DESIGNING EARTHING SYSTEM FOR DISTRIBUTION TRANSFORMERS IN HIGH RESISTIVE SOILS AT RESTRICTED AREAS

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Degree of Master of Science

Department of Electrical Engineering

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Thesis Submitted in partial fulfillment of the requirements for the degree Master of Science in Electrical Installations

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DECLARATION

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The above candidate has carried out research for the Master's thesis under my supervision.

Signature of the supervisor:…………………………..

Dr. W.D.Asanka S. Rodrigo

Date…………………………………………………….

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ABSTRACT

Earthing of Distribution Transformer is very important in the sense of safety and protection of human beings, livestock and equipment. The construction personals have faced critical issues on earthing when they engage in Installations of Electrical equipment due to high values of earth resistance. The research was carried out to find solutions for two objectives. One of objectives is to design an earthing system for high resistive soil. The other objective is to find solution for earthing in restricted area.

It was found that high resistive soil exists in sandy soils in coastal areas as well as hard rocky areas in central part of the Island. There are some rocks located in coastal area too. The soil resistivity plays vital role in earthing of electrical installations. Thus the research was done by using soil enhancement materials such as Charcoal, Lime and Sand of the same location. The mixture of above materials improves the electrolytic property of soil to bring down soil resistivity.

The research was done in the field and at laboratory by varying the ratios of Charcoal, Lime and Sand. The test results showed that resistivity becomes minimum value, when the ratio becomes 1:1:3.of Charcoal: Lime and Sand respectively. The usage of optimum land area for earthing of distribution transformers were achieved by using the base of poles of transformer structure as alternative earth pits. A new design for earth mesh for pole base earth pits was introduced as a result of the research. An economic analysis was carried out to find the benefits of using soil enhancement materials instead of cement block earths. As a result of eliminating cement block earth, there is a financial gain of 18.39%.

The case studies were carried in Chilaw area for two different soil types by mixing soil enhancement materials. In this study moisture content of the soil was measured to identify the effect of presence of moisture in soil. The results of the research indicated that the earth resistance drastically reduces due to the presence of moisture content and the organic substances of the soil in addition to the soil enhancement material.

Finally, the Ansys-Maxwell software was used for simulate the earthing system in homogeneous medium. The results of simulation were shown that major portion of the energy absorbed by the narrow region, very close to the earth rod. Therefore, the diameter of the earth pit can be reduced to minimize the area of land required for earthing of distribution transformers. It shows the voltage distribution and energy dissipation in the critical cylinder very clearly.

In this research a new conceptual design was carried out to reduce earth resistance in newly designed earthing system and in existing transformers by increasing the moisture content around the earth rods of earth pits. An external water container is introduced to

provide water drops to earth pit to keep it at wet condition in dry season to improve the efficiency and effectiveness of the earthing system.

Contents

LIST OF ABBREVIATIONS

R- Resistance

ρ- Resistivity

J- Current density

L- Length

A- Cross sectional area

I- Currant

V- Voltage

l- Length

kA- kilo Ampere

kV- kilo Volts

s – seconds

µs- micro seconds

HV –High voltage

MV- Medium voltage

LV – Low voltage

RE- Rural Electrification

CEB- Ceylon Electricity Board

LTL- Lanka Transformers (pvt) Ltd

NWP- North Western Province

EE- Electrical Engineer

ES- Electrical Superintendent

DGM- Deputy General Manager

FEM- Finite Element Method

ABC- Aggregate based course

DDLO – Drop Down Lift Off switch.

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background survey and Previous Work

In power systems, Generating stations, Transmission network and Distribution network are involved. To distribute electrical energy for electricity consumers, Distribution Transformers and Low Voltage Distribution Network are used. Earthing of Distribution Transformers plays vital role for the safety of electricity consumers as well as general public.

In Sri Lanka TT System is used for earthing in Electrical Installations. In the TT System, both source and loads are earthed at their neutral and common earthing points respectively to earth mass [1]. The earthing system is an essential part of power networks at both high and low voltage levels. It required for protection of buildings and Electrical Installations against lightning, for safety of human beings and livestock by limiting touch and step potentials to safe values. Earth resistance of the soil is main important factor in earthing of Electrical Installations [2][3]. The Electrical properties of the soil are characterized by the earth resistivity of the soil (ρ).The Soil map of Sri Lanka shows the different types of soils available in the country (See Appendix A).

Therefore, determining soil resistivity in different locations is complicated due to following reasons.

1. The ground (earth) does not have homogeneous structure. It has stratified (layers) structure of different soil types [4].
2. The Soil resistivity of a given type of ground varies with the moisture content of the soil [5].

3. The soil resistivity depends on the dissolved salts with the water at the particular location [6].

1.1.1 Soil Resistivity

The soil resistivity is defined as specific soil resistance [6]. The relationship between Soil Resistance (R) ,Soil resistivity (ρ), Length of the earth rod (l) and the cross sectional area of the rod (A) is given by following equation.

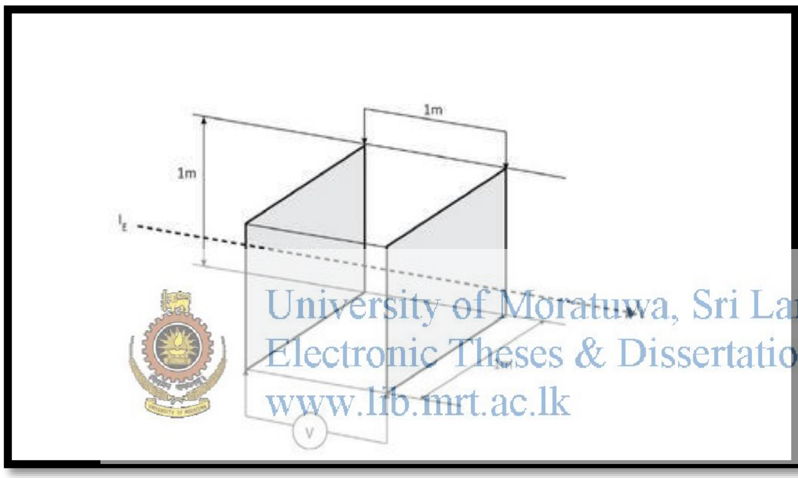

Figure 1: Illustration of Physical sense of Soil resistivity.

Source: Application Note: Earthing Systems

$$R = \rho \frac{l}{A}$$

In Figure 1, l= 1m, A= 1m x 1m

$$\therefore R = \rho$$

Figure 1 Illustrate the physical sense of soil resistivity. According to the diagram, the soil resistivity is the resistance between opposite sides of a cube having dimension of 1m.

Resistance 'R' can be determined by varying the current passing through opposite sides of the cube and measuring the respective voltage drop across two sides.

$$R = \frac{V}{I}$$

The soil resistivity is determined by the quantity of moisture in soil and the dissolved conductive salts within the soil. When the soils become dry the soil becomes nonconductive and resistivity becomes high [5].

1.1.2 Factors that affect soil resistivity.

1 Type of Soil
1. Salts dissolved in contained water
2. Moisture content of soil
3. Temperature
4. Grain Size
5. Closeness of packing and pressure

<u>Following soil types have low soil resistance</u>

- Soil with humus and moisture
- Alluvial Soils
- Clay Soils

<u>However, following soil types have high soil resistance</u>

- Rock
- Mountain tops – generally salt depleted and rocky
- Coarse sand and gravel
- Sand near sandy beaches – since moisture tends to drain from sand

1.1.2 Seasonal behavior of soil resistivity

It is observed that soil resistivity varies with seasons. In wetter months the soil resistivity will be low and in drier months it will be higher [6]. Figure 2 indicates the variation of soil resistivity with moisture content of soil. Adequate earthing system should be installed to ensure required earth resistance in wetter seasons and also in drier seasons. However, in areas having poor soil conductivity, or high soil resistivity due to soil composition or seasonal variation, further attention is needed to design good and effective earthing system.

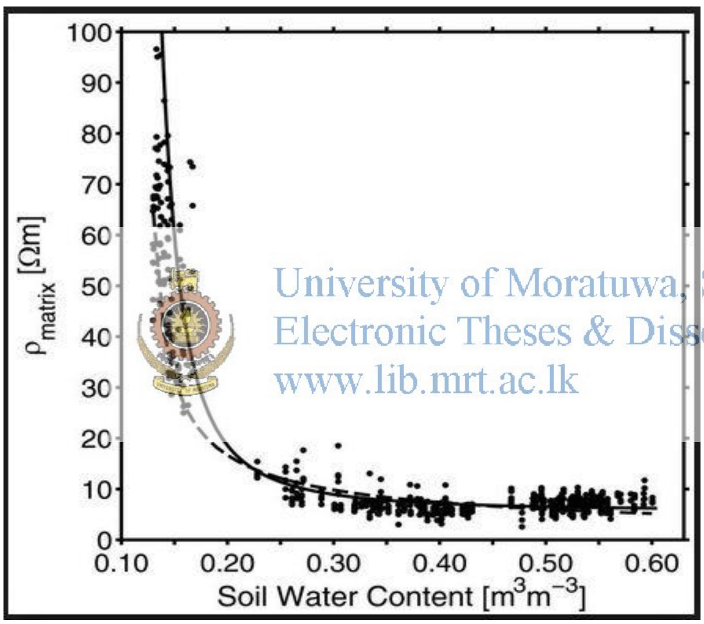

Figure 2: Variation of soil resistivity with moisture content of soil.

Source :Designing for a low resistance Earth interface[3]

The potential distribution on the earth surface is very important factor in assessing the degree of protection against electric shock because it determines the touch and step potentials.

During earth faults, large fault currents may flow via the earth mass on route to the neutral point of the source transformer. The impedance of any earthed metalwork such as transformer tanks, switchgear enclosures, earth grids with respect to the 'true' or 'reference' earth can lead to rise in potential. It may lead to hazardous situations to people, livestock and equipment.

The design of the earthing system ensures that:

1. All metalwork and equipment can be touched by a person standing on the ground up to 2.4m above the ground are earthed.
2. Hazardous touch, step and transfer voltages are mitigated during fault conditions.
3. A low impedance path is available for lightning, switching surges and 50Hz earth fault currents to limit thermal and mechanical damage of plant and to ensure operations of protective devices such as protection relays, fuses and surge arresters.

Earthing electrodes, joints and earth conductors should be designed to:

a. Ensure earth fault currents are conducted to earth mass without damage to the earthing components.
b. Minimize the possibility of mechanical damage
c. Avoid inadvertent interference
d. Minimized chemical deterioration

It is very important to ensure three phase loads are balanced to minimize the unbalance current flow in the neutral which flows to the earth mass [6]. Harmonic currents may also cause an increase in neutral current flow to earth mass.

1.1.3 Types of Earthing Electrodes

There are different types of earth electrodes used. Following earth electrodes are commonly used.

1. Rod type electrodes
2. Plate type electrodes
3. Pipe type electrodes

In order to achieve low values of earth resistance the current density flowing from the earth electrode metal to the earth mass should be low. Therefore, the volume of earth through which the current flows should be as large as possible.

Current density (J) is defined as current per unit area.

$$J = \frac{I}{A}$$

It was identified by previous researches [2], rods, pipes and wire electrodes have a much lower dissipation resistance than plate electrodes with the same surface area. The low current density extends life of earth electrodes. Exact theoretical equations of earth resistance are usually used only for simple structures of earth electrode. For extended and mesh type earth electrodes, approximations of earth resistance are used [1].

According to the code of practice for earthing BS 7430 [1], approximated calculations are used as per the geometry of earth rods connected in parallel.

Rod type earths are used in restricted areas having limited land space [2]. The moisture content in the deep layers of the soil is higher and stable than shallow layers. Therefore, deep rods are driven to the soil to obtain lower values of earth resistance.

However, it is not possible to drive rod type electrodes to the preferred depth always due to geological reasons such as on rocks or on bedrock.

1.1.4 Properties of Earth at high impulse currents

At lightning impulse currents have high magnitudes in the range up to few hundred of kA. The rise time of the lightning impale is very short in the range of microseconds (μs). Thus, the typical lightning strike reaches a few hundreds of kA/μs. The current density of the soil near the earth rod becomes very high value. As a result of that, the electric field strength increases up to values which causes electrical dischargers in small gaseous voids in the soil resulting ionization of soil around earth electrode, decreasing the ground resistivity and earth resistance [2]. This phenomenon occurs mainly near earth electrode. The intensity of this phenomenon is very high when the soil is dry or high resistive.

The inductance of the metal parts of earth electrode is usually neglected when considering earth impedance at network frequency of 50Hz. However, the inductance becomes an important parameter when the current flow rate is high in the range of kA/μs.

During Lightning strikes inductive voltage drop, $L\frac{di}{dt}$ reaches very high value and it lead to reduce the flow of surge current to the earth mass. The earth resistance for lightning surges increases in comparison with it's resistance for static conditions. Thus increasing the length of earth electrode over the critical length does not cause any reduction of earth impendence to transients.

During lighting strikes both phenomenon exists but act in opposite directions. The high earth current decreases resistance while high frequency increases the impedance. The overall effect of the impedance is depends on the magnitude of the dominating effect during the lightning.

In communication tower grounding, insulated down conductors were used due to lack of soil near the tower legs on the solid rocks. Therefore, down conductor has been extended for about 20m-60m below the tower foot level [10]. The down conductors were inserted into a bore drilled in the rock and the bore hole has been filled with cement like material. When calculating voltage drops along the resistance and inductance of the down conductor, it shows high voltage in the range of Mega volts experience due to inductance of the down conductor, but the voltage drop due to the resistance shows the value is about 1 Kilo volt for the lightning strike of 50 kA/μs. Potential at given height with respect to the ground was considering as $V = IR + L\frac{dI}{dt}$, Where 'R' is the resistance of ground conductor, 'L' is the inductance and 'I' is the current due to lightning strike.

In the case of communication towers additional water tanks were used to provide water to the earthing system to maintain wet environment around the earthing system even in dry weather. The researchers have found that the presence of moisture in high resistive soils lead to reduce earth resistance to required value. As a result of that, they were able to eliminate the risk of occurring lightning hazards to communication towers.

1.2 Scope of Present Work

The scope of the research is to design suitable earthing system for installation of distribution transformers. In this research it was planned to utilize soil enhancement materials such as Charcoal powder, Lime and soil for earthing instead of concrete block earthing system. At the initial stage, selection of suitable sites having high resistive soil was the main target. Therefore, earth resistance measurements to be taken and the calculated values of earth resistivity to be tabulated in statistical manner to identify high resistive locations among sites of data collected.

The objectives of the research encouraged to collect soil samples in various locations of MV network in NWP (See Appendix B), having different soil types and different moisture contents. Wenner method is comparatively easy to use with the help of field staff. Therefore, Wenner method is to be used to measure earth resistances of sites. Using the collected soil resistance data, soil resistivity (ρ) can be calculated using the formula given under Wenner method, $\rho = 2\pi LR$ [12].Where 'L' is the separation between probes in meters (m) and 'R' is the measured value of earth resistance in Ohms (Ω).

CHAPTER 2

OBJECTIVES

2.1 Objective Statements

Main objective of the research is Designing Earthing system for Distribution Transformers in restricted area having high resistive soil. To analyze this issue widely, it can be divided into two objectives as follows.

- Designing Earthing system for soils having high resistivity.
- Designing Earthing Systems for restricted areas.

2.1.1 Designing Earthing system for soils having high resistivity.

Designing of earthing systems for Substations and Distribution Transformers are very essential and important in safety and protection of people, animals and equipment are concerned. It is a vast field to study. There are various types of Substations available in Sri Lanka depending upon the requirement of the National Grid.

In Electrical Power Generating Stations, the substations are named as Generating Substations. At Generating Substations, the generating voltage of power generated from the power plant, varies from 10kV to 13.5kV depend upon the design of the power station. The generating voltage of power, step up to higher values such as 132kV or 220kV, by Power Transformers to transmit to distant locations where load centers are exists. To design earthing systems for substations, Fault level at particular substation should be calculated by fault analysis. Earthing design is to be carried out after finding the fault current and the soil resistivity of the proposed location of the substation.

In Sri Lanka, Transmission network consists of tower lines having voltages of 132kV and 220kV.The substations at the Load Centers are named as Grid Substations. At Grid Substations the step down Power Transformers are used to reduce Transmission voltages to Medium voltage of 33kV. At Grid substations, MV distribution network starts and runs through the country to feed distribution transformers installed in towns, villages, factories and shops etc.to provide Electricity to consumers. Electricity consumers consume power at various voltage levels. To design suitable earthing systems for Transmission lines and Grid substations, fault analysis to be carried out to identify the maximum fault levels at such locations to design earthing systems for transmission lines and Grid substations.

Domestic consumers use single phase power at 230V. Industrial and Business type consumers and few domestic consumers use three phase power at 400V. Bulk supply consumers use 400V three phase power supplies if the contract demand is less than 1MVA. If the contract demand is higher than 1MVA, they get power at 33kV or 11kV level. The transformers use to step down 33kV to 11kV are named as Primary Transformers.

In NWP, voltage of distribution network is 33kV, except coastal areas of Wennappuwa area, Chilaw area, Puttalam area and Kurunegala town. Distribution transformers are fed from 33kV and 11kV MV network. To ensure the safety and protection against hazardous voltages the Distribution transformers must earth at their neutral point and the lightning arrester with tank of the transformer to the earth mass. The earth mass has non homogeneous characteristics. As a result of that, the earth resistance varies considerably when location varies. The earth resistance is mainly depends on soil resistivity. For designing earthing systems, apparent soil resistivity value to be calculated. There are number of accepted methods available to calculate this feature of soil. In addition to that fault level of the distribution transformer to be identified.

In Sri Lanka there are some locations where the soil resistivity is more than 1000Ωm, 2000Ωm and etc. There are very few locations have the soil resistivity more than 4000

Ωm. Therefore, new earthing system to be developed to solve the earthing issues of high resistive soils to install distribution transformers. When fault occurs in distribution network, fault current flows to the ground through neutral earth. To ensure the healthy operations of protective devices, the earth resistance must be kept at it's minimum value. Fault analysis to be carried out for MV network also for better earthing design for high resistive soil.

2.1.2 Designing Earthing Systems for restricted areas

Restricted areas can be defined as lands having very small area to carry out construction work related to any new installation or any expansion of existing installation. When the Power System, Road network, Communication network, Railway network expands as per the development projects of the country, it is a duty of Engineers in any discipline to find optimum solutions by minimizing cost of projects. In electrical installations the cost can be minimized by minimizing land utilized, by minimizing payment of compensations etc.

Due to the urbanization, land became scarce resource. For earthing of distribution transformers, sufficient land area is needed to install both neutral earth and lightning arrester earths. Due to the scarcity of land and restrictions imposed by land owners and various authorities, it is required to design earthing system using minimum land area for distribution transformers. The minimization of land can be done by minimizing the number of parallel earths or introducing deep rods for the installation. There is another method available to be used to improve the soil resistivity of soil enhancing material.

The other option is to design an earthing pit by minimizing the land space required for earthing. This can be done by using two bases of two poles of the transformer structure. A special earth mesh to be designed to be used for pole bases of transformer structure.

CHAPTER 3

PROBLEM STATEMENT

3.1 Preliminaries

The North Western Province (NWP) is one of nine provinces in Sri Lanka. The Soil Map of Sri Lanka clearly shows the type of soils available in the province (See Appendix A). It's boundaries are Kala-oya in North direction, Ma-oya in South and South-East directions, Indian Ocean in the West direction and chain of mountains of Matale region in East direction. Figure 3 shows the soil types available in NWP.

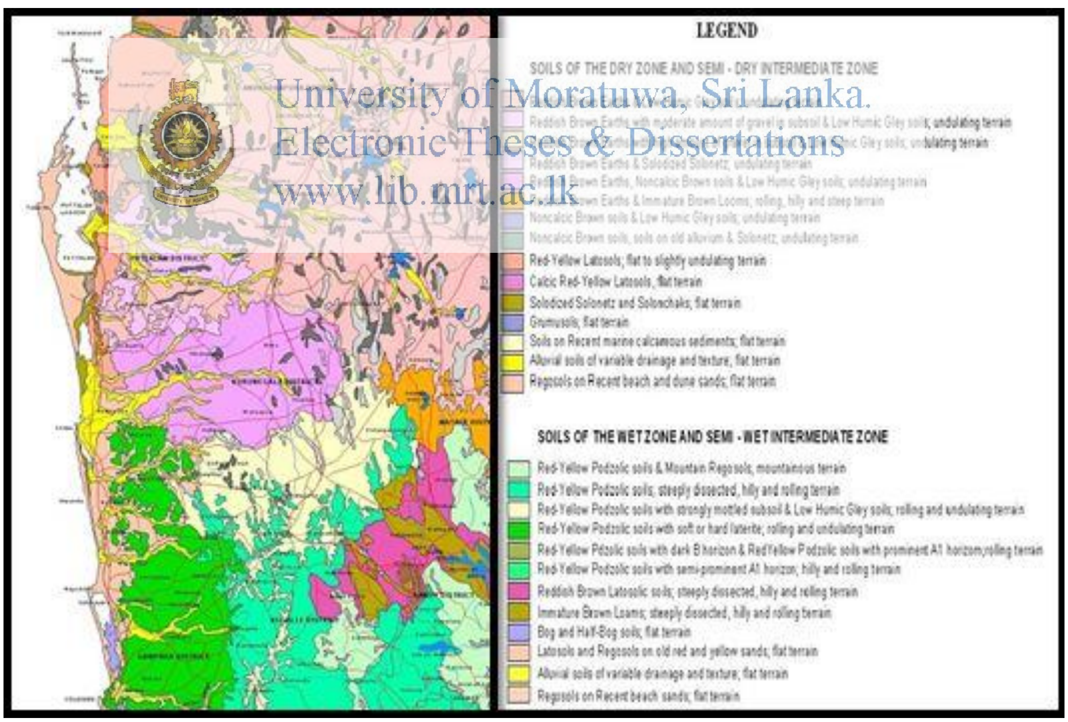

Figure 3: Soil Map of North Western Province

Source: Survey Department of Sri Lanka

North western province is developing rapidly in various sectors such as Industrialization, Tourism, Businesses, Poultry farming, Prawn farming and Agriculture etc. The government of Sri Lanka has allocated required funds for developing infrastructure facilities such as roads, electricity to the people. Rural electrification projects are planned to implement in the country to provide electricity supply for all potential customers through 100% Electrification Project. According to the experience gained on the transformer installations, it was found that the earth resistivity values of some locations were affecting on earthing of distribution transformers resulting high earth resistance.

3.2 Problem identification

3.2.1 Existing earthing system

The present earthing system used in Ceylon electricity board is based on "Guideline for Distribution System Earthing (part 1)". It was issued in 1998 by Distribution Planning branch in Colombo. In that guideline it was recommended to use concrete earth blocks method for the soils having resistivity less than 200Ωm. Installation of distribution transformers were done according to the above guideline. Before commissioning the transformers, commissioning tests are carried out by responsible ES of the site and the results are recorded in Commissioning Test Report (See Appendix C). By analyzing earth resistance values of neutral earth and lightning arrester earth measured during commissioning tests, it was found that some transformer locations have very high earth resistances than the recommended value of 10Ω. The list of locations having high earth resistances are given in Table 2.

Table 1: Earth Resistance Values in Different Transformer Locations.

S. No.	Name of RE Scheme of Transformer Location	Earth Resistance(Ω)		Area
		Neutral earth	Lightning Arrester earth	
01.	Mahamaeliya	10	12	Chilaw
02.	Koshena	12	10	Kuliyapitiya
03.	Pinnagolla Watta	15	10	Maho
04.	Minuwanpola	12	10	Wariyapola
05.	Karawitagara Dambakele	11	13	Chilaw
06.	Hirigollayaya	16	12	Chilaw
07.	Tonigala Watta	34	27	Anamaduwa
08.	Mahingala Coloney	20	14	Puttalam
09.	Hewanpellessa	18	17	Wariyapola
10.	Thammitagama Damsopura	22	9.5	Rajanganaya
11.	Pallekote	19.5	14.2	Maho
12.	Kongahayaya Colony	30	29	Chilaw
13.	Ottukulama	20	22	Wariyapola
14.	Nirmalapura	28	20	Puttalam
15.	Mahamewnawa	20	18	Narammala

3.2.2 Enact laws against Sand mining and transportation

There was a problem faced by engineers and construction staff due to the new law imposed by Environment Authority of Wayamba Provincial Council of North Western Province regarding sand mining from sand deposits in rivers, clay mining from clay deposits and transportation of sand and clay within the province. There was a big issue in using sand for concrete earth pits. The contractors of construction units have refused to undertake construction works to install earth pits due to the above difficulties, faced by them. To solve that issue, Engineers of Construction branch of CEB in NWP assigned construction jobs related to high voltage lines, transformers, low voltage lines except earth pits to the contractors. As a result of that, the transformer earthing installations were assigned to construction gangs which have permanent staff of CEB. However, the police had not granted permission to CEB gangs to transport sand from sand mines or from hardware shops in the market to the locations of construction sites. It was not an easy task to CEB gangs to install earthing system for each and every new transformer in the province.

Therefore, the author has carried out a separate research to find the possibility of using ABC (metal with quarry dust) to replace the usage of sand for concrete block earths. In that research cement and ABC mixed properly according to the ratio of 1:8 respectively with water and used for earth pits. The research was successful and results of research forwarded to DGM (NWP). Permission was granted to use ABC for concrete mixtures for earth pits when installing transformers. This issue also exited the mind of the author to find new solution for using locally available soil or sand with soil enhancement material such as charcoal and lime to minimize the cost incurred.

3.2.3 High Earth resistance during dry season

There is another issue on transformer earthing which was identified from Chilaw area. Such transformers were located close to the sea. The Area Engineer (Chilaw) informed about the issue to find solution to improve earthing system of existing transformers. The reason is increase of earth resistance more than 10Ω due to dryness of sand in coastal area because of lack of rain. Therefore earth resistance measurements were taken in Chilaw Area to find a solution. The data collected from existing transformer earth are given below.

Table 2: Soil Resistance Values during Dry Season in Chilaw Area

Location	Earth Resistance(Ω)	Weather condition	Moisture content (%)
Chilaw Beach	52	Dry	12
Thalwila Church	38	Dry	10
Ambakandawila	25	Dry	13
Thoduwawa	40	Dry	10
Mahawewa	43	Dry	15

The Table 2 shows the earth resistance of distribution transformers during dry weather conditions. All values are above 25Ω. It is required to find solution to keep the earth resistance below the required value (10Ω) even in the dry season

3.2.4 Non homogeneous Nature of Soil.

The soils in very few locations have homogeneous characteristics. However, it shows non -homogeneous characteristics in most part of the country. The Figure 4 shows earth has stratified nature. In actual situation soil has different layers such as Humus, Loam, Sand, Gravel and rock.

Figure 4: Stratified Nature of the soil

3.2.4 Lack of Know How.

The field staff of construction gangs or electrical superintendents have no idea about the resistivity of the soil when they going to install a transformer. They don’t have any knowledge or experience for measuring soil resistivity value of the site beforehand. Therefore, they use the same method used in low resistive soil for high resistive soil too.

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However, the guideline clearly indicated to carry out further studies for high resistive soil to obtain another earthing method for such soils. But no one has taken that challenge to find alternative earthing system for high resistive soils since 1998 after publishing the present guideline. Therefore, the author has taken that challenge to find solution for earthing in high resistive soils and decided to narrow down the study within NWP, due to limited resources available such as man power, vehicles and measuring equipment.

CHAPTER 4

DESIGN CRITERIA

To design, an earthing system, the designer should have an idea about the fault level of the site and the fault current that can be flow to the ground at faulty conditions. Different types of faults can be occurred in the electrical network due to various reasons.

4.1 Types of earth faults

Faults could be identified as Balance faults and Unbalanced faults

4.1.1 Hazardous Voltages

While Earth potential Rise (EPR) exists on an earthing system, during any fault condition, hazardous voltages exists in the form of Touch , Step and Transfer potentials [3][6]. Figure 5 indicates the presence of Step potential and Touch potential during fault condition.

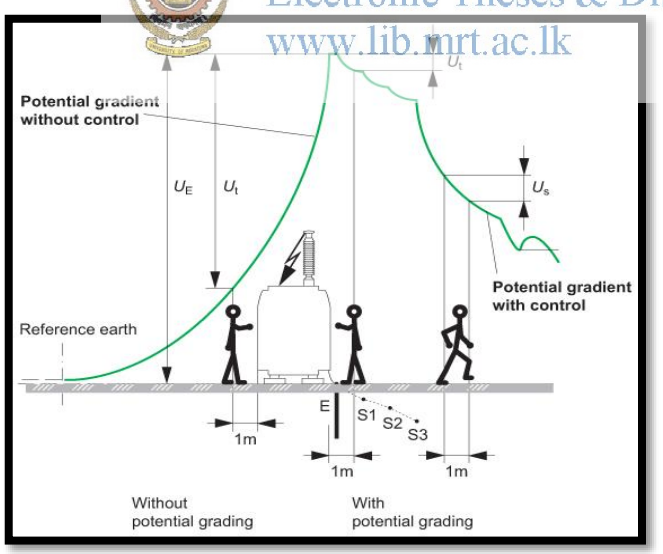

Figure 5: Step Potential & touch potential

Source: Application Note-Earthing System [2]

4.1.1.1 Touch Potential

The difference between EPR of earthing system and the ground surface potential at a distance of 1.0m is defined as Touch potential. This is the potential difference between a person's hand touching an energized object and their feet which in typically assumed to be 1.0m out from the energized object.

4.1.1.2 Step Potential

The difference in ground surface potential experienced by a person bridging a distance of 1.0m with the feet without contacting any ground objects is defined as Step potential [7].

4.1.1.3 Transfer Potential

The potential difference that may exist between the local earthing system and a metallic object such as fences, pipes bonded to a distant location that may be at a different potential is defined as Transfer voltage.

4.2 Environmental Factors that increase resistivity

High resistive soils were found at hilly areas where the rocks are located. In North western province the eastern boundary is covered by chain of Matale Mountains. Therefore the cross section of the North Western province consists of sea beaches, loam soils, clayey soil, gravel, and rocks. The reasons for the high resistive soil at mountains are washing out the organic substances for longer period due to rain and the composition of the rock. Therefore research to be conducted to find ways to reduce the earth resistance when installing transformers in hilly areas.

4.3 Public protests against installation of transformers

It was noticed that huge public protest aroused when implementing construction work of transformers, high voltage lines, medium voltage and low voltage lines when poles or transformer structure is planted very close proximity to premises of land owners or people closed to the site identified for electrical installations. In recent past there were lots of protesters have filed cases in courts and got injunction orders to stop the proposed construction work, rural electrification schemes and bulk supplies. In addition to that people protest to release required lands for installation of transformer earth pits. Even today some court cases are exists stopping the construction work related to very important projects. To minimize the utilization of land area required for earth pits and transformer structure a new earthing system is needed. To fulfill that need a research to be done to find alternative methods.

4.4 High isokeraunic level at mountains.

In Sri Lanka the mountains are located at the central part of the country. Under this research, soil samples are collected, to find the soil resistivity in rocky areas too. A lot of communication towers are located at mountain peaks. To provide the power supply for such locations distribution transformers are to be installed at mountains where the isokeraunic levels are high when compared to lower elevations. Therefore special attention must be given when designing earthing systems for distribution transformers in mountains.

The factors given above are considered in designing earthing system.

CHAPTER 5

THEORITICAL DEVOLOPMENT

5.1. Rationale

The research has to be done to find out new earthing system for distribution transformers to be located in high resistive soils. In addition to that, possible ways to be found to minimize the land area required for installation of transformers and earth pits. The main reason is the scarcity of lands in urban areas. The outcome of this research will be beneficial for personal who engage in electrical installations in the field of electrical engineering.

To achieve this target the research should be focused on high resistive soils and digging earth pits in congested areas such as busy towns, populated area and public parks etc. During the literature review on this research it was found earlier researchers have done a lot of experiments to bring down the earth resistance in high resistive grounds. They have used techniques to improve the electrolytic properties of soil, close to the earth electrode. They have considered the critical cylinder of the soil to enhance it. In this research a conceptual framework has been developed to find the earth resistivity of different combinations of soil enhancement material by doing laboratory tests.

In achieving objectives there are two main problems came across. One problem was the very high soil resistivity found in sand close to coastal areas. The other problem faced was non availability of enough land space to install parallel earth pits, to bring down the required earth resistance of 10Ω.

To handle those two issues, an optimum ratio of soil enhancement material should be identified. A research has been done to get optimum ratio mathematically. This ratio of soil enhancement material can be used for the particular soil to bring down the earth resistance.

To minimize the land area required for earthing, two pole pits of the transformer structure can be used as alternative earths. In literature review it was found that some researches have done this method [6] to bring down the earth resistance in special locations such as play grounds, populated areas and water recreation areas. The combination of above two earthing techniques may lead to reduce the number of parallel earths required to obtain the required earth resistance

5.2 Mathematical derivations

5.2.1 Earth Resistance of the Earth Rod in Homogeneous Soil

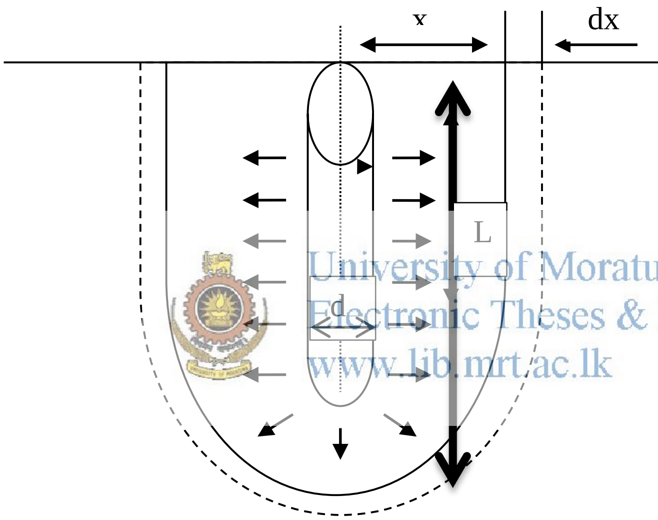

Figure 6: Earth Resistance of the Earth Rod in Homogeneous Soil

A uniform soil model can be utilized if the apparent soil resistivity value varies moderately. In homogeneous soil this type of variation can be obtained. But in practice it is very difficult to find homogeneous soils. If the apparent soil resistivity has larger variations, the uniform soil model cannot be utilized for analysis purposes. For this kind of soil types, two-layer model can be used

$$R_H = \int_{d0/2}^{\infty} \rho \frac{dx}{2\pi x L + 2\pi x^2}$$

By solving above equation,

$$R_H = \frac{\rho}{2\pi L} . ln \frac{2L}{d_0}$$

5.2.2 Earth Resistance of Earth Rod in Concrete Block

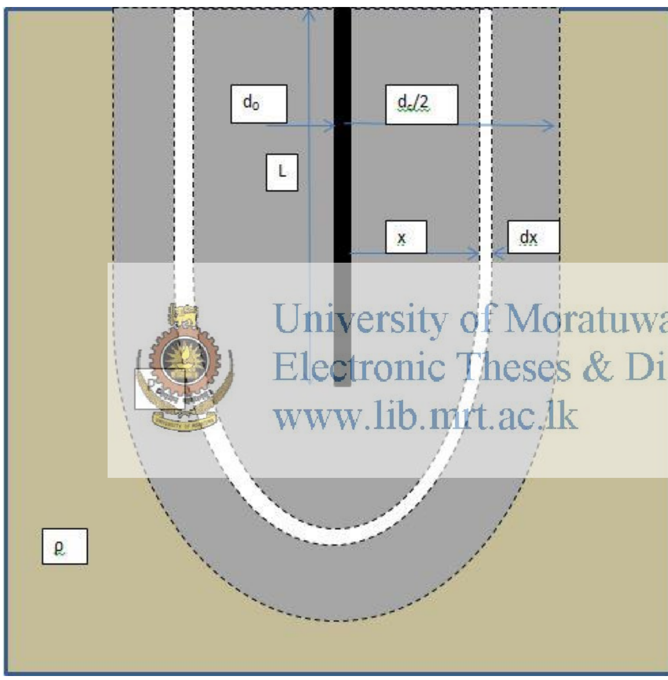

Figure 7: Concrete Block Earth Pit

$$d_c < 2L$$

$$d\mathrm{R}_{eq} = dR_c + dR_h$$

$$R_{eq} = \int_{d_0}^{dc/2} \rho_c \frac{dx}{2\pi x L + 2\pi x^2} + \int_{dc/2}^{\infty} \rho \frac{dx}{2\pi x L + 2\pi x^2}$$

$$R_{eq} = \frac{1}{2\pi L}\left[\rho_c ln\left(1+\frac{2L}{d_0}\right) + (\rho - \rho_c) ln\left(1+\frac{2L}{d_c}\right)\right]$$

According to the code practice for earthing the equation given for vertical earth electrode surrounded by infill material is given by:

$$R = \frac{1}{2\pi L}\left[(\rho - \rho_c)\left(ln\left(\frac{8L}{D_c}\right) - 1\right) + \rho_c\left(ln\left(\frac{8L}{d}\right) - 1\right)\right]$$

5.2.3 The potential at distant point from set of charges

The potential distribution at distant point can be derived in following manner. If surge absorbed by' n' number of earth rods, It can be simulated as a set of charges having 'n' numbers.

Let's consider origin O and point p at a distance place having position vector r. If the position vector of i^{th} charge q_i as r_i. Therefore the potential at p can be determined by the equation,

$$\text{Ø}(r) = \frac{1}{4\pi\sum_0} \sum_{i=1}^{N} \frac{q_i}{|r-ri|}$$

Assume r>>>>ri

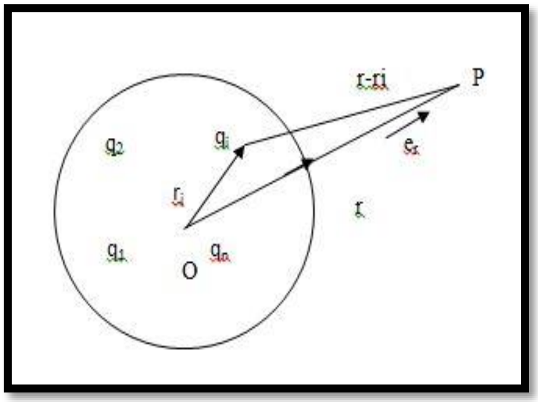

Figure8: Potential at distant point

$$(r-r_i) = r - r_i e_r = r\left(1-\frac{r_i}{r} e_r\right)$$

$$\emptyset(r) = \frac{1}{4\pi\Sigma_0} \sum_{i=1}^{N} \frac{q_i}{r\left(1-\frac{r_i}{r} e_r\right)}$$

$$\emptyset(r) = \frac{1}{4\pi\Sigma_0} \sum_{i=1}^{N} \frac{q_i}{r} \left(1-\frac{r_i}{r} e_r\right)^{-1}$$

$$\emptyset(r) = \frac{1}{4\pi\Sigma_0} \sum_{i=1}^{N} \frac{q_i}{r} \left(1+\frac{r_i}{r} e_r\right)$$

$$\emptyset(r) = \frac{1}{4\pi\Sigma_0} \sum_{i=1}^{N} \frac{q_i}{r} + \frac{1}{4\pi\Sigma_0} \sum_{i=1}^{N} \frac{q_i r_i e_r}{r^2}$$

$$\emptyset(r) = \frac{1}{4\pi\Sigma_0} \sum_{i=1}^{N} \frac{q_i}{r} + \frac{1}{4\pi\Sigma_0} \left[\sum_{i=1}^{N} \frac{q_i r_i}{r^2}\right] e_r$$

According to the derived formula the potential at point ‘P’ is inversely proportional to the distance from the origin [13].

For homogeneous soil for rod type earth electrode, the earth resistance is,

$$R_H = \frac{\rho}{2\pi L} . ln \frac{2L}{d_0}$$

This shows the soil resistance is directly related with resistivity of the medium and inversely proportional to the length of the earth rod. Therefore the soil enhancement material could be used to reduce the resistivity of the medium.

5.2.3 Non homogeneous two-layer model.

In this model two layer of soil having different soil resistivity are concerned. It consists of an upper layer of finite depth with different resistivity than the lower layer of the infinite depth. Analysis of two layer method can be done by Sunde's graphical method [7]. The abrupt change in resistivity at the boundaries of each soil layer can be described by means of reflection factor 'k'.

5.2.5 Two Layer Model

A two layer soil model is shown in Figure 9. It can be represented by an upper layer soil of a finite depth above a lower layer of infinite depth. This nature can be occurred due to the stratified nature of the soil

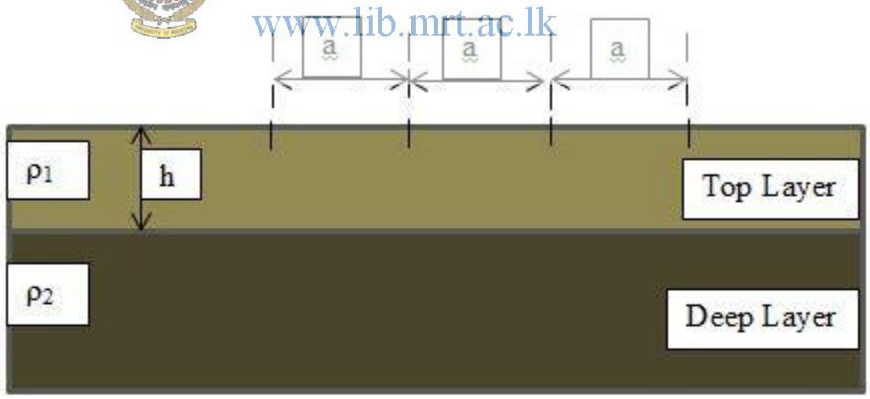

Figure 9: Two layer model of soil

At the boundary of two soil types there is an abrupt change in resistivity. The resistivity of two soil types has considerable difference. This can be described by a reflection factor, K where,

$$K = \frac{\rho_2 - \rho_1}{\rho_1 + \rho_2}$$

where , ρ_1 – The soil resistivity of the upper layer, in Ωm.

and ρ_2 – The soil resistivity of the lower layer, in Ωm.

To find the average value of apparent resistivity, Sunde's graphical method was used [5]. According to the Sunde's graphical method shown in Figure 10, the apparent resistivity was obtained as 1000 Ωm and the depth of the top soil layer was found to be 0.5m.

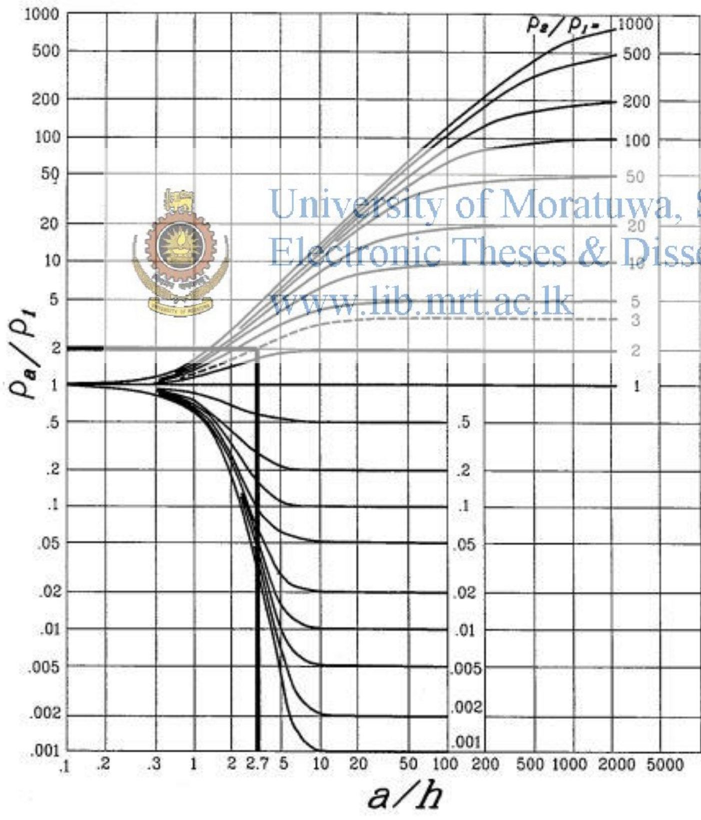

Figure10: Sunde's Graphical Method

Source: IEEE Std. 80-2000 [7]

5.2.6 Theory of Graphical method for resistivity derivation.

The current passing through the sample of the mixture of soil enhancement material can be measure by varying the voltage. The graph can be drawn as given in Figure 11.

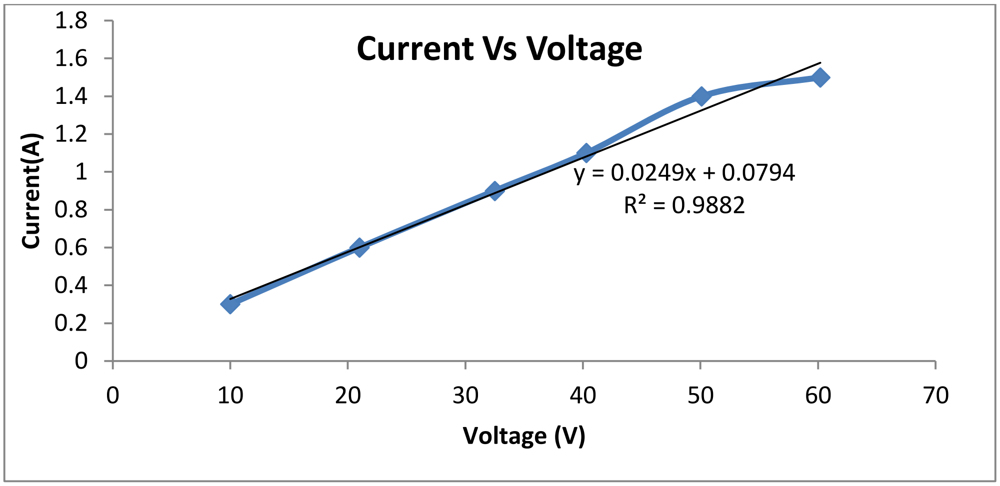

Figure 11: The graph of Current Vs Voltage

The gradient of the graph, $m = \frac{I}{V}$

The resistance across the sample can be calculated from the relationship

$$R = \frac{V}{I}$$

$$\therefore R = \frac{1}{m}$$

But $R = \rho \frac{l}{A}$

Let the dimensions of the soil sample be l X w X h

$$\therefore R = \frac{\rho l}{wXh}$$

$$\rho = whR/\text{l}$$

CHAPTER 6

DATA COLLECTION: MEASUREMENT OF SOIL RESISTIVITY

North Western province is selected for data collection and it shows good cross section of soil types such as sand, loam, clay, marshy lands, gravel, rocks and mixtures of these soil types. Soil resistance samples were taken from 32 locations by Wenner method. This method is also called 4 pole method. Figure 12 shows Four Pole Earth Megger. It was used in data collection within the province.

Figure 12: Four pole earth Megger

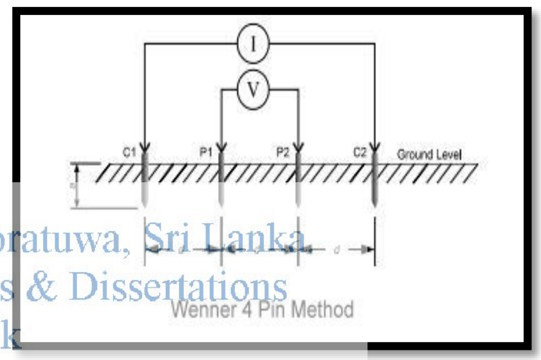

Figure 13: Circuit diagram of Wenner method

Source : IEEE Std 80-2000

Figure 14: Earth resistance Measurement at Field

6.1 Different characteristics of soil at different locations

Earth resistance measurements were taken by using Wenner method as per the Figure 13. Different types of characteristics of soil resistivity observed in different locations. Such variations are given in Figure 15,16,17,18,19,21,23 and Figure 24.

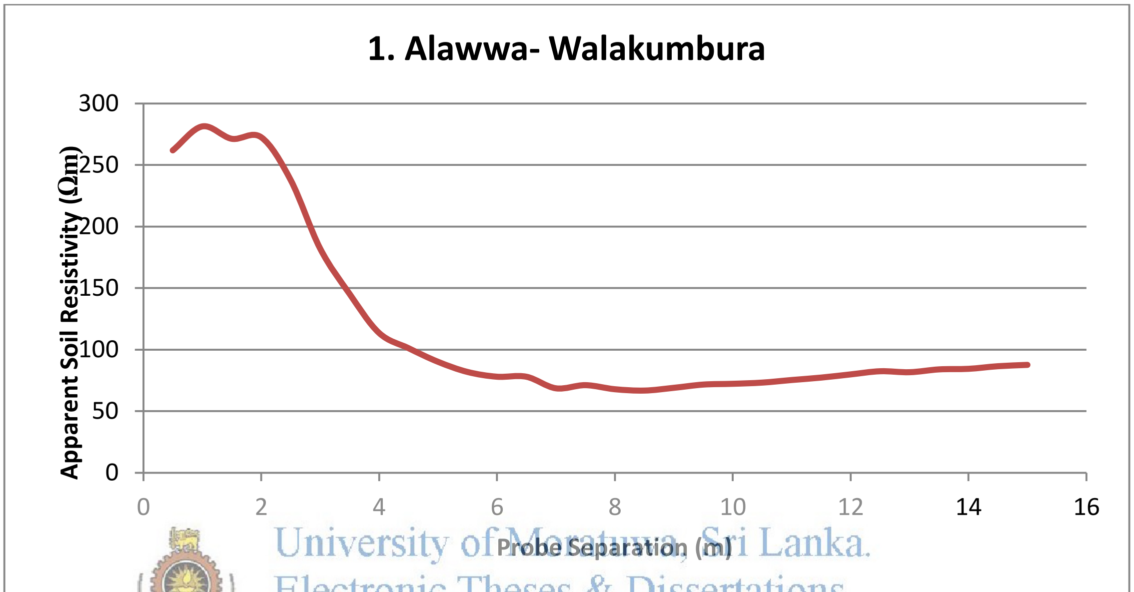

Figure 15: Clay layer Under Gravel

Alawwa - Walakumbura is located in Kurunegala District, close to Ma-Oya, one of boundaries of North Western Province. The area is fairly rocky with clayey nature. The Figure 15 shows the variation of soil resistivity. The top layer soil has high resistivity due to rocky nature and lower layer shows low resistivity due to high moisture condition of the soil due to the water level of the Ma-oya. It shows the 2 layer of soil.

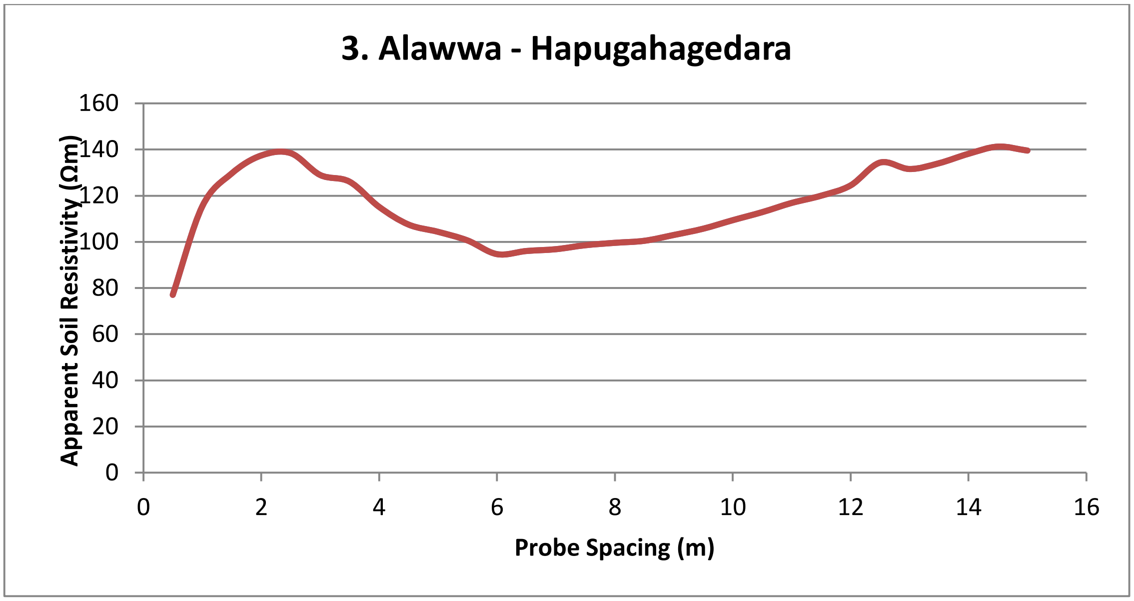

Figure 16: Stratified Clayey Soil

Alawwa – Hapugahagedara is located in Kurunegala District, at clayey rocky village area. The Figure 16 shows the variation of soil resistivity at top layer is higher than the lower layer and it again increases due to 3 layers of the soil.

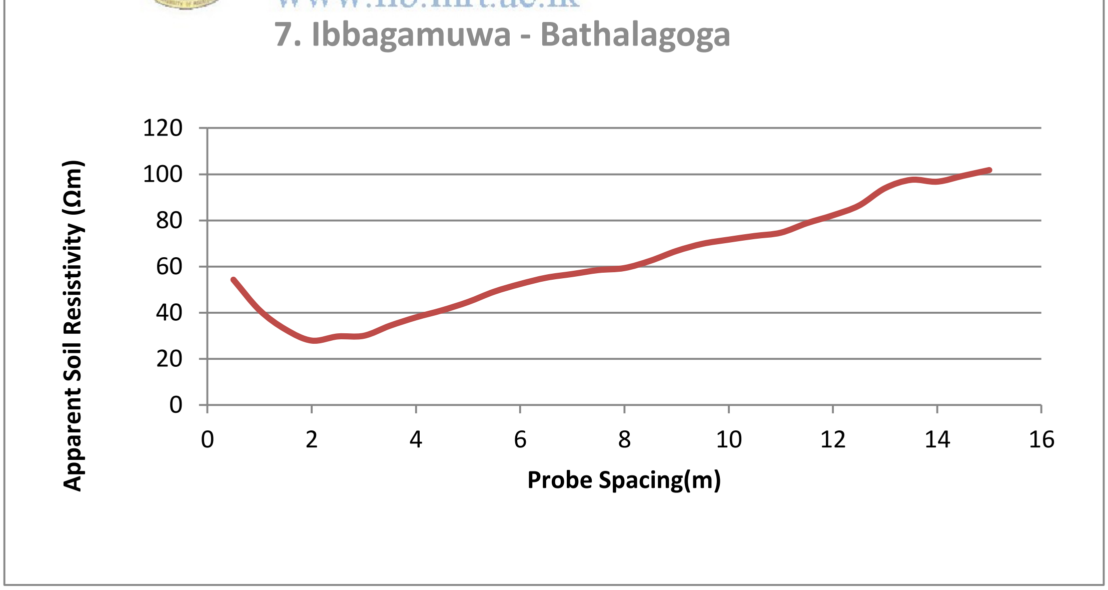

Figure 17: Clayey Soil near the Bathalagoda Lake.

Ibbagamuwa – Bathalagoda is located in Kurunegala District, close to Bathalagoda tank. It's East side has covered by the ring of Matale mountains, one of boundary of NWP. The soil is clayey nature. Figure 17 shows the variation of soil resistivity with separation of probes. It shows two layer nature of soil.

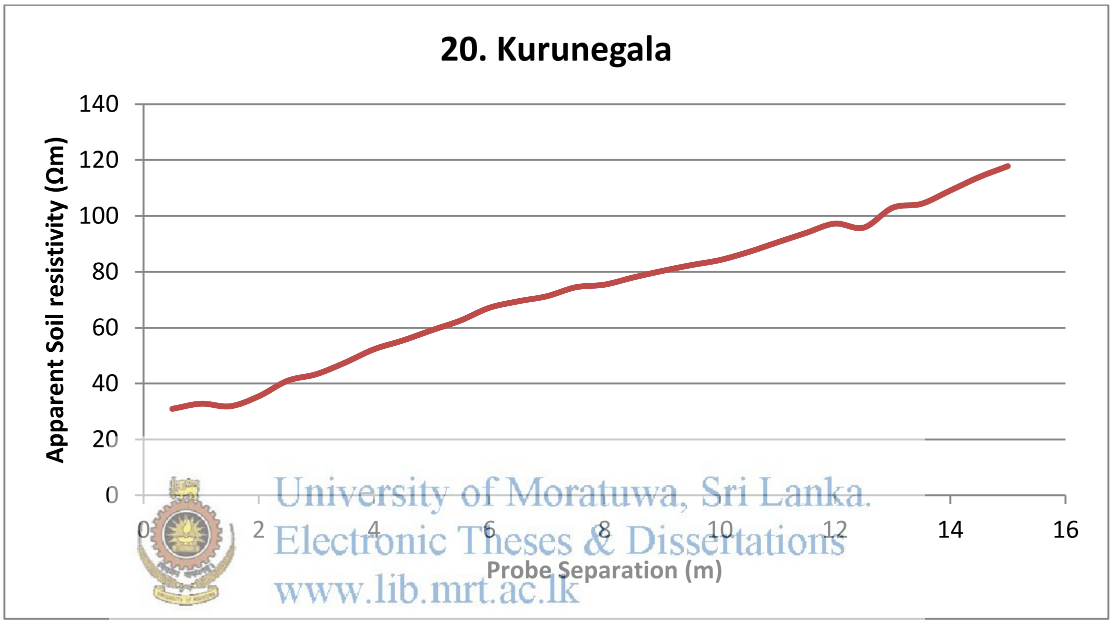

Figure 18: Loam and Rock

Kurunegala is the city of North Western Province. The huge rock called Ethugala is located at Kurunegala town. Figure 18 indicate the variation of soil resistivity with separation of probes. It shows the top layer has very low value of resistivity due to deposit of organic substances depleted from the top of the mountain. It gradually increases due to rocky nature of the bottom layer of the soil. It shows 2 layer nature of soil.

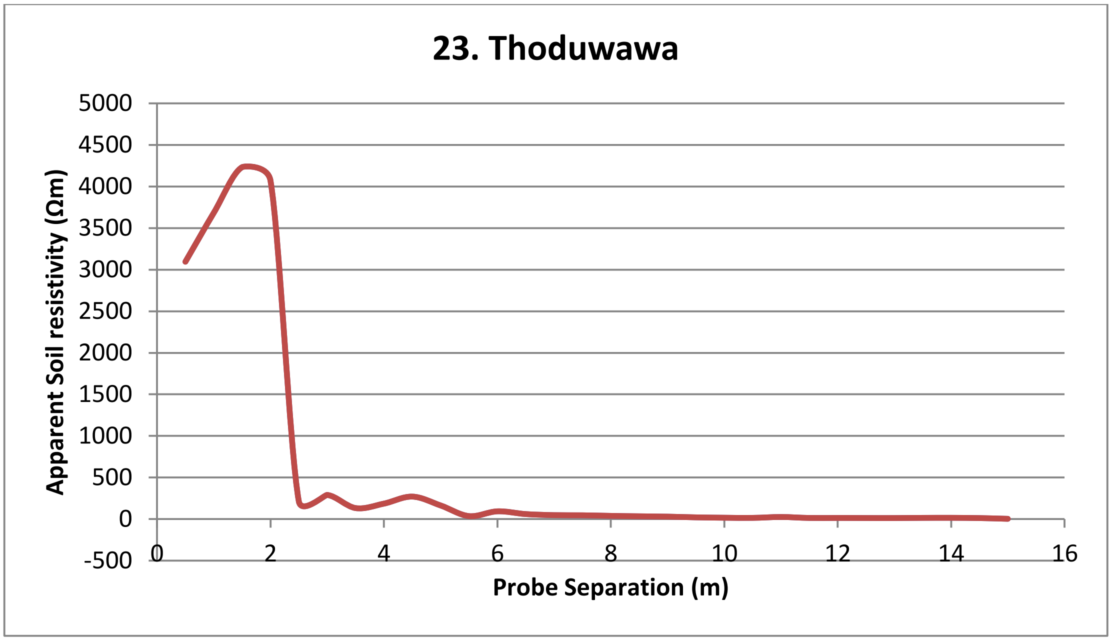

Figure 19: Sudden variation of soil resistivity in Sandy soil.

Thoduwawa is located in Puttlam district, close to the sea, West boundary of the NWP, The soil is sandy and dry at top layer. The figure 19 shows very high soil resistivity value at top layer due to non-retention of the water. This occurs due to the granular nature of sand particles. The bottom layer of the soil has high moisture content due to the sea water level. Thus, the resistivity becomes very low as a result of high moisture content and high dissolved salts. This characteristics show two soil layers.

Figure 20: Sudden elevation change in Sandy soil-Thoduwawa Beach.

Physical nature of Thoduwawa beach shows in Figure 20. The mean sea level is located about 3 m below the top surface of the soil. Thus, top surface of the soil shows very high resistivity. It shows very low soil resistivity due to presence of salts and moisture at the bottom layer of the soil.

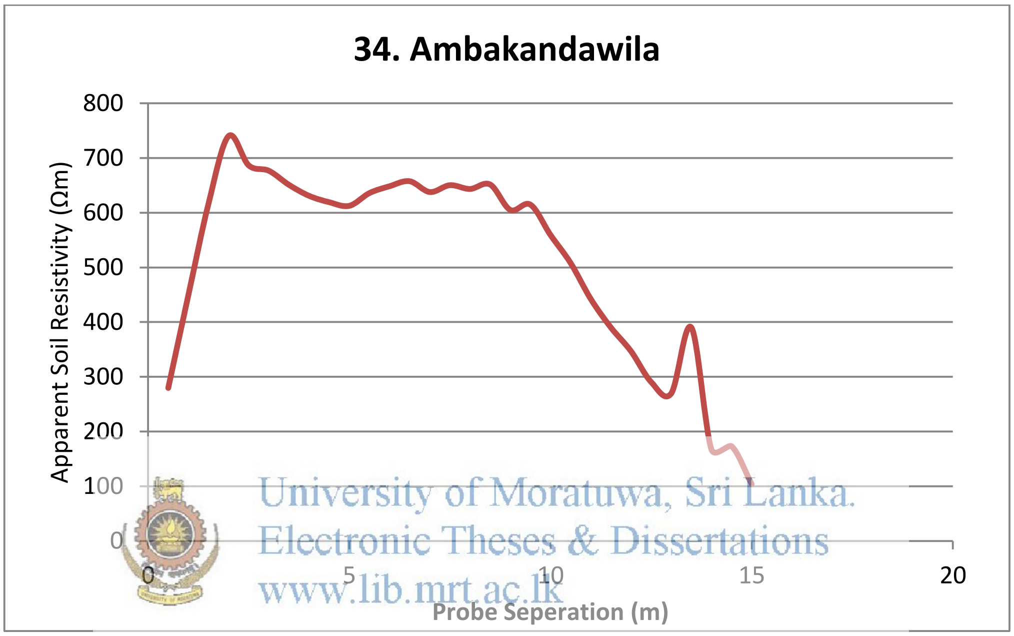

Figure 21: Rock Bed under Sandy Soil

Ambakandawila is located in Puttlam district, towards the west boundary of NWP which is sea. In this area the bed rock is lying under the sand layer forming a reef which reduces sea erosion. Figure 21 shows the variation of soil resistivity of this soil profile.

At the top layer the soil resistivity increases and remains fairly constant value due to the bed rock. Then it reduces the resistivity at bottom layers due to high moisture content and salt concentration. This shows 3 layer soil characteristics.

Figure 22 : Ambakandawila beach-Rock Bed under Sandy Soil.

Ambakandawila in Chilaw area has a reef in the sea about 30 m away from the land. The Figure 22 indicates the part of reef and the bed rock located around Sri Lanka. Soil erosion due to sea waves is minimized due to presence of the reef and bedrock in this area.

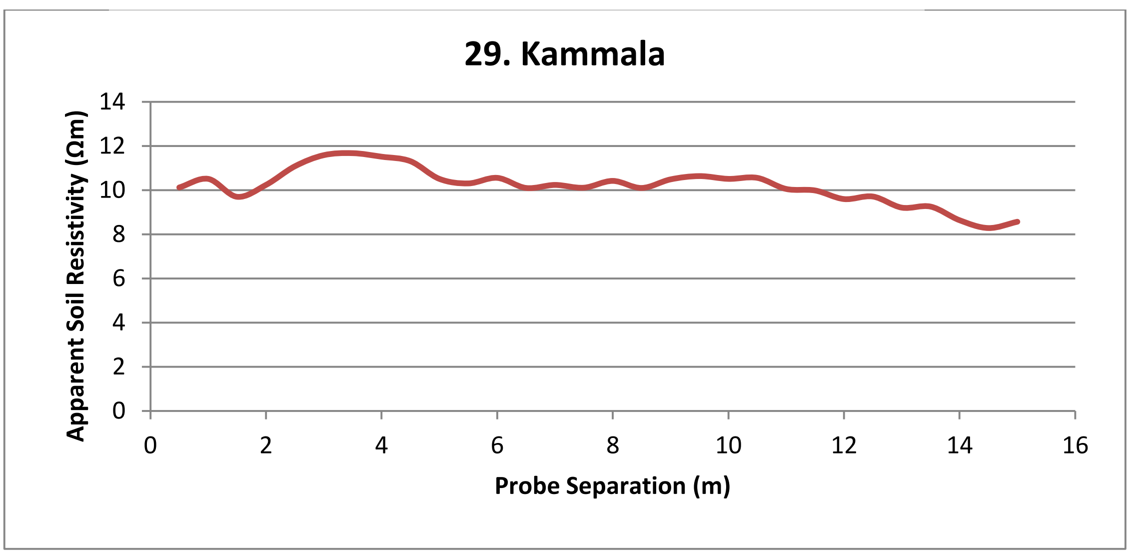

Figure 23: Pure Clayey Soil

Kammala is located about 2km away from the sea towards the land side. Ma oya, south boundary of the province is located about 1km. This area is very rich in tile manufacturing and brick making due to the clayey nature of the soil. Due to the presence of high water content of the area, the soil tends to be clayey. Clay minerals are very rich in cations of magnesium and aluminum. Thus it's electrolytic properties are very high. Figure 23 shows a constant variation for more than 10m of probe separation which implies homogeneous nature of the clayey soil layer which is thicker than 10m below the surface.

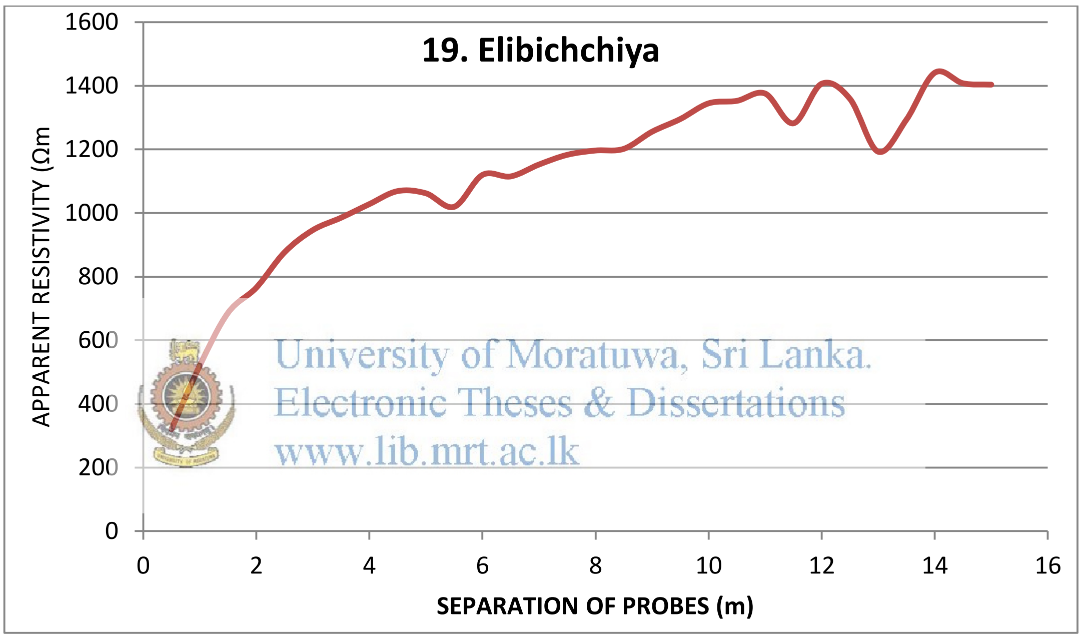

Figure 24: Hard rock under the Gravel layer

Elibichiya is located in Kurunegala district. There are lots of hard rocks available in this area. Due to the presence of hard rocks metal crushing industries are very popular in this area. Figure 24 shows the continuous increase of the resistivity with the depth of the soil. This variation shows a two layer soil profile.

6.2 High soil resistivity found in sandy soil.

When analyzing the soil data collected from locations very close to the sea, it was found that the soil resistivity is very high more than 2000Ωm. The reason for that issue is due to poor interaction among sand grains and leaching off organic substances and salts to lower layers of sandy soil. As a result of that water retention is very poor at top surface of the sand layers. When the water comes due to rain, the water particles drain directly to the bottom layers through sand particles. That is the main reason for getting high resistivity in the sandy soil very close to sea beaches. This phenomenon leads to do the research focused on sandy soil to find solution for earthing of distribution transformers in the coastal region.

Table 3: List of locations measured soil resistance & Soil resistivity.

S.No.	Area	C.S.C	Transformer Site	Resistivity (Ωm)			Soil Type	Average Resistivity Classification
				Min	Max	Average		
1	Chilaw	Chilaw	Ambakandawila	103	740	687	Sand	High
2	Chilaw	Chilaw	Munneshwaram	5	14	9	Sandy Loam	Very Low
3	Chilaw	Chilaw	Bingiriya	37	223	150	Gravel	Low
4	Narammala	Giriulla	Walakumbura	67	282	238	Gravel	Medium
5	Narammala	Giriulla	Hapugedara	95	142	139	Gravel/Clay	Low
6	Narammala	Giriulla	Meepitigedara	112	254	192	Sandy Rock	Low
7	Narammala	Giriulla	Alawwa	70	217	89	Gravel Clay	Very Low
8	Narammala	Narammala	Narammala	5	79.8	7	Sandy Rock	Very Low
9	Narammala	Narammala	Kalugamuwa	40	115	48	Sandy Rock	Very Low
10	Kurunegala	Pothuhera	Bandawa	21	180	33	Gravel	Very Low
11	Kurunegala	Mallawapitiya	Mawathagama	49	168	163	Clay	Low
12	Kurunegala	Rideegama	Rideegama	51	137	62	Sandy Loam	Very Low
13	Kurunegala	Gokarella	Bathalagoda	28	102	30	Clay	Very Low
14	Kurunegala	Mallawapitiya	Mallawapitiya	252	486	327	Sand	High
15	Kurunegala	Kurunegala	Malkaduwawa	56	1352	761	Sandy Rock	High
16	Kurunegala	Kurunegala	Kurunegala	31	118	41	Loam Rock	Very Low
17	Kuliyapitiya	Pan.Nuwara	Bowatta	14	54	26	Gravel	Very Low
18	Kuliyapitiya	Pannala	Bopitiya	37	482	169	Clay	Very High

19	Kuliyapitiya	Pannala	Elibichchiya	321	1442	877	Rock/Gravel	High
20	Kuliyapitiya	Pannala	Makandura	613	3507	1622	Sandy Clay	Very High
21	Kuliyapitiya	Pannala	Pannala	35	619	117	Gravel/Clay	Low
22	Kuliyapitiya	Pannala	Pannala	31	160	75	Clay	Very Low
23	Wennappuwa	Bolawatta	Kammala	8	833	745	Sandy Loam	High
24	Wennappuwa	Bolawatta	Kammala Beach	109	4273	3614	Sand	Very High
25	Wennappuwa	Bolawatta	Kammala	8	12	11	Clay	Very High
26	Wennappuwa	Bolawatta	Morukkuliya	202	626	610	Gravel/Clay	High
27	Wennappuwa	Bolawatta	Matikotuwa	311	1320	896	Gravel	High
28	Wariyapola	Nikawetiya	Kumbkwewa	51	104	56	Clay/Gravel	Very Low
29	Wariyapola	Nikawetiya	Subasethagama	21	113	29	Clay	Very Low
30	Chilaw	Madampe	Madampe	8	230	123	Sand/ Gravel	Low
31	Chilaw	Madampe	Mahawewa	60	1213	182	Gravel	Low
32	Chilaw	Madampe	Thoduwawa	13	4233	214	Sand	Medium

Thus new ways are to be found to bring down the earth resistance to the required level by improving soil and the moisture content around the proposed earth of such transformers.

Table 4 shows the apparent resistivity values at locations where data collected and the Figure 25 shows the statistical data representation of number of locations of data collected against the range of soil resistivity.

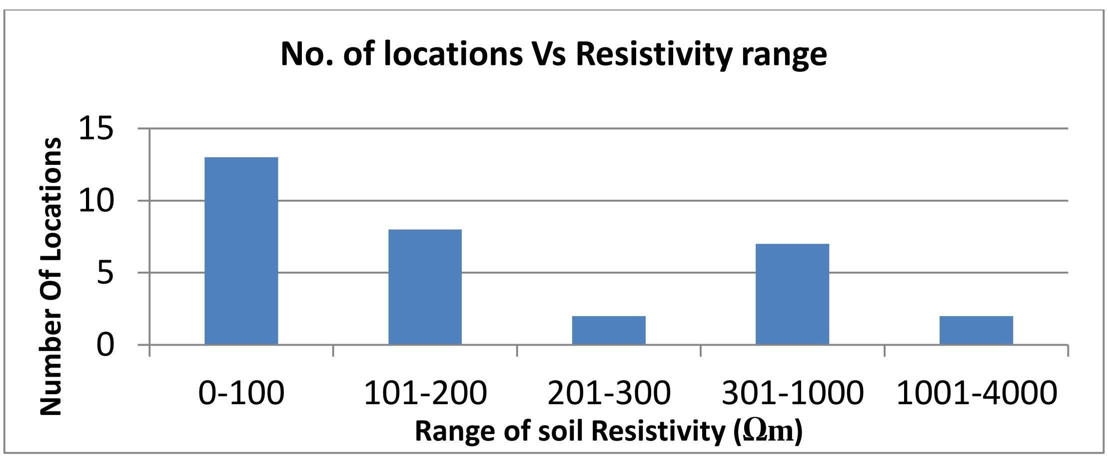

Figure 25: Statistical representation of number of locations Vs Range of soil resistivity

CHAPTER 7

DATA ANALYSIS

7.1 Mathematical Analysis

7.1.1 Case Study for Sandy Soil

The research was carried out for high resistive sandy soil in Thoduwawa area. The variation of resistivity against the separation of rods is shown in Figure 26.

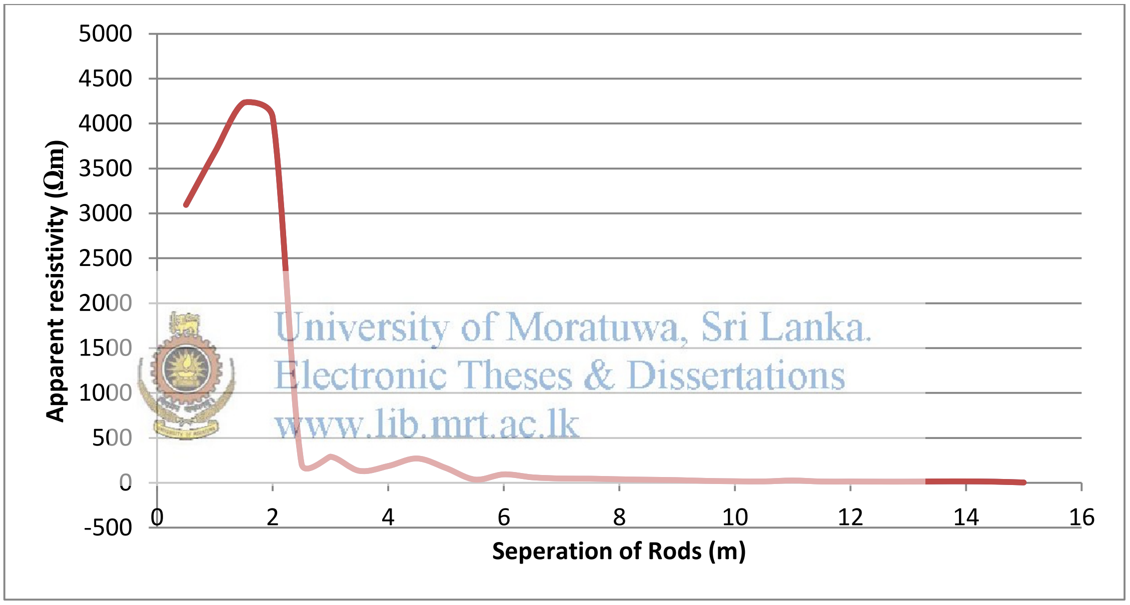

Figure26: Variation of resistivity in sandy soil near sea

The figure 26 shows the apparent resistivity at top layer is around 4000Ωm. In practice, the earth rods having length of 1.2m are used for earthing of distribution transformers. According to the values in Figure 26, the resistivity of the soil layer of 1.2m depth is about 3700 Ωm. The resistivity value drastically reduced to 213 Ωm at the depth of 2.5m. These values show the two layers of soil exist at this location.

The research was done at Thoduwawa transformer, close to the beach, during the construction of transformer and earth pits. Charcoal and Lime were mixed with sand of the site. The earth resistance was measured by changing the proportions of the soil enhancement material as in Table 5.

Table 4: Tests results on effect of Soil Enhancement.

Apparent Earth resistivity(Ωm)	Rod length (m)	Diameter of Earth pit(m)	Ratio of Charcoal	Ratio of Lime	Ratio of Soil	No. of rods	Earth Resistance(Ω)
1000	1.2	0.85	1	1	10	1	46.8
1000	1.2	0.85	2	2	10	1	19.0
1000	1.2	0.85	3	3	10	1	10.4
1000	1.2	0.85	4	4	10	1	7.4
1000	1.2	0.85	5	5	10	1	2.4

The composition of soil enhancement materials changed as per Table 5, Ratio of sand, Earth rod length and diameter of earth pit remains unchanged. The earth resistance reduced considerably with the increase of ratio of Charcoal and Lime as Figure 27

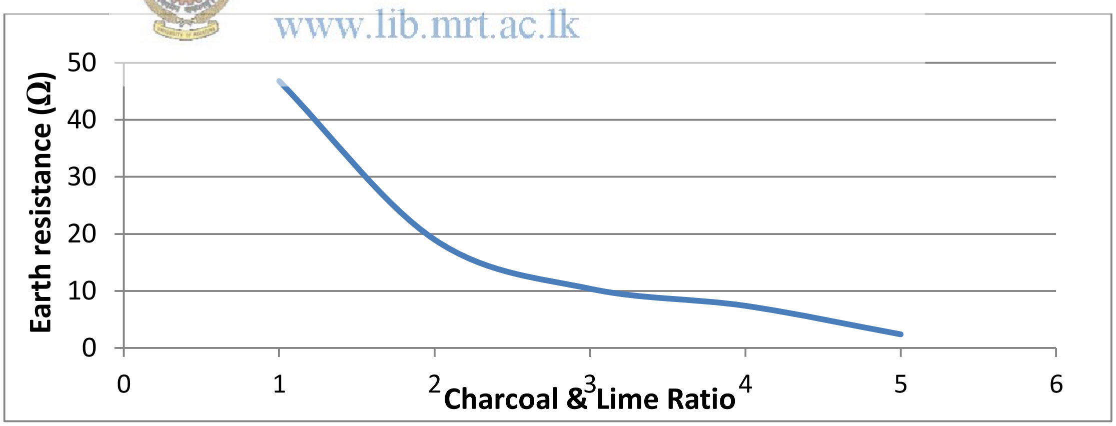

Figure 27: Variation of earth resistivity with Soil Enhancement

The variation shows nonlinear characteristics of the curve. Therefore analysis was done by adopting nonlinear regression analysis.

7.1.2 Derivation of Mathematical expression by Non Linear Regression Analysis

- Assume the function of the curve as Exponential

$$y= ab^x$$

$$\log y= \log a + \log b^x$$

$$\log y= \log a + x \log b$$

$$\log y= A + xB$$

where $A=\log a$

$B=\log b$

$$A=\frac{\sum y}{n} - b\frac{\sum x}{n}$$

$$B=\frac{n\sum xy-\sum x\sum y}{n\sum x^2-(\sum x)^2}$$

By substituting values to ‘x’ and ‘y’ to above equations, values of ‘A’ and ‘B’ are calculated.

$A=1.9398$

$B=-0.2989$

Derived equation By Non Linear regression Analysis is given below.

$$y=87.0662\times0.5024^x$$

Equation of the Best fit curve derived by computer software analysis (Microsoft Excel 2013)

$$y=87.09\times0.5066^x$$

The Best fit curve derived by MS Excel program is approximately equal to the derived formula

7.2 Finding the soil resistivity of mixture of soil enhancement materials.

The earth resistance is directly depends on the soil resistivity. When the soil enhancement material is prepared to apply to the earth pit the required resistivity of the mixture should be identified beforehand and the required ratio of charcoal, lime and sand should be identified to get the required value (10Ω) as the ultimate result of earthing.

In this research a laboratory test was conducted for sand samples collected from Thoduwawa beach to find the soil resistivity of the mixtures of soil enhancement materials. Five (5) samples were taken by changing the ratios of charcoal, lime and sand as per Table 6.

Table 5: Ratio of Soil enhancement material

Sample number	Ratio of Soil enhancement material		
	Charcoal	Lime	Sand
1	1	1	1
2	1	1	2
3	1	1	10
4	1	1	12
5	1	1	3

7.2.1 Test Procedure

A wooden box of 0.2mx0.2mx0.2m having cubical shape was made and inner walls of two opposite sides were covered with aluminum foils to ensure proper electrical contact with soil samples. Then they were filled with soil samples. And a variable voltage was applied to the two metal sheets and measured the corresponding voltage and current using voltmeter and ammeter.

Figure 28: The Wooden Box

Figure 29: The Sample under Test

7.2.1.1 Preparation of Mixture of Soil Enhancement material.

When mixing soil enhancing materials the performance changes according to such ingredients. To obtain the optimum ratio of soil enhancement materials, different ratios of charcoal lime and sand are mixed with water.

Figure 30: Soil Enhancement materials and Mixture

Figure 31: Mixing of charcoal, lime and sand

7.2.3 Laboratory testing procedure

The main idea of this laboratory test is to find the soil resistivity of samples of soil enhancement material. The voltage across the soil sample was varied by a Variac and the current passing through the circuit measured by the ammeter. The circuit diagram of this test is given in Figure 32 and the test results were tabulated.

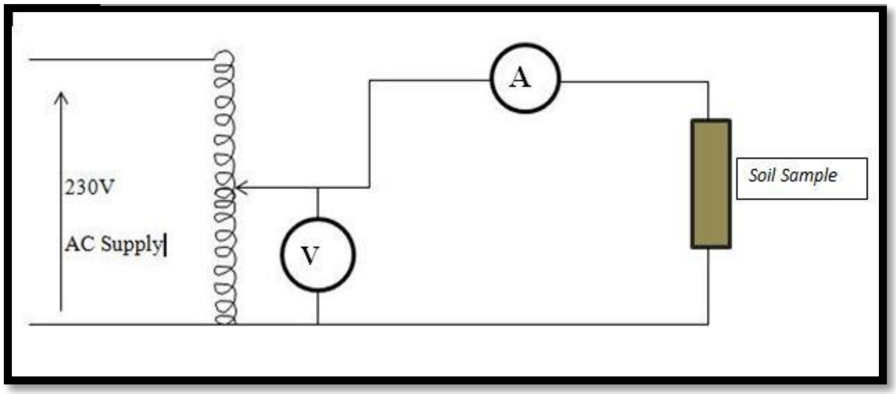

Figure 32: Circuit Diagram

When mixing soil enhancing materials, it was required to get the actual values of soil resistivity of such mixtures. To find that values a laboratory test was done. The cubic shape wooden boxes were fabricated and filled with samples of five different ratios of charcoal, lime and sand. The AC test was carried out by changing the voltage by using Variac the current passes through the samples were measured by Ammeter. From this laboratory test, the resistance of sample was calculated graphically.

The voltage and current data were tabulated and graphs were drawn for the 5 samples. The observations and the graphs of Current Vs voltage are shown in Table 7, 8,9,10 and Table 11 and Figure 33, 34, 35, 36 and Figure 37 respectively.

Table 6: Sample 1:- Ratio 1:1:1-(Charcoal:Lime:Sand)

Voltage(V)	Current(A)
10	0.3
21	0.6
32.5	0.9
40.3	1.1
50.1	1.4
60.2	1.5

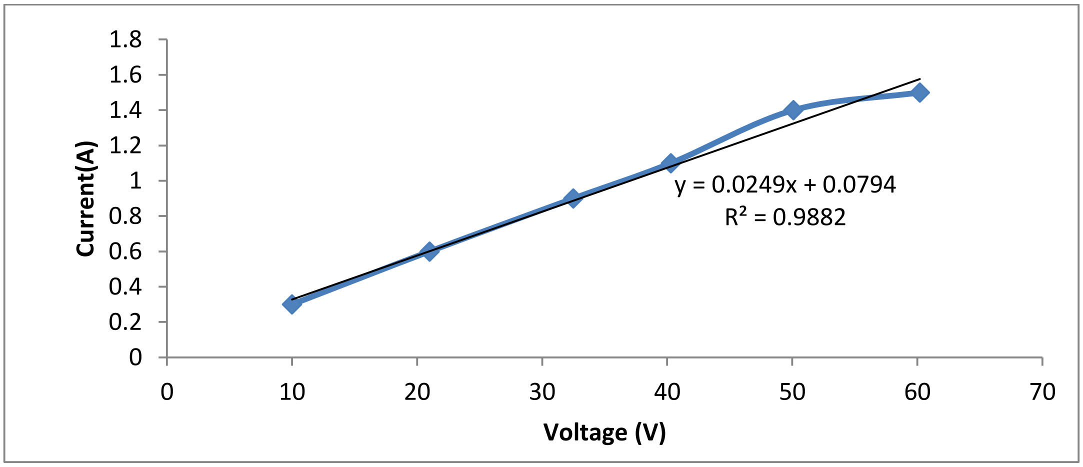

Figure 33: Current Vs Voltage of Sample 1

Table 7: Sample 2: Ratio 1:1:2 -(charcoal:lime:sand)

Voltage(V)	Current(A)
10.5	0.2
20.3	0.3
30	0.5
40	0.6
50.2	0.7
62	0.9

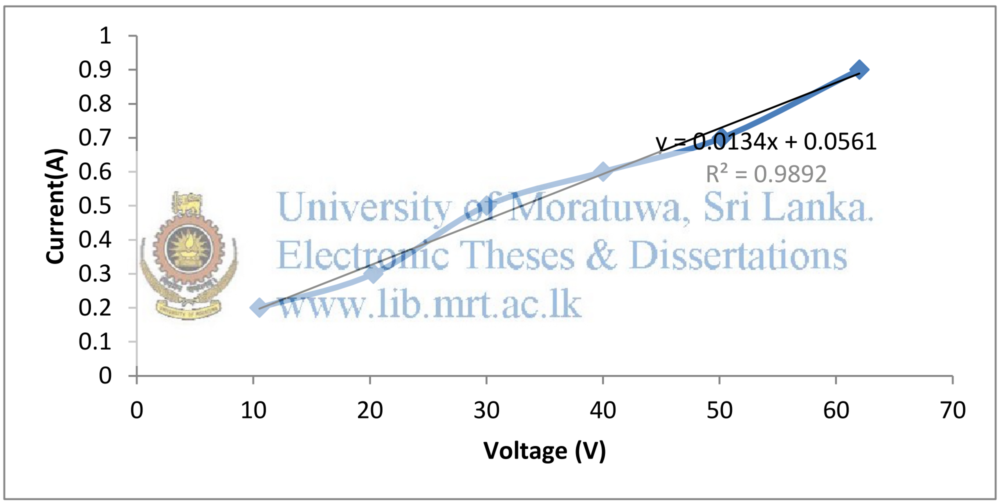

Figure 34 : Current Vs Voltage of Sample 2

Table 8: Sample 3: Ratio 1:1:10 -(charcoal:lime:sand)

Voltage(V)	Current(A)
12	0.1
22	0.3
31	0.4
40.1	0.5
50	0.6
60.2	0.7

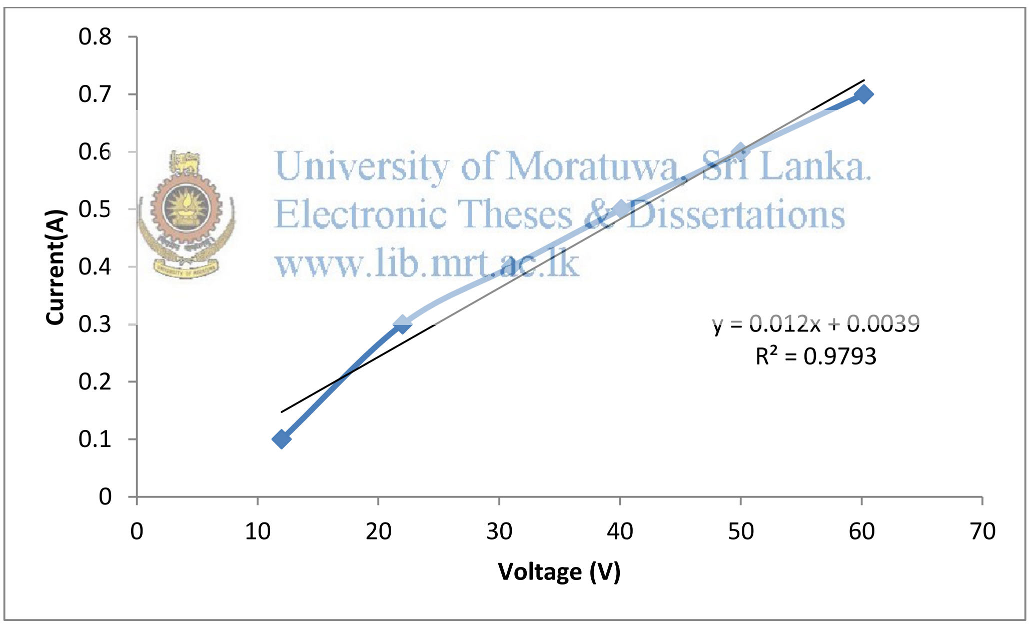

Figure 35: Current Vs Voltage of Sample 3

Table 9: Sample 4: Ratio1:1:12 -(Charcoal:Lime:Sand)

Voltage(V)	Current(A)
10.5	0.1
20.2	0.2
30	0.4
40.2	0.5
51	0.6
63.1	0.8
70.2	0.8

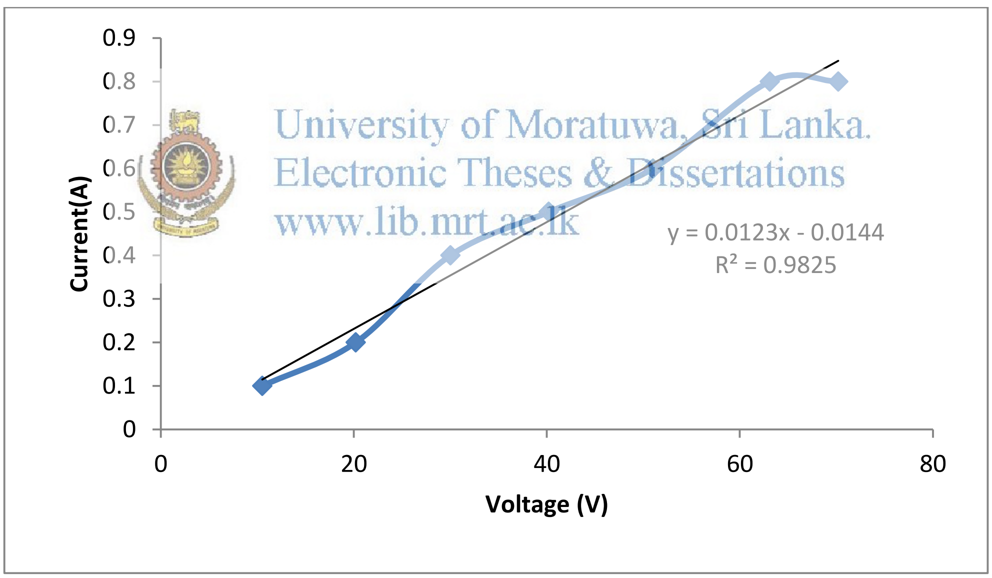

Figure 36: Current Vs Voltage of Sample 4

Table 10: Sample5: Ratio 1:1:3-(Charcoal:Lime:Sand)

Voltage(V)	Current(A)
11	0.3
20	0.5
30	0.8

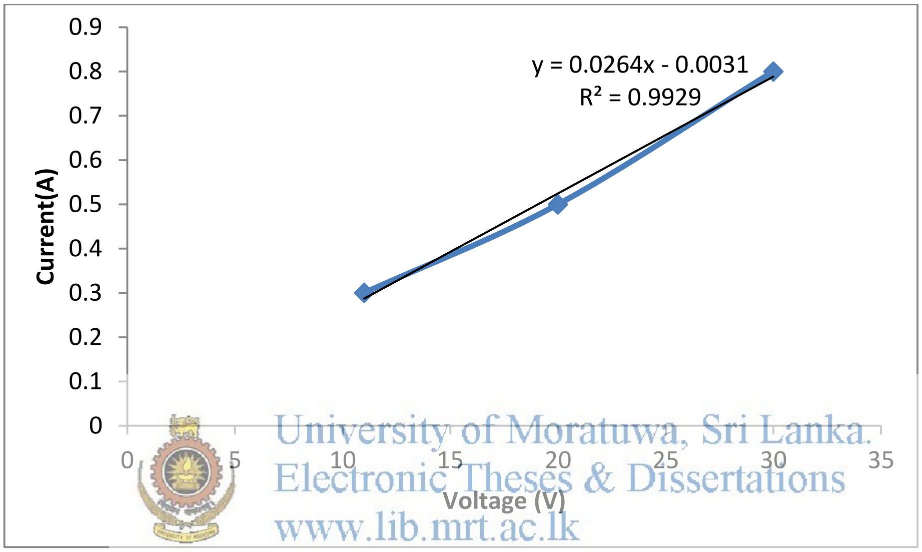

Figure 37: Current Vs Voltage of Sample 5

The gradient of the graph, $m = \frac{I}{V}$. But the resistance R across the sample can be calculated from the relationship $R = \frac{V}{I}$

Therefore $R = \frac{1}{m}$

But $R = \rho \frac{l}{A}$

In the soil sample length l=0.2m and

Area A=0.2m x 0.2m

Therefore $R = \frac{\rho}{0.2}$

$\rho = 0.2R$

Using this equation resistivity of the sample is calculated.

Table 11: Soil Resistivity Variation of Enhanced Samples

Sample	Gradient=m	Resistance=1/m	Resistivity=0.2xRes:
1	0.0249	40.16	8.03
2	0.0134	74.62	14.97
3	0.0120	83.33	16.66
4	0.0123	81.30	16.26
5	0.0264	37.87	7.57

According to the Table 12, the soil resistivity changes with the change of ratios of the soil enhancement material. The sample 5 shows the lowest value of resistivity of 7.57Ωm. In the sample 5 the ratio of Charcoal: Lime: Sand is 1:1:3. It clearly shows that when the Charcoal and Lime ratio increases with respect to sand, the electrolytic property increases resulting lower the soil resistivity value of the mixture.

This method can be used for any type of soil to get optimum ratio of soil enhancing material. A set of curves can be drawn on graph to find the most suitable ratios of such materials to get required earth resistance value of 10 Ω using standard copper clad steel earth rod having length of 1.2m and the diameter of 19mm .By using this method number of parallel earths can be reduced to minimum level by minimizing the land area.

CHAPTER 8

ANALYSIS USING ANSYS MAXWELL SOFTWARE

8.1 Ansys Maxwell Software

The Ansys Maxwell software is widely used in designing and optimizing electrostatic, electromagnetic and eddy current problems. It is based on finite element method. In this method minimization of potential energy is considered. Therefore 3D model is used. In IEEE model also used rod type electrode in similar manner. In this software solution is done by dividing the volume within the critical cylinder into number of tetrahedrons and start to analyses the potential distribution in various elements attached with previous set of elements. Thus continuous solution can be obtained within the specified boundaries of the critical cylinder.

8.2 Simulation results.

8.2.1 Design Summary Report generated by Ansys Maxwell V.16

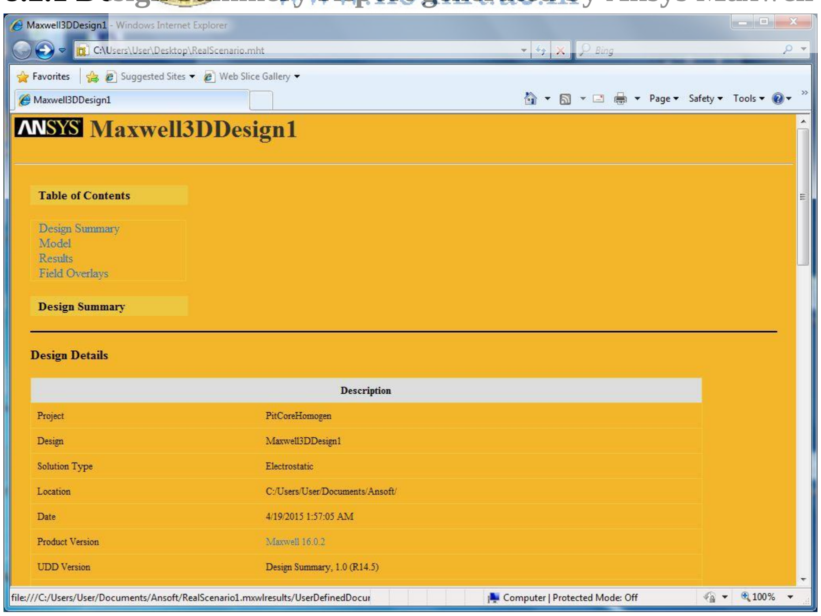

Figure 38: Design Details

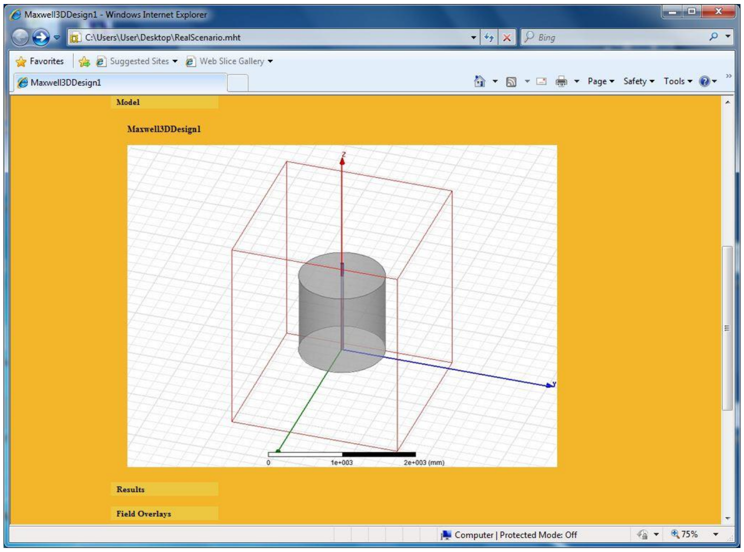

Figure 39: Model

To simulate the earth electrode the core and the pit should be modeled in 3-D plane with real dimensions of earth pits. Also a simulation region should be defined to perform simulations. Material properties are assigned to each element and the current is applied to the top surface of the core. The simulations are done within the specified region.

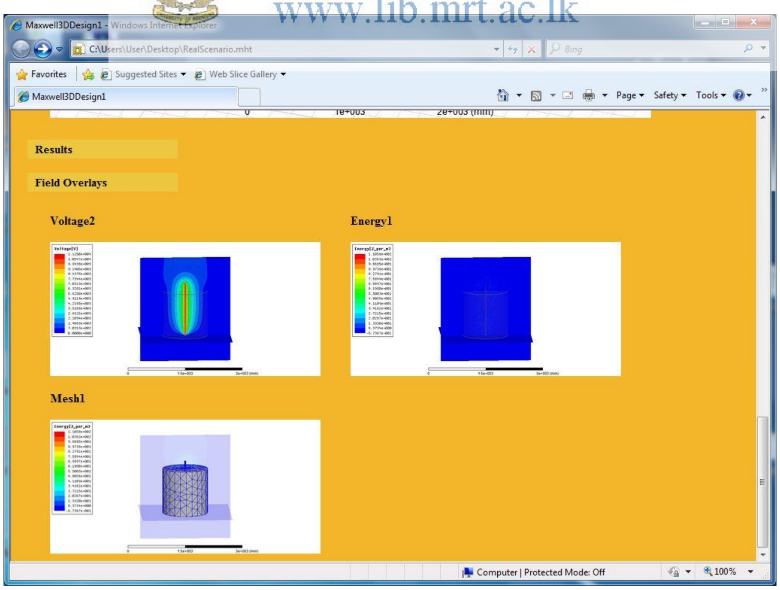

Figure 40: Field Overlays

In this section all the field simulations done in the project are appeared as a summery. In the simulated example it shows the variation of Voltage, Energy and the Mesh which is used in simulation by FEM.

8.2.2 Discussion of simulation results

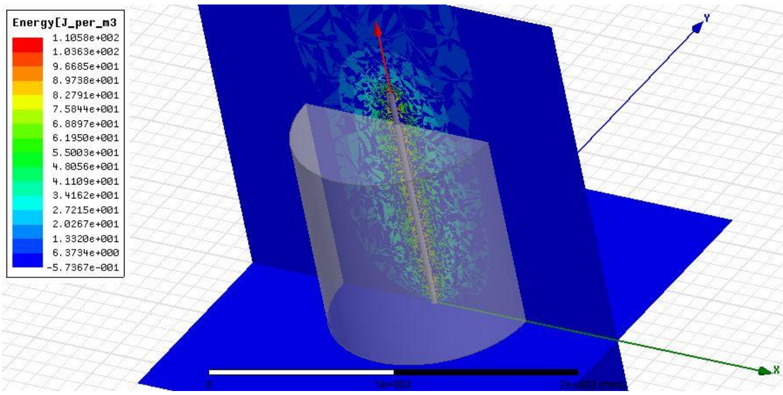

Figure 41: Energy variation in the XZ Plane

As per the results of Ansys Maxwell simulation software, it was found that the inner cylinder close to the earth rod absorbed more energy and the stresses around it increases. This can be used to simulate the earth resistance by getting the simulation results on power loss inside the earth pit.

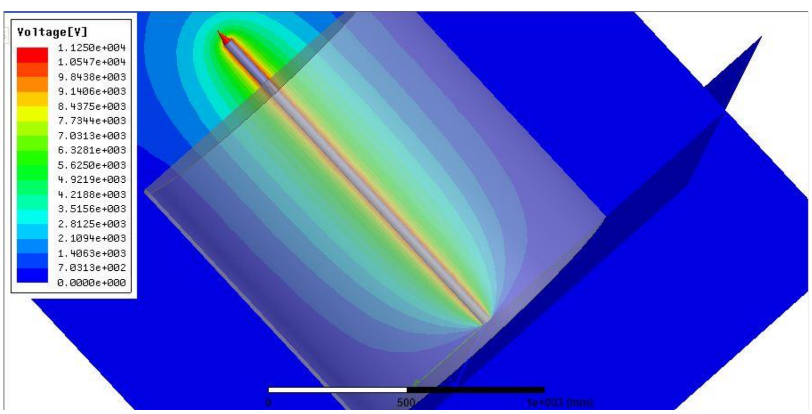

Figure 42: Voltage Variation in XZ plane

Figure 47 shows the voltage variation around the earth electrode inside the critical cylinder, which shows maximum voltage at very close proximity of the earth rod and gradually reduce when the distance increases along the radius if the pit. In Ansys Maxwell modeling, the scale and the legend is given. Geometrical planes (XY, YZ, ZX) could be selected according to the requirement of the modeling.

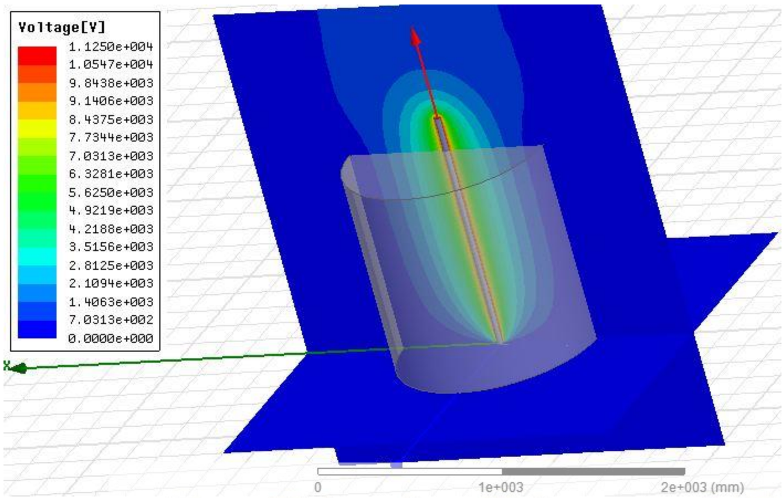

Figure 43: Voltage Variation in XZ plane

The analysis of the grounding rod has been carried out with first order triangular finite element method in the 3cm 15cm and 200cm from the rod, since 25%, 50% and 90% of the rod resistance is within the region [14].

The Ansys Maxwell simulations are carried out with real values in a practical scenario. To validate the results of this computer simulation, a comparison is done around the 3cm region of the core.

For the 3 cm region.

Applied voltage to the rod =11250V

Therefore total potential Drop=11250V

Potential within 3cm region= 8437V

Therefore potential drop within the 3cm region= 11250V-8550V

=2700V

Voltage drop as a percentage = $\frac{2700}{11250}\text{X}100 = 24\%$

For the 15 cm region.

Applied voltage to the rod =11250V

Therefore total potential Drop=11250V

Potential within 15cm region= 5710V

Therefore potential drop within the 15cm region= 11250V-5710V

=5540V

Voltage drop as a percentage = $\frac{5540}{11250}\text{X}100 = 49.24\%$

For the 200 cm region.

Applied voltage to the rod =11250V

Therefore total potential Drop=11250V

Potential within 200cm region= 703.13V

Therefore potential drop within the 200 cm region= 11250V-703.13V

=10546.87V

Voltage drop as a percentage = $\frac{10546}{11250}X100 = 93.7\%$

In the computer model a current of 10kA is applied, therefore the potential is proportional to the Earth resistance.

Table 13: Comparison of Results

Distance from the center of the core(cm)	Percentage Voltage Drop Of Computer simulation (%)	Percentage Resistance Drop of Computer simulation (%)	Percentage Drop of resistance as per [15]	Difference	Percentage Error (%)
3	24	24	25	1	4.00
15	49.24	49.24	50	0.76	1.52
200	93.7	93.7	90	-3.7	-4.30

According to the Table 13, the error percentage is considerably low. Therefore the results of the computer simulations carried out by Ansys Maxwell software have similar trends of the of the research work [14]. Therefore the simulated model can be validated.

The above results of Ansys Maxwell simulation shows that more energy dissipates very close to the earth rod. To minimize the use of land for earth pits in restricted areas, diameter of earth pit can be further reduced than the standard diameter of 850 cm. It will reduce the cost of excavation of earth pits, volume of soil to be excavated, required volume of soil enhancement materials and the total cost incurred for earth pits. It is required to carry out research in future to identify the optimum diameter of earth pits.

By reducing the diameter of earth pits, public protests and objections can be minimized to increase the efficiency and effectiveness of construction works related to distribution transformers in restricted areas.

CHAPTER 9

PROPOSED SOLUTION

9.1 Conceiving features of a relevant solution

To design a new earthing system, previous studies done by researchers were studied during literature review. It was found that many researches have done researches all over the world on this matter using their own thinking and ideas extracted from previous researches.

The research has been done to implement the new idea conceived in mind of author to find suitable solution in earthing of distribution transformers. There are two objectives to find solutions for earthing. One is to find solution for areas having high soil resistivity. The other one is to find optimum ways of earthing in restricted areas. Those are burning issues in power distribution sector in the installation of power distribution transformers. The area having sandy soils and hard rocks have high resistivity.

Before commence the soil resistance measurement of proposed sites, the list of proposed sites for implementing rural electrical schemes, bulk supply transformers and transformers required to augment the power network was taken from construction branch of North Western Province of CEB. Field measurements were commenced after giving proper training on using Wenner method (Four pole method) to electrical superintendents attached to Construction branch and Distribution Maintenance branch.

Soil resistance measurements were taken from 32 locations where the new transformers are proposed, Soil resistance measurements were taken at every half a meter as per the data sheet prepared by the author, soil resistivity values were calculated and graphs were drawn to get clear idea about the geography and the soil condition of each potential sites. It was found that locations such as Kammala (Figure 23) have clayey soil and it shows homogeneous characteristics, however sandy soil close to sea such as Thoduwawa

(Figure 19), Ambakandwila (Figure 21) and Mahawewa and soil at hilly areas such as Alawwa (Figure 15), and Elibichchiya (Figure 24) in Bopitiya area indicated non homogeneous characteristics.

9.1.1 Earthing of distribution transformers in high resistive soil

The aim of the research is to find a suitable solution for earthing of distribution transformers having high soil resistivity and restricted areas due to various constraints such as objections of land owners, objections by various authorities and physical constraints such as valuable ancient buildings, trees utilized for religious activities etc.

During the literature review it was found that the interference of earthing resistance varies with the separation of electrodes. The separation should me more than twice the length of the earth rod. It was noted to maintain the separation as indicated in Figure 44.

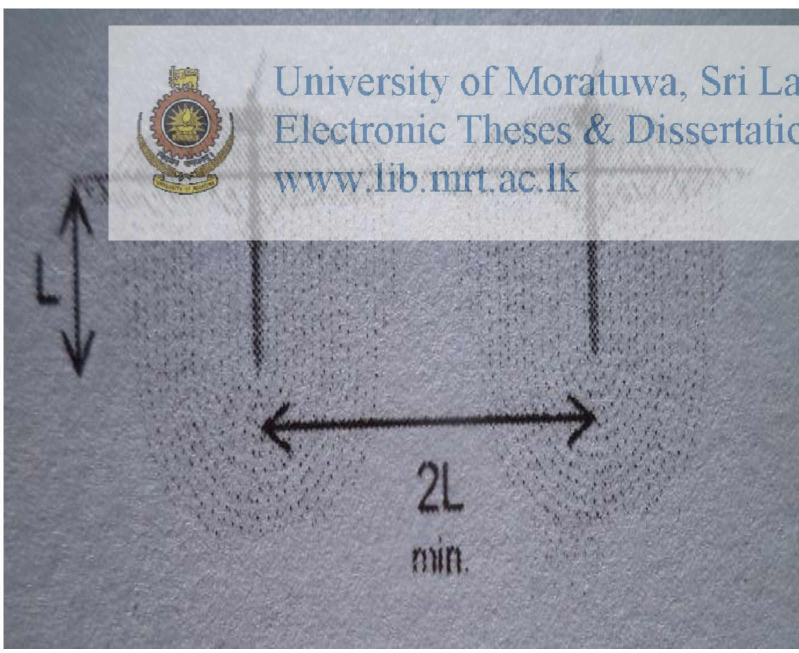

Figure 44: Separation of earth rods.

Source: Energex Distribution earthing manual [6]

If the separation of the two earth rods is less than twice the length of earth rod, overlap between two critical cylinders are take place.

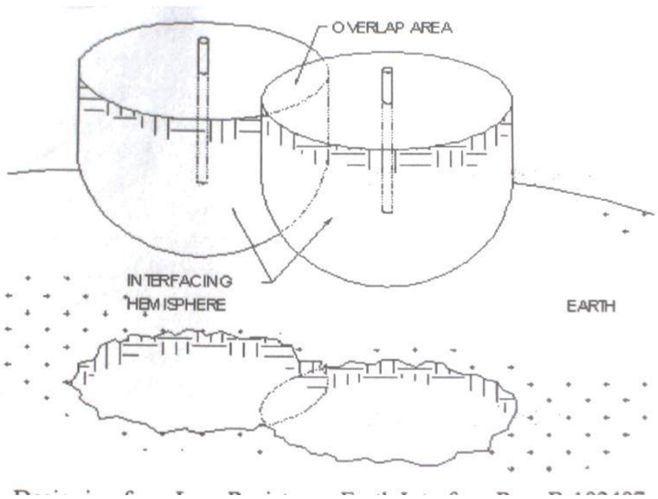

Figure 45: Overlapping of Critical Cylinders

Source: Energex Distribution earthing manual[6]

Due to the overlapping of critical cylinders the earth resistance of one earth rod influences the other earth rod.

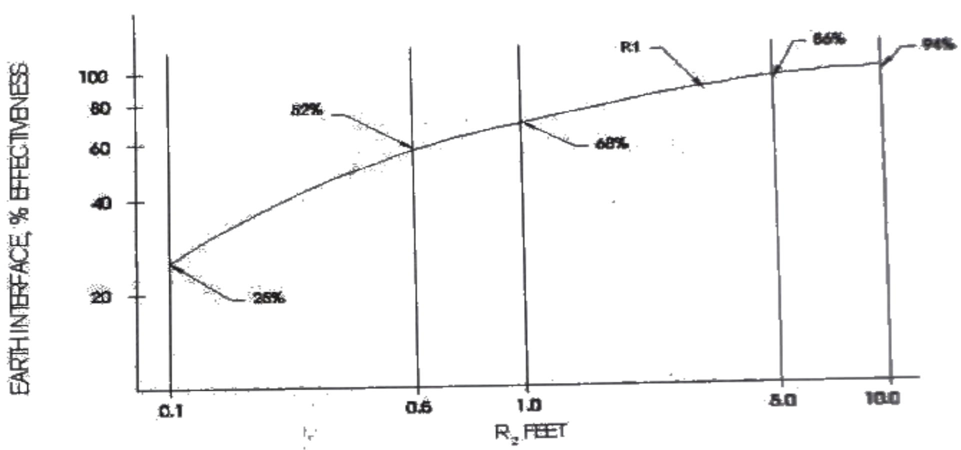

Figure 44: Effect of resistance of one rod on the rod due to overlapping

Source: Energex Distribution earthing manual[6]

At the beginning, earth resistance measurements were taken on existing transformers and it was noticed that the earth resistance at coastal area and hilly area shows high resistance values. The reason is non -availability of moisture in concrete block earths. It is required to find ways to be replaced concrete block earthing system by using some other materials or mixtures having good hygroscopic quality.

To prepare this mixture charcoal powder, calcium oxide (lime) and sand were mixed properly with water and made a slurry and poured into the earth pit having 0.85m diameter and rod length having 1.2m long. When examine characteristics of soil data, it was found that the top layer soil in the coastal belt has high resistivity and low layer has low resistivity. Thus extended earth rods were used and achieved required level of earth resistance.

9.1.2 Installations of distribution substations in restricted area.

Urban areas are highly populated and congested. It is very difficult to find free spaces to install transformers and earth pits. To find solutions for this issue a non-conventional earthing system [3] has been designed to minimize the required land area for earthing. The special earth mesh was designed to implement the new concepts of such earth (Figure 47). The procedure of installation of pole based earth is shown in Figure 45 and Figure 46. In this design two pole pits were used to earth lightning arrester earth and neutral earth.

In construction of distribution substations, bases of two poles are concreted to have sound structure. In the new design those two pole pits were used as earths. By immersing earth mesh around the butt of the pole and copper clad galvanized steel earth rods were used to connecter the down conductor of both neutral and lightning arrester earth. The newly conceived method can be identified as **pole based earthing system.**

9.2 APPLICATION OF THE PROPOSED METHOD

The proposed method is mainly focused on sandy soil. It is a special segment of soil having high soil resistivity. There are only few locations such as sea beach, in North Western Province having these types of soil characteristics. According to the present practicing method, it is not possible to have large number of parallel concrete blocks earths in parallel to achieve 10Ω earth resistance. If more land area required for earthing, issues will arise due to some constraints such as non-availability of enough land area, constraints due to the physical objections such as roads, drainage systems, buildings and parapet walls etc. Therefore there was a high need of implementing this type of earthing system to address this issue.

The new method of earthing is implemented in coastal areas such as Amabakandawila, Thoduwawa and Chilaw and observed results. The results achieved are acceptable and those were within the required value of 10Ω.

9.2.1 Implementation of proposed system.

The proposed earthing system based on scientific research done by various researchers and the authors. The earthing is very essential in installations of transformers to ensure the safety and protection of human beings, livestock and equipment. To implement this new method of earthing, the soil resistivity of the proposed site is to be measured using 4 pole earth tester according to the Wenner method. If the soil is homogeneous, the apparent soil resistivity value can be taken for future steps of the earthing.

If the soil has stratified nature the sundae's method for two layer soil models can be used to get the apparent resistivity. The apparent resistivity can be used for designing earth pits for high resistivity soils.

To implement this new earthing system, within the NWP, the people who are really engaged in construction work to be trained properly by educating them regarding the theory behind the proposed system. The research was done for the sandy soil having soil resistance more than 1000Ωm. Thus the research to be implemented for rocks in hilly area too. In future, the soil resistance measurements are to be taken by selecting locations from hilly area.

A training programs to be done to electrical superintendents and linesmen including theoretical and practical sessions to educate them for future research. Through this process better results can be achieved after giving proper training for them.

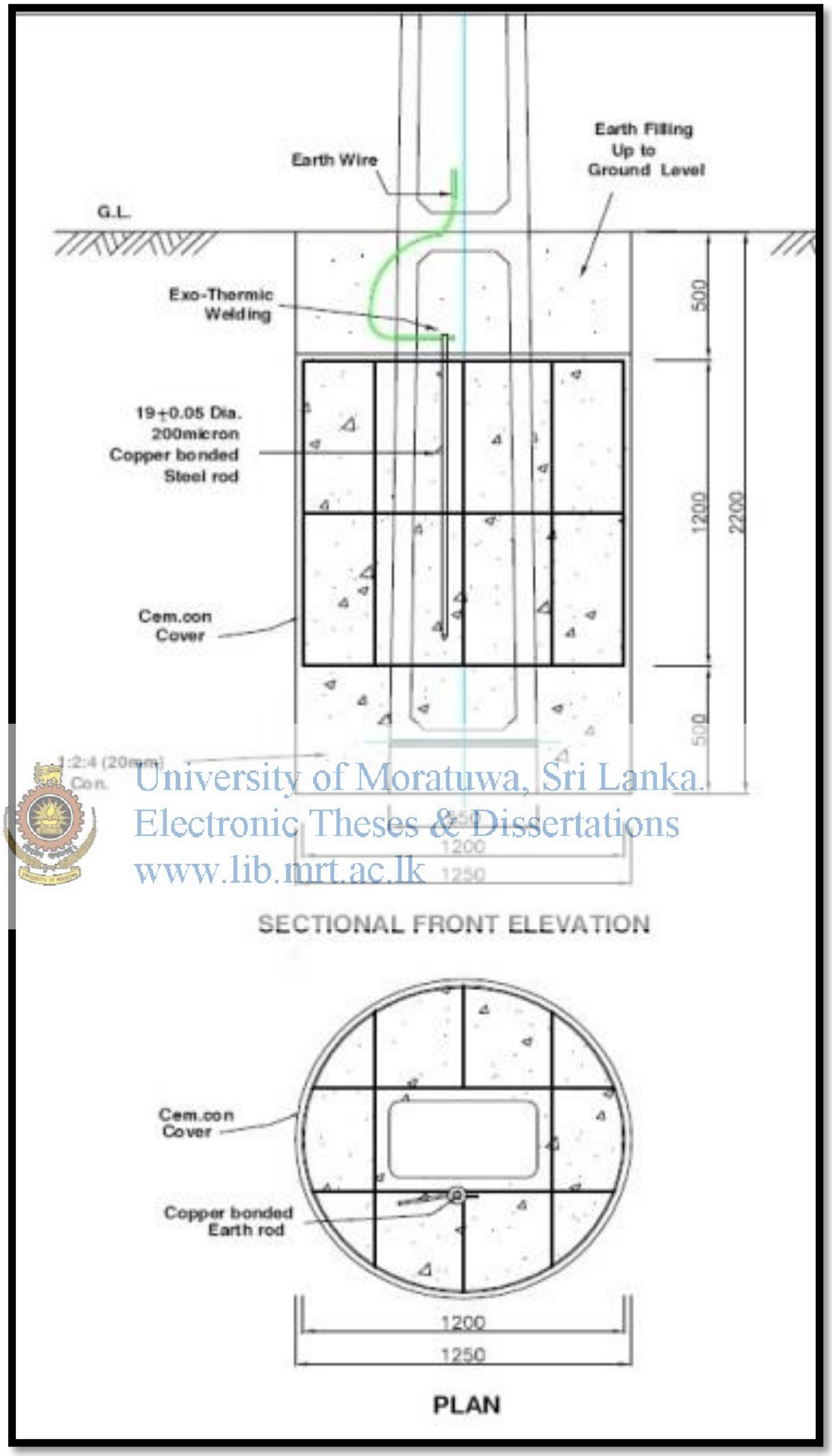

Figure 45: Pole base of a pole based earthing system.

In urbanized areas the lands are very expensive and it is very difficult to find locations for transformers and earthing systems. To materialize the conceptual framework build up to for earthing in urban areas, a special design for earth mesh was carried out by the author for earthing at pole base. In construction field, pre- stressed poles are using for mounting transformers. The measurements of pole bases are taken and designed the earth mesh and construction of earth mesh was done with the help of earth mesh suppliers of the province.

9.2.2 Advantages and disadvantages of pole based earthing system

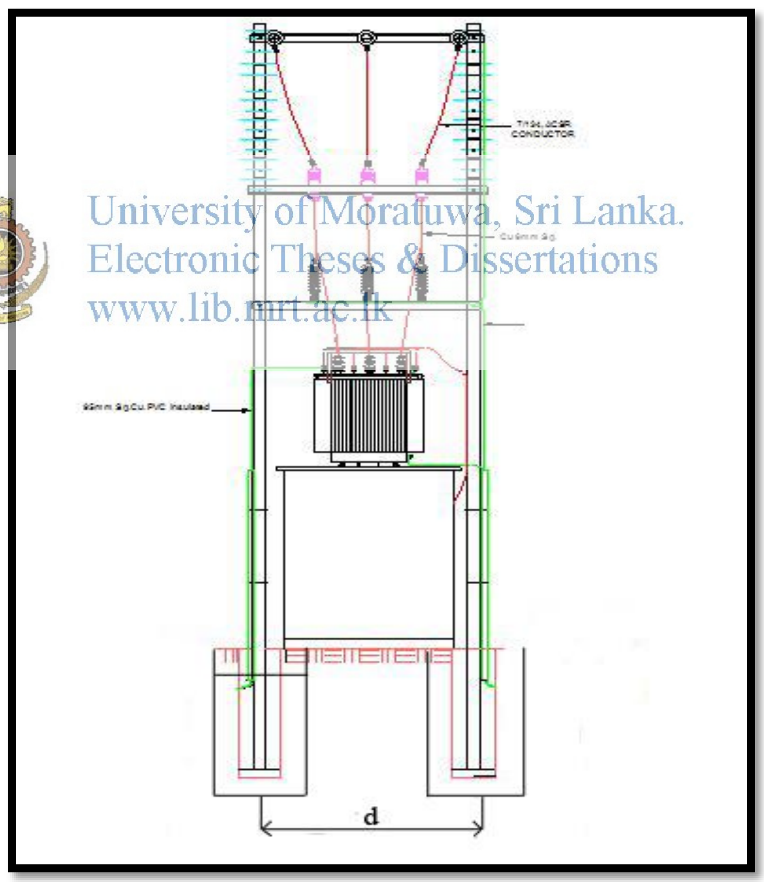

Figure 46: pole based earthing system.

The minimization of the land area required for earthing is the great advantage. In urban areas land is very valuable and scares resource when installing transformers in conventional manner. It is required to dig two pole pits for transformer structure, two earth pits for lightning arrester earths and another two earth pits for neutral earth. Using the pole based earthing system four earth pits could be eliminated if the earth resistance of each earth gets the required value of 10Ω. If the earth resistance of each earth greater than 10Ω then it is required to install maximum of another two earth pits, for lightning arrester and neutral earth eliminating two earth pits.

In this earthing design, bases of two poles of the double pole structure should be filled with concrete to maintain the stability and strength of the structure. For those two earth pits using soil enhancement material is not advisable. But if required additional earth to reduce the earth resistance soil enhancement material are recommended for those earths.

Depending upon the requirement only one additional earth can be installed only for lightning arrester earth, if the neutral earth resistance is greater than 10Ω but less than 20Ω.[15]. This earthing system can be used for single pole mounted transformers too. In this case lightning arrester earth can be fixed to the pole based earth and neutral earth can be fixed more than 3m apart from the lightning arrester earth. In this case the land area utilization has been minimized.

In double pole structure of distribution transformers the length of the cross arms which are used to mount the transformer, set of lightning arrester and set of DDLO switch is 2.2m long. The length of the earth rod is 1.2m long. The separation between adjacent earth rods should be greater than twice the length of earth rod. That means the separation between two earth rods mounted under the pole base is less than the required separation. As a result of that 0.2m overlap will take place and there may be 10% interference of potential from one earth rod to the other earth rod. It is a disadvantage.

9.3 Methods and Techniques

It is required to find the solutions using available resources for earthing. It was found that the earth resistances of several distribution transformers installed in coastal areas such as Chilaw, Ambakandawila, Thoduwawa, and Wennappuwa have high earth resistances in the range of 50Ω to 100Ω in dry weather conditions. Similarly the transformers installed at hilly areas have earth resistance in the range of 40Ω to 80Ω. Those values are very high in the earthing standards of distribution transformers are concerned.

The Lanka Transformers (pvt) Ltd, a subsidiary of Ceylon Electricity board is the only manufacturer of distribution transformers as well as primary transformers. According to the guidelines for installations and maintenance of transformers, the recommended earth resistance value of the lightning area earth should be less than 5Ω. It has also given that value should be between 5Ω-20Ω ranges [15]. However, to avoid possible electric shocks the earth resistance should be as much as lower as possible.

In communication towers the grounding resistance should be less than 10Ω. The code of practice for earthing has indicated that the site should be selected to manage the moisture content in the soil is between 15% to 20% [10]. However, this type of soil cannot be found in coastal areas or at peaks of mountains. It is a big issue faced when designing the proposed earthing system for high resistive soil. The present guideline used within Ceylon Electricity Board has recommended to maintain the earth resistance of the lightning arrester earth below 10Ω and the resistance of the neutral earth below 20Ω. However, it is required to maintain earth resistance of lightning arrester earth in distribution transformers below 10Ω. That guideline is recommended that method for soil having low resistivity below 200Ωm.

9.3.1 Procedure of Self Pole Earthing System

9.3.1. Construction of earth Mesh

Mild steel rods having 6mm diameter was used to construct earth mesh for self-pole earthing system. There are different types poles used for installation of transformers. The base sizes of all pole types are measured and different earth meshes are designed to enable each type of pole to be inserted to the earth mesh.

Figure 47: Earth Mesh designed for Self Pole Earthing.

The pole is embedded to the earth mesh through the pole placing hole. The dimensions of pole placing hole may vary from 600mmx300mm to 700mmx370mm. All the intersection points of the earth mesh is welded properly to ensure proper mechanical strength.

Figure 48: Earth mesh In Pole Pit

During the pole installation stage, it is very important to handle the pole with extra care. Since the pole should be inserted carefully without damaging the earth mesh or pole pit, experienced crane operator with skilled helpers should be assigned for this process.

Figure 49: Planting Pole in Earth mesh

The copper clad steel earth rods must be inserted to earth pit to connect earth cables coming from Lightning arrester earth and Neutral earth. To ensure the safety of the transformer structure, the pole base must be filled with concrete of 1:3:6 (Cement :Sand: Aggregate) or concrete mixture using ABC of 1:8 ratio.(Cement: ABC)

9.4 ECONOMIC ANALYSIS

According to the results obtained from laboratory tests, the optimum solution on soil resistivity is received from the combination of soil enhancement material having ratio of 1:1:3 (Charcoal:Lime:Sand).To compare the cost involved to install one earth pit using concrete block earthing system 1:3:6 (Cement:Sand:Metal) and the soil enhancement material the following calculations were done.

Table 13: Cost involved in one unit of cement block earth.

Material	Quantity	Units	Rate(Rs)	Cost(Rs)
Metal	28.8	Cubic ft.	55	1584
Sand	14.4	Cubic ft.	75	1080
Cement	3.2	Bags	980	3136
Labour	15	Labor Hrs.	414	6210
Transport	1	Unit	2500	2500
Earth mesh	1	Unit	1800	1800
Total Cost (Rs)				16310

Table 14: Cost involved in one unit of earth with soil enhancement material

Material	Quantity	Units	Rate(Rs)	Cost(Rs)
Charcoal	9.3	Cubic ft.	312.5	2906.25
Lime	9.3	Cubic ft.	200	1860
Sand	18.4	Cubic ft.		0
Labour	15	Labor Hrs.	414	6210
Transport		Unit		1000
Earth Mesh	1	Unit	1800	1800
Total Cost(Rs)				13776.25

Cost Analysis :	
Cost of concrete block earth	=Rs.16310.00
Cost of earth with soil enhancement	=Rs.13776.25
Cost Difference	=Rs.2533.75
Percentage Saving	=18.3%

The above cost comparison indicates the cost saving for one unit of earth block is Rs.2533.75. Normally four earth pits are used for installation of distribution transformers. Therefore, the total cost saving is about Rs. 10,135.00. The percentage saving is 18.39%

CHAPTER 10

DISCUSSION

The research on designing earthing system for restricted area having high resistive soil was done to find solution for earthing of distribution transformers. The main intension was to solve the issues faced by Electrical Engineers and Electrical Superintendents of Construction Branch in North Western province. In the present practicing guide line, there is no any proposed method to reduce earth resistance in high resistive soil. The earthing guideline has given only the concrete block earthing system for Distribution Transformers.

After collecting data, the resistivity values were calculated according to the formula given under Wenner method. The graphs of resistivity values were plotted against the separation of probes. According to the Wenner method, the rod separation is equal to the depth of soil layer. The author was able to demonstrate the soil types available at different locations of NWP and their characteristics according to the calculated values of apparent resistivity. The author has given instructions to the staff of Construction Branch to take soil resistance measurement before starting the excavation works of pole pits and earth pits to install a new transformer. This helped to identify the apparent resistivity of the site and it leads to design proper earthing system. The construction staff of CEB of NWP is still using present guideline [16] to carryout earthing of Distribution Transformers.

According to the soil resistivity data, the high resistive area in the coastal belt was selected and the research was totally confined to the sandy soil having soil resistivity more than 1000Ωm. In this research the usage of cement was replaced by soil enhancement material such as Charcoal and Lime. The Lime (CaO) is purchased from hardware shops which has building construction materials. Charcoal and Lime were used to enhance the electrolytic properties of sand.

Even in the busy construction programs of Rural Electrification projects the ESS, Linesmen and other workers have devoted their time and effort to give better service to achieve targets of the research. They worked hard on taking earth resistance measurements periodically. During dry season the soil resistivity increases and it leads to increase the earth resistance of transformers. A conceptual design was done to eliminate that issue. An external water container was introduced to provide water supply as drops to earth pits to maintain the moisture content around the earth electrode and earth pit. As a result of that even in dry season the earth resistance would maintain below 10Ω. A layer of wet form would laid on the top surface of the earth pit to retain the moisture content as favorable level. It is a new concept conceived in the mind of author to retain the moisture condition in the earth pits. The external water container can be installed at the side of the concrete pole of the transformer structure about 2m above the ground.

Earthing in restricted area is another issue in installation of Distribution Transformers and earth pits. In practice two earth pits are connected in parallel using exothermic welding. This method used for both neutral and lightning arrester earths separately. The minimum separation between lightning arrester earth and neutral earth should be twice the length of earth rod. In practice, construction works are carried out keeping the separation between two earths as 3m. However, in restricted locations, it is very difficult to maintain such separation. Normally the earth rod used is 1.2m long. Therefore, the minimum separation should be greater than or equal twice the length of the rod (i.e. 2.4m separation). But according to the construction standards of Distribution Transformers, the separation between two poles of transformer structure is 2.2m. As a result of that 0.2m overlap between two critical cylinders exists. Therefore, only 10% of earth resistance will experience on the other earth pit. Comparatively this value is very small. If the land is available enough to install earth pits, to avoid the interference of lightning arrester earth to neutral earth, separate earth pit should be installed having 3m separation.

If the location is a restricted area there is no space to install separate earth for lightning arrester earth and neutral earth. Therefore two separate earths can be installed using two bases of poles of the transformer structure. If the earth resistance values are 10Ω or below, those two earth pits can be kept as it is. If earth resistance values are more than 10Ω, those two earths can be connected in parallel to provide earth for lightning arrester and another separate earth pit should be installed 2.4m apart for neutral earth of the transformer. In this case Soil Enhancement materials are used to reduce earth resistance.

It was found that the earth resistance depends on the resistivity of soil enhancement material. Therefore, earth resistance was calculated in graphical manner by doing a laboratory test. In this case voltage measured between two opposite sides of a cube by varying the voltage using a Variac and current was measured by ammeter. By changing the ratios of Charcoal, lime and Sand, the different values of resistivity were obtained. The graphs were drawn current against voltage. The reciprocal of such gradients gave the resistance of such samples. By considering the results obtained, it was noticed that the resistivity of such samples reduced when increase ratio of Charcoal, Lime and Sand as 1:1:3.

The distribution of potential due to lightning surge was simulated by using Ansys Maxwell software version 16. It was noticed that major part of the energy of lightning surge absorbed within the region close to the earth rod. The total energy loss in the earth pit was used to calculate the earth resistance of the earth rod. These values were validated with the results of the formula given under earthing manual (BS7430) this formula is called Dwite formula. This research is to be extended for other types of soils having high resistivity. Therefore it is necessary do such research for hard soils or rocks located on mountain peaks.

10.1 Analyzing Results obtained by new Earthing Design.

According to the results obtained by the research, the new earthing design was implemented for sandy soil in Chilaw area. In the implementation at Chilaw City Hotel, soil enhancement materials such as Charcoal and Lime mixed with sand collected from the site. The site is located about 80 m away from the sea. The mixture was prepared having ratio of 1: 1:3 of Charcoal: Lime: sand. One of lightning arrester earth pit filled with the mixture including Earth rod and Earth mesh. The moisture condition of the soil was measured by moisture meter and it is recorded as 16% at the site of Chilaw City Hotel. To compare the results of both methods, one of neutral earth pit was filled with concrete mixture having ratio of 1:8 of Cement: ABC. The results obtained are indicated in Table 16.

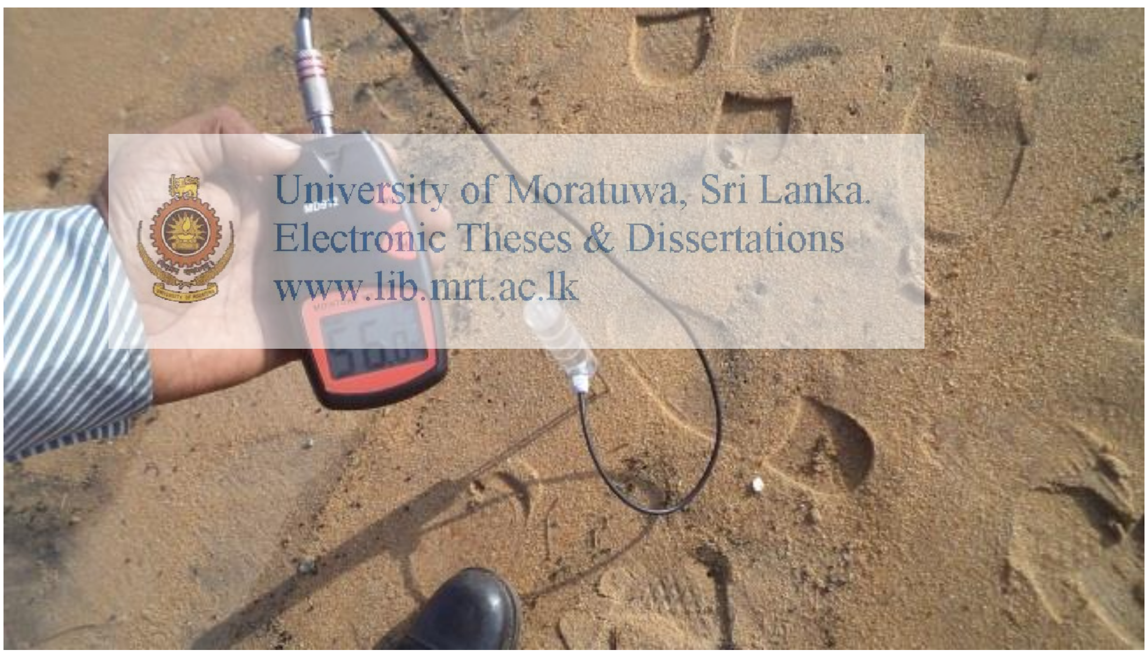

Figure 50: Measurement of Moisture content of Soil

This research was carried out for another site situated very close to marshy land. In this case, Charcoal and Lime mixed with the soil extracted from the marshy land. That soil is very rich in organic substances. The color of the soil is black. The ratio of 1:1:3 of Charcoal: Lime: organic soil was mixed properly and put into one of earth pit of lightning arrester earths with Earth mesh and Earth rod. For one of neutral earths cement block earth was applied to compare both results. The soil at this site is wet and the moisture content was recorded as 56%.The results were recorded in Table 16.

Table 16: Earth resistance measurement results in Chilaw area.

Location	**Soil Condition**		**Method Implemented**	**Earth resistance (Ω)**		**Earth resistance of parallel combination (Ω)**
	Soil Type	**Moisture Content (%)**		**Pit 1**	**Pit 2**	
Chilaw City Hotel	Sandy	16	Concrete earth pit	48	50	26
			Charcoal, Lime Sand mixture	25	30	13
Cargills Food City, Chilaw	Marshy	56	Concrete earth pit	18	14	10
			Charcoal, Lime Sand mixture	3.8	4.0	2

According to the results obtained from both case studies it clearly shows that moisture content of the soil and the soil enhancement material plays vital role in reduction of earth resistance of distribution transformers. When the results obtained from above research is concerned, applying Charcoal and Lime gives better results than adding Cement with ABC. The economic evaluation also indicated that use of soil enhancement material give saving of 18.39%. Therefore, it is recommended to use mixture of soil enhancement materials to earth distribution transformers in restricted areas having high resistive soils.

CHAPTER 11

CONCLUSION

The research was carries out to find solutions for two objectives. First one is to find out a new solution for earthing of Distribution Transformers in high resistive soil. The second objective is to find solution for earthing at restricted areas such as towns. As per the results found from the research, it is recommended to use soil enhancement materials such as Charcoal, Lime and Sand according to the ratios of 1:1:3 respectively. The above proportion gives the lowest value of soil resistivity of the mixture. According to the economic evaluation the use of above mixture give the saving of about 18.3%. It is very economical to use soil enhancing material by eliminating use of cement.

The solution for the second objective is the use of two pole pits of the transformer structure to minimize the land usage. If the required earth resistance not achieved from this alternative method of using two pole pits, additional earths should be installed with the soil enhancement material. The final design of the earthing system is the combination of both solutions found in the research.

11.1 Recommendations for future research.

11.1.1 A conceptual alteration to existing transformers to reduce soil resistivity

A conceptual design was done to improve the efficiency and effectiveness of the earthing system of existing transformers as well as for proposed earthing systems. It is needed to monitor these earthing systems periodically during dry season to top up the water in water container if needed. However during rainy season the soil around the earth electrode become wet and the soil resistivity of the earth pit become low value.

Normally the North Western province receive rain from two inter monsoon seasons. South -West inter monsoon acts during the months of March and April and North -East inter monsoon during October and November. During the rainy season the water container attached to the proposed earthing system automatically filled by rain water. Thus during rainy season, the external water supply can be stopped by closing the gate valve of the water system.

In dry season the ground water level goes down and the soil surrounding the earth electrode become dry. In this period, the soil resistance goes up and the soil resistivity also increased. Supervisory control is needed to act during this period to open the gate value of the external water supply. It is also required to measure earth resistance of the earth pit having soil enhancement material to cross check the value of earth resistance.

To streamline these supervisory activities, the items mentioned above should be included on computer based maintenance program. A database can be used specially for transformers to check the earth resistance and water level of external tank with proper maintenance activity sheet. Once the work of a particular transformer is completed, the database of the computer to be updated to get next maintenance activity sheet after the specific time period.

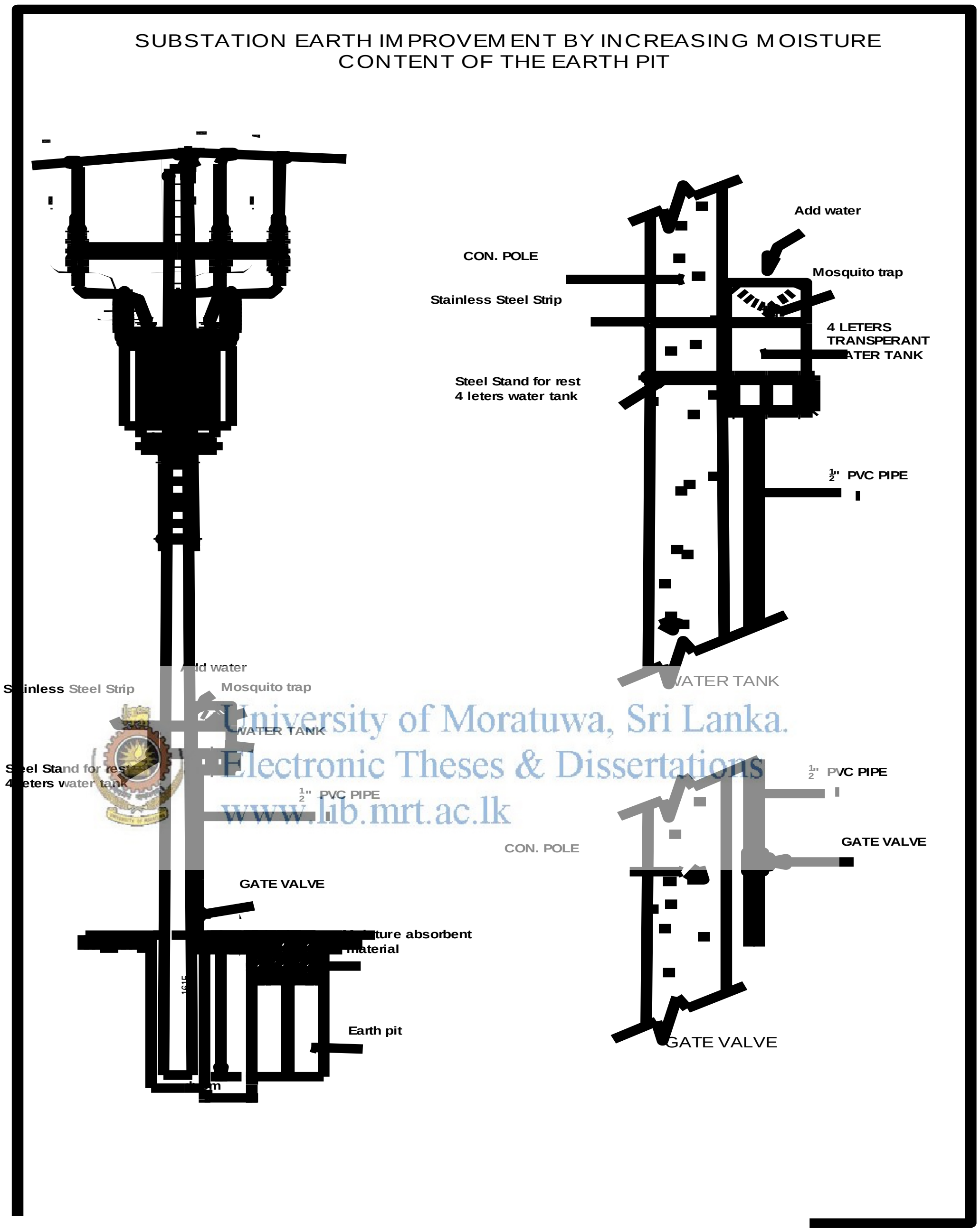

Figure 51: Water Droplet treatment for Earth Pit

A drawing of the conceptual design is shown in Figure 50. It is required to do a research on this design to enhance the efficiency and effectiveness of the earthing system. This system can be adopted for existing transformers installed in sandy soil, on hard rocks in dry weather conditions.

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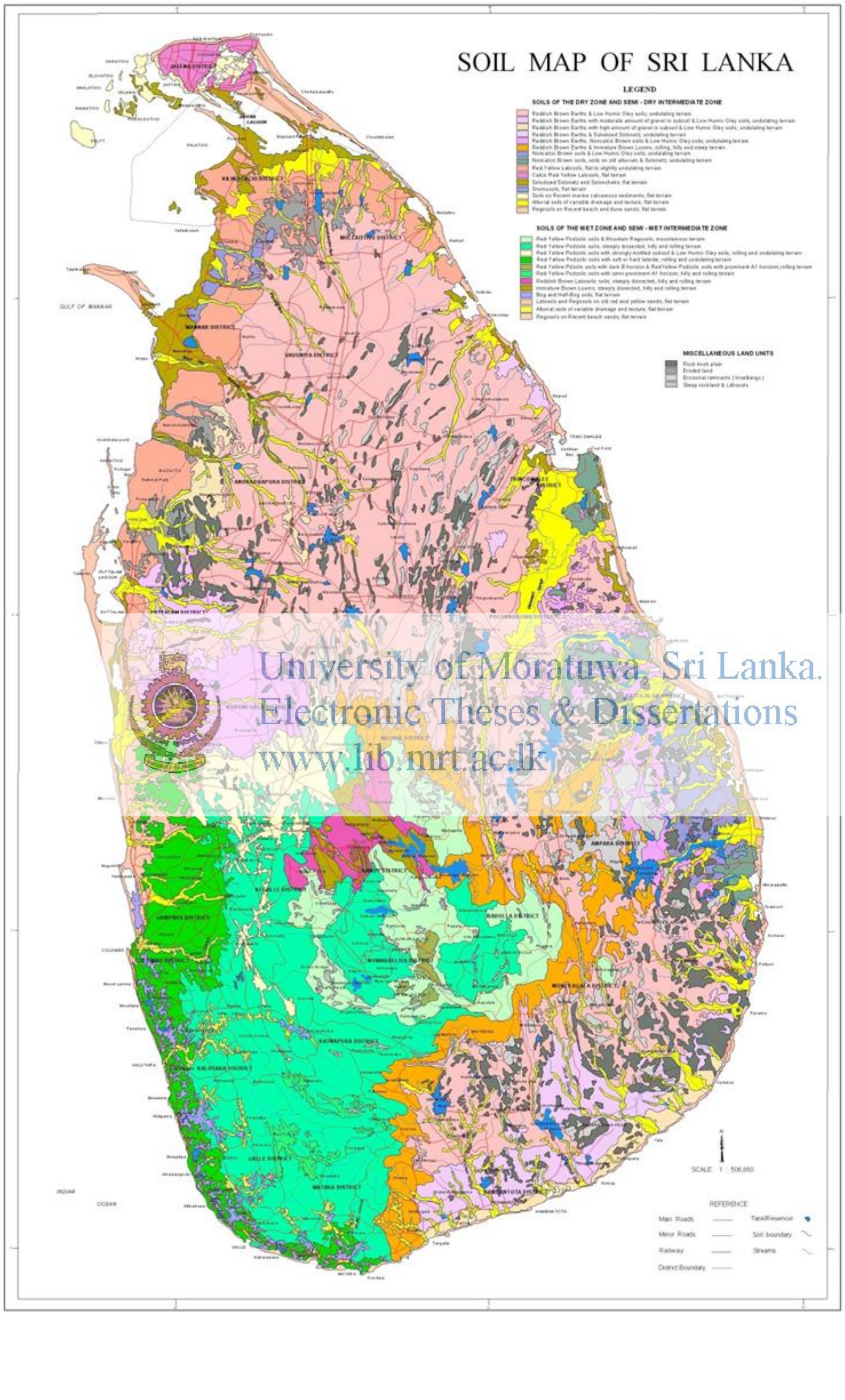
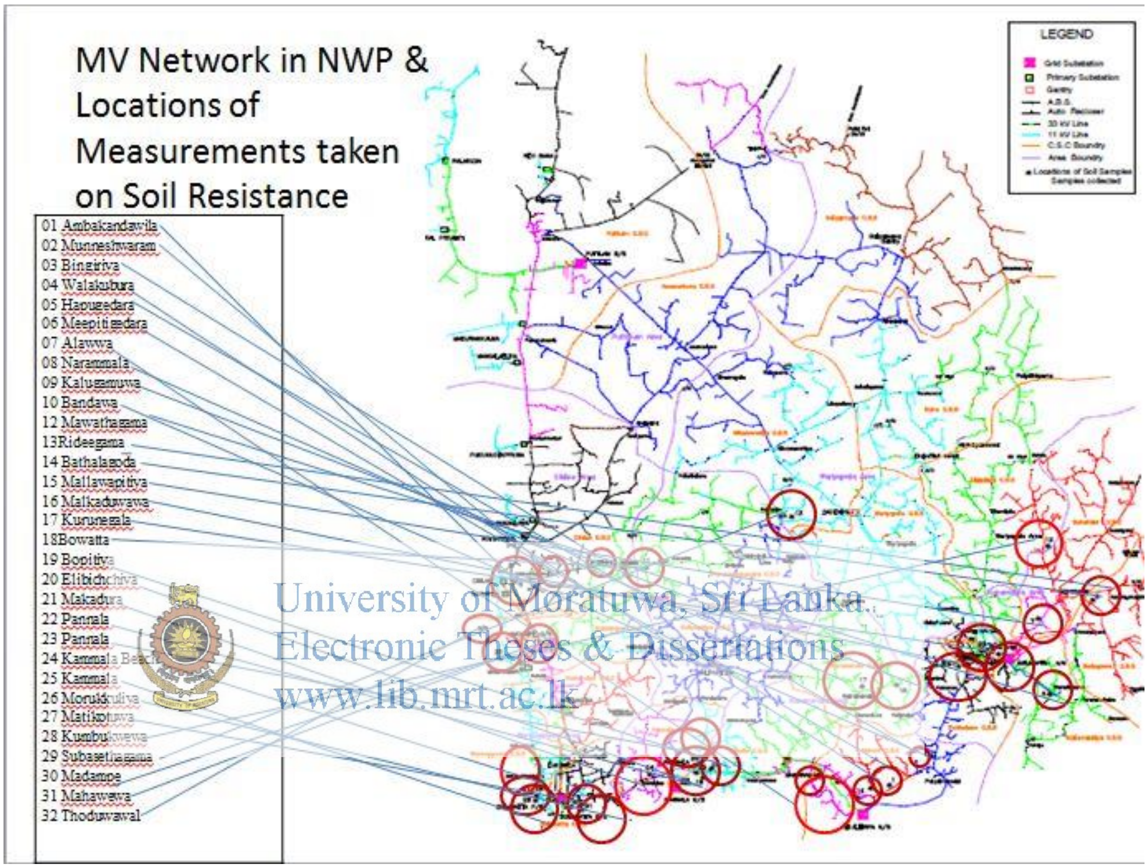
LIST OF APPENDICES

AppendixA:SoilmapofSriLanka



Appendix B: MV Network in NWP and locations of measurement taken on soil resistance



Appendix C: Commissioning Test Report

16 MAR 201.

Commissioning Test Report

1. Name of the Scheme/ Work :-- TONIGALA WATTA R·E Scheme.
2. Job No: --450-20/1340/1440/1460/SD 18/9 3. Job Category : ---- SIDA
4. Capacity of the Transformer: --100----KVA 5. Voltage Ratio: ---- 33/LT
6. Transformer Serial No: T09U010030745 7. SIN: ---- N 147
8. Tests Carried out and Results

L.T.Line

(a) Visual Inspection

(i) Standard :--------------------------------

(ii) Way leave :------OK------------------

(iii)Crossing of Main roads Railway & Telephone lines etc :---NO-------

(b) Insulation Testing

(i) R-Y ----------- Mohm R-E ------------Mohm

(ii) Y-B ------------Mohm Y-E ----------- Mohm

(iii) B-R ------------Mohm B-E ------------Mohm

(iv) N-E ------------Mohm L+N –E -------Mohm

Substation

(a) Visual Inspection

(i) Neatness of wiring :------OK------------------------

(ii) Fixing DDLO Set :------OK------------------------

(iii) Fixing LT Fuses :------OK------------------------

(iv) Concreting Earth Pits :------OK.------------------------

SIN No. plate :----Fixed WP-N-4084 147

(b) Insulation Testing

(i) R-E ------600------------ Mohm

(ii) Y-E ------[illegible]------------ Mohm

(iii) B-E ------600.------------ Mohm

(iv) N-E ------600.------------ Mohm

(v) L+N-E------600.------------ Mohm

(c) Earth Resistance

(i) Neûtral Earth ---34----------ohm

(ii)LA Earth ---------27----------ohm

Cables

(a) Visual Inspection :--

(b) Insulation Testing

(i) R-Y -------------------------- Mohm

(ii) Y-B -------------------------- Mohm

(iii)B-R -------------------------- Mohm

...sted by : ---------------------------

(...ectrical Superintendent) 2010...

B.N.W.B. Thilakarathna
Electrical Superintendent
C. E Office (Construction)
Ceylon Electricity Board
Kuliyapitiya.

...te Commissioned :- ---------------------------- Date Energized :-------------------------

...tified by: -- Date :-------------------------------

(...e Engineer)