

Optimal Analysis of Grounding System Design for Distribution Substation

T. Lantharthong, N. Rugthaicharoencheep, A. Phayomhom

Abstract—This paper presents the electrical effect of two neighboring distribution substation during the construction phase. The size of auxiliary grounding grid have an effect on entire grounding system. The bigger the size of auxiliary grounding grid, the lower the GPR and maximum touch voltage, with the exception that when the two grids are unconnected, i.e. the bigger the size of auxiliary grounding grid, the higher the maximum step voltage. The results in this paper could be served as design guideline of grounding system, and perhaps remedy of some troublesome grounding grids in power distribution's system. Modeling and simulation is carried out on the Current Distribution Electromagnetic interference Grounding and Soil structure (CDEGS) program. The simulation results exhibit the design and analysis of power system grounding and perhaps could be set as a standard in grounding system design and modification in distribution substations.

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

I. INTRODUCTION

THIS paper focuses on grounding grid performance during construction phase of new permanent distribution substation in order to renovate existing one, while the other substation has not yet been removed. During the time of two ground grids left disconnected, the effect of 'auxiliary grounding system' (de-energized electrical power site's) to the main station which remains energized cannot be ignored. Because it will help create high ground potential rise (GPR), especially, the boundary waveform is very steep between the ground grids. For safety purpose, ground grid design for the safety of personal working around the vicinity of substation construction site should be ensured. Safety step and touch voltage are analyzed with reference to safety criteria based on body weight defined in IEEE Std. 80-2000 systems [1], [2].

II. SIGNIFICANT FACTOR

A. Earth Resistivity

Typical ranges of resistivity for various soils and should be used only for comparison purpose as show in Table I.

Although have several method for measuring but the mostly

Thong Langtharthong is with the Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Phra Nakhon, Bangkok, Thailand (e-mail: thong.l@rmutp.ac.th).

Nattachote Rugthaicharoencheep is with the Department of Electrical Engineering, Faculty of Engineering, Rajamangala University of Technology Phra Nakhon, Bangkok, 10800, Thailand (phone: 662 913-2424 ext. 150; fax: 662 913-2424 ext. 151; e-mail: nattachote.r@rmutp.ac.th).

Att Phayomhom is with the Power System Planning Department, Metropolitan Electricity Authority (MEA), Bangkok, 1192, Thailand (phone: 662 348-5561; fax: 662 348-5133; e-mail: attp@mea.or.th).

accurate and used is four point method or Wenner arrangement. Wenner arrangement is as 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

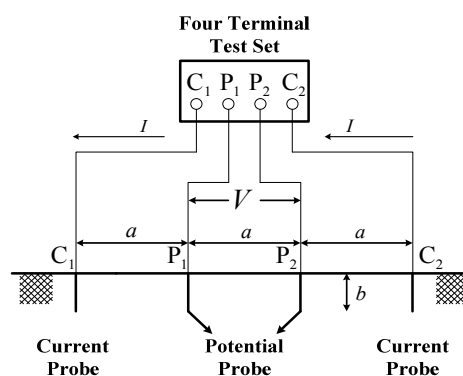


Fig. 1 Wenner arrangement

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].

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 safety of the design. If it was secured both of voltage should not exceed the limit [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

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

where ρ_a is apparent resistivity of the soil (Ωm)
 R is resistance (Ω)
 b is depth of the electrodes (m)
 a is distance between two adjacent electrodes (m)

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

$$\rho_a = 2\pi aR \quad (2)$$

Two-layer soil model is shown in Fig. 2. The soil resistivity can be computed by using Wenner method. The formulas are shown in (3) and (4).

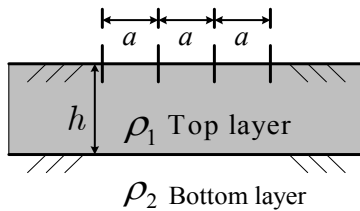


Fig. 2 Two-layer soil

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

$$K = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \quad (4)$$

where ρ_1 is top layer resistivity (Ωm)
 ρ_2 is bottom layer resistivity (Ωm)
 h is top layer height (m)
 K is reflection coefficient

B. Ground Potential Rise

Ground potential rise is determined from (5)

$$GPR = I_G \cdot R_g \quad (5)$$

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

C. Safety Criteria

Step voltage criteria is determined from (6)

$$E_{\text{step}} = (1000 + 6C_s \cdot \rho_s) \frac{k}{\sqrt{t_s}} \quad (6)$$

Similarly touch voltage criteria can be obtained from (7) and (8)

$$E_{\text{touch}} = (1000 + 1.5C_s \cdot \rho_s) \frac{k}{\sqrt{t_s}} \quad (7)$$

$$C_s = 1 - \frac{0.09 \left(1 - \frac{\rho}{\rho_s} \right)}{2h_s + 0.09} \quad (8)$$

where E_{step} is step voltage (V)
 E_{touch} is touch voltage (V)
 C_s is surface layer derating factor
 ρ_s is surface material resistivity (Ωm)
 k is 0.116 for 50 kg body weight
 0.157 for 70 kg body weight
 t_s is duration of shock current (s)
 h_s is the thickness of the surface material (m)
 E_{step} is step voltage (V)
 E_{touch} is touch voltage (V)
 C_s is 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 (9).

$$E_m = \frac{\rho_a \cdot K_m \cdot K_i \cdot I_G}{L_M} \quad (9)$$

where E_m is mesh voltage (v)
 ρ_a is apparent resistivity of the soil (Ωm)
 K_m is mesh factor defined for n parallel conductors

K_i is corrective factor for current irregularity

L_M is effective length for mesh voltage (m)

Step for design shown in Fig. 3. [2].

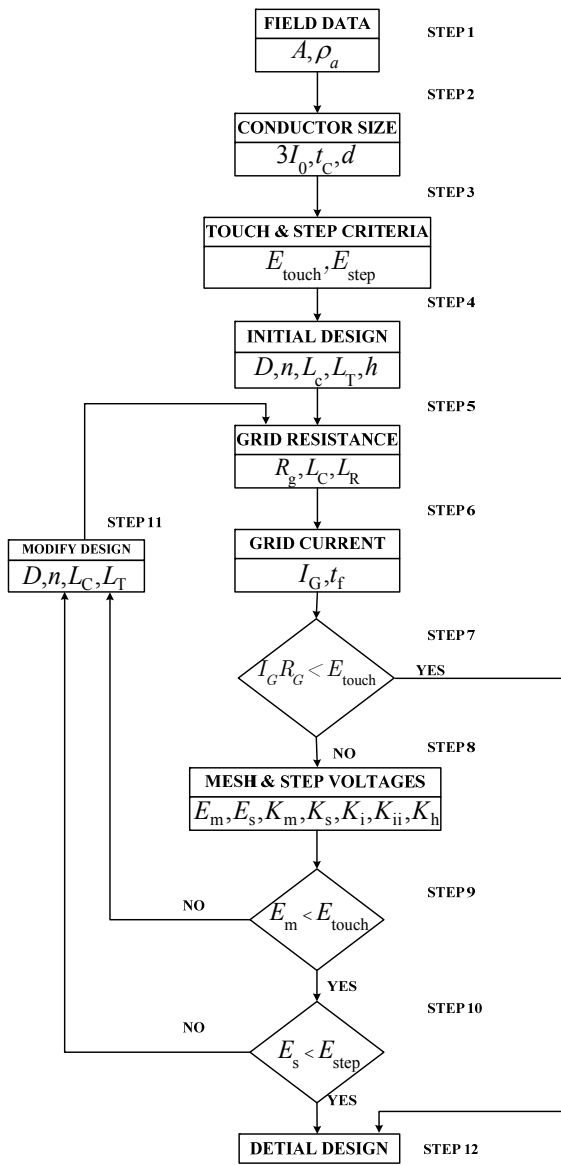


Fig. 3 Step for design procedure

The step voltage is determine from (10)

$$E_s = \frac{\rho_a \cdot K_s \cdot K_i \cdot I_G}{L_s} \quad (10)$$

where E_s is step voltage (v)

K_s is step factor defined for n parallel conductors

c is effective length for step voltage (m)

IV. CASE STUDY

Sizing of small (S) medium (M) and large (L) are 15x15 m²,

30x30 m² and 45x45 m² respectively shown in Fig. 4. There are three cases those are grid M-L M-M, and M-S, all of 3 cases have distance between grid (d) 5 m. Grid on the left is exist distribution substation, grid on the right is auxiliary distribution substation. Details of constraints that use for simulation are shown in Table II.

The results are carried out by CDEGS as shown in Table III and Fig. 5–10.

TABLE II
 DETAILS OF CONSTRAINTS USING FOR SIMULATION

Earth Resistivity	10 (Ωm)
Depth of Grid	0.5 m
Size of Conductor	95 mm ²
Compression Ratio	1
Fault Current	25 kA
Rod Height and Diameter	3 m and 5/8 inches

TABLE III
 RESULTS FROM CASE STUDY

Type	GPR (V)		Touch (V)	Step (V)
	Main	Aux		
M-L	3,154.1	1,058.0	2,014	427
M-M	3,225.5	1,292.5	2,076	406
M-S	3,311.4	1,556.7	2,526	383

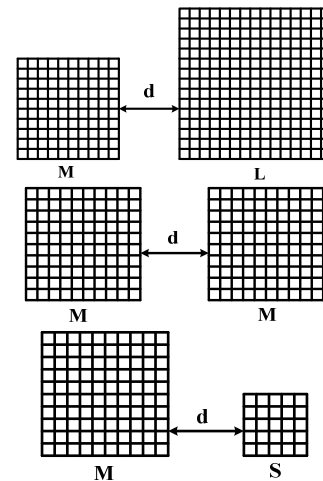


Fig. 4 Two neighbouring distribution substation is unconnected

The ground grid constant is medium (M) 30x30 m² and then vary the size of the ground grid by a side that does not dispatch power is called auxiliary grounding system. It is found that when the size of the auxiliary grounding system is large, Therefore GPR of the main ground grid and auxiliary grounding system of minimal size.

Type M-L is the maximum touch voltage minimum, is equal to 2,014 V, and if the auxiliary grounding system size is medium (M) and small (S) is the value of the maximum touch voltage is equal to 2,076. V and 2,526 v, respectively, but for the value of the maximum step voltage is reversed. Type M-S is the lowest value of the maximum step voltage is 383 V.

2-D touch voltage magnitude of grid type M-L, M-M and M-S are shown in Figs. 5, 7 and 9. The results show that colors orange and red of type M-S is area of voltage more than other type. 2-D step voltage magnitude is shown in Figs. 6, 8 and 10. The results show that the maximum step voltage which included by orange and red are on the edge of main ground grid.

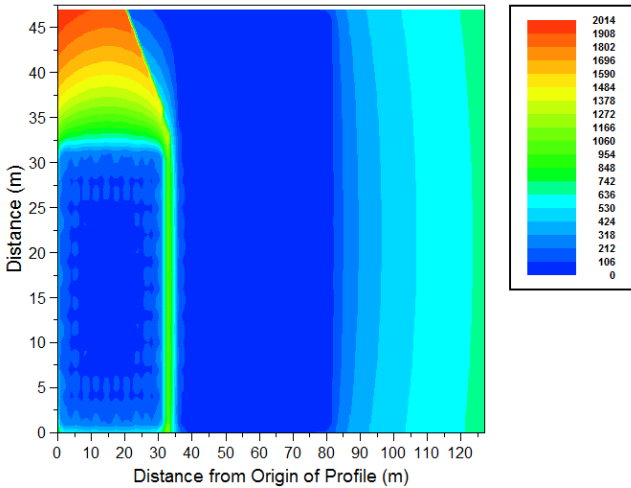


Fig. 5 2-D touch voltage magnitude for type M-L

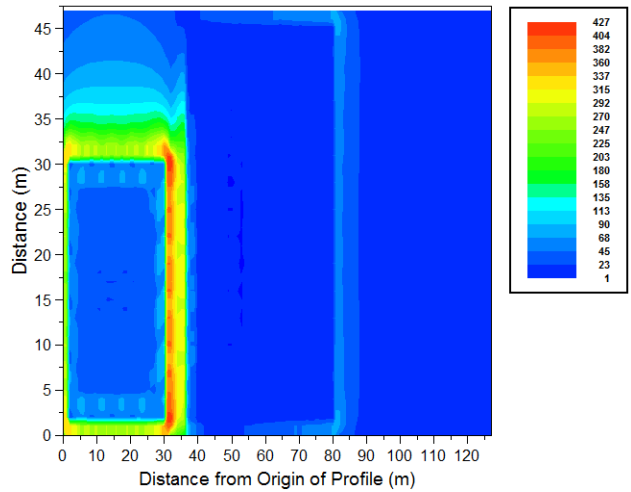


Fig. 6 2-D step magnitude for type M-L

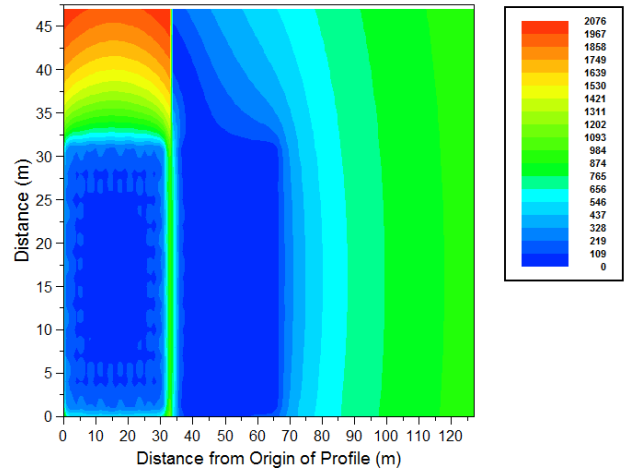


Fig.7 2-D touch voltage magnitude for type M-M

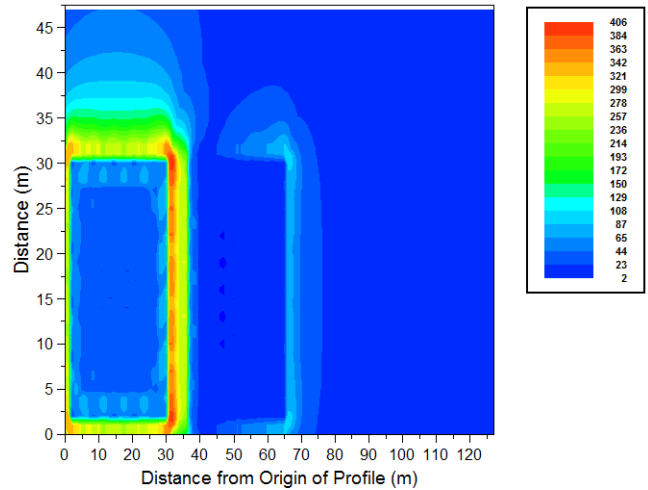


Fig. 8 2-D step magnitude for type M-M

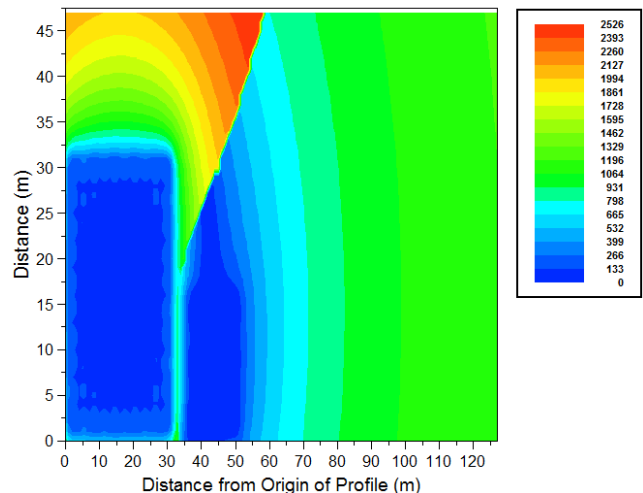


Fig. 9 2-D touch voltage magnitude for type M-S

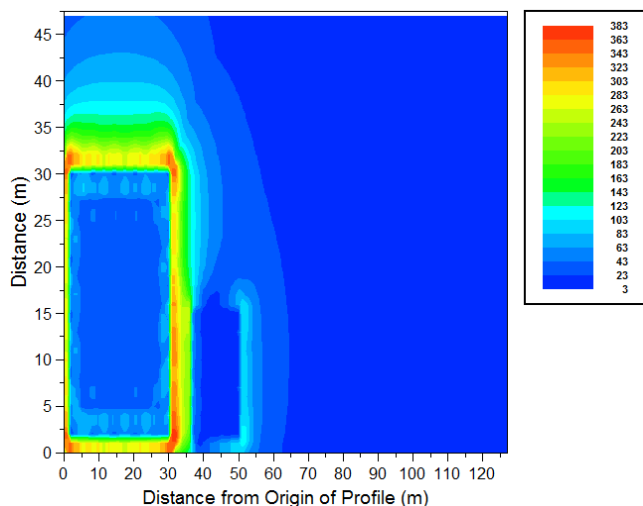


Fig. 10 2-D step magnitude for type M-S

V. CONCLUSION

The simulation results exhibit the design and analysis of power system grounding and perhaps could be set as a standard in grounding system design and modification in distribution substations. The results show that sizing of the auxiliary distribution substation grid is inversely proportional to GPR and touch voltage. As shown in Table III, when the size of the grid increases from M-S to M-L, GPR decreases by 5% and touch voltage decreases by 20%. On the contrary, the step voltage is proportional to the size of the grid. This is because in this case the compression ratio is 1. Increasing the grid size makes the conductors lines more parallel than the smaller size. The smaller the resistance value, the better the current flows into the ground.

ACKNOWLEDGMENT

The authors would like to express his gratitude to Rajamangala University of Technology Phra Nakhon, Thailand for support and Mr. Boonserm Ainsuk for his technical support.

REFERENCES

- [1] A. Phayomhom, and et.al., "Safety analysis for grounding potential rise of two neighbouring substations: case study of metropolitan electricity Authority's System. In *Proc. 44th International Council on Large Electric Systems (CIGRE)*, Paris, France, August 2012.
- [2] IEEE Std 80-2000, "IEEE guide for safety in AC substation grounding," 2000.
- [3] ANSI/IEEE Std 81-1983, "IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System," 1983.
- [4] A. Phayomhom, and et.al., "Safety design planning of ground grid for outdoor substation in MEA's power distribution system," in *Proc. Electrical Engineering/Electronics Computer Telecom. and Information Technology International Conf.*, pp. 298-302, 2010.
- [5] P. A. Zotos, "Ground grid design in large industrial plants," *IEEE Trans. Industry Applications*, vol. 24, no. 3, pp.521-525, May/June, 1988.
- [6] IEEE Std 367-1996, "IEEE recommended practice for determining the electric power station ground potential rise and induced voltage from a power fault," 1996.

- [7] M. Mitolo, P. E. Sutherland and R. Natarajan, "Effects of High Fault Currents on Ground Grid Design," *IEEE Trans. Industry Applications*, vol. 46, no. 3, May/June, 2010
- [8] A. Puttarach, et.al., "Substation grounding grid Analysis with the Variation of Soil layer depth Method," in *Proc. IEEE Conf. Lausanne, Power Tech*, pp. 1881-1886, 2007.
- [9] H. M. Khodr, et. al., "Design of grounding systems in substations using a mixed-integerlinear programming formulation," *Electric Power Systems Research*, vol. 79, pp. 126-133, 2007.
- [10] J. He, and et.al., "Seasonal influences on safety of substation grounding system," *IEEE Trans. on Power Delivery*, vol. 18, no. 3, July 2003.

Thong Lantharhong received his M.Eng in Electrical Engineering from Rajamangala University of Technology Thanyaburi, Pathumthani, Thailand in 2010. He is currently an assistant professor at the Department of Electrical Engineering, Faculty of Engineering Rajamangala University of Technology Phra Nakhon (RMUTP), Bangkok, Thailand. His research interests include power system operation, optimization technique, and distributed generation.

Nattachote Rugthaicharoencheep (M'10) received his Ph.D. in Electrical Engineering from King Mongkut's University of Technology North Bangkok (KMUTNB), Thailand in 2010. He is currently a assistant professor at the Department of Electrical Engineering, Faculty of Engineering Rajamangala University of Technology Phra Nakhon (RMUTP), Bangkok, Thailand. His research interests include power system operation, optimization technique, and distributed generation.

Att Phayomhom (M'14) received his Ph.D. degree in the Electrical Engineering Department from the King Mongkut's University of Technology North Bangkok (KMUTNB), Thailand in 2010. He has worked for Power System Planning Department of Metropolitan Electricity Authority (MEA) Thailand since 1996. He is responsible for power system planning. His main research interests are power system planning, safety design of ground grid in substation and lightning performance.