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CONNECTION WITH EARTH

GUIDE

UNDERSTANDING REGULATION 43

CENTRAL ELECTRICITY AUTHORITY

(Measures Relating to Safety and Electric Supply) Regulations, 2023

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This guide is published by NFE to improve the general understanding of CEA Safety Regulation 43 and as a part of NFE's knowledge dissemination program. The explanations are from relevant IS/IEC standards. Neither CEA nor BIS have any responsibility on the contents of this document. In case of any clarifications, users are requested to contact NFE.

Reason for the Guide:
NFE has been conducting seminars and webinars throughout the nation for the last few years. Throughout the nation, the requirements of the Regulations and IS standards are rarely followed, resulting in accidents. One area of confusion is the earthing. NFE felt the need of making a guide with pictures from IS and IEC standards for dissemination of knowledge to the engineering community.

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IEC	TC64: (Safety) MT 3, MT 12, MT 40, MT 41, WG 43
	TC81: (LPS) MT 3, MT 14, MT 21, WG 18
	SC 37 A: (SPD) WG 03 & WG 05
	SyC LVDC WG 01
BIS	NBC (Part 8, Section 2 – Electrical installation),
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Guide on Understanding Regulation 43

Central Electricity Authority

(Measures Relating to Safety and Electric Supply) Regulations, 2023

1 Introduction

The Central Electricity Authority (Measures relating to Safety and Electric Supply) Regulations, 2023 (hereafter called as "regulation" or “regulations”) modified the electrical safety requirements from the preceding documents. This guide explains the modifications in the regulation 43 with pictures for users to understand and follow the regulation 43.

Regulation 43: Connection to Earth - Safety provisions for electrical installations and apparatus of voltage not exceeding 650 V

Note: Cluse 2.7 Explains the requirement of Regulation 50 (1).

2 References in detail.

The regulations, definitions, standards and the significance of IS and IEC standards in the regulations are used in this guide.

2.1 Regulation 43.

Note: Quotes from regulations are given in blue colour throughout this guide.

Connection with earth. – The following conditions shall apply to the connection with earth of systems at voltage exceeding 50 V but not exceeding 650 V, namely: –

(i) neutral conductor of a three phase, four-wire system and the middle conductor of a two-phase, three-wire system shall be earthed as per the relevant standards;

(ii) neutral conductor shall also be earthed at one or more points along the distribution system or service line in addition to any connection with earth which shall be at the consumers premises;

(iii) in the case of a system comprising electric supply lines having concentric cables, the external conductor or armour of such cables shall be earthed by two separate and distinct connections with earthing system;

(iv) in a direct current system, earthing and safety measures shall be as per the relevant standards;

(v) every building shall have protective equipotential bonding by interconnecting the exposed and extraneous conductive parts as per the relevant standards;

(vi) the alternating current systems which are connected with the earth as provided in this regulation shall be electrically interconnected:

Provided that each connection with the earth is bonded to the metal sheathing and metallic armouring, if any, of the electric supply lines;

(vii) the frame of every generator, stationary motor, portable motor, and the metallic parts, not intended as conductors, all transformers and any other apparatus used for regulating or controlling electricity, and all electricity consuming apparatus, of voltage exceeding 250 V but not exceeding 650 V shall be earthed by two separate and distinct connections with earth by the owner as specified in the relevant standards;

(viii) all metal casing or metallic coverings containing or protecting any electric supply line or apparatus shall be connected with the earth and shall be so joined and connected across all junction boxes and other openings as to provide good mechanical and electrical connection throughout the length:

Provided that the conditions mentioned in this regulation shall not apply, where the supply voltage does not exceed 250 V and the apparatus consists of wall tubes or brackets, electroliers, switches, ceiling fans or other fittings, other than portable hand lamps and portable and transportable apparatus, unless provided with the earth terminal and to class-II apparatus and appliances of the relevant standards:

Provided further that where the supply voltage is not exceeding 250 V and where the installations are either new or renovated, all plug sockets shall be of the three pin type, and the third pin shall be permanently and effectively earthed;

(ix) All earthing systems shall, –

(a) consist of equipotential bonding conductors capable of carrying the prospective earth fault current without exceeding the allowable temperature limits as per relevant standards in order to maintain all non-current carrying metal works reasonably at earth potential and to avoid dangerous contact potentials being developed on such metal works;

(b) have earth fault loop impedance sufficiently low to permit adequate fault current for the operation of protective device within the time stipulated in the relevant standards; and

(c) 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 earth bonding as per the relevant standards, before the electric supply lines or apparatus are energised;

(x) all earthing systems belonging to the supplier shall in addition, be tested for resistance on dry day during the dry season at least once in a year;

(xi) earth fault loop impedance shall be tested to ensure the automatic operation of the protective device and a record of every earth test made and the result thereof shall be kept by the supplier for a period of not less than two years after the day of testing and shall be available to the Electrical Inspector when required;

(xii) earth fault loop impedance of each circuit shall be limited to a value determined by the type and current rating of the protective device used such that, on the occurrence of an earth fault, disconnection of the supply shall occur before the prospective touch voltage reaches a harmful value; and

(xiii) the neutral point of every generator and transformer shall be earthed by connecting it to the earthing system not by less than two separate and distinct connections.

2.2 Forms of Inspection report in regulations

In schedule II, sl. no 19 of FORM II (Installations of voltage level more than 250 V up to and including 650 V), demand the compliance to regulation 43. The following subjects are added in regulations 2023.

- Is the protective equipotential bonding tested,
- Is the fault loop impedance at origin of installation tested,
- Is the fault loop impedance of each circuit tested,
- Is the fault loop impedance tested for all sources.

Methods of these tests are included in clause 8 of this guide.

2.3 Definitions from the regulations.

The following definition from the regulations are used in this guide.

(u) "earthing" means connection of the exposed conductive and extraneous parts of an installation to the main earthing terminal of that installation or connection of neutral of transformer or generator or equipment to general mass of earth or earth bonded bar of that installation;

(v) "earthing arrangement or earthing system" means all the electric connections and devices involved in the earthing of a system, an installation or equipment;

(za) "equipotential bonding" means an electrical connection putting various exposed conductive parts and extraneous conductive parts at a substantially equal potential;

(zb) "exposed conductive part" means a conductive part which can readily be touched and which is not normally live, but which may become live under fault conditions;

(zc) "extraneous conductive part" means a conductive part not forming part of the electrical installation and liable to introduce an electric potential, generally the electric potential of a local earth;

2.4 Relevant Standards referred

Guidance have been taken from the following Indian standards for detailed explanation.

(i) NEC (2023) (SP-30): National Electrical Code of India

(ii) IS 3043 (2018): Code of Practice for Earthing

(iii) IS 732 (2019): Code of Practice for Electrical Wiring Installations

(iv) IS/IEC 61936-1: Power installations exceeding 1 kV AC - Part 1: AC

2.5 Standards referred in regulations

In Chapter III, General safety requirements, Regulation 14: General safety requirements pertaining to construction, installation, protection, operation and maintenance of electric supply lines and apparatus, the following sub regulations apply;

(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.

(3) The material and apparatus used shall conform to the relevant standards.

The regulations also define "standard" as

(zze) "standard" means Indian Standard and in absence of Indian Standard, International Electrotechnical Commission Standard, Institute of Electrical and Electronic Engineers Standard, European Norms Standard in the sequence of their appearance unless stated otherwise;

2.6 Significance of IS and IEC standards in the CEA regulations

Compliance to NEC (SP 30) and NBC (SP 7) and other Indian standards are made mandatory in the regulation (ref 14(2)). All products used shall also conform the IS standards (ref 14 (3)).

Note: The standards are defined as Indian standards and in the absence of an IS standard, IEC/IEEE/EN in the sequence applies. How ever for almost all applications IS standards or IEC are available, hence the need for IEEE/EN standards is remote.

2.7 Regulation 50

This guide does not explain requirement of regulation 50, except in clause 5. How ever the requirement of regulation 50, applicable for industrial and commercial premise where there is a supply up to 33 kV is reproduced below.

Regulation 50. Connection with earth for apparatus exceeding 650 V. –

(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,

- (i) limit the touch and step potential to tolerable values as per relevant standards,
- (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.

3 Explanations of the Regulation 43

3.1 Sub Regulation (i)

neutral conductor of a three phase, four-wire system and the middle conductor of a two-phase, three-wire system shall be earthed as per the relevant standards;

System earthing is classified as TN/TT. Refer cluse 4.1.5.8.2 of IS732:2019 to understand more on the subject.

3.2 Sub Regulation (ii)

neutral conductor shall also be earthed at one or more points along the distribution system or service line in addition to any connection with earth which shall be at the consumers premises;

The distribution system where the neutral conductor is earthed along the distribution is called as TN-C-S system. The requirements of various regulations are included in fig.1, in which the respective regulations are mentioned in (blue).

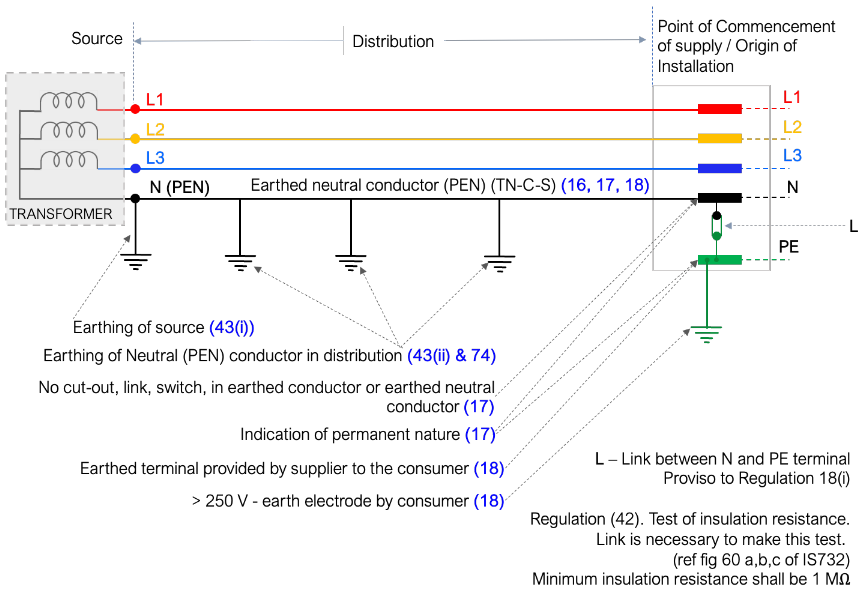


Fig. 1: TN-C-S System with Earthed Neutral conductor (PEN conductor) at distribution indicating requirements of various CEA Regulations.

The minimum insulation resistance after the point of commencement of supply shall be 1 MΩ. Neutral is a current carrying conductor and shall be insulated like phase conductors within the consumer premise. Under any condition, Neutral conductor shall not be earthed within the consumer premise (N and PE conductors shall be strictly separate within the consumer premise).

3.3 Sub Regulation (iii)

in the case of a system comprising electric supply lines having concentric cables, the external conductor or armour of such cables shall be earthed by two separate and distinct connections with earthing system;

In the case of the supplier's distribution using armoured cable, the armour also to be earthed. In a TN-C-S system, the neutral and the protective conductors at the distribution should be interconnected to become combined PE and N conductors. See fig.1 for more information.

3.4 Sub Regulation (iv)

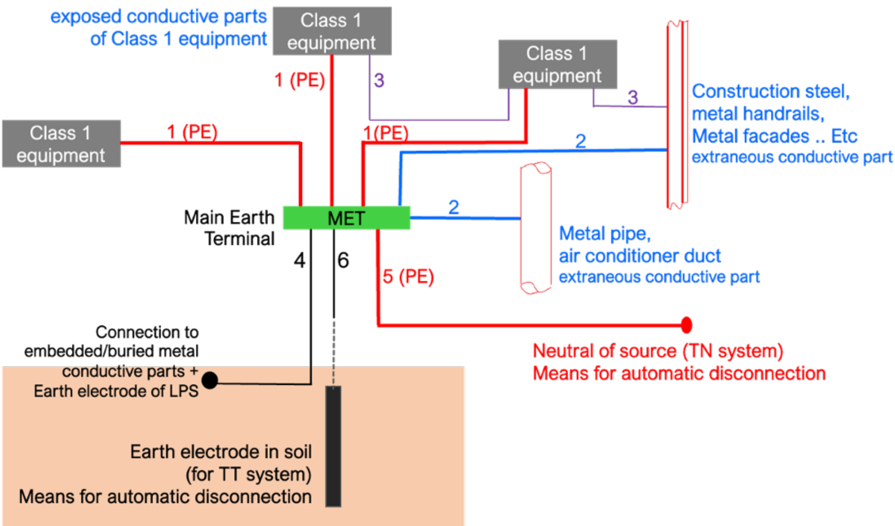
in a direct current system, earthing and safety measures shall be as per the relevant standards;

See fig. 22 to 26 of IS732:2019 for more information.

3.5 Sub Regulation (v)

every building shall have protective equipotential bonding by interconnecting the exposed and extraneous conductive parts as per the relevant standards;

Protective equipotential bonding as per NEC 2023 with different terms used are explained in fig. 2.



Key:

a) MET: Main Earthing Terminal, also called as Main Earth Busbar or Equipotential Bonging Bar or Conductor.

b) Connecting class 1 equipment to MET is called as "protective earthing" or "earthing". The conductors are called as Protective Earthing conductor (or PE conductor, also called as circuit protective conductor in some old documents still used in India). They are to be identified with the colour green/yellow.

c) Connecting extraneous conductive parts to equipotential bonding system is called as "protective bonding". Such a bonding is necessary near the mains incoming (*Main DB, called as Main Equipotential Bonding, which are connected to MET*) and locations where more electrical equipment are located (*called as supplementary equipotential bonding*). The conductors are called as Protective bonding conductors They are to be identified with the colour green/yellow.

d) All buried metal parts are also to be bonded to MET. These conductors are called as earthing conductor. They are to be identified with NO colour other than colour of the bare conductor.

e) To enable automatic disconnection during fault, there shall be a bonding to the means of earthing to carry the fault current safely to the source. This is achieved by

- In TN system MET is connected to earthed point of the source (e.g. Neutral of the source) through a metallic conductor.
- In TT system MET is connected to an electrically independent earth electrode.

Fig. 2: Illustration of Protective Equipotential Bonding with examples of various terms used.

Refer NEC (SP 30) fig. 1 in part 1 section 18 for more information. Sizing of various conductors are included in clause 5 of this guide.

Note: In most of the buildings, protective equipotential bonding is not carried out as recommended in IS standards, which is a volition of the regulation and is one of the main reasons for electrocution during a fault.

3.6 Sub Regulation (vi)

the alternating current systems which are connected with the earth as provided in this regulation shall be electrically interconnected:

Provided that each connection with the earth is bonded to the metal sheathing and metallic armouring, if any, of the electric supply lines;

The AC system which are earthed (see regulation 43(i)) shall be interconnected. This regulation further explains the need of electrical interconnection of TN/TT supply system, various exposed and extraneous conductive parts including metal sheathing, armouring.

3.7 Sub Regulation (vii)

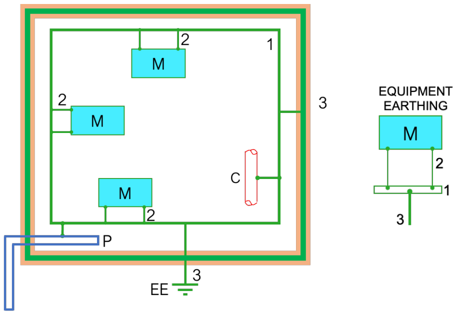
the frame of every generator, stationary motor, portable motor, and the metallic parts, not intended as conductors, all transformers and any other apparatus used for regulating or controlling electricity, and all electricity consuming apparatus, of voltage exceeding 250 V but not exceeding 650 V shall be earthed by two separate and distinct connections with earth by the owner as specified in the relevant standards;

Fig. 31 of IS3043: 2018 explains the need to have two separate and distinct connection of exposed conductive parts to MET. Conventionally this is called as double earthing. In locations where external influences (*e.g. mechanical reasons, corrosion etc*), can deteriorate an earth connection, two earth connections are being recommended for redundancy. With the introduction of protective measures such as IP and IK, one reliable connection may be enough, provided the class 1 equipment have only one provision for such a connection.

Note:

1. Double earthing does not mean two earth electrodes in soil. earthing as per fig. 4 to fig. 6 shall be prohibited.

2. Due to the emergence of modern electrical equipment conforming to latest standards, where each of the termination including protective earthing are made in ingress protected terminal boxes, there is no provision of double earthing on equipment (except in cases where the leakage current is higher than 10 mA). In cases where there is no provision for double earthing, protective conductor as a part of incoming cable is be preferred (e.g. 3 core cable for single phase application (1 phase, 1 neutral and 1 PE conductor) and 4 core cable (3 phases, and 1 PE conductor) for 3 phase application without Neutral and 5 core cable (3 phases, 1 neutral and 1 PE conductor) for 3 phase application with Neutral.



M: Exposed conductive parts of class 1 equipment
P: Incoming metallic service
C: Extraneous conductive parts
EE: Earth electrode
1: Equipotential bonding conductor (MET).
2: Protective Earthing conductor (in duplicate)
3: Earthing conductor (to soil embedded or foundation embedded earth electrodes)

Fig. 3: Illustration of double earthing as in fig 31 of IS3043:2018. Double earthing is made from a class 1 equipment to MET.

3.8 Sub Regulation (viii)

all metal casing or metallic coverings containing or protecting any electric supply line or apparatus shall be connected with the earth and shall be so joined and connected across all junction boxes and other openings as to provide good mechanical and electrical connection throughout the length:

Provided that the conditions mentioned in this regulation shall not apply, where the supply voltage does not exceed 250 V and the apparatus consists of wall tubes or brackets, electroliers, switches, ceiling fans or other fittings, other than portable hand lamps and portable and transportable apparatus, unless provided with the earth terminal and to class-II apparatus and appliances of the relevant standards:

Provided further that where the supply voltage is not exceeding 250 V and where the installations are either new or renovated, all plug sockets shall be of the three pin type, and the third pin shall be permanently and effectively earthed;

- Metallic installations to protect electric supply lines or apparatus shall be bonded properly to ensure good mechanical and electrical connection.
- Protective earthing is not required for class 2 equipment.
- All plug and sockets shall be 3 pin type, the third pin shall be effectively earthed.

3.9 Sub Regulation (ix)

All earthing systems shall, –

> *consist of equipotential bonding conductors capable of carrying the prospective earth fault current without exceeding the allowable temperature limits as per relevant standards in order to maintain all non- current carrying metal works reasonably at earth potential and to avoid dangerous contact potentials being developed on such metal works;*
>
> *have earth fault loop impedance sufficiently low to permit adequate fault current for the operation of protective device within the time stipulated in the relevant standards; and*
>
> *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 earth bonding as per the relevant standards, before the electric supply lines or apparatus are energised;*

The equipotential bonding conductors shall be sized, made and maintained to avoid temperature rise during an earth fault and to provide equipotentiality. See cl. 5 of this guide for sizing of protective earthing and equipotential bonding conductors.

Maintain Low earth fault loop impedance as explained in cl 8.2 and cl. 8.3.

Tested to ensure earth bonding as explained in cl 8.1.

3.10 Sub Regulation (x)

all earthing systems belonging to the supplier shall in addition, be tested for resistance on dry day during the dry season at least once in a year;

Earthing system belonging to the supplier (*efficiency of protective conductor, local earthing of PEN conductor at the distribution and earth fault loop impedance of the source*) shall be tested annually. See 8.2.

3.11 Sub Regulation (xi)

earth fault loop impedance shall be tested to ensure the automatic operation of the protective device and a record of every earth test made and the result thereof shall be kept by the supplier for a period of not less than two years after the day of testing and shall be available to the Electrical Inspector when required;

The supplier of electricity shall carryout earth fault loop impedance test and the result shall be kept for a period of two years and to be submitted to electrical inspector when required. The suppliers can carry out fault loop impedance as explained in cl. 8.2.

3.12 Sub Regulation (xii)

earth fault loop impedance of each circuit shall be limited to a value determined by the type and current rating of the protective device used such that, on the occurrence of an earth fault, disconnection of the supply shall occur before the prospective touch voltage reaches a harmful value;

Efficiency of automatic disconnection of every circuit shall be ensured. This need to be carried out by the owner of the building. see cl. 8.2 & cl. 8.3.

3.13 Sub Regulation (xiii)

the neutral point of every generator and transformer shall be earthed by connecting it to the earthing system not by less than two separate and distinct connections.

Refer the definition of earthing system. The fig. 9 to fig. 13 explains earthing of Transformer and DG. The practice explained in fig. 4 to fig. 6 is a violation of the CEA regulation and shall be prohibited

4 Misinterpretation of various regulations including Regulation 43.

Misinterpretation of the regulation and standards lead to unsafe electrical installation. One such misinterpretation is the use of two separate earth electrodes for the neutral and body of each source (e.g. Transformer / DG) as shown in fig 4. Neither the regulations nor any standards demand an earthing system as shown in fig. 4 to fig. 6.

The use of “independent”, "isolated" earth electrodes for safety or functionality of a system is a mis concept, hence prohibited in several nations (see IEC 61000-5-2). 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 can occur between this isolated earthing system and other parts of the installation, which is a safety hazard.

Fig. 4 to fig. 6 shows examples of violation of regulation. Using two separate earth electrodes for the neutral of each transformer/DG, two separate earth electrodes for the body of each transformer/DG, separate earth electrodes for distribution boards, lifts, UPS, electronics etc are violation of CEA regulations and IS/IEC standards. This dangerous practice shall be prohibited.

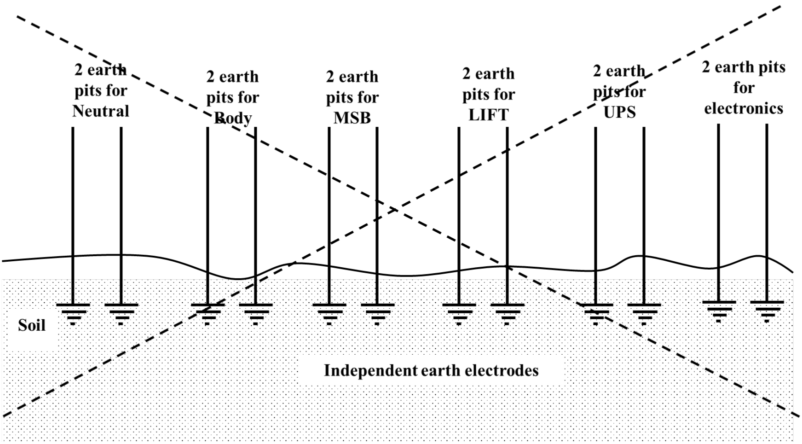


Fig. 4: Misconception of separate earth electrodes.

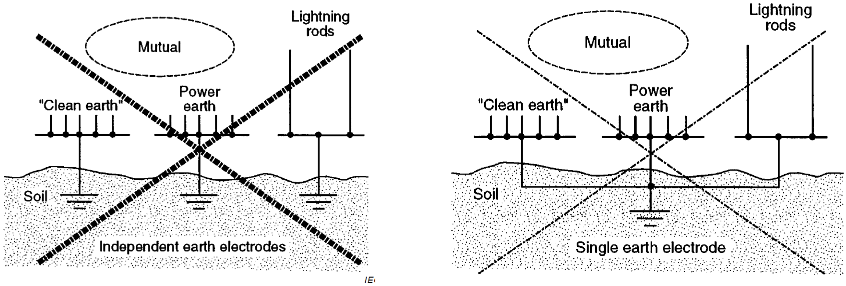


Fig. 5 & fig. 6 misconception of "dedicated", "independent", or "isolated" earth electrodes.

5 Earth Electrodes

5.1 Type of Earth Electrodes

Earth electrodes recommended in NEC 2023 are,

a) concrete-embedded foundation earth electrode,

b) soil-embedded foundation earth electrode,

c) metallic electrode embedded directly in soil vertically or horizontally (for example, rods, wires, tapes, pipes or plates etc),

d) metal sheath and other metal coverings of cables,

e) other suitable metallic underground (for example, pipes), and

f) welded metal reinforcement of concrete (except pre-stressed concrete) embedded in the earth.

5.2 Use of Earth Electrodes

Earth electrodes are to dissipate current to earth.

For Low Voltage supply from electricity supplier above 250 V, an earth electrode is necessary at mains incoming as per regulation 18 connected to the earthed terminal provided by the supplier through a suitable link.

(Note: To understand more refer our guide "NFE guide on Understanding Regulation 18", which is expected to be published in March 2025).

For Low Voltage side of Industrial and commercial premises, earth electrode as shown in fig. 18 or fig. 19 is necessary, which is in addition to the PE conductor as explained in clause 7.7.

For High Voltage side of transformer in Industrial and Commercial premises, the touch and step potentials are to be limited within the tolerable value as required in IS/IEC 61963-1 & Regulation 50. For this purpose, vertical rods or plates may not be effective. Horizontal conductors as potential grading ring around the installation are effective in limiting the touch and step potentials. Conductors in foundation mesh or ring connected to potential grading rings are effective in Industrial and commercial premises. Earth electrodes embedded in concrete or in soil as shown in fig. 18 or fig.19 combined with potential grading rings could provide very low earth resistance which will be helpful in limiting the potentials of earth electrode reaching high values during an earth fault in HV side of the installation. A calculation and measurement are recommended in this case.

5.3 Earth Electrode Resistance

The following are the requirements of earth electrode resistance (resistance of the earth electrode to earth).

a) Under any circumstance a fixed minimum value of earth electrode resistance is necessary in a Low Voltage Electrical Installation for safety and functional needs (see the exception in b).

   Note: There is no need to keep a resistance of 1 Ω or 2 Ω or 10 Ω or 25 Ω. Demanding such values for the application as explained in fig. 4 to fig. 6 is WRONG and cannot ensure safety and reliability.

b) Resistance of 10 ohms is preferred for Type A earth electrodes for Lightning Protection System in a structure.

c) For High Voltage Electrical Installation, step and touch voltage reduction measures are mandatory (*see cl 5.2 or NFE guide on Understanding Regulation 50*).

6 Sizing of various conductors for protective equipotential bonding

Conductors for protective equipotential bonding are termed as

- Main Earthing Terminal (MET): Terminal or busbar of an installation, enabling the electric connection to a number of conductors used for earthing or bonding purposes. They were also called as Equipotential Bonding Conductors or Main Earthing Busbar in previous standards.
- 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.

  Note: The PE conductor in final circuits is also called as circuit protective conductors (CPC) in some existing documents.
- Protective Bonding Conductor: Conductors used to connect extraneous conductive parts to MET. They are used in main equipotential bonding and supplementary equipotential bonding.
- 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.

The type and sizes of various conductors are as below

6.1 General requirement of Protective conductors

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

a) conductors in multicore cables,
b) insulated or bare conductors in a common enclosure with live conductors,
c) fixed installed bare or insulated conductors,
d) metallic cable sheath, cable screen, cable armour, wire braid, concentric conductor, metallic conduit, provided they are tested to withstand the expected fault current of the system.

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 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.

6.2 Size of Protective Earthing (PE) conductors

Simplified methods are explained herein. For detailed calculations, refer IS 732 clause 5.4.3.1.

In TN system, the minimum cross-sectional area of PE conductors shall satisfy the following,

Cross-sectional Area of Line Conductor, S (mm^2 Cu)	Minimum Cross-sectional Area of the Corresponding Protective Conductor (mm^2)	
	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 selected from Tables 3 of IS732, according to the materials of the conductor and insulation;		
k_2 is the value of *k* for the protective conductor, selected from Tables 58 to Table 62 of IS732 as applicable.		

Table 1: minimum cross-sectional area of PE conductor

In TT systems, the cross-sectional area of PE conductor need not exceed:

- 25 mm^2 copper,
- 35 mm^2 aluminium.

Note: Regulations recommend TN system.

6.3 Size of Protective bonding conductors

6.3.1 Main Protective bonding conductors

Main Protective bonding conductors are for connection to the MET of the installation, which is generally located near the mains incoming. Main Protective bonding conductors 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.

The cross-sectional area of main protective bonding conductors need not exceed 25 mm^2 Copper or an equivalent cross-sectional area for other materials.

6.3.2 Supplementary Protective bonding conductors

Supplementary protective bonding conductors are for connection to the Sub Earthing terminals which are downstream the mains incoming for connecting two exposed-conductive-parts or exposed-conductive-parts to extraneous conductive-parts depending upon the requirement of the location.

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

Supplementary 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.

Note: Supplementary equipotential bonding is necessary for large buildings or special locations. For multistorey buildings with electronic installations, supplementary equipotential bonding is recommended in each floor. For industrial buildings this is necessary at various locations, depending upon the type of electrical equipment. An assessment can be made to determine the location of supplementary equipotential bonding. Special locations where supplementary equipotential bonding is necessary are bathrooms, swimming pools, group 1 and group 2 medical locations etc and in locations where automatic disconnection is difficult. Refer NEC 2023 for more information.

6.4 Size of Earthing Conductor

Earthing conductors 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 13 of IS732.

Where no noticeable fault current is expected to flow through the earth electrode the earthing conductor may be dimensioned according to Main Protective bonding conductors (see clause 5.3.1).

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).

Aluminium shall not be used as earthing conductors.

7 Earth fault loop impedance and its significance in Electrical Safety

7.1 What is Earth Fault Loop Impedance

Earth Fault Loop Impedance is defined as 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 protective earthing conductor,

b) the consumer's earthing terminal and earthing conductor,

c) for TN systems, the metallic return path to the source neutral,

d) for TT and IT systems, the earth return path through the earth electrodes,

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.

7.2 Automatic disconnection during an earth fault

Note: Fault protection is achieved by protective earthing, protective equipotential bonding and automatic disconnection of supply.

Every circuit of an electrical installation need over current protection (*OCPD - e.g. MCB, Fuse etc*). If the earth fault loop impedance is low, sufficient current can flow through these OCPD's to operate them within the specified times. See IS 3043 & IS 732 for more information.

If the earth fault current is less due to high loop impedance, the OCPD's are not efficient to give automatic disconnection of the supply. In such case the options are to reduce the impedance of the loop or provide an RCD for automatic disconnection or provide supplementary equipotential bonding.

7.3 Earth Fault Loop Impedance in TN-S system

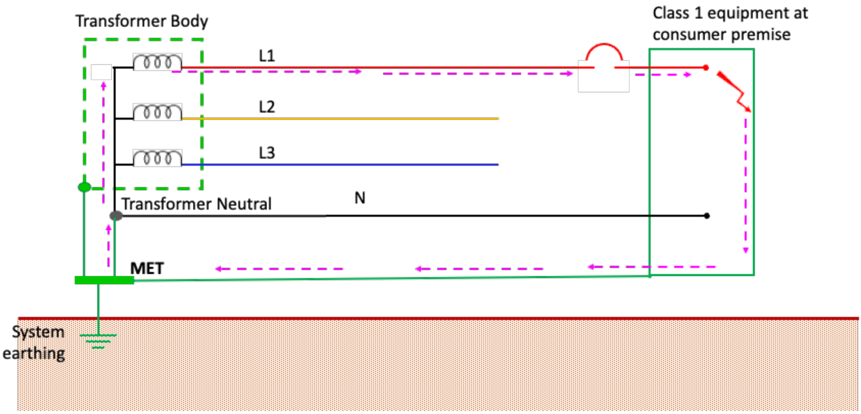


Fig. 7: Components of earth fault loop impedance in TN system.

7.4 Earth Fault Loop Impedance in TT system

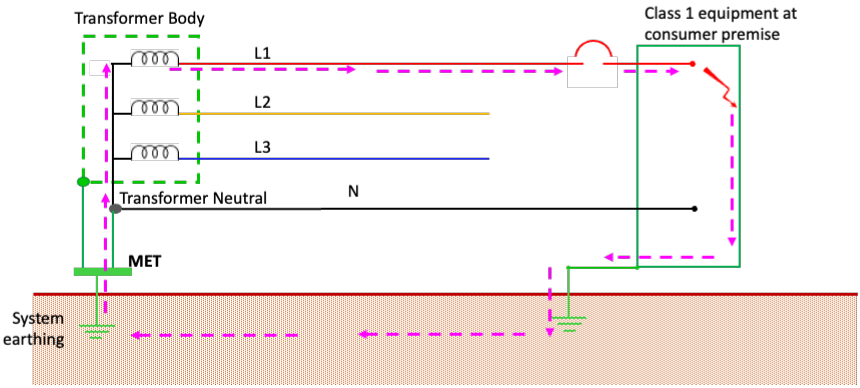


Fig. 8: Components of earth fault loop impedance in TT system.

7.5 Earth Fault Loop Impedance and efficiency of Automatic disconnection of supply during fault.

The characteristics of the protective devices enabling automatic disconnection and the circuit impedances shall fulfil the requirement of maximum time allowed for automatic disconnection (see Table 4). 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,

$$Z_s(\Omega) \leq \frac{2}{3} \times \frac{U_o}{I_a}$$

where,

$Z_s(\Omega)$ is the measured impedance of the fault current loop starting and ending at the point of fault (measured in Ω);

U_o is the line conductor to earthed neutral voltage (V); and

I_a is the current causing the automatic operation of the protective device within the stipulated disconnection time.

7.6 Maximum earth fault loop impedance values for MCBs

Maximum earth fault loop impedance values for MCBs conforming to IS/IEC 60898-1 are given in Table 2. For other OCPDs, refer to manufacturer's data.

MCB I_n in Amps	6	10	16	20	25	32	40	50	63	80	100
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
Type C	2.56	1.53	0.96	0.77	0.61	0.48	0.38	0.31	0.24	0.19	0.15
Type D	1.28	0.77	0.48	0.38	0.31	0.24	0.19	0.15	0.12	0.10	0.08

Table 2: Maximum allowed earth fault loop impedance Z_S for MCB'S

7.7 Mandatory requirement as per NEC 2023 & IS732.

The recommended system is 5 wires within any installation (3 phase, Neutral and PE conductor including MET). PE conductor is the primary fault return path, influencing fault loop impedance. The grid interconnecting exposed conductive parts and neutral of the system reduces fault loop impedance and is an additional fault return path. The grid contributes to reduction of fault loop impedance and improves efficiency of automatic disconnection. PE conductor shall be sized according to clause 5.2.

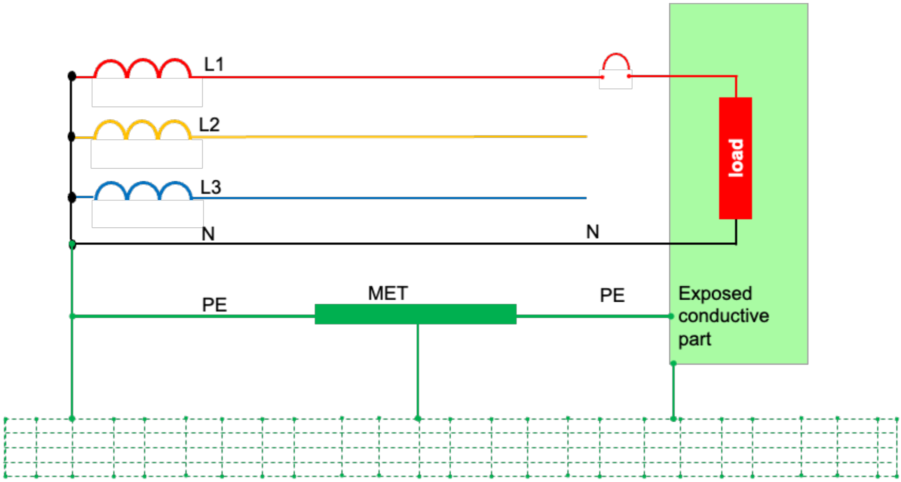


Fig. 9 System with Separate Protective Earth Conductor (TN-S) and grid interconnecting exposed conductive parts of the installation and neutral of source (called as Protective Multiple Earthing (PME) in IS3043).

8 Earthing of transformer and DG to comply the Regulation 43.

8.1 Earthing of DG and Transformers

Figures from various standards are reproduced for easy explanation. Please note in all these figures the neutral and body of the source are bonded to the common bus bar (MET). The regulations and standards recommend TN-S or TN-C-S system.

- Fig. 10: reproduction of fig 38 from IS3043:2018 (Single low voltage standby generator).
- Fig. 11: reproduction of fig 39 from IS3043:2018 (low voltage standby generators with neutrals connected). Further explanations also can be found in fig. 16, and Fig. 37, of IS732:2019.
- Fig. 12 to fig. 14 are having common explanation.
- Fig. 15 and fig.16 are reproduced from IEC 61000-5-2, IS 732 including information from IS/IEC 62305-3 as two-dimensional explanation of earth electrodes and bonding.
- Fig. 17 is reproduced from IS/IEC 62305-3 and IEC 61000-5-2 as a three-dimensional earthing arrangement in a multi floor building consisting of bonding network interconnected with the earth termination system.

– Fig. 18 and fig. 19 are reproduced from IEC 62305-4 as an example of earth electrodes in multistorey building and industrial premise.

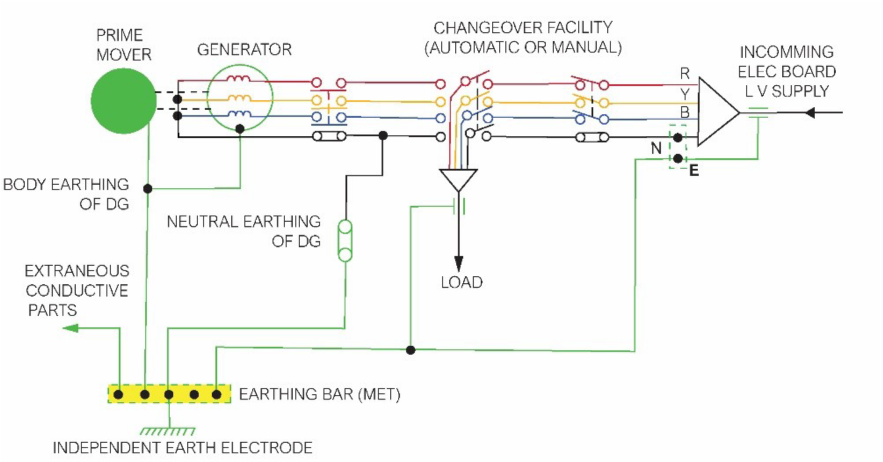


Fig. 10: Single low voltage standby generator (without paralleling facility)

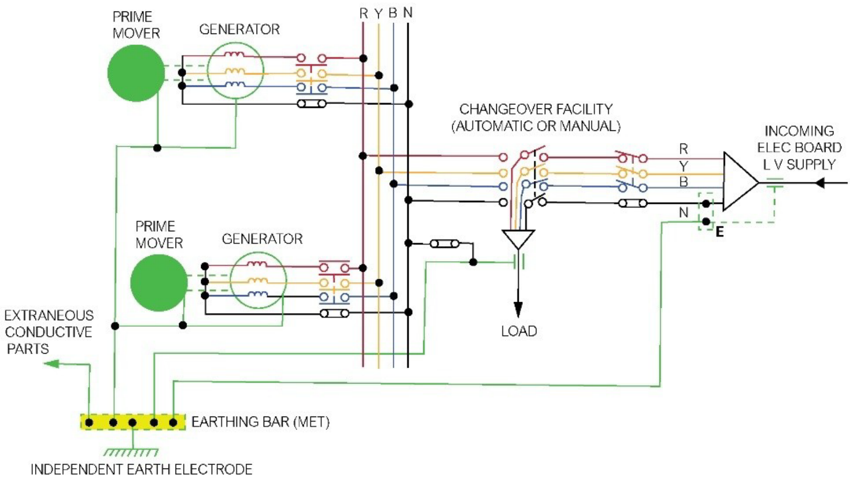


Fig. 11: Low voltage standby generators with neutrals connected

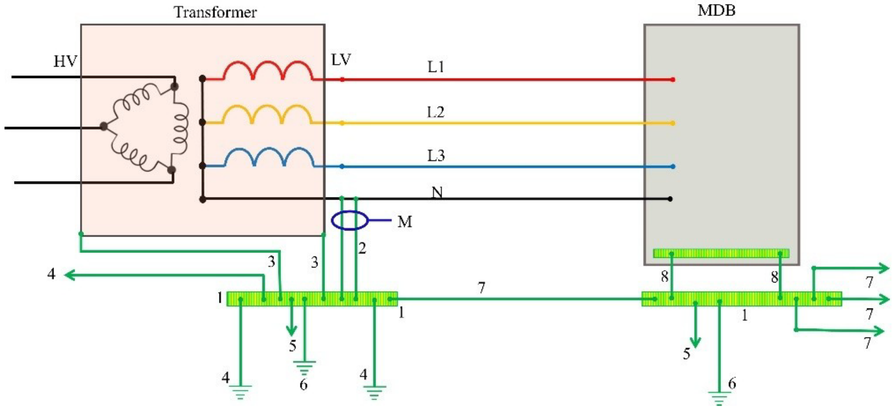


Fig. 12: Typical schematic of earthing of one transformer and installation. TN-S system

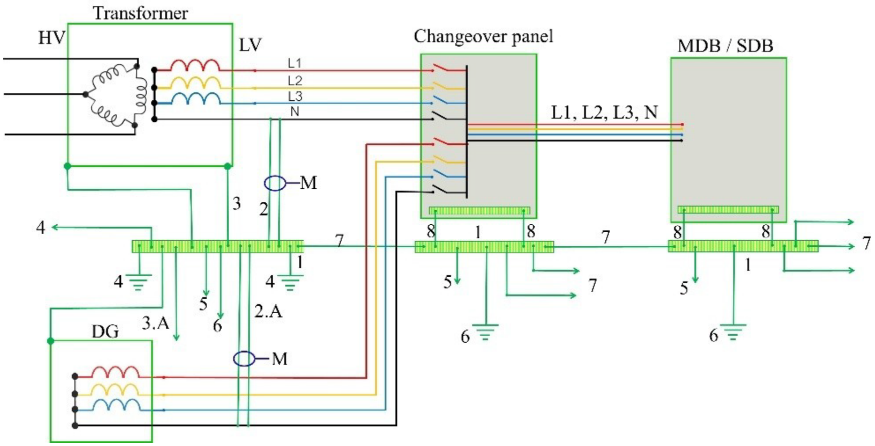


Fig. 13: Typical schematic of earthing of one transformer and DG manual change over TN-S system.

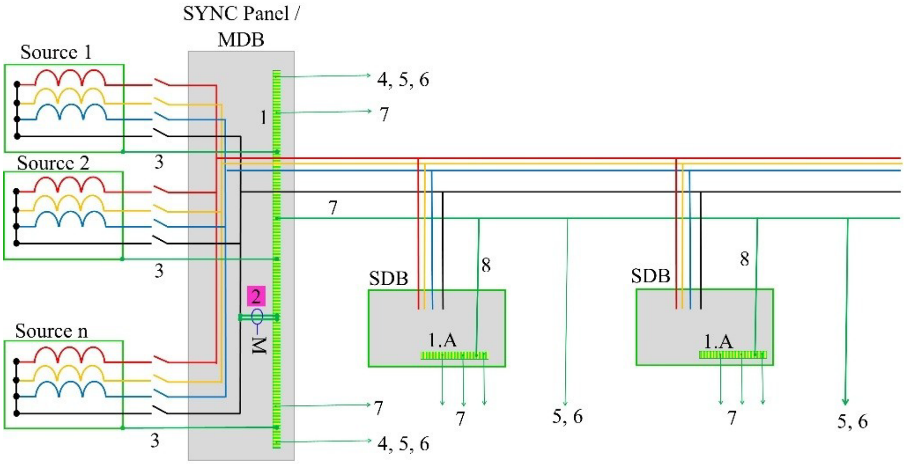


Fig. 14: Typical schematic of earthing of multiple sources running parallel. TN-S system.

Key: (Common for Fig. 11, Fig. 12 & Fig. 13)

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 Source: 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 electrodes. The earth electrodes at HV side of transformer shall limit touch and step potentials within the tolerable value as required in IS/IEC 61963-1 & Regulation 50.
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 (ref IS 15086-5 for more information).

5 Protective Bonding Conductor: Connections to accessible extraneous conductive parts.

6 Protective Bonding (Global Earthing System as recommended in IS/IEC 61936-1) 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.
For multiple circuits through the same cable route, shared PE conductor may be used satisfying the requirement in IS 3043 / IS732.
Where multiple runs of armoured cables are used, the armouring can be used as PE conductor provided, they are bonded as per IS3043.
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).

M Measurement of earth leakage / earth fault current for disconnection or monitoring.

MDB Main distribution board

SDB Sub distribution board

8.2 Correct method of earth electrodes and bonding

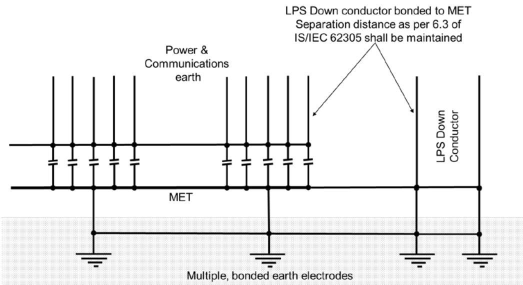


Fig. 15:
Recommended configuration for the earth electrodes, earthing network and an electrically insulated LPS.

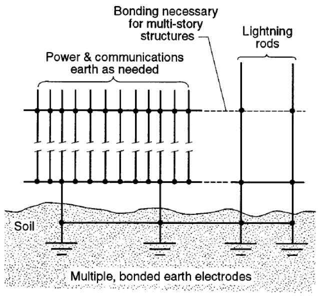
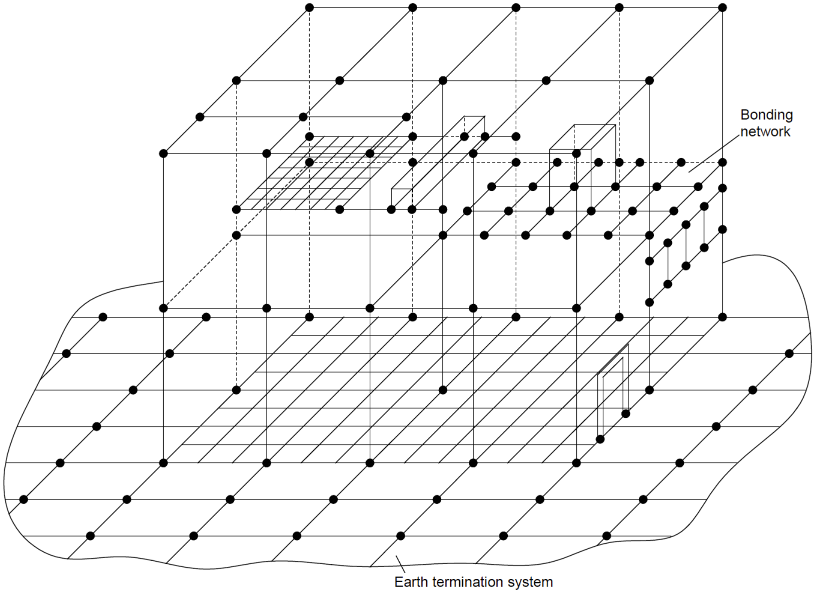


Fig. 16:
Recommended configuration for the earth electrodes, earthing network and attached LPS



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.

Fig. 17: Example of a three-dimensional earthing arrangement in a multi floor building consisting of bonding network interconnected with the earth termination system.

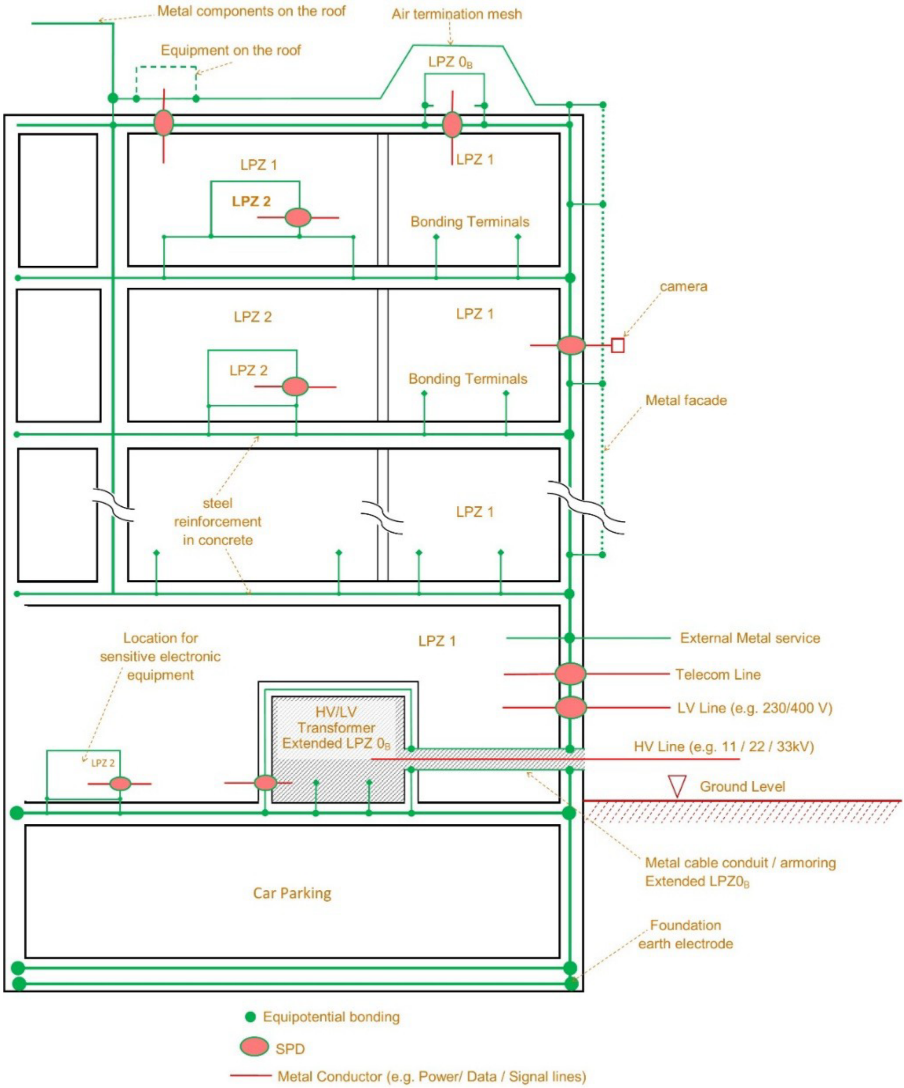
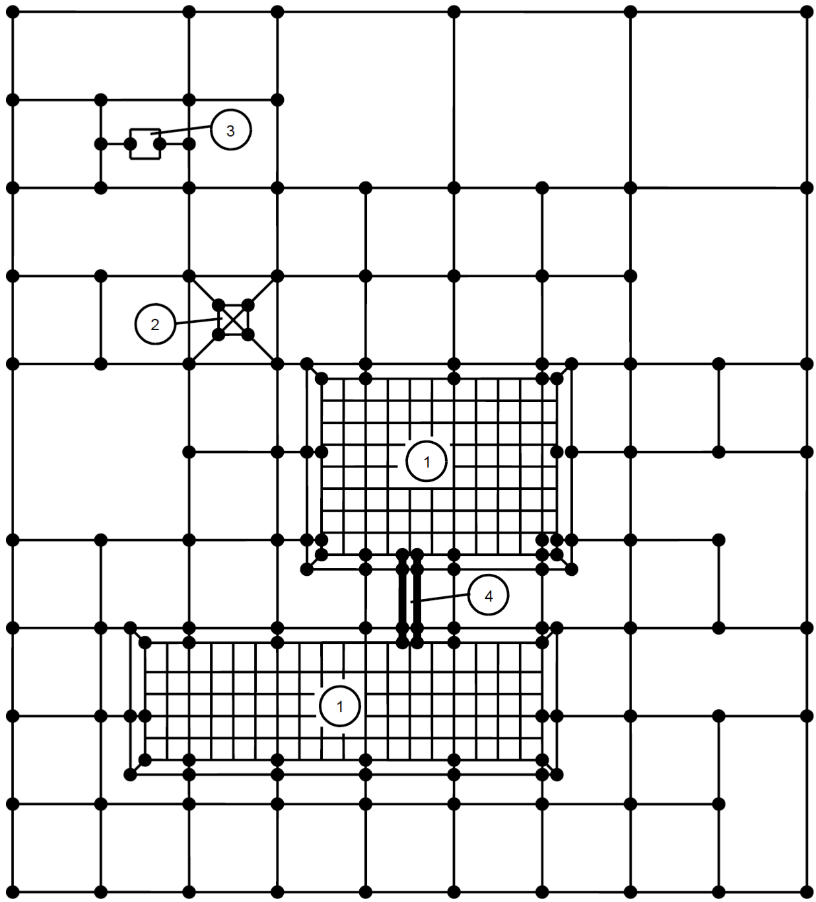


Fig. 18: Example of earthing arrangement and lightning protection zones in a multi floor building with transformer (inside or close to the structure).



Key:

1. Building with meshed network of the reinforcement
2. HV tower inside the plant
3. Standalone equipment (e.g. Transformer / DG).
4. Cable tray

Fig. 19: Meshed earth termination system of an industrial premise.

8.3 Global Earthing System for Industrial and commercial premises

For Industrial and commercial premises, Global Earthing System (see fig. 17 to fig.19) as recommended in IS/IEC 61936-1 & NEC 2023 (SP 30) can be implemented by interconnecting earthing system of building, power installations of various voltages, telecommunication and ICT installations, etc. Global earthing system ensures that touch and step voltages are limited with in the tolerable limits to meet the requirements of regulation 50.

9 Testing of Protective equipotential bonding and automatic disconnection of supply.

9.1 Testing to ensure effective earthing and bonding.

Every protective earthing and protective equipotential bonding shall be tested for its continuity resistance. Resistance of conductors are to be found out from the respective standards. The maximum allowed resistance between two terminations is the resistance of the conductor used for bonding. Use class 1 / class 2 conductors for this purpose.

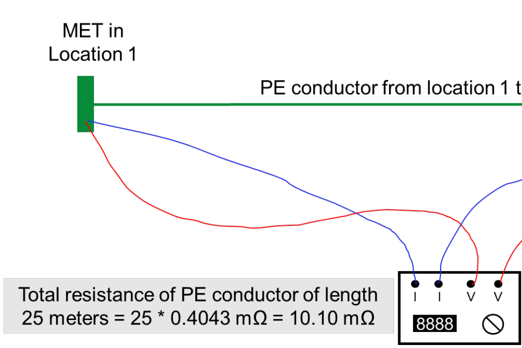


Fig. 20: Continuity resistance measurement.

9.2 Conditions of test

1. Sized acc. to the line conductor (ref table 14 of IS732 (e.g. 50 mm^2 copper with a resistance 0.4043 mΩ/M)
2. Continuity resistance of the PE conductor for a length of 25 meters = 25 * 0.4043 mΩ = 10.10 mΩ.
3. Test Instrument with minimum 10 Amps Test current (called as micro-ohm meter)

4. Tests shall be carried out between the Earth terminals.
5. The maximum allowed resistance between MET and Earth terminal of class 1 equipment is 10.10 mΩ.
6. The tested resistance includes the resistance of PE conductor and its connections to both earth terminals.
7. The test ensures that the conductor including connections are good to use.
8. This test is be carried out in power OFF condition.
9. Continuity resistance test of all protective earthing, main protective bonding and supplementary bonding conductors is mandatory.
10. Continuity resistance test has to be made during the erection of electrical installation.
11. IS732 recommends continuity resistance test of phase and neutral conductors in the final circuits.

9.3 Testing to ensure effective fault loop impedance and efficiency of automatic disconnection.

Loop impedance is measured between a phase conductor and protective conductor or between a phase conductor and neutral or between two phase conductors by using the voltage drop when the circuit under test is loaded. Fault loop impedance meters confirming to IEC 61557-3 are to be used to carry out this test, preferably with a test current as below.

Test current of the equipment	Preferred maximum current of the circuit	Expected maximum fault current	Voltage	Rating of suitable over current protective device
25 A	63 A	1 kA	415 V	63 A
35 A	125 A	5 kA	415 V	125 A
200 A	2500 A	50 kA	415 V	125 A

Table 3: Selection of device for fault loop impedance test.

If RCD’s are used for earth fault protection, they are to be tested with RCD testers according to IEC 61557-6.

The following conditions and steps are to be fulfilled for carrying out test on efficiency of automatic disconnection of supply with OCPD's.

1. Measure the fault loop impedance.
2. The test shall be carried out at the final point of the circuit protected by the device ensuring automatic disconnection of the circuit.

3. Verification of the measured value with the rating and characteristics of the associated protective device. (*e.g. short time or instantaneous tripping setting for circuit-breakers or current rating and type for fuses.*).

4. Automatic disconnection of supply during fault is effective if the conditions in table 4 and sl. no 5 to sl. No 11 are fulfilled.

System	50 V < U_O ≤ 120 V s		120 V < U_O ≤ 230 V s		230 V < U_O ≤ 400 V s		U_O >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
U_O is the nominal a.c. or d.c. line to earth voltage.								
Note: Disconnection may be required for reasons other than protection against electric shock.								

Table 4: Maximum disconnection times for earth fault.

5. Maximum disconnection times as per this table 4 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.

6. In TT systems where 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.

7. The maximum disconnection time stated in Table 4 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.

8. In TN systems, a disconnection time not exceeding 5 s is permitted for distribution circuits, and for circuits not covered by sl. no 7, subject to the condition of sl. no.5.

9. In TT systems, a disconnection time not exceeding 1 s is permitted for distribution circuits and for circuits not covered by sl. no 7, subject to the condition of sl. no.5.

10. 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, refer the respective standard for other measures (*e.g. source voltage reduction during fault*).

11. Disconnection may be required for reasons other than protection against electric shock.

9.4 Influence of source impedance in fault loop impedance and requirement of the Regulation.

Impedance of the source is a primary subject influencing the fault loop impedance. The fault loop impedance of a circuit varies with source. This poses a risk of non-disconnection of supply when connected to different sources (e.g. Transformer, DG & UPS). The CEA regulation require the following,

- Fault loop impedance at origin of installation shall be tested for supplies up to 650 V. This test ensures that the protective device at origin of installation is rated based on fault loop impedance.
- Fault loop impedance of each circuit must be tested by the user. For existing installations, the protective device must be sized (if required derated) in order to pass the test. For new projects, it is recommended to calculate the fault loop impedance of every circuit and select protective device based on the fault loop impedance.
- Fault loop impedance test is mandatory for all sources.

NATIONAL FEDERATION OF ENGINEERS FOR ELECTRICAL SAFETY

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Registration no: SRG/Chennai Central/343/2022 under Tamil Nadu Societies Registration Act

Who we are: We are a group of passionate engineering professional working in the field of electrical safety. Our members have decades of experience as electrical inspectorates, electrical designers, safety officers, and engineers in the field of quality and standards.

VISION: To make every electrical installation free of accidents such as electrocution and fire due to short circuits and increasing the reliability of the electrical installation, thus contributing to the saving of life and property and supporting sustainable development.

MISSION: We shall strive to achieve our vision through getting accredited for product and personnel certification which shall focus on electrical safety by design, manufacturing, installation and maintenance of electrical product & installation by competent and qualified manpower using quality resources including product, processes and procedures.

OBJECTIVE: Make every consumer/prosumer property free from electrical accidents and avoid failures in electrical installation and connected equipment.

MEMBERS: Anyone (professionals working in private or governmental organisations, teachers, students) interested in electrical safety can become member of NFE and participate in various activities of NFE.

- Seminars and webinars for professionals on electrical safety based on national regulations and national / international standards.
- Voluntary certification scheme ESPCS based on ISO 17024 for electrical safety professionals.
- Fault Loop Impedance test engineer (FLIT Engineer) training and certification.
- Mass awareness programs on schools and engineering colleges.

TRAINING AND CERTIFICATION PROGRAMS

ELECTRICAL SAFETY PROFESSIONAL CERTIFICATION SCHEME (ESPCS)

ESPCS is based on ISO 17024, aims to create skilled and knowledgeable Electrical Safety Professionals who are competent in the safety requirements of IEC 60364 / IS732. Electrical Safety Regulations of most developed nations follow the structure of IEC 60364. Certified competence as per NEC's ESPCS becomes an easy way to enhance your knowledge and secure your career in India, but secure international employment as well.

- NFE certified Electrical Consultant
- NFE certified Electrical Installer
- NFE certified Electrical Safety Verifier

NFE CERTIFIED

FAULT LOOP IMPEDANCE TESTING (FLIT) PROFESSIONAL

FLIT is a part of Verification to ensure efficiency of automatic disconnection of supply, thereby ensuring some amount of safety against electric shock and thermal effects (fire) in Low Voltage Electrical Installations.

FLIT is included in the CEA safety Regulation 2023 as a mandatory test in every electrical installation. Modern electrical safety standards (Including NEC 2023, IS17900- Lifts, IS732, IS3043 etc) demand verifying the efficiency of automatic disconnection during commissioning and periodically.

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https://www.nfees.org/become-a-member.html

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4	Corporate	Corporate companies	Rs.10000/-	Rs.5000/-
5	MSME	MSME's	Rs.5000/-	Rs.2500/-

NATIONAL FEDERATION OF ENGINEERS
FOR ELECTRICAL SAFETY

Guide on

Understanding Regulation 43

Central Electricity Authority
(Measures Relating to Safety and Electric Supply) Regulations, 2023

Connection with Earth

National Federation of Engineers for Electrical Safety
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