The Effect of Inter-Distance of the Main and the Auxiliary Grounding System in MEA's Power Distribution Substation

A. Phayomhom, K. Kveeyarn, W. Kulwongwit and J. Thamjaroen

Abstract— *This paper presents the electrical effect of two neighbouring distribution substation during the construction phase. The study performed in the paper can be divided in 3 parts. 1) The effect of unconnected grids versus their inter-distances and soil resistivity: the greater their inter-distance, the higher their ground potential rise (GPR) and maximum touch voltage, but the lower their maximum step voltage will be. 2) The effect of connected grids versus their different inter-distance and soil resistivity: All the three voltages are trend to decrease when the grids are connected, with the exception that when the grids' inter-distance is short and the grid conductor buried in the two-layered soil that the upper soil layer resistivity is lower and the size of auxiliary grounding system (auxiliary ground grid) is equal or smaller than the main ground grid, their maximum touch voltages will not come down but go up instead. 3) The effect of the size of grid of auxiliary grounding system: the bigger the size of auxiliary grounding grid, the lower the GPR and maximum touch and step 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 MEA's power system.*

Keywords— **Ground grid, Ground potential rise, Step voltage, Touch voltage, Two neighbouring substations.**

1. INTRODUCTION

Metropolitan Electricity Authority (MEA) is an electric utility that is responsible for power distribution covering an area of 3,192 square kilometers in Bangkok, Nonthaburi, and Samutprakarn provinces of Thailand. MEA serves approximately 32.10 % of the whole country power demand in 2012. MEA's networks consist of transmission, sub-transmission and distribution systems. The transmission line voltage is 230 kV, while the 69 and 115kV used in sub-transmission systems and 12 and 24 kV in the distribution feeders.

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.

To achieve this, modeling and simulation are carried out on the Current Distribution Electromagnetic interference Grounding and Soil structure (CDEGS) software package. Safety step and touch voltage are analyzed with reference to safety criteria based on body weight defined in IEEE Std. 80-2000.

2. EFFECTS OF NEARBY AUXILIARY GROUNDING SYSTEM OF SUBSTATION

Many a time, a new distribution substation is under construction while the existing substation is still in operation and has not yet been removed. There are two grounding systems in close distance, and are left disconnected. The ground grid of the substation that is still energized is called main ground grid (energized electrical power site) whereas that of the under construction substation (temporary or permanent distribution substation) is called auxiliary grounding system (auxiliary ground grid). During the time of disconnecting of these ground grids, the under construction distribution substation is de-energized, the substation surrounding area then exposes to the risk of high GPR caused by the main distribution substation which is still in operation. The GPR's steepness is located between the main and auxiliary ground grid.

3. DEFINITION OF TOLERABLE VOLTAGE

According to [1], the following definitions for various voltages considered in this paper are given as follows:

This work was financially supported by Metropolitan Electricity Authority (MEA), Thailand.

A. Phayomhom (corresponding author) is with Power System Planning Department, Metropolitan Electricity Authority (MEA), 1192 Rama IV Rd., Klong Toey, Bangkok, 10110, Thailand. Phone: +66-2-348-5561; Fax: +66-2-348-5133; E-mail: att_powermea@hotmail.com, attp@mea.or.th.

K. Kveeyarn is with the Department of Electrical Engineering, Faculty of Engineering, Kasetsart University, 50 Ngam Wong Wan Rd., Ladyao, Chatuchak, Bangkok, 10900, Thailand. Phone: +66-2-797-0999 ext.1516; E-mail: fengkyk@ku.ac.th.

W. Kulwongwit is The Engineering Institute of Thailand (EIT) and with Watts Consultant Co., Ltd., 5/1250 Baan Prachachuen Soi 8, Samakee Street, Pakred, Nonthaburi, 11120, Thailand. Phone: +66-2-980-0596-7; Fax: +66-2-503-7071; E-mail: watkul@ksc.th.com.

J. Thamjaroen is with Power System Planning Department, Metropolitan Electricity Authority (MEA), 1192 Rama IV Rd., Klong Toey, Bangkok, 10110, Thailand. Phone: +66-2-348-5559; Fax: +66-2-348-5133; E-mail: jatupornt@mea.or.th.

Ground Potential Rise (GPR)

Ground Potential Rise (GPR) is the maximum electrical potential relative to a distant grounding point assumed to be at the remote earth that a substation grounding grid can withstand. This GPR is equal to the maximum grid current times the grid resistance.

$$GPR = I_G \times R_g \tag{1}$$

where GPR is ground potential rise (V)

I_G is maximum grid current (A)

R_g is resistance of grounding system (Ω)

In the process of designing the ground grid system, safety criteria is firstly calculated to specify a safety level, then the maximum touch and step voltage are calculated to compare with the safety criteria to determine whether it is safe to work on the area of substation. This part will show a calculation of safety criteria, touch and step voltage.

Touch Voltage

Touch voltage is the potential difference between the point where a person is standing and the person's hand in contact with a grounded structure.

The tolerable touch voltage in volts is defined as [1]

$$E_{touch} = I_B \times \left(R_B + 1.5 C_s \rho_s\right) \tag{2}$$

where E_{touch} is tolerable touch voltage for human (A)

R_B is resistance of the human body (Ω)

C_s is surface layer derating factor

ρ_s is surface layer resistivity ($\Omega \cdot$ m)

$$I_B = \frac{k}{\sqrt{t_s}} \tag{3}$$

where I_B is current through the body (A)

k is 0.116 for 50 kg body weight
0.157 for 70 kg body weight

t_s is duration of current expose (s)

The safety of a person depends on how to prevent the critical amount of shock energy from being absorbed by the body, before the fault is cleared and the system de-energised. To ensure safety, the magnitude and duration of the current conducted through a human body should be less than the value that can cause ventricular fibrillation of the heart. Fibrillation current is assumed to be a function of individual body weight. The tolerable body current limits for body weights of 50 kg and 70 kg are listed in IEEE std 80-2000.

Step Voltage

Step voltage is the potential difference between two points of 1 (one) meter apart and on which a person is bridging with his feet without contacting any other grounded object.

The tolerable step voltage in volts is defined as [1]

$$E_{step} = I_B \times \left(R_B + 6 C_s \rho_s\right) \tag{4}$$

where E_{step} is tolerable step voltage for human (V)

Maximum of Mesh and Step Voltage

The maximum touch voltage within a mesh of a ground grid [4] is calculated by

$$E_m = \frac{\rho_a K_m \cdot K_i \cdot I_G}{L_m} \tag{5}$$

where E_m is mesh voltage (V)

ρ_a is apparent resistivity of soil (Ω-m)

K_m is mesh factor defined for n parallel conductors

K_i is corrective factor for current irregularity

I_G is maximum rms current flowing between ground grid and earth (A)

L_m is effective length of $L_C + L_R$ for mesh voltage (m)

For grids with or without ground rods, the effective buried conductor length, L_s, is

$$L_s = 0.75 \cdot L_C + 0.85 \cdot L_R \tag{6}$$

where L_s is effective length of $L_C + L_R$ for step voltage (m)

L_C is total length of grid conductor (m)

L_R is total length of ground rods (m)

The step voltage is determined from

$$E_s = \frac{\rho_a \cdot K_s \cdot K_i \cdot I_G}{L_s} \tag{7}$$

where E_s is step voltage (V)

K_s is mesh factor defined for n parallel conductors

To calculate both maximum touch and step voltage, apparent resistivity factor is required and it can be obtained by applying Wenner arrangement method.

The resistivity of two-layered soil as shown in Figure 1 can be determined by the Wenner method. In this method, the apparent resistivity is calculated using Eqs (7) and (8) [1], [2-4]:

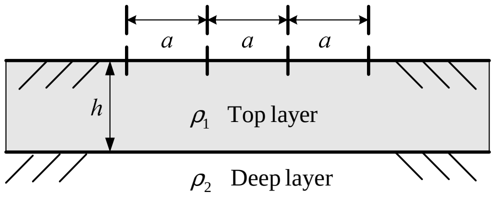


Fig. 1. Two Layered Earth Model.

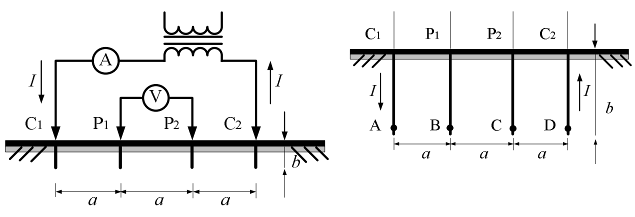
$$\rho_a = \rho_1\left(1+4\sum_{i=1}^{\infty}\frac{K^n}{\sqrt{1+\left(2n\frac{h}{a}\right)^2}}-\frac{K^n}{\sqrt{4+\left(2n\frac{h}{a}\right)^2}}\right) \quad (8)$$

$$K=\frac{\rho_2-\rho_1}{\rho_2+\rho_1} \quad (9)$$

where ρ_a is apparent resistivity of the soil in ($\Omega \cdot$ m)
h is first layer height (m)
K is reflection factor
ρ_1 is first layer resistivity ($\Omega \cdot$ m)
ρ_2 is deep layer resistivity ($\Omega \cdot$ m)

The measurement of apparent soil resistivity within the substation area is applied by the Wenner arrangement method as shown in Eq. (8). After apparent resistivity is obtained, maximum touch and step voltage can be determined accordingly. The Wenner arrangement approach to obtain apparent resistivity is explained as follows:

The four- point method as shown in Figure 2 is one of the most accurate and practical methods in measuring the average resistivity of large volumes of undisturbed earth. In the figure, four electrodes are buried in equally-spaced small holes at points C_1, C_2, P_1 and P_2. The soil resistance *R* in ohm is calculated from the ratio of *V/I*, where *I* is the injected current between the two outer electrodes and *V* is the measured voltage between the two inner electrodes
[1], [3-4].



(a) (b)

(a) Principal diagram of an earth resistivity meter

(b) Current injection into the soil

Fig. 2. Wenner Arrangement.

With this arrangement, the resistivity ρ_a can be expressed in terms of a, b and soil resistance as follows:

$$\rho_a=\frac{4\pi aR}{1+\frac{2a}{\sqrt{a^2+4b^2}}-\frac{a}{\sqrt{a^2+b^2}}} \quad (10)$$

where R is measured resistance (Ω)
a is distance between adjacent electrodes (m)
b is depth of the electrodes (m)

When b is small compared with a, and hence negligible. Eq (10) then becomes

$$\rho_a = 2\pi aR \quad (11)$$

4. CASE STUDY

For all scenarios studied herein, the cross section of the ground grid conductor is 95 mm^2 and 15.875 mm in diameter, ground rod is 3.0 m long. All the ground grid conductors are buried 0.5 m deep in the top layer soil. The ground rods are spread out to cover the grounding area. The auxiliary ground grid has 3 sizes: small (S) 15 m x 15 m; medium (M) 30 m x 30 m; and large (L) 45 m x 45 m, while the main grid has single size: (M) 30 m x 30 m. Table 1 shows all the ground grids configurations.

The value of the soil resistivity is chosen to be 10 $\Omega \cdot$ m in case of uniform soil, 10/100 or 100/10 $\Omega \cdot$ m in case of two layered soil. The reason why these values are chosen because they are the soil resistivity found in MEA service area. However, the 10/100 $\Omega \cdot$ m resistivity is a special case for lower resistivity of top layer soil. The top layer soil normally has more resistivity than the bottom layer's (deep layer) due to number of factors such as soil moisture content, chemical composition, concentration of salts dissolved in the contained water, and grain size [4, 5]. However the 10/100 $\Omega \cdot$ m resistivity soil is rarely found in MEA unless in the flood area. The thickness of the soil is determined to be 2 m. Thus, the short circuit current of 25 kA is specified. The inter-distance between ground grids is chosen to be 25 m and 5 m for all combinations of size both connection and un-connection of main and auxiliary grids as shown in Table 1.

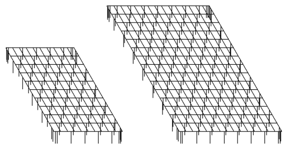
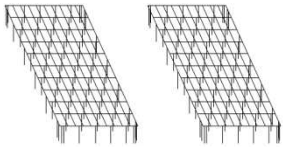
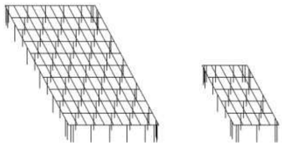
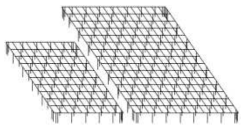
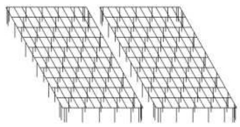
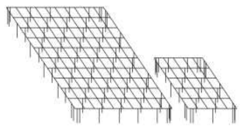
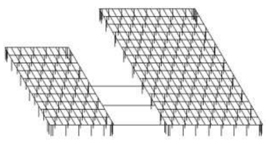
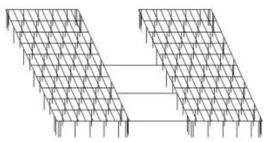
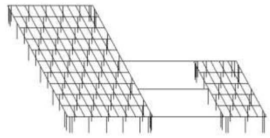
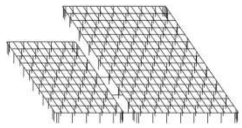
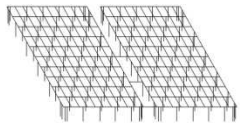
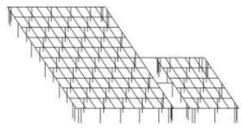
The result of the study will be discussed based on 3 parameters: inter-distance, interconnection and size as detailed in each Part:

Part 1: The effect of unconnected grids versus their different inter-distance: 25m (scenario 1 to 3) and 5 m (scenario 4 to 6), and soil resistivity as shown in Tables 2 and 3 respectively.

Part 2: The effect of connected [6] grids versus for different inter-distance 25m (scenario 7 to 9) and 5 m (scenario 10 to 12), and soil resistivity as are shown in Tables 4 and 5 respectively.

Part 3: The effect of size of grid of auxiliary grounding system as shown in Tables 2 to 5.

Table 1. Two Neighbouring Distribution Substation is Unconnected and Connected Together

Scenario	Configuration			
1	Unconnected 25 m		M	L
2	Unconnected 25 m		M	M
3	Unconnected 25 m		M	S
4	Unconnected 5 m		M	L
5	Unconnected 5 m		M	M
6	Unconnected 5 m		M	S
7	Connected 25 m		M	L
8	Connected 25 m		M	M
9	Connected 25 m		M	S
10	Connected 5 m		M	L
11	Connected 5 m		M	M
12	Connected 5 m		M	S

Sce: Scenario

Table 2. GPR, GPR Ratio, Maximum Touch and Step Voltage of Two Unconnected Grids 25 m Apart

ρ_a $(\Omega \cdot m)$	Sce	GPR (V)		Aux/ Main (%)	Touch (V)	Step (V)
		Main	Aux			
10	1	3,325	663	19.96	2,259	360
	2	3,338	752	22.54	2,342	358
	3	3,348	854	25.51	2,556	357
10/100	1	17,721	6,135	34.62	8,876	1,015
	2	17,936	6,857	38.23	9,416	993
	3	18,136	7,643	42.14	10,974	974
100/10	1	4,466	664	14.86	3,385	682
	2	4,475	753	16.82	3,471	683
	3	4,482	857	19.13	3,687	683

Main: Main ground grid, Aux: Auxiliary ground grid
Sce: Scenario

***Part 1*:** As per Table 2, the different voltages result from ground grid buried in soil of different resistivity show that: In 10 $\Omega \cdot m$ soil resistivity, GPR, maximum touch and step voltage are the lowest compared with 10/100 and 100/10 $\Omega \cdot m$ soil resistivity. This is due to all conductors of the grid are buried in the low soil resistivity that can by far withstand the given short circuit current. The 10/100 $\Omega \cdot m$ soil resistivity is on the contrary, its GPR, maximum touch and step voltage are the highest, because the grid's ground rod penetrating deeper in the high resistivity soil layer. It can be concluded that, regardless the grids' inter-distance, the GPR, maximum touch and step voltage of 10 $\Omega \cdot \mathrm{m}$ soil resistivity case remain the lowest as are evident by Table 2 and 3. When bring the effect of grids' inter-distance into consideration for all unconnected grids as per Tables 2 and 3, it should be noted that, for the same grid configuration by shortening the inter-distance to 5 m, the GPR and maximum touch voltage will decrease but the maximum step voltage increase.

Table 3. GPR, GPR Ratio, Maximum Touch and Step Voltage of Two Unconnected Grids 5 m Apart

ρ_a ($\Omega \cdot \mathrm{m}$)	Sce	GPR (V)		Aux/ Main (%)	Touch (V)	Step (V)
		Main	Aux			
10	4	3,154	1,058	33.54	2,014	427
	5	3,226	1,293	40.07	2,076	406
	6	3,311	1,557	47.01	2,526	383
10/100	4	5,847	9,127	57.59	6,803	1,276
	5	6,701	10,692	64.02	7,258	1,155
	6	7,703	12,234	69.11	10,527	1,086
100/10	4	4,363	1,046	23.98	3,194	738
	5	4,410	1,284	29.13	3,244	723
	6	4,461	1,567	35.13	3,676	695

Table 4. GPR, GPR Ratio, Maximum Touch and Step Voltage of Two Connected Grids 25 m Apart

ρ_a ($\Omega \cdot \mathrm{m}$)	Sce	Type of Voltage (V)			Electrode Resistance (Ω)	Length (m)
		GPR	Touch	Step		
10	7	1,651	889	153	0.06605	2,850
	8	2,009	1,319	197	0.08038	1,875
	9	2,468	1,935	272	0.09873	1,329
10/100	7	10,659	3,814	473	0.42637	2,850
	8	12,278	5,967	575	0.49114	1,875
	9	14,178	9,098	743	0.56714	1,329
100/10	7	2,052	1,294	269	0.08206	2,850
	8	2,589	1,896	358	0.10356	1,875
	9	3,322	2,792	516	0.13288	1,329

Table 5. GPR, GPR Ratio, Maximum Touch and Step Voltage of Two Connected Grids 5 m Apart

ρ_a ($\Omega \cdot \mathrm{m}$)	Sce	Type of Voltage (V)			Electrode Resistance (Ω)	Length (m)
		GPR	Touch	Step		
10	10	1,814	1,084	169	0.07255	2,790
	11	2,258	1,694	217	0.09032	1,797
	12	2,806	2,331	297	0.11224	1,179
10/100	10	11,633	5,003	526	0.46534	2,790
	11	13,693	8,379	657	0.54773	1,797
	12	15,994	11,455	855	0.63976	1,179
100/10	10	2,215	1,488	288	0.08860	2,790
	11	2,846	2,283	391	0.11385	1,797
	12	3,646	3,171	542	0.14583	1,179

Now look at the Aux/Main, it is the ratio of the GPR of auxiliary grounding grid to the GPR of the main ground grid. When we compare the Aux/Main ratio of the grids having the same grid configuration as those listed in Table 2 and 3. For example, Table 2, 10 $\Omega \cdot \mathrm{m}$ soil resistivity, scenario 1: Aux/Main [7] ratio is 19.6 % while the maximum touch voltage is 2,259 V. but in Table 3, scenario 4, the same grid configuration and soil resistivity, the Aux/Main ratio is 33.54 % while the maximum touch voltage is 2,014 V (Aux/Main ratio is in reverse proportional to its maximum touch voltage). This can be explained that touch voltage is itself the ground potential difference (GPD) between the person's point of standing (GPR) and his hand in touching zero potential (grounding object), therefore, the more the GPR, the higher the touch voltage, but since the GPR is the divisor of the Aux/Main ratio, then the more the GPR, the less the ratio.

Part 2: When the two ground grids are connected as scenario 7 to 12 listed in Tables 4 and 5, all voltages tend to decrease, but it depends on the soil resistivity the grids buried. For example, for Table 2; scenario 1; 10 $\Omega \cdot \mathrm{m}$ soil resistivity, the resulted GPR, maximum touch voltage are 3,325 V and 2,259 V, the 3D and 2D voltage profile of which is shown in Figures 3 and 4 respectively. But when the two ground grids are connected, Table 4; scenario 7 presents the resulted GPR and maximum touch voltage which comes down to 1,651V and 889 V, its 3D and 2D voltage profile is shown in Figures 5 and 6 respectively. The interconnected grids also make the maximum step voltage decrease. It is found that after connection, GPR of both grids are equalized and more uniform not as steep as it used to be between two grids. Maximum touch and step voltage are equal to 889 V and 153.4V respectively. (Safety criteria for 50-kg person, the touch and step voltage cannot exceed 1,488 V and 5,085 V respectively). This is a safe condition for both values are within the limits, however, care should be taken for safety criteria depends on weight of person, soil resistivity and fault clearing time. One thing should also be noted, the come down of all voltages in Table 4 and 5 are good for soil resistivity 10 and 100/10 $\Omega \cdot \mathrm{m}$ only but not the 10/100 $\Omega \cdot \mathrm{m}$.

For example, Table 3; scenarios 5 and 6; at 10/100 $\Omega \cdot \mathrm{m}$, when ground grids are interconnected, its maximum touch voltage does not decrease, instead it increases more than the value when grids are unconnected. This is because even the interconnection of two ground grids together lowers the grids resistance, but their ground rods have to reach the high soil resistivity layer which increases the grids resistance. So when the resulted grids resistance is not low enough, its GPR and touch voltage value will remain high. The interconnected ground grid with 25 m inter-distance as of Table 4 compares with 5 m inter-distance as of Table 5, all the voltages tend to increase when the inter-distance is closer. This is all due to the connected ground grids resistance of Table 4 is lower than that of Table 5 for each soil resistivity and configuration. In other words, the loosely connected ground rods contribute lower total electrode resistance than that of tightly connected ones. We must be careful when handling the ground grid design in the area of two layered soil - the soil resistivity of lower (bottom) layer is higher than that of upper (top) layer; the grids' inter-distance is closed and the size of auxiliary grounding system is equal to or smaller than that of the main ground grid's, for these conditions, when interconnecting both ground grids together will increase the touch voltage.

Part 3: This part analyzes the effects of sizes of auxiliary grounding grid, regardless the soil resistivity. From Table 2 to 5; scenarios 1, 4, 7 and 10; L size of auxiliary grounding grid provides lowest GPR and lowest maximum touch voltage while scenarios 3, 6, 9 and 12; S size of auxiliary grounding grid provide the opposite results. As per the maximum step voltage, the L size of auxiliary grounding grid provides higher maximum step voltage, until the grids are connected. So we can conclude that the bigger the size of auxiliary grounding grid, the lower the GPR and maximum touch and step 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.

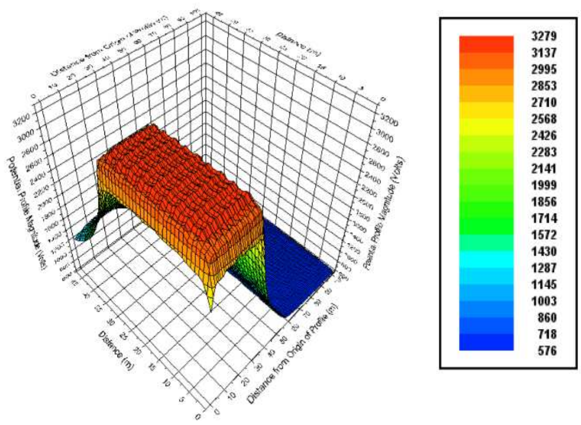


Fig. 3. 3-D Ground Potential Rise for Scenario 1.

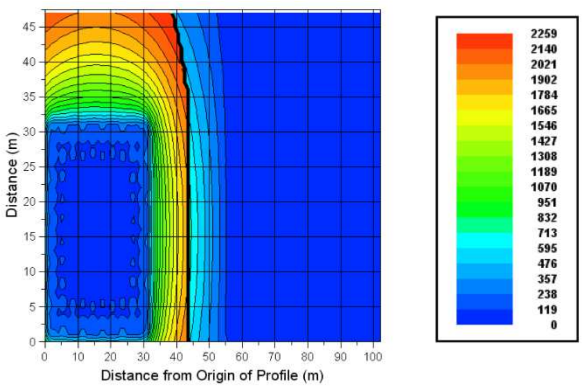


Fig. 4. 2-D Touch Voltage Magnitude for Scenario 1.

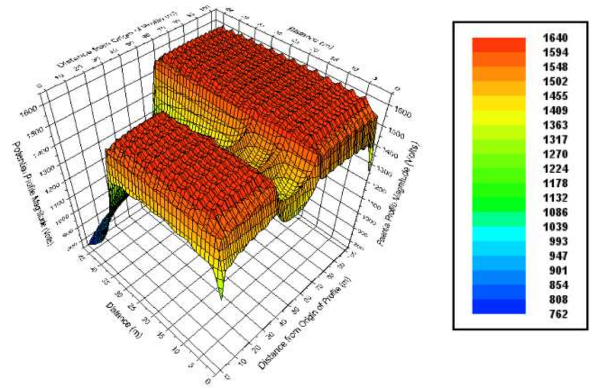


Fig. 5. 3-D Ground Potential Rise for Scenario 7.

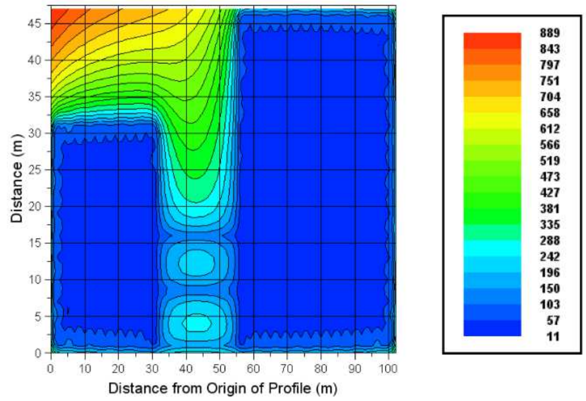


Fig.6. 2-D Touch Voltage Magnitude for Scenario 7.

5. CONCLUSION

If the renovation of a distribution substation is planned but either a nearby temporary or old substation still exists and remains energized, the following points should be noted.

1. If two distribution substation ground grids leave unconnected, the more its inter-distance, the higher its GPR and maximum touch voltage, but the lower its maximum step voltage will be. The bigger the grid size of the auxiliary grounding system than the main ground grid's, the lower its GPR and maximum touch voltage, but the higher its maximum step voltage will be.

2. Care shall be taken when handling the ground grid design in the area of two layered soil - the soil resistivity of lower (bottom) layer is higher than that of upper (top) layer; the auxiliary and main grid's inter-distance is closed, and the size of auxiliary grounding system is equal to or smaller than that of the main ground grid's. Whenever the interconnection of both grids taking place, it will increase the GPR and the maximum touch voltage.

3. Aux/Main ratio serves as a good figure in considering GPR and maximum touch voltage for constant configuration and soil resistivity but varying grid inter-distance: The greater the Aux/ Main, the lower the GPR and maximum touch voltage. The ratio is also applicable when the configuration and inter-distance are constant and the different soil resistivity is varying, but limit to uniform and two layered soil which upper layer resistivity higher than the lower's. In this paper is 10 and 100/10 $\Omega \cdot m$.

ACKNOWLEDGMENT

Firstly, the author would like to express his deepest gratitude to the late Assoc. Prof. Dr.Jamnarn Hokierti, Kasertsart University, Thailand, Mr.Tirapong Kasirawat, Operation Network Department, Provincial Electricity Authority (PEA), Northern Region1, Chiangmai, Thailand, Mr.Praditpong Suksirithaworngule, ABB, Thailand, and Mr.Arwut Puttarach, Rajamangala University of Technology Lanna (RMUTL), Chiang Mai, Thailand, for teaching him the essential knowledge of power system. Sincere thanks would go to Provincial Electricity Authority for CDEGS program and Metropolitan Electricity Authority (MEA) for the technical data used in this research. High appreciation is given to Power System Planning Department of MEA for research time and strong support of this work.

REFERENCES

[1] IEEE std 80-2000. Guide for Safety in AC Substation Grounding, New York, USA, 2000.

[2] Puttarach, A., Chakpitak, N., Kasirawat, and T. Pongsriwat et al, C. 2007. Substation grounding grid analysis with the variation of soil layer depth method. In *Proceedings of Powertech*, Lausanne, Switzerland, 1-5 July.

[3] ANSI/IEEE Std 81-1983. IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System, , New York, USA, 1983.

[4] Dawalibi, F.P. and Blattner C.J. 1984. Earth resistivity measurement interpretation techniques. In *Proceedings of IEEE Transactions on Power Apparatus and Systems*, PAS-103(2): 374-382.

[5] Code of Practice for Earthing, BS std. 7430, 1998.

[6] IEEE Std. 837. IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding, New York, USA, 2002.

[7] Phayomhom, A., Chirataweewoot, N., Intharaha, S., Sirisumrannukul, S., Kasirawat, T., and Puttarach, A., 2012. Safety analysis for Grounding Potential Rise of Two Neighbouring Substations: Case Study of Metropolitan Electricity Authority's System. 44th International Council on Large Electric Systems (CIGRE), Paris, France, 27 – 31August.