# Protection against Lightning and Electric Fire Safety Standard Handbook


## APP/National Disaster Risk Reduction Centre (NDRC)
## March 2022

# 1 PROTECTION AGAINST LIGHTNING

## 1.1 Basics

Lightning is the most dramatic and most common natural activity that occurs in our atmosphere. Lightning is a natural atmospheric phenomenon, which is caused by the instability of charge distribution within a cloud or between any two regions of the atmosphere. A lightning flash originates inside a cloud, several kilometres above the ground level. Except for ball lightning, which is a very rare phenomenon, lightning is a complicated spark that electrically bridges a cloud and ground, between two clouds or between two parts of a cloud cell. Basically, lightning activities are divided into two categories, namely 1) Cloud to ground flashes (that bridge the clouds and the ground) 2) Cloud flashes (that bridge two regions of clouds). The cloud to ground flashes cause destruction and pose much threat on the humans, animals and structures on the ground. Thunderstorm activity in a region depends on its geographic location and elevation of the place. In tropics and oceanic regions thunderstorm activities are higher than that in temperate regions and sub-tropical regions. Hilly regions and elevated objects on the ground usually record higher cloud to ground flash density as compared to the plain region at a given geographical location. It is therefore, the threat on life and structure over the hilly regions is very high.

Lightning strikes cause tremendous losses each year and pose threat to property. It can cause severe damages to physical structures and can claim lives. Transmission towers, communication towers, transmission lines and other tall physical structures are more vulnerable to the lightning activities. Lightning ignites fires that may bring an entire building or a house down to ashes. At a lower degree of damage, the lightning current may destroy electrical, electronic and communication equipment beyond repair. With the advent of the technology and the increasing dependency of human beings on the electronic gadgets has further aggravated the threat from lightning. The increasing susceptibility of electrical and electronic equipment to electromagnetic impulses, the wide spread usage of electrical and electronic appliances, the modification of the atmosphere due to high rise buildings and anthropogenic activities have further increased the threat of lightning.

Nepal being a hilly country due to lightning on humans and property is high. Although, the human race has made tremendous progress in the field of technology, it is not yet capable of averting the natural phenomena. It is therefore, we cannot avert the lightning phenomena but can adopt necessary scientific measures to protect ourselves from its deleterious effects. Lightning flashes to, or nearby, structures (or lines connected to the structures) are hazardous to people, to the structures themselves, their contents and installations as well as to lines. This is why lightning protection measures are essential.

***'It should be noted that 'there are no devices or methods capable of modifying the natural weather phenomena to the extent that they can prevent lightning discharges and hence the thunderstorm activities cannot be averted. The only thing we can do is to take preventive measures against lightning hazards'***.

## 1.2 General Concepts

In order to protect a building and its occupants from possible lightning related damage a comprehensive structural protection system is required. With foremost importance, it should be understood that the purpose of a lightning protection system designed for a structure is to intercept a lightning stepped leader approaching the building and pass the lightning current safely into ground without creating any dangerous potential rise. **Under no circumstance, the lightning protection system should be considered as a device which prevents or repels lightning.**

A typical structural protection system consists of two, an external and an internal, lightning protection systems.

**An external LPS** is intended to:

- intercept a direct lightning flash to the structure (with an air-termination system)
- conduct the lightning current safely towards earth (using a down-conductor system)
- disperse the lightning current into the earth (using an earth-termination system)

**An internal LPS** prevents dangerous sparking within the structure using either equipotential bonding or a separation distance (and hence electrical insulation) between the external LPS components and other electrically conducting elements internal to the structure.

## Sources of damage, types of damage and types of loss

The actual sources of damage are lightning strikes that are subdivided into four groups depending on the point of strike

S1: Direct lightning strike to a structure;
S2: Lightning strike near a structure;
S3: Direct lightning strike to an incoming line;
S4: Lightning strike near an incoming line.

These sources of damage may result in different types of damage which cause the loss. The standard specifies three types of damage

D1: Injury to living beings by electric shock as a result of touch and step voltage;
D2: Fire, explosion, mechanical and chemical reactions as a result of the physical effects of the lightning discharge;
D3: Failure of electrical and electronic systems as a result of surges.

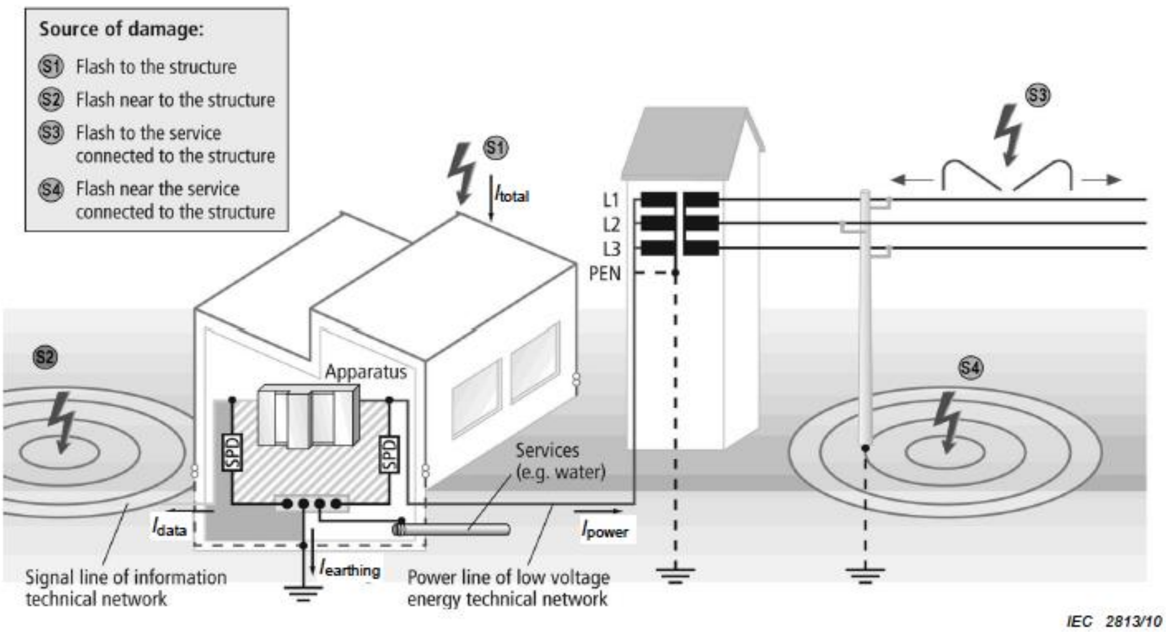



**Figure 1.1: Basic example of Different source of damage to a structure and Lightning Current Distribution within a system**

The Lightning Protection System (LPS) should therefore, be designed and installed to serve the purpose of addressing the above mentioned sources of damage and types of losses.
Although, the general principles of LPS are clear and were elucidated by Benjamin Franklin over 260 years ago (in 1753) the detailed design of the LPS including the geometry of lightning rods (e.g. length and diameter etc) and the necessary number and locations of the has been argued since the time of Franklin. There have been rigorous research and experiments since 1753, and some standards have been developed. A committee comprising of lightning experts, scientists, and engineers has developed an international standard on lightning protection and is termed as International Electrotechnical Commission (IEC). The latest modified version of standard is IEC-62305 and has five parts and each part deals with various aspects of LPS as is mentioned below:

1. IEC 62305-1 (2010): Protection against lightning - General principles
2. IEC 62305-2 (2010): Protection against lightning - Risk management

3. IEC 62305-3 (2010): Protection against lightning - Physical damage and life hazard
4. IEC 62305-4 (2010): Protection against lightning - Electrical and electronics systems
5. IEC 62305-5 (2010): Protection against lightning - supply lines

The present standard has been developed based on the IEC standard but modified in the context of Nepal.

## 1.3 Scopes of Protection

The decision of whether a building should be protected or not (requirement of protection) should be taken after a proper risk analysis (IEC 62305-2). Once the risk factor is calculated and if the building requires protection, then the level of protection should be decided. There are 4 levels of protection defined in IEC standards 62305-3. They are classified as level I, II, III and IV. Depending on the level of protection needed for a given structure levels of LPS (I, II, III and IV) should be installed.

Each class of LPS is characterized by the following.

a. Data dependent upon the class of LPS
   1. lightning parameters
   2. rolling sphere radius, mesh size and protection angle
   3. typical distances between down-conductors and between ring conductors
   4. separation distance against dangerous sparking
   5. minimum length of earth electrodes

b. Data not dependent upon the class of LPS
   1. lightning equipotential bonding
   2. minimum thickness of metal sheets or metal pipes in air-termination systems
   3. LPS materials and conditions of use
   4. Material, configuration and minimum dimensions for air-terminations, down-conductors and earth-terminations
   5. minimum dimensions of connecting conductors

## 1.4 Risk Assessment

The need for protection, the economic benefits of installing protection measures and the selection of adequate protection measures should be determined in terms of risk assessment. Before proceeding with the detailed design of a lightning protecting system, the following essential steps should be taken:

**a)** Decide whether or not the structure needs protection and, if so, what are the special requirements (*IEC 62305 – 2)*

**b)** Modern buildings with electronic equipment need protection from radiated surges of Lightning. To achieve this structural steel of the building should form a part of lightning protection system (*IEC 62305 – 3)*. Ensure a close liaison between the architect, the builder, the lightning protective system engineer, and the appropriate authorities throughout the design stages.

**c)** Include Lightning Protection measures in the structural drawing including foundation.

**d)** Follow the procedures for testing and future maintenance *(IEC 62305 – 3)*

To reduce the loss due to lightning, protection measures may be required. Whether they are needed, and to what extent, should be determined by risk assessment (*IEC 62305-2)*. The protection measures should ensure that the calculated risk is less than the tolerable risk explained in IEC 62305-2. Tolerable risk is maximum value of the risk which can be tolerated for the structure to be protected.

**Table 1.1: Typical values of tolerable risk ($R_T$)**

| Type of loss | Tolerable risk |
|---|---|
| Loss of human life or permanent injuries | $10^{-5}$ (One injury out of 100,000 Strikes) |
| Loss of service to the public | $10^{-3}$ (One service loss out of 1000 Strikes) |
| Loss of cultural heritage | $10^{-4}$ (One damage out of 10,000 Strikes) |
| Economic Loss | $10^{-3}$ (One failure out of 1,000 Strikes) |

## 1.5 Risk Analysis and Lightning Protection Level (LPL)

Risk is analysed considering the following factors and protection is divided in to four protection levels (LPL 1 to 4)

- Source of Damage such as flashes to a structure, flashes near a structure, flashes to a line, flashes near a line.
- Type of damage - injury to living beings by electric shock, physical damage, failure of electrical and electronic systems

Type of Loss - loss of human life (including permanent injury), loss of service to the public, loss of cultural heritage, loss of economic value (structure, content, etc.).

### a) Risk

Risk **(R)** is the value of a probable average annual loss**.** For each type of loss which may appear in a structure or in a service, the relevant risk shall be evaluated. The risks to be evaluated are as follows for each source & type of damage

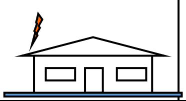
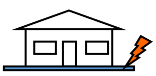
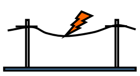
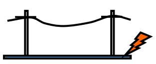
*R*1: risk of loss of human life;
*R*2: risk of loss of service to the public;
*R*3: risk of loss of cultural heritage;
*R*4: risk of loss of economic value.

Each risk component $R_X = N_X \times P_X \times L_X$

Where $N_X$ is the number of dangerous events per annum
$P_X$ is the probability of damage to a structure
$L_X$ is the consequent loss

Total risk R is the sum of various risk components. If $R \leq R_T$, lightning protection is not necessary.
Where, $R_T$ – Tolerable Risk.
Besides the need of lightning protection for a structure or for a service, it may be useful to ascertain the economic benefits of installing protection measures in order to reduce the economic loss L4. The assessment of components of risk $R_4$ for a structure allows the user to evaluate the cost of the economic loss with and without the adopted protection measures

**Table 1.2: Sources and types of Damage and Types of loss**

| | | **Structure** | | **Service** (Metal lines such as power, telephone etc.) | |
|---|---|---|---|---|---|
| **Point of strike** | **Source of damage** | **Type of damage** | **Type of loss** | **Type of damage** | **Type of loss** |
|  | S1 | D1<br>D2<br>D3 | L1, L4 2)<br>L1,L2, L3, L4<br>L1*, L2, L4 | D2<br>D3 | L`2, L`4<br>L`2, L`4 |
|  | S2 | D3 | L1 1) , L2 , L4 | | |
|  | S3 | D1<br>D2<br>D3 | L1, L4 2)<br>L1, L2, L3, L4<br>L1 1), L2, L4 | D2<br>D3 | L`2, L`4<br>L`2, L`4 |
|  | S4 | D3 | L1 1), L2, L4 | D3 | L`2, L`4 |

1) Only for structures with risk of explosion, and for hospitals or other structures where failures of internal systems immediately endangers human life.
2) Only for properties where animals may be lost.

## 1.6 Design of the LPS

A technically and economically optimized design of an LPS is possible especially if the steps in the design and construction of the LPS are coordinated with the steps in the design and construction of the structure to be protected. In particular, the design of the structure itself should utilize the metal parts of the structure as parts of the LPS.

The design of the class and location of the LPS for existing structures shall take into account the constraints of the existing situation.

The design documentation of an LPS shall contain all the information necessary to ensure correct and complete installation.

## 1.7 Lightning Protection Level (LPL)

Based on the risk assessment if protection is necessary, Lightning protection is divided into four levels (LPL 1 to 4) that help in designing and implementing protection measures for an economical implementation. LPL 1 provides the maximum protection and expensive whereas LPL 4 provides the least protection and less expensive.

**Table 1. 3: Lightning Protection Level corresponding to typical buildings:**

| Application | LPL* |
|---|---|
| Computer Data Centres, Military Applications, Nuclear Power Stations, high rise hospitals, communication services such as telecom, television, radio, etc, airports, refineries, gas storage etc | I |
| Hotels, low rise hospitals EX-Zones in the industry and chemical sector, gas stations, fuel retail outlets and similar structures | II |
| Schools, Banks, low rise Hotels, Temple, Churches, Mosques Residential Buildings, libraries and similar structures | III |
| Animal sheds, farm houses, ware houses etc | IV |

*LPL – Lightning Protection Level

*Note: Protection measures are separate for External (to the structure) & Internal (electrical/electronic equipment). Both protection measures should complement each other*.

## 1.8 Application of an external LPS

The external LPS is intended to intercept direct lightning flashes to the structure, including flashes to the side of the structure, and conduct the lightning current from the point of strike to ground. The external LPS is also intended to disperse this current into the earth without causing thermal or mechanical damage, nor dangerous sparking which may trigger fire or explosions. In most cases, the external LPS may be attached to the structure to be protected.

An isolated external LPS should be considered when the thermal and explosive effects at the point of strike, or on the conductors carrying the lightning current, may cause damage to the structure or to the contents. Typical examples include structures with combustible covering, structures with combustible walls and areas at risk of explosion and fire.

The use of an isolated LPS may be convenient

a. where it is predicted that changes in the structure, its contents or its use will require modifications to the LPS.
b. when the susceptibility of the contents warrants the reduction of the radiated electromagnetic field associated with the lightning current pulse in the down-conductor.

### 1.8.1 Components of External Lightning Protection System

The external lightning protection system comprises of an a) **air termination** b) **down conductor and** c) **earth termination.** The function of

- Air termination system is to intercept a direct lightning flash to the structure.
- The down conductor is to conduct the lightning current safely towards earth
- Earth termination system is to disperse the lightning current into the earth.

### 1.8.2 Positioning of air-terminals

Air-termination components installed on a structure shall be located at corners, exposed points and edges (especially on the upper level of any facades) in accordance with one or more of the following methods.

1. the protection angle method;
2. the rolling sphere method;
3. the mesh method.

- The protection angle method is suitable for simple-shaped buildings but it is subject to limitations of the height of the structure. This method is valid upto the height equal to the rolling sphere radius for the respective protection level as is governed by the graph in figure 5.
- **The rolling sphere method is suitable in all cases**.
- The mesh method is a suitable form of protection where plane surfaces are to be protected. While adopting the mesh method the following conditions should be met.

***Note: Research on lightning inflicted damages has shown that the edges and corners of a roof are most susceptible to damage. Therefore, Air termination conductors must be positioned on the roof edges, roof overhangs and on the ridges of the roof. On the structures with flat roofs perimeter conductors should be installed as close to the outer edges of the roof as practicable. And No metal installation should protrude above the air termination system.***

Figures 1.2, 1.3 and 1.4 give an idea of the application of the protective angle, rolling sphere and mesh methods

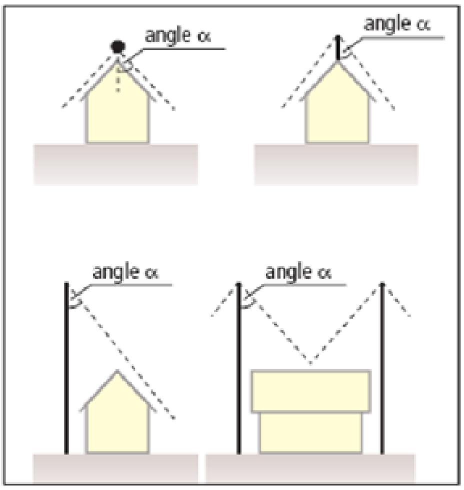



**Figure-1.2:** The application of the protective angle method for both attached and isolated protection systems

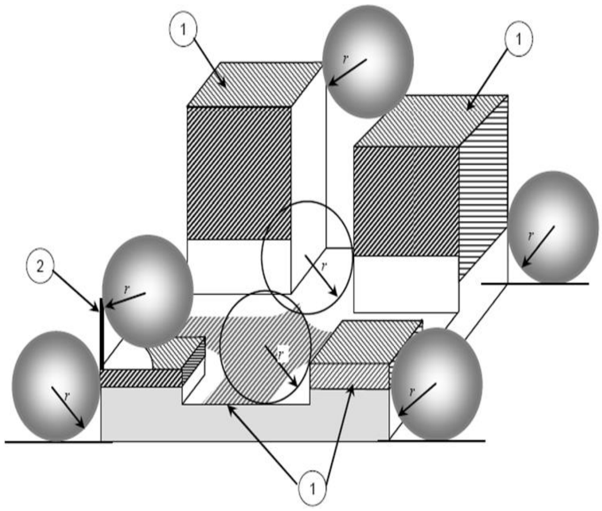



**Figure-1.3:** The application of the rolling sphere method to a building. Shaded areas (marked 1) are exposed to lightning strikes and need protection. Marked as 2 are the metallic masts installed for protection

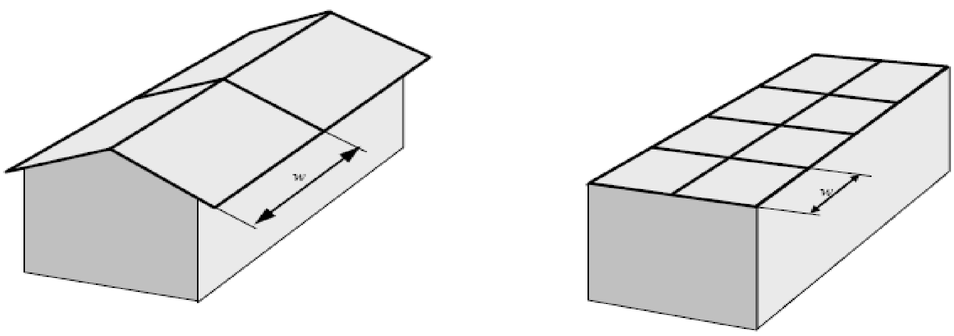



**Figure-1.4:** The application of the mesh method to both slanted roof and flat roof.

**Table 1.4: Maximum values of radius of the sphere, mesh size and protection angle corresponding to the class of LPS**

| Class of LPS | Rolling sphere radius in meters | Mesh size in meters | Protection angle w.r.t height (in meters) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 10 m | 20 m | 30 m | 45 m | 60 m |
| I | 20 | 5 x 5 | 45 | 23 | Cannot be used | | |
| II | 30 | 10 x 10 | 54 | 38 | 23 | Cannot be used | |
| III | 45 | 15 x 15 | 62 | 48 | 36 | 23 | Cannot be used |
| IV | 60 | 20 x 20 | 65 | 54 | 45 | 34 | 23 |

A graph in figure-1.5 shows more detailed method of obtaining the protective angle method. Note that the method cannot be applied for buildings above certain heights depending on the level of protection, whereas, below 2 m of height the angle remains constant but varies from level to level. Fig 1.6 shows a typical example of installing air terminal based on protective angle method.

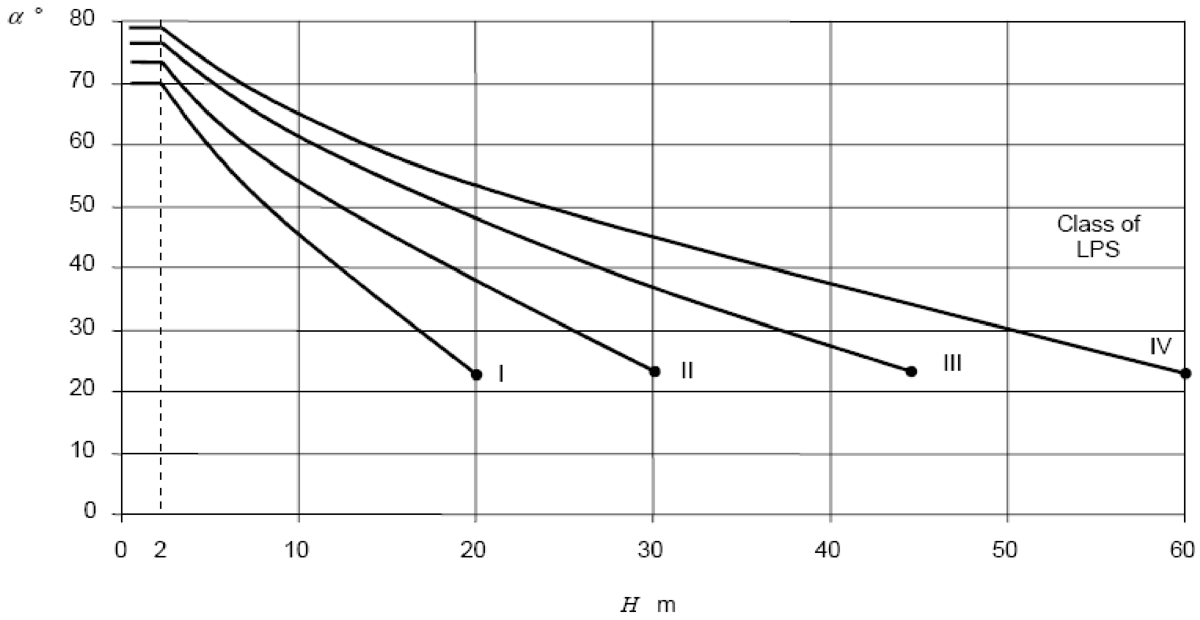



**Figure 1.5: Detailed graph for obtaining the value of protective angle.**

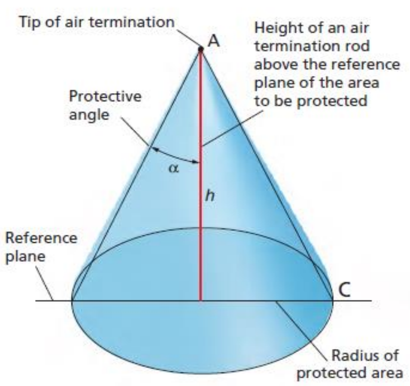



Figure 1.6 a: The protective angle technique for a single air terminal

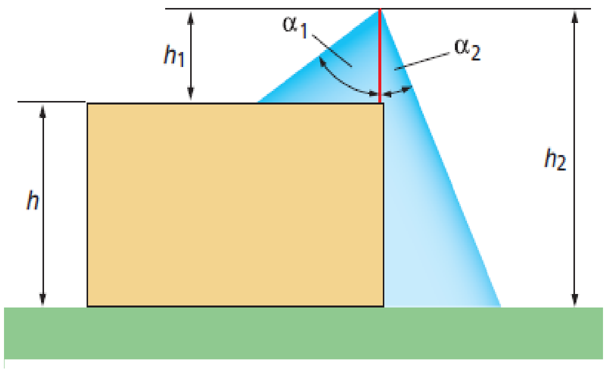



Figure 1.6 b: Effect of height of the air terminal from the reference plane on the protective angl**e.**

**Figure 10.6: Illustrations of positioning the air terminal system based on protective angle method.**

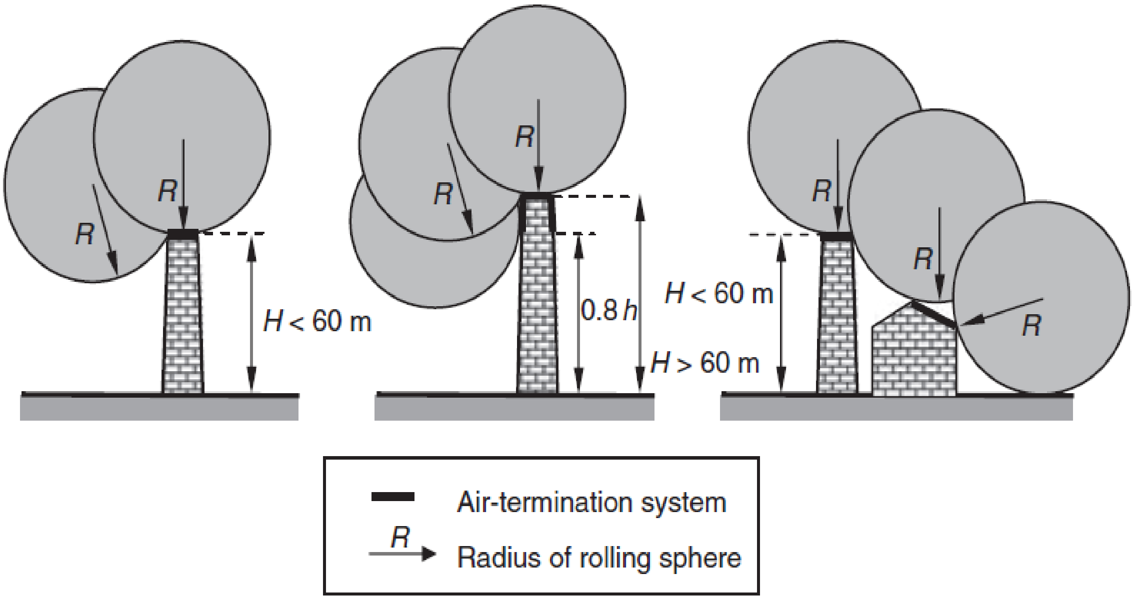



**Figure 1.7: Design of a lightning protection system air termination according to the rolling sphere method. The rolling sphere radius R complies with the selected lightning protection level**

**Note:**

**a)** Roof mounted electrical/electronic equipment (e.g. chillers, antennas, cameras, bill boards, aviation lamps etc.) need vertical air termination to avoid direct flashover. All parts of lightning protection should maintain safety distance from those electrical / electronic equipment or appliances. Power and data connection to these appliances should have proper SPD's to avoid failures. Overhead cables such as cable TV lines from one building to the other should be avoided.

**b)** Unearthed metallic roofs should be avoided. Metallic roofs shall be connected either to steel reinforcement or to other earthed steel parts of the building satisfying the requirements of number of down conductors. Small buildings with metallic roofs less than 1000 SQFT must be earthed at least not less than 2 places.

**c)** **Air terminals like Early Streamer Emission (ESE), Dissipation Array System(DAS), Control Streamer Emitter (CSE) that do not have scientific basis and are not confirming to well accepted Lightning Protection Standards adhering with International Electrotechnical Commission (IEC) shall not be used and should strictly be discouraged**.

### 1.8.3 Calculating Distance between air terminals according to rolling sphere method

Protection zone of a lightning protection system may be defined as the volume of space inside which an air termination provides protection against a direct lightning strike by attracting the strike to itself. The commonly used engineering tool for determining zone of protection of lightning protection system is the 'Electrogeometric Model'. This method recognizes that the attractive effect of the air terminal device is a function of a striking distance which is determined by the amplitude of lightning current. The striking distance is the length of the final jump of the stepped leader as its potential exceeds the breakdown resistance of the last gap of air to ground. The EGM model assumes that point on a structure equidistant from the striking distance are likely to receive a lightning strike, whereas points further away are less likely to be struck.
A sphere of radius equal to the striking distant is usually employed to visualize the likely stroke termination point, the so-called Rolling Sphere Method (RSM). Application of RSM involves rolling an imaginary sphere of a prescribed radius over the air termination network. The sphere rolls up and over (and is supported by) air terminal, shield wires, and other grounded metal objects intended for direct lightning protection. A piece of equipment is protected from a direct stroke if it remains below a curved surface of the sphere by virtue of the

sphere's being elevated by air terminals or other devices. The effectiveness of the Rolling Sphere Method has been verified from theoretical and empirical basis and found to be useful for engineering application.
The concept of striking distance is essential in the design of lightning protection system for earthed structures. According to the basic idea of EGM, a downward leader stroke is considered to propagate randomly and uncontrollably at the beginning. As a charge of a cloud is lowered along the downward leader, electric field on the surface of a grounded object increases. Finally, at a striking distance, the critical electric field for breakdown of air at the surface of the grounded object is reached, and an upward streamer starts from the object to meet the leader stroke. Since the electric field at the tip of a structure is mainly influenced by the downward leader propagation and charge distribution in the leader channel, and the charge is related to the return-stroke current, it was believed that the striking distance is a function of the lightning current.

The distance of the last step of a downward leader is termed **the striking distance** and is determined by the amplitude of the lightning current. This striking distance can be represented by a sphere with a radius equal to the striking distance. The striking distance *r* is given by:

$$r = 10\, I^{0.65}$$

Where ***I*** is the peak current of the resulting stroke.

**Notes:**

i. *The larger the amount of charge carried by the lightning leader, the larger the resulting lightning current, the greater will be the distance at which this happens.*
ii. *The head of the downward leader approaches the objects on the ground, unaffected by anything, until it reaches the final striking distance.*
iii. *It is more difficult for an air-terminal to intercept a smaller lightning flash than a larger flash, as the smaller flash must approach closer to the air-terminal before the upward leader is launched.*
iv. *To protect the structure against smaller lightning flashes, air-terminals must be spaced closer together. For smaller lightning flashes there is a risk that an air terminal may not be close enough to intercept the down leader, thus a closer structural point releases an upward leader which intercepts the flash (i.e. the building is struck).*

When rods are to be used as the air-termination for the protection of plane surfaces the following formula can be used:

$$d = 2\sqrt{2rh - h^2}$$

Where:

***d*** = distance between two rods (m)
***r*** = radius of the rolling sphere (m)
**h** = height of the rods (m)

The following **table 10.5** shows some examples of rolling sphere protection distance (distance between Air terminals) according to the Air terminals height and the Rolling Sphere Radius according to lightning protection level LPL.

Table 10.5 Estimating the distance between air terminals according to the rolling sphere method.

| Height of the rod (m) | Distance Between air-terminations (m) | | | |
|---|---|---|---|---|
| | LPL-I (r=20 m) | LPL-II (r=30 m) | LPL-III (r=45 m) | LPL-IV (r=60 m) |
| 0.5 | 8.8 | 10.9 | 13.3 | 15.4 |
| 1 | 12.4 | 15.3 | 18.8 | 21.8 |
| 1.5 | 15.2 | 18.7 | 23.0 | 26.6 |
| 2 | 17.4 | 21.5 | 26.5 | 30.7 |

| | | | | |
|---|---|---|---|---|
| 2.5 | 19.4 | 23.9 | 29.6 | 34.3 |
| 3 | 21.0 | 26.1 | 32.3 | 37.4 |

### 1.8.4 Special cases

**a) Structures 60 meter in height or more**

On structures taller than 60 m, flashes to the side may occur, especially to points, corners and edges of surfaces. In general, the risk due to these flashes is low, but electrical and electronic equipment on walls outside structures may be destroyed even by lightning flashes with low current peak values.

An air-termination system shall be installed to protect the upper part of tall structures (i.e. typically the top most 20% of the height of the structure as far as this part exceeds 60 m in height) and the equipment installed on it. The rules for positioning the air-termination systems on these upper parts of a structure shall meet at least the requirements for LPL IV with emphasis on the location of air-termination devices on corners, edges, and significant protrusions (such as balconies, viewing platforms, etc.).

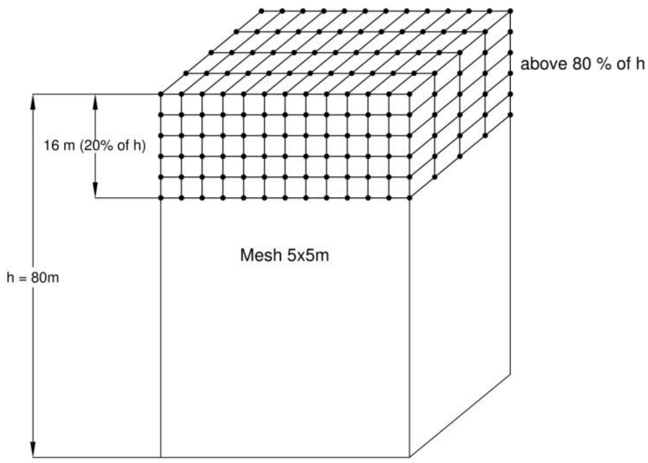



**Figure 1.8: Air termination to avoid side flash for a building with more than 60-meter height**

***Note:*** *Required only if electronic components are installed. LPL 1 to 4 can be considered depending upon the Risk involved*

**b) Buildings with roof top Solar PV and Water Heaters**

Vertical air terminals are required for protecting roof mounted installations such as solar PV, water heaters, chillers as well as water tanks. Protection angle to be considered is 45 degrees. Vertical air terminals need to be connected to the air termination mesh / down conductors. Metal support structure of these installations must be bonded to the air termination mesh / down conductors. Class 1 or class 2 Surge Protective Devices (SPDs) should be installed in the electrical lines to protect the installations inside the building typically DC SPD for SOLAR PV output (at inverter or junction box level) and AC SPD for inverter output and mains input.

**c) Large Solar PV Power Plants**

Vertical air terminals for PV modules based on LPL IV connected directly to the frame shall protect against direct lightning impact (e.g. 1-meter rod at 0.5-meter height from the panel at four corners provides protection to approximately 12 x 9 M area). Maximum height of the air termination rod above the panel must be restricted to less than 0.5 meters considering the influence of shadow of air terminal in current generation. To reduce step potential, structures must be interconnected with underground earth mats.

**d) Buildings with Rooftop Telecom Towers**

The metallic tower itself will act as air termination. Antennas mounted in these towers (If antenna mounted below the top of tower by more than one metre, then no air terminal is required on top of tower) need individual air terminals connected to the main structure. The main structure must be connected to the air-termination conductors for the balance of the building if available. Two separate down conductors with a size of minimum 150 $mm^2$ are to be used in addition to regular down conductors to make the bonding between tower and ring earthing.
Every power, coaxial, data and other metallic lines connected between the telecom installation and the other parts of the building must be protected with SPD's.

## 1.9 Down Conductor System

In order to reduce the probability of damage due to lightning current flowing in the LPS, the down-conductors shall be arranged in such a way that from the point of strike to earth:
a) several parallel current paths exist;
b) the length of the current paths is kept to a minimum;
c) equipotential bonding to conducting parts of the structure is performed

Typical values of the distance between down-conductors are in table 10.6. These values can be used for horizontal ring conductors installed for a tall building more than 60-meter height. The minimum number of down-conductors shall be 2 for building with an area less than 100 $m^2$.

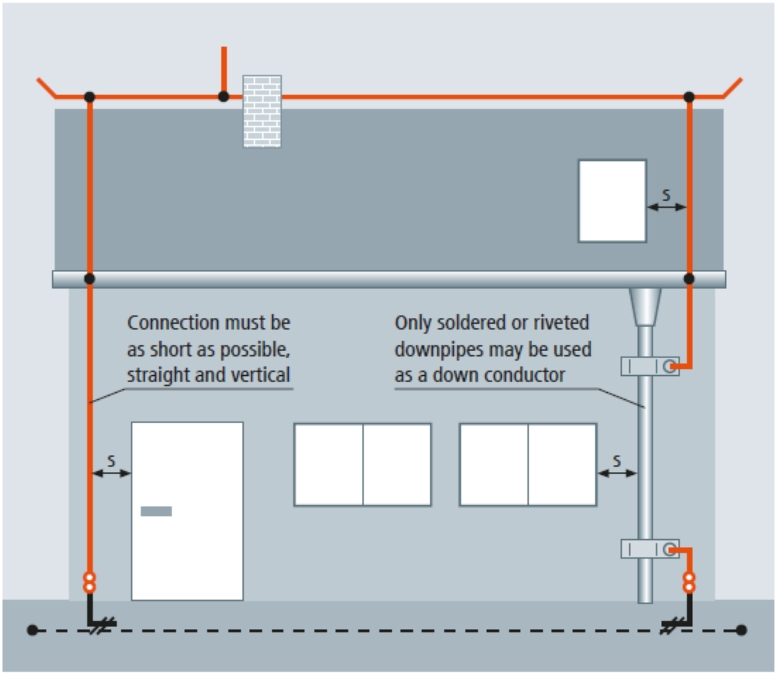



Figure 10.9: Down conductor system

**Table 1.6: Minimum distance between down conductors corresponding to the LPL**

| Level (class) of LPS | Distance between down conductors in meters |
|---|---|
| I | 10 |

| | |
|---|---|
| II | 10 |
| III | 15 |
| IV | 20 |

Down-conductors shall be installed so that, as far as practicable, they form a direct continuation of the air-termination conductors. It shall be installed straight and vertical such that they provide the shortest and most direct path to earth. The formation of sharp bends and loops shall be avoided. Every down conductor should be connected to a type B ring/foundation earthing. Connection of down conductor to a type. An earthing is allowed only in case of space constraints or existing buildings where installations are difficult.

While routing the down conductors, safety distance need to be calculated based on [IEC 62305-3] and maintained from live parts / services.

The installation of as many down-conductors as possible, at equal spacing around the perimeter interconnected by ring conductors, reduces the probability of dangerous sparking and facilitates the protection of internal installations (IEC 62305-3). This condition is fulfilled in metal framework structures and in reinforced concrete structures in which the interconnected steel is electrically continuous.

Routing of down conductors (insulated or un-insulated) through electrical and other service shafts are not allowed as it can create fire and explosion during lightning.

Single run of down conductor using high voltage insulated cable from air terminal to earthing are not confirming to (IEC 62305-3). Insulated down conductors can only avoid safety distance to live parts of the building. In such case safety distance should be calculated based on (IEC 62305-3) and recorded to ensure safety.

The down conductor shall be supported on structure like column at every 1 meter using suitable clamps or connectors or exothermic welding. The clamps or connectors or exothermic welding shall be tested for the lightning current as per selected LPL.

Special cables tested for lightning current and with high voltage insulation can be used wherever necessary to avoid flashovers in case separation distance is not possible to be maintained.

At the structures, which cannot be punctured for holding the down conductors, like tin roofs, Glass structures etc., the down conductors should be supported with adhesive type clamps tested for weather durability and for withstanding lightning currents as per selected LPL.

## 1.10 Earth Termination System

When dealing with the dispersion of the lightning current (high frequency behaviour) into the ground, whilst minimizing any potentially dangerous over voltages, the shape and dimensions of the earth-termination system are the important criteria. In general, a low earthing resistance (if possible lower than 10 Ohms when measured at low frequency) is recommended. From the viewpoint of lightning protection, a single integrated structure earth-termination system is preferable and is suitable for all purposes (i.e. lightning protection, power systems and telecommunication systems).
Earth termination systemcan vaguely be divided into two types namely type A and type B system.
**Type A earth termination** comprising of vertical / horizontal conductor or **Type B earth termination** comprising of Ring Earthing / Foundation earthing shall be used satisfying the requirements of this code as well as IS IEC 62305 3 & 4.

*I)* *Type A Earthing* Length of the earth electrode depends on the soil resistivity and LPL. For Type A minimum number of earth electrodes should be 2 (see table 10.7 for details).

**Table 10.7: Minimum Length of vertical earth electrode**

| Class of LPS | Typical Length of each vertical earth electrode based on Soil resistivity | | | |
|---|---|---|---|---|
| | Up to 500 Ω M | 1000 Ω M | 2000 Ω M | 3000 Ω M |
| 1 | 2.5 meter | 10 meters | 25 meters | 40 meter |
| 2 | 2.5 meter | 5 meter | 15 meters | 22 meter |
| 3 | 2.5 meter | 2.5 meter | 2.5 meter | 2.5 meter |
| 4 | 2.5 meter | 2.5 meter | 2.5 meter | 2.5 meter |

*II)* **Type B earthing**: This type of arrangement comprises either a ring conductor external to the structure to be protected, in contact with the soil for at least 80% of its total length, or a foundation earth electrode. Such earth electrodes may also be meshed. For the ring earth electrode (or foundation earth electrode), the area enclosed by the ring earth electrode (or foundation earth electrode) shall be not less than the value of type A earthing as given in above table.

In structures where only electrical systems are provided, the type A earthing arrangement may be used, but a type B earthing arrangement is preferable. In structures with electronic systems, the type B earthing arrangement is recommended.

In Industrial and commercial structures, the ring earth electrode around the structure or the ring earth electrode in the concrete at the perimeter of the foundation, should be integrated with a meshed network under and around the structure, having a mesh width of typically 5 m. This greatly improves the performance of the earth-termination system. If the basement's reinforced concrete floor forms a well-defined interconnected mesh and is connected to the earth-termination system, typically every 5 m, it is also suitable.

For buildings without steel reinforced foundation (brickwork / Stones) a type B earth-termination (Ring Earthing) shall be installed.

## 1.11 Protection of People outside building

On the structures or regions where large numbers of people frequently assemble or in an area adjacent to the structure to be protected, further potential control for such areas should be provided. More ring earth electrodes should be installed at distances of approximately 3 meter from the first and subsequent ring conductors.

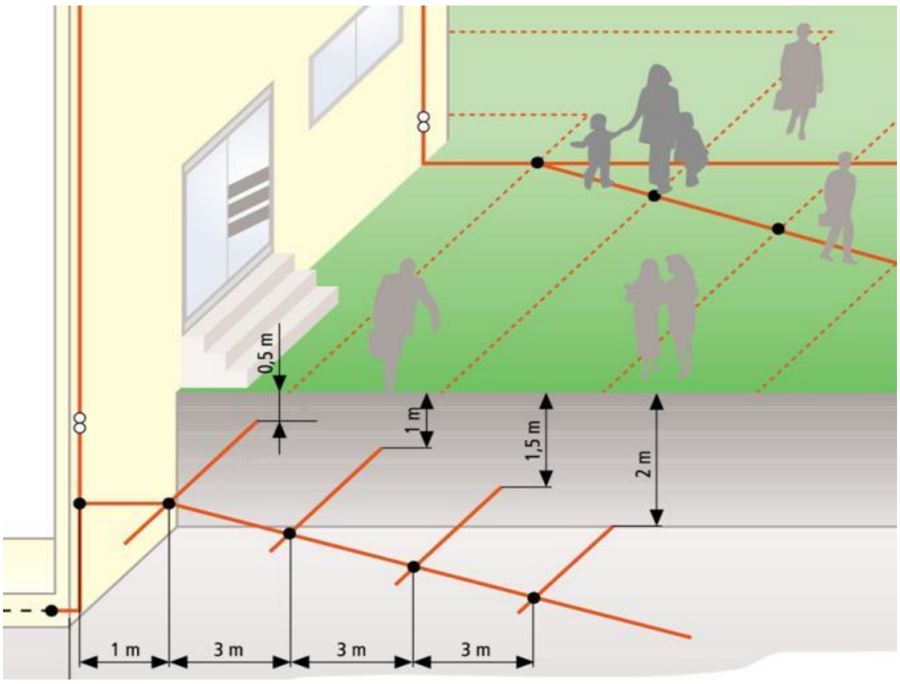


**Figure 1.10: Mesh / Ring Earthing – reduction of step potential**

Ring electrodes farther from the structure should be installed more deeply below the surface i.e. those at 4 meter from the structure at a depth of 1 meter, those at 7 meter from the structure at a depth of 1.5 meter and those at 10 meter from the structure at a depth of 2 meter. These ring earth electrodes should be connected to the first ring conductor by means of radial conductors. The earth grid thus formed will reduce the step potential so that people in this area are safe.

For buildings integrating structural steel as down conductor and earth termination, earth resistivity measurements are not required. Proper drawings should be made based on the actual installation and submitted to authorities if necessary.

## 1.12 Internal Lightning Protection and Protection of Electrical / Electronic Equipment

The internal LPS shall avoid the occurrence of dangerous sparking within the structure to be protected due to lightning current flowing in the external LPS or in other conductive parts of the structure. Dangerous sparking between different parts can be avoided by means of equipotential bonding or electrical insulation between the parts.

Permanent failure of electrical and electronic systems can be caused by the lightning electromagnetic impulse (LEMP) via:

a. conducted and induced surges transmitted to equipment via connecting wiring;
b. the effects of radiated electromagnetic fields directly into equipment itself.

Surges to the structure can originate from sources external to the structure or from within the structure itself

- surges which originate externally from the structure are created by lightning flashes striking incoming lines or the nearby ground, and are transmitted to electrical and electronic systems within the structure via these lines
- surges which originate internally within the structure are created by lightning flashes striking the structure itself or the nearby ground. Surges can also originate internally within the structure from switching effects (e.g. switching of inductive loads).

The coupling can arise from different mechanisms

- resistive coupling (e.g. the earth impedance of the earth-termination system or the cable shield resistance);
- magnetic field coupling (e.g. caused by wiring loops in the electrical and electronic system or by inductance of bonding conductors)

In general, Electrical and electronic systems are subject to damage from a Lightning Electromagnetic impulse (LEMP). Special Protection Measures (SPM) need to be provided to avoid failure of internal systems. The design of SPM should be carried out by experts in lightning and surge protection who possess a broad knowledge of EMC and civil/electrical installation practices.

## 1.13 Lightning Protection Zone Concept

Protection against LEMP is based on the Lightning Protection Zone (LPZ) concept. The zone containing systems to be protected shall be divided into three LPZs. These zones are theoretically assigned part of space (or of an internal system) where the LEMP severity is compatible with the withstanding level of the internal system. Successive zones are characterized by significant changes in the LEMP severity. The boundary of an LPZ is defined by the protection measures employed.

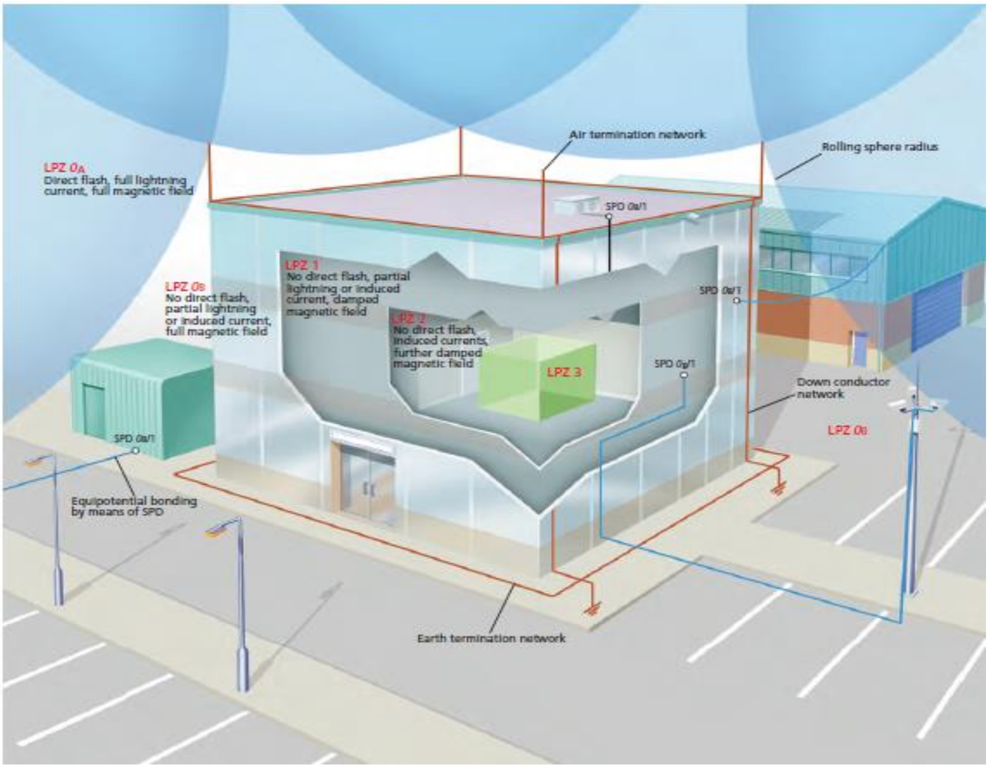
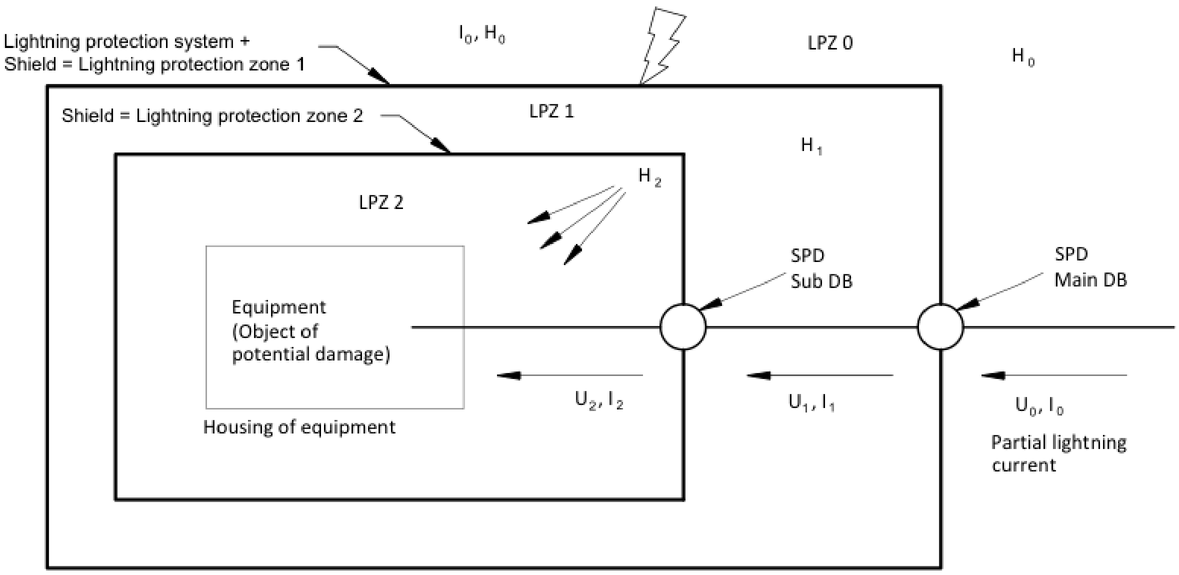



**Figure 1.11: An illustration of the division of Lightning Protection Zones (LPZ), on a building.**




Key
LPZ – Lightning Protection Zone
U – Conducted Surge Voltage,
I – Conducted Surge Current,
H – Radiated Magnetic field

$(U_2 << U_1 << U_0)$ $(I_2 << I_1 << I_0)$ $(H_2 << H_1 << H_0)$

**Figure 1.12: Special Protection Measures with spatial shields and a coordinated SPD system**.

## 1.14 Equipment Protection Principles

For protection against the effects of radiated electromagnetic fields impinging directly onto the equipment, SPM consisting of spatial shields and/or shielded lines, combined with shielded equipment enclosures should be used.

For protection against the effects of conducted and induced surges being transmitted to the Equipment via connection wiring, SPM consisting of a coordinated SPD system should be used. SPD to be used according to their installation position are as follows

a) *At the line entrance into the structure (at the boundary of LPZ 1, for example at the Main Distribution Panel):*
   - SPD tested with $I_{imp}$ (typical waveform 10/350, for example, SPD tested according to class I)
   - SPD tested with $I_n$ (typical waveform 8/20, for example, SPD tested according to class II)

b) *Close to the apparatus to be protected [at the boundary of LPZ 2 and higher, for example, at Secondary Distribution Board (SB), or at a socket outlet (SA)]*:
   - SPD tested with In (typical waveform 8/20 *for example*, SPD tested according to class II)
   - SPD tested with a combination wave (typical waveform 8/20 *for example*, SPD tested according to class II)

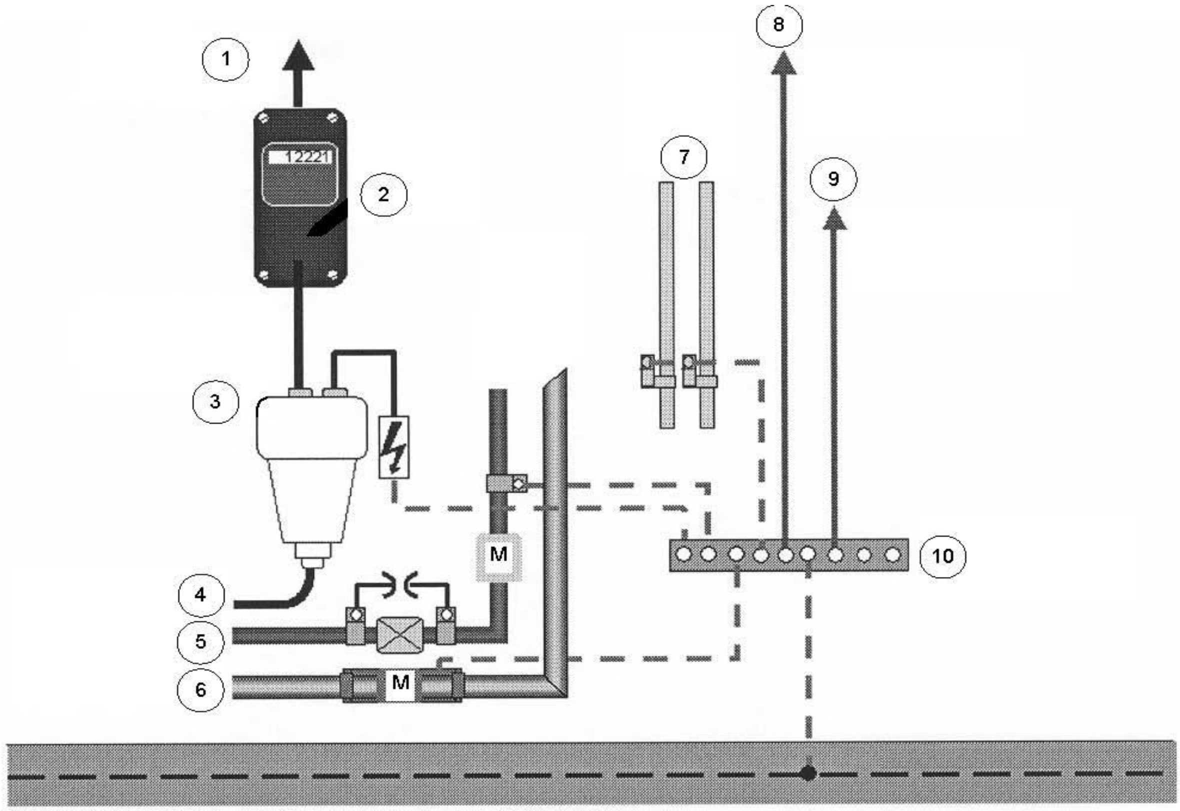
Failures due to electromagnetic fields impinging directly onto the equipment can be considered negligible provided the equipment complies with the relevant radio frequency emission and immunity EMC product standards.

In general, equipment is required to comply with the relevant EMC product standards therefore SPM consisting of a coordinated SPD system is usually considered sufficient to protect such equipment against the effects of LEMP.

For equipment not complying with relevant EMC product standards, SPM consisting of a coordinated SPD system as well as additional magnetic shielding measures need to be considered. Coordinates SPD protection should ensure the voltage impulses due to conducted surges are less than the voltage impulse withstanding capacity of the equipment as well as Shielding measures should ensure the radiated surges are within the withstanding capacity of the equipment.

## 1.15 Equipotentialization of Services to LPS

Equipotentialization is achieved by interconnecting the LPS with structural metal parts, metal installations, internal systems, external conductive parts and lines connected to the structure.




**Key**

| | | | |
|---|---|---|---|
| 1. Power to user | 2. Power meter | 3. House connection box | 4. Power from utility |
| 5. Gas | 6. Water | 7. Central heating system | 8. Electronic appliances |
| 9. Screen of antenna cable | 10. Equipotential bonding bar. | | |
| **S.** Surge Protection Device | M Meter | | |

**Figure 1.13 - Example of an equipotential bonding arrangement**

Interconnecting can be done with bonding conductors, where the electrical continuity is not provided by natural bonding or using surge protective devices (SPD's), where direct connections with bonding conductors is not feasible (eg installation of SPD's for Power, Data, Telecom lines etc). SPD's shall be installed in such a way that they can be inspected. SPD is a device intended to limit transient over voltages and divert surge currents. It contains at least one non-linear component. All SPD's at the service entrance to an installation should be tested for 10/350 µS Impulse current depending upon selected level of protection. A three phase four wire system should be designed for 50 percent of the $I_{imp}$ of selected LPS and single phase two wire system should be designed for 25% of the $I_{imp}$ of selected LPS for fire safety reason only encapsulated spark gap should be used at mains entry. The lightning current distribution for three phase four wire system is given in fig. 10. 15.

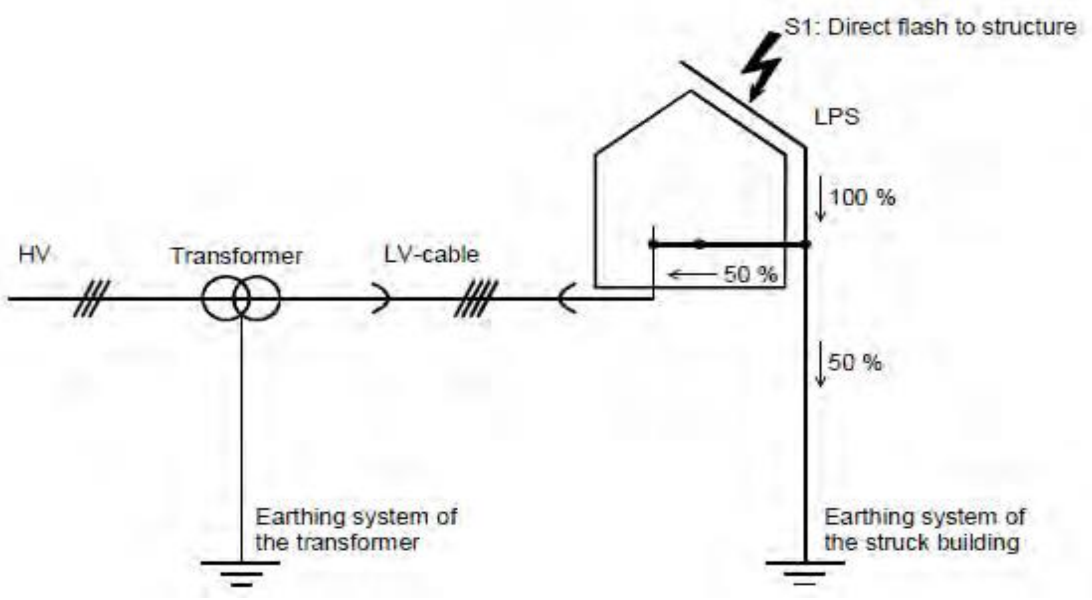



**Figure 1.14 Basic example of balance current distribution**

## 1.16 Protection Measures with Surge Protection devices (SPD's)

Lightning surges frequently cause failure of electrical and electronic systems due to insulation breakdown or when over voltages exceed the equipment's common mode insulation level. Equipment is protected if its rated impulse withstand voltage *U*W at its terminals is greater than the surge overvoltage between the live conductors and earth. If not, an SPD must be installed.

Implementing coordinated SPD's will provide protection against radiated surges for equipment. Shielding and Routing of power and data lines, Bonding of Services and various Lightning Protection Zones (LPZ), Earthing also plays major role in protecting electrical and electronic equipment.

SPD's are used to protect under specified condition, electrical systems and equipment against various over voltages and impulse currents such as lightning and Switching Surges. SPD shall be selected according to their environmental conditions and the acceptable failure rates of the equipment and the SPD's

*Failure of SPD's* - Possibility of failure of any line to neutral or neutral to earth connected SPDs should not be ruled out, hence SPD's which can withstand 2 hours Temporary Over Voltage (TOV only shall be allowed. (Eg each line to Neutral SPD shall withstand a TOV of up to Line to line for 2 hours). It should be ensured that spark gap SPD's do not emit ionized plasma during their operation for fire safety

*Status Indicators* - Each SPD should have inbuilt health indicator so as to show if protection is available. SPD should be installed in a way that visual inspection is easily possible. Failed SPD shall be replaced.

SPD's for power line need to be installed according to the type of service such as TN, TT, IT, etc. In general the SPDs connected as per connection diagram given below is suitable for TN and TT connections.

## 10.17 Installation of Surge Protection Device in TT and TN system

TT (Three-phase, 3+1)

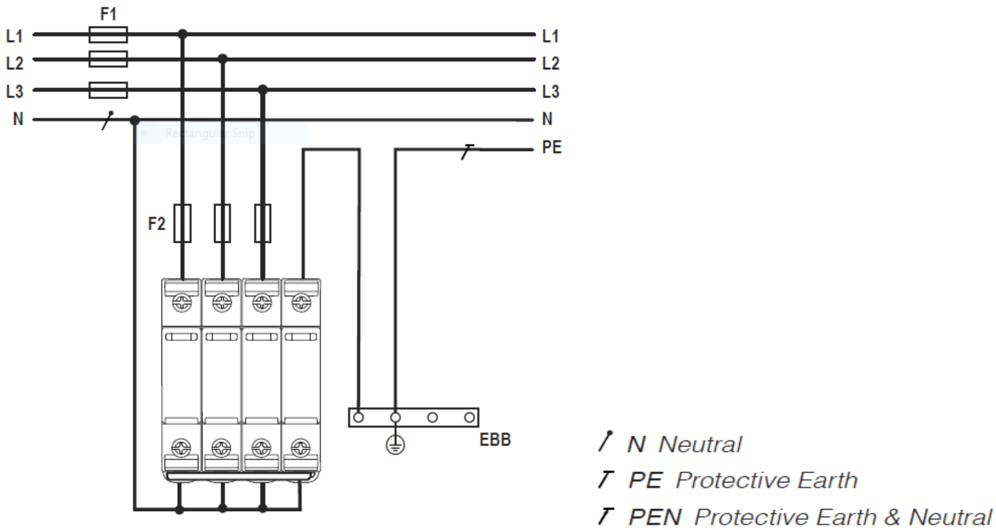



**Figure 1.15a: Connection Diagram for 3 phase 4 wire SPD in panels (3+1) type**

TT (Single-phase, 1+1)

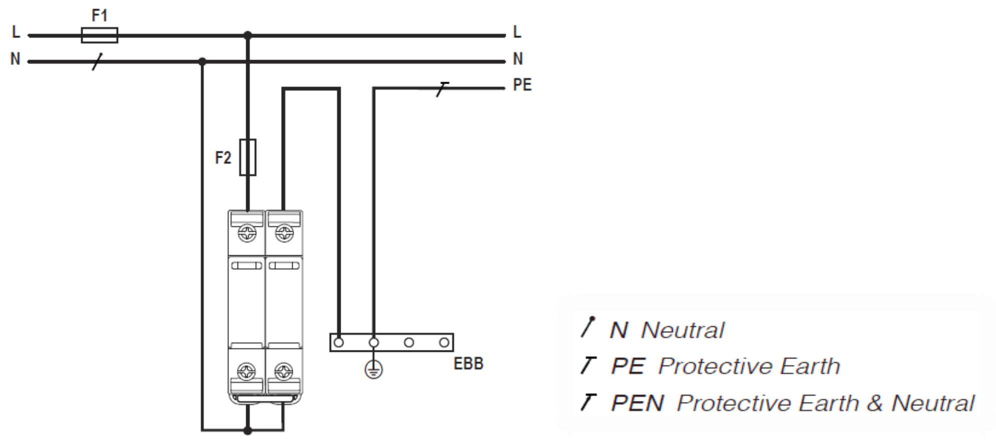



**Figure 1.15b: Connection Diagram for 1 phase 2 wire SPD in panels (1+1) type**

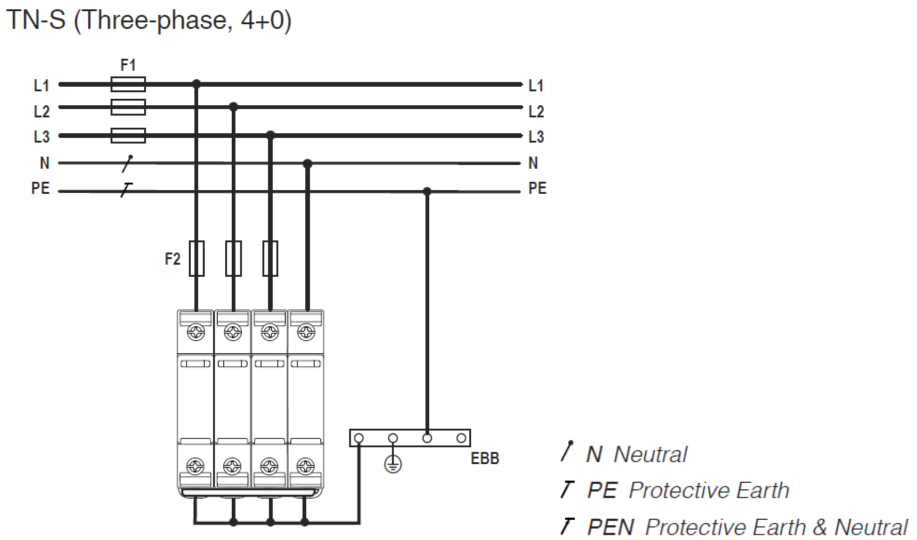



**Figure 1.15c Connection Diagram for 3 phase 4 wire SPD in panels (4+0) type**

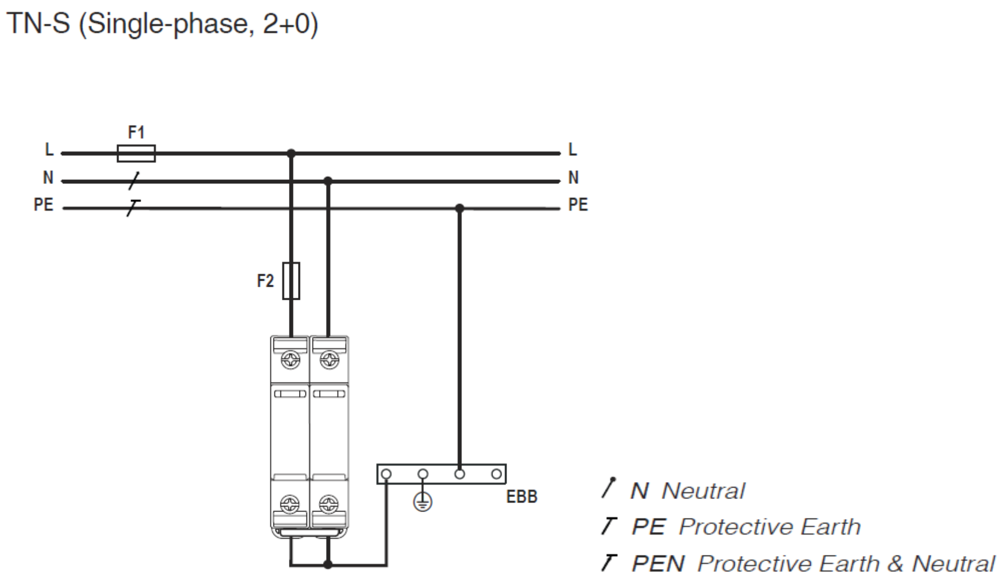



**Figure 1.15d: Connection Diagram for 1 phase 2 wire SPD in panels (2+0) type**

*Note: Here,*
*EBB. Main Earthing terminal or Equipotential Bonding Bar*
*F1. Protective Device at the Origin of Installation*
*F2. Protective Device required by the SPD manufacturer*

SPD's need to be selected based on the place of installation as well the impulse voltage withstanding capacity of the equipment. $\mathbf{I}_{imp}$, and $\mathbf{I}_n$, are test parameters used to categories class I and class II SPD's. They are related to the maximum values of discharge currents, which are expected to occur at the LPL probability level at the location of installation (LPZ) of the SPD in the system $\mathbf{I}_n$ is associated with class II tests and $\mathbf{I}_{imp}$ is associated with class I tests.
*Typical values for Level 1 protection* : Class 1 SPD: 10/350 µS, $I_{imp}$= $I$n = 100 kA (that is, 50 percent of 200 kA)

*a) Distribution of current in 3 + 1 Network*

Neutral to Earth connected SPD $I_{imp} = I_n$ = 100 KA(10/350 µs& 8/20 µs)
Line to Neutral connected SPD in 4 wire = 100 KA/4 = 25kA (10/350 µs& 8/20 µs)

b) For Single phase:

Neutral to Earth connected $I_{imp} = I_n$ for SPD = 25% of 200 kA i.e 50 kA (10/350 µs& 8/20 µs)
Line to Neutral Connected SPD in 2 wire = 50 kA/2 = 25kA (10/350 µs& 8/20 µs)

**c) Selection of SPD's:**

Power line protection is fundamental, however equal importance should be given to Data, Communication and instrumentation lines of the equipment that need protection.

If no risk analysis according to IEC 62305-2 has been carried out or if the current value of SPD cannot be established, Class 1 SPDs has to be installed with an $I_{imp}$ not less than 12.5 kA (10/350µS) for connection according to fig 15A or between L to N or PE. $I_{imp}$ shall not be less than 50 KA (10/350µS) between N and PE for three-phase systems and 25 kA (10/350µS) between N and PE for single-phase systems. Otherwise the currents shall be considered as per level of protection.

Follow current is the short circuit current which flows through the **Spark gap** SPD connected between Line to Neutral or Line to PE when it gets switched on due to lightning strike or surges. The SPD has to restore back to normal condition by breaking this short circuit current before back up fuse / switch gears are stressed, in order to retain the availability of the services by the load or to retain the availability of protection in the network.

Wherever class II tested SPD are required at or near the origin of installation, the value of *I*n shall be not less than 5 kA for connections according to fig 10.15a or between L to N or PE. For class II tested SPDs connected between neutral and PE for connection in fig 10.15b, *I*n shall not be less than 20 kA for three-phase systems and 10 kA for single-phase system.

Voltage Protection Level of SPD – It is the voltage that is finally exposed to the equipment. The voltage protection level (Up) should be less than the withstand voltage of the equipment. The voltage protection level of the SPD shall be as low as possible to have better protection but it should be ensured that it should not get switched on due to normal voltage variations or during low spark over voltages. The values of the withstand voltages of the equipment at various supply voltages is given in table 10.8:

**Table 1.8 Rated Impulse Voltage for the Equipment Energized Directly from the Low-Voltages Mains**

| Nominal voltage of the supply system [1] based on IEC 60038 [3] | | Voltage line to neutral derived from nominal voltages a.c. or d.c. up to and including | Rated impulse voltage [2] | | | |
|---|---|---|---|---|---|---|
| | | | Overvoltage category [4] | | | |
| Three phase | Single phase | | I | II | III | IV |
| V | V | V | V | V | V | V |
| | | 50 | 330 | 500 | 800 | 1 500 |
| | | 100 | 500 | 800 | 1 500 | 2 500 |
| | 120-240 | 150 [5] | 800 | 1 500 | 2 500 | 4 000 |
| 230/400 277/480 | | 300 | 1 500 | 2 500 | 4 000 | 6 000 |
| 400/690 | | 600 | 2 500 | 4 000 | 6 000 | 8 000 |
| 1 000 | | 1 000 | 4 000 | 6 000 | 8 000 | 12 000 |

1) See Annex B for application to existing different low-voltage mains and their nominal voltages.

2) Equipment with these rated impulse voltages can be used in installations in accordance with IEC 60364-4-44.

3) The / mark indicates a four-wire three-phase distribution system. The lower value is the voltage line-to-neutral, while the higher value is the voltage line-to-line. Where only one value is indicated, it refers to three-wire, three-phase systems and specifies the value line-to-line.

4) See 4.3.3.2.2 for an explanation of the overvoltage categories.

5) Nominal voltages for single-phase systems in Japan are 100 V or 100-200 V. However, the value of the rated impulse voltage for the voltages is determined from columns applicable to the voltage line to neutral of 150 V (See Annex B).

See figure 1.16 on connection diagram for SPD.

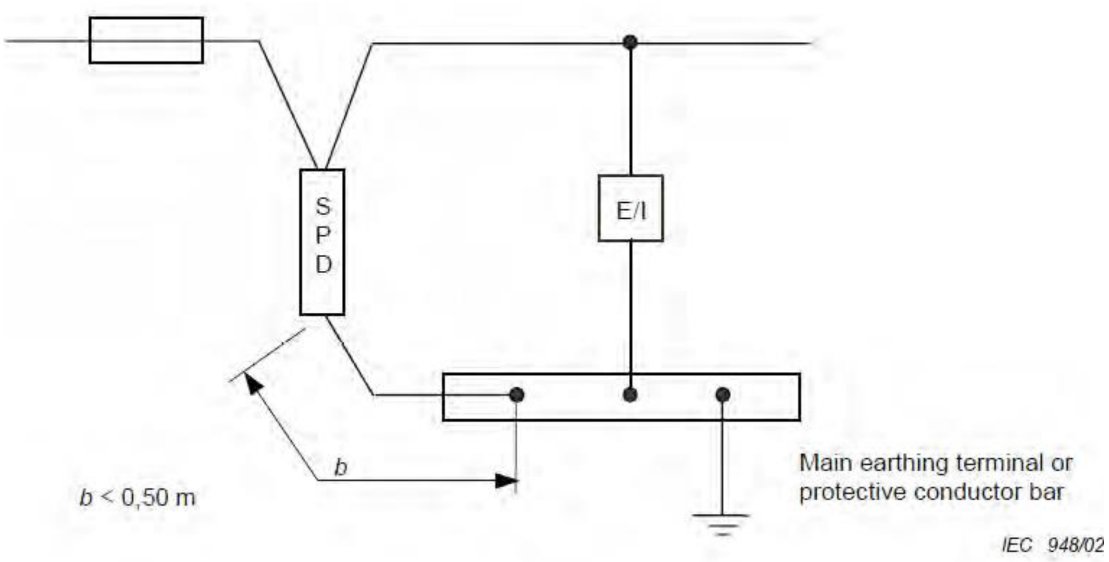



**Figure1. 16: Connection of the SPD with a bonding bar**

For Small residential buildings Power Line SPD at the mains incoming panel will enhance the life of electronic equipment such as TV, Music system, Refrigerators, LED lights etc

For large buildings Power Line SPD is required at incoming panel as well as for Sub Distribution panels based on the LPZ principle.

For Industrial and commercial buildings, critical and sensitive loads such as Drives, PLC's, automation panels etc require protection with SPD in addition to incoming power panels and sub distribution boards. For example, zones and hazardous area the SPDs shall be selected accordingly meeting the requirement of these zones.

Lifts and escalators shall be protected with SPD in control panels
All electrical and control panels related to safety and security of building shall be protected with appropriate SPDs.
SPDs should be installed for outdoor equipment such as CCTV cameras, LED street lights, Weighbridges, Roof top SOLAR PV. This will ensure protection of people and equipment inside the building.

Failure of equipment and chance of fire in electrical installations are more for buildings near tall structures (eg Telecom tower). These buildings should be protected with SPD at power incoming and Ring Earthing to avoid fire and equipment failure
All SPDs should have status indication to show their healthy state for discharging the lightning current. The possibility of failure of L-N as well as N-PE connected SPD cannot be ignored.
Maximum continuous operating voltage of the SPD (*U*c) should not be less than 1.1 x *U*nominal= 1.1 x 230 = 253 V however neutral disconnect tests are done at much higher voltages (above 440 V) to simulate this condition. Class 1 and Class2 SPD's connected between L and N or L to PE shall be tested to withstand Temporary over Voltage of 440 volts under neutral disconnect condition in an LV distribution line.

SPDs for data/telecommunication line shall be selected considering following parameters

a) Place of installation (lightning protection zone concept refer Fig. 10.11 and 10.12),
b) Immunity of terminal equipment,
c) Earthing of the system to be protected (balanced/unbalanced),
d) Requirement on interface (transmission parameters: Voltage, Freq, and Current)
e) Mounting interface.

## 1.18 Use of Natural Components

Natural components are conductive component installed in a building not specifically for lightning protection which can be used to provide the function of one or more parts of the LPS

Natural components made of conductive materials, which will always remain in/on the structure (e.g. interconnected steel-reinforcement, metal framework of the structure, steel roof, metal façade, hand rails etc.) should be used as parts of an LPS such as air termination, down conductor and earthing if it satisfies the requirement according to IEC 62305. Bonding of different metallic installations in the building should be done to avoid dangerous potential differences which results in flashover. This integrated method is not only economical but does not influence or spoil the aesthetics of the building. It also reduces the failure of electronic equipment inside the building from radiated lightning effects.

In case of natural down-conductors combined with foundation earth electrodes, test joints are not required and earth resistance measurements are not necessary.

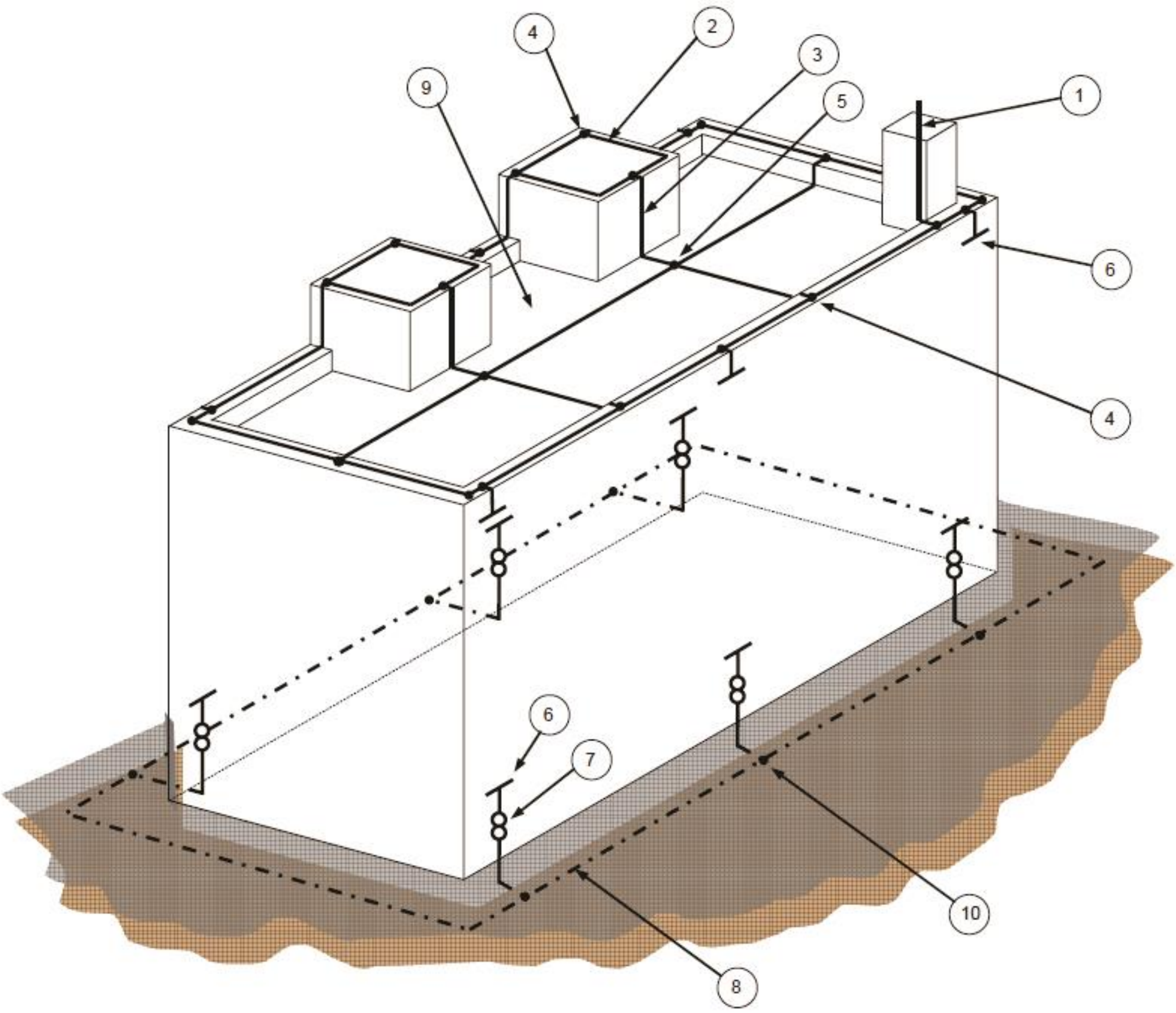
## 1.19 Continuity of steelwork in reinforced concrete structures

Steelwork within reinforced concrete structures is considered to be electrically continuous provided that

1. the major part of interconnections of vertical and horizontal bars are welded or otherwise securely connected.
2. connections of vertical bars shall be welded, clamped or overlapped a minimum of 20 times their diameters and bound or otherwise securely connected. For new structures, the connections between reinforcement elements shall be specified by the designer or installer, in cooperation with the builder and the civil engineer.

3. For structures utilizing steel reinforced concrete (including pre-cast, pre-stressed reinforced units), the electrical continuity of the reinforcing bars shall be determined by electrical testing between the uppermost part and ground level. **The overall electrical resistance should not be greater than 0,2 Ω measured using test equipment suitable for this purpose. If this value is not achieved, or it is not practical to conduct such testing, the reinforcing steel shall not be used as a natural down-conductor as discussed earlier**. In this case it is recommended that an external down-conductor be installed: In the case of structures of pre-cast reinforced concrete, the electrical continuity of the reinforcing steel shall be established between individual adjacent pre-cast concrete units.

Natural components made of conductive materials, which will always remain in/on the structure and will not be modified (e.g. interconnected reinforced steel, metal framework of the structure, etc.) may be used as parts of an LPS. Other natural components should be considered as being additional to an LPS.




**Key**

1 Air-termination rod
2 Horizontal air-termination conductor
3 Down-conductor
4 T-type joint
5 Cross type joint
6 Connection to steel reinforcing rods
7 Test joint
8 Earth electrode type B earthing arrangement, ring earth electrode
9 Flat roof with roof fixtures
10 T-type joint – corrosion resistant

NOTE The steel reinforcement of the structure should comply with IEC 62305 – 3 . All dimensions of the LPS should comply with the selected protection level.

**Figure 1.17: Construction of external lps on a structure of steel-reinforced concrete using the reinforcement of the outer walls as natural components**

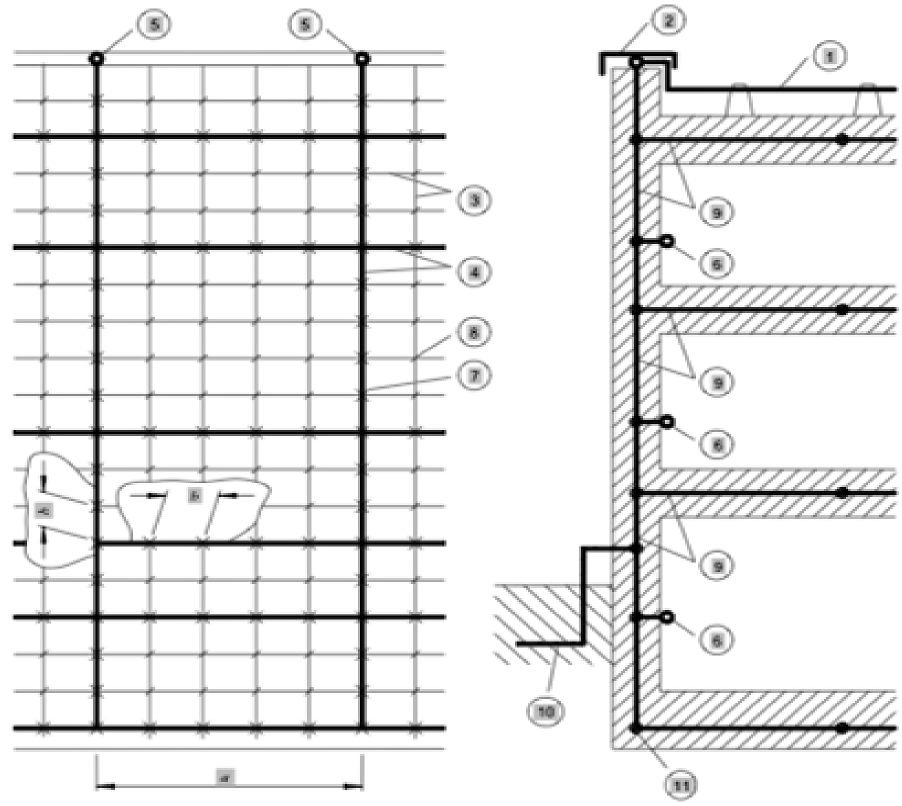
## 1.20 Bonding Network

A low impedance bonding network is needed to avoid dangerous potential differences between all equipment inside the building. Moreover, such a bonding network also reduces the magnetic field, thereby reduces the radiated surges inside the building and provides more protection for electronic equipment.

This can be realised by a meshed bonding network integrating conductive parts of the structure, or parts of the internal systems, and by bonding metal parts or conductive services at the boundary of each LPZ directly or by using suitable SPDs.

The bonding network can be arranged as a three-dimensional meshed structure with a typical mesh width of 5 m. This requires multiple interconnections of metal components in and on the structure (such as concrete reinforcement, elevator rails, cranes, metal roofs, metal facades, metal frames of windows and doors, metal floor frames, service pipes and cable trays). Bonding bars (e.g. ring bonding bars, several bonding bars at different levels of the structure) and magnetic shields of the LPZ shall be integrated in the same way.

Conductive parts (e.g. cabinets, enclosures, racks) and the protective earth conductor (PE) of the internal systems shall be connected to the bonding network.



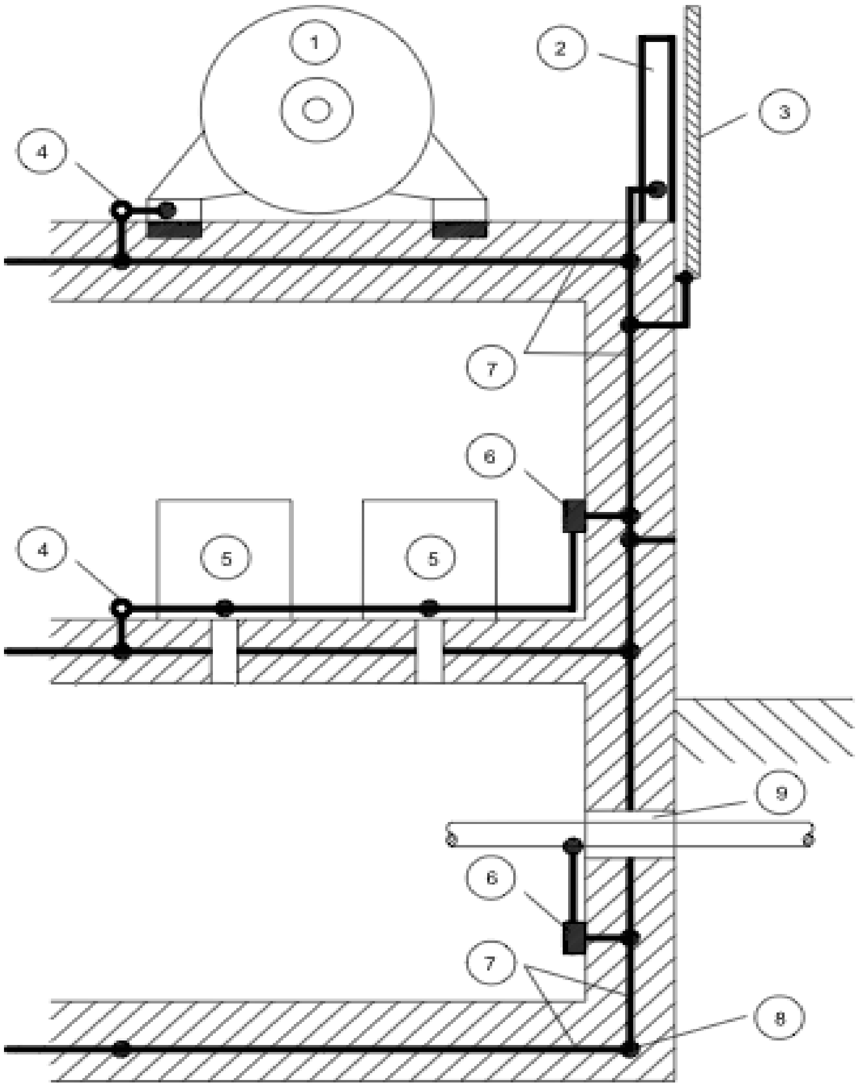
Key

| | | | |
|---|---|---|---|
| 1 | air-termination conductor | 7 | Connection made by welding or clamping |
| 2 | metal covering of the roof parapet(or handrail) | 8 | Arbitrary connection |
| 3 | Steel reinforcing rods | 9 | Steel reinforcement in concrete (with super imposed mesh conductor) |
| 4 | Mesh conductors superimposed on the reinforcement | 10 | Ring earthing electrode (if any) |
| 5 | Joint of the mesh conductor | 11 | Foundation earthing electrode |
| 6 | Joint of the internal bonding bar | | |

a. typical distance of 5 m for superimposed mesh conductor

b. typical distance of 1 m for connecting this mesh with reinforcement

**Figure 1.18: Utilisation of reinforcing rods of a structure for equipotent bonding**




| | | | |
|---|---|---|---|
| 1 | Electrical power equipment | 6 | Bonding bar |
| 2 | Steel girder | 7 | Steel reinforcement in concrete (with superimposed mesh conductors) |
| 3 | Metal covering of the facade | 8 | Foundation earth electrode |
| 4 | Bonding joint | 9 | Common entry point for different services |
| 5 | Electrical or electronic equipment | | |

**Figure 1.19**: **Equipotential bonding in a structure with steel reinforcement**

## 1.21 Materials and Dimensions

Copper and aluminium are recommended for exposed areas on installations required to have a long life. Galvanized steel may be preferred for temporary installations such as exhibition centres. Although it is a common practice to use material in the form of strip for horizontal air terminations, down conductors and bonds, it is more convenient to use round material, particularly as it facilitates the making of bends in any plane. If different materials are used in an installation, care should be taken to avoid galvanic corrosion by the use of Bi metallic connectors.

**Table 1.9: LPS materials and conditions of use (IEC 62305-3)**

| Material | Use | | | Corrosion | | |
|---|---|---|---|---|---|---|
| | In open air | In earth | In concrete | Resistance | Increased by | May be destroyed by galvanic coupling with |
| Copper | Solid<br>Stranded | Solid<br>Stranded<br>As coating | Solid<br>Stranded<br>As coating | Good in many environments | Sulphur compounds<br>Organic materials | – |
| Hot galvanized steel [c, d, e] | Solid<br>Stranded | Solid | Solid<br>Stranded | Acceptable in air, in concrete and in benign soil | High chlorides content | Copper |
| Steel with electro-plated copper | Solid | Solid | Solid | Good in many environments | Sulphur compounds | |
| Stainless steel | Solid<br>Stranded | Solid<br>Stranded | Solid<br>Stranded | Good in many environments | High chlorides content | – |
| Aluminium | Solid<br>Stranded | Unsuitable | Unsuitable | Good in atmospheres containing low concentrations of sulphur and chloride | Alkaline solutions | Copper |

a. This table gives general guidance only. In special circumstances more careful corrosion immunity considerations are required

b. Stranded conductors are more vulnerable to corrosion than solid conductors. Stranded conductors are also vulnerable where they enter or exit earth/concrete positions. This is the reason why stranded galvanized steel is not recommended in earth.

c. Galvanized steel may be corroded in clay soil or moist soil.

d. Galvanized steel in concrete should not extend into the soil due to possible corrosion of the steel just outside the concrete.

e. Galvanized steel in contact with reinforcement steel in concrete may, under certain circumstances, cause damage to the concrete.

**Table 1.10: Material, Configuration and Minimum Cross sectional area of air-termination conductors and rods, earth lead-in rods and down conductors (IEC 62305-3)**

| Material | Configuration | Minimum cross-sectional area $mm^2$ |
|---|---|---|
| Copper<br>Tin plated Copper | Solid tape | 50 |
| | Solid round[b] | 50 |
| | Stranded[b] | 50 |
| | Solid round[c] | 176 |
| Aluminium | Solid tape | 70 |
| | Solid round | 50 |
| | Stranded | 50 |
| Aluminium Alloy | Solid tape | 50 |
| | Solid round | 50 |
| | Stranded | 50 |
| | Solid round[c] | 176 |
| Copper coated aluminium alloy | Solid round | 50 |
| Hot dipped galvanised steel | Solid tape | 50 |
| | Solid round | 50 |
| | Stranded | 50 |
| | Solid round[c] | 176 |
| Copper coated steel | Solid round | 50 |
| | Solid tape | 50 |
| Stainless steel | Solid tape[d] | 50 |
| | Solid round[d] | 50 |
| | Stranded | 50 |
| | Solid round[c] | 176 |

a. Mechanical and electrical characteristics as well as corrosion resistance properties shall meet the requirements of IS IEC 62561 series

b. 50 $mm^2$ (8 mm diameter) may be reduced to 25 $mm^2$ in certain application where mechanical strength is not an essential requirement. Consideration should in this case, given to reducing the space between fastners

| | |
|---|---|
| c. | Applicable for air-termination rods and earth lead-in rods. For air-termination rods where mechanical stress such as wind loading is not critical, a 9.5 mm diameter, 1 meter long rod may be used. |
| d. | If the thermal and mechanical considerations are important, then these values should be increased to 75 mm$^2$ |

**Table 1.11: Material Configuration and Minimum Dimensions of Earth Electrodes (IEC 62305-3)**

| Material | Configuration | Minimum dimensions | | |
|---|---|---|---|---|
| | | Earth rod diameter ( mm) | Earth conductor (mm$^2$) | Earth plate mm) |
| Copper<br>Tin plated Copper | Stranded | | 50 | |
| | Solid round | 15 | 50 | |
| | Solid Tape | | 50 | |
| | Pipe | 20 | | |
| | Solid plate | | | 500 x 500 |
| | Lattice plate[c] | | | 600 x 600 |
| Hot dipped galvanised steel | Solid round | 14 | 78 | |
| | Pipe | 25 | | |
| | Solid tape | | 90 | |
| | Solid plate | | | 500 x 500 |
| | Lattice plate | | | 600 x 600 |
| | Profile | [d] | | |
| Bare steel [b] | Stranded | | 70 | |
| | Sold round | | 78 | |
| | Solid tape | | 75 | |
| Copper Coated Steel | Sold round | 14[f] | 50 | |
| | Solid tape | | 90 | |
| Stainless steel[g] | Solid round | 15 | 78 | |
| | Solid tape | | 100 | |

a. Mechanical and electrical characteristics as well as corrosion resistance properties shall meet the requirements of IS IEC 62561 series
b. Shall be embedded in concrete for a minimum depth of 50 mm
c. Lattice plate constructed with a minimum total length of conductor of 4.8 meter
d. Different profiles are permitted with a cross-section of 290 mm$^2$ and a minimum thickness of 3 mm.
e. In case of a type B arrangement foundation earthing system, the earth electrode shall be correctly connected at least every 5 meters with the reinforcement steel.
f. 250µm minimum radial copper coating, with 99.9 % copper content

**Table 1.12: Lightning Protection Implementation for typical buildings**

| Sl no | Type of building | place | Implementation |
|---|---|---|---|
| 1 | Buildings with No steel reinforced foundation with electricity connection (One or two family private dwellings) | Close to tall structures / trees [a] | SPD & Ring earthing connected to the power incoming switchboard Earth terminal |
| | | Isolated | Class IV External LPS, SPD[b] and Ring Earthing |
| 2 | Buildings with steel reinforced foundation with electricity connection (One or two family private dwellings) | Close to tall structures / trees [a] | SPD[b] & bonding of steel reinforcement to earthing bonding bar[C] |
| | | Isolated | Air termination grid (max 20 meter X 20 meter) connected to reinforcement and down conductor[e] (max every 20 meter). SPD[b] and [c]bonding of steel reinforcement to earthing bonding bar |
| 3 | Buildings with steel reinforced foundation with electricity connection( low rise buidings) | | |
| 4 | Residential tall high rise buildings (more than 20 meter height) with steel reinforced columns/pillars | Urban/suburban/Rural | |
| 5 | Educational buildings (school/ college/ training) for education or recreation for not less than 20 students | Urban/Suburban/Rural | Recommended[F] class III LPS and SPD[b] and bonding of steel reinforcement to earthing bonding bar[C]. Additional step/touch potential reduction measures in pathways / play grounds |
| 6 | Institutional Buildings (Hospitals/Jails) | Urban/Suburban/Rural | |
| 7 | Assembly Buildings (theatres/ passenger stations(rail/bus/Air)/ exhibition halls/ religious buildings | Urban/Suburban/Rural | |

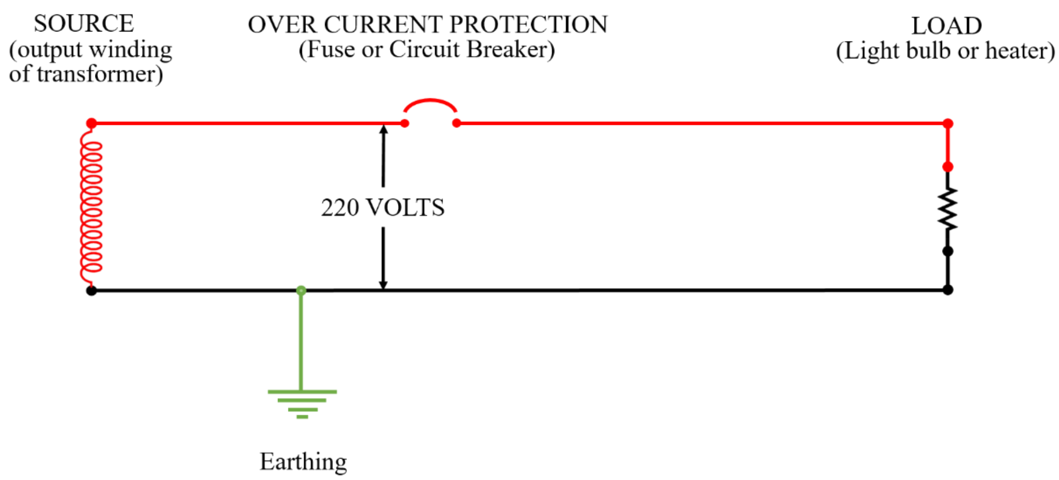
| | | | |
|---|---|---|---|
| | Assembly Buildings (more than 5000 people)<br>Rail stations/ Airport/ Hill stations/ Mines | | In addition to LPS as per IEC 62305, lightning safety areas shall be declared for the assembly of people during thunderstorm |
| 8 | Offices, Banks, data centers, telephone exchanges, Broadcasting stations | Urban/Suburban/Rural | Recomended[F] LPS as per IEC 62305. SPD[b] and bonding of steel reinforcement to earthing bonding bar[C]. Ring earthing for the safe assembly area. Lightning Warning system can add safety. |
| 9 | Industrial Buildings/ Storage buildings ( without the risk of combustible materials ) | Urban/Suburban/Rural | |
| 10 | Hazardous Buildings(storage and handling of highly flammable or explosive materials, liquids or gases [g] | Urban/Suburban/Rural | |

Note:

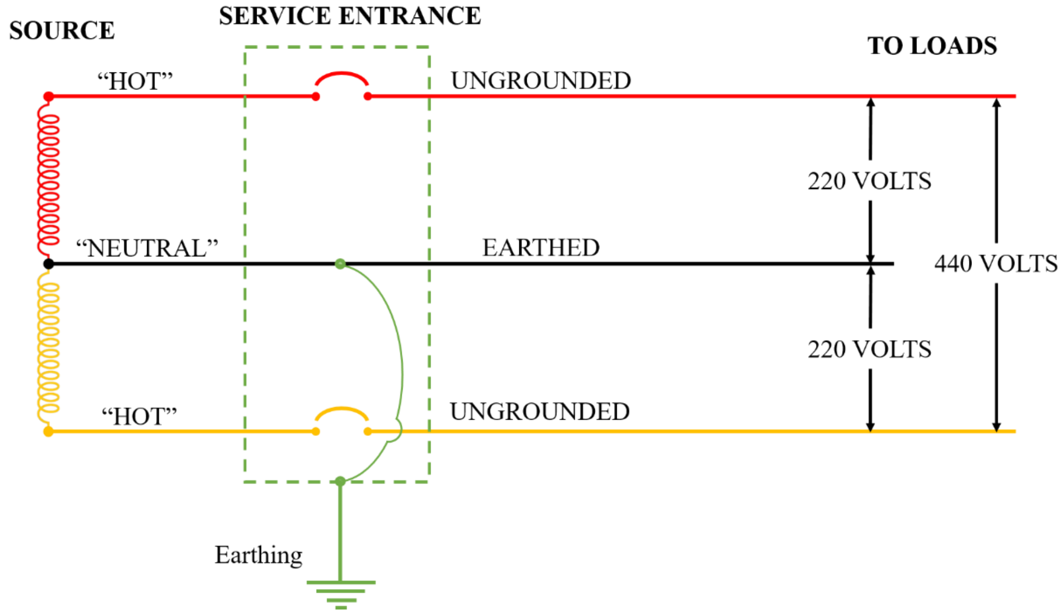
a. Side flashes from trees / tall structures are expected if the building is within 5 meters. To reduce the impact of side flash, metal conductors (down conductors) connected to ring earthing need to be installed near the tall structure
b. SPD shall be installed in all the incoming services like power, telephone, data etc.
c. May not be possible for an existing building. Ring Earthing is recommended as an alternate. Provision to bond the steel reinforcement to the earthing bus bar shall be provided during the construction of the building using a corrosion resistant metal (Stainless steel)
d. Direction boards towards lightning safe area shall be shown, where lightning warning systems are installed
e. Down conductor can be avoided if reinforcement steel is interconnected.
f. Recommended LPS – Class of LPS derived in a risk assessment calculation as per IS IEC 62305-2
g. Lightning Protection with insulated materials can avoid safety distance of LPS from these installations
h. The quality of the connectors and other components of the LPS shall be ensured by following tests:
    i) Salt mist test;
    ii) Humid sulfur atmosphere treatment tests;
    iii) Electrical tests for lightning current and resistance;
    iv) Mechanical strength tests - tensile strength, min elongation test; and
    v) Metal compatibility tests.

# 2. ELECTRICAL PROTECTIVE DEVICES

As a power source, electricity can create conditions almost certain to result in bodily harm, property damage, or both. It is important for workers to understand the hazards involved when they are working around electrical power tools, maintaining electrical equipment, or installing equipment for electrical operation.




Single phase two wire circuit




Single phase 3-wire circuit

The *electrical protective devices* include fuses, circuit breakers, and ground-fault circuit-interrupters (GFCIs). One way to reduce the risk is to use a clever protective device called a **residual current device** (**RCD**), or **residual current circuit breaker** (**RCCB**), that instantly breaks an electric circuit to prevent serious harm from an ongoing electric shock. In the Europe these are better known by their initials **RCD**, and a combined RCD+MCB (miniature circuit breaker) is known as a **RCBO** (**residual-current circuit breaker with overcurrent protection**). In the America, the device is more commonly known as a **ground fault circuit interrupter** (**GFCI**), **ground fault interrupter** (**GFI**) or an **appliance leakage current interrupter** (**ALCI**). In Australia, they are sometimes known as **safety switches** or an **RCD**. An earth leakage circuit breaker (ELCB) may be a residual current device, although an older type of voltage operated earth leakage circuit breaker also exists. These devices are critically important to electrical safety. *Overcurrent devices* should be installed where required. They should be of the size and type to interrupt current flow when it exceeds the capacity of the conductor. Proper selection takes into account not only the capacity of the conductor, but also the rating of the power supply and potential short circuits.

## 2.1 Overcurrent and its causes

The currents in the circuit can be over than the marked limit and/or safety limit. There are various types and their causes of overcurrent.

Types of Overcurrent and their causes

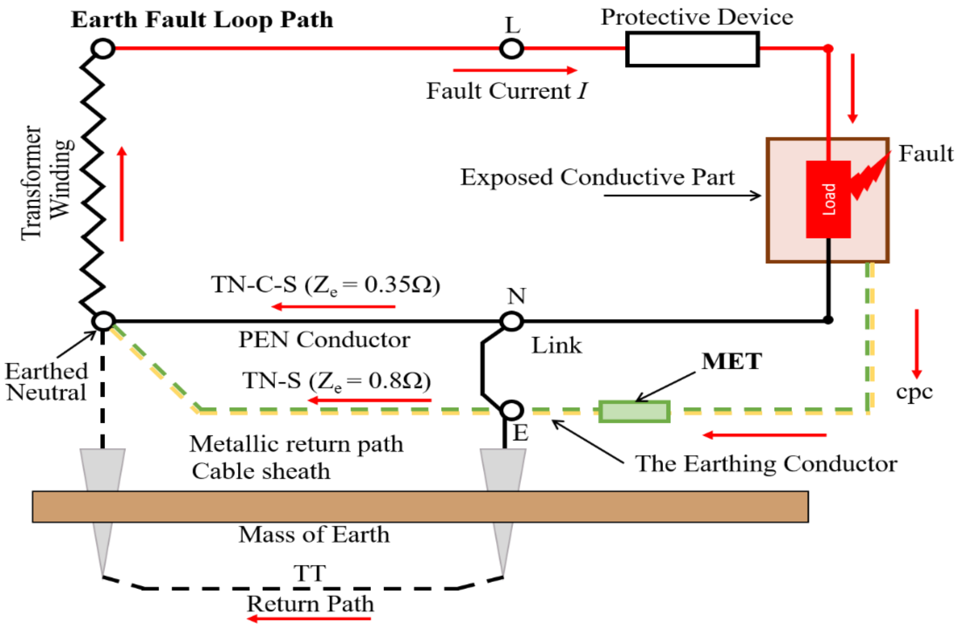
There are two types of overcurrent:

1. Overload - When you ask a 10 hp motor to do the work of a 12 hp motor, an overload condition exists. The overcurrent may be 150 percent of normal current.
2. Fault - When insulation fails in a circuit, fault current can result that may be from 5 times to 50 times that of normal current.

When a circuit is **overloaded**, the plasticizers in the insulation are vaporized over a long period of time, and the insulation becomes brittle. The brittle insulation has slightly better electrical insulating properties. However, movement of the conductors due to magnetic or other forces can crack the insulation, and a fault can result. Conductors should be protected from overload and the eventual damage that results.

**Faults** occur in two ways. Most of the time a fault will occur between a conductor and an enclosure. This is called a *ground fault*. Infrequently, a fault will occur between two conductors. This is called a *short circuit*, and was discussed earlier in this module.

In order to predict what will happen in a normal circuit and a ground-fault circuit, we first need to understand the terminology used to describe electrical systems. The figure below should aid in this discussion. The enclosures that cover the service panel, conduit, and boxes enclosing switches, controllers, equipment terminals, etc. The conduit bonds all of the enclosures together such that there is no electrical potential between them. It also provides an emergency path for ground-fault current to return to the voltage source which in this case is shown as secondary windings of a transformer.



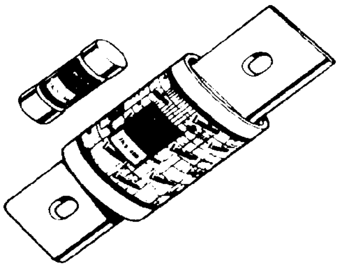

## 2.2 Over Current Protective Devices (OCPD)

How do they protect?
As shown in the above figure, notice that there must be a wire between the grounded conductor and the enclosure to allow the fault current to return to its source. This wire is called the *main bonding jumper*. If there is no wire, then the electrical system is isolated and requires extra safety features. The basic idea of an overcurrent protective device is to make a weak link in the circuit. In the case of a fuse, the fuse is destroyed before another part of the system is destroyed. In the case of a circuit breaker, a set of contacts opens the circuit. Unlike a fuse, a circuit breaker can be re-used by re-closing the contacts. Fuses and circuit breakers are designed to protect equipment and facilities, and in so doing, they also provide considerable protection against shock in most situations. However, the only electrical protective device whose sole purpose is to protect people is the ground-fault circuit-interrupter. These various protective devices are further discussed below.

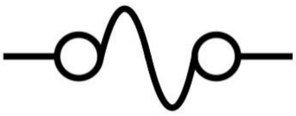
Various protective Devices

Fuses

A fuse is an electrical device that opens a circuit when the current flowing through it exceeds the rating of the fuse. The "heart" of a fuse is a special metal strip (or wire) designed to melt and *blow out* when its rated amperage is exceeded.
Overcurrent devices (fuses, circuit breakers) are always placed in the "hot" side of a circuit (usually a black wire) and in series with the load, so that all the current in the circuit must flow through them.



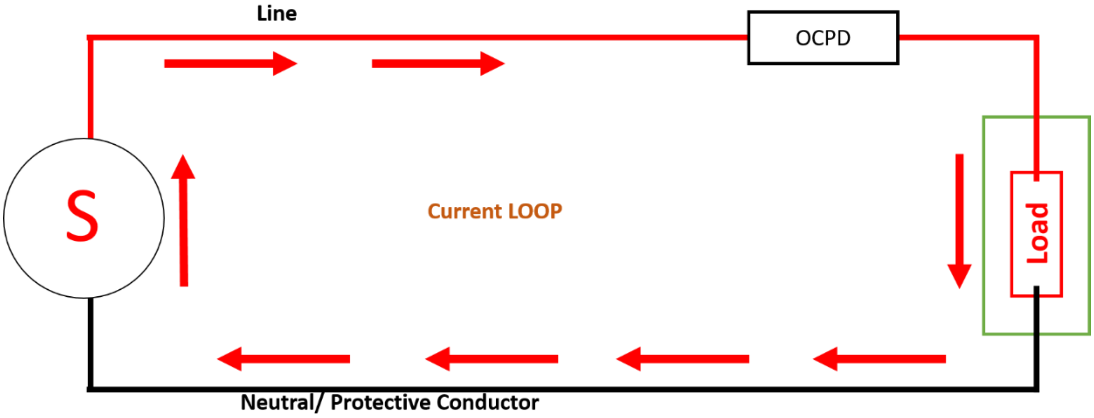
If the current flowing in the circuit exceeds the rating of the fuse, the metal strip will melt and open the circuit so that no current can flow. A fuse cannot be re-used and must be replaced after eliminating the cause of the overcurrent. Fuses are designed to protect equipment and conductors from excessive current. It is important to always replace fuses with the proper type and current rating. Too low a rating will result in unnecessary blowouts, while too high a rating may allow dangerously high currents to pass. The symbol for a fuse is shown in the accompanying figure.



Circuit Breaker

Circuit breakers provide protection for equipment and conductors from excessive current without the inconvenience of changing fuses. Circuit breakers *trip* (open the circuit) when the current flow is excessive. There are two primary types of circuit breakers based on the current sensing mechanism. In the *magnetic* circuit breaker, the current is sensed by a coil that forms an electromagnet. When the current is excessive, the electromagnet actuates a small armature that pulls the trip mechanism - thus opening the circuit breaker. In the *thermal type* circuit breaker, the current heats a bi-metallic strip, which when heated sufficiently bends enough to allow the trip mechanism to operate. The symbol for a circuit breaker is shown in the accompanying figure.

**Working of an MCB**



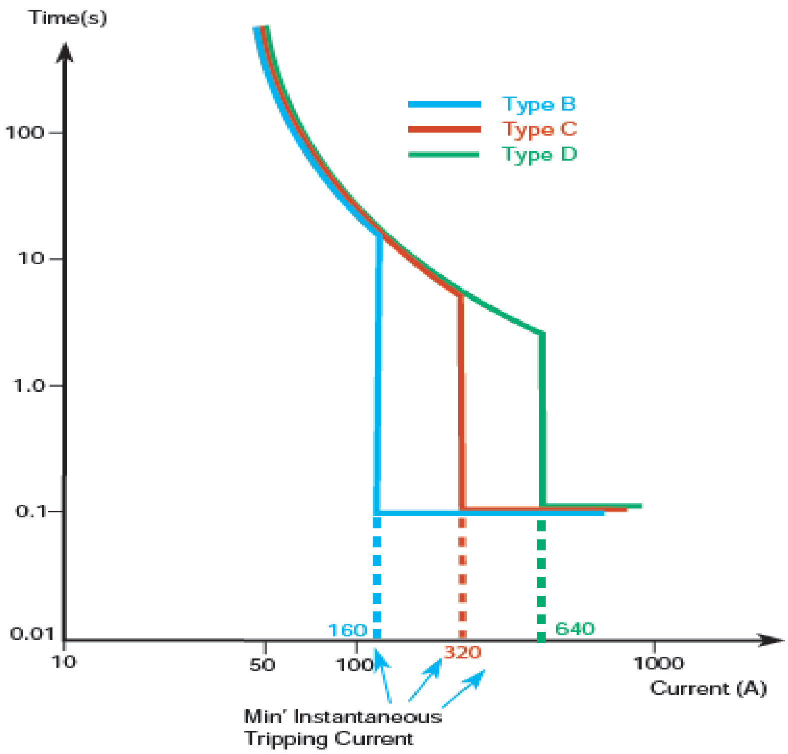




**Figure: A comparison of sensitivity characteristics of 32A MCB.**

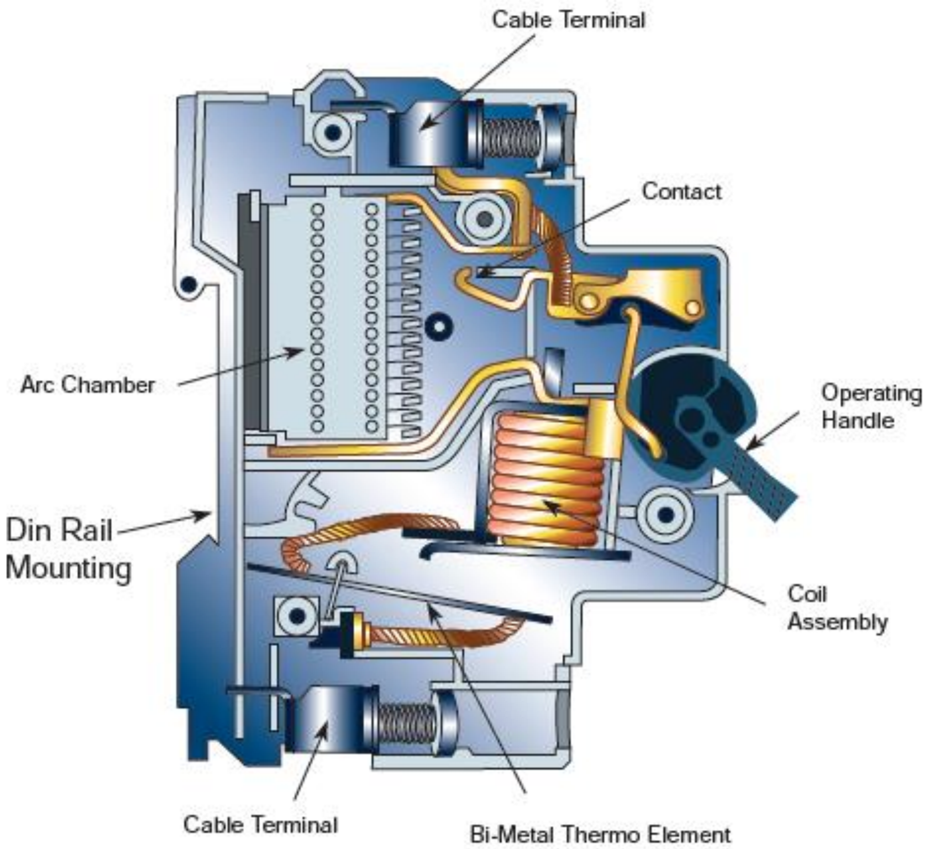



**Figure: Internal view of an MCB**

**Working of an MCB**

A miniature circuit breaker (MCB) is an Electrical Switch which automatically switches off the electrical circuit during an abnormal condition of the network means in overload condition as well as faulty condition. Whenever continuous overcurrent flows through MCB, the bimetallic strip is heated and deflects by bending. This deflection of bi-metallic strip releases a mechanical latch. As this mechanical latch is attached with the operating mechanism, it causes to open the miniature circuit breaker contacts, and the MCB turns off thereby stopping the current to flow in the circuit. To restart the flow of current the MCB must be manually turned ON. This mechanism protects from the faults arising due to overcurrent or overload and short circuit. But during short circuit condition, the current rises suddenly, causing electromechanical displacement of plunger associated with a tripping coil or solenoid. The plunger strikes the trip lever causing immediate release of latch mechanism consequently open the circuit breaker contacts. This was a simple explanation of a miniature circuit breaker working principle.

**Residual Current Devices**

## Protection of people and equipment

A **Residual Current Device** (**RCCB, ELCB, RCBO, GFCI** etc.) is a device that is designed to provide protection against electrocution or electrical fires by cutting off the flow of electric current automatically when it senses a 'leakage' of electric current from a circuit.
Residual current protective devices are classified according to their various versions.

- RCD is the generic term for all types of residual current protective device.

- RCCBs are residual current operated circuit-breakers without integral overcurrent protection.
- RCBOs are devices which feature an integrated overcurrent protection unit for overload and short-circuit protection in addition to protection against residual currents.

## Operating Principle of a Residual Current Device

The basic operating principle of a residual current device (RCCB, ELCB, RCBO etc.) is given in the figure below.

When the load is connected to the supply through the **Residual Current Device** (**RCD**), the line and neutral conductors are connected through primary windings on a transformer.
In this arrangement, the secondary winding is used as a sensing coil and is electrically connected to a sensitive relay or solid state switching device, the operation of which triggers the tripping mechanism.
When the line and neutral currents are balanced, as in a healthy circuit, they produce equal and opposite magnetic fluxes in the transformer core with the result that there is no current generated in the sensing coil.
When the line and neutral currents are not balanced they create an out-of-balance flux. This will induce a current in the secondary winding which is used to operate the tripping mechanism. It is important to note that both the line and neutral conductors pass through the toroid.

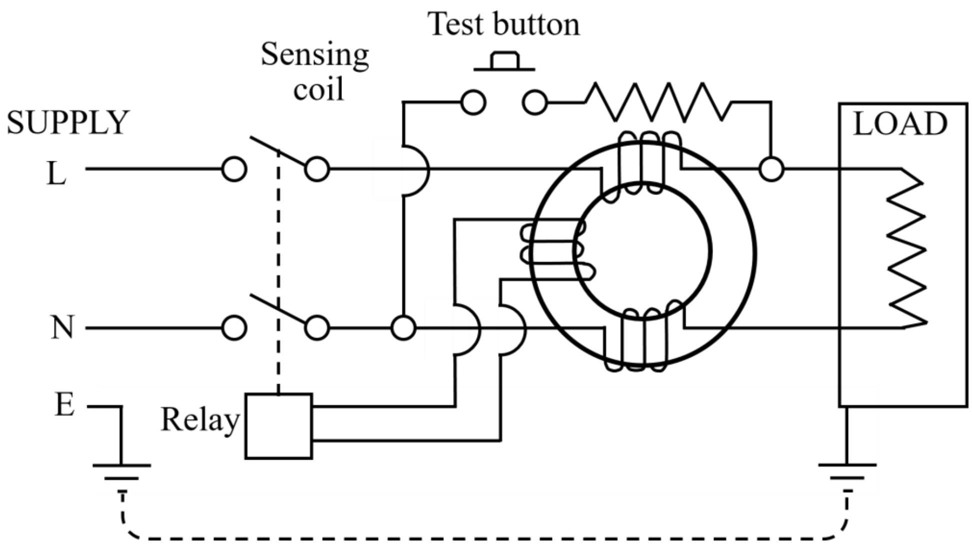



Figure: Operating principle of Residual Current Circuit Breaker

A common cause of unwanted tripping is the failure to connect the neutral through the **RCD**, **RCDs** work equally well on single phase, three phase or three phase and neutral circuits, but when the neutral is distributed it is essential that it passes through the toroid.

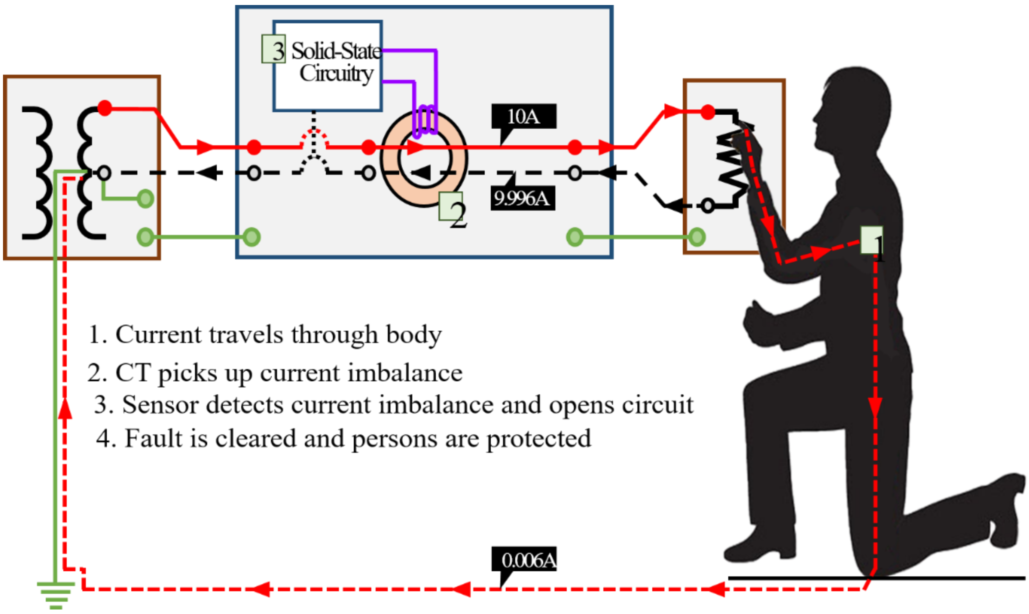



Figure: Mechanism of how an RCD protects from electrocution

**Test Circuit in RCD**

A test circuit is always incorporated in the **RCD**. Typically, the operation of the test button connects a resistive load between the line conductor on the load-side of the **RCD** and the supply neutral.

The test circuit is designed to pass current in excess of the tripping current of the RCD to simulate an out-of-balance condition. Operation of the test button verifies that the RCD is operational. It is important to note, therefore, that the test circuit does not check the circuit protective conductor or the condition of the earth electrode.

On all RCDs a label instructs the user to check the function of the RCD at regular intervals and to observe that the RCD trips instantly.

**Types of Residual Current Device**

There are different types of residual current devices available now. Some of them are mentioned below.

**1.** *RCCB*

They are Residual Current Operated Circuit-Breaker without Integral Overcurrent Protection. A mechanical switching device 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.

It is not designed to give protection against overloads and/or short-circuits and must always be used in conjunction with an overcurrent protective device such as a fuse or circuit-breaker.

**2.** *RCBO*

RCBO is a Residual Current Operated Circuit-Breaker with Integral Overcurrent Protection.

A mechanical switching device 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.

In addition, it is designed to give protection against overloads and/or short-circuits and can be used independently of any other overcurrent protective device within its rated short-circuit capacity.

#### Working of a Residual Current Device

In an **RCD**, the line and neutral conductors of a circuit pass through a sensitive current transformer. If the line and neutral currents are equal and opposite, the core remains balanced.
If there is an earth fault the neutral current will be lower than the line current. This imbalance produces an output from the current transformer which is used to trip the **RCD** and so break the circuit.

In practice, the main Miniature Circuit Breaker (MCB) for the premises will probably trip, or the service fuse so the situation is unlikely to lead to catastrophe, but it may be inconvenient. **RCDs** normally don’t offer protection against current overloads: **RCDs** detect an imbalance between the live and neutral currents. A current overload, however large, cannot be detected. If a line neutral fault occurs (a short circuit, or an overload), the **RCD** won’t trip, and may get damaged.
It is now possible to get an MCB and **RCD** in a single unit called an **RCBO**. Replacing an MCB with an **RCBO** of the same rating is generally safe. ***RCBO** is **Residual Current Circuit Breaker with Overcurrent Protection.***

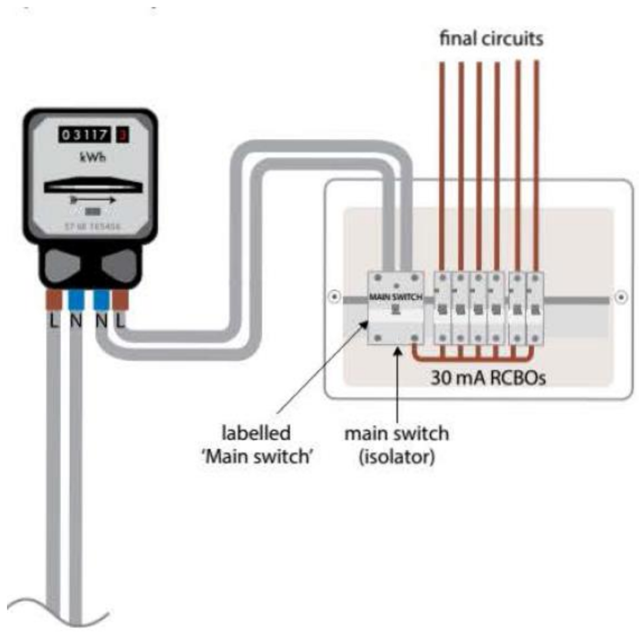




Figure: An example of RCBO and layout for installation of RCBOs in an electrical wiring.

## 2.3 Earthing

Earthing (or Grounding) must be taken into account wherever electrical current flows. It can never be stressed too strongl that proper grounding and bonding must be correctly applied if the system, the equipment, and the people that come in contact with them are to be protected.

***Effective earthing*** means that the path to ground: (1) is permanent and continuous, and (2) has ample current-carrying capacity to conduct safely any currents liable to be imposed on it, and (3) has impedance sufficiently low to limit the potential above ground and to facilitate the operation of the overcurrent devices in the circuit.

***Effective bonding*** means that the electrical continuity of the grounding circuit is assured by proper connections between service raceways, service cable armor, all service equipment enclosures containing service entrance conductors, and any conduit or armor that forms part of the grounding conductor to the service raceway.

***Effective earthing has no function unless and until there is electrical leakage from a current-carrying conductor to its enclosure***. When such a *ground fault* occurs, the equipment grounding conductor goes into action to provide the following:

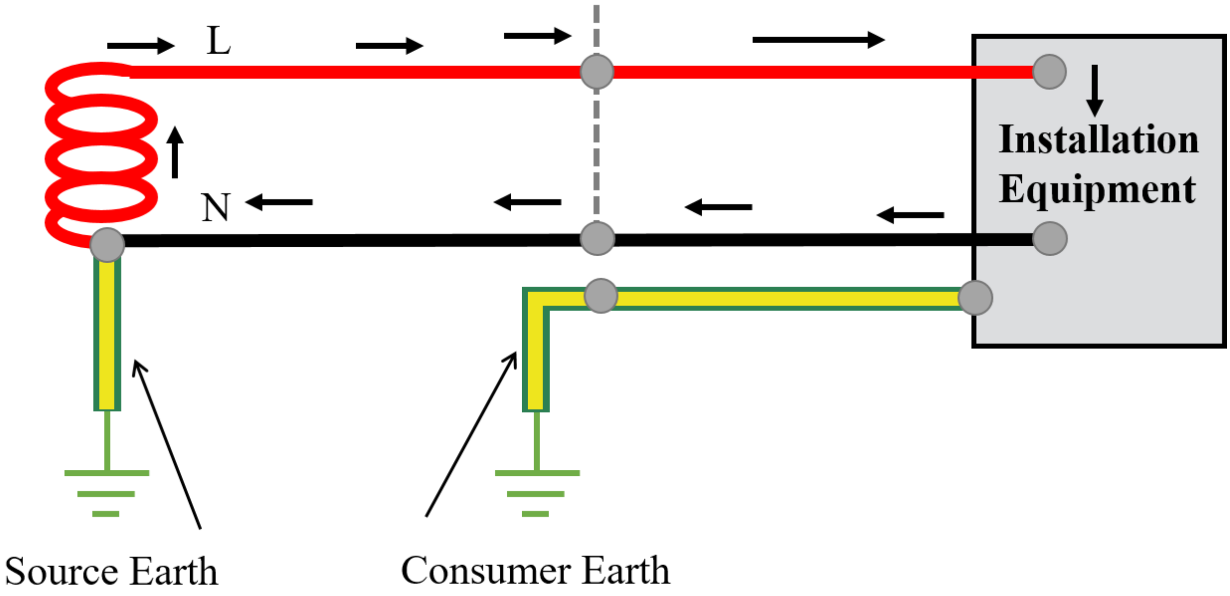
- It *prevents voltages* between the electrical enclosure and other enclosures or surroundings.
- It *provides a path* for large amounts of fault or overload current to flow back to the service entrance, thus blowing the fuse or tripping the circuit breaker.

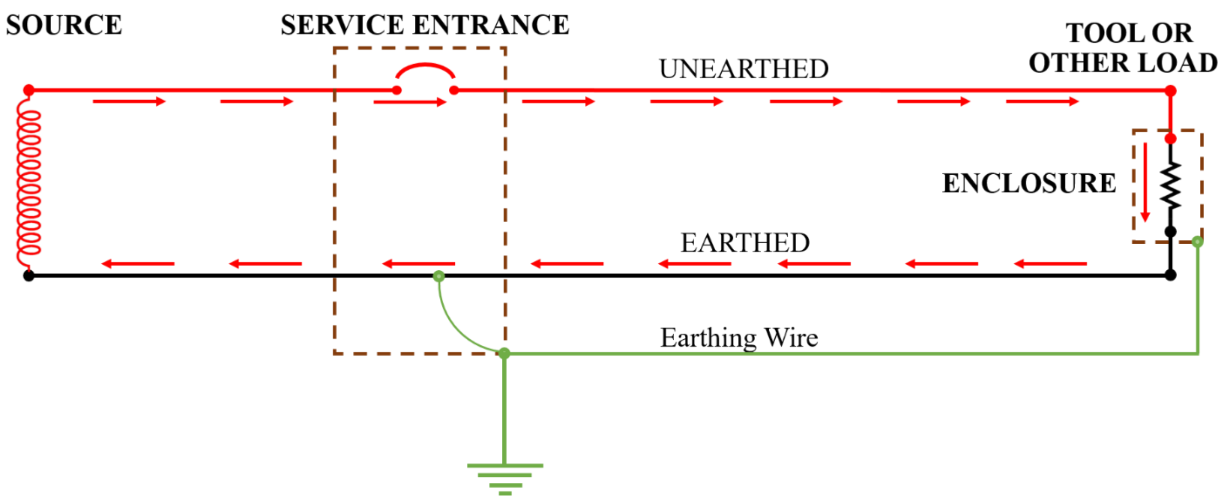
How does grounding do its job?

Proper grounding requires connecting all of the enclosures (equipment housings, boxes, conduit, etc.) *together, and back to the service entrance enclosure*. This is accomplished by means of the green wire in the cord (portable equipment), and the conduit system or a bare wire in the fixed wiring of the building.

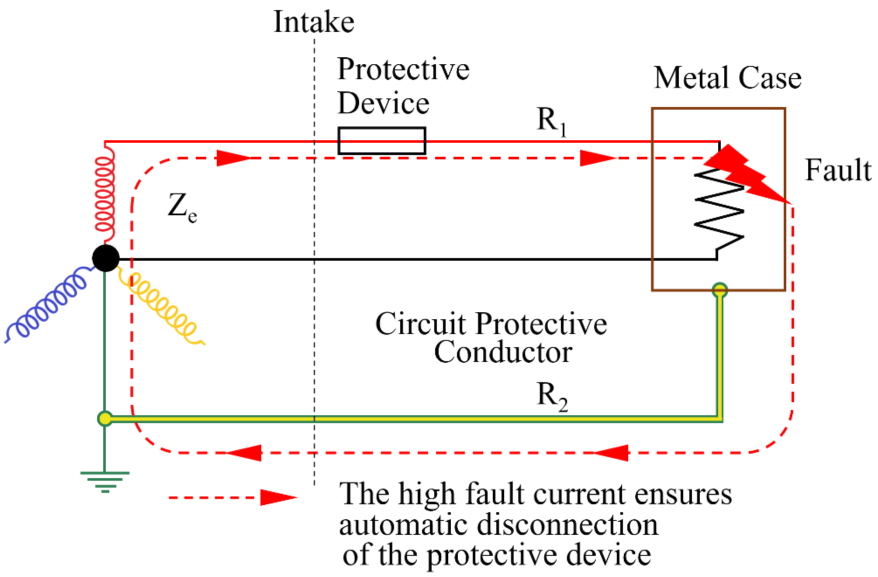
When a ground fault occurs, as in a defective tool, *the grounding conductor must carry enough current to immediately trip the circuit breaker or blow the fuse*. This means that the ground fault path must have low impedance. The only low impedance path is the green wire (in portable cord) and the metallic conduit system (or an additional bare wire if conduit is not used).

Note that the normal useful current flows in the "current-carrying" loop from the transformer over the red wire, through the tool motor and back over the blue/black wire to the transformer. The grounding conductor carries no current. See the figure below.




However, when the insulation on the red (ungrounded) conductor fails and the copper conductor touches the case of the tool, the ground-fault current flows through the green (grounding) conductor and the conduit system back to the service entrance. This is shown in the figure below.

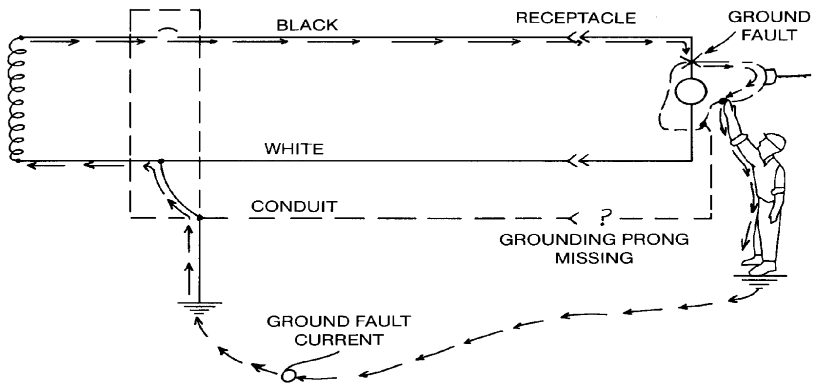



**The ground fault loop** (*The metallic conduit or a bare wire in place of conduit provides the low impedance ground fault path*)

*If the equipment-grounding conductors are properly installed*, this current will be perhaps 10 times or greater than normal current, so the circuit breaker will trip out immediately.

What happens if the earthing does not do the job?

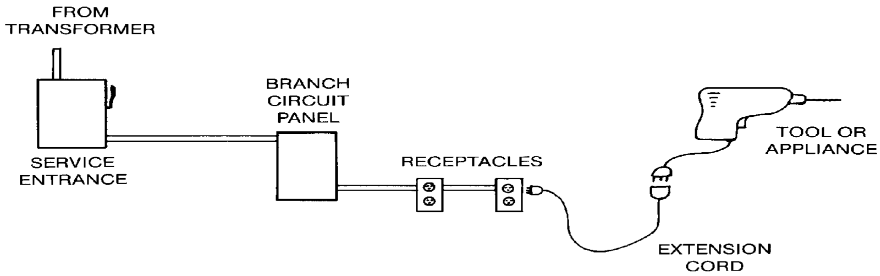
If the ground-fault path is not properly installed, it may have such high impedance that it does not allow a sufficiently large amount of current to flow. Or, if the grounding conductor continuity has been lost (as when the "U"-shaped grounding prong has been broken off the plug), no fault current will flow. In these cases, the circuit breaker will not trip out, the case of the tool will be energized, and *persons touching the tool may be shocked*. See figure below.




**EQUIPMENT-GROUNDING CONDUCTOR NOT COMPLETE**
(THEREFORE THE CIRCUIT BREAKER DOES NOT TRIP OUT WHEN GROUND-FAULT OCCURS.)

The hazard created is that persons touching the tool may provide a path through their body and eventually back to the source of voltage. This path may be through other surfaces in the vicinity, through building steel, or through earth. The dangerous ground-fault current flowing through this high-impedance path will not rise to a high enough value to immediately trip the circuit breaker. Only the metallic equipment-grounding conductor, which is carried along with the supply conductors, will have impedance sufficiently low so that the required large amount of fault current will flow.

So the only way to ensure that the equipment grounding conductor does its job is to be certain that the grounding wire, the grounding prong, the grounding receptacle, and the conduit system are intact and have electrical continuity from each electrical tool back to the service entrance. This is illustrated in the figure below.




**PICTORIAL DIAGRAM OF TYPICAL INSTALLATION**

THE FIXED WIRING FROM THE SERVICE ENTRANCE TO THE RECEPTACLES PROVIDES EQUIPMENT GROUNDING THROUGH CONDUIT OR A BARE WIRE. THE FLEXIBLE CORDS PROVIDE GROUNDING THROUGH A GREEN WIRE AND THE U-SHAPED PRONGS, THUS COMPLETING THE GROUND-FAULT PATH.

As we have discussed, effective grounding along with overcurrent devices (fuses and circuit breakers) are used to protect equipment and facilities, and in so doing, they may also provide considerable protection against shock in most situations. However, the only protective device whose sole purpose is to protect people is the ground-fault circuit-interrupter. The GFCI is discussed in the next section of this module.

## Types of earthing system in Low Voltage (LV) electrical systems

Earthing of the source (sometime called as system earthing or functional earthing), is done to have a balanced potential in the network. In a 3 phase 4 wire system, start point of the transformer is earthed (Neutral). A 3 phase 3 wire system is earthed through a neutral earthing transformer. The earthing systems are classified as TN System, TT System and IT System. In TN/TT system, safety is achieved by disconnection of supply during fault whereas, in IT system, continuity of supply is possible during first fault.

i) **TN System** – It 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 system is further sub-divided into TN-C, TN-S and TN-CS systems.

ii) **TT System** – It 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).

iii) **IT System** – It 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.

These are the commonly used methods..

The first letter T in the network denotes the source earthing. "T" stands for Terra which is a French word meaning "direct connection to earth" (soil or foundation steel).

| | | |
|---|---|---|
| First letter | T | Connected directly to main earth at a certain point in the power system, normally at the supplying transformer (T= earth or Terre in French) |
| | I | The power system is insulated from earth or connected to earth through a sufficient high impedance (I = Isolated) |
| Second letter | T | The exposed conductive parts are connected directly to earth independently of the earthing of any point of the power system |
| | N | The exposed conductive parts are connected directly to earth at the main earthing point (in a.c. systems, the earthed point of the power system is normally the neutral point or, if a neutral point is not available, a line conductor). |
| Additional letter(s) *-arrangement of neutral and protective conductor* | S | The Protective Conductor (PE) and Neutral Conductor (N) are two different and separate conductors (S = Separate). |
| | C | The Protective Conductor (PE) and Neutral Conductor (N) are one common conductor (PEN) (C = Combined/ Common). |

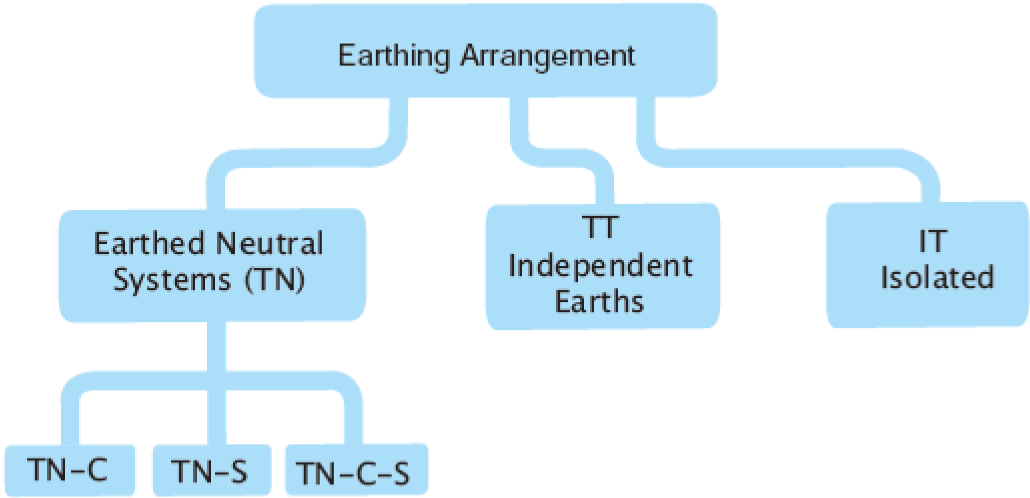



**Fig: Types of earthing system**

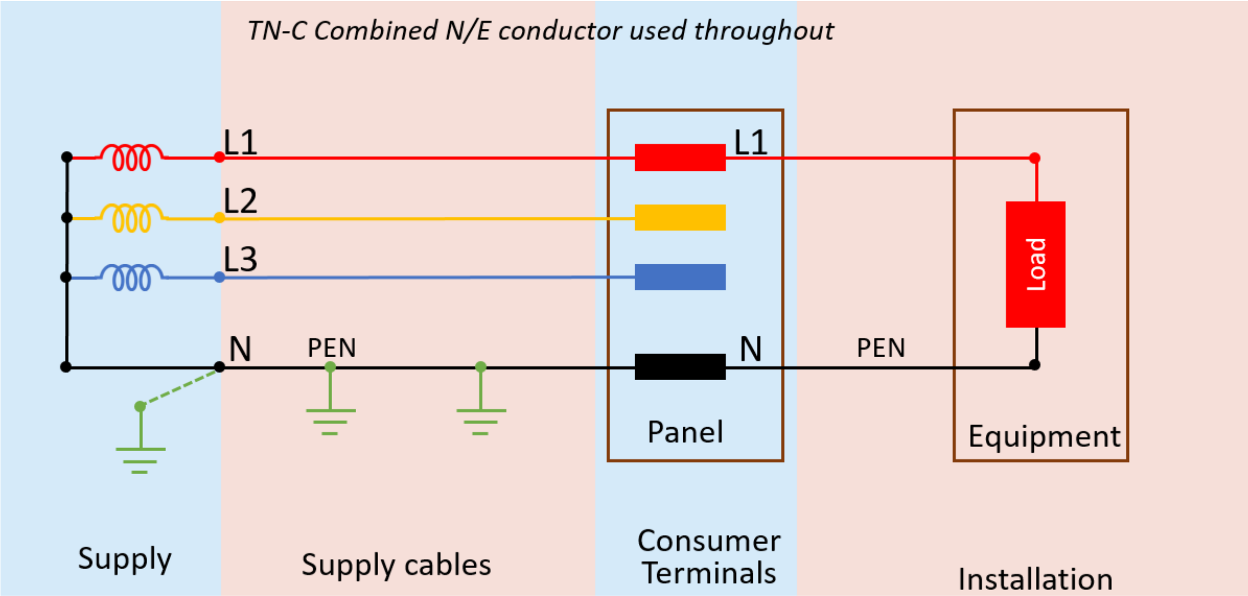



Figure: TN-C system earthing

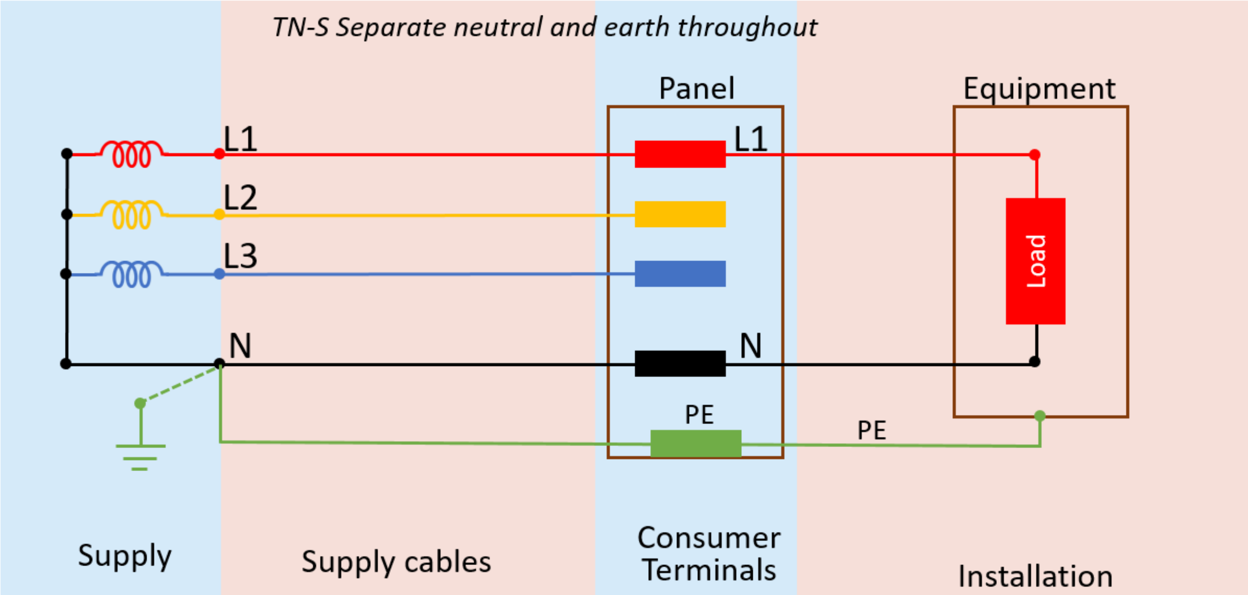



Figure: TN-S system earthing

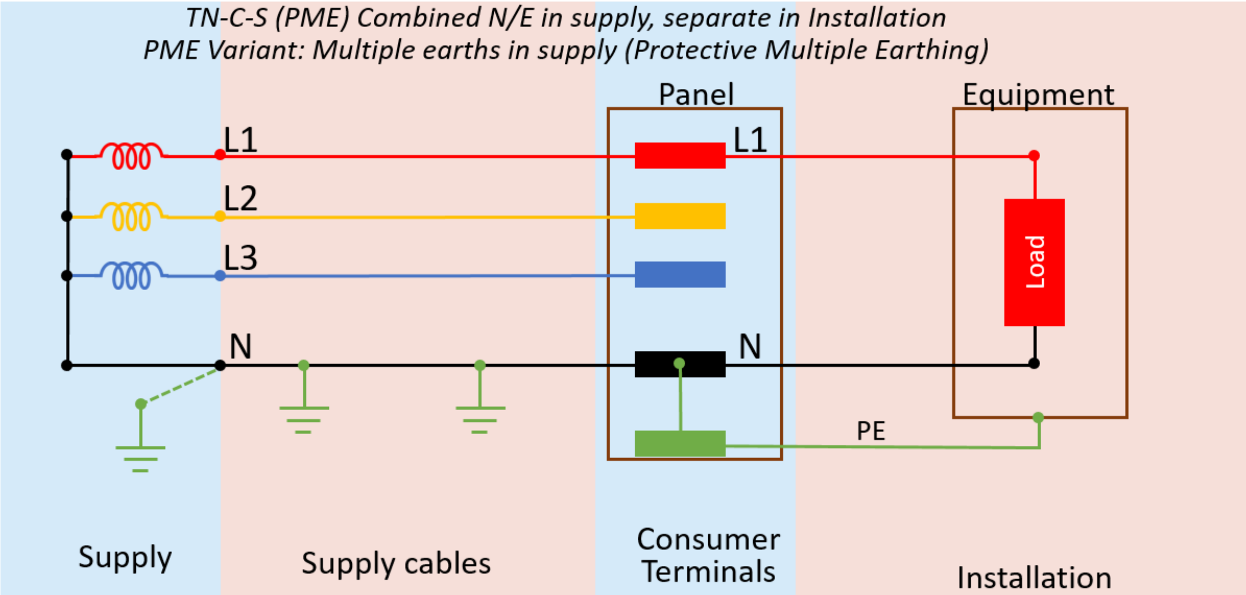



Figure: TN-C-S System earthing with PME.

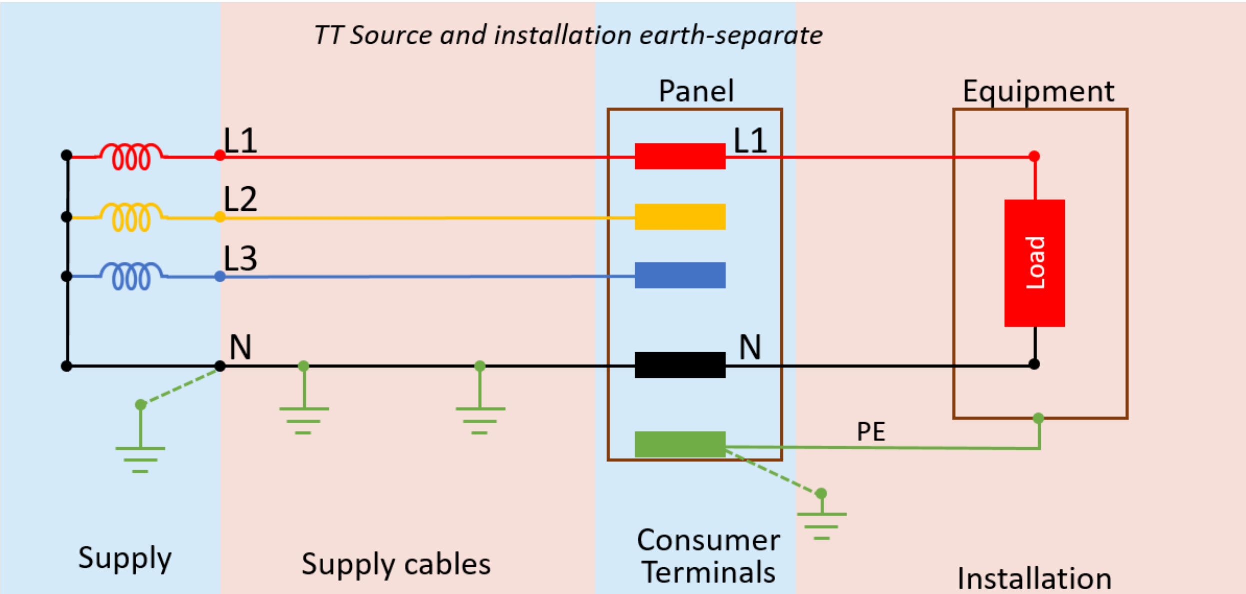



Figure: TT System earthing

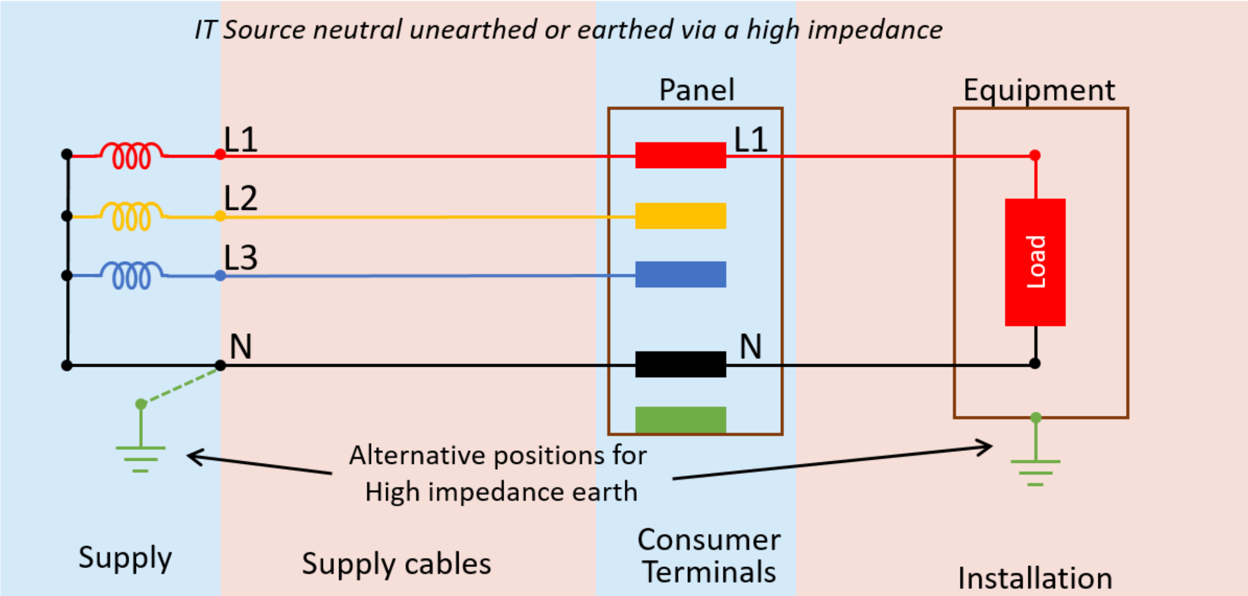



Figure: IT System earthing

Earthing: Getting it right: Some good practices and misconceptions (Myths)

**a. Separate Earth Pit**

Myth: Standards and regulation recommend connection to two separate earth pit for transformer neutral, transformer body, DG neutral, DG body, UPS neutral, UPS body, Panel body, elevator, each and every electrical appliance. All earth electrodes under soil need interconnection under soil as a grid.

Fact: The subject of earthing is about achieving safety during an earth fault by implementing various electrical safety rules. The most common rule is "protective equipotential bonding and automatic disconnection of supply"(also called as earthed equipotentia1 bonding and automatic disconnection of supply).

**b. Chemical earth pit improves the system**

Myth: Chemical earth, digital earth, pipe in pipe, plate in pipe, NCE charge electrode, earth enhancing compound, chemical compound, granule backfill compound. Carbon earth, gel earthing electrode and other attractive names are used to call earth electrodes. Some of them claim that they can absorb lightning, fault current and solve major electrical problems. There are claims that the various types of earthing are capable of providing clean earth pit resistance close to 1ohm in any soil.

Fact: All the above claims are false. The compounds used are fly ash, bentonite, carbon flakes, graphite, cement or combination of these. They are called in attractive names. Except conductive cement, others seem to be creating problem to earth electrode in long run.

**c. Earth pit of 1 Ohm is required for safety and operation of electronics.**

Fact: Resistance of an earth pit in soil does not influence any LV electrical installation. There is no need of a 1 Ohm resistance for an earth pit in an electrical system including DG or transformer.

**d. Chemicals in a chemical earth pit produce low resistance.**

Fact: Resistance of an electrode to soil is influenced by the (1) resistance of the metal electrode, (2) contact resistance to soil and (3) the resistivity of the surrounding soil. Out of these three, the main influencing factor is the soil resistivity surrounding the electrode over an area of few meters. Chemicals (such as salt) which influences the area surrounding the soil will leach in a short time and of no use after few months. Some compounds help in reducing the contact resistance between the electrode and soil, hence can be used in rocky areas to have some reduction in the resistance of an earth electrode. However, a value in the range of 1 Ohm or 100 Ohms does not influence the total LV system.

**e. The best way of installing an earth electrode is to use with a chemical compound.**

Fact: Best results are achieved by hammering the electrode in soil. However, this is not possible in rocky areas, hence an enhancing compound such as conductive concrete may help in getting better results.

**f. Earth pit resistance influence the tripping time of an Over Current Protective Device.**

Fact: Earth fault loop impedance (not earth pit resistance) influence the tripping time of an OCPD

**g. Lightning protection require an earth electrode of 10 ohms.**

Fact: Type A electrodes can have an optional resistance of 10 Ohm. However, the recommended practice for modern buildings are Type B earthing which is a ring earthing or a foundation earth electrode. For Type B earthing, 10 Ohm resistance is not mandatory.

**h. Earthing in high-rise buildings:**

Myth: Type A, vertical rod electrodes are installed in basements inside the periphery of buildings, in order to dissipate lightning current to earth.

Fact: This is a violation of standard IEC 62305-3. The standard explains, "Type A arrangement comprises horizontal or vertical earth electrodes installed outside the structure to be protected connected to each down conductor or foundation earth electrodes not forming a closed loop".

**i. Grounding & earthing:**

Myth: Grounding is for transformer neutral and earthing is for metal objects in an installation.

Fact: Both terms are the same. "Grounding" is used in USA and "Earthing" is used in IEC standards.

An electrical system may work without a fault for years. Good earthing practices are to ensure that the installation is safe during fault. However wrong practices create accidents during fault

**j. Myth: Neutral require two separate and distinct connections to earth electrode in soil:**

Fact: Neutral shall be earthed to MET, the best practice is to connect the neutral as per the connection in the following figure.

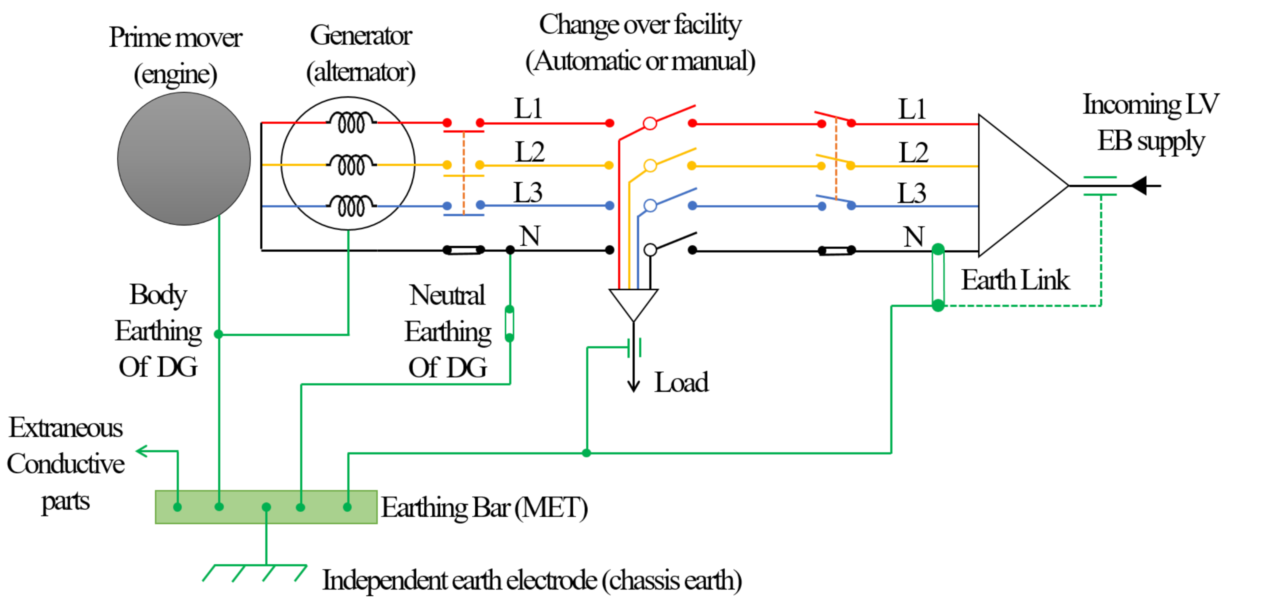
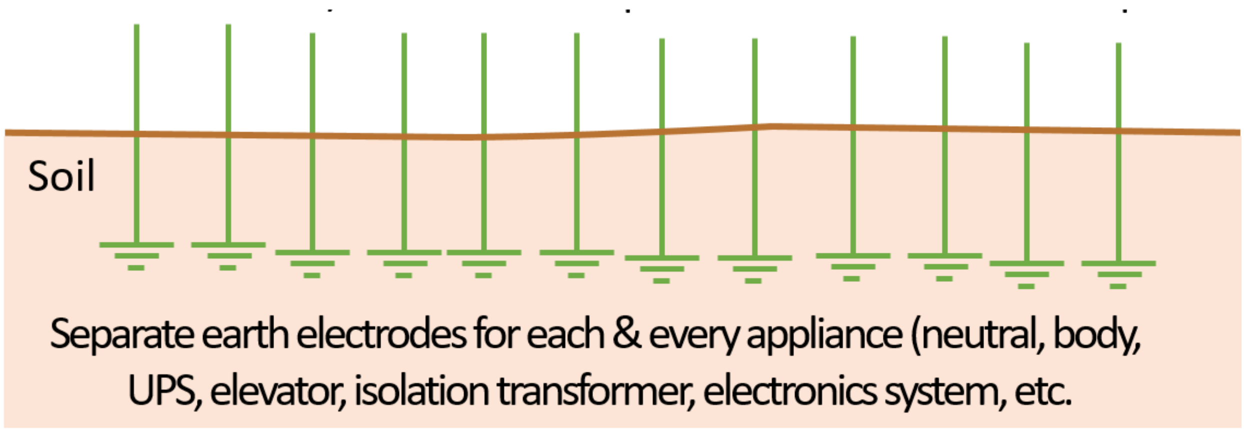
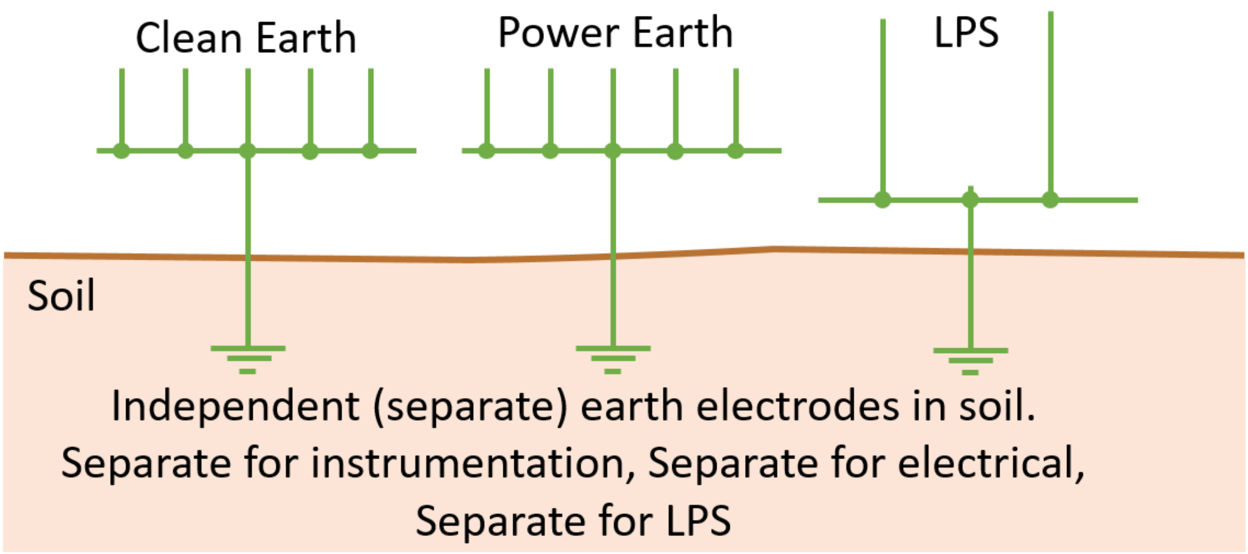


**Figure:** Typical method of earthing in a TN-C-S by the Neutral to earth link (the correct way of earthing)

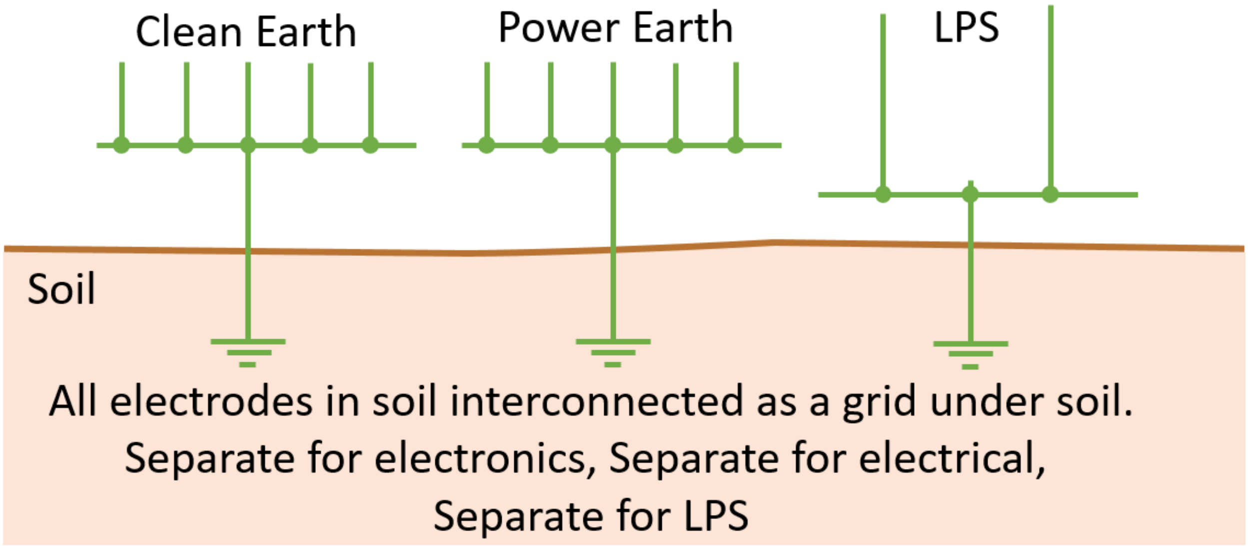
**Some examples of wrong practice in earthing:**



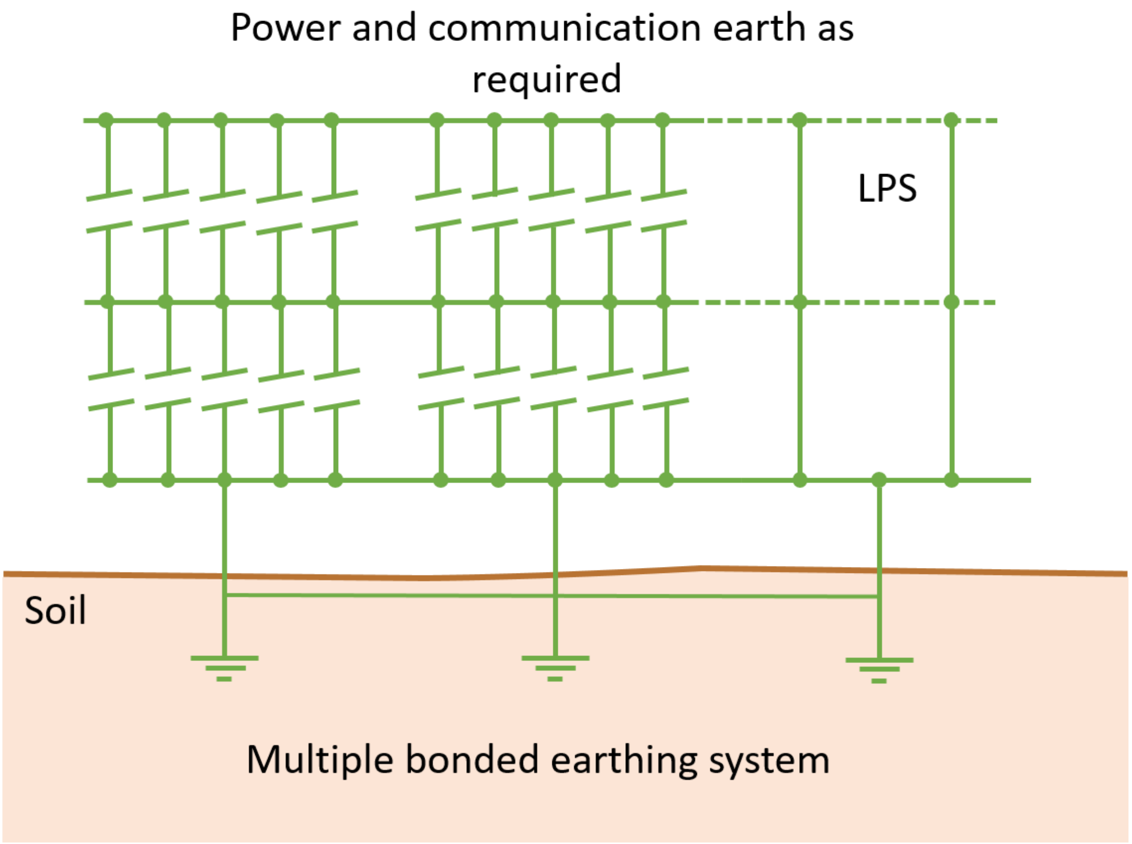

(a) Wrong practice no 1.




(b) Wrong practice no 2.




(c) Wrong practice no 3.




**(d) Good Practice: This will enhance the life of electrical and electronic systems and provide the maximum safety against electrical faults and hazards.**

## 3.4 Possible bad practices in the perspective of Reverse Polarity

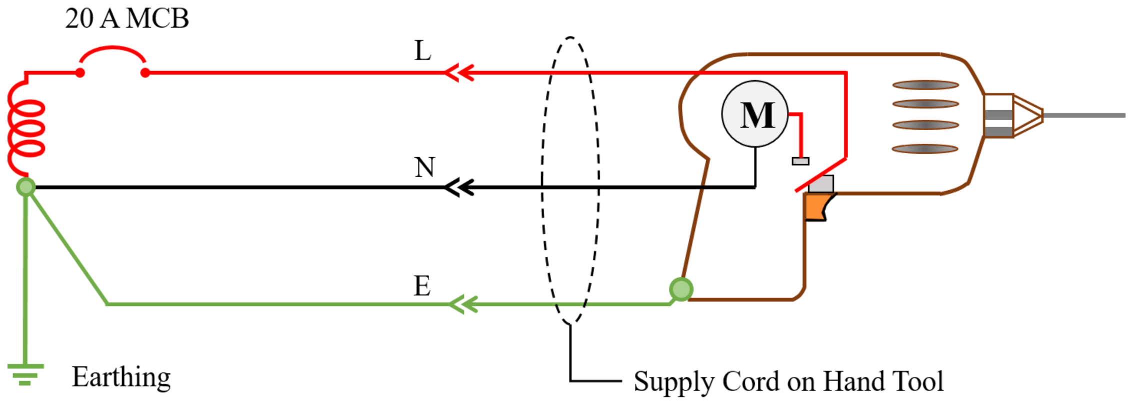



**Figure: Good practice (correct wiring)**

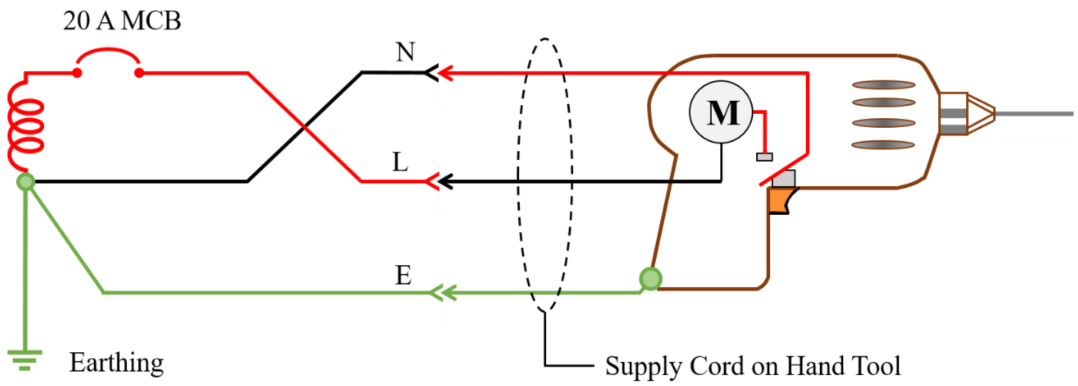



**Figure: Bad practice (incorrect wiring)**

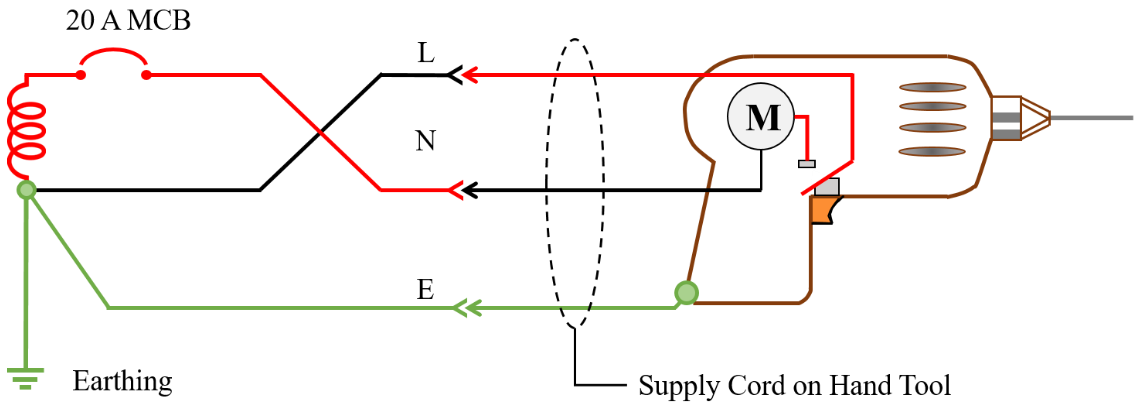



**Figure: Bad practice (incorrect wiring)**

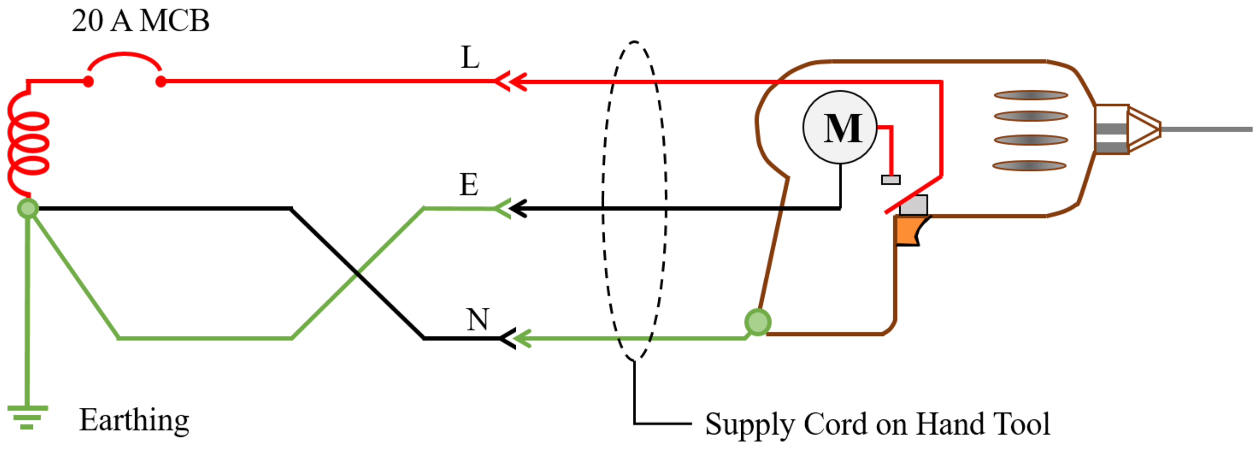



**Figure: Bad practice (incorrect wiring)**

# 3. FIRES CAUSED BY ELECTRICAL FAULTS

## 3.1 Common Causes of Electrical Fires

Electrical faults or short circuit are the most common causes of the home fires. Main reason for the ignition of the fire from electrical installation is the excessive rise of temperature in the conductors or installations. The common causes of electrical fires are as follows.

**1. Faulty electrical outlets and aging appliances.** This can include faults in appliance cords, receptacles and switches. If an appliance has a worn or frayed cord it can generate dangerous levels of heat, igniting surfaces like rugs and curtains, starting a fire.

**2. Using ungrounded plugs.** Appliances have the third prong so they can be only used in outlets designed to handle the demands of higher wattage appliances. Never circumvent the ground on an appliance or power cord.

**3. Overloading light fixtures.** Installing a high wattage bulb into a lamps or light fixtures that it is not designed for is a leading cause of electrical fires. Always install a bulb that is within the recommended wattage.

**4. Placing flammable material near light fixtures.** Placing cloth or paper over a lampshade can cause the material heat up and ignite, causing a fire.

**5. Extension cord misuse.** Large appliances should not be plugged into an extension cord. If you do not have a nearby outlet for your appliances, you should have one installed.

**6. Space heaters.** Placing electric heater too close to combustible surfaces such as curtains, bedding and furniture is a leading cause of house fires. Coil space heaters should be avoided if possible. Liquid filled "soft heat" electric heaters are safest.

**7. Old wiring.** If your home is over twenty years old, it may not have the capacity to handle today's energy intensive homes. In addition, outdated breaker boxes often have worn connectors that do not work, causing the system to overload.

***Apart from the above mentioned causes, there are three more crucial causes that are generally overlooked and preventive measures are not being adopted. Those causes are:***

8. **Quality of the conductor**: The resistance of a conductor plays a vital role in generating heat in the circuit that leads to the degradation of insulation failure, short circuit and ignition of fire. This results due to the loose contact, non-standard dimensions of the conductor and the material of the conductor.

**9. Fault loop impedance**: The fault loop impedance is another serious issue that has generally been overlooked by the professionals. When the fault loop impedance increases in the circuit, there will be a drop in current due to which automatic disconnection of the over current protective device (OPCD) say fuse, MCB, MCCB etc. will not be attained or the protective devices will not trip. This will result in the excessive heat of the conductor leading to the fire.

The occurrence of an earth fault in an installation creates two possible hazards.
Voltages appear between exposed conductive parts and extraneous conductive parts (if these parts are simultaneously accessible), constitute a shock hazard (indirect contact).
The fault current that flows in the phase and those protective conductors, may cause an excessive temperature rise in conductors, thereby creating a fire hazard.
The protective measure known as "protective earthing, protective equipotential bonding and automatic disconnection of 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 (TN/TT) of which the installation is part, because:
Either

i) the earth fault loop impedance has to be low enough to allow adequate earth fault current to flow to cause an overcurrent protective device (for example, a fuse or circuit breaker) in the faulty circuit to operate in a sufficiently short time.

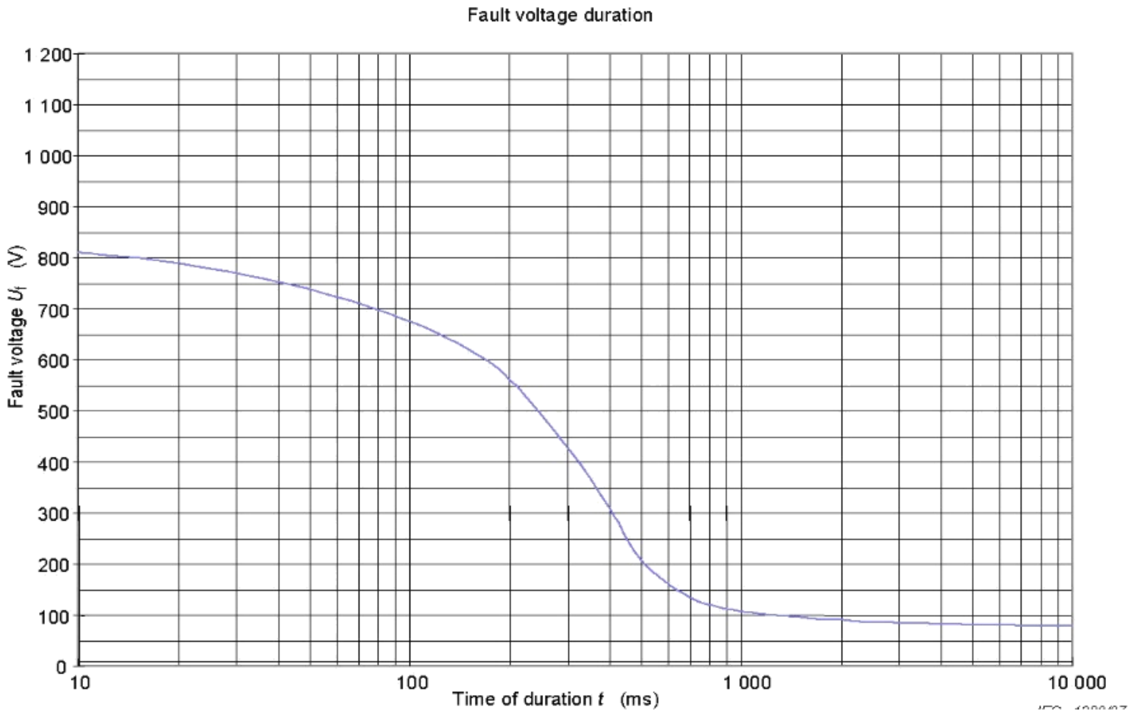
Or

ii) 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) of 30 mA rating.

Touch voltage and disconnection time for earth fault
Disconnection times and allowed touch voltages are explained in various standards. Table below depicts the allowed touch voltage and disconnection time for DRY and WET conditions during an earth fault (Ref. IEC61936-1).
Over Current Protective Devices (OCPD, e.g. fuse mcb, mccb) require multiples of rated current to disconnect the supply within the specified time. Impedance of the earth fault loop decide the fault current.

**Table: Touch voltage and disconnection time**

| **Range of Voltage** | **50V< *U*o≤ 120V (Time in sec)** | | **120V< *U*o≤ 230V (Time in sec)** | | **230V< *U*o≤ 400V (Time in sec)** | | ***U*o >400V (Time in sec)** | |
|---|---|---|---|---|---|---|---|---|
| System | ac | dc | ac | dc | ac | dc | ac | dc |
| TN | 0.8 | | 0.4 | 5 | 0.2 | 0.4 | 0.1 | 0.1 |
| TT | 0.3 | | 0.2 | 0.4 | 0.07 | 0.2 | 0.04 | 0.1 |
| Where in TT systems the disconnection is achieved by an overcurrent 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. | | | | | | | | |
| *Note: Disconnection may be required for reasons other than protection against electric shock.* | | | | | | | | |




Earth fault Loop impedance and disconnection by OCPD

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. The time of operation would depend on the magnitude of the contact potential. As a general rule, 65 V may be cleared within 10 seconds and voltages of the order of 240 V and above shall be cleared instantaneously. This requirement is met if

$$Z_s \times I_a \leq U_o$$

where,

$Z_s$ = fault loop impedance in Ω; $I_a$ = current ensuring the automatic operation of disconnecting device; and $U_o$= conventional voltage limits.

To ensure thermal protection to the protective conductor & considering the tolerance requirement, the measured value of $Z_s$ in an installation shall be 2/3$^{rd}$ of the calculated value.

In general, every circuit is provided with a means of overcurrent protection. If the earth fault loop impedance is low enough to cause these devices to operate within the specified times (that is, sufficient current flows to earth under fault conditions), such devices may be relied upon to give the requisite automatic disconnection of supply. If the earth fault loop impedance does not permit the overcurrent 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 additional earth. It may be electrodes (public for distribution system) or protective multiple earthing (industrial & commercial system).

**Table: Recommended fault loop impedances for different type and rating of MCB's**.

| | MCB rating in amps (A) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Type of MCB** | 6 | 10 | 16 | 20 | 25 | 32 | 40 | 50 | 63 | 80 | 100 | 125 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Type B** (Zs in Ω) | 5.11 | 3.07 | 1.92 | 1.53 | 1.23 | 0.96 | 0.77 | 0.61 | 0.49 | 0.38 | 0.31 | 0.26 |
| **Type C** ( Zs in Ω) | 2.56 | 1.53 | 0.96 | 0.77 | 0,61 | 0.48 | 0.38 | 0.31 | 0.24 | 0.19 | 0.16 | 0.12 |
| **Type D** ( Zs in Ω) | 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 earth fault loop impedance is not less than the recommended values, disconnection shall be initiated by fitting a residual current device (RCD) of 30 mA rating.

**10. Electrical surges:** The sudden rise in the voltage or current in the electrical circuits that may last for a few micro-seconds are generally termed as electrical surges. Although, the electrical over-voltages are normally protected by MCB, MCCB etc. they fail to handle the micro-second scale electrical surges owing their slow response time i.e. a few milliseconds. With the technological advancement, the modern era is overwhelmingly dependent on the electronic appliances that make incredible use of semiconductor devices. The semiconductor devices are very much susceptible to the micro-second scale electrical surges. The electronic appliances not only get damaged by the electrical surges but they may ignite the fire that in turn leads to the home fire.

The safety measures against the fire due to above mentioned causes have generally been addressed as follows:

a) Life safety (evacuation, fire-fighter safety, etc.)
b) Passive fire protection (stopping fire spread).
c) Active fire protection (detection, warning and suppress)
d) Manual fire protection (extinguisher, hydrants etc.)

**However, the above measures do not avert/prevent the ignition of the fire. Neither does the usage of fire survival cables stop ignition of the electrical fires**.

Electrical safety means to avoid the 1) electrocution and 2) Ignition of fire. These measures can be achieved by the proper design, erection (installation) and testing.

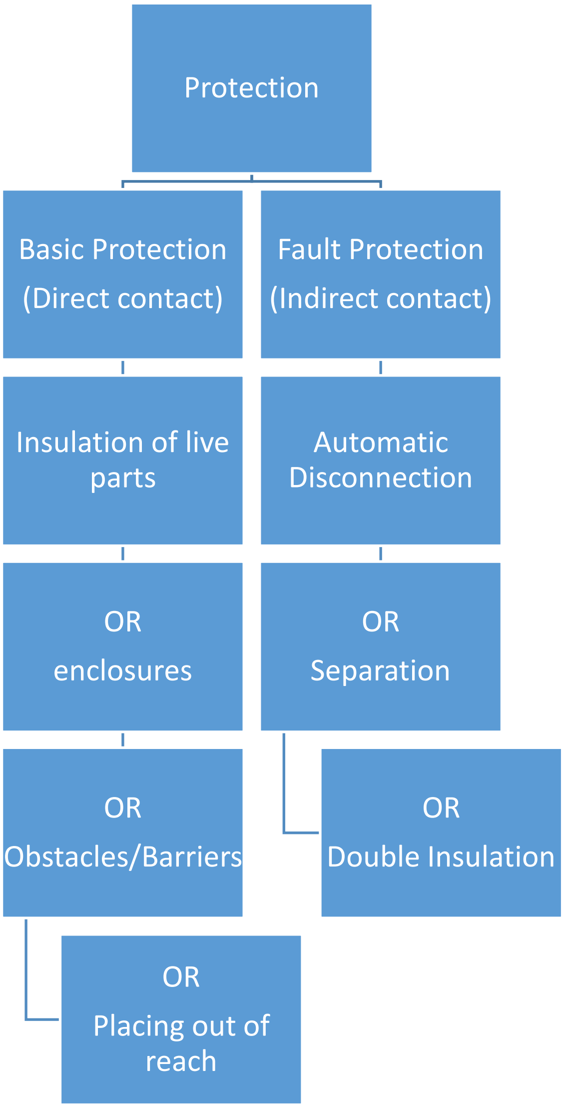
**In addition to the above mentioned common causes of electrical fire, there are some critical issues that are generally overlooked or are subject to malpractice.**

## 3.2 Preventive measures of electrical fire hazards

In order to avoid the potential electrical fire hazards, preventive / protective measures are to be ensured while carrying out electrical installations and from time to time later on. The various protective measures are discussed in this section. For supplementary information and some reference data, please refer to **Annex – A1**.

### 3.2.1 Protective measures in Low Voltage System

***Basic and Fault Protections*:**
Protection against electric shock can be achieved by practicing the following chart




Apart from the protective measures mentioned in the above chart, the use of Residual Current Device (RCD) with a residual operating current ($I_{\Delta n}$) not exceeding 30 mA, and operating time not exceeding 40 ms can be used as an additional protective measure against electric shock in the event of failure of basic/fault protection or carelessness by users. The additional fault protection can be achieved by means of automatic disconnection using **protective earthing, protective equipotential bonding and automatic disconnection of supply.**

The purpose of **protective earthing** is to ensure that, in the event of a fault, such as between a line conductor and an exposed-conductive-part or circuit protective conductor, sufficient current flows to operate the protective device, i.e. fuse to blow, circuit-breaker to operate or RCD to operate, in the required time.

Every *exposed-conductive-part* (a conductive part of equipment that can be touched and which is not a live part but which may become live under fault conditions) shall be connected by a protective conductor to the main earthing terminal and, hence, the means of earthing for the installation.

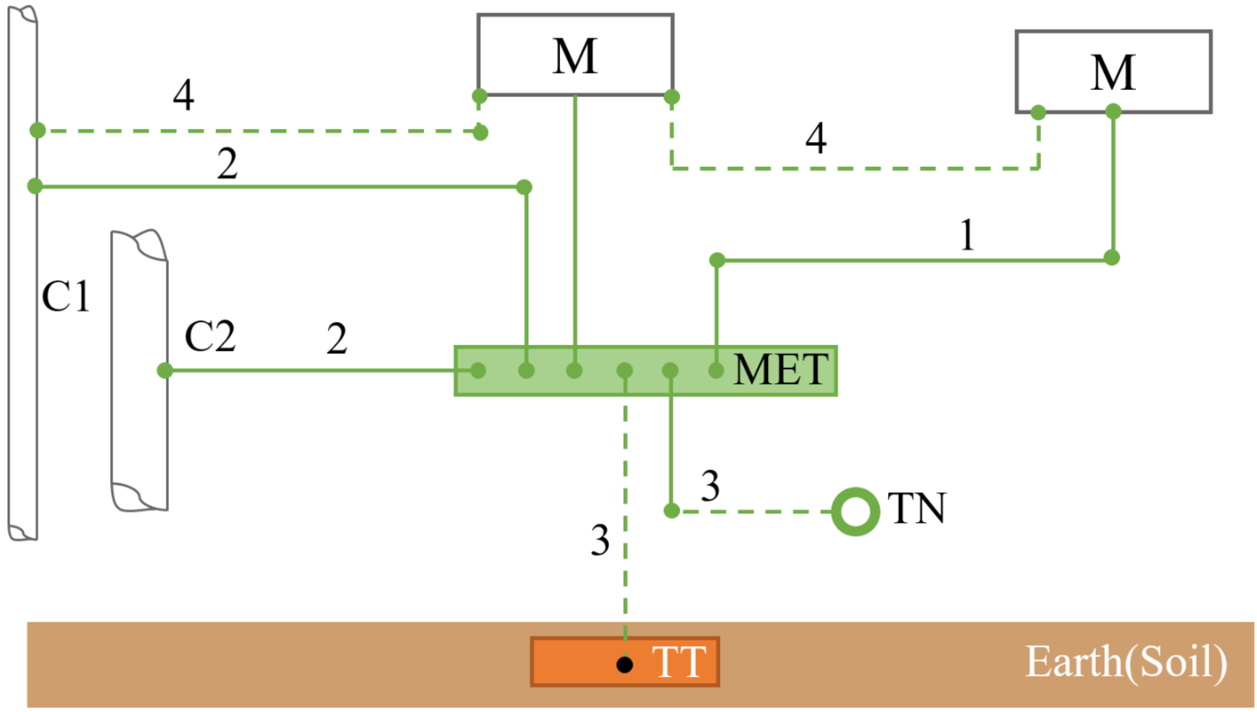



Figure: Example of protective earthing and protective equipotential bonding in an installation

**Legends in the figure:**

M - Exposed conductive part
MET - Main Earthing Terminal
C1 - Steel reinforcement in concrete (Extraneous conductive part)
C2 - Main Metallic water pipe
TT - Earth electrode (TT and IT system)
TN - Other types of earthing (TN system, e.g. earth point or neutral of source.

1 - Protective earthing conductor
2 - Main equipotential bonding conductor
3 - Earthing conductor
4 - Supplimentary equipotential bonding conductors

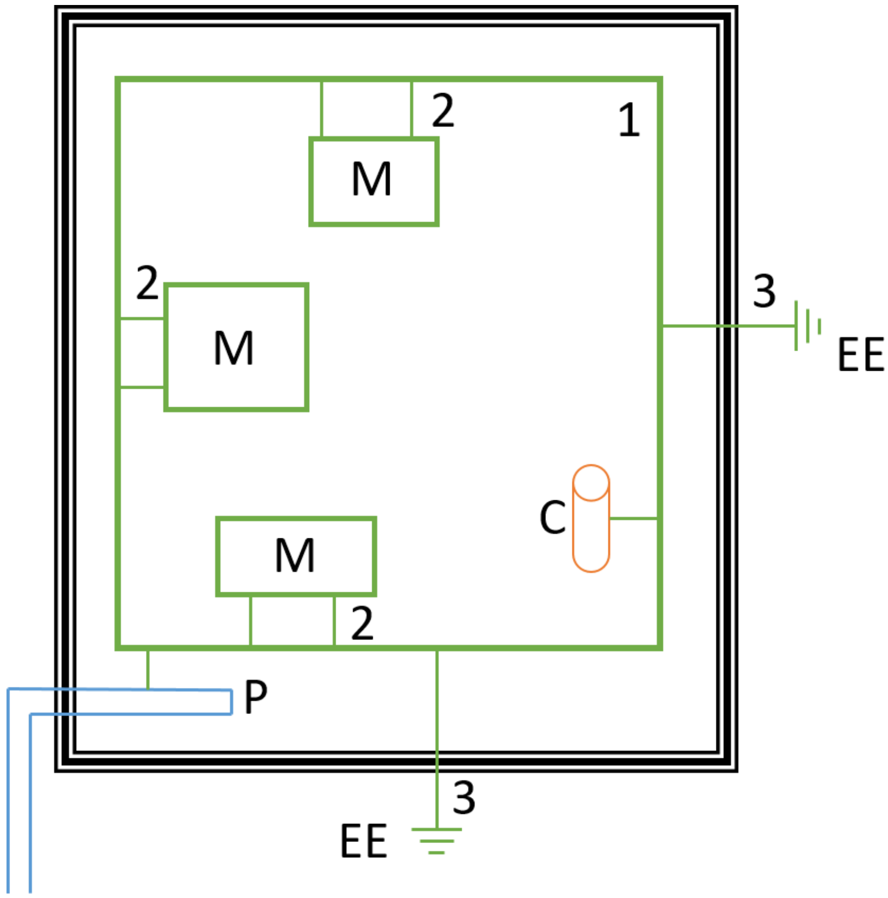
the

(protective equipotential bonding).

***Protective Earthing and Protective Equipotential Bonding***:

**a. Equipment Earthing (Protective Earthing):**

This is the connection of all exposed conductive parts to the MET of the installation by protective conductors. The purpose is to facilitate the automatic disconnection of supply by the protective device during earth fault.




In the Fig.:

M = Exposed conductive parts = Incoming metallic service

C = Extraneous conductive parts

EE = Earth electrode

1 = Equipotential bonding conductor (MET) (in case of small domestic installations 1 starts from the neutral link - TN-C-S network)

2 = Protective earthing conductor (PE)

3 = Earthing conductor

**b. Main Equipotential Bonding:**

It is the equipotential bonding at origin of installation. Where extraneous conductive parts originate outside the building, it shall be bonded as close as possible to their point of entry to the building. A common entry point is preferred to reduce the overvoltage created due to induction currents.

**Purpose of main and supplementary equipotential bonding:**

Equipotential bonding at the origin of installation is made to reduce touch voltage (UT) during the fault. Large installations where the impedance of the PE conductor is higher due to its length, the fault current flow through the PE conductor may induce voltage between simultaneously accessible metallic parts downstream the installation, strong enough to create a shock. To enhance safety against electric shock, supplementary protective equipotential bonding as an additional fault protection shall be carried out.

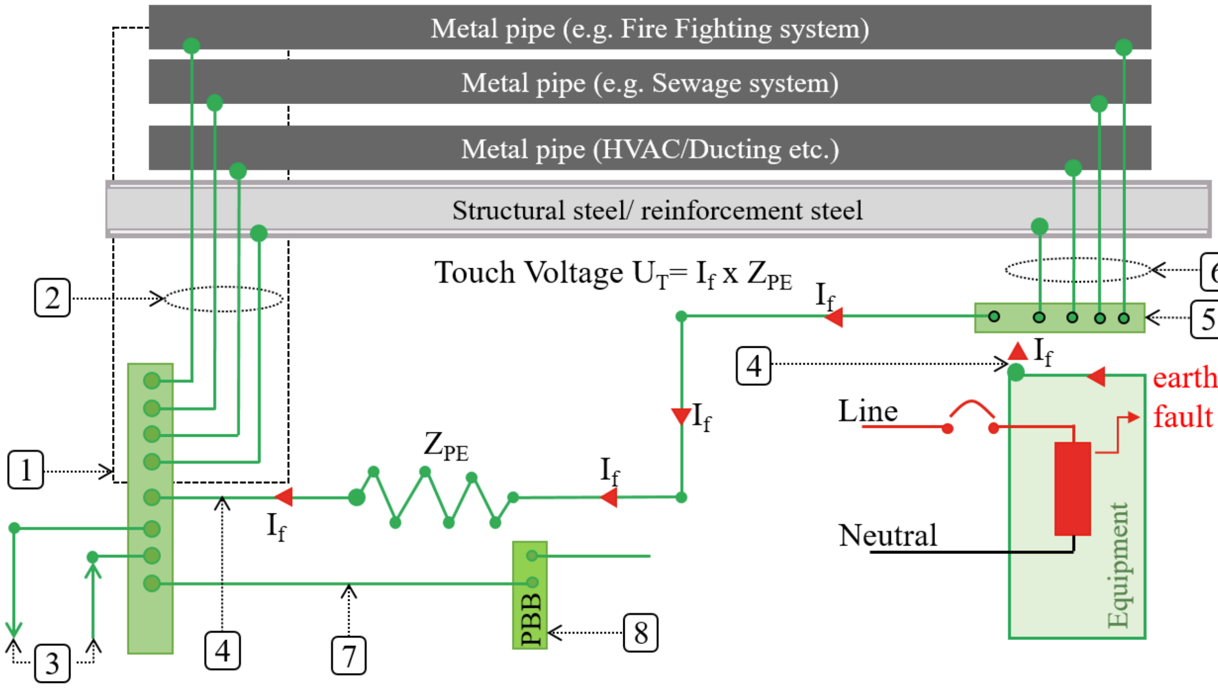



Figure: Illustration of main and supplementary equipotential bonding

As indicated in the figure:

1. **Main equipotential bonding** (connection between MET and extraneous conductive parts).
2. Main equipotential bonding conductor (individual connection, no looping). In case of large number of extraneous conductive parts, an earthing terminal can be located near the extraneous conductive parts for individual connection to these parts and a common connection from this earthing terminal to MET. Suitable indications shall be made to every connection of equipotential bonding conductor to avoid accidental disconnections.
3. Earthing conductor. (Connects MET & earth point of the source in TN system or MET and earth electrode in case TT/ IT system). One connection of MET is also necessary for LPS if installed.
4. Protective earthing by Protective Earthing conductor (PE).
5. **Supplementary equipotential bonding** terminal (SEBT) to reduce touch voltage during a fault to a level less than 32 volts.
6. Supplementary equipotential bonding conductor
7. Functional Earthing conductor (FE) (e.g. Telecommunication bonding conductor.
8. Parts of functional earthing system (e.g. PBB - Primary bonding busbar of a Telecom bonding network.

An installation may consist of a number of equipotential bonding zones. For example, when an installation supplies a number of buildings, equipotential bonding is necessary for 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. Large buildings shall have several zones within the building.

Rapid disconnection of circuit in which the earth fault occurs 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 earth fault, disconnection will occur before the protective touch voltage reaches a harmful value.

Parts to be earthed for proper protection

**a. Exposed Conductive parts to be earthed**

- All metal work associated with wiring system (other than current carrying parts) including cable sheaths and armour, conduit, ducting, trunking, boxes and catenary wires;
- The exposed metal work of all class I fixed and portable current using equipment;
- The exposed metalwork of transformers used in the installations other than those that are an integral part of equipment

Exposed conductive parts that cannot be gripped or contacted (owing to their small dimension or disposition), by a major surface of the human body (*not exceeding 50 mm X 50 mm*) need not be earthed if the connection of those parts to a protective conductor cannot readily be made and reliably maintained. For example, fixing screws for non-metallic accessories need not be earthed, provided that there is no applicable risk of the screws coming into contact with live parts.

**b. Extraneous Conductive parts to be earthed**

- Metallic pipes supplying services into the building such as water, sewage, gas etc.;
- Metallic air conditioning systems;
- Structural extraneous conductive parts, if accessible in normal use;
- Metallic reinforcement of building RCC, if practical;
- Lightning Protection system as per IEC 62305-3

**c. Earthing installation with external Lightning Protection System (LPS) in place**

When the external lightning protection system is in place the following connection is to be followed. The figure will provide the correct information about the earthing system for electrical installation for all kinds of structures including commercial and industrial buildings.

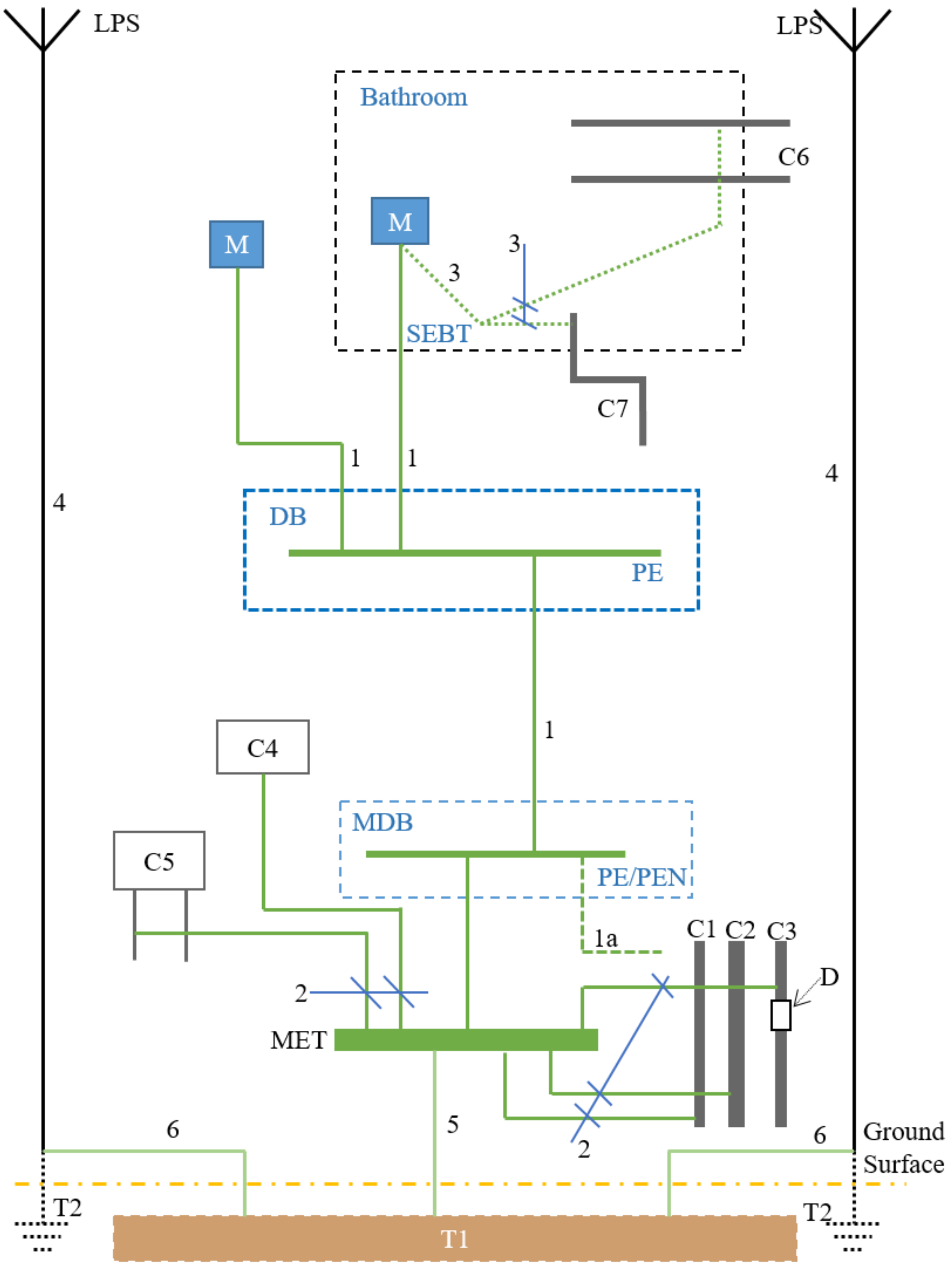



**Figure**: Illustration of the earthing and bonding of electrical installation and wiring along with the external lightning protection system.

**Legend for the figure:**

| **Key** | **Description** |
|---|---|
| C | Extraneous conductive part |
| Cl | Water pipe, metal from outside |
| C2 | Wastewater 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 | Wastewater 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 |
| 5 | Earthing conductor |

### 3.2.2 Electrical Surges and Surge Protecting Devices (SPD)

Causes of electrical surges

Surges are primarily caused by:

- Transient switching operations
- Lightning due to atmospheric discharges
- Electrostatic discharges
- Faulty switching operations

**Switching operations:** Switching operations (switching electromagnetic pulse, SEMP) can generate induced surge voltages that spread to supply lines. In the case of large switch-on currents or short circuits, very high currents can flow within a few milliseconds. These short- term current changes can lead to transient overvoltages.

Surges from electrical switching events are created when large inductive loads, such as motors or air conditioning units, switch off and release stored energy which dissipates as a transient overvoltage. Switching surges are, in general, not as severe as lightning surges but are more repetitive and can reduce equipment lifespan.

The typical duration and amplitude of the surge voltage varies depending on the cause.

**Lightning strikes**:

It is above all lightning strikes (lightning electromagnetic pulse, LEMP) that have the greatest potential for damage among all the causes of occurrence. They cause transient overvoltages that can extend across great distances and are often associated with high-amplitude surge currents. Even the indirect effects of a lightning strike can lead to a surge voltage of several kilovolts and result in a surge current of tens of thousands of amperes. In spite of the very brief duration – a few hundred microseconds to a few milliseconds – such an event can lead to total failure or even the destruction of the affected installation. Overvoltages of atmospheric origin, i.e. created by lightning events, in particular, can present a risk of fire and electric shock owing to a dangerous flashover.

**Electrostatic discharges**: Electrostatic discharges (ESD) occur if bodies with different electrostatic potential approach each other and result in a charge exchange. A sudden charge exchange leads to a brief surge voltage. This presents a hazard, especially for sensitive electronic components.

**Protection against transient over-voltages shall be provided where the consequence caused by overvoltage:**

**(a)** results in serious injury to, or loss of, human life, (e.g. hospitals, care homes, home dialysis equipment)

**(b)** results in interruption of public services and/or damage to cultural heritage, (e.g. data centers, heritage status buildings like museums and castles)

(c) results in interruption of commercial or industrial activity (e.g. banks, hotels, supermarkets, industrial plants, farms)

**(d)** affects a large number of collocated individuals (e.g. offices, universities, schools, residential tower blocks)

Surge Protecting Devices (SPD)
Depending upon the nature of electrical surge and the electrical installation three types of SPDs are allocated for the AC power circuits:
**Type 1 SPDs** are only used where there is a risk of direct lightning current and, typically, are installed at the origin of the installation
**Type 2 SPDs** are used at distribution boards
**Type 3 SPDs** are used near terminal equipment.

Combined Type SPDs are classified with more than one Type, e.g. Type 1 & 2, Type 2 & 3, and can provide both lightning current with overvoltage protection in addition to protection between all conductor combinations (or modes of protection) within a single unit. Combined Type SPDs provide high surge current handling combined with better overvoltage protection levels (Up) - the latter being a performance parameter of an SPD.

Installations of SPDs
To gain maximum protection the connecting conductors to SPDs must be kept as short as possible, to minimize additive inductive voltage drops across the conductors. The total lead length *(a + b)* should preferably not exceed 0.5 m but in no case exceed 1.0 m;

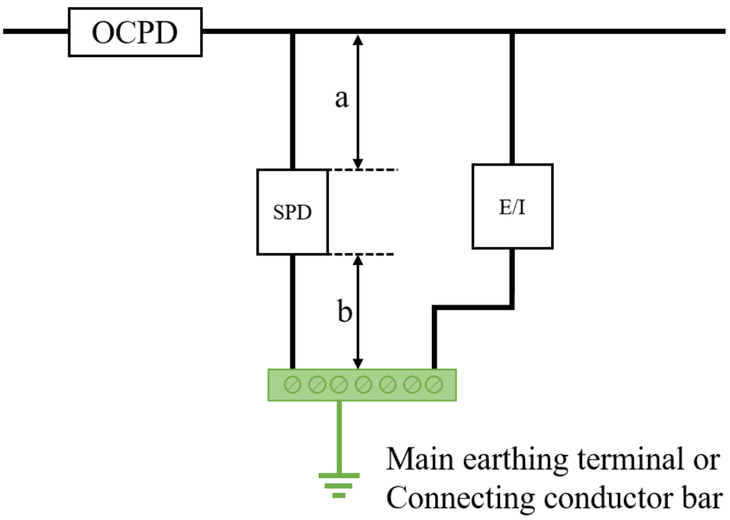



***Figure: Installation of SPD in an electrical circuit***.

Here;

OCPD - Over Current Protective device

SPD- Surge Protective Device

E/I- Equipment or Installation to be protected.

Primarily, the installation of SPDs must follow the manufacturer's instructions but minimum SPD connections at the origin of the electrical supply are usually made as those shown in Figure (i) (TN-C-S, TN-S, TT)

Type 1 SPDs should be installed upstream from any RCD to avoid unwanted tripping.

Where this cannot be avoided, the RCD should be of the time-delayed or S-type.

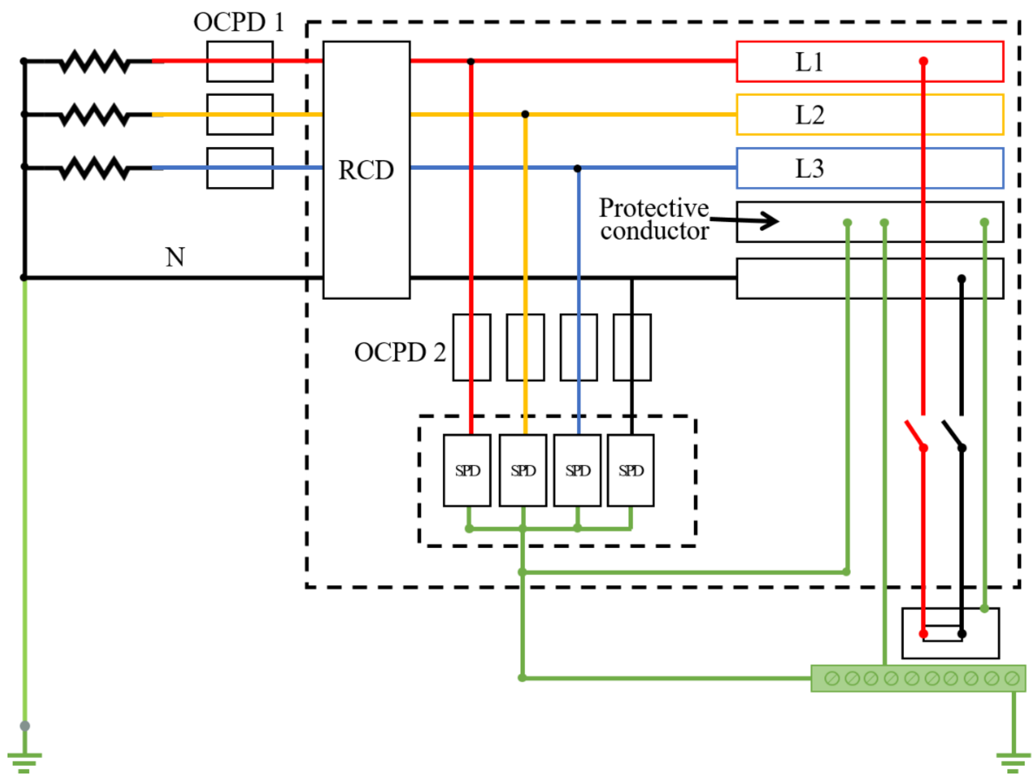



Figure (i): Installation of SPD on load side of RCD.

# 4. Electrical Codes and Electrical Auditing

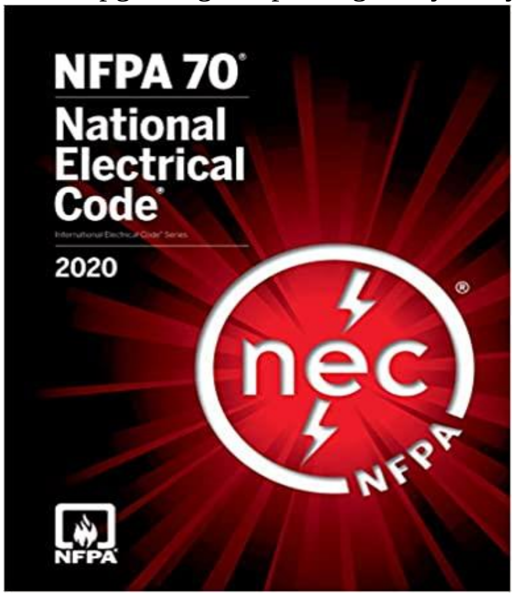
## 4.1 National and International Standards and Electrical Codes

Standards / Electrical Codes of other countries:

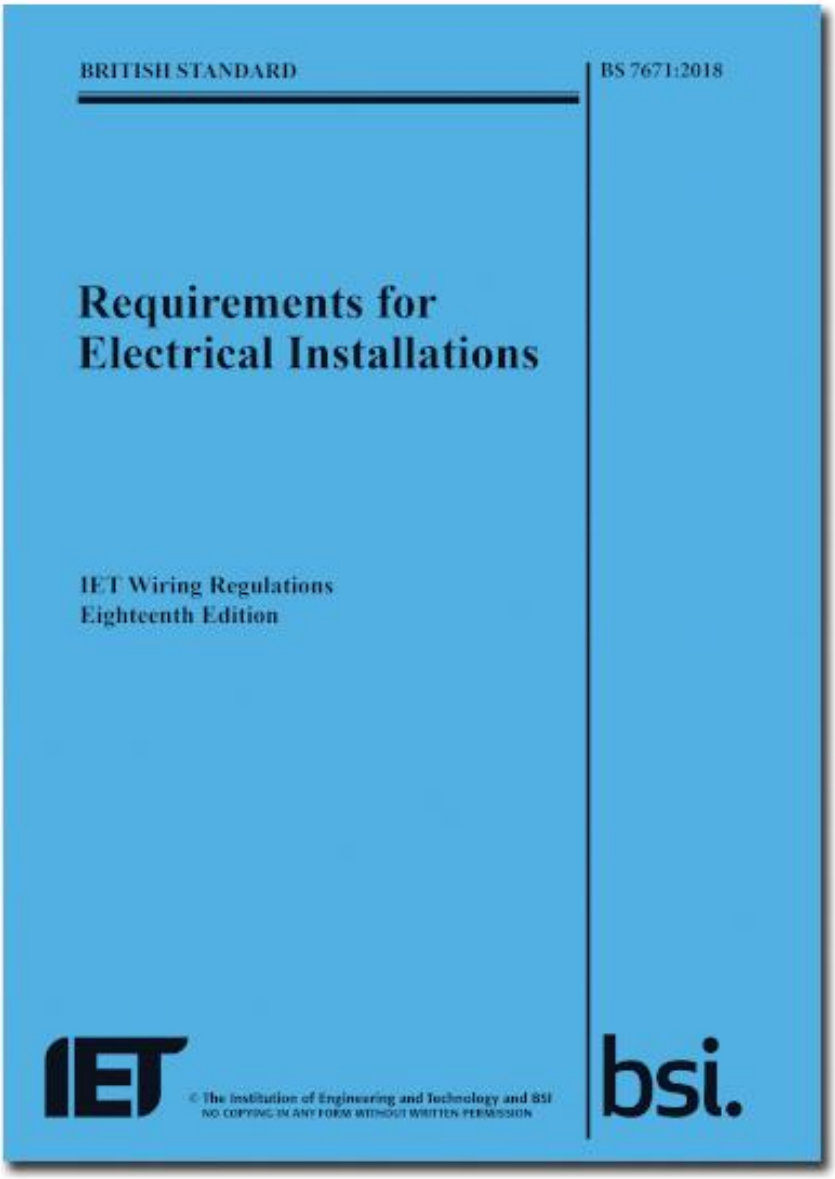
Electricity has become an integral part of life; however, at the same time, it is responsible for causing damages to the physical property and fatal accidents. Although it is a basic need today, safety measures against electrical faults is generally overlooked particularly in the developing countries. Electrical faults due to various reasons are becoming major threats to the rural as well as urban populations and settlements.

Although the electrical hazards do occur in the developed countries, the extent of loss is comparatively very less than that in the developing countries. The main reason behind this discrepancy is the adoption of the national standards and codes on electrical installation.

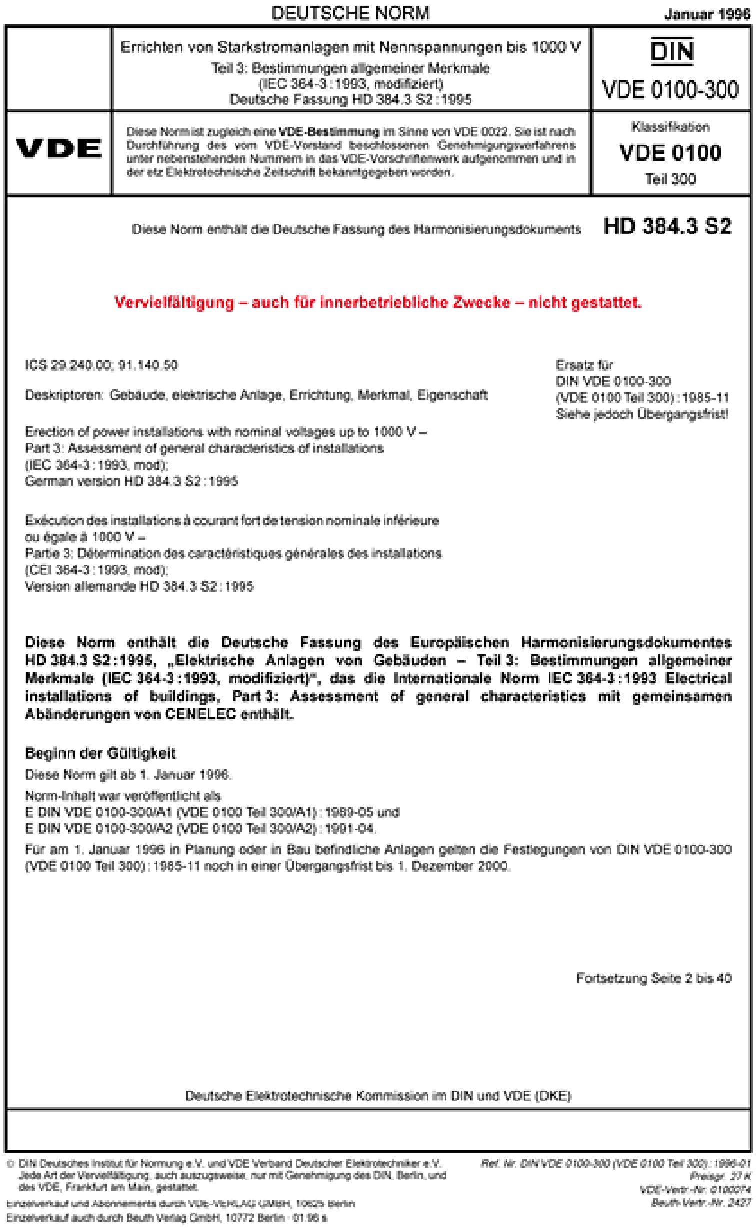
An **electrical code** is a set of regulations for the design and installation of electrical wiring in a building. The intention of a code is to provide standards to ensure electrical wiring systems that are safe for people and property. In the developed countries the electrical code is made mandatory for acquiring building completion certificate to be used for any legal provisions. Whereas, in the developing countries, either the codes are not available or are not implemented effectively. For instance, in USA safety measures against electrical hazards are strictly incorporated in the national code named National Fire Protection Association (NFPA)-70. The NFPA was brought into force in 1897, upgrading or updating every 3-5 years since then.




Similarly, in the United Kingdom, the electrical safety measures are incorporated in BS 7671. The British code 7671 brought into action in 1882 published by the Institution of Electrical Engineers (IEE).




This is currently being published jointly by Institution of Engineering and Technology (IET) and British Standard Institution (BSI) and upgraded every 3 years.
Whereas, in Germany the electrical code was implemented in 1895 known as VDE 0100 and published by the Association of Electrical Engineers (VDE).



DEUTSCHE NORM Januar 1996

Errichten von Starkstromanlagen mit Nennspannungen bis 1000 V
Teil 3: Bestimmungen allgemeiner Merkmale
(IEC 364-3 : 1993, modifiziert)
Deutsche Fassung HD 384.3 S2 : 1995

DIN VDE 0100-300

VDE

Diese Norm ist zugleich eine **VDE-Bestimmung** im Sinne von VDE 0022. Sie ist nach Durchführung des vom VDE-Vorstand beschlossenen Genehmigungsverfahrens unter nebenstehenden Nummern in das VDE-Vorschriftenwerk aufgenommen und in der etz Elektrotechnische Zeitschrift bekanntgegeben worden.

Klassifikation **VDE 0100** Teil 300

Diese Norm enthält die Deutsche Fassung des Harmonisierungsdokuments **HD 384.3 S2**

**Vervielfältigung – auch für innerbetriebliche Zwecke – nicht gestattet.**

ICS 29.240.00; 91.140.50

Deskriptoren: Gebäude, elektrische Anlage, Errichtung, Merkmal, Eigenschaft

Ersatz für
DIN VDE 0100-300
(VDE 0100 Teil 300) : 1985-11
Siehe jedoch Übergangsfrist!

Erection of power installations with nominal voltages up to 1000 V –
Part 3: Assessment of general characteristics of installations
(IEC 364-3 : 1993, mod);
German version HD 384.3 S2 : 1995

Exécution des installations à courant fort de tension nominale inférieure ou égale à 1000 V –
Partie 3: Détermination des caractéristiques générales des installations
(CEI 364-3 : 1993, mod);
Version allemande HD 384.3 S2 : 1995

**Diese Norm enthält die Deutsche Fassung des Europäischen Harmonisierungsdokumentes HD 384.3 S2 : 1995, „Elektrische Anlagen von Gebäuden – Teil 3: Bestimmungen allgemeiner Merkmale (IEC 364-3 : 1993, modifiziert)", das die Internationale Norm IEC 364-3 : 1993 Electrical installations of buildings, Part 3: Assessment of general characteristics mit gemeinsamen Abänderungen von CENELEC enthält.**

**Beginn der Gültigkeit**

Diese Norm gilt ab 1. Januar 1996.

Norm-Inhalt war veröffentlicht als
E DIN VDE 0100-300/A1 (VDE 0100 Teil 300/A1) : 1989-05 und
E DIN VDE 0100-300/A2 (VDE 0100 Teil 300/A2) : 1991-04.

Für am 1. Januar 1996 in Planung oder in Bau befindliche Anlagen gelten die Festlegungen von DIN VDE 0100-300 (VDE 0100 Teil 300) : 1985-11 noch in einer Übergangsfrist bis 1. Dezember 2000.

Fortsetzung Seite 2 bis 40

Deutsche Elektrotechnische Kommission im DIN und VDE (DKE)



Einzelverkauf und Abonnements durch VDE-VERLAG GMBH, 10625 Berlin
Einzelverkauf auch durch Beuth Verlag GmbH, 10772 Berlin · 01.96 s

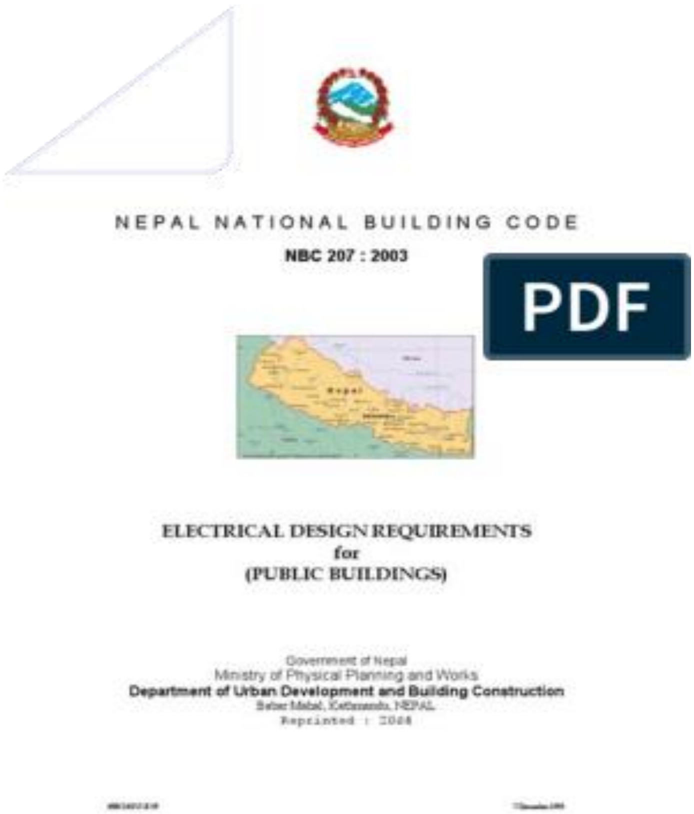
*Ref. Nr. DIN VDE 0100-300 (VDE 0100 Teil 300) : 1996-01*
*Preisgr. 27 K*
*VDE-Vertr.-Nr. 0100074*
*Beuth-Vertr.-Nr. 2427*

However, in the developing nations such codes/standards have not been implemented even if they exist. For example, in the neighboring country India, electrical code was brought into action in 1937, that has been recently upgraded, under National Building Code (NBC as IS732) in 2019, but the implementation of the code is very poor. The electrical hazards and preventive measures have very well been covered in the code. But in Nepal, although the code has been upgraded recently (2020), it is not yet implemented and the existing electrical code that was upgraded in 2003 does not cover much on the safety measures and the upgraded electrical code has not been brought into effect as of today. The electrical code was introduced for the first time in 1993. The curricula designed for electrical sub-engineers also do not cover much about the safety issues though protective devices have been discussed.

International Electro-technical Commission (IEC) standard

The international standards on electrical installations on building was established in 1962 under Technical committee -64 (TC-64) as IEC 364 and is currently known by IEC-60364. This international code is being used as basic guideline for the national standards.


Electrical Code in National Building Code of Nepal




The electrical code has been published by the Department of Urban Development and Building Construction, Ministry of Urban Development Government of Nepal in 2003. There is a very poor coverage on the electrical hazards in the code. Realizing the obsoleteness of the existing code, the Department had upgraded the code in 2020 though it is yet to be implemented.

## 4.2 Electrical Auditing

Background

The purpose of an electrical safety inspection or audit is **to identify potentially hazardous electrical situations and provide corrective actions for these situations**, review and provide corrective actions for electrical safety work processes. The Electrical Audit includes visual inspection, measurement, thermal scanning and evaluation of results to understand the circuit condition and any potential or actual overheating of the circuit. Since poor wiring and use of undersize/oversize protection devices are the common practice, the requirement of standards relating to these has been profusely used. It is a structured process of collecting independent information on the efficiency, effectiveness and reliability of the system and drawing up plans for corrective actions.

Inspection and Testing

In order to know health status of the electrical installations / wiring in households, certified technical persons (trained electricians / electrical engineers) will physically visit the houses, inspect the installations and carry out the testing by measuring various quantities following standard procedures / checklist. Please refer to Annex-A2 for the checklist to follow for inspection and testing.

**Testing**

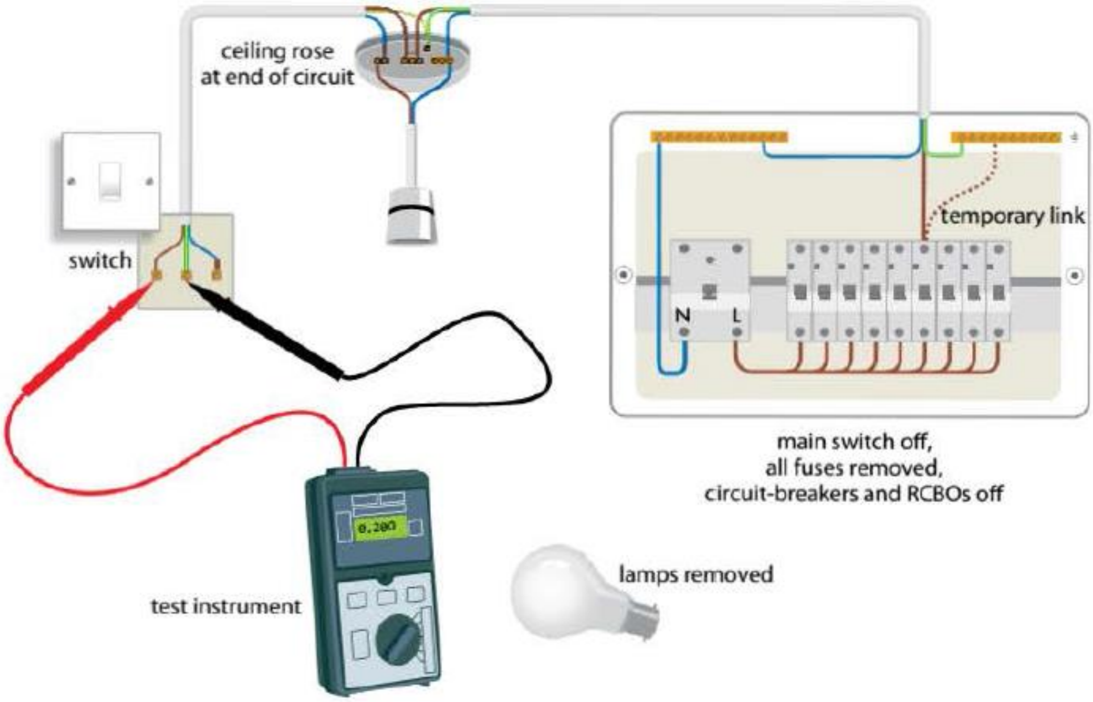
The testing of the health of electrical installations (wiring) is done by checking/measuring the following things:

a) Continuity of conductors
b) Insulation resistance
c) Insulation of resistance of SELV, PELV, or electrical separation,
d) Floor or wall resistance/impedance
e) Polarity test
f) Effectiveness of automatic disconnection of supply
g) Effectiveness of additional protection
h) Phase sequence
i) Functional test
j) Voltage drop

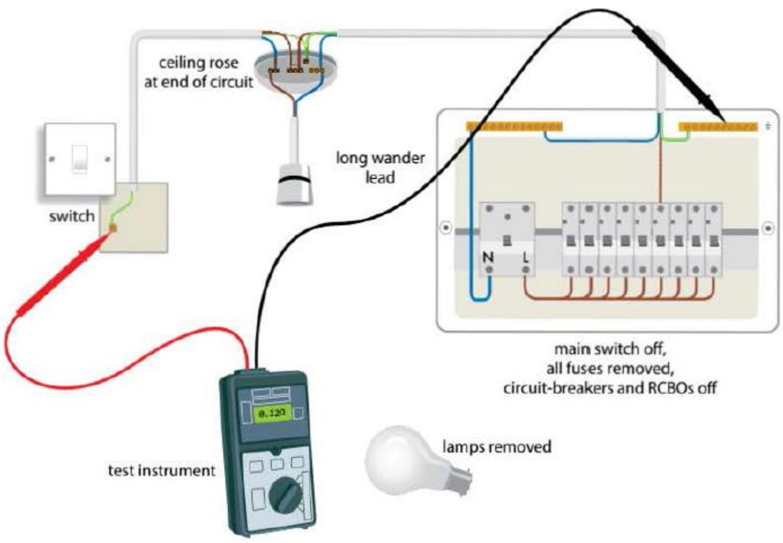
These tests are carried out as follows:

**Test 1: Continuity of conductors**

Loose contact between the conductors may increase the resistance of the circuit ~~which~~ leads to heating of the wire and insulation failure leading to a fire accident. This test is nothing but the measurement of the resistance of a conductor inside a conduit. For this, one has to measure the resistance of 1) protective conductors including protective bonding conductors, 2) exposed conductive parts, 3), live conductors such as phase and neutral conductors in the case of ring final circuits. The following table can be used as a reference for the test of resistance (adopted from IEC 60364-6) of copper conductor.




Or




**Reference table for resistance for continuity testing**

| Cross sectional area 'S' in mm$^2$ | Conductor resistance 'R', at 30°C Ω/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 |

For other temperatures the conductor resistance $R_\theta$ can be calculated using

$$R_\theta = R_{30°}[1+\propto(\theta - 30)]$$

where, $\theta$ is the desired temperature at which resistance is to be computed.

$\propto$ is the temperature coefficient ( for copper $\propto = 0.00393/K$

Generally, there are four types of copper conductors used in Nepal; class 1 (Solid conductor), class 2 (multi strand conductor), class 5 (highly flexible wire generally used in panel board) and class 6 (welding wire). The resistances of class 5 and class 6 copper conductors (most commonly used in Nepal) are higher than the recommended values in IEC 60364-6.

PVC flexible wires with class 5/6 conductors lead to higher heat dissipation and higher fault loop impedance leading to (1) higher voltage drop, (2) faster degradation of insulation reducing life, (3) non-disconnection of protective device due to increased fault loop impedance results to an accident. ***Most of the fire accidents that happen in the final circuit is due to the use of low grade class 5 wires. More importantly, it is the higher fault loop impedance and non-disconnection of supply that is more responsible for the ignition of fire (this is because, if the fault loop impedance is higher, there will be a drop in current through the circuit due to which the protective device say MCB, will not trip.***
Tool: One should use micro-ohm meter for the continuity test.

**Test 2 and 3: Insulation resistance of LV, ELV and electrical separation.**

The insulation resistance shall be measured between:

- Live conductors,
- Live conductors and earthing arrangement
- Non-earthed protective conductors and earth

***Table: Recommended test voltage and minimum values of insulation resistance.***

| Nominal voltage (V) | Test Voltage DC (V) | Minimum insulation resistance (MΩ) |
|---|---|---|
| SELV and PELV | 250 | 0.5 |
| ≤ 500 V or FELV | 500 | 1 |
| >500 V | 1000 | 1 |

Live conductors may be connected together. Test shall be conducted during the erection of the installation before connecting the equipment.

For equipment that is likely to influence the results or be damaged, only a measurement between the line conductors connected together and earth shall be made or shall be disconnected before carrying out the insulation resistance test. If the equipment cannot be disconnected (e.g. in case of fixed socket outlet incorporated with SPD) the test voltage for the particular circuit may be reduced to 250 V d.c. but the insulation resistance shall have a value of at least 1 MΩ.

Main switch board and each distribution circuit are tested separately, with all its final circuit connected but with current-using equipment disconnected. Neutral conductors shall be disconnected from the MET. In TN-C systems, a measurement should be made between the live conductors and the PEN conductor.

Insulation resistance values are usually much higher than those given in the above table.

**Test for ELV:**

- SELV: live parts from those of other circuits and from earth
- PELV: Live parts from other circuits
- Protection of electrical separation: live parts from those of other circuits and from earth. (the values should satisfy the above table).

**Test 4: Insulation resistance/impedance of floors and walls**:

This test is required in non-conducting locations, intended to prevent simultaneous contact with parts which may be at different potential during failure of the basic insulation.

**Test 5**: **Polarity:**

The polarity of the supply at the origin of the installation shall be verified before the installation is energized. Where single pole switching devices are not permitted in the neutral conductor, a test shall be made to verify that such devices are connected in the line conductor(s) only. It should be verified that:

a) Every fuse and single-pole control and protective device is connected in the line conductor only
b) Wiring has been correctly connected to socket-outlets and similar accessories.

**Test 6: Automatic disconnection of supply:**

Effectiveness of the fault protection by automatic disconnection of supply is carried out by testing and establishing the disconnection times of protective devices.

a) For a TN system: Measurement of the earth fault loop impedance and comparing the characteristics of protective device (*for RCDs testing with an RCD tester*).
b) For a TT system: Measurement of the resistance of the earth electrode for exposed conductive parts of the installation or external earth fault loop impedance and comparing the characteristics of protective device.

**Test 7: Additional protection:**

RCD test and the effectiveness of main and supplementary protective bonding are the additional protective measures.

**Test 8: Phase sequence test:**

It is necessary for multiphase circuit.

**Test 9: Functional testing:**

This test is to ensure that the equipment (*such as switch gear and control gear assemblies, drives, controls and interlocks, system for emergency switching off and emergency stopping, insulation monitoring*) are properly mounted, adjusted and installed.

**Test 10: Voltage drop**: It shall be evaluated by measurement of the following.

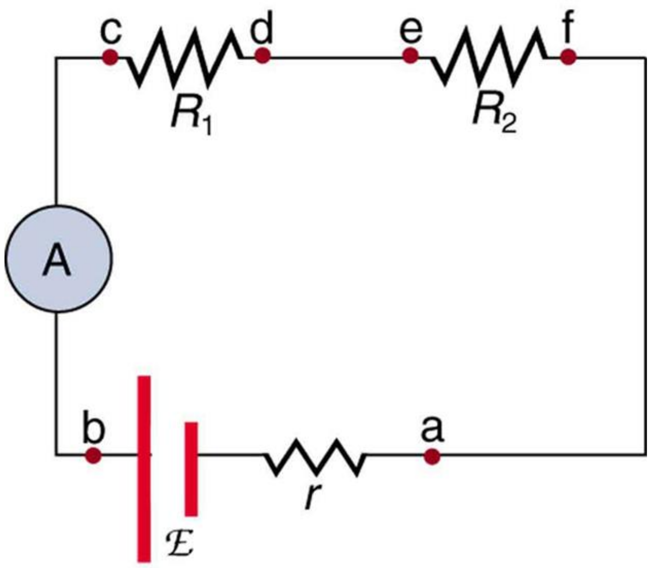
- The difference between the voltage with and without the designed load
- The difference between the voltage with and without any known load and calculate the designed load
- By calculation of circuit impedance values

**The Electricians / Electrical Engineers will follow the Standard Operating Procedure (SOP) for Electrical Auditing and they need to go through a separate training for this.**

# 5. Measuring Tools and Method to use

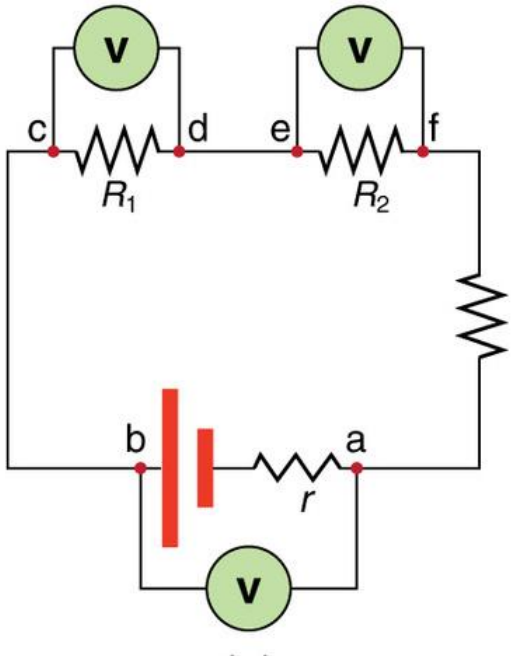
## 6.1 Ammeter

An ammeter measures the electric current in a circuit. The name is derived from the name for the SI unit for electric current, amperes (A).
In order for an ammeter to measure a current through a device in a circuit, it must be connected in series to that device. This is necessary because objects in series experience the same current. They must not be connected to a voltage source — ammeters are designed to work under a minimal burden, (which refers to the voltage drop across the ammeter, typically a small fraction of a volt).




## 6.2 Voltmeter

A voltmeter is an instrument that measures the difference in electrical potential between two points in an electric circuit. An analog voltmeter moves a pointer across a scale in proportion to the circuit's voltage; a digital voltmeter provides a numerical display. Any measurement that can be converted to voltage can be displayed on a meter that is properly calibrated; such measurements include pressure, temperature, and flow.
In order for a voltmeter to measure a device's voltage, it must be connected in parallel to that device. This is necessary because objects in parallel experience the same potential difference.




## 6.3 Earth-resistance Meter and soil resistivity tester

When an earth electrode system is designed and installed, it is usually necessary to measure and confirm the earth resistance between the electrode and “true Earth”. The most commonly used method of measuring the earth resistance of an earth electrode is the 3-point measuring technique.

**Soil resistivity measurement**

Soil resistivity is necessary when determining the design of the grounding system for new installations (green field applications) to meet your ground resistance requirements. Ideally, you would find a location with the lowest possible resistance. Poor soil conditions can be overcome with more elaborate grounding systems. The soil composition, moisture content and temperature all impact soil resistivity. Soil is rarely homogenous and its resistivity will vary geographically and at different depths. Moisture content changes seasonally, varies according to the nature of the sublayers of earth and the depth of the permanent water table. It is recommended that the ground rods be placed as deep as possible into the earth as soil and water are generally more stable at deeper strata.

*Calculating soil resistivity*

The measuring procedure described here uses the Wenner method and uses the formula:

$\rho = 2\,\pi\,A\,R$

where:

$\rho$ = the average soil resistivity to depth $A$ in: ohm-cm.

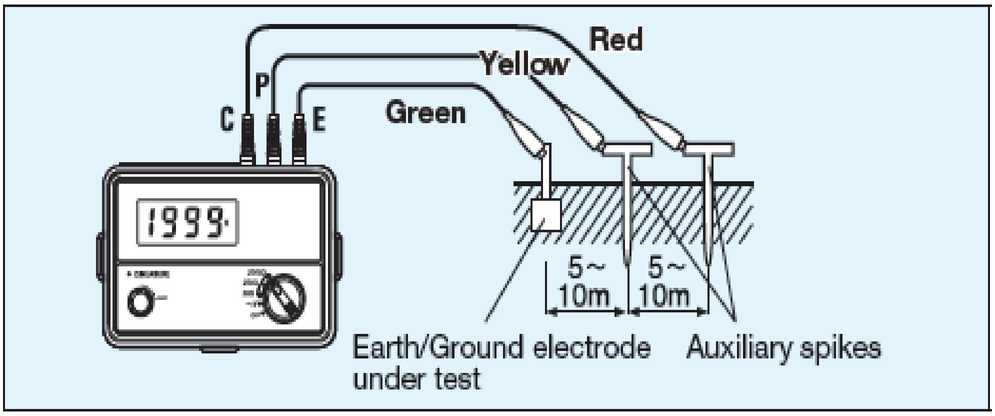
$\pi$ = 3,1416.

$A$ = the distance between the electrodes in cm.

$R$ = the measured resistance value in ohm from the test instrument.

**Measuring soil resistance**

To test soil resistivity, connect the ground tester as shown in Fig. 1. Four earth ground stakes are positioned in the soil in a straight line, equidistant from one another. The distance between earth ground stakes should be at least three times greater than the stake depth. The Fluke1625 earth ground tester generates a known current through the two outer ground stakes and the drop in voltage potential is measured between the two inner ground stakes. The tester automatically calculates the soil resistance using Ohm’s Law ($V=IR$)




## 6.4 Multi-Meter

A **multimeter** is a measuring instrument that can measure multiple electrical properties. A typical multimeter can measure voltage, resistance, and current, in which case it is also known as a **volt-ohm-milliammeter** (**VOM**).

**Multi-meter as a continuity tester**

Continuity testing is the act of testing the resistance between two points. If there is very low resistance (less than a few Ωs), the two points are connected electrically, and a tone is emitted. If there is more than a few Ωs of resistance, than the circuit is open, and no tone is emitted. This test helps insure that connections are made correctly between two points. This test also helps us detect if two points are connected that should be connected or not. This feature allows us to test for conductivity of materials and to trace where electrical connections have been made or not made.

## 6.5 Insulation test meter

Insulation starts to age as soon as it's made. As it ages, its insulating performance deteriorates. Any harsh installation environments, especially those with temperature extremes and/or chemical contamination, accelerates this process. Stresses due to different factors like:

**Electrical stresses:** Mainly linked to overvoltage and under-voltage.

**Mechanical stresses:** Frequent start-up and shutdown sequences can cause mechanical stresses.

Balancing problems on rotating machinery and any direct stress to the cables and the installations in general.

**Chemical stresses:** The proximity of chemicals, oils, corrosive vapors and dust, in general, affects the insulation performance of the materials.

**Stresses linked to temperature variations:** When combined with the mechanical stresses caused by the start-up and shutdown sequences, expansion and contraction stresses affect the properties of the insulating materials. Operation at extreme temperatures also leads to aging of the materials.

**Environmental**: Contamination causes aging acceleration of insulation.

This wear and tear can reduce the electrical resistivity of the insulating materials, thus increasing leakage currents that lead to incidents which may be serious in terms of both safety (people and property) and the costs of production stoppages. Thus it's important to identify this deterioration quickly so that corrective steps can be taken. In addition to the measurements carried out on new and reconditioned equipment during commissioning, regular insulation testing on installations and equipment helps to avoid such incidents through preventive maintenance. These tests detect ageing and premature deterioration of the insulating properties before they reach a level likely to cause the incidents described above.

## How Insulation Resistance is Measured?

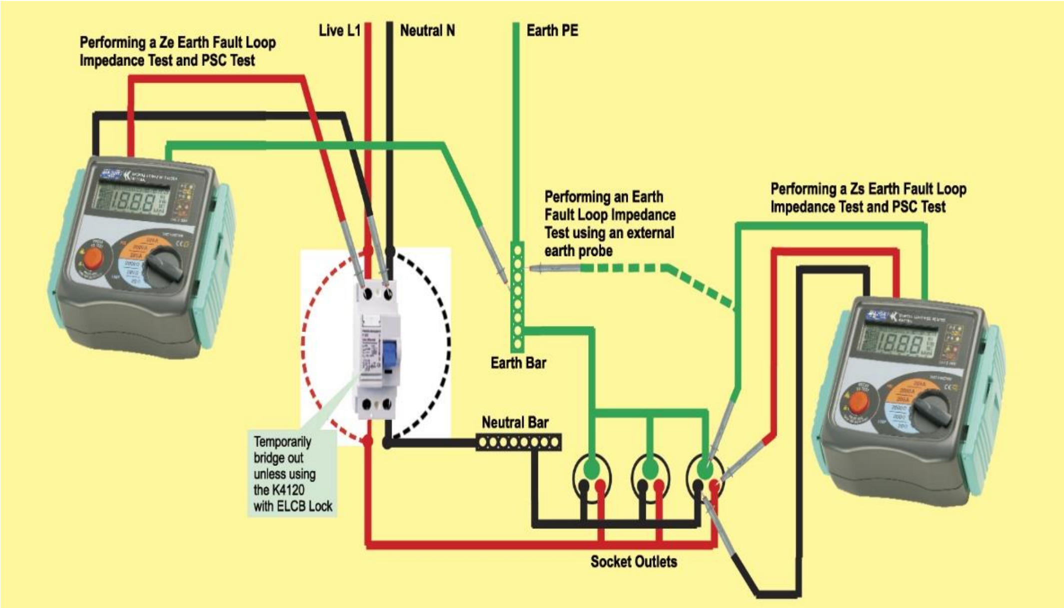
Insulation resistance measurement is done using an IR tester. This is a portable tool that is more or less an ohmmeter with a built in generator that's used to produce a high DC voltage. The voltage usually measures at least 500V, and causes a current to flow around the surface of the insulation. This gives a reading of the IR in ohms.

Insulation resistance measurement is based on Ohm's Law. (R=V/I). By injecting a known DC voltage lower than the voltage for dielectric testing and then measuring the current flowing, it is very simple to determine the value of the resistance. In principle, the value of the insulation resistance is very high but not infinite, so by measuring the low current flowing, the megohmmeter indicates the insulation resistance value, providing a result in kW, MW, GW and also TW (on some models). This resistance characterizes the quality of the insulation between two conductors and gives a good indication of the risks of leakage currents flowing.

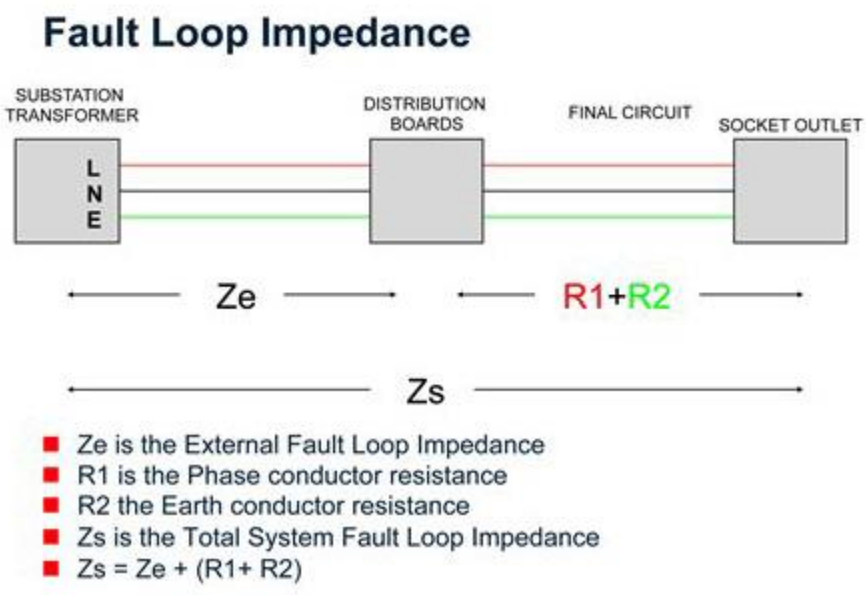
Value of insulation resistance is often expressed in giga-ohms [GΩ].

Good Insulation is when megger reading increases first then remain constant. Bad Insulation is when megger reading increases first and then decreases.

## 6.6 Fault loop impedance testing




The formula for determining the fault loop impedance `Zs is
**Zs=Ze + (R1+R2)**
Zs - earth fault loop impedance of the circuit tested
Ze - earth fault loop impedance external to the supply
(R1+R2) - Sum of the resistance of Line and Earth for the tested circuit.




**The External Earth Fault Loop test sequence (Ze)**
(This is a live test so extra care should be taken!)
**Step 1.** Use an Earth Fault Loop Tester or select the Earth Fault Loop Test option on a multifunctional tester
**Step 2.** Test on the incoming side of the installation. Connect one test lead to the Line terminal, the second test lead to the Neutral terminal and the third (usually green) test lead to the incoming Earth conductor.
**Step 3.** Press the TEST button. The measurement should be a low reading ohm value.

**The Earth Fault Loop test sequence (R1+R2):**
(This is a live test so extra care should be taken!)

**Step 1.** Locate the furthest point on the circuit to be tested (such as the furthest socket)
**Step 2.** With the appropriate Earth Fault Loop Tester, connect the test leads to the Line, Neutral and Earth terminals.
Step 3. Measure and write down the test results on the Schedule of Test Results.
Note: If the circuit is RCD protected than one has to select the “No trip” function of the tester (say Megger 1553) to avoid nuisance tripping of the RCD. If tester does not have this option, then one will have to link out the RCD.

MAXIMUM VALUES OF EARTH FAULT-LOOP IMPEDANCE FOR THE TOTAL CIRCUIT INCLUDING THE SUPPLY TRANSFORMER ($Z_s$ AT 230 V) VALUES RELATING TO OPERATION OF PROTECTIVE DEVICES ON THE FINAL SUBCIRCUIT

| Protective device rating Amps | MCBs on the final subcircuit | | | Fuses on the final subcircuit | |
|---|---|---|---|---|---|
| | Type B | Type C | Type D | | |
| | Disconnection times | | | | |
| | 0.4 s | | | 0.4 s | 5 s |
| | Maximum earth fault-loop impedance $Z_s$ Ω | | | | |
| 6 | 9.6 | 5.1 | 3.1 | 11.5 | 15.3 |
| 10 | 5.8 | 3.1 | 1.8 | 6.4 | 9.2 |
| 16 | 3.6 | 1.9 | 1.2 | 3.1 | 5.0 |
| 20 | 2.9 | 1.5 | 0.9 | 2.1 | 3.6 |
| 25 | 2.3 | 1.2 | 0.7 | 1.6 | 2.7 |
| 32 | 1.8 | 1.0 | 0.6 | 1.3 | 2.2 |
| 40 | 1.4 | 0.8 | 0.5 | 1.0 | 1.6 |
| 50 | 1.2 | 0.6 | 0.4 | 0.7 | 1.3 |
| 63 | 0.9 | 0.5 | 0.3 | 0.6 | 0.9 |
| 80 | 0.7 | 0.4 | 0.2 | 0.4 | 0.7 |
| 100 | 0.6 | 0.3 | 0.2 | 0.3 | 0.5 |
| 125 | 0.5 | 0.2 | 0.1 | 0.2 | 0.4 |
| 160 | 0.4 | 0.2 | 0.1 | 0.2 | 0.3 |
| 200 | 0.3 | 0.2 | 0.1 | 0.1 | 0.2 |

# Annexes

## Annex - A1: Supplementary information

### A1.1 Sizing of conductors for protective equipotential bonding, earthing and protective earthing.

**General Conditions:**

1. Use of steel for a protective conductor is accepted.
2. Protective conductors shall be protected against mechanical and chemical deterioration and electrodynamic forces. A 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.
3. Aluminium shall not be used as earthing conductor
4. Consideration for corrosion shall be added to the minimum dimensions.
5. Disconnection facility from MET with a tool is mandatory.
6. For a PEN conductor, the cross-sectional area shall also follow the rules for sizing of the neutral conductor.

### A1.2 Colour Coding of protective conductors

- Protective earth conductor (PE): Green and Yellow
- Earthing conductor: No colour other than the colour of the bare conductor. If insulated, avoid red, yellow, blue, black, cream & green/ yellow.
- Functional earth conductor (FE): Cream

The bi-colour combination, green and yellow shall be used for identifying the protective conductor only. 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 an 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, one of these colours covers at least 30 percent and not more than 70 percent, the other colour covering the remaining of that surface.

Where the protective conductor can be easily identified from its shape, construction or position, (e.g. 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.

### A1.3 Main & Supplementary protective equipotential bonding conductor.

**Main bonding conductors:**

Cross-sectional area is not less than half the cross-sectional area of the largest PE conductor within the installation and not less than:

- 6 $mm^2$ copper or 16 $mm^2$ aluminium or 50 $mm^2$ steel.
- Need not exceed 25$mm^2$ copper or an equivalent cross-sectional area for other materials.

**Supplementary bonding conductors:**

Connecting two exposed conductive parts shall have a size not less than that of the smaller protective conductor connected to the exposed conductive parts.

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.

Other cases

- 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.

**Earthing conductor**

The cross-sectional area of earthing conductor in air and in soil is,

**In air:**

Minimum 6 $mm^2$ for copper or 50 $mm^2$ for steel without LPS;

Minimum 16 $mm^2$ for copper or 50 $mm^2$ for steel with LPS.

OR

Satisfy the requirement of main equipotential bonding conductor if there is no noticeable fault current is flowing.

**In Soil:**

- Copper: Horizontal - 50 $mm^2$, Vertical - 15 mm dia
- Copper coated Steel: Horizontal - 8 mm dia (250 microns coating) or 10 mm dia (70 microns coating). Vertical - 14 mm dia
- SS - 10 mm dia horizontal and 16 mm dia vertical

## A1.4 Protective Earthing conductor (PE)

In order to prevent overheating of the protective conductor during a fault, the cross-sectional area of a protective conductor(s) shall be not less than that determined by the adiabatic formula as follows:

$S = \frac{\sqrt{I^2 t}}{k}$ or alternatively arranged as $S = \frac{I\sqrt{t}}{k}$

where:

***S*** is the nominal cross-sectional area of conductor in $mm^2$.

***I*** is the value of fault current in amperes (rms for a.c.) for a fault of negligible impedance.

***T*** is the operating time of the disconnecting device in seconds, corresponding to the fault current. It is found from the protective device characteristic curve.

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

In conductive TT systems, where the earth electrodes of the source and exposed conductive parts at installations are electrically independent, the cross sectional area of protective conductors need not exceed:

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

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 a protective earthing conductor shall either be calculated in accordance to the table A1, or selected in accordance with tables A2 to A6.

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

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

**TableA1: Minimum cross-sectional area of protective conductors**

| Cross-sectional area of line conductor | Minimum cross-sectional area of the | protective conductor |
|---|---|---|
| | Cu - mm$^2$ | |
| S (Cu) mrn$^2$ | Protective conductor is of the same material as the line conductor | Protective conductor is not of the same material as the line conductor |
| s <6 | s | $k_l \div k_2 \times S$ |
| 16 < s <35 | 16 | $k_2 \div k_2 \times 16$ |
| s > 35 | S*2 | $k_1 \div k_2 \times S \div 2$ |
| $k_1$ is the value of k, for the line conductor according to the materials of the conductor and insulation and $k_2$ is the value of k for the protective conductor | | |

### A1.5 Main Earthing Terminal (MET)

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

- **Protective bonding conductors** (MET and extraneous conductive parts);
- **Earthing conductors** (MET to earth pit in TT / IT system or MET to source earthing terminal in TN system);
- **Protective Earthing** (PE) conductors (MET to exposed conductive parts);
- **Functional Earthing** (FE) conductors, if relevant (MET to electronic system).

Where more than one earthing terminal (MET or SEBT) is provided, they shall be inter-connected. The conductors used for interconnection shall be rated for the expected fault current.

## Annex -A2 : Checklist for Electrical Auditing (Inspection & Testing)

### Ensuring the avoidance of electrical fire hazards

**Electrical auditing**
**(Inspection and testing)**
**Checklist**

| S.N | Inspection | YES | NO |
|---|---|---|---|
| 1 | Does the electrical installation have overcurrent protective devices (OCPD,MCB,MCCB)? | | |
| 2 | Does the installation have properly installed Earth leakage circuit breakers (ELCB)? | | |
| 3 | Does the electrical installation have main bonding conductors ? | | |
| 4 | Does the electrical installation have supplementary bonding conductors ? | | |
| 5 | Does the electrical installation have an earthing conductor ? | | |
| 6 | Does the electrical installation have a protective conductor ? | | |
| 7 | Does the electrical installation have a main earthing terminal ? | | |

| | | | |
|---|---|---|---|
| 8 | Does the structure have an external lightning protection system ? | | |
| 9 | Does the installation have Surge Protective Devices? | | |
| 10 | Does the installation have earthing conductors (MET to earth pit in TT /IT or MET to Source Earthing as per TN System)? | | |
| 11 | Does the installation have a functional earthing (FE) conductor (MET to the electronic system)? | | |
| 12 | Does the installation have protective bonding conductors in place? | | |
| 13 | Does the installation have earthing conductors? | | |

*If there are SPDs in place please state the following,*

1. What class of SPD is in place?

---

2. How many SPD's are installed?

---

3. How many SPD's are functioning healthy?

---

*Please select from the choices given below,*

1. What kind of earthing system has been adopted?
   ❑ TT ❑ TN-S ❑ TN-CS ❑ IT

2. What is the rating of MCB
   ❑ 6A ❑ 16A ❑ 32A ❑ 63A

# TESTING

1. Cross sectional area of Main bonding conductor $mm^2$
   (REF > 6$mm^2$ (Cu) / 6$mm^2$ (Al) / 30$mm^2$ (Steel) )

2. Cross sectional area of Protective Earthing conductor $mm^2$
   (REF > 25$mm^2$ (Cu) / 35$mm^2$ (Al) )

3. Cross sectional area of Supplementary bonding conductors $mm^2$

   (REF > 25$mm^2$ (Cu) / 16$mm^2$ (Al) Protection against mechanical damage is provided )

   (REF > 4$mm^2$ (Cu) / 16$mm^2$ (Al) Protection against mechanical damage is not provided )

4. Cross sectional area of Earthing conductor $mm^2$

   (REF > 16$mm^2$ (Cu) / 50$mm^2$ (Steel) Without ELPS )

   (REF > 16$mm^2$ (Cu) / 50$mm^2$ (Steel) With ELPS )

5. Cross sectional area of Earthing conductor in soil $mm^2$

   (REF > 15 mm dia (Cu) vertical / 17mm dia for copper coated steel)

6. Continuity test :

Resistance of conductor (i) ……... Ω (ii) …………Ω (iii) …………Ω (iv) …………Ω……....

7. Insulation resistance between conductors Ω.

8. Impedance of floor ………Ω.

9. Impedance of walls …….Ω.

10. Resistance of SELV ……..Ω.

11. Resistance of PELV …….Ω.

12. Value of fault loop impedance………Ω.

13. Contact resistance of earth electrode……Ω.

14. Soil resistivity(ρ) …………Ωm.