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Soil resistivity and ground resistance for dry and wet soil

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Abstract In this paper, soil resistivity and ground resistance at two different sites near an electrical substation are measured using a grounding system grid with and without rods. With the Wenner four-pole equal-method, the soil resistivity is measured at both selected sites, one of which contains wet soil while the other contains dry soil. Cymgrd simulation software is then used to determine the acceptability of these measured resistivity values by finding out the root mean square error between the measured and calculated values for both wet and dry soil sites. These values for wet and dry soil sties were found to be only 0 % and 4.92 %, respectively, and deemed acceptable. The measured soil resistivity values were then used to evaluate the ground resistance values of a grounding grid 'with rod' for the wet soil site and 'without rods' for the dry soil site, and then compared with the simulated ground resistance values. These comparisons were also found to be in good agreement. In addition, ground potential rise, maximum permissible step and touch potentials have also been estimated using the simulation software.

Keywords Grid with rods, Grid without rods, Fall-of-potential method, Soil resistivity, Ground resistance

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1 Introduction

A grounding system with high ground resistance provides unsafe path for the fault current, which increases the risk of equipment failure as well as the likelihood of severe injury to human being. In this case, if a fault current does not find any path to pass to the ground through a properly designed grounding system, it finds an alternate path either via some sophisticated equipment or, in the worst case scenario, through the human body. Also, a poor grounding system leads to instrumentation errors and harmonic distortions in any electrical system. Therefore, a good grounding system is very important not only for safety reasons but also for preventing damages to industrial plants and equipment. The design of a good grounding system depends on many factors such as the weather, characteristics of the soil, the surrounding environment of the power plant, the arrangement of the grounding electrodes, etc.

After looking into the importance of a good grounding system design, many researchers have carried out extensive studies in this area. Ref. [1] provided information about grounding grid performance in different soil structures after an extensive parametric study. A method for calculating the grounding grid resistance was presented in [2] based on the theoretical manipulations of the numerical moment method and the current image. This method has been shown to be dependent on the substation grounding grid design. Ref. [3] presented an analysis on evaluating grounding grids of different shapes in substations. Different shapes of grounding grids have also been considered in [4] in calculating ground resistance using the finite-element method (FEM). A substation grounding grid has been analyzed with the variation of soil layer depth in [5]. Ref. [6] conducted a study where they measured the impedances of four grounding grids using tuned-frequency test equipment operating close to the system operating frequency. FEM was used in [7] for computing the grounding grid resistance. A scheme was proposed in [8] for calculating the ground resistance using FEM to the resolution of solid models in 3D view. As discussed in many literatures including [3, 4, 7], although FEMs are the most accurate methods for computing grounding grid resistance, these methods are quiet complicated and time consuming for grounding system design purpose. In [9], it is shown that the low or high resistivity soil layer formed in raining or freezing season affects the safety of grounding system, and leads to the changes of grounding resistance of the grounding system, step and touch voltages on the ground surface. A practical example of ground resistance measurement has been presented in a 154 kV substation under commercial operating condition [10]. In [11], a research study has been carried out to show the validity of the formula available in the literature against the measured earth resistance values at the field site. Ref. [12] has evaluated the role played by the foundations in a substation yard as grounding element and estimated the magnitude of the fault and leakage currents carried by the foundations. An artificial intelligent network approach is used for developing the relationship between the ground resistance and the vertically inserted electrode in the soil in [13]. Dimensional and grid electrodes are used for the measurement of ground resistance near a residential area in [14]. A methodological approach has developed for estimating the ground resistance of the several grounding system with various ground enhancing compounds using ANN [15]. Ref. [16] has measured soil resistivity and grounding resistance at the four selected sites of the Lambak Kanan residential area of Brunei Darussalam and compared with simulation results. However, the main drawback is the smaller number of measurement sites. A linear three-pole wiring method has proposed to measure the grounding resistance of buildings structure in water through variance analysis and correlation coefficient analysis methods, and solves the problem about how to measure the grounding resistance of buildings structure in water [17]. AC, DC and impulse tests have performed on rod and grid electrodes and the measured quantities are compared with computed values obtained from numerical models. Measured ground resistance and impedance at low frequency showed reasonable agreement with simple standard formulae and computational models, but revealed a significant falloff with current magnitude in the range often used for the practical testing of the high-voltage grounding systems [18].

From all the above mentioned research studies, it is apparent that there is no uniqueness in the soil property. Also, there is no exclusive method to measure the ground resistance which is a prime requirement in designing a ground field for any power plant or substation. By taking these facts into account, this paper presents an on-site investigative result on resistivity and ground resistance for dry and wet soils near a substation. In measuring the resistivity of the soil, Wenner four-pole equal-method has been considered in the investigation while a grounding system grid with and without rods are used as test bed. The measured values have been compared with the simulation results derived from the Cymgrd simulation software. The simulation software has also been used to estimate the ground potential rise, maximum permissible step and touch potentials.

2 Experimental measurement

2.1 Experimental site

Two sites were selected to measure the soil resistivity and grounding resistance near Gadong 66 kV substation of Brunei Muara District of Brunei Darussalam. The first measurement site was located at around 0.9 m away from the water drain, where the soil was identified as wet soil. The second measurement site was located very close to the substation, where the soil was identified as dry soil.

2.2 Soil resistivity measurement

Wenner four-pole equal method [19] has been considered in measuring the soil resistivity and its connection

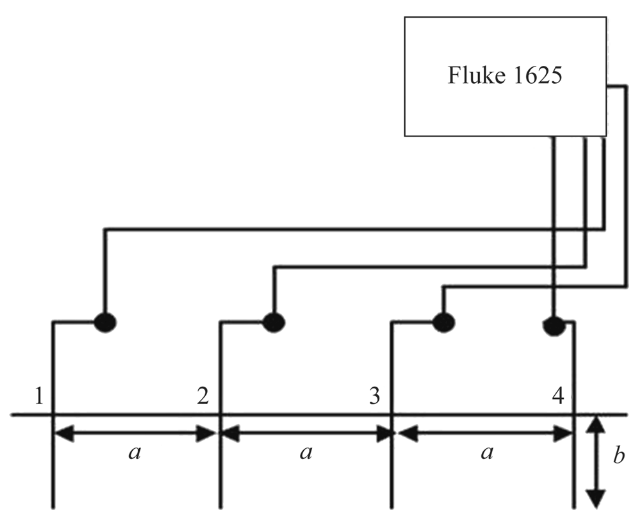

Fig. 1 Connection of soil resistivity measurement

Table 1 Soil resistivity data for wet soil

Probe distance (m)	Soil resistance, R_e (Ω)	Soil resistivity, ρ (Ω m)
0.3	14.75	27.79
0.6	7.93	29.88
0.9	6.37	36.00
1.2	4.36	32.86
1.5	4.31	40.60
1.8	4.23	47.82

diagram is shown in Fig. 1. In this experimental setup, four equidistant probes were vertically inserted into the soil on a straight line and the distance b was maintained to be 10 % of a, that is, $b = 0.1a$.

For Site 1 (wet site), the distance between the probes was varied from 0.3 to 1.8 m, in steps of 0.3 m during the experiment. This distance could not be extended in a straight line due to the location of the drain. A generator (Fluke meter 1625) was used to inject a current I, between two outer probes (1 and 4). The potential V was then measured between two inner probes (2 and 3) by the Fluke meter and finally the soil resistance was measured by the meter. The measurement was repeated for each a and the corresponding resistance value was tabulated in Table 1.

The corresponding value of the resistivity in Table 1 for each of these measured soil resistance values was then calculated theoretically, by using the following mathematical expression for $a \gg b$ [19]:

$$\rho = 2\pi a R_e \tag{1}$$

where ρ is originally given by [15],

$$\rho = \frac{4\pi a R_e}{\left(1 + \frac{2a}{\sqrt{a^2+4b^2}} - \frac{a}{\sqrt{a^2+b^2}}\right)} \tag{2}$$

2.3 Ground resistance measurement

In this scheme, a grounding grid with rods was used for Site 1. The grid was made of eight equal-length copper electrodes, four of which were placed vertically (to be inserted into the ground as rods) and the other four were placed horizontally as shown in Fig. 2. The length and the diameter of each rod used for this experiment were 1.689 m and 14 mm, respectively. For Site 2 (dry soil site), the grid without rods was chosen due to the hard, and brittle soil structure. This grid was made of two by three copper electrodes (two electrodes along the length and three electrodes along the width) as shown in Fig. 3. In this case, the length and the diameter of each copper electrode were kept the same as the copper rod used for 'grid with rod' setup. Both measurement sites were dug to a depth of 0.5 m based on the IEEE 80-2000 Standard [20] on the minimum burial depth. For Site 1, the grid with rod was placed in the dug hole and earth tester equipment was connected to the grid as shown in Fig. 2. The inner and outer probes of the equipment were inserted vertically into the soil at a depth of 0.25 m. Then the earth electrode, inner probe and outer probe were connected to the terminals of earth-electrode ($HC1$), inner probe ($SP2$) and outer probe ($HC2$), respectively. According to the fall-of-potential method [16], the ratio between the distances x and D were always maintained to be 0.62 where x is the distance between $HC1$ and $SP2$ while D is the distance between $HC1$ and $HC2$ shown in Fig. 2. With this arrangement, the values of ground resistances were measured with the Fluke meter by varying the distance D and the corresponding x-distance to ensure that $x/D = 0.62$ from 1.5 to 9 m, in steps of 1.5 m. These results are shown in Table 2. For Site 2, similar procedure was carried out by burying the 'grid without-rod' into the dug hole as shown in Fig. 3. In this case, the measured ground resistances are shown in Table 3.

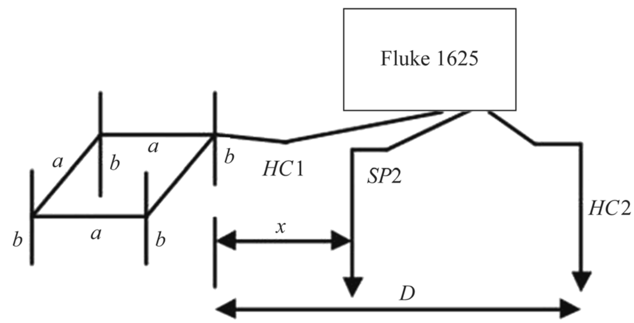

Fig. 2 Connection of grid with rods

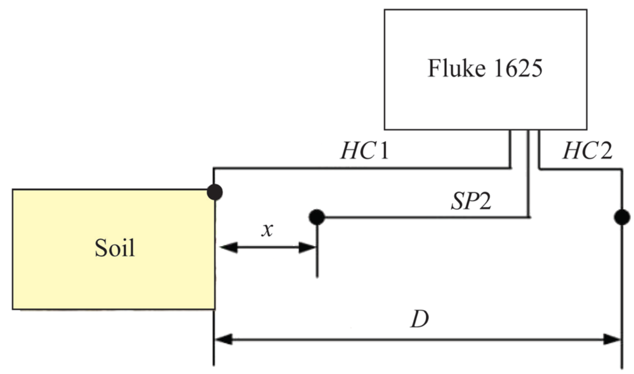

Fig. 3 Connection of grid without rods

3 Simulation results and discussion

In the Cymgrd simulation, two-layer soil model [20] was used to calculate ground resistance, ground potential rise and other relevant parameters. To simulate ground resistance, step and touch potentials, the body weight, surface layer thickness, surface layer resistivity and shock duration

Table 2 Soil resistivity data for dry soil

Probe distance (m)	Soil resistance, R_e (Ω)	Soil resistivity, ρ (Ω m)
0.3	71	133.83
0.9	38.09	215.4
1.5	28.88	292.17
2.1	19.5	257.3
2.7	14.17	240.4

Table 3 Measured ground resistance at the wet soil

Distance, D (m)	Distance, x (m)	R_e (Ω)
1.5	0.93	7.08
3.0	1.86	7.57
4.5	2.79	7.13
6.0	3.72	7.75
7.5	4.65	7.09
8.5	0.93	7.08

were considered to be 70 kg, 0.2 m, 2500 Ω m, and 0.5 s, respectively. These values were chosen according to the IEEE standard [20]. A two-layer soil model is generally represented by an upper layer soil of a finite depth h, sitting above a lower layer of infinite depth. In the simulation phase, the apparent resistivity has been calculated by the equation provided in [19]. In the simulation process, the measured soil resistivity values from Table 1 were first entered into the software from which the resistivity and length graph was generated by the software after discarding the doubtful data-points, as shown in Fig. 4. Same procedure was carried out for the soil resistivity data items in Table 4 and in this case, the resulting resistivity and length graph was obtained as shown in Fig. 5. The soil analysis reports are shown in Table 5 and Table 6 at the wet and dry soils, respectively, where the input parameters were set (for the software) according to the IEEE standard, and the output parameters were obtained as a result.

As shown in Table 5, it is found that the calculated upper-layer and lower-layer resistivity values are 26.19 and 47.13 Ω m, respectively. Also, the rms error, maximum permissible touch and step potentials are found to be 0 %, 903.32 and 2947.19 V, respectively. The rms error 0 % represents higher accuracy between the measured and simulation soil resistivity. In case of dry soil (shown in Table 6), the rms error, maximum permissible touch and step potentials are found to be 4.92 %, 671.58 and 2194.17 V, respectively. From these comparisons, it is observed that the rms error, step and touch potentials are slightly greater in case of dry soil. In the simulation, the burial depth of the grid into the soil with and without rods

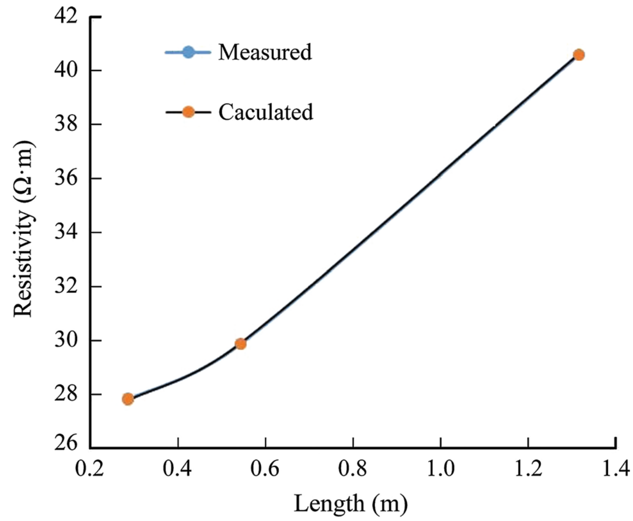

Fig. 4 Wet soil analysis report

Table 4 Measured ground resistance at the dry soil

Distance, D (m)	Distance, x (m)	R_e (Ω)
1.5	0.93	83.8
3.0	1.86	57.1
4.5	2.79	49.3
6.0	3.72	43.7
7.5	4.65	42.9
9	5.58	34.5

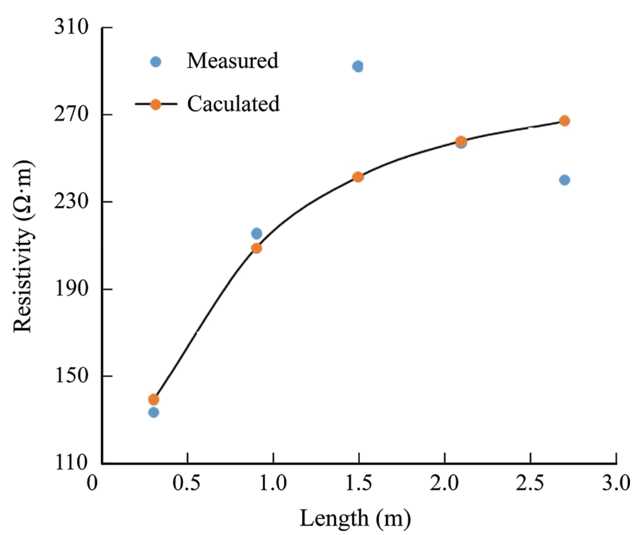

Fig. 5 Dry soil analysis report

was considered to be 0.5 m to find the ground related parameters. The grid (with and without rods) analysis reports using wet and dry soils are shown in Table 7 and Table 8, respectively. From Table 3 and Table 7, it is

Table 5 Grid analysis report for wet soil

Input Parameter	
Bus ID	66 kV
Nominal frequency	50 Hz
LG Fault Current	1000 A
Remote contribution	100 %
Upper Layer Thickness	0.55 m
Upper Layer Resistivity	26.19 Ω m
Lower Layer Resistivity	47.13 Ω m
Output Parameter	
Ground Potential Rise	7432.08 V
Calculated ground Resistance	7.24 Ω
Equivalent Impedance	7.24 Ω

Table 6 Grid analysis report for dry soil

Input Parameter	
Bus ID	66 kV
Nominal frequency	50 Hz
LG Fault Current	1000 A
Remote contribution	100 %
Upper Layer Thickness	0.3 m
Upper Layer Resistivity	118.17 Ω m
Lower Layer Resistivity	273.8 Ω m
Output Parameter	
Ground Potential Rise	28522.1 V
Calculated ground Resistance	27.87 Ω
Equivalent Impedance	27.87 Ω

Table 7 Grid with rods analysis report for wet soil

Input Parameter	
Bus ID	66 kV
Nominal frequency	50 Hz
LG Fault Current	1000 A
Remote contribution	100 %
Upper Layer Thickness	0.55 m
Upper Layer Resistivity	26.19 Ω m
Lower Layer Resistivity	47.13 Ω m
Output Parameter	
Ground Potential Rise	7432.08 V
Calculated ground Resistance	7.24 Ω
Equivalent Impedance	7.24 Ω

observed that the minimum values of the measured and the calculated (simulation) ground resistances, with the application of grid with rods for the wet soil, are found to be 7.08 and 7.24 Ω, respectively. In this case, the simulated ground resistance is very close to the measured ground resistance. For the dry soil with the application of grounding grid without rods, the minimum values of the measured and the calculated grounding resistance are found to be 34.5 and 27.87 Ω, respectively, as shown in Table 4 and Table 8. In this case, the difference between the measured and calculated ground resistance is slightly larger when compared to the wet soil values. This difference is occurred due to higher soil resistivity values at that site.

Table 8 Grid without rods analysis report for dry soil

Input Parameter	
Bus ID	66 kV
Nominal frequency	50 Hz
LG Fault Current	1000 A
Remote contribution	100 %
Upper Layer Thickness	0.3 m
Upper Layer Resistivity	118.17 Ω m
Lower Layer Resistivity	273.8 Ω m
Output Parameter	
Ground Potential Rise	28522.1 V
Calculated ground Resistance	27.87 Ω
Equivalent Impedance	27.87 Ω

The color coded bar, obtained from the simulation for the grid with rods for wet soil is shown in Fig. 6. A region colored between green and light blue in the bar represents that the values of the touch potentials within that region are less than 25 % of the maximum permissible touch potential of 667.42 V. On the other side of the bar, a region colored between purple and red represents that the values of the touch potentials within that region are higher than 75 % of the maximum permissible touch potential. The region beyond 100 % of the maximum permissible touch potential represents unsafe condition. The purple color about 75 % region represents the surface potential which characterizes safe grounding system. Same explanation can be drawn in case of grid without rods as shown in the color coded bar in Fig. 7. The maximum permissible touch potential for the grid without rods for dry soil is 671.85 V, which is slightly higher than the grid with rods for wet soil. However, the touch potentials for grids with and without rods are approximately 2.6 and 11.5 kV for the wet and dry soils respectively as shown in the contour curves given in Figs. 8 and 9. The touch potential of grid without rods for dry soil is found to be way larger than the grid with rods for the wet soil and, this was an expected result. The potential profile plots for grid with and without rods for wet and dry soils are shown in Figs. 10 and 11, respectively. The ground potential rise (GPR) of the grid with rods for wet soil is found to be 7432.08 V, whereas this value is 28522.10 V for the grid without rods for dry soil as can be seen in Table 7 and Table 8, respectively. The extremely high GPR for the dry soil site is obtained due to its high ground resistance.

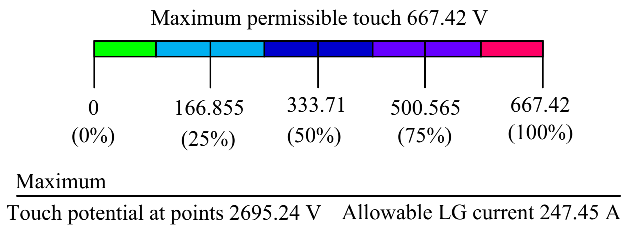

Fig. 6 Color coding of grid for wet soil

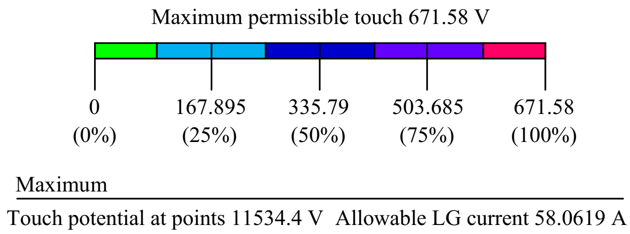

Fig. 7 Color coding of grid for dry soil

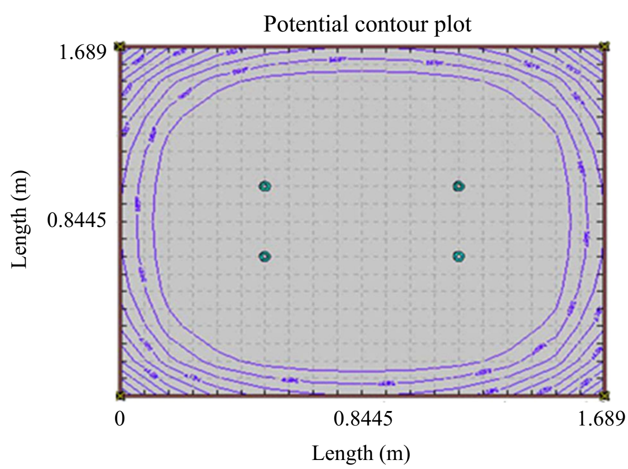

Fig. 8 Touch potential contour plots of grid for wet soil

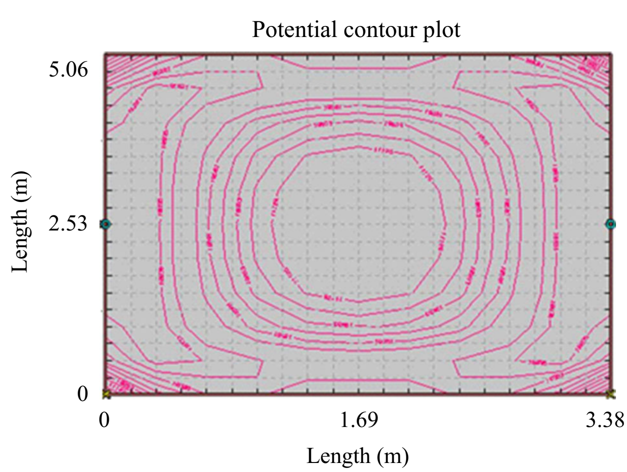

Fig. 9 Touch potential contour plots of grid for dry soil

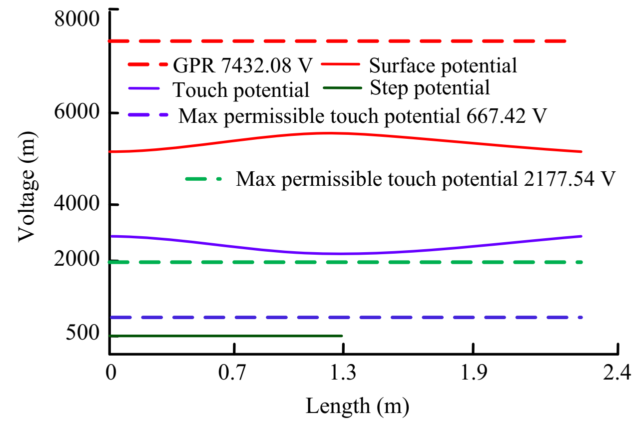

Fig. 10 Potentials profile of grid for wet soil

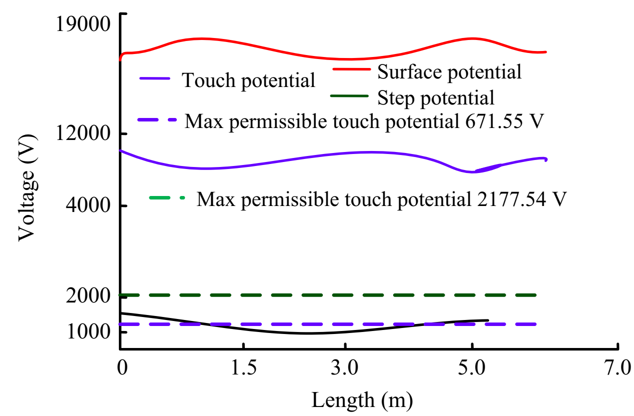

Fig. 11 Potentials profile of grid for dry soil

4 Conclusion

The soil resistivity at the two selected sites near Gadong 66 kV substation has been measured and simulated by Cymgrd software. The rms errors between the measured and calculated soil resistivity values are found to be 0 % and 4.92 %, respectively. The minimum values of the measured ground resistances have been found to be 7.08 and 34.5 Ω using the grid with and without rods at the wet and dry soils sites, respectively. Based on the soil (wet and dry) resistivity data and grid configuration, the simulated grounding resistance values have been obtained as 7.24 and 27.8 Ω for the grids with and without rods. From these findings, it has been observed that the measured ground resistances match closely to the simulated grounding resistance values especially for the grounding grid with rods at the site of the wet soil. The GPR in case of the grid without rods for dry soil is found to be extremely higher than that of the grid with rods for the wet soil due to the higher resistance value encountered in the dry soil.

References

[1] Dawalibi FP, Ma J, Southey RD (1994) Behaviour of grounding systems in multilayer soils: a parametric analysis. IEEE Trans Power Deliv 9(1):334–342
[2] Chow YL, Salama MMA (1994) A simplified method for calculating the substation grounding grid resistance. IEEE Trans Power Deliv 9(2):736–742
[3] Thapar B, Gerez V, Balakrishman A et al (1991) Evaluation of ground resistance of a grounding grid of any shape. IEEE Trans Power Deliv 6(2):640–647
[4] Guemes JA, Hernando FE (2004) Method for calculating the ground resistance of grounding grids FEM. IEEE Trans Power Deliv 19(2):595–600
[5] Puttarach A, Cchakpitak N, Kasirawat T et al (2007) Substation grounding grid analysis with the variation of soil layer depth method. In: Proceedings of the 2007 IEEE Lausanne power tech conference, Lausanne, Switzerland, 1–5 July 2007, pp 1881–1886
[6] Southey R, Ruan W, Dawalibi F et al (2009) Measurement and interpretation of ground impedance of substations by non-conventional fall-of-potential methods. In: Proceedings of the 2009 international conference on electrical engineering (ICEE'09), Shenyang, China, 5–9 July 2009, 3 pp
[7] Hajebi P, Heidari AA, Mirzaei A (2010) Resistance to earth of grounding grids in two-layer soil structure using FEM and GA. In: Proceedings of the progress in electromagnetics research symposium (PIERS'10), Xi'an, China, 22–26 Mar 2010, pp 132–135
[8] Güemes JA, Rodriguez F, Ruiz JM et al (2003) Determination of the ground resistance and distribution of potentials in grounding grids using FEM. In: Proceedings of the international conference on renewable energies and power quality (ICREPQ'03), Vigo, Spain, 9–12 Apr 2003, pp 1–4
[9] He JL, Zeng R, Gao YQ et al (2003) Seasonal influence on safety of substation grounding system. IEEE Trans Power Deliv 18(3):788–795
[10] Choi JK, Ahn YH, Woo JW et al (2007) Evaluation of grounding performance of energized substation by ground current measurement. Electr Power Syst Res 77(11):1490–1494
[11] Nor NM, Rajab R, Ramar K (2008) Validation of the calculation and Measurement techniques of earth resistance values. Am J Appl Sci 5(10):1313–1317
[12] Thapar B, Ferrer O, Blank DA (1990) Ground resistance of concrete foundations in substation yards. IEEE Trans Power Deliv 5(1):130–136
[13] Salam MA, Al-Alawi SM, Maqrashi AA (2006) An artificial neural networks approach to model and predict the relationship between the grounding resistance and length of buried electrode in the soil. J Electrostat 64(5):338–342
[14] Salam MA (2012) Grounding resistance measurement by grid electrode in Brunei Darussalam. Int J Energy Technol Policy 8(2):196–208
[15] Androvitsaneas VP, Gonos IF, Stathopulos IA (2014) Artificial neural network methodological for the estimating of ground enhancing compounds resistance. IET Sci Meas Technol 8(6):552–570
[16] Salam MA (2013) Grounding resistance measurement using vertically driven rods near residential areas. Int J Power Energy Convers 4(3):238–250
[17] Yang L, Qin BQ, Luo F et al (2014) Field experimental study on the measurement of grounding resistance of buildings in water. In: Proceedings of the 2014 international conference on lightning protection (ICLP'14), Shanghai, China, 11–18 Oct 2014, pp 942–945
[18] Clark D, Guo DS, Lathi D et al (2014) Controlled large-scale tests of practical grounding electrodes—part II: comparison of analytical and numerical predictions with experimental results. IEEE Trans Power Deliv 29(3):1240–1248
[19] IEEE Std 81-2012 IEEE guide for measuring earth resistivity, ground impedance, and earth surface potentials of a ground system, 2012
[20] IEEE Std 80-2000 IEEE guide for safety in AC substation grounding, 2000

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