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Design of Grounding System for an Electrical Substation: An Overview

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Abstract The main purpose of this paper is to acquaint the reader with various types of grounding systems prevalent in an Electrical substation and their importance. Brief discussions about different parameters which affect the designing of an efficient grounding system are also discussed. The standards used comply with the Indian Electricity Grid Code (IEGC) and Grid Standards formulated under various regulations by CEA and IEEE-80. This paper is written to provide a good insight into the designing of grounding system for novice readers.

Index Terms— Electrical substation, Engineering design, Grounding systems, Grid resistance, Ground potential rise, Mesh voltage, Step potential, Touch potential

I. Introduction

Grounding system is one of the most important points inside the transmission systems and electric power distribution design. The main purpose of power system substation grounding grids is to maintain reliable operation and provide protection for personnel and apparatus during fault conditions. Grounding system allows controller harmonics and drain to earth the fault currents.

With today's advances in electronics and technology, grounding has become an essential part of everyday electricity and one cannot think any electrical installation without proper grounding system but still common tendency is that, it is so simple to drive a rod down the earth or install a earth electrode or plate and connect body of the equipment or neutral of the transformer or generator & forget it. Several people lose their lives every year due to this simple belief and face frequently accidents in work area. Such type of accidents can be avoided up to some extent if Design Engineer adopt different techniques for safe design. There are number of methods available but final aim is high degree of perfection with optimize design.

Without a properly designed grounding system, large potential differences can exist between different points within the substation itself. Under normal circumstances, it is the current flow through the grounding grid from line-to-ground faults that constitutes the main threat to personnel.

II. Objectives of a grounding system

A. Primary object of a Grounding system:

a) It should stabilize circuit potential with respect to ground and limit the overall potential rise.

b) It should protect life & property of device from over voltages.

c) It should provide low impedance path to fault current for reliable & prompt operation of protective devices during ground fault.

d) It should keep the maximum voltage gradient along the surface inside & around the substation within safe limits during ground faults.

B. Most affected parameters for design of Earthing Grids are:

a) Magnitude and duration of fault current.

b) Soil and surface resistivity at the substation site (soil structure and soil Model)

c) Property and cross-section of material used for earth mat conductor.

d) Earthing mat geometry (Area covered by Earth mat).

e) Permissible touch and step potentials.

III. Designing procedures

Designing a proper substation grounding system is complicated. Numerous parameters affect its design, and it is often difficult to obtain accurate values for some of these parameters. Furthermore, temperature and moisture

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conditions can cause extreme variations in the actual resistivity of the ground in which the system is installed.

Methods of dealing with the design problem are necessarily based to some extent on approximations and the exercise of engineering judgment. The design approach has to be conservative because of the aforementioned uncertainties.

A good grounding system provides a low resistance to remote earth in order to minimize the ground potential rise. 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 to 5 Ω, depending on local conditions.

The different methodologies adopted for grounding grid design but we adopt universal method as per IEEE-80 discussed in this section.

- A Grounding design starts with a site analysis, collection of geological data, and soil resistivity of the area. Typically, the site engineer or equipment manufacturers specify a resistance-to-ground number. The National Electric Code (NEC) states that the resistance-to-ground shall not exceed 25 Ω (ohms) for a single electrode. However, some reputed manufacturers will often specify 3 or 5 Ω, depending upon the requirements of their equipment and safety. For sensitive equipment and under extreme circumstances, a 1Ω specification may sometimes be required. When designing a ground system, the difficulty and costs increase extremely as the target resistance-to-ground approaches the unobtainable goal of zero ohms.
- The earth resistance shall be as low as possible and shall not exceed the following limits:

* Power Stations- 0.5 Ω. * EHT Substations-1.0 Ω.
*33KV Stations- 2.0 Ω.

- Find out Area of grid from substation layout Plan. (For that decides pattern of grid i.e. Square grid, L shaped or rectangular grid)
- Measure soil resistivity by selection of

different test location throughout the substation as shown in Fig:1

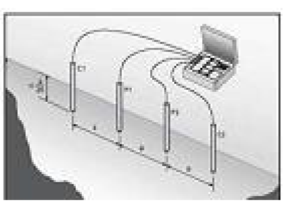

Fig :1 Earth tester.

(Wenner 4 pin electrode method is recommended for the soil resistivity measurement approximately and takes average resistance for whole substation site).

- Determine the maximum ground fault current and fault clearing duration from authority.
- Determine size of Earth mat conductor.

(As per IEEE-80).

$A = I \times 12.3 \sqrt{t}$	For Steel	Welded joint
$A = I \times 15.13 \sqrt{t}$	For steel	Bolted joint

Determine corrosion correction factor: for moisture and softy soil 15 % allowance and for rocky area (0% allowance is permissible).

- Find out maximum grid current

IG = Cp x Df x Sf x (3 x I_0) Where:

IG =Maximum grid current in K.A
Cp = corrective projection factor
(for future expansion)
Df = Decrement factor of D.C
offset S_f = current division factor
(Fraction of total current passed through irregular path)
I_0 = Zero Sequence fault current in K.A

- Find Resistivity of surface layer ρ_s.

The crushed metal or gravel is used in substation in order to reduce the risk of possible high step Potential so as far as safety is concerned. It is recommended to spread the metal or gravel of 8- 20 m.m. in switch yard.

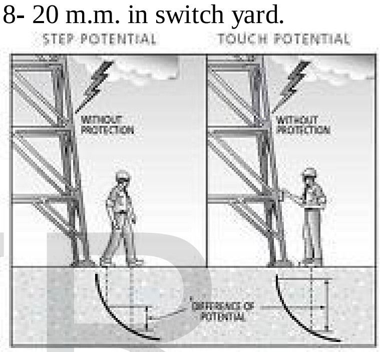

Fig :2 Step & Touch Potential

- Find out tolerable touch & Step potentials.

IV. PRELIMINARY DESIGNING OF EARTH MAT

Soil resistivity is the key factor that determines the resistance or performance of an electrical grounding system. It is the starting point of any electrical grounding design. As you can see in Tables 1 soil resistivity varies drastically.

Table 1

Type of Surface Material	Resistivity of Sample in Ohmmeters	
	Dry	Wet
Crusher granite	140×10^6	1,300
Crusher granite 1.5"	4,000	1,200
Washed granite – pea gravel	40×10^6	5,000
Washed granite 0.75"	2×10^6	10,000
Washed granite 1-2"	1.5×10^6 to 4.5×10^6	5,000
Washed granite 2-4"	2.6×10^6 to 3×10^6	10,000
Washed limestone	7×10^6	2,000 to 3,000
Asphalt	2×10^6 to 30×10^6	10,000 to 6×10^6
Concrete	1×10^6 to 1×10^9	21 to 100

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After that follows the steps given below in sequence:

i). Decide grid pattern (square grid, rectangular grid, L-shaped) assume spacing between two conductors such that it is continuous and reasonably uniform spacing. From the arrangement of total length of Conductor can be determined for design calculation.

ii). Find out grid resistance.

iii). Indicate Maximum grid current. iv).
Find out Estep & E touch Potential.

v). Find out Ground potential rise and Mesh voltage.

Table 2

Soil Types or Type of Earth	Average Resistivity in Ohm-meters
Bentonite	2 to 10
Clay	20 to 1,000
Wet Organic Soils	10 to 100
Moist Organic Soils	100 to 1,000
Dry Organic Soils	1,000 to 5,000
Sand and Gravel	50 to 1,000
Surface Limestone	100 to 10,000
Limestone	5 to 4,000
Shale’s	5 to 100
Sandstone	20 to 2,000
Granites, Basalt’s, etc.	1,000
Decomposed Gneiss’s	50 to 500
Slates, etc.	10 to 100

Now compare GPR < Etouch voltage
if yes then design is safe

If GPR > E touch

Then Find E mesh and E Step
Now compare E mesh < E touch
If yes then

Compare E step actual < E step
permissible if yes then design is safe

Otherwise, modify by increasing or decreasing spacing of conductor, Length of conductors. Calculate again.

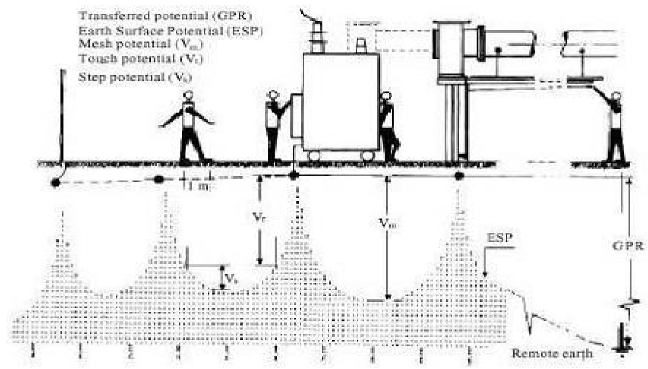

Fig:3 GPR ,Vmesh, Vtouch and Vstep voltages

V. Conclusion

The use of grounding grid with specific spacing will reduce both accidents as well as cost of earthing grid without affecting safety of personnel working in substations. In the design optimization process, especially for high value projects and complex systems, Prediction and simulation using a numerical method with high accuracy and reliability is an essential.

VI. References

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