MULTI LAYER SOIL MODELLING

NUR SHAHWANI BINTI ISHAK

BACHELOR OF ELECTRICAL ENGINEERING WITH HONOURS
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

Multi-layer Soil Modelling

NUR SHAHWANI BINTI ISHAK

A report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electrical Engineering with Honours

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this thesis entitled “Multi-layer Soil Modelling is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : *nur shahwani*

Name : NUR SHAHWANI BINTI ISHAK

Date : 5 JULY 2021

APPROVAL

I hereby declare that I have checked this report entitled "Multi-layer soil modelling" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : DR. FARHAN BIN HANAFFI

Date : 5 JULY 2021

DEDICATIONS

Allah, Our Creator

Muhammad S.A.W, our Prophet

my father, my mother and siblings

My supervisor

My friends

Thanks for being on my behalf and give all the moral support, spirit, advice to complete this project.

ACKNOWLEDGEMENTS

In the Name of Allah, the Beneficent, the Merciful. First praise in to Allah, the Almighty, on whom ultimately, we depend for sustenance and guidance. First of all, I would to express my deepest gratitude to almighty Allah for giving me the health and strength for me to prepare this report on time.

I would like to thanks Dr. Farhan bin Hanaffi, my supervisor for his time to guide me, his support, advice and idea to complete this research. I also would like to thank my first panel Dr. Mohd Shahril bin Ahmad Khiar because willingly accept my report and my second panel PM. Dr. Hidayat bin Zainuddin for his advice on my project. Lastly, special thanks to my beloved family and my friend for their support.

ABSTRACT

A good electrical system must have an excellent protection of grounding system. This action can avoid a dangerous event to human and also prevent damage on the electrical equipment. One of the factors that can affected the grounding was a soil resistivity where it must low in order to presented a lower resistance reading on the soil. So, a multilayer soil modelling proposed a measuring method for soil resistivity using computer software, COMSOL Multiphysics. The operation started with simulated the uniform soil and then validate it boundary of soil and model itself. Then, a two-layer soil model was simulated and then evaluated using COMSOL to yield a potential different value which then used to calculate both resistance and apparent resistivity value. A comparison between simulated COMSOL soil model with simulated mention in the IEEE80-2000 was carried out to observe any differences on the apparent resistivity reading. Besides that, the parameter analysis also was done for several set of reading for three type of parameters which were distance between rod, depth of soil and resistivity each layer of soil. In this analysis, any changes on the reading of apparent resistivity were observe with increasing of distance between rod and depth of soil and same goes to resistivity each layer soil. The analysis on resistivity each layer of soil was carried out at two conditions, when resistivity upper layer more than lower layer ($\rho 1 > \rho 2$) and when resistivity upper layer lower than the lower layer ($\rho 1 < \rho 2$). All the data then presented in the form of graph on result section. The result that come out show there was a huge different on apparent resistivity value for both method due to different efficiency of the method. It was also founded that Sunde's method used to evaluate the model has play many assumptions which then yield varied on apparent resistivity. A recommendation was suggested to solve this problem by increasing the current to yield approximately result on both simulation method. Depth of soil must at reasonable depth and distance between rod also must at moderate spacing. This can yield a good approximation of two-layer soil model.

ABSTRAK

Sistem elektrik yang bagus seharusnya memiliki perlindungan pada sistem pembumian yang sangat baik. Dengan adanya sistem ini dapat mengelakkan kejadian berbahaya kepada manusia dan juga mencegah kerosakan pada peralatan elektrik. Oleh yang demikian, salah satu faktor yang dapat mempengaruhi sistem pembumian adalah ketahanan tanah di mana nilainya mesti rendah untuk menghasilkan nilai bacaan rintangan yang lebih rendah di tanah. Justeru itu, di dalam projek ini, pemodelan tanah pelbagai lapisan mencadangkan kaedah pengukuran ketahanan tanah menggunakan perisian komputer, COMSOL Multiphysics. Operasi dimulakan dengan mensimulasikan tanah seragam ("*uniform soil*") dan kemudian mengesahkan sempadan tanah dan model itu sendiri. Kemudian, model tanah dua lapisan ("*two-layer soil")* disimulasikan dan kemudian dinilai menggunakan COMSOL untuk menghasilkan voltan di mana kemudian digunakan untuk mengira nilai rintangan dan ketahanan jelas ("*apparent resistivity*"). Perbandingan antara model tanah yang disimulasikan menggunakan COMSOL dengan yang disimulasikan dalam IEEE80-2000 dilakukan untuk melihat perbezaan pada bacaan resistiviti yang jelas ("*apparent resistivity*"). Selain itu, analisis parameter dilakukan untuk beberapa set pengiraan untuk tiga jenis parameter seperti jarak antara rod, kedalaman tanah dan ketahanan *("resistivity*") setiap lapisan tanah. Dalam analisis ini, setiap perubahan pada pembacaan ketahanan jelas diperhatikan dengan peningkatan jarak antara batang dan kedalaman tanah dan sama dengan resistiviti setiap lapisan tanah. Analisis resistiviti setiap lapisan tanah dilakukan pada dua keadaan, pada ketika resistiviti lapisan atas lebih tinggi dari lapisan bawah ($\rho1 > \rho2$) dan ketika resistiviti lapisan atas lebih rendah dari lapisan bawah ($\rho1 < \rho2$) Semua data kemudian dipaparkan dalam bentuk graf pada bahagian keputusan (*Result*). Hasil yang ditunjukkan, terdapat perbezaan yang ketara pada nilai resistiviti bagi kedua-dua kaedah kerana kadar kecekapan pada kaedah yang digunakan adalah berbeza. Dinyatakan juga bahawa kaedah Sunde yang digunakan untuk menilai model mempunyai banyak andaian yang berkemungkinan menghasilkan pelbagai nilai pada ketahanan jelas ("*apparent resistivity*"). Satu cadangan dicadangkan untuk menyelesaikan masalah ini dengan meningkatkan arus untuk menghasilkan nilai yang hampir sama pada kedua kaedah simulasi. Kedalaman tanah mesti pada kedalaman bersesuaian dan jarak antara rod juga mesti pada jarak sederhana. Ini dapat menghasilkan model dua lapisan tanah yang bagus dengan nilai hampir tepat.

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

TABLE OF CONTENT

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the electrical system, the important elements to ensure safety is by providing good grounding system. For an electrical flow, the ground is known as the common point for it to return. It has backup pathway which is provide another route for electrical current to flow straight into the ground before fire or shock occurs. Figure 1.1 shows two types of grounding which are system grounding and equipment grounding.

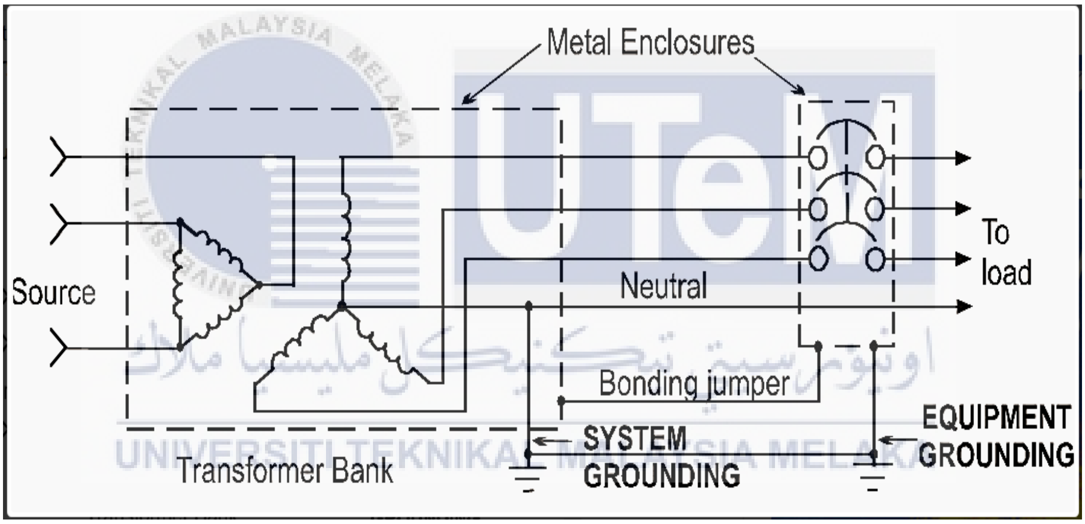

Figure 1.1: Grounding system.

Then, soil is known as suitable medium for grounding as it behaves as both conductor and dielectric. Basically, calculation of a ground resistance mostly using a two-layer soil model and followed the IEEE standard 80-2000. A few methods have been purposed to carried out this measurement but the mostly used is Wenner 4-probe method. This is by planted the four electrodes along straight line with equal distance and on certain depth.

In brief, a detail of measuring techniques already described in IEEE Standard 80-2000 because the data from Annex [E] being used to carried out this analysis [4]. A Sunde’curve is used to calculated a value of apparent resistivity and suitable probe spacing and then obtained a depth of upper layer for two-layer soil model. The resistance then can be calculated using that parameters value. Later, it will be used to decide on what depth should the electrode been planted to obtained a suitable resistance value or lower than 10 Ohm to follow authority requirements.

A finite element method used to modellings the soil model and calculated to the parameters value needed for a simulation part.

1.2 Problem Statement

Earth resistance depend upon many factors such as soil resistivity, environmental effects, materials used for earth electrode, length and diameter of earth electrode and some others related factors. For a better earth resistance value, soil resistivity must be low. In a resistivity analysis, uniform soil layer and two-layer soil model are the most commonly used. Soil resistivity measurement can be obtained using Wenner-four probe method. But this method itself has weakness which is yield inaccurate of reading because it plays many assumptions. While graphical method, Sunde'curve used to measure the resistivity and depth, of each layer with the help of data from fall on method. Unfortunately, depth and spacing value are varied for each type of soil and resulted vary on the apparent resistivity. This problem needs to overcome in providing the best approximation on two-layer soil model's apparent resistivity value. So that, an analysis on two-layer soil model being done by comparison simulated on IEEE80-2000 with simulated model using COMSOL.

1.3 Motivation

Multi-layer soil model is needed to yields a best approximation of apparent resistivity value and thus provide a good grounding system for an electrical system. All these problems motivate me to come up with an analysis for apparent resistivity changes in both simulation on how much they are equal or differ from each other. A COMSOL is used to done the simulation work by simulated the soil modelling and evaluate the model to yield a voltage reading which then used to divide current to get resistance reading. This analysis capable to ensure the ground system get good resistance value and meet standard limitation, below than 10 Ohm.

1.4 Objective

In order to solve the problem being stated, there are a few objectives need to achieve. The objective of this project as follow:

i. To model two-layer soil structure using computerized software, COMSOL Multiphysics.
ii. To analyze the two-layer soil model using COMSOL by carried out the parameter analysis on depth of soil, distance between rod and resistivity each layer of soil.
iii. To evaluate model that propose by IEEE80-2000 explore by comparing the two-layer's COMSOL model with simulated result of standard IEEE 80-2000.

1.5 Scope

Since apparent resistivity of soil will variously change depend on different condition. Parameter analysis on depth of soil, distance probe spacing and resistivity each layer will carried out to observe which one likely affect apparent resistivity calculation. Reading will be taken at three different depth and distance which are 5m,10m, and 15m. resistivity soil layer will be analyze at two different condition which is during resistivity upper layer higher than lower layer and when resistivity upper layer lower than lower layer.

The scope of this research will be focusing on how to simulate two-layer soil model using COMSOL Multiphysics software and evaluate apparent resistivity reading on it. Then, a comparison between that simulated model with IEEE 80-2000 will be carried out. Any similarity or differences on both simulated wills be analyzed to figure out any solution can be done for future measurement to provide better grounding system.

But, at first, a uniform soil will be simulated and validation of boundary model along with validation of model itself will be done. This step is compulsory before a two-layer soil model simulated. All the data then calculated using Excel and presented in form of graph.

CHAPTER 2

LITERATURE REVIEWS

2.1 Protection System

When fault such as an over-current or short circuit suddenly occur, the protection system will act up immediately. This system responsible to separating the faulty part from the rest of system and thus protecting electrical system. So, the other electrical system can workings normally without any severe damage cause by fault current. Figure 2.1 shown lightning rod protection system for a residential building where the flow of current from a lightning strike is channeled harmlessly outside house and into the ground.

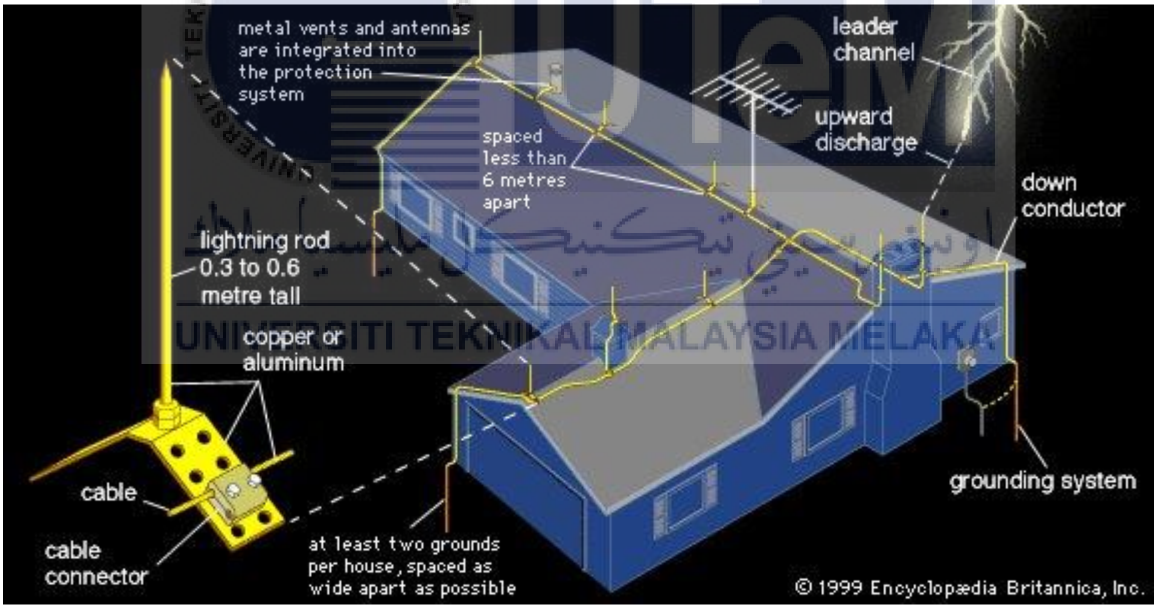

Figure 2.1: Example of protection system.

In brief, it is important to equip our electrical installation with a grounding system. This is to prevent any fatal shock or damage especially to user. Then, it also to protect against electrical overload that cause by surges in electricity lightning strike. This is actually can lead to a high voltage of electricity being dangerously produced in a system. So, the current must be grounded properly to allow any excess electricity freely flow into the earth.

2.1.1 Types of Electrical Protection

Electrical protection is known as a system which functionally to saving the electrical system from any dangerous event that can harm both human and electrical equipment. Due to that, there are a few types of protection as follows:

i. Overcurrent protection
ii. Over and under voltage protection
iii. Earth fault protection against leakage current
iv. Over and under frequency protection
v. Distance protection

2.2 Power System Grounding

The grounding system used to protect peoples and devices in case of lightning strike. According NEC (National Electrical Code) defines ground as a "conducting connection, whether intentional or accidental between an electrical circuit or equipment and earth or some conducting body that serves in place of the earth" [1].

By grounding the electrical system, it can make an entire system safer and at the same time provide protection against the fault in power supply. Human lives also can be secure and avoid electrical equipment from heavy damages. Basically, the grounding system works by sending any excess current or unwanted current to the ground that flowing through an earthing electrode. Figure 2.2 shows an example of fault that occur in grounding system where leakage current flowing through the appliances and if human accidentally touch it cause the current flow through the body. Its consequences from that event cause shock or immediately death.

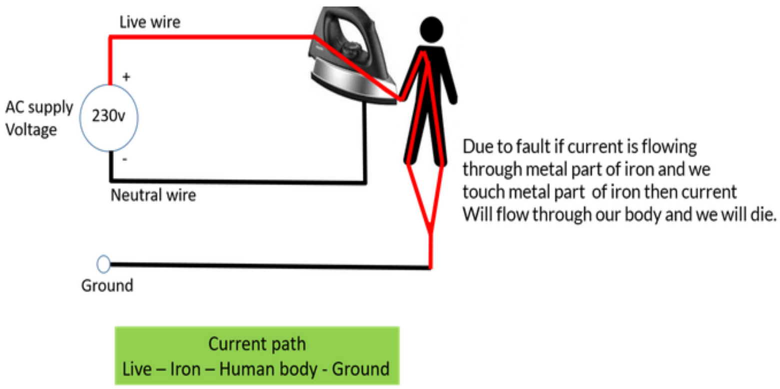

Figure 2.2: Example of fault in grounding system.

2.2.1 Types of Grounded System

There are three different types of grounding system involved for protecting the entire electrical system.

(i) Ungrounded Systems

Ungrounded system means there is no intentional connection to ground when an electrical power system operates.

(ii) Resistance grounded systems

Resistance grounding systems is when an electrical power system has a connection between neutral line and the ground through resistor. The resistor is used to limit the fault current through a neutral line.

(iii) Solidly grounded systems

For this kind of systems, an electrical system is directly connected to the ground and there is no intentional added impedance in the circuit.

2.2.2 Factors Affecting the Grounding System Installation

An excellent grounding system need to consider a few factors can affect its system before been designing.

(i) Soil condition

Good soil condition can determine the efficacy of grounding because grounding in wet soil and rocky soil completely different from each other. For example, the depth of soil must at suitable depth that can lower the resistance value.

(ii) Soil resistivity

Different soil conditions give different kinds of soil resistivity and soil having low resistivity is extremely corrosive. For dry soil, resistivity will be high and then the electrode’s earth resistance will be high.

(iii) Dissolved salts

Soil resistivity depends on water resistivity which depend on the quantity as well as the nature of salts that dissolved in it.

(iv) Moisture in soil

For maintaining the moisture especially in a dry soil, it is important to watering in the earth and surrounding it.

(v) Location of Earth Pit

Location where grounding been implemented play a big role. For example, in a dry climate, there lack of water. So, the backfill compound is not workable for moisture as the pit on surrounding will dry.

(vi) Physical Composition

A varied in soil composition influence different in resistivity.

(vii) Climate Condition

In a dry climate, the resistivity is high and in wet, the resistivity is low.

2.3 Soil Resistivity

Resistivity in soil will determining first for every work of grounding system to ensure proper installation practice and thus guarantee safety of the human and electrical system. Soil resistivity is a measurement of how much soil resists or conducts electric current or sometimes refers as the measure of the resistance offered by the soil in the flow of electricity.

2.3.1 Factors That Influence the Soil Resistivity

There are a few factors that most likely influence soil resistivity such as moisture content, moisture temperature and salt content. The resistivity also varies with the depth. The soil having low resistivity is good for grounding system design and it is measured in ohmmeter.

At 0 ℃ resistivity increasing due to water starts to freeze and if more than 0 ℃, it is negligible. The lower the temperature, the higher the resistivity. The grounding electrodes must be ensured is extend below frozen soil in cold regions.

Table 2.1: Effect of Temperature on Soil Resistivity Sandy Loam, 15.2% Moisture Content.

Temperature (℃)	Resistivity (Ω.m)
20	7,200
10	9,900
0 (Water)	13,800
0 (Ice)	30,000
-5	79,000
-15	130,000

Usually for dry ground like sand in a desert is highly resistive. As in Table 2.2 below, the soil moisture increased make resistivity decreases as well.

Table 2.2: Effect moisture content on soil resistivity.

Moisture content (% by weight of the dry soil)	Top soil (Ω.cm)	Sandy loam (Ω.cm)
0	$> 10^0$	$> 10^0$
0.25	250,000	250,000
5	165,000	43,000
10	53,000	18,500
15	19,000	10,500
20	12,000	6,300
30	6,400	4,200

Mineral salts itself has significant impact on reducing resistivity and it is a must for soil having salts content forming an electrolyte to conduct electricity.

As already know, the soil apparent resistivity also influenced by depth of soil and distance of rod planted on ground. The thicker the depth of soil, soil resistivity will increase with condition of high soil resistivity is presented on top and low resistivity lower layer. It is effective to achieve a low resistance of soil. This is because a good conductor must have low resistance while high resistance is known as bad conductor. Then, it also to limit the potential rise from the potential of surrounding earth. So, this will prevent danger especially to a person in a situation which he is standing on ground but touching.

Soil resistivity also said make from spacing between adjacent current and potential probes. For example, when probes far from each other, soil resistivity will indicate the average deep soil characteristics. But if both probe and adjacent current are close, local surface soil characteristic will be indicated by soil resistivity.

2.4 Resistivity Measurements

Testing on soil resistivity will be carried out to determine variations resistivity with depth. If the resistivity varies appreciably with depth, it is often desirable to use an increased range of probe spacing in order to obtain an estimate of the resistivity of deeper layers [4].

Usually, the resistivity of the soil is measured by the four spike methods where four spikes are arranged in the straight line driven into the soil at equal distance. The most common test types are the Wenner 4-Probe Method, Schlumberger Method, and the Driven Rod (3-Probe) Method.

2.4.1 Wenner 4-Probe Method

In the Wenner method, four probes are planted along a straight line, at equal distances *a* apart, driven to a depth *b* as shown in Figure 2.3 below. In short, it is possible to measure average soil resistivity of the soil between the two probes to a depth equal to the probe spacing between adjacent probes. As an example, the average soil resistivity is measuring at greater depth when probe spacing increases.

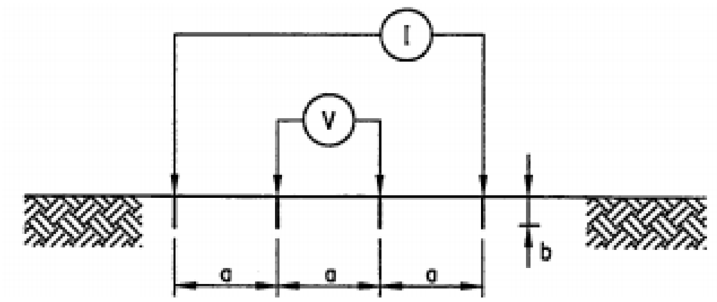

Figure 2.3: Wenner-four-pin method.

Then,

$$\rho_{\alpha} = \frac{4\pi a R}{1 + \frac{2a}{\sqrt{a^2+4b^2}} - \frac{a}{\sqrt{a^2+b^2}}} \qquad (1)$$

where,

ρ_{α} = apparent resistivity of the soil (Ωm)

R = resistance (Ω)

a = distance between adjacent electrodes (m)

b = depth of the electrodes (m)

An apparent resistivity is determined based on the surface measurement if the penetration of the probe, b is small compared to the spacing of the four probes [4]. Then formula below will be used.

$$\rho\alpha = 2\pi\alpha R \qquad (2)$$

2.4.2 Schlumberger Method

Schlumberger Method is inspired by the Wenner method on a condition where the larger the probe spacing, the greater the sensitivity will be produced. This method actually needed that the outer probes be moved four or five times each position of the inner probes [4]. Since there less probe placements than in Wenner method, it is reduced the time consuming which then give similar results as in Wenner method. Equation 3 below use to measure apparent resistivity based on the surface measurement as shown in Figure 2.4.

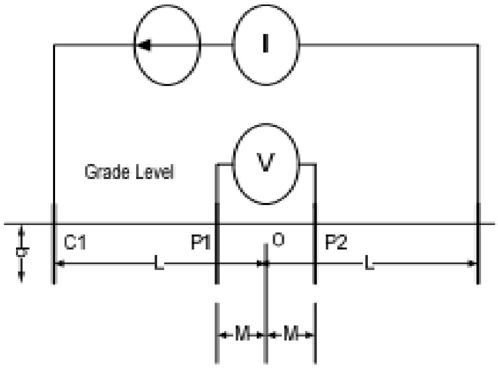

Figure 2.4: Schlumberger method.

$$\rho_{\alpha} = \frac{\pi L^2 R}{2M} \quad (3)$$

where,

ρ_{α} = apparent resistivity (Ωm)

L = distance from the center line to the outer probes (m)

M = distance from the center line to the inner probes (m)

R = resistance (Ω)

2.4.3 Driven Rod (3-Probe) Method

The measurement using this method is obtained without required the spacing as in other method being mention above. Its ability is can determined on what hat depth the earth electrode need to be planted.