Earthing System

Earthing Systems

١. Introduction

In any medium or low voltage three-phase system there are three single-phase voltages which are measured between each phase and a common point called the "neutral point". In balanced operating conditions these three voltages are phase shifted by ١٢٠° and have the value:

U / ٣

U being the phase-to-phase voltage measured between phases (see fig. ٢-١).

From a physical point of view, the neutral is the common point of three star-connected Windings. It may or may not be accessible, may or may not be distributed and may or may not be earthed, which is why we refer to the **earthing system**.

The neutral may be connected to earth either directly or via a resistor or reactor. In the first case, we say that the neutral is solidly (or directly) earthed and, in the second case, we say that the neutral is impedance-earthed.

When there is no intentional connection between the neutral point and earth, we say that the neutral is isolated or unearthed.

The earthing system plays a very important role in a network. On occurrence of an insulation fault or a phase being accidentally earthed, the values taken by the fault currents, touch voltages and over voltages are closely related to the type of neutral earthing connection.

A solidly earthed neutral helps to limit over voltages; however, it generates very high fault currents. On the other hand, an isolated or unearthed neutral limits fault currents to very low values but encourages the occurrence of high over voltages.

In any installation, service continuity in the presence of an insulation fault also depends on the earthing system. An unearthed neutral allows continuity of service in medium voltage, as long as the security of persons is respected. On the other hand, a solidly earthed neutral, or low impedance-earthed neutral, requires tripping to take place on occurrence of the first insulation fault.

The extent of the damage to some equipment, such as motors and generators having an internal insulation fault, also depends on the earthing system.

In a network with a solidly earthed neutral, a machine affected by an insulation fault suffers extensive damage due to the high fault currents.

On the other hand, in an unearthed network or high impedance-earthed network, the damage is reduced, but the equipment must have an insulation level compatible with the level of over voltages able to develop in this type of network.
The earthing system also has a considerable amount of influence on the nature and level of electromagnetic disturbances generated in an electrical installation.
Earthing systems which encourage high fault currents and their circulation in the metallic structures of buildings are highly disturbing.
On the other hand, earthing systems which tend to reduce these currents and which guarantee good equipotential bonding of exposed conductive parts and metallic structures are not very disturbing.
The choice of earthing system, as much in low voltage as in medium voltage, depends both on the type of installation and network. It is also influenced by the type of loads, the service Continuity required and the limitation of the level of disturbance applied to sensitive equipment.

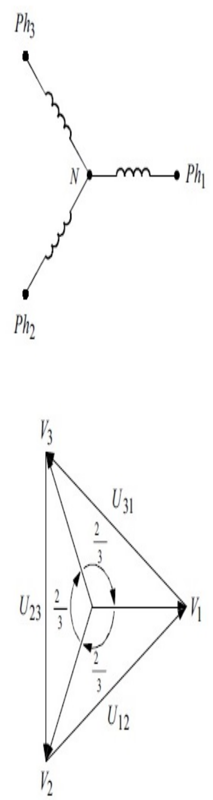


Figure 2-1: three-phase system

Vi : phase-to-neutral voltage
UiJ : phase-to-phase voltage

٢. *Earthing plays a vital role in all electrical systems. The main reasons for earthing are:-*

- *To protect people and livestock*
- *To protect equipment*
- *To permit the equipment to function correctly*
- *To ensure the reliability of electrical services*

٣. *A good earth connection should possess the following characteristics:-*

a) **Low electrical resistance** *between the electrode and earth. The lower the earth electrode resistance, the more likely the fault current will choose to flow down that path in preference to any other, allowing the current to be conducted safely to and dissipated in the earth.*

b) **Good corrosion resistance**. *The choice of material for the earth electrode and its connections is of vital importance. It will be buried in soil for many years so has to be totally dependable.*

c) ***Ability to carry high current repeatedly***.

d) *Ability to perform the above functions for a minimum of* **٣٠ years**.

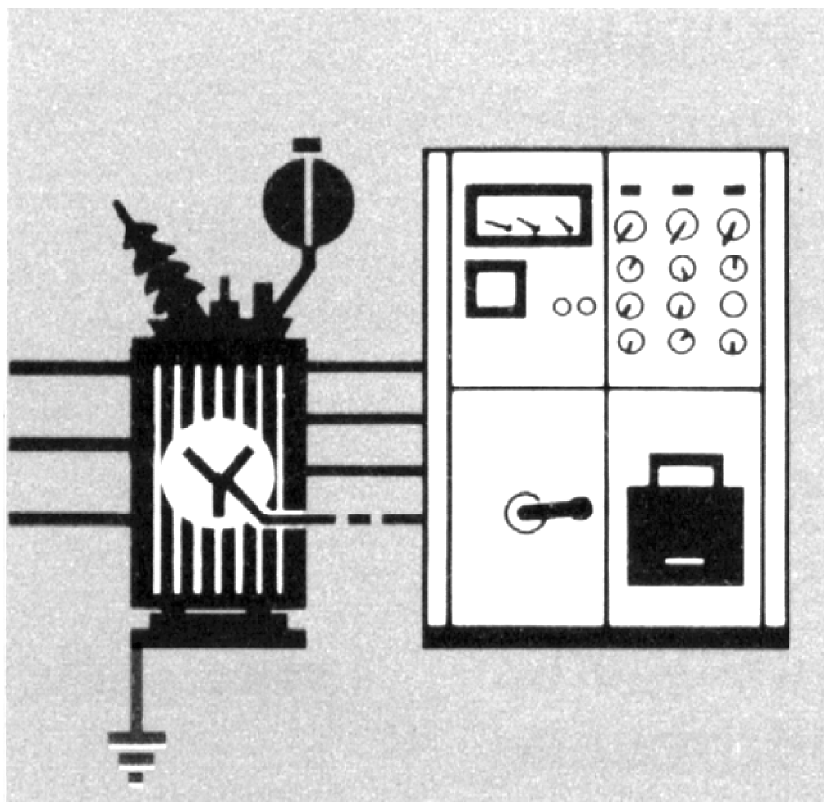
٤. *In electrical installations three types of earthing systems are used :*

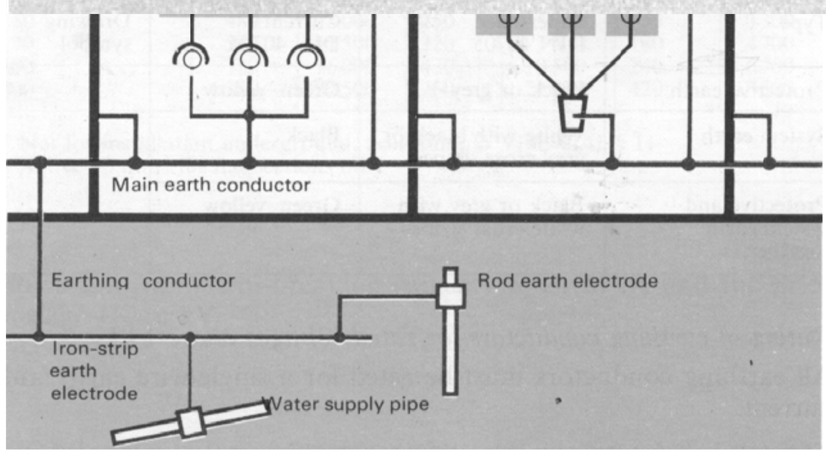
<u>High–Voltage Protective Earthling:</u>

According to International Regulations for earthing in AC installations with rated voltage above ١ kV, all metal parts of installations and equipment operating at rated voltages above ١ kV, **which are not part of the working circuit** *and may become live in the event of a defect in insulation, must be earthed. Therefore, switchgear components and all relevant parts of the plant must be connected to an earth conductor which in turn is connected to the earth electrodes.*

Steel frames which from a built-up unit, e.g prefabricated switchboards, may be used for earthling all parts mounted up on them.

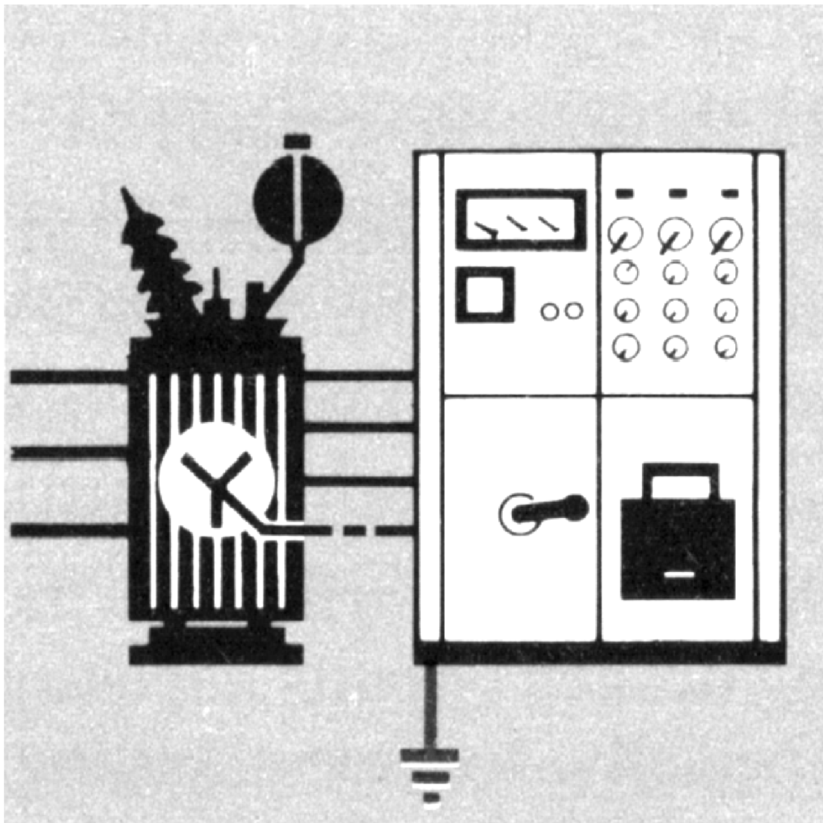
In the case of reinforced steel-concrete structures , the earthing conductors can be embedded in the concrete, providing they are continuous and have easily accessible connection points. The steel reinforcement can also be used as earthing conductor, providing that the cross-sectional area is sufficiently large and that all parts are reliably welded together throughout. The rating of the protective earth system is determined by the earth current which flows through the protective earth in the event of a fault. The following figures shows examples of high voltage protective earthing.




Main earth conductor
Earthing conductor
Rod earth electrode
Iron-strip
earth
electrode
Water supply pipe

Low Voltage Protective Earthing:

Low voltage protective earthing, is the connection to earth of all conductive parts of equipment or of the installation, which do not form a part of the operating circuit. Its purpose is to provide safety for personnel in case of contact with metallic bodies of low voltage distribution boards and equipment. The figure shows an example of the low voltage protective earthing.



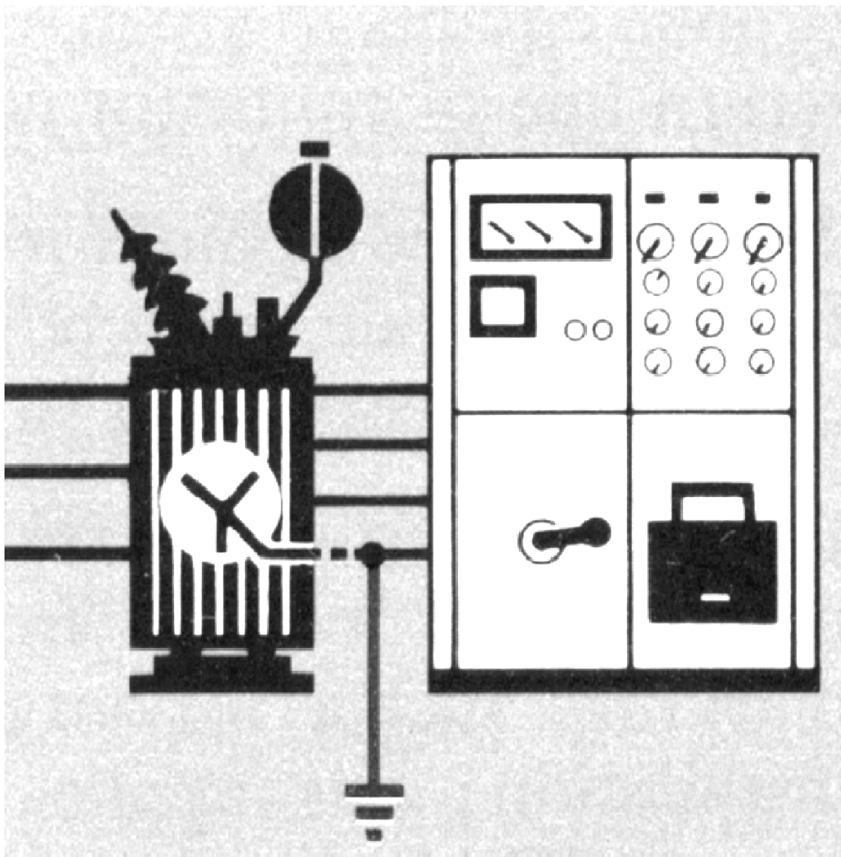
Example of the Low Voltage Protective Earthing

Low Voltage System Earthing:

The low-voltage system earthing is the earthing of parts of the electric circuit, e.g. the neutral (or star-point) of transformers and generators.

The type of system earthing affect the selection of the appropriate protective measures to be used for an electrical installation.

The selection of measures for protection against electric shock depends on the earthing arrangement at the source of energy and the type of path intended for earth fault current.



Low Voltage System Earthing

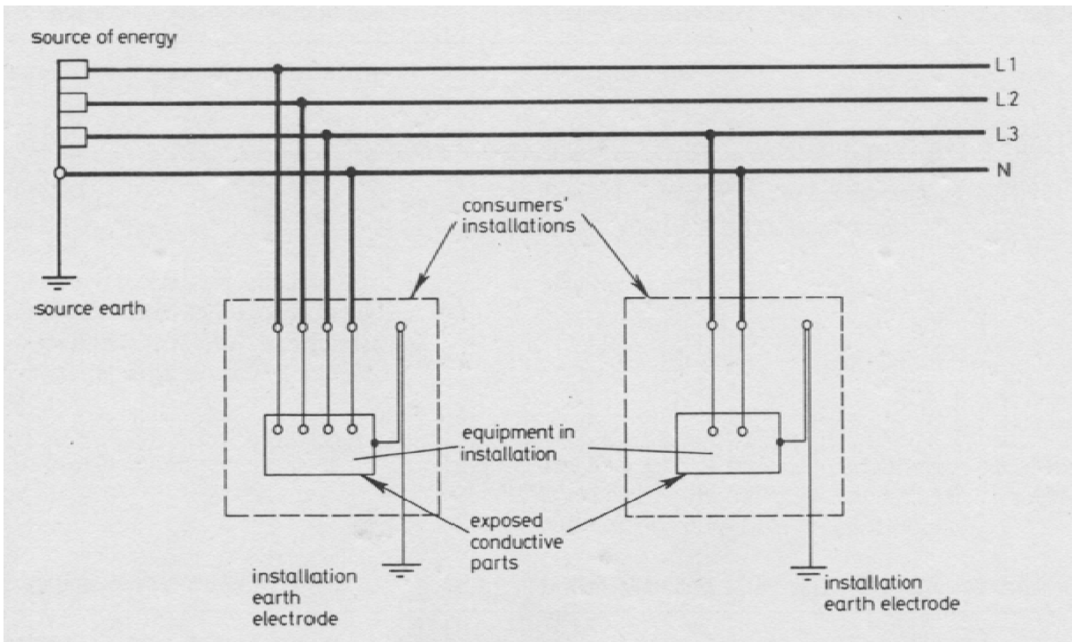
٥. ***Earthing and protective electrical systems***

The public source of energy is the property and responsibility of the supply authorities and the installations connected to the source are the consumer's responsibility. In some industrial and residential situations the source of energy, the wiring and the current-using equipment are all owned and controlled by the user and constitute what is usually called a private electrical installation.

Several earthing and protective electrical systems are available and used in various parts of the world and these are:-

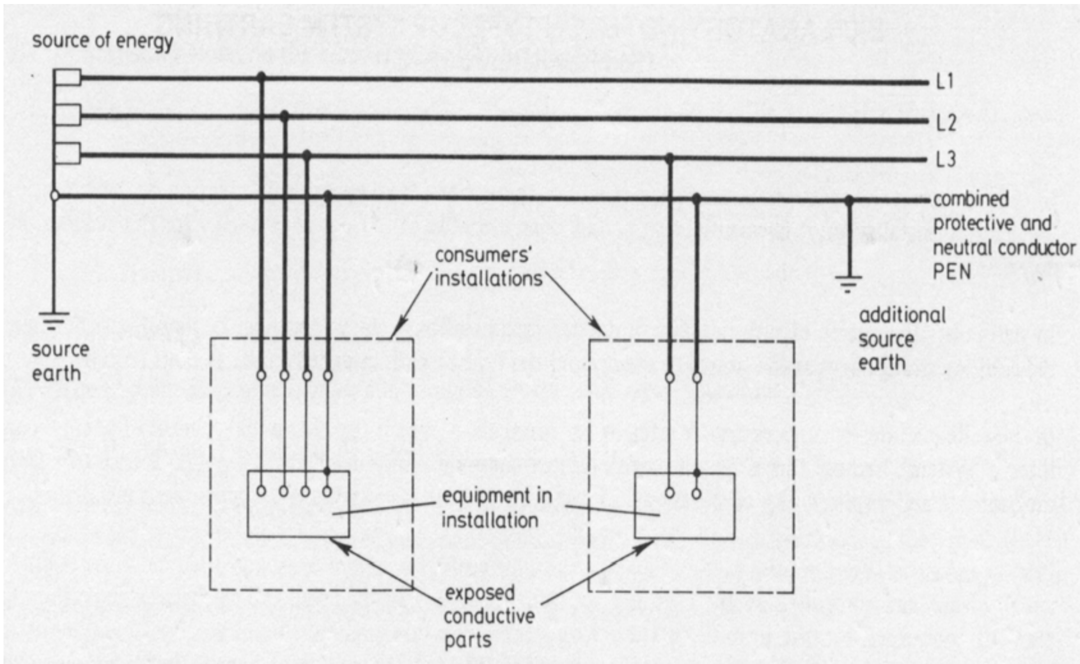
The TT system

All exposed conductive parts of the installation are connected to an earth electrode which is electrically independent of the source earth. ***This system is used in Iraq.***



<u>The TN-C system</u>

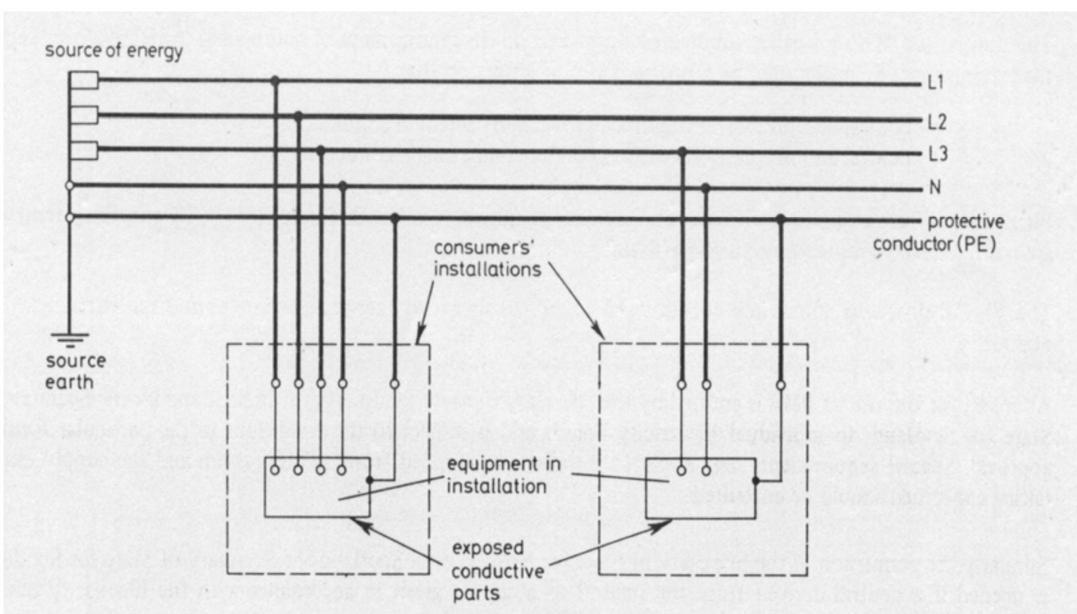
Neutral and protective functions are combined in a single conductor throughout the system. All exposed conductive parts of an installation are connected to the PEN conductor.



The TN-S system

Separate neutral and protective conductors throughout system. The protective conductor (PE) is the metallic covering of the cable supplying the installations or a separate conductor.

All exposed conductive parts of an installation are connected to this protective conductor via the main earthing terminal of the installation.



The TN-C-S system

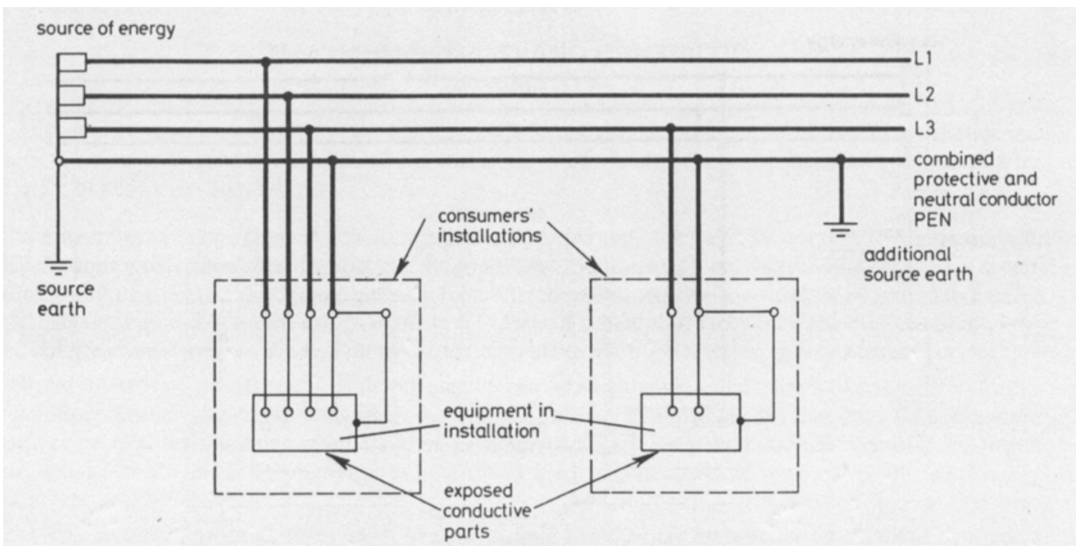
Neutral and protective functions are combined in a single conductor in a part of the system.

The usual form of a TN-C-S system is as shown, where the supply is TN-C and the arrangement in the installations is TN-S.

This type of distribution is known also as Protective Multiple Earthing and the PEN conductor is referred to as the combined neutral and earth (CNE) conductor.

The supply system PEN conductor is earthed at several points and an earth electrode may be necessary at or near a consumer's installation.

All exposed conductive parts of the installation are connected to the PEN conductor via the main earthing terminal and the neutral terminal, these terminals being linked together.

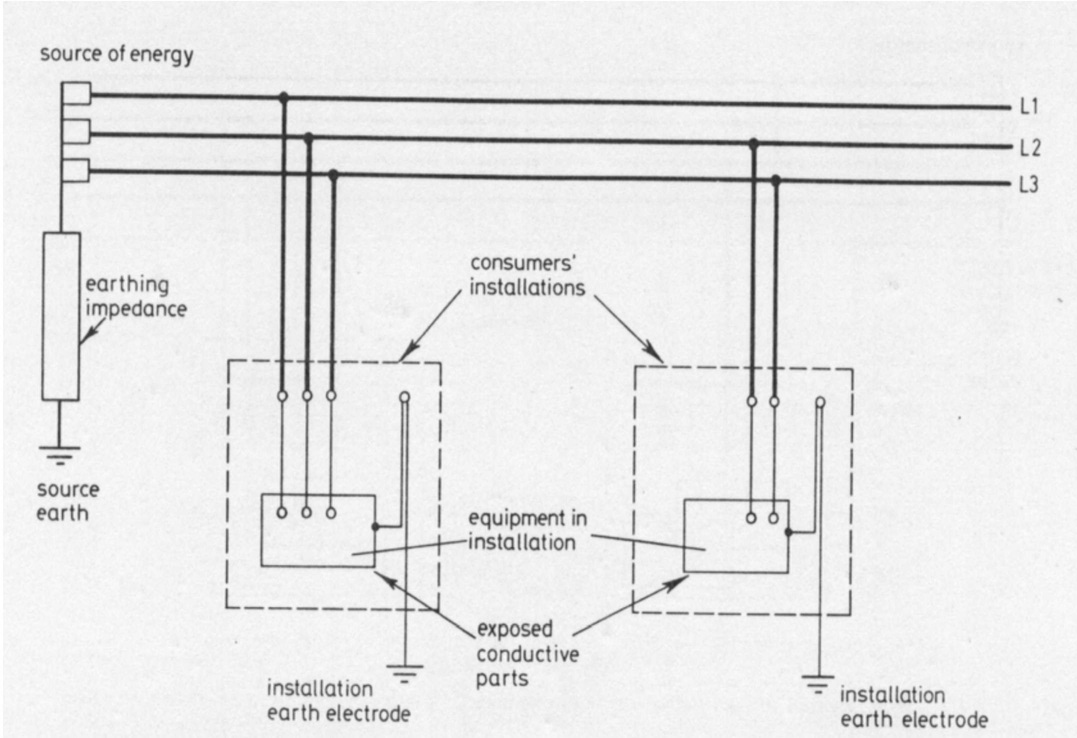


The ITN system

All exposed conductive parts of the installation are connected to an earth electrode.

The source is either connected to earth through a deliberately introduced earthing impedance or is isolated from Earth.

UNDER THE ELECTRICITY SUPPLY REGULATIONS (IEE) THIS SYSTEM MUST NOT BE USED FOR PUBLIC SUPPLIES.



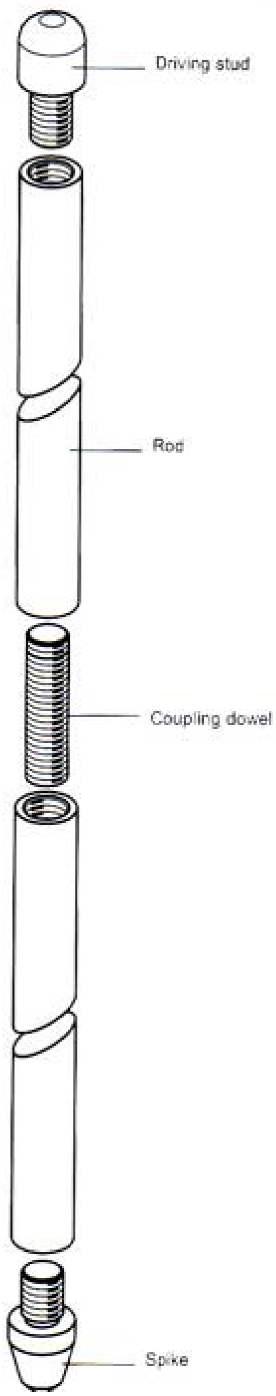
٦. Earthing System Components:

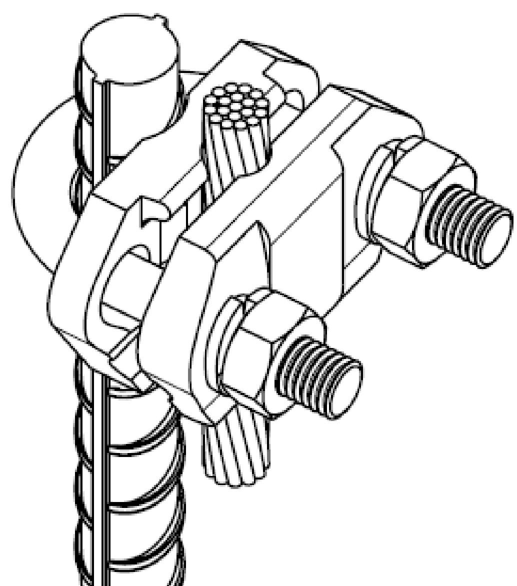
The earthing system is composed of many components which should be carefully designed and selected. Some of the earthing system components are :-

- ***Earthing conductor*** *: this is a conductor connecting part of an installation with an earth-electrode, but only as far as it is outside the soil or is insulated where buried in the soil.*
- ***Main earth conductor*** *: this is an earthing conductor to which several earth conductors are connected.*
- ***Earthing Electrode System****: this could be a single earthing rod, multiple rods connected together, a plate, or an earthing grid. The earthing electrodes are usually made of copper, stainless-steel, or copper molecularly bonded onto a steel core.*
- ***Earthing System accessories****: this include various types of clamps, joints, fixing and supporting materials.*

If necessary, protection must be provided against mechanical and chemical damage for various earthing system components. The laying of bare earth conductors in concrete is permitted. All earthing conductors must be rated for a single phase to earth fault current.

All joints and connections in the earthing system must be carefully made to ensure that they are electrically sound. Welded connections are preferred, but bolted or clamped connections are also permitted. Bolted joints including the bolts must be protected against corrosion. Earth electrodes must be in good contact with the surrounding subsoil. In dry subsoil locations the electrodes should be wetted.



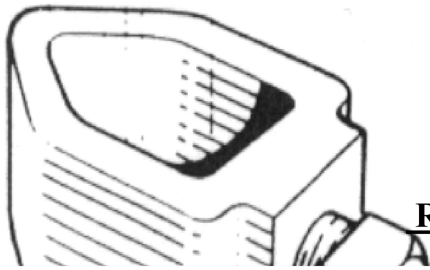
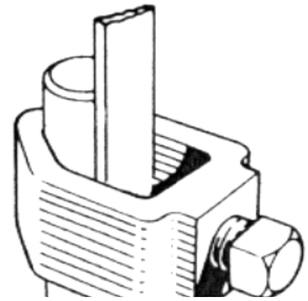


C

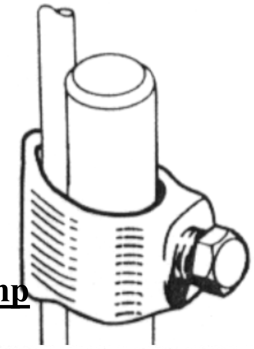
to the Rei

Earthing Rod

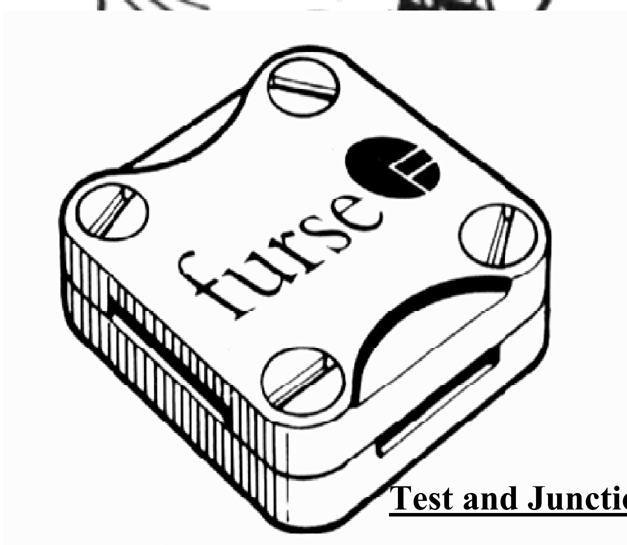
Details

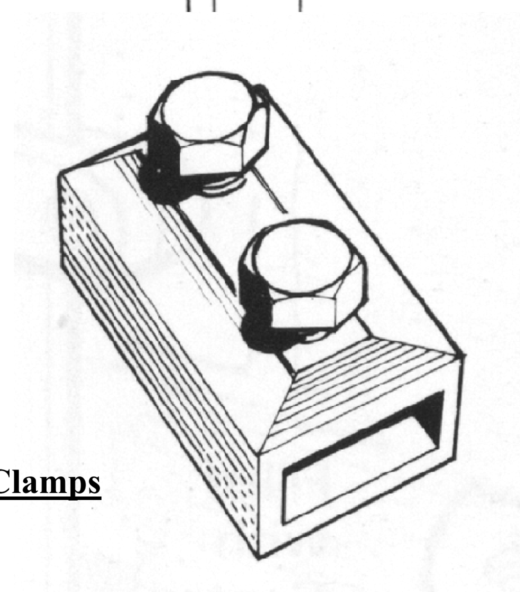



Rod to Tape Clamp

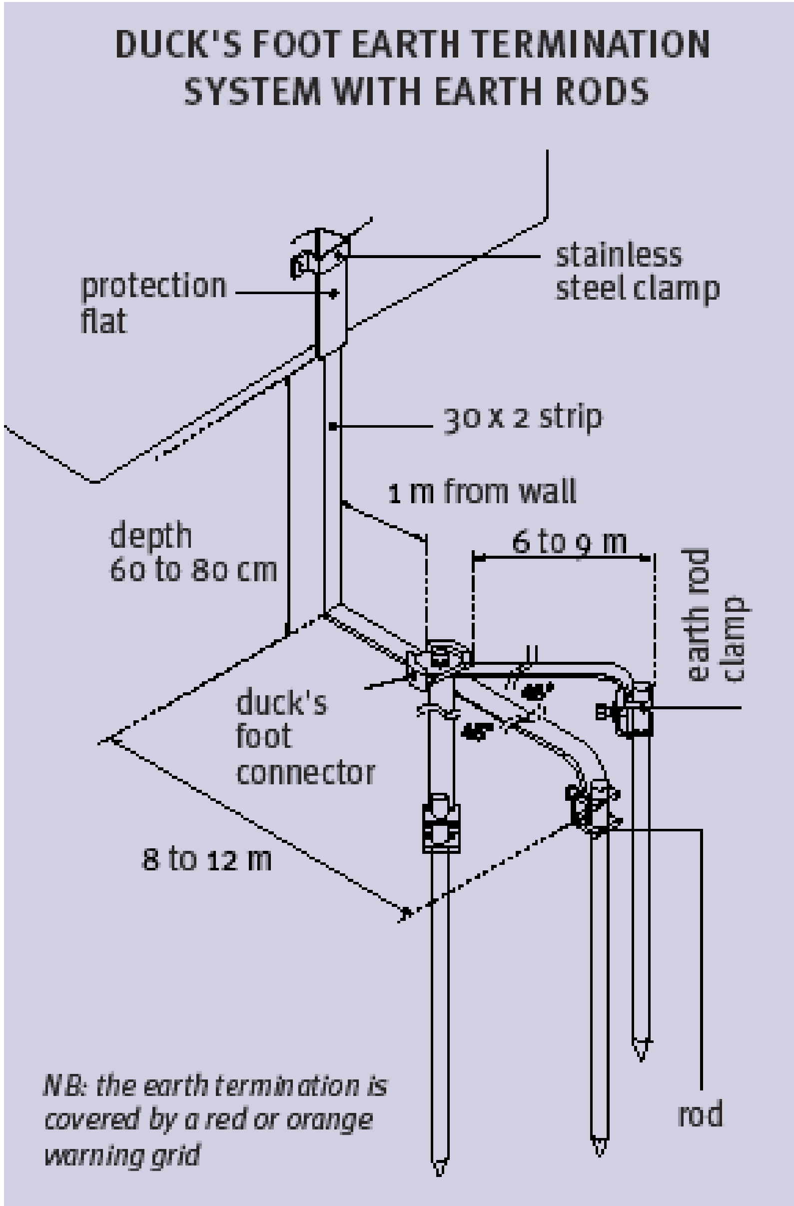



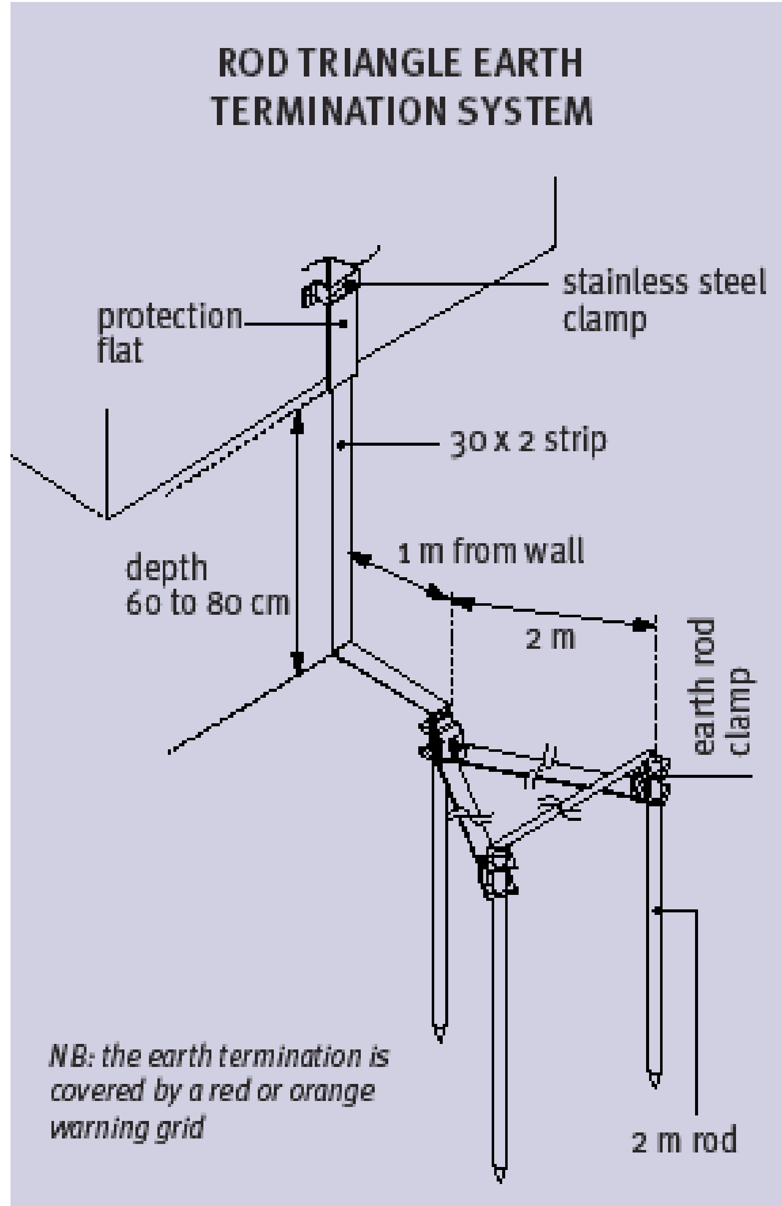
Rod to Cable Clamp





Test and Junction Clamps


DUCK'S FOOT EARTH TERMINATION SYSTEM WITH EARTH RODS
protection flat
stainless steel clamp
30 x 2 strip
1 m from wall
6 to 9 m
depth 60 to 80 cm
earth rod clamp
duck's foot connector
45°
8 to 12 m
rod
NB: the earth termination is covered by a red or orange warning grid


ROD TRIANGLE EARTH TERMINATION SYSTEM
protection flat
stainless steel clamp
30 x 2 strip
1 m from wall
depth 60 to 80 cm
2 m
earth rod clamp
2 m rod
NB: the earth termination is covered by a red or orange warning grid

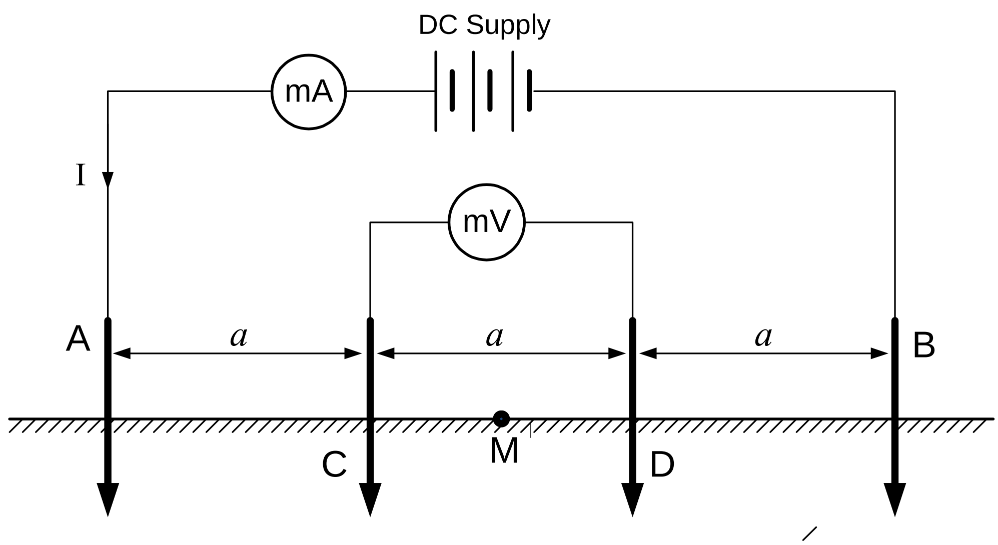
٧. **Measurement of Soil Resistivity**

One of the most important factors influencing the performance of the earthing system is the resistivity of the soil in which the earth electrodes are situated. Therefore, the main requirement for a good earthing system design is the knowledge of soil resistivity which is measured in Ohm-meter.

One ohm-meter represents the resistivity of the soil when it has a resistance of one ohm between the opposite faces of a cube of the soil having one meter sides.

It is important to find the resistivity of the soil as accurately as possible, since the value of the resistance of the earthing system electrode is directly proportional to the soil resistivity. If an incorrect value of soil resistivity is used at the design stage, the earthing system resistance may prove to be significantly different to that planned. This could, in turn, have serious consequences.

The most widely used method for soil resistivity measurement is called the ***Wenner Method*** *which is shown below:*



Soil Resistivity Test Arrangement
using the Wenner method

In this method four electrodes are driven into the ground in a straight line as shown on the diagram, spaced at an equal distance of "a" meters apart. The depth to which each electrode is driven should not exceed "a" divided by ٢٠ and is not normally greater than ٠.٣ meters. The outer two electrodes A and B should be connected to the DC power supply and used for current injection. A voltmeter is connected across the inner electrodes C and D for voltage measurement.

The apparent soil resistivity at point M can be obtained from the following equation:-

. $\rho_s = 2\pi a R$ *(Ohm-meter)*

In the above equation:

ρ_s - *apparent soil resistivity*

a - *spacing of electrodes in meters*

R - *resistance value as found from instruments and Ohm's law.*

*The term "**apparent resistivity**" is used since the formula assumes the soil is uniform within a hemisphere to a depth approximately "a" meters below the centre of the measurement array. We are able to obtain information about the actual soil layering by taking a series of readings, where "a" is increased in steps.*

Factors Affecting Soil Resistivity

Soil resistivity is subject to a great fluctuation which may result from various conditions such as: moisture contents, salt concentration, porosity, climatic fluctuations, etc.

a) Type of Soil

The soil composition which could be clay, gravel, sand, stones, chalk, etc., have a large influence on soil resistivity. Very often, the soil conditions and composition in the top ground layer is different from the deeper layers and often a two layer model is adopted.

Type of Soil	*Resistivity (Ohm-meter)*
Garden soil	٥ - ٥٠
Clay	٥ - ١٠٠
Clay, sand & gravel	٤٠ - ٢٥٠
Porous chalk	٣٠ - ١٠٠
Rock	١٠٠٠ - ١٠٠٠٠

b) Climatic Conditions

Obviously, dray and rainfall climates are at opposite extremes for the conditions of soil resistivity.

c) Seasonal variation

The effects of heat, moisture, drought, and frost can introduce wide variation in soil resistivity. Soil resistivity usually decreases with depth, and an increase of only few percent of moisture in a normally dry soil will noticeably decrease soil resistivity. Also soil temperature below freezing greatly increase soil resistivity.

In finding the grounding rod resistance, uniform earth (or soil) resistivity throughout the volume is assumed (although this is seldom the case in nature).

The most commonly used formula for finding the resistance of single grounding electrode is:

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

R = resistance in ohms of the ground rod to the earth (or soil)

L = grounding electrode length, m

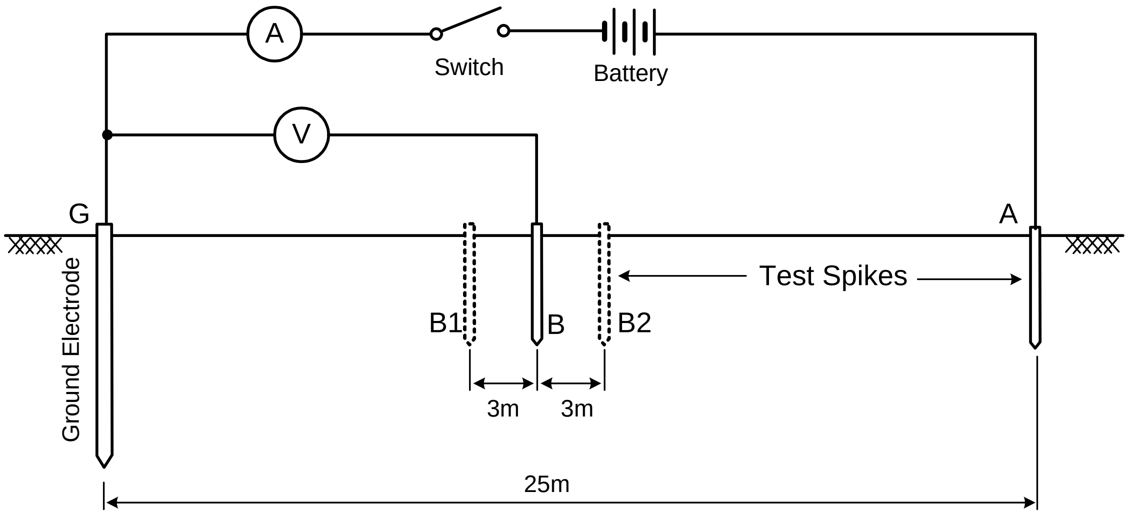
d = grounding electrode diameter, m

ρ = average soil resistivity in ohm-m.

٨. <u>Measuring the Grounding Electrode Resistance</u>

The equation given above can only determine the approximate value of the grounding electrode resistance, depending on the theoretical value of resistivity of the soil at a particular site for the purpose of design work. The exact resistance of the grounding electrode must be determined at the site of installation to support theoretical assumptions and the grounding conditions adjusted, if necessary, to obtain the required ground resistance.

The resistance of a grounding electrode resistance can be measured with the help of a specially designed ground tester, which generates a constant voltage for accurate measurement. It also can be conducted with the help of a battery, voltmeter and an ammeter, as illustrated in the figure below:



Test Setup for Measuring the Grounding Electrode Resistance

A test spike A is driven into the ground at about ٢٥ m from the grounding electrode G, whose resistance is to be measured. A second spike B is placed between the two. The battery is connected between G & A to inject current through the ground soil and a voltmeter is used to measure the voltage between G & B. Then the grounding electrode resistance could be found by using ohm's law. Two more readings should also taken by shifting the spike B, ٣ m on either side of the original location. For an accurate results, the three readings should be approximately the same. *If they are not, the probe B is still within the resistance area of the grounding electrode G. Shift away probe A by another ٥ m and repeat the same procedure until you get approximately the same results for the three measurements.*

٩. ***Improving the Grounding System Resistance***

If it is determined that a grounding electrode resistance to remote earth is not low enough, there are several ways that it can be improved (lowered):

a) The first approach would be to **lengthen** *the electrodes, which puts them deeper into the ground. However, it is difficult to drive long ground rods (above ٣ meters) deep into the ground especially in soil containing gravel, rock, and stones.*

b) Another approach would be to use **multiple ground rods**. *The National Electrical Code (NEC) states that if one electrode is being used and it's resistance to remote earth is greater than ٢٥□, then additional one (or two) electrodes should be installed.*

c) A third method to help lower the resistance to remote earth for a grounding system, is to **treat the soil** *with some type of ground enhancing material (salt, carbon, moisture, etc.). However, this method introduces the risk of corrosion.*

d) By **increasing the diameter** *of the electrodes used. But using this method provides only a small difference and it is not very economical.*

١٠. Lightning Protection

What is lightning?

Lightning is a high-energy luminous electrical discharge from a thundercloud to the ground accompanied by thunder. In our atmosphere, two types of discharges take place:

- **Inter-Cloud** *- It is the most common type of discharge (Although it is not the most damaging and dangerous) . This occurs between charge centers in two different clouds with the discharge bridging a gap of clear air between them or between oppositely charged centers within the same cloud. Usually the process looks from the outside of the cloud like a diffuse brightening which flickers and could be seen for many kilometers. This type is most dangerous to aircrafts.*
- **Cloud to Ground -** *When the discharge take place between thunderclouds and ground. This type is the most damaging and affects our life and property and so it is of concern to us.*

An exception to this is the aircraft hit by inter-cloud lightning. Annually in the USA only, lightning causes more than ٢٦,٠٠٠ fires with damage to property in excess of ٢- ٣ billion US $.

Lightning discharge is a very fast process. It occurs at millions of volts with a current of up to ٣٠٠ kA and the discharge creates temperatures of about ٣٠,٠٠٠℃ within a few tens of milliseconds. Prediction of lightning as to the precise time and location is very difficult or impossible. However, somewhat a season or period of lightning occurrence at many regions of the World is well known.

Lightning effects can be direct and/or indirect. Direct effects are from resistive heating, arcing and burning. Indirect effects are more probable. They include capacitive, inductive and magnetic behavior.

Lightning is responsible for more deaths and property loss than tornadoes, hurricanes and floods combined, but of these violent forces of nature, lightning is the only one we can economically afford to protect ourselves against.

A lightning protection system does not prevent lightning from striking; it provides a means for controlling it and preventing damage by providing a low resistance path for the discharge of lightning energy to ground.

Lightning can enter a building in one of the following ways:

١. *It can strike a metal object on the roof.*
٢. *It can strike a building directly (called a direct strike).*
٣. *It can strike a tree or fence near the building and jump to the building. This occurs when the building provides an easier path to ground.*
٤. *It can strike a power line or a wire and follow it to the building.*

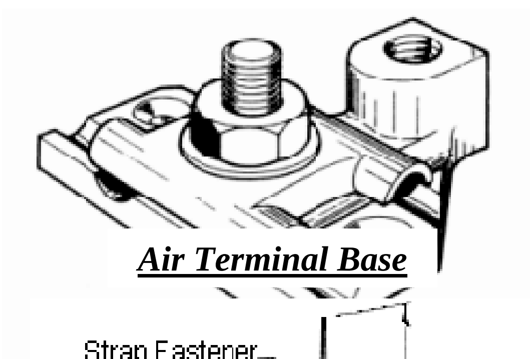
The lightning protection system is usually composed of the following parts:

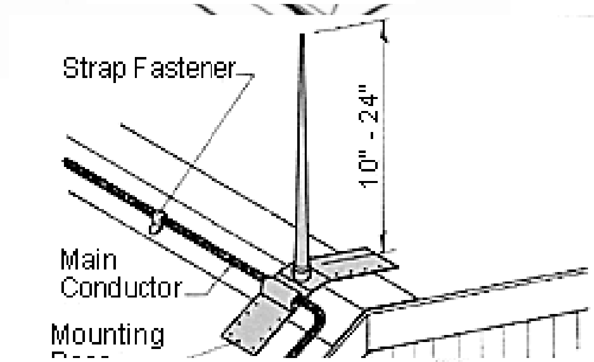
a) <u>Air Termination Network</u>

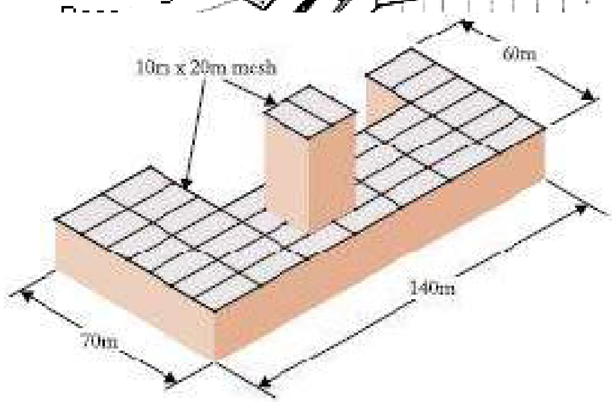
The upper part of the building's ground system is the air termination. Air Termination is one of the best known and has been in use in protecting buildings and facilities for many years.

The main purpose of the lightning air terminal is to provide a point above the structure to be protected with a very good, earthed connection so that the lightning energy gets diverted into ground without damaging the structure. It has no role in preventing a lightning occurrence.

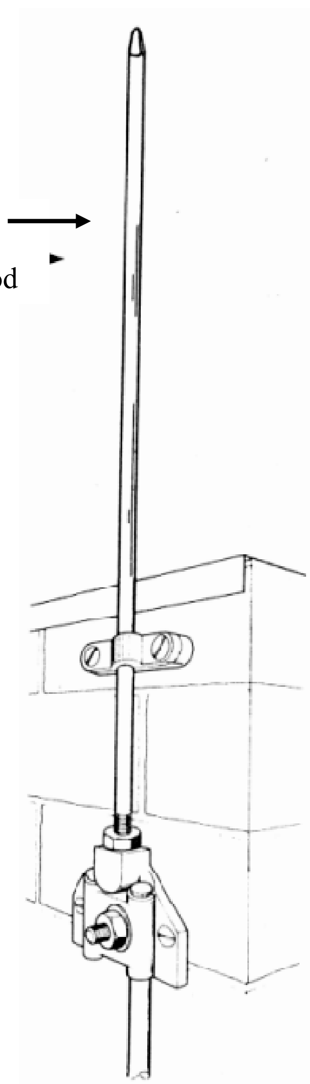
Air terminals are usually placed around the perimeter of the building at intervals not exceeding ٨-١٠ meters.

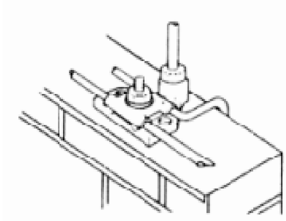






Taper-pointed
Air Terminal Rod





Air Termination Components

b) Down Conductors

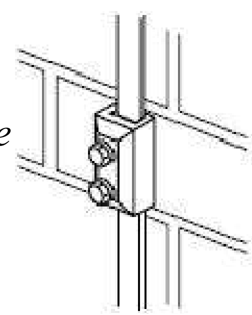
These are conductors connecting the air termination network with earth stations. Down conductor positioning is often dictated by architectural constraints, but there should be one down conductor for every ٢٠m or part thereof of the building perimeter at roof or ground level (whichever is greater). If the building height is above ٢٠m, or of an abnormal risk this distance should be reduced to ١٠m.

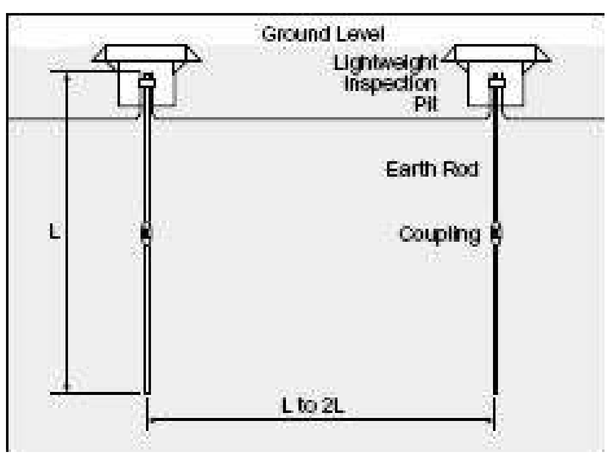
Down conductors could be stranded or flat tape type and should be routed as directly as possible from the air termination network to the earth station to avoid risks of side flashing.

c) Earth termination System

Each down conductor must have a separate earth termination. Moreover provision should be made in each down conductor, for disconnection from the earth for testing purposes. This is achieved by using a test clamp as shown.

BS ٦٦٥١ stipulates that the resistance to earth of the lightning protection system measured at any point, should not exceed ١٠ ohms. If the required resistance could not be achieved by using a single earth rod with each down conductor, two or three rods could be used in parallel.

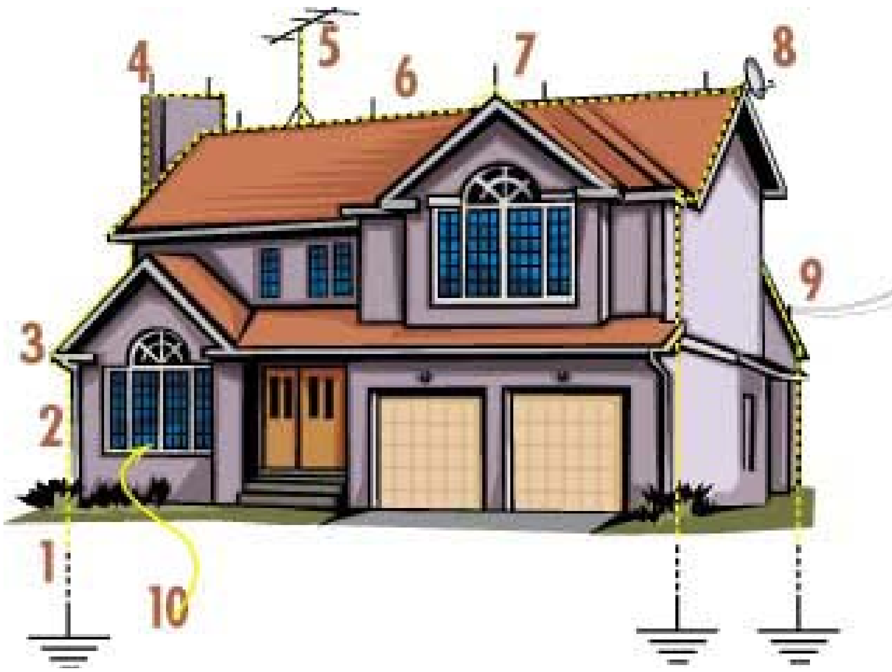




d) Lightning Arrestors

The electrical power supply circuits that feed the building and other components are vulnerable to surges coming in on the primary power line from the public utility. This could be caused by direct lightning strikes into low-voltage overhead lines or lightning protective devices for the building. The resulting surge currents and surge *voltages, with respect to their amplitude and energy content, pose a major threat to the electrical installations.*

It is also possible to have over-voltages as a result of indirect (or remote) lightning strikes. To protect electrical installations in buildings due to over-voltages caused by direct or indirect strikes of lightning; surge diverters or lighting arrestors are installed at the main power intake and at critical supply locations in the building.



WHEN LIGHTNING STRIKES

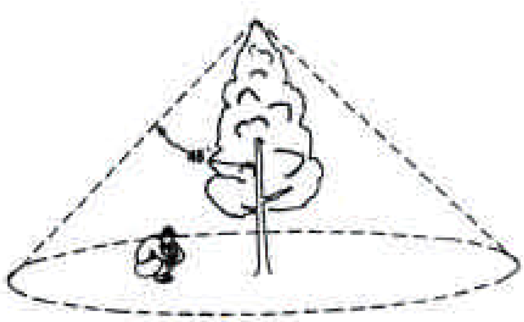
Seek safe shelter immediately! If you're unable to find shelter in a building or residence that is equipped with a lightning protection system, the Lightning Protection Institute suggests the following guidelines:

When Indoors

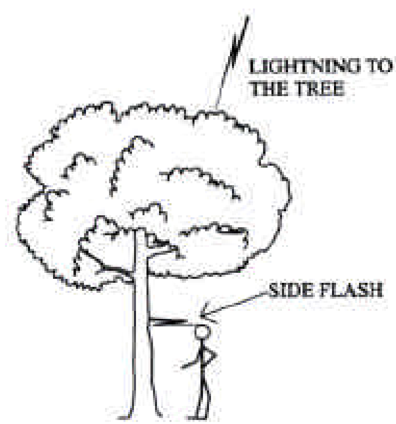
- Stand away from windows, doors, and electrical appliances.
- Unplug appliances well before a storm nears – never during because lightning can follow the wiring.
- Avoid contact with piping, including sinks, baths, and faucets because pipes can conduct electricity.
- Do not use the telephone except for emergencies. People have received severe electrical shocks while using the phone. Cell phones are not a problem.

When Outdoors

- Get in a hard-topped car.
- Avoid areas that are higher than the surrounding landscape.
- Never use a tree as a shelter. (If in the woods, find an area protected by a clump of trees; never stand underneath a single tree in the open).
- Keep away from metal objects, including bikes, golf carts, fencing, and machinery, etc.
- Avoid standing near tall objects such as towers, tall trees, fences, telephone lines, or power lines.
- Immediately get out and away from pools, lakes, and other bodies of water.
- Spread out – don't stand in a crowd of people.
- If you feel a tingling sensation or your hair stands on end, lightning may be about to strike! Immediately crouch down and cover your ears. Do not lie down or place you hands on the ground.
- Victims of lightning shock should be administered CPR (Cardio-Pulmonary Revival) and get medical attention.



SUGGESTED POSTURE NEAR TREE IF SURPRISED BY LIGHTNING ARROUND



THE SIDE FLASH FROM A NEARBY TREE

The 'Lightning Crouch'

Lightning safety experts have invented a "lightning crouch" that is important to know if you are caught in a thunder storm and can't find shelter. If you think this position is hard to do, you are right. It is. So practice it until you can stay in it for several minutes, because it ***could save your life****.*

There are several reasons for doing the lightning crouch:

- *In the lightning crouch, you are a smaller target. Lightning usually hits the tallest thing around and this is one time that you don't want to be tall.*
- *With your heels together, if lightning hits the ground, it goes through the closest foot, up to your heel and then across to the other foot and back to the ground again. If you don't put your feet together, lightning could go through your heart and possibly kill you.*
- *You put your hands over your ears to protect them from thunder.*