

DESIGN OF SUBSTATION GROUNDING IN A TWO

LAYER EARTH STRUCTURE

(A CASE STUDY OF 132KV SUBSTATION)

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ABSTRACT

Earth mat provides a common ground for the electrical equipment as well all the metallic structures in the substation. The personnel safety and protection of equipment depends solely upon the effective Grounding system and hence its design becomes a critical aspect in substation. When there is an Earth Fault, it gives rise to potential gradient (GPR) within and around the substation. This GPR has to be restricted to a value which is not detrimental to the surrounding personnel and equipment. The GPR depends on various factors, one of which is the type of soil in substation. In this paper, design of the grounding grid for rectangular configuration is done for a 2 layer soil and analysis is done by ETAP software. The methodology adopted for designing is based on IEEE Std. 80-2013.

Keywords : Earthing / Grounding, Earth mat, Electrode, ETAP, Ground Resistance, Step Potential, Touch Potential, Ground Potential Rise.

I. INTRODUCTION

For the uniform and continuous soil models, simple algorithms can be developed to analyze the effectiveness of earthing system. However, where there is a significant variation in the resistivity with respect to depth, Multilayer soil models may also be adopted. The simplest is a 2 layer model, which can be a good approximation for analysis purpose. Another aspect which makes the design critical is the unequal spacing in the earth mat. It is always desirable to use computer software to design and analyze the grounding mesh using multilayer soil models and earth mats with varying spacing. One of the best software for this purpose is ELECTRICAL TRANSIENT ANALYZER PROGRAM (ETAP).

ETAP facilitates an engineer to carry out ground grid design as well as analysis with considerations specified in various standards such as IEEE-80-1986, IEEE-80-2000 and IEEE-665-1995. Moreover, this software also provides finite element modeling (FEM) of the ground grid for an accurate analysis. Both aspects, technical and commercial can be very well taken care using this software.

II. SOIL RESISTIVITY AND IT'S MEASUREMENT

The resistance of an earth electrode is mainly influenced by the resistivity of the soil in which it is driven. Hence, the soil resistivity measurement is an important aspect and its accurate measurement ensures a perfect design. Apart from knowledge of the soil resistivity at the project site, it is also important to understand the behavior of soil with be economically accomplished and retained over the life time of the earthing installation.

There are basically 2 types of earths. One is the system earth and the other is the equipment earth. The idea of earth installations is to achieve a common reference potential for the power supply system as well as equipment,

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instruments, raceways and plant structure and building. To achieve this objective, a suitable low resistance connection to ground is desirable. However, many a times this is difficult to achieve as it depends on a various factors:

- Soil resistivity and soil stratification
- Size and type of electrode used
- Depth to which the electrode is driven or buried
- Moisture and chemical content of the soil
- Area of substation
- Fault current being handled

The purpose of resistivity testing is to obtain a set of measurements which may be used to derive an equivalent model of earth system seen by the electrical system.

Wenner 4 Pin Method

The Wenner array method has certain limitations such as requirement of longest cable layout, largest electrode spreads and for large spacings one person per electrode is necessary to complete the survey in a reasonable time. Also, because all four electrodes are moved after each reading the Wenner Array is most susceptible to lateral variation effects.

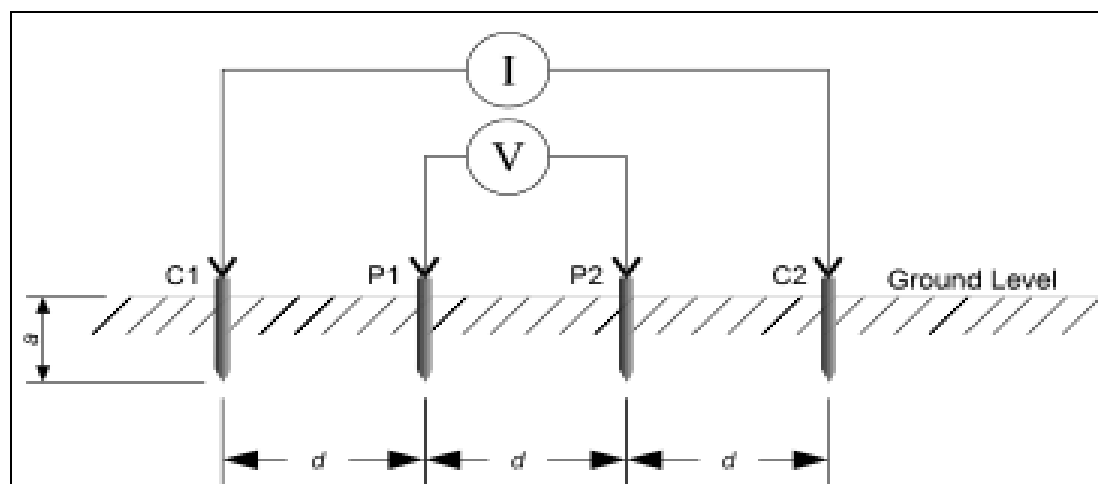


Fig. 1. Wenner 4 Pin Method

However the Wenner array is the most efficient in terms of the ratio of received voltage per unit of transmitted current. Where unfavorable conditions such as very dry or frozen soil exist, considerable time may be spent trying to improve the contact resistance between the electrode and the soil.

III. EASE OF CALCULATION FOR STEP AND TOUCH POTENTIAL USING ETAP

In normal practice for earthing design and analysis we use the ETAP software just to calculate the step and touch potentials, as their calculations are tedious and time consuming. We can design an earthing grid and place the earth electrodes using ETAP. It can also optimize the use of electrodes considering the cost in concern. We can obtain the 3-D graphs for the step and touch potentials. There are basically two methods available for the step and touch potential calculations. They are finite element method (FEM) and IEEE method. We can choose any of these methods as per our convenience. The best option is finite element method because it is flexible as

compared to IEEE in designing the shape of the grid. If we choose FEM method then can model any shape of grid as per the plan dimensions while in case of IEEE method some specific shapes are given. We cannot design any complex shape of grid in IEEE method. So it is better if we choose FEM method.

One more important consideration is the type of soil considered. In ETAP we can choose different layers of soil. In international standards for earthing system design generally multiple layers of soil are considered. The top most layers will have more resistivity than the deeper layers. Top most level generally consists of gravels which have higher resistivity. In ETAP the approximate values of resistivity of different layers are given and they can be edited if required.

IV. SAFETY CRITERIA FOR SUBSTATION GROUNDING DESIGN AS PER IEEE STD.

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A person working in substation may be subjected to five shock situations namely, Step voltage, Touch voltage, Mesh voltage, Metal to metal touch voltage and Transferred voltage. Step and Touch voltage are used to derive the safety criteria for Grounding grid design. A good grounding system should have the actual mesh and step voltages well below tolerable touch and step voltages respectively. Fibrillation discharge limit of body current is used to determine the tolerable safety criteria for grounding system design. The main consideration that is taken into account for substation grounding design is that under any circumstance actual step and mesh voltages must not exceed the tolerable Voltage limits.

V. TWO LAYER SOIL MODEL BY SUNDE'S GRAPHICAL METHOD

In Sunde's method, the graph shown in Figure 2 is used to approximate a two-layer soil model.

Parameters ρ_1 and ρ_2 are obtained by inspection of resistivity measurements. Only h is obtained by Sunde's graphical method, as follows:

- Step 1: Plot a graph of apparent resistivity ρ_a on y-axis vs. pin spacing on x-axis.
- Step 2: Estimate ρ_1 and ρ_2 from the graph plotted in step 1. ρ_a corresponding to a smaller spacing is ρ_1 and for a larger spacing is ρ_2 . Extend the apparent resistivity graph at both ends to obtain these extreme resistivity values if the field data are insufficient.
- Step 3: Determine ρ_2/ρ_1 and select a curve on the Sunde graph in Figure 2, which matches closely, or interpolate and draw a new curve on the graph.

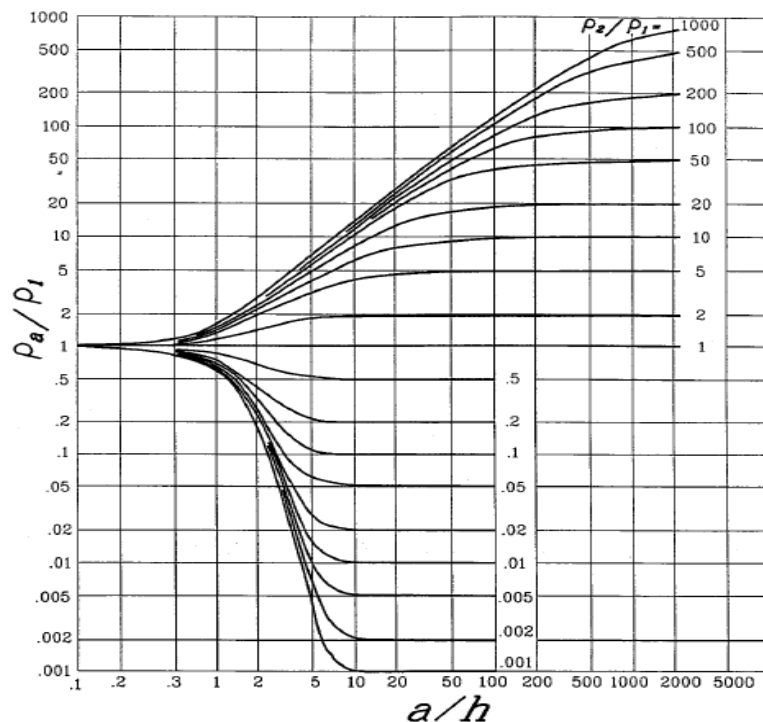


Fig. 2.Sunde,s Graphical Method

- Step 4: Select the value on the y-axis of ρ_a / ρ_1 within the sloped region of the appropriate ρ_2 / ρ_1 curve of Figure 2.
- Step 5: Read the corresponding value of a/h on the x-axis.
- Step 6: Compute ρ_a by multiplying the selected value, ρ_a / ρ_1 , in step 4 by ρ_1 .
- Step 7: Read the corresponding probe spacing from the apparent resistivity graph plotted in step 1.
- Step 8: Compute h , the depth of the upper level, using the appropriate probe separation.

VI. MATHEMATICAL CALCULATION

A. Prerequisites

The following information is required / desirable before starting the calculation:

- A layout of the site.
- Maximum earth fault current into the earthing grid.
- Maximum fault clearing time.
- Ambient (or soil) temperature at the site.
- Soil resistivity measurements at the site (for touch and step only).
- Resistivity of any surface layers intended to be laid (for touch and step only).

B. Step and touch voltage criteria

The safety of a person depends on preventing the critical amount of shock energy from being absorbed before the fault is cleared and the system de-energized. The maximum driving voltage of any accidental circuit should not exceed the limits defined as follows.

- The tolerable step voltage criteria is

$$E_{Step} = [1000 + (6 \times Cs \times \rho_s)] \frac{0.116}{\sqrt{t_s}} \quad (1)$$

- The tolerable touch voltage criteria is

$$E_{Touch} = [1000 + (1.5 \times Cs \times \rho_s)] \frac{0.116}{\sqrt{t_s}} \quad (2)$$

Where,

Estep = the step voltage in V

Etouch = the touch voltage in V

Cs= 1 for no protective layer

ρs = the resistivity of the surface material in Ω·m

ts = the duration of shock current in seconds

- The earth grid conductor size formula is mentioned below

$$I = A \sqrt{\frac{(TCap \times 10^4)}{t_c \times \alpha_r \times \rho_r} \ln \left(\frac{k_0 + T_m}{k_0 + T_a} \right)} \quad (3)$$

Where,

I = rms value in kA

A = conductor sectional size in mm²

Tm = maximum allowable temperature in °C

Ta = ambient temperature for material constants in °C

a0 = thermal coefficient of resistivity at 0°C

αr = thermal coefficient of resistivity at reference temperature Tr

ρr = the resistivity of the ground conductor at reference temperature Tr in uA/cm³

K_o = 1/ a0 or 1/ a0 - Tr

tc = time of current flow in sec

TCAP = thermal capacity factor

- Spacing factor for mesh voltage (Km)

$$K_M = \frac{1}{2\pi} \left[\ln \left(\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d} \right) + \frac{K_{ii}}{K_h} \ln \frac{8}{\pi(2n-1)} \right] \quad (4)$$

Where,

D = spacing between conductor of the grid in m

d = diameter of grid conductor in m

KM = spacing factor for mesh voltage

Kii = 1 for grids with rods along perimeter

Kh = Corrective weighting factor for grid depth

- Spacing factor of step voltage (Ks)

$$K_S = \frac{1}{\pi} \left[\frac{1}{2h} + \frac{1}{(D+h)} + \frac{1}{D} (1 - 0.5^{n-2}) \right] \quad (5)$$

Where,

D = spacing between conductor of the grid in m

h = depth of burial grid conductor in m

n = number of parallel conductor in one direction

- Evaluation of ground resistance

A good grounding system provides a low resistance to remote earth in order to minimize the GPR. For most transmission and other large substations, the ground resistance is usually about 1 Ω or less. In smaller distribution substations, the usually acceptable range is from 1 Ω to 5 Ω, depending on the local conditions. For calculation of grounding resistance, the following formula is used

$$R_g = \rho \left[\frac{1}{L_T} + \frac{1}{\sqrt{125A}} \left(1 + \frac{1}{1+2h\sqrt{\frac{125}{A}}} \right) \right] \quad (6)$$

Where,

ρ = soil resistivity Ωm

L_T = total length of grid conductor m

A = total area enclosed by earth grid m²

h = depth of earth grid conductor m

- For calculation of grid current, equation

$$IG = (CP \times Df \times Sf \times I) \quad (7)$$

- For calculation of grid potential rise

$$GPR = (IG \times R_g) \quad (8)$$

- Actual Step Potential & Touch Potential Calculations

Formula for calculation of mesh voltage is

$$E_m = \left[\frac{\rho \times K_m \times K_i \times K_{im}}{LL + LB + LA + (1.15 \times LE)} \right] \quad (9)$$

Formula for calculation of step voltage is

$$E_s = \left[\frac{\rho \times K_m \times K_i \times K_{is}}{LL + LB + LA + (1.15 \times LE)} \right] \quad (10)$$

$$L_T = (LL + LB + LA + LE) \quad (11)$$

Where,

ρ = soil resistivity, ohms-m

E_m = mesh voltage at the center of corner mesh in V

E_s = step voltage between point in V

K_m = spacing factor for mesh voltage

K_i = spacing factor of step voltage

K_{im} = correct factor for grid geometry

LL = Length of grid conductor along length of switch yard

LB = Length of grid conductor along breadth of switch yard

LA = Length of riser and auxiliary mat in switch yard

LE = Length of earth electrodes in switch yard

L_T = Total length of earth conductor in switch yard

VII. RESULTS

A real time project is considered for this case study and a ETAP modeling is developed to carry out the earth mat design. This project has 132 KV GIS substation and 66/11 KV AIS substations. Earth mat is proposed for GIS as well as for AIS substations. Soil resistivity tests were conducted at project site area and same data was used for doing design calculations. Soil resistivity is the key factor which determines the resistance or performance of an electrical grounding system. Based on the soil data, 2 layer model is derived using Sunde's Graphical Method. Below are the input data details.

Surface layer resistivity : 10,000 ohm-m

Depth of Surface Material : 0.12 m

Soil Model : 2 Layer

Top layer resistivity : 30.15 ohm-m

Depth of Top layer : 1.96 m

Lower layer resistivity : 2.49 ohm-m

Conductor & Rod type : MS

Fault Current : 40kA

Duration of Fault Current : 3 Sec

Based on site area, we decided to choose rectangular grid pattern (different grid patterns are available-L shape, T-shape) and spacing between conductors is 3 meters. Grid is buried at a depth of 0.6m. The configuration of the grid is shown in the below Figure 5. As per the calculations required number of conductors is 54 and the rods are 98. It is found that both manual and simulated values are satisfactory. Figure 6 shows 2 layer soil model in ETAP and Figure 7 shows ground grid layout in ETAP.

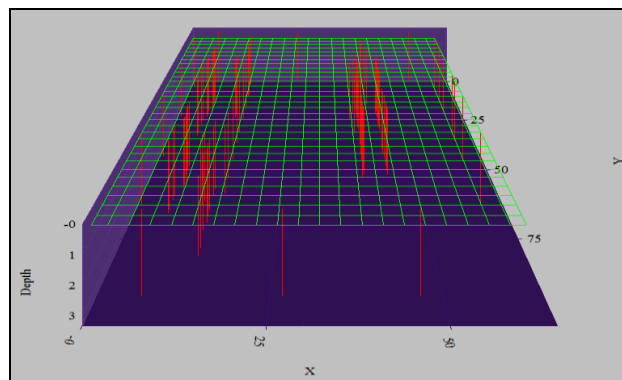


Fig. 3.ETAP Ground Grid Model

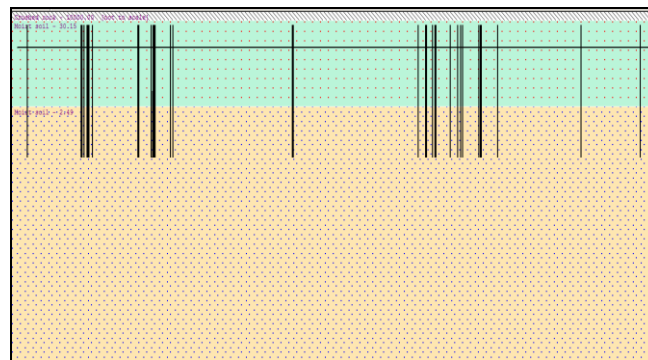


Fig. 4.ETAP Ground Grid Soil Model

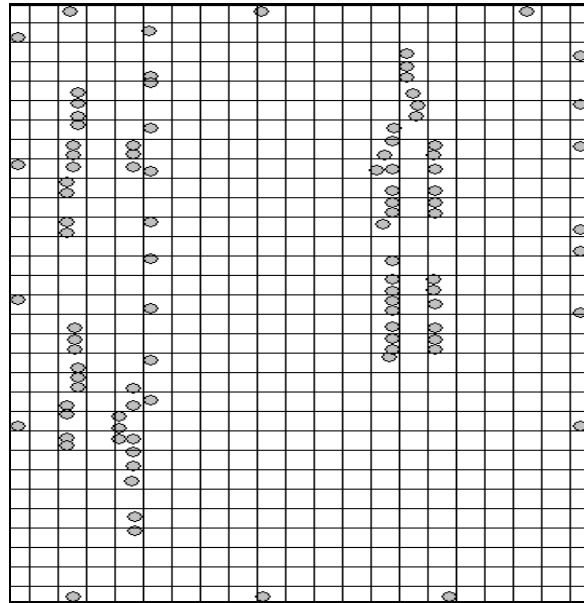


Fig. 5.ETAP Ground Grid Layout

The following 3-D Potential profiles are available for analysis of GGS study with the FEM method. Figure 8 shows Absolute potential profile, Figure 9 and 10 shows Touch Potential and Step Potential profile with over voltage limit.

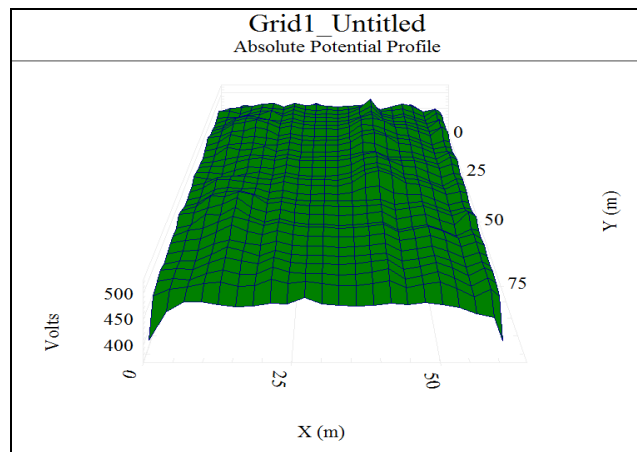


Fig. 6.Absolute Potential Profile

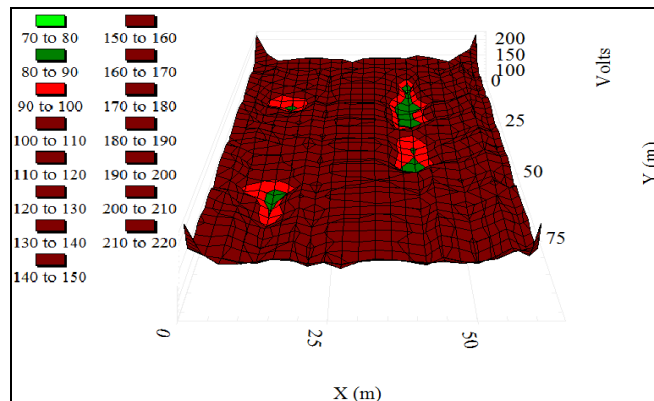


Fig. 7.Touch Potential Profile

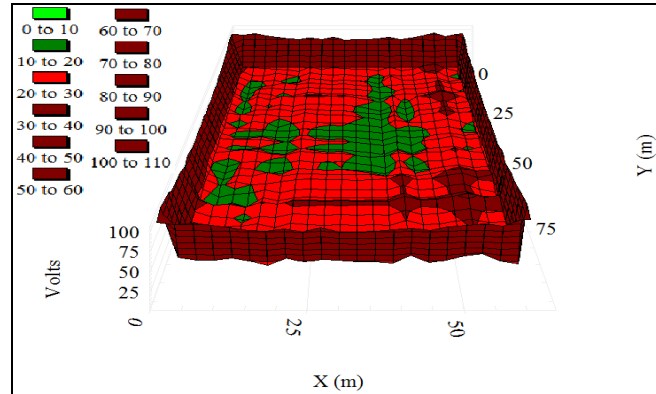


Fig. 8. Step Potential Profile

VIII. CONCLUSION

The results for earthing system are obtained by ETAP software. For earthing conductor and vertical earth electrode, mild steel is used. Step by step procedure has been considered in the long hand calculations. 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 the actual values based on design must be maintained below the tolerable values. Importance is to be given to the transfer of Ground Potential rise (GPR) under fault conditions to avoid dangerous situations to the personnel and even the animals in the vicinity of substations. The values of step and mesh voltages obtained for 132 kV substation are respectively 105.3 Volt and 217.0 Volt which are within the permissible limits. Table 1 shows summary of earthing grid design.

TABLE I. EARTHING DESIGN SUMMARY

Sr No.	Parameter Description	Value	Unit
1	Surface Material	Bitumen	
2	Surface Material Resistivity	10000	Ω m
3	Surface Material Thickness	0.12	m
4	Soil Resistivity(ρ)	30.149	Ω m
5	RMS value of the AC Ground fault current(I_f)	40	kA
6	Duration of fault current(t_c)	3	Sec.
7	Maximum length of the grid in the x direction(L_x)	61.5	m
8	Maximum length of the grid in the y direction(L_y)	92.5	m
9	Type of Earthing conductor	M.S FLAT	
10	Buried conductor size	65x10	mm ²
11	Type of Earthing rods	Cu electrode	
12	Earthing rod size	Diameter	32 mm
		Length	3 m
13	Total length of Earth Grid in the horizontal grid(L_c)	4003	m
14	Earth Electrodes	98	Nos.
15	Spacing between parallel conductors(D)	3	m
16	Depth of ground grid conductors	0.6	m
17	Maximum allowable step voltage(E_{step50})	7330.6	Volt
18	Maximum allowable touch voltage($E_{touch50}$)	1955.7	Volt
19	Actual mesh voltage (E_m)	217.0	Volt

20	Actual step voltage (E_g)	105.3	Volt
21	Total Resistance of earth grid(R_g)	0.024	Ω
22	Ground potential rise(GPR)	592.1	Volt

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