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Design of Earthing System for a Substation : A Case Study

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Abstract

This paper presents the design of earthing system for 132 KV substation and simulation for calculation of required parameters. This paper is to provide information pertinent to safe earthing practices in ac substation design and to establish the safe limits of potential difference under normal and fault conditions. The grounding grid system of a practical 220 kV substation is calculated by MATLAB program. The supporting data has been obtained from actual field tested at the substation. 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 selection the proper horizontal conductor size, vertical electrode size and soil resistivity, the best choice of the project for safety is performed. This paper mentions the calculation of the desired parameters which are simulated by MATLAB program. Some simulated results are evaluated.

Keywords

component; Safe earthing system, Grounding, resistivity , AC substation, MATLAB program, Flowchart

1. Introduction

In 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). Earthing system thus design must be easily maintained and future expansion must be taken into account while designing the dimensions of earth mat.

This paper is concerned with earthing practices and design for outdoor AC substation for power frequency in the range of 50 Hz. DC substation GIS and lightening effects are not covered in this paper. With proper caution, the method described here is also applicable to indoor portion of such substation. By using proper conductor and electrode size, earthing system may be able to overcome lightening effects.

2. Earthing system for a substation

A. Components of earthing system

An effective substation earthing system typically consists of earth rods, connecting cables from buried earthing grid to metallic parts of structures and equipments, connections to earthed system neutrals, and the earth surface insulating covering material briefly discussed in [1,3]. Current flowing into the earthing grid from lightening arrester operation impulse or switching surge flashover of insulators and line to ground fault current from the bus or connected transmission lines all cause potential differences between earthed points in the substation. Without a properly designed earthing system, large potential differences can exist between different points within the substation itself. Under normal circumstances, it is the current constitutes the main threat to personal.

B. Data needed for design of earthing

- Substation grid area
- Soil resistivity at the site
- Fault clearing time
- Maximum grid current
- Resistivity of soil at surface

C. Factors on which design of earthmat depends

- Materials used for earth electrodes and conductors must be chosen carefully taking into account physical, chemical and economical constraints. Ground conductor must be adequate for fault current (considering corrosion). Basic requirements are thoroughly studied in paper [4].
- Conductor sizing depends on fault current and conductivity as well as mechanical strength of material used.
- Resistivity of soil and surface layer determines the STEP and TOUCH potentials, which

determine safe values of operation as described in reference [1, 5-9]. Also the multilayer resistivity has been a subject of continuous attention by the researchers [10-13].

- A good grounding system provides a low resistance in order to minimize GPR (ground potential rise)[14].
- Grid geometry is a major factor in determining the step, touch and mesh potential contours and current distribution in grid. The limitations on the physical parameters of a ground grid are based on economics and the physical limitations of the installation of the grid.

D. Fault Clearing Time

The faults clearing time is governed by system stability consideration and depend on protection and switchgear equipment. Generally a value of 0.5 seconds is assumed.
The size of the conductor is based on a time of 1 second.

E. Determination of Maximum Grid Current

A single line to ground fault is more common and causes more fault current as compared to a double line to ground fault. Therefore , the design is based on single line to ground fault current. For calculation of this current grid resistance and fault resistance are assumed to be zero. Then
$I_g = S_f I_f$
Where

I_g= symmetrical grid current , Amp
I_f= rms value of symmetrical ground fault current, Amp
S_f= current division factor relating the magnitude of fault current to that of its portion flowing in the earthing grid.

Only a part of the total fault current flows through the grid. The remaining current flows through the overhead ground wires and other ground return paths. The factor S_f gives this current division and can be calculated, if the system data is known, from the value of I_g the design value of grid current is found as

$$I = G_f D_f I_g$$

Where

I= maximum grid current
G_f= A factor to account for increase in fault current due to system growth during life span of grid.
D_f= Decrement factor to account for asymmetry of the fault current wave.

Typical values of G_f assumed in design, lie in the range of 1.2 to 1.5 depending on the rate of growth of the system.

F. Selection of Electrode material

The material for grounding grid should have good conductivity, be mechanically rugged and resist fusing and deterioration of joints.
Copper was very commonly used in the past. It has high conductivity and is resistant to underground corrosion. However, a grid of copper forms a galvanic cell with other buried structure and pipes and is likely to hasten the corrosion of the latter. Aluminium is not used because of corrosion problem.

3. Mathematical Description

G. Safe limits and values of potentials

The safety of a person depends on preventing the critical amount of shock energy from being absorbed. The maximum driving voltage of any accidental circuit should not exceed the limits defined as follows.
The tolerable step voltage criteria is

$$E_{step} = \frac{(1000 + 6C_s \rho_s)\,.116}{\sqrt{t_s}} \qquad (1)$$

The tolerable touch voltage criteria is

$$E_{touch} = \frac{(1000 + 1.5C_s \, . \, \rho_s)\,.116}{\sqrt{t_s}} \qquad (2)$$

Where
C_s = 1 for no protective surface layer
ρ_s= the resistivity of the surface material in A-m
t_s = duration of shock circuit in seconds
The minimum conductor size formula is mentioned below-

$$A^2_{mm} = I \times \sqrt{\frac{\frac{t_r \times \alpha_r \times \rho_r \times 10^4}{TCAP}}{\ln\left[1+\left(\frac{T_r - T_a}{K_o + T_a}\right)\right]}} \cdots \qquad (3)$$

Where
K_o = $1/\alpha_o$ or $1/\alpha_o - T_r$
t_c = time of current flow in sec
TCAP = thermal capacity factor

For grounding resistance, the following formula is used

$$R = \rho\left[\frac{1}{L} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{h\sqrt{\frac{20}{A}}}\right)\right] \qquad (4)$$

Where
ρ = soil resistivity
L_t = total length of grid conductor
A = total area enclosed by earth grid
h = depth of earth grid conductor

For calculation of grid current, equation (5) is used

$$I_g = S_f \times 3I_o \ \ldots \tag{5}$$

Where
I_g = maximum grid current
$3I_o$ = symmetrical fault current in substation for Conductor sizing in A
S_f = current diversity factor
Equation (6) is expressed for grid potential rise (GPR)

$$\text{GPR} = I_g\ R_g \tag{6}$$

Maximum attainable step and touch voltages are given by:
Formula for c-alculation of mesh and step voltage are

$$E_m = \frac{\rho\ K_m K_i I_g}{L_g + 1.15\ L_r N_r} \tag{7}$$

$$E_m = \frac{\rho\ K_s K_i I_g}{L} \tag{8}$$

Where
ρ = soil resistivity, ohms-m
E_m = mesh voltage at the center of corner mesh
E_s = step voltage between point
K_m = spacing factor for mesh voltage
K_s = spacing factor of step voltage
K_i = correct factor for grid geometry

$$K_m = \frac{1}{2\pi}\left[\text{In}\left(\frac{D^2}{16hd} + \frac{(D+2h)^2}{8Dd} - \frac{h}{4d}\right) + \frac{K_{ii}}{K_h}\ \text{In}\frac{8}{\pi(2n-1)}\right] \tag{9}$$

Where
D = spacing between conductor of the grid
d = diameter of grid conductor
K_m = spacing factor for mesh voltage
K_{ii} = 1 for grids with rods along perimeter
K_h = Corrective weighting factor for grid depth

$$K_s = \frac{1}{\pi}\left[\frac{1}{2h} + \frac{1}{(D+h)} + \frac{1}{D}\left(1 - 0.5^{n-2}\right)\right] \tag{10}$$

Where
D = spacing between conductor of the grid
h = depth of burial grid conductor
n = number of parallel conductor in one direction

The length required to keep mesh voltage within safe limits, can be calculated by

$$L = \frac{\rho * Km * Ki * I * \sqrt{t}}{(1000 + 1.5 * \rho s) * (0.116)} \tag{11}$$

If the length of conductor in the Preliminary design is less than that given eqn. (11) a revision in design is necessary.

H. Design procedure

Values of maximum attainable touch voltages are calculated. If the GPR of the preliminary design is below the tolerable touch voltage, no further analysis is necessary. Only additional conductor required to provide access to equipment grounds is necessary.

If the computed mesh voltage is below the tolerable touch voltage, the design may be complete. If the computed mesh voltage is greater than the tolerable touch voltage, the preliminary design should be revised. If both the computed touch and step voltages are below the tolerable voltages, the design needs only the refinements required to provide access to equipment grounds. If not, the preliminary design must be revised.

Further for the safe design we need to compare the length of the electrode in the preliminary design to the length of the electrode required to keep mesh voltage within safe limits

If either the step or touch tolerable limits are exceeded, revision of the grid design is required. These revisions may include smaller conductor spacing, additional ground rods, and use of closer spacing of conductor. In case the length given by eqn. (11) is too small to allow for connections to all equipments, more conductor may be required even though it is not necessary for safety ,etc as discussed in reference [1].

If the length of the conductor in the preliminary design is less than the length required to keep mesh voltage within safe limits. , then the design needs to be revised by entering more number of electrodes or by decreasing spacing between the conductors, otherwise the design is accurate. Further, if the Ground Potential Rise (R*Ig) is less than the tolerable value of touch potential then the design of the electrical grid is considered to be safe otherwise we need to guard personnel and other communication equipment against transferred potential.

Checking of step Potential:-
The tolerable step potential and actual step potential can be calculated from eqn (1) and eqn (8). If actual step potential is more than tolerable, a revision in design is necessary. The final step in design includes provision of closer meshes in the area frequently visited by operating personnel, additional ground rods for surge arrester leads, etc., and provision of risers for connection to equipments.

Impulse behaviour of earthing system:
The degree of protection provided by an earthing system under lightning discharge conditions depends on its impulse impedance (i.e.,impedance under impulse conditions) and not the power frequency resistance. The impulse impedance is different from the power frequency resistance due to effect of 1st soil ionization 2nd electrode inductance.

When the magnitude of impulse current is high, the soil in the vicinity of electrode may break-down causing a decrease in resistance. When the length of electrode is large, its inductance may cause only a part of the earthing system to be effective in dissipating current and, thus result in an increase in impedance.

The relative contributions of these two factors depend on the type of earthing system. The effect of soil ionization is very predominant in driven rods so that the impulse resistance of a driven rod is always less than its power frequency resistance.

The whole procedure can be shown by this flowchart:

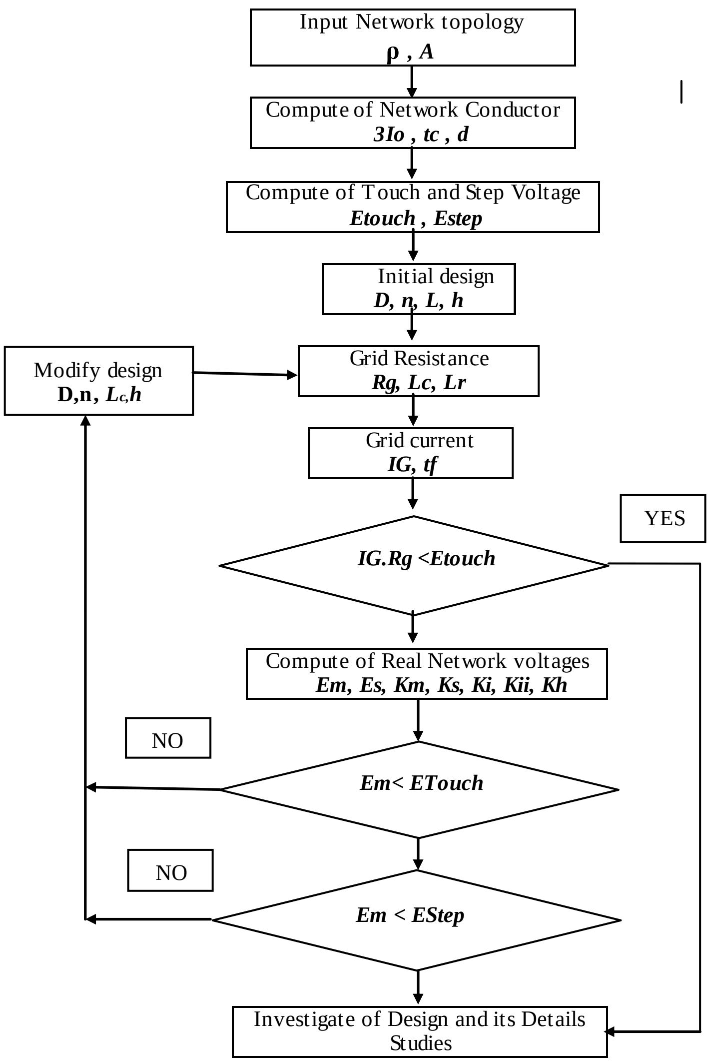

Fig 1. Design procedure

Table I

Constant values for design calculations		
Quantity	***Symbol***	***Value***
Ambient temperature	T_a	40
Maximum allowable temperature	T_m	620
Fault duration time	t_s	1s
Thermal coefficient of resistivity	α_r	0.0042
Resistivity of conductors	ρ_r	15
Resistivity of substation soil	ρ	220
Resistivity of surface material	ρ_s	3300
Thermal capacity factor	TCAP	3.7490
Depth of burial conductor	h	0.6m
Diameter of grid conductor	d	25mm
Length of one earth rod	L_r	3m

Table II

Output results for grid construction design		
Quantity	***Symbol***	***Value***
Earth conductor size	A_c	376.2573
Maximum grid current	I_G	15750
Ground resistance	R_g	0.9646
Ground potential rise	GPR	1512
Spacing factor for mesh voltages	K_m	0.2244
Spacing factor for step voltages	K_s	0.4338
Touch voltage criteria	E_{touch}	689.97
Step voltage criteria	E_{step}	2267.72
Maximum attainable step voltage	E_s	1453.93
Maximum attainable mesh voltage	E_m	581.61

4. Result

These results are obtained by a MATLAB program.

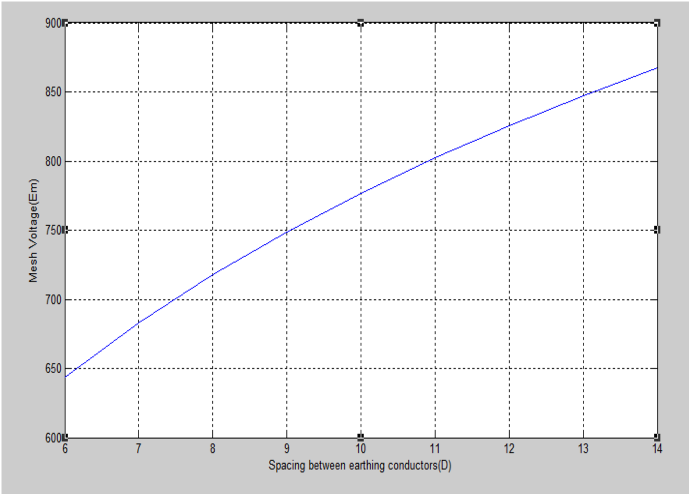

Fig. 2 Mesh Voltage with Different Values of Spacing Between Conductors.

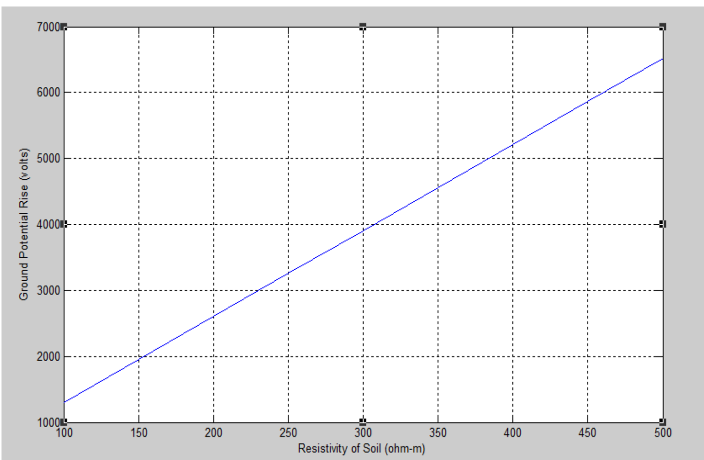

Fig. 3 Grid Potential Rise with Different Values of Resistivity of Soil

5. Significance and Touch Voltage

The step and touch voltages are dangerous for human body. Human body may get electric shocks from step and touch voltages. From the safety point of view it is necessary to calculate step and touch voltage. When high voltage substations are designed step and touch voltages should be calculated and must be in specified standard. The expected shock current caused by touch voltage can be effectively limited by applying inexpensive insulating layers on the earth's surface .The limits of step and touch potentials varies in different seasons because the resistivity of the soil layer is affected by different seasons .The step and touch voltage calculations are very significant while designing substation.

6. Conclusion

This paper has a focus on designing of an AC substation.The results for earthing system design are obtained by MATLAB program for earthing conductor and vertical earth electrode mild steel is used.

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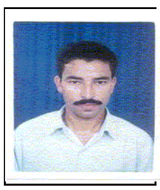

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