TYPES OF EARTHING SYSTEM

Layla sulaiman hamasur

Electrical engineer

What is earthing?

- The whole of the world may be considered as a vast conductor which is atreference (zero) potential.

- In the UK it is referred to this as 'earth' whilst in the USA it is called 'ground'.

- People are usually more or less in contact with earth, so if other parts which are open to touch become charged at a different voltage from eartha shock hazard exists.

- The process of earthing is to connect all these parts which could becomecharged to the general mass of earth, to provide a path for fault currents and to hold the parts as close as possible to earth potential. In simple theory this will prevent a potential difference between earth and earthed parts, as well as permitting the flow of fault current which will cause theoperation of the protective systems.

- The standard method of tying the electrical supply system to earth is to make a direct connection between the two. This is usually carried out atthe supply transformer, where the neutral conductor (often the star pointof a three-phase supply) is connected to earth using an earth electrode. Figure 1 shows such a connection.

Types of Earthing System

1- TT systems

This arrangement covers installations not provided with an earth terminal by theElectricity Supply Company. Thus it is the method employed by most (usually rural) installations fed by an overhead supply. Neutral and earth (protective) conductors must be kept quite separate throughout the installation, with the finalearth terminal connected to an earth electrode by means of an earthing conductor.

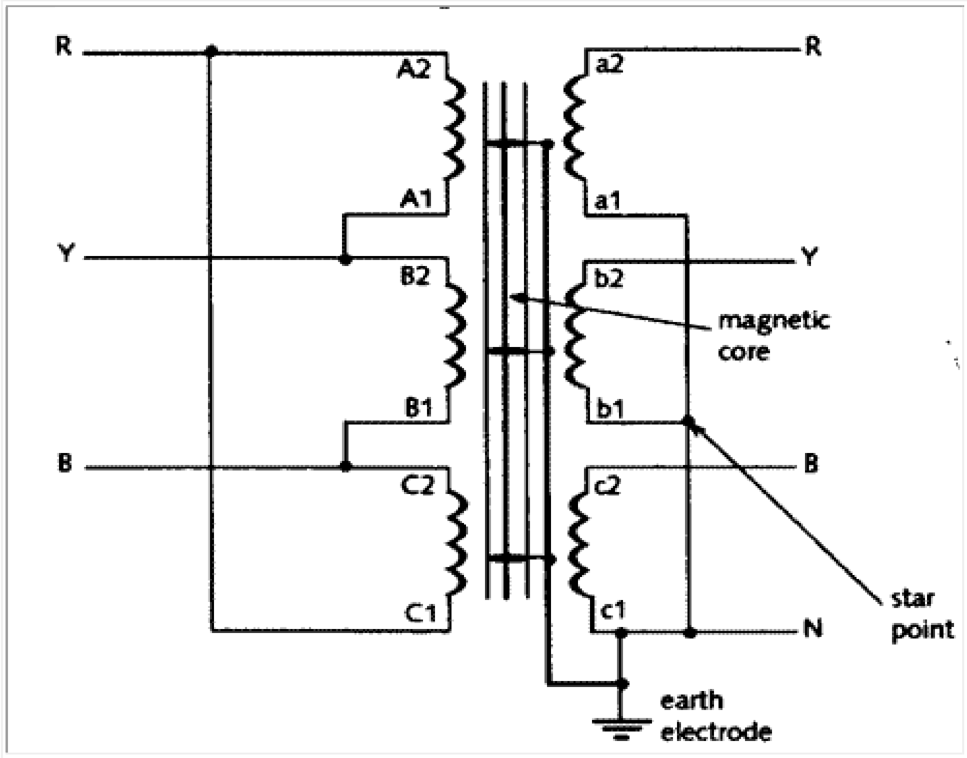

Fig .1 - Three-phase delta/star transformer showing earthing arrangements.

Effective earth connection is sometimes difficult. Because of this, socket outlet circuits must be protected by a residual current device (RCD) with an operating current of 30 mA . Fig. 2 shows the arrangement of a TT earthing system.

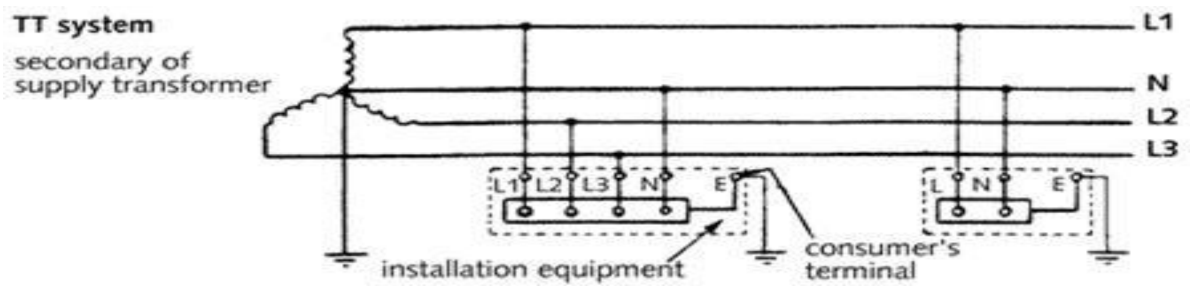

Fig.2 - TT earthing system

2 - TN-S system

This is probably the most usual earthing system in the world, with the Electricity Supply Company providing an earth terminal at the incoming mains position. This earth terminal is connected by the supply protective conductor (PE) back to the star point (neutral) of the secondary winding of the supply transformer, which is also connected at that point to an earth electrode. The earth conductor usually takes the form of the armour and sheath (if applicable) of the underground supply cable. The system is shown diagrammatically in {Fig.3}.

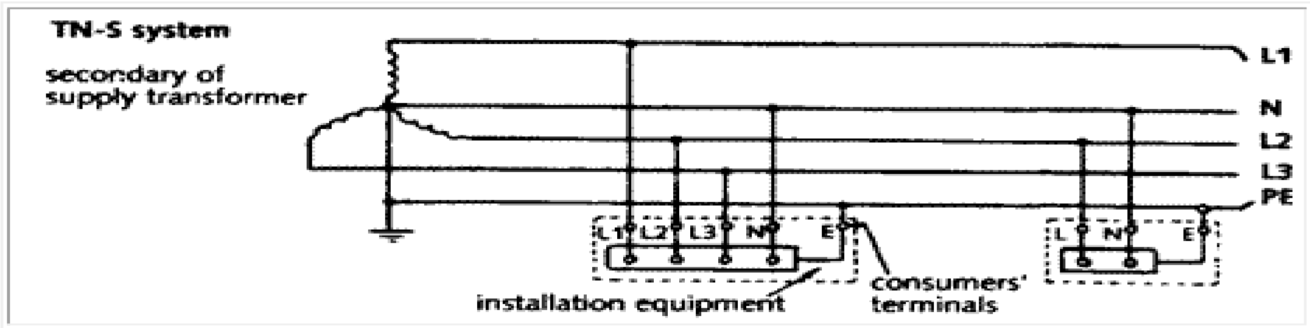

Fig.3 - TN-S earthing system

3 - TN-C-S system

In this system, the installation is TN-S, with separate neutral and protective conductors. The supply, however, uses a common conductor for both the neutral and the earth.This combined and neutral system is sometimes called the 'protective and neutral conductor' (PEN) the 'combined neutral and earth'conductor (CNE). The system, which is shown In Fig.4 is most usually protective multiple earth (PME) system.

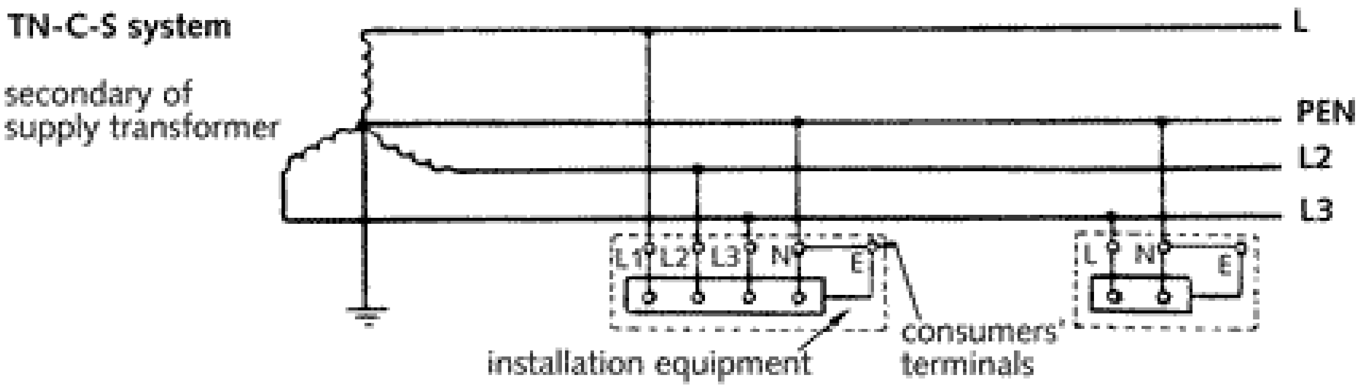

Fig.4 - TN-C-S earthing system - protective multiple earthin

4-TN-C system

This installation is unusual, because combined neutral and earth wiring is used in both the supply and within the installation itself. Where used, the installationwill usually be the earthed concentric system, which can only be installed underthe special conditions (mostly used in France).

5 - IT system

The installation arrangements in the IT system are the same for those of the TT system . However, the supply earthing is totally different. The IT system can have an unearthed supply, or one which is not solidly earthed but is connected to earth through a current limiting impedance.IT system is shownin Fig.5.

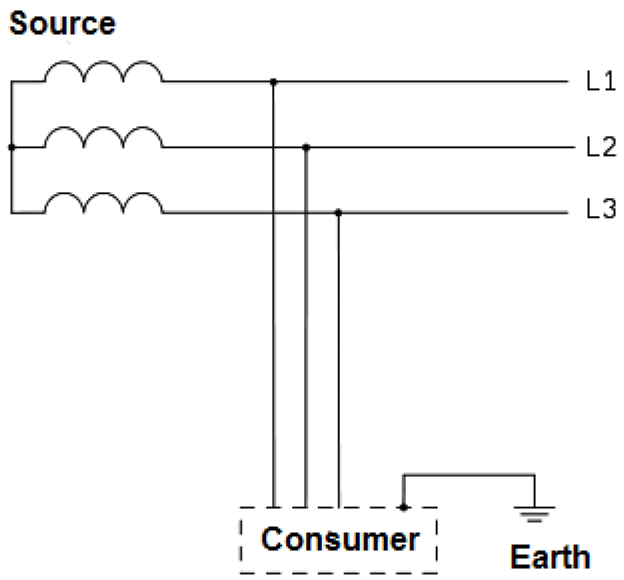

Fig.5 - IT earthing system

Principle of earthing system

- The path followed by fault current as the result of a low impedance occurring between the phase conductor and earthed metal is called the**earth fault loop**. Current is driven through the loop impedance by thesupply voltage.
- The extent of the earth fault loop for a TT system is shown in {Fig .6},and is made up of the following labelled parts.

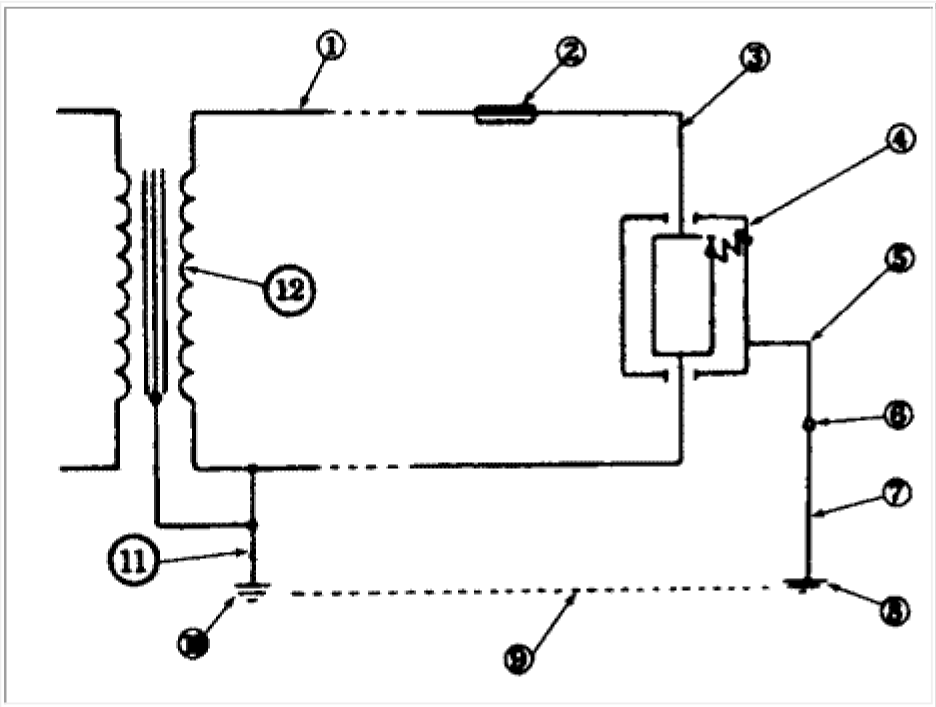

Fig.6 The earth fault loop

l. - the phase conductor from the transformer to the installation

2-the protective device(s) in the installation

3-the installation phase conductors from the intake position to the fault

4. - the fault itself (usually assumed to have zero impedance)

5. - the protective conductor system

6. - the main earthing terminal

7. - the earthing conductor

8. - the installation earth electrode
9. - the general mass of earth

10. - the Supply Company's earth electrode

11. - the Supply Company's earthing conductor

12- the secondary winding of the supply transformer

- For a TN-S system (where the Electricity Supply Company provides an earth terminal), items 8 to 10 are replaced by the PE conductor, which usually takes the form of the armouring (and sheath if there is one) of theunderground supply cable.

- For a TN-C-S system (protective multiple earthing) items 8 to 11 arereplaced by the combined neutral and earth conductor.
- For a TN-C system (earthed concentric wiring), items 5 to 11 are replacedby the combined neutral and earth wiring of both the installation and of the supply.

It is readily apparent that the impedance of the loop will probably be a good deal higher for the TT system, where the loop includes the resistance of two earth electrodes as well as an earth path, than for the other methods where the complete loop consists of metallic conductors.

Earthing system components (**6,7 and 8**)

Earthing system has three main componens

- Earthing conductors
- **Earthing electrods**
- Inspection points (earthing well)

1- Earthing conductors

The earthing conductor is commonly called the earthing lead. It joins the installation earthing terminal to the earth electrode or to the earth terminal provided by the Electricity Supply Company. It is a vital link in the protective system, so care must be taken to see that its integrity will be preserved at all times.

2- Earth electrodes

The principle of earthing is to consider the general mass of earth as a reference (zero) potential. Thus, everything connected directly to it will be at this zero potential. The purpose of the earth electrode is to connect to the general mass of earth ,(see Fig.7).

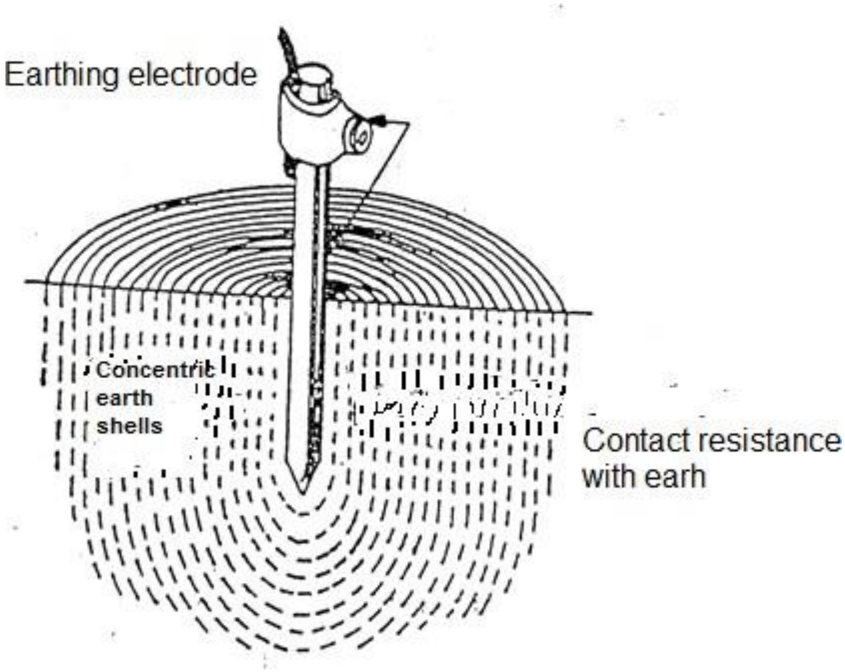

Fig.7 **Earth electrode**

Calculation of earthing resistance for one electrode driven at the earth

Equation used to calculate earthing resistance is:

$$R = \left(\frac{\rho}{2\pi l}\right)[\ln\left(\frac{81}{d}\right) - l] \ldots\ldots\ldots\ldots\ldots (1)$$

Where,

ρ = earth resistivity in ohm.m

l = length of the electrode (m)

d= diameter of the electrod in (m)

Example 1 : calculate the earthing resistance of an earthing electrode of length 3m and its diameter is 2 cm driven in an earth of 60 Ω.m resistivity.

Solution:

$R_I = (\rho / 2\pi\ l)[\ln (8l /d) -1] = (60 / 2\pi x3)[\ln (8x3/ 0.02)-1] = 19.4\ \Omega$

This is very large value. To reduce this resistance we can put another rode (electrode) at distance D in parallel with the first rode. Hence the total earthing resistance R_{II} will be:

$$R_{II} = ((1+ \alpha) / 2) R_I$$

$$\alpha = (\rho / 2\pi\ D\ R_I) \qquad (2)$$

Example 2: For example 1 above calculate the erthing resistancse when two similar electrod are put in parallel.

Solution:

From example 1 R_I=19.4 Ω

$$\alpha = (\rho / 2\pi\ D\ R_I) = (60/ 2x3.14x3x19.4) = 0.16$$

$$R_{II} = \{(1+ 0.16) /2 \} (19.4) = 11.25\ \Omega$$

For standard building, it is found that the best earthing system is to use thee rodes connected in triangular form as shown in Fig.8, in this case the earthing resistance will be reduce to $R_{III}= R_I/3$.

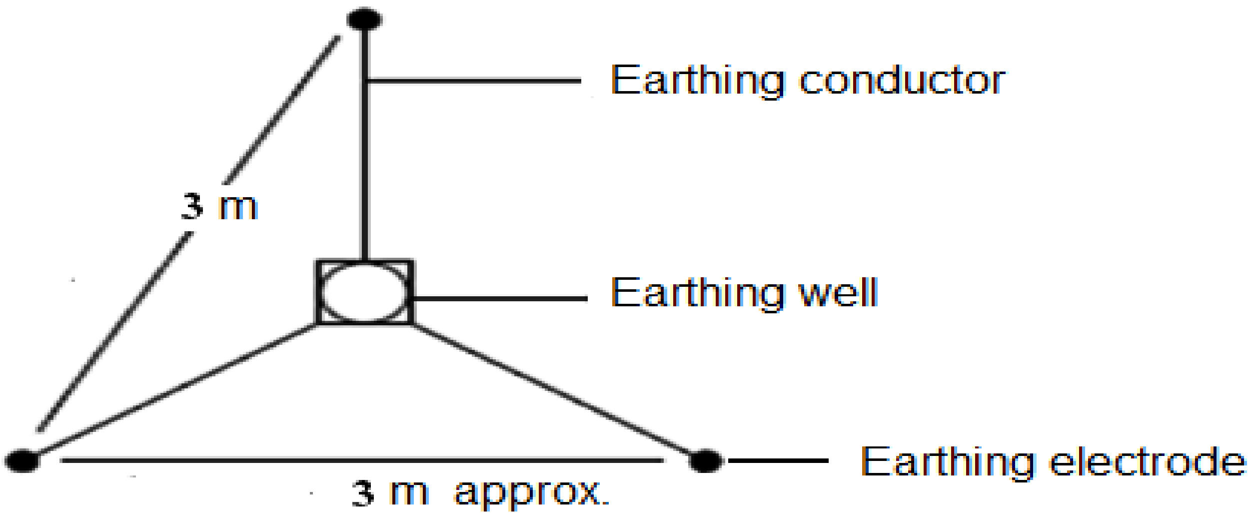

Fig.8

For any number of rods in parallel, we can calculate the earhing resistance from the following equation and table:

$$R_{eq} = [\ RI\ /\ \text{No. of rods.}]\ x\ F \qquad (9\text{-}4)$$

Where F is a multiplying factor that can be taken from the following table-1.The resistivity (ρ) in .)Ω . m(for various types of soils are given table-2.

Table-1

F	No.of rods
1.16	2
1.29	3
1.36	4
1.68	8
1.8	12
1.92	16
2.0	20

Table-2

.) m. Ω (ρ المقاومية	Type of soil نوع التربة
33 – 5	مستنقعات وترب مغمورة بالماء
133 – 23	تربة طينية
533 – 53	طين – رمل
3333 – 233	رمل سليكوني
3333 – 1533	ارض صخرة

3-Inspection points (Earthing well)

For protection of the earthing rod and earthing conductors and also for maintenance and inspection purposes an earth well is constructed as shown in Fig.9. Earthing conductors, as well as protective and bonding conductors, must be protected against corrosion. Probably the most common type of corrosion is electrolytic, which is an electro-chemical effect between two different metals when a current passes between them whilst they are in contact with each other and with a weak acid. The acid is likely to be any moisture which has become contaminated with chemicals carried in the air or in the ground.

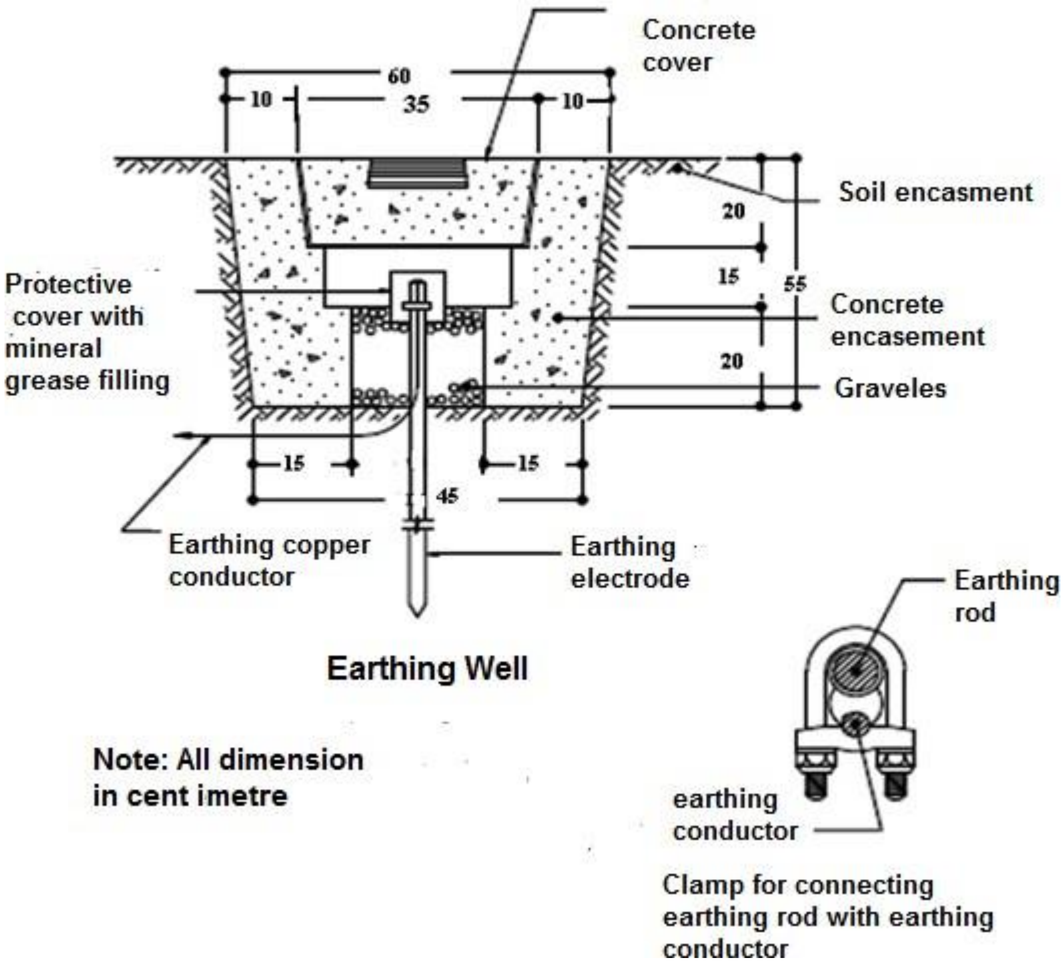

Fig.9 Earthing well

- A main earth terminal or bar must be provided for each installation to collect and connect together all protective and bonding conductors. Itmust be possible to disconnect the earthing conductor from this terminal for test purposes, but only by the use of a tool. This requirement is intended to prevent unauthorised or unknowing removal of protection.

- Where the final connection to the earth electrode or earthing terminal ismade there must be a clear and permanent label **Safety Electrical Connection - Do not remove** (see {Fig.10}).
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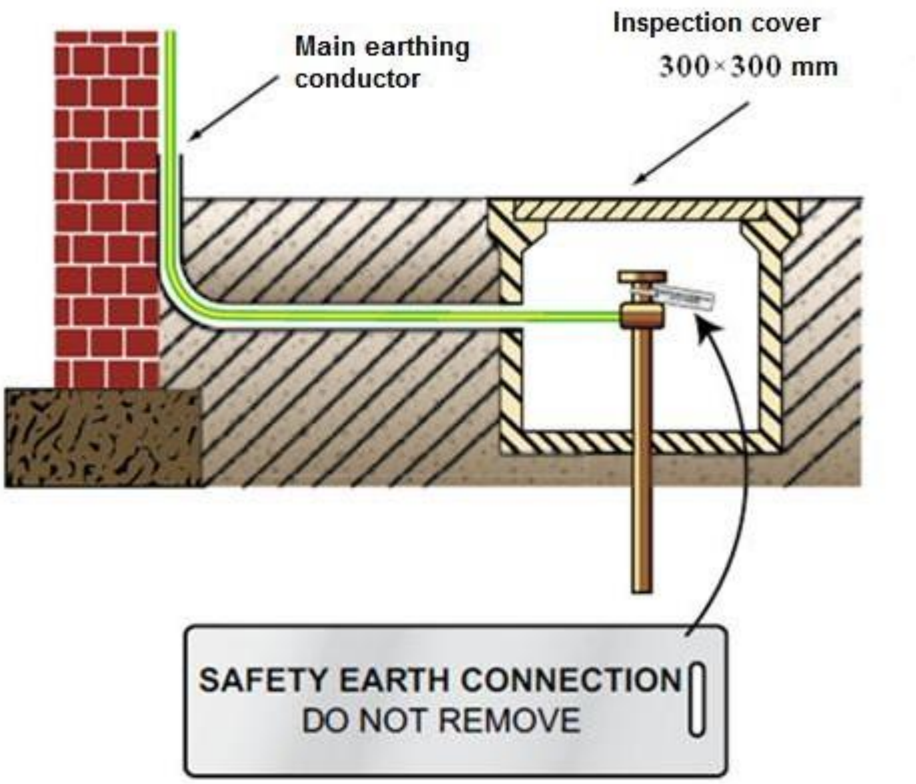


Fig.10

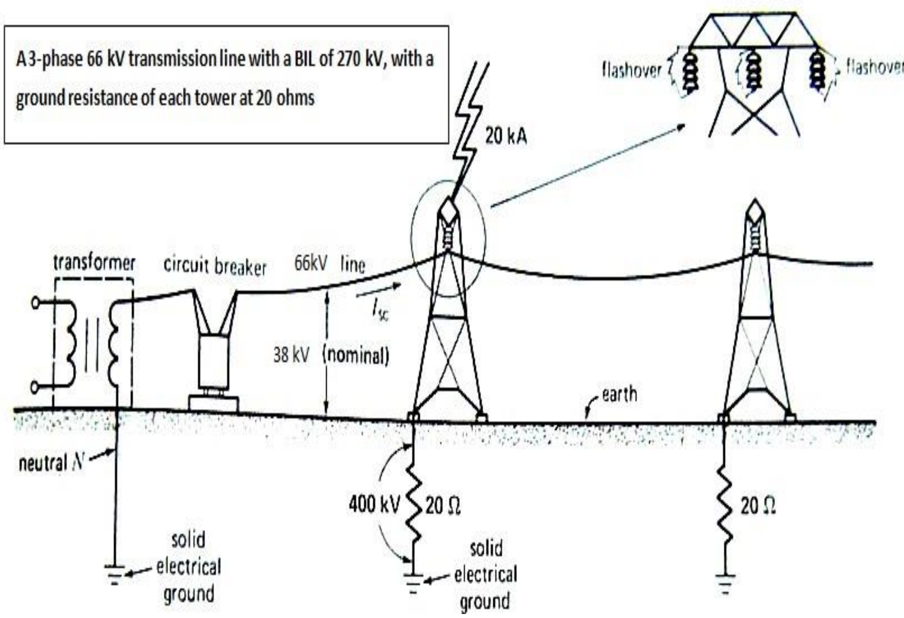
- With the increasing use of underground supplies and of protective multiple earthing (PME) it is becoming more common for the consumer to be provided with an earth terminal rather than having to make contact with earth using an earth electrode.

What is protective multiple earthing?

- If a continuous metallic earth conductor exists from the star point of the supply transformer to the earthing terminal of the installation, it will run throughout in parallel with the installation neutral, which will be at the same potential. It therefore seems logical that one of these conductors should be removed, with that remaining acting as a combined protective and neutral conductor (PEN). When this is done, we have a TN-C-S installation .***The combined earth and neutral system will apply only to the supply, and not to the installation.***
- PME can be installed by the Electricity Supply Company ***only*** after the supply system and the installations it feeds must have complied with certain requirements.
- The great virtue of the PME system is that neutral is bonded to earth so that a phase to earth fault is automatically a phase to neutral fault. The earth-fault loop impedance will then be low, resulting in a high value of fault current which will operate the protective device quickly. It must be stressed that the neutral and earth conductors are kept quite separate within the installation: the main earthing terminal is bonded to the incoming combined earth and neutral conductor by the Electricity Supply Company. The difficulty of ensuring that bonding requirements are met on construction sites means that PME supplies must not be used. Electricity Supply Regulations forbid the use of PME supplies to feed caravans and caravan sites.

How important is *Earthing* in electricity transmission and distribution systems?

Proper *Earthing* is arguably even more important in power transmission systems than in distribution systems. A single transmission line outage can cause a “black out” of an entire region and also entail huge economic losses. It is common knowledge that hydropower generation and sales is Bhutan’s economic “backbone” and is needless to point out that transmission infrastructure is a critical component. Of paramount concern are the impact of lightning and the role of *Earthing* in the dissipation of lightning surges. Transmission lines traversing the rugged and mountainous Himalayan terrain are very vulnerable to lightning strikes and the line towers are deliberately installed on sTable rocky foundations. Such sites may provide a strong foundation but are certainly not favourable for achieving good reliable *Earthing* (due to very high soil resistivity). The importance of transmission tower *Earthing* is illustrated in **Figure 6** below.



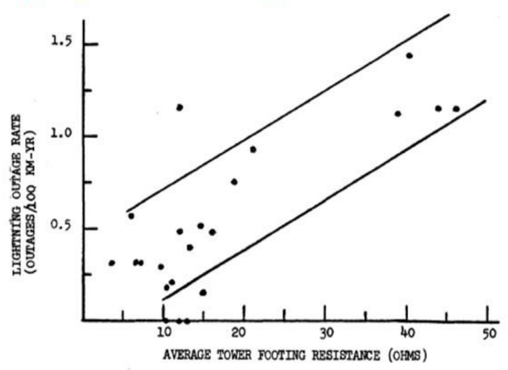
Tower footing earthing electrodes that provide larger area of contact with soil will provide higher capacitance necessary to lower *surge impedance* during lightning discharges.

Figure 6 : *Impact of high tower footing resistance*

Figure 6 above illustrates a key *Earthing* application and shows a 66 kV line with a BIL of 270kV and tower footing resistance of 20 Ohms that is struck by a lightning of 20 kA. As can be seen in the illustration, 400 kV will appear across the insulators and will flash over (i.e. will transfer the excess surge voltage to the transmission line conductors) since the Basic Insulation Level (BIL) of 270 kV is exceeded. However, if the tower footing resistance is 10 ohms, the lightning would be safely discharged with be no flashover across the insulators since the momentary 200kV surge that would be generated is lesser than the insulator BIL. Actually the tower footing impedance (rather than resistance) would be more relevant here but resistance is assumed for simplicity to explain the concept. This example uses a case where lightning strikes the tower (or shield wire), but lightning flashovers also can happen when it strikes the phase conductors (happens even when shield wires are installed). It is also possible to have flashovers when lightning strikes the ground near a transmission line (by electromagnetic induction). In all these cases, *Earthing* plays a vital role in the protection and returning transmissions systems to normalcy.

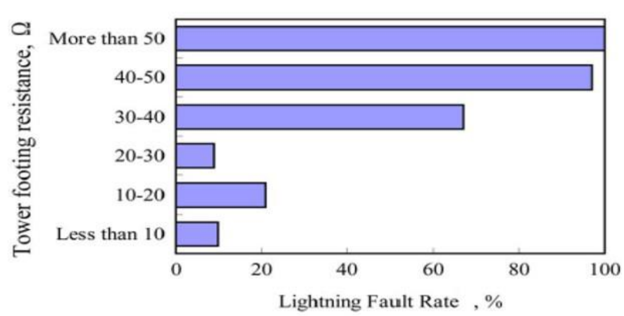
Field studies conducted abroad have shown that the transmission line outage due to lightning strikes is directly proportional to the tower footing resistance. The results of two such studies are reproduced below.

Lightning outage rate vs tower footing resistance for a 500 kV line



Source: James T. Whitehead, Lightning performance of TV's 500-kV and 161-kV transmission lines, IEEE Transaction on Power Apparatus and Systems, vol. PAS-102, No. 3, pp. 752-768, 1983.

Tower footing resistance vs. lightning fault rate



Source: Tomohiro Hayashi, Yukio Mizuno and Katsuhiko Naito, Study on transmission- line arresters for tower with high footing resistance, IEEE Transaction on Power Delivery, vol. 23, No. 4, pp. 2456-2460, 2008.

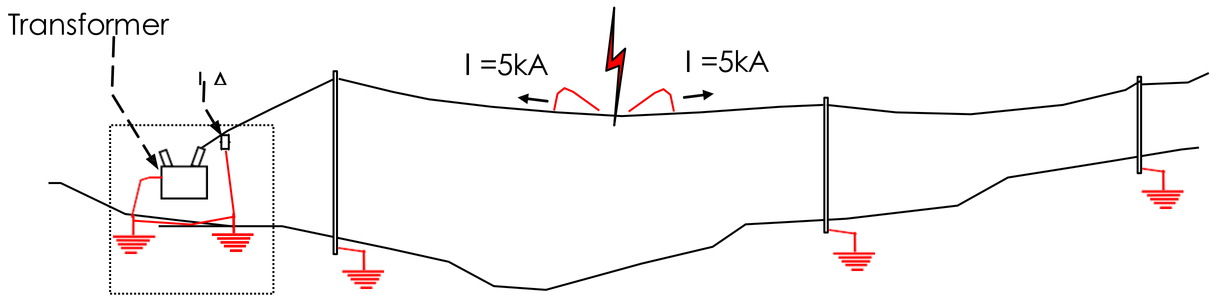
Another study even concluded that higher transmission footing resistance, E.g. 50Ω, may cause outage rate of the shielded transmission line higher than that of the unshielded one! [**Source**: P. Chowdhuri, S. Li and P. Yan: Rigorous analysis of back-flashover outages caused by direct lightning strokes to overhead power lines, IEE Proceedings- Generation, Transmission and Distribution, vol. 149, No. 1, pp. 58-65, January 2002].

It is therefore not difficult to see the importance of ensuring proper transmission tower *Earthing*

and it would certainly be worthwhile to regularly monitor our transssion tower footing

resistances. This is the very reason why IEEE Std. 1313.2-1999 states that electrical resistance of the tower footing is a significant parameter affecting back flash over voltage across the insulator(s) in transmission systems and (BS EN 62305-3: 2011 Code of Practice for Protection of Structures against lightning recommends *Earthing* resistance < =10 ohms).

As in the case of power transmission systems, lightning strikes (i.e. direct and indirect) also subject MV electricity infrastructure (lines, switchgear, and transformer stations) to damaging surge voltages often in excess of the line insulation level. The over voltages therefore need to be sufficiently attenuated or shunted to *Earth* prior to reaching the connected line equipments (arrestors, transformers, switchgears, etc). While these voltage impulses are also attenuated as it travels along the line, the MV steel pole *Earthing* plays an importance role in reducing the voltage surges by conducting the flash over voltage to *Earth*. However, the MV pole *Earthing* should be reliable and of low surge impedance to minimize the step and touch potential (which could otherwise be hazardous to both humans and animals). This situation is illustrated below where a lightning impulse current of 10kA splits into 5kA each at the point of lightning strike which then travels (almost at the speed of light) in opposite directions along the MV line. Assuming a MV line surge impedance of 400 ohms (i.e. usually around 400 to 500 ohms), this translates to an impulse voltage of 2000kV travelling in the two opposite directions. Since 2000kV impulse is well over the insulation rating of MV insulators, it will flashover to the cross arms and the pole which must conduct the flashover safely to *Earth*.



From the illustration above, it is evident that huge lightning voltage impulses can overwhelm the LA (especially if the MV poles are not effectively *Earthed*). It is possible that the LA energy dissipation capacity is exceeded (MOV blocks typically have a specific heat capacity of about 3.3 J/cm^3/°C), leading to thermal runaway and failure of LA. The resulting thermo-mechanical shocks can also cause damage and failure of LA. With an ineffective LA, all connected equipment (transformers, switchgears) is vulnerable to damage and failure (it will only be matter of time).

Note: From above discussions, it is clear that the MV poles need to have reliable low impedance *Earthing* so that it diverts any large flashovers into *Earth* and reduces excessive voltage impulses reaching the arrestors. Also, it must be ensured that the MV pole *Earthing* do not create excessive voltage gradients (*MV poles with a single spike driven into the ground near the pole base will definitely not be adequate at least in Bhutan's rocky soil conditions*). Providing proper *Earthing* for MV poles need to be prioritized in the lightning prone regions of the country

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Note: The basic rule is “The lower the surge impedance of the *Earthing*, the greater is the surge energy shunted to the *Earth*”.

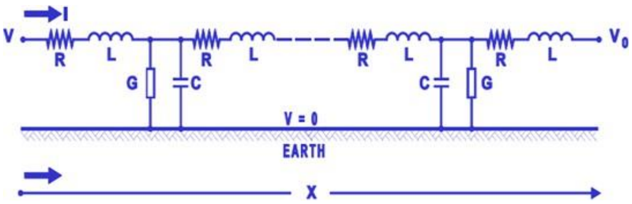
As can be seen from the typical BIL values for MV infrastructure tabulated above, it is evident that lightning over voltages (usually surges greater than 1000kV peak) due to lightning strikes (which commonly are in excess of 20kA) can easily cause MV line outages if Lightning Arrestors do not discharge effectively (which will not happen without proper LA *Earthing*).

Equipment	33 kV	11 kV
Surge Arrestor maximum residual voltage - steep current impulse	100 kV (p)	30 kV (p)
Transformers/switchgear (BIL) Rated impulse withstand voltage (peak)	170 kV (p)	75 kV (p)

Equipment	33 kV	11 kV
Puncture voltage (pin insulator)	185 kV	145 kV
Puncture voltage (disc insulator)	330 kV	110 kV
Wet flashover voltage (power frequency, pin insulator)	95 kV	70 kV
Wet flashover voltage (power frequency, disc insulator)	135 kV	45 kV

What is the difference between low *Earthing* impedance and low *Earthing* resistance?

For protection and mitigation of lightning strikes, it is very important to distinguish impedance from resistance. As indicated above, low *Earthing* impedance is more important than low *Earthing* resistance when dealing with rapidly varying voltages and currents (i.e. transients) such as those of lightning surges (high frequency components are superimposed too). When dealing with surges/transients, the inductance and capacitance encountered by the transients/surges are very significant. Therefore to safely and efficiently discharge lightning surges, an *Earthing* system must have low surge impedance. The **surge impedance** (Z) of an *Earthing* system is estimated using the following model (i.e. same as “lossy” transmission line model).



$$Z = \frac{\sqrt{R + j\omega L}}{\sqrt{G + j\omega C}}$$

Z is Surge Impedance

R is resistance **(**is a function of material used for grounding)

G is *Earth* conductance (related to soil resistivity and contact resistance between *Earth* electrode and soil)

L is Inductance of the *Earthing* system

C is Capacitance between *Earth* and *Earthing* electrodes

From the Surge Impedance (Z) formula above, it can be seen that Z increases with the increase in R and L and that Z decreases with the increase in G and C. Since ω is 2πf (and f is frequency which is very large for a typical lightning surge), it obvious that L and C are the dominant parameters in determining the value of Z. Therefore in the installation of *Earthing* systems that must safely and efficiently dissipate lightning surges, we must minimize the inductance (L). This translates to minimizing the length of *Earthing* conductors and ensuring minimum bends. The other dominant factor is capacitance (C) which must be maximized. In order to maximize C, the surface area of an *Earthing* electrode in contact with the soil must be maximized.