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# Earthing of High Voltage Laboratory

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**Abstract:** The study discusses salient points about development of a typical earthing mat installation that has been designed for meeting safety requirement for users of a high voltage laboratory. The details of the earthing practice followed and pattern of earthing mat resistivity variation under different conditions are discussed. The effectiveness of a good earthing system demands not only sound knowledge of design of the earthing mat system but also need experienced personals to implement the design during earth digging, filling soft soil, laying earth electrodes their interconnection and proper maintenance and upkeep at regular interval during all atmospheric conditions.

**Key words:** Earthing, high voltage labortory, pattern of earthing, atmospheric, installastion, resistivity variation

## INTRODUCTION

Earth is commonly used as a reference point for building and structure wiring systems. This term is used interchangeable with the term "ground". Earthing is a connection to earth. Engineers in the US (RSIGCPS, 1992) use the term "ground" and "grounding" in describing the involvement of ground or earth in the operation of electrical circuits. Their European counterparts use the term "earth" and "earthing". In the context in which these terms have been applied in some of their respective literatures, the words "ground" and "earth" appears to be synonymous (Dunki, 2006).

An Electrode is a conductor through which, an electric current enters or leaves a medium, such as earth. An equipment grounding therefore, refers to the interconnection of all the non-current-carrying metal parts of equipment, such as electrical equipment housings, metallic raceways and other metallic enclosures, to the ground electrode and/or the system grounded conductor at the service entrance equipment or at a separately derived ground.

The primary purpose of grounding is to protect and safe guard operating personal and equipment, power distribution systems, solid-state systems and computers, static and lightning protection systems. Improper earthing-grounding installations can result in equipment damage or improper operation. Improper earthing-grounding systems can result in not only electrical injures and shocks, but has resulted in electrocution (Zipse, 2001).

## FACTORS INFLUENCING OCCURRENCE OF EARTHING FAULTS

There are several factors which make electric current dangerous to human body like the magnitude of current, duration of flow, path through the human body, position and condition of a person and frequency of supply voltage. Danger of electricity to a human being is due to burns and scalds, cessation of respiration due to blocking in associated parts of the nervous system and reduction in blood circulation owing to ventricular fibrillations caused by uncoordinated heart beating.

The extent of danger to human being depends on the magnitude of current flow, which in turns depends on the electrical resistance of a human body which varies with persons under different conditions. It is difficult to specify a definite voltage which can be considered fatal to every human being. Electric resistance of the human body depends on several factors, such as contact area, moistness of skin, duration of current flow and magnitude of current. Resistance of body seems to be mostly at the skin and it is therefore, natural that it depends on area of the surface coming in contact (It makes enormous difference if a live wire is touched by tip of a finger or held in hand). The path of current flow through a body plays a vital role in fatality of an accident, which may be instantly fatal if the body contact is such that the heart lies directly in current path through the body.

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## RELIABILITY OF AN EARTH CONNECTION

A reliable earth connection is must for catering to the safety needs of user/operators and the connected equipments. Under abnormal operation on the power system network the touch potential and contact potential may attain dangerously levels which can hamper normal operation of the system/lab concerned. For complete reliability on earth electrodes following points are considered:

- Length of time for which electrode are expected to remain in a satisfactory and reliable condition. If a long life without much inspection and testing is to be expected, it is necessary to spend additional money to secure a durable grounding station.
- Nature of soil resistivity, i.e whether resistivity increases or decreases with depth. If the former is the case shallow electrodes would be required, while deeper electrodes would be the solution for the latter condition.
- Necessity of applying artificial treatment of an electrode, such as watering or using charcoal and salt.
- In case soil resistivity is very high, determination of other means from the point of view of effectiveness and cheapness of the installation must be explored.
- Selection of effective disconnecting means to protect the electric installation against damage and also provide insurance against accidents through electric shocks.

## BASIC DESIGN ASPECTS OF GROUNDING OF HIGH VOLTAGE LAB

For the grounding of high voltage lab, to be safe and satisfactory, should comply with the following requirements:

- The electrodes shall have adequate current carrying capacity so that maximum available fault currents would flow through the ground without excess increase in the ground resistance and consequent excessive temperature rises for a set time, to permit protective gears to operate.
- Voltage gradient along the surface of the ground around the electrode should not be permitted to be dangerously steep.
- Electrode materials and electric connections should have high resistance to soil corrosion.
- Changes in the electrode resistances should not be permitted to vary appreciably from time to time and shall remain low enough to permit proper operation of the protective equipment and safety of the operators (Kuka, 1971).

## DESIGN ASPECTS OF AN EARTHING ELECTRODE

The connection to earth, an electrode, can be made using many different forms conductor, a plate, or the reinforcing bar or a length of copper conductor buried in the concrete foundation. The earthing rod can be made out of several different materials of specified dimensions based on the ground strata. The usual material is copper or copper clad steel, Galvanized steel or even for special cases stainless steel can be used (Zipse, 2001). Normally, three types of metal electrodes are used for earthing of electrical equipment, namely pipes, plates and strips. Pipes and plates are more common than strips (Kuka, 1971). The resistance of the electrode to earth is made up of several components: -

- Resistance of the electrode
- The condition of the soil such as Moisture content, temperature of the soil, material content, type of soluble chemicals in the soil, concentration of soluble chemicals in the soil, contact resistance between the electrode and the soil, geometry of the current flow in the soil outward from the electrode to infinite earth (Zipse, 2001)

The following expression is normally used to find earth resistance of pipe electrode and plate electrode which is given as below.

For pipe electrode, $R = \frac{s}{2\pi a} \log \frac{4a}{d}$

For plate electrode, $R = \frac{s}{2\pi a} \log \frac{a^2}{dh}$

Where s = Ground specific resistance, ohm-meter
a = Length of the pipe in ground (or) width of the plate
d = Diameter or thickness of the electrode
h = Depth below surface to which a plate is buried.

Generally pipes of 2.5-5 cm diameter are used either single or multiples connected in parallel. Values of log 4a/d or such pipes within the length of a couple of meters would be approximated to about 5.8 m. The ground station resistance of a single pipe electrode would therefore be,

$$R = 0.9\frac{s}{a}$$

In case of plate electrode, normally with a square plate of width ‘a’, the electrode ground resistance is approximated as

$$R = 0.25\frac{s}{a}$$

It may be appreciated that the electrode-ground resistance does not vary proportional to the dimension ‘a’. It is therefore, not economical to select very large diameter pipes or larger width plates when earthing stations are installed in practice. Plates are limited to 2 $m^2$ and pipes to 4 m lengths.

A general equation for earthed-electrode resistance is written as

$$R = C\frac{s}{a}$$

Where C = 0.9 for pipe electrodes.
= 0.25 for plate electrode with square sides.

## MULTIPLE ELECTRODES

To reduce effective earth resistance of a grounding station, it is necessary to bury two or more electrodes and connect them in parallel. It should however be appreciated that the electrodes should not be placed too near one another as the current spreading into the ground will be mutually distributed. Normally for plates, best results are obtained when distance between separate plates is kept to about 3m and for pipe it is about 2 to 4m. Minimum effective resistance is obtained when the distance between the electrodes is equal to the radius of the circle (Kuka, 1971).

## SOIL RESISTIVITY

It is one of the most important parameters in designing the high voltage/station grounding system is the resistivity of the soil in the area. To obtain these values, an extensive soil resistivity survey should be conducted in the station area. The most common test methods are the Wenner Four-Probe method, which is used to measure large volumes of soil and the Soil Box Method, which is used to measure soil samples.

Very early in the generating station design phase, extensive soils exploration is required before detailed civil and structural design can begin. Soil boring logs or a formal soils report is usually available, or a cognizant civil engineer has knowledge of subsurface conditions. If test pits are dug, there will be an opportunity to measure subsurface soils directly.

If the extreme values of all soil resistivity data points fall within 30% of each other, a uniform soil assumption can be made. Because a uniform soil assumption is required in order to proceed with a preliminary design, a single value for soil resistivity will have to be chosen. Even though a uniform soil assumption may not be possible for the entire station site, it may be appropriate for the portions of the site that will be analyzed by calculation. If a uniform soil resistivity assumption cannot be made, then the final design should be based on an analysis technique that can incorporate a two-layer or more sophisticated soil model. In determining a resistivity value to be used, attention should be paid to the conditions that existed at the time the measurements were taken. Soil moisture content, temperature and salt content have a significant effect on resistivity measurements.

Caution should be used when determining a design resistivity value because large volumes of soil are frequently excavated and replaced by fill. The depth of the excavation may invalidate a single or two-layer soil model that is based on resistivity measurements from the upgraded site. This would require re-evaluation and/or the use of additional computational techniques (GGSG, 1982).

## INFLUENCES OF RAINING AND FREEZING SEASONS ON SOIL RESISTIVITY

The electrical property of sandstone sample like resistivity was tested; its resistivity almost keeps unchanged above, 0°C but obviously increases below 0°C. Its resistivity is about $10^6$ Ω m at -20 C. The resistivity of soil in nature is decided by the water content, the property and the density of the electrolyte solution, which has the characteristics of ion conduction. Ordinarily, the resistivity of the soil with more water is small and the resistivity of the dry soil is high. The clay sample states that its resistivity changes very quickly when the water content is smaller than 10%. When the water content of the clay sample is 2.5%, its tested resistivity is 1400 Ω m, but when its water content increases to 10%, its tested resistivity decreases to 200 Ω m and when its water content increases to 25%, its tested resistivity decreases to 15 Ω m.

For a fine sand sample, when the water content is 2.5%, the tested resistivity is higher than 10,000 Ω m, but when the water content increases to 10%, the tested resistivity decreases to 2,000 Ω m and when the water content increases to 25%, the tested resistivity decreases

Table 1: Resistivity of affected soil layer and surface material

| Condition | Soil resistivity: Seasonal affected soil layer | Soil resistivity: Normal soil | Resistivity of surface material |
|---|---|---|---|
| Normal condition | No | 200 Ω m | 15000 Ω m |
| Raining season | 10~200 Ω m | 200 Ω m | 5000 Ω m |
| Freezing season | 200~5000 Ω m | 200 Ω m | 15000 Ω m |

to 100 Ω m. When the water content of the fine sand sample is small, its resistivity decreases sharply with the increase of the water content. When its water content exceeds 40%, its resistivity increases very slightly. Because after the water forms a electrolyte solution channel, if continuing to increase the water content, its influence on the whole conducting characteristic is very small. So, the raining season leads to a significant decrease in resistivity of surface soil layer in substations (Jinliang *et al*., 2003).

The resistivity of affected soil layer and surface material is shown in Table 1. When the influence of season factor is not considered, the soil is homogeneous; the resistivity of normal soil is 200 Ω m. This is called as the normal condition, the grounding resistance, step and touch voltages in normal condition is used to measure the influence of different season on safety of the grounding system.

In raining season, there is a wet surface soil layer with decreased the resistivity of the affected surface soil layer is changed in the range of 10 to 200 Ω m to consider the influence of raining season on the surface soil layer. In freezing season, there is a freezing surface soil layer with increased resistivity, the resistivity of the affected surface soil layer is changed in the range of 200 to 5000 Ω m to consider the influence of freezing season on the surface soil layer.

The resistivity of the granite layer in raining season is assumed as 5000 Ω m and its resistivity in normal condition and in freezing season is assumed as 15 000 Ωm (GSASG, 2000).

## FILLING THE SOIL PORES WITH WATER

If there are pores in dry soil which would affect the current dispersing into soil from the grounding electrode, the current must round the pores. But these soil pores in the nearby region around the deep ground well would be filled with groundwater, then the current can directly pass through these pores, the current dispersing resistance is decreased.

On the other hand, the deep ground well sometimes can contact with or puncture through a low-resistivity soil layer, then fault current can directly disperse into this low-resistivity soil layer (Jinliang *et al*., 2005).

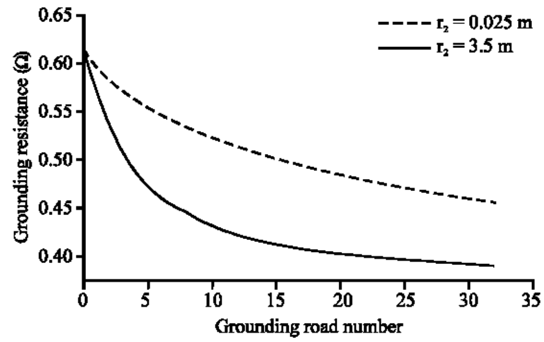


Fig. 1: Relationship between the number N of the rods and the grounding resistance R

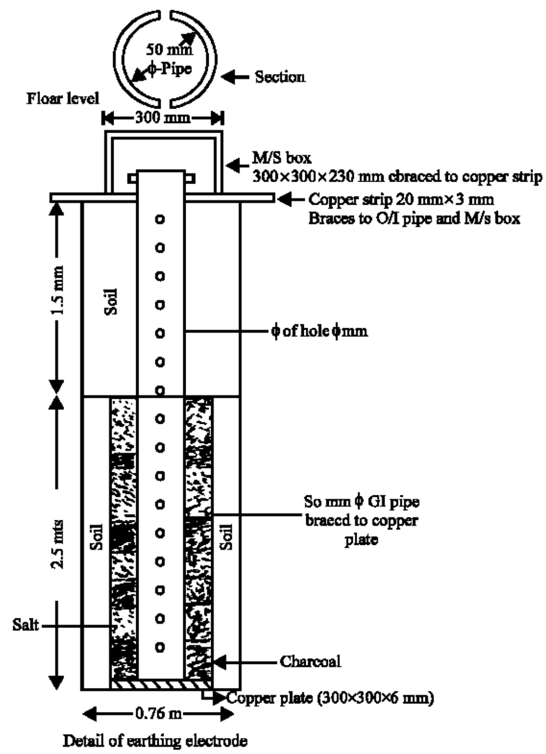


Fig. 2: Details of earthing electrode

## NUMBER OF VERTICAL GROUNDING RODS

Vertical rods are added to the existed horizontal grounding grid. The length of the rods is 50 m. The relationship between the number *N* of the rods and the grounding resistance R is illustrated in Fig. 1. Here the rod radius are $r_2$ = 3.5 m and $r_2$ = 0.025 m used in calculation, Radius of 3.5 m is the result considering the effect of explosion technique. From Fig. 2, we observed that while other conditions are fixed, grounding resistance decreases with the increase of the number of rods. However, the decrease of R reaches saturation when N reaches a certain number because the shielding effects increase with the decrease of the interval among rods. Besides rods can restrain the dispersed current on the grid, i.e. the total grounding resistance is not the simple parallel connection of grounding resistances of the grounding grid and vertical grounding rods. There is a shielding coefficient of horizontal grounding grid to the vertical grounding rods. The shielding coefficient increases with the number of the grounding rods. When the rod radius is 3.5 m, their effects to decrease grounding resistance reach 35 %, which is better than that when the rod radius is 0.025 m (Rong *et al*., 2000).

## SOME OTHER METHODS OF EARTH CONNECTIONS

**Ground loops:** The construction of ground loops has been used for past several years for the purpose of earthing connection. However, it is the least effective and most cost expensive design. The ground loop ends up being broken from actions of other user's leading to discontinuity.

**Metal underground water piping:** Before the use of plastics, metallic water piping was installed in residences and other facilities. With the water piping in intimate contact with the earth, it was natural to make use of it as a grounding electrode. The metallic water pipe was an excellent conductor and could serve as a low resistance (impedance) path to allow sufficient fault current to flow and operate the protective device in the past.

Problems developed with the use of the water pipe as an earthing electrode. Where houses are in close proximity to each other, connected by underground metallic water piping, stray current could flow from one house to another.

**Building steel:** The building steel is a structure consisting of a steel skeleton, with the steel columns bolted to the foundation piers and the foundations having steel reinforcing rods. It has been found that in such construction, the steel columns are inherently connected to earth through the column bolts in the footers contacting the steel reinforcing rods. One of the four bolts installed to hold the steel column in place is usually, either deliberately or accidentally making contact with the reinforcing rods or the bolt is physically wire tied to the reinforcing rods. The multitude of parallel electrical paths within a steel building reduces the impedance to a low value.

**Butt pole electrode:** The wooden pole used to support utility lines usually has a bare spiral wound copper conductor attached to the bottom of the pole that acts as a grounding electrode. With the weight of the pole pressing down on the bare copper wire on the bottom of the pole, the copper wire is placed into intimate contact with the earth. Tests have shown that this is the least effective earthing electrode.

## GROUND GRID OR GROUND MAT DESIGN

It is a system of horizontal ground electrodes that consists of a number of interconnected bare conductors buried in the earth, providing a common ground for electrical devices or metallic structures, usually in one specific location. The object of installing a ground grid is to reduce step and touch voltage, provide a ground plane for connection of computer grounds and to make a low impedance connection to earth. A ground grid is usually installed in utility substations where persons standing to operate equipment could encounter a hazard step or touch potential resulting from high fault currents (Zipse, 2001).

Grids buried horizontally near the surface of the earth are also effective in controlling the surface potential gradients. A typical grid usually is supplemented by a number of ground rods and may be further connected to auxiliary ground electrodes to lower its resistance with respect to remote earth (GGSG, 1987).

## GROUNDING MAT CONNECTION IN HIGH VOLTAGE LABORATORY

In the existing high voltage lab grounding mat installation, a network of earthing electrodes (13 in number) have been installed by digging earthing pits of dimension ($1\times1\times4$ m$^3$) which are equally spaced along all sites with in the building of high voltage lab as per sectional view provided in Fig. 3. Each earthing pipe is made up of GI material having diameter 50 mm and length 4.15 m with perforations each of diameter 9 mm around whole periphery of GI hollow pipe. At the bottom of GI pipe, a copper plate having dimensions ($300\times300\times6$) mm$^3$is brazed. The top portion of GI is affixed with a mild steel box with dimensions ($300\times300\times230$) mm$^3$ with a provision of removable lid to cover the top of earthing electrode. The base of the lid is also brazed to the GI pipe along with the copper strip of dimension ($20\times3$) mm$^2$. After digging the e arthing pits, the GI earthing pipe is placed centrally with proper supports all around after putting soils at the bottom of earthing copper plate. Their after the charcoal layer of around 30 cm depth is poured to facilitate good earthing connectivity with the ground plane. Then soft soil of around 20 cm is spread around the charcoal layer extremities. Above the charcoal layer, a salt layer of 30cm is spread around the axial pipe and the extremities is filled with soft soil and the process of putting alternate layers

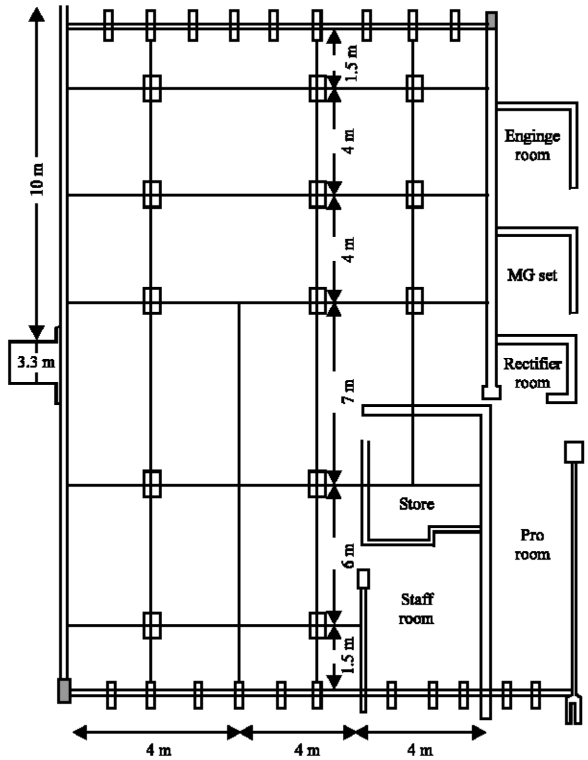


Fig. 3: Layout of grounding mat connection

of charcoal and salt is repeated upto 2.5m from the bottom. There after the soft soil is filled in the earthing pit around the GI pipe upto the floor level touching the lid at the top of earth rod as shown in Fig. 2. A copper strip of (20×3) $mm^2$ is solidly brazed at the top end of GI pipe through nut bolts connections and is used for multiple network connection of the grounding mat. A complete layout of grounding mat consisting of 13 earth electrodes connected in the grounding grid form is shown in Fig. 3.

## CONCLUSION

In this study, general points related with sound, safer and reliable earthing system have been discussed. Different factors influencing occurrence of ground faults have been highlighted. Basic earthing design considerations w.r.t. high voltage lab requirement are given for the safety of operators and the equipments. The factors like soil resistivity, its variation due to rain and freezing season is also explained. The grounding principle for H.V. Installation has been explained. Ground mat/grid design for a typical H.V. Lab is presented with detail procedural layout.

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