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PERFORMANCE OF ELECTRICAL GROUNDING SYSTEM IN SOIL AT LOW MOISTURE CONTENT CONDITION AT VARIOUS COMPRESSION LEVELS

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Abstract

The paramount of an effective grounding system is to safeguard building, equipment and human beings from electric hazard in the event of earth faults. Effective grounding system is a crucial feature and yet concepts of electrical grounding system are still less likely to be emphasized which leads to electric hazards. Soil resistivity plays a major factor in designing the grounding system along with the contact resistance between the grounding electrode and soil and the arrangement of the electrodes in a grounding system to ensure ground electrodes have sufficiently low resistance to minimize potential shock. It is more difficult and complex to design and install a grounding system in an area where the soil resistivity is high due to the low moisture content of the soil. Moisture content and compression level of soil are the major components that govern the soil resistivity. The objective of this study is to investigate the effect of the moisture content and compression level of soil on the performance of an electrical grounding system at low moisture content. Hence, quantitative study has been conducted. Clay and fine sand samples were dried in the oven at 110 ± 5°C to ensure the water content on both samples is 0% before proceeding to the experiment. The soil resistivity of the samples at various moisture content and compression level was then calculated respectively in a laboratory setup. From the soil resistivity results, the ground resistance was computed starting from the simplest grounding system configuration to horizontal buried strip configuration. From the computed ground resistance, it was found that the ground resistance decreased with the increased of moisture content and compression level of soil respectively in which this further justified that such factors were having influences on the overall effectiveness of the grounding system.

Keywords: Soil resistivity, Grounding system, Soil compaction, Ground electrode, Low moisture content.

1. Introduction

The objective of electrical grounding system is to ensure effective protection of system or equipment in the event of earth fault currents by disconnecting the source of energy from the system or equipment to avoid impacts of excessive currents produced under earth fault conditions [1]. Electrical grounding system is utilized to drain off unwanted flow of electrical charges such as fault and lightning induced currents to the earth or return to the generator via earth mass [2, 3]. In other words, the function mechanism of an electrical grounding system is to provide protective grounding, functional grounding in electrical power systems and lightning protection that serves to not only safeguard building and equipment but also more importantly to protect people [4, 5].

Although an effective grounding system is referred as one of the most crucial features in the event of electrical design and installations, yet concepts of electrical grounding in electrical industry are still less likely to be emphasized or rather misunderstood despite knowing that failure of achieving effective grounding may lead to serious damages including fatalities [6]. In this context, there were 64 accidents related to electricity involving 27 fatalities throughout Malaysia in year 2014 [7, 8]. Among the major causes of these disastrous events was due to the poor consideration of safety work procedures in the event of installation and maintenance [8]. As a result of these accidents, the design of electrical grounding has been seriously taken into considerations as it is the major parameter that affects the behaviour of earth fault in an electrical power system [9, 10].

However, there are chances that the electrical grounding system may not perform satisfactorily due the connection of the system to earth is not adequate for the particular installation. That being said, the ground connection plays a crucial role in ensuring the whole electrical safety grounding system performs satisfactorily and one of the most fundamental designs of the system is to ensure the ground electrodes have sufficiently low resistance for grounding to minimize potential for shock and limit transient overvoltage. Ideally, the lower the ground resistance, the better the grounding system in terms of adequately meeting the requirements. Yet, the value of ground resistance varies from different installations as larger systems with higher levels of fault current requires lower ground resistance than smaller systems which yield lower level of fault current. In general, ground resistance ranging from 1 ohm to 5 ohm is suitable for large commercial installations and industrial plant substations and building as stated in IEEE 142-2007 Green Book [11].

Referring to [12-15], it is well known that soil resistivity plays a key factor in determining the design of an effective electrical grounding system and lightning protection system due to the fact that the soil resistivity will affect the depth of a grounding electrode to be driven in order to attain low ground resistance. The soil resistivity varies widely depending on the geological structure of the ground due to the several factors that govern the parameter of the soil resistivity and the most significant ones are moisture content, chemical composition, soil compaction, temperature, vertical thickness, depth and divisions. That being said, the design of the ground electrode is highly dependent on the profile of soil resistivity in order to achieve low ground impedance [13]. However it is important to realize that at low frequency, the ground impedance can be represented by a single resistor which means capacitive and inductive reactance are assumed to be negligible. Hence, ground impedance is equal to ground resistance on low frequency behaviour of grounding system.

Under ordinary soil condition where the moisture content in the soil is relatively high, the grounding configurations required are usually simpler due to the low resistivity of soil. However, this is not true when the moisture condition of the soil is low in which the soil resistivity is high. When the soil resistivity is high, it is more difficult to design and install a grounding system where its ground resistance is low enough to dispose the unwanted current during the ground fault. This is because the computation of ground resistance for an effective grounding system is greatly affected by the soil resistivity. That being said, in order to achieve a low ground resistance in a high resistivity soil, a more complex of grounding configuration is usually required.

Unlike the enormous amount of research which has been conducted on studying the relationship of moisture content and compression level of soil to the soil resistivity respectively, there is still limited research done on the influence of moisture content and compression level of soil to the performance of an electrical power grounding system especially at low moisture content [1-2, 4-6, 13, 15]. Hence, this work is conducted to determine the influence of these two factors to the electrical grounding system at low moisture content condition. Therefore in this research topic, two different types of soil samples which are clay and fine sand would be measured at various moisture composition and different compression level respectively in a laboratory setup to study the influence of these two factors on the computation of ground resistance of a typical electrical power grounding system during low frequency behaviour. In nature, the sand and clay can hold up to 88% and 50% of moisture weightage respectively. Hence, moisture content below 10% is regarded as low for these two types of soil [16].

The obtained soil resistivity measurement values are then compared with the values from literature. On the other hand, the ground resistance is calculated based on the obtained measurement values of soil resistivity and hence is computed accordingly starting from the simplest grounding system configuration.

Based on surveyed literature [2, 12-15], most of the studies conducted stop at the stage of soil resistivity. The researchers did not proceed further to discuss the effects of factors that govern the soil resistivity on the performance of an electrical grounding system especially at low moisture content. One related research is to study the relationship of soil resistivity with moisture content. However, the impact of moisture content on the performance of a grounding system has yet to be discussed and addressed quantitatively. This implies the necessity of conducting this research study in order to investigate the factors that affect the soil resistivity and how these factors possess a direct impact to the overall effectiveness of a grounding system.

This investigation serves to contribute to the electrical grounding system field by providing a quantitative study on the variation of moisture content and compression level of soil in designing the most adequate electrical grounding system when the soil is of low moisture content condition. In this context, the value of ground resistance at different moisture content and compression level of soil is determined and hence can be used as a reference value in the event of designing and installing an effective grounding system. That being said, this research topic links the study of factors that affect the soil resistivity conducted by other researchers to the performance of a grounding system.

2. Literature Review

Grounding system is necessary for any electrical power system and soil resistivity is one of the major factors that determine its performance. These factors also include the size and geometry of the ground electrode connected to the system. Environmental effects such as proximity of ground electrode to trees, slopes and water containment should not be discounted as well and this is also why localised soil resistivity should be considered when designing grounding systems [17, 18].

There are four main types of soils that can be commonly found in Malaysia and it can be grouped into clay and clay soil, peat soil, acid sulphate soils and sandy soil [19]. Soil can be generally characterized based on its composition, colour, texture, soil water, organic matter, structure and chemistry as stated in [20]. Soil resistivity is an indication of a soil's ability to conduct flow of current and is determined by the transport of ions dissolved in moisture. Soil resistivity can be defined as resistance measured between the opposite sides of a cube of soil with a side dimension of 1 meter [13]. Besides, soil resistivity has a direct effect on the resistance of a grounding system and is largely determined by the composition of soil itself according to [1].

According to [21], there are other factors affecting the soil resistivity other than the type of soil itself. These factors include temperature, moisture, salt content and compactness of the soil. The relationship of these factors towards the soil resistivity respectively can be explained by referring to the graph as shown in Fig. 1. Figure 1 illustrates the effects of moisture content, temperature and salt content upon soil resistivity. It can be clearly seen that with the increment of percentage in salt content, moisture and temperature, the soil resistivity decreases. On the other hand, it is observed that the effect on soil resistivity is minor once the moisture content exceeds approximately 22% as shown in IEEE Std-80-2000 [22]. Moisture content is one of the main factors governing the parameter of the soil resistivity, this is due the flowing of electricity in soil is essentially electrolytic. This can be further proven by referring to Fig. 1 where the soil resistivity of sand soil increases abruptly whenever the moisture content accounts for less than 15% of the soil weight. This is due to the presence of moisture content allowing the conduction of electricity through movement of ions in pore water [23].

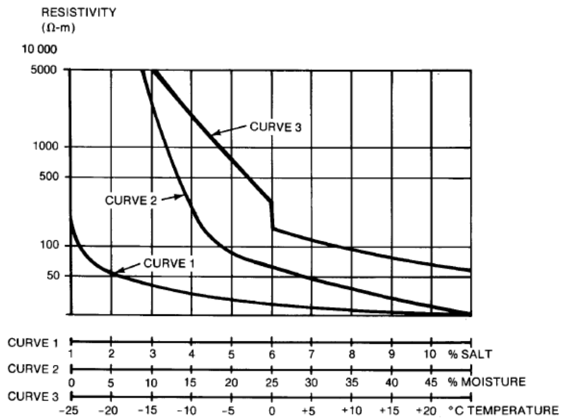

Fig. 1. Effects of moisture, temperature and salt content upon resistivity on sand soil [22].

3. Research Methodology

The methodology consisted of quantitative investigation regarding (i) the influence of moisture content on the performance of an electrical power grounding system and (ii) the influence of compression level of soil on the performance of an electrical power grounding system. The measurement values of soil resistivity at (i) and (ii) were then compared with the values from literature. From the obtained results at (i) and (ii), the ground resistance was computed starting from the simplest grounding system configuration. This research topic was conducted quantitatively in a laboratory experimental setup to study the influence of moisture content and compression level of soil to ground resistance at low moisture content. Laboratory experiment was chosen over on-site measurement because in the latter, moisture content and compression level cannot be controlled. Soil resistivity of two types of soils, clay and fine sand at various moisture content and compression level respectively were recorded and quantitative analysis of the factors influencing the parameters of ground resistance were done. An overall flow chart as shown in Fig. 2 was constructed to provide an overview to this research topic.

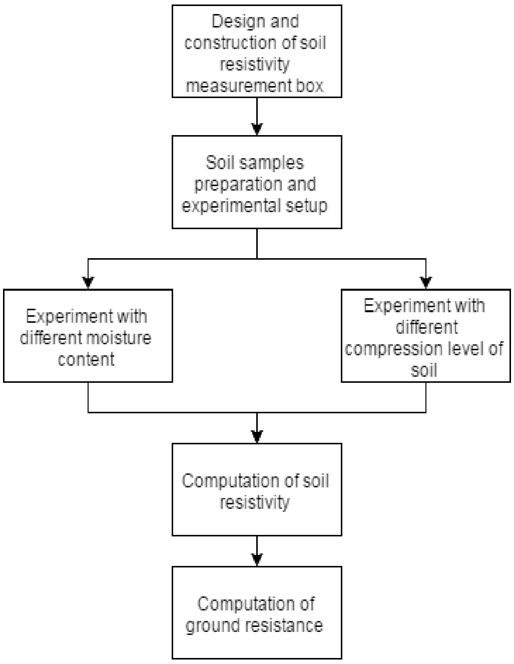

Fig. 2. Flow chart of the overall research topic.

3.1. Design and construction of soil resistivity measurement box

The design of the soil resistivity measurement box is referred to [24] and design sketches of the soil resistivity measurement box are shown in Fig. 3. The required tools and materials for the construction of soil resistivity measurement box were acrylic sheet, screws, aluminium conductive plate, washers, rubber, washer and nut set. The outer part of the soil box was constructed using acrylic sheet as it provides good electrical insulation, greater impact resistance than glass, crack resistance and chemical resistance. The purpose of using acrylic sheet is to prevent the soil box from cracking sideways when the soil in it is compressed during the investigation of soil resistivity at various compression levels. The aluminium conductive plates in this context acted as electrode to allow conduction of electrical current. Referring to Fig. 3, the electrode was locked using screws at both side of the soil box respectively. This allowed the experiments of measuring the soil resistance to be easily carried out as the Kelvin clips from the LCR meter could be connected to the screws at both side of the soil box respectively.

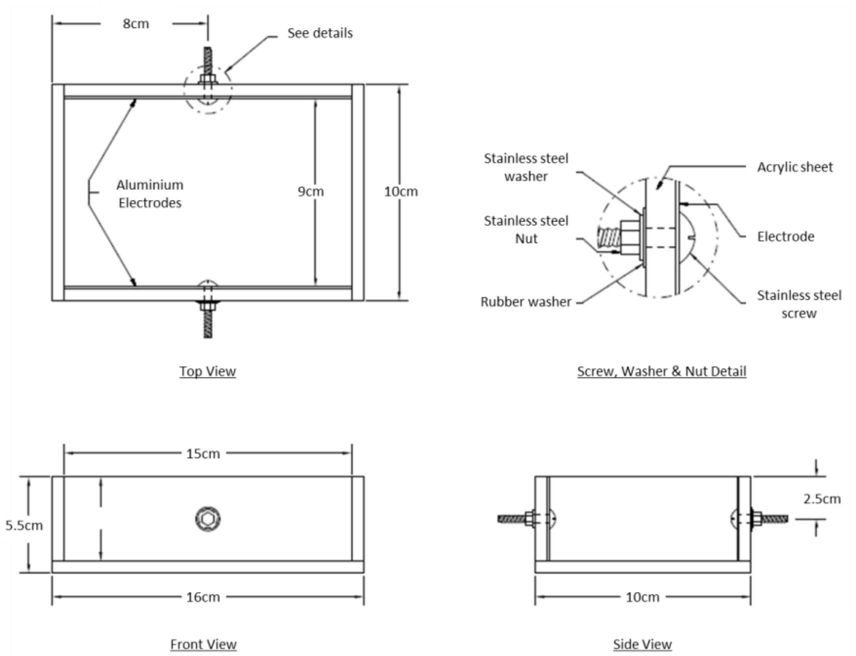

Fig. 3. Design sketches of the soil resistivity measurement box in top view, front view, side view and detailed illustration of screw, washer and nut [24].

3.2. Soil samples preparation and experimental setup

In this process, LCR meter was used to measure the resistance of the soil and then later computed to soil resistivity by multiplying to the soil box factor. The types of soil samples prepared for the investigation were clay and sand. The purpose of conducting the research study using these two types of soils is due to the difference of texture and composition in the soils hence ground resistance from two different types of soils can be computed and analyzed. 500g of each type of soil was used to conduct the experimental study. The soil box was designed in a smaller scale to ensure the current is able to flow through the soil. This is because the further the distance between the electrodes, the ability of current to flow through the soil is weaker hence the soil resistance reading obtained in the LCR meter might be inaccurate. Usage of 500g of soil was to ensure the soil filled in the volume of the soil box hence increasing the contact of the soil with the electrodes in order to obtain a more stable soil resistance value. The experimental setup process flow was prepared as shown in Fig. 4.

Fig. 4. Experimental setup process flow.

Before proceeding to the experimental stage, the clay and sand samples were dried in the oven at 110±5°C for 16 hours to obtain constant mass of the soil samples as stated in ASTM D2216 [25].

The volumetric water content (VWC) of wet soil is spatial and temporal in nature. Hence, it is difficult to obtain a predefined VWC. Therefore, volumetric water content test was done to reduce the error while commencing the experiment. The preparation of volumetric water content test was accomplished in 3 steps starting from calculating the bulk density of the dry soil then followed by calculating the approximate amount of water to achieve the target percentage and adding water to the dry soil. The actual volumetric water content of the soil was calculated hereafter [26]. The bulk density of the dry soil can be expressed as:

$$\rho_{bulk} = \frac{mass\ of\ dry\ soil}{volume\ of\ dry\ soil} \tag{1}$$

The approximated volume of water to be added to the soil samples to achieve the target moisture content can be calculated by referring to Eq. (2) which is expressed as:

$$Volume\ of\ water = VWC \times \frac{mass\ of\ soil}{bulk\ density\ of\ the\ soil} \tag{2}$$

After adding the calculated amount of water to the soil, the actual VWC of the soil can be obtained by referring to Eq. (3).

$$VWC_{actual} = \frac{Volume\ of\ water}{Total\ volume\ of\ wet\ soil} \tag{3}$$

Figure 5 refers to the experimental setup of the investigation where the Kelvin clips from the LCR meter were connected to the two ends of the screws as shown in Fig. 5. From this, the soil resistance value was obtained from the LCR meter as shown in Fig. 6.

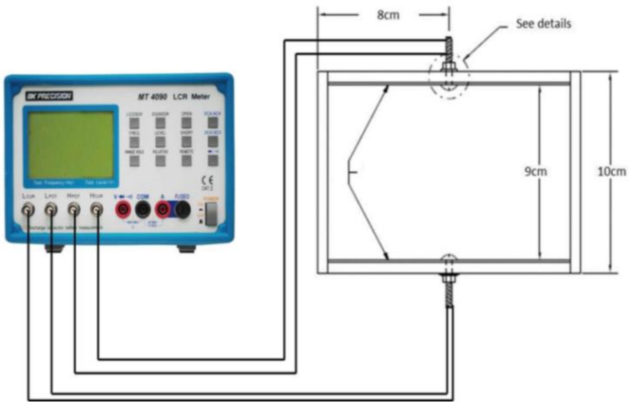

Fig. 5. Connection of LCR meter to the soil resistivity measurement box.

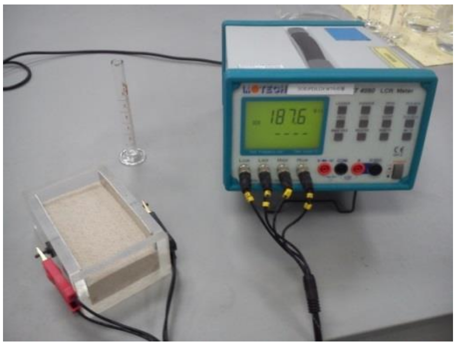

Fig. 6. Actual experiment setup.

3.3. Experiments with different moisture content

Due to the maximum weightage of moisture content that clay and sand can hold in nature is 50% and 88% respectively, hence moisture content below 10% on these types of soil is considered significantly low. The experiment was conducted at moisture content from 1% to 10% based on the percentage of water used for 500g of original oven dried soil to investigate the soil behaviour at low moisture content. For example, a constant volume of water based on the target volumetric moisture content was added consistently and mixed thoroughly into the oven-dried soil and the soil resistance value reading from the LCR meter was recorded. The test was then repeated at the same procedure until the volumetric water content reaches 10%. In this context, a constant pressure of 30 kPA was applied before taking any reading from the LCR meter to reduce the error due to different compaction level of the soil. The purpose of conducting the experiment at a range of 1% to 10% is due to the significant changes of soil resistivity at this range based on the surveyed literature [1, 22].

3.4. Experiments with different compression level of soil

The variation of soil compression level was done using the Newton Weights to compress the soil sample in the soil box. The soil samples were exposed to the applied pressure of 5, 10, 15, 20, 25, 30, 35 and 40 kPA successively and the soil resistance reading on the LCR meter were recorded for each applied pressure.

3.5. Computation of soil resistivity

Do notice that the readings obtained from the LCR meter was soil resistance and in order to convert it to soil resistivity the soil box factor (SBF) was taken into consideration when calculating the soil resistivity as stated in [24]. The soil resistivity can then be computed by multiplying the SBF with the soil resistance reading obtained in the LCR meter. The SBF can be expressed as:

$$SBF = \frac{A}{D} \tag{4}$$

Where A = area of one electrode in m^2, D = distance between electrodes in m.

$$\rho = SBF \times R_{soil} \tag{5}$$

where ρ = soil resistivity in Ωm, R = soil resistance in Ω. At this stage, the soil resistance obtained from the moisture and compression experiments was converted to the soil resistivity and the ground resistance can be computed hereafter. Graphs of soil resistivity against moisture content and applied pressure on soil were plotted to provide a better understanding on the relationship between these three values.

3.6. Computation of ground resistance

The final and most crucial process in the methodology of this research topic is to compute ground resistance based on the measurement value of soil resistivity obtained. From the surveyed literature, most of them may have provided the relation of soil resistivity with moisture content and compression level respectively. However, relationship between ground resistance with moisture content and compression level respectively has yet to be demonstrated in a quantitative manner.

The connection to ground of a system in general contains complex impedances, resistance, capacitance and inductance. These resistive, capacitive and inductive components determine the current-carrying capabilities of a grounding system. That being said, ground impedance determines the effectiveness of a grounding system [21]. Several studies have been conducted on the behaviour of grounding system which includes electrical characteristics of soil under high voltage or current impulse conditions [27-33]. Vertical single ground rod is one of the most commonly used grounding electrode system for grounding due to its simplicity in approximating the grounding resistance at low frequency especially at 50 or 60 Hz [34]. Ground impedance is usually measured at low frequencies in an electrical power system and it can be represented by a single resistor under such condition [34, 35]. Figure 7 refers to the low frequency equivalent circuit for vertical ground rod.

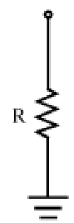

Fig. 7. Low frequency equivalent circuit [24]

As mentioned in [1], a grounding electrode has a direct impact on the parameters of the ground resistance. It is affected by the contact resistance between the rod and soil, resistance of the conductor to the connection and the most significant factor is the resistance in the surrounding earth to current flow.

Referring to [1, 21, 36], to compute ground resistance, soil resistivity throughout the volume is assumed to be uniform in this context though it is seldom case in nature. Due to the fact that equations for systems of electrodes are complex, hence it is often expressed only as an approximation and the most common one is the single ground electrode (rod) system and can be expressed as follow:

$$R = \frac{\rho}{2\pi l}\left(ln\frac{4l}{r} - 1\right) \tag{6}$$

where R = resistance in ohms of the ground rod to the soil, l= grounding electrode length, r = grounding electrode radius, ρ = average resistivity in Ωm

Referring to Eq. (6), the ground resistance can be computed with given grounding electrode length and radius and using soil resistivity as the main factor in varying the computation of ground resistance. Once computation for single vertical rod was done, the work can be extended for other common ground electrode configuration such as multiple vertical driven electrodes, plates and horizontal buried strip configurations. Hence, possible conclusion can be drawn on the extent of influence of variation of moisture content and compression strength on different ground electrode configuration.

4. Result and Discussion

In this section, ground resistance of different grounding configurations is computed. Ground resistance of a single driven rod can be approximated by referring to Eq. (6). According to IEEE Std 142-2007, for grounding system consists of 2 to 24 rods having one rod length distance from each other in a line, hollow, triangle or square will provide ground resistance divided by number of rods and multiplied by the factor F as tabulated in Table 1 [11].

Table 1. Multiplying factors for multiple rods.

Number of rods	F
2	1.16
4	1.36
8	1.68
16	1.92
24	2.16

In this context, 3 m length with a diameter of 12.7mm of copper rod is used to compute the ground resistance where the 3 m length meets the code requirement of minimum standard length buried and the small diameter of 12.7 mm rod has an advantage in meeting the driving requirements [37]. For plate type of ground configurations, area of 1.9 m^2 is commonly used [11]. For the evaluation of plate type ground configuration, the equation is expressed as:

$$R_p = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} \tag{7}$$

RP is the ground resistance Ω, ρ is soil resistivity (Ωm) and A is the area of plate in m^2 [11].

If the computed ground resistance from multiple driven rods and plate configuration does not meet the NEC of 25Ω for ground rods [37], a horizontal buried strip grounding configurations can be implemented and it is expressed as:

$$R = \frac{\rho}{P\pi L}\left(ln\frac{2L^2}{wh} + Q\right) \tag{8}$$

where R is the ground resistance Ω, ρ is soil resistivity (Ωm) and L is the length of strip conductor (m), h is the depth of electrode (m), w is the width of conductor (m) , P and Q are the coefficient for different arrangements of electrode. In this case, the coefficient for P and Q for four lengths of strip conductors at 90°C is 8 and 3.6 respectively [1].

4.1. Effect of moisture content on ground resistance

Moisture content is one of the major factors that govern the soil resistivity and affect the performance of an electrical grounding system. Referring to Fig. 8, it is noticed that the soil resistivity decreases with the increment of moisture content for both clay and sand. This is due to the presence of moisture content facilitates the movement of ions in pore water hence allowing the conduction of electricity [22]. The soil resistivity of sand at 0% moisture content is not included in the results as the resistivity is too high to be measured in such moisture condition.

In general, the average resistivity of clay is lower than sand however based on the obtained results as shown in Fig. 8, it is seen that at low moisture condition, the resistivity of clay is greater than sand. This can be explained by referring to literature [38], it is more difficult to remould clay clods at low compaction and dry of optimum water content in which it results in relative large interclod pores of clay in low moisture condition. In such condition, the pores are usually filled with air which is dielectric and the contacts between the inter particles are poor thus this indicates the high soil resistivity of clay in low moisture condition. In contrast, at high compaction and wet of optimum water content, it is easier to remould the clay clods hence the pores become smaller in size and more saturate in which the dielectric air filled pores are reduced whereas the water filled pores increased. Under such condition, the contacts of the inter particle is strong and hence reduces the resistivity of the soil. Referring to [39], due to the level of porosity of clay is higher than sand, the tendency of clay in the absorption of water is greater than sand. Thus, it can be stated that the clay resistivity is significantly more moisture-dependent than sand resistivity. Referring to Fig. 8, it is seen that the clay resistivity continues to drop and it is significantly lower than sand resistivity when the moisture content surpasses 10%. Such statement can be justified by referring to [13, 38] where the findings show that clay resistivity is significantly lower than sand resistivity.

Contrary to common understanding that clay has lower soil resistivity, it is not the case when moisture content is low. In fact in all relevant standards such as IEEE Standard-80, IEEE Standard-81 and IEEE Standard-142, the average value and the range of value of clay resistivity is given without specifying at what moisture content or at what range of moisture content. Resistivity-moisture content curve is only available for sand and rarely for clay [11, 21-22].

Figures 9 and 10 refer to the computed ground resistance of clay and sand samples on different grounding configurations. It is noticed that due to the high soil resistivity caused by the low moisture content, the ground resistance computed by a single driven rod and plate configuration is nowhere in meeting NEC requirements of grounding. Hence, multiple driven rods are considered and even with 24 rods driven, the ground resistance is still appear to be high in low moisture content. Therefore, it is necessary to implement the horizontal strips configuration where the ground resistance of this configuration is highly dependent on the length of the conductor and has minor effect on the width and the depth of the strip as stated in [1]. With such implementation it is noticed that even at low moisture content, the computed ground resistance is much lower compared to other configurations. However, such configuration is very expensive due to the long length of the copper strips conductor and it is difficult to bury into the ground. That being said, such implementation will only be applied in the event of very high soil resistivity whereas in ordinary soil condition multiple driven rods grounding configuration is sufficient.

Besides, it is noticed that the computed ground resistance drops abruptly with slight increase on moisture content in both soil samples and it continues to drop with an increment of moisture content. Referring to Figs. 9 and 10, it can be clearly seen that the 4 horizontal strips configuration is not affected by the moisture content as much as the others configurations. Hence, implementing a 4 horizontal buried strips in a high moisture content soil is considered as excessively designed where such complex design can actually be easily replaced by a simpler grounding configuration. That being said, a less expensive grounding configuration such as single ground rod can be used and this further implies the influence of moisture content on the performance of an electrical grounding system.

From the findings, the ground resistance computed based on the resistivity of clay is higher than sand. Hence it can be stated that clay is not as effective as sand as a grounding medium for moisture content lower than 10% due to its high resistivity. However, type of clay used may also be influential as resistivity value of different types of clay varies.

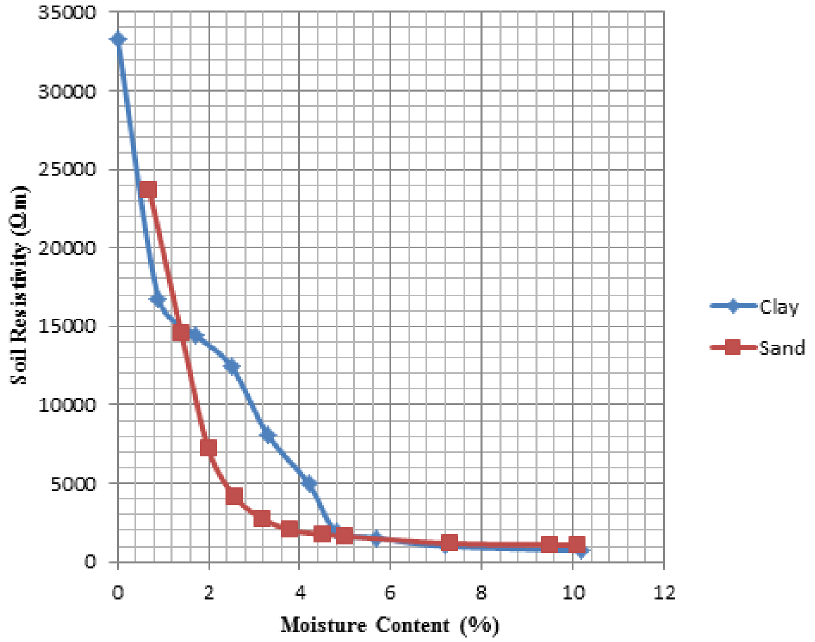

Fig. 8. Soil resistivity of clay and sand at various moisture content.

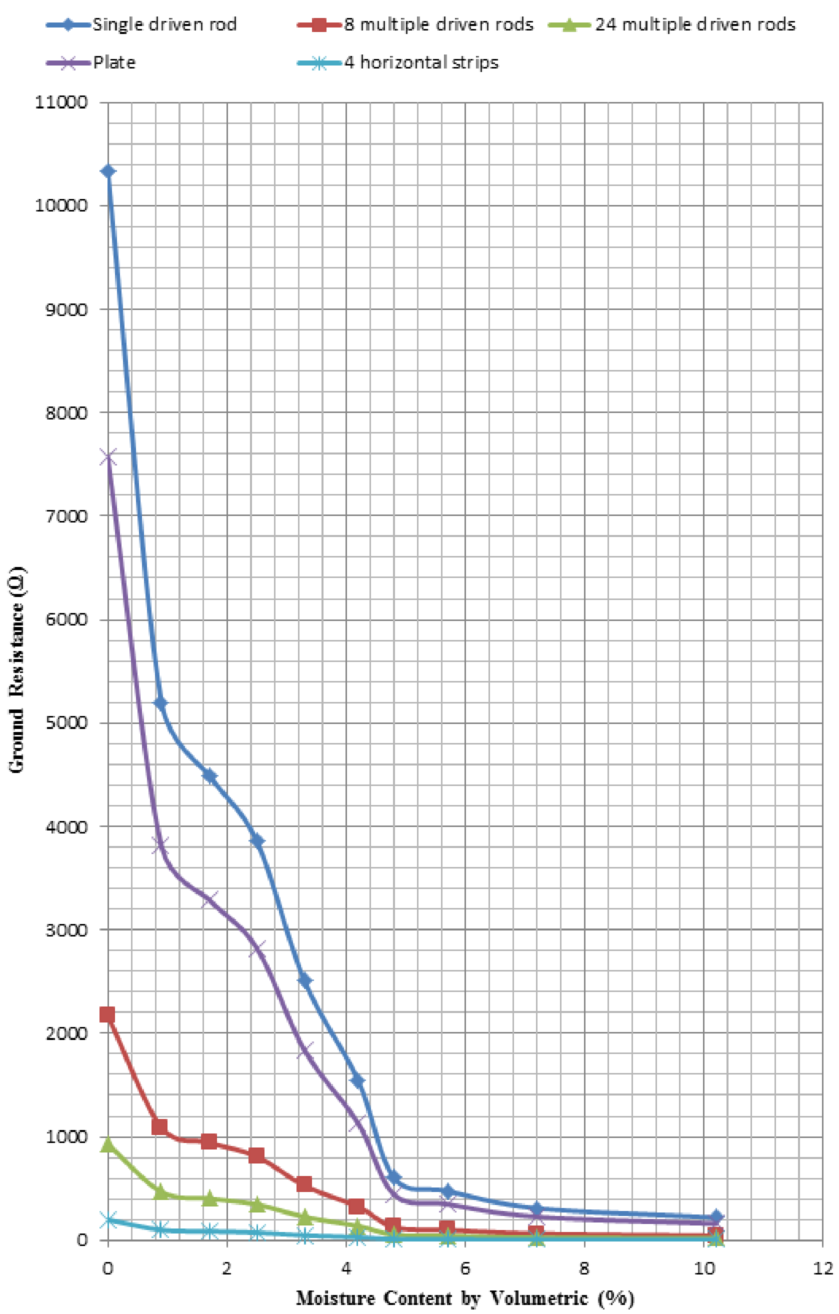

Fig. 9. Ground resistance of different grounding configurations on clay.

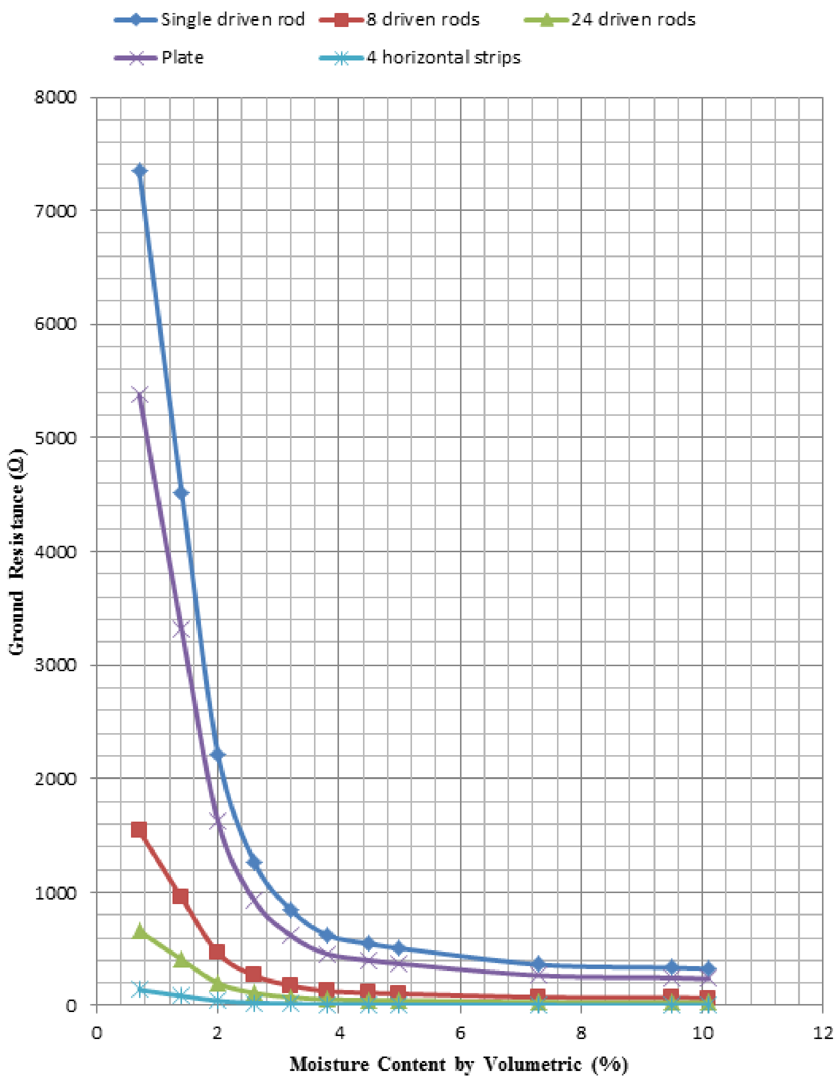

Fig. 10. Ground resistance of different grounding configurations on sand.

4.2. Effect of compression level of soil on ground resistance

In this context, constant moisture content of 2.7% was applied to both clay and sand while conducting the experiment. This is to study the effect of compaction effort at low moisture content as change in compaction effort at high moisture content soil does not significantly affect the soil resistivity as stated in [38].

In the event of soil compaction, the soil particles are pressed together resulting in the reduction of pore space between them. There are few large pore contained in heavily compacted soils in which it will reduce the rate of both water infiltration and drainage from the compacted layer hence this explains that it is effective for water to move through the soil due to the presence of large pores when it is saturated [40]. Referring to Fig. 11, a decrease in the compression level of soil will lead to an increase in the soil resistivity and this is due to the low density of soil causing the soil porosity to be filled with air whereas an air filled void possess a higher resistivity than water filled void [41]. Besides, it is noticed that the soil resistivity of clay drops abruptly even in 10 kPA of applied pressure. This is could be due to the particle size of the clay is smaller than the sand and the porosity level of clay is higher than sand [41]. That being said, clay particle absorb more water than sand particle. In this context, the air void ratio is reduced hence it is easier to become saturated in which it reduces the resistivity. According to [42], air void ratio is affected by the degree of compaction and when the compaction effort increases, the soil resistivity decrease. However, the soil resistivity of clay is still greater than sand is because of the moisture content of the soil is very low. If the moisture content increases, it will reach to a point where the soil resistivity of clay is lower than the sand as shown in Fig. 8 [38, 40].

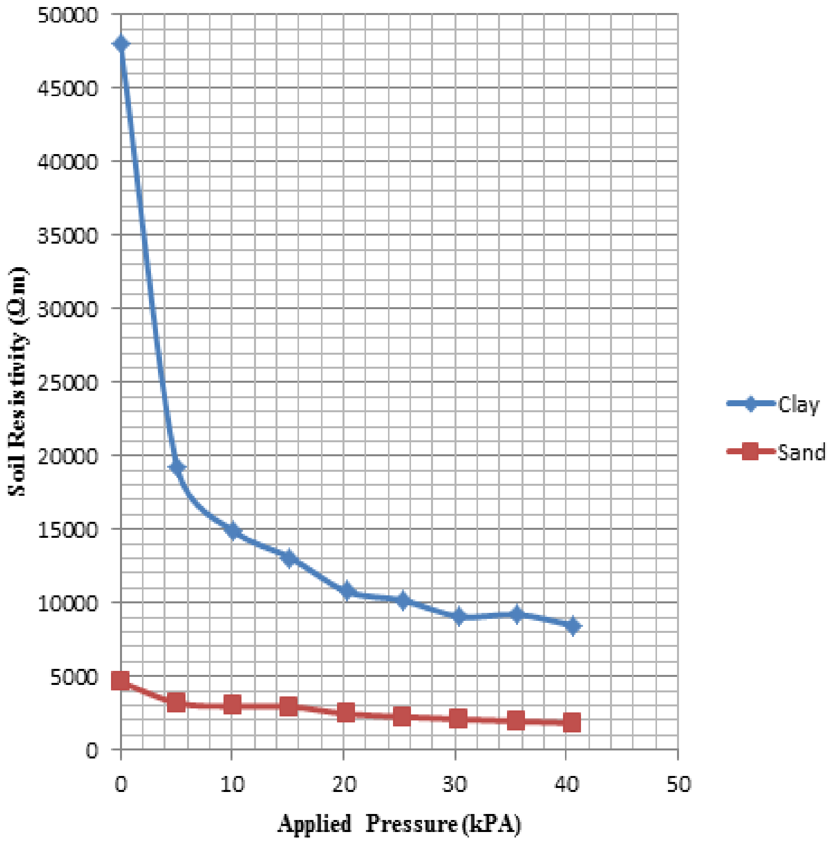

Fig. 11. Soil resistivity of clay and sand at various applied pressure.

Referring to Figs. 12 and 13, it is noticed that level of soil compression has a direct influence towards the computation of ground resistance where the ground resistance drops abruptly with the increase in applied pressure to the soil. This is because by referring to the Eqs. (6), (10) and (11), the soil resistivity plays a major role in determining the computed ground resistance and the soil resistivity varies at different soil compression. Based on these results, compaction should be of concern when filling the trench of buried conductors in grounding systems.

Besides, the change in the soil resistivity due to the increase of compression level of clay is more significant that sand. However, due to the low moisture content, the effectiveness of clay as a grounding medium is lower than sand. Again, this is only for low moisture content and at wet and high compaction effort optimum moisture content, clay is essentially a better grounding medium than sand as clay can be further compressed to saturation that results in the reduction of resistivity [38].

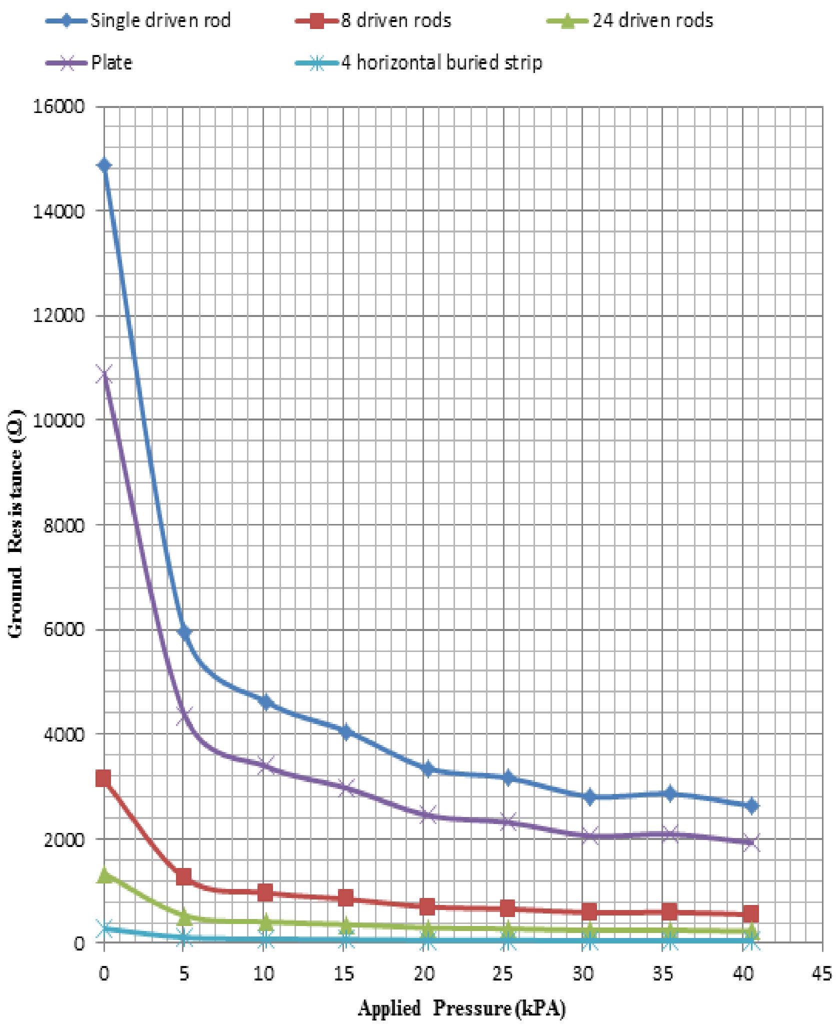

Fig. 12. Ground resistance of different grounding configurations on clay.

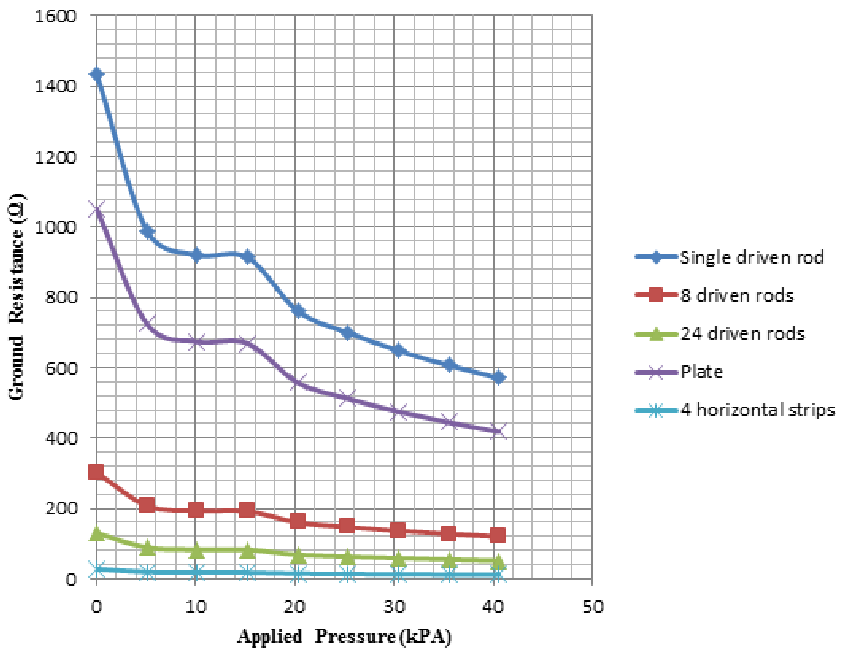

Fig. 13. Ground resistance of different grounding configurations on sand.

5. Conclusions

Effect of moisture content and compression level of soil on the computation of ground resistance respectively at low moisture content have been studied and analysed quantitatively. This investigation only focuses on low frequency behaviour of a grounding system hence capacitive and inductive reactance are neglected. The performance of an electrical grounding system is highly dependent on the value of ground resistance and the ground resistance is governed by the soil resistivity. In this research, it is noticed that both clay and sand decrease in resistivity when the moisture content and the applied pressure increase respectively. This indicates that the ground resistance will decrease too.

From the findings, it is noticed that the resistivity of clay is higher than sand at low moisture content and low compression level. This is possibly because it is difficult for the clay clods to remould at low moisture content. Hence, the pores are large and filled with dielectric air resisting the conduction of current. In this condition, the soil resistivity of the clay is greatly increased to a point that it is greater than sand. However, it is noticed that at moisture content of 10% and more, the clay resistivity drops and becomes lower than the sand. This is due to increase in the presence of water causing the clay clods to be easily remoulded and because clay is more moisture-dependent than soil, it absorbs more water filling the void and the resistivity of water filled void is much lower than dielectric air filled void. In this context, the water facilitates the flow of current causing the overall resistivity to be lower. It is noticed that at 10% moisture content, the effect of moisture content on the sand is minor and this is because the porosity of the sand is lower and the tendency of sand in becoming saturated is easier than clay. When soil is saturated, further increment of moisture content has minor effect on its resistivity.

Besides, results show that the effect of level of compression in clay is greater than sand where the resistivity of clay decreases abruptly when the level of compaction increases. This is due to the particle size of clay is smaller than sand and the porosity is higher resulting in greater air void ratio. Hence the contact between the inter particle for the clay can be increased more with higher compaction whereas due to small air void ratio of sand, a higher compaction will not yield any significant effect on it.

From the experiment, the approximated single ground rod resistance computed at low moisture content and compaction is nowhere meeting the requirement of the NEC standard. As for the horizontal buried strip configuration, even at such condition, the computed ground resistance is low enough to meet the requirement. However, at high moisture content and soil compaction, the difference of the computed ground resistance between the single rod driven configuration and horizontal buried strip condition is very low.

Based on this research, conclusion can be drawn that at either lower moisture content or compression level of soil, a more complex grounding configuration is needed such as the horizontal buried strip electrode to assure the ground resistance computed meets the requirement of the NEC standard. In fact, the compression level of soil is a very important issue when installing grounding system conductors buried in the soil, and it is also recommended to fill the trench with compacted fill material by at least three layers, wetting before compaction, in order to make the system better thus enhancing the benefits of the soil material.

However, when the soil condition is of higher moisture content or more compact, simpler grounding configurations such as single driven rod or multiple driven can be considered to achieve the NEC standard of ground resistance value. Thus it can be concluded that the effectiveness of clay as a grounding medium is lower than sand at low moisture and low compaction level. However, at moisture content greater than 10%, the clay as a grounding medium is more effective due to its low resistivity.

This research study can be further extended to investigate the performance of grounding system on different types of soil samples under the same condition applied in this research. While computing the ground resistance based on different grounding configurations, the ground potential rise of the grounding system will vary hence it is necessary to perform a ground potential rise evaluation to assure the potential rise is of tolerable step and touch voltage.

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