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Parameters Effecting Substation Grounding Grid Resistance

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ABSTRACT

One of the key parameters in substation grounding design is to calculate accurately the grounding resistance of the system. The substation grounding grid resistance to be used to design a safe grounding system has been receiving a lot of attention in recent years. It is important that the substation ground has a low ground resistance, adequate current carrying capacity, and safety features for personnel and equipment. 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. In this paper the various parameters affecting the calculation of substation grounding grid resistance is briefly explained.

Keywords: *Grounding, ground resistance, resistivity, grounding grids, substation*

1. INTRODUCTION

Good substation grounding is essential for safe and reliable operation of a power system. The selection of a suitable grounding system is an important aspect in the construction of a high voltage substation. The aim of the grounding system is to drive the ground fault current efficiently to the earth, and to protect the people within and in the surroundings of the substation. Effect of the various parameters which influence grounding grid performance in uniform and two - layer soils are soil characteristics and grounding grid configuration, grid burial depth, conductor current density, grid resistance, step and touch potentials. A large number of grounding grids in substations have shapes other than a square or a rectangle, whereas the formulas and graphs for the ground resistance of a grounding grid available in the literature are applicable only to nearly square or rectangular grids. The grounding systems commonly used, consist of single rods, rod beds or arrays of rods, grounding grids and combinations of the previous types. The grounding resistance of a system can be calculated by various methods. Depending on the type of the grounding system and the soil structure either uniform or multilayer, different methods have been proposed in the literature. These methods however exhibit significant differences in their results, especially when used in multilayer soils. As a result, the selection of the proper calculating method for each case is a difficult aspect. Analysis of substation grounding systems, including buried grids and driven rods, has been a subject of many recent papers [1-5].

Many formulas are proposed for the calculation of the substation grounding grid resistance. Most of these formulas are accurate within certain ranges of grid depths or grid sizes. Some of these formulas are recommended to be used for estimating the maximum fault current. Some are helpful in estimating the substation ground potential rise for preliminary design evaluation. For accurate calculation of the ground resistance of the grid, formula such as Schwartz formula should be used [6-13].

2. BASIC COMPONENTS AND PURPOSE OF GROUNDING SYSTEM

The grounding system consists of four basic components:

1. The soil beneath and around the substation site which is very complicated and heterogeneous in composition as well as in structures.

2. The ground grid which is a network of interconnected conductors embedded or buried beneath the substation surface. Usually, a typical substation ground system will take the form of a grid of horizontally buried conductors.

3. Ground rods connected to the ground grid and installed beneath the site, usually reaching lower resistivity soil to control the surface gradients and lower the overall grounding system resistance.

4. The finished surface covering the site, in most high voltage substations, a layer of crushed rock or gravel is applied to the surface. The purpose of a grounding system at a substation includes the following:

- To provide the ground connection for the grounded neutral for transformers, reactors and capacitors.
- To provide the discharge path for lightning rods, surge arrestors, spark gaps and other similar devices.
- To ensure safety to operating personnel by limiting potential differences that can exist in a substation.
- To provide a means of discharging and de energizing equipment to proceed with maintenance on the equipment.
- To provide a sufficiently low resistance path to ground to minimize rise in ground potential with respect to remote ground.

3. SOIL RESISTIVITY AND GROUND POTENTIAL RISE

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The grid resistance and the voltage gradients within a substation are directly dependent on the soil resistivity. Because in reality soil resistivity will vary horizontally as well as vertically, sufficient data must be gathered for a substation yard. The Wenner method is widely used [7]. When a grounding system is designed, the fundamental method to ensure the safety of human beings and power apparatus is to control the step and touch voltages in their safe regions. In different seasons, the resistivity of the surface soil layer would be changed, which would affect the safety of grounding system, and the grounding resistance, step and touch voltage would move to the safe side, or to the hazard side. In rainy season , the low resistivity soil layer leads the grounding resistance and the step voltage smaller than the respective values in normal condition, it is good for safety of human beings, but the raining season perhaps leads the touch voltage higher than its limit value, so the influence of raining on the safety of grounding grid should be considered.

The burial depth of the grid affects the Ground Potential Rise (GPR) to some extent as well as the ground rod, connected with the grid, and also plays an important role in GPR reduction. In case that the top soil-layer resistivity is more than the bottom-layer, the ground grid with and without ground rod will greatly reduce the value of GPR. On the contrary, in case that the top soil-layer resistivity is less than the bottom-layer resistivity, the ground grid with and without ground rod will slightly reduce the value of GPR. This indicates that the current density over the grid affects directly to the current distribution to the soil layer. Therefore, the design and construction of grounding grid in the area which the top soil-layer resistivity is less than the bottom-layer resistivity, can lessen the number of ground rod used in the grid because the value of GPR is insignificantly different. Finally, the deeper the grid buries in the layer, the lesser is the value GPR.

Due to the different in soil characteristics at each substation, ground grid design must carefully be done to gain acceptable safety as well as optimal investment. From the past, ground grid design without rods and with rods was carried out. A vertical rod is more effective electrode than a horizontal rod. The rod length is varied to determine the influence of rod length on GPR, furthermore, when the soil structure is two-layer structure, the optimum ground layer depth and rod length for ground grid must be determined to gain safety and proper investment. Therefore, the study of ground grid buried in each layer depth is done to determine the effect of GPR [14-15].

4. DIFFERENT FORMULAS FOR CALCULATING GROUNDING GRID RESISTANCE

1.The formula given by Dwight [6] for calculating substation grounding grid resistance is:

$$R_g = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} \qquad (1)$$

where

R_g is the substation ground resistance in Ω

ρ is the soil resistivity in Ω.m

A is the area occupied by the ground grid in m^2

2. An upper limit of the substation grounding grid resistance can be obtained by adding a second term to the above formula, as proposed by Laurent and Nieman, also called IEEE Std. 80 - 2000 formula [7] is given by:

$$R_g = \frac{\rho}{4}\sqrt{\frac{\pi}{A}}+\frac{\rho}{L_T} \qquad (2)$$

L_T *is* the total buried length of conductors in m

3. As per Nahman and Skuletich [8] the substation ground resistance can be obtained by the formula:

$$R_g=\rho\left(\frac{0.53}{\sqrt{A}}+\frac{1.75}{L\ n^{1/3}}\right)\left(1-0.8\ \frac{100\ h\ d}{n\sqrt{A}}\right)^{1/4} \qquad (3)$$

Where,

n = the number of parallel conductors in one direction of the grid

n = n' +1

n' = the number of meshes in one direction

4.The formula given by Schwartz [9] for calculating substation grounding grid resistance is:

$$R_g=\frac{\rho}{\pi L}\left[In\left(\frac{2L}{h'}\right)+K_1\left(\frac{L}{\sqrt{A}}\right)-K_2\right] \qquad (4)$$

Where,

$h'=\sqrt{d_0 h}$ for conductor buried at depth h

h'= 0.5 for conductor buried at depth zero

K_1 = -0.04W +1.41 for h=0

K_1 = -0.05W +1.2 for $h=\frac{1}{10}\sqrt{A}$

K_1 = -0.05W +1.13 for $h=\frac{1}{6}\sqrt{A}$

W= Length / Width of the grid

K_2 = 0.15W +5.50 for h=0

K_2 = 0.10W +4.68 for $h=\frac{1}{10}\sqrt{A}$

K_1 = -0.05W +4.40 for $h=\frac{1}{6}\sqrt{A}$

5.The formula given by Sverak [10,11] for calculating substation grounding grid resistance is:

$$R_g=\rho\left[\frac{1}{L_T}+\frac{1}{\sqrt{20A}}\left(1+\frac{1}{1+h\sqrt{20/A}}\right)\right] \qquad (5)$$

where

h is the depth of the grid in m

L_T is the total buried length of conductors in m

The second term recognizes the fact that the resistance of any actual grounding system that consists of a number of conductors is higher than that of a solid metallic plate. The difference will decrease with the increasing length of buried conductors and will approach 0 for infinite L_T, when the condition of a solid plate is reached.

6. EPRI Computerized analysis results [12].This method was developed by the Georgia Institute of Technology. The results of these computerized analysis was presented in the following form.

$$R_g = K_g R_{80} \qquad (6)$$

Where

R_{80} resistance predicted by IEEE Std 80

K_g the grid resistance correction factor [12]

7.The formula given by Chow and Salama [13] for calculating substation grounding grid resistance is:

$$R_g=\rho\left[\frac{1}{4}\sqrt{\frac{\pi}{4}+\frac{1}{N\Delta l}\left(\frac{1}{\sqrt{2\pi}}In\frac{0.165\Delta l}{d_0}\right)}\right](1-\frac{2h}{\sqrt{A}}x1.128) \qquad (7)$$

Equation (7) gives the earth resistance due to a grid made of N meshes, each mesh has dimensions of $\Delta l\ x\ \Delta l$ and conductor

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diameter d_0. The grid is buried at a depth h in a homogeneous soil with resistivity ρ. The overall area of the grid is A.

5. PARAMETERS AFFECTING THE CALCULATION OF SUBSTATION GROUNDING GRID RESISTANCE

It is observed from all seven formulas as shown in equations (1- 7) that the variables are as follows:
ρ = the resistivity of the soil in ohm.m
A= the area of the grid in square meter
L= the total length of the buried conductors in meter
h = the depth of the buried grid in meter
n = the number of parallel conductors in one direction of the grid
n' = the number of meshes in one direction
N = the number of meshes in the grid
d_o = the diameter of the grid conductor
$\Delta l = the$ length of one side of a square mesh in the grid

The grid resistance and the voltage gradients within a substation are directly dependent on the soil resistivity. Because in reality soil resistivity will vary horizontally as well as vertically, sufficient data must be gathered for a substation yard. The Wenner method is widely used for measuring soil resistivity. A decrease in total grid resistance will decrease the maximum GPR
and, hence, the maximum transferred voltage. The most effective way to decrease ground grid resistance is by increasing the area occupied by the grid. Deep driven rods or wells may be used if the available area is limited and the rods penetrate lower resistivity layers. A decrease in substation resistance may or may not decrease appreciably the local gradients, depending on the method used [7].

In Fig.1 grounding grid resistance versus grid depth and in Fig.2 grounding grid resistance versus conductor length has been shown. In Fig. 3 grounding grid resistance versus number of meshes and in Fig.4 grounding grid resistance versus wire diameter has been shown. From these four figures it is clear that grounding grid resistance is affected by grid depth, conductor length, number of meshes and wire diameter. In all the four figures curve 1 for Dwight formula (HD), curve 2 for Laurent and Niemann formula (L&N), curve 3 for Nahman and Skuletich formula (N & S) , curve 4 for Schwartz formula *(SS)*, curve 5 for Sverak formula (JS), curve 6 for EPRI method (EPRI), curve 7 for Chow and Salama formula(PM).

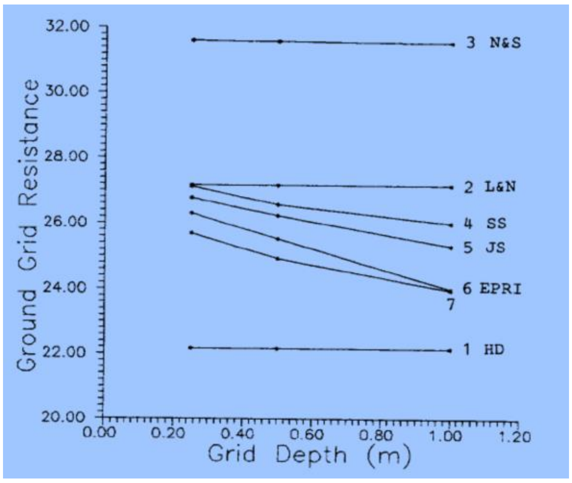

Fig. 1 Grounding grid resistance versus grid depth

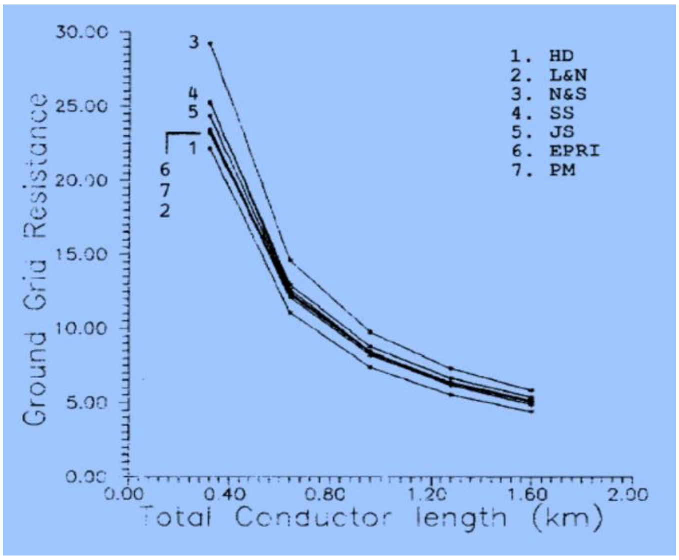

Fig. 2 Grounding grid resistance versus conductor length

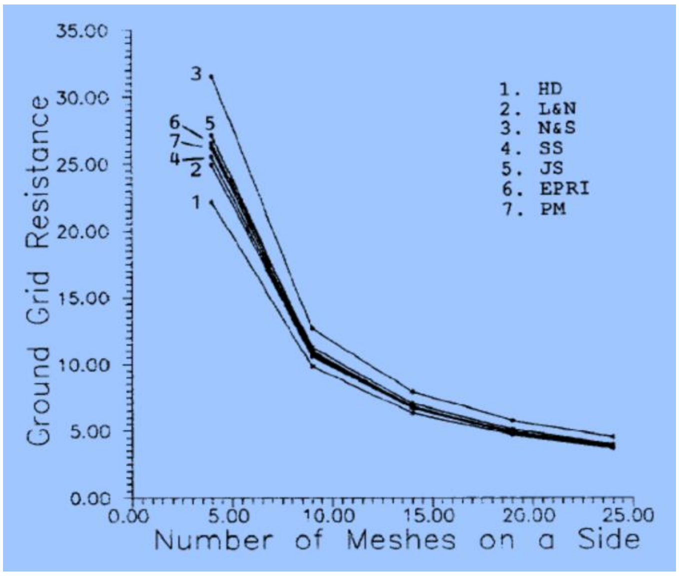

Fig. 3 Grounding grid resistance versus number of meshes

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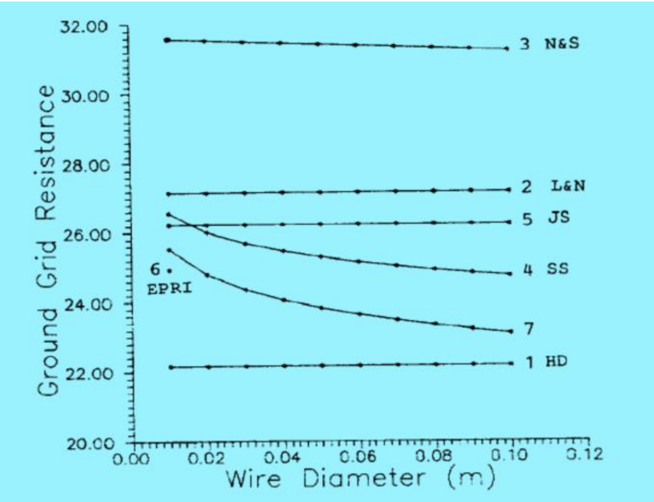

Fig. 4 Grounding grid resistance versus wire diameter

6. CONCLUSION

The various parameters like grid area, soil resistivity, conductor length, depth of the buried grid, number of meshes and diameter of the grid conductor play an extremely vital role in the calculation of substation grounding grid resistance. Therefore, these parameters should be observed and measured carefully, so that substation grounding grid resistance can be calculated accurately. The substation grounding grid resistance affects the ground potential rise.

REFERENCES

[1] F. Dawalibi, and D. Mukhedkar, “Parametric Analysis of Grounding Grid”, IEEE Transactions on Power Apparatus and Systems, Vol.PAS-98, No.5 Sept/Oct 1979, pp.1659-1668.
[2] F. Dawalibi, and J. Ma, “Behaviour of Grounding Systems in Multilayer Soils: A Parametric Analysis”, IEEE Transactions on Power Delivery, Vol. 9, No. 1, 1994, pp. 334-342.
[3] E. B. Joy, and R. E. Wilson, “Accuracy Study of the Ground Grid Analysis Algorithm”, IEEE Transactions on Power Delivery, Vol. 1, No. 3, 1986, pp. 97-103.
[4] J. Lazara, and N. Barbeito, “Simplified Two Layer Model Substation Ground Grid Design Methodology“, IEEE Transactions on Power Delivery, Vol. 5, No. 4, 1990, pp.1741-1750.
[5] B. Thapar, V. Ferez, and A. Balakrishnan, D. A. Blank, “Evaluation of Ground Resistance of a Grounding Grid of any Shape”, IEEE Transactions on Power Delivery, Vol. 6, No. 2, 1991, pp 640-645.
[6] H.B. Dwight, "Calculations of Resistances to Ground", AIEE Transactions, December 1936, pp.1319-1328.
[7] IEEE Std. 80-2000, IEEE Guide for Safety in A.C Substation Grounding, Institute of Electrical and Electronic Engineers, New York, 2000.
[8] J. Nohman, and S. Skuletich, “Irregularity Correction Factors for Mesh and Step Voltages of Grounding Grids” , IEEE Transactions on Power Apparatus and Systems, vol. PAS-99, No.1, 1980, pp. 174-180.
[9] S. J. Schwartz, “Analytical Expression for Resistance of Grounding Systems” , AIEE Transactions, vol. 73, Part 111-B, 1954, pp. 1011-1016.
[10] J. G. Sverak, “Optimized Grounding Grid Design Using Variable Spacing Technique” , IEEE Transactions on Power Apparatus and Systems, vol. PAS-95, 1976, pp. 362 – 374.
[11] J.G. Sverak, “Simplified Analysis of Electrical Gradients Above a Ground Grid: Part I – How Good is the Present IEEE Method?” , IEEE Transactions on Power Apparatus and Systems, Vol. PAS-103, 1984, pp. 7-25.
[12] EPRI report, “Analysis Techniques of Power Substation Grounding Systems; volume 1**:** Design Methodology and Tests” , EPRI EL-2682, October 1982.
[13] Y.L.Chow, and M.M.A.Salama, “A Simplified Method for Calculating the Substation Grounding Grid Resistance” , IEEE Transactions on Power Delivery, Vol. 9, No. 2, April1994, pp. 736-742.
[14] F. P. Dawalibi, and D. Mukhedkar, “Optimum Design of Substation Grounding in Two - Layer Earth Structure Part I, Analytical Study”, IEEE Trans. PAS, Vol.94, No.2, March / April 1975, pp. 252-261.
[15] J. Ma, F. P. Dawalibi, and W.K. Daily, “Analysis of Grounding Systems in Soils With Hemispherical Layering”, IEEE Trans. PWRD, vol.8, No.4, October 1993, pp. 1773- 1781.

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