Effects of Nearby Auxiliary Grounding Imposed on Main Square and Rectangle Ground Grids of Distribution Substation

A. Phayomhom, T. Kasirawat, W. Pobporn, C. Pongsriwat, and A. Puttarach

Abstract— *The case study presents touch voltage reduction for uniform or two-layer soil by applying compression ratio technique to square or rectangle ground grid. Current Distribution Electromagnetic interference Grounding and Soil structure (CDEGS) program is used for the study purpose. The ground grid design is examined with the aim to assess its performance in terms of ground potential rise (GPR), maximum touch and step voltage. The parameters are analyzed to ensure that they are safe conforming to the IEEE 80-2000. It is found that in uniform or two-layer soil, the soil resistivity of top layer is lower than the bottom's, for a given GPR, the maximum touch and step voltage of the rectangle ground grid, regardless its compression ratio, are lower than that of the square one. This means rectangle grid is safer than square one. So, one should not ignore the shape of ground grid in the design, especially when they are placed close together. This is the case when a new substation is under construction near the old one which is still energized. The grounding system of the old substation can create steep ground potential rise to the other, therefore, the GPR can harm personnel working nearby and cause damage to equipment particularly when the two ground grids are isolated.*

Keywords— **Distribution substation, Ground potential rise, Optimum compression ratio, Step voltage, Touch voltage.**

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 35.32 % of the whole country power demand in 2010. MEA's networks consist of transmission, subtransmission and distribution systems. The transmission line voltage is 230 kV, while the 69 and 115kV used in subtransmission systems and 12 and 24 kV in the distribution feeders.

Based on MEA's experience, one of the main causes of a sustainable fault is the short circuit fault right at the substation itself. The short circuit generates large amount of currents that flow in the aboveground structures to the grounding system and finally dissipate in the soil. The high currents may cause damage to equipment and may be dangerous to personnel working nearby. It is therefore important for the substation designer to take into account the safety issue pertaining to step and touch voltage limit that may exceed the safety criteria. [1, 2].

Talking about the grounding system design, people tend to familiar with ground grid that its conductors are laid equally apart, while pay little attention to the one with unequal separation. One of the reasons for this may be owing to the fact that many grounding system standards focus on ground grid designs with regularly spaced conductors [3] and put little emphasis on alternative design options based on unequal conductor spacing. The most likely reason should blame the lack of adequate information concerning the most promising, efficient grounding system configuration as a starter to avoid lengthy trials in the ground grid design process. In others words, there is a need of suitable reference containing necessary guidelines so that a grounding system designer can focus quickly on the most efficient design. This is exactly the main purpose of this paper [4].

2. EFFECTS OF NEARBY AUXILIARY GROUNDING SYSTEM OF SUBSTATION

Many a time, the new temporary (small) or permanent distribution substation is under construction while the existing substation is still in operation and not yet removed. There are two grounding systems for each substation that is not connected each other. The ground grid of the main substation is called main ground grid (energized electrical power site) whereas that of the other distribution substation (temporary or permanent) distribution substation) is called auxiliary ground grid. During the time of disconnecting of ground grid, the small or permanent distribution substation is de-energized, its auxiliary grounding system however

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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. OPTIMUM COMPRESSION RATIO (OCR)

The proper design of grounding system can ensure the personnel safety in the distribution substation while maintain reliable operation of the power system. This calls for the optimum compression ratio (OCR) be applied in the design together with the target to keep the touch voltage its minimum value [5].

Figure 1 shows the configuration of a ground grid the grounding conductors of which are of exponent regularity arrangement. This arrangement cannot only decrease the potential gradient of the ground surface, but also regarded as a safe and economic design model. The problem is how this exponent regularity be defined. As one can notice, the grounding conductors arranged according to an exponent regularity, its conductor span decreases exponentially from its centre to the edge of the grounding grid. The i th conductor span from the centre is given in Eq. (1) [4, 6].

$$d_i = d_{\max} C^i, \ (i = 0 \text{ to } m) \quad (1)$$

where d_i is the i th conductor span from the center (m)

$d_{\max}$ is maximum conductor span (m)

c^i is the i th compression ratios

where C is the compression ratio, whose value ranges from zero to 1 ($0 \le C \le 1$), if C = 1, then the grounding grid is of equal conductor span design. Let N denotes the number of (perpendicular) conductors to the side of interest of the grounding grid, if N is an even number; m = N/2-1; if N is an odd number; then m = (N-1)/2-1. The 1 th conductor span was counted from the centre of the grounding grid, not from the edge [6, 7].

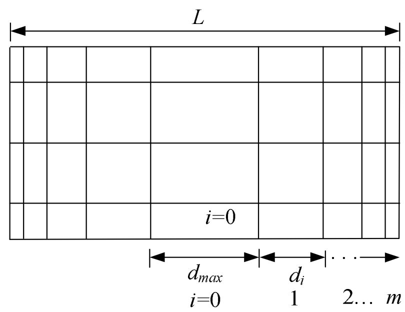

Fig. 1. Grounding Grid Scheme Arranged with Exponential Rule.

The conductors are perpendicular to the side, then the central span(s) is defined by equation either Eq. (2) or (3).

$$d_{\max} = \frac{L(1-C)}{1 + C - 2C^{(N/2)}} \quad , N \text{ is even} \quad (2)$$

$$d_{\max} = \frac{L(1-C)}{2(1 - C^{(N-1)/2})} \quad , N \text{ is odd} \quad (3)$$

where N is the number of conductor perpendicular to the side of grounding grid

L is is the length of the side (m)

4. CASE STUDY

This paper studies the effects of nearby auxiliary grounding system of substation by comparing the configuration of main ground grid between square main ground grid and rectangle main ground grid as shown in Figures 2 and 3. The compression ratio is varied from 0 to 1.0 to notice the different of GPR ,touch voltage and step voltage. Auxiliary ground grid is determined as the square ground grid at 1.0 constant compression ratio.The distance between main ground grid and auxiliary grounding system is 25 m.

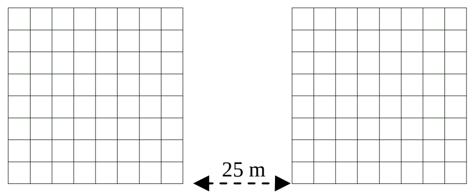

Fig. 2. Two Neighbouring Distribution Substation with Main Square Ground Grid.

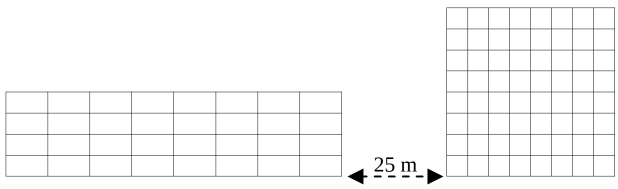

Fig. 3. Two Neighbouring Distribution Substation with Main Rectangle Ground Grid.

This research presents compression ratio technique which its values are varied from 0 to 1.0 with different dimension (square and rectangle) but the same of ground grid.

MEA's permanent distribution substation's ground grid is approximately 40 m x 40 m. This paper then studies the 40 m x 40 m (1,600 m^2) square ground grid while varying the compression ratio from 0 to 1.0 as shown in Fig 2. All ground grid conductors are 95 mm^2 (0.54979 cm. in radius) and buried at a depth of 0.5 m. The number of conductor in width and long side are 9 conductors. Total buried length of main electrode is 720 m. Top views of ground grid configuration are shown in Figure 4.

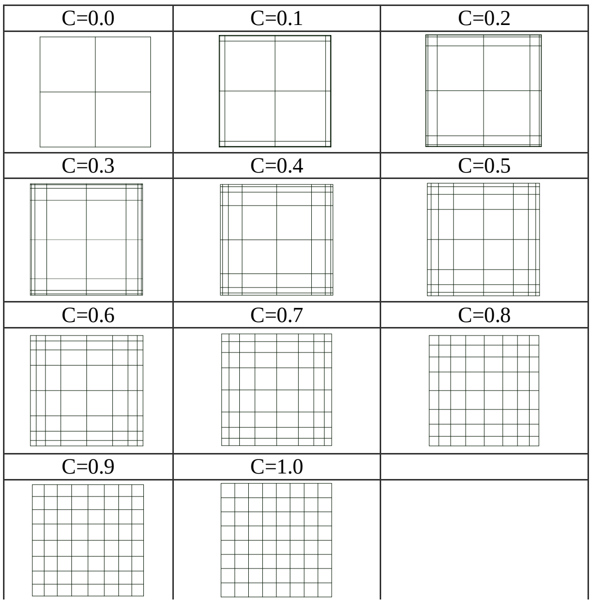

Fig. 4. Grounding Grid with Various Conductor Compression Ratio with 40 m x 40 m.

If we compare the resulted GPR, maximum touch voltage and step voltage of the square ground grid with a rectangle one 20 m x 80 m (1,600 m^2) ground grid. The ground grid configurations with compression ratio varied from 0 to 1.0. All ground grid conductors are 95 mm^2 (0.54979 cm in radius) and buried at a depth of 0.5 m. The number of conductors in width and long side are 9 and 5 conductors respectively. Total buried length of main electrode is 580 m. Top views of ground grid configuration are shown in Figure 5.

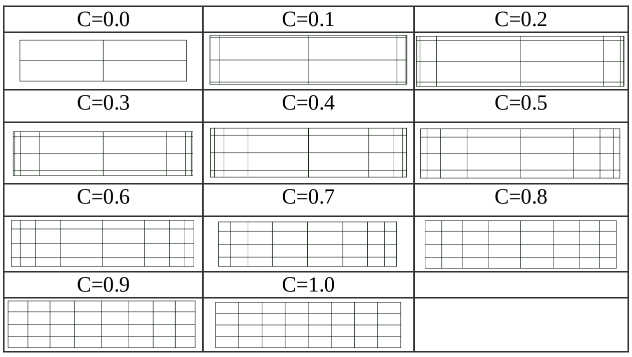

Fig 5. Grounding grids with various conductor compression ratios with 20 m x 80 m dimension.

The top layer has a more resistivity than the bottom layer (deep layer) or on the other hand due to a number of factors such as moisture content of the soil, chemical composition, concentration of salts dissolved in the contained water, and grain size [8, 9].

There are 3 cases of configuration studied.

Case 1: the conductors of square and rectangle ground grid are buried in the 10 Ω.m soil resistivity.

Case 2: the conductors of square and rectangle ground grid are buried in 100/10 Ω.m soil resistivity and.

Case 3: the conductors of square and rectangle ground grid are buried in 10/100 Ω.m soil resistivity.

The details of each case are as follows:

Case 1

The result in case1 shown in Table 1 are from the square main ground grid installation and from rectangle main ground grid in Table 2. The comparison of touch voltage graph is shown in Figure 6.

Table 1. GPR, GPR Ratio Touch and Step Voltage with 40 m x 40 m for Case 1

C	Square 40x40(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	3,447.7	643.9	18.68	2,818.0	512.8
0.1	2,992.7	644.6	21.54	2,362.7	433.7
0.2	2,888.6	644.1	22.30	2,259.4	416.5
0.3	2,840.1	643.7	22.67	2,211.3	395.3
0.4	2,816.3	642.9	22.83	2,187.6	377.0
0.5	2,804.7	642.3	22.90	2,176.3	360.1
0.55	2,803.6	642.1	22.90	2,175.4	343.0
0.6	2,804.1	642.0	22.89	2,176.0	343.8
0.7	2,808.4	641.7	22.85	2,180.5	320.3
0.8	2,815.1	641.5	22.79	2,187.4	320.7
0.9	2,817.7	641.3	22.76	2,190.2	324.6
1.0	2,827.1	641.2	22.68	2,199.7	325.1

Table 2. GPR, GPR Ratio Touch and Step Voltage with 20 m x 80 m for Case 1

C	Rectangle 20x80(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	2,999.5	523.7	17.46	2,184.2	456.8
0.1	2,693.6	526.6	19.55	1,874.8	418.8
0.2	2,649.3	526.5	19.87	1,830.8	386.8
0.3	2,631.1	523.3	19.89	1,816.5	332.2
0.4	2,624.4	525.3	20.02	1,807.5	333.9
0.5	2,626.0	524.6	19.98	1,809.7	326.6
0.55	2,627.0	524.3	19.96	1,811.1	317.0
0.6	2,628.5	524.0	19.93	1,813.0	320.3
0.7	2,631.1	523.3	19.89	1,816.5	332.2
0.8	2,635.6	522.8	19.84	1,821.7	320.9
0.9	2,640.2	522.4	19.79	1,826.9	322.2
1.0	2,650.0	522.3	19.71	1,836.9	341.8

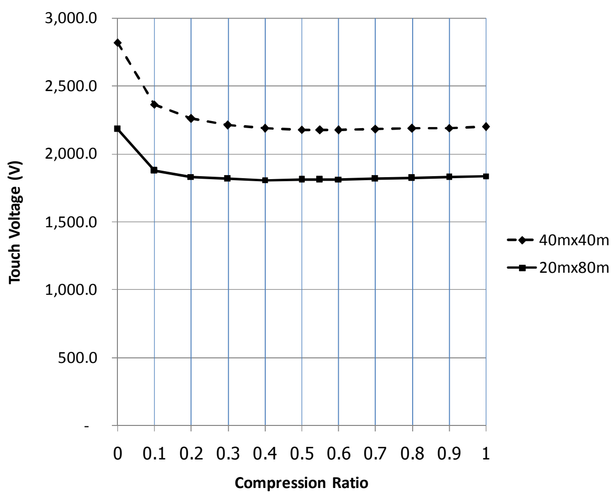

Fig. 6. Touch Voltage as A Function of Conductor Compression Ratios for Cases 1.

The result found that all voltage at every value of compression ratio of square main ground grid are lower than rectangle main ground grid. At 0.55 OCR, GRP, touch voltage and step voltage are equal to 2803.6 V, 2,175.4 V and 343 V respectively. The study also found that at the worst case, compression ratio is equal to 0. When the configuration of OCR is used instead, touch voltage can be reduced for 22.80% (from 2,818 V to 2,175.4V). At 0.55 OCR, %GPR ratio is 22.90%. More GPR cause more reduction of voltage. The safety is also increased.

For the rectangular main ground grid at 0.4 OCR, GPR, touch voltage and step voltage are 2624.4 V, 1807.5V and 333.9 V respectively. Comparison touch voltage at 0 compression ratio found that touch voltage can be reduced for 17.25% (from 2,184.2 V to 1,807.5 V). For rectangle ground grid with OCR 0.4, 3-dimension GPR touch and step voltage are in Figures 7 to 9 respectively.

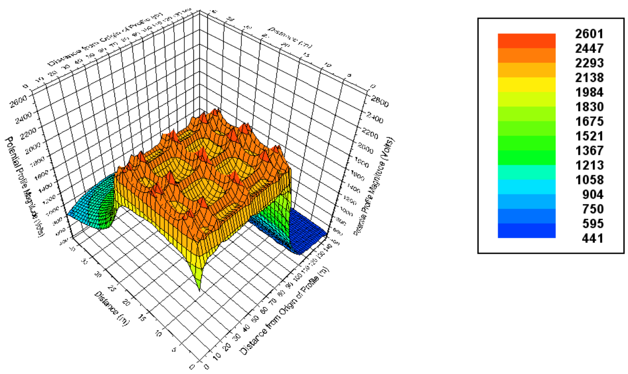

Fig. 7. 3-Dimension GPR for Case 1 with Rectangle Main Ground Grid at OCR 0.4.

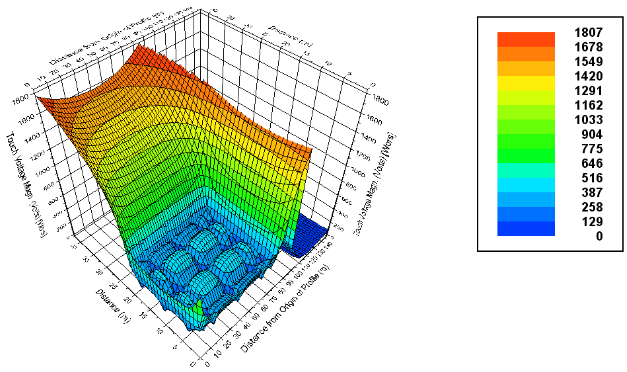

Fig. 8. 3-Dimension Touch Voltage for Case 1 with Rectangle Main Ground Grid at OCR 0.4.

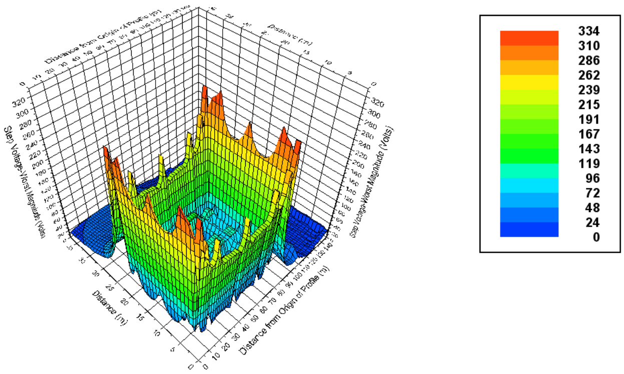

Fig.9. 3-Dimension Step Voltage for Case 1 with Rectangle Main Ground Grid at OCR 0.4.

Case 2

The study of case 2 is shown in Tables 3 and 4. Touch voltage graph is in Figure 10.

Table 3. GPR, GPR Ratio Touch and Step Voltage with 40 m x 40 m for Case 2

C	Square 40x40(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	14,198.0	654.7	4.61	13,553.0	4,429.9
0.1	9,575.2	646.0	6.75	8,939.4	2,980.1
0.2	8,484.4	644.5	7.60	7,849.3	32,619.5
0.3	7,963.8	654.6	8.22	7,319.3	2,317.7
0.4	7,576.5	643.8	8.50	6,942.4	2,095.4
0.5	7,384.6	653.0	8.84	6,741.3	1,902.4
0.6	7,269.1	652.4	8.97	6,626.2	1,833.4
0.7	7,209.9	651.8	9.04	6,567.5	1,719.7
0.8	7,130.4	641.1	8.99	6,498.1	1,700.0
0.87	7,054.3	641.4	9.09	6,422.4	1,757.1
0.9	7,059.9	641.3	9.08	6,428.1	1,713.3
1.0	7,078.4	641.0	9.06	6,446.8	1,781.4

Table 4. GPR, GPR Ratio Touch and Step Voltage with 20 m x 80 m for Case 2

C	Rectangle 20x80(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	11,600.0	525.5	4.53	10,775.0	3,599.6
0.1	8,602.1	530.1	6.16	7,771.8	2,796.5
0.2	8,053.7	529.2	6.57	7,223.0	2,459.3
0.3	7,504.7	522.4	6.96	6,680.7	1,996.9
0.4	7,637.2	526.1	6.89	6,809.0	2,052.1
0.5	7,577.1	524.5	6.92	6,750.2	1,978.6
0.6	7,535.9	523.2	6.94	6,710.3	1,980.3
0.7	7,504.7	522.4	6.96	6,680.7	1,996.9
0.8	7,499.5	522.0	6.96	6,676.7	2,012.6
0.87	7,543.7	523.5	6.94	6,699.3	2,025.6
0.9	7,505.0	522.1	6.96	6,683.4	2,023.1
1.0	7,575.7	518.7	6.85	6,755.6	2,069.5

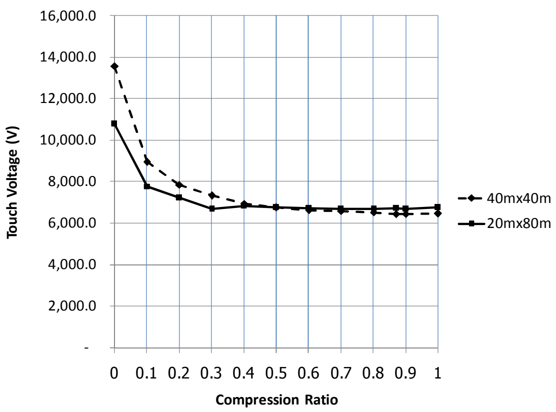

Fig. 10. Touch Voltage as A Function of Conductor Compression Ratios for Cases 2.

The result found that at 0.87 OCR , GRP ,touch voltage and step voltage are equal to 7,054.3 V, 6,422.4 V and 1,757.1 V respectively. The study also found that at the worst case ,compression ratio is equal to 0. When the configuration of OCR is used instead ,touch voltage can be reduced for 52.61% (from 13,553 V to 6,422.4V) . At 0.87 OCR, %GPR ratio is 9.09%.

For the rectangle main ground grid at 0.8 OCR, GPR, touch voltage and step voltage are 7,499.5 V, 6,676.7 V and 2,012.6 V respectively. Comparison touch voltage at 0 compression ratio found that touch voltage can be reduced for 42.44% (from 11,600 V to 6,676.7 V).

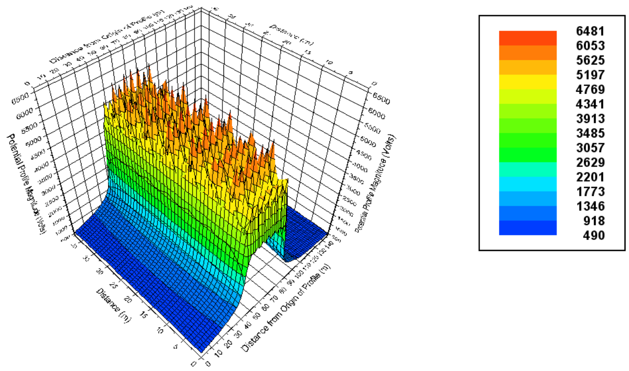

Fig. 11 3-Dimension GPR for Case 2 with Square Main Ground Grid at OCR 0.87.

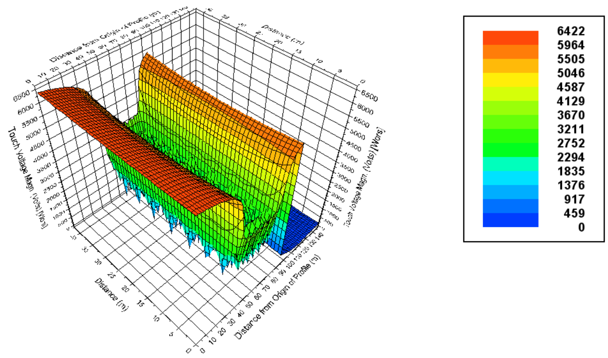

Fig.12. 3-Dimension Touch Voltage for Case 2 with Square Main Ground Grid at OCR 0.87

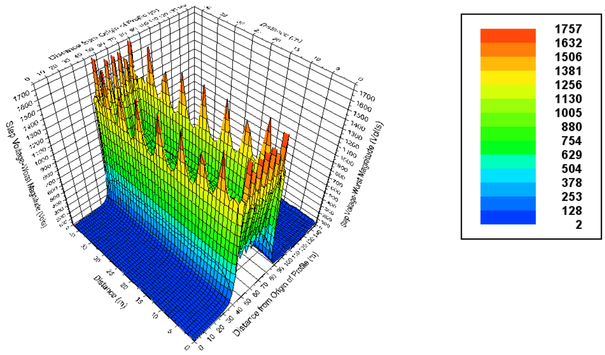

Fig.13. 3-Dimension Step Voltage for Case 2 with Square Main Ground Grid at OCR 0.87

As mention,at 0 to 0.4 compression ratio, GPR, touch voltage and step voltage of square ground grid are lower than rectangle square ground grid. For square ground grid with OCR 0.88, 3-dimension GPR touch and step voltage are in Figures 11 to 13 respectively.

Case 3

The results which is square main ground grid installation in case 3 are shown in Table 5. Table 6 is the results of rectangle main ground grid installation. Comparison of touch voltage graphs are shown in Figure 14.

Table 5. GPR, GPR Ratio Touch and Step Voltage with 40 m x 40 m for Case 3

C	Square 40x40(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	15,611.0	6,034.5	38.66	9,780.9	715.9
0.1	15,023.0	6,038.6	40.20	9,193.2	906.4
0.2	14,972.0	6,038.8	40.33	9,146.7	903.1
0.3	14,966.0	6,039.5	40.35	9,141.6	897.1
0.4	14,986.0	6,034.1	40.26	9,158.6	883.7
0.5	15,011.0	6,030.5	40.17	9,183.8	870.7
0.6	15,041.0	6,029.4	40.09	9,214.3	820.0
0.7	15,068.0	6,028.6	40.01	9,242.2	783.1
0.8	15,091.0	6,028.0	39.94	9,265.2	759.6
0.9	15,113.0	6,027.4	39.88	9,288.7	758.6
1.0	15,140.0	6,027.1	39.8	9,314.3	732.9

Table 6. GPR, GPR Ratio Touch and Step Voltage with 20 m x 80 m for Case 3

C	Rectangle 20x80(m^2)				
	GPR (V)		R/M (%)	Touch (V)	Step (V)
	M	R			
0.0	14,151.0	5,063.3	35.78	6,986.4	755.5
0.1	13,769.0	5,057.9	36.73	6,583.7	887.6
0.2	13,765.0	5,058.6	36.75	6,580.1	878.9
0.3	13,850.0	5,045.1	36.43	6,676.1	728.9
0.4	13,787.0	5,052.6	36.65	6,607.5	765.9
0.5	13,821.0	5,050.4	36.54	6,642.9	754.3
0.6	13,808.0	5,001.2	36.22	6,687.5	739.4
0.7	13,850.0	5,045.1	36.43	6,676.1	728.9
0.8	13,868.0	5,042.8	36.36	6,697.0	724.9
0.9	13,885.0	5,041.6	36.31	6,716.7	705.5
1.0	13,852.0	4,996.1	36.07	6,734.4	724.7

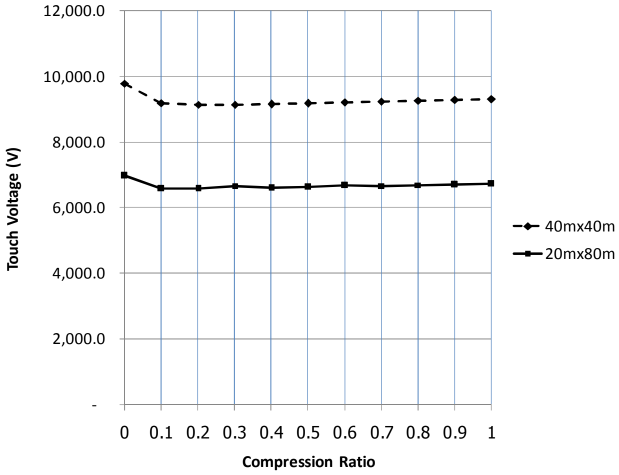

Fig. 14. Touch Voltage as A Function of Conductor Compression Ratios for Cases 3.

The study found that at various value of voltage at 0.3 OCR , GRP ,touch voltage and step voltage are equal to 14,966 V, 9,141.6 V and 897.1 V respectively. Comparison with 0 compression ratio touch voltage can be reduced for 6.54% (from 9,780.9 V to 9,141.6 V).

The study of various voltage value for the rectangle main ground grid at 0.2 OCR, GPR, touch voltage and step voltage are 13765 V, 6580.1 V and 878.9 V respectively. Comparison touch voltage at 0 compression ratio found that touch voltage can be reduced for 5.82% (from 6,986.4 V to 6,580.1 V).

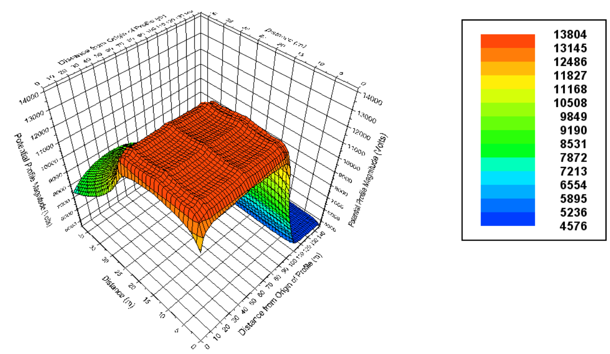

Fig. 15. 3-Dimension GPR for Case 3 with Rectangle Main Ground Grid at OCR 0.2.

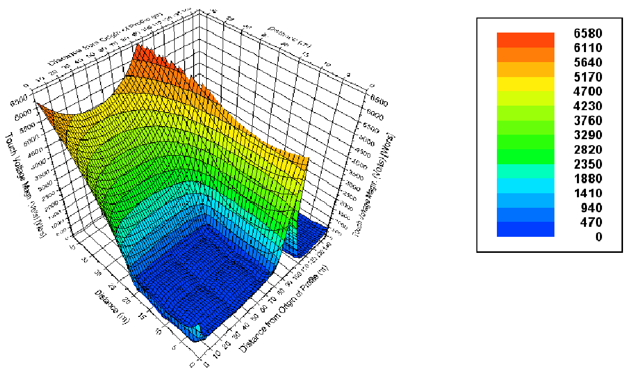

Fig.16. 3-Dimension Touch Voltage for Case 3 with Rectangle Main Ground Grid at OCR 0.2

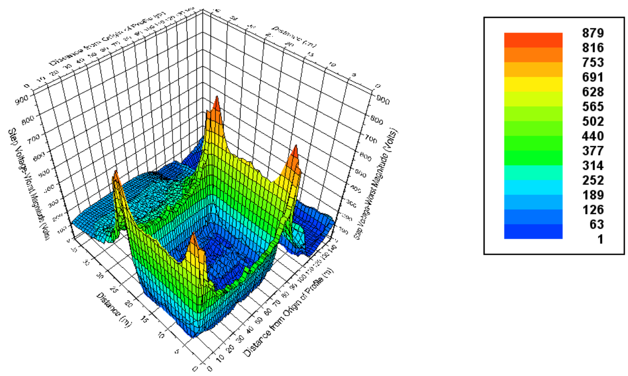

Fig. 17. 3-Dimension Step Voltage for Case 3 with Rectangle Main Ground Grid at OCR 0.2.

This research found that all voltage value at every compression ratio of rectangle main ground grid are lower than square main ground grid. For square ground grid with OCR 0.2, 3-dimension GPR touch and step voltage are in Figures 15 to 17 respectively.

5. CONCLUSION

The study of square and rectangle main ground grid shape without ground rod in different soil resistivity can be concluded as follows.

1. At uniform soil characteristic and soil resistivity of top layer soil is lower than bottom layer soil, GPR, maximum touch voltage and maximum step voltage at every value of compression ratio of rectangle main ground grid are lower than in square main ground grid. This mean rectangle main ground is more safety than square main ground.

2. When soil resistivity of top layer soil is more than lower bottom soil all voltage value of square main grid are more than rectangle main grid at 0 to 0.4 compression ratio. Whereas 0.4 to 1.0 interval, all value of voltage are lower than rectangle main ground grid.

3. The percentage value of GPR ratio of square main grid and rectangle main grid are safety indicator. More percentage value means higher safety. The comparison must only be in the same shape of ground grid configuration at various compression ratio. Between square and rectangle or same shape with different soil resistivity can not be compared. The comparison of the safety must consider maximum touch voltage and maximum step voltage whether all of these values exceed the determined safety criteria.

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