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Technique for Grounding System Design in Distribution Substation

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***Abstract*—**This paper presents the significant factor and give some suggestion that should know before design. The main objective of this paper is guide the first step for someone who attends to design of grounding system before study in details later. The overview of grounding system can protect damage from fault such as can save a human life and power system equipment. The unsafe conditions have three cases. Case 1) maximum touch voltage exceeds the safety criteria. In this case, the conductor compression ratio of the ground gird should be first adjusted to have optimal spacing of ground grid conductors. If it still over limit, earth resistivity should be consider afterward. Case 2) maximum step voltage exceeds the safety criteria. In this case, increasing the number of ground grid conductors around the boundary can solve this problem. Case 3) both of maximum touch and step voltage exceed the safety criteria. In this case, follow the solutions explained in case 1 and case 2. Another suggestion, vary depth of ground grid until maximum step and touch voltage do not exceed the safety criteria.

***Keywords*—**Grounding System, Touch Voltage, Step Voltage, Safety Criteria.

I. INTRODUCTION

GROUNDING systems for substation is the important countermeasure to maintain the safe and reliable operation of power system and ensure the safety of power apparatus and operators. But have many details for design, so this paper will consider with only significant factor that included the earth resistivity, safety criteria, ground potential rise (GPR), design procedure, calculating equation and have suggestion for design. The safety design is complete when the GPR is less than touch voltage criteria. If it is not less than the criteria, so mesh and step voltage are need to calculate for compare with the safety criteria later. If mesh voltage and step voltage are less than the safety criteria, then the safety design is totally complete. But if it not at least one condition, the modify design is necessary for get the acceptable condition such as decrease total grid resistance by deep driven rods, closer spacing of grid conductor, decrease fault clearing time, etc. and the calculation and comparison processes are repeated [1-2].

II. SIGNIFICANT FACTOR

A. Earth Resistivity

Table I shows typical ranges of resistivity for various soils and should be used only for comparison purpose. Although have many several method for measuring but the mostly accurate and used is four point method or Wenner arrangement. Wenner arrangement is shown In Fig.1. Four electrodes are buried in equally space at point C1, C2, P1, and P2.

TABLE I
RANGE OF EARTH RESISTIVITY

Type of Earth	Average Resistivity $(\Omega{\cdot}m)$
Wet Organic Soil	10
Moist Soil	100
Dry Soil	1000
Bed Rock	10000

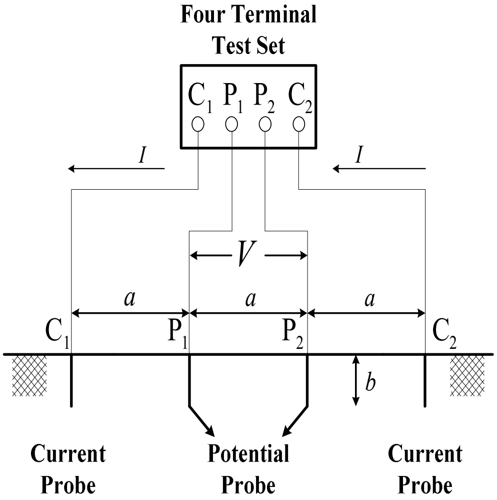

Fig. 1 Wenner arrangement

The resistance R in ohm determine by V/I. Where I is current pass between two outer electrodes and V is voltage between two inner electrodes [2-5].

B. Ground Potential Rise (GPR)

The GPR is equal to the product of the station ground grid impedance and that portion of the total fault current that flows through it [6].

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C. Safety Criteria

The safety of a person depends on preventing the critical amount of shock energy. The safety criteria are very important value. It should be first thing for calculate to specific a safety level, then the maximum touch and step voltage are calculated to compare with the safety criteria to define it is safe or unsafe [2-4].

D. Maximum Touch and Step Voltage

Step voltage is defined as the voltage different between distant of 1 m with the feet without contacting [2].

Touch voltage is defined as the voltage different between ground potential rise and the surface potential at the point where a person is standing while at the same time having a hand in contact with a grounded structure [4] [7].

Step voltage and touch voltage are used to determine if a grounding system is safe for people and equipment. Both of them should not exceed the limit for safety [4].

III. CALCULATING PROCEDURE [2],[8-10]

A. Earth Resistivity

The resistivity ρ in the terms of the length units in which a and b are measured is

$$\rho_a = \frac{4\pi aR}{1+\frac{2a}{\sqrt{a^2+4b^2}}-\frac{a}{\sqrt{a^2+b^2}}} \tag{1}$$

where ρ_a = apparent resistivity of the soil $(\Omega\cdot\text{m})$
R = resistance (Ω)
b = depth of the electrodes (m)
a = distance between two adjacent electrodes (m)

If b is small compared to a. Equation (1) can be reduced to equation (2).

$$\rho_a = 2\pi aR \tag{2}$$

Two-layer soil model is shown in Fig. 2 resistivity determination using the Wenner method. In this method the resistivity can calculate by equation (3).

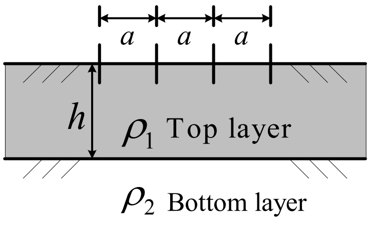

Fig. 2 Two-layer soil

$$\rho_a = \rho_1\left(1+4\sum_{i=1}^{\infty}\frac{K^n}{\sqrt{1+\left(2n\frac{h}{a}\right)^2}}-\frac{K^n}{\sqrt{4+\left(2n\frac{h}{a}\right)^2}}\right) \tag{3}$$

$$K = \frac{\rho_2-\rho_1}{\rho_2+\rho_1} \tag{4}$$

where ρ_1 = top layer resistivity $(\Omega\cdot\text{m})$
ρ_2 = bottom layer resistivity $(\Omega\cdot\text{m})$
h = top layer height (m)
K = reflection coefficient

B. Ground Potential Rise

Ground Potential Rise is determine from equation (5)

$$GPR = I_G \cdot R_g \tag{5}$$

where I_G = maximum rms current flowing between ground grid and earth (A)
R_g = resistance of grounding system (Ω)

C. Safety Criteria

Step Voltage Criteria is

$$E_{\text{step}} = \left(1000+6C_S\cdot\rho_S\right)\frac{k}{\sqrt{t_S}} \tag{6}$$

Similarly touch voltage criteria is

$$E_{\text{touch}} = \left(1000+1.5C_S\cdot\rho_S\right)\frac{k}{\sqrt{t_S}} \tag{7}$$

$$C_S = 1-\frac{0.09\left(1-\frac{\rho}{\rho_S}\right)}{2h_S+0.09} \tag{8}$$

where E_{step} = step voltage (V)
E_{touch} = touch voltage (V)
C_S = surface layer derating factor
ρ_S = surface material resistivity $(\Omega\cdot\text{m})$
k = 0.116 for 50 kg body weight
0.157 for 70 kg body weight
t_S = duration of shock current (s)
h_S = the thickness of the surface material (m)
E_{step} = step voltage (V)
E_{touch} = touch voltage (V)
C_S = surface layer derating factor

If no protective surface layer is used, then

$$C_S = 1$$

$$\rho_S = \rho$$

D. Maximum Touch and Step Voltage

The Maximum touch voltage within a mesh of a ground grid is calculated by

$$E_m = \frac{\rho_a \cdot K_m \cdot K_i \cdot I_G}{L_M} \tag{9}$$

where E_m = Mesh voltage (V)

ρ_a = apparent resistivity of the soil $(\Omega\text{·m})$

K_m = Mesh factor defined for n parallel conductors

K_i = Corrective factor for current irregularity

L_M = Effective length for mesh voltage (m)

The step voltage is determine from

$$E_S = \frac{\rho_a \cdot K_S \cdot K_i \cdot I_G}{L_S} \tag{10}$$

where E_S = step voltage (V)

K_S = Step factor defined for *n* parallel conductors

L_S = Effective length for step voltage (m)

IV. DESIGN PROCEDURE

Step for design. The detail in each step can find in the reference shown in Figure 3 [2].

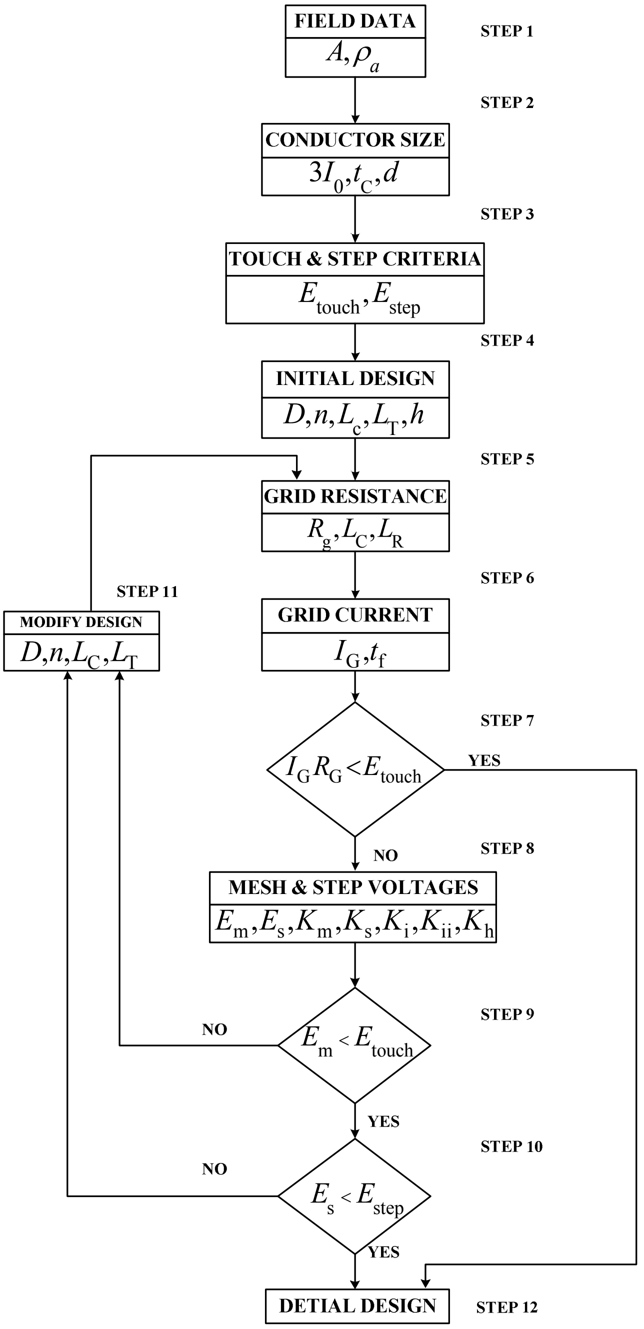

Fig. 3 Step for Design Procedure

V. SUGGESTION

A) Sometimes the problems either step 9 or step 10 in fig 3 is happened or both. The modify design is necessary for solve this problem. Have many solutions for solve it such as reduce ground resistance, add multiple electrodes in parallel. The resistance can be reduced further by using chemical electrodes. The preferred chemical electrode consists of the rod placed in concrete [11].

B) In the other way earth resistivity, GPR, safety criteria, maximum mesh and step voltage can achieve by computer program for convenience, such as

Current Distributed Electromagnetic Interference Grounding and Soil Structure (CDEGS) program.

C) Grounding system with unequal spacing conductor is better than equal spacing conductor [12].

D) Number of ground rod does not have an effect with mesh voltages [13].

E) In raining season, touch voltage probably higher than the limit value, so the influence of raining season should be considered [14].

F) The unsafe conditions have three cases. Case 1) maximum touch voltage exceeds the safety criteria. In this case, the conductor compression ratio of the ground gird should be first adjusted to have optimal spacing of ground grid conductors. If it still over limit, earth resistivity should be consider afterward. Case 2) maximum step voltage exceeds the safety criteria. In this case, increasing the number of ground grid conductors around the boundary can solve this problem. Case 3) both of maximum touch and step voltage exceed the safety criteria. In this case, follow the solutions explained in case 1 and case 2. Another suggestion, vary depth of ground grid until maximum step and touch voltage do not exceed the safety criteria.

VI. CONCLUSION

All of factor above are elementary things that should know before design of grounding system in substation that mean a safe design has been obtained. On the other hand, if design without a knowledge of significant factor for grounding system. The disaster will happen when a fault occurs in the substation. It can harm the personnel who work in the substation or nearby by step voltage or touch voltage and the GPR will increase to high can damage intelligent electronic devices and electronic controller.

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