

DESIGN OF EARTHING SYSTEM FOR HV/EHV AC SUBSTATION

(A CASE STUDY OF 400kV SUBSTATION AT AURANGABAD, INDIA)

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ABSTRACT

This paper presents the design of Earthing system for 400 KV substation and calculation of its parameters. 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. Grounding system has to be safe as it is directly concerned with safety of persons working within the substation. Main purpose of this work is designing safe and cost effective grounding systems for HV / EHV substations situated at such locations where soil of the substation site is not uniform. Initially significance of Earthing is explained & methodology for design of substation grounding system is discussed for HV / EHV substations. 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 the project for safety can be performed. This paper mentions the calculation of the desired parameters for 400 kV substation. A case study is done at 400 kV substation at Aurangabad in Maharashtra state of India.

KEYWORDS: Earthing, Earth electrodes, Ground grid, HV/EHV substations, Power systems, Safety, Touch and Step voltages

I. INTRODUCTION

Earthing practices adopted at Generating Stations, Substations, Distribution structures and lines are of great importance. It is however observed that this item is most often neglected. The codes of practice, Technical Reference books, Handbooks contain a chapter on this subject but they are often skipped considering them as too elementary or even as unimportant. Many reference books on this subject are referred to and such of those points which are most important are compiled in the following paragraphs. These are of importance of every practicing Engineer in charge of Substations. Earthing system thus design must be easily maintained and future expansion must be taken into account while designing the dimensions of earth mat

Substation earthing system is essential not only to provide the protection of people working in the vicinity of earthed facilities and equipments against danger of electric shock but to maintain proper function of electrical system. Reliability and security are to be taken in considerations as well as adherence to statutory obligations (IEEE and Indian standards on electrical safety [1-2] and

environmental aspects). This paper is concerned with earthing practices and design for outdoor AC substation for power frequency in the range of 50 Hz

1.1 importance

The earthing system in a plant / facility is very important for a few reasons, all of which are related to either the protection of people and equipment and/or the optimal operation of the electrical system. These include:

Equipotential bondings of conductive objects (e.g. metallic equipment, buildings, piping etc) to the earthing system prevent the presence of dangerous voltages between objects (and earth).

- The earthing system provides a low resistance return path for earth faults within the plant, which protects both personnel and equipment.
- For earth faults with return paths to offsite generation sources, a low resistance earthing grid relative to remote earth prevents dangerous ground potential rises (touch and step potentials)
- The earthing system provides a low resistance path (relative to remote earth) for voltage transients such as lightning and surges / overvoltages
- Equipotential bonding helps prevent electrostatic buildup and discharge, which can cause sparks with enough energy to ignite flammable atmospheres
- The earthing system provides a reference potential for electronic circuits and helps reduce electrical noise for electronic, instrumentation and communication systems [1-3]

This calculation is based primarily on the guidelines provided by IEEE Std 80 (2000), "Guide for safety in AC substation grounding".

II. EARTHING DESIGN FOR A H.V./E.H.V SUBSTATION

2.1 Earthing

“Earthing means an electrical connection to the general mass of earth to provide safe passage to fault current to enable to operate protective devices and provide safety to personnel and Equipments.”

2.2 Types of Earthing

The earthing is broadly divided as

➤ System Earthing

This is primarily concerned with the protection of Electrical equipment by stabilizing the voltage with respect to ground (Connection between part of plant in an operating system like LV neutral of a Power Transformer winding and earth).

➤ Equipment Earthing (Safety grounding)

This is primarily concerned with the protection of personnel from electric shock by maintaining the potential of noncurrent carrying equipment at or near ground potential. Connecting frames of equipment (like motor body, Transformer tank, Switch gear box, operating rods of Air break switches, etc) to earth.

The system earthing and safety earthing are interconnected and therefore fault current flowing through system ground raises the potential of the safety ground and also causes steep potential gradient in and around the Substation. But separating the two earthing systems have disadvantages like higher short circuit current, low current flows through relays and long distance to be covered to separate the two earths. After weighing the merits and demerits in each case, the common practice of common and solid (direct) grounding system designed for effective earthing and safe potential gradients is being adopted.[5-6]

2.3 Types of Earth Electrode

1. Rod electrode.
2. Pipe electrode.

Step Potential is the difference in the voltage between two points which are one meter apart along the earth when ground currents flowing

B. Touch Potential

Touch Potential is the difference in voltage between the object touched and the ground point just below the person touching the object when ground currents are flowing.[7]

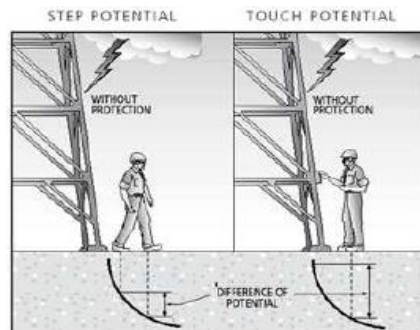


Figure 4. Step & Touch potentials

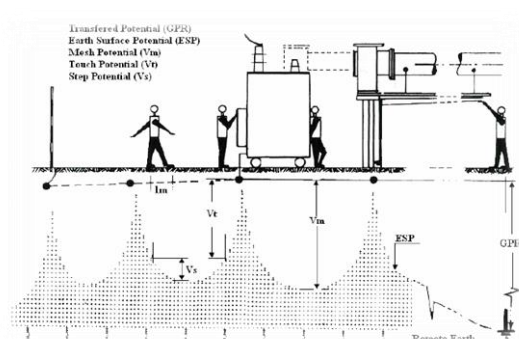


Figure 5. Ground Potential Rise

C. Ground Potential Rise (GPR)

The maximum electrical potential that a sub-station grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth. This voltage is equal to:

$$GPR = (I_G \times R_g)$$

where, I_G = Maximum earth grid current

R_g = Earth Grid resistance
(‘Earth grid’ i.e. Earthing system)[11]

D. Mesh Potential:

The maximum touch potential within a mesh of the grid.

E. Transferred potential:

A special case of touch potential where a potential is transferred into or out of the sub-station from or to a remote point external to the sub-station site.

A person standing in a sub-station coming in contact with say rails/water pipeline/neutral coming from an adjacent sub-station at the time of occurrence of earth-fault at that sub-station gets exposed to the transferred potential which equals difference in GPRs of the two sub-stations.

➤ **Specification of Earthing**

Depending on soil resistivity, the earth conductor (flats) shall be buried at the following depths.

Table 2.

Sr. No.	Soil Resistivity in ohms/meter	Economical depth of Burial in meters
1)	50 – 100	0.5
2)	100 – 400	1.0
3)	400 – 1000	1.5

To keep the earth resistance as low as possible in order to achieve safe step and touch voltages, an earth mat shall be buried at the above depths below ground and the mat shall be provided with grounding rods at suitable points. All non-current carrying parts at the Substation shall be connected to this grid so as to ensure that under fault conditions, none of these parts are at a higher potential than the grounding grid.

- Following points should be follow to keep the earth resistance as low as possible.
 - Remove Oxidation on joints and joints should be tightened.
 - Poured sufficient water in earth electrode.
 - Used bigger size of Earth Electrode.
 - Electrodes should be connected in parallel.
 - Earth pit of more depth & width- breadth should be made.

Plate Earths

Taking all parameters into consideration, the size of plate earths are decided as

- Power Stations & EHV Station - Main - 100 x 16mm
- Auxiliary - 50 x 8mm
- Small Stations - 75 x 8mm

2.7 Earth Mat Design

Earthing System in a Sub Station comprises of Earth Mat or Grid, Earth Electrode, Earthing Conductor and Earth Connectors.

2.7.1 Earth Mat or Grid

Primary requirement of Earthing is to have a low earth resistance. Substation involves many Earthlings through individual Electrodes, which will have fairly high resistance. But if these individual electrodes are inter linked inside the soil, it increases the area in contact with soil and creates number of parallel paths. Hence the value of the earth resistance in the inter linked state which is called combined earth value which will be much lower than the individual value.

The inter link is made thro flat or rod conductor which is called as Earth Mat or Grid. It keeps the surface of substation equipment as nearly as absolute earth potential as possible. To achieve the primary requirement of Earthing system, the Earth Mat should be design properly by considering the safe limit of Step Potential, Touch Potential and Transfer Potential.

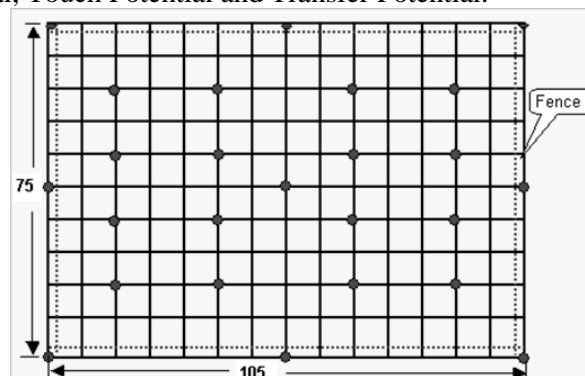


Figure 6. General configuration of earth mat

2.7.2 The factors which influence the Earth Mat design are:

- Magnitude of Fault Current
- Duration of Fault
- Soil Resistivity
- Resistivity of Surface Material
- Shock Duration
- Material of Earth Mat Conductor
- Earthing Mat Geometry

2.7.3 The design parameters are :

- Size of Earth Grid Conductor
- Safe Step and Touch Potential
- Mesh Potential (Emesh)
- Grid configuration for Safe Operation
- Number of Electrodes required

III. MATHEMATICAL CALCULATION

3.1 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).

3.2 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.

For step voltage the limit is

- The tolerable step voltage criteria is

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

- The tolerable touch voltage criteria is

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

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

α₀ = thermal coefficient of resistivity at 0°C

α_r = thermal coefficient of resistivity at reference temperature Tr

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

K₀ = 1/α₀ or 1/α_r - 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.[3]

For calculation of grounding resistance, the following formula is used

$$R_g = \rho \left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}} \left(1 + \frac{1}{1+h\sqrt{\frac{20}{A}}} \right) \right] \tag{6}$$

Where

ρ = soil resistivity Ωm

Lt = 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[11]

$$I_G = (C_P \times D_f \times S_f \times I) \tag{7}$$

- For calculation of grid potential rise

$$GPR = (I_G \times R_g) \tag{8}$$

- **Actual Step Potential & Touch Potential Calculations**

Formula for calculation of mesh voltage are

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

Formula for calculation of step voltage are

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

Where

ρ = soil resistivity, ohms-m

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

Es = step voltage between point in V

Km = spacing factor for mesh voltage

Kis = spacing factor of step voltage

Kim = 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

LT= Total length of earth conductor in switch yard

$$LT = (LL + LB + LA + LE) \tag{11}$$

IV. RESULT

The Input Constant values for design calculations & Output results for grid construction design are given in following tables

Table 3 Input Constant values for design calculations

Parameters	Symbol	Value	Units
Ambient temperature	Ta	45	°c
Maximum allowable temperature	Tm	450	°c
Fault duration time	ts	1s	Sec
Thermal coefficient of resistivity	αr	0.0032	
Resistivity of conductors	ρr	20.1	μΩ/cm

Resistivity of substation soil	ρ	201.8	Ωm
Resistivity of surface material	ρ_s	2000	Ωm
Thermal capacity factor	TCAP	3.931	$\text{j}/\text{cm}^3/^\circ\text{c}$
Depth of burial conductor	h	0.6	m
Reference depth of grid	h_o	1	m
Conductor spacing	D	7	m
Diameter of grid conductor	d	34	mm
Length of one earth rod	Lr	3	m

Table 4 Output results for grid construction design

Parameters	Symbol	Value	Units
Earth conductor size	A	793.1	mm^2
Maximum grid current	IG	20	KA
Ground resistance	Rg	0.301732	Ω
Ground potential rise	GPR	6034.633	Volt
Spacing factor for mesh voltages	Km	0.380395	
Spacing factor for step voltages	Ks	0.352793	
Touch voltage criteria	Etouch	554.0823	Volt
Step voltage criteria	Estep	1724.183	Volt
Maximum attainable step voltage (Actual step voltage)	Es	389.6783	Volt
Maximum attainable mesh voltage(Actual touch voltage)	Em	374.1747	Volt
Total length of earth conductor in switch yard	LT	34405.5	m

The main electrical properties of an earthing system are:

- Earthing resistance
- Earth surface potential distribution
- Current carrying ability

The most favorable earth surface potential distribution concepts have horizontal earth electrodes, especially meshed ones, whose surface potential can be controlled relatively simply. The potential distribution of vertical electrodes is the most unfavorable, with high values of touch potential. On the other hand, vertical electrodes can easily reach low earthing resistance with stable values, largely independent from seasons. Vertical electrodes are also used in combination with horizontal ones in order to reach lower values of earthing resistance. These results are obtained above prove that this earth grid design is safe for 400 kV substation in the range of soil resistivity 100-350 Ωm .

V. FUTURE WORK

- Mathematical modeling and simulation.
- Programming and Designing by using MATLAB & E-TAP Software.
- Focus on the study to minimize the problems in earthing.
- Recommendation to minimize the problems in earthing in Existing substation.

VI. CONCLUSION

This paper has a focus on designing of a 400 kV HV/EHV AC substation earthing system. The results for earthing system are obtained by computational method. For earthing conductor and vertical earth electrode, mild steel are used. 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 values of step and mesh voltages obtained for 400 kV substation are respectively 389.6783 Volt and 374.1747 Volt which are within the permissible limits.

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