inside buildings.

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 arresters should be of sample cross-section and as direct as possible; they should not pass through iron pipes which would increase the impedance to surges of the connection. The earth connections of the arresters should be interconnected with the main earthing system since, for the effective protection of the substation equipment, a definite connection of low impedance between the equipment and surge arresters is essential (See IS 15086: Part 5: 2020 cl5.2.5.5.4 e.g. the arrester is earthed directly at the transformer tank. The loop L1 + L2 + L3 + LMO is short). In this way, the inductances are kept to a minimum.

10.12.2 Design

10.12.2.0 General

The term earthing grid applies only to that part of the grid which is buried in soil. For design calculations of the grid resistance to the soil, only the buried part of the grid is to be taken into account. The part of the grid embedded in concrete and also reinforcement do lower the combined grid resistance.

10.12.2.1 Conductors installed above ground

Earthing conductors for power stations and substations will normally be selected from copper or aluminium or steel sections adequately rated in size to carry the designed earth fault or three phase fault current for the appropriate designed maximum duration without exceeding a temperature given in Table 17. Compliance with this requirement will additionally ensure satisfactory bonding without excessive voltage difference along any conductor.

The required cross-sectional area of the earthing conductor is determined by the choice of conductor material and the maximum duration of the fault current. The generally accepted duration for design purposes are 1 s, provided, adequate fast acting earth fault protection shall be provided to isolates the system within 1 s..

10.6.2.2 Conductors buried as strip electrodes

The earthing grid consists of horizontal conductors which may be connected to vertical electrodes forming an earthing grid. It is recommended that the duration of earth fault current should be taken as 1 s all voltage levels, provided fast acting earth fault protection is provided which isolates the system within 1 s for voltage below 33 kV.

The other factors which shall be taken as the consideration while designing the earth grid are given below:

a) Factor of safety for the ability of the earthing conductor to carry the fault current during the period the fault persists, without any thermal and mechanical damage to the conductor;
b) The relative importance of the installation for which the earthing system is being designed;
c) The likely increase in the near future in the fault level in the area where the earth conductor has been installed;
d) Operating time of the protective devices;
e) Corrosion of the earth conductor;
f) Factor of safety for workmanship in jointing, etc; and
g) Maximum permissible temperature rise for the buried part of the grid (see Table 17 for temperature limits in earthing conductor).

10.12.2.3 Sizing

The amount of current flowing to earth (I_E) through that part of the grid should be considered. The cross-section of the area of the grid conductor shall not be less than the value stipulated in 7.3.2, where the value of k is to be taken from Table 17.

10.12.3 Construction

10.12.3.1 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, therefore, has to 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.

10.12.3.2 Laying conductors

Buried bare conductors (see Table 24) forming part of the earthing system should be at about 300 to 600 mm deep which, in addition to giving protection to the conductor and connections, should ensure that it will normally be below frost line. Aluminium should only be used for above ground connections.

NOTE — If the indigenous soil is hostile to copper, that is, acidic with a pH value of less than 6 or alkaline with a pH value of more than 10, soil surrounding the electrode should be different, or the electrode is encased in concrete.

Where an adequate earthing installation is provided, the supplementary connections from the main earth grid to equipment may be laid at a depth and by routes most appropriate to site connections. For convenience in connecting to equipment, they may be laid at a depth of about 250 mm, and as they are, therefore, in ground more subject to seasonal or progressive changes of resistivity, it may be assumed that they make negligible contribution towards reducing station earth resistance. On the other hand, they do serve to reduce surface gradient within the station site. Conversely where these connections are also required to improve the earth value of the station, the 600 mm depth is required. The above recommendations deal mainly with stations on normal sites. Where ground conditions restrict the installation depth or where the soil resistivity is excessive, additional measures may be required beyond the station boundary to improve the overall earth value.

The earthing installation within the station will, however, bond the station plant and restrict touch potentials to acceptable limits.

Where bare metal conductor is buried under metal fencing, and the fencing is independently earthed, the conductor should be insulated by threading through non-metallic pipe extending for at least 2 m each side of the fence or alternatively insulated conductor may be used.

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

10.12.3.3 Fixing conductors

In fixing aluminium or copper conductors to structures, etc, insulated or Stainless steel clips should be used to avoid drilling and prevent electrolytic action. Galvanized clips should not be used. Fixing 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 (for example, 100 mm from the top).

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

Sharp bends required in aluminium strip should be formed by the use of a bending machine.

Aluminium earthing conductors will give satisfactory performance in contact with concrete, cement, plaster and brickwork, if they are used at the surface, however aluminium shall not be buried in concrete or soil. In outdoor installations, the conductor will weather to a grey appearance and in marine or industrial atmospheres slight surface pitting may occur. This will not affect performance since the sections are relatively large. The interfaces of all 'mechanical' joints should be protected with a suitable electrical joint compound, particularly any bimetallic joints. All bimetallic joints should then be encapsulated in a grease impregnated tape, mastic compound or bitumastic paint, etc, to exclude moisture.

In general, aluminium should only be used above ground and not inside concrete and the connections to earth electrodes made above ground with bimetallic joints. Aluminium can be used below ground only if efficiently protected or sheathed against contact with soil and moisture.

10.12.3.4 Jointing conductors

a) General — All crossings of conductors in the main earth grid should be bonded. Compression type joints may be used for stranded conductors. Non-conductor strip should be drilled for a bolt having a diameter greater than one-third of the width of the strip. If this diameter will be exceeded, than a wider flag should be jointed to the strip.
   Note: Aluminium shall not be used in buried (soil or concrete) application.

b) Aluminium to aluminium — When possible, joints on strip conductor should be arc welded using either the tungsten inert-gas arc (TIC) or metal inert gas arc (MIG) techniques. Oxy-acetylene gas welding or brazing may also be used.

   Ranges of compression fittings and tools are available for round conductors. Round conductors can also be flattened and punched with suitable tools to form a terminal.

   Round and rectangular conductors can be joined with bolted clamps.

   Rectangular conductors can 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 greased or 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 for the joints and procedures.

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

c) Aluminium to copper — Joints between aluminium and copper should be of the bolted type and be installed in the vertical plane at a minimum distance of 150 mm above ground level.

The rating surface of the aluminium should be cleaned thoroughly by wire brushing and greased or an approved jointing compound applied and the copper tinned. Grease or an approved jointing compound should be applied to the melting surface of the aluminium. After bolt tightening by torque spanner, excess grease or compound should be wiped off and discarded, and the joint protected from the ingress of moisture by the application of suitable plastics compound or irradiated polyethylene sleeve with mastic lining. Alternatively, the joint may be protected by a bitumastic paint.

Aluminium conductor connections to equipment should, where possible, be in the vertical plane. Surface preparation of the aluminium and the making of the joint should be as previously described. The finished joint should be protected by a bitumastic paint.

d) Copper to copper — The following methods may be used:
   1) Brazing using zinc-free brazing material with a melting point of at least 600°C;
   2) Bolting;
   3) Riveting and sweating; and
   4) Exothermic welding.

Earthing conductor connections to equipment should, as far as practicable, be made onto vertical surfaces only. In the case of painted metal, the paint should be carefully removed. Earthing conductors should be tinned where connected to galvanized steelwork. No connection point should be less than 150 mm above ground level. In any position, subject to corrosion, the finished joint should be protected by bitumastic paint.

e) Loops for portable earths - Loops of plain aluminium or copper should be provided on the earth conductor at each location where portable earthing leads may be applied. The loops should not be less than 180 mm long and 75 mm clear of the earth conductor; they should be at a convenient height and should be formed separately, not by bending the earth strip itself. Loops should be jointed to the earth conductor using a method given in 10.6.3.4 (d).
f) Steel — For steel, (bare of galvanized) it is recommended to use only welded joints. The joints shall be protected with corrosion proof cover.
g) Copper Bonded steel – Exothermic welding or by stainless steel clamps.

10.13 EARTHING OF HIGH VOLTAGE CABLE SHEATHS

10.13.1 Three-Core Cables

Modern high voltage power cables are generally provided with a polymeric insulating over sheaths. The sheath of solid type cables are generally directly earthed at their terminations and joints, the cable sheaths being bonded at joints. The sheath earth connections of pressure type cables are generally made via a removable link in a lockable box to permit periodic testing of the over sheath insulation, the joints being insulated, but the sheaths bonded through. The test requirement also means that insulating glands should be provided at the cable termination boxes of transformers, switchgear, etc and at cable sealing ends or joints.

10.13.2 Single-Core Cable Tails

The sheaths of single-core cables have a longitudinal induced voltage, the magnitude of which is directly proportional to the current flowing in the core. When both ends of a single-core cable are bonded to earth, a current flows in the sheath and the thermal effects of this sheath current derates the capacity of the cable core. Where this derating is unacceptable and the value of the standing induced voltage is acceptable, it is usual to earth the sheaths of the single-core cables at the trifurcating box or in the case of single-core mains, the end of the trefoil formation, the cable glands at sealing ends or plant cable boxes being of the insulated type. The acceptable level of the maximum sheath voltage is generally taken as 65V with full rated current flowing in the cable, but where the ratio of fault current to full rated current is so high that the voltage developed across an insulated gland is unacceptable, it is necessary to derate the permissible voltage to some level lower than 65 V.

10.13.3 Single-Core Cable Mains

The choice of termination and earthing arrangements for single-core cable mains is a matter of economics. The possible methods of earthing are as follows:

a) Solid Bonding — In this system, the sheath bonding and earthing arrangements are such that the sheaths are maintained near earth potential throughout their length.
b) Single Point Bonding — This method is as described in 10.7.2 for single core tails, and is subjected to practical limitations of cable lengths permissible.
c) Cross-Bonding — In this method, the cable length is divided into three equal sections (or into a multiple of three such sections) and at each section junction, an insulating joint is provided. At these joints, the sheath of each cable section is bonded to the sheath of a different phase cable of the next section through lockable link boxes. By suitable connection, the phasor sum of the longitudinal sheath voltage is zero, and at the cable terminations, the sheaths of all three cables are bonded to earth. It is usual to provide a three-phase star-connected set of cable protections at each intermediate insulating joint; these protectors are non-linear resistors presenting low impedance to surge currents. The cross-bonding method permits the full rating of the cable to be maintained, but incurs considerable cost in the provision of insulating joints, link boxes, protectors, etc.

10.14 MISCELLANEOUS MATTERS IN POWER STATIONS AND SUBSTATIONS

If two or more stations are adjacent on what may be considered to be one site, the earthing systems and the stations should be interconnected to form a single earthing system. Where the stations actually adjoin, the extremities of their earthing systems should be connected together so that the whole area is enclosed by the earthing system. Where the separation is too large to treat as adjoining stations, an interconnecting earth conductor of substantial cross-section should be run to ensure that, as far as practicable, fault currents are diverted from cable sheaths and armour. This is of particular importance where fault current flowing in one station is provided from the adjoining station, for example, where a switching station adjoins power or transforming station sites so that an earth fault in the switchgear causes current flow between the two sites in order to reach the system neutral at the generators or transformers. Such interconnections between sites can include links suitably disposed to assist in testing.

Except where special insulation is called for, sheaths of all main cables should be connected to the station earth system. With multi-core cables the connection is generally made at the termination.

Where high earth-fault currents are to be expected, and an appreciable rise of potential of the station system with respect to the general mass of the earth may arise, special care is necessary while connecting metal cables or pipes entering the station, other than main cables or lines, such as water pipes and telephone or pilot cables. Water pipes should include an insulated section; polymeric piping is often suitable. In several cases, isolating transformers may be necessary for telephone connections. Pilot cables should be provided with insulated glands and so disposed as to minimize the possibility of fault currents being carried by the sheaths.

Where carrier-current equipment is employed, a further earth-electrode, normally a driven rod, should be provided at or immediately adjacent to each structure supporting the coupling capacitors. This earth electrode is an additional one for the high frequency equipment and should be bonded into the main earthing system. The structures supporting the coupling capacitors should be earthed in the normal way.

For large installations, such as at EHV/HV substations, it is common to make provision for the testing of earth grid and electrodes. Measurements shall be carried out two weeks after construction, where necessary, to verify the adequacy of the design. If the design found to be not adequate, the additional necessary steps to be taken to improve. Measurements may include the earthing system impedance, prospective touch and step voltages at relevant locations and transferred potential, if appropriate. When measuring touch and step voltages under test conditions, e.g current injection test, two choices are possible. Either measure the prospective touch and step voltages using a high impedance meter or measure the effective touch and step voltages appearing across an appropriate resistance which represents the human body.

10.15 TRANSFERRED POTENTIALS TO TELECOMMUNICATION AND OTHER SYSTEMS

Cables and insulated metallic pipes going into or out of a substation can be exposed to voltage differences during an earth fault inside the substation. Depending on the way the cable screen and/or armouring are earthed (at one or both ends) significant stress voltages or currents in the screen and/or armouring could occur. The insulation of cables or pipes shall be dimensioned accordingly.

In case of earthing at one end this may be done inside or outside the substation. Attention is to be paid to the possible touch voltages at the insulated other end. Following precautions, may be taken where necessary:

- interruption of the continuity of metallic parts where they leave the area of the earthing system;
- insulation of conductive parts or areas;
- installation of suitable barriers around conductive parts or areas to prevent their being touched;
- installation of an insulated barrier between parts connected to different earthing systems;
- suitable potential grading;
- limiting overvoltages by using suitable devices;
- metallic structures, e.g. metallic fences and guard rails, installed outside but in the proximity of the power installation.

If a high voltage earthing system becomes part of a global earthing system, where normally no dangerous potential differences appear, problems may arise if conductive parts of insulated pipes, cables, etc. connected to a remote earth potential and earthed conductive parts of the high voltage installation are simultaneously accessible.

It is therefore necessary for this equipment to be placed at a sufficient distance from the areas influenced by earth electrodes. If this is not possible, suitable measures shall be taken.

A general distance cannot be specified, the degree of danger shall be determined for each individual case.

10.16 REDUCTION FACTORS RELATED TO EARTH WIRES OF OVERHEAD LINES AND METAL SHEATHS OF UNDERGROUND CABLES.

10.16.1 General

Earth wires of overhead lines and metal sheaths of underground cables participate in carrying fault currents returning to earth. They take over a part of the earth current of the corresponding circuit in accordance with Fig. 52 of this document. By this effect the earthing system of a high voltage installation affected by an earth fault will be discharged effectively in respect of the earth fault current. The extent of this relief is described by the reduction factor.

The reduction factor r for an earth wire of a 3-phase overhead line is the ratio of the return current in the earth to sum of the zero sequence current of the 3-phase circuit.

$$r = \frac{I_E}{3I_O} = \frac{3I_O - I_{EW}}{3I_O}$$

Where:
I_{EW} current in the earth wire (in balanced stage)
I_E earth return current
3 I_0 sum of zero sequence currents

The same definition is relevant to the reduction factor r of an underground cable with metal sheath, screen, armouring or an enveloping steel pipe. Instead of the current in the earth wire IEW the current in the metal sheath etc. shall be used.

For the balanced current distribution of an overhead line the reduction factor of an earth wire can be calculated on the basis of the self impedances of the phase conductors Z_{L-E} and the earth wire Z_{EW-E} and the mutual impedance between phase conductors and earth wire Z_{ML-EW}.

$$\underline{r} = \frac{\underline{Z}_{EW-E} - \underline{Z}_{ML-EW}}{\underline{Z}_{EW-E}} = 1 - \frac{\underline{Z}_{ML-EW}}{\underline{Z}_{EW-E}}$$

The most influencing term for $\underline{Z}_{ML-EW}$ is the mean distance between phase conductors and earth wire, for $\underline{Z}_{EW-E}$ the resistance of the earth wire. By this the reduction effect of an earth wire in respect of the earth current is increasing (r shows a tendency reducing) with lower distance of phase conductor and earth wire and with lower resistance of the earth wire.

The calculation of the reduction factor for overhead lines with earth wire or underground cables with metal sheaths can be established using the formulas in IS 13234-3: 2009, Clause 7 and 8. Calculation examples are given in IS 13234-3, Annexes C and D.

10.16.2 Typical values of reduction factors of overhead lines and cables (50 Hz)

Reduction factor depends on many parameters and conditions, so, it presents a great variability. The following values of reduction factor reported are purely indicative.

Earth wires of overhead lines (110 kV)

– Steel 50...70 mm^2	r = 0.80 – 0.98
– ACSR 44/32 mm^2	r = 0.77
– ACSR 300/50 mm^2	r = 0.61
– AACSR[*1] 59–94[*2] with 1 earth wire	r = 0.70 – 0.85
– AACSR with 2 earth wires	r = 0.60 – 0.80
– AACSR 116 - 288 with 1 earth wire	r = 0.55 – 0.80
– AACSR 116 – 288 with 2 earth wires	r = 0.50 – 0.70
– OPGW[*3] 157[*4]	r = 0.60 – 0.70

Paper-insulated cables (10 kV and 20 kV)

– Cu 95 mm^2/1.2 mm lead sheath	r = 0.20 – 0.60
– Al 95 mm2/1.2 mm aluminium sheath	r = 0.20 – 0.30

Single-core XLPE cables (10 kV and 20 kV)

– Cu 95 mm^2/16 mm^2 copper screen	r = 0.50 – 0.60

Single-core oil filled cables (110 kV)

– Cu 300 mm^2/2.2 mm aluminium sheath r = 0.37

Gas-pressure cables in steel pipe (110 kV)

– Cu 300 mm^2/1.7 mm steel r = 0.01 – 0.03

Single-core XLPE cables (110 kV)

– Cu 300 mm^2/35 mm^2 copper screen r = 0.32

Single-core XLPE cables (150 kV)

– Cu 800 mm^2/700 mm^2 lead screen r = 0.20

Single-core oil filled cables (400 kV)

– Cu 1200 mm^2/1200 mm^2 aluminium sheath r = 0.01

NOTE

1. The reduction factor of cables links can be further reduced by installing extra bonding cables of suitable section (e.g. 150 mm^2 copper) in the same trench and by earthing them at the locations where the screens are earthed.
2. The reduction factor is also valid for cable sections with cross bonding scheme.

*1 AACSR - Aluminium alloy conductor steel reinforced.
*2 The total cross-section in mm² of aluminium plus steel wire
*3 OPGW – Optical ground wire
*4 The total cross-section in mm² of aluminium plus steel wire

10.16.3 Influence of the resistances to earth on current in cable sheath

The current returning as cable sheath current is composed of two components as given in Fig. 64.

The substation where a line to earth fault occurs is A. The substation A is fed from a remote substation through an underground cable A-B with length *l*. The cable sheath is earthed at both ends. R_{EA} and R_{EB} represent the resistances to earth at A and B.

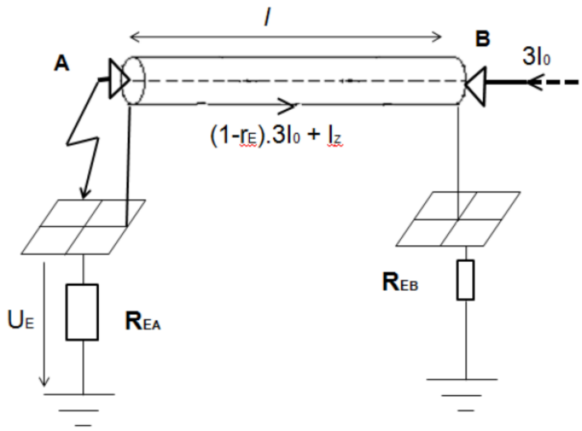


FIGURE 65 PARAMETERS RELEVANT FOR CABLE SHEATH CURRENT

The current in the cable sheath is composed of:

- induced current (1- $\underline{r}_E$).3I_0
- conductive current I_z

The main influencing parameters on the current in the cable sheath are the value of the resistances to earth, the length (*l*) of the underground cable and the location of the return points.

10.17 SPECIAL CONSIDERATIONS FOR GAS-INSULATED SUBSTATIONS (GIS)

Due to the limitation in area, it may be difficult in a GIS to obtain adequate earthing solely by conventional methods. Particular attention should be given to the bonding of the metallic enclosures of the GIS assembly, as these enclosures carry induced currents of significant magnitude, which must be confined to specific paths.

As a result of the compact nature of GIS and its short distances, electrical breakdown in the insulating gas, either across the contacts of a switching device during operation or under fault conditions can generate very high frequency transients that can couple onto the grounding system. These transients may cause high magnitude, short duration ground rises and are also the source of electromagnetic interference (EMI) in the GIS, where special EMI mitigation techniques are to be implemented.

Note:

1) VFT is a class of transients generated internally within a GIS characterized by short duration and very high frequency. VFT is generated by the rapid collapse of voltage during breakdown of the insulating gas, either across the contacts of a switching device or line-to ground during a fault. These transients can have rise times in the order of nanoseconds implying a frequency content extending to about 100 MHz. Very Fast Transients Overvoltage (VFTO) may be generated from VFT.
2) Very fast transient is found on the earthed enclosure of GIS systems. Longer length of protective bonding leads may produce higher potential differences.

Frequent bonding and earthing of GIS enclosures is the best solution to minimize hazardous touch and step voltages within the GIS area. Additional measures include the use of conductive platforms (earth mats) that are connected to GIS structures and to the earth electrode (eg. Concrete embedded earth electrode).

To limit the undesirable effects caused by circulating currents, the following requirements should be met:

a) The earthing arrangement should ensure that no significant voltage differences exist between individual enclosure sections and that neither the supporting structures nor any part of the earthing systems is adversely influenced by the flow of induced currents.
b) To avoid the circulation of enclosure currents beyond regular return path within the GIS assembly, power cable sheath earthing should be bonded to the earthing arrangement via connections that are separated from the GIS enclosures. To facilitate this isolation, the design of cable terminations should use a spark gap or proper insulation material designed or recommended by OEM.
c) Enclosure return currents also cannot be permitted to flow through any mounted current transformers.

Usually it is the GIS manufacturer who defines clearly what constitutes the main earth bus of the GIS and specifies what is required of the user for connecting the GIS assembly to the substation ground. Ample documentation is necessary to assure that none of the proposed connections from the main earth bus to the earth grid will interfere with the required enclosure current path or any other operational feature of the GIS design. That may be especially pertinent if the main earth bus consists of a system of interconnections between the GIS components and structures, and no separate busbar (continuous common ground bus loop) is furnished.

Usually the GIS manufacturer is responsible for

- Providing the subassembly-to-subassembly bonding to establish safe voltage gradients that meet safety requirements between all intentionally earthed parts of the GIS assembly and between those parts and the main earth bus of the GIS.
- Providing accessible connectors of sufficient mechanical strength and dimensions to carry the anticipated maximum fault current in that portion of the circuit without overheating.
- Providing earthing studs or connectors, or both, allowing, at least, for two paths to earth from the main earth busbar, or from each metallic enclosure and auxiliary piece of GIS equipment designated for a connection to the substation earth if the main earth busbar of the GIS assembly does not actually exist.
- Recommending proper procedures for connections between dissimilar metals.

Sources of fault current and the expected magnitudes and durations that should be considered in the design. Following subjects are to be considered,

a) Connections for the neutral conductor of equipment or apparatus and for dissipating surges caused by lightning and switching within the GIS.
b) Devices for dissipating lightning and switching surge currents external to the GIS assembly.

c) Requirements of protective relaying and satisfying the provisions necessary for communication facilities.
d) Earthing connections to all GIS supporting frames and structures, metallic sheaths, and installation of shielding for cable terminations where applicable.
e) Safe step and touch potentials & metal to metal touch potential under both normal and abnormal operating conditions external to the GIS assembly.
f) Compliance with the specifications, related to correct earthing practices, as mutually agreed to by the GIS manufacturer and the user.

Precautions should be taken by OEM to prevent excessive currents from being induced into adjacent frames, structures, or reinforcing steel, and to avoid establishment of current loops via other substation equipment, such as transformers or separate switchgear.

If there is the possibility of undesirable current loops via earth connections, or if any sustained current path might partially close or pass through earthed structures, the substation earthing scheme and the physical layout should be carefully reviewed.

Where applicable, all isolating elements should be able to withstand the full potential difference that may occur between the locally earthed system and that external to the GIS. In many cases, the very fast transients generated by switching or by faults in the GIS may cause very high transient voltages to appear at these points. Bonding of structure at regular interval with earth bus must be done as per recommendation of OEM.

In all circumstances, close cooperation with the GIS manufacturer at the early stages of design is very important.

In the limited space of GIS substations, a substantial part of the substation area is often occupied by concrete foundations. A simple monolithic concrete steel reinforced slab is advantageous. If a continuous floor slab is used, its reinforcing steel mesh to the main earth busbar shall be bonded so that both the GIS enclosures and the structural steel in and above the
foundation will be approximately the same potential level.

GIS foundations, which include reinforcing bars and other metals, can act as auxiliary earth electrodes and may be so used provided that under no circumstances would the discharge of current result in a damage of concrete because of local overheating or a gradual erosion of the concrete-steel bonds. This must be done with consultation with civil engineer in charge at site.

11 EARTHING OF SPECIFIC APPLICATIONS

11.1 INDUSTRIAL AND COMMERCIAL INSTALLATION

11.1.1 General

Many industrial installations take their supply from DISCOM operated at a voltage which might be above 1000V ac 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.

So far as the consumers taking supply at 240 V are concerned, it is the responsibility of the supplier to provide earthed terminal at the premises of the consumer. In the cases of consumers taking supply at higher voltages, earthing scheme should be so designed as to satisfy the basic statutory requirements (see 4). A global Earthing System interconnecting HV and LV systems is recommended..

Note: Any earthing made as explained in clause 6.3.1 and Fig. 22 to Fig. 24 is prohibited.

11.1.2 Earth fault loop impedance

As in the case of supplies exceeding 650 V, low resistance paths for the return of earth fault current in industrial and commercial power supply of 250 V but not exceeding 650 V is necessary, and the earth fault loop impedance should be sufficiently low as to allow the operation of a suitably chosen protective device, fuse, circuit-breaker or RCD within the disconnection time given in 7.4.1.8, 7.4.1.9 and 7.4.1.10.

Note: Maintaining low Earth fault loop impedance in each circuit is a mandatory requirement in CEA safety regulations.

11.1.3 Protective Equipotential Bonding

Every building shall have protective equipotential bonding by interconnecting the exposed and extraneous conductive parts (See 7.2.1, 7.4.8.3, Fig. 29 A, Fig. 29 B, Fig. 30 and Fig. 31). The maximum allowed fault voltage shall be limited to > 50 Va.c.

Note: Maintaining protective equipotential bonding is a mandatory requirement in CEA safety regulations 2023.

11.1.4 Minimum cross-sectional area of protective conductors and earthing conductors

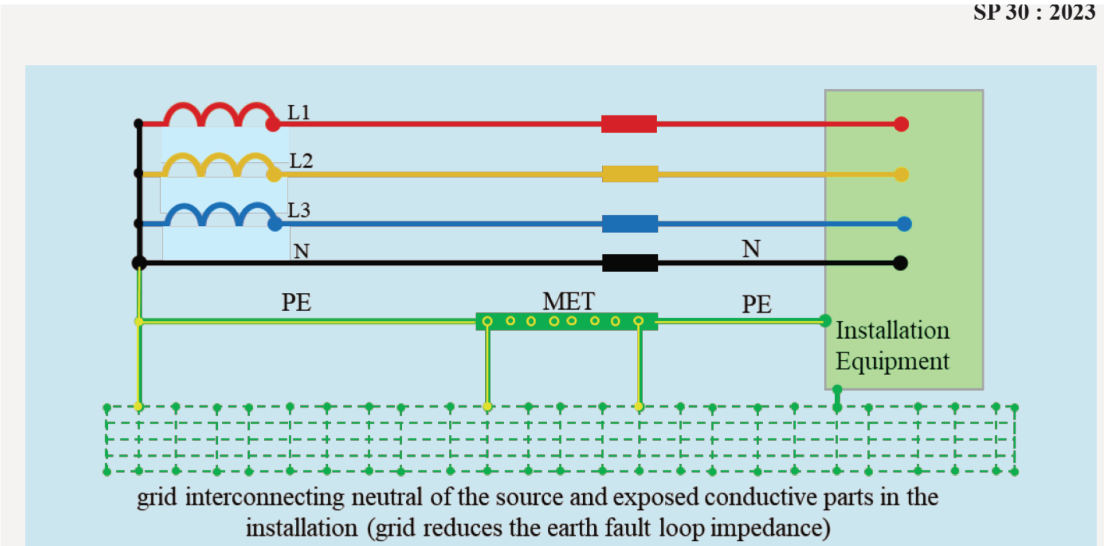
The cross-sectional area of every protective conductor shall satisfy the conditions for automatic disconnection of supply and be capable of withstanding mechanical and thermal stresses caused by the prospective fault current during the disconnection time of the protective device. The minimum cross-sectional area of protective conductors and earthing conductors shall satisfy 7.3.

11.1.5 Where single-core cables are used in low voltage installations, 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 armours should be reduced to low values and the sheaths or armours may 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 the reduction is not acceptable, sheaths and armours may be bonded at one end of the run (single-point bonding) and a separate protective conductor is then necessary.

11.1.6 The earthing system below 1000 V a.c should be designed as a PME system with separate protective conductor (TN-S) (see Fig. 65). The neutral conductor from the source (e.g. transformer / Generator) should be connected to the MET (called as system referencing conductor or neutral earthing conductor) by duplicate connections if they are outdoor and not protected against corrosion and mechanical damages. One connection is enough if it can be made reliable and protected against corrosion and mechanical damaged. For multiple sources, operating in parallel, the system referencing conductor should be located within the switchgear assembly. In the case of solidly earthed system, the earth fault current can be of the order of symmetrical short-circuit current and hence the thermal design of the protective conductors should depend upon the maximum symmetrical short circuit current available.

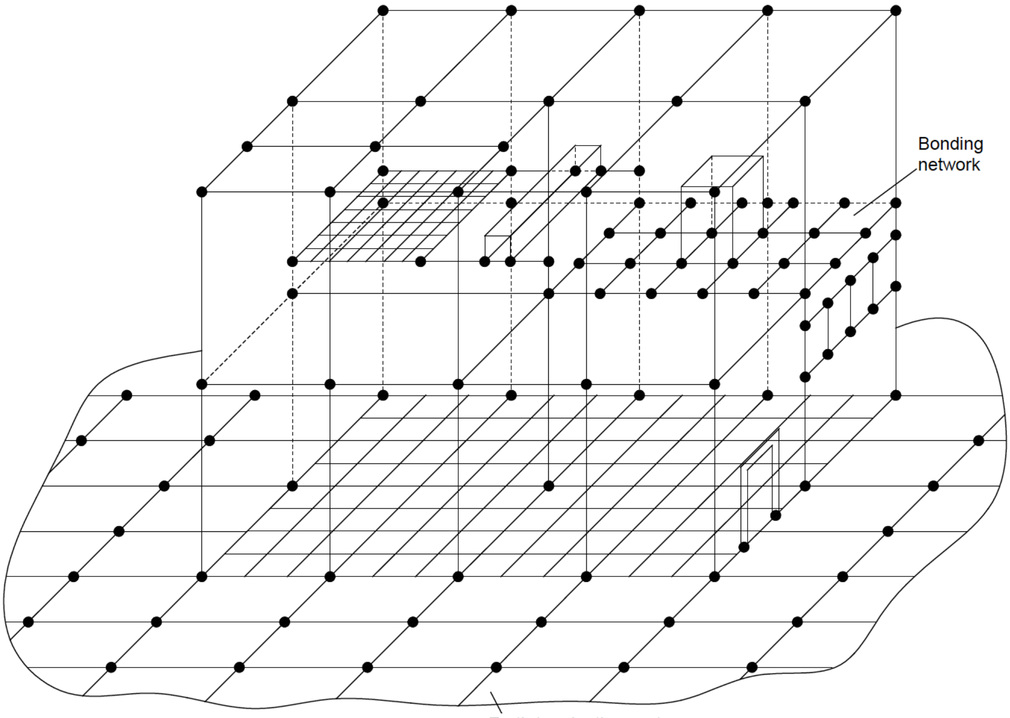
11.1.7 From the point of safety consideration the objective is to reach a low earth fault loop impedance as explained in 11.1.2. An earth grid connected to protective equipotential bonding helps in reducing shock voltage and reduce the fault loop impedance, support as an earth electrode, create a reference plane and help in improving EMC. The extent and size of earth grid will always depend upon the disposition of plant electrics. The layout should be done in such a manner as to keep the earth continuity resistance of the grid to a minimum value. In the case of a protective multiple earthing system where the neutral of the supply transformer and the non-current carrying metal parts in the system are interconnected by the common earthing arrangement, which is designed for the prospective fault current, there is no reason to design the earth grid assuming that total earth fault current is dissipated through the earth grid. Hence, while designing the earth grid, the thermal capability of the earth electrodes need be verified only with reference to the portion of the current which may take the earth return path. In the normal range between 10 and 1000 m, this division of current is found to be in between 80 percent and 20 percent for design purposes. Based upon the above philosophy, the following guidelines for the design of an earthing system in industrial and commercial consumers premises are issued.

11.1.8 All the non-current carrying metal parts of the equipment, switchboards, etc, will be solidly connected to MET and to the earth grid by duplicate earth connections of adequate size. The transformer neutral should be solidly connected to this earthing arrangement as explained in 11.1.6.



Note: Neutral shall be earthed only once through a link. The link shall be disconnected while carrying out insulation resistance test.

FIGURE 66 TN-S SYSTEM WITH SEPARATE PROTECTIVE CONDUCTOR AND EARTH GRID AS PROTECTIVE MULTIPLE EARTHING (PME).



NOTE All drawn conductors are either bonded structural metal elements or bonding conductors. Some of them may also serve to intercept, conduct and disperse the lightning current into the earth.

FIGURE 66A - EXAMPLE OF A THREE-DIMENSIONAL EARTHING ARRANGEMENT IN A MULTIFLOOR BUILDING CONSISTING OF BONDING NETWORK INTERCONNECTED WITH THE EARTH TERMINATION SYSTEM.

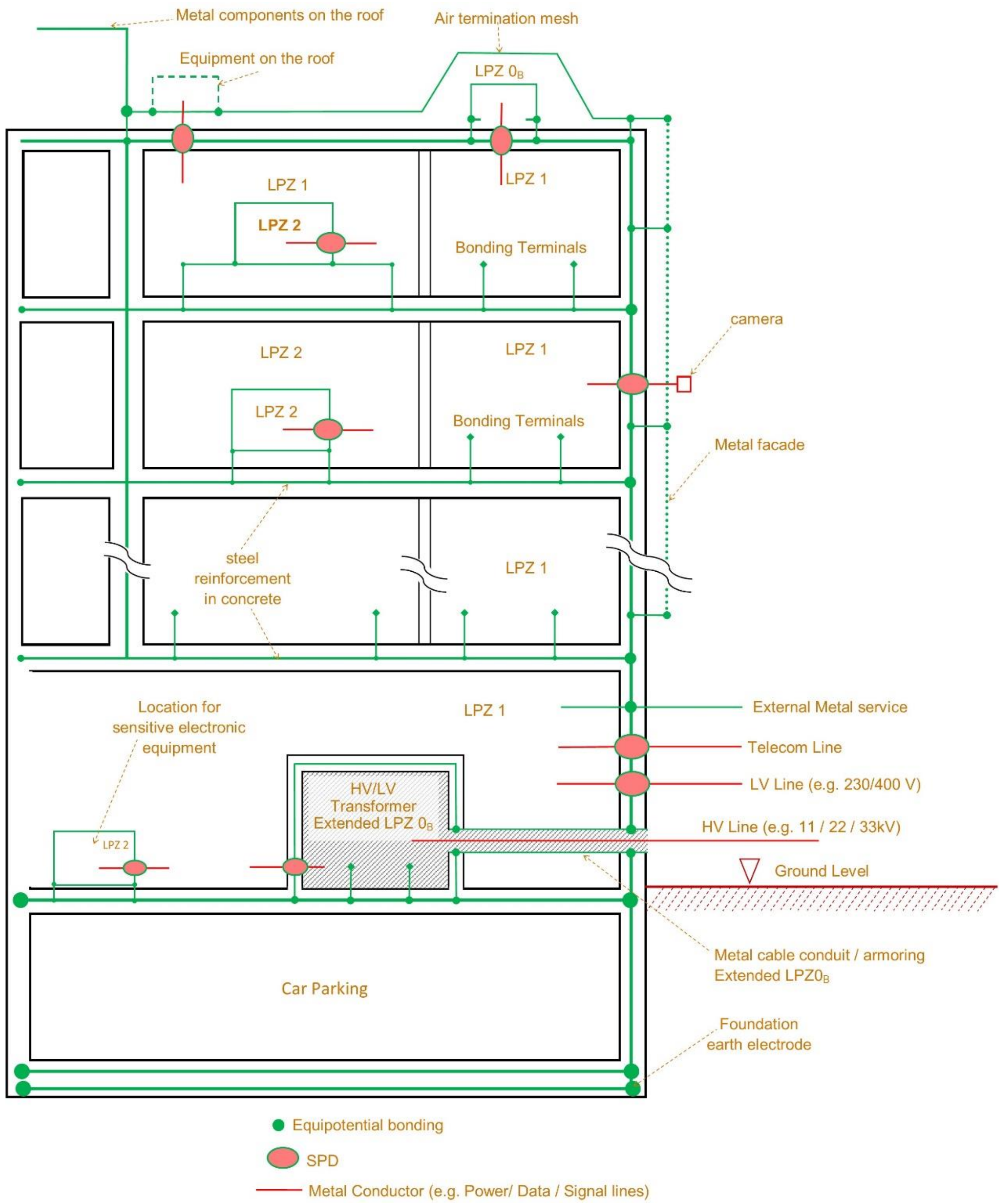
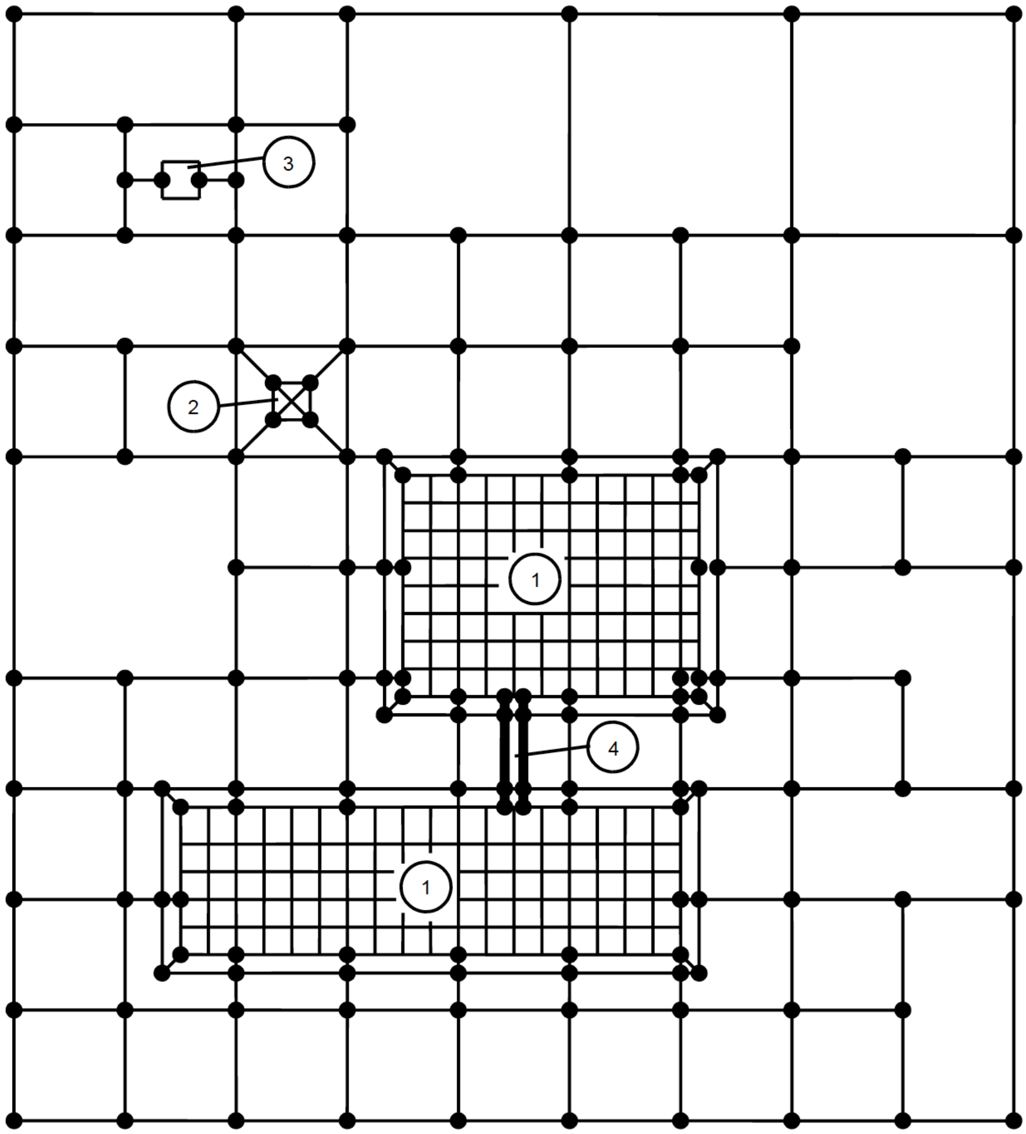


FIGURE 67B EXAMPLE OF EARTHING ARRANGEMENT AND LIGHTNING PROTECTION ZONES IN A MULTIFLOOR BUILDING WITH TRANSFORMER (INSIDE OR CLOSE TO THE STRUCTURE).



Key:

1 building with meshed network of the reinforcement
2 tower inside the plant
3 stand-alone equipment
4 cable tray

FIGURE 68 MESHED EARTH TERMINATION SYSTEM OF AN INDUSTRIAL PREMISE.

11.1.9 The earth termination system can be soil embedded or concrete embedded. The soil embedded earth grid should run at a minimum depth of 500 mm below ground level. If the installation is below foundation, preferred location is above PCC. When bare conductors are used as earth grid, this can also be assumed to dissipate the fault/lightning current to the mass of the earth. For calculating the effective value of the earth resistance of this grid, this grid can be treated as a horizontal electrode and the standard formula can be applied for calculating the earth resistance of the grid, if required. Additionally, 11.1.9.1 For entries of external services above the surface of the ground, the bonding bars should be connected to a horizontal ring conductor inside or outside the outer wall bonded to the down conductors of the LPS and to the metallic reinforcement of the structure, if applicable.

11.1.9.2 The ring conductor should be connected to the steel reinforcement, and other metallic elements of the structure, at regular intervals, typically every 5 m to 10 m.

11.1.9.3 In buildings principally designed for computer centres, communication buildings and other structures requiring a low level of LEMP induction effects, the ring conductor should be connected to the reinforcement, typically every 5 m.

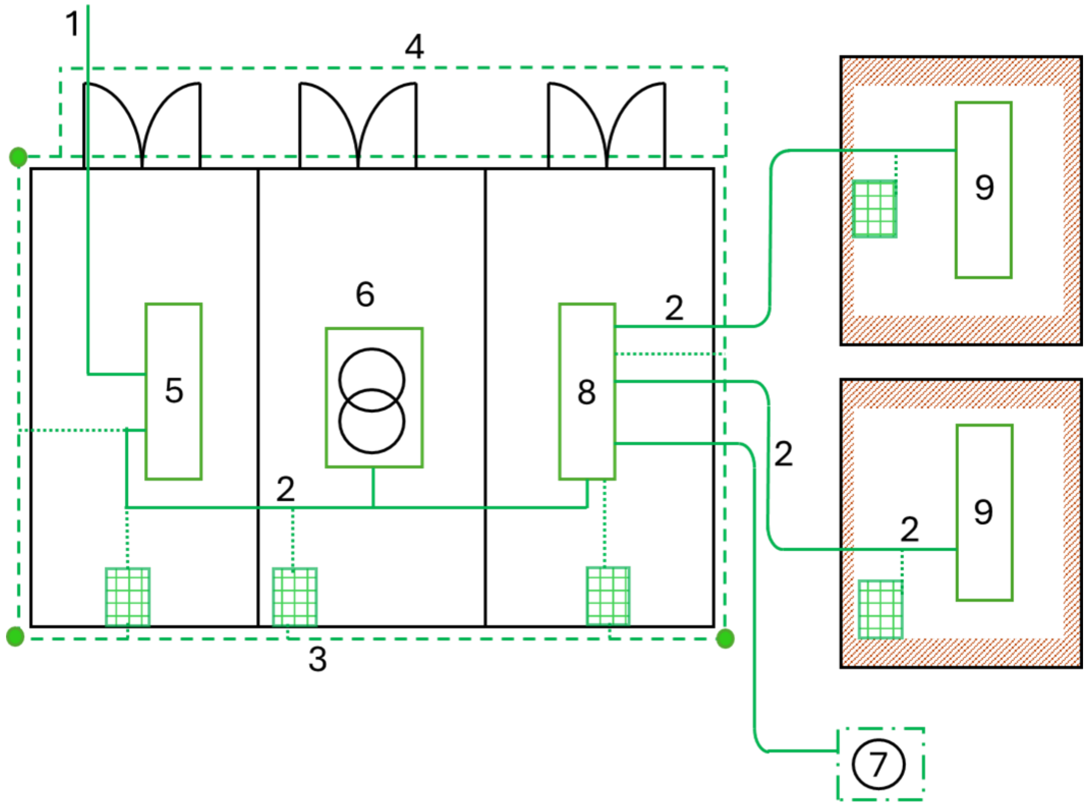
11.1.9.4 For the bonding of external services in reinforced concrete buildings which contain large communication or computer installations, and for structures where EMC demands are severe, an earthed ground plane with multiple connections to the metallic reinforcement of the structure or other metallic elements should be used.

11.1.10 The continuity resistance of the earth return path through the earth grid should be maintained as low as possible and shall not be greater than the continuity resistance of protective earth conductor in the respective section of electrical installation.

11.1.11 In the case of HV/EHV substations within the premise, a global earthing system shall be implemented.

Note: The prevailing fault current I_F can be obtained from the supplier, verified based on 5.1. The current to earth electrodes I_E can thus be calculated. See10.2.3.6 and 10.5.2.

11.1.12 Earthing arrangement and earth electrode of HV supply and associated equipment including LV side of Transformer may be made as in Fig. 68 & Fig. 69.



Protective Conductor

Foundation earth electrode

Earth Electrode

Earthing Conductor

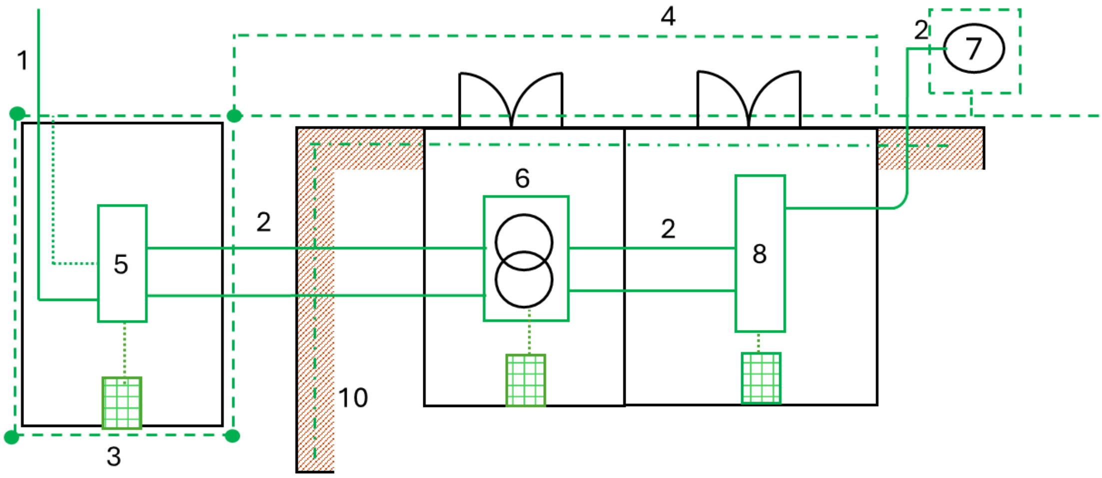
Vertical earth rods (if provided)

1. Protective conductor with incoming cable (if provided) or cable armour.
2. MET / Protective earth conductor along with cable (in duplicate for redundancy if required)
3. Earth electrode as a foundation ring
4. Extended ring for potential grading (if necessary).
5. HV switchgear
6. Transformer
7. LV Generator
8. LV Main panel
9. LV panel

Note

1. System reference connection (Neutral earthing) of LV side of the Transformer or DG can be placed inside LV main panel.
2. Each source need system referencing connection (Neutral earthing) in case of change over.
3. If systems are working in parallel (synchronized), there shall be only one system referencing connection.

FIGURE 69 COMMON HV/LV EARTHING TO SUPPLY MULTIPLE BUILDINGS (TN-S)



Protective Conductor

Foundation earth electrode

Earth Electrode

Earthing Conductor

Vertical earth rods if provided

Foundation earth electrode

1. Protective conductor with incoming cable (if provided) or cable armor.
2. MET / Protective conductors along cable (in duplicate for redundancy if required)
3. Earth electrode as foundation ring
4. Extended ring for potential grading (if required)
5. HV switchgear
6. Transformer
7. LV Generator
8. LV Main panel
9. LV panel
10. Main building

Note

1. System reference connection (Neutral earthing) of LV side of the Transformer or DG can be placed inside LV main panel.
2. Each source need system referencing connection (Neutral earthing) in case of change over
3. If systems are working in parallel (synchronized), there shall be only one system referencing connection

FIGURE 70 COMMON HV/LV EARTHING WITH TRANSFORMER INSIDE THE BUILDING (TN-S)

11.1.13 Large buildings with substantial amount of electronics (e.g. Datacentre) shall adopt additional EMI mitigation measures as a part of earthing (see Annex B).

11.2 MEDICAL ESTABLISHMENTS

11.2.1 General

11.2.1.1 In the context of this Clause 'installation', means any combination of interconnected electrical equipment within a given space or location intended to supply power to electrical equipment used in medical practice.

11.2.1.2 As such, some parts of the installation may be present in the patient's environment, where potential differences that could lead to excessive currents through the patient, must be avoided. For this purpose a combination or earthing of equipment and potential equalization in the installation is essential. Requirements in Part 3 section

9 of National Electrical Code of India 2023 (SP-30) applies. Provisions of 11.1 of this code applies in all locations, 11.2 applies additionally in Group 1 and Group 2 medical locations.

11.2.1.3 Power supply system including a separated protective conductor is recommended for general locations (TN-S System) in medical establishment (see 6.2.3.1, Fig. 7 and **7.4.2**).

Note: Any earthing made as explained in clause 6.3.1 and Fig. 22 to Fig. 24 is prohibited.

11.2.1.4 Earth fault loop impedance

As in the case of supplies exceeding 650 V, low resistance paths for the return of earth fault current in industrial and commercial power supply of 250 V but not exceeding 650 V is necessary, and the earth fault loop impedance should be sufficiently low as to allow the operation of a suitably chosen protective device, fuse, circuit-breaker or RCD within the disconnection time given in 7.4.1.8, 7.4.1.9 and 7.4.1.10.

Note: Maintaining low Earth fault loop impedance in each circuit is a mandatory requirement in CEA safety regulations.

11.2.1.5 Protective Equipotential Bonding

Every building shall have protective equipotential bonding by interconnecting the exposed and extraneous conductive parts (See 7.2.1, 7.4.8.3, Fig. 29A and Fig. 70 and Fig. 71). The maximum allowed fault voltage shall be limited based on the location.

Note: Maintaining protective equipotential bonding is a mandatory requirement in CEA safety regulations.

11.2.1.6 Proper coordination shall be ensured between the architect, building contractor, the electrical designer and the user on the various aspects of installation design. The necessary special features of installations shall be ascertained before using the facility with reference to Table 28.

Note;

1. Biomedical equipment installers may demand dedicated earth electrodes for sensitive equipment. This demand is a violation of standards, hence shall not be entertained. Such equipment needs an individual bonding to the common earth terminal of the location. (e.g. equipotential bonding bus bar of the location). Any earthing made as explained in clause 6.3.1 and Fig. 22 to Fig. 24 is prohibited.
2. ME equipment as per IS 13450-1 can operate with a potential up to 230 V between Neutral Conductor (N) and Protective Earth Conductor (PE). Functional earthing of ICT equipment shall be made based on the requirements of IEC 30129. All protective and functional earthing conductors should be connected to one single MET.

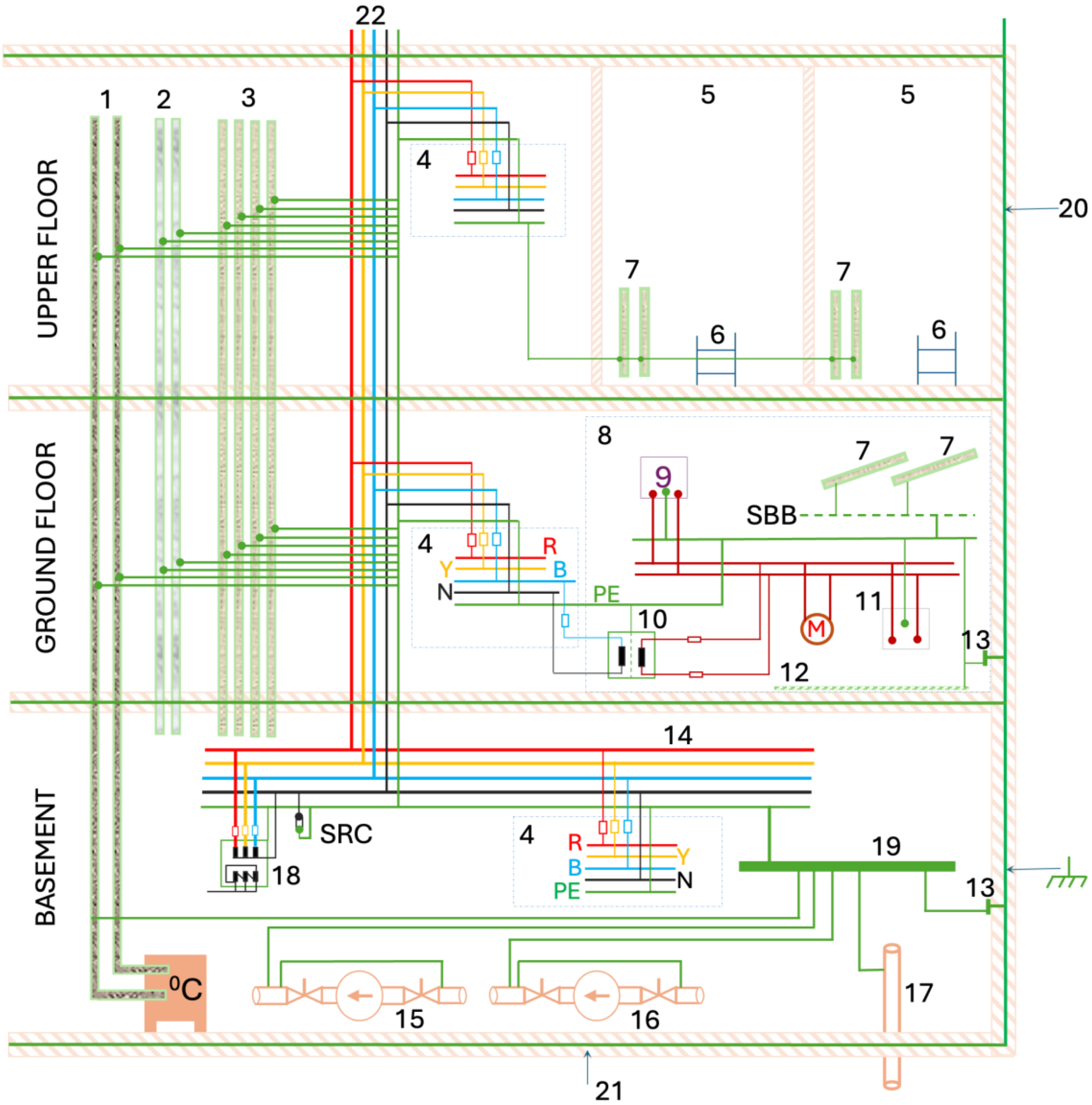
11.2.1.7 In addition the following provisions shall be required, in group 1 and group 2 medical locations:

a) Additional requirements concerning protective conductors and protective devices to restrict continuous voltage differences.
b) Restriction of voltage differences by supplementary equipotential bonding in group 1 and group 2 locations. During the application of equipment with direct

contact to the patient, at least a potential equalized zone around the patient shall be provided with a patient centre bonding bar to which the protective and functional earth conductors of the equipment are connected. All accessible extraneous conductive parts in the zone shall be connected to this potential equalization bar as shown in Fig. 71.

c) The permissible touch voltage in group 1 and group 2 medical locations are 25 V a.c. or 60 V d.c. This voltage can be maintained by supplementary equipotential bonding (See Fig. 71).
d) Restriction of the potential equalization zone around one patient, meaning practically around one operation table or around one bed in an intensive care room.
e) If more than one patient is present in an area, connection of the various potential equalization centers to a central potential equalization bush, which should preferably be connected to the protective earth system of the power supply for the given area. In its completed form, the equipotential bonding network may consist partly of fixed and permanently installed bonding and partly of a number of separate bonding which are made when the equipment is set up near the patient. The necessary terminals for these bonding connection should be present on equipment and in the installation.
f) Restriction of the duration of fault voltage by the application of RCD’s.
g) Continuity of power supply to certain equipment in the case of a first fault to earth by application of medical IT systems for group 2 medical locations.

NOTE — Additional safety measures are required besides earthing described in this Clause. These cover fire safety, safety supply systems and interference suppression. Reference shall be made to NEC 2023 (SP 30).



1 = Heating / Air condition pipes 2 = Water supply 3 = Gas supply 4 = Distribution board 5 = General ward 6 = Hospital bed 7 = Metal pipes (water, oxygen, etc) 8 = Group 2 medical location 9 = Insulation monitoring device 10 = Medical isolating transformer 11 = Socket outlet	12 = Antistatic Grid 13 = Bonding for PME 14 = Main Distribution Board 15 = Water meter 16 = Gas meter 17 = Waste water 18 = Transformer 19 = MET 20 = Down Conductor of LPS 21 = Foundation earth 22 = Busbar trunking	R, Y, B = phase conductors (shown in red, yellow green) N = neutral conductors (shown in black colour) PE = protective conductor SBB = Supplementary Bonding Bar M = Class 2 ME equipment. SRC = System Referencing Conductor Chassis earth (5020) All protective conductors are
SRC = Neutral earthing of Transformer through a disconnectable link – Preferably inside Main Distribution Board		

FIGURE 71 EXAMPLE OF AN ELECTRICAL INSTALLATION IN A MEDICAL ESTABLISHMENT

11.2.2 Safety Provisions

11.2.2.1 Safety measures from the point of view of earthing are divided into a number of provisions as given in Table 28.

11.2.2.2 Provision P0 shall be applicable to all buildings containing medically used rooms. Provision P1 shall be applicable for all medically used rooms.

Other requirements of Table 28, need not be complied with, if:

a) a room is not intended for the use of medical electrical equipment, or
b) patients do not come intentionally in contact with medical electrical equipment during diagnosis or treatment, or
c) only medical electrical equipment is used which is internally powered or of protection Class II.

The rooms mentioned under (a), (b) and (c) may be, for example, massage rooms, general wards, doctor’s examining room (office, consulting room), where medical electrical equipment is not used.

(clause *11.2.2)*

TABLE 28 SAFETY PROVISIONS

Provisions	Principal Requirement	Installation Measures
(1)	(2)	(3)
P0	Duration of touch voltage restricted to a safe limit	TN-S , TT or IT system (see note1)
P1	As P0 but additionally, Touch voltages in patient environment restricted to a safe limit	Additional to P0 Supply system with additional requirements for protective earthing, etc
P2	As P1 but additionally, Resistance between extraneous conductive parts and the protective conductor busbar of the room not exceeding 0·1 Ω	Additional to P1 : Supplementary equipotential bonding
P3	As P1 or P2 but additionally, Potential difference between exposed conductive parts and the protective conductor busbar not exceeding 10 mV in normal condition.	As P1 or P2: Measurement necessary, corrective action possibly necessary
P4	As P1 or P2. Additional protection against electric shock by limitation of disconnecting time	Additional to P1 or P2 : Residual current operated protective device
P5	Continuity of the mains supply maintained in case of a first insulation fault to earth and currents to earth restricted	Additional to P1, P2 or P3 : medical IT systems for group 2 medical locations
Note: TT system may be used in small premise with Low Voltage supply from DISCOM, provided fault protection is achieved by RCD as explained in 7.5.4.		

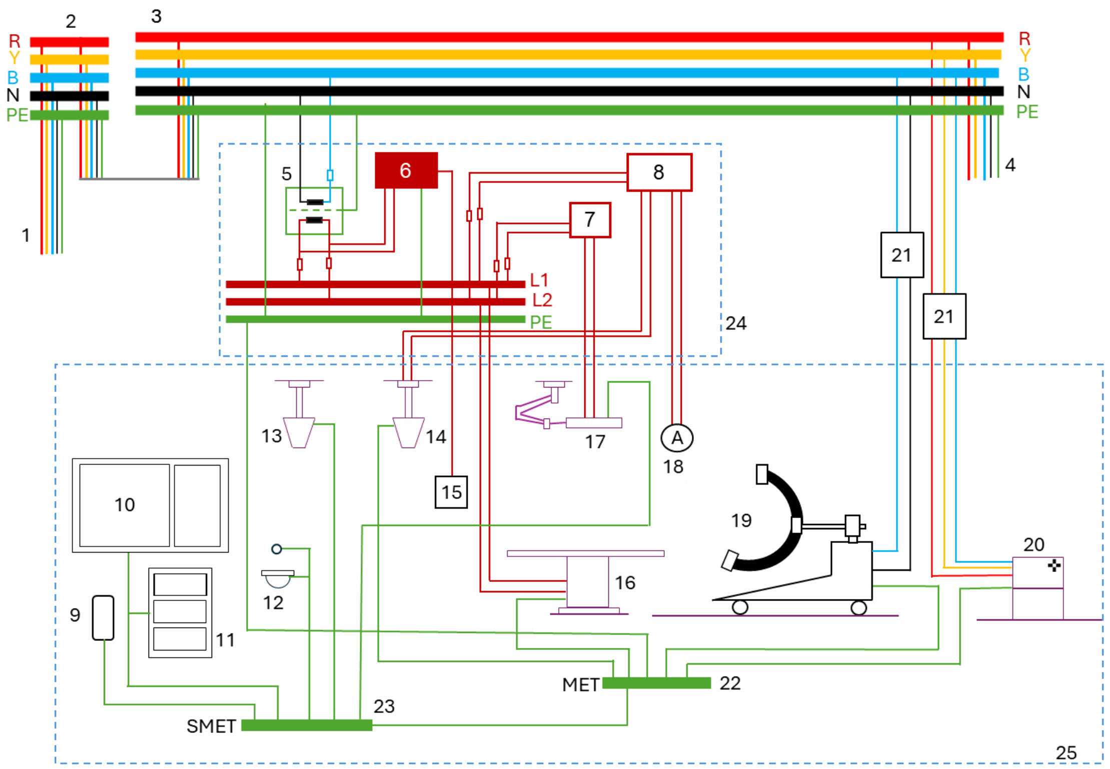
11.2.2.3 Guidance on the application of the provisions are given in Table 28.

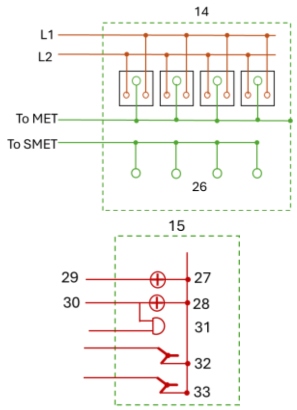
TABLE 29 EXAMPLES FOR ALLOCATION OF GROUP NUMBERS AND CLASSIFICATION FOR SAFETY SERVICES OF MEDICAL LOCATIONS

Medical location	Group			Class	
	0	1	2	≤ 0.5 s	> 0.5s ≤ 15 s
1. Massage room	x	X			X
2. Bedrooms		X			
3. Delivery room		x		X[a]	X
4. ECG, EEG, EHG room		x			X
5. Endoscopic room		X[b]			X[b]
6. Examination or treatment room		X			X
7. Urology room		X[b]			X[b]
8. Radiological diagnostic and therapy room, other than mentioned under 21		X			X
9. Hydrotherapy room		X			X
10. Physiotherapy room		X			X
11. Anesthetic room			X	X[a]	X
12. Operating theatre			X	X[a]	X
13. Operating preparation room		X	X	X[a]	X
14. Operating plaster room		X	X	X[a]	X
15. Operating recovery room		X	X	X[a]	X
16. Heart catheterization room			X	X[a]	X
17. Intensive care room			X	X[a]	X
18. Angiographic examination room			X	X[a]	X
19. Haemodialysis room		X			X
20. Magnetic resonance imaging (MRI) room		X			X
21. Nuclear medicine		X			X
22. Premature baby room			X	X[a]	X

[a] Luminaries and life-support medical electrical equipment which needs power supply within 0.5s or less.
[b] Not being an operating theatre.

11.2.2.4 More information on electrical installation in a hospital is given in part 3 section 9 of NEC 2023 (SP 30).





1. Feeder from the main service entrance
2. Distribution of the floor supply system
3. Operating theatre distribution panel
4. Safety supply system
5. Medical isolating transformer
6. Insulation Monitoring Device
7. Special safety supply system E1
8. Special safety supply system E2
9. Central heating
10. Metal window-frame
11. Metal cabinet for instruments
12. Meal washing-basin and water supply
13. Ceiling stand with outlets for gas supply
14. Ceiling stand with mains socket outlets (with terminals for equipotential bonding, enclosure connected to the protective, conductor bar)
15. Alarm device for the insulation monitoring device (example)
16. Operating table (electrically driven)
17. Operating lamp
18. Ampere meter for special safety
19. X-ray equipment
20. Sterilizer
21. Residual-current protective device
22. MET: Main Earthing Terminal of the location
23. SMET: Sub earthing terminal of the location
24. Medical IT system
25. Group 2 medical location
26. Terminals for equipotential bonding
27. Operation (button)
28. Warning (button)
29. Green
30. Red
31. Buzzer
32. Stop button for buzzer
33. Test button

PE = Protective Earth conductor/bar
MET: Main Earth Terminal (e.g. for bonding of exposed conductive parts)
SMET = Sub MET (e.g. for bonding of extraneous conductive parts
L1, L2, L3 = phase conductors
N = neutral conductor

All protective and functional earthing system and conductors there of including connections are shown in green colour

FIGURE 72 SCHEMATIC PRESENTATION OF PROTECTIVE CONDUCTORS AND EQUIPOTENTIAL BONDING IN OPERATING THEATRES

11.2.3 Circuit Installation Measures for Safety Provisions.

11.2.3.1 General Provisions

11.2.3.1.1 All buildings in the hospital area which contain medically used rooms shall have a TN-S power system. The conventional touch voltage limit is fixed at 50 V ac.

11.2.3.1.2 TT system if used in small premises with Low Voltage supply from DISCOM shall be protected with an RCD as a fault protection at origin of installation (see 7.5.4.)

NOTE - The use of TN-C system in which the PEN-conductor may carry current in normal condition can cause safety hazards for the patients and interfere with the function of medical electrical equipment, data processing equipment, and signal transmission lines, etc.

11.2.3.2 Provisions in Group 1 and Group 2 medical locations.

11.2.3.2.1 The conventional touch voltage limit is fixed at 25 V ac in group 1 and group 2 medical locations.

11.2.3.2.2 Protective conductors inside a group 1 and group 2 medical locations shall be insulated; their insulation shall be coloured green-yellow.

11.2.3.2.3 Exposed conductive parts of equipment being part of the electrical installation used in the same room shall be connected to a common protective conductor.

11.2.3.2.4 An MET shall be provided near the main service entrance. Connections shall be made to the following parts by bonding conductors as shown in Fig. 70 to MET and Sub MET:

a) lightning down conductor;
b) earthing systems of the electric power distribution system;
c) the central heating system;
d) the conductive water supply line;
e) the conductive parts of the waste water line;
f) the conductive parts of the gas supply; and
g) the structural metal frame work of the building, if applicable.

11.2.3.2.5 Each locations shall have its own MET, which should have adequate mechanical and electrical properties and resistance against corrosion.

11.2.3.2.6 The impedance (Z) between the MET and each connected protective conductor contact in wall sockets or terminals should not exceed 0·2 Ω, if the rated current of the over current protective device is 16 A or less. In case of a rated current exceeding 16 A, the impedance should be calculated using the formula:

$$z = \frac{25}{I_a} \Omega$$

in all cases Z shall not exceed 0·2 Ω .

(I_a is the current in amperes (A) causing the automatic operation of the disconnecting device within the time specified in 7.4.1.8, and 7.4.1.9. When a residual current protective device (RCD) is used this current is the residual operating current providing disconnection in the time specified in 7.4.1.8, or 7.4.1.10;).

NOTE - The measurement of the protective conductor impedance should be performed with an ac current not less than 10 A and not exceeding 25 A from a source of current with a no-load voltage not exceeding 6 V, for a period of at least 5 s.

11.2.3.2.7 The cross-sectional area of every protective conductor shall satisfy the conditions for automatic disconnection of supply and be capable of withstanding mechanical and thermal stresses caused by the prospective fault current during the disconnection time of the protective device. The minimum cross-sectional area of protective conductors and earthing conductors shall satisfy 7.3.

11.2.3.2.8 It may be necessary to run the protective conductor separate from the phase conductors, in order to avoid measuring problems when recording bioelectric potentials.

11.2.3.3 Supplementary Equipotential Bonding group 1 and group 2 medical locations.

11.2.3.3.1 In order to minimize the touch voltage, all extraneous conductive parts shall be connected to SMET.

11.2.3.3.2 Connections shall be provided from the SMET to extraneous conductive parts such as pipes for fresh water, heating, gases, vacuum and other parts.

Additionally, in operating theatres, intensive care rooms, heart catheterization rooms and rooms intended for the recording of bioelectrical action potentials, all parts should be connected to the SMET via direct and separate conductors.

11.2.3.3.3 The following requirements shall be fulfilled:

a) The resistance between extraneous conductive parts and the equipotential bonding bar shall not exceed 0.1Ω.
   NOTE - The measurement of this impedance should be performed with a current not less than 10 A and not exceeding 25 A from a source of current with a no-load voltage not exceeding 6 V, for a period of at least 5 s.
b) All equipotential bonding conductors shall be insulated, the insulation being colored green yellow.
   NOTE - Insulation of the equipotential bonding conductors is necessary, to avoid loops by contact and to avoid picking up of stray currents.
c) Equipotential conductors between permanently installed extraneous conductive parts and the equipotential bonding bar shall have a cross-sectional area of not less than 4 mm^2 copper or copper equivalent.
d) The equipotential bonding bar, if any, should have adequate mechanical and electrical properties, and resistance against corrosion.
e) The conductors connected to the equipotential bonding bar shall be marked and shall be similarly designated on drawings of the installation system.

f) The MET and SMET in group 1 and group 2 medical locations shall be interconnected with a conductor having a cross-sectional area of not less than 16 mm^2 copper or copper equivalent.

g) Adequate number of SMET other than MET those for protective conductor contact or pins of socket outlets should be provided in each room for the connection of an additional protective conductor of equipment or for reasons of functional earthing of equipment.

11.3 SOLAR PV

11.3.1 General

TN or TT type electric system, except TN-C is recommended in AC side of the PCE. For any kind of system earthing, there shall be a system reference earthing when the solar PV works in islanding mode, if necessary, to identify earth fault.

PV array configuration shall be permitted with or without functional (Active) DC earthing. For DC side few configurations are explained in 11.3.2. DC earthing is generally carried out in the PCE and the related control / monitoring is carried out as per the recommendation of the manufacturer. For more information ref IEC 63112. In all systems at DC side separate protective conductor is necessary.

Note:

1. TN-C system shall not be used,
2. Where there is no simple separation, AC side of the PCE shall be protected with a TYPE B RCD of 30 mA.
3. Connecting DC side earthing, AC side earthing and lightning protection earthing to separate earth electrodes as shown in 6.3.1 is prohibited.

11.3.2 DC Side Earthing

TABLE 30 PV DC CONFIGURATIONS

DC Side	Ref. Fig. no	Application Circuit	Consequence on the Status of the PV Array
Un earthed	Fig. **72A**	AC side connected via a PCE with a transformer inside of the PCE	floating
	Fig. **72B**	AC side connected via a PCE without a transformer	Fixed by the status of the neutral or a line conductor of the supply circuit
Earthed	Fig. **72C**	AC side connected via a PCE with a transformer inside of the PCE	Fixed to earth
	Fig. **72D**	AC side connected via a PCE without a transformer inside of the PCE but a transformer outside of the PCE	Fixed to earth

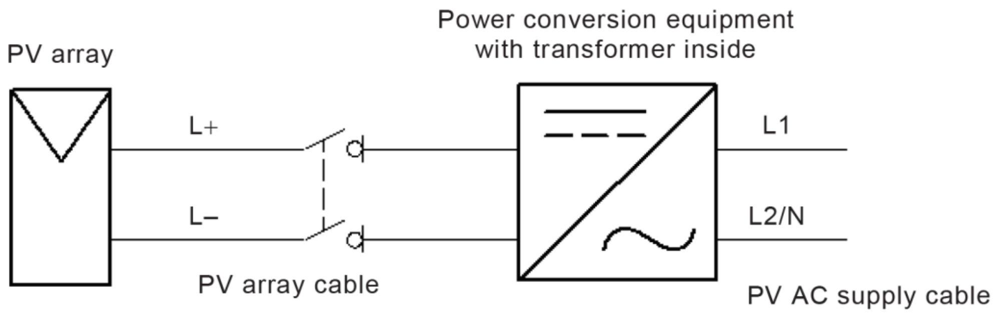


FIG. 72A - UNEARTHED PV ARRAY CONNECTED TO THE AC SIDE VIA A PCE WITH TRANSFORMER

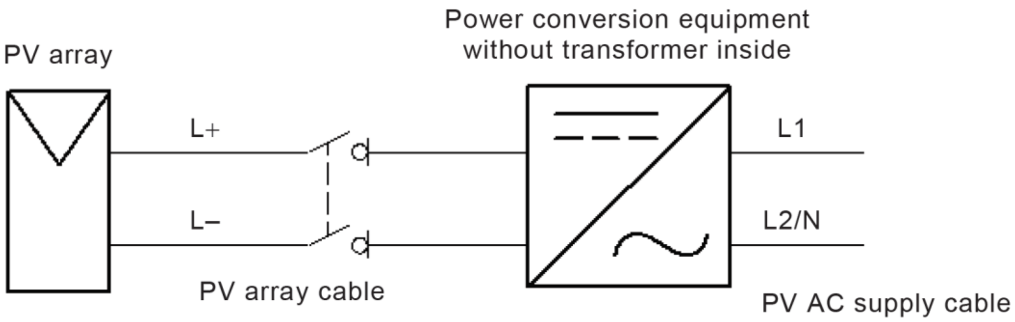


FIG. 72B - UNEARTHED PV ARRAY CONNECTED TO THE AC SIDE VIA A PCE WITHOUT A TRANSFORMER

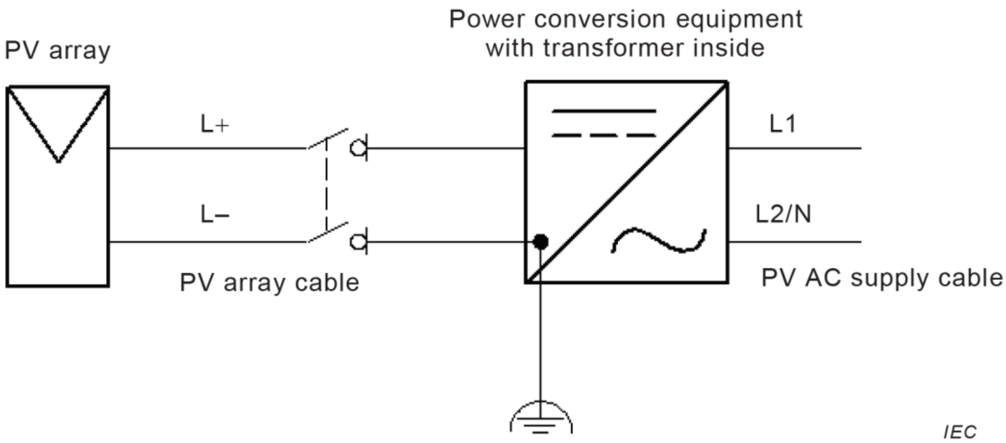


FIG. 72C - EARTHED PV ARRAY CONNECTED TO THE AC SIDE VIA A PCE WITH TRANSFORMER

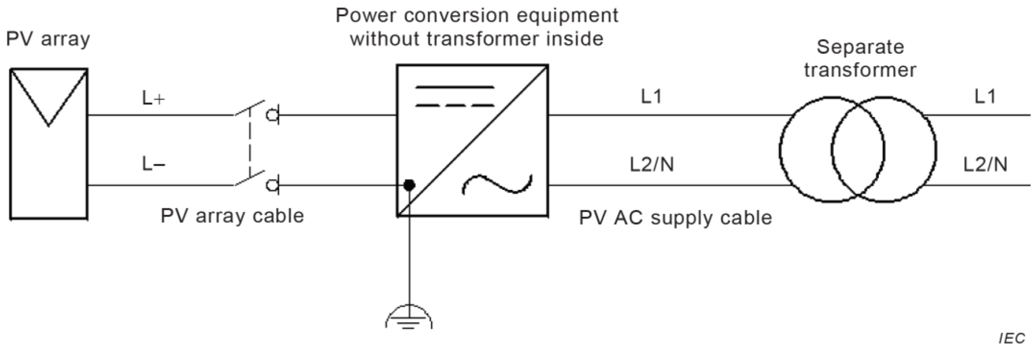


FIGURE 73D EARTHED PV ARRAY CONNECTED TO THE AC SIDE VIA A PCE WITHOUT A TRANSFORMER, THE TRANSFORMER BEING SEPARATE

11.3.3 Earthing Components

11.3.3.1 Earthing Cables and Strips

All DC and AC protective conductors, earthing conductors and earth electrodes installations shall comply with this code.

Following best practices shall be followed.

a. Earthing arrangement shall confirm Fig. 73 or Fig. 74.
b. The DC earthing conductor should be rated for 1.56 times the maximum short circuit current of the PV string/sub-array/array. (25 percent design safety factor and 25 percent irradiance factor).
c. Min. 6 mm^2 copper conductor, outdoor rated cable shall be used for PV module frame interconnections.
d. Earth electrodes shall satisfy Table 24.
e. System referencing conductor shall be introduced as per Annexure A, in islanding mode.

Note: Connecting DC side earthing (e.g. frame of module), AC side earthing, PCE and lightning protection earthing to separate earth electrodes as shown in 6.3.1 is prohibited.

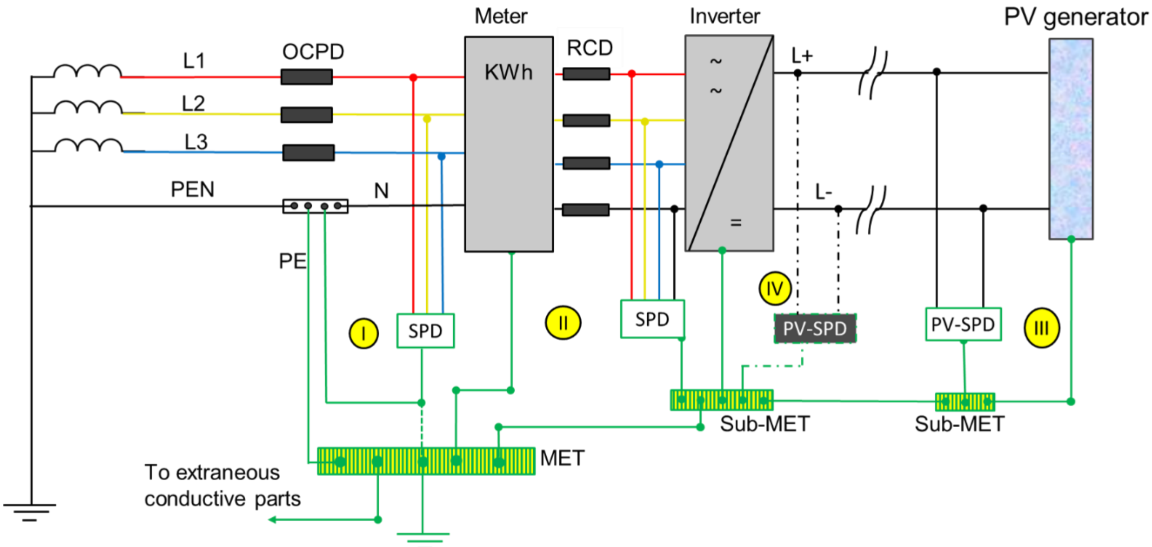


FIGURE 74 TYPICAL EARTHING, EQUIPOTENTIAL BONDING AND SPD'S IN A SOLAR PV SYSTEM WITH TN-C-S LV SUPPLY FROM DISCOM

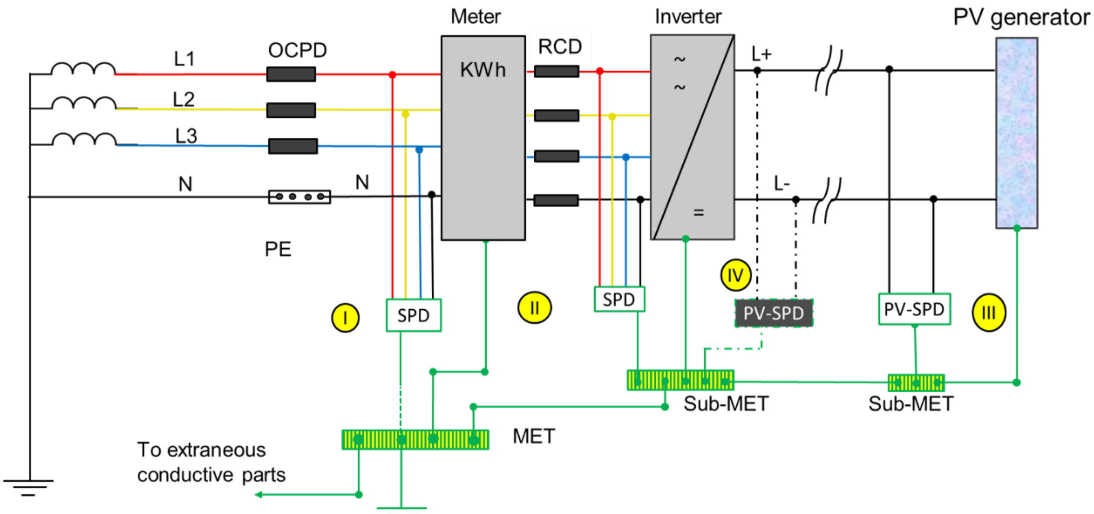
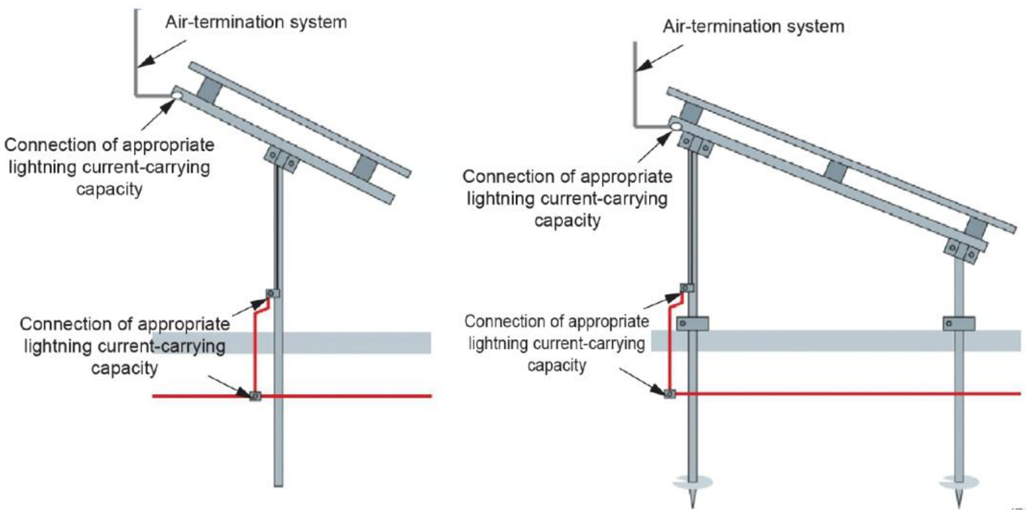


FIGURE 75 TYPICAL EARTHING, EQUIPOTENTIAL BONDING AND SPD'S IN A SOLAR PV SYSTEM WITH TT LV SUPPLY FROM DISCOM



a) pile driven foundation, single row

b) earth screw foundation, two part

FIGURE 76 (A AND B) - CONNECTION OF MODULE TABLES TO THE EARTHING SYSTEM FOR PILE DRIVEN FOUNDATIONS AND GROUND SCREW FOUNDATIONS.

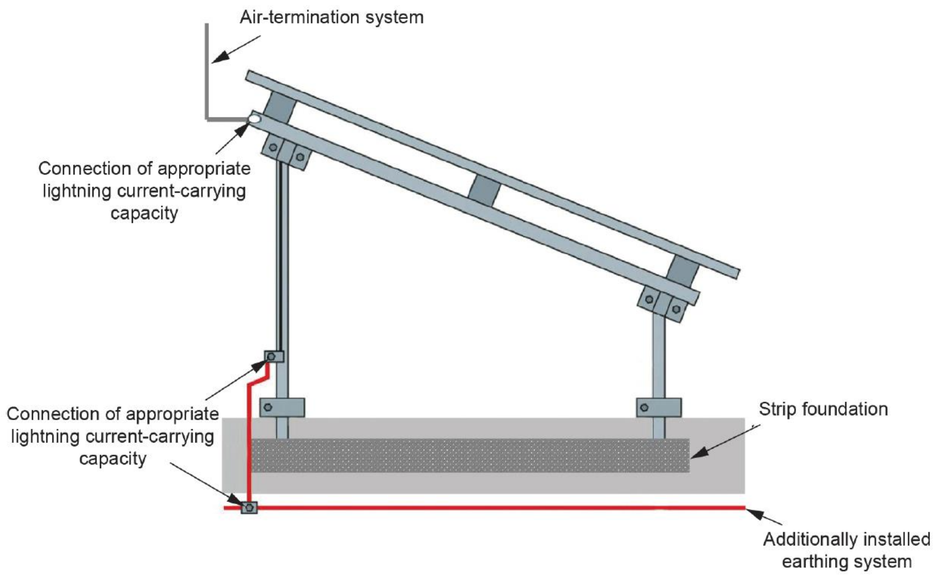


FIGURE 77 CONNECTION OF MODULE TABLES TO THE EARTHING SYSTEM FOR STRIP FOUNDATIONS

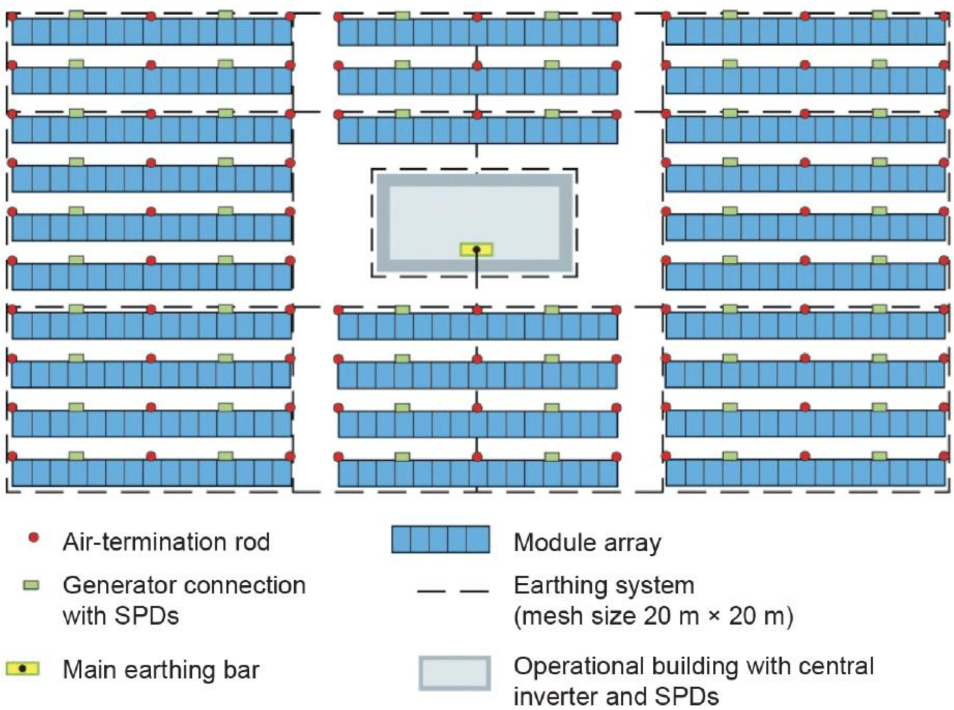


FIGURE 78 EARTHING CONCEPT AND ARRANGEMENT OF THE SPD'S FOR A GROUND MOUNTED SYSTEM

11.4 POTENTIALLY HAZARDOUS AREAS

11.4.1 Earthing and Bonding

11.4.1.1 Earthing should be in accordance with the relevant clauses of this Code. All earthing arrangement shall be mechanically and electrically made and secured by using adequate metallic fitting. The earthing arrangement shall be sufficiently strong and thick, and the portions of conductor which are likely to be corroded or damaged shall be well protected. Earthing Arrangement shall not reach a hazardous high temperature due to the earth fault current.

11.4.1.2 Specific guidelines for installations in hazardous locations are given in IS/IEC 60479.

11.4.1.3 Portable and transportable apparatus shall have protective earth conductor as a core of flexible power supply cable. The PE conductor and the metallic screen, wherever provided for the flexible cable, should be bonded to the appropriate metalwork of the apparatus and to earthing pin of the plug. The continuity resistance shall be ensured as recommended in the product standard.

11.4.1.4 Efficient bonding should be installed where protection against stray currents or electrostatic charges is necessary (see 7.2 to 7.5).

11.4.1.5 Earthing and Bonding of Pipelines and Pipe Racks

Unless adequately connected to earth elsewhere, all utility and process pipelines should be bonded to a common conductor by means of earth bars or pipe clamps and connected to the earthing system at a point where the pipelines enter or leave the hazardous area except where conflicting with the requirements of cathodic protection. In addition, it is recommended that steel pipe racks in the process units and off-site areas shall be bonded at every 25 m.

11.4.2 Permissible Type of Earthing System

11.4.2.1 Guidance on permissible power systems is given below:

a) If TN system earthing is used, it shall be type TN-S (with separate neutral N and protective conductor PE) in the hazardous area, i.e. the neutral and the protective conductor shall not be connected together, or combined in a single conductor, in the hazardous area. At any point of transition from TN-C to TN-S, the protective conductor shall be connected to the equipotential bonding system in the non-hazardous area.
b) If TT power system is used in Zone 1, it shall be protected with a residual current device even if it is a safety extra-low voltage circuit (below 50 V). The type TT power system is not permitted in Zone 0. Where the earth resistivity is high, such a system may not be acceptable.
c) For an IT power system (neutral isolated from earth or earthed through impedance), an insulation monitoring device should be used to indicate the first earth fault. However, equipment in Zone 0 shall be disconnected instantaneously in case of the first earth fault, either by the monitoring device or by a residual current operated device.
d) For power systems at all voltage levels installed in Zone 0, due attention should be paid to the limitation of earth fault currents in magnitude and duration. Instantaneous earth fault protection shall be installed.
e) It may also be necessary to provide instantaneous earth fault protection devices for certain applications in Zone 1.

11.4.2.2 Potential Equalization

To avoid dangerous sparking between metallic parts of structures, potential equalization is always required in all Zones (Zone 0 and Zone 1 and Zone 2 areas). Therefore, all exposed and extraneous conductive parts shall be connected to the main or supplementary equipotential bonding system.

The bonding system may include protective conductors, conduits, metal cable sheaths, steel wire armouring and metallic parts of structures but shall not include neutral conductors. The conductors for supplementary equipotential bonding shall have a conductance corresponding to a cross-section of at least 10 mm^2 of copper.

For additional information, see relevant clauses of this Code.

However, there are certain pieces of equipment, for example, some intrinsically safe apparatus, which are not intended to be connected to the equipotential bonding system.

11.4.3 Earthing of conducting screens

Where a screen is required, except as in a) through c) below, the screen shall be electrically connected to earth at one point only, normally at the non-hazardous area end of the circuit loop. This requirement is to avoid the possibility of the screen carrying a possibly incendive level of circulating current in the event that there are local differences in earth potential between points that may be available for connection to earth.

If an earthed intrinsically safe circuit is run in a screened cable, the screen for that circuit shall be earthed at the same point as the intrinsically safe circuit which it is screening.

If an intrinsically safe circuit or sub-circuit which is isolated from earth is run in a screened cable, the screen shall be connected to the equipotential bonding system at one point.

Special cases:

a) a) If there are special reasons (for example when the screen has high resistance, or where screening against inductive interference is additionally required) for the screen to have multiple electrical connections throughout its length, the arrangement of Fig. 78 may be used, provided that
   - the insulated earth conductor is of robust construction (normally at least 4 mm^2 but 16 mm^2 may be more appropriate for clamp type connections);
   - the arrangement of the insulated earth conductor plus the screen are insulated to withstand a 500 V a.c. rms or 700 V d.c. as applicable insulation test from all other conductors in the cable and any cable armour;
   - the insulated earth conductor and the screen are only connected to earth at one point which shall be the same point for both the insulated earth conductor and the screen, and would normally be at the non-hazardous end of the cable;
   - the insulated earth conductor shall be installed in positions that will prevent them being exposed to mechanical damage, to corrosion or chemical influences (for example solvents), to the effects of heat and to the effects of

UV radiation Where exposure of this nature is unavoidable, protective measures, such as installation in protecting conduit, shall be taken or appropriate cables selected (for example, to minimize the risk of mechanical damage, armoured, screened, seamless aluminium sheathed, mineral insulated metal sheathed or semi-rigid sheathed cables could be used). Where cables are subject to other conditions e.g. vibration or continuous flexing, they shall be designed to withstand that condition without damage.

- the inductance/resistance ratio (L/R) of the cable, installed together with the insulated earth conductor, additional requirements shall be established (see IEC 60079-14 cl 16.2.2.5).

b) If the installation is effected and maintained in such a manner that there is a high level of assurance that potential equalization exists between each end of the circuit (i.e. between the hazardous area and the non-hazardous area), then, if desired, cable screens may be connected to earth at both ends of the cable and, if required, at any interposing points.

c) Multiple earthing through small capacitors (for example 1 nF, 1 500 V ceramic) is acceptable provided that the total capacitance does not exceed 10 nF.

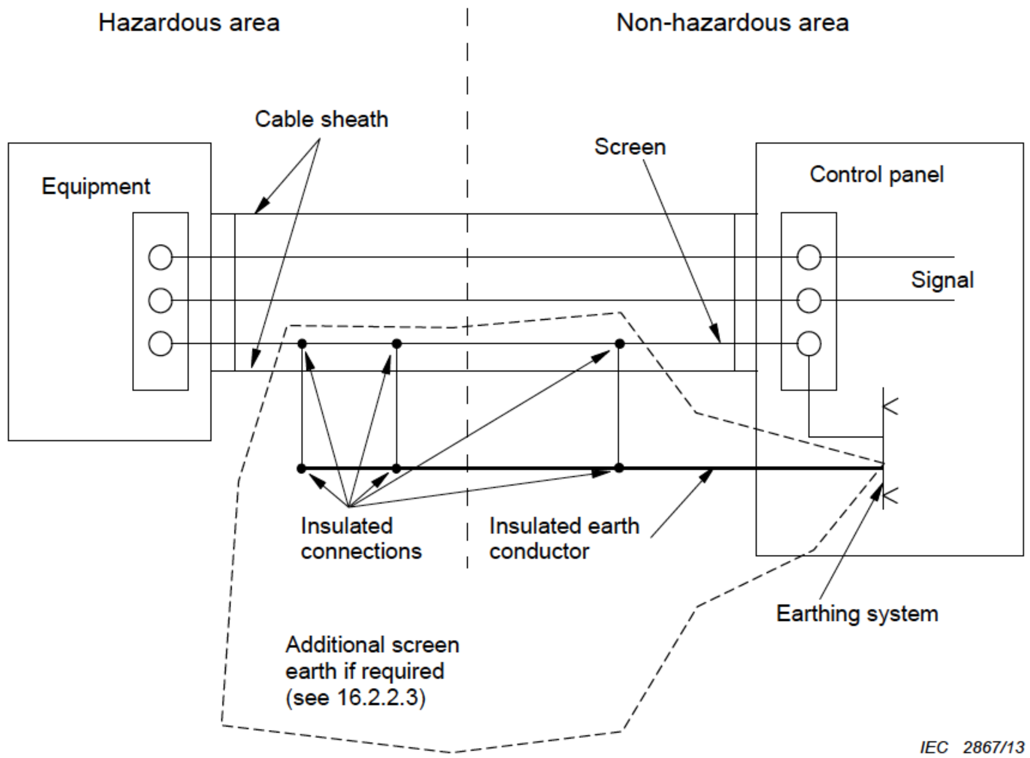


FIGURE 79 EARTHING OF CONDUCTING SCREENS

11.4.3 Nonstandard earthing (see 6.3.1) shall be prohibited.

Note: Demanding different earth electrode with certain resistance values (e.g. 4 Ohms for electrical systems and metallic structures, 7 Ohms for storage tanks, 1 Ohm for main earth grid, and bonding connections between joints in pipelines and associated facilities and 2 Ohms for each electrode to the general mass of the earth) are violation of the safety measures recommended in this code.

11.5 CONSTRUCTION SITES

11.5.1 In the often damp and rough environment of construction sites, precautions to prevent electrical hazards have to be robust and regularly inspected and this particularly applies to the earthing arrangement.

It is unlikely that the where the supply is below 650 V, supply authority will offer an earthed terminal and where the supply system has a multiple earthed neutral, it is of great difficulty to ensure that all incoming metallic services and extraneous metalwork are bonded to the neutral terminal (or earthed conductor) of the supply system, to thus satisfy the requirements of the TN-C-S with PME. If the supply is at a voltage higher than 650 V, the developer will have to provide a TN-S system on the low voltage side.

11.5.2 The main protection against electrical hazards on a construction site is the use of an Extra low voltage system for power tools (110 V between phases and 55 V to mid-point earth or 65 V to star-point earth) and safety extra low voltage (SELV) for supplies to headlamps, etc.

The earth fault loop impedances on an Extra low voltage system or on a 240/415 V system serving fixed equipment shall be low enough to allow disconnection within the safe duration (see Table 1, 7.4.1.8, 7.4.1.9).

11.5.3 Use of electricity in construction sites shall be through a Type A RCD with a residual current RCD with $I_{\Delta n} \leq 30$ mA.

11.6 MINES AND QUARRIES

11.6.1 General

Earthing arrangement for mines and quarries are based on the broad principle that exposed conductive parts of apparatus should be efficiently connected to equipotential bonding system or otherwise protected by other equally effective means to prevent danger resulting from a rise in potential on these conductive parts.

In some mines and certain quarries (quarries include open cast coal sites), in addition to shock risk, there are also dangers associated with the possible presence of flammable gas and explosive materials. In these cases, supplementary equipotential bonding with local earthing may be necessary to avoid incendive sparks caused by static electrical discharge.

11.6.2 Power System Earthing

If the supply is from a transformer (or generator), that is, the property of the supply authority, and is on site, a request should be made for them to facilitate connection of the consumer's earthing system to the neutral or mid-voltage point, i.e. a TN-S system. In some cases, the supply authority will allow the use of their earthed conductor or earthed neutral conductor (i.e a TN-S or a TN-C-S system) for consumers use, in this event the consumer shall maintain a protective equipotential bonding. If the supply is from a transformer that is not the property of the supply authority, or if the consumer generates electricity privately, then the consumer should provide and maintain the system as TN-S.

If the supply transformer (or generator) is distant from the consumer's premises, provision of TN-C-S system with PME should be requested. The earth terminal should be made available by the DISCOM through a protective conductor in the supply cable or overhead line.

NOTE — The supply cable sheath and armouring may serve the purpose of this protective conductor provided that they are bonded to the supply source earth, i.e. neutral or mid-voltage point and meet the conductivity requirement as per 7.3.2.

If the provision of such an earth terminal is impracticable, then it is imperative that the earth electrodes at the supply source and consumers' premises are maintained as a TT system, and fault protection is achieved by an RCD.

In all cases, the aim should be to maintain protective equipotential bonding and automatic disconnection of supply, irrespective of site conditions, for example, soil/rock resistivity.

The mains supply system neutral or mid-voltage points should be earthed at one point only and in the case of mines, this should be on the origin of installation or near the source. The mains supply system neutral connection to earth may either be a solid connection or via an impedance to limit the prospective earth fault current and in the case of impedance earthed systems, suitable earth fault protection is provided, that is, capable of detecting the restricted flow of fault current.

11.6.3 Apparatus Earthing at Coal and Other Mines

Every metallic covering of any cable should be earthed. See 7.3 for sizing of conductors for protective equipotential bonding.

Cables incorporating steel tape armour (unless supplementing steel wire), aluminium armour or copper sheathed (mineral insulated) cables are unsuitable for use below ground. Generally single or double, steel wire armoured cables are used. The use of paper-insulated lead covered cable is also discouraged.

The following are excluded from the requirements to be earthed, when used solely at the surface of the mine:

a. any lamp holder, that is, efficiently protected by a covering which is insulated or earthed and made of fire resisting material;
b. any hand held tool that is double insulated;
c. any portable apparatus working at less than 50 V dc or 30 V ac; and

In the case of electrical circuits used for control, interlocking and indicating instruments, the regulations allow one pole of the auxiliary transformer secondary winding serving these circuits to be connected to earth as an alternative to mid-point earthing.

Below ground, where self-contained mobile apparatus is used, for example, battery locomotives, these should be operated as totally insulated systems (to avoid sparks between metal parts of the apparatus). Warning systems should be provided to give an indication of leakage to frame.

At places below ground, where flammable gas may occur in quantity to indicate danger (usually deemed to be places where 0·25 percent flammable gas could be present in the general body of air), then limitation of the maximum prospective earth fault current is called for on power systems working at voltages between 250 V and 1200 V (the range of voltage normally used for coal winding machinery served by flexible trailing cables). In these cases, the maximum prospective earth fault current should be limited (normally by impedance earthing) to 16 A at voltages between 250 V and 650 V and to 2 A at voltages between 650 V and 1 200 V. In either case, the switchgear controlling the circuit should be able to detect and cut-off the supply of electricity with less than one-third of the maximum prospective earth fault current flowing.

NOTE — The ratio between maximum prospective earth fault current and protection settings is known as the 'tripping ratio'. In practice it has been found that in order to take account of voltage depressions occurring when a short circuit coincides with an earth fault the tripping ratio should be set to at least 5: 1. IT system is allowed at any place in a mine, including places where flammable gas may occur, provided that a transformer is used which has a means to cut off the supply and prevent danger should a breakdown occur between the primary and secondary windings. In these systems the maximum prospective earth fault current does not usually exceed 2 A and switchgear is set to trip at less than one-fifth of this value.

Signalling and telephone circuits may be connected to earth where safety is enhanced and the method of connection is approved by the concerned authority for that type of apparatus.

11.6.4 Apparatus Earthing at Miscellaneous Mines and Quarries

Every cable at a miscellaneous mine or quarry operating at voltages exceeding 250 V dc or 125 V ac, other than flexible cables and those not required to be covered by insulating material, should be protected throughout by a suitable metallic covering that has to be earthed. Metallic covering does not include any metals other than iron or steel, therefore cables with armouring or metallic cover made of soft metals such as aluminium and copper (MICC cable) cannot be used on these premises where the voltages exceed 250 V dc or 125 V ac.

Where flexible cable is used to supply portable apparatus at voltages exceeding 250 V dc or 125 V ac, such cable should be protected by one of the following:

a. A metallic covering (flexible wire armouring) that encloses all the conductors and having a conductance of not less than that of the largest current carrying conductor.
b. A screen of wires to enclose all the conductors (collectively screened type cable) having a conductance not less than that of the cross-sectional area of conductor.
c. A screen of wires arranged to individually enclose each conductor (individually screened type cable), other than the earth conductor. Cables of this construction for use in quarries have to be approved by HSE. For miscellaneous mines, the screens should each have a conductance of not less than that of 6 mm^2 cross-sectional area copper conductor.

Where flexible cables are used with portable apparatus at quarries and the size of the conductor is such as to make the use of one multicore cable impracticable, single core cables of such construction and bonded in such a manner as HSE may approve, may be used.

In all the above cases efficiency of automatic disconnection shall be verified before putting the device into service.

11.7 STREET LIGHTING AND OTHER ELECTRICALLY SUPPLIED STREET FURNITURE

NOTE — Street furniture includes fixed lighting columns, illuminated traffic signs, bollards and other electrically supplied equipment permanently placed in the street.

11.7.1 In all cases the local supply authority should be consulted before design work on new street furniture to ascertain the type of system earthing that will supply the new installation.

11.7.2 Street lighting and other electrically supplied street furniture shall normally be fed from TN-S or TN-C-S systems.

11.7.3 In all cases fault protection by automatic disconnection of supply shall be ensured (see. In critical locations where chance of people often getting in touch with street furniture (e.g. public places, parks, industrial units etc) additional protection by an RCD of $I_{\Delta n} \leq 30$ mA shall be ensured. Type of RCD shall be based on the type of load. Periodical testing of RCD’s shall be carried out to ensure its effective operation.

11.7.3.1 TN-S Systems

Street furniture may be fed from a TN-S system where a supply cable with separate line, neutral and protective earth conductors is required. 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 protective earth conductors. Exposed conductive parts of the item of street furniture (metal body including its foundation) being supplied should be bonded by connecting them to the protective earthing terminal within the equipment. The protective terminal itself should be connected to the supply protective earthing conductor.

If the installation is of 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 Class I and Class II Street furniture should have a protective earth conductor run to and appropriately terminated at each point in wiring and at each accessory.

11.7.3.2 TN-C-S Systems

An alternative method of supplying and protecting the street furniture is by means of a TN-C-S system. In such cases a combined neutral and earth conductor cable may normally be used upstream the street furniture. For example, to an individual lighting column or for larger installations, a local TN-C-S with PME supply is used up to a feeder pillar. From the feeder pillar, downstream the supply is made with cables using separate line, neutral and protective conductors to feed items of street furniture in the carriageway.

Exposed conductive parts of the item of street furniture (metal body including its foundation) should be bonded by connecting them to the earthing terminal within the equipment. In the case of circuits feeding more than one item of street furniture, for example, by looping using a cable with separate line, neutral and protective earth conductors, an earth electrode should be installed preferably both at the point of supply and at the last or penultimate unit and this electrode combination should be such as to make the resistance to earth at any point less than 20Ω, if not, other earth electrodes equally spaced along the circuit should be installed.

11.7.3.3 TT Systems

Where the electricity distributor does not provide an earthed terminal (See regulation 17 and 18), a TT system with own earth electrode shall be established. In such case fault protection shall be ensured by installing an RCD with $I_{\Delta n} \leq 30$ mA.

11.7.4 Wiring on the load side of the protective device in the units being supplied should use, separate phase, neutral and protective earth conductors.

11.7.5 In the case of circuits feeding more than one item of street furniture, for example, by looping, an earth electrode should be installed at the last or penultimate unit and this electrode should be such as to make the resistance to earth at any point less than 20 Ω. Should the provision of one electrode result in not meeting the 20 Ω requirement other earth electrodes equally spaced along the circuit have to be installed.

11.7.5 There are two further possibilities that may arise in streetlights on highways / public roads:

a) where the supply system is TN-C but where the lighting authority wishes to use a TT system, and
b) where the supply authority does not provide an earthed terminal.

In both of these cases, the lighting authority should provide its own earthing electrode and the system will be the TT-system. In such case fault protection shall be ensured by installing an RCD with $I_{\Delta n} \leq 30$ mA. In case of LED lights a TYPE A RCD shall be used.

11.8 EARTHING OF CONDUCTORS FOR SAFE WORKING

11.8.1 General

This clause deals only with the broad principles of the earthing of conductors for safety purposes. It is intended to cover the safety earthing of both light and heavy current equipment and is generally applicable to high voltage equipment; however, in some circumstances it may, where required, be applied as an additional safety feature to low voltage equipment. Where applicable, the use of safety earths should be part of overall safe system of work, which will include isolation, locking off, permits to work or similar documents and liaison between parties in control of the supplies and in control of the work. To ensure that a safe system of work is clearly set out, a set of detailed rules and procedures will be necessary in each particular case.

11.8.2 Safety Earthing

When maintenance or repair work, etc, is to be undertaken on or near to high voltage apparatus or conductors, precautions in connection with safety earthing should be taken generally as indicated below.

a) All phases or conductors of any apparatus or main to be worked on should be made dead, isolated and earthed and should remain earthed until work is completed.
b) Due regard should be taken of changing conditions during the progress of work which may necessitate revision of earthing arrangements to ensure the continuity of safety measures, for example, if a connection is made to another source of supply, whilst work is in progress, then additional earths would be necessary as work proceeds.

Safety earthing equipment may be available as permanent equipment, such as earthing switches, as part of permanent equipment such as provision for integral earthing of a circuit breaker, or as portable earthing equipment such as portable earthing leads. All such equipment needs to receive regular maintenance and should be inspected before use. Copper or tin-plated copper are preferred over other materials as earthing lead.

Wherever possible, initial earthing should be carried out via a circuit-breaker of other suitable fault-rated device.

Earthing leads should, in every case, be of adequate cross-sectional area to carry with safety, during the time of operation of the protective devices, the maximum short-circuit current that may flow under fault conditions. If possible, they should either be flexible, braided or stranded bare copper conductors suitably protected against corrosion and mechanical damage.

In no case, even for the earthing of light current equipment (for example, high voltage testing equipment), should the cross-sectional area of the earthing lead be less than 6 mm^2.

It has been found in some cases that a 70 mm^2 copper equivalent earthing lead is the largest that can be conveniently handled. In such cases, where a larger size of lead is necessary to carry with safety, the maximum short-circuit current that can occur, it may be necessary to use multiple leads of 70 mm^2 or other suitable size in parallel.

Before earthing leads are applied, it should be verified that the circuit is dead and, where applicable, a test by means of a suitable type of voltage indicator should be applied (the indicator itself being tested immediately before and after verification) before applying earth connections.

Earthing leads should first be efficiently bolted or clamped to the permanent earthing system or to a substantial electrode of low resistance (See. Fig. 66 and Fig. 67). Should no convenient permanent earth electrode be readily available, a substantial earth electrode (see Fig. 35 or Fig. 36) driven well into the ground can be utilized to provide a quick and convenient temporary earth electrode.

Whilst such a spike is not generally adequate as a primary safety earth, it will give a degree of protection against energizing by induction.

Earthing leads should then be securely bolted or clamped to apparatus of conductors to be worked on and these connections should be removed in all cases before the earthing leads are disconnected from the earth electrode or earthing system.

A suitable insulated pole or device should be used to apply earthing leads to apparatus or conductors on which work is to be undertaken.

Earthing leads should be kept as short as possible and be placed in such a position that they cannot be accidently disconnected or disturbed whilst work is in progress.

11.8.3 Precautions Relating to Apparatus and Cables

In the case of switchgear, phases of the section in which the work is to be done should be short-circuited and earthed to the same earthing system. Self-contained or portable apparatus is generally available for this purpose. Wherever possible, automatic tripping features of circuit breakers should be rendered inoperative by being disconnected from the tripping battery before the circuit-breaker is closed and the breaker operating mechanism should be locked in the closed position.

With transformers, if there is any possibility of any winding becoming inadvertently live, the terminals of all windings should be earthed so that no danger from shock can occur. When the neutral points of several transformers are connected to a common Earthing Terminal, which is then earthed through a resistance of an arc suppression coil, the neutral point of any transformer that is to be worked on should be disconnected and directly earthed as well as the phase terminals.

When liquid earthing resistors are to be worked on, particularly when they are drained for work inside, the central electrode should be shorted to the tank and not earthed remotely. This is especially important where two liquid resistors are located side-by-side and one remains in commission while the other is opened for maintenance.

When work is to be carried out on equipment that is capable of capacitively storing electrical energy, for example, cables and capacitors, such equipment has to be discharged to earth prior to work commencing. As, in some circumstances, charge can reappear on such apparatus without reconnecting it to a source of supply, it is important work that the equipment should remain earthed whilst is in progress. The cutting of a cable during the course of work may disconnect conductors from safety earths and precautions should be taken to prevent this happening.

11.8.4 Precautions Relating to Overhead Lines

After a line has been made dead, isolated, discharged and earthed at all points of supply, a working earth should be securely attached to each phase of the line at the point or points where work is to be carried out.

The provision of a working earth entails a connection to a continuous earth wire or to a temporary earth electrode, the resistance of which need not be low (e.g. 20 to 50 Ω). The application of earths to all phase conductors will, in addition to earthing the conductors, apply a short-circuit to all phases.

The connection of the earthing lead to each conductor of the overhead line should be made using a suitable mechanical clamp placed round the conductor by means of an insulated earthing pole which can also be utilized to secure the clamp tight round the line conductor. When it is required to remove the working earth from the line, the mechanical clamp can be unscrewed and released from the conductor by means of this rod. Even when an overhead line is earthed at each point of supply, it is necessary to place a working earth at each and every position where work is being carried out on the line on account of the danger of the line becoming energized by induction from other power lines and to safeguard against the charging of the line by atmospheric disturbances. Where the work entails breaking a conductor, for example, on the jumper at a sectioning point, it is necessary to provide a working earth on both sides of the working point.

11.8.5 Safety Earthing of Low Voltage Conductors

In some circumstances, it may be necessary to apply safety earthing to low voltage conductors in order to prevent danger. Such circumstances may include, for example, work on capacitors or work on bare overhead crane trolley wires. Where the earthing of low voltage conductors is adopted, then the general principles set out in 11.8.2, 11.8.3 and 11.8.4 should be applied and due consideration should be taken of fault current levels.

12 MAINTENANCE OF EARTHING ARRANGEMENT AND EARTH ELECTRODES.

12.1 MAINTENANCE OF PROTECTIVE EARTHING

12.1.1 It is recommended that periodical inspection and testing of all earthing arrangement should be carried out. Records should be maintained of such checks.

12.1.2 Testing of earthing arrangement consists of continuity of protective conductors including connections to MET and connections from MET to earth electrodes if any. The resistance of the conductors for protective earthing and protective bonding are measured. The continuity resistance of conductors shall not exceed the values mentioned in Annex yy.

12.1.3 For Low Voltage Installations

12.1.3.1 Measurement of resistance of earth electrodes shall be carried out for lightning protection with Type A earthing according to IS/IEC 62305.

Note: Type A earthing according to IS/IEC 62305-3, in locations where soil resistivity $\leq$ 500 Ω-m vertical earth rods of 2.5 meters or horizontal conductors of 5 meters can be used. Earthe electrode resistance measurement may not be necessary in such cases.

12.1.3.2 In all cases earth fault loop impedance of Low Voltage supply lines shall be measured to comply the regulations (see clause 4.1 and 4.2).

12.1.3.3 Where RCD's are employed, its operation shall be verified by an RCD tester. Additionally, a verification on the associated earthing arrangement is also necessary.

12.1.4 For High Voltage Installations

12.1.4.1 Impedance to earth and continuity resistance measurements of all connected exposed and extraneous parts should be performed in new and existing installations, where earth grids are installed to limit touch, step potentials and to avoid abnormal operating conditions due to fault currents (See 13.4).

12.2 MAINTENENCE OF EARTH ELECTRODES

12.2.1 For Low voltage installations, no specific value of earth electrode resistance is required except Type A earth electrodes for Lightning Protection System as per IS/IEC 62305-2 (see 8.1.2 c). However fault protection and additional protection measures shall be implemented (see 7.4 and 7.5).

12.2.2 For all installations where Global Earthing System is implemented, a touch/step voltage measurement should be carried out once in two years.

12.2.3 Substations and Generating Stations (Other than Global Earthing System)

12.2.3.1 Records shall be kept of the initial resistance of substation and generating station earth electrodes and of subsequent tests carried out.

12.2.3.2 Normally annual measurement of earth electrode resistance of substation shall be carried out but local circumstances in the light of experience may justify increase or decrease in this interval but it should not be less than once in two years.

12.2.3.3 Periodical visual inspection of all earth connections, wherever available, shall be carried out to ensure their rigidity and other signs of deterioration.

12.2.3.4 In rural substations, particularly those connected to overhead high-voltage and low-voltage lines, greater reliance should be placed on the electrode system, and therefore facilities for testing the resistance of the electrode to general mass of earth, annually or as required by clause 4.5.2.2 of IS732 should be provided.

12.2.3.5 Where installations are earthed to a metal sheath of the supply cable, it shall be verified periodically that the earth-fault loop impedance is in a satisfactory state.

12.2.3.6 Where an installation is earthed to a cable sheath which is not continuous to the substation neutral (that is, there is an intervening section of overhead line without earth wire), a supplementary electrode system may be necessary. The adequacy of the electrode system shall be checked initially by an earth-fault loop impedance test.

12.2.3.7 Keeping the neighbouring soil to the earth electrode in moist situation, may be helpful in certain substations and generating stations, however other fault protective measures shall be ensured in locations other than substations and generating stations including substations belonging to a consumer (e.g. an industrial and commercial buildings).

12.2.3.8 Any abnormality observed during inspection shall be corrected to required level.

13 MEASUREMENT OF SOIL RESISTIVITY AND EARTH ELECTRODE.

13.1 MEASUREMENT OF SOIL RESISTIVITY

13.1.1 Resistivity of the Soil

13.1.1 The resistivity of the earth varies within extremely wide limits, between 1 and 10 000 ohm-metres (Ω-m). The resistivity of the soil at many station sites has been found to be non-uniform. Variation of the resistivity of the soil with depth is more predominant as compared to the variation with horizontal distances. Wide variation of resistivity with depth is due to stratification of earth layers. In some sites, the resistivity variation may be gradual, where stratification is not abrupt. Highly refined techniques for the determination of resistivity of homogeneous soil are available. To design the most economical and technically sound earthing system for large stations (e.g. EHV stations, generating stations), it is necessary to obtain accurate data on the soil resistivity and on its variation at the station site. Resistivity measurements at the site will reveal whether the soil is homogeneous or non-uniform. In case the soil is found uniform, conventional methods are applicable for the computation of soil resistivity when the soil is found non-uniform, either a gradual variation or a two-layer model may be adopted for the computation of soil resistivity.

13.1.1.2 The resistivity of soil varies over a wide range depending on its moisture content. It is, therefore, advisable to conduct soil resistivity tests during the dry winter or dry summer season in order to get conservative results.

13.1.2 Test Locations

13.1.2.1 In the evaluation of earth resistivity for substations and generating stations, at least eight test directions shall be chosen from the centre of the station to cover the whole site. This number shall be increased for very large station sites of the test results obtained at various locations show a significant difference, indicating variations in soil formation.

13.1.2.2 In case of transmission lines, the measurements shall be taken along the direction of the line throughout the length approximately once in every 4 km.

13.1.3 Principle of Tests

13.1.3.1 Wenner’s four electrode method is recommended for these types of field investigations. In this method, four electrodes are driven into the earth along a straight line at equal intervals. A current I is passed through the two outer electrodes and the earth as shown in Fig. 79 and the voltage difference V, observed between the two inner electrodes. The current I flowing into the earth produces an electric field proportional to its density and to the resistivity of the soil. The voltage V measured between the inner electrodes is, therefore, proportional to the field. Consequently, the resistivity will be proportional to the ratio of the voltage to current. The following equation holds for:

$$\rho = \frac{4s\pi R}{1+\frac{2s}{\sqrt{s^2+4e^2}}-\frac{2s}{\sqrt{4s^2+4e^2}}} \ldots(7)$$

where

ρ	=	resistivity of soil in ohm-metre (Ω-m),
s	=	distance between two successive electrodes in metres,
R	=	resistivity meter reading in ohms (Ω), and
e	=	depth of burial of electrode in metres.

13.1.3.1.1 If the depth of burial of the electrodes in the earth is negligible (in case where depth of burial is less than $l/20^{th}$ of spacing) compared to the spacing between the electrodes. Resistivity meter normally used for these tests comprise the current source and meter in a single instrument and directly read the resistance. The most frequently used resistivity meter is the four-terminal resistivity meter shown in Fig. 79. When using such a resistivity meter, the resistivity may be evaluated from the modified equation as given below:

$$\rho = 2\pi sR \ldots(8)$$

where

ρ	=	resistivity of soil in ohm-metres (Ω-m),
s	=	distance between successive electrodes in metres, and
R	=	resistivity meter reading in ohms (Ω).

13.1.4 Test Procedure

13.1.4.1 At the selected test site, in the chosen direction, four electrodes are driven into the earth along a straight line at equal intervals, s. The depth of the electrodes in the earth shall be of the order of 10 to 15 cm. The resistivity meter is placed on a steady and approximately level base, the link between terminals P1 and C1 opened and the four electrodes connected to the instrument terminals as shown in Fig. 79. An appropriate range on the instrument is thus selected to obtain clear readings avoiding the two ends of the scale as far as possible. Resistivity is calculated by substituting the value of R thus obtained in the Equation (8). In case where depth of burial is more than l/20th of spacing, Equation (7) should be used instead of Equation (8).

13.1.4.2 Correction for Potential Electrode Resistance

In cases where the resistance of the potential electrodes (the two inner electrodes) is comparatively high, a correction of the test results would be necessary depending on its value. For this purpose, the instrument is connected to the electrodes as shown in Fig. 80. The readings are taken as before. The correction is then effected as follows.

13.1.4.2.1 Let the readings of the resistivity meter be R_p with the connections as shown in Fig. 80 and the electrode spacing in metres. If the uncorrected value of soil resistivity is r‘ and the resistance of the voltage circuit of the instrument used to obtain R (as indicated inside the scale cover of the meter) is R_v, the corrected value of the earth resistivity would be:

$$\rho = \frac{\rho' \times (R_v + R_P)}{R_v}$$

13.1.5 Testing of Soil Uniformity

13.1.5.1 During the course of above tests, it would be desirable to get information about the horizontal and vertical variations in earth resistivity over the site under consideration for the correct computation of the resistivity to be used in the design calculations. The vertical variations may be detected by repeating the tests at a given location in a chosen direction with a number of different electrode spacings, increasing from 2 to 250 m or up to the boundary of the site/substation, preferably in the steps 2, 5, 10, 15, 25 and 50 m or more. If the resistivity variations are within +/- 30 %, the soil in the vicinity of the test location may be considered uniform. Otherwise a curve of resistivity versus electrode spacing shall be plotted and this curve further analyzed to deduce stratification of soil into two or more layers of appropriate thickness or a soil of gradual resistivity variation. The horizontal variations are studied by taking measurements in various directions from the centre of the station.

13.1.6 Computation of Earth Resistivity of Uniform Soil

13.1.6.1 When the earth resistivity readings for different electrode spacings in a direction is within +/- 30 %, the soil is considered to be uniform. When the spacing is increased gradually from low values, at a stage, it may be found that the resistivity reading is more or less constant irrespective of the increase in the electrode spacing. The resistivity for this spacing is noted and taken as the resistivity for that direction. In a similar manner, resistivities for at least eight equally spaced directions from the centre of the site are measured. These resistivities are plotted on a graph sheet in the appropriate directions choosing a scale. A closed curve is plotted on the graph sheets jointing all the resistivity points plotted to get the polar resistivity curve. The area inside the polar resistivity curve is measured and equivalent circle of the same area is found out. The radius of this equivalent circle is the average resistivity of the site under consideration. The average resistivity thus obtained may be used for the design of the earthing grid and other computations and the results will be reasonably accurate when the soil is homogeneous (see Fig. 81).

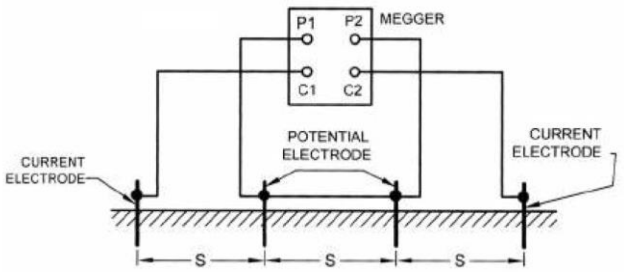


FIGURE 80 EARTHING OF CONDUCTING SCREENS

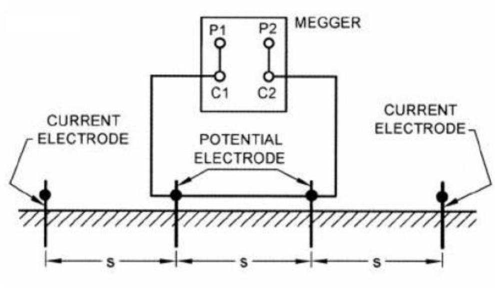


FIGURE 81 TEST CONNECTION TO MEASURE THE SUM OF THE POTENTIAL ELECTRODE RESISTANCE

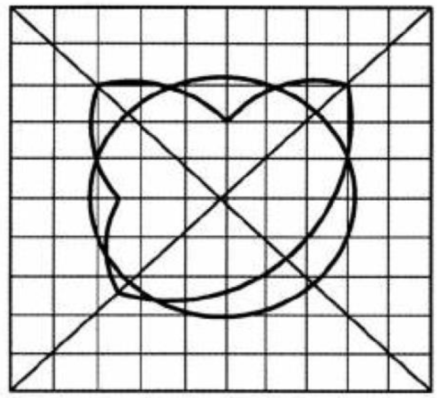


FIGURE 82 POLAR CURVE

13.1.7 Two-layer soil model

Where it is determined that a uniform soil model is not appropriate, two-layer models may be used which are often good approximations of many actual soil structures. A two-layer soil model consists of an upper layer of finite depth and with different resistivity than a lower layer of infinite thickness. There are several techniques to determine an equivalent two-layer model from apparent resistivity obtained from field tests. In some instances, a two-layer model can be approximated by visual inspection of a plot of the apparent resistivity versus probe spacings. Other methods are available including Sundes graphical method and the reflection method. Computer programs are also available to the industry and may be used to derive two layer soil models.

13.1.8 Multi-layer soil model

Highly non-uniform soil conditions may be encountered. Such soil conditions could require the use of multi-layer modelling techniques if an equivalent two-layer soil model is not feasible. A multi-layer soil model may include several horizontal layers or vertical layers. Techniques to interpret highly non-uniform soil resistivity could require the use of computer programs which could also allow inclusion of volume resistivity blocks.

13.2 MEASUREMENT OF EARTH ELECTRODE RESISTANCE

13.2.1 Measurement of earth electrode resistance using an earth electrode test instrument

The following procedure may be adopted when measurement of the earth electrode resistance is necessary.

Note: The measurement of earth electrode resistance is NOT to be carried out inside the substation premises. It is be done from the edge of the substation.

An alternating current of a steady value is passed between the disconnected earth electrode, E, and a temporary auxiliary earth electrode, H, placed at a distance from E such that the resistance areas of the two electrodes do not overlap.

A second temporary probe electrode, S, which may be a metal spike driven into the earth, is then inserted half-way between E and H, and the voltage drop between E and S is measured. In most cases S should be placed at a distance of approximately 20 m from E and H. The electrodes may be arranged in a linear formation (see Fig. 82 A) or triangular formation (see Fig. 82 B) to suit available space.

The resistance of the earth electrode is then the voltage between E and S, divided by the current flowing between E and H, provided there is no overlap of the resistance areas.

To check that the resistance of the earth electrode is a true value, two further readings are taken with the second electrode, S, moved approximately 10 % of the linear distance between E and H from the original position. If the three results are substantially in agreement, the mean of the three readings is taken as the resistance of the earth electrode E. If there is no such agreement, the tests are repeated with the distance between E and H increased.

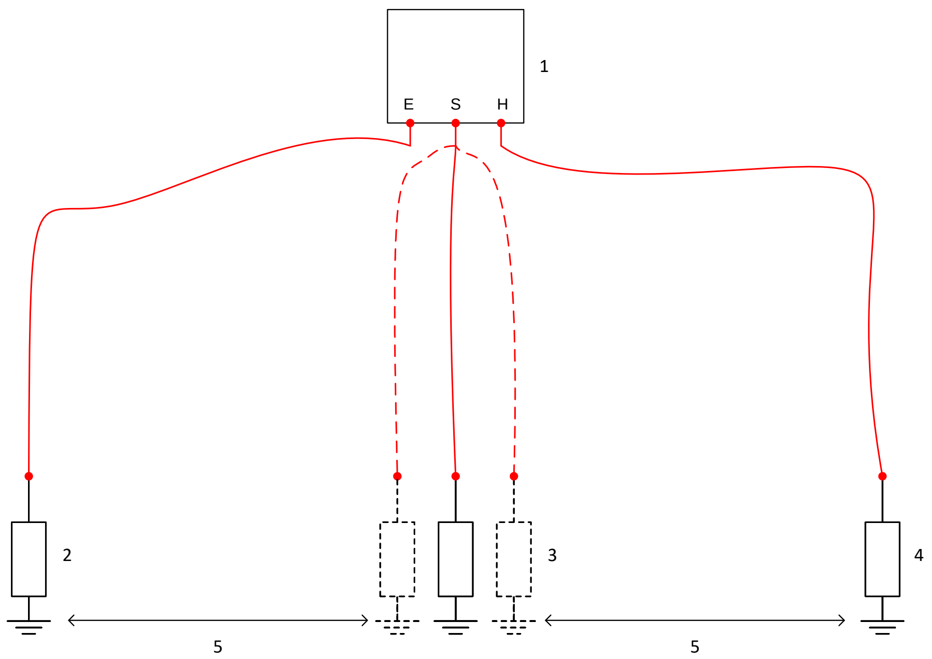


FIGURE 82A ELECTRODES ARRANGED IN LINEAR FORMATION

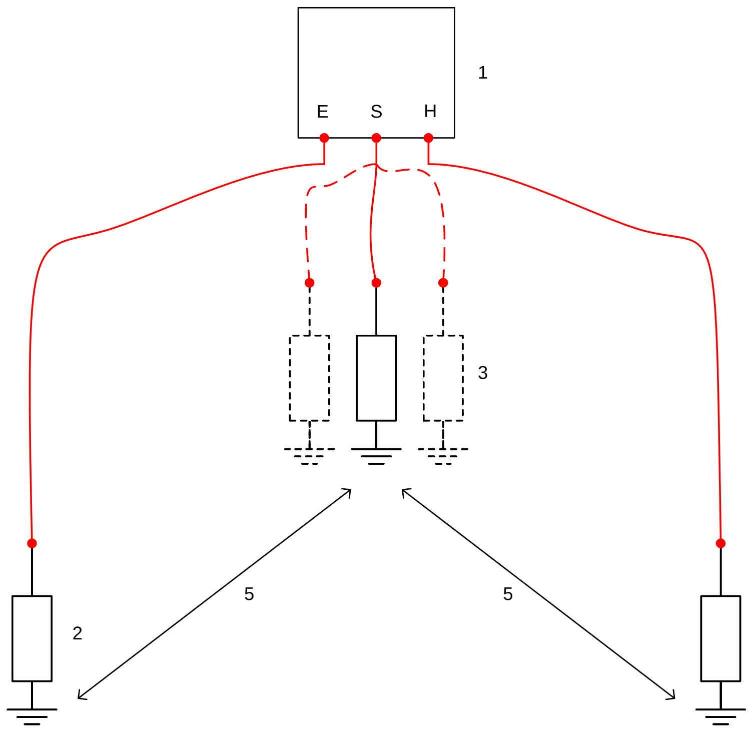


FIGURE 82B - ELECTRODES ARRANGED IN TRIANGULAR FORMATION

Key
1) Earth electrode test instrument according to IEC 61557-5

2) Earth electrode resistance R_E
3) Temporary probe electrode resistance (voltage) R_S
4) Temporary auxiliary probe earth electrode resistance (current) R_H
5) Distance between electrodes

FIGURE 83 MEASUREMENT OF THE EARTH ELECTRODE RESISTANCE

13.2.2 Measurement of earth electrode resistance using current clamps

Note: The measurement of earth electrode resistance is NOT to be carried out inside the substation premises. It is be done from the edge of the substation.

The following procedure may be adopted as an alternative method for the measurement of the earth resistance.

With reference to Fig. 83 the first clamp induces a measuring voltage U into the loop, the second clamp measures the current I within the loop. The loop resistance is calculated by dividing the voltage U by the current I.

As the resulting value of parallel resistances R1 … Rn is normally negligible, the unknown resistance is equal to, or slightly lower than, the measured loop resistance.

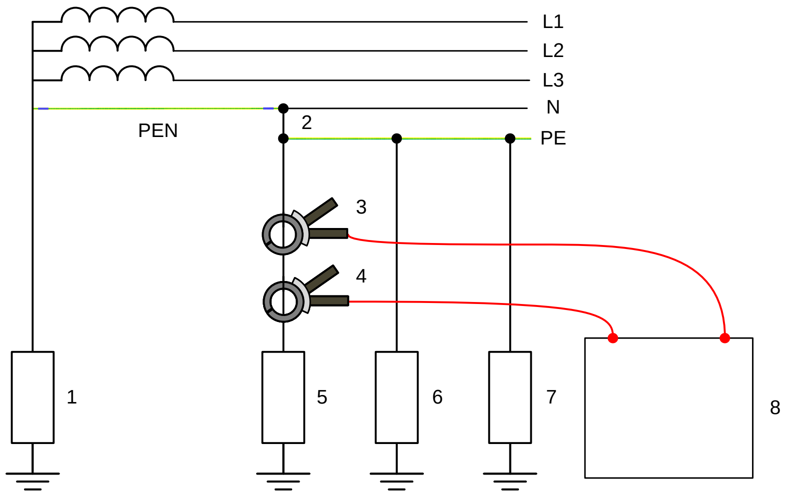
The voltage and current coils may be in individual clamps separately connected to an instrument or in a single combined clamp.

This method is directly applicable to TN systems and within meshed earthing of TT systems.

In TT systems, where only the unknown earth connection is available, the loop can be closed by a temporary connection between earth electrode and neutral conductor (quasi TN system) during measurement.

To avoid possible risks due to currents caused by potential differences between neutral and earth, the system should be switched off during connection and disconnection.

It should be noted that the values of resistance obtained using this method will typically be higher than those obtained using method explained in 13.2.1 because of the earth loop measurement.



Key

1) R_B - resistance of the earth electrode of the supply
2) Main earthing terminal test link
3) Voltage clamp of the test instrument
4) Current clamp of the test instrument
5) R_A - resistance of the earth electrode of the installation
6) R_1 - resistance of the additional earth electrode of the installation
7) R_n - resistance of the additional earth electrode of the installation
8) Test instrument according to IEC 61557-5

FIGURE 84 MEASUREMENT OF EARTH ELECTRODE RESISTANCE USING CURRENT CLAMPS

13.2.3 Measurement of earth electrode resistance using a fault loop impedance test instrument

Measurement of the earth fault loop impedance at the origin of the electrical installation may be carried out with a test instrument according to IEC 61557-3.

The test should be performed on the live side of the main switch with the supply to the installation switched OFF and with the earthing conductor temporarily disconnected from the MET.

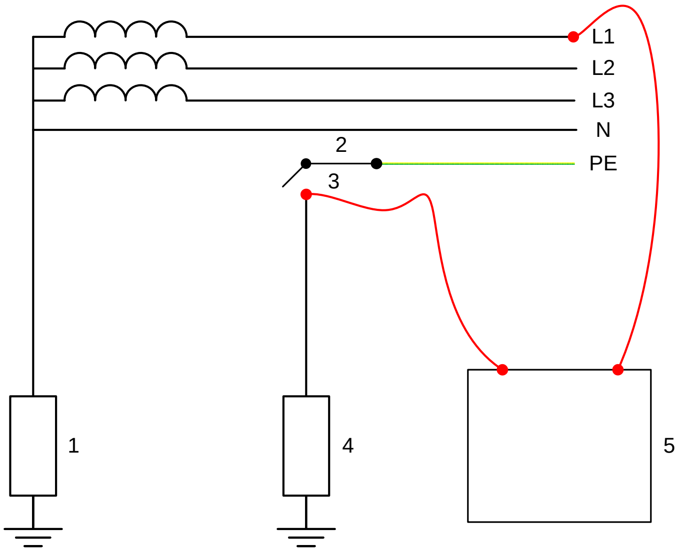
The test instrument should be set to a range appropriate for the value of earth fault loop impedance likely to be expected for a given system earthing arrangement (typically in the region of 0 Ω to 20 Ω).

The test instrument should be connected as shown in Fig. 84. Where any doubt exists the instrument should be connected as described in the manufacturer's instructions.

Only a small proportion of the measured earth fault loop impedance is derived from those parts of the loop other than the electrode and so the result obtained from this test can be taken as a reasonable approximation of the earth electrode resistance.

The test result should not exceed the product of 50 V / $I_{\Delta n}$ (see 7.4).

It is important that the earthing conductor is reconnected to the MET of the installation before the supply is reinstated.



Key

1) R_B - resistance of the earth electrode of the supply
2) MET - Main earthing terminal
3) Test link to be temporarily disconnected from the main earthing terminal (MET) during testing
4) R_A - resistance of the earth electrode for the installation
5) Earth fault loop impedance test instrument according to IEC 61557-3

FIGURE 85 MEASUREMENT OF THE EARTH ELECTRODE RESISTANCE USING AN EARTH FAULT LOOP IMPEDANCE TEST INSTRUMENT.

13.3 MEASUREMENT OF EARTH FAULT LOOP IMPEDANCE

13.3.1 The current, which will flow under earth fault conditions and will thus be available to operate the overload protection, depends upon the impedance of the earth return loop. This includes the line conductor, fault, earth-continuity conductor and earthing lead, earth electrodes at consumer's premises, and substations and any parallel metallic return to the transformer neutral as well as the transformer winding. To test the overall earthing for any installation, depending for protection on the operation of over current protective devices, for example, fuses, it is necessary to measure the impedance of this loop under practical fault conditions. After the supply has been connected, earth fault loop impedance measurement shall be done by the use of an earth loop impedance tester as per IEC 61557-3.

13.4 MEASUREMENT OF RESISTANCES TO EARTH AND IMPEDANCES TO EARTH

These resistances and impedances may be determined in different ways. Which method is suitable depends on the extent of the earthing system and the degree of interference (see 13.6).

NOTE Attention is given to the fact that while the measurements and preparations are carried out, even when disconnected, but especially during the measurement, on and between earthed parts (for example between tower and lifted-off earth wire) touch voltages exceeding permissible limit values could occur.

Examples for suitable methods of measurements and types of instruments are:

a) Fall-of-potential method with the earth tester

> This instrument is used for earth electrodes and earthing systems of small or medium extent, for example single rod earth electrodes, strip earth electrodes, earth electrodes of overhead line towers with lifted off or attached earth wires, medium voltage earthing systems and separation of the low-voltage earthing systems. The frequency of the used alternating voltage should not exceed 150 Hz.
>
> Earth electrode under test, probe and auxiliary electrode shall lie on a straight line as far apart as possible. The distance of the probe from the earth electrode under test should be at least 5 times the maximum extension of the earth electrode under test (in measuring direction), but not less than 20 m; the distance of the auxiliary electrode is at least 8 times the maximum extension, but not less than 40 m.

b) Heavy-current injection method (see Fig. 85)

> This method is used particularly for the measurement of the impedance to earth of large earthing systems.
>
> By applying an alternating voltage of approximately system frequency between the earthing system and a remote earth electrode, a test current IM is injected into the earthing system, leading to a measurable potential rise of the earthing system.
>
> Earth wires and cable sheaths with earth electrode effect, which are operationally connected to the earthing system, shall not be disconnected for the measurement.
>
> The modulus of the impedance to earth is given by

$$Z_E = \frac{U_{EM}}{I_M \times r}$$

where

U_{EM} is the measured voltage between the earthing system and a probe in the area of the reference earth (remote earth) in Volts

I_M is the measured test current in Amperes

r is the reduction factor of the line to the remote earth electrode (see 10.16). The reduction factor may be determined by calculation or by measurement.

For the reduction factor for overhead lines without earth wires and cables without shield or armouring is r = 1.

Earth wires of lines which run on a separated support parallel to the test line between earthing system and remote earth electrode shall be taken into account if they are connected to the earthing system under test and the remote earth electrode. If a cable with low-resistance metal sheath, earthed on both sides, is provided, then the greatest part of the test current will return via the sheath. If there is an insulating covering around the sheath it can be suitable to disconnect the earthing of the sheath.

However, for cables which perform the function of an earth electrode, the earthing of the metal sheaths shall not be disconnected.

The distance between the tested earthing system and the remote earth electrode should be large enough to ensure separate zones of influence, e.g. 5 km for extended earthing systems, depending on local conditions. Local conditions are e.g. size of interconnected earthing system, soil layer configuration.

Note For small earthing systems smaller distances can be sufficient.

The test current should be, as far as possible, selected at least so high that the measured voltages (earth potential rise as well as touch voltages, referred to the test current) are greater than possible interference and disturbance voltages. This is generally ensured for test currents above 50 A, e.g. depending on elimination method, size of impedance to earth, resulting earthing current of test circuit, noise level. Also, smaller or higher test currents could be suitable.

The internal resistance of the voltmeter should be at least 10 times the resistance to earth of the probe.

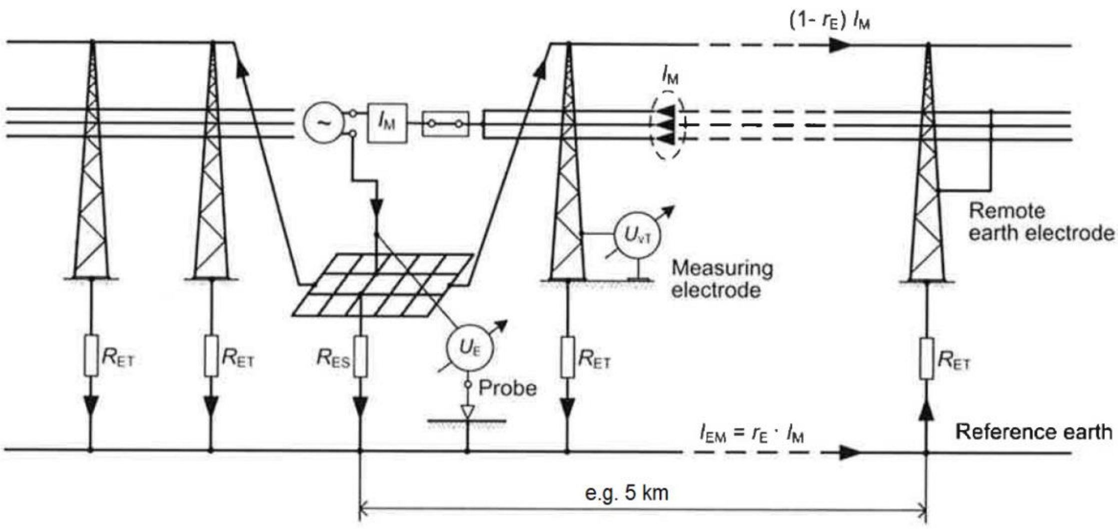
Possible interference and disturbance voltages shall be eliminated (see 13.6).

c) Determination from the individual resistances

If the earthing system consists of separate earth electrodes, which practically do not interfere with each other, but which are interconnected via connecting conductors, for example earthing conductors or earth wires of overhead lines, then the impedance to earth Z_E can be determined in the following way:

The resistance to earth of each earth electrode is determined for disconnected connecting conductors by the fall-of-potential method, the impedances of the connecting conductors are calculated, and the impedance to earth is determined from the equivalent circuit of the resistance to earth and the impedances of the connecting conductors.

Where the resistance to earth R_{ES} (Fig. 85) of the designed meshed earth grid has to be determined, the measurement of the test current and the other currents leaving this earth grid, e.g. by earth wire overhead lines or cable sheathes, allows to obtain the current flowing through the resistance to earth RES. In general, vector measurements of these currents are required.



Key

I_M	Test current (generally only the modulus of the voltage and the current is determined)
I_{EM}	Current to earth during the measurement (in this case not directly measurable)
r_E	Reduction factor of the line to the remote earth electrode
R_{ES}	Resistance to earth of the mesh earth electrode
R_{ET}	Resistance to earth of the tower
U_E	Earth potential rise during measurement
U_{vT}	Prospective touch voltage during measurement

FIGURE 86 EXAMPLE FOR THE DETERMINATION OF THE IMPEDANCE TO EARTH BY THE HEAVY-CURRENT INJECTION METHOD

13.5 MEASUREMENTS OF TOUCH VOLTAGE AND PROSPECTIVE TOUCH VOLTAGE

Measurements of the touch voltage U_T or prospective touch voltage U_{vT} are always based on heavy current injection method, as described in 13.4. The measurements of touch voltages shall be done at relevant locations within and outside the installation.

In order to get a rapid overview, the prospective touch voltages U_{vT} can be measured by a voltmeter with a high internal resistance (eg > 1 MΩ) and a probe driven about 10 cm deep. As these prospective touch voltages U_{vT} are always higher than the touch voltages U_T, the measured values of the prospective touch voltages can be checked against the permissible touch voltage (U_{Tp}; see Fig. 4). This is often sufficient and additional measurements of touch voltages are not required.

The conditions for measuring the touch voltages are the following:

- The measuring electrode(s) for simulation of the feet shall have a total area of 400 cm^2 and lie on the earth with a minimum total force of 500 N, shall be placed at a distance of 1 m from the exposed part of the installation, and for concrete or dried soil it shall be on a wet cloth or water film. An alternative measuring electrode is to use a probe driven at least 20 cm deep into the soil.

- The measuring electrode(s) for simulation of the hand is a tip-electrode and shall be capable of piercing a paint coating (not insulation) reliably.
- One terminal of the voltmeter is connected to the hand electrode, the other terminal to the hand or feet electrode, depending on the local conditions.
- The human body shall be simulated by a resistance of 1 kΩ.

The procedures shown are based on a given fault duration t_f and a test current. The measured voltages on site shall be converted from test current level to fault current level. Depending on the design of the earthing systems different types of touch voltage measurement could be necessary.

For a design without additional resistances the following touch voltage measurements apply (Fig. 86, Fig. 87):

- Measurement of U_{vT} according to Fig. 86

  If the criteria $U_{\mathrm{vT}} \leq U_{\mathrm{Tp}}$, then the requirement is fulfilled. If not, then measurement Fig. 87 shall be done

- Measurement of U_{T} according to Fig. 87

  If the criteria $U_T \leq U_{Tp}$, then the requirement is fulfilled. If not, then the design shall be improved or special measures may be taken (e.g. additional resistances).

For a design with additional resistances the following touch voltage of measurements apply (Fig. 88, Fig. 89):

Either

- Measurement of U_{T} according to Fig. 88

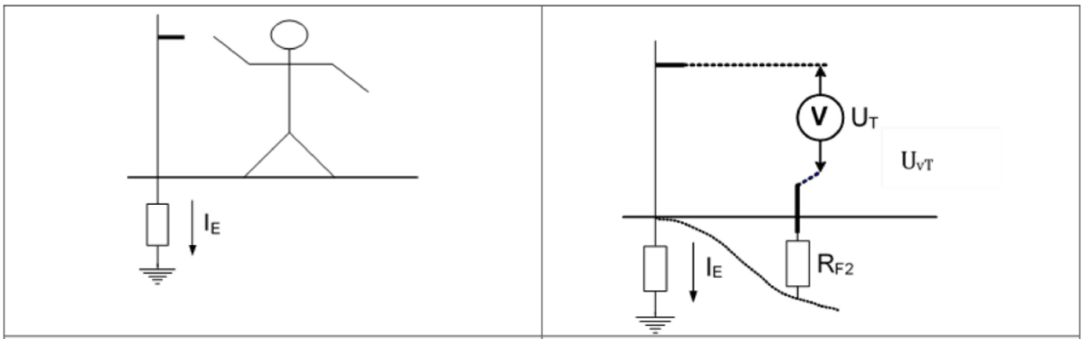
If the criteria $U_{\mathrm{T}} \leq U_{Tp}$, then the requirement is fulfilled. If not, then the design shall be improved or special measures may be taken (e.g. higher additional resistances).

or

— Measurement of U_{vT} according to Fig. 89

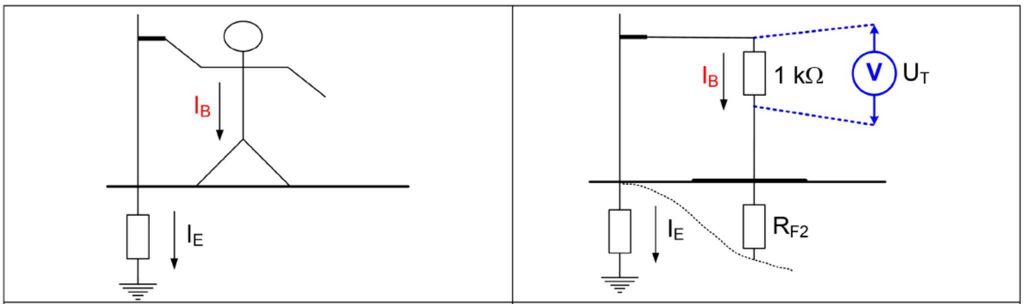
If the criteria $U_{vT} \leq U_{vTp}$, then the requirement is fulfilled. If not, then the design shall be improved or special measures may be taken (e.g. higher additional resistances).

A flowchart giving the possible options and requirements for the measurement of touch voltage and prospective touch voltage is given in Fig. 90.



Configuration simulated by measurement (no contact)	Measurement configuration

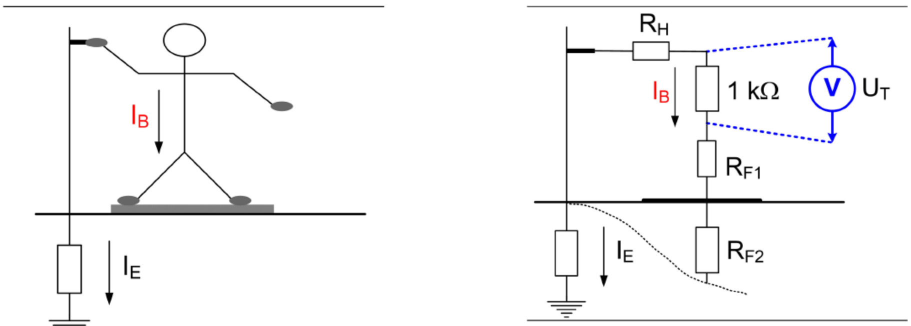
FIGURE 87 MEASUREMENT OF PROSPECTIVE TOUCH VOLTAGE U_{VT}



Configuration simulated by measurement (touching with bare skin at hand and feet)	Measurement configuration

NOTE An alternative measuring electrode is to use a probe driven up to 20 cm deep into the soil.

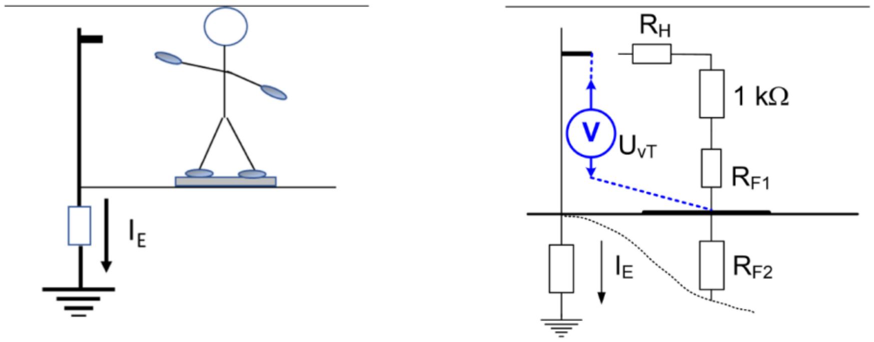
FIGURE 88 MEASUREMENT OF TOUCH VOLTAGE U_T



Configuration simulated by measurement (presence of gloves, shoes, surface layer of gravel or high resistivity surface materials)

Measurement configuration. The standing point resistance R_{F2} is increased by the additional surface layer R_{F1}.

FIGURE 89 MEASUREMENT OF TOUCH VOLTAGE U_T WITH ADDITIONAL RESISTANCE.



Configuration simulated by measurement (no contact), (presence of gloves, shoes, surface layer of gravel or high resistivity surface materials)

Measurement configuration
The standing point resistance R_{F2} is increased by the additional surface layer R_{F1}.

NOTE This open circuit measurement of U_{vT} measured without the voltage across the additional resistance R_{F2} is for comparison with the limit of U_{vTp}.

FIGURE 90 MEASUREMENT OF PROSPECTIVE TOUCH VOLTAGE U_{VT} WITH ADDITIONAL RESISTANCE.

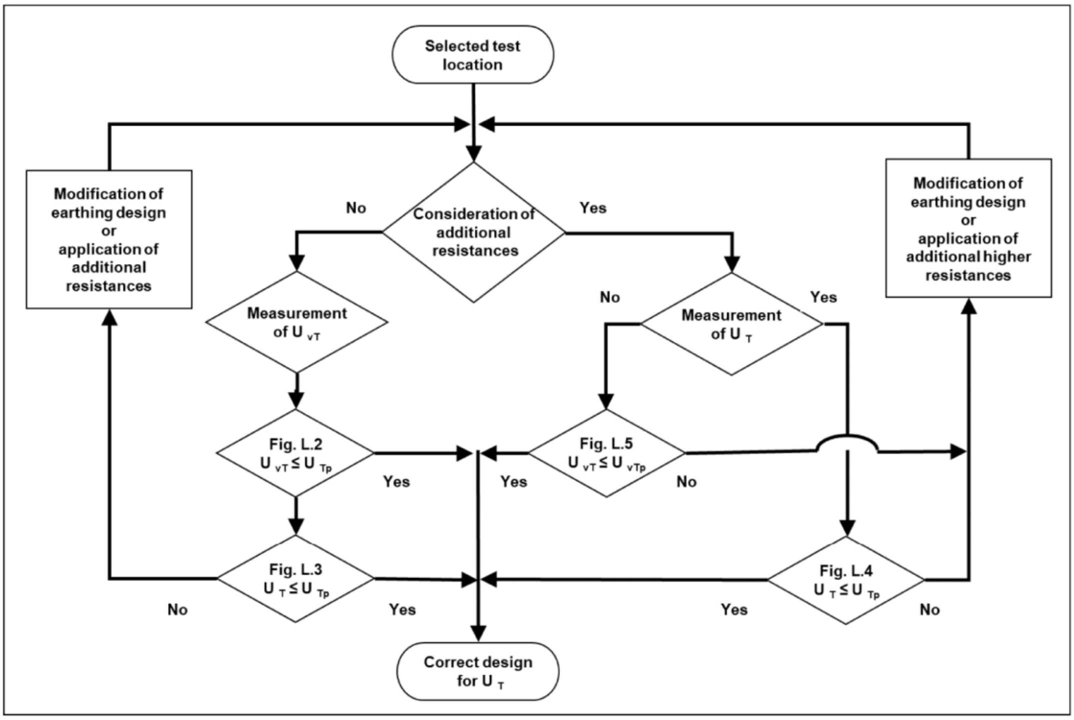


FIGURE 91 OPTIONS AND REQUIREMENTS FOR THE MEASUREMENT OF TOUCH VOLTAGE AND PROSPECTIVE TOUCH VOLTAGE.

13.6 ELIMINATION OF INTERFERENCE AND DISTURBANCE VOLTAGES FOR EARTHING MEASUREMENTS

For the determination of the earth potential rise (see 13.4b) distortions of the measured values due to interference and disturbance voltages of every type (for example inductive interference of the test circuit by parallel systems in operation) may occur. Examples for methods proved useful in practice for the elimination of such disturbing effects are:

a) Beat method

In this case a voltage source (for example emergency generating set) is used, whose frequency deviates some tenth of a Hertz from the system frequency. The voltages caused by the test current are added vectorially to possible disturbance voltages U_d, whose modulus and phase angle for sufficiently short duration of a measuring cycle may be regarded as constant. Due to the asynchronous superposition the pointer or the display of the voltmeter swings between a maximum value U_1 and a minimum value U_2. The voltage caused by the test current is determined by

$$U = \frac{U_1 + U_2}{2} \text{ for } 2 * U_d < U_1$$

$$U = \frac{U_1 - U_2}{2} \text{ for } 2 * U_d > U_1$$

$$U = \frac{U_1}{2} \text{ for } 2 * U_d = U_1$$

b) Polarity reversal method

For this purpose, a system synchronous voltage source (transformer) is used, whose voltage is reversed 180° electrically in the phase angle after a dead interval. During the flow of the test current the occurring voltages U_a before the reversal, U_b after the reversal and the disturbance voltage U_d for the test current switched off are measured. For a sufficiently short duration of a measuring cycle the possible disturbance voltages U_d is regarded as constant with respect to modulus and phase angle. The disturbance voltage contains mainly the contribution of the test current frequency. Because of vectorial relations the voltage caused by the test current is calculated by

$$U = \sqrt{\frac{U_a^2 + U_b^2}{2} - U_d^2}$$

c) Vector measurement

Long measuring leads should be laid rectangularly to the test line, as far as possible. If this is not possible because of space conditions, the part of the voltage induced in the measuring line by the test current can partly be eliminated by vector measurement equipment.

d) Blocking of direct currents

If the disturbance voltages have high direct voltage contents, a voltmeter which blocks the direct voltage could be required.

e) Frequency selective method

A test current with a frequency above or below the power frequency is injected. The voltages and currents are measured frequency selective.

13.7 CONTINUITY RESISTANCE MEASUREMENT

Measuring the continuity resistance (impedance) and comparing the result with the requirement of the particular application is an essential part of protective and functional earthing. The test equipment shall be capable of measuring in a four-lead configuration (two voltage measuring leads and two current injecting leads) as illustrated in Fig. 91. The injected current depends upon the application and in most cases, should be about 10 A. (See respective standard for more information)

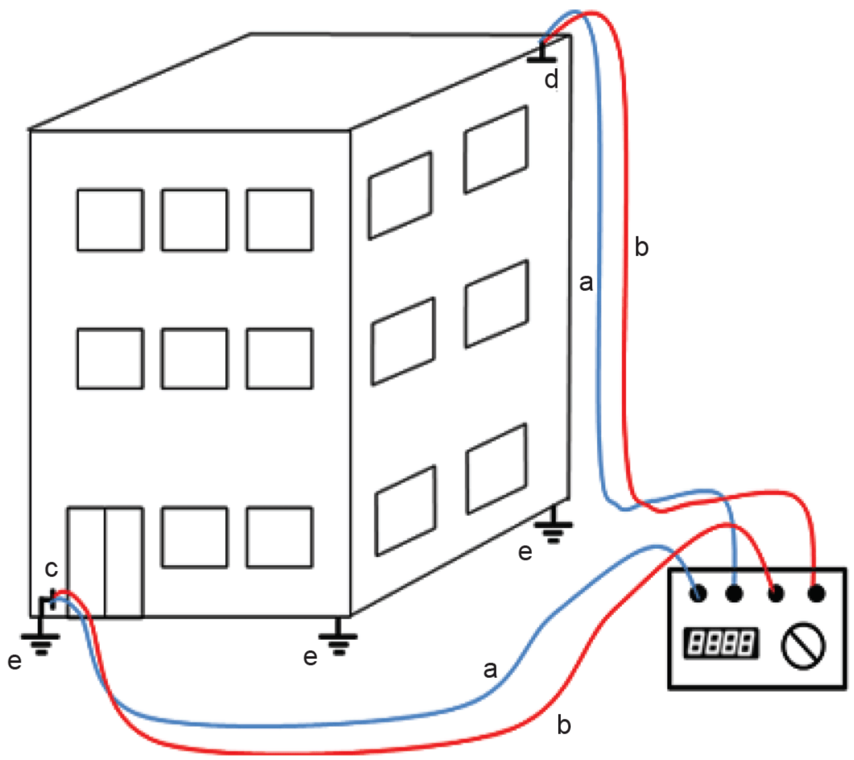
Note: Example of some of the applications are

1. IS 732 & NEC 2023 (SP 30): Resistance of all protective conductors including the joints shall be verified. Maximum allowed resistance depends on the size and length of protective conductor. Maximum allowed resistance of conductors are include in NEC 2023 (SP 30) part 1 section 17, annex B. Where copper conductors are used, they shall be class 1 / Class 2 conductors.

2. IS/IEC 60439-1 Low-voltage switchgear and controlgear assemblies: The resistance between protective earthing terminal to exposed conductive parts shall not exceed 0.1 Ω, measured with a meter of at least 10 Amps.

3. See 11.2.3.2.6 and 11.2.3.3.3 for requirements of continuity resistance in medical locations.

4. Lightning protection as per IS/IEC 62305-3: Maximum overall resistance of 0.2 Ω between the air-termination system and the equipotential bonding bar or other connection to the structure's (lightning) earth network.



Key

a current carrying test leads
b voltage measuring test leads
c bonding bar or earth network connection
d connection to steel reinforcement rods
e earth network connection

FIGURE 92 EXAMPLE OF MEASURING THE OVERALL CONTINUITY RESISTANCE OF STEEL REINFORCEMENT.

ANNEX A
EARTHING OF MULTIPLE SOURCES

(Informative)

A.1 TN SYSTEM

The contents of this clause are related to any kind of Generating stations such as synchronous machines, solar PV, wind etc.

Note:

1. System with more than one source in TN system, refer IS732.
2. Other methods of multiple source system with changeover facility are explained in Fig. 44 to Fig. 46.

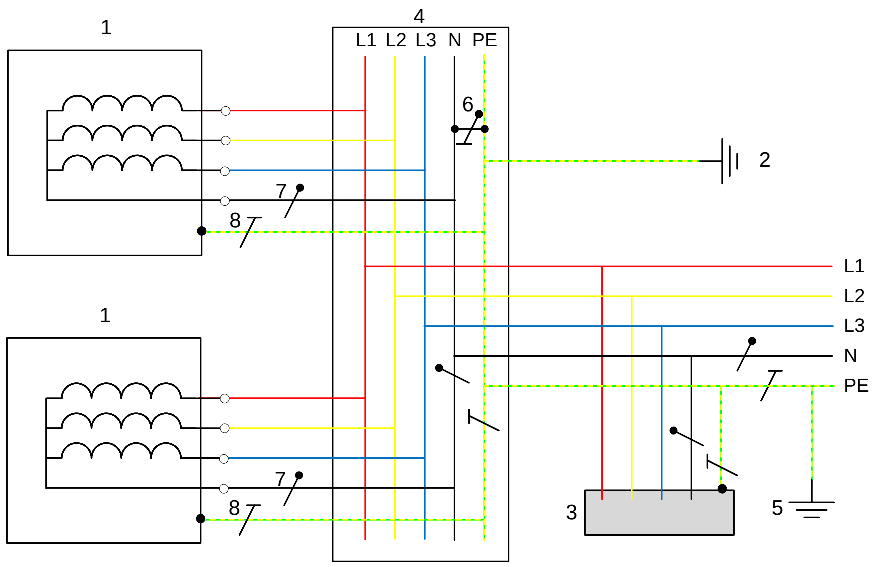
In the case of an inappropriate design of an installation forming part of a TN system with more than one source some of the operating current can flow through unintended paths. These currents can cause

- fire;
- corrosion;
- electromagnetic interference

Installations with more than one source shall be designed as to reduce the probability for current in the protective earthing conductors under normal situation to a minimum, and shall comply with the following:

- no direct connection between the neutral point of the transformer and/or of the generating sets and earth shall be established (see “1” in Fig. A1),
- the neutral conductor connecting the neutral point of the transformer and/or generating sets to the (main) distribution board shall be insulated and shall not be connected to any current-using equipment (see “7” in Fig. A1 and (see “7” and "10" in Fig. A2),
- only one connection between the interconnected neutral points of the sources and the protective earthing conductor shall be provided in the installation. This connection shall be located inside the distribution board (see “6” in Fig. A1 and 93),
- the protective earthing conductor shall be connected to an earth electrode through the MET (see “2" in Fig. A1 and Fig. A2),
- downstream of the distribution board, the neutral conductor and the protective earthing conductor shall not be interconnected. However, additional earthing of the protective earthing conductor in the installation may be provided (see “5” in Fig. A1 and Fig. A2);
- circuits supplying distribution boards to which an internal source is connected, shall not be provided with means for disconnection of the neutral conductor (fault protection provided to the installation during the islanding mode the internal source may be affected in case of disconnection of Neutral conductor);
- in TN-C-S System with at least one local source and one external source a system-referencing-conductor shall be installed as part of the electrical installation, see Fig. A2.

Where an installation is extended with more generating sets, the protective measures shall remain effective in all situations.



Key

1) Local source;
2) Earth electrode for earthing of the system;
3) Electrical equipment with exposed-conductive-part;
4) Distribution board;
5) Additional earthing which may be provided throughout the installation;
6) System-referencing-conductor;
7) Neutral conductor connecting the neutral point of the source to the distribution board;
8) Protective conductor for protective earthing of the source.

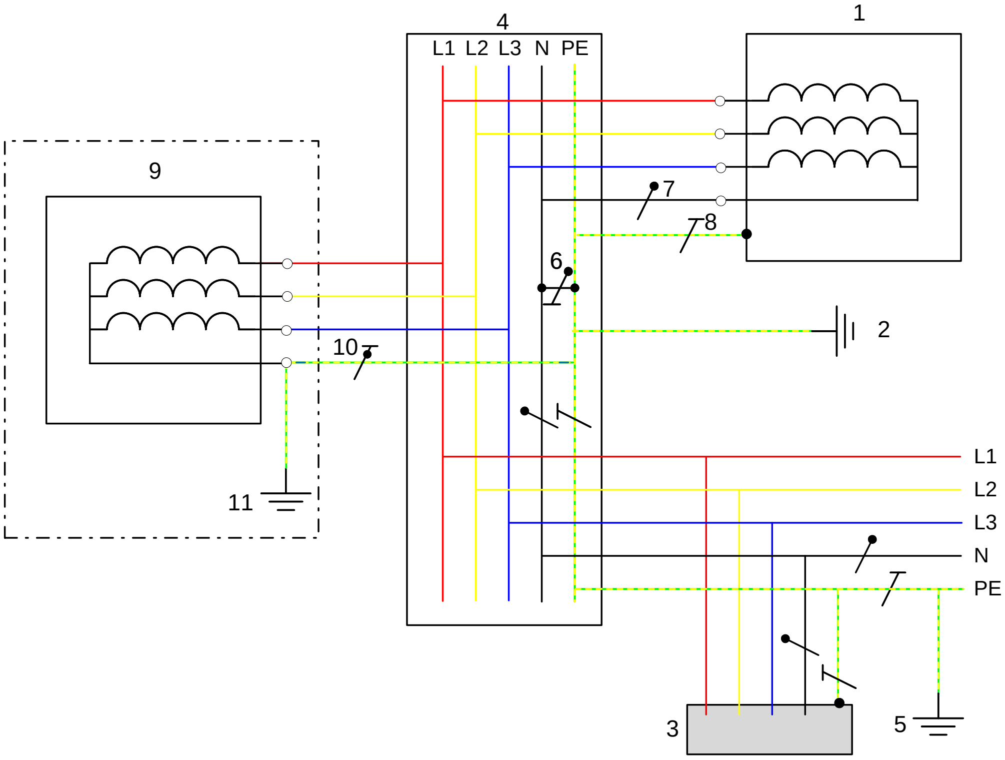
FIGURE A 1 EXAMPLE OF AN AC TN-S MULTIPLE SOURCE SYSTEM WITH TWO LOCAL SOURCES

Where an installation is supplied from an external distribution network (either public or private), especially where the distribution network is originating from outside a building housing the installation, special measures need to be considered:

a) The live conductors of the distribution network need to be provided with a system-referencing-conductor within the installation itself (preferably at origin of installation), independent of any electrical source being connected to it. The distribution network cannot rely upon a system-referencing-conductor being installed in one of the electrical installations as that installation might be disconnected.

b) An electrical installation with an internal source, intended to operate in island mode, may be disconnected from the distribution network. Therefore, it cannot be assumed that a live part of the installation is effectively connected to earth, as the system-referencing-conductor in the distribution network might not be present.

Additional earthing of a protective earthing conductor may be provided throughout the system/installation. PEN conductor additionally earthed at the distribution only (before origin of installation). Therefore, where an electrical installation with an internal power source is connected to a distribution network and supplied with a PEN-conductor, the neutral conductors in the electrical installation reliably connected to the installation protective earthing conductor.



Key

1) Local source;
2) Earth electrode for earthing of the system in the installation;
3) Electrical equipment with exposed-conductive-part;
4) Distribution board;
5) Additional earthing which may be provided throughout the installation;
6) System-referencing-conductor;
7) Conductor between the neutral point of the source and the distribution board;
8) Protective conductor for protective earthing of the source;
9) External source, e.g., from distribution network;
10) PEN conductor between external source and the distribution board;
11) Earth electrode for the earthing of the system at the external source (e.g., the distribution network).

FIGURE A 2 EXAMPLE OF AN AC TN-C-S MULTIPLE SOURCE SYSTEM WITH ONE LOCAL SOURCE AND ONE EXTERNAL SOURCE (E.G., PUBLIC POWER SUPPLY NETWORK)

A2 TT SYSTEM

The contents of this clause are related to generating stations such as solar PV, wind etc.

Note: System with more than one source in TT system also refer IS732.

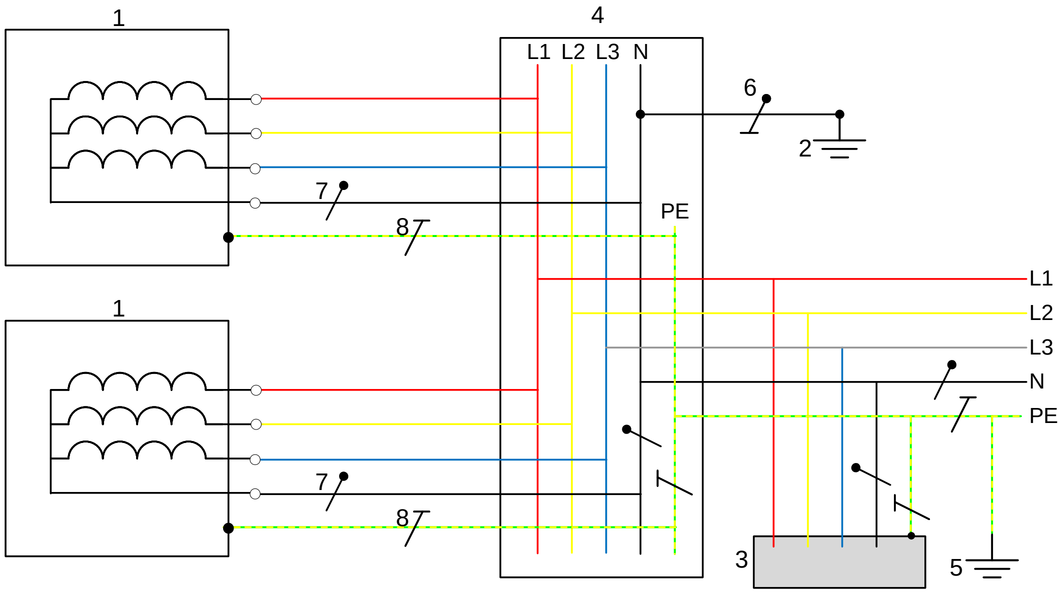
In the case of an inappropriate design of an installation forming part of a TN system with more than one source some of the operating current can flow through unintended paths. These currents can cause

- fire;
- corrosion;
- electromagnetic interference

Installations with more than one source shall be designed so as to reduce the probability of current in the protective earthing conductors under normal conditions to a minimum, thus:

- no direct connection between the neutral point of the transformer and/or the generating sets and earth is established, see "1" in Fig. A3,
- the neutral conductor connecting the neutral point of the transformer and/or the generating sets to the (main) distribution board is insulated and is not connected to any current-using equipment, see "7" in Fig. A3.
- only one connection between the interconnected neutral points of the sources and an earth electrode is provided. This connection is located inside the distribution board, see "6" in Fig. A3,
- the exposed-conductive-parts in the installation are earthed to a separate, independent earth electrode.

Fig. A3shows an installation with two local sources only and the earthing electrode for the system earthing and the earth electrode for the earthing of the exposed-conductive-parts are electrically independent of each other.



Key

1) Local sources within the electrical installation
2) Earth electrode for earthing of the system (of the sources at only one point)
3) Electrical equipment with exposed-conductive-part
4) Distribution board
5) Earthing of exposed-conductive-parts
6) System-referencing-conductor
7) Conductor between the neutral point of the source and the distribution board
8) Protective conductor for protective earthing of the source

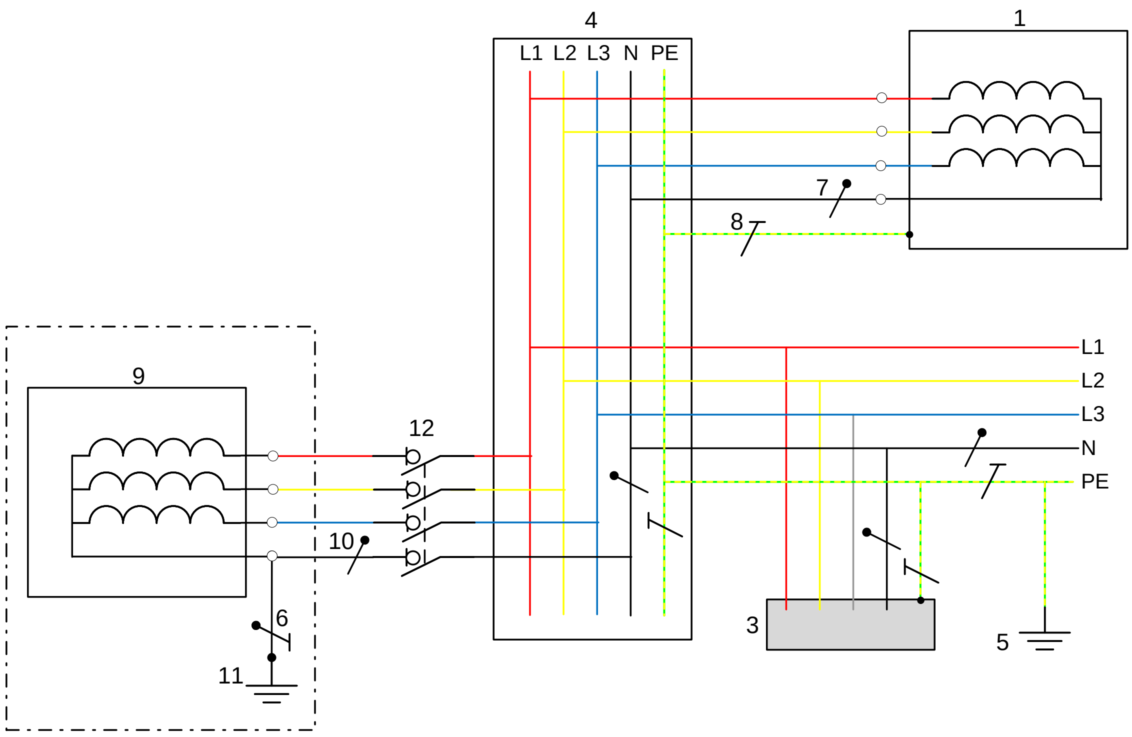
FIGURE A 3 EXAMPLE OF AN AC TT MULTIPLE SOURCE SYSTEM WITH TWO LOCAL SOURCES

Where an installation is supplied from an external distribution network, especially where the distribution network is originating from outside a building housing the installation, the principles laid out in Fig. A3need to be amended because:

a) The live conductors of the distribution network need to be provided with a system-referencing-conductor within the distribution network itself, independent of any electrical installations being connected to it. The distribution network cannot rely upon a system-referencing-conductor being installed in one of the electrical installations as that installation might be disconnected.
b) An electrical installation with an internal source might be disconnected from the distribution network (islanding mode). Thus, the installation cannot rely upon that the system-referencing-conductor located somewhere in the distribution network is always present, and consequently, a system-referencing-conductor needs to be installed as part of the electrical installation.

A fundamental characteristic of a TT electrical system is that the earth electrode provided for earthing of the system-referencing-conductor is electrically independent of the earth electrode used for earthing of the exposed-conductive-parts. Therefore, where an electrical installation with an internal source is connected to a distribution network, special measures need to be taken as follows:

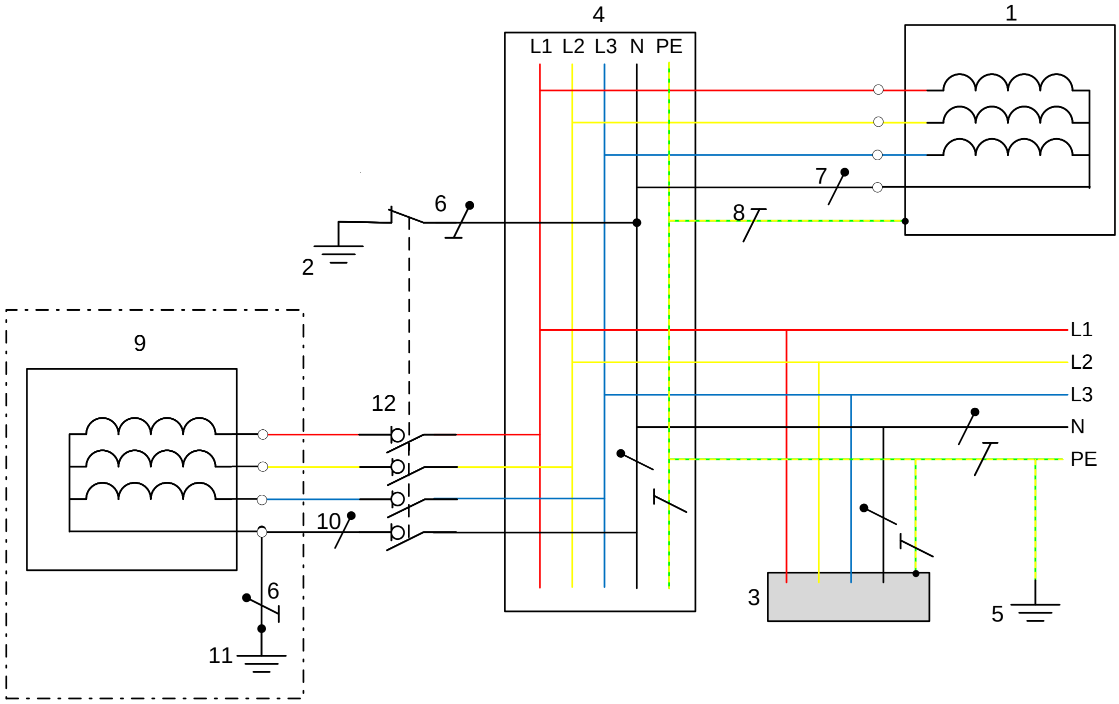
1) When the installation is disconnected from the external distribution network, the installation is operated as an IT installation see Fig. A4, or
2) Where an earth electrode can be provided that is electrically independent from the one used for earthing of exposed-conductive-parts, a system-referencing-conductor is established when the installation is disconnected from the external distribution network, enabling the neutral conductor of the installation to be connected to an earth-electrode, see Fig. A5, or
3) Where an earth electrode that is electrically independent from the one used for earthing of exposed-conductive-parts cannot be provided, and exposed-conductive-parts are connected to the same earth electrode, a system-referencing-conductor is established between the neutral conductor of the installation and the protective earthing conductors used for protective earthing of exposed-conductive-parts when the installation is disconnected from the external distribution network, and the installation operates as a TN-system, see Fig. A6.



Key

1) Local source
2) Not used
3) Electrical equipment with exposed-conductive-part
4) Distribution board
5) Earthing of exposed-conductive-parts
6) System-referencing-conductor
7) Conductor between the neutral point of the local source and the distribution board
8) Protective conductor for protective earthing of the source
9) External source, e.g., external electric power network
10) Neutral conductor between external power source and distribution board
11) Earth electrode for the earthing of the system at the external source (e.g., the distribution network)
12) Isolating switch for disconnection of the external supply

FIGURE A 4 EXAMPLE OF AN EXTERNAL SOURCE IN AN AC TT SUPPLY SYSTEM WITH A LOCAL SOURCE IN AN INSTALLATION OPERATING AS AN IT INSTALLATION WHEN DISCONNECTED FROM THE EXTERNAL SOURCE.

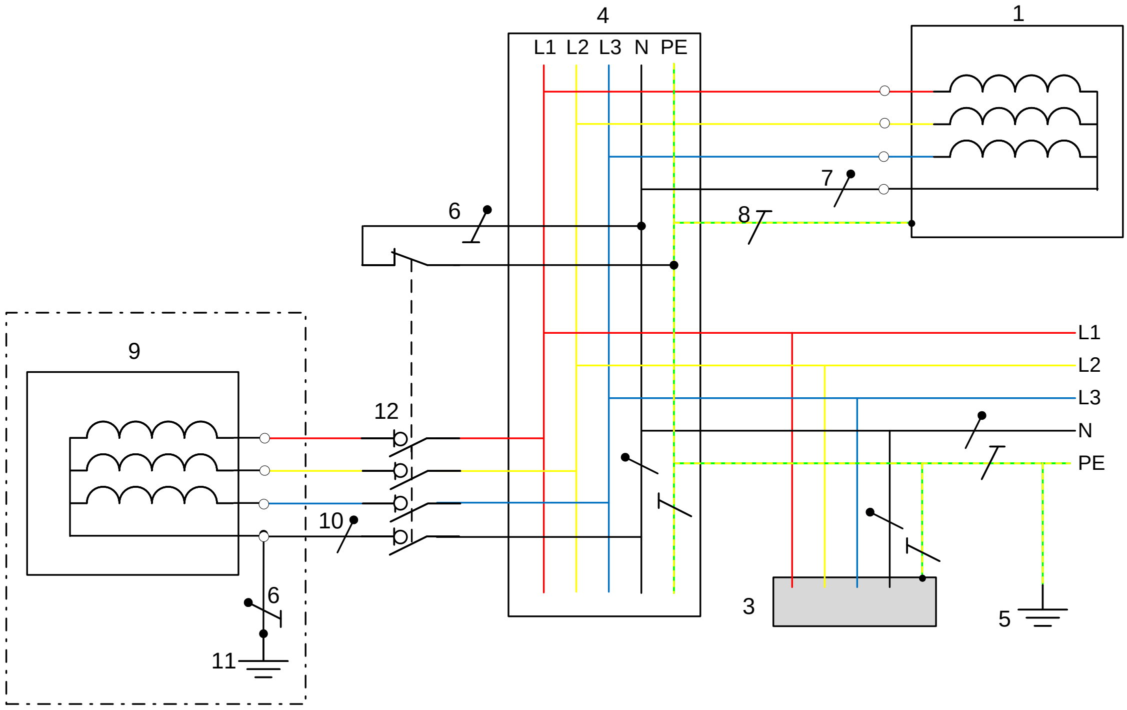


Key

1) Local source;
2) Earth electrode for earthing of the system when the external source is disconnected;
3) Electrical equipment with exposed-conductive-part;
4) Distribution board;
5) Earthing of exposed-conductive-parts;
6) System-referencing-conductor;
7) Conductor between the neutral point of the source and the distribution board;
8) Protective conductor for protective earthing of the local source;
9) External source, e.g., external electric power network;
10) Neutral conductor between external power source and distribution board;
11) Earth electrode for the earthing of the system at the external source (e.g., the distribution network);
12) Isolating switch for disconnection of the external supply, interlocked with a SRC switching device.

Note: No 2 and 5 shall be electrically independent.

FIGURE A 5 EXAMPLE OF AN EXTERNAL SOURCE IN AN AC TT SUPPLY SYSTEM WITH A LOCAL SOURCE IN AN INSTALLATION OPERATING AS A TT INSTALLATION WHEN DISCONNECTED FROM THE EXTERNAL SOURCE



Key

1) Local source;
2) Not used;
3) Electrical equipment with exposed-conductive-part;
4) Distribution board;
5) Earthing of exposed-conductive-parts or;
6) System-referencing-conductor;
7) Conductor between the neutral point of the source and the distribution board;
8) Protective earthing conductor for protective earthing of the local source;
9) External source, e.g., external distribution network;
10) Neutral conductor between external power source and distribution board;
11) Earth electrode for the earthing of the system at the external source (e.g., the distribution network);
12) Isolating switch for disconnection of the external supply, interlocked with a SRC switching device;

FIGURE A 6 EXAMPLE OF AN EXTERNAL SOURCE IN AN AC TT SUPPLY SYSTEM WITH A LOCAL SOURCE IN AN INSTALLATION OPERATING AS AN TN INSTALLATION WHEN DISCONNECTED FROM THE EXTERNAL SOURCE.

ANNEX B
EARTHING AND BONDING: EMC IN BUILDINGS

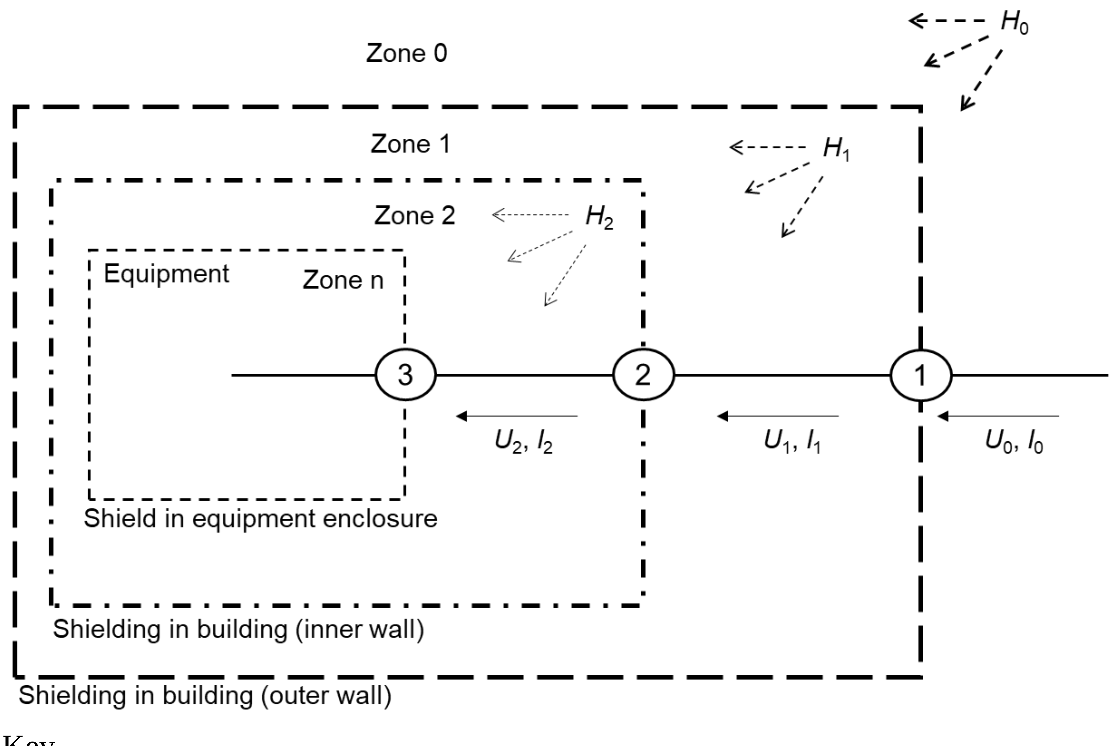
(Informative)

Large buildings with substantial amount of electronics (e.g. Datacentre, Telecom Installations, Hospitals) shall adopt additional EMI mitigation measures combined with earthing.

Note: Functional earthing and bonding requirements of application where large concentration of electronic systems are involved (e.g. datacentre, telecom installation, hospitals etc) are to be carried out based on ISO/IEC 30129 & IEC 61000 (various parts).

Effect of conducted and radiated EMI inside a protected volume is reduced by shielding & bonding measures. Every exposed and extraneous conductive parts including system earthing of an electrically separated supply (e.g. Neutral of an isolation transformer) shall be bonded to the respective common bonding busbar of the zone. Use of shielded cables and their routing also shall satisfy the requirement of shielding.

Note: Nonstandard practices explained in Fig. 22 to Fig. 24 is prohibited.



Key

H	Radiated EMI
H_1 AND H_2:	Reduced effect of EMI due to shielding
U, *I* :	Conducted EMI
U_1, I_1 & U_2 I_2:	Reduced effect of EMI due to Filters/SPD and equipotential bonding
1, 2 & 3:	Filters / SPD

FIGURE B 1 ZONAL CONCEPT OF BONDING AND SHIELDING TO REDUCE CONDUCTED AND RADIATED EFFECTS OF EMI.

Common bonging network including protective earthing, functional earthing and grid-like spatial shields consisting of metal reinforcement in the ceilings, walls and floors, the metal framework, the metal roofs, and metal facades reduce the effect of radiated EMI.

ANNEX C
PORTABLE EQUIPMENT FOR EARTHING OR EARTHING AND SHORT-CIRCUITING FOR LIVE WORKING

(Informative)

C 1 General

Portable equipment for earthing or earthing and short-circuiting are used for temporary earthing or earthing and short-circuiting of electrically isolated or de-energized a.c. and d.c. installations, distribution and transmission networks, whether they are overhead or underground for all voltages.

The equipment comprises an earthing or a short-circuiting or an earthing and short-circuiting device and insulating component. An example is given in Fig. C1 A and Fig. C1 B. It also covers:

- earthing or short-circuiting or earthing and short-circuiting devices intended to be installed with insulating means. An example of an earthing device is given in Fig. C1 C;
- separate components, such as conductive extension (see Fig. C1 C) or clamp or cable with end fittings.

Note: Commonly these devices are also called as discharge rod / earthing rod / portable earthing rod.

The performance of equipment, devices and components used for this application shall consider electro-dynamic and electro-thermal effects acting during short-circuit. The withstand capability of the devices and equipment is expressed by their rated values of current, time and peak factor. No rated voltage is given, but the geometrical dimensions of the equipment are also linked to the voltage of the installation.

Examples of connection diagrams of earthing and short-circuiting devices are given in Fig. C2 and Fig. C3. Associated usual lengths of cables are given in Table C1.

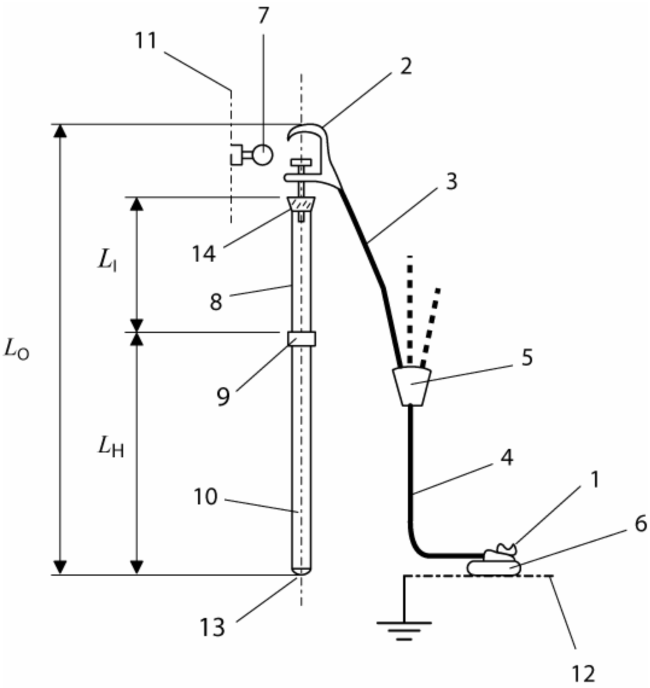


FIGURE C 1.A – MULTI-PHASE EQUIPMENT

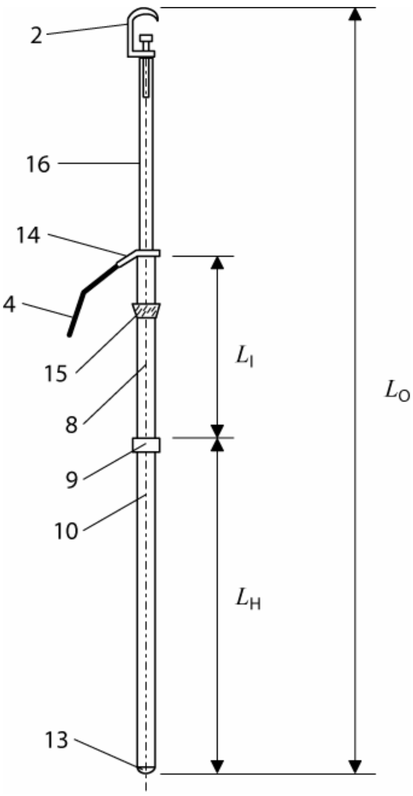


FIGURE C 1.B – SINGLE-PHASE EQUIPMENT WITH EXTENSION

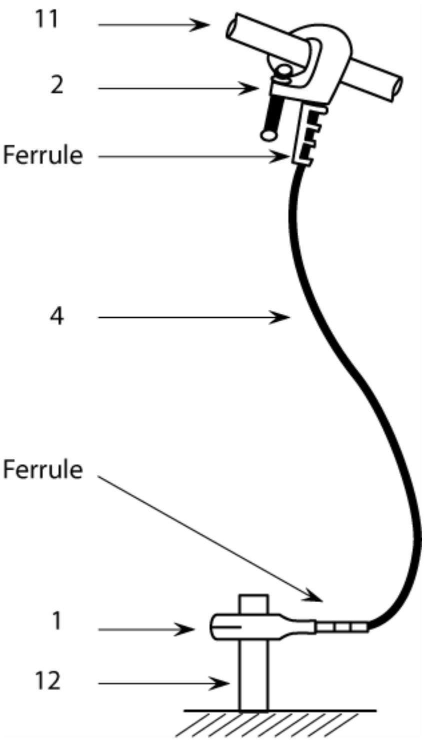


FIGURE C 1.C – EARTHING DEVICE

Note: The same device can be used for short-circuiting.

Key

1. Earth clamp or rail clamp
2. Line clamp or contact line clamp
3. Short-circuiting cable(s)
4. Earthing cable(s)
5. Connecting cluster
6. Earth permanent connection point or rail
7. Line permanent connection point or overhead contact line profile
8. Insulating element
9. Handle limit mark
10. Handle of earthing stick
11. Installation conductor or bar
12. Earthing system
13. End cap of stick
14. End fitting, permanent or detachable
15. Stick coupling, detachable for transport reasons
16. Conductive extension

LI Length of insulating element
LH Length of handle
LO Overall length of earthing stick and conductive extension component
NOTE

1. The earthing and short-circuiting device comprises components 1, 2, 3, 4, 5 and 16.
2. The earthing stick comprises components 8, 9, 10, 13, 14 and 15.

3. The earthing device comprises components 1, 2 and 4.

FIGURE C 1 EXAMPLES OF PORTABLE EQUIPMENT AND DEVICE FOR INSTALLATIONS, NETWORK AND RAILWAY SYSTEMS APPLICATION

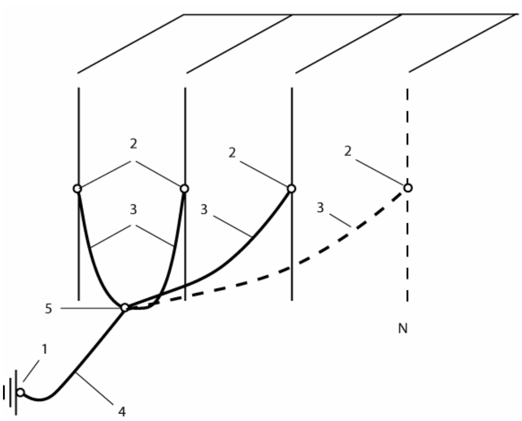


FIGURE C 2.A

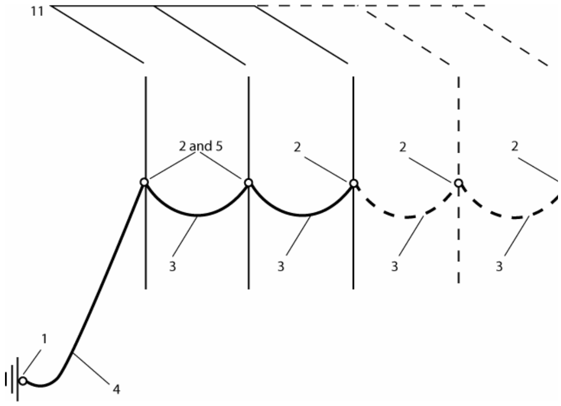


FIGURE C 2.B

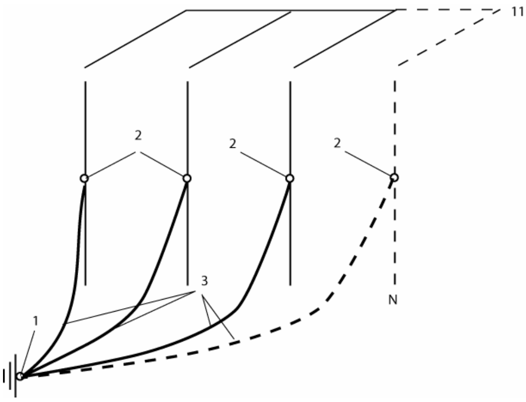


FIGURE C 2.C

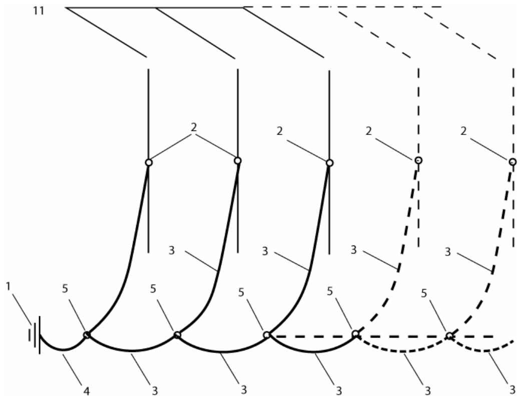
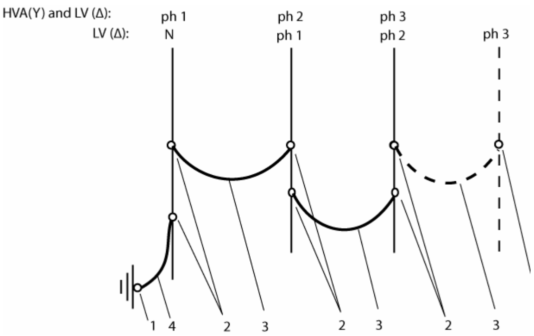


FIGURE C 2.D



Key
1 Earth clamp
2 Line clamp
3 Short-circuiting cable(s)
4 Earthing cable(s)
5 Connecting cluster
11 Installation conductor or bar
16 Conductive extension

HVA (Y) = High voltage distribution, Y Neutral system
LV (Δ) = Low voltage, Δ Neutral system

FIGURE C 2.E

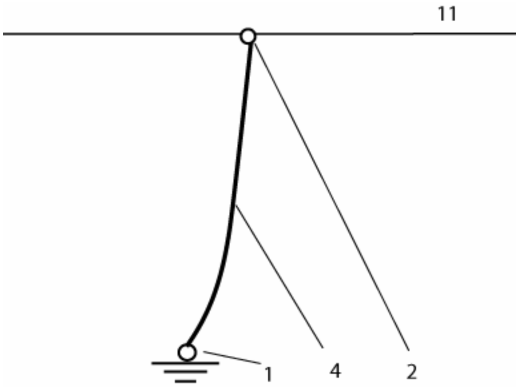


FIGURE C 2.F

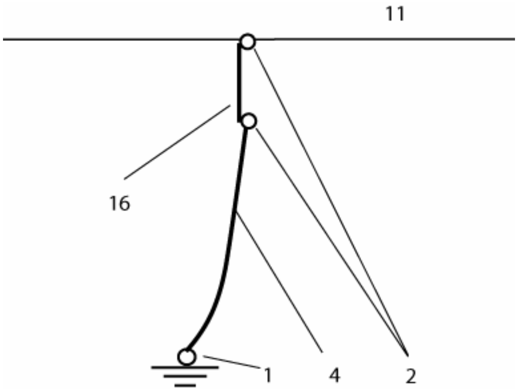


FIGURE C 2.G

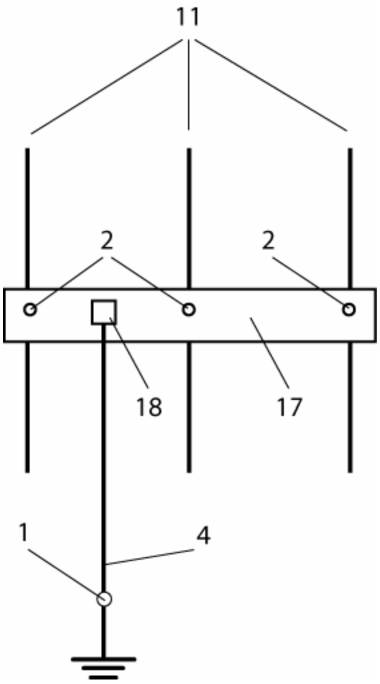
FIGURE C 2 CONNECTION DIAGRAMS OF SINGLE AND MULTI-PHASE EARTHING AND SHORT-CIRCUITING DEVICES FOR NETWORK APPLICATION

NOTE Figure 99 shows examples only of connection arrangements. Not all are suitable for all situations. It is the responsibility of the user to consider movement of connecting cables from magnetic forces. This has to be considered prior to a final connection.

TABLE C 1 USUAL LENGTHS OF EARTHING AND SHORT-CIRCUITING CABLES FOR DIFFERENT TYPES OF INSTALLATIONS AND DIFFERENT VOLTAGE LEVELS

Classes of operating voltages	Overhead line	Open air substation	Metal enclosed or indoor substation
Low voltage [a]	Multi-phase Figures 2a, 2b, 2c, 2d key 3 = 0,5 m key 4 = 12 m to 16 m	Multi-phase Figure 2c ; key 3 = 0,5 m Figure 2a ; key 3 = 0,5 m and key 4 = 1 m to 10 m	Specific
	Single-phase Figure 2f key 4 = 0,5 m to 10 m		
Distribution [a]	Multi-phase Figures 2a, 2b, 2c, 2d key 3 = 2 m to 2,5 m key 4 = 8 m to 10 m	Multi-phase Figures 2a, 2b, 2c key 3 = 7,5m to 10 m key 4 = 2,5 m to 3 m	Multi-phase Figure 2a key 3 = 0,7 m key 4 = 2 m
	Multi-phase + 5 m extension Figure 2g key 4 = 8 m to 10 m		
	Single-phase Figure 2f key 4 = 8 m to 10 m	Single-phase Figure 2f key 4 = 10 m to 12 m	
Transmission [a]	Single-phase Figure 2f key 4 = 8 m	Single-phase Figure 2f key 4 = 10 m to 12 m	Multi-phase Figure 2a key 3 = 3 m key 4 = 3 m
		Single-phase + 2 m to 5 m extension Figure 2g key 4 = 7 m to 8 m	Single-phase Figure 2f key 4 = 3 m to 4 m

[a] The voltage limits for the different classes of operating voltage are conventional values and could be modified by national regulations or national practice.



Key
1 Earth clamp
2 Line clamp
4 Earthing cable(s)
11 Installation conductor
17 Short-circuiting bar
18 Earthing cable connection

FIGURE C 3 ILLUSTRATION OF A THREE-PHASE EARTHING AND SHORT-CIRCUITING DEVICE WITH SHORT-CIRCUITING BAR AND EARTHING CABLE(S) FOR INSTALLATION AND NETWORK APPLICATION.

C 2: REQUIREMENTS

C 2.1: General requirement

The equipment, devices and components shall be designed to contribute to the safety of the users provided the equipment, devices and components are used by skilled persons, in accordance with safe methods of work and the instructions for use (see IEC 61230).

NOTE
1. According to safe procedure, electrical installations are considered energized or live until all protective earthing and short-circuiting equipment have been properly installed.
2. Where applicable, national or regional regulations should be followed, such as live working or dead working procedures.

Earthing and short-circuiting devices and their components shall be designed to withstand all the mechanical stresses to which they are submitted during normal use. Devices and components shall withstand the maximum short-circuit current, time and Joule integral for which they are rated. They also should be designed in order to also accept transit current.

Earthing and short-circuiting devices, when installed according to instructions for use, shall be able to withstand all stresses from short-circuit currents for which they are designed without causing electrical, mechanical, chemical or thermal danger to persons.

NOTE
1. For indoor use and enclosed space, poisonous effects should be considered.
2. Highest possible temperature rise of cables is therefore adopted to reduce weight.

The manufacturer or the end assembler of all component parts of the equipment shall be responsible to ensure that the equipment meets all the requirements of IEC 61230. Examples of some of the requirements are listed form C 2.2 to C 2.10

C 2.2 Electrical rating

Earthing and short-circuiting devices and their components shall be rated in terms of a short circuit current (Ir), a time (tr) and the corresponding peak factor.

For d.c. applications, the values shall be the same.

Most common values for the rated time are the following:

3 s, 2 s, 1 s, 0,75 s, 0,5 s, 0,25 s, 0,1 s

The rating of the complete device shall be expressed as rated current in kiloamperes, as rated time in seconds and rated peak factor (see C 2.9).

Separate components of the equipment shall be provided with their rated values and their corresponding test configurations (see C 2.10).

C 2.3 Cables for earthing and short-circuiting

Earthing and short-circuiting cables, whether they are made of aluminium or aluminium alloy or made of copper, shall be designed to meet the performance requirement of their rating. Cables shall have adequate mechanical, chemical, environmental and electrical properties to meet all the requirements of this standard (see IEC 61230).

Cables for earthing and short-circuiting purposes shall be flexible. Cables shall be insulated for mechanical protection.

The selection of the nature of the insulating material shall be made to fulfil chemical, environmental and temperature conditions met in practice.

Earthing cables used on solidly earthed systems shall have the same cross-section as the associated short-circuiting cables or bars.

Earthing cables used on non-solidly earthed systems may have a cross-section less than the corresponding short-circuiting cables or bars, but never less than that given in Table 2. For values in between those listed in the first column, the value of the second column shall be the next higher size.

TABLE C 2 MINIMUM CROSS-SECTION OF EARTHING CABLES RELATED TO THE CROSS-SECTION OF THE SHORT-CIRCUITING CABLES AND/OR BARS ON NON-SOLIDLY EARTHED (NEUTRAL) SYSTEMS.

Copper equivalent cross-section of short-circuiting cables and/or bars mm^2	Minimum copper equivalent cross-section of earthing cables mm^2
16	16
25	16
35	16
50	25
70	35
95	35
120	50
150	50

C 2.4 Short-circuiting bars

Short-circuiting bars, whether they are made of aluminium or aluminium alloy or made of copper, shall be designed to meet the performance requirement of their rating. They shall be designed to be compatible with the installation on which they may be positioned. For this purpose, dimensions of short-circuiting bars are not standardised (see IEC 61230).

C 2.5 Connections of cables to rigid parts within devices

Excellent fatigue resistance is required for the connections of cables to rigid parts (ferrules, cable lugs, end fittings, clusters, etc.). The connections shall be made with great care to ensure that the specified minimum characteristics of the cables are maintained. Soldered connections are not permitted. The connection between end fittings and cables shall be protected from water penetration. All attachments shall be protected against unintentional loosening. Single screws or nuts, if used, shall always be combined with a device, for instance lock washers, that positively prevents slippage or rotation. Ferrules, cable lugs, end fittings, etc., shall have at least a current-carrying capacity equivalent to the associated cables (see IEC 61230).

C 2.6 Clamps

Clamps shall be designed to withstand the stresses for which they are rated. They shall provide reliable contact performance and shall withstand the thermal and mechanical stresses produced by the rated short-circuit currents. Line and earth clamps shall be suitable for the surface and shape of the connecting point and shall permit easy and safe installation without causing damage to clamps and without danger for personnel.

For tightening type, the manufacturer or the end assembler shall provide a rated torque which shall be properly defined for the installation. For other types such as spring clamps they shall not require an unusual force during the positioning and the removing operations.

Each different design of clamp of the same rating shall be type tested in the same conditions in order to be considered equivalent.

C 2.7 Earthing and short-circuiting device

The different components of an earthing and short-circuiting device may come from the same manufacturer or from different manufacturers. The final assembly shall be made under the responsibility of the manufacturer or the end assembler of the device. Manufacturer or supplier of separate components shall give sufficient information in order to maintain the capability of the complete device. The final quality of the device after assembly relies only on its end assembler. An earthing and short-circuiting device can use cables in parallel as short-circuiting or earthing cables.

For a multi-phase earthing and short-circuiting device, all cables exposed to a rated shortcircuit current shall have the same cross-section, but the earthing cable(s) may have a smaller cross-section in case of use on non-solidly earthed system.

C 2.8 Basic safety requirements for the insulating element(s) of the insulating component

The insulating elements(s) of the insulating component (earthing stick or other type) shall make use of insulating material(s) and shall be designed such as to provide basic electrical insulating properties to permit the workers to establish the appropriate electrical insulation when installing and removing the portable equipment for earthing or earthing and short circuiting.

The manufacturer shall identify the design parameters associated with the basic insulating properties of the insulating element.

C 2.9 Marking

The marking shall be clearly legible. It shall be durable and not removable. Each device, cable and clamp shall be marked properly. When a device is made of several components of different rating, the marking of the rated values of the device shall be the minimum of the rated capacity of each component and under the responsibility of the final assembler.

C 2.10 Instructions for use

Each device or equipment shall be supplied with manufacturer’s written information and instructions for use and care. These instructions shall be prepared in accordance with the general provisions given in IEC 61477.

They shall include at least the following:

- instructions for assembling the complete device or equipment;
- limitation, if any, of the main characteristics such as rated values, temperature conditions, indoor use, etc.;
- rated values (current, time and peak factor) of the separate components;
- guidelines for maintenance, use, storage and inspection;

- torque and force values and instructions for securing of auxiliary fasteners, which may loosen during use;
- information about the use of aluminium for cables, clamps and other parts of the devices, if relevant;
- statement that “the devices shall be removed from service after exposure to short-circuit current”;
- number of the relevant IEC standard and the year of publication with amendment, if any.

NOTE Additional instructions for use may be requested by the customer.

ANNEX D
MAXIMUM ALLOWED RESISTANCE OF PROTECTIVE CONDUCTORS

(Normative)

The continuity of protective conductors and connection to exposed-conductive-parts and extraneous-conductive-parts, if any, shall be verified by a measurement of resistance. The measurement includes the length of the protective conductor including its connections to the earthing arrangement. Test instrument with higher test current (e.g. 10 A) may provide accurate values. Table D1 provide the maximum allowed resistance value likely to be obtained during continuity resistance measurement.

TABLE D 1 SPECIFIC CONDUCTOR RESISTANCE R FOR COPPER WIRING AT 30 °C DEPENDENT ON THE NOMINAL CROSS-SECTIONAL AREA S FOR ROUGH CALCULATION OF CONDUCTOR RESISTANCES

Nominal cross-sectional area *S* mm^2	**Specific conductor resistance *R* at 30 °C** $m\Omega/m$
1.5	12.5755
2.5	7.5661
4	4.7392
6	3.1491
10	1.8811
16	1.1858
25	0.7525
35	0.5467
50	0.4043
70	0.2817
95	0.2047
120	0.1632
150	0.1341
185	0.1091

The specific conductor resistance values are related to a conductor temperature of 30 °C. For other temperatures the conductor resistances R_θ can be calculated by the use of the following formula:

$$R_\theta = R_{30}[1 + \alpha(T_\theta - T_{30})]$$

where α is the temperature coefficient (for copper α = 0,003 93)

ANNEX E
CALCULATION OF EARTH FAULT LOOP IMPEDANCE

(Informative)

E1: General

This informative annex may be used in low voltage installations. The Central Electricity Authority (Measures Relating to Safety and Electric Supply) Regulations, 2023, regulation 43 made compliance of fault loop impedance mandatory in every circuit.

Earth Fault Loop Impedance of a circuit is the impedance of the earth fault current loop (phase-to-earth loop) starting and ending at the point of earth fault. The earth fault loop impedance has to be low enough to allow adequate earth fault current to enable automatic disconnection of a protective device. This impedance is denoted by the symbol Z.

The earth fault loop comprises the following impedances, starting at the point of fault:

a. the protective conductor (from the equipment to MET);
b. the MET;
c. for TN systems, the metallic fault return path from the installation to the earthed point of the source (typically the neutral). The impedance through earth electrodes in this case is considerably higher and not consistent, hence need not be considered;
d. for TT and IT systems, the fault return path through earth electrodes and the general mass of earth;
e. the path through the earthed neutral point of the transformer;
f. the transformer winding; and
g. the line conductor from the transformer to the point of fault.

In order to calculate earth fault loop impedance, the size and length of each of the conductors in the loop (circuit) are to be known, from which the impedance of the circuit conductors are calculated. The Impedance of the transformer winding is added to the impedance of the circuit conductors. A safety margin of 2/3 is taken into account, considering the increase in the resistance of the conductors with the increase of temperature during fault conditions.

E2: Requirement of fault protection by automatic disconnection

From the calculated fault-loop impedance, the current causing the automatic operation of the protective device as explained in Eq E.2 shall be ensured.

The maximum allowed fault-loop impedance shall satisfy the following (see 7.4.2.7):

$$Z_s(m) = \frac{2}{3} \times \frac{U_o}{I_a} \qquad \text{Eq. E.1}$$

Where:

$Z_s(m)$ is the measured/calculated fault loop impedance starting and ending at the point of the fault (Ω)

U_o is the nominal a.c. or d.c. line to earth voltage in volts (V)

I_a is the current in amperes (A) causing the automatic operation of the protective device
within the time specified in Table 1. When a residual current device (RCD) is used this current is the residual operating current providing disconnection in the time specified in Table 1.

Based on Eq. E.1, the current causing the automatic operation of the protective device within the time specified in Table 1 shall meet the following requirement:

$$I_a = \frac{2}{3} \times \frac{U_o}{Z_s} \qquad \text{Eq. E.2}$$

Where:

Z_s is the calculated fault loop impedance starting and ending at the point of the fault (Ω),

U_o is the nominal a.c. line to earth voltage in volts (V),

I_a is the current in amperes (A) causing the automatic operation of the protective device within the time specified in Table 1. When a residual current device (RCD) is used this current is the residual operating current providing disconnection in the time specified in Table 19.

E3: Calculation of Impedance of two-winding transformers

The impedance of two-winding transformers shall be calculated from the rated transformer data as follows:

$$Z_T = \frac{u_{kr}}{100\%} \times \frac{U_{rT}^2}{S_{rT}} \qquad \text{Eq. E.3}$$

$$R_T = \frac{u_{Rr}}{100\%} \times \frac{U_{rT}^2}{S_{rT}} = \frac{P_{krT}}{3 \times I_{rT}^2} \qquad \text{Eq. E.4}$$

$$X_T = \sqrt{Z_T^2 - R_T^2} \qquad \text{Eq. E.5}$$

Where:

U_{rT} is the rated voltage of the transformer on the low-voltage side;

I_{rT} is the rated current of the transformer on the low-voltage side;

S_{rT} is the rated apparent power of the transformer;

P_{krT} P_{krT} is the total loss of the transformer in the windings at rated current;

u_{kr} is the short-circuit voltage at rated current in per cent (also known as short circuit impedance of the transformer- see table E1)

u_{Rr} is the rated resistive component of the short-circuit voltage in per cent.

Note: For more information see 6.3 of IS 13234-0

The resistive component u_{Rr} can be calculated from the total losses P_{krT} in the windings at the rated current I_{rT}, both referred to the same transformer side.

The short-circuit voltage at rated current in per cent (also known short circuit impedance of the transformer) shall be taken from manufacturers' data. In the absence of such details during the initial design stage, the below table, taken from IS 2086-2 shall be considered.

TABLE E1: RECOGNISED MINIMUM VALUE OF SHORT CIRCUIT IMPEDANCE FOR TRANSFORMERS AS PER TABLE-1 OF IS 2026-5.

Short-circuit impedance at rated current	
Rated Power (kVA)	Minimum short circuit impedance (%)
25-630	4.0
631-1 250	5.0
1 251-2 500	6.0
2 501-6 300	7.0
6 301-25 000	8.0
25 001-40 000	10.0
40 001-63 000	11.0
63 001-100 000	12.5
Above 100 000	12.5

Note: For generators, 16 % may be considered as short circuit impedance.

E4: Calculation of Impedance of conductors

The impedance (Z) consists of a resistive component (R) and a reactive component (X), expressed as:

$$Z = \sqrt{R^2 + X^2} \qquad \text{Eq. E.6}$$

For simplified calculation the reactive component may be neglected as its influence is negligible in small installations. However, for high current application, the influence of reactive component is substantial (e.g. larger than resistive component). Hence a detailed calculation may be necessary.

E4.1: Resistance of conductors

The resistance of conductors shall be obtained from manufacturer data, or reference to IS 8130 (if the conductor is an insulated conductor), or by calculation as below:

The resistance of a conductor, for a particular length is calculated by the following equation:

$$R = \frac{\rho}{S} \times \frac{L}{1000} \qquad \text{Eq. E.7}$$

Where:
R is the resistance of the length of conductor, in Ω,
ρ is the resistivity of the conductor, in mΩ mm^2 / m,
S is the cross-sectional area of the conductor, in mm^2,
L is the length of the conductor in m.

Values of ρ may be taken from Table E2.

TABLE E2 RESISTIVITY OF CONDUCTORS AT 20oC (ρ)

Copper (mΩ mm^2 / m)	**Aluminium** (mΩ mm^2 / m)	**Aluminium Alloy** (mΩ mm^2 / m)	**Steel** (mΩ mm^2 / m)
18.51	29.41	32.26	158.00

E4.2: Reactance of conductors

The reactance of conductors shall be obtained from manufacturer data, or reference to IS 13234-2 (if the conductors are single core cables), or by calculation as below:

$$X = x \times \frac{L}{1000} \qquad \text{Eq. E.8}$$

Where:
X is the reactance of the length of conductor, in Ω
x is the reactance of the conductor, in mΩ / m
L is the length of the conductor in m
Note: the calculation of reactance in this method does not consider the conductor cross-sectional area.

Values of *x* may be taken from Table E3.

TABLE E3 REACTANCE PER METRE OF CONDUCTORS (*x*)

Multicore cables (mΩ / m)	**Single core cables in trefoil arrangement** (mΩ / m)	**Flat touching single core cables** (mΩ / m)	**Flat spaced single core cables** (mΩ / m)
0.08	0.08	0.09	0.13

For conductors having a cross-sectional area of less than 25 mm^2, reactance may be neglected as it is considerably smaller than the resistance.

E5: Example Calculation:

Consider an electrical installation as illustrated in Figure E1

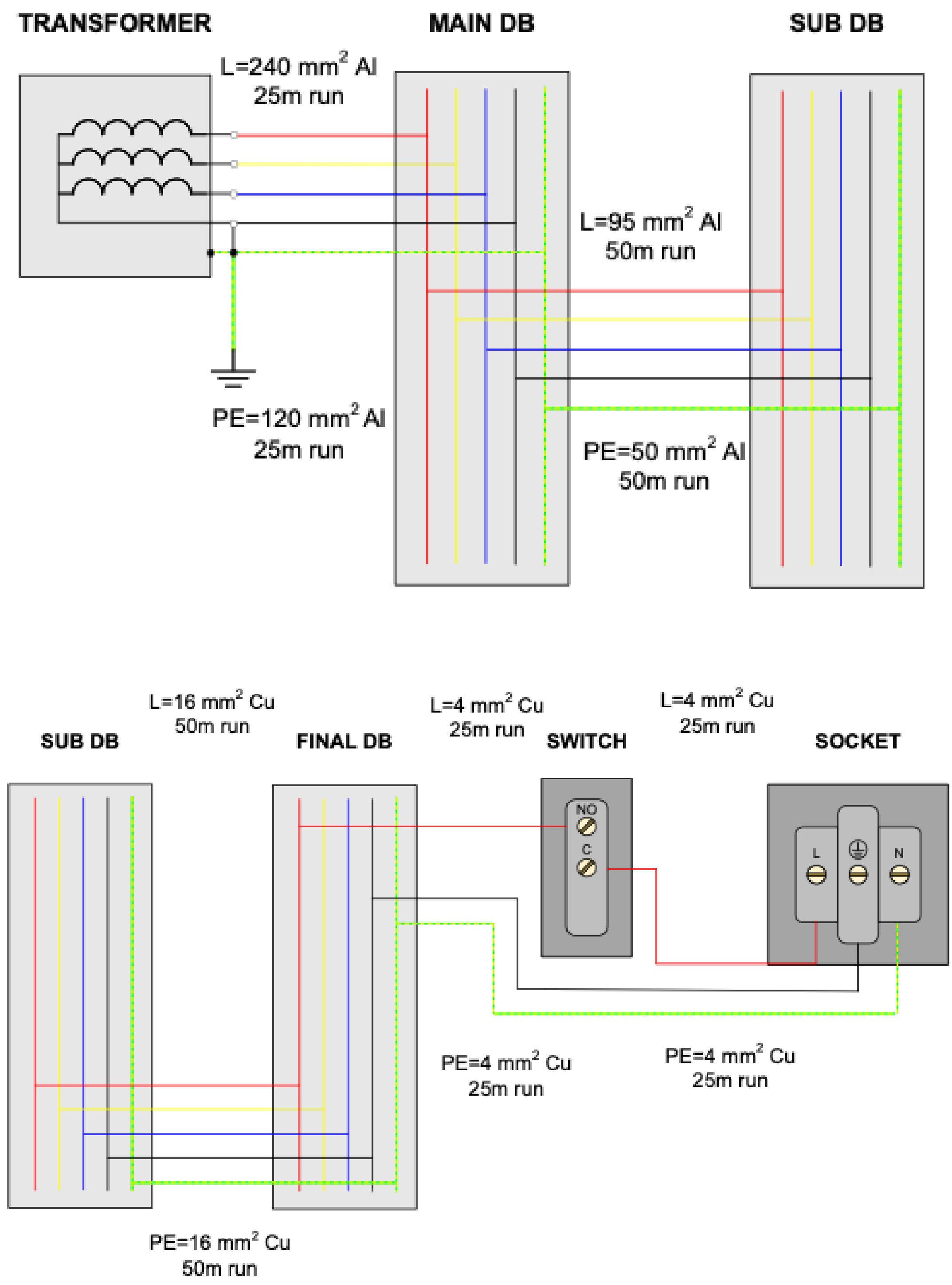


Figure E1: Illustration of an electrical installation for calculation.

Note: Fig. E1 is divided into two (transformer to sub-DB and sub DB to socket) to be understood as one circuit.

The transformer, is a two-winding transformer having the following characteristics:

Rated Primary Voltage	11 kV
Rated Secondary Voltage	433 V
Rated Apparent Power	315 kVA
Load losses at 75°C	2800 W

Impedance Voltage (Z)	4.75 %
Resistance	0.89 %

The cables used are multicore cables.

E5.1: Method 1 (Simplified Calculations):

This method of calculation considers the impedance of the transformer as calculated in Eq. E.3. It does not consider the individual resistive and reactive components of the transformer's impedance. For conductors, E5.1 considers only their resistance. It does not consider their reactance.

E5.1.1: Impedance of Transformer

From Eq. E.3, the impedance of the transformer (in ohms) is calculated as below:

$$Z_{Transformer} = \frac{4.75}{100} \times \frac{433^2}{315000} = 0.0283$$

E5.1.2: Impedance of conductors from the Transformer to the Main DB:

For the line conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{29.41}{240} \times \frac{25}{1000} = 0.0031$$

For the PE conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{29.41}{120} \times \frac{25}{1000} = 0.0061$$

E5.1.2.1: For an earth fault occurring at the incoming terminals of the main DB, the earth-fault loop impedance is calculated as:

	Impedance (Z) Ω
Impedance of Transformer	0.0283
Line conductor from Transformer to Main DB	0.0031
PE conductor from Transformer to Main DB	0.0061
Total $\boldsymbol{Z}_{\boldsymbol{main\ DB}}$	0.0375

E5.1.3: Impedance of conductors from the Main DB to the Sub DB:

For the line conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{29.41}{95} \times \frac{50}{1000} = 0.0155$$

For the PE conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{29.41}{50} \times \frac{50}{1000} = 0.0294$$

E5.1.3.1: For an earth fault occurring at the incoming terminals of the sub-DB, the earth-fault loop impedance is calculated as:

	Impedance (Z) Ω
Impedance of Transformer	0.0283
Line conductor from Transformer to Main DB	0.0031
PE conductor from Transformer to Main DB	0.0061
Line conductor from Main DB to Sub DB	0.0155
PE conductor from Main DB to Sub DB	0.0294
Total $Z_{sub\ DB}$	0.0824

E5.1.4: Impedance of conductors from the Sub DB to the Final DB:

For the line conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{16} \times \frac{50}{1000} = 0.0578$$

For the PE conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{16} \times \frac{50}{1000} = 0.0578$$

E5.1.4.1: For an earth fault occurring at the incoming terminals of the final DB, the earth-fault loop impedance is calculated as:

	Impedance (Z) Ω
Impedance of Transformer	0.0283
Line conductor from Transformer to Main DB	0.0031
PE conductor from Transformer to Main DB	0.0061
Line conductor from Main DB to Sub DB	0.0155
PE conductor from Main DB to Sub DB	0.0294
Line conductor from Sub DB to Final DB	0.0578
PE conductor from Sub DB to Final DB	0.0578
Total $Z_{final\ DB}$	0.1980

E5.1.5: Impedance of conductors from the Final DB to the Switch:

For the line conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{4} \times \frac{25}{1000} = 0.1157$$

For the PE conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{4} \times \frac{25}{1000} = 0.1157$$

E5.1.5.1: For an earth fault occurring at the incoming terminals of the Switch, the earth-fault loop impedance is calculated as:

	Impedance (Z) Ω
Impedance of Transformer	0.0283
Line conductor from Transformer to Main DB	0.0031
PE conductor from Transformer to Main DB	0.0061
Line conductor from Main DB to Sub DB	0.0155
PE conductor from Main DB to Sub DB	0.0294
Line conductor from Sub DB to Final DB	0.0578
PE conductor from Sub DB to Final DB	0.0578
Line conductor from Final DB to Switch	0.1157
PE conductor from Final DB to Switch	0.1157
Total $Z_{up\ to\ switch}$	0.4294

E.5.1.6: Impedance of conductors from the Switch to the Socket:

For the line conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{4} \times \frac{25}{1000} = 0.1157$$

For the PE conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{4} \times \frac{25}{1000} = 0.1157$$

E5.1.6.1: For an earth fault occurring at the terminals of the socket, the earth-fault loop impedance is calculated as:

	Impedance (Z) Ω
Impedance of Transformer	0.0283
Line conductor from Transformer to Main DB	0.0031
PE conductor from Transformer to Main DB	0.0061

Line conductor from Main DB to Sub DB	0.0155
PE conductor from Main DB to Sub DB	0.0294
Line conductor from Sub DB to Final DB	0.0578
PE conductor from Sub DB to Final DB	0.0578
Line conductor from Final DB to Switch	0.1157
PE conductor from Final DB to Switch	0.1157
Line conductor from Switch to Socket	0.1157
PE conductor from Switch to Socket	0.1157
Total $\boldsymbol{Z}_{\textit{up to socket}}$	0.6608

E5.2. Method 2 (Detailed calculation)

This method of calculation considers the reactive and resistive components of the transformer's impedance. For the conductors with a cross-sectional area >=25 mm^2, their resistance and reactance are considered. For conductors with a cross-sectional area <25 mm^2, their resistance is only considered.

E5.2.1: Impedance of Transformer

From Eq. E.3, the impedance of the transformer (in ohms) is calculated as below:

$$Z_T = \frac{4.75}{100} \times \frac{433^2}{315000} = 0.0283$$

From Eq. E.4, the resistive component of the transformer impedance (in ohms) is calculated as below:

$$R_T = \frac{0.89}{100} \times \frac{433^2}{315000} = 0.0053$$

The resistive component of the transformer impedance (in ohms) may also be calculated from the load losses with Eq. E.5 as below:

$$R_T = \frac{2800}{3 \times 420.01^2} = 0.0053$$

Note: As observed, the results as per Eq. E.4 and Eq. E.5 are substantially the same. Both equations are provided annex E, in order to avoid confusion as each are considered in some standards.

From Eq. E.5, the reactive component of the transformer impedance (in ohms) is calculated as below:

$$X_T = \sqrt{0.0283^2 - 0.0053^2} = 0.0278$$

Therefore, from Eq. E.6, for an earth fault occurring at the terminals of the transformer, the earth-fault loop impedance (in ohms) is calculated as below:

$$Z_{transformer} = \sqrt{0.0053^2 + 0.0278^2} = 0.0283$$

Note that this value is the same as E5.1.1, However for larger transformers (say > 1500 kVA), there can be an influential difference.

E5.2.2: Impedance of conductors from the Transformer to the Main DB:

For the line conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{29.41}{240} \times \frac{25}{1000} = 0.0031$$

From Eq. E.8, the reactive component (in ohms) is calculated as below:

$$X = 0.08 \times \frac{25}{1000} = 0.0020$$

For the PE conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{29.41}{120} \times \frac{25}{1000} = 0.0061$$

From Eq. E.8, the reactive component (in ohms) is calculated as below:

$$X = 0.08 \times \frac{25}{1000} = 0.0020$$

E5.2.2.1: For an earth fault occurring at the incoming terminals of the main DB, the earth-fault loop impedance is calculated as:

	Resistive component (R) Ω	Reactive Component (X) Ω
Transformer	0.0053	0.0278
Line conductor from Transformer to Main DB	0.0031	0.0020
PE conductor from Transformer to Main DB	0.0061	0.0020
Total	0.0145	0.0318

E5.2.2.2: Therefore, from Eq. E.6, for an earth fault occurring at the incoming terminals of the main DB the earth-fault loop impedance is calculated as:

$$Z_{main\ DB} = \sqrt{0.0145^2 + 0.0318^2} = 0.0349$$

E5.2.3: Impedance of conductors from the Main DB to the Sub DB:

For the line conductor:
From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{29.41}{95} \times \frac{50}{1000} = 0.0155$$

From Eq. E.8, the resistive component (in ohms) is calculated as below:

$$X = 0.08 \times \frac{50}{1000} = 0.0040$$

For the PE conductor:

From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{29.41}{50} \times \frac{50}{1000} = 0.0294$$

From Eq. E.8, the resistive component (in ohms) is calculated as below:

$$X = 0.08 \times \frac{50}{1000} = 0.0040$$

E5.2.3.1: For an earth fault occurring at the incoming terminals of the sub DB, the earth-fault loop impedance is calculated as:

	Resistive component (R) Ω	Reactive Component (X) Ω
Transformer	0.0053	0.0278
Line conductor from Transformer to Main DB	0.0031	0.0020
PE conductor from Transformer to Main DB	0.0061	0.0020
Line conductor from Main DB to Sub DB	0.0155	0.0040
PE conductor from Main DB to Sub DB	0.0294	0.0040
Total	0.0594	0.0398

E5.2.3.2: Therefore, from Eq. E.6, for an earth fault occurring at the incoming terminals of the sub DB, the earth-fault loop impedance is calculated as:

$$Z_{sub\ DB} = \sqrt{0.0594^2 + 0.0398^2} = 0.0715$$

E5.2.4: Impedance of conductors from the Sub DB to the Final DB:

For the line conductor:

From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{16} \times \frac{50}{1000} = 0.0578$$

Reactive component neglected (= 0 ohms) as conductor cross-sectional area is < 25 mm^2

For the PE conductor:

From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{16} \times \frac{50}{1000} = 0.0578$$

Reactive component neglected (= 0 ohms) as conductor cross-sectional area is < 25 mm^2

E5.2.4.1: For an earth fault occurring at the incoming terminals of the final DB, the earth-fault loop impedance is calculated as:

	Resistive component (R) Ω	Reactive Component (X) Ω
Transformer	0.0053	0.0278
Line conductor from Transformer to Main DB	0.0031	0.0020
PE conductor from Transformer to Main DB	0.0061	0.0020
Line conductor from Main DB to Sub DB	0.0155	0.0040
PE conductor from Main DB to Sub DB	0.0294	0.0040
Line conductor from Sub DB to Final DB	0.0578	-
PE conductor from Sub DB to Final DB	0.0578	-
Total	0.1750	0.0398

E5.2.4.2: Therefore, from Eq. E.6, for an earth fault occurring at the incoming terminals of the final DB, the earth-fault loop impedance is calculated as:

$$Z_{final\ DB} = \sqrt{0.1750^2 + 0.0398^2} = 0.1795$$

E5.2.5: Impedance of conductors from the Final DB to the Switch:

For the line conductor:

From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{4} \times \frac{25}{1000} = 0.1157$$

Reactive component neglected (= 0 ohms) as conductor cross-sectional area is < 25 mm^2

For the PE conductor:

From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{4} \times \frac{25}{1000} = 0.1157$$

Reactive component neglected (= 0 ohms) as conductor cross-sectional area is < 25 mm^2

E5.2.4.1: For an earth fault occurring at the incoming terminals of the switch, the earth-fault loop impedance is calculated as:

	Resistive component (R) Ω	Reactive Component (X) Ω
Transformer	0.0053	0.02798
Line conductor from Transformer to Main DB	0.0031	0.0020
PE conductor from Transformer to Main DB	0.0061	0.0020
Line conductor from Main DB to Sub DB	0.0155	0.0040
PE conductor from Main DB to Sub DB	0.0294	0.0040
Line conductor from Sub DB to Final DB	0.0578	-
PE conductor from Sub DB to Final DB	0.0578	-
Line conductor from Final DB to Switch	0.1157	-
PE conductor from Final DB to Switch	0.1157	-
Total	0.4064	0.0398

E5.2.4.2: Therefore, from Eq. E.6, for an earth fault occurring at the incoming terminals of the switch, the earth-fault loop impedance is calculated as:

$$Z_{switch} = \sqrt{0.4064^2 + 0.0398^2} = 0.4084$$

E5.2.6: Impedance of conductors from the Switch to the Socket:

For the line conductor:

From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{4} \times \frac{25}{1000} = 0.1157$$

Reactive component neglected (= 0 ohms) as conductor cross-sectional area is < 25 mm^2

For the PE conductor:

From Eq. E.7, the resistive component (in ohms) is calculated as below:

$$R = \frac{18.51}{4} \times \frac{25}{1000} = 0.1157$$

Reactive component neglected (= 0 ohms) as conductor cross-sectional area is < 25 mm^2

E5.2.6.1: For an earth fault occurring at the incoming terminals of the socket, the earth-fault loop impedance is calculated as:

	Resistive component (R) Ω	Reactive Component (X) Ω
Transformer	0.0053	0.0278
Line conductor from Transformer to Main DB	0.0031	0.0020
PE conductor from Transformer to Main DB	0.0061	0.0020
Line conductor from Main DB to Sub DB	0.0155	0.0040
PE conductor from Main DB to Sub DB	0.0294	0.0040
Line conductor from Sub DB to Final DB	0.0578	-
PE conductor from Sub DB to Final DB	0.0578	-
Line conductor from Final DB to Switch	0.1157	-
PE conductor from Final DB to Switch	0.1157	-
Line conductor from Switch to Socket	0.1157	-
PE conductor from Switch to Socket	0.1157	-
Total	0.6378	0.0398

E5.2.6.2: Therefore, from Eq. E.6, for an earth fault occurring at the terminals of the socket, the earth-fault loop impedance is calculated as:

$$Z_{socket} = \sqrt{0.6378^2 + 0.0398^2} = 0.6391$$

E6: Conclusion:

From simplified calculation the fault loop impedance at the final socket as calculated in E5.1.6.1: 0.6608 Ω and with detailed calculation as per E5.2.6.2: 0.6391

From Eq. E.2 The minimum current required for automatic disconnection of the protective device can be calculated for a 230/400-volt system as below

From E 5.1.6.1 the resultant current available for disconnection is

$$I_a = \frac{2}{3} \times \frac{230}{0.6608} = 348\ A$$

From E 5.2.6.2 the resultant current available for disconnection is

$$I_a = \frac{2}{3} \times \frac{230}{0.6391} = 359\ A$$

However, for larger transformers (say > 1500 kVA), there can be an influential difference, while considering the reactance of the loop.

ANNEX F
EARTHING AND SHARED PE CONDUCTORS

(informative)

This informative annex is only for the purpose of explaining earthing in industrial premise, where the source of energy is within the premise of the consumer. As recommended in the code, HV side and LV side of the transformer are interconnected as a Global Earthing System (see 10.2.3.5) and TN-S system is considered in LV (see 11.1.6). This annex is not suitable for applications in public distribution except in cases where the source of energy, owned by DISCOM is installed within the consumer premise.

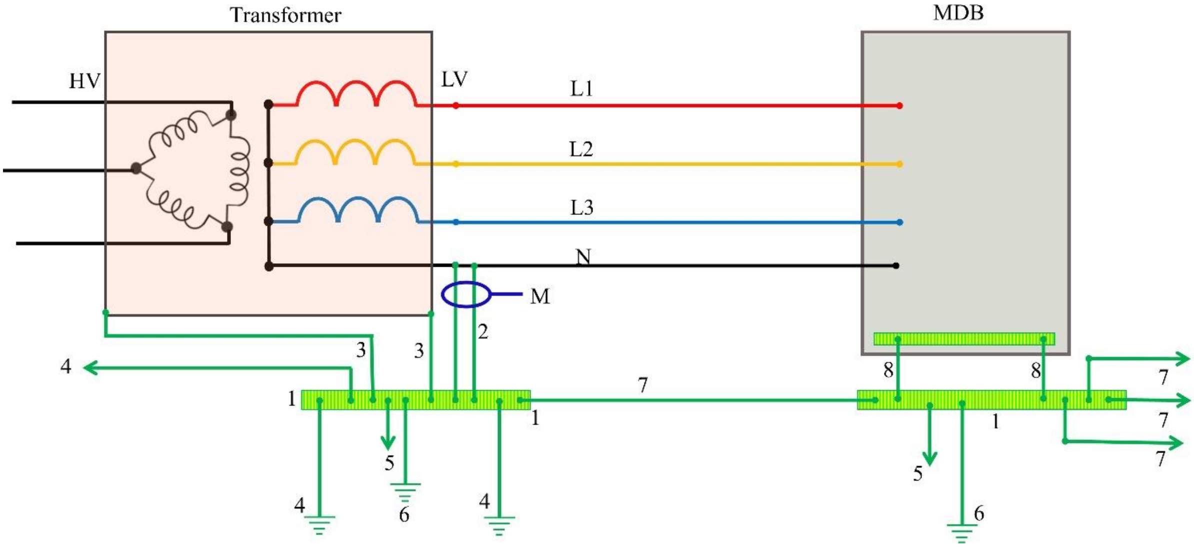


FIGURE F 1 TYPICAL SCHEMATIC OF EARTHING OF ONE TRANSFORMER AND INSTALLATION. TN-S SYSTEM

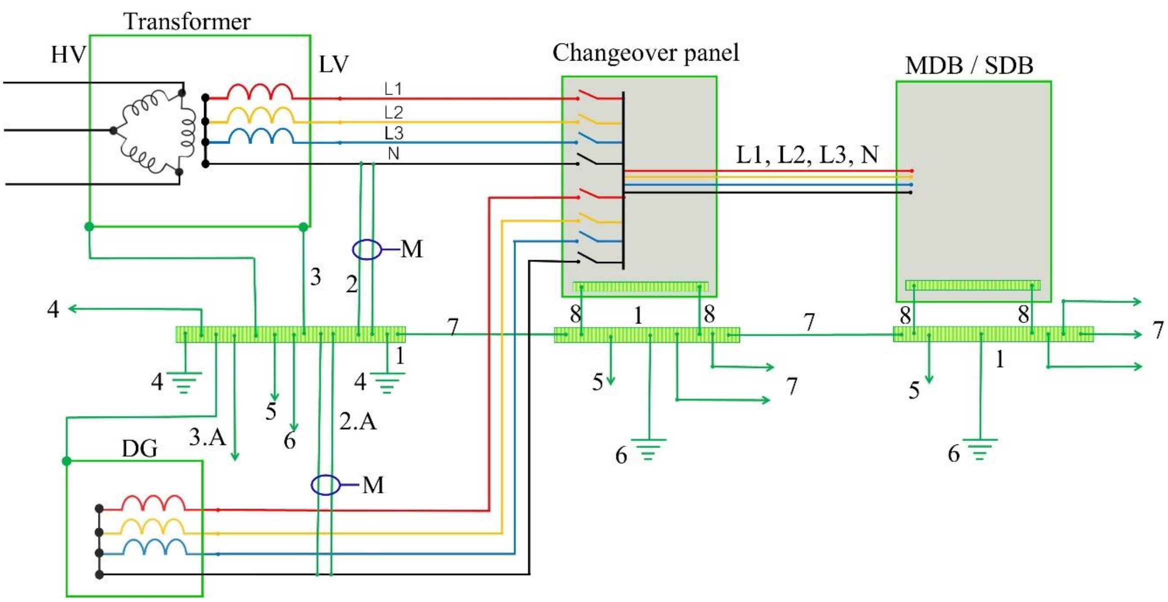


FIGURE F 2 TYPICAL SCHEMATIC OF EARTHING OF ONE TRANSFORMER AND DG MANUAL CHANGE OVER TN-S SYSTEM

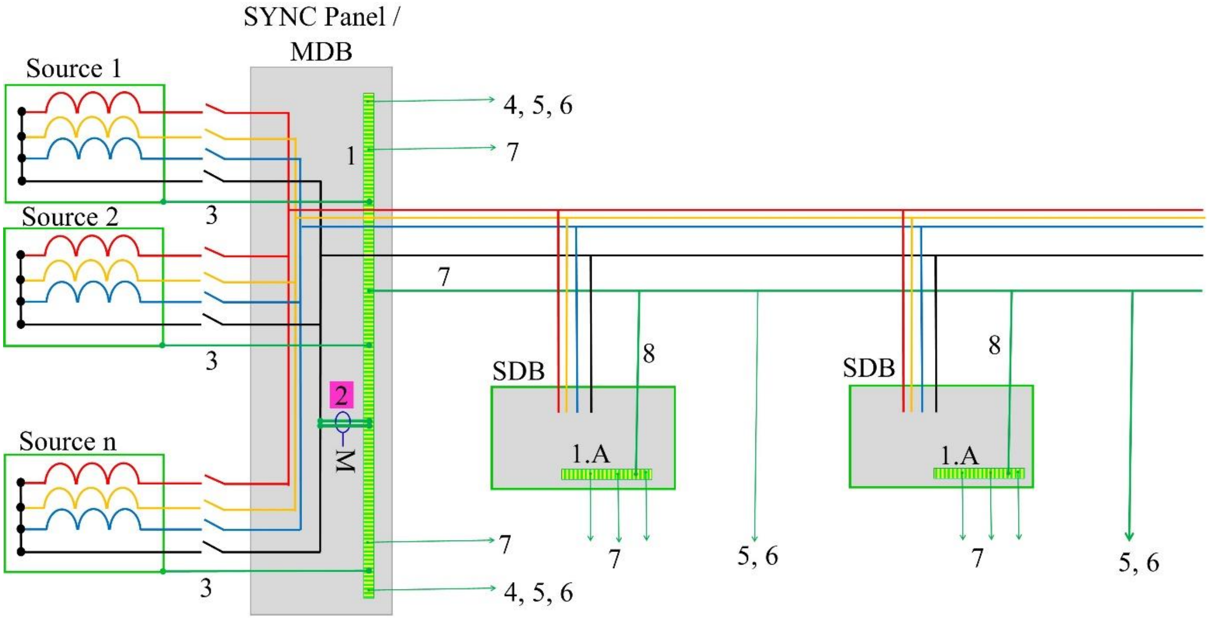


FIGURE F 3 TYPICAL SCHEMATIC OF EARTHING OF ONE TRANSFORMER AND DG MANUAL CHANGE OVER TN-S SYSTEM

Key: (Common for Fig. F1, Fig. F2, Fig. F3)

1 Main Earth Terminal (MET or Main Earth Bar)

2 System Referencing Conductor (Neutral Earthing of Energy Source): Typically, 2 connections are recommended, however the number can be reduced to one if a reliable connection is made. Providing disconnection link in System Referencing Conductor may be useful during insulation resistance test. Measurement or monitoring (M) of current through System Referencing Conductor is useful to implement earth leakage monitoring / earth fault protection.

3 Protective Earthing of Transformer: Typically, 2 connections are recommended. However unitised substations (Compact Substation or Package Substation) may have only one provision. In such care should taken to insist the supplier to make provision for two earthing. Modifications at the site for providing additional earth terminal should be avoided.

4 Earthing conductor: Connection to earth electrode (See 8.2.1).
There shall be additional connections to the armouring of incoming HV cable (if available).
Note: HV Surge arrester should be earthed inside the panel / on the structure for better performance.

5 Protective Bonding Conductor: Connections to accessible extraneous conductive parts.

6 Protective Bonding (global earthing system) reduces fault loop impedance, reduces touch/step voltages, improve shielding efficiency of building from lightning and other radiated effects of EMI.
Bonding to Lightning Protection of building (either to down conductor or to ring earth electrode - applicable if the transformer is inside or close to the building) is necessary if isolated LPS or electrically separated LPS is implemented in the premise.
(Note: Connections to Sl no.4, 5, 6, can be to a foundation embedded earth electrode with bonding to structural columns in building. (e.g. An earth grid in soil / floor interconnecting structural columns for an industrial premise. For commercial / high rise buildings, this earth grid is a superimposed mesh conductor in RCC).

7 Protective Earth (PE) conductor (also called as equipotential bonding conductor):
PE conductor shall run as close as possible to the line conductors, if possible, through the same cable tray or busbar trunking system (see 4.5.5).
Size of PE conductor can be selected as per 7.3.2.
For multiple circuits through the same cable route, shared PE conductor may be used satisfying the requirement in 4.5.4.
Where multiple runs of armoured cables are used, the armouring can be used as PE conductor provided, they are bonded satisfying 4.5.6.

Earth grid or similar arrangements are in addition to PE conductor and shall not be considered as an alternate to PE conductor.
PE conductor can be connected to the MET of the location.

8 Protective Earth conductor of 3 phase equipment (connections in duplicate). (see 4.5.1 to 4.5.3)

M Measurement of earth leakage / earth fault current for disconnection or monitoring.

MDB Main distribution board

SDB Sub distribution board

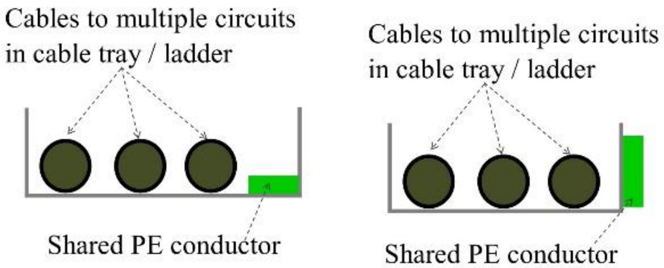


FIGURE F 4 SHARED PE CONDUCTOR – THE GENERAL PRACTICE IS TO USE GALVANISED STEEL AS PE CONDUCTOR RUNNING IN CONTACT WITH CABLE TRAY. THE K VALUE FOR BARE STEEL IN TABLE 14 IS RECOMMENDED.