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Earthing Design for 220/66 KV Hybrid (AIS and GIS) Sub-Station

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ABSTRACT

Main purpose of this paper is designing safe and cost effective grounding systems for 220/66 KV Hybrid (AIS/GIS) substation situated at such locations where soil of the substation site is not uniform. Standard equations are used in the design of earthing system to get desired parameters such as touch and step voltage criteria for safety, earth resistance, grid resistance, maximum grid current, minimum conductor size and electrode size, maximum fault current level and resistivity of soil. By selecting the proper horizontal conductor size, vertical electrode size and soil resistivity, the best choice of earthing design for safety can be performed.

Keywords: Substation, GIS, AIS, step and touch potential, GPR.

I. INTRODUCTION

Successful operation of entire power system depends to a considerable extent on efficient and satisfactory performance of substations. Hence substations in general can be considered as heart of overall power system. In any substation, a well-designed grounding plays an important role. Since absence of safe and effective grounding system can result in mal-operation or non-operation of control and protective devices, grounding system design deserves considerable attention for all the substations.

Good grounding path of sufficiently low impedance ensures fast clearing of faults. A fault remaining in the system for long may cause several problems including those of power system stability. Faster clearing thus improves overall reliability. It also ensures safety.

A ground fault in equipment causes the metallic enclosure potential to rise above the 'true' ground potential. An improper grounding results in a higher potential and also results in delayed clearing of the fault (due to insufficient current flow). This combination is essentially unsafe because any person coming into contact with the enclosure is exposed to higher potentials for a longer duration.

Grounding system has to be safe as it is directly concerned with safety of person's working within the substation.

Functions of an Earthing System

There are two primary functions of a safe earthing system

i) Ensure that a person who is in the vicinity of earthed facilities during a fault is not exposed to the possibility of a fatal electrical shock,
ii) Provide a low impedance path to earth for currents occurring under normal and fault conditions.

II. METHODS AND MATERIAL

2. Terminology Associated to Earthing [3]

2.1 Ground Potential Rise (GPR)[9]

The substation earth grid is used as an electrical connection to earth at zero potential reference. This connection is not ideal due to the resistivity of the soil within 0which the earth grid is buried.

During typical earth fault conditions, the flow of current via the grid to earth will therefore result in the grid rising in potential relative to remote earth to which other system neutrals are also connected.

This produces potential gradients within and around the substation ground area - this is defined as ground potential rise or GPR.

The GPR of a substation under earth fault conditions must be limited so that step and touch potential limits are not exceeded, and is controlled by keeping the earthing grid resistance as low as possible.

Step, Touch, Mesh & Transferred Potentials [9]

In order to ensure the safety of people at a substation, it is necessary to ensure that step and touch potentials in and around the substation yard during earth-fault conditions are kept below set limits.

2.2 Step Potential

The step potential is defined as the potential difference between a person's outstretched feet, normally 1 metre apart, without the person touching any earthed structure.

2.3 Touch Potential

The touch potential is defined as the potential difference between a person's outstretched hand, touching an earthed structure, and his foot. A person's maximum reach is normally assumed to be 1 metre.

2.5 Mesh Potential

The mesh potential is defined as the potential difference between the centre of an earthing grid mesh and a structure earthed to the buried grid conductors.

This is effectively a worst-case touch potential - for a substation grid consisting of equal size meshes; it is the meshes at the corner of the earth grid that will have the highest mesh potential.

2.6 Transferred Potential

This is a special case of a touch potential in which a voltage is transferred into or out of a substation for some distances by means of an earth referenced metallic conductor. This can be a very high touch potential as, during fault conditions, the resulting potential to ground may equal the full GPR.

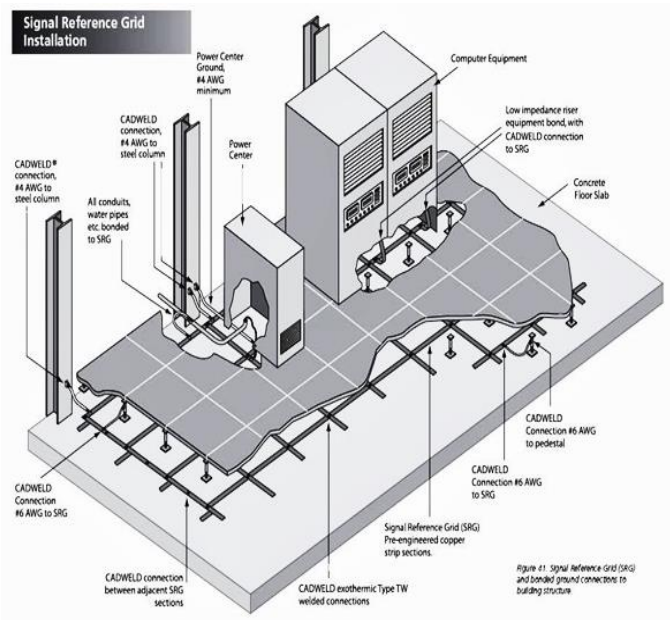

Figure 1. Substation Earthing

3. Earthing System Design Considerations [2]

Conductors - a substation earthing grid will consist of an earthing system of bonded cross conductors. The earthing conductors, composing the grid and connections to all equipment and structures, must possess sufficient thermal capacity to pass the highest fault current for the required time. Also, the earthing conductors must have sufficient mechanical strength and corrosion resistance. It is normal practice to bury horizontal earthing conductors at a depth of between 0.5m and 1m.

3.1 Vertically Driven Earth Rods

Where there are low resistivity strata beneath the surface layer then it would be advantageous to drive vertical earth rods down into this layer - to be effective the earth rods should be on the periphery of the site. The length of the earth rod is chosen so as to reach the more stable layers of ground below. The earth rods would stabilise the earth grid resistance over seasonal resistivity changes at the grid burial depth.

3.2 Substation Fences

The earthing of metallic fences around a substation is of vital importance because dangerous touch potentials can be involved and the fence is often accessible to the general public.

Fence earthing can be accomplished in two different ways:

- Electrically connecting the fence to the earth grid, locating it within the grid area or alternatively just outside
- Independently earthing the fence and locating it outside the earth grid area at a convenient place where the potential gradient from the grid edge is acceptably low.[7]

III. RESULTS AND DISCUSSION

4. Ensuring Proper Grounding [6]

The following steps, when put into practice, will ensure a reliable, safe and trouble-free substation grounding system:

1. Size conductors for anticipated faults
2. Use the right connections
3. Ground rod selection
4. Soil preparation
5. Attention to step and touch potentials
6. Grounding using building foundations
7. Grounding the substation fence
8. Special attention to operating points
9. Surge arrestors must be grounded properly
10. Grounding of cable trays
11. Temporary grounding of normally energized parts.

5. Calculation of 220 kV AIS Bus Section

5.1 Size of Earthling Conductor :

$$Amm^2 = \frac{I}{\sqrt{\left(\frac{TCAP\times 10^{-4}}{t_c \alpha_r \rho_r}\right)\ln\left(\frac{K_0+T_m}{K_0+T_a}\right)}}$$

$A_{kcmil} = 819.37\ mm^2$

The size of conductor selected = 23.0 mm

Diameter of the Grid Conductor d = 0.0229 m

5.2 Touch & Step Criteria

Reflection factor between different material resistivity

$$K = \frac{\rho - \rho_s}{\rho + \rho_s}$$

Surface layer derating factor

$$C_s = \frac{0.09\left(1-\frac{\rho}{\rho_s}\right)}{2hs+0.09}$$

Therefore,

$$E_{step\,70} = (1000 + 6C_s \times \rho_s)\frac{0.157}{\sqrt{t_s}}$$

$$E_{touch\,70} = (1000 + 1.5C_s \times \rho_s)\frac{0.157}{\sqrt{t_s}}$$

5.3 GRID Resistance

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1+\frac{1}{1+h\sqrt{20/A}}\right)\right]$$

A = Area of the Grid = 247.5 m²

5.4 Maximum GRID Current

$$I_G = D_f \times I_g$$

I_g = Maximum grid current in A = 40,000

D_f = Decrement factor for the entire duration of fault, given in s = 0.415

5.5 Ground Potential Rise

$$GPR = I_G \times R_g$$

of electrical potential to dangerous value during earth fault current.

6. Calculation for Actual Derived Step & Mesh Voltage [1]

6.1 Mesh Voltage:

$$Emesh(Design) = \frac{\rho \times I_G \times K_m \times K_i}{L_c + \left[1.55 + 1.22\left(\frac{L_r}{\sqrt{L_x^2 + l_{Ly}^2}}\right)\right] \times L_R}$$

Ki = Corrective factor for current irregularity
Where,

$$K_i = 0.644 + 0.148n$$
$$n = n_a \times n_b \times n_c \times n_d$$
$$n_a = \frac{2 \times L_T}{L_P}$$

n_a = 7.1
n_b = 1.050917456
n_c = 1 for square and rectangular grids
n_d = 1 for square and rectangular grids and L Shaped grids

$$Km = \frac{1}{2\Pi}\ln\left[\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d}\right] + \frac{Kii}{Kh}\ln\left[\frac{8}{\Pi(2n-1)}\right]$$

$$\sqrt{\left(1+\frac{h}{ho}\right)} \qquad K_{ii} = \frac{1}{(2\times n)^{\frac{2}{n}}}$$

6.2 Step Voltage

Voltage developed for step as per the earthing system proposed during full Earth fault current.

$$Estep(Design) = \frac{[(Ks \times Ki \times \rho \times I_G)]}{[0.75 \times L_C + 0.85 \times L_R]}$$

Where,
K_s = Spacing factor for Step voltage

$$Ks = \frac{1}{\Pi}\left[\frac{1}{2h} + \frac{1}{D+h} + \left(\frac{1-0.5^{n-2}}{D}\right)\right]$$
$$Ki = 0.644 + 0.148n$$

7. Calculation of 220 Kv GIS Bus Section

7.1 Size of Earthling Conductor:

$$Amm^2 = \frac{I}{\sqrt{\left(\frac{TCAP \times 10^{-4}}{t_c \alpha_r \rho_r}\right)\ln\left(\frac{K_0 + T_m}{K_0 + T_a}\right)}}$$

A_{kcmil} = 451.22 mm^2

The size of conductor selected = 17.1 mm
Diameter of the Grid Conductor d = 0.0170m

7.2 Touch & Step Criteria

Reflection factor between different materials Resistivity

$$K = \frac{\rho - \rho_s}{\rho + \rho_s}$$

Surface layer derating factor

$$C_s = \frac{0.09\left(1 - \frac{\rho}{\rho_s}\right)}{2hs + 0.09}$$

K = -0.98
C_s= 0.77

7.3 GRID Resistance

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right]$$

A = Area of the Grid = 702.3618 m²

7.4 MAXIMUM GRID CURRENT

$$I_G = D_f \times I_g$$

I_g = Maximum grid current in A = 40,000
D_f = Decrement factor for the entire duration of fault, given in s = 0.415

7.5 Ground Potential Rise

$$GPR = I_G \times R_g$$

8. Calculation for Actual Derived Step & Mesh Voltage

8.1 Mesh Voltage

$$Emesh(Design) = \frac{\rho \times I_G \times K_m \times K_i}{L_C + \left[1.55 + 1.22\left(\frac{L_r}{\sqrt{L_x^2 + l_{Ly}^2}}\right)\right] \times L_R}$$

Ki = Corrective factor for current irregularity
$K_i = 0.644 + 0.148n$

Where,

$$n_a = \frac{2 \times L_T}{L_P} \quad \& \quad n = n_a \times n_b \times n_c \times n_d$$

$n_a = 8.6$
$n_b = 1.011310427$
$n_c = 1$ for square and rectangular grids
$n_d = 1$ for square and rectangular grids and L Shaped grids

$$Km = \frac{1}{2\Pi} \ln\left[\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d}\right] + \frac{Kii}{Kh} \ln\left[\frac{8}{\Pi(2n-1)}\right]$$

Kh = $K_{ii} = \dfrac{1}{(2 \times n)^{\frac{2}{n}}}$ $\qquad Estep(Design) = \dfrac{[(Ks \times Ki \times \rho \times I_G)]}{[0.75 \times L_C + 0.85 \times L_R]}$

8.2 Step Voltage

Voltage developed for step as per the earthing system proposed during full Earth fault current.

$$Ks = \frac{1}{\Pi}\left[\frac{1}{2h} + \frac{1}{D+h} + \left(\frac{1-0.5^{n-2}}{D}\right)\right]$$

Where,
K_s = Spacing factor for Step voltage

$$\sqrt{\left(1 + \frac{h}{ho}\right)}$$

Result Table 1 for 220 kv AIS Bus section

Parameters	Calculated Value	Actual Value(Designed)
E_{step}	255.34 V	1191.75 V
E_{touch}	230.36 V	1169.50 V

Result Table 2 for 220 kv GIS Bus section

Parameters	Calculated Value	Actual Value(Designed)
E_{step}	886.97 V	3304.00 V
E_{touch}	627.32 V	992.52 V

In both the cases Calculated Step Voltage is lower than the Tolerable Step Voltage and Touch voltage is lower than Tolerable Touch Voltage.

Hence the Design is Safe

Result table 3 : Different parameters of 220 kv GIS and AIS Earthing Design

Parameters	AIS	GIS
Size of earthing conductor (mm2)	415.08	228.58
Step Potential	255.34 V	886.97 V
Touch potential	230.36 V	627.32 V
Grid Resistance	0.74 Ω	0.45 Ω
Max. Grid current	16.6 kA	16.6 kA
Ground potential rise	12287.2 V	7448.6 V

IV. CONCLUSION

This paper has a focus on designing of a 220 kV HV/EHV AC substation earthing system. The results for earthing system are obtained by computational method. The step by step approach for designing a substation earthing system is presented. The various kinds of conductor sizes for earth equipment are mentioned in this paper. Construction of earthing grid is expressed in here. The step and touch voltages are dangerous for human body. Human body may get electric shocks from step and touch voltages. When high voltage substations are to be designed, step and touch voltages should be calculated and values must be maintained specified standard. Importance to be given to the transfer of Ground Potential rise (GPR) under fault conditions to avoid dangerous situations to the public, customer and utility staff. The safety to personal is specified by IEEE 80, which requires limiting the development of electrical potential to dangerous value during earth fault current. The regulation stipulates the following parameters to be within permissible limits:

i) Step voltage (foot to foot contact)
ii) Touch voltage (hand to foot contact)

The values of step and touch voltages obtained for 220 kV (AIS & GIS) substation are respectively as shown in result table 3.

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