DESIGNING AN EARTH ELECTRODE FOR DISTRIBUTION SUBSTATIONS

A dissertation submitted to the
Department of Electrical Engineering, University of Moratuwa
In partial fulfillment of the requirements for the
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In Electrical Installation

by
P. P.B. SAMARASEKARA

Supervised by: Prof. Ranjith Perera

Department of Electrical Engineering
University of Moratuwa, Sri Lanka

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Abstract

In electrical engineering, the term ground or earth has several meanings depending on the specific application areas. Ground is the reference point in an electrical circuit from which other voltages are measured, a common return path for electrical current (earth return or ground return), or a direct physical connection to the earth.

Electrical circuits may be connected to ground (earth) for several reasons. In a power circuit, a connection to ground is done for safety purposes to protect people from the effects of faulty insulation on electrically powered equipment. A connection to ground helps limit the voltage built up between power circuits and the earth, protecting circuit insulation from damage due to excessive voltage.

There are several types of earthing in the world. They are TT system, TN system and IT system. But in Sri Lanka most common method is the TT system. That means both the consumer and the source end should separately be earthed. Those earth electrodes should have less resistance and non corrosive perfect bonding.

In the power distribution system in Sri Lanka normally the main source is the CEB transformer. According to the TT system, the. substation should be earthed properly. If not it will affect the consumers by creating neutral leakage current, unbalancing voltage" voltage fluctuations and poor lightning protection etc. As a result transformer can be damaged, customer's electrical equipment and installation can be damaged .Life of humans and animals are in danger as the step and touch voltages have high values.

Generally CEB distribution substation has two earth electrodes: one for neutral and the other for lightning arrestor and the body. According to the CEB rules and IEE regulations the earth resistance of those electrodes should be less than 10 Ohms.

During last 20 years, CEB has used different types of earth electrodes for distribution substations. That is 10 feet long cast iron pipes, 6 feet long GI pipes, 1 m long copper plated steel rod with concrete mesh etc. But according to my investigations most of distribution substations of CEB have the resistance of around 100 Ohms. Hence I decided to select this topic as a project.

Therefore the aim of this project is to design an earth electrode with high performance for distribution substations. This electrode can be used at consumer end too. First , an electrode was designed for a better surface area. The electrode was a combination of a rod and a semi sphere. According to the soil type, the length of the rod can be varied. However to reduce the resistivity of the surrounding soil, a special mixture was prepared with a resistivity of around 4 ohm m 'and it was used to back fill the electrode. , An Aluminum or Galvanized barrel was used to avoid mixing that solution with the soil. As a result, the resistance of the electrode was reduced. I have designed eight types of electrodes for different soil types. However, the electrode-type D, that is 3m rod and a radius of O.75m barrel can be used at the most of areas since the resistivity is below 650 Ohm m in Sri Lanka Therefore we can maintain the level of earth resistance below 10 ohms easily.

DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

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P.P.B.Samarasekara

Date: 30.11.2009

I endorse the declaration by the candidate.

UOM Verified Signature

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Prof. Ranjith Perera

Supervisor

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Chapter 1

Introduction

Earthing is the subject of adopting methods of connecting to earth the components of an electrical system and metal work associated with equipment, apparatus and appliances for limiting potential with respect to the general mass of earth in order to ensure safety.

Earthing also covers the problem of conduction of electricity surges and fault currents into earth. Although the earth provides a low impedance return path for fault currents, it mainly serves to fix the voltage of the system neutrals. Also neutral to earth connections improve service continuity and avoids damage to equipment and danger to human life.

In any power distribution system even if a specific earthing arrangement is not provided the voltage levels of various equipment and metal work with respect to the earth would stabilize as determined by the various leakage paths for electric currents according to the insulation resistance present.

But it is always advisable and advantageous to provide a specific method of earthing of equipment and metal work for the following reasons.

i) Definite leakage paths for currents would operate and these would determine definite voltage levels with respect to earth for equipment and metal work where insulation resistance can be recommended to prevent unwanted current leakage paths.
ii) A definite plan can be followed in providing for the safety of personnel handling equipment and using them.
iii) In the event of voltage/current surges under switching conditions as well as lightning conditions a definite plan for the safety of equipment as well as the safety of people can be devised by introducing special earthing equipment and special protective devices.
iv) Easy leakage paths can be provided for leakage currents under fault conditions, firstly facilitating the operation of protective devices and secondly providing the safety of equipment and people.

In an electricity distribution system, earthing can be divided into two distinct sections. ie, the earthing of the High Voltage System and earthing of Low Voltage Distribution system. The methods of the HV system protection techniques are different from the LV and the two earthing systems should be separate and should not be combined. In this project mainly covers the LV Distribution from 33kV/400 and 11kV/400 substations and associated earthing systems.

LV distribution system earthing too can be divided in to following three categories,

a) Earthing at Distribution Substations
b) Earthing of Distribution Lines - System Earthing
c) Earthing of Consumer Installation - Equipment Earthing

Earthing of consumer installations involve.

a) Consumer neutral earthing (if any)
b) Equipment apparatus & appliance earthing

Earthing arrangement of a distribution Substation was analyzed in this project. Hence it can be used for, earthing of distribution lines and earthing of consumer installation. According to the CEB rules earthing of distribution substation should have following characteristics.

i. Neutral of the transformer shall be connected to one earth electrode.
ii. Transformer tank, Lightning Arresters and all other metal parts shall be separately earthed.

  - Separation of minimum 3 meter to be maintained between above two electrodes.
  - The earth resistance of each electrode should be less than 10Ω.

But the earth resistance of earth electrode in the most of locations of CEB is more than 75 Ohm. According to the site condition, it is very difficult to install earth electrodes properly in some places. Therefore the size and shape should be varied according to the site soil condition. However it should have less than 10 Ohm of earth resistance everywhere.

Hence the aim of my project is to design a better earth electrode which has the earth resistance of less than 10 Ω.

Figure 1.1 Distribution Substation

Chapter 2

Requirements of the Earthing System

The function of the earthing system is two-fold.

To provide a low enough impedance path, via the earth conductors, back to the supply source so that in the event of a failure to earth of a live conductor, sufficient current will flow safely along a predetermined route to enable the circuit protective to operate.

To limit the potential rise on all metalwork to which persons and animals normally have access, to a safely value under normal and abnormal circuit conditions.

2.1 Earth Conductors

Main equipotential bonding conductors which interconnect together and to earth, exposed conductive parts which do not normally carry current, but could do so under a fault condition. Therefore bonding and earth conductors within electricity substations need to be of sufficient size that they can carry a certain amount of fault current for three seconds, without damage. Hence when considering the material of the conductors, copper conductors are better than the Aluminum and the other materials for distribution substations and other places as they have good conductivity.

2.2 Earth Electrodes

The earth electrode is the component of the earthing system which is in direct contact with the ground and thus provides a means of releasing or collecting any earth leakage currents. In earthed systems it will normally be required to carry quite a large fault current for a short period of time and so will need to have a cross sectional area large enough to be able to carry this safely. Electrodes must have adequate mechanical and electrical properties to continue to meet the demands on them over a relatively long period of time, during which actual testing or inspection is difficult. The material should have good electrical conductivity and should not corrode in a wide range of soil conditions.

Materials used include copper, galvanized steel, Stainless steel and cast iron. Aluminum is sometimes used for above ground "bonding", but most of standards forbid its use as an earth electrode due to the risk of accelerated corrosion. The corrosive product – an oxide layer – is non conductive, so could reduce the effectiveness of the earthing.

2.3 Corrosion

Electricity supplies are required in all areas of the country, which include rural areas, city centers and industrial areas. Earthing system components are installed above and below ground and in both situations must cope with a wide range of environments. In air , there may be smoke from process plants, or rain water which has dissolved airborne material. Underground, the moist environment may include naturally occurring minerals, chemicals (fertilizers etc.) or contaminated substances which have been buried. As mentioned previously, the earthing system is a critical part of the electricity supply system and needs to perform, normally unseen, over a considerable period of time. The security required can be assured by careful selection of material.

2.4 Corrosion Susceptibility of Metals

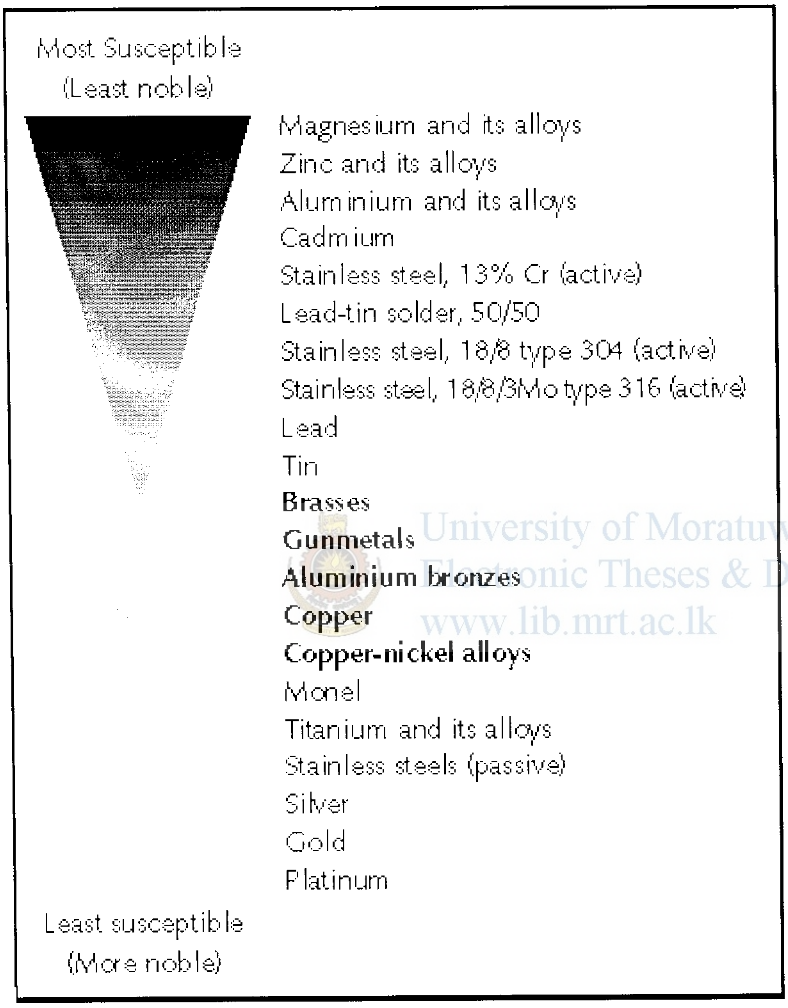

Figure 2.1 Corrosion Susceptibility of Metals [1]

According to the above table copper is the best material by considering mechanical properties and the cost of the material. Many of applications of copper and its alloys rely on good corrosion resistance, particularly in many aqueous, chemical and underground environments. Therefore copper can be selected as an engineering material for earthing purposes.

Chapter 3

Earth Electrode Types

Earth resistance depends on the configuration of the earth electrode. To decrease the value of earth resistance, the contact area of the electrode and the soil should be high. There are various types of earth electrodes and some of them are rod type, plate type, hemisphere type and strip or conductor type described as follows.

3.1 Rod type

These generally offer the cheapest and most convenient means of installing an electrode. Earth rods are commonly made from either solid copper, stainless steel or steel with copper bonding. Copper bonded earthing rods or copper bonded Grounding rods are commonly used due to strength, corrosion resistance and comparatively low cost. Solid copper and stainless steel rods offer a very high level of corrosion resistance at the expense of lower strength and higher cost.

Figure 3.1 Rod type Electrodes [5]

When the single earth rod , strip or plate will not achieve the desired resistance alone, we can increase the number of electrodes installed. Normally the separation distance between the two electrodes should be equal or more than the driven depth for rod electrodes.

The earth resistance of an electrode is varied according to its shape and size. If we considered a rod type electrode its earth resistance will vary according to its buried length as follows.

3.1.1 Increasing the length of an earth rod

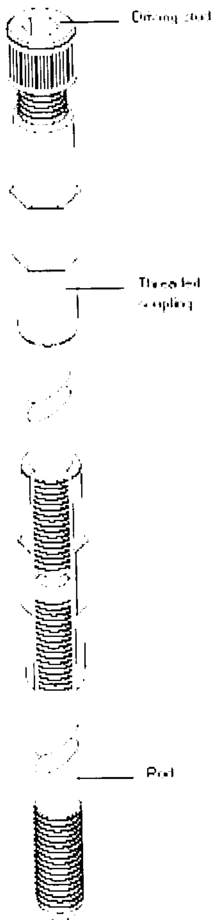

Figure 3.2 **Method of increasing the length of the rod type Electrode[6]**

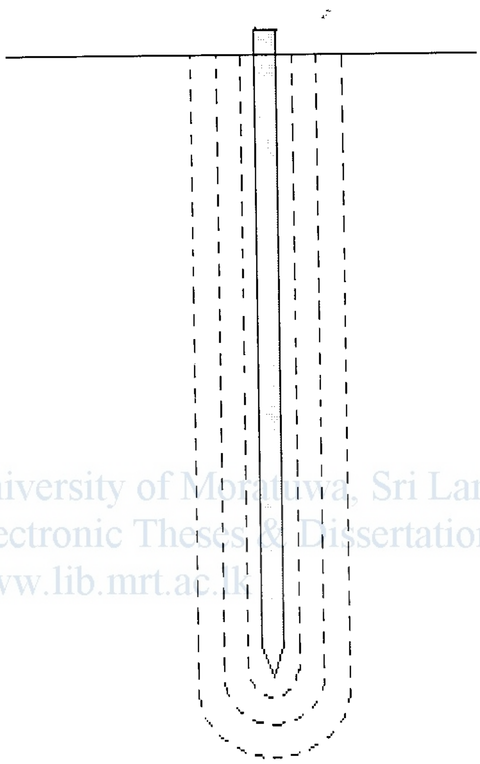

Figure 3.3 Voltage dissipation of a rod type Electrode

We can increase the length of the rod by connecting one by one as above. Hence the voltage dissipation of the rod is as figure 3.3. Therefore we can understand when the length of the rod is increasing the earth resistance will decrease, as the outer surface area of the rod is increased. But actually it will happen as follows.

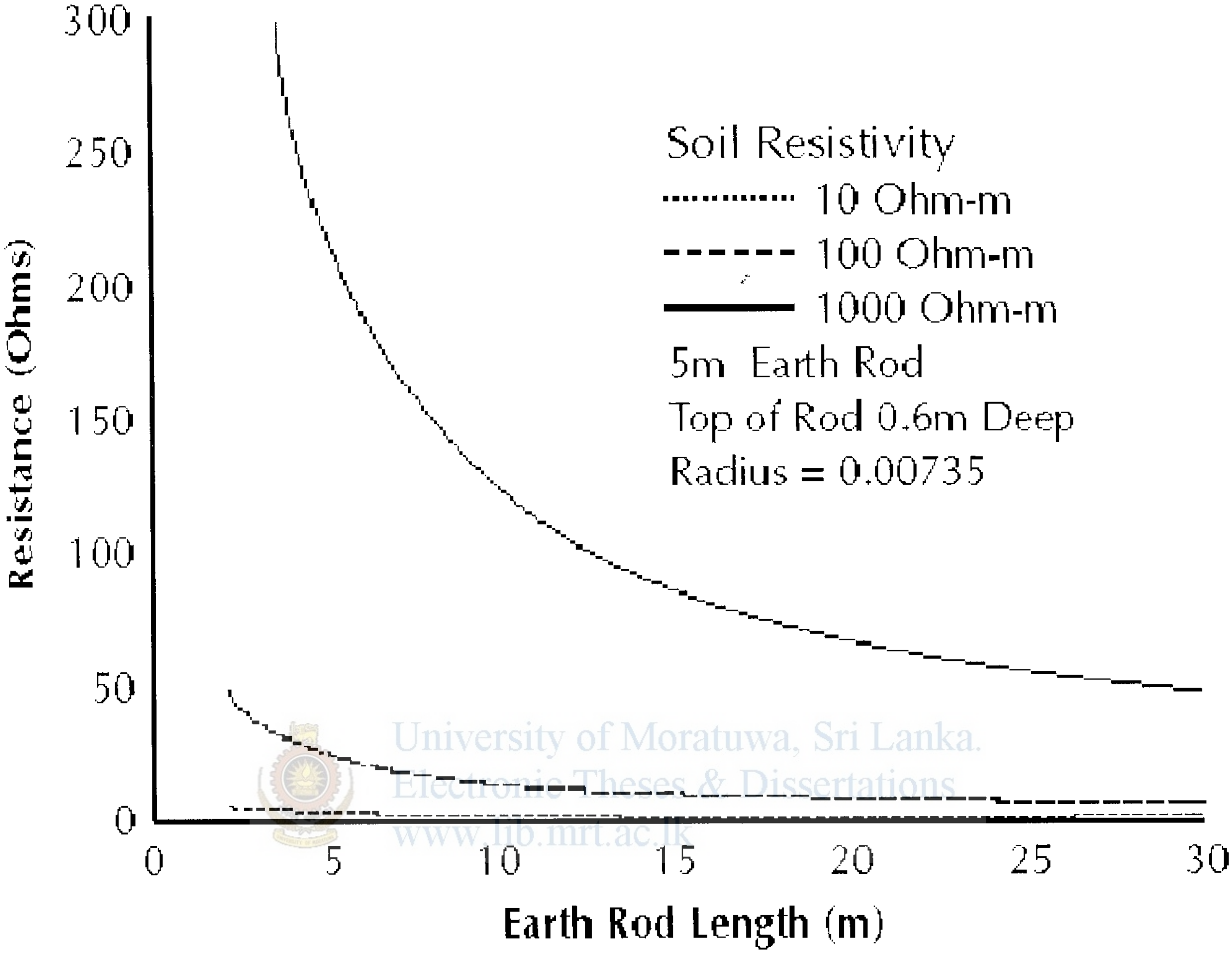

Figure 3.4 **Resistance Vs Rod length in uniform soil [1]**

From the above graph we can understand if the soil resistivity is high, the earth resistance is reduced quickly as the length of the rod increases. But when the rod reaches about 15m length, gradually the falling of resistance gets low. Therefore it is not necessary to increase the length of the rod unnecessarily, to improve the earth resistance in a uniform soil. There is an effective length according to the soil resistivity for an earth rod.

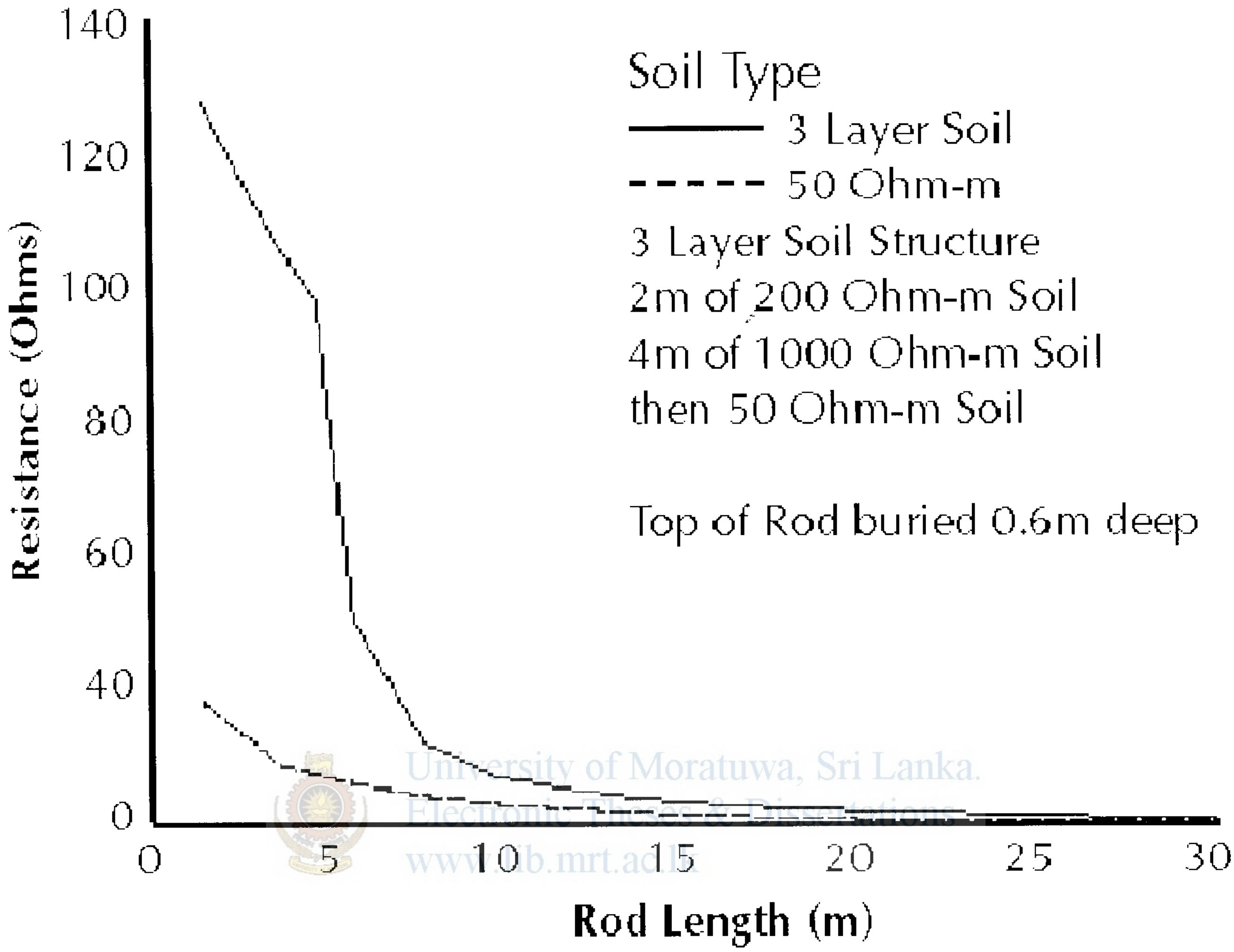

Figure 3.5 Resistance Vs Rod length in multilayer soil [1]

In some soil conditions, particularly where there is a limited area available, use of vertical rods may prove to be the most effective option, but it does depend on the soil structure.

Finally, it is important to note that vertical rods give a degree of stability to the impedance of an earthing system. Normally they should be of sufficient length that they are in or near the water table (if it exists at reasonable depth at the location) and below the freezing line. This means that the impedance should be less influenced by seasonal variations in water content or temperature.

3.1.2 Increasing the radius of an earth rod

Following figure shows the benefit that can be achieved in soils of different resistivity by increasing the radius of the rod. There is a rapid reduction in the benefit per unit increase in diameter once this exceeds 0.05m, except in soil of high resistivity where the same effect is noticed at about 0.2m diameter. Normally there is little to be gained by extending the radius of earth electrodes beyond that necessary to deal with the mechanical and corrosion requirements

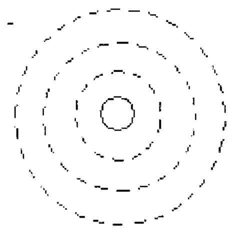

Figure 3.6 Equipotential pattern of a rod electrode

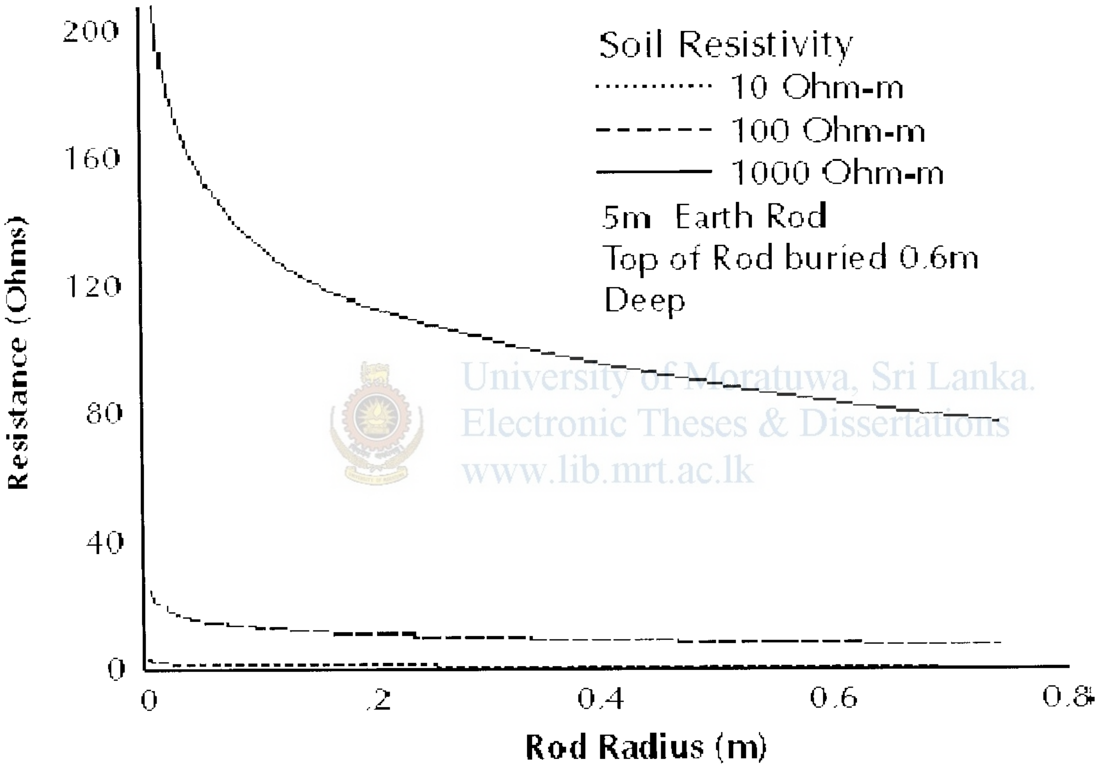

Figure 3.7 Resistance Vs the radius of an earth rod [1]

3.2 Plate Type

The plate type electrodes can be used to deal with greater currents by increasing the plate dimensions. The fault current easily can be absorbed to the earth as the outer surface is larger than the rods. But this type has some disadvantages. For example, they generally require manual or mechanical excavation and so the installation cost can be quite high. To reduce the amount of excavation required, plates are normally installed in the vertical plane about 0.5 meters below the surface. It is easier to pack the soil thoroughly against the plate when backfilling, if they are installed vertically. Another disadvantage is due to the locations chosen for earth plates. Often they are positioned too close to each other and then their zones of influence overlap.

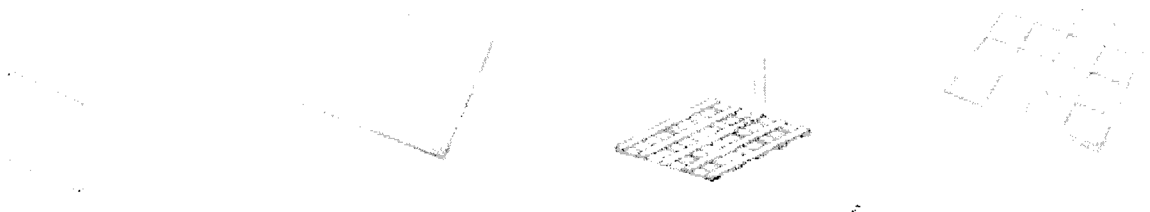

Figure 3.8 Different plate type electrodes [5]

3.3 Hemisphere Type

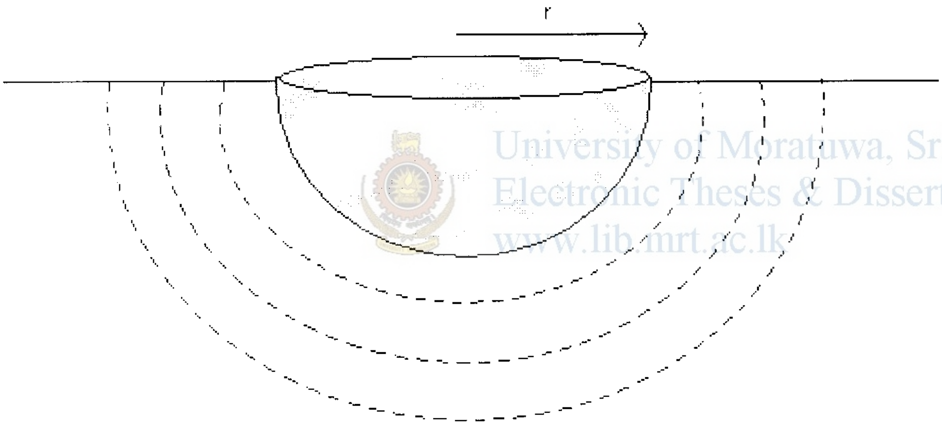

Figure 3.9 A Hemisphere Type Electrode

The earth resistance of a hemisphere is as follows.

$$R = \rho / 2\pi r$$

The hemisphere type electrodes can also be used for large fault current, as we can increase the outer surface by increasing the diameter of the hemisphere. The backfilling cost is some what less than for the plate type electrode. If we use copper plated steel, we can increase the resistance for corrosion and can reduce the total cost.

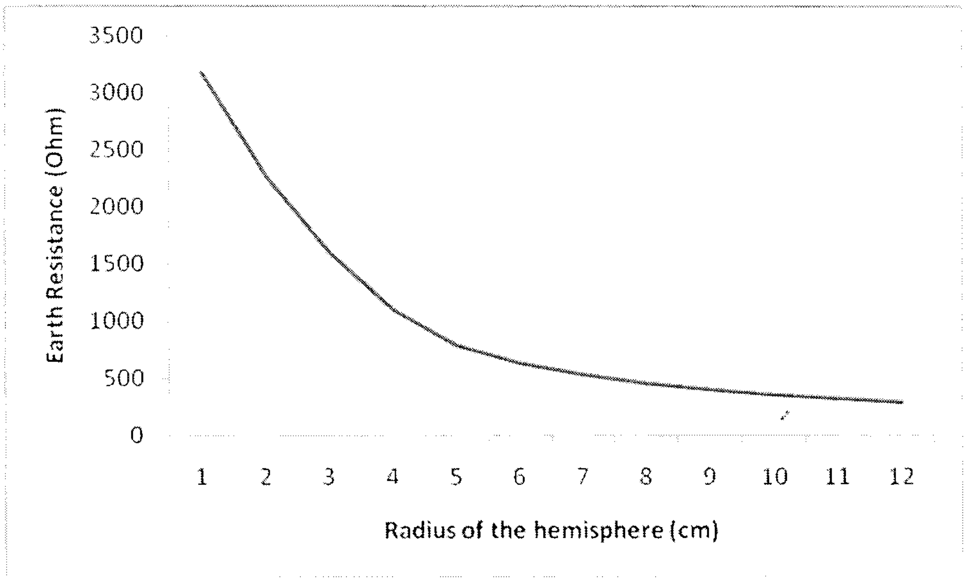

Figure 3.10 Resistance Vs radius of the hemisphere in uniform soil (ρ = 200 Ohm m)

According to the above graph we can understand decrease in resistance is low beyond a certain radius of the hemisphere. Therefore it is not necessary to increase the radius of the hemisphere too much to reduce the earth resistance.

3.4 Conductor or Strip Type

We can use this type at the places where is it difficult to excavates. The conductor or the strips have to be buried until it achieves the required resistance. Copper, Alluminium, Stainless Steel, Galvanize Steel are the low cost and suitable materials for these types of electrodes.

3.5 Relative Advantages and Disadvantages of the principal types of earth Electrodes.

Type	Advantages	Disadvantages
Vertical Rods	Simple design. Easy to install in good soils. Hardware readily available. Can be extended to reach the water table.	High impedance. Hard to install in rocky soil. Step voltage on earth surface can be high under large fault currents or during a direct lightning strike.
Plates	Can achieve low resistance contact in limited are.	Most difficult to install. Should be installed vertically.
Horizontal dare wires (radials)	Low impulse impedance. Good RF counterpoise when laid in star pattern.	Subject to resistance fluctuations with soils drying. Not recommended with unstable soils.

Incidental electrodes (water pipes, ufer grounds, buried tanks)	Can achieve very low resistance in certain applications.	Little or no control over future alternations. Must be employed with other electrodes, not as sole electrode.
Ring ground	Straightforward design. Easy to install around existing facility. Hardware readily available. Very efficient due to volume.	Problems with asphalt and concrete around the facility? Not desirable where large rocks are near surface.

Table 3.1 Relative Advantages and Disadvantages of the principal types of earth Electrodes [12]

3.6 Proposed design for an Earth electrode

Considering the above types of electrodes a new electrode is designed as shown in the figure 3.11 and it is a combination of a rod and a hemisphere.

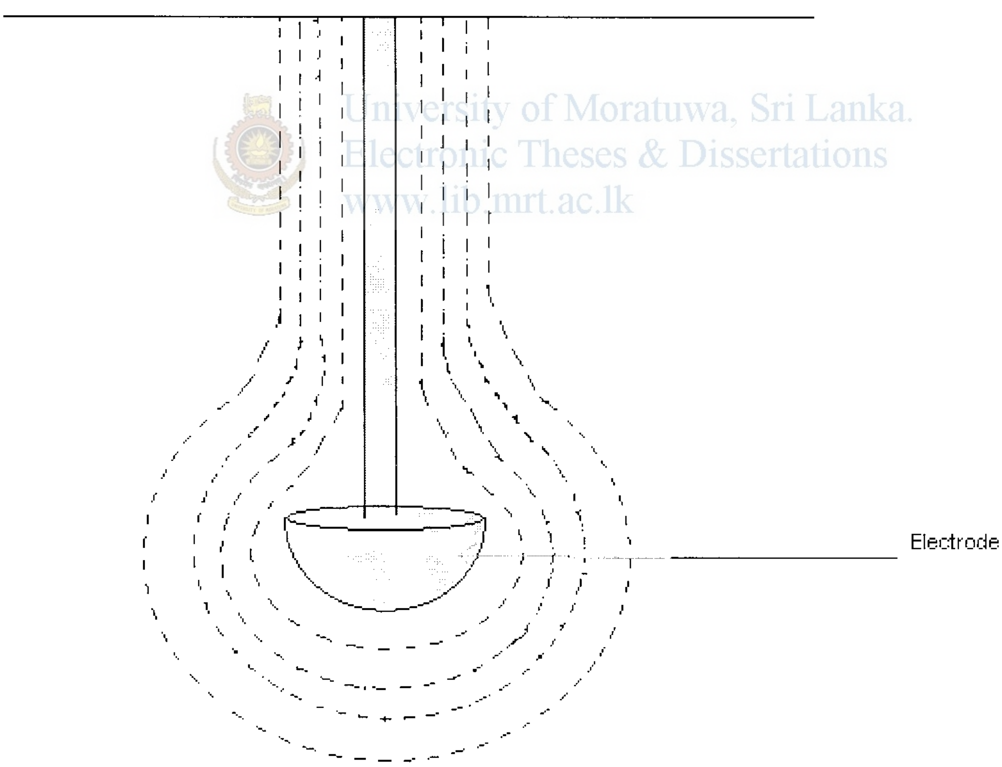

Figure 3.11 Voltage distribution of the proposed earth electrode

Figure 3.12 Proposed earth electrode

It is made from steel and plated copper to protect from corrosion. Due to the hemisphere part the high fault current also can be absorb to the earth easily and the outer surface area can be increased than the rod. Therefore Total resistance of this electrode is less than the individual of these types as they are in parallel.

Figure 3.13 Proposed earth electrode

Chapter 4

Performance of earth electrode

To design a better earthing system it should be satisfied two tasks. They are to achieve a required impedance value and to ensure that touch and step potentials are satisfactory.
Therefore it is needed to reduce the above values to design an earth electrode.

When considering impedance there are two influencing factors. They are the physical dimensions and attributes of the earth electrode system and soil conditions (composition, water content etc.).

The earthing system consists of conductive material above ground (bonding conductors etc), metal electrodes within the soil and the surrounding soil itself. Each of these will contribute towards the overall impedance value.

4.1 Connection between the earth conductor and the earth electrode

The impedance of the metal electrode material is usually relatively small, consisting of the linear impedance of the rod and/ or horizontal conductors. But the most important place is the joint which is at the earth electrode rod and the earth conductor. There are several jointing methods used include mechanical, brazed, exothermic and welded etc.

4.1.1 Mechanical Connection:-

These are commonly used and can be mechanical (bolted connection) or hydraulic (compression). The connection must meet the requirement of the applicable standards. If there are any loose connection the resistance of the joint will be high. This method of jointing is clearly not suited to deal with the higher values of fault current.

4.1.2 Brazed connections :-

Brazing is widely applied to copper and copper alloys. This method has the advantage of providing a low resistance joint which will not corrode. But a good joint can be difficult to make on site particularly where large cross sectional areas are involved. Clean flat surfaces are essential as brazing materials are generally not free flowing like solder.

4.1.3 Exothermic joints :-

These are made via graphite mould which is designed to fit the specific type of joint and conductor sizes. A powder mix of copper oxide and aluminium is ignited using a flint gun and the subsequent reaction forms a virtually pure copper joint around the conductors. The high temperature reaction takes place within the confines of the graphite mould. Each mould, if properly maintained, can be used for between 50 and 70 joints. Benefits claimed for this type of joint are that it :-

- provides a corrosion resistant, low resistance, permanent joint.
- uses relatively unskilled jointing techniques.
- can operate at high temperatures, possibly enabling the conductor size to be decreased.

The joint of exothermic welding is shown in following figure.

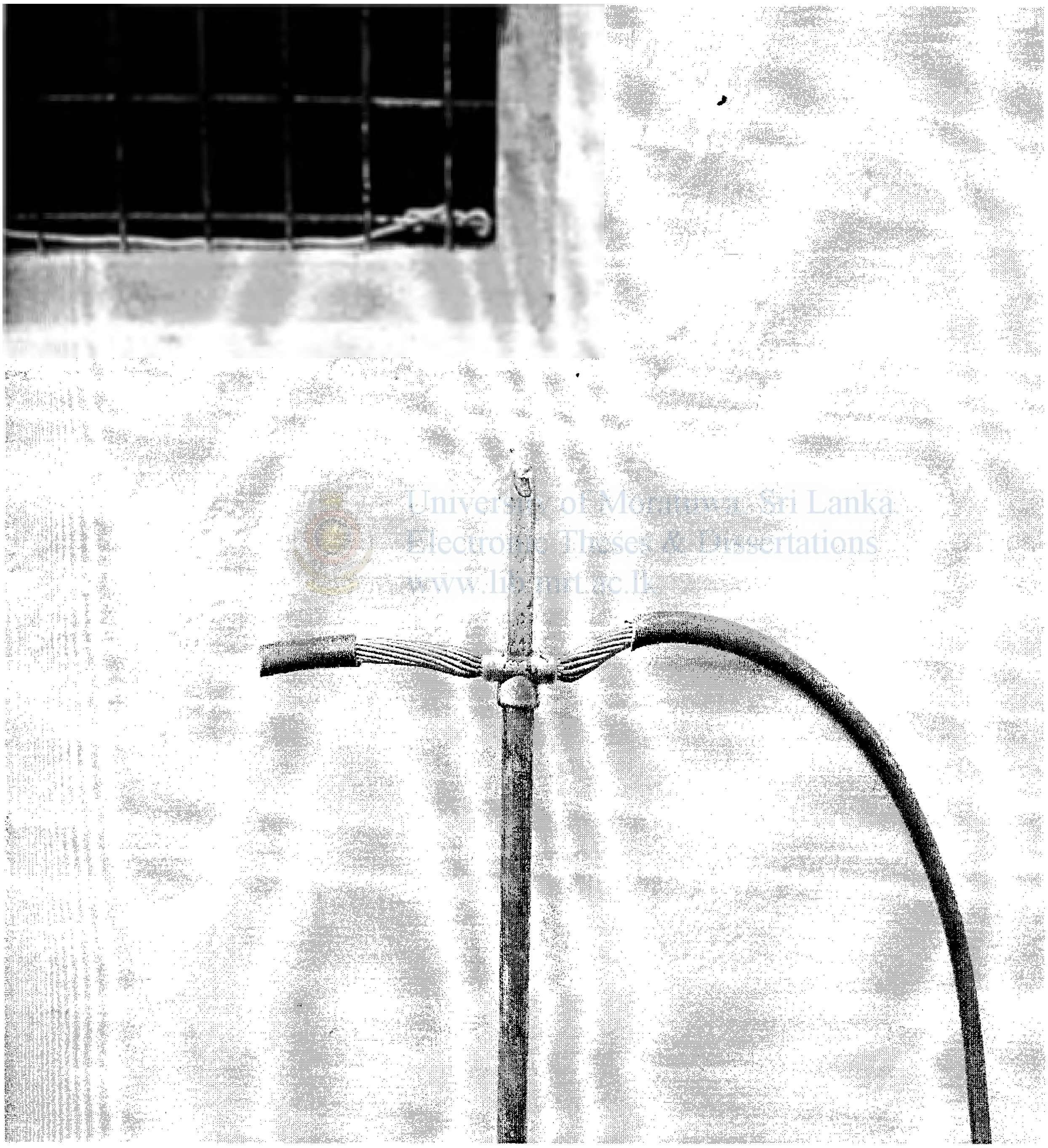

Figure 4.1 **A Joint of Exothermic Welding**

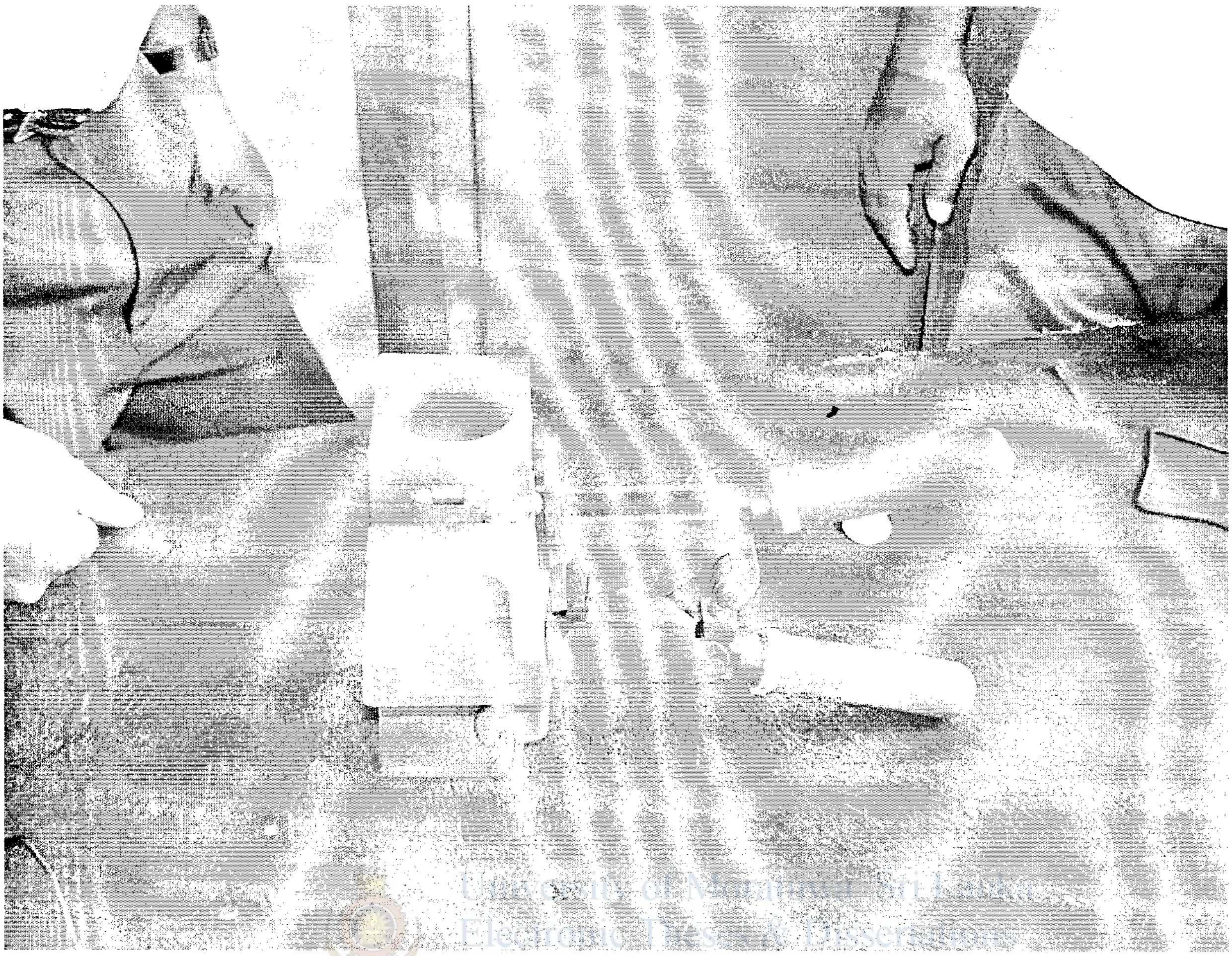

Figure 4.2 Exothermic welding mould.

4.1.4 Welded connections :-

Copper can be jointed by bronze welding or gas shield arc welding. Bronze welding is an effective, low cost jointing technique, used primarily to make on site joints. When heavier gauge copper components need to be jointed, then gas shielded arc welding is used.

Chapter 5

Soil Resistivity

The most important remaining factor influencing the impedance of the earthing system is the impedance of the medium in which the earth electrodes are situated. i.e the soil.

5.1 Effects of soil resistivity on ground Electrode Resistance

Accurate design of a grounding system requires an accurate assessment of the site's soil conditions, since the value of the resistance of the electrode is directly proportional to the soil resistivity. However, even a small site will often have widely varying soil resistivity from one spot to another. Therefore it is very important to measure the soil resistivity accurately.

The soil composition, moisture content and temperature all impact the soil resistivity. Soil is rarely homogeneous and the resistivity of the soil will vary geographically and at different soil depths. Moisture content changes seasonally, varies according to the nature of the sub layers of earth, and the depth of the permanent water table.

5.2 Measurement of soil resistivity

The test is traditionally carried out by Wenner four point method, i.e. using a four-terminal earth tester. Four spikes are driven into the ground as shown in the diagram.

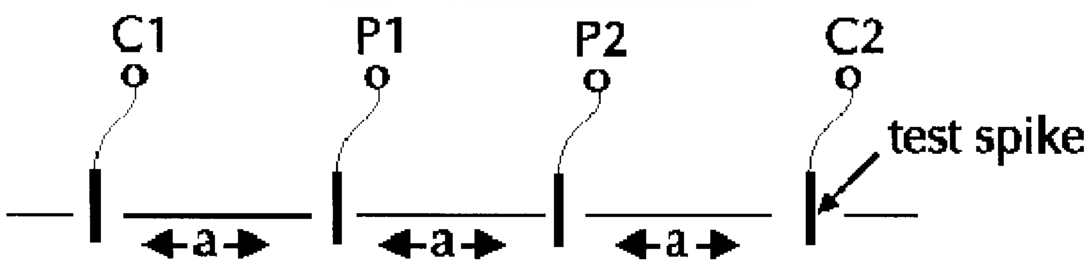

Figure 5.1 Connecting method of test spikes for measurement of soil resistivity. [7]

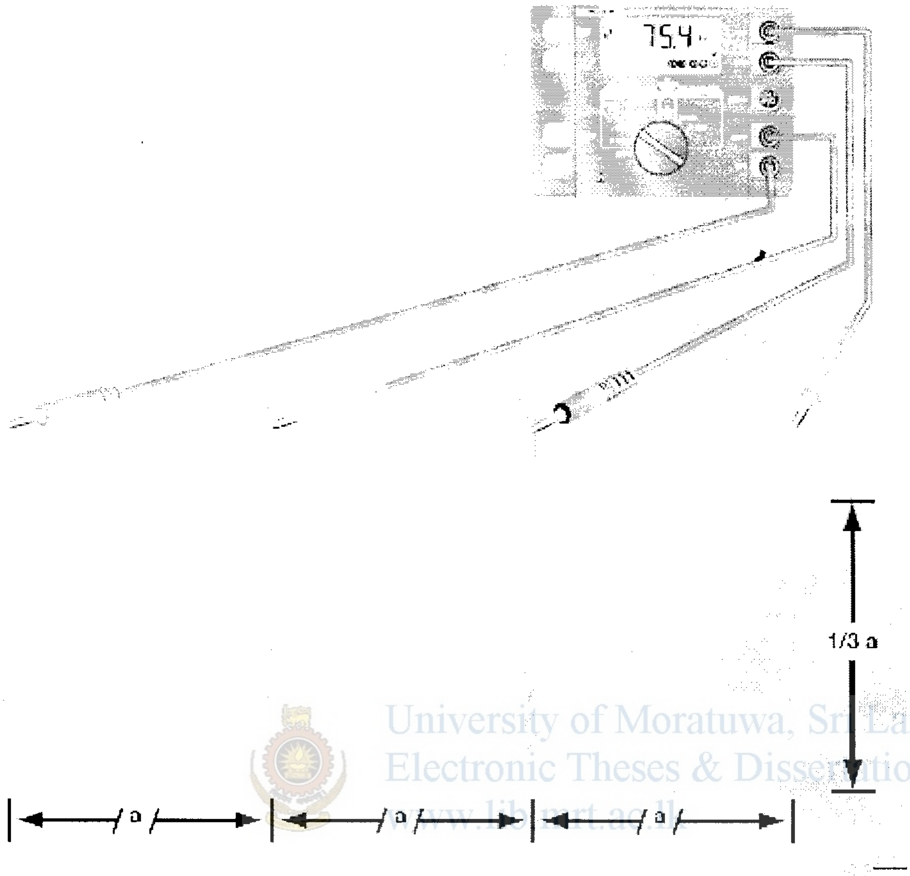

Figure 5.2 Measurement of soil resistivity [7]

The four rods need not be in same diameter but should be forced into the soil to approximately the same depth in at the soil surface. The rods should be in straight line, uniformly separate apart 'a'. Spacing should be at least three, preferably four time depth. But very wide spacing need a large test current and a fairly high supply voltage for accuracy. A current is driven between the two outermost rods and measured. The resulting voltage between the inner pair of rods is measured. Then calculate as follows:

Soil Resistivity (ohm meter) = $2 \times \pi \times$ spacing in meters (a) $\times$ Resistance (Ohm) (R)

The term "apparent resistivity" is used since the above formula assumes that the soil is uniform to a depth "a" meters below the centre point of the measurement traverse.
The voltmeter must be a high resistance type, at least 20 times the resistance of the soil between the pair of electrodes. To avoid errors due to extraneous earth currents or electro-chemical potentials, take the mean of measurements with rapid current reversals, or use an alternating 50 Hz supply current.

We are able to obtain information about the actual soil layering by taking a series of readings, with "a" being increased by 1m steps up to 6m separation, then 6m steps up to typically 30m separation.
A curve of resistivity against separation should be drawn during the measurement exercise. This will provide information on the general structure of the soil in the locality, identify, rough readings and help in deciding how many measurements are required.

Apparent soil resistivity plotted against test spike separation – relatively uniform soil.

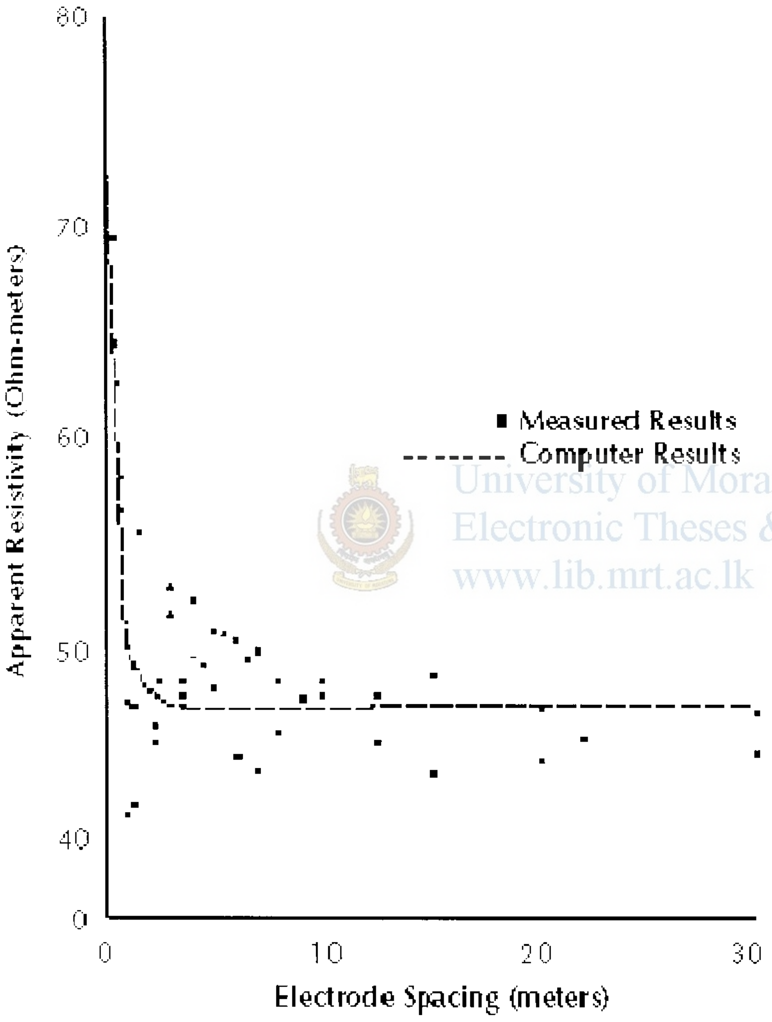

Figure 5.3 A Grape of soil resistivity Vs Electrode space [1]

Chapter 6

Factors Affecting soil Resistivity

Following factors are affecting soil resistivity.

- moisture Content
- temperature
- salt Content

6.1 Effect of moisture content on soil resistivity

Moisture content is one of the controlling factors in soil resistivity. Following figure shows the variation of resistivity of different soils with percentage of moisture. The moisture content is expressed in percent by weight of the dry soil. According to the figure that above about 20 percent moisture, the resistivity is very little affected, while below 20 percent the resistivity increases very abruptly with the decrease in moisture content. A difference of a few percent moisture will therefore, make a very marked difference in the effectiveness of earth connection if the moisture content falls bellow 20 percent. The normal moisture content of soils ranges from 10 percent in dry seasons to 35 percent in wet seasons, and an approximate average may be perhaps 16 to 18 percent.

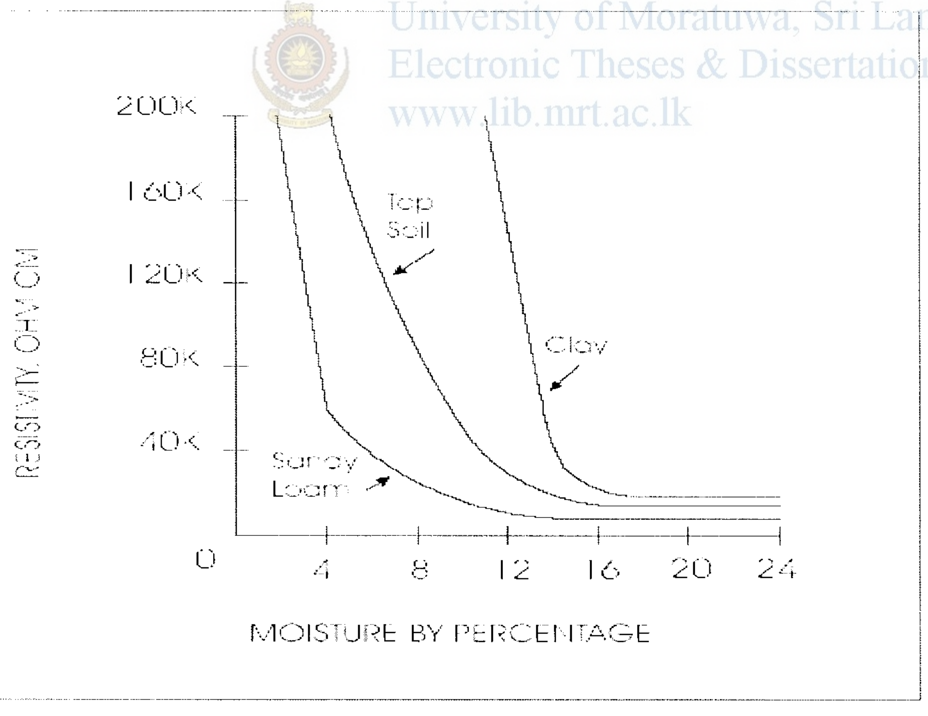

Figure 6.1 The influence of moisture content [2]

It should be recognized, however, that moisture alone is not the predominant factor in the low resistivity of soils. If the water is relatively pure, it will be high resistivity and unless the soil contains sufficient natural elements to form a conducting electrolyte, the abundance of water will not provide the soil with adequate conductivity. The value of high moisture content in soils is advantageous in increasing the solubility of existing natural elements in the soil, and in providing for the solubility of ingredients which may be artificially introduced to improve the soil conductivity.

6.2 Effect of Temperature on soil resistivity

The temperature coefficient of resistivity for soil is negative, but is negligible for temperature above freezing point. At about 20°C, the resistivity change is about 9 percent per degree Celsius. Below 0°C the water in the soil begins to freeze and introduce, a tremendous increase in the temperature coefficient, so that the temperature becomes lower the resistivity rises enormously.

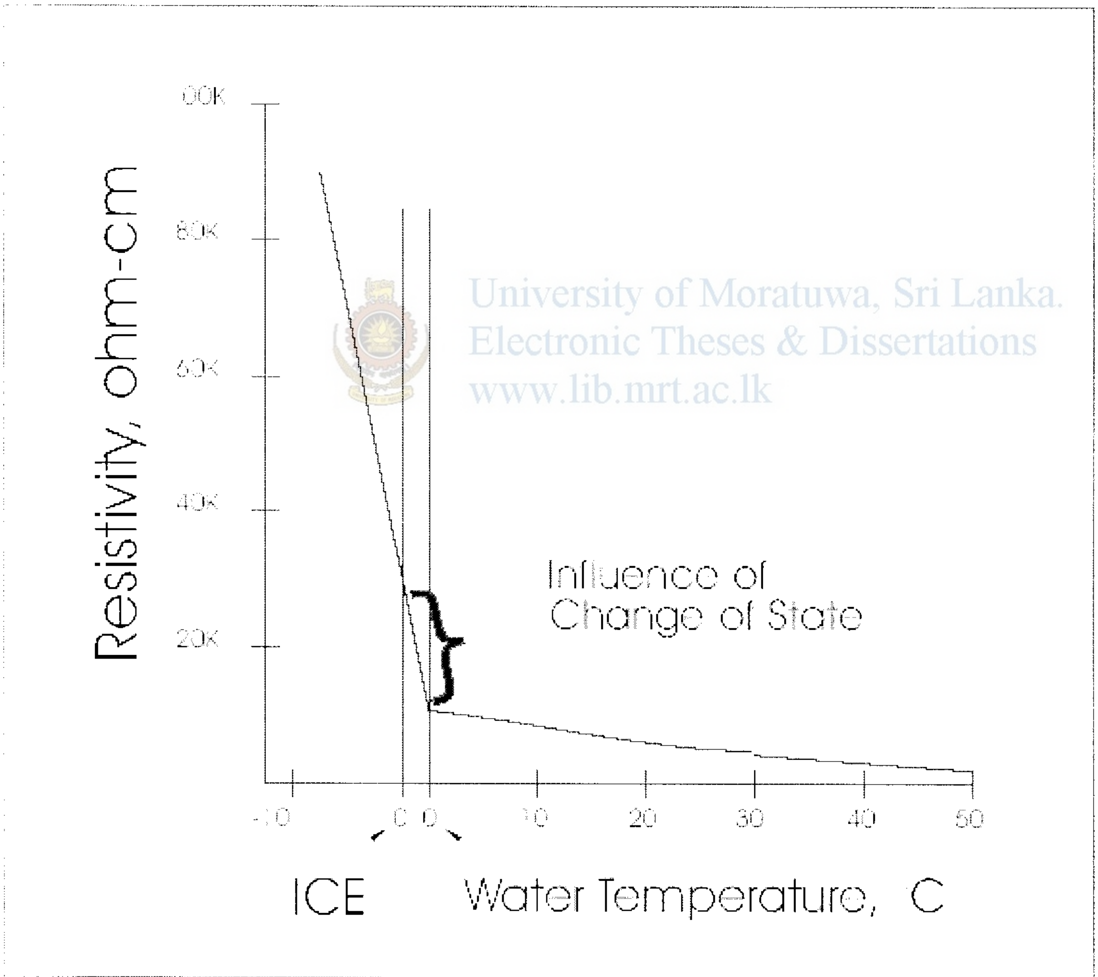

Figure 6.2 The influence of temperature [2]

6.3 Effect of salt content on soil resistivity

The mineral content has the most dramatic influence, as illustrated by the following figure. The higher mineral content also reduces soil sensitivity to moisture content. It is therefore, obvious that increasing the mineral content is the first step to be considered in soil conditioning.

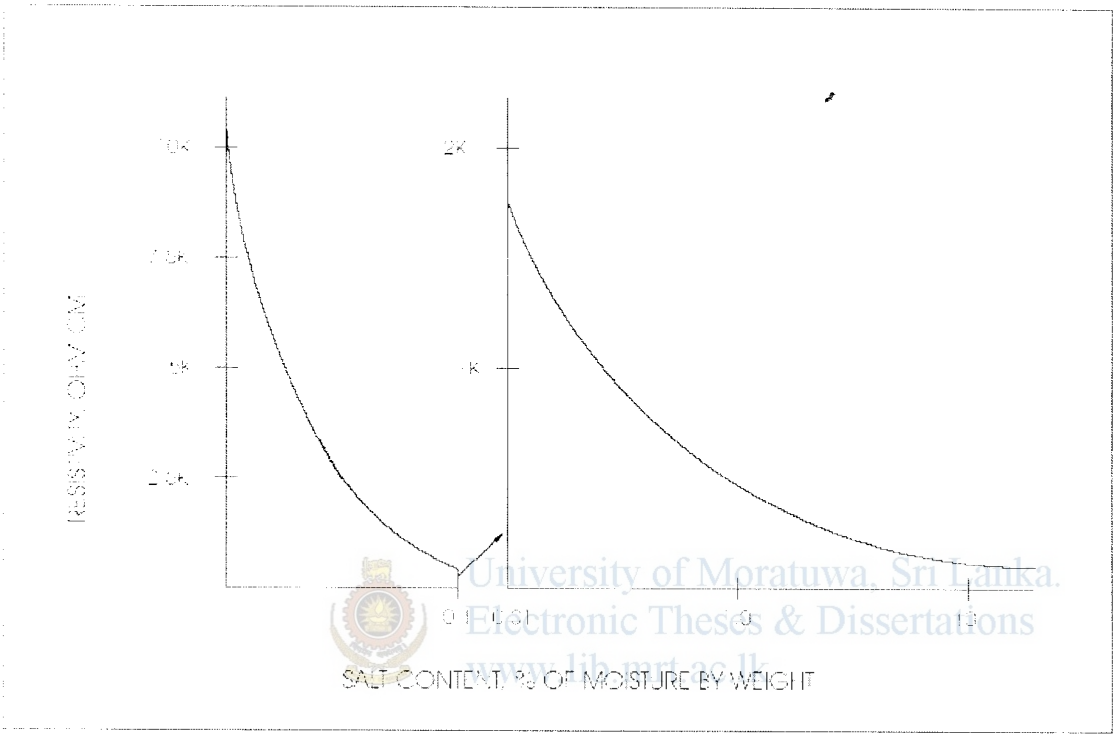

Figure 6.3 The influence of salt content [2]

Chapter 7

Critical Cylinder

7.1 Replacing soil in the Interfacing Hemisphere (IH)

Since about 95% of the grounding resistance of a given electrode is determined by the character of the soil within the Interfacing Hemisphere, it is obvious that replacing that soil with a more conductive soil could achieve the desired objective. However, that action may prove impractical. A more practical action may be to replace only that part of the soil that exercises the greatest influence on the ultimate grounding resistance and to use the lowest resistivity soil available. Figure 7.1 presents a plot demonstrating the influence of the surrounding soil as a function of the radius of what we choose to call the "Critical Cylinder" (that is, the amount of backfill to be placed around the grounding electrode). Notice that if we use a 10 feet rod, 52% of the connection is completed by a 12-inch-diameter Critical Cylinder, and 68% of that connection is completed by a 24-inch Critical Cylinder. The most productive option is therefore expected to be between these two diameters.

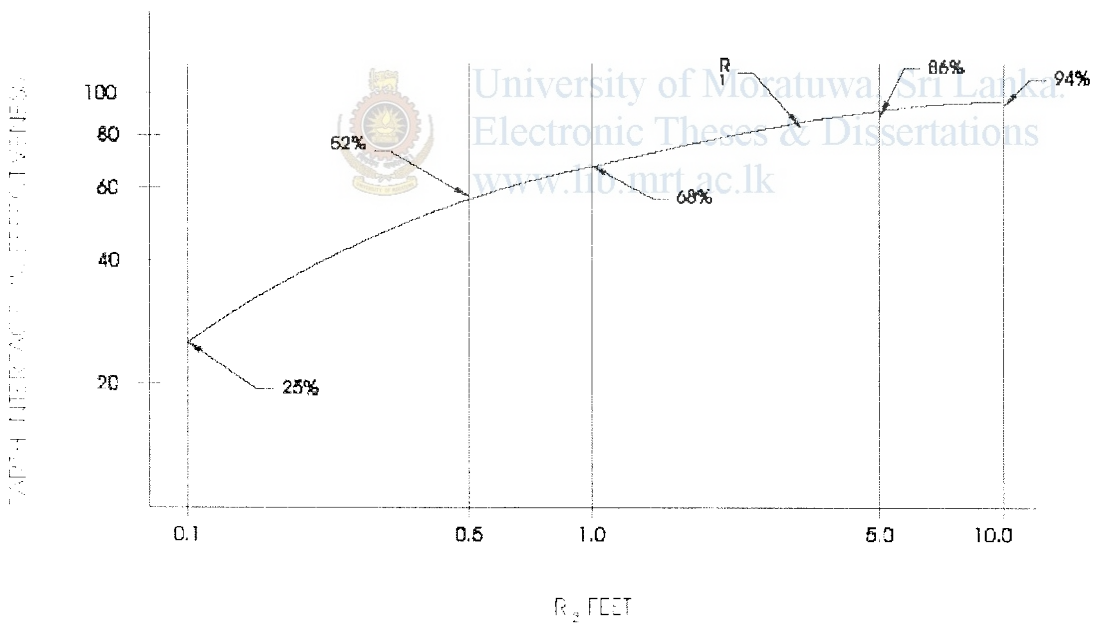

Figure 7.1 The influence of soil within the critical cylinder. [2]

The measured resistance change as a function of distance from the rod as follows.

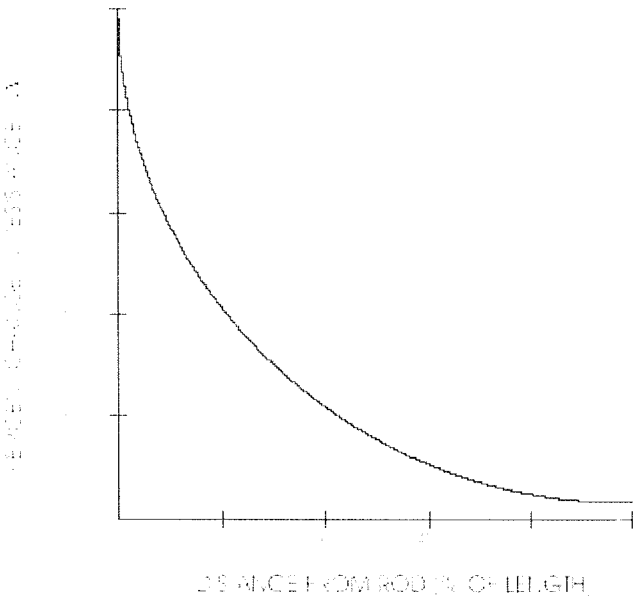

Figure 7.2 Percent Change in Resistance Vs Distance from Rod [2]

According to the above figure we can understand that the change in measured resistance decreases exponentially with distance from the rod.

However at about 1.1 times the length of the rod in earth, the change in resistance becomes negligible. This indicates that its connection to earth is nearly complete. Actually, about 95% ± 2% of the connection has been completed.

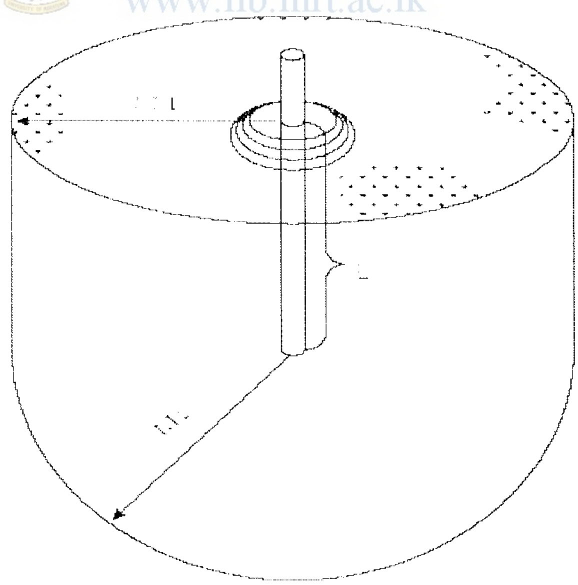

Figure 7.3 The Interfacing Hemisphere [2]

From these data, we know that for every rod driven into earth, an interfacing hemisphere of that earth is required to complete the electrical connection. The diameter of that hemisphere is approximately 2.2 times the length of the rod (L) in earth, as illustrated by the above figure. When more than one rod is required, they should be spaced no closer than 2.2 times the length of that rod in any direction. If multiple rods are driven too close together, those connections are considered incomplete; because all rods do not have a complete interfacing hemisphere, and the effectiveness of those additional rods are reduced proportionately and in reality, wasted.

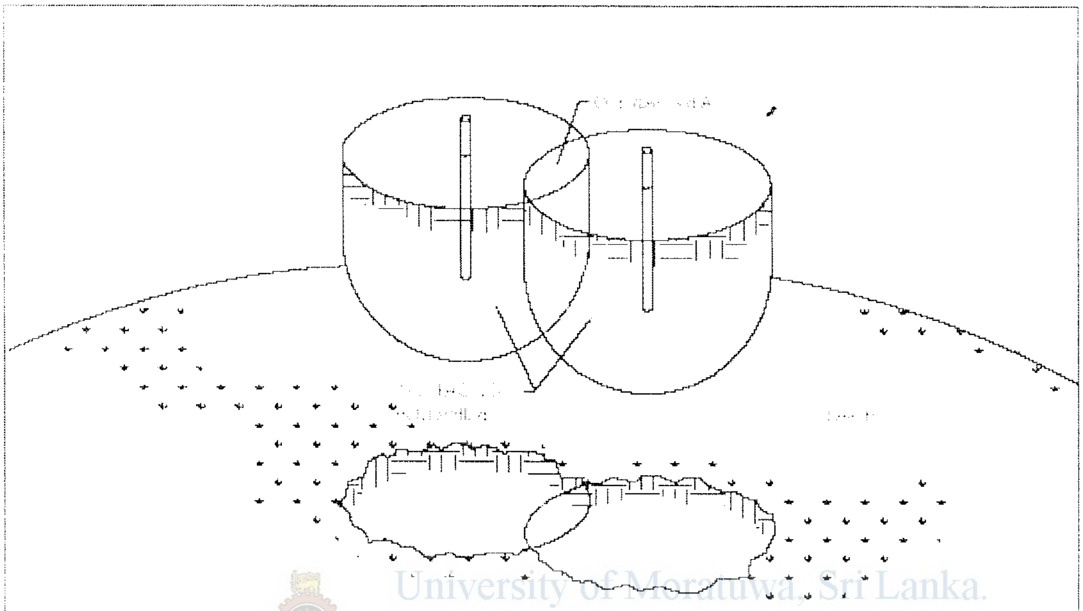

Figure 7.4 Rods too close [2]

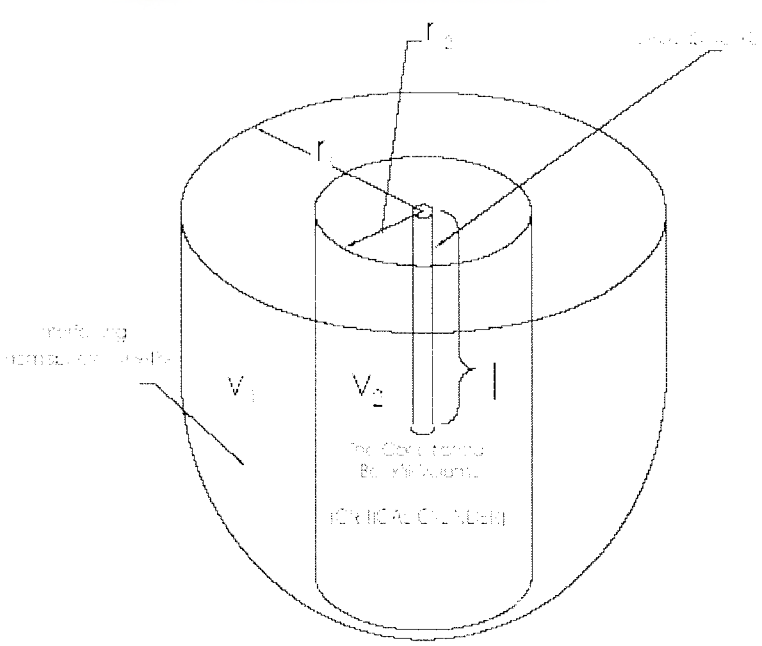

Figure 7.5 Critical Cylinder [2]

Chapter 8

Backfilling

According to the data in chapter 7 the soil in the interfacing hemisphere should have low resistivity to get a low earth resistance. Normally, the resistivity of various type of soil is as follows.

Soil type	Typical resistivity Ohm-m
Marshy ground	2 - 2.7
Loam and clay	4 - 150
Chalk	60 - 400
Sand	90 - 8,000
Peat	200 upwards
Sandy gravel	300 - 500
Rock	1,000 upwards

Table 8.1 Typical resistivities of various soil types [5]

Presently CEB use copper plated steel rod with a GI cage as the earth electrode and concrete as back filling material. But its earth resistance is over 50 Ohm. So I conducted three tests to clarify the result .In order to do the test, three electrodes were installed as follows. One method is earth rod with a GI cage (Presently CEB use this method) and the other one is earth rod without the GI cage. For both tests, equal volume of concrete was used for back filling. Final method is an electrode rod without GI cage and existing soil as the back filling material. The results were as follows.

Resistivity of the soil is around 850 Ohm m.

Method	Earth Resistance (Ohm)
Rod without GI cage with existing soil	750
Rod without GI cage with concrete	195
Rod with GI cage with concrete	82

According to that result we can understand concrete is not a good backfilling material. But now a days CEB use concrete to protect the GI cage from corrosion. However earth resistance of 10 ohm target cannot be achieved from these methods.

Figure 8.1 Earth electrode without GI cage

Figure 8.2 Earth electrode with GI cage.

8.1 Backfilling Material

According to the table 8.1 we can understand the resistivity of the soil varies from place to place. Therefore at least the resistivity of the soil which is in the critical cylinder should be very low to get a better earth resistance reading. Then it will become independent from the surrounding soil type. So special type of mixture was prepared considering following factors

According to the chapter 6 some percentage of moisture should be in that mixture. To keep the moisture content for a long period, coir dust is a very good material. But it is very difficult to compact it properly. Therefore coir dust is mixed with clay and prepared a mixture. After that charcoal dust, carbon powder were collected to that mixture as carbon is a good conductive material. In addition to that, salt, gypsum and sodium carbonate (washing soda) were added for this mixture. Finally that mixture is mixed with water and measured the resistivity. Then it was around 4 Ohm m.

But after few rainy days the artificial chemical which we added to that mixture was absorbed by the earth and the soil around the earth electrode became neutral. To over come that problem a barrel which is made from aluminum or galvanized was used as follows. Hence all chemicals which are in that mixture will remain there. Then the moisture content also can be maintained without absorbing it to the earth due to that barrel.

Figure 8.3 The barrel which is used for backfilling

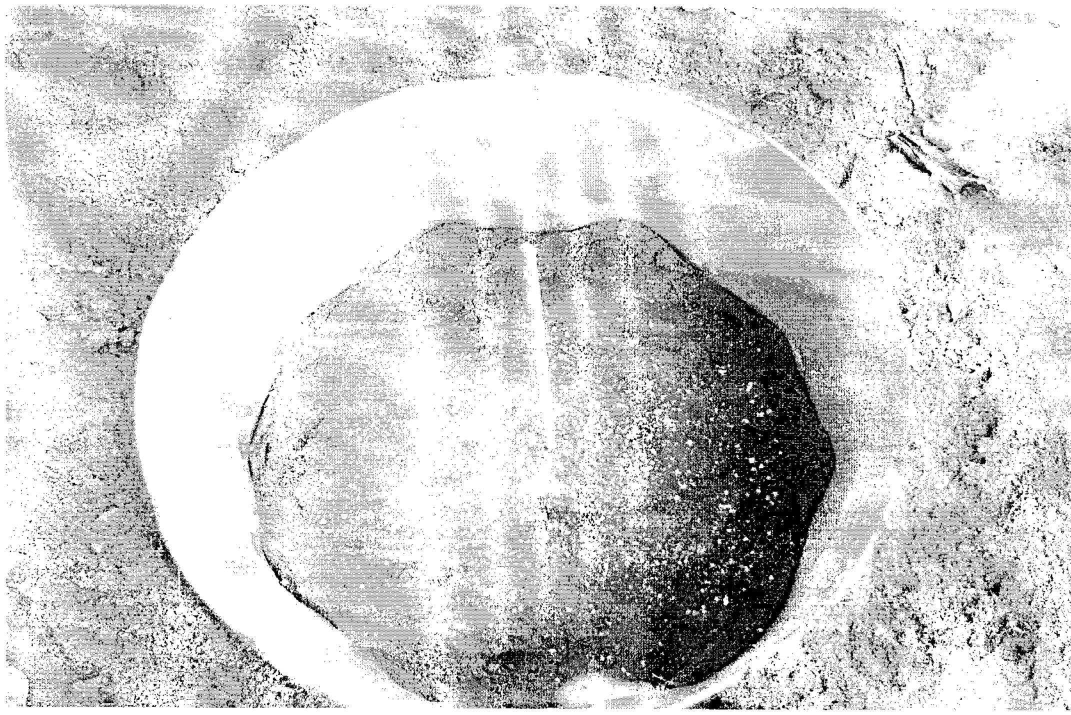

Figure 8.4 Backfilling method by adding chemicals

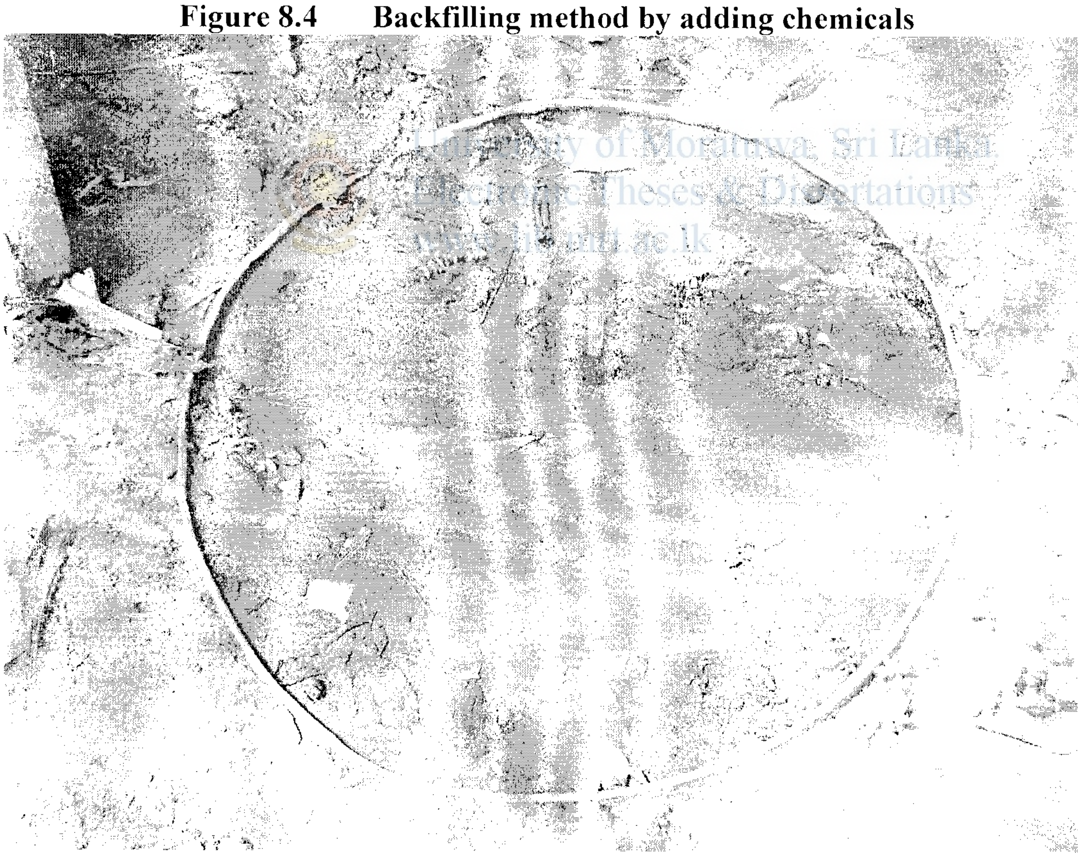

Figure 8.5 After 6 months

Initially this electrode will take somewhat higher value for the earth resistance. But after a few months it will properly compact and earth resistance will be reduced. After backfilling, the earth resistance was measured monthly. Next the results were tabulated as follows. According to the graph the resistance will drop from 57 to 33. The reduction percentage is 42.1%. That is because of. naturally it is compacted and the chemicals are properly mixed with the soil. Figure 8.5 is the best example for maintain the moisture condition. After raining the collected water around the electrode will not be absorbed to the ground due to the barrel. But because of sun rays that water can be vaporized. However the moisture level of the soil in the barrel can be maintained at a higher level than the normal soil of the ground because of the coir dust in the mixer.

Time in month	Resistance in Ohm
(First day) 0	57
1	48
2	40
3	36
4	34
5	33
6	33

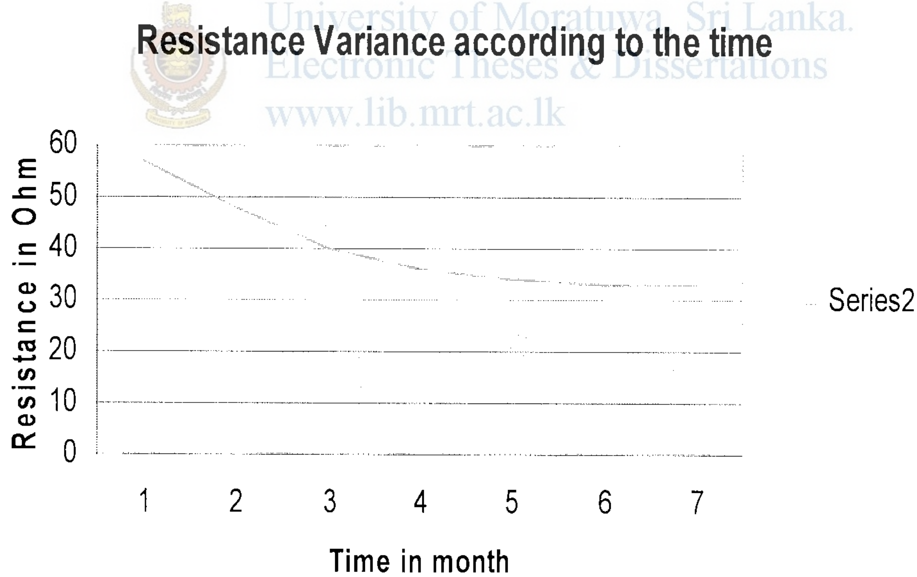

Figure 8.6 Earth resistance Vs Time

The resistivity of the surrounding soil is around 400 Ohm m. The lowest measured overall earth resistance is around 33 Ohm after 6 months. Hence the resistivity of the mixture can be assumed as 10hm m at that time. Otherwise it is very difficult to measure the resistivity of the mixture in the barrel. That is because the soil in the barrel is properly mixed with the chemicals and compacted properly. The total cost for this electrode is around Rs. 3000.00 only. Therefore this is a very low cost method which is not available in the market. The main advantage of this electrode is the very low resistance which exists for a longer period

8.2 Other Backfilling material

In addition to above there are some chemicals in the market to reduce the earth resistivity of the soil and they can be used for backfilling as described follows. But it is very expensive.

8.2.1 Bentonite

Bentonite is one of chemical which is used for backfilling of earth electrodes. It is a natural forming, pale olive brown clay. It can absorb nearly five times its weight of water and in doing so, can swell up to thirteen times its dry volume. Its chemical name is sodium montmorillonite. When in situ, it can absorb moisture from the surrounding soil and this is the main reason for using it., since this property helps stabilize the electrode impedance throughout the year. It has low resistivity approximately 5 Ohm meters (Ref1), and is non- corrosive. Under extremely dry conditions, the mixture can crack thereby affording little contact to electrode.

Figure 8.7 Bentonite (21)

8.2.2 Marconite

. Marconite is one of chemical which is use for reduce the earth resistivity of the soil. By adding Marconite in place of sand and aggregate, to cement, a conductive concrete is formed. This electrically conductive concrete is very good for use as a backfilling material for earth electrodes. When used as a backfill for earth electrodes, Marconite impregnated concrete greatly increases the electrodes surface area thus lowering its resistance to earth.

Marconite contains a crystalline form of carbon and the overall material has a low sulphur and chloride content. It has been observed that some corrosion of ferrous metal and copper occure whilst the Marconite is in slurry form, but it is suggested that a thin protective layer forms. When the concrete has set, corrosion is said to cease. Metal should ideally be painted with bitumen or a bitumatic paint as it enters the Marconite structure to prevent corrosion at this point. Aluminium, tin coated or galvanized steel should not be installed in Marconite.

Normally Marconite is considered as having a resistivity of 2 Ωm. When it is mixed with concrete, its resistivity can fall to as low as 0.1 Ohm- meter (Ref"1). It will retain its moisture even under quite dry conditions, so has been used in the hotter climates.

Marconite is good backfilling material for earth electrodes which are in rocks. Hence we can reduce the resistance of earth electrode by increasing the volume of Marconite.

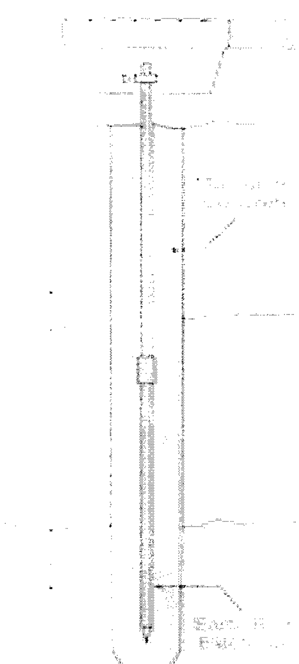

Figure 8.8Earth electrode in a rock [21]

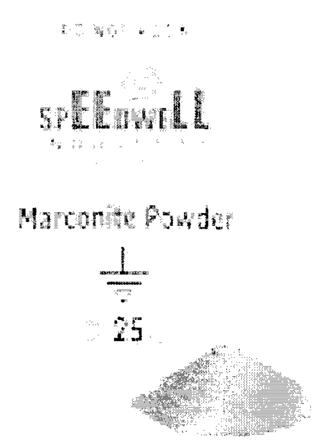

Figure 8.9 Marconite [21]

Chapter 9

Measuring Earth Resistance

There are several methods to measure the earth resistance of an electrode. But fall of potential method is the most popular and the accurate method for test the earth resistance. It is as follows.

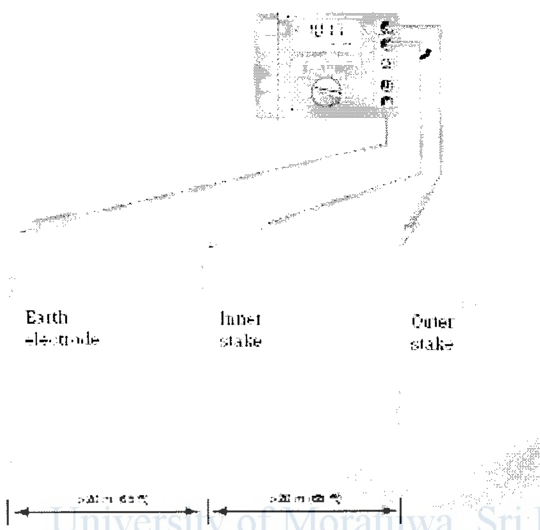

Figure 9.1 Measuring the Earth resistance [7]

First, the earth electrode of interest must be disconnected from its connection to the site. Second, the tester is connected to the earth electrode. Then for the 3 pole fall of potential test, two earth stakes are placed in the soil in a direct line away from the earth electrode. Normally, spacing of 20 meters (65 feet) is sufficient.

A known current is generated between the outer stake (auxiliary earth stake) and the earth electrode, while the drop in potential is measured between the inner earth stake and the earth electrode. Using Ohm's law (V=IR), the tester automatically calculates the resistance of the earth electrode.

Connect the ground tester as shown in the above figure. Press START and read out the R_E (resistance) value. This is the actual value of the ground electrode under test. If the ground electrode is in parallel or series with other ground rods, the R_E value is the total value of all resistances.

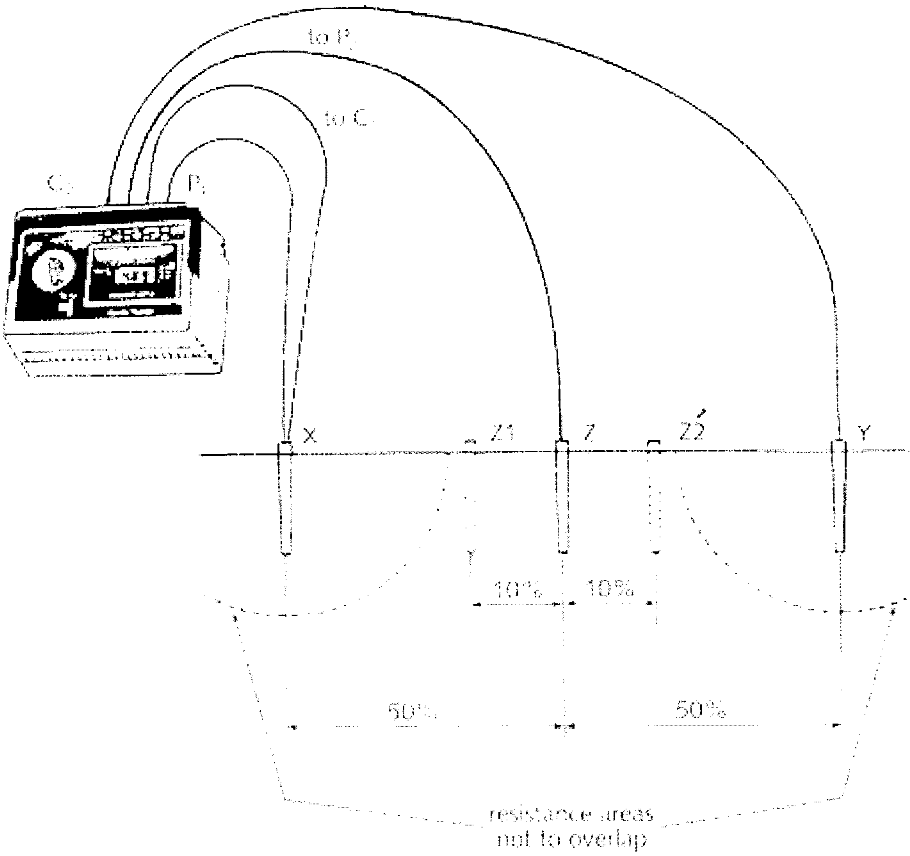

Figure 9.2 Method of measuring the earth resistance [7]

This figure shows the arrangement of spikes. Then C_1 P_1 terminals may be bridged at the instrument and connect to the earth electrode with a single lead. Terminals C2 and P2 are connected to temporary spikes which driven into the ground, making a straight line with the electrode under test. It is important that the test spikes are far enough from each other and from the electrode under test.

To ensure that resistance areas do not overlap, second and third tests are made with the electrode Z 10% of the X to Y distance nearer to, and then 10% further from X. If three readings are substantially in agreement, this is the resistance of electrode under test. If not, test electrode Y and Z must be moved further from X and the test repeated.

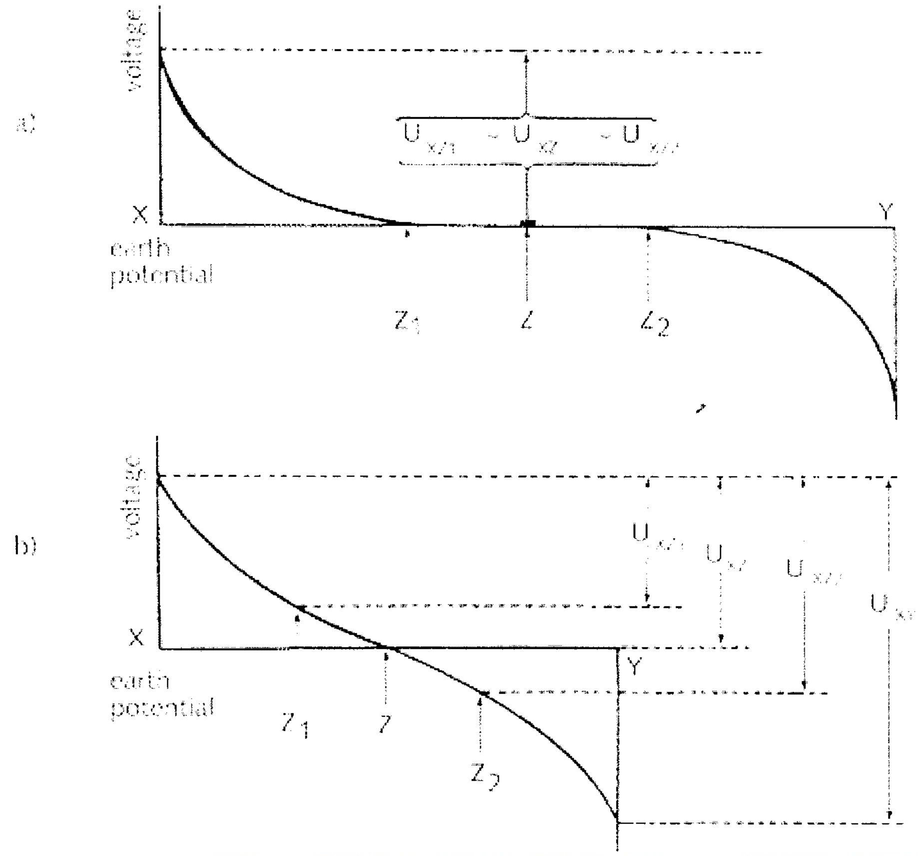

Figure 9.3 Effect of overlapping resistance areas, [7]
(a) resistances areas not overlapping
(b) resistance areas overlapping

The above figure shows the variance of the voltage according to the distance between the spikes. Then the earth resistance Vs distance between the electrode shows in the following figure.

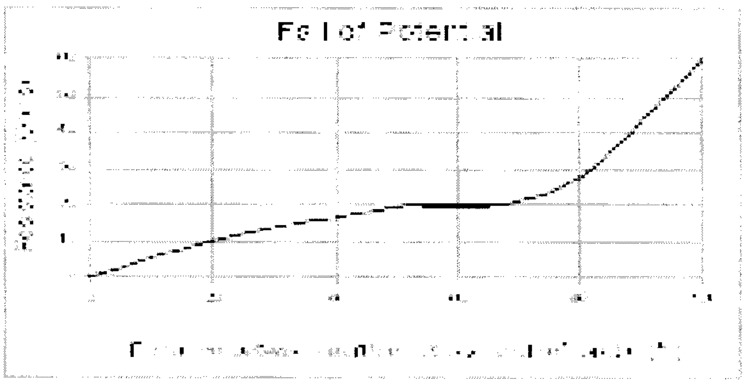

Figure 9.4 Earth resistance Vs Distance between Electrode and probe [7]

9.1 Maintenance of an Earthing System

The frequency of maintenance and the recommended practice at any installation depend upon the type and size of the installation. All forms of installation should be subject to two types of maintenance. They are inspection and examination.

9.1.1 Inspection :-

Inspection of the earthing system at an installation normally takes place in association with visits for other maintenance work. It consists of a visual inspection only of those parts of the system which can be seen, particularly looking for evidence of decay, corrosion, vandalism or theft.

For distribution substations it is required regular inspection, typically once a year, with the earthing arrangements being visibly inspected. Where the low voltage network is overhead, the earthing system on the network is checked as part of the regular line patrols.

9.1.2 Examination:-

Examination of an earthing system normally takes place as part of the examination of the whole electrical system. The examination consists of a very thorough, detailed inspection of the whole earthing system. Apart from looking for the obvious, the examiner will check wether the system meets the current earthing standard.

For a distribution substations examination is carried out less frequently – typically once every 5 or 6 years. A very thorough inspection is recommended, removing covers etc. where appropriate. The examiner is particularly required to check that the bonding of all normally accessible metal work, transformer tank, lightning arrestor connections, neutral bushing connection etc. In addition to that the value of electrode resistance should be measured and compared with its design value. This may mean isolatingthe earth electrode, and may thus require that the supply is switched off during the period of the test.

Chapter 10

Calculation

Considering above details to design a low resistance electrode, the outer surface should be maximize and interfacing hemisphere should have low rsistivity soil. Therefore the electrode which I was designed and described in chapter 4.6 was used for this. After that the solution was used with the barrel which is described in chapter 9. Then the earth resistance was calculated as follows.

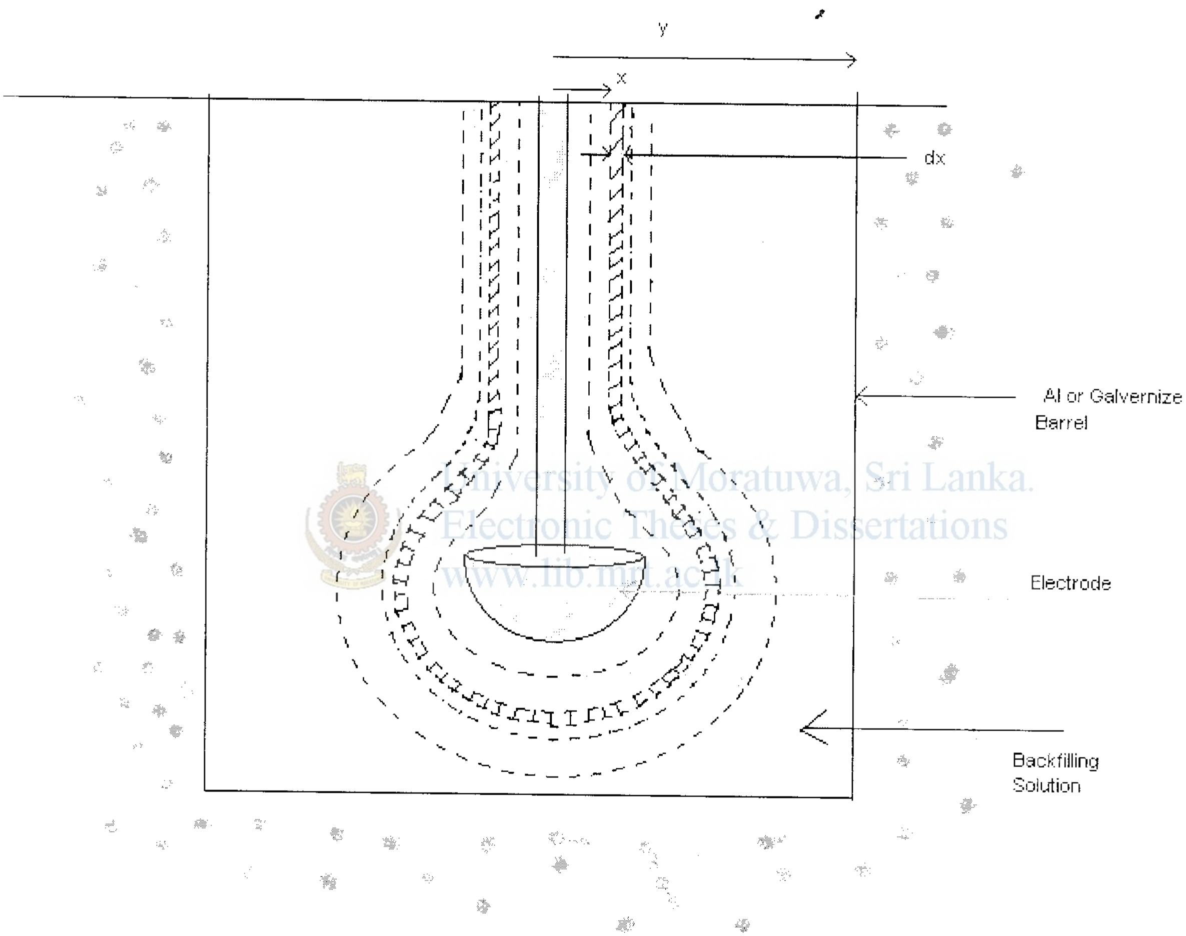

Figure 10.1 Voltage Dissipation of the Electrode (Cross section)

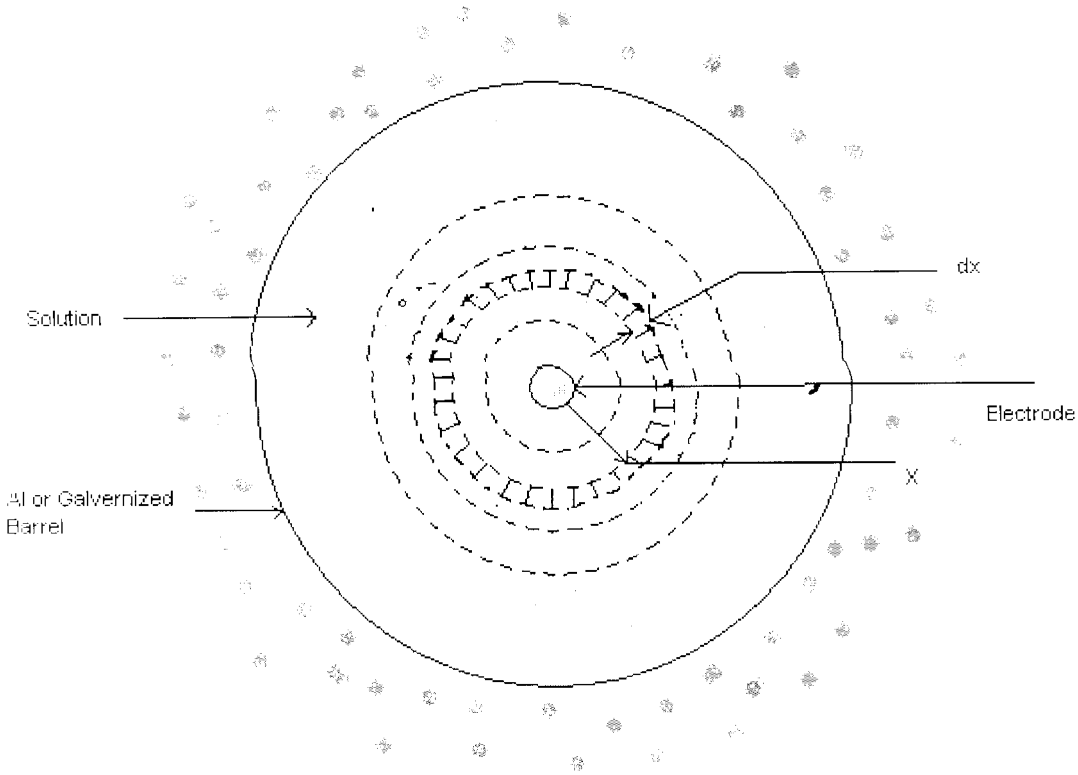

Figure 10.2 Voltage Dissipation of the Electrode (Plan view)

Let R_1 is the resistance of the top part of the electrode (i.e. rod portion) and the R_2 is the resistance of bottom part of the electrode (i.e. hemisphere portion).

Considering a small strip at a distance of x from the center point and having a width of dx as shown in the figure.

Assume

The resistivity of the solution in the barrel	ρ_1
Out side soil resistivity	ρ_2
Radius of the rod	r
Radius of the hemisphere	R
Radius of the barrel	y

Considering the top part of the electrode (rod portion)

Resistance of the strip

$$dR_1 = \frac{\rho_1}{2\pi x l} dx$$

Hence total resistance of the rod

$$R_1 = \int^{y} \frac{\rho 1}{2\pi x l}\, dx + \int_{y}^{\infty} \frac{\rho 2}{2\pi x l}\, dx$$

$$= \text{[illegible]}$$

[illegible]

For the bottom part of the electrode (hemisphere potion)

Resistance of the strip

[illegible]

Hence total resistance of the hemisphere

[illegible]

Therefore total resistance of the electrode is

$R = R_1 // R_2$

$\mathbf{R = (R_1 \times R_2) / (R_1 + R_2)}$

Considering varies type of soil and site conditions four types of electrodes were designed as follows.

10.1 Type A

As the first type 1m long rod and 1m diameter barrel were selected. The radius of the hemisphere selected as 10 cm because there is no use by increasing its radius too much according to the chapter 3.3. This type is better for the sites which cannot excavate too much deep. Then we can achieve our target which is 10Ω earth resistance by increasing the number of electrodes.

Then assume $r = 0.01m$, (radius of the rod)
$R = 0.1m$, (radius of the hemisphere)
$l = 1m$, (length of the rod)
$y = 0.5m$, (radius of the barrel)
$\rho_1 = 4\ \Omega m$. (resistivity of the solution)

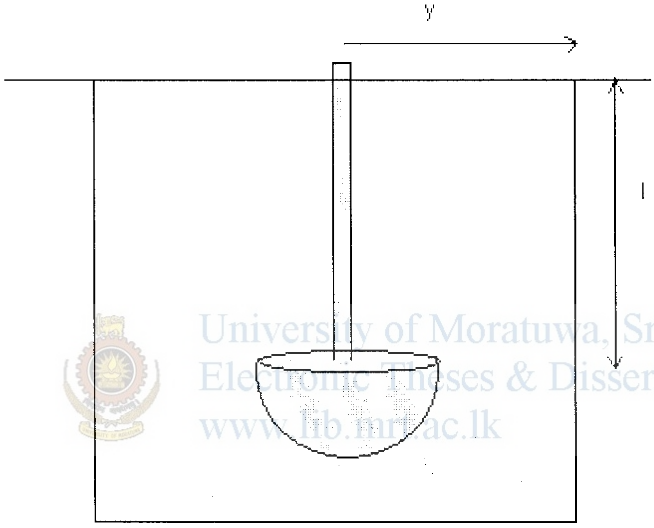

Figure 10.3 Type A Electrode

Then resistance of the rod

$$R_1 = \frac{\rho_1}{2\pi l}\ln\frac{y}{r} - \frac{\rho_2}{2\pi l}\ln y$$

$$R_1 = \frac{4}{2\pi \times 1}\ln\frac{0.5}{0.01} - \frac{\rho_2}{2\pi \times 1}\ln 0.5$$

$= 0.64 \times 3.91 - \rho_2\,(-0.11)$

$= \mathbf{2.5 + 0.11}\rho_2$

Resistance of the hemi sphere

$$R_2 = \frac{\rho_1}{2\pi}\left[\frac{1}{r} - \frac{1}{[illegible]}\right] + \frac{\rho_2}{2\pi}\frac{1}{[illegible]}$$

$$R_2 = \frac{[illegible]}{2\pi}\left[\frac{1}{1} - \frac{1}{0.5}\right] + \frac{\rho_2}{2\pi}\frac{1}{0.5}$$

$$= 0.637 \times 8 + 0.318\,\rho_2$$

$$\mathbf{= 5.09 + 0.318}$$

$$R = R_1 \,//\, R_2$$

Hence from above equations we can calculate the earth resistance for various soil types and can select the number of electrodes required as follows.

ρ_2 Resistivity of soil Ohm m	R1(Ohm)	R2 (Ohm)	R (Ohm)	No. of Electrode Required
Upto 100	13.5	36.89	9.8	1
100-220	26.7	75.05	19.6	2
220 - 340	39.9	113.21	29.5	3
340 - 460	53.1	151.37	39.3	4
460 - 590	67.4	192.71	49.9	5
590 -710	80.6	230.87	59.74	6
710 - 830	93.8	269.03	69.5	7
830 - 950	107	307.19	79.3	8
950 - 1080	121.3	348.5	89.9	9
1080 - 1200	134.5	386.6	99.7	10
1200 - 1320	147.7	424.8	109.6	11

Table 10.1 No. of type A Electrode required for various type of soil

10.2 Type B

Assume $r = 0.01m$, (radius of the rod)
$R = 0.1m$, (radius of the hemisphere)
$l = 2m$, (length of the rod)
$y = 0.5m$, (radius of the barrel)
$\rho_1 = 4\ \Omega m$. (resistivity of the solution)

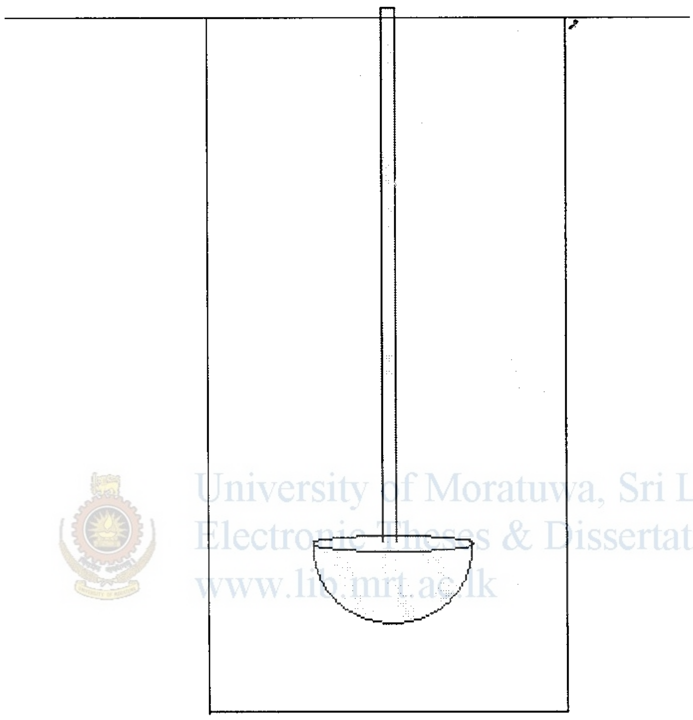

Figure 10.4 Type B Electrode

Then resistance of the rod

$$R = \frac{\rho_1}{2\pi l}\ln\frac{y}{r} - \frac{\rho_2}{2\pi l}\ln y$$

$$R = \frac{4}{2\pi \times 2}\ln\frac{0.5}{0.01} - \frac{\rho_2}{2\pi \times 2}\ln 0.5$$

$= 0.318 \times 3.91 - (-0.055)\ \rho_2$

$= 1.24 + 0.055\ \rho_2$

Resistance of the hemi sphere

[illegible]

[illegible]

$= 0.637 \times 8 + 0.318\, \rho_2$

$= \mathbf{5.096 + 0.318}\, \rho_2$

$$R = R_1 // R_2$$

Hence from above equations we can calculate the earth resistance for various soil types and can select the number of electrodes required as follows.

ρ_2 Resistivity of soil Ohm m	R1(Ohm)	R2 (Ohm)	R (Ohm)	No. of Electrode Required
Upto 190	11.69	65.5	9.9	1
190 -400	23.24	132.3	19.8	2
400 - 620	35.34	202.3	30	3
620 - 830	46.89	269	39.9	4
830 - 1040	58.44	335.8	49.7	5
1040 - 1250	69.99	402.6	59.6	6
1250 - 1470	82.1	472.6	69.9	7

Table 10.2 No. of type B Electrode required for various type of soil

10.3 Type C

Assume $r = 0.01$m, (radius of the rod)
$R = 0.1$m, (radius of the hemisphere)
$l = 2$m, (length of the rod)
$y = 0.75$m, (radius of the barrel)
$\rho_1 = 4\ \Omega$m. (resistivity of the solution)

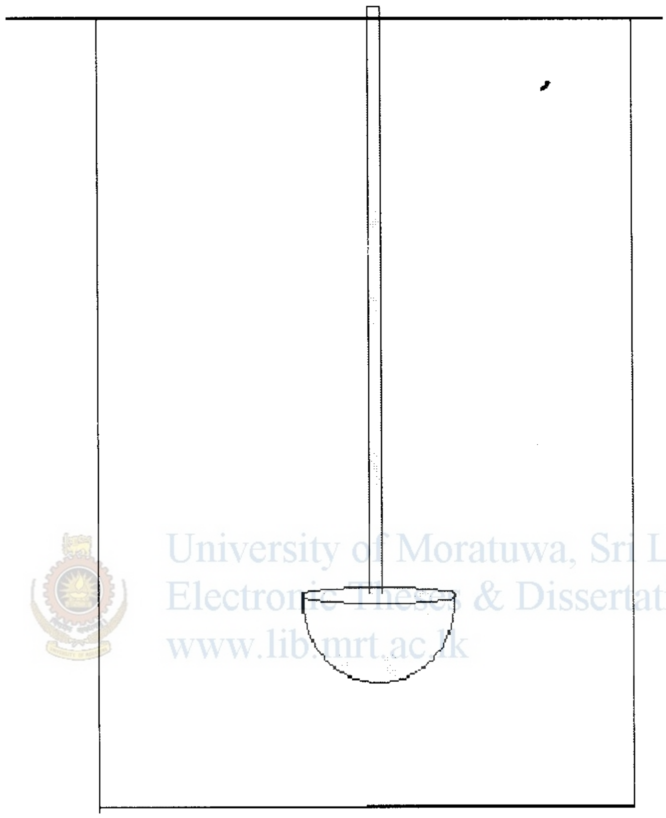

Figure 10.5 Type C Electrode

Then resistance of the rod

$$[illegible] = \frac{\rho_1}{2\pi l}\ln [illegible] - \frac{\rho_1}{2\pi l}\ln [illegible]$$

$$= \frac{4}{2\pi \times 2}\ln\frac{1.75}{0.01} - \frac{\rho_1}{2\pi \times 2}\ln 0.75$$

= 0.318 x 4.317 – (-0.023)

= 1.373 +0.023

Resistance of the hemi sphere

[illegible]

[illegible]

$$= 0.637 \times 8.66 + 0.212\,\rho_2$$

$$= \mathbf{5.516 + 0.212}\,\rho_2$$

$$R = R_1 \,//\, R_2$$

ρ_2 Resistivity of soil Ohm m	R1(Ohm)	R2 (Ohm)	R (Ohm)	No. of Electrode Required
Upto 420	11.0	94.6	9.8	1
420 - 900	22.1	196.3	19.8	2
900 - 1350	32.4	291.7	29.2	3
1350 - 1850	43.9	397.7	39.5	4

Table 10.3 No. of type C Electrode required for various type of soil

10.4 Type D

Assume $r = 0.01m$, (radius of the rod)
$R = 0.1m$, (radius of the hemisphere)
$l = 3m$, (length of the rod)
$y = 0.75m$, (radius of the barrel)
$\rho_1 = 4\ \Omega m$. (resistivity of the solution)

Figure 10.6 Type D Electrode

Then resistance of the rod

[illegible]

[illegible]

= 0.212 x 4.318 – (-0.015)

=0.915 + 0.015 ρ_2

Resistance of the hemi sphere

[illegible]

$$R_2 = \frac{4}{2\pi}\left[\frac{1}{0.1} - \frac{1}{0.75}\right] + \frac{\rho_2}{2\pi}\frac{1}{0.75}$$

=0.637 x 8.67 + 0.212 ρ_2

= 5.52+0.212 ρ_2

R = R_1 // R_2

ρ_2 Resistivity of soil Ohm m	R1(Ohm)	R2 (Ohm)	R (Ohm)	No. of Electrode Required
Upto 650	10.6	143.3	9.9	1
650 - 1350	21.1	291.72	19.7	2
1350 - 2000	30.9	429.5	28.8	3
2000 - 2800	42.9	599.12	40	4
2800 - 3500	53.4	747.5	49.8	5

Table 10.4 No. of type D Electrode required for various type of soil

10.5 Type E

In rocky area it is very difficult to excavate too much deep. Therefore we cannot use above type electrode for those areas. Then we are using Maconite with concrete as backfilling material. Its resistivity is around 0.1 Ohm m and electrode resistance is as follows.

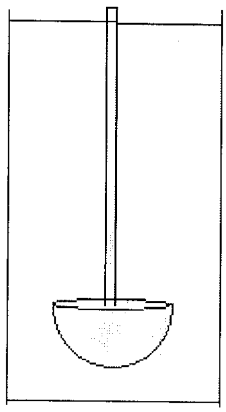

Figure 10.7 Type E Electrode

Assume

Assume	$r = 0.01m$,	(radius of the rod)
	$R = 0.1m$,	(radius of the hemisphere)
	$l = 1m$,	(length of the rod)
	$y = 0.25m$,	(radius of the concrete cylinder)
	$\rho_l = 0.1\Omega m$.	(resistivity of the Marconite Concrete)

Then resistance of the rod

[illegible]

[illegible]

$= 0.0159 \times 3.22 -$ [illegible] (-0.22)

$\mathbf{= 0.051 + 0.22}$ [illegible]

Resistance of the hemi sphere

[illegible]

[illegible]

$= 0.0159 \times 6 + 0.636$

$\mathbf{= 0.0954 + 0.636}$

$$R = R_1 // R_2$$

ρ_2 Resistivity of soil Ohm m	R1(Ohm)	R2 (Ohm)	R (Ohm)	No. of Electrode Required
Upto 60	13.25	38.26	9.8	1
60 - 120	26.4	76.4	19.6	2
120 - 180	39.6	114.6	29.5	3
180 - 240	52.85	152.7	39.26	4
240 - 300	66	190.89	49.1	5
300 - 360	79.25	229.1	58.8	6
360 - 420	92.45	267.2	68.6	7
420 - 480	105.65	305.37	78.5	8
480 - 540	118.85	343.5	88.3	9
540 - 600	132	381	98	10

Table 10.5 No. of type E Electrode required for various type of soil

10.6 Type F

Assume $r = 0.01m$, (radius of the rod)
$R = 0.1m$, (radius of the hemisphere)
$l = 1m$, (length of the rod)
$y = 0.5m$, (radius of the concrete cylinder)
$\rho_1 = 0.1\Omega m$. (resistivity of the Marconite Concrete)

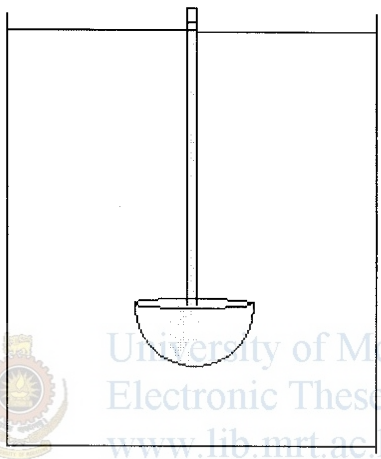

Figure 10.8 Type F Electrode

Then resistance of the rod

$$R_1 = \frac{\rho_1}{2\pi l}\ln\frac{y}{r} - \frac{\rho_2}{2\pi l}\ln y$$

$$R_1 = \frac{0.1}{2\pi \times 1}\ln\frac{0.5}{0.01} - \frac{\rho_2}{2\pi \times 1}\ln 0.5$$

$= 0.159 \times 3.91 - (-0.11)\rho_2$

$\mathbf{= 0.622 + 0.11\rho_2}$

Resistance of the hemi sphere

[illegible]

[illegible]

= 0.159 x 3 + 0.318

= 0.477 + 0.318

R = R_1 // R_2

ρ2 Resistivity of soil Ohm m	R1(Ohm)	R2 (Ohm)	R (Ohm)	No. of Electrode Required
Upto 100	12.7	35.4	9.3	1
100 - 240	27	76.7	19.9	2
240 - 360	40.22	114.9	29.7	3
360 - 480	53.4	153.1	39.6	4
480 -600	66.6	191.2	49.4	5
600 - 720	79.8	229.4	59.2	6
720 - 850	94.1	270.7	69.8	7

Table 10.6 No. of type F Electrode required for various type of soil

10.7 Type G

Assume
- $r = 0.01m$, (radius of the rod)
- $R = 0.1m$, (radius of the hemisphere)
- $l = 0.5m$, (length of the rod)
- $y = 0.5m$, (radius of the concrete cylinder)
- $\rho_1 = 0.1\Omega m$. (resistivity of the Marconite Concrete)

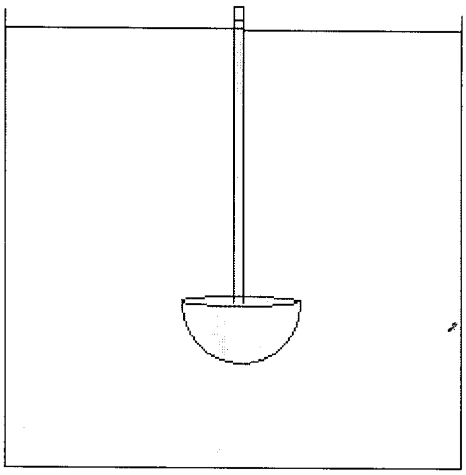

Figure 10.9 Type G Electrode

Then resistance of the rod

[illegible]

[illegible]

$=0.0318 \times 3.91 -$ [illegible]

$\mathbf{= 0.124 + 0.22}$

Resistance of the hemi sphere

[illegible]

[illegible]

$= 0.0159 \times 3 +$ [illegible]

$\mathbf{= 0.0477 + 0.318}$

$$R = R_1 // R_2$$

ρ_2 Resistivity of soil Ohm m	R1(Ohm)	R2 (Ohm)	R (Ohm)	No. of Electrode Required
Upto 70	15.5	22.3	9.1	1
70 - 150	33.1	47.74	19.5	2
150 - 230	50.7	73.2	29.9	3
230 - 300	66.1	95.4	39	4
300 - 380	83.7	120.88	49.4	5
380 - 460	101.3	146.3	59.8	6
460 - 530	116.7	168.6	68.9	7
530 - 610	134.3	194	79.3	8

Table 10.7 No. of type G Electrode required for various type of soil

10.8 Type H

Assume
$r = 0.01m$, (radius of the rod)
$R = 0.1m$, (radius of the hemisphere)
$l = 0.75m$, (length of the rod)
$y = 0.5m$, (radius of the concrete cylinder)
$\rho_1 = 0.1\Omega m$. (resistivity of the Marconite Concrete

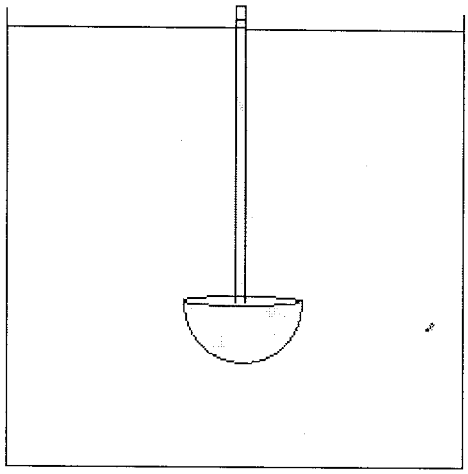

Figure 10.10 Type F Electrode

Then resistance of the rod

[illegible]

[illegible]

= 0.021 – (-0.147)

= 0.021 + 0.147

Resistance of the hemi sphere

$$R_2 = \frac{\rho_1}{2\pi}\left[\frac{1}{R} - \frac{1}{r}\right] + \frac{\rho_2}{2\pi}\frac{1}{r}$$

$$= \frac{0.1}{2\pi}\left[\frac{1}{0.1} - \frac{1}{0.5}\right] + \frac{\rho_2}{2\pi}\frac{1}{0.5}$$

= 0.159 x 8 + 0.318

= 1.272 +0.318

$$R = R_1 // R_2$$

ρ_2 Resistivity of soil Ohm m	R1(Ohm)	R2 (Ohm)	R (Ohm)	No. of Electrode Required
Upto 90	13.25	29.9	9.1	1
90 - 190	27.9	61.6	19.2	2
190 - 290	42.6	93.5	29.3	3
290 - 390	57.35	125.3	39.3	4
390 - 490	72	157	49.3	5
490 - 590	86.71	188.9	59.4	6
590 - 690	101.5	270.7	69.5	7

Table 10.8 No. of type H Electrode required for various type of soil

Chapter 11

Conclusion

The most important part of a distribution transformer is the earthing system. A better earthing system helps to avoid imbalance voltages, voltage fluctuations, electromagnetic compatibility, neutral leakage current and lightning etc. An electrode with the resistance below 10Ω, provide a better earthing system.

According to the above result type D electrode is the best solution to get the better earth reading. However D type single earth rod gives the earth resistance of 10 Ohm in the soil which is the resistivity is less than 650 Ohm m. Normally most of areas soil resistivity is less than 500 Ohm m. Therefore this type electrode can be installed at anywhere without measuring the soil resistivity to get the high performance.

The main disadvantage of this type electrode is, it cannot install in rocky areas as it need a 1.5m diameter and 3m depth cylindrical pit. If it is not possible to excavate a pit like that way, the other types of electrode can be used as follows.

ρ_2 Resistivity of soil Ohm m	Type A	Type B	Type C	Type D
Upto 100	1	1	1	1
100 -190	2	1	1	1
190 - 220	2	2	1	1
220 - 340	3	2	1	1
340 - 400	4	2	1	1
400 - 460	4	3	2	1
460 - 590	5	3	2	1
590 - 650	6	3	2	1
650 - 830	7	4	2	2
830 - 900	8	5	2	2
900 - 1040	9	5	3	2

Table 11.1 No. of Electrode required according to the soil condition

But for rock area we cannot use these types of electrodes as it is very difficult to excavate too deep. Therefore we can use Marconite mixed concrete for backfilling in rock areas. Hence the earth resistance can be reduced as the surface area is increased due to Marconite concrete. Then as discussed in chapter 10.5, 10.6,10.7 and 10.8 like type E, F, G and H various types of electrodes can be used according to the site condition. But they are very expensive. The numbers of electrodes required according to the soil resistivity are as shown in below.

ρ_2 Resistivity of soil Ohm m	Type E	Type F	Type G	Type H
Upto 60	1	1	1	1
60 - 90	2	1	1	1
90 - 120	2	2	2	2
120 - 150	3	2	2	2
150 - 180	3	2	2	3
150 - 230	4	2	3	3
230 - 290	5	3	3	4
290 - 360	6	3	4	5
360 - 420	7	4	5	6
420 - 460	8	4	5	6
460 - 530	9	5	6	7
530 - 590	10	5	6	8

Table 11.2 No. of Electrode required according to the soil condition

Appendix 1

DISTIBUTION EARTHING SYSTEMS

Any distribution system has two basic components.

- Power Source
- Installation

Power source includes Generator/ transformer & transmission/ distribution network.
Installation includes the building or location, where the load is available.

Considering the arrangement of earthing of source and installation, distribution earthing system is classified in internationally accepted two letter code (xx).

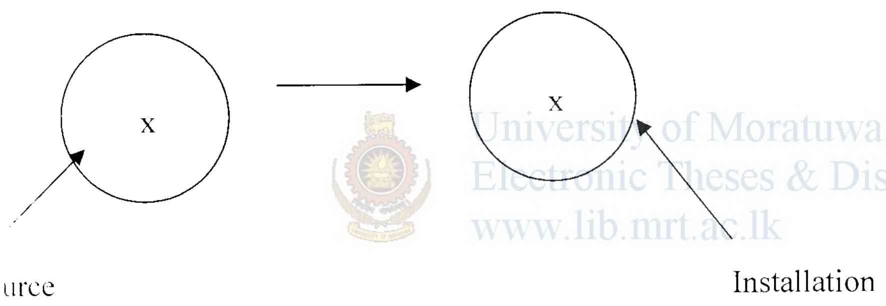

Figure AP 1.1 Basic Component of a distribution system

The first letter classifies the type of source earth

T - Neutral point of source is solidly earthed. (T stand for Latin "Tera" which means "Earth")

I - Neutral point of source unearthed or earthed through a high impedance (I stand for Isolated)

The second letter classifies the type of installation earth.

T Installation is separately earthed (T stand for "Tera")
N Installation earth is electrically connected to the source Neutral using a metallic connection. (N stands for connected to "Neutral")

There are 03 basic earthing systems widely used in the Distribution Networks.

IT - Source unearthed or earthed through high impedance : Installation is directly earthed to mass earth

TN- Source is directly earthed to mass earth : Installation earth is connected to source neutral.

TT - Source is directly earthed to mass earth : Installation is directly earthed to mass earth.

AP 1.1 IT System

In this system, source is unearthed or usually earthed through deliberately introduced high impedance. The high impedance reduces the level of fault currents in case of line to ground faults and improve the service continuity. Further, it is advantages to have high impedance (over unearthed condition) as it reduces the voltage oscillation in case of faults and improve the stability of the system.

Installation earth is connected directly to mass earth, independent from source earth. This system has the advantage of low ground-fault currents and supply continuity in case of minor single earth faults etc. Since source is not earthed or earthed through high impedance, risk of electrocution by direct and indirect contact is less.

However, it has the advantage that multiple ground faults may develop serious disasters. Hence, this system is not recommended for public Electricity supply under IEE Regulations. IEE regulation allows this system for private use in case there is no alternative, provided a permanent earth fault monitoring device is supplied.

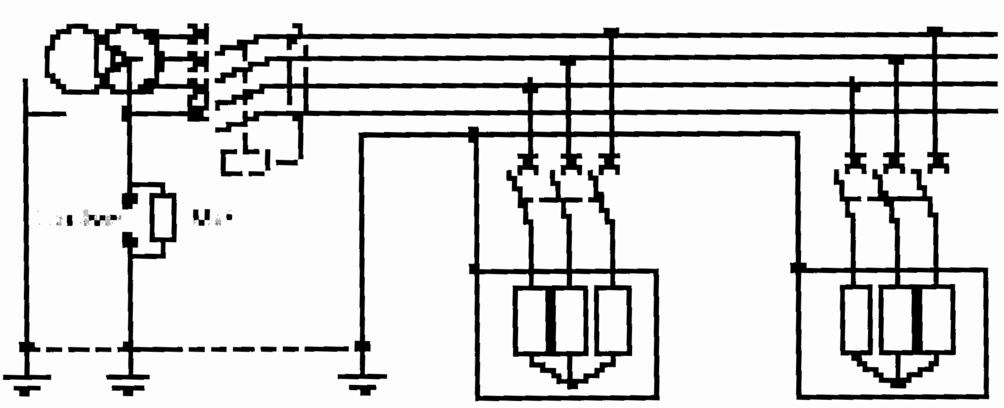

Figure AP 1.2 IT System [22]

AP 1.2 TN System

It has 3 derivatives and they are as TN-C, TN-S and TN-C-S.

AP 1.2.1 TN – C System

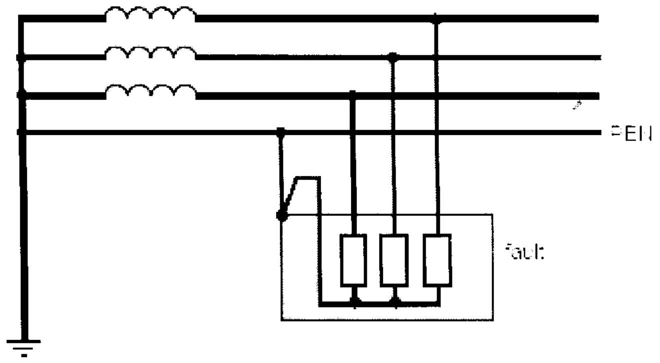

Figure AP 1.3 TN – C System

Here, source is directly earthed, Installation earth and Neutral, a common system, is connected to the combined Neutral and Earth conductor supplied by the source. This combined conductor, supplied from source is called PEN (Protective Earth and Neutral) conductor.
This system has a low resistance for earth faults since earth loop consists of a metallic path which exhibits a very low resistance.
Installation receiving supply from this type of system can provide supplementary protection against direct and protection against indirect contacts even with fuses and MCBs, since earth fault loop impedance is very low. IEE regulations provide the limits of Earth Fault (E/F) loop impedance for different applications of this type of systems.

AP 1.2.2 TN – S System

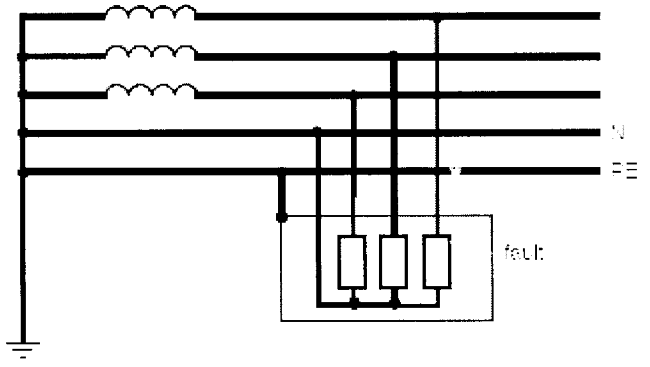

Figure AP 1.4 TN – S System

Here too, source is directly earthed. Installation is provided with metallic Earth Connection and Neutral, from source, separately. Installation, too has its earth and neutral separate and they are connected to earth and neutral supplied from the source separately. This system too has a very low earth loop impedance path, but is usually higher than that of TN – C system.
Installations which receive supply from this type of systems can provide supplementary protection against direct and protection against indirect contacts even with fuses and MCBs, since E/F loop impedance is relatively low. IEE regulation provides the limits of E/F loop impedance for different of this type of system.
TN – S has further advantage that under abnormal conditions, Earth and Neutral at the installation are at same potential since both are supplied from source and earthed at the source. Hence, under abnormal conditions such as lightning surges, spikes etc. installation earth will not drift from neutral considerably. Hence TN – S System is favorable for installation where sensitive equipment are used.
Further, this is mainly used in high- rise buildings and in urban areas, since providing electrically independent direct earthing to each installation is not practicable due to scarcity of space.
Specially with UG cable system this earthing system is preferable since earthing connection can be provided with neutral conductor in four core cable.

AP 1.2.3 TN – C- S

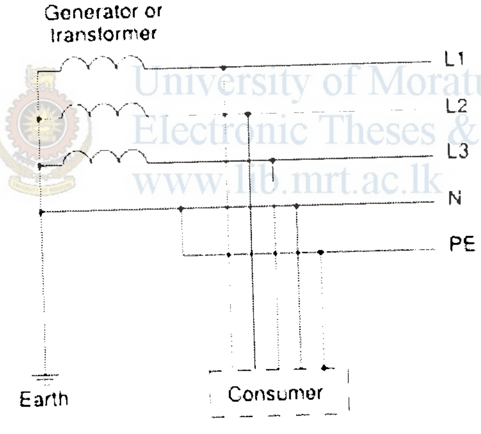

Figure AP 1.5 TN-C-S System [4]

Part of the system uses a combined PEN conductor, which is at some point split up into separate PE and N lines. The combined PEN conductor typically occurs between the substation and the entry point into the building, whereas within the building separate PE and N conductors are used.

AP 1.3 TT System

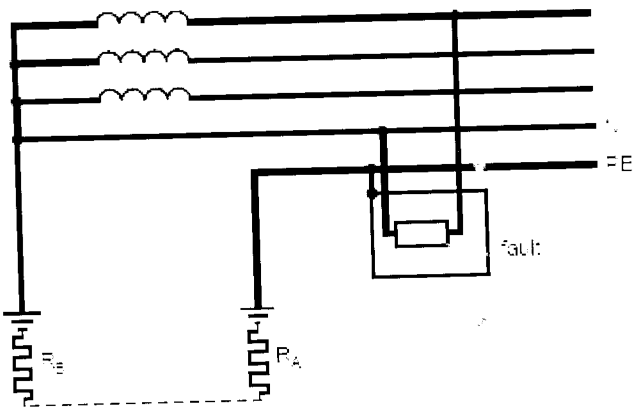

Figure AP 1.6 TT System

In this system, source is solidly earthed (denoted by first 'T' of 'TT'). Installation protection system is also directly earthed. There is metallic electrical path from source earth to installation earth. The only path, under faulty condition, from source earth to installation earth, is through mass earth.

The earth fault loop consists of phase conductor, installation live conductor, protective conductor, earth electrode, mass earth, substation earth electrode and substation neutral earthing conductor. Most dominant factors of this loop are earth electrode resistance of substation and that of installation as resistance of other components are considerably low.

In order to provide supplementary protection against direct contact and protection against indirect contact at the installation maximum earth loop impedance should be limited to a certain accepted value.

Thus, in order to provide protection against indirect contact, a Residual Current Device (RCD) has to be installed at the installation. Operating current (I_a) of the RCD and the earth electrode resistance (R_a) of the installation should satisfy the following condition.

$$I_a . R_a \leq 50V$$

Where I_a - is the current causing the automatic operation of the protective device within 5 seconds.

R_a - is the sum of the resistance of the earth electrodes and the protective conductor(s) connecting it to the exposed conductive part.

This ensures that under faulty condition, installations will not gain a potential over 50V for more than 5 seconds (as required by IEE Regulation) according to the characteristic curve of the Residual Current Device generally used.

AP 1.4 CEB system

CEB system is generally a TT system and therefore it is necessary to incorporate RCD's at consumer Installations to provide protection against shock and fire Hazards.

AP 1.4.1 Provision of TN – S System to CEB Consumers

It should also be noted that is also possible to provide a TN – S system to individual consumers who have dedicated distribution transformers. No other consumers shall be connected to such installation. One of the main advantages of the TN – S System is the improved quality of power supply to the consumers with sensitive equipment.

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