AN INVESTIGATION TO IMPROVE PERFORMANCE OF GROUNDING SYSTEM

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UNIVERSITI MALAYSIA PAHANG

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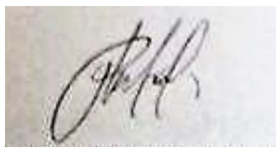
Signature : 

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This report is dedicated to my dearest father and mother

Shafie Bin Aziz and Norhasimah Bt. Abd. Halim

Siblings

And

To all my lecturers, for their encouragement and guidance
To all my friends, for their sincerity and support

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ABSTRACT

An ideal grounding system is very important to dissipate short circuit current and to protect people from shock. Engineers often face difficulty when designing a satisfactory grounding system for building especially located at high soil resistivity. To improve the performance of grounding system, backfilled with low soil resistivity must be added in the grounding system. In this study, rice straw ashes, cow dung and oil palm husk are tested together with existing material which is bentonite. Fall of potential method is used as it's compatible for different type of grounding medium and this study need extensive research site. Based on analysis, rice straw ashes shows 77% increase in its resistance efficiency compared to bentonite. In conclusion, Rice straw ashes have been determined as the favorable waste material to reduce earth resistance as compared to cow dung and oil palm husks.

ABSTRAK

Sistem pembumian ideal adalah sangat penting untuk menghilangkan litar pintas dan untuk melindungi orang dari kejutan. Jurutera sering menghadapi kesukaran apabila mereka bentuk satu sistem asas yang memuaskan bagi bangunan terutamanya yang terletak di tanah yang mempunyai rintangan yang tinggi. Untuk meningkatkan prestasi sistem pembumian, tanah yang dikambus balik dengan bahan yang mempunyai rintangan yang rendah mesti ditambah dalam sistem pembumian. Dalam kajian ini, abu jerami padi, najis lembu dan sabut kelapa sawit diuji bersama-sama dengan bahan yang sedia ada iaitu bentonit. Perbezaan potensi voltan telah digunakan kerana ia serasi untuk pelbagai jenis medium asas dan kajian ini perlu tapak penyelidikan yang luas. Berdasarkan analisis, abu jerami padi menunjukkan peningkatan 77% dalam kecekapan rintangan berbanding bentonit. Kesimpulannya, abu jerami padi telah ditentukan sebagai bahan buangan yang menggalakkan untuk mengurangkan rintangan bumi berbanding dengan najis lembu dan sekam kelapa sawit.

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LIST OF ABBREVIATIONS

RHA	–	Rice Straw Ashes
CD	–	Cow Dung
OPH	–	Oil Palm Husks
GPR	–	Ground Potential Rise
PVC	–	Polyvinyl Chloride
IEEE	–	Institute of Electrical and Electronics Engineers
AC	–	Alternating Current

LIST OF SYMBOL

Ω	–	Resistance
p	-	Soil resistivity
φ	–	Function for Soil Resistivity
m	–	Meter
V	–	Voltage
I	–	Current
a	–	Distance between Adjacent Rod - m
A	–	Grounding Area – m^2
R_g	–	Grounding Rod Resistance - Ω

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CHAPTER 1

INTRODUCTION

1.1 Grounding System

According to the IEEE Guide for Safety Grounding Design, the two main design goals to be accomplished by any ground system under fault conditions and both normal are [5]:

1. To not exceed any operating and equipment limits by providing way to dissipate electric currents into the earth.

2. To assure the danger of critical electric shock is not exposed to a person in the surrounding of grounded facilities.

In order to ensure the safety and well-being of personnel who may come close to conductive media, it is significant to do proper and practical analysis and calculations of design grounding systems parameters. In other words, the primary purpose of creating ground systems is to avoid the injury of human beings during unbalanced fault conditions. However, important aspect such as the type of soil used for the grounding rod must be taken care. Most engineers use their trial-and-error techniques or long term experience in order to reduce the soil resistance as path for fault conditions situation.

There are two factors that affect the grounding system performance that are: soil parameter and size and material of electrode. Generally, soil resistivity give high influence to the performance of grounding system. Soil resistivity depends on many factors, such as humidity, temperature, type of soil, salt content, etc. and varies upon time and depends on the season of the year, reaching maximum values during the summer months. Unfortunately, due to geological environmental, the soil resistivity value is not good enough. Thus, by increasing the size of grounding rod, a better grounding performance can be achieved. Still, this method involved more cost. Therefore, by modifying the soil characteristic, it will increase the effective area around the grounding electrode. For further analysis, backfilled with low resistivity must be added in the system. In this project, rice straw ashes, cow dung and oil palm husks is used.

1.2 Safety Aspect in Grounding

There are three main intention of the grounding system [11]. The first part is overvoltage protection. Electrical distribution system wire can be damaged by line surges, lightning or intentional contact with higher voltage lines as its can boost dangerous high voltages. Thus, to minimize damage from such occurrences, grounding provide an alternative path around the electrical system of the building. By the same token, the role of grounding system is for voltage stabilization. There are many resources of electricity such as transformer that can be considered as separate source. Their relationship to each other will be extremely difficult to calculate if all these voltage sources were not a common reference point. The earth is the most omnipresent conductive surface, and so it was adopted in the very beginnings of electrical distribution systems as a nearly universal standard for all electrical system. In order to facilitate the operation of overcurrent devices, current path must be provided. The purpose of grounding system is very important to be understand. Grounding system provides certain level of safety to property and humans in case of equipment damages.

1.3 Background of Study

The used of galvanized steel in one the interest in this study. As the copper is more expensive than galvanized steel, it caused some problem especially the theft issues. In addition, the used of copper will result in high construction cost. Thus, different alternative material needs to be used to replace copper as grounding electrode, in order to reduce theft issues and as well as to reduce the cost. By referring to the previous research conducted by Mohd Hazrek Bin Hamzah

[1], has shown that grounding grid using enhancement of additive material as well as galvanized steel will give the grounding system a low resistance.

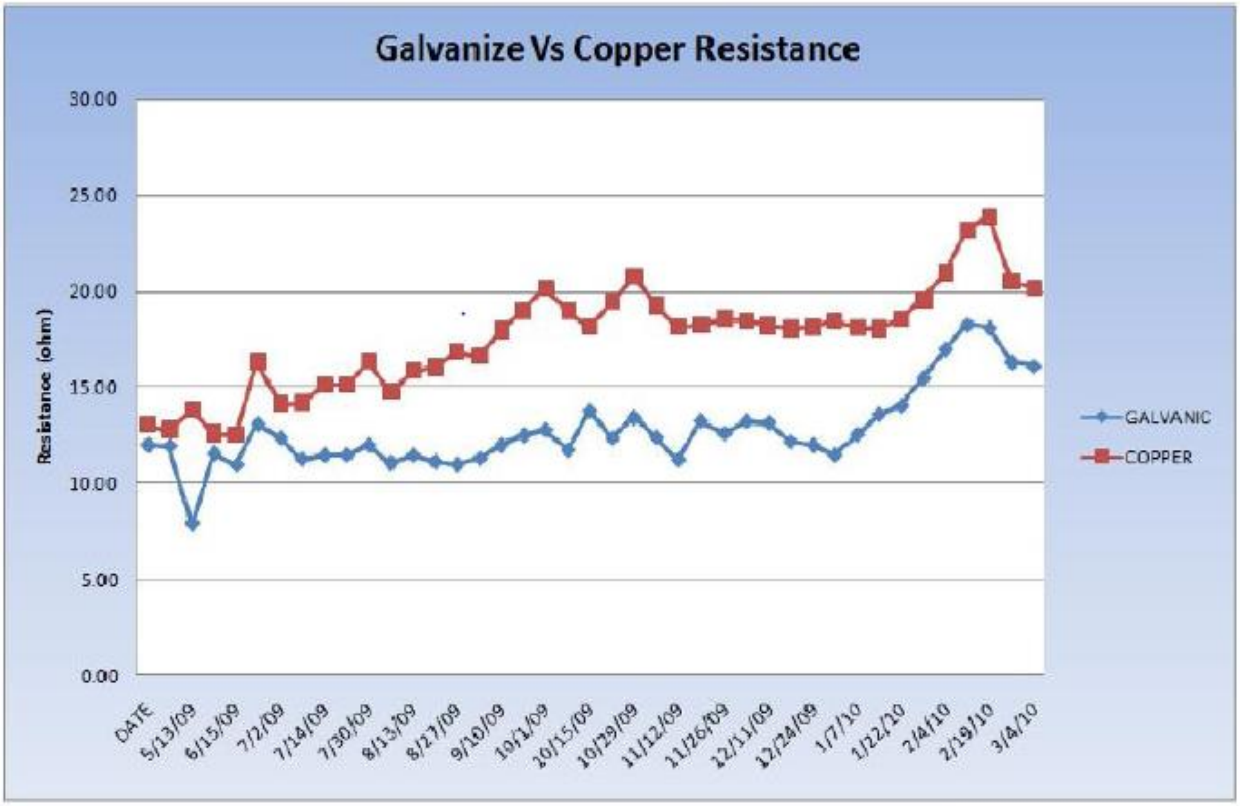
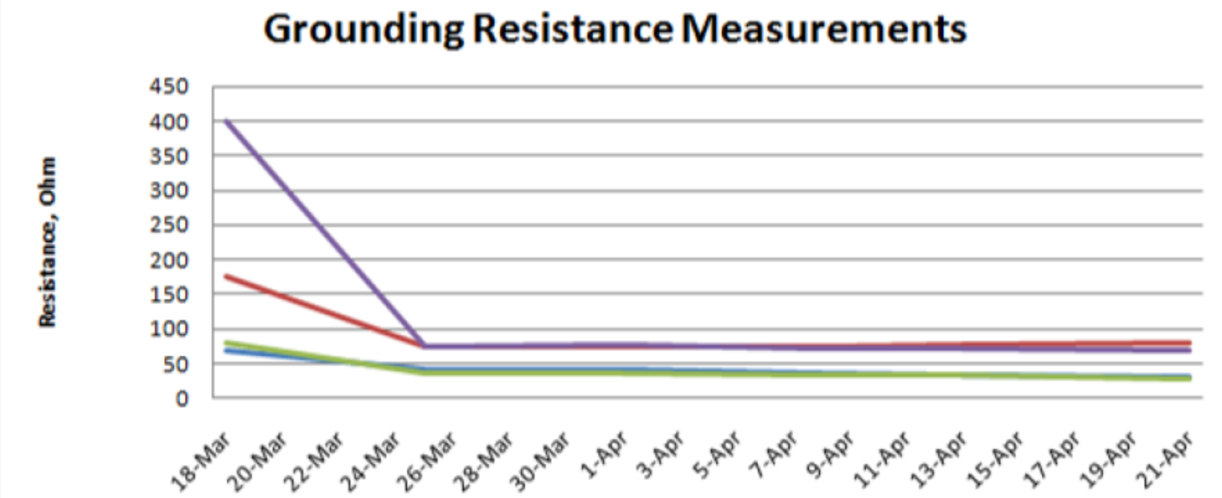


Figure 1.1: Resistance Reading for Copper and Galvanized Steel [1]

Other than that, the used of enhancement material is also one the important aspect in this project. As environmental issues are became main topic nowadays, the used of waste material is encouraged to keep preserve the environment. Hence, by adding after product generated from various sectors into grounding system, the improvement of grounding system can be achieved. By referring to the previous study done by Nazarrudin Bin Nazri [12] has shown that low resistance of grounding system can be achieved by using a very fine size of oil palm carbon ashes.



	18-Mar	25-Mar	1-Apr	8-Apr	13-Apr	21-Apr
Gray (Raw)	70	40	40	37	32	30
Black (Raw)	175	74	74	74	77	80
Gray (Fine)	80	36	37	33	33	28
Black (Fine)	400	76	78	74	73	70

Figure 1.2: Ground Resistance Result by Using a Very Fine Size of Carbon Ashes [12]

In this study, to improve performance of grounding system, cow dung, oil palm husks, and rice straw ashes has been used as additive material. This additive materials are common and very easy to find in this country, and to normal people, this material are just wastes normally, while others will find that this materials can be used as organic fertilizer. Therefore, this study is to investigate whether this wastes can be used to improve the grounding performance for local soil and the best material that can give lowest resistance value.

1.4 Problem Statement

The main objective of a grounding system is to provide a way to ground under the condition of short-circuit currents. To design an earthing electrode system to not exceed required low earth resistance is one of the biggest obstacles that an electrical engineer faces. The limiting earth resistance that should be achieved for a given installation is different based on various electrical engineering standards [5].

In recent years, cable stealing from substation, telecommunications and power system network are reported on numerous newspaper and still on increased. The problem affect the continuity of the systems, disrupt the services and; both customer and provider suffer economic losses. Copper are made on most of grounding electrodes. Thieves are attracted to steal grounding electrodes and transformer at substations since the price of recycled copper is good. This situation is not only dangerous to the systems, but to the thieves as well. The cost for damages and replacement borne by the energy provider is high. In this case, the energy provider in Malaysia is Tenaga Nasional Berhad (TNB).

The use of copper as a grounding electrode is proposed to be replaced with galvanized steel to overcome this problem. But it is not widely used because galvanized steel is shadowed by performances and popularity of copper. Actually, the use of galvanized steel provides an advantage in terms of installation costs for the ground system. This is because the galvanized steel is much cheaper than the copper as well as the price of recycled market for galvanized steel is cheaper By using galvanized steel as grounding rod in grounding system rather than copper, the performance of grounding system will be improved as galvanized steel's resistance is lower than copper. An alternative solution to consider is to modify the composition of the soil environment, so that the effectiveness of the soil can be improved. The usage of cow dung, oil palm husks, and rice straw ashes are expected to improve the performance of grounding system.

However, achieving a low earth resistance is not merely important for high performance of grounding system. A high performance ground should give predictable, long lasting, and testable and seasonably stable performance. Thus, by conducting this study, it is expected to show us how high performance of grounding system can be achieved.

Recently, the main topic in various research areas is the issue on environmental preservation and sustainability. This issue leads to new innovations by using after product generated from various sectors. Therefore, by using this additive materials as project materials, it is expected to help keep and preserve the environment.

1.5 Objective

i. To analyse the earth resistance of localized soil after using additive material which is cow dung, oil palm husks and rice straw ashes.

ii. To find the best material that will give lowest resistance value as compared with bentonite as reference material.

1.6 Scope of Project

The scopes of project function as guidelines to achieve the goal of the study. It is to ensure the objectives is fulfilled and development of the project is heading to the direction. There are several scopes need to be followed:

i. Location of the experiment.

The test will be conducted at the wind turbine area near the main entry gate of Universiti Malaysia Pahang.

ii. Apparatus that will be used is Earth Tester Kyoritsu Model 4102.

iii. The ground electrodes that will be used are vertical type.

iv. Ground electrode is 1.6ft long buried in 6 inch in diameter hole filled with three types of sample.

v. Backfilled used to enhance effective area of grounding electrode is rice straw ashes, cow dung and palm oil husks.

vi. Scale model test for determination of the grounding performances.

vii. The earth electrodes will be measured by using Fall of potential method.

viii. The result will be recoded and compared to ensure which sample will give a lower soil resistance

1.7 Organization of Thesis

Chapter 1 basically explain the definitions of grounding system and give general introduction of using additive material in order to enhance the grounding performance. The problem statement and objectives for this project to be achieved is discussed. Moreover, scope of project are explained an act as guidelines to complete the project.

Chapter 2 briefly gives explanation of rice straw ashes, cow dung, oil pal husks and some literature review from journal published. Furthermore, terms including resistivity, ground impedances, step and touch voltages and earth potential will be explained. It is also briefly discussed about factor contributing to earth resistivity, safety precautions and type of grounding.

Chapter 3 will discuss about designing approach of the grounding systems, selection of conductor, soil characteristic and determination of maximum current. Other than that, the method for measurement will also be explained briefly in this chapter.

Chapter 4 will discuss the result achieved on the experiment that has been done. The result is shown in graphical form in order for ease of interpretation.

Chapter 5 will briefly discuss about the conclusion and answering the objective of this project. Furthermore, recommendation for future work and research also will be discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 Fundamental of Grounding System

Grounding is a very important part in electrical system. It is a system that has form of grid of horizontally buried conductors, supplemented by a number of vertical rods connected to the grid [1]. There are few element that impact the development of the grounding system. Those are stratification, soil resistivity, sort of electrode utilized and size, profundity which the terminal is covered and finally the dampness and substance of the soil [13]. On the off chance that 'zero impedance' can be reached at grounding resistance, it is a perfect grounding system. However, nothing in this world is impeccable or perfect, thus it is difficult to get that value. Consequently, in actuality, and pragmatic circumstance, the grounding system intended to get the most minimal ground resistance value that is as close as could to zero impedance.

In this cutting edge and time, the grounding system has been truly examined all around the globe. To accomplish the desire grounding system, there are so much change had been made with a specific and goal as it can forestall harm to hardware, human life and structures. In China, a study entitled Seasonal Influences Safety of Substation Establishing System [14] discussed about the safety in grounding system is influence by atmosphere in China. Based on this study, the low resistivity soil layer was framed during raining season. In this situation, the touch voltage would expand and at the same time littler than the real touch voltage. Meanwhile in freezing season, high resistivity soil layer was framed that result in expanding of step and touch voltage in the system.

The increasing of step and touch voltage amid this season was over the breaking point of the step and touch voltage chose by surface granite layer. Similar studies related to the enhancement of grounding system were also conducted by Ramualdo-Torres [15] and Lee [16]. Both of them are discussed about the improvement of ground resistance of power system. A considerable measure of study the grounding system these days demonstrate how important is the grounding system itself.

2.2 Important Aspect in Grounding System

It is important to view grounding comprehensively as a system and not just a buried electrode or means of contacting the soil. Other critical elements include insulation of wiring and equipment and proper connection from equipment to electrode [7].

The main consideration when designing the grounding system is [6]:

(a) The grid must be able to retain the maximum fault current without any problem occur related to the burn or melting electrode.

(b) The grid need to provide adequately low voltage between two points on the ground to prevent any hazardous to personnel. Step, touch and mesh potential are important items need to be consider.

(c) The grid also needs to lessen the Ground Potential Rise (GPR) with respect to remote ground by having low contact resistance to ground.

2.3 Earth Resistivity

Soil resistivity measuring techniques are almost the same for most measurements. However, the recorded data can be varying especially when encountered with non-uniform soil resistivity. The added complexity caused by non-uniform soils is common, and in only a few cases, the soil resistivity are constant with increasing depth.

Usually there are several layers of soil, each having a different resistivity. Lateral changes can also occur, but in general, these changes are gradual and negligible in the vicinity of the sites concerned. In most cases, the measurement will show that the resistivity *a* ρ is mainly a function of depth *z*. For purposes of illustration, we will assume that this function can be written as follows:

$$\rho = -\varphi(z)$$

The function (φ) is generally not simple and usually used approximation. It is nearly not possible to obtain best approximation of soil resistivity from measurements on sample. This is due to samples itself, soil compaction and moisture content can be differing [5].

2.4 Ground Impedance

Connections to earth are not simply contained only resistive, but other components also exist such as capacitive and inductive. And all this components affect the capability of the connection for the carrying current. Resistivity of the soil in the area of connection give effect to the resistance of the electrodes while capacitive and inductive components are concerned with higher frequencies such as lightning and telecommunications link that connected [8].

The purpose of ground impedance being measured such that:

(a) To determine ground connections actual impedances.

(b) To prove calculations value.

(c) To determine rise in ground potential and its variation on particular area, which result from fault

(d) To determine whether grounding connections for lightning protection is suitable.

(e) To determine whether grounding connections for radio frequency transmission at transmitter is suitable.

Connections of grounding systems for power and telecommunications network must be studied to determine variation in ground potential that can occur during fault or atmospheric discharge. This must be done to make sure human safety, insulation reliability and continuity of services. The grounding connections characteristics are differ due to composition and physical state of the soil. Besides that, the configurations of the electrodes also can change the connections characteristics. At any locations, soil s composed by variations of dry earth, swampy ground, gravel, sandstone or any other material with range of resistivity. It can be assumed homogenous at large area. Consequently, the characteristics of grounding impedance vary with effect of temperature, moisture content, salt content, compactness of soil and season changing.

Grounding systems effectiveness is large dependent on its size. This can be shown by calculation at any given soil. The buried conductor and driven rods added also reduce the ground impedances. By adding more conductor or electrodes, the reduction can be obvious. In example, to reduce ground resistance of transmission line tower is to install radial counterpoise.

After installation of grounding systems to an electrical network, the ground impedance tends to decrease or increase during the first or two years. This is due to weather changes.

The grounding systems impedance is measured in terms of resistivity because the reactance is negligible compare to resistive components. But reactance must be taken into account for large grounding systems with impedance value below 0.5 Ω and grounding systems designed for lightning protection purposes. The resistance will not vary greatly after from year to year after the first or second. Even grounding grid buried only half a meter below the surface, the variation of resistance for large stations is slightly small with respect to depth. This is especially to grid equipped with long driven rod in contact with deep soil which is not subjected to weather condition. Temperature and moisture changes usually result only for the top layer soil resistivity variations. Bear in mind that it is not true for the grids buried in high resistivity area or for small electrodes with area less than $50m^2$.

Resistance of the electrodes may be different largely if compared between theoretical and measured value. There are several elements contributing to this error.

(a) Equations used in the calculation of resistance insufficient.

(b) The measurement of the conditions of the soil are taken. The assumption is differing from resistivity while doing calculations.

(c) The resistivity survey is inaccurate. For example probe spacing and instruments used.

(d) The presents of metallic buried structure and underground cable. The amount of test current can be divert.

2.5 Soil Resistivity

The important key for the perfect grounding system is the soil resistivity that will be determined the resistance of grounding electrode, and the depth measurement that needed to achieve the lower soil resistivity. All around the word, there are verity of soil resistance that changes seasonally [9]. The soil resistivity is determined according to their content of electrolyte that consists of:

a) Moisture

b) Mineral

c) Dissolved salt

d) Temperature

For an example, the dry soil such as dessert have the high resistivity because lack of moisture and dissolved salt.

2.6 Factors Affecting Soil Resistivity

There are several factors that affecting the soil resistivity temperature, humidity, salt content and composition of soil. Moreover, the size, shape, spacing, number of electrodes and the depth to which these are driven also affect the value of soil resistivity [5]. Electrolytic is a medium that allowed the electrical to conduct in the soil. Thus, the resistivity of soil usually rises sharply if the moisture content is less than 15% of the weight.

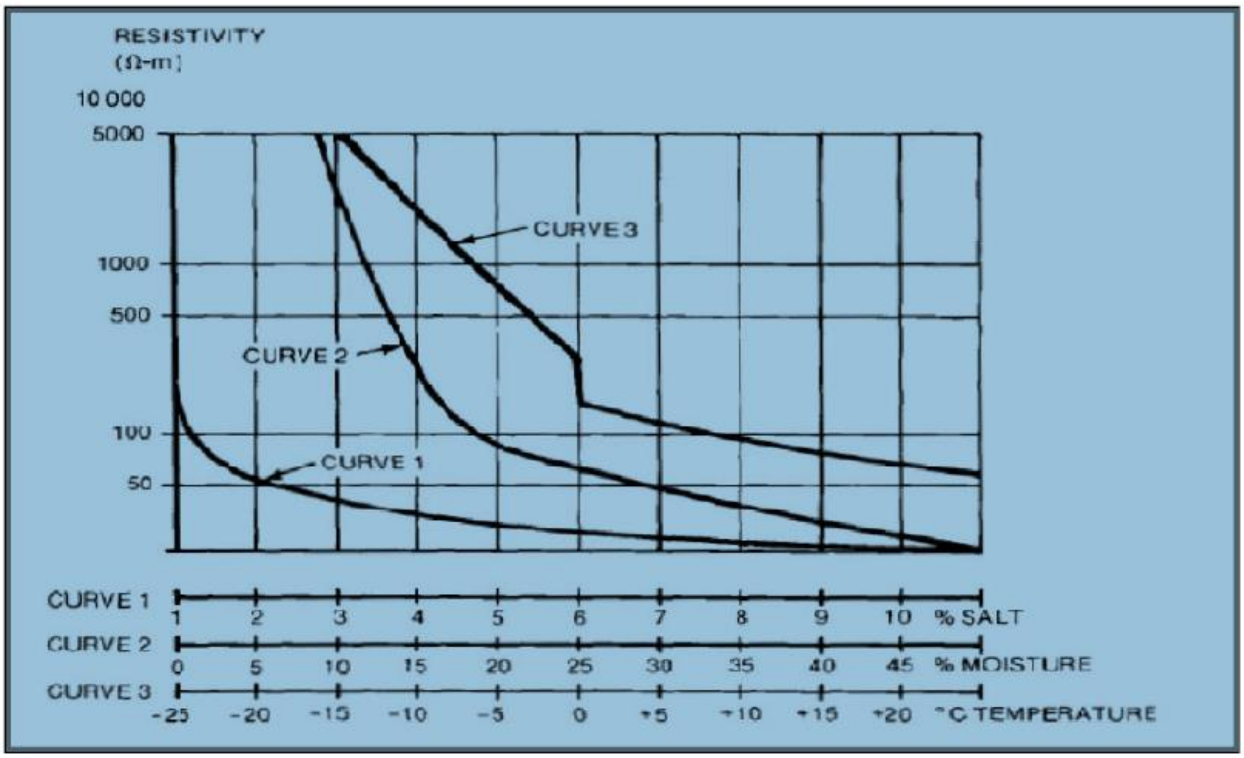


Figure 2.1: Effects of Moisture, Temperature, and Salt upon Soil Resistivity [5]

As shown in Figure 2.2, curve 2, the resistivity is little affected once the moisture content exceeds 22%. The effect of temperature on soil resistivity is nearly negligible for temperatures above the freezing point. At 0^{0}C, the water in the soil starts to freeze and resistivity increases rapidly. Curve 3 shows this typical variation for a clay soil containing 15.2% of moisture by weight. The composition and the amount of soluble salts, acids, or alkali present in the soil may considerably affect its resistivity. Curve 1 of illustrates a typical effect of salt (sodium chloride) on the resistivity of a soil containing 30% of moisture by weight.

2.7 Rice Straw Ashes

Rice straw is waste products of the process for obtain rice apart from rice grains. Ashes of rice straw can be obtained from burning process in the field. There are two types of rice straw ash which can be obtained from the stubble burning activities that is white ashes (carbon-free) and black ashes. The black ashes is in black color. They still have unburned carbon compare to the white carbon that are completely burnt its carbon. The black carbon is denser and rougher, while the white carbon is lighter and smoother. Ashes in general, have low resistivity significantly. Appendix B shows the resistivity of several types of earthing medium. From the table, it can be seen ashes that have low resistivity compare to several kind of soil.

Rice straws have about 15% ash after burning, thus for 1000kg of rice straw being burned, 150kg ash are produced and contain about 82% of silica. Because of the high silica in the rice straw ashes it made the rice straw is one of the hydrophilic polymer that are easily to absorb water [2]. But the resistance of the polymer, it made the ashes to reduce the amount of water being absorbed. So to get the ashes to absorb more water, the large amount of ashes need to be use.

2.8 Cow Dung

Cow dung, sometimes also known as cow pats, cow pies or cow manure, defined as a waste product from cow and other bovine animal species. It is a very common waste in Malaysia as the cow is normal animal that can be seen in any region of Malaysia. Almost all parts of cows are used by people in this country such as meat, skin, tail and also its waste. The waste or cow dung is normally used as organic fertilizer to the plantation.

Few studies have been conducted on the use of cow dung or agricultural manure or agricultural compost for the degradation of oil contaminated soils. As cow dung contains a diverse group of microorganisms and have a tendency to remediate the soil. Addition of cow dung in soil also enhances the physical and chemical properties by increasing its fertility (by adding nutrients), moisture absorbing capacity and more. If used in clay soils where water logging is a problem cow dung increases the porosity of the soil or if the soil is porous not retaining the water, such as sandy soils then cow dung acts as a water holding carriers [10].

From the characteristic of the cow dung, it can be concluded that cow dung also can act as water absorbent polymer. Therefore, in this study, cow dung will be used to improve the grounding system. It will be used as the backfill to the local soil so that the ground resistance can be reduced.

Figure 2.2: Cow dung

2.9 Oil Palm Husks

Oil palm husk ashes are wasted material from palm oil mill. It is result from burning husk, shell and nuts of palm oil fruit. There are two types of ashes that can be obtained from palm oil mill which chimney ashes and boiler ashes. Ashes from chimney are grayish in color and sometimes whitish due to absence of unburned carbon. It is more delicate and intense. While boiler ashes are blacks in color. These kinds of ashes are less delicate and intense if compare with chimney ashes. Ashes in general, have significantly low resistivity. Appendix A shows resistivity of several type of earthing medium. From this table, it can be seen that ashes has low resistivity compare to several kind of soil.

2.10 Bentonite

The bentonite that has been used as backfilled in rocky and hardpan soil will increase the performance of grounding system (Jones, 1980). From these paper showed that bentonite can be excellent conductive fallen. The characteristics are unique where it can absorb almost 5 times its weight and swell up to 13 times it dry value. The research is done on soil with differ resistivity. The use of bentonite as additive material, offers rod effectiveness and reducing the soil resistivity up to 36%. According to Jones, the interface between soil and road can be enhanced by using bentonite.

Bentonite hydrates chemically hold water in its structure and act as drying agent to the surrounding environment. As long there is moisture available it will maintain its density. There is no additive to enhance its characteristics. It is also noncorrosive, stable and will not change characteristics in long time. It has resistivity of 2.5 -m at 300% moisture. The low resistivity is a result of the electrolyte formed by adding water. Water allow mineral salt in bentonite such NA2O (soda), K2O (potash), CaO (lime), MgO (magnesia) to ionize.

2.11 Water Absorbent Polymer

Water absorbent polymers can be used to increase the effective grounding electrodes size and thus obtain low ground resistance. Yamane et al. (1990) proposed new method to reduce grounding resistance by using water absorbent polymers. Refer to their report, water absorbent polymers have ability to absorb water and keep it for a long time and stable. The polymers also reduced the corrosion of grounding electrodes.

In their research, polymer is used as ground resistance reducing material because the stability under long term temperature fluctuations. The amount used is weighted only 1/160 of the bentonite but the effectiveness is almost equal to the bentonite. For allowing the polymer to absorb water, it is solidified by using epoxy, which is a plastic hardener. Even epoxy is kind of insulator, it becomes conductive when mixed with the polymer.

Ground resistance performance is monitored for their long term stability under both dry and wet condition. Under these two conditions, water absorbent polymer give better result compares to electrode that using bentonite as backfilled.

2.12 Earth Potential

The definition or earth potential is a result obtains from the current that flow from electrode through the earth in a path. The different voltage across this path can be using to determine the step voltage.

2.13 Step and Touch Voltages

Step and touch voltages are proportional to the earth current and top soil resistivity. Figure 2.3 and Figure 2.4 shows step and touch voltages criteria at a grounded structure. Step voltages defined as the difference in surface potential experienced by a person bridging a distance of 1 meter with the feet without contacting any other grounded object. While touch voltages is the potential different between the ground potential rise (GPR) and the surface potential at the point where a person is standing and have a hand contact with a grounded structure [3].

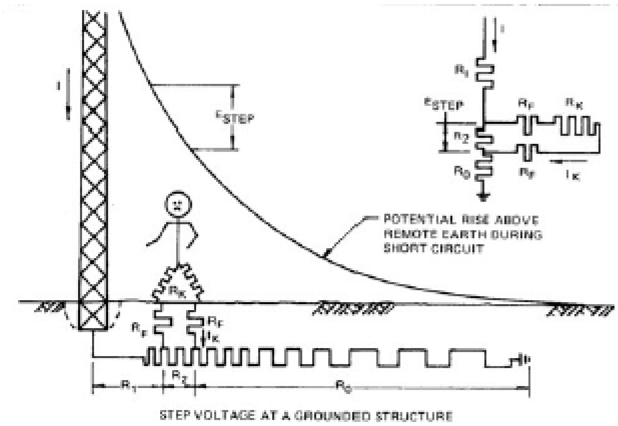


Figure 2.3: Step Voltages [3]

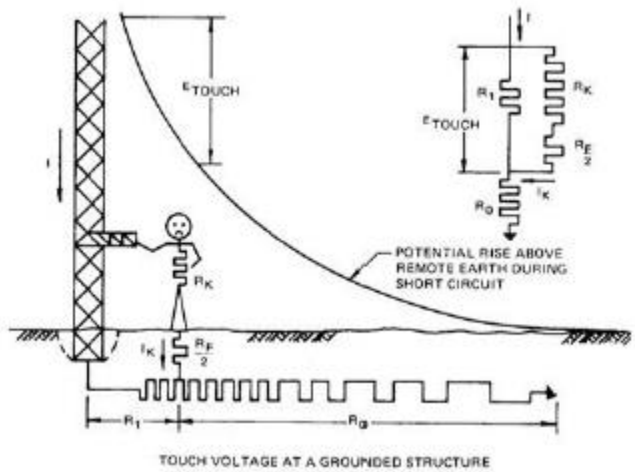


Figure 2.4: Touch Voltages [3]

2.14 Type of Grounding

There are several types of grounding electrodes being installed. The variety of installations are related to the circumstance and needed by the user. Each of them has their own advantages and disadvantages. Table 2.2 shows different type of grounding systems arrangements.

Table 2.1: Several Type of Grounding System Arrangements

Type	Advantages	Disadvantages
Ring Ground	Easy to design and installed. Readily available. Can be extending to reach water table.	Not useful when large rock formations near the surfaces.
Radial	Can achieve low resistance where rock formations prevent use of vertical rods	Subject to resistance fluctuations with soil drying.
Horizontal Grid	Minimum surface potential gradient. Easy to install if done before construction. Can achieve low resistance contact in areas where rock formations prevent the use of vertical rods. Can be combined with vertical rods to stabilize resistance fluctuations.	Subject to resistance fluctuations with soil drying if vertical rods not used
Vertical Rods	Simple design. Easiest to install particularly around an existing facility. Hardware readily available. Can be extended to reach water table	Not useful where large rock formations are near surface. Step voltage on earth surface can be excessive under high fault currents.
Plates	Can achieve low resistance contact in limited area.	Most difficult to install.
Incidental Electrodes (pipes, foundation, etc)	Can show very low resistance.	Little or no control over future alterations. Must be employed with other electrodes.

2.15 Safety in Grounding Systems

Grounding systems test of substation or other type of power systems is exposed to high degree atmospheric disturbances or power systems line to ground faults and ground potentials rise (GPR). The precautionary measures must be taken out in order to avoid any fatal that can happen. Thus, based on IEEE 81-2002 [5], there are safety precautions need to be followed during the test, such as:

i. Hands or other parts of body are not allowed to complete the circuit between points of possible high-potential differences. Gloves and dielectrically rated footwear can reduce the hazards associated with handling test leads that extend outside the station grid.

ii. Exposed test leads and electrodes are isolated from workers and general public prior to applying test voltages. Exposed test leads and electrodes are isolated from workers and the public prior to connecting the leads to a station ground grid or other grounding systems that might be exposed to system ground fault currents.

iii. A signal is applied for short test periods, and all test leads are promptly removed after the test is completed.

iv. If remote current and potential probes are not within sight of test personnel or if the test leads are located in an area accessible to the public, then these points are under continuous observation using a spotter in radio contact with the test equipment operator as long as the test signal is applied or remote potentials are over 50 V. One or more test leads that are electrically connected to a ground grid can cause a transfer of potential under fault conditions that would far exceed 50 V, and a spotter would be necessary as long as the test leads are connected to the ground grid.

v. If the ungrounded ends of test leads parallel an energized line for several hundred feet, then a hazardous voltage can be induced into the test leads if large currents are flowing in the energized line. This issue can sometimes be mitigated by the physical orientation of test leads, grounding or both.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In each grounding system design, it has two main objectives to be achieved in a state of either healthy or faulty condition. Firstly, grounding connection is intended to provide access to an electric current without exceeding any operating limitations. And second, to protect people who are in an environment with grounding facilities are not getting electric shock. Grounding system is also designed to provide continuous services.

The design procedure is to ensure the safety from dangerous step and touch voltages in substations. By using only a single electrode, it is able to provide safety but when using more than one electrode, and connected together, the results will be more favorable for the grid arrangement. Furthermore, if the electrode was just installed in soil that has good conductance, it will show an excellent grounding system.

If the magnitude of faulty current is high, electrodes with low resistance will not generate GPR that is unsafe for human. Thus, grounding systems that use low resistivity soil has an advantage in this case. Electrodes that penetrating low resistivity soils are effective in dissipating fault current.

3.2 Selection of Conductor

Conductor selected for the grounding systems should have good reliability since it will be used in long period of time. To meet expected lifetime, the conductor must have sufficient conductivity so substantially voltage different will not generated. Conductor must also resist fusing and mechanical deterioration under worst fault magnitude and duration. The mechanical characteristics must be reliable and rugged to a high degree for the conductor selected. Even exposed to corrosion, the conductor must be able to maintain its function.

Steel can be used as grounding electrodes. But it cannot withstand due to underground system. The solution for this corrosive problem is using copper. It is popular on their good conductivity. Copper also has advantages of resistant to underground corrosion because its cathodic compare to the other metal.

3.3 Criterion of Soil

In this study, there might be some factor that will affect the performance of the soil such as moisture content, salinity, and also compactness of the soil. The effect of temperature to the soil can be neglected as the temperature in Malaysia does not change too much like other countries. The moisture content and salinity of the soil can be determined through chemical analysis to the local soil.

3.4 Experiment Sample

The samples that will be analysed contain four type of sample. One of the sample will be reference/control experiment. Each sample will be label for data analysis. Below are the lists of the sample that will be conduct in the experiment:

a) Local soil with Rice Straw ashes

b) Local soil with Cow Dung.

c) Local soil with Palm Oil Husks

d) Local soil with Bentonite (reference soil)

3.5 Measurement Method

Method that will be used in this experiment is following the recommendation from IEEE Standard 81-1983 [5]. According to this standard, the Fall of Potential Method is the chosen method that can be apply because it is applicable to all type of ground impedance and due to lack of measuring tools. It also has several variations but the basic theory still the same.

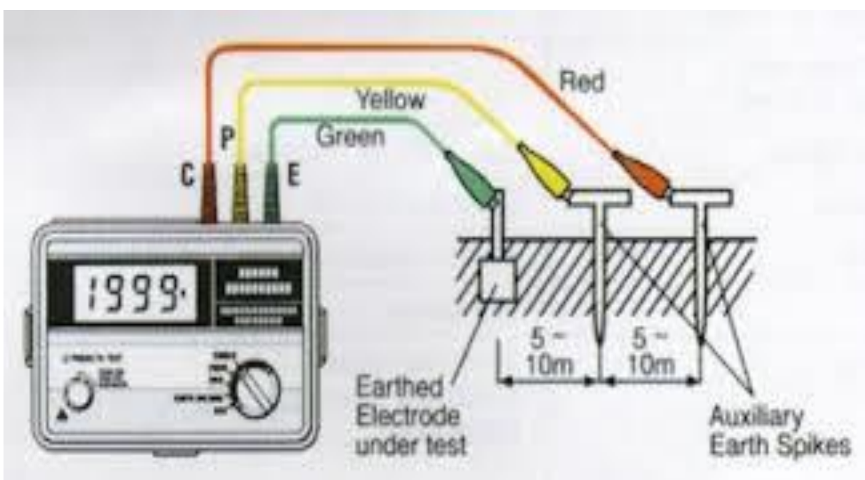


Figure 3.1: Fall of Potential Method [5]

To gather the data, Kyoritsu model 4102A analogue earth tester as in Figure 3.1 will be used. The method use is three-point-method which is for probe earth, potential and current. This method is used to obtain earth resistance value Rx by applying AC constant current I between the measurement object E (earth electrode) and C (current electrode) and finding out potential difference V between E and P (potential electrode) as shown in Figure 3.2.

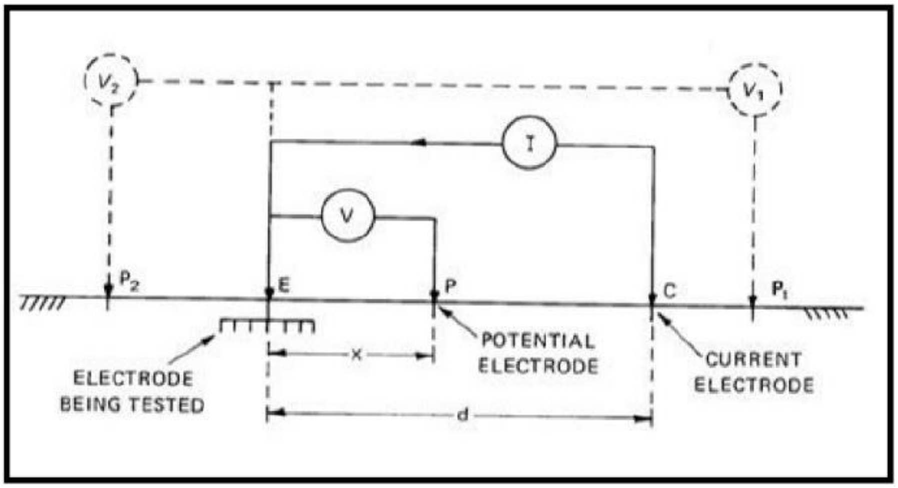


Figure 3.2: Fall of Potential Method Probe Arrangement [5]

$$R_{soil} = \frac{V_s}{I_i} \qquad (3.1)$$

Where

V_s is voltage supply to the sample

I_i is current that flow through test sample

The test will be conducted 3 times to find average resistance of the object E (earth electrode).

$$\frac{Rx1 + Rx2 + Rx3}{3} \qquad (3.2)$$

3.6 Construction of Grounding System

The construction of grounding system is shown in Figure 3.3. While the probe arrangement is shown in Figure 3.4. The arrangement of sample is shown in Figure 3.5. In this project, scale model will be conduct using vertical ground rod type. The rod is 1.6ft long and the hole that will be used to fill with additive materials are 1ft depth and 6 inch for it diameter. Each holes will be filled with 500 gram of additive material as the parameter for this experiment must be same. It is to ensure each type of additive material used will not be affected by the weight of material. Thus, the resistance value will only depend on the type of additive materials.

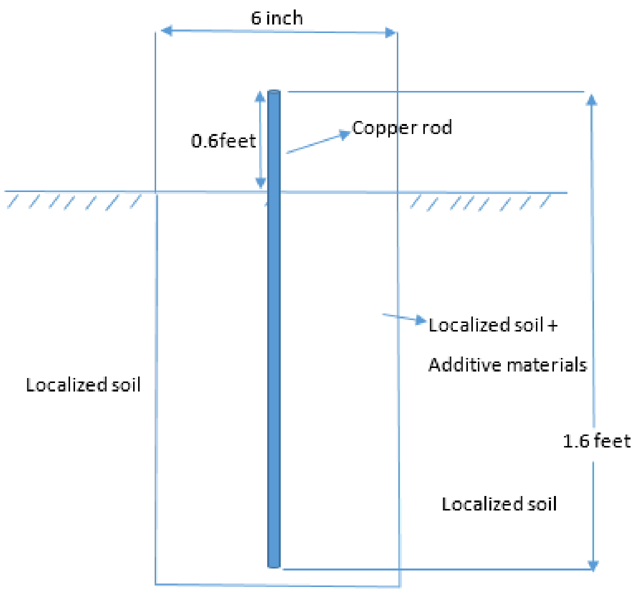


Figure 3.3

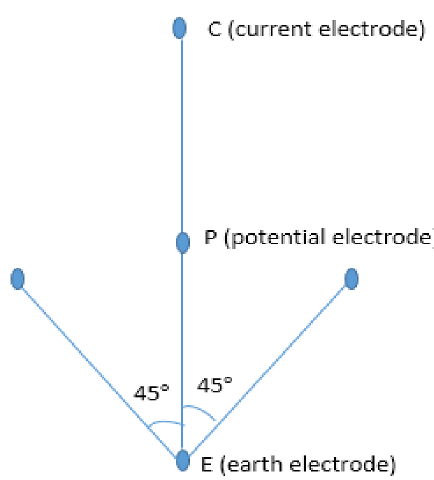


Figure 3.4

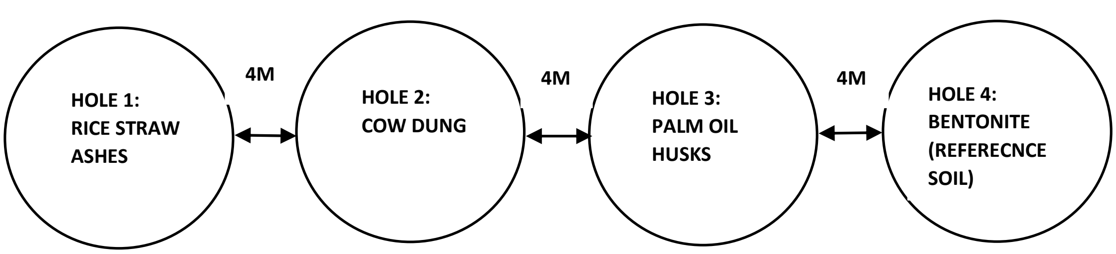


Figure 3.5

3.7 Installation of Grounding Electrode

The selected place for this experiment is near the wind turbine's building. Four holes were prepared and each of the holes was filled with rice straw ashes, cow dung, oil palm husks and bentonite. The electrodes were then is placed in the center of the holes and buried in depth of 1 ft. Original soil from the area of installation then were put to cover the holes. The electrodes were cover by earth chamber to ensure the safety of people walking there from step into that area. Figure 3.6 shows the installation process of the grounding experiment.

Figure 3.6: Installation Process of Grounding System

3.8 Result Monitoring

The sample will be monitor weekly in two days interval. The monitoring activity will be conducted in a same time and the same weather. If it is rainy day at that time, the measurement will be done after the rain because if the measurement conducts in the rainy period, it will give non-consistent data. Thus, it is important to take out the reading weekly.

CHAPTER 4

EXPERIMENTAL RESULT AND ANALYSIS

4.1 Ground resistance result

The grounding resistance are recorded for all four grounding system that have been installed. The result will be compared and then the type of additive materials that gives good performance in grounding system will be determined.

4.2 Result

Results of the recorded data can be divided into four. Each table is shown representing each material for the grounding system. After that, all data will be combined once to see a comparison between the four materials of experiment. The data is shown in Table 4.1 for Rice Straw Ashes, Table 4.2 for Cow Dung, Table 4.3 for Oil Palm Husks and Table 4.4 for resistance value of Bentonite (reference soil).

Table 4.1: Resistance of Rice Straw Ashes for one month

RICE STRAW ASHES		
DATE	WEATHER	EARTH RESISTANCE
9.10.2016	WET(AFTER RAIN)	990 Ω
11.10.2016	DRY	975 Ω
13.10.2016	DRY	970 Ω
15.10.2016	WET(AFTER RAIN)	950 Ω
17.10.2016	WET(AFTER RAIN)	945 Ω
19.10.2016	DRY	950 Ω
21.10.2016	WET(AFTER RAIN)	750 Ω
23.10.2016	DRY	740 Ω
25.10.2016	WET(AFTER RAIN)	720 Ω
27.10.2016	DRY	710 Ω
29.10.2016	DRY	700 Ω
31.10.2016	WET(AFTER RAIN)	660 Ω
2.11.2016	DRY	650 Ω
4.11.2016	WET(AFTER RAIN)	620 Ω
6.11.2016	DRY	630 Ω
8.11.2016	DRY	635 Ω
10.11.2016	WET(AFTER RAIN)	620 Ω

Table 4.2: Resistance of Cow Dung for one Month

COW DUNG		
DATE	WEATHER	EARTH RESISTANCE
9.10.2016	WET(AFTER RAIN)	985 Ω
11.10.2016	DRY	960 Ω
13.10.2016	DRY	950 Ω
15.10.2016	WET(AFTER RAIN)	935 Ω
17.10.2016	WET(AFTER RAIN)	920 Ω
19.10.2016	DRY	930 Ω
21.10.2016	WET(AFTER RAIN)	810 Ω
23.10.2016	DRY	790 Ω
25.10.2016	WET(AFTER RAIN)	770 Ω
27.10.2016	DRY	780 Ω
29.10.2016	DRY	785 Ω
31.10.2016	WET(AFTER RAIN)	760 Ω
2.11.2016	DRY	795 Ω
4.11.2016	WET(AFTER RAIN)	765 Ω
6.11.2016	DRY	785 Ω
8.11.2016	DRY	785 Ω
10.11.2016	WET(AFTER RAIN)	760 Ω

Table 4.3: Resistance of Oil Palm Husks for one Month

OIL PALM HUSKS		
DATE	WEATHER	EARTH RESISTANCE
9.10.2016	WET(AFTER RAIN)	985 Ω
11.10.2016	DRY	965 Ω
13.10.2016	DRY	960 Ω
15.10.2016	WET(AFTER RAIN)	945 Ω
17.10.2016	WET(AFTER RAIN)	930 Ω
19.10.2016	DRY	915 Ω
21.10.2016	WET(AFTER RAIN)	780Ω
23.10.2016	DRY	760Ω
25.10.2016	WET(AFTER RAIN)	735Ω
27.10.2016	DRY	705Ω
29.10.2016	DRY	645Ω
31.10.2016	WET(AFTER RAIN)	640Ω
2.11.2016	DRY	655Ω
4.11.2016	WET(AFTER RAIN)	635Ω
6.11.2016	DRY	645Ω
8.11.2016	DRY	655Ω
10.11.2016	WET(AFTER RAIN)	640Ω

Table 4.4: Resistance of Bentonite (reference soil) for one month

BENTONITE(REFERENCE SOIL)		
DATE	WEATHER	EARTH RESISTANCE
9.10.2016	WET(AFTER RAIN)	985 Ω
11.10.2016	DRY	965 Ω
13.10.2016	DRY	960 Ω
15.10.2016	WET(AFTER RAIN)	945 Ω
17.10.2016	WET(AFTER RAIN)	930 Ω
19.10.2016	DRY	915 Ω
21.10.2016	WET(AFTER RAIN)	770 Ω
23.10.2016	DRY	760 Ω
25.10.2016	WET(AFTER RAIN)	735 Ω
27.10.2016	DRY	695 Ω
29.10.2016	DRY	700 Ω
31.10.2016	WET(AFTER RAIN)	660 Ω
2.11.2016	DRY	670 Ω
4.11.2016	WET(AFTER RAIN)	665 Ω
6.11.2016	DRY	665 Ω
8.11.2016	DRY	670 Ω
10.11.2016	WET(AFTER RAIN)	660 Ω

The second set of recorded data can be divided into five. This time all the material used will be compared with local soil without enhancement material. Table shown the resistance for each material used for the grounding system for one week. All the data will be combined and compared to see the effectiveness between five types of material used. The data is shown in table 4.5 for Rice Straw Ashes, Table 4.6 for Cow Dung, Table 4.7 for Oil Palm Husks, Table 4.8 for Bentonite and Table 4.9 for Local Soil (Reference Soil).

Table 4.5: Resistance of Rice Straw Ashes for one week

RICE STRAW ASHES		
DATE	WEATHER	EARTH RESISTANCE
18.11.2016	DRY	320 Ω
19.11.2016	DRY	310 Ω
20.11.2016	WET(AFTER RAIN)	260 Ω
21.11.2016	WET(AFTER RAIN)	240 Ω
22.11.2016	WET(AFTER RAIN)	210 Ω
23.11.2016	DRY	200 Ω
24.11.2016	DRY	200 Ω

Table 4.6: Resistance of Cow Dung for one week

COW DUNG		
DATE	WEATHER	EARTH RESISTANCE
18.11.2016	DRY	340 Ω
19.11.2016	DRY	330 Ω
20.11.2016	WET(AFTER RAIN)	305 Ω
21.11.2016	WET(AFTER RAIN)	285 Ω
22.11.2016	WET(AFTER RAIN)	250 Ω
23.11.2016	DRY	235 Ω
24.11.2016	DRY	230 Ω

Table 4.7: Resistance of Oil Palm Husks for one week

OIL PALM HUSKS		
DATE	WEATHER	EARTH RESISTANCE
18.11.2016	DRY	335 Ω
19.11.2016	DRY	325 Ω
20.11.2016	WET(AFTER RAIN)	310 Ω
21.11.2016	WET(AFTER RAIN)	300 Ω
22.11.2016	WET(AFTER RAIN)	290 Ω
23.11.2016	DRY	300 Ω
24.11.2016	DRY	315 Ω

Table 4.8: Resistance of Bentonite for one week

BENTONITE		
DATE	WEATHER	EARTH RESISTANCE
18.11.2016	DRY	335 Ω
19.11.2016	DRY	330 Ω
20.11.2016	WET(AFTER RAIN)	280 Ω
21.11.2016	WET(AFTER RAIN)	275 Ω
22.11.2016	WET(AFTER RAIN)	260 Ω
23.11.2016	DRY	260 Ω
24.11.2016	DRY	265 Ω

Table 4.9: Resistance of Local Soil (Reference Soil) for one week

LOCAL SOIL		
DATE	WEATHER	EARTH RESISTANCE
18.11.2016	DRY	1100 Ω
19.11.2016	DRY	1100 Ω
20.11.2016	WET(AFTER RAIN)	1050 Ω
21.11.2016	WET(AFTER RAIN)	1000 Ω
22.11.2016	WET(AFTER RAIN)	1000 Ω
23.11.2016	DRY	1050 Ω
24.11.2016	DRY	1100 Ω

4.3 Data interpretation

The result in Figure 4.3 is showing the graphical representation of ground resistance result after 1 month. In this line chart, the value of three materials can be compared with the Bentonite as reference additive material so that the material that gives the best lower resistance can be determined. Next, the result in Figure 4.4 is showing the graphical representation of ground resistance result after one week. The value of four material used can be compared with local soil as reference to find the top-hole of lowest resistance.

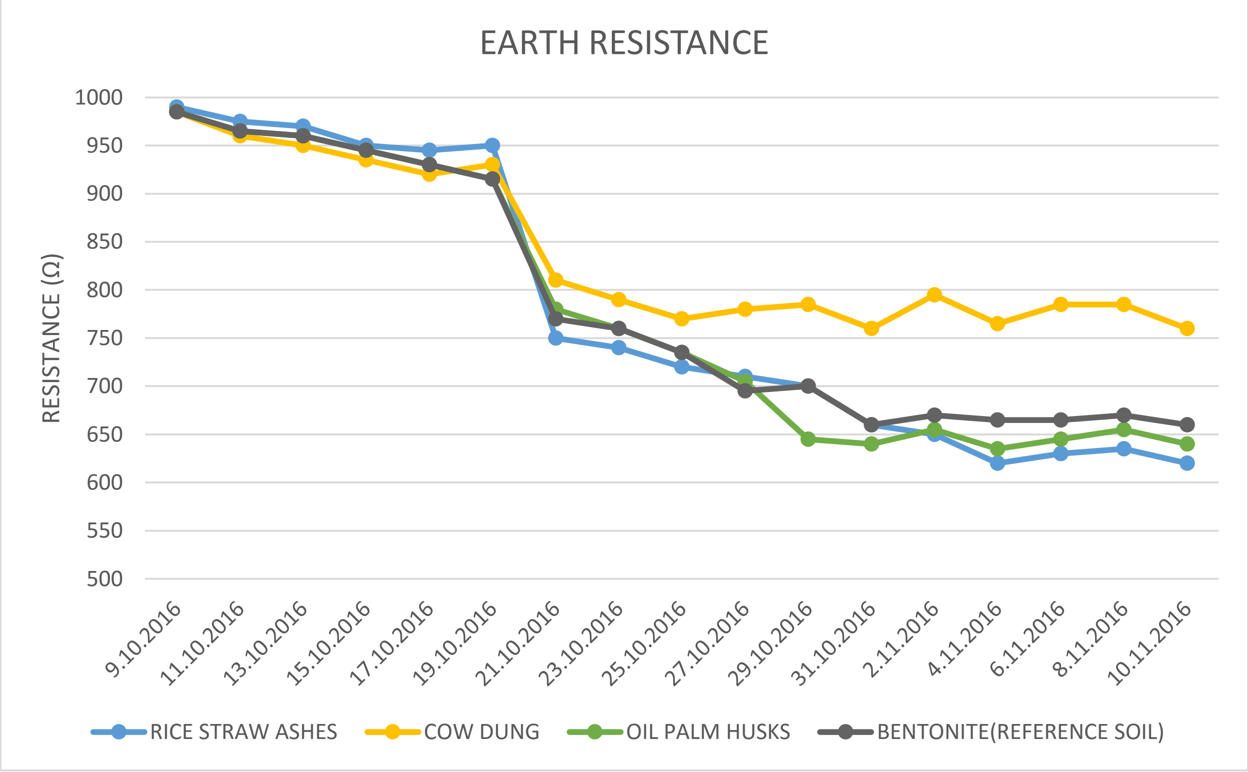


Figure 4.3.: Ground Resistance for One Month

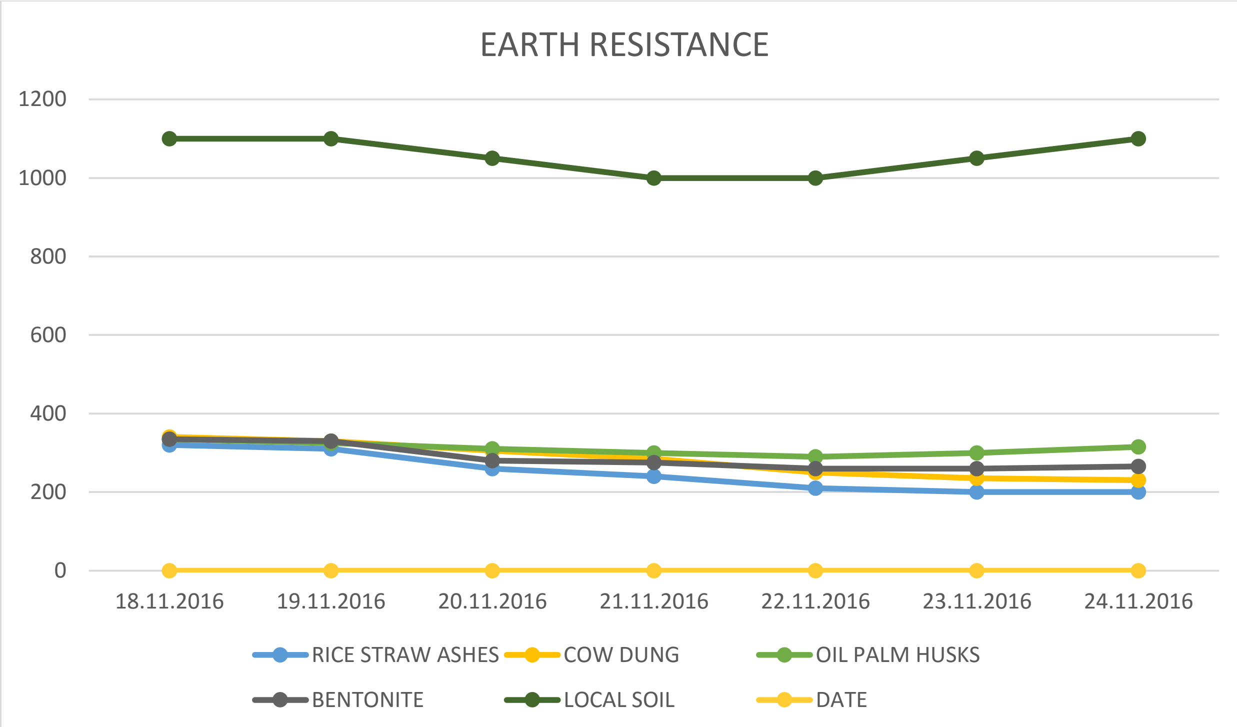


Figure 4.4: Ground Resistance for One Week

4.4 Data Analysis

In this experiment, ground enhancement material have been exposed to two types of weather, which is rainy day and dry day where there are a lot of heavy rains and almost no rainy on that day.

After a week from the installation period, the reading is significantly drops. This is because just after the installation, the materials are wet and the water content is high. That means the materials water absorption is in high level as it exposed to the raining that make it absorb and hold amount of water. It can be said that water content in the materials is increase; the ground resistance will significantly drops. After 1 month prior to the installation, the reading still not stable.

From the second set of graph, it shown that rice straw ashes give the lowest value of earth resistance which is 200 **Ω**. The reason is in the rice straw ashes there is lignin function as moisture resistance of the polymer that will reduce the amount of water that being absorbed. By comparing with the value from Bentonite which is 260 **Ω** as reference material, it is proofs that rice straw ashes is the best material compared to cow dung and oil palm husks. The reason for the material give a 77% increase in resistance efficiency compared to the Bentonite is because rice straw ashes are easily to absorb water because it’s a material that belong in hydrophilic group.

CHAPTER 5

CONCLUSION

5.1 Conclusions

Rice straw ashes gives a better grounding performance even the moisture content is smaller. This is due from material compactness and density that are high. Furthermore, the absences of unburned carbon in the Rice Straw Ashes contribute to better conductivity and less resistivity.

As a conclusion, the grounding performance can be improved by using Rice Straw Ashes. The objectives discuss earlier are achieved. This project also proved that by using 1.6 foot depth of holes filled with waste material can enhanced the performance of grounding system.

5.2 Problems

There are problems encountered during this study; lack of measuring equipment in the faculty and the difficulty to get the best location of test. Due to these problems, different test cannot be constructed to determine the actual characteristic of additive materials used.

Moreover, the scale model used in this study was unable to give accurate results as the actual grounding system. Using a scale model, the actual value of grounding resistance cannot be determined, but the scale model is able to predict the performance under actual size grounding performances.

5.3 Recommendation for Future Research

For a new grounding system, the resistance readings for the grounding system are not stable in the early period of installation. Therefore, continuous observation are needed, so the actual reading can be recorded. In addition, it also can determine whether the study material can be accepted as a material to improve the performance of grounding system. The best period for this study is one year.

Determination of additive materials used and its characteristic is important because it gives the grounding performance information. The moisture test can be conduct to see the moisture in the materials and to see how well it hold. Beside that the sieves test can also be conducted to see the actual distribution and to get very fine size of materials used as it will absorb more moisture. It is recommended for characteristic test analysis is done in future.

The grounding system also is subjected to the underground corrosion activities. The laboratory and field test are recommended after certain time of period to see the corrosion activities effect by the enhanced materials used.

Lastly, the two test that are highly recommended for future research are the ability of experiment materials to hold moisture and the test related to the absorption rate of the experiment sample. These two type of tests need to be conducted to determine the ability of experimental material to retain moisture and also the rate of absorption of experiment material.

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APPENDIX A

RESISTIVITY VALUE OF EARTHING MEDIUM

1 SOIL RESISTIVITY

The resistivity of a given type of soil will vary by several orders of magnitude as a result of small changes in the moisture content, salt concentration, and soil temperature. A broad variation of resistivity occurs as a function of soil types. Knowledge of exactly what type of soil we have at a given site will help to design in a precise manner the earth electrode.

Table 1: Resistivity values of the earthing medium

Medium	Resistivity (•m)		
	Minimum	Average	Maximum
City, industrial area		1000	10 000
Surface soil, loam	1		50
Clay	2		100
Sand and gravel	50		100
Surface limestone	100		10 000
Limestone	5		4000
Shale	5		100
Sandstone	20		2000
Granite, basalt		10 000	
Decomposed gneiss	50		500
Freshwater lake		200	200 000
Sea water	20	100	200
Pastoral, low hills, rich soil		30	
Marsh	2	100	
Pastoral, medium hills		200	
Fill, ash, cinder	6	25	70
Rocky soil, steep hills	10	500	1000
Clay, shale, gumbo	3	40	200
Gravel, sandstone, with little clay or loam, granite	500	1000	10 000
Sandy, dry, typical coastal country	300	500	5000

APPENDIX B

GROUNDING ELECTRODE MATERIAL CONSTANT

Table 1—Material constants

Description	Material conductivity (%)	α_r factor at 20 °C (1/°C)	K_o at 0 °C (0 °C)	Fusing[a] temperature T_m (°C)	ρ_r 20 °C (μΩ·cm)	TCAP thermal capacity [J/(cm^3·°C)]
Copper, annealed soft-drawn	100.0	0.003 93	234	1083	1.72	3.42
Copper, commercial hard-drawn	97.0	0.003 81	242	1084	1.78	3.42
Copper-clad steel wire	40.0	0.003 78	245	1084	4.40	3.85
Copper-clad steel wire	30.0	0.003 78	245	1084	5.86	3.85
Copper-clad steel rod[b]	20.0	0.003 78	245	1084	8.62	3.85
Aluminum, EC grade	61.0	0.004 03	228	657	2.86	2.56
Aluminum, 5005 alloy	53.5	0.003 53	263	652	3.22	2.60
Aluminum, 6201 alloy	52.5	0.003 47	268	654	3.28	2.60
Aluminum-clad steel wire	20.3	0.003 60	258	657	8.48	3.58
Steel, 1020	10.8	0.001 60	605	1510	15.90	3.28
Stainless-clad steel rod[c]	9.8	0.001 60	605	1400	17.50	4.44
Zinc-coated steel rod	8.6	0.003 20	293	419	20.10	3.93
Stainless steel, 304	2.4	0.001 30	749	1400	72.00	4.03

[a]From ASTM standards.
[b]Copper-clad steel rods based on 0.254 mm (0.010 in) copper thickness.
[c]Stainless-clad steel rod based on 0.508 mm (0.020 in) No. 304 stainless steel thickness over No. 1020 steel core.

Equation (37) and Equation (38), in conjunction with Equation (39) (which defines *TCAP*), reflect two basic assumptions

a) That all heat will be retained in the conductor (adiabatic process).
b) That the product of specific heat (*SH*) and specific weight (*SW*), *TCAP*, is approximately constant because *SH* increases and *SW* decreases at about the same rate. For most metals, these premises are applicable over a reasonably wide temperature range, as long as the fault duration is within a few seconds.

APPENDIX C

FALL OF POTENTIAL METHOD

of the grounding systems are required as a minimum. This method becomes awkward for large substations, and some form of the fall-of-potential method is preferred, if high accuracy is required.

8.2.1.3 Ratio Method

In this method the resistance of the electrode under test is compared with a known resistance, usually by using the same electrode configuration, as in the fall-of-potential method. Since this is a comparison method the ohm readings are independent of the test current magnitude if the test current is high enough to give adequate sensitivity.

8.2.1.4 Staged Fault Tests

Staged high-current tests may be required for those cases where specific information is desired on a particular grounding installation. Also, a ground impedance determination can be obtained as auxiliary information at the time of actual ground faults by utilizing an oscillograph or one element of the automatic station oscillograph.

In either case the instrumentation is the same. The object is to record the voltage between selected points on one or more oscillograph elements. The voltages to be recorded will probably be of such great magnitude that potential step-down transformers will be required. The maximum voltages that can be expected and thus the ratios of the potential transformers required may be determined in advance of the staged tests by using the fall-of-potential method at practical values of test current.

Another important consideration is the calibration of the oscillograph circuit, which is composed of a potential transformer with a possible high resistance in the primary. This resistance is composed of the remote potential ground in series with a long lead. A satisfactory calibration of the deflection of the oscillograph element may be made by inserting a measured voltage in the primary circuit in series with the lead and the remote potential ground as used during the test.

The location of the acutal points to be measured is dependent on the information desired; but in all cases due allowance must be made for coupling between test circuits, as given in 6.5.

8.2.1.5 Fall-of-Potential Method

This method has several variations and is applicable to all types of ground impedance measurements. As mentioned in 6.5, the impedance of a large grounding system may have an appreciable reactive component when the impedance is less than 0.5 Ω, therefore, the measured value is an *impedance* and should be so considered although the terminology often used is *resistance*.

The method involves passing a current into the electrode to be measured and noting the influence of this current in terms of voltage between the ground under test and a test *potential* electrode.

A test *current* electrode is used to permit passing a current into the electrode to be tested (see Fig 6).

The current I through the tested electrode E and the current electrode C, results in earth surface potential variations. The potential profile along the C, P, E, direction will look as in Fig 7. Potentials are measured with respect to the ground under test, E, which is assumed for convenience at zero potential.

The fall-of-potential method consists of plotting the ratio of $V/I = R$ as a function of probe spacing x. The potential electrode is moved away from the ground under test in steps. A value of impedance is obtained at each step. This impedance is plotted as a function of distance, and the value in ohms at which this plotted curve appears to level out is taken as the impedance value of the ground under test (see Fig 8).

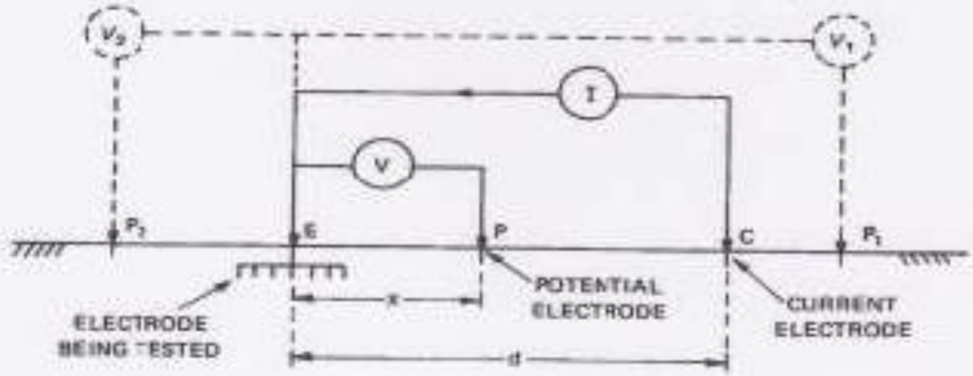

Figure 6—Fall-of-Potential Method

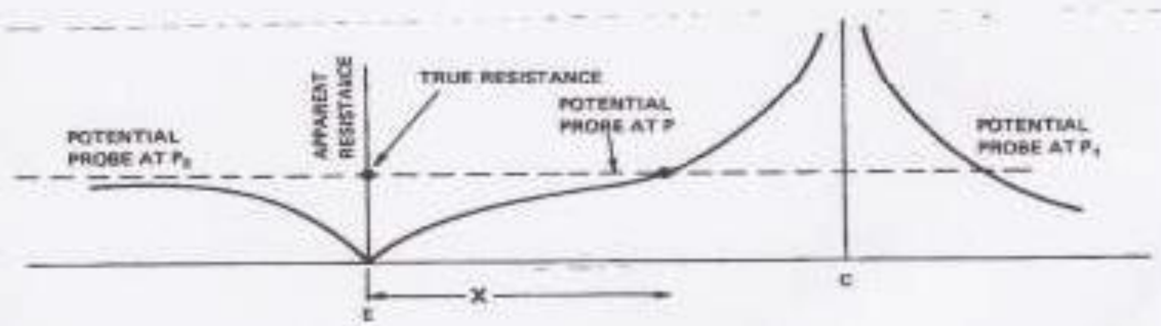

Figure 7—Apparent Resistance for Various Spacings X

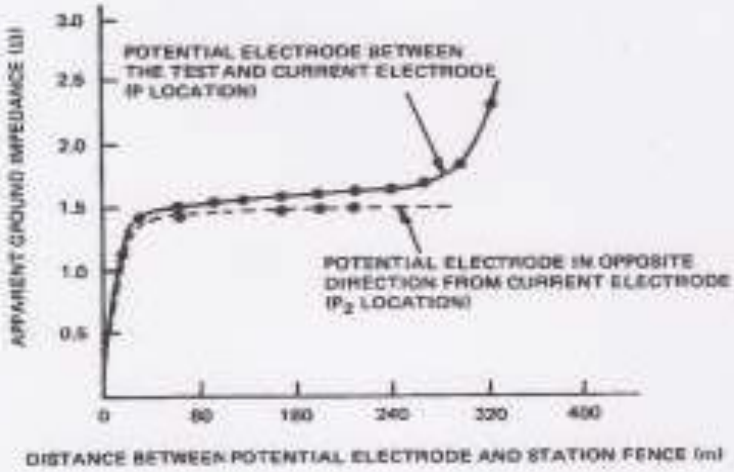

Figure 8—Case of a High-Impedance Ground System

This rule of thumb must be applied carefully since it gives satisfactory results only if a flat portion has been established very clearly. The theory of the fall of potential method is explained in Appendix C.

In order to obtain a flat portion of the curve it is necessary that the current electrode be effectively outside the *influence of the ground to be tested*. This influence is sometimes called *extent of station ground* and may be considered as the distance beyond which there is a negligible effect on the measured rise of ground voltage caused by ground current. Theoretically the influence extends to infinity; but practically there is a limit, because the influence varies inversely as some power of the distance from the ground to be tested. This influence is determined and allowed for during the test on ground grids or deep-driven ground rods of 1 Ω ορ λεσσ. Ιν τηε χασε οφ σμαλλ-area, such as single rod driven grounds, tower footings (not connected to overhead wires or counterpoises) the influence can be renderd negligible by keeping spacings in the order of 50 m which is practical and easy to achieve on site.

For large grounds the spacings required may not be practical or even possible. Consequently the flat portion of the curve will not be obtained and other methods of interpretation must be used.

It is important to note at this stage that theoretical analysis of the fall of potential problem [B14], [B19], [B40], [B41], shows that placement of the potential probe P at the opposite side with respect to electrode C (P_2) will result always in a measured apparent resistance smaller than the true resistance.

Moreover, when P is located on the same side as electrode C but away from it (P_1), there is a particular location which gives the true resistance.

It should be emphasized, however, that the P_2 arrangement presents the advantage of minimizing the coupling problem between test leads. If reasonably large distances between P_2 and C are achieved (with respect to the electrode E under tests), then it is possible to use this method to obtain a lower limit for the true resistance of electrode E.

A representative curve for a large grid ground is shown in Fig 9. The data for this figure were taken from a test made on a station that had a ground grid approximately 125 m by 150 m. Distances were measured from the station fence; hence the impedance is not zero at zero distance on the curve. Curve B is obtained with the potential probe located between E and C. Curve A is obtained with the potential probe located at the opposite side with respect to the current electrode C.

The test shows the existence of a mutual resistance between the current electrode and the station ground and that is why curve B does not level out. Curve A does seem to level out and can be used to obtain a lower limit for the impedance value of the electrode under test.

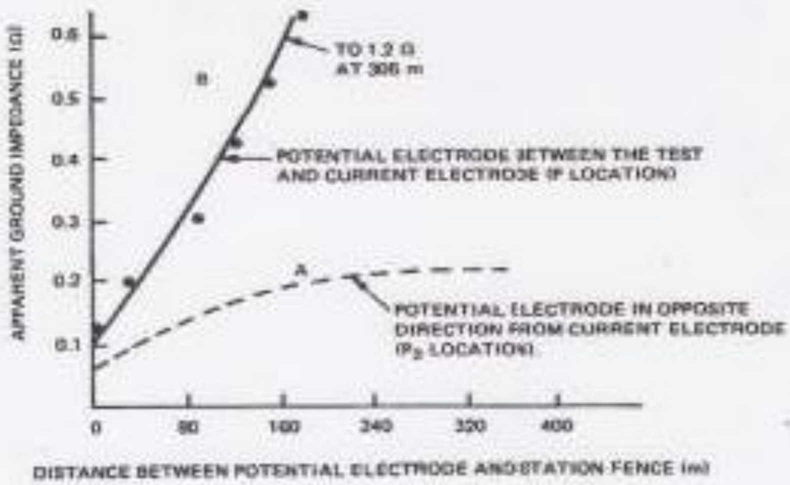

Figure 9—Case of a Low-Impedance Ground System

8.2.1.6 Interpretation of the Results

Appendix C shows that there is one potential probe spacing which gives the true ground impedance of the ground being tested.

The correct spacing may be very difficult, however, to determine especially if the ground grid has a complex shape (see [B8], [B12] and [B14] for additional information). The correct spacing is also a function of the soil configuration as demonstrated in [B12] and illustrated by Fig 10, which is applicable to small ground systems. As indicated in this figure the required potential probe spacing x (when the probe is between E and C and when the soil is uniform) is such that the ratio $x/d = 0.618$. This was first proved by E.B. Curdts [B8] for small hemispherical electrodes.

The above statements show that in order to apply the 61.8% rule the following conditions should exist:

1) A fairly uniform soil
2) Large spacings so that the electrodes may be assumed hemispherical.

Also the reference origin for the measurement of spacing must be determined. For hemispherical grounds, the origin is the center of the ground. For large ground systems some authors introduce the concept of *electrical center* and a method of determining the impedance of extensive ground systems imbedded in a uniform soil (based on the concept of electrical center) is described in a paper by Thug [B40]. It should be noted, however, that there is no proof that the *electrical center* is a physical constant (such as gravity center) which is not influenced by the current electrode location and characteristics.

As a general conclusion, the best guarantee of a satisfactory measurement is to achieve a spacing such that all mutual resistances are sufficiently small and the fall-of-potential curve levels out. The main advantage of the fall of potential