DESIGN OF EARTHING SYSTEM FOR GRID STATIONS AND PROBLEMS ASSOCIATED WITH REMEDIAL MEASURES

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Abstract: The earthing system of a grid station is of the utmost importance, primarily to ensure electrical safety for persons working within or near the substation and also to limit any electrical interference with third-party equipment to acceptable values. Adequate forethought can help prevent unwanted surprises and avoid unnecessary and sometimes retrospective expenditure to achieve an adequate earth grid impedance value. This paper reviews earthing practices with special reference to safety and also provides guidance and information pertinent to safe earthing practices in A.C Grid stations design.

1. Introduction

Earthing means a conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth or some conducting body of relatively large extent that serves in place of the earth". [1] This is achieved by electrically connecting the respective parts in an installation to some systems of electrical conductor or electrode placed in intimate contact with the soil some distance below the ground level. [6]

The function of an earthing system for an electrical installation can be split into three broad bands,

- To limit the potential of any part of an installation to a pre-determine value with respect to the general mass of earth.
- To permit the flow of current to earth so that the protective equipment has time to operate and thus isolate the faulty circuit in the event of fault.
- To ensure that, if a fault occurs, non-current carrying metal work associated with the equipment does not attain a dangerous potential with respect to the general mass of earth.

The earthing system should possess low electrical resistance between the electrode and earth. The lower earth electrode resistance, the more likely the lighting or 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. [1,3].

2. Basic Considerations for Design Earthing System

Table 1 highlights the possible aspects of designing the earthing system and recommended materials, which are used in earthing design.

Table:1 Recommended Materials

Recommended Material in process	**BS No**
Ingots for cast components	
Leaded gun metal Aluminium silicone bronze Aluminium Alloy Cast iron	BS 1400 BS 1400 **BS 1490** BS 1452
Forgings and stampings (hot or cold formed)	
Copper Navel brass Aluminium Steel	BS 2872 BS 2872 BS 1474 BS 970
Bar, Rods and Tubes (For Machined components fittings)	
Hard drawn copper Annealed copper Copper Silicon Phoshor Bronze Aluminium Bronze Aluminium Naval Brass Steel (General use) Steel (Galvanizing)	BS 2874 BS 2874 BS 2874 BS 2874 BS 2871 BS 1471 BS 2874 BS 970 BS 970

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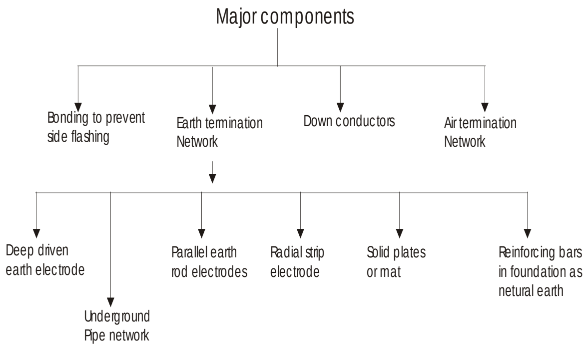
The major components used for the designing earth system are,



3. Basic Design Requirements

- No earth plate should be less than 2ft × 2ft in area and 1/8 inch for copper, so the plate are buried at least one foot below the permanent level.
- If lower resistance is required for an installation, more than two plates are connected in parallel keeping each plate at least 10 feet away from each other.
- If electrical apparatus is present, then at least two plates are buried at maximum distance which is never less than 10 feet [1,6],

4. Effect on Different Parameters

4.1 Effect of Soil on Resistance

The resistance of the ground connection depends upon the soil surrounding the electrode. The chemical ingredients and the amount of moisture in the soil determine the electrical conductance of soil. The resistance varies inversely as the cross section and within a few feet from the electrode where the conducting path is small.

4.2 Effect of Moisture on Soil

A variation in the moisture of soil will make a difference in the effectiveness of ground connection with the electrode.

4.3. Effect of Temperature

The variation in soil resistivity with temperature for red clay soil having moisture contents of 18.6% is quite considerable. In winter season the earth freezes to a considerable depth below the surface, below 32^0 F the water in the soil freezes and thus causes tremendous increase in the temperature coefficient of resistivity for soil. So, the coefficient is negative when temperature goes down, then resistivity rises and resistance of earth connection is increased.

4.4. Effect of Size of Electrode

A very little change in resistance would result by using large diameter electrodes.

4.5. Effect of Voltage Gradient

The resistance is not affected by the voltage gradient, unless it exceeds a critical value. This value will vary with the nature of soil but it is of the order of few kilovolts per cm. The earthing system is normally designed to keep the gradient well below these critical values.

4.6. Effect of Current Magnitude

It has been found that high currents are not of sufficient magnitude to result in extremely high voltage gradient.

4.7. Tolerable Limits of Body Current

The magnitude and duration of the current conducted through a human body at 50 or 60 Hz should be less than to cause ventricular fibrillation. Much higher currents can be tolerated without causing fibrillation if the duration is very short. 99.5% of all the human beings could withstand current, without fibrillation given by the equation.

$$I_k = \frac{0.116}{\sqrt{t}} \qquad (1)$$

where
I_k = rms current through a body in amperes
t = time duration of shock in seconds

5. Design Procedure of Earthing

The step-by-step procedure of designing the earthing system is as follows,

5.1. Investigation of Soil Characteristics

Investigation of station site will normally include at least a determination of the general soil composition. The resistivity of the soil is measured by the formula

$$\rho = \frac{2\pi AR}{i + \frac{2A}{\sqrt{A^2 + 4B^2}} - \frac{2A}{\sqrt{4A^2 + 4B^2}}} \text{.....................(2)}$$

Where ρ = resistivity of soil in ohm-meters

R = resistance in ohms obtained by dividing the voltage between the potential probes with current
A = distance between the adjacent electrodes in meters
B = depth of electrode in meters

When B < A, then the above equation becomes
Resistivity $\rho = 2\pi AR$

5.2. Determination of Maximum Earth Fault Current

Following steps are performed to calculate the maximum earth fault current

- Determine which of the possible type of ground fault will result in the greatest flow of current between the ground grid and surrounding earth.
- Determine the maximum symmetrical rms value of earthing fault current flowing between the station grounds and surrounding earth by short circuit study.
- Apply a correction factor where appropriate to allow for future increase in fault current due to expansion of the system.

6. Resistance Calculation of Earthing

It is not necessary to know the exact value of resistance but rather to know whether it is the order of 1 ohm to 1000 ohms. The resistance of driven electrode is not to exceed 25 ohms. So the earthing resistance can be calculated as,

$$R = \frac{\rho}{4r} \text{......................(3)}$$

Where
R = Station resistance in ohms
ρ = Average earthing resistivity in ohm-meters
r = Radius of a circle having the same area of
the designed grid

It can also be written as

$$R = \frac{\rho}{4r} + \frac{\rho}{L} \text{..............................(4)}$$

Where
L = Total length of the buried conductor in meters
Note that the second term of this equation has the total length of buried conductor in meters and L reaches to infinity.

7. Calculation of Maximum Grid Potential Rise

The resistance of the mat is calculated as the maximum rise in potential above remote earth so that

E = I R

Where

E = Maximum rise in grid potential in volts
I = Maximum short circuit current in grid in amperes
R = Grounding grid resistance in ohms

8. Calculation of Step Voltage

It is the potential difference shunted by the body and limited to the maximum value between two accessible points on the ground separated by a distance one meter. It can be calculated by the equation,

$$E_{step} = KKi.\rho\, I/L \text{.....................(5)}$$

Where
K = Correction factor
Ki = Irregularities factor
I = Fault current in amperes
L = Total length of buried conductors in meters
ρ = Ground resistivity in ohm-meters

9. Touch Voltage

The potential difference that appears from hand contact to feet contact is termed as touch potential. It is calculated by the equation,

$$E_{touch} = [\tfrac{1}{2}\ln\frac{(h^2+x^2)(D+x^2)}{hdD^2} + \tfrac{1}{\pi}\ln(\frac{2D+x}{2D})(\frac{3D+x}{3d})...]..\tfrac{I}{L}....(6)$$

Where
X = Horizontal distance on the surface of earth
from the buried conductor in meters.
d = diameter of buried conductor in meters

9.1 Calculation of Mesh Voltage

Mesh Voltage is determined by the expression,

$$E_{mesh} = KmKi.\ \rho\ .\tfrac{I}{L}..................(7)$$

Where Km = constant which is the effect of number of parallel conductors buried

$$Km = \tfrac{1}{2\pi}\ln\frac{(D^2)}{16hd} + \tfrac{1}{\pi}\ln[(\tfrac{3}{4})(\tfrac{5}{0})(\tfrac{7}{0})+.....]....(8)$$

10. Causes and Effects of Failure of Earthing and Remedial Measures

Following are the causes and effects of failure of earthing system,

10.1 Corrosion

Earthing conductor, rod, electrode plates and their joints are buried under the ground where water logging. Under the ground, salinity badly affects the termination and produce oxide compound at the joint and electrode which can cause damage to the equipment.

10.2 Improper Material Loose Connections

If the material is not used as per specification, the earth resistance increases and will resist the flow of fault current. This badly affects the performance of the equipment.

10.3 Arcing

Arcing in earthing system may be due to the following reasons,

- The grid station earthing resistance is approximately 2 ohm. If the resistance of the earthing is increased, then during the flow of fault current, arcing may result.

- If the two different earthing conductors have different ohmic value, then during fault condition, very heavy current will flow towards the lower resistance conductor, which can produce arcing in the system.

10.4 Effect of Failure of Earthing on Grid Station Equipment

In the neutral of power transformer, if the failure of earthing occurs, then voltage of transformer winding will rise which causes failure of installation. During the fault, heavy current flows and this heavy current will not pass through the neutral of the earthing system but keeps on circulating in the transformer winding producing excessive thermodynamic stress. This will result in the deformation of the core and damages the winding. Therefore, the body of the transformer is earthed at least two diagonally different conducting points. If the earth of transformer body is open having high value of resistance greater than 2ohm, then the transformer bushing provides the protection.

10.5 Effect on Lightning Arrestor

Lightning arrestors are installed at every grid station for safety against lightning strokes but it is always earthed. The lightning stokes are diverted through a non-linear resistance connected with ground. However, if earth is disconnected due to any fault, then the lighting stroke will not be grounded. This will cause heavy heating in the non-linear resistance that can damage the arrestor.

10.6 Effect on Instrument Transformers

Potential transformer is a step down transformer. One terminal of potential transformer is connected with line voltage and other terminal is solidly grounded. If the potential transformer is opened due to any fault, then the line voltage will appear on the neutral terminal and insulation is damaged. This will damage the potential transformer.

A current is a step up transformer. The secondary side of current transformer is earthed. If the earthing connection gets open, then high voltage will appear on the secondary winding. This can damage the insulation of secondary winding and destroy the current transformer.

11. Remedial Measures

Following remedial measures are taken to achieve proper ohmic resistance according to standard specification.

- Soil conditioning agents are introduced into ground to reduce the soil resistivity and also to reduce earth resistance.
- In order to avoid corrosion effect, the earthing material should be galvanized and standard copper conductor as per standard specification may be used.
- All joints should be cad welded used, then minimum corrosion occurs.
- Loose connections should be avoided.
- When digging in grid station yard with respect to proper layout of earth mesh, proper route for fresh excavation should be selected.
- All the metallic parts of grid station should be solidly earthed at least two points through standard copper conductor to mesh.
- The termination joints of the metallic body should be inspected regularly and tightened every time.
- The neutral point of the transformer should be earthed separately with insulated copper conductor from the bushing to avoid contact with transformer body.
- Earth testing should be carried out regularly and compared with last result.
- Lighting arrestors should be earthed with insulated conductor.

12. Conclusions

Frequency of accidents from ground fault gradients has been limited by low probability of coincidence of all the adverse factors required. Never the less, one fatal accident, which could be prevented, is too many. Precise calculation in this field is seldom attainable.

Field measurements of local potentials, when the ground system is loaded with relatively high-test current are quite conclusive, but too expensive for routine application. It is hoped, however that the material here presented may help engineers to avoid both the more dangerous situations, on the one hand and extreme over design on the other.

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