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Design of Grounding System of Substation: A Comparative Study of the effects of variation of number of Earth Electrodes and Grid conductor.

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***Abstract*: -- Grounding system has a dominant effect on the design of all substations and its design strategy needs substantial attention as it plays an indispensable role in the proper functioning of the substation. Designing of an effective grounding system is very imperative as it encompasses a great deal of personal safety and appropriate operation of the substation equipment. In this present work, a case study of a 33/11kV substation is done using the IEEE Standards 80-2000 as a reference. The procedure for designing of the grounding system is carried out with the help of a MATLAB program. The same is then used to calculate the values of the Ground resistance, the Ground Potential Rise (GPR), the Step potential and the Touch potential. The calculations are then followed by a comparative analysis of the effects of the increase in the number of electrodes and/or the ground rods on ground resistance, ground potential rise, step potential and touch potential.**

***Keywords*— Ground Resistance, Ground Potential Rise (GPR), Step Potential, Touch Potential.**

I. INTRODUCTION

A grounding system should be so designed so as to reduce the effect of ground potential rise to voltages that will not imperil the safety of the personnel and equipments under the normal and faulty conditions. "People often assume that any grounded object can be safely touched. A low substation ground resistance is not, in itself, a guarantee of safety, there is no simple relation between the resistance of the ground system as a whole and the maximum shock current to which a person might be exposed. Therefore, a substation of relatively low ground resistance may be dangerous, while another substation with very high resistance may be safe or can be made safe by careful design." [1] The excessive rise of ground potential is a real problem for the people working at the substation. Thus before the commissioning of the substation it should be ensured that the step potential and touch potential is within the tolerable limits. In this present work, the grounding system of a typical 33kV/11kV substation is investigated using the IEEE Standard 80-2000 as reference. The same procedure is used to evaluate the effects of variation in the number of ground rods and grid conductors on the Ground Resistance, Ground Potential Rise (GPR) and the Step Potential and Touch Potential.

II. PROCEDURE FOR GROUNDING SYSTEM DESIGN

The fig. 1 illustrates the steps to be followed while designing of a grounding system of a substation. The first step involves the gathering of field data and calculation of tolerable step voltage and touch voltage. Next, the value of ground resistance is calculated and multiplied with the fault current to derive the Ground Potential Rise. If this Ground Potential Rise (GPR) is less than the tolerable Touch potential and Step potential then no further modification is required else modification will be required. In this paper, we will not be focusing our attention to calculate the size of conductor as it is beyond the scope of this paper.

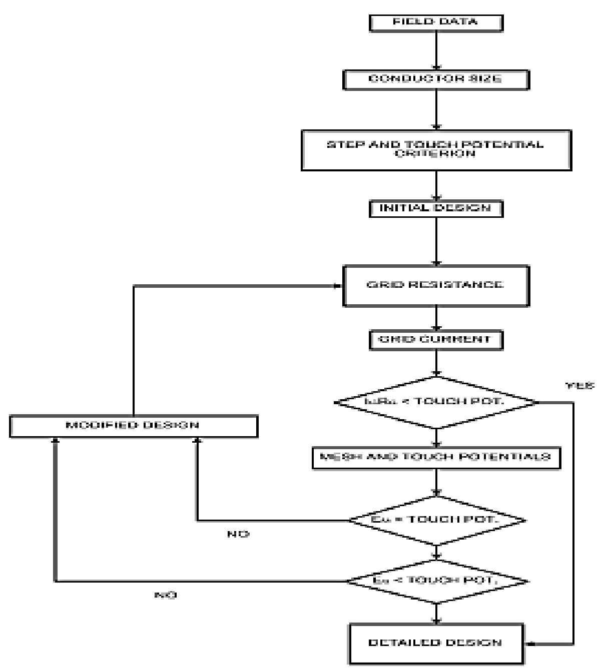

Fig. 1 Flowchart for designing of grounding system of substation

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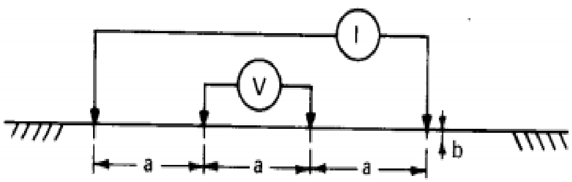

Fig. 2 Wenner's four pin method

With this arrangement the electrodes are equally spaced as shown in fig. 2. Let a be the distance between two adjacent electrodes. Then, the resistivity ρ in the terms of the length units in which a and b are measured is:

$$\rho = \frac{4\pi aR}{1+\frac{2a}{\sqrt{a^2+4b^2}}-\frac{a}{\sqrt{a^2+b^2}}} \quad (1)$$

If b is less than 0.1a then the above equation reduces to

$$\rho = 2\pi a R \quad (2)$$

A set of readings taken with various probe spacing gives a set of resistivity which, when plotted against spacing, indicates whether there are distinct layers of different soil or rock and gives an idea of their respective resistivity and depth.

The value of the ground resistance is calculated by [1]:

$$R_g = \rho\left[\frac{1}{L_T}+\frac{1}{\sqrt{20A}}\left(1+\frac{1}{1+h\sqrt{20/A}}\right)\right] \quad (3)$$

Where, ρ is resistivity of soil, LT is total effective length of grounding system conductors, A is total area enclosed by ground grid, h is the depth of ground grid conductors

Assuming the fault current to be Ig, if IgRg < Tolerable touch potential then we need not go for further modifications.

The tolerable step and touch potentials for 50kg and 70kg person are given below:

$$E_{t50} = (1000+1.5C_s\rho_s)\frac{0.116}{\sqrt{t_s}} \quad (4)$$

$$E_{t70} = (1000+1.5C_s\rho_s)\frac{0.157}{\sqrt{t_s}} \quad (5)$$

$$E_{s50} = (1000+6C_s\rho_s)\frac{0.116}{\sqrt{t_s}} \quad (6)$$

$$E_{s70} = (1000+6C_s\rho_s)\frac{0.157}{\sqrt{t_s}} \quad (7)$$

Where, Et and Es denotes the touch and step potentials, respectively, Cs is the surface layer derating factor, ρs is the resistivity of surface layer, ts is the fault clearing time

If the value of IgRg exceeds the value of Tolerable Touch Potential then modification is done using the following formulae:

$$E_t = \frac{\rho\times I_G\times 1000\times K_m\times K_i}{L_m} \quad (8)$$

$$E_s = \frac{\rho\times I_G\times 1000\times K_S\times K_i}{L_S} \quad (9)$$

Where, Et and Es are the values of touch and step potentials after modification, Km is the spacing factor for mesh voltage, Ks is the spacing factor for step voltage, Ki is the correction factor for grid geometry, Lm is the effective length for mesh voltage, LS is the effective length for step voltage

Following the above explained procedure, we can develop the grounding system for a substation.

III. STUDY OF THE GROUNDING SYSTEM OF A 33kV/11kV SUBSTATION

The study will be conducted using the algorithm shown by the flowchart of Fig 1 and using the formulae from (1) to (9).

TABLE 1. DATA COLLECTED FROM THE 33/11KV SUBSTATION

System fault current (If)	25kA
Length of switchyard (L)	42m
No. of electrodes(NR)	30
Depth of burial (hS)	0.6m
Duration of fault (tc)	0.15sec
Breadth of switchyard (B)	35m
Soil Resistivity(ρ)	10
Diameter of electrode(d)	0.023m

A basic design of the grounding grid without electrodes is shown below in fig 3. The grid is placed at a distance of 7m in the y-direction and at a distance of 6m in the x-direction.

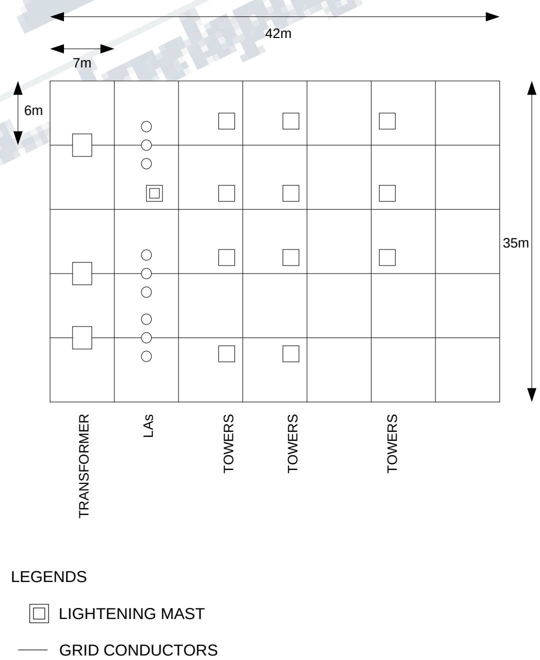

Fig. 3 Basic design of the ground mat

The value of ground resistance is calculated using equation (3), and its value is 0.12Ω.

Using the formulae in equations (4) to (6), the tolerable values of step and touch potentials are calculated and the values are tabulated in table 2.

TABLE 2. TOLERABLE VALUES OF STEP AND TOUCH POTENTIALS BASED ON BASIC DESIGN

Et50	732.48V	Et70	991.37V
Es50	2437.76V	Es70	3299.39V

The ground potential rise comes out to be 1802V which is above the tolerable touch and step potentials, so further modification is required.

Using the equations (8) and (9), we get the values of the final mesh and step potentials.

TABLE 3. VALUES OF MESH AND TOUCH POTENTIALS AFTER MODIFICATION.

Em	191V
Es	243V

The final design of the ground mat with ground electrodes is shown below in fig 4. The design shows the presence of total 30 ground electrodes and 14 grid conductors. The design shown in fig 4 ensures that the final values of mesh and step potentials, as tabulated in table 3 after modifications are below the tolerable limits as tabulated in table 2.

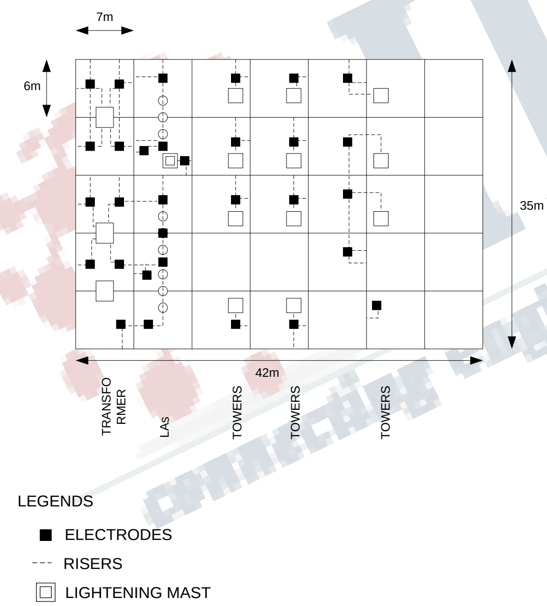

Fig. 4 Final design of ground mat with electrodes

A COMPARATIVE STUDY OF THE EFFECTS OF VARIATION OF NUMBER OF EARTH ELECTRODES AND GRID CONDUCTOR

The analysis is carried out by using the algorithm given in fig. 1 but with an assumption that the grid conductors are placed equidistant from each other, both in the x-direction and the y-direction with two distances being used, that is 6m and 7m. Firstly, the ground electrodes are increased keeping the distance between the grid conductors as 6m and then the same is done keeping the grid conductors at a distance of 7m. The tolerable touch and step potentials are given below.

Et50 : 1337.3 V
Et70 : 1810 V
Es50 : 4450.7 V
Es70 : 6023.8 V

From Fig. 5a to Fig. 5d, we can determine that as the number of electrodes increase, the value of ground resistance, GPR, step potential and touch potential decrease. But as the distance between grid conductors rise, the area of the ground required also increases.

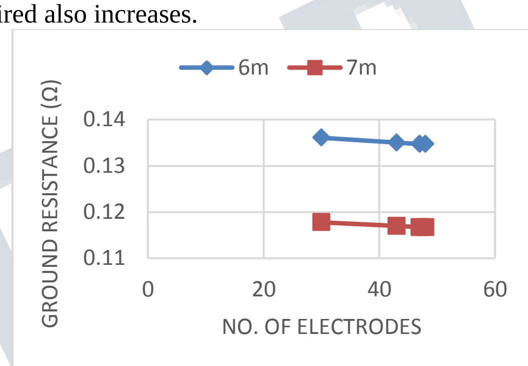

Fig. 5a Plot of Ground Resistance versus No. of Electrodes

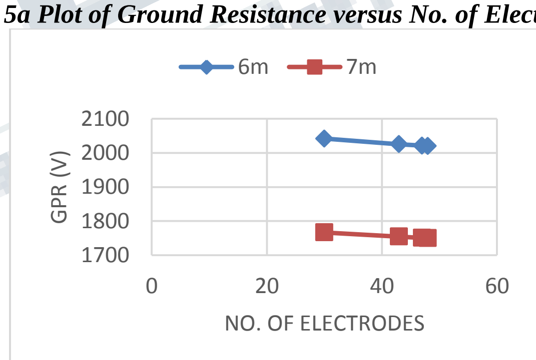

Fig. 5b Plot of GPR versus No. of Electrodes

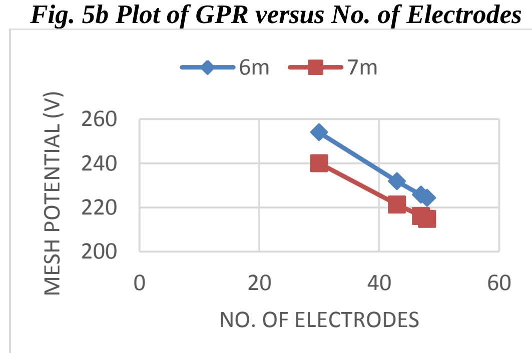

Fig. 5c Mesh voltage of modified grid versus no. of electrodes

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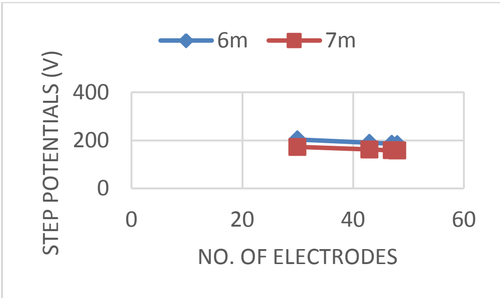

Fig. 5d Step Potential of modified grid versus No. of Electrodes

Now, the number of electrodes are varied in distinct steps at 30, 43 and 47 and for each step the number of grid conductors are varied and the results are plotted in fig 6a and fig 6b.

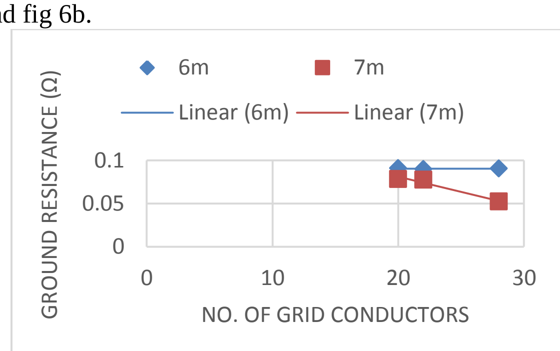

Fig. 6a Ground Resistance vs No. of Grid Conductors for 30 ground electrodes

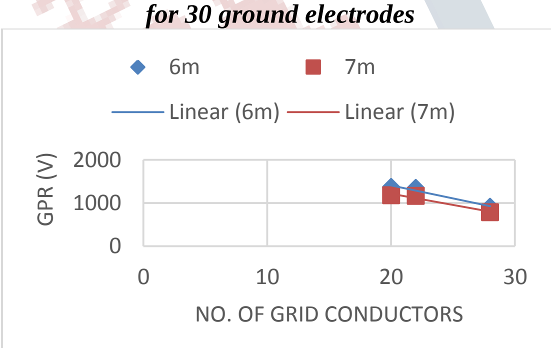

Fig. 6b GPR vs no. of grid conductors for 30 ground electrodes

From the graphs in Fig 6a and Fig 6b, it is evident that the value of ground resistance and GPR falls, as the number of ground grid conductors increase. When the number of grid conductor reaches to 28 (for both cases, i.e. for 6m and 7m grid conductor separation) then the GPR falls below the tolerable touch potential. As the value of step and touch potentials drop below tolerable touch and step potentials so no further modifications are required.

Again increasing the ground electrodes to 43 and then increasing the no of grid rods, we see the plots as below in fig 7a and fig 7b.

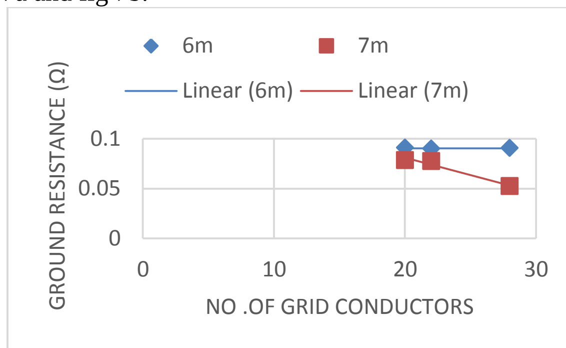

Fig. 7a Ground Resistance vs No. of Grid Conductors for 43 ground electrodes

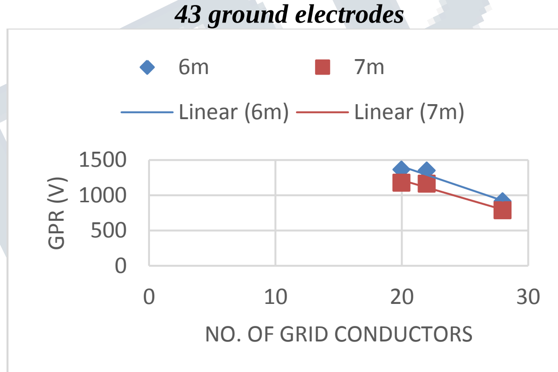

Fig. 7b GPR vs no. of grid conductors for 43 ground electrodes

From the graphs in fig 7a and fig 7b, it is evident that as the number of ground grid conductors increase the value of ground resistance and GPR shows a decreasing trend. When 28 grid conductors are used for both 6m and 7m, the value of GPR falls below the tolerable touch voltage and so no further modification is required.

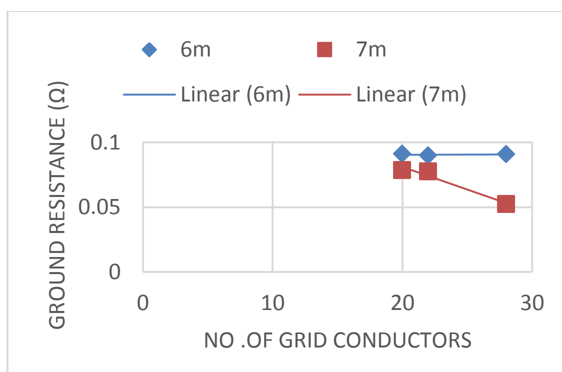

Fig. 8a Ground Resistance vs No. of Grid Conductors for 47 ground electrodes

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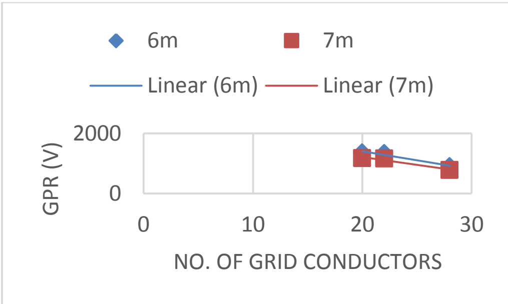

Fig. 8b GPR vs No. of Grid Conductors for 47 Ground Electrodes

The values of ground resistance and GPR when plotted against the variation in number of grid conductors, the plots show a decreasing trend as shown in fig 8a and fig 8b. The increase in the number of grid conductors results in a reduction in the ground resistance and GPR. When the grid rods used is 28 then the GPR falls below the tolerable limit of touch potential, as shown in fig 8b, giving us a safe operating condition.

V. CONCLUSION

This study shows that an increase in the number of ground electrodes and grid conductors, results in a safe value of GPR. While increasing the number of ground electrodes or grid conductors it should be kept in mind to keep two electrodes at safe distance from each other, i.e. the minimum distance between the grid conductors should be equal to twice the length of the electrodes. Keeping this in mind, if the number of grid conductors and ground electrodes are increased then at certain values (in this case, when the grid conductors used is 28) it provides GPR values that is below tolerable touch and step potentials and further designing is not necessary

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