DIRECTIONAL BEHAVIOR OF MEASURED EARTH RESISTANCE OF ANTENNA STRUCTURES AND ESTIMATION OF EARTH RESISTANCE

Kasun Sameera Hettiarachchi

(128763X)

Degree of Master of Science

Department of Electrical Engineering

University of Moratuwa
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Dissertation submitted in partial fulfillment of the requirements for the Degree Master of Science in Electrical Installations

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DECLARATION OF THE CANDIDATE & SUPERVISOR

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128763X

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ABSTRACT

The rapid increase in the use of mobile phones during the past two decades in Sri Lanka, a large numbers of tall Telecom Towers (20m to 100m) has been constructed, which due to the inherently slim and tall nature attracts lightning to itself. While this action protects the neighbourhood from direct lightning strikes, the lightning current thus caused need to be dissipated to earth within the small base area of the tower, giving a rise in the ground potential and a possible hazard to the neighbourhood.

For high soil resistivity and soil with a high degree of discontinuities, there should be a properly designed earthing arrangement. Under the guidelines of the TRCSL, earth resistance values need to be maintained below 5Ω.

The behavior of earth resistance is very hard to predict. The earth resistance is measured through an earth resistance meter, and the interpretation of the readings are subject to many assumptions, including homogenity in all directions. This thesis emphasizes the key reasons for observed deviations in directional earth resistance values, measured from tower legs.

Simulated ER profiles of base stations have been compared with the calculated and measured ER results of actual base stations. Calculations have been done with reference to the as-built drawings of eathing arrangement. The same earthing arrangment was modelled in Ansys Maxwell software which developed from Maxwell equations, to simulate the ER profile. Based upon the comparison of the calculated and measured values, simulated ER profiles have been validated.

This thesis extends the analysis of Earth resistance towards different soil formations and soil types.With that analysis this thesis concludes the reasons for directional ER variation of a base station and highlights key parameters to get an accurate ER measurement.

DEDICATION

To my loving parents and wife

who made all of this possible,

for their endless

encouragement and patience.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my advisor Prof. J R Lucas for the continuous support of my MSc, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my MSc study.

Besides my advisor, I would like to thank Dr Rasara Samarasinghe and Eng Rienzie Fernando, for their insightful comments and contribution, but also for the hard questions which incented me to widen my research from various perspectives.

This research was supported by Dialog Axiata PLC. I thank the Head and my peers from Energy Management Division of Dialog who provided insight and expertise that greatly assisted in this research.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
BTS	Base Transceiver Station
TRCSL	Telecommunications Regulatory Commission of Sri Lanka
GPR	Ground Potential Rise
SPD	Surge protective device
IEEE	Institute of Electrical and Electronic Engineers
LPES	Lightning Protection and Earthing System

1. INTRODUCTION

1.1. Background

Contemporary scientists seek ways to interconnect this solar system going beyond task of connecting the world.Within the context of connecting the world, telcommunication concepts play a vital role.Now a days, its a very common sight of having a mobile in hand for almost all the people.with the higher demand for mobile connectivity,telco operators urge to build towers to sustain the strengh of signal transmission.

Most of these towers are located in at higher elevations where it can clearly transmit signal without any obstacle or distubance.These towers are taller as 60m to 100m and high chance of getting a lightining strike due to the heigth and the formation of tower. Inherently, this leads to sites with high earth electrode resistance as these sites are quite often on tops of rocks.

1.2. Problem Statement

One of the problems that is quite often encountered is that the earth electrode resistance is different in different directions.Figure 1.1 shows this graphicaly. As a result of distorted resistance behavior, it increases the openings for step and touch potential damages along the deviated path.

The potential of the ground can temporarily increase due to a lightning strike to the tower causing high currents to flow in the ground. The flow of the lightning current into the ground would result in a potential being developed in the metallic antenna structure. This potential would very quickly decay as the distance from the structure increases. If the decay is insufficient, this ground potential rise could lead to excessive potentials being very temporarily developed in earthing of domestic and other electrical installations in very close proximity. This in turn could cause damage to sensitive electronic equipment located in the vicinity.

The most important criteria to minimize the step and touch potentials, under lightning conditions, is to keep the equivalent electrical earthing impedance of the system at a very low value (e.g. less than 5 Ω). However, lowering the impedance alone does not guarantee satisfactory step and touch voltages in the neighborhood. Thus the profiles of the voltage rise and the voltage gradient (electric field) need to be studied in more detail through simulation of the earthing system to yield the required profiles.

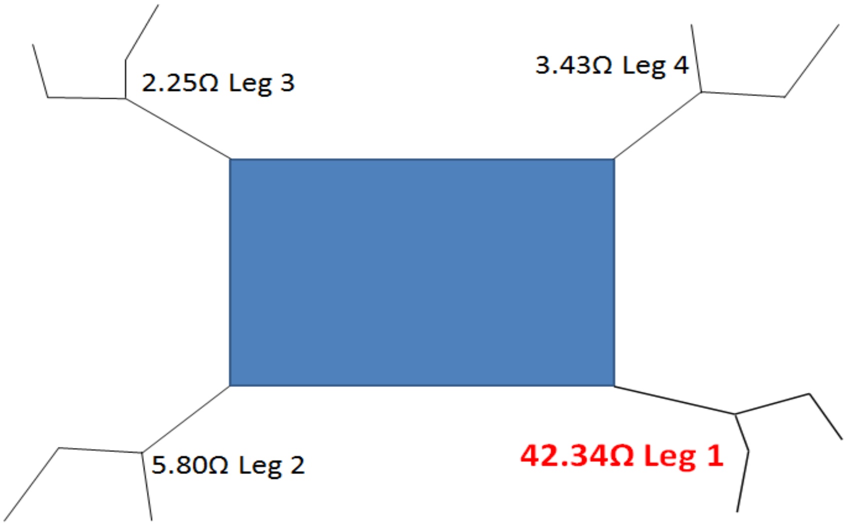


Figure 1.1 Deviated Earth Resistance in one direction(leg1)

There are more than 3200 Telecommunication tower structures under Dialog Axiata PLC and those sites are distributed all over the island. Table 1.1 shows the distribution and figure 1.4 shows the demarcation of each region. With the experience the highest number of lightning incidents were recorded in Western South, Central and Uva regions over the last 10 years.

Most of the telecommunication tower structures are less than 100 m in height and the perimeter of around legs is 40m.Ontop of the tower there is a Franklin rod/air terminal and that connects to the down conductor which is either in copper or Aluminum. This down conductor connects to the ring earth of tower structure and distributes out words of tower legs as crowfoot arrangement. BTS (Indoor/Outdoor) also protected through a ring earth. BTS ring earth and tower ring earth connected each other. Figure 1.2 shows the typical earthing arrangement of a telecommunication base station and figure 1.3 shows the telecommunication tower structure details.

Inside the equipment cabin there are Base band units along with various telecommunication equipment which are very expensive. Surge protective devices are used to protect electrical equipment, and filters are also used to mitigate damages via IF cables which come from the telecommunication antenna structure. The tower consists of antennas and RRUs .

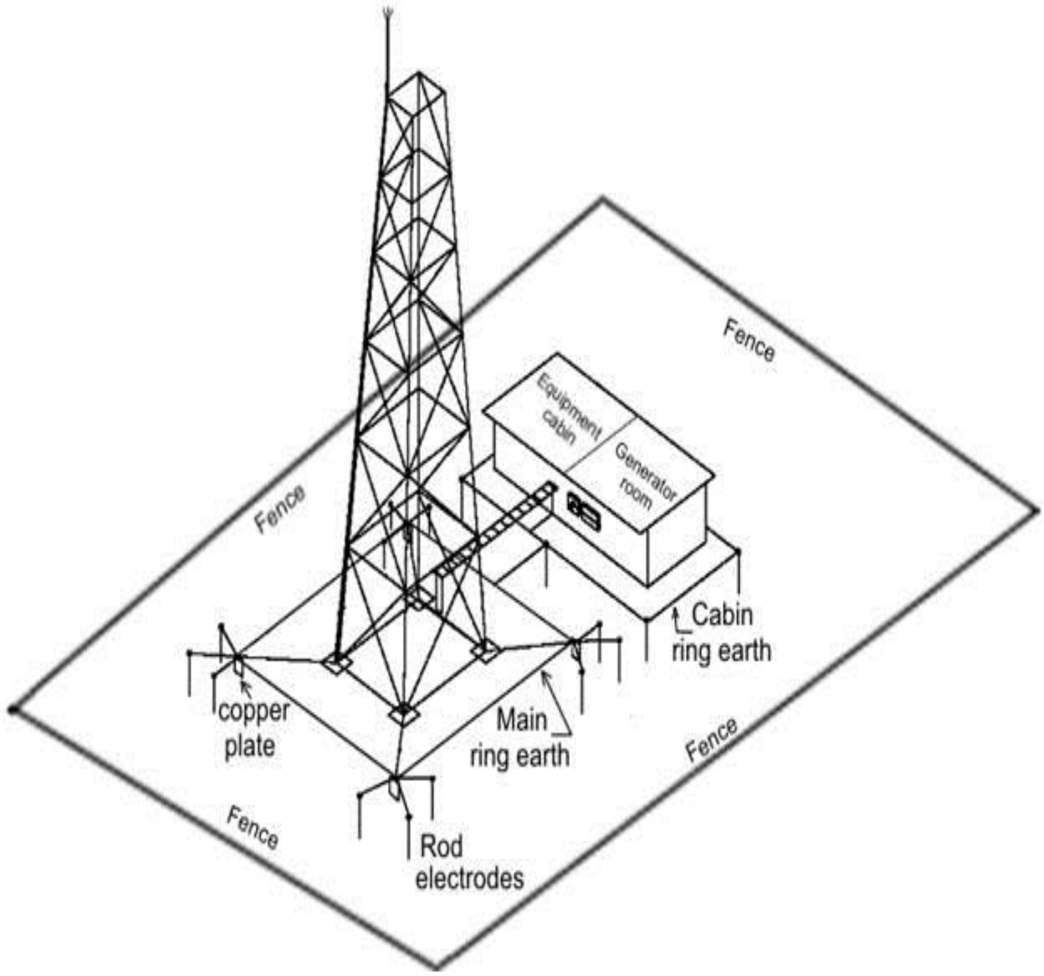


Figure 1.2 General Arrangement of Telecommunication tower earthing system [1]

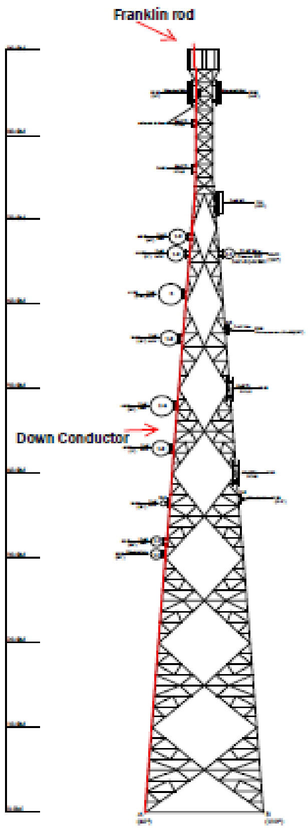


Figure 1.3 Air terminal and down conductor arrangement of a tower structure

Basically, there are two types of BTSs in industry as Indoor and Outdoor. Under those Systems there are different types of telecommunication tower structures as below.

- Indoor Base-station with Self-support tower -20m to 100m
  - Three legged towers
  - Four Legged towers
- Outdoor Base-station with Self-support tower -20m to 100m
  - Three legged towers
  - Four Legged towers
- Indoor Base station with rooftop towers- 3m to 15m
  - Mono pole towers
- Outdoor Base station with rooftop towers- 3m to 15m
  - Mono pole towers

Region	Number of sites
Central	368
Western Central	760
Western North	376
Western South	117
Uva	302
Southern	294
Northern	154
North Central	303
North Western	303
Eastern	231
	3208

Table 1.1 Regional level telecommunication tower distribution

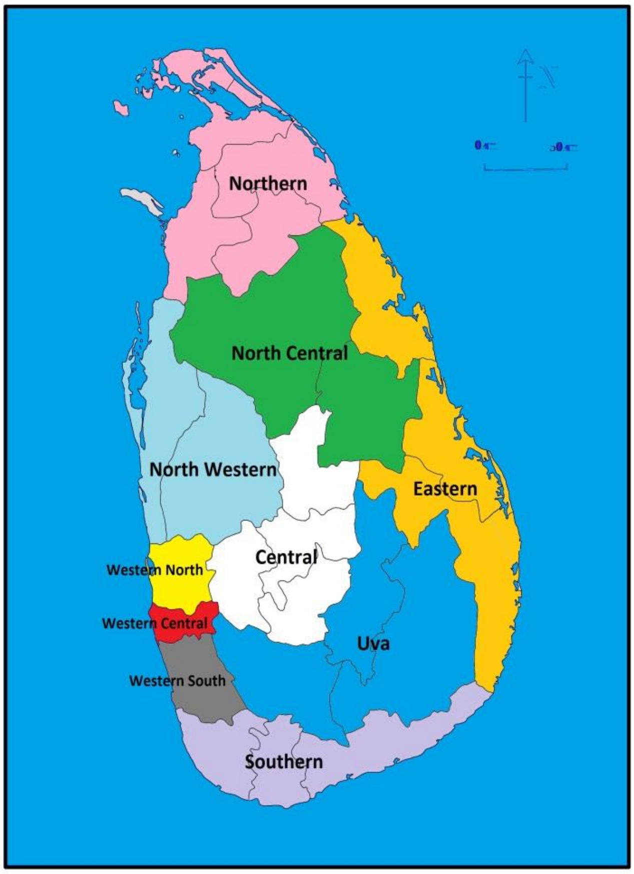


Figure 1.4 regional distribution of telecommunication tower structures

1.3. Challenges of ER measurement

- In practical scenario, we are not getting homogenous soil layers. There are different soil layers beneath the top soil layer. Measurement of soil resistivity cannot be done easily due to not having accessibility for the deeper soil layers. The soil resistivity we are measuring is mostly applicable to the soil layer where we fix measuring pegs.

- Legs of telecommunication tower structures are not in the same elevation. Sites with deviated earth resistances are observed in such elevated BTSs.

- As a practice, most of the time earth resistance measures for the distance of maximum 20m from the tower leggings due to not having space to go further. Under such measurement, the values are subjected to the buried copper rods and copper tapes.

1.4. The Aim and Scope of the Thesis

Past investigations have indicated that earth resistance is one of the main factor to mitigate damages to live ware and equipment. This study will theoretically demonstrate reasons for deviations in resistive values along different paths and elaborate a method of estimating accurate resistance value in earth electrode.

To do this analysis theoretical calculations and measured values have been compared against the simulated values and outcomes of Ansys Maxwel Software.

Chapter 01 is for the introduction and problem identification of the research. the objectives of the research and structure of this thesis are explained. Chapter 02 is for the literature review of the research. Chapter 3 conclude the methodology of the research. Technical analysis is presented in detailed in chapter 04. Validation of the simulated results is presented in the Chapter 05. Finally, Chapter 06 is for the discussion on concluding remarks and the future work that needs to be done.

2. LITERATURE REVIEW

2.1 Background

Lightning protection and precautions to protect equipment and live-ware from lightning have been used for a long time. However, there are still some inaccuracies in methods and concepts used in lightning protection. Grounding (or earthing) is normally understood to be the connection of various exposed conductive parts (that are not current carrying under normal circumstances) of equipment together and to a common terminal (main grounding terminal), which is in turn is connected by the earthing conductor to an earth electrode. There are two misconceptions in this statement, if applied very generally. First, grounding is not only limited to equipment but also involves the electrical power system, the two being related and may, in some cases, refer to the same physical installation. Second, the term grounding, may not necessarily be the same thing as earthing. In the context of this research, the term Grounding is used when a lightning strike is grounded and causes currents to flow outwards from the point struck in the Earth or to a large conducting body, not necessarily Earth. Earthing is used in case of a mal-functioning of some part of the system causing the current to return to the source through the physical earth. Therefore, the admitted definition of grounding according to [1] is the conducting connection whether intentional or accidental between an electrical circuit or conductive equipment part and a common terminal which is in turn connected by a conductor to an earth electrode or to some conducting body of relatively large extent that serves in place of the earth.

The theoretical background to lightning protection, grounding, different grounding techniques, importance of telcommunication antenna structure grounding and methods of earth resistance measurement are presented in this Chapter. A brief introduction on tower earthing and the effects of earthing resistance is also discussed.

2.1.1 Base Transmission Station (BTS)

In a broadband network, the base transmission station (BTS) is a very critical component. A typical BTS mainly consists of a telecom tower, an equipment cabin, and the associated equipment and cabling system. The system design of BTS must take into consideration of business efficiency, reliability and maintainability to provide for maximum accessibility of services. A broadband transmission network generally requires thousands of BTS to be erected. Hence it is important that the design should optimizes both cost and technical performance.

Downtime of a BTS causes the biggest revenue loss to a Telecom Operator. Telecommunication companies invest a lot of money to mitigate the downtime of the BTS. Lightning related damages to BTSs have been a major cause of downtime for broadband services in South East Asian countries where the level of lightning activities is among the highest in the world. BTSs built on vacant land, particularly those located on hill tops, are highly exposed to lightning strikes. [2]

Mainly there are two type of Lightning sources associated with the BTS, namely

a) direct lightning strikes to the BTS compound, and

b) transmitted surges via the overhead power lines.

A comparison of the collection areas from the two sources of lightning threats, for a site under investigation [2], reveals that there are significantly more lightning induced surges originating from the overhead ac supply cable than from direct strike on the BTS structure. That the power line transmitted surges are more frequent is due to the large lightning collection area of the long overhead power distribution cable route in open terrain. Lightning is a natural phenomenon and not possible to control. So, it’s a must requirement to provide protection against lightning.

An effective lightning protection design requires the following to be accomplished.

- Protection against direct lightning strikes
- Effective earth termination network for discharge of lightning current
- Integration of power supply and lightning protection earthing systems

- Mitigation of ground potential rise Prevention.
- Prevention of conducted surges and into equipment cabin

These are described in the following sections.

2.2 Protection against Direct Lightning Strikes

Direct lightning strikes to the telecommunication tower can cause permanent physical damage to the equipment installed on it or attached to it, such as antennas and feeders, ac power supply equipment, radio and communication equipment. Workers operating or maintaining the equipment are exposed to the risk of dangerous touch and step potential. Personnel within the compound are generally well shielded from direct strike by the tall tower.[6] However, attention should be taken for placement of antennas and associated electronic equipment and cabling to prevent them from direct lightning strike. Commonly, direct lightning strikes are protected by placing a Franklin type of lightning spikes at the tower top and at the roof top of the cabin, as shown in Figure 2.1. The height of the spike should be sufficient to protect the tower and equipment connected directly to it.

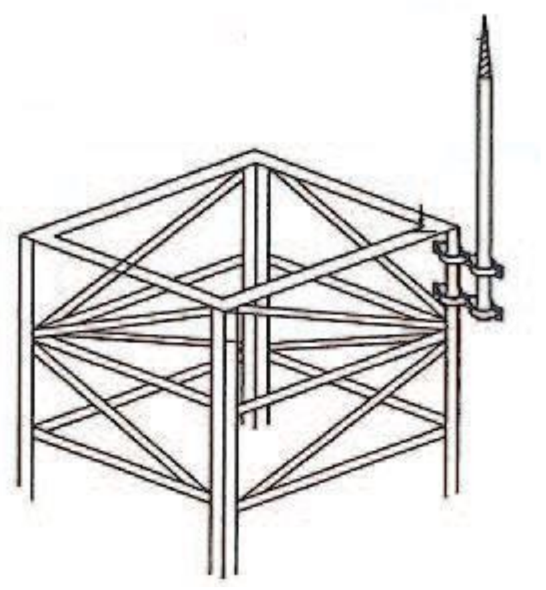


Figure 2.1. Lightning Arrestor

A surge current discharged through the metallic tower structure can cause a significant rise of potential at the metallic structure with respect to the remote earth.

Excessive ground potential rise (GPR) can damage electronic equipment, when equipotential bonding is not effectively achieved. The tower structure must be effectively grounded to limit the GPR. In addition to a separate Copper or Aluminum down conductor, generally required by the standards, the whole metallic structure of the tower also acts as a down-conductor for the lightning discharge, if all joints of the structural steel are properly bonded. Near the ground level, each tower footing of a telecommunications structure is bonded to a perimeter earth ring, to allow multi-path discharge of lightning current and to minimize the ground currents in any direction. Thus, the IF/RFcables and power supply cables attached to the tower must be sufficiently insulated from the metallic structure if an integrated common earthing scheme is not effectively implemented.

2.2.1 Step Potential

A person standing above ground in an area where the ground currents, due to lightning, are flowing would probably experience a potential difference between his two feet. The potential built up would depend on the relative positioning of his two feet with respect to the direction of flow of the ground current, and to the separation between his two feet. Since the maximum likely human step is around 1m, the step potential is defined as the difference in earth surface potential experienced by a person bridging 1m with his/her feet without contacting any other grounded structure. In such circumstances, the current enters the body through one foot and leaves from the other. The body resistance when the current passes between extremities is conservatively considered to be 1000 Ω.

2.2.2 Touch Potential

As in the case of Step Potential, a person touching a structure being struck would experience a potential difference between his hand on the structure and his feet on the ground. Thus, the difference between the earth potential rise and the earth surface potential at the point where the person stands 1m from the earthed structure and at same time touches that structure is known as the touch potential. If the ground connection between the tower and the soil is high resistance (common with some soil conditions), the tower itself (and any conductive item touching the tower) can be energized. Touch potential is the voltage between the energized object and the feet of a person in contact with the object.

Step voltages are usually considered less hazardous than touch voltages. This is because the human body can tolerate higher currents for a path from foot to foot than current from hand to feet which passes through the chest, as described in IEC 479-1 [3]. Given the step voltage is lower than the touch voltage, if a system is safe for touch scenarios, it should also be considered safe for step scenarios.

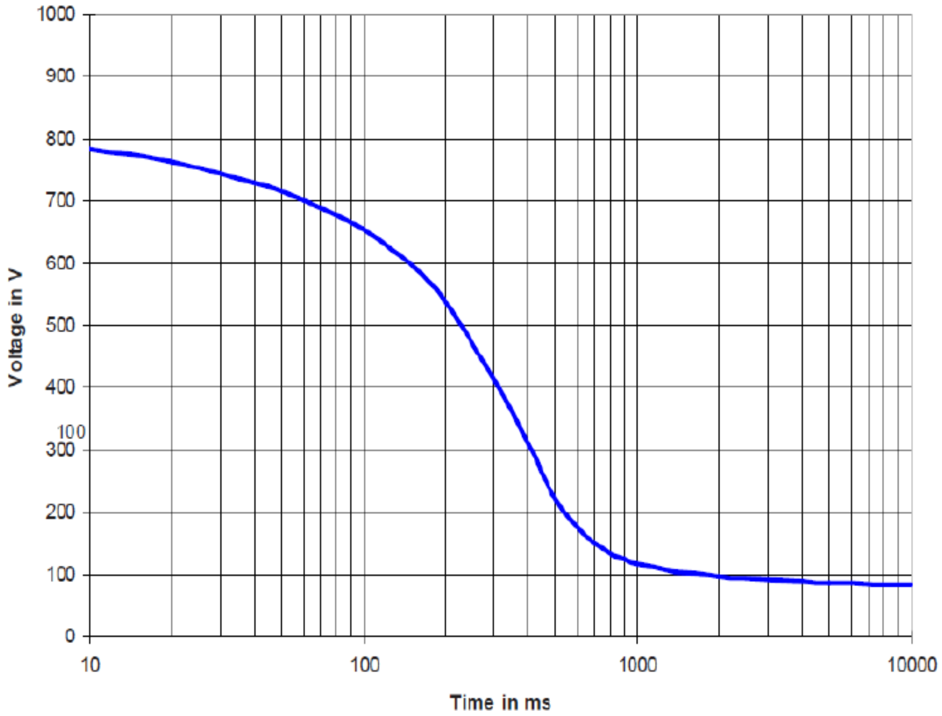


Figure 2.2 Tolerable touch voltage

Parameters of the electrocution circuit, made up of human body resistance and additional resistances such as footwear, are suggested for different scenarios. Importantly, consideration of the touch voltage scenario is restricted to towers which are freely accessible and defined as frequently occupied. The permissible voltage against fault duration for an electrocution current with assumed typical resistances is based on hand to feet or hand to hand contact (without taking into consideration footwear or shallow material of high resistivity). [4] Figure 2.2 shows the variation of tolerable touch voltages with duration of current.

2.3 Effective earth termination network

Prime intentions of earth termination can be summarized as follows.

- To prevent people from electric shock
- To provide Electrical earth for power system
- As a good medium to discharge lightning current to earth
- Equipotential bonding
- Potential control near conductive building walls
- Interception of the lightning current when propagating on the earth's surface

Design that takes advantage of the "natural" earth termination can provide the lowest resistance to the earth at a minimum cost, as the reinforced concrete foundation of the tower, as shown in Fig. 2.3. The ground rings around the tower and the equipment cabin act as an effective electrode in further lowering the overall earth resistance value. The earth ring also performs the important function of potential equalization of the tower legs at the ground level and helps to reduce the potential gradient around the electrodes. [2]

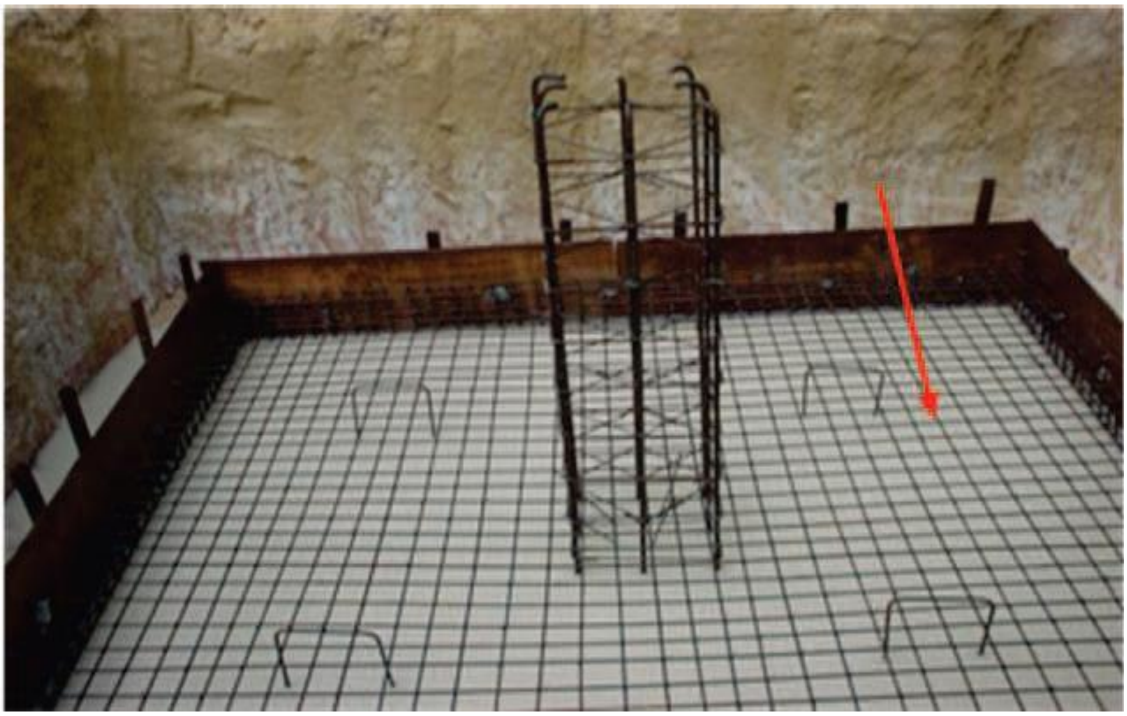


Figure 2.3 Reinforced concrete foundation of the tower effectively providing low earth resistance

2.4 Integration of power supply and LPES

The cabin's earth termination network should be provided for both ac supply earth as well as lightning protection earth. Since the different requirements of earthing should be reconciled into one earthing system, it should be designed from a total system viewpoint. An integrated earthing network should incorporate all earthing functions such as safety earth, lightning protection earth, static electricity earth and functional earth for information technology and communication equipment.

The basis of this integrated earthing system is the earth grid or interconnected earth rings installed around the tower and the equipment cabin. No separate earthing system with dedicated earth electrodes should be installed.[5] The focus of the design is the bonding of all structural elements, including concrete reinforcement, steel structures, cable shield and equipment cabinets to the earth grid to provide a low impedance ground plane reference over a wide range of frequencies. An integrated ground which serves as common equipotential reference can be achieved without much difficulty through proper grounding and bonding practice if the BTS has no hard-wired connections with the outside world.

2.5 Problems and Mitigation of Ground Potential Rise

Due to the earth, potential difference between the remote supply earth and the BTS earth termination network, the power distribution board and the cabin equipment can get damaged. Most of the power supply is delivered via overhead cable system. The system earth of the supply is the TT type in Sri Lanka, unless a dedicated distribution transformer has been used. The neutral conductor of the 3-phase supply transformer is earthed at the remote utility substation, as shown in Fig. 2.4.

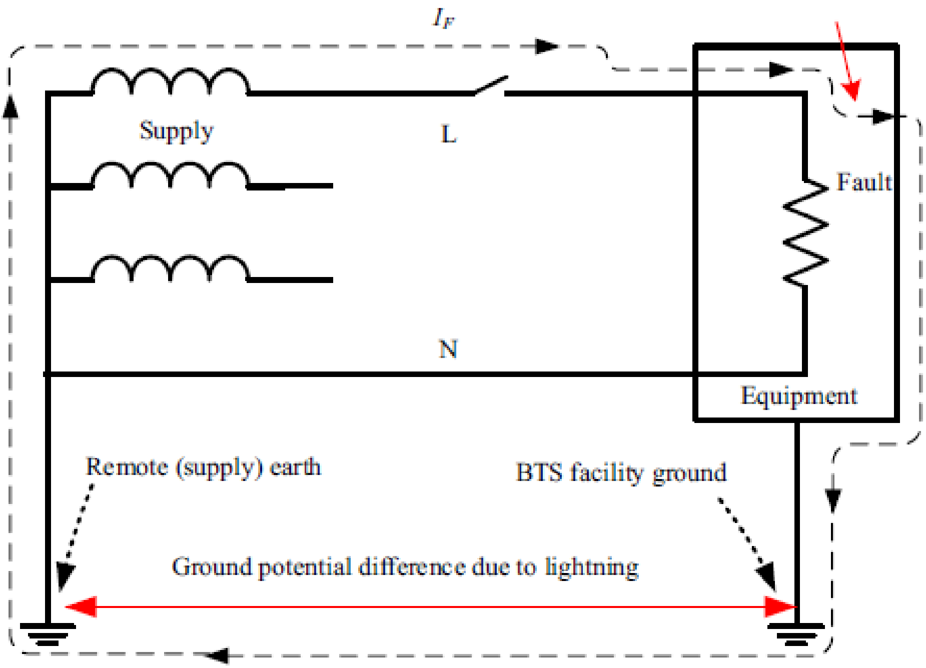


Figure 2.4 Ground potential rise due to remote earth reference of power supply

Lightning discharge can cause the ground potential at the BTS site to rise to a value hundreds of kV above the remote earth, exceeding the insulation withstand capability of the electronic equipment.

Application of surge protective devices alone, is generally inadequate to address the overvoltage breakdown of equipment arising from ground potential rise. Ground isolation using isolation transformer, is the more effective mitigation technique to solve the GPR problem. Obviously, the isolation transformer must have adequate impulse withstand capability to prevent its own failure.

2.5.1 Application of SPDs in a telecommunication base station

Surge Protections Devices (SPDs) serve to mitigate the influence of surges on power and telecommunication lines from damaging equipment. Thus, the application of SPDs, is a mandatory requirement for telecommunication base stations under the guideline of TRC. As per the TRC guideline, specification should be incorporated at the level 1 protection.

The power line to the equipment cabin should be installed with SPDs at the main panel, with the specifications [13] given in Table 2.1,

#	Characteristic	Value
1	System Voltage	230V or relevant
2	MCOV	300V or above
3	I_{max} 8/20 μs per phase	60kA or above *
4	I_{imp} 10/350 μs per phase	30kA or above *
5	V_{clamp} at I_{max} per phase	1.8 kV or below

Table 2.1 Characteristic of SPDs at main panel

* Higher values may be used for better safety of the equipment in the cabin.

SPD installation should be done based upon the following parameters.

- Based on high lightning occurrence density (HLOD) zones and low lightning occurrence density (LLOD) zones. Since still not having a clear demarcation on HLOD and LLOD, need to consider all sites as HLOD.
- Height of the Telecommunication antenna structure
- Perimeter of the Telecommunication antenna structure

Most of the telecommunication antenna structures are clustered into the category of less than 100m in height and less than 40m in perimeter. Under such framework, it’s recommended to install SPDs with below specifications.

- 3L-N; 1 N-E for 3 phase supply-4 mode protection
- 1L-N; 1 N-E for 1 phase supply-2 mode protection
- Minimum I_{max} (8/20 µs): 50 kA per phase
- Minimum I_{imp} (10/350 µs): 30 kA per phase

Surge	current capacity:
L-N	15 kA
L-E	15 kA
N-E	60 kA
Tested wave form @Imax	15kA between P-N, P-E and 60kA between N -E
	Tested with 8/20µs wave shape
Maximum let through voltage	< 600 V
Tested wave form	6kV 1.2/50µs (Open circuit Voltage)
	3 kA 8/20µs (Short Circuit Current)
Operating temperature	0 to 80^0 C
Protector Connection	Series or Shunt

Table 2.2 Characteristic of SPDs at equipment level.

In telecommunication industry, no specific guide line given for the equipment level protection and that should be aligned with the equipment installed inside the base station. Below is the SPD specification more commonly use for class 3 protection.

2.5.2 Application of cables and copper tapes in a base station

All the equipment should be interconnected with each other and should be bonded with the earthing of the base station at least with 50 mm^2 copper cables or tapes. [13] Upon this as a practice, use thin coper tapes with higher width to mitigate the skin effect.

1. The metallic base of the antenna structure should be connected to the earth grid by copper tapes of minimum cross sectional area 50 mm^2.
2. The cable sheaths of all signal lines from the antenna structure should be terminated at the point of bulkhead. The bulkhead shall be electrically connected to the cable rack by copper tapes of minimum cross sectional area 50 mm^2. No conducting part inside the cabin should be directly connected to the outside bulkhead.
3. An earth inspection pit should be installed underneath the bulkhead. The bulkhead should be connected to the earth termination rod in the pit by a copper tape of minimum cross section 50 mm^2. The earth pit should be integrated with the earth grid by copper tapes of minimum cross sectional area 50 mm^2.
4. The earth terminal of the SPD should be connected to the to the earth bar via copper wire of minimum cross section 16 mm^2 and maximum length of 50 cm.

5. The earth bar should be connected to an external earth pit with copper conductors of minimum cross section 50 mm^2. The earth pit should be integrated with the earth grid specified in Annexure II (b) by copper tapes of minimum cross sectional area 50 mm^2.

2.6 Prevention of conducted surges and into equipment cabin

The ideal solution to protect equipment is to prevent lightning from entering the cabinet. A single-point grounding system should be applied for equipment. All the power cable and signal cable should be earthed at the point of bulk head. It is desirable for both power and telecom cables to enter the cabin from the same side of the cabin to achieve the single-point grounding [13], Figure 2.5 and 2.6 illustrate the configuration of grounding, bonding and signal reference for a typical equipment cabin.

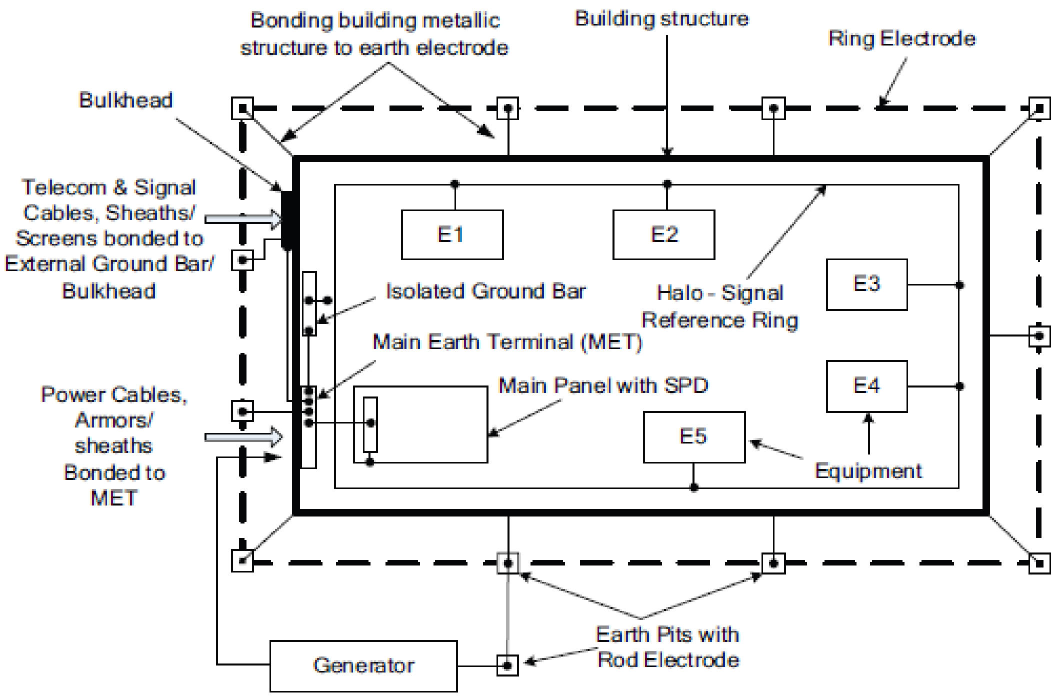


Figure 2.5 single point grounding for equipment cabin

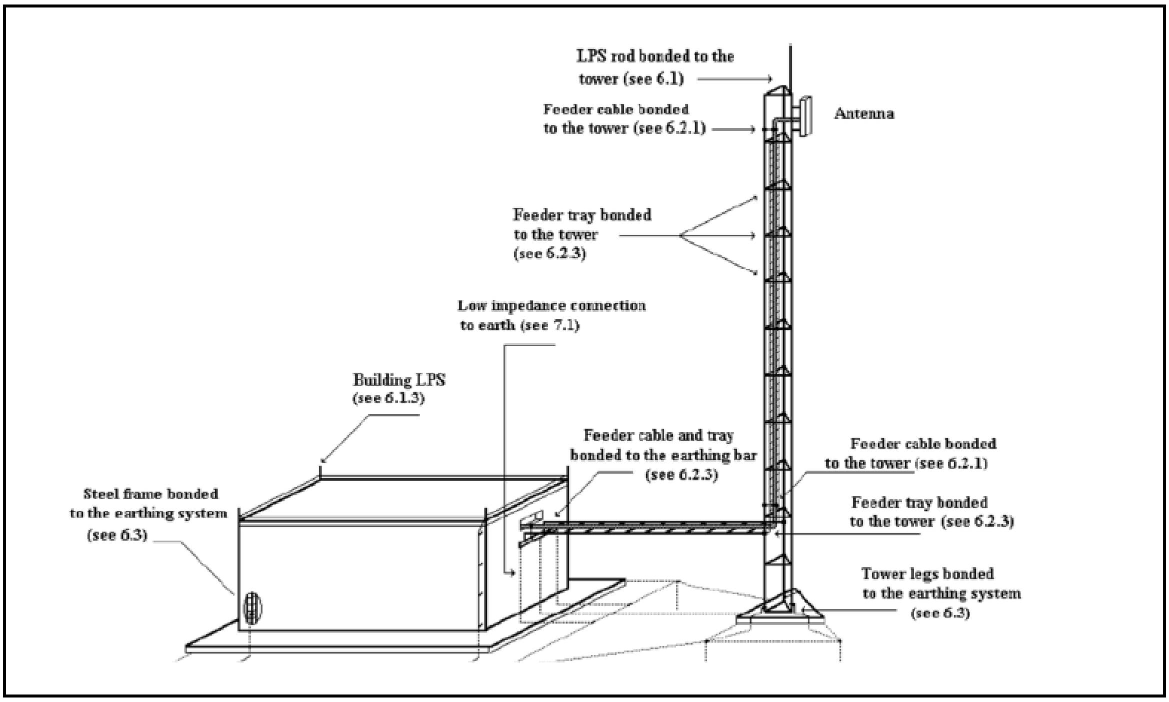


Figure 2.6 single point grounding for equipment cabin

2.7 Grounding Methods

Grounding methods can be classified into two groups as conventional methods and finite element methods. In the following sections, these methods are introduced.

2.7.1 Conventional method

a. One rod grounding design methods

If there is an electrode in the ground, the resistance to ground depends on the soil resistivity. Assume, one use a rod as an electrode located in the ground with a certain soil type. Many researchers studied on one rod grounding and they found different empirical equations to calculate ground resistance. Three of these methods are taken from references in the order of [10], [11] and [12].

Method 1

Equation (2-1)

$$R = \frac{\rho}{2\pi C}$$

where R is resistance in Ω, ρ is soil resistivity in Ωm, C is electrostatic capacitance (computed by Eq. (2-2)) of one rod in Farads. Electrostatic capacitance of one rod is given by the following formula.

$$C = \frac{13.25L_r}{1.55 + \log(\frac{L_r}{d})}$$

Equation (2-2)

Lr - rod length in feet

d - rod diameter in inches.

By putting the computed electrostatic capacitance into Eq. (2-1), one can obtain resistance to ground value of a one rod grounding by knowing soil resistivity, rod length and rod diameter. For more detailed information refer to [10].

Method 2

Ground resistance of one rod or pipe grounding can be computed by Eq. (2-3).
where ρ is soil resistivity in Ωm, Lr is rod length in cm, d is rod diameter in cm.

$$R = \frac{100\rho}{2\pi L_r} \times \left(\ln \frac{8L_r}{d} - 1 \right)$$

Equation (2-3)

In this method, the diameter of copper rods recommended between 13mm and 19mm. Also, length of copper rods recommended between 1.22m and 2.44m.

Method 3

This method is the most commonly used equation (given in Eq. (2-4)) for single rod grounding, which is developed by Prof. H. R. Dwight and called as Dwight method.

$$R = \frac{\rho}{2\pi L} \times \frac{\{(\ln 4L_r) - 1\}}{r}$$

Equation (2-4)

where ρ is soil resistivity in Ωm, Lr is rod length in cm, r is rod radius in cm.

b. Two rods system grounding method

If there are two electrodes in the ground, which are separated with a distance S, electrostatic capacitance given in Eq. (2-5) is valid.

$$C = \frac{61L_r}{3.56 + 2.3\log(\frac{L_r}{d}) + \frac{L_r}{S} + \frac{1}{3}(\frac{L_r}{S})^3 + \frac{2}{5}(\frac{L_r}{S})^5}$$

(2-5)

By computing the capacitance of two rods from Eq. (2-5) and putting it in Eq. (2-1), one can obtain resistance to ground value of two rods grounding by knowing soil resistivity, rod length and rod diameter [10].

c. Multi-rods system grounding

There is no specialized method to compute grounding resistance of a multi-rods system. In this kind of systems, only computation way to measure grounding resistance is using finite element analysis.

d. System grounding with grids in uniform soil conditions

Grounding grid is an intermeshed network of conductors which are located under the area which requires control of potential caused by a fault current. Resistance to ground calculation method for a uniform soil covered by a grounding grid region used to be studied by many researchers. As per the IEEE 80-2000 below methods use commonly.

- Laurent-Niemann Method,
- Sverak Method,

- Schwarz Method-This method is used for the earth resistance calculation in this research
- Thapar-Gerez Method.

e. Two layer or multilayer system grounding

In practical scenario, we can’t find ideal homogenous soil condition. The most common soil conditions are blend of different soil types. Highly non-uniform soil characteristics may be encountered from Wenner Test results of the grounding design region. In such soil conditions, both two layer and multilayer soil models can be used. Multilayer soil models can be used if and only if there does not exist a feasible two-layer equivalent design according to [13]. A multilayer soil model includes several horizontal soil layers. Techniques to interpret highly non-uniform soil resistivity require the use of computer programs or graphical methods developed by the researchers. As it is given in [13], that in most cases, the grounding regions can be modeled, based on an equivalent two-layer model that is sufficient for designing a safe grounding system.

Two-layer soil models can be designed by using below three methods.

1. Determination of an earth model by minimizing error function
2. Determination of an earth model by graphical data
3. Determination of an earth model by finite element model

2.7.2 Finite Element Model

The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. Finite element Model then uses various from the calculus of variations to approximate a solution by minimizing an associated error function

Finite element analysis, which is used in determination of ground resistance, is capable of both one or multi rod grounding and uniform or non-uniform soil models grounding computations. In non-uniform resistivity soil conditions, using two-layer soil model or multilayer soil model is essential.

2.8 Soil Resistivity

Soil resistivity is defined as the resistivity of a 1 m3 sized cube between the two opposite sides, and is measured in ohmmeter(Ωm) or ohmcentimetres(Ωcm). Soils have generally been deposited in layers, which can have different values of soil resistivity.

3. METHODOLOGY

Methodology used for the research consists of six key steps as mentioned below.

3.1. Collection of data on actual tower earthing arrangements.

The first step was to select sample telecommunication antena structures to meaure actual earth resistance of the site.Then it clusted as problamtic sites and non problematic sites based on the earth resisitance vlaues obtained from the measurment.

If the earth resistance value is deviated in considerable amount along a direction that was considered as roblamatic site.Sites which has almost the same earth resistance values are considered as non problematic sites.Based on the problamatic sites the reseash extended the simulaions.

Site	Site ID	Region	District	Site Height	Leg 1 ER value(Ω)	Leg 2 ER value(Ω)	Leg 3 ER value(Ω)	Leg 4 ER value(Ω)	Remarks
Moragala	KL0025	Western South	Kaluthara	60	**41**	4.5			
Pokunuwita	KL0035	Western South	Kaluthara	60	**35**	3.8			
Mathugama	KL0010	Western South	Kaluthara	60	26	38	**19**	**46**	
Ingiriya	KL0022	Western South	Kaluthara	60	15	**56**	**38**	26	
Atalugama		Western South	Kalutara	60	**32**	10	**60**	12	
Kallar Dialog	BA0014	Eastern	Batticaloa	40	**19**	8	15	8	
Belihul Oya Dialog	RA0009	Uva	Ratnapura	60	10	**28**			
Wellatha Dialog	KL0107	Western South	Kaluthara		**13**	0.55			

Table 3.1 Problematic site.

Out of the identified problematic sites Mathugama and Atalugama sites are taken for further analsysis due to below parameters

- One leg of the telecommunication tower located on a rock.
- One side of the soil layer has high elevation

Few complaigns obtained regarding lighning cases on these sites.

Site	District	Site Height	Leg 1 ER value(Ω)	Leg 2 ER value(Ω)	Leg 3 ER value(Ω)	Leg 4 ER value(Ω)
Waga Dialog	Colombo	70	4.2	7.6	2.1	4.3
Udahamulla Dialog	Colombo	50	4.1	3.6	4.3	3.9
Irattaperiyakulama Dialog	Vavnia	80	2.4	2.4	2.8	2.6
Neriyakulam MTU	Vavnia	40	3.1	2.8	2.9	2.9
Weeramunai Dialog	Ampara	30	1.2	0.7	1.0	1.1
Mawaramandiya Dialog	Gampaha	60	5	2.4	3.8	4.9
Biyagama Town Dialog	Gampaha	60	9.1	3.1	3.4	2.9
Raddoluwa Dialog	Gampaha	50	6	8.1	7.2	6.7

Table 3.2 Non-problematic site.

3.2. Model specific configurations via Ansys Maxwell

By inserting site actual and hypothetical parameters to simulate the behavior of earth resistance and voltage profile by using Ansys Maxwell Electromagnetic

Sofware.Figure 3.1 is a voltage profile of a sigle rod earthing system.

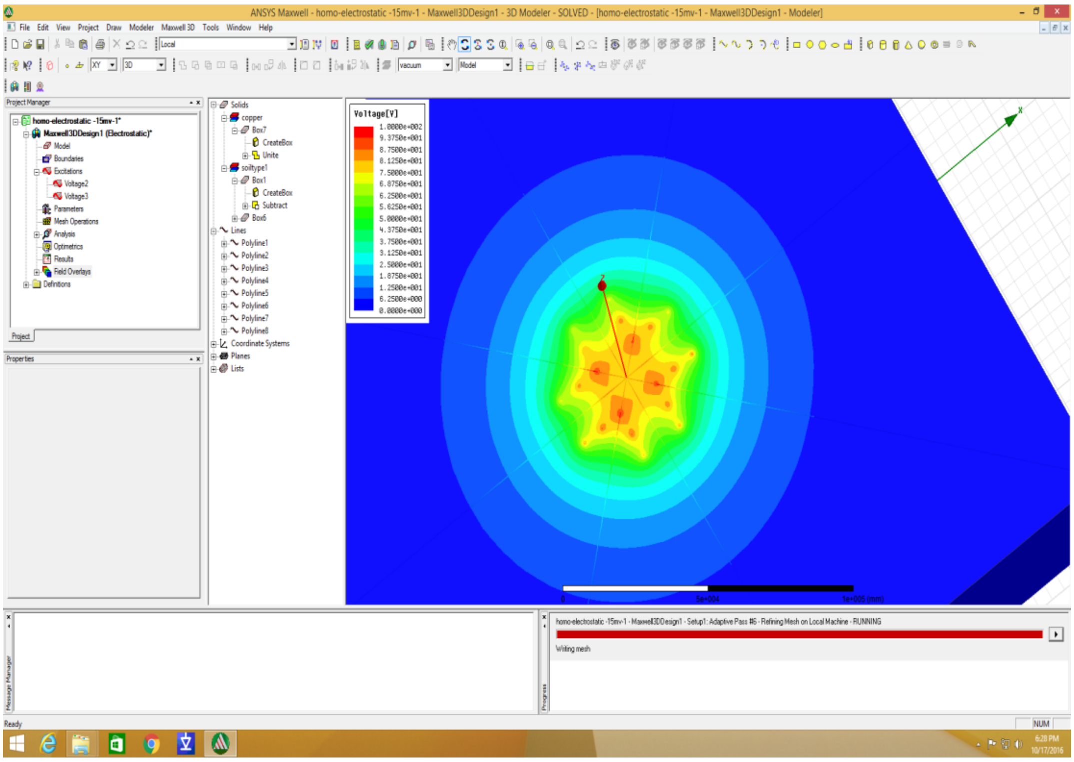


Figure 3.1 voltage profile of a typical erthing system.

Based upon the soil formation and soil type simulations are done for five models.

Model 1 : Uniform Soil layer-With a square Boundary

Uniform soil layers are very rare to find and most of the soil is a blend of soil types along horizontal and vertivcal planes.But for the analysing perspective homogenuos soil has been selected for the first.Figure 3.3 illustrates the voltage behavior of the soil layer.

Below are the given parameters of the earthing structure.

Dimention of the Soil cube (L*W*H)	:	120m*120m*45m
Lengnth of the copper rod	:	3m
Diameter of the copper rod	:	0.016m
Cross sectional area of the copper tape	:	25 mm^2

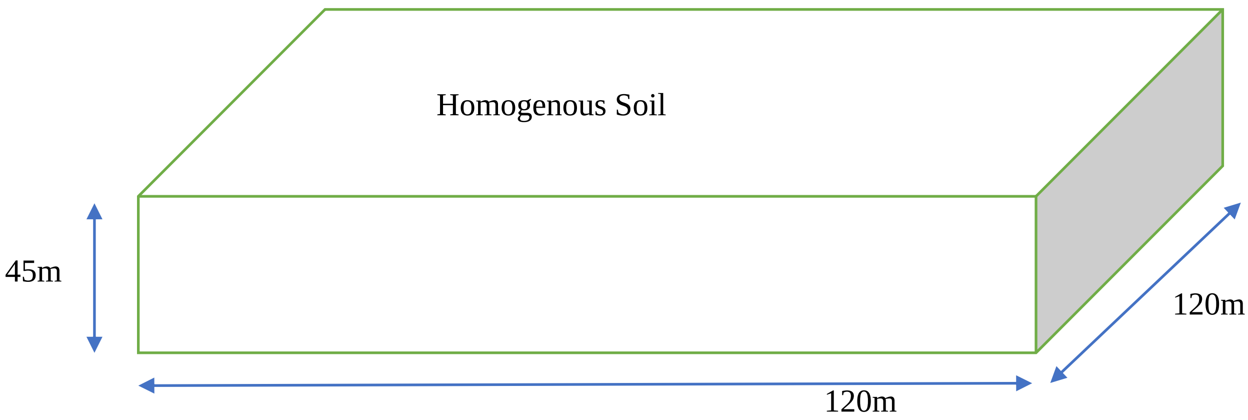


Figure 3.2 Uniform Soil layer-With a square Boundary

The parameters of the Simulation-Ansys Maxwell Software.

Voltage	: 100V
time set up	: 5ms for 100 times
Resistivity of soil	: 100 Ωm

As per the figure 3.3,simulation it shows the symmetrical distribution of voltage from the four corners.

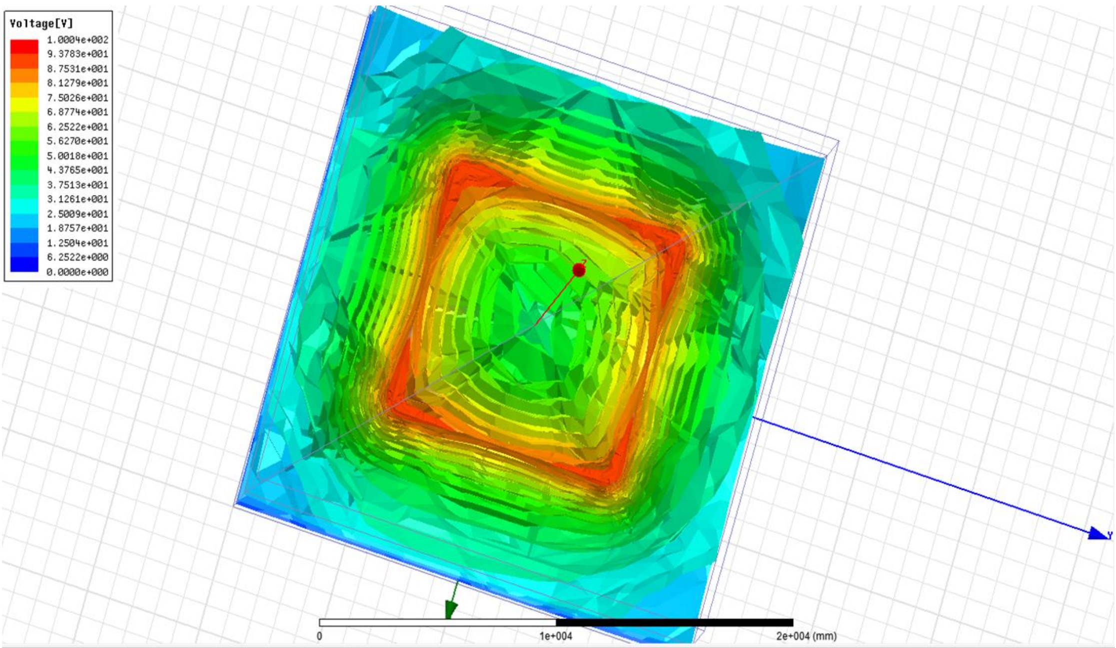


Figure 3.3 voltage profile of a interconneted four rods.

Model 2 : Uniform Soil layer-With a cylindrical Boundary

The second model used is a homogenous soil with a cylindrical boundary as per the figure 3.4 .Simulation showed very similar voltage profile distribution with compared to model 1.With that it concludes when the dimesion of the soil is comparatively higher with respect to the earthing structure,the impact of the type of boundry doesn’t count much.

Below are the given parameters of the earthing structure.

Dimention of the cylindrical cube :

Depth : 30m
Radius : 60m

Length of the copper rod	:	3m
Diameter of the copper rod	:	0.016m
Cross sectional area of the copper tape	:	25 mm^2

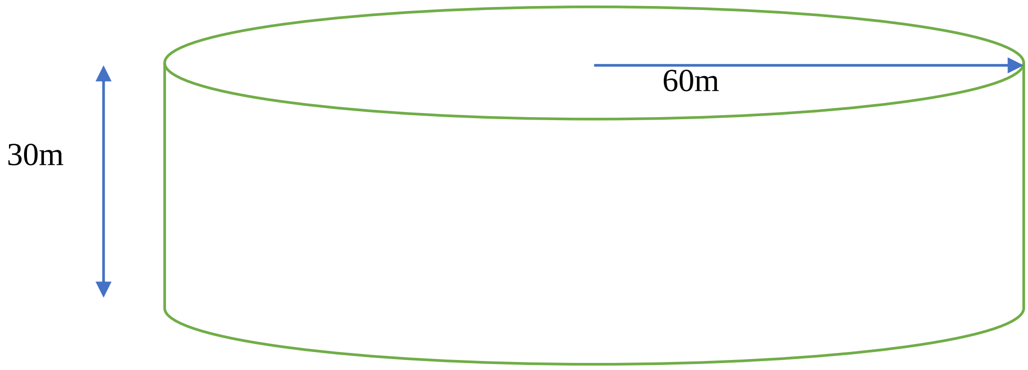


Figure 3.4 Uniform Soil layer-With a cylindrical Boundary

Model 3: Horizontally four-layer soil-with Square Boundary

As the third model selected four layer with a square boundary as the figure 3.5. Each quadrant consists of different types of soil and the soil resistivity differs from quadrant to quadrant.

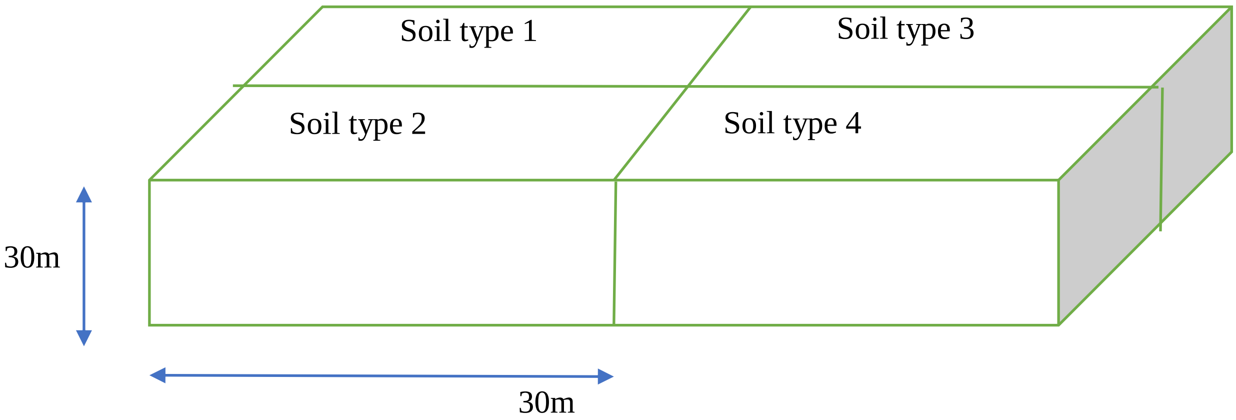


Figure 3.5 Horizontally four-layer soil-with Square Boundary

Below are the given parameters of the earthing structure.

Dimention of the Soil cube (L*W*H)	:	60m*60m*30m
Lengnth of the copper rod	:	3m
Diameter of the copper rod	:	0.016m
Cross sectional area of the copper tape	:	25 mm^2

Below are the given parameters of the Simulation-Ansys Maxwell Software.

Voltage	:	100V
time set up	:	5ms for 100 times
Resistivity of soil 1	:	10 Ωm
Resistivity of soil 2	:	100 Ωm
Resistivity of soil 3	:	1000 Ωm
Resistivity of soil 4	:	10000 Ωm

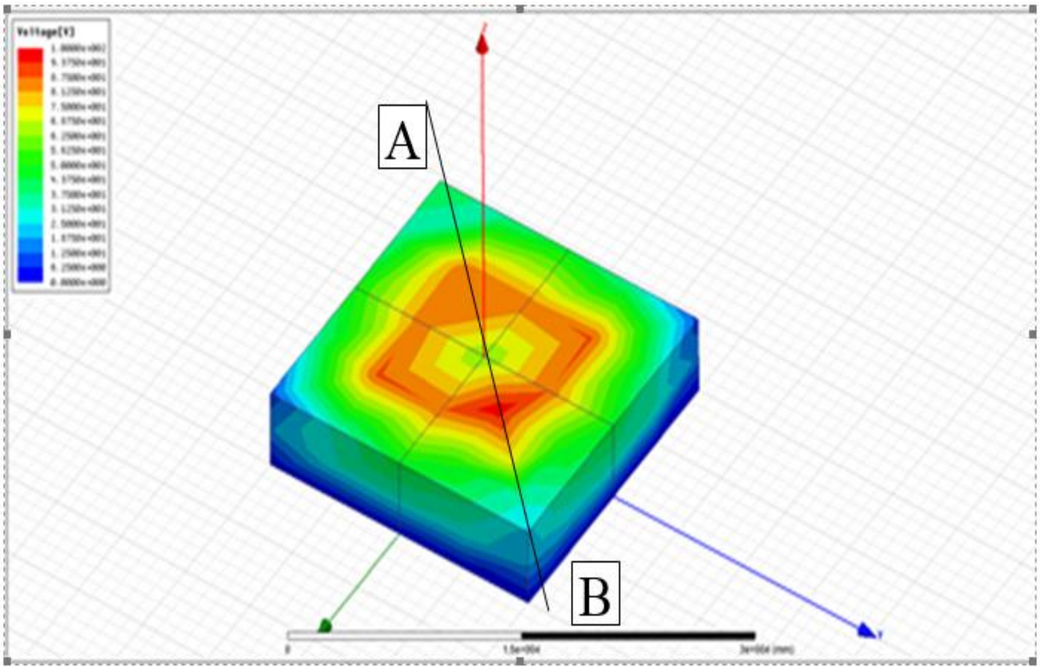


Figure 3.6 Voltage profile of four-layer soil formation

As per the figure 3.6 the voltage distribution is deviated along the diagonal. All other parameters kept the same and this deviation along the diagonal is due to the different soil resistivity. Figure 3.7 illustrates the voltage curve along the soil layer from point A to point B axis. This axis contains soil resistivity of 10 Ωm to 1000 Ωm.

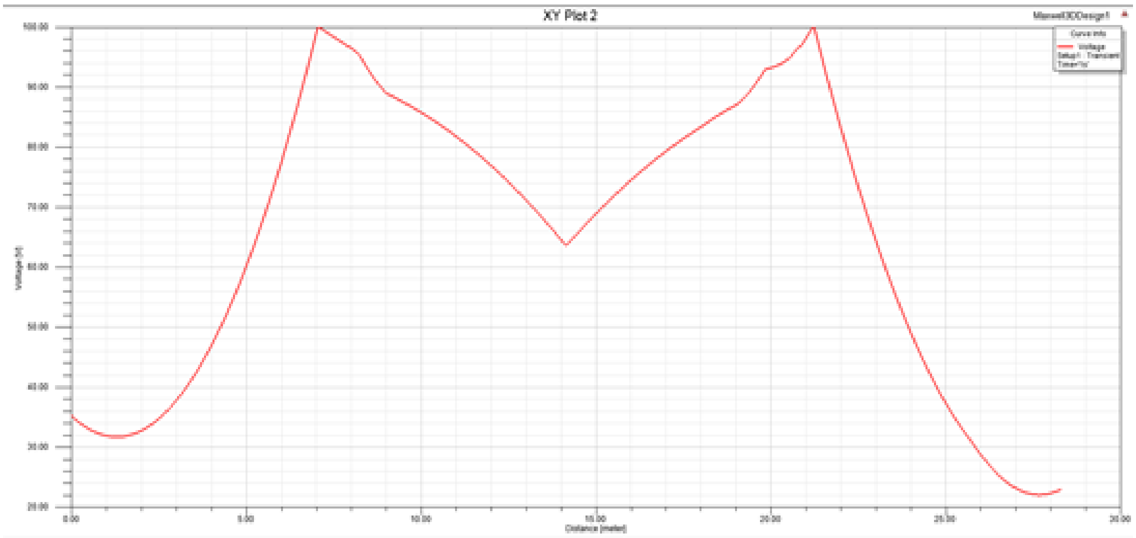


Figure 3.7 Voltage profile of four-layer soil formation along the A-B Axis

Model 4: Same soil type in different elevations

One key observation of problematic sites is having an elevated soil structure. Under such circumstances the earth resistance is more deviated with respect to the other readings. To observe the voltage distribution of such soil formations below configuration can be used.

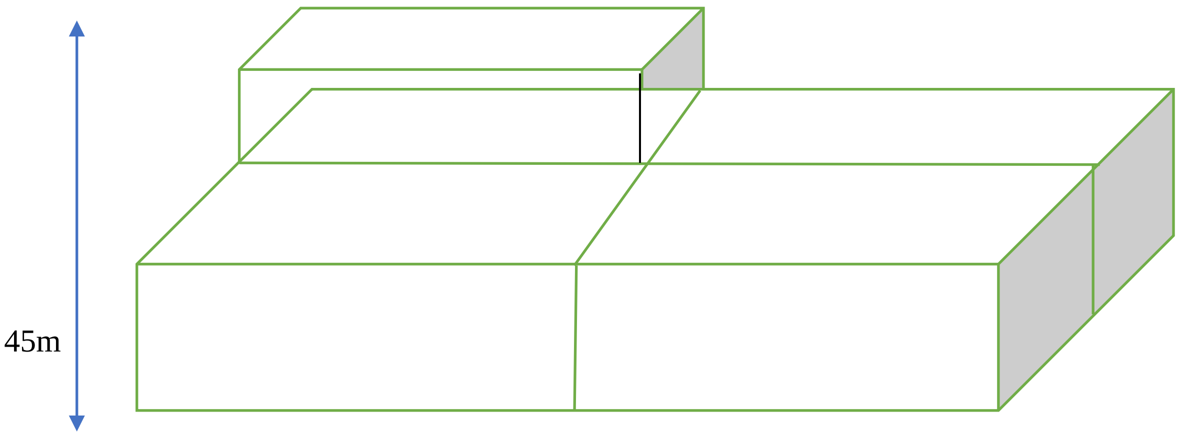


Figure 2Figure 3.8 soil formation with elevation

Below are the given parameters of the earthing structure.

Maximum Depth of the soil	: 45m
Length and width of soil cube	: 60m*60m
Lengnth of the copper rod	: 3m
Diameter of the copper rod	: 0.016m
Cross sectional area of the copper tape	: 25 mm^2

Below are the given parameters of the Simulation-Ansys Maxwell Software.

Voltage	: 100V
time set up	: 5ms for 100 times
Resistivity of soil	: 100 Ωm

Model 5: Different soil types in vertically with a square boundary.

The final model is different soil types in vertically and the elevation kept the same. As per the figure 3.10 the voltage distribution of the top surface is almost symmetrical. But the voltage distribution beneath 5m is deviated a lot and this will be discussed more in chapter four under analysis.

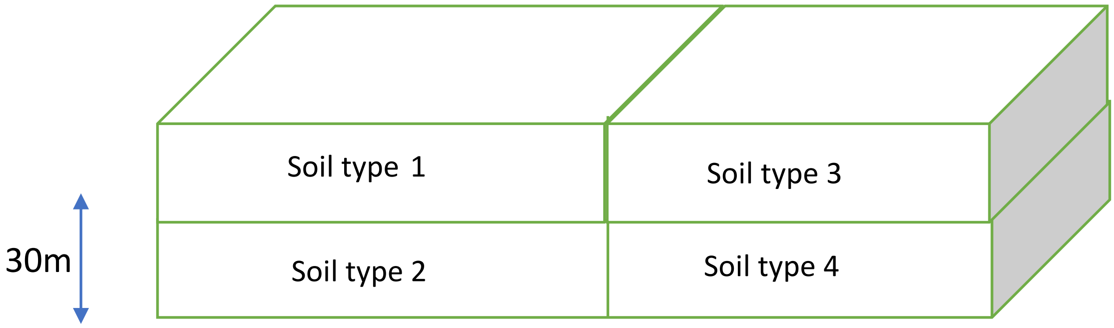


Figure 3Figure 3.9 Different soil type in vertically

Below are the given parameters of the earthing structure.

Dimension of the soil cube	: 60m*60m*45m
Lengnth of the copper rod	: 3m
Diameter of the copper rod	: 0.016m
Cross sectional area of the copper tape	: 25 mm^2

Below are the given parameters of the Simulation-Ansys Maxwell Software.

Voltage	: 100V
time set up	: 5ms for 100 times
Resistivity of soil 1	: 10 Ωm
Resistivity of soil 2	: 100 Ωm
Resistivity of soil 3	: 10 Ωm
Resistivity of soil 4	: 10000 Ωm

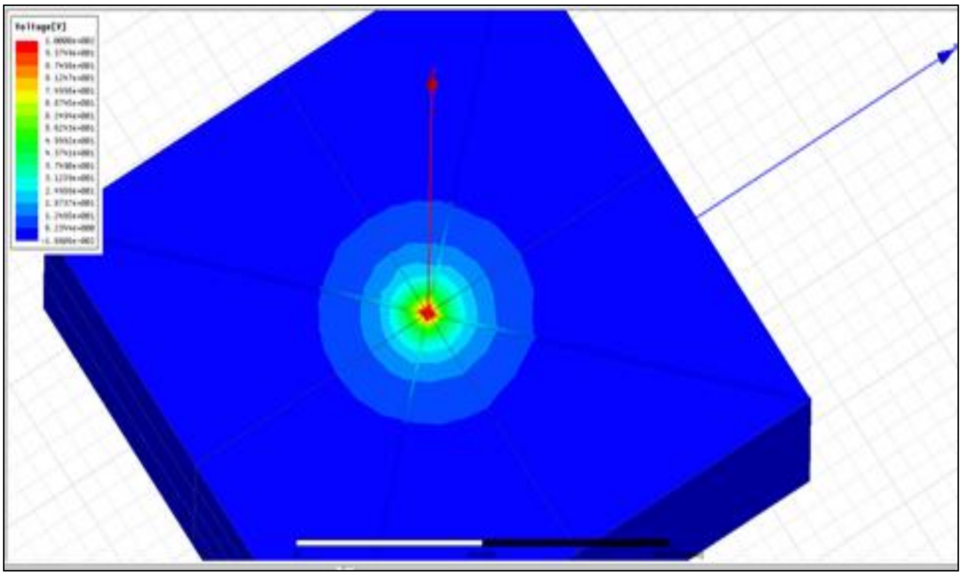


Figure 4Figure 3.10 voltage distribution of the surface

3.3.Determine the 2-D and 3-D voltage profiles.

With the information of actual sites, simulations were done to obtain voltage profile and electric field. Atalugama site was selected to do the simulation due to the availability of the actual earthling as built drawing. Figure 3.11 shows the earthing arrangement used for the simulation under the Atalugama site and figure 3.12 is the actual earthing arrangement of the Atalugama site. The practical issue encountered to model earthing arrangement with bends in the software. The earthing arrangement of the simulation can be considered as identical in shape for the actual earthing arrangement. The Coper tapes and the copper rods count is the same of actual side condition.

Once the actual earthing arrangement modeled in Ansys Maxwell software,2D and 3D voltage profiles were obtained and figure 3.13 is such example of 2D voltage profile. As per the figure 3.13 it can be observed higher voltage density is around the coper tapes and copper rods.

Below are the given key parameters of the Simulation-Ansys Maxwell Software.

Voltage of copper tapes	: 100V
Voltage of bottom plane	: 0V
time set up	: 5ms for 100 times
Resistivity of soil 1	: 1281 Ωm
Resistivity of soil 2	: 1941 Ωm
Resistivity of soil 3	: 1112 Ωm
Resistivity of soil 4	: 502 Ωm

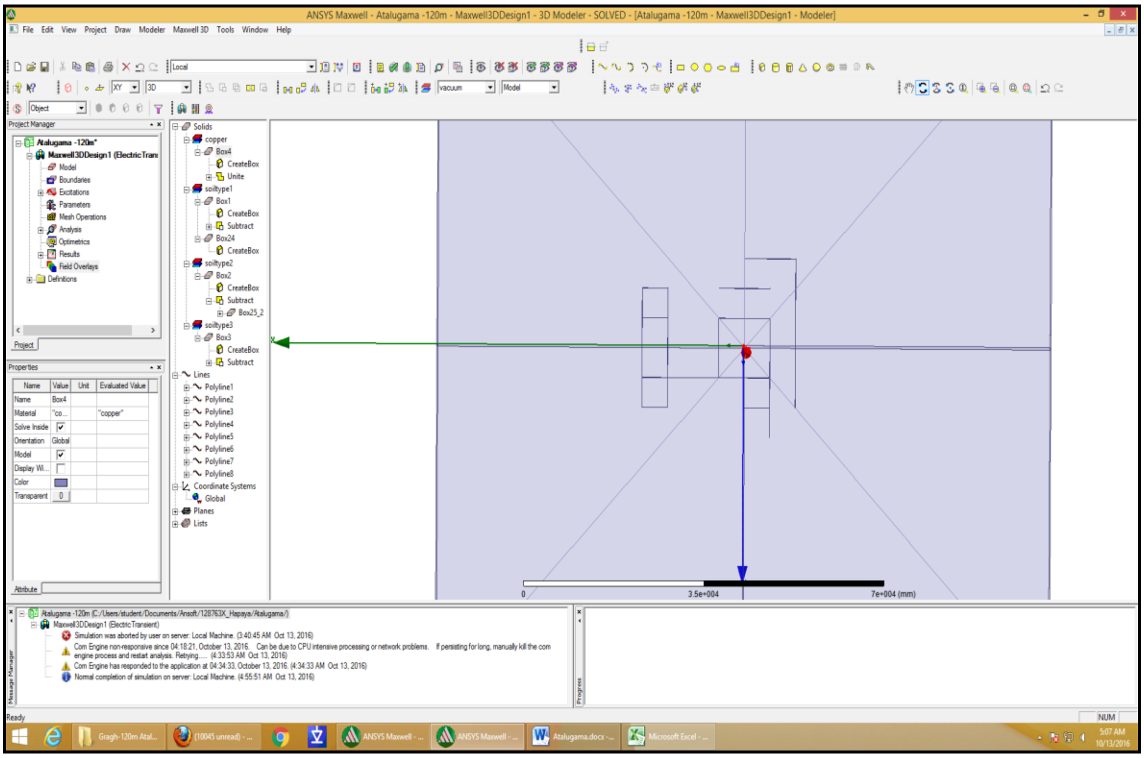


Figure 3.11 Earthing arrangement of the Atalugama site -Ansys Maxwell Software

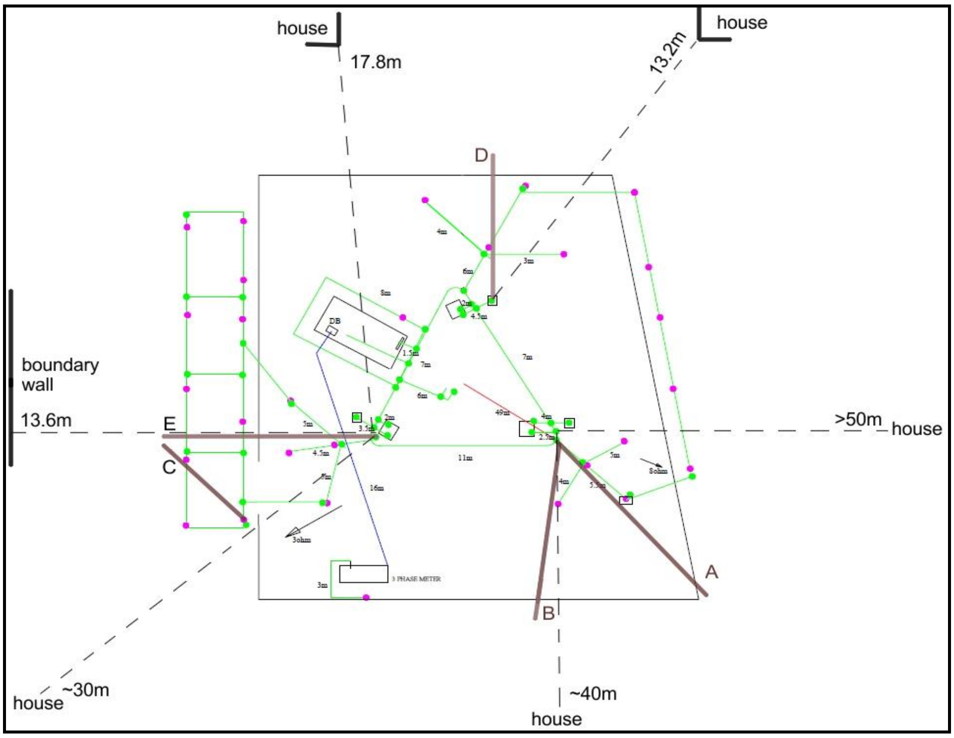


Figure 3.12 Earthing arrangement of the Atalugama site- actual earthing arrangement

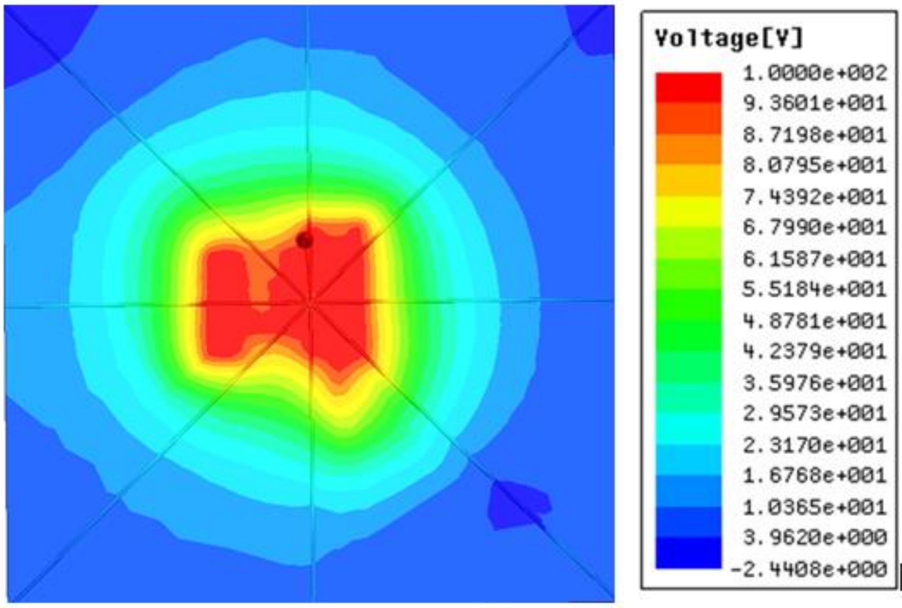


Figure 3.13 2D voltage profile obtained for Atalugama Earthing arrangement

3.4. Analyse the behavior of the profiles.

As the step 4 comparison has done each against the simulated results,calculated values and measured values.As per the table 3.3 it can be observed that there are variations in calculated values against the measured earth resistance. These deviations are observed in the problematic sites which has deviated earth resistance values with respect to others.

Direction	Measured ER(Ω)	Soil resistivity(Ωm)	Calculated ER(Ω)	Variation
A	27	1944.288	60.83	-125%
C	15	1281.12	10.05	33%
D	12	1112.816	32.80	-173%

Table 3.3 Comparison of measured and calculated earth resistance

Soil resistivity calaculates by using the Wenner method.

$$\rho_E = \frac{4 \cdot \pi \cdot a \cdot R_W}{1 + \frac{2 \cdot a}{\sqrt{a^2 + 4 \cdot b^2}} - \frac{a}{\sqrt{a^2 + b^2}}}$$

where:

a Electrode spacing

b Depth of electrodes

R_w Resistance reading

ρ_E Soil Resistivity in Ωm

Earth Resistance(ER) theoretical calculation

$$R_1 = \frac{\rho}{\pi L}\left[\ln\left(\frac{4L}{(dh)^{1/2}}\right) - 1\right] \qquad R_2 = \frac{\rho}{2\pi L}\left[\ln\left(\frac{8L}{d}\right) - 1\right]$$

where:

ρ	Soil Resistivity in Ωm –(ρ_E)
R_1	Total Earth resistance of a single rod
R_2	Total Earth resistance for copper tapes
R_m	Mutual Resistance
L	Buried Length of the electrode in m
d	Diameter of the electrode in m
h	Buried depth of the electrode in m

$$R_g = \frac{R_1 R_2 - R_m^2}{R_1 + R_2 - 2R_m}$$

where:

R_g Resultant ER

3.5. Estimate the ER values based on profiles obtained

Assumption:

Mutual resistance considered as zero
Earthing of legs considered as separate
ER enhancement due to GEM is neglected

Base on the voltage curves, obtained a curve which represents the earth resistance. Earth resistance curve is not numerically equal to the voltage curve. But the shape is fairly the same and with vertical and horizontal shifting the earth resistance curve comes on to the voltage inverse curve.

The highest voltage value point gives the lowest earth resistance value. So, it can derive an earth resistance curve by deducting the spontaneous voltage value and it looks like inverse voltage curve.

Figure 3.14 shows the voltage curve obtained from center to a corner. For the Atalugama site.

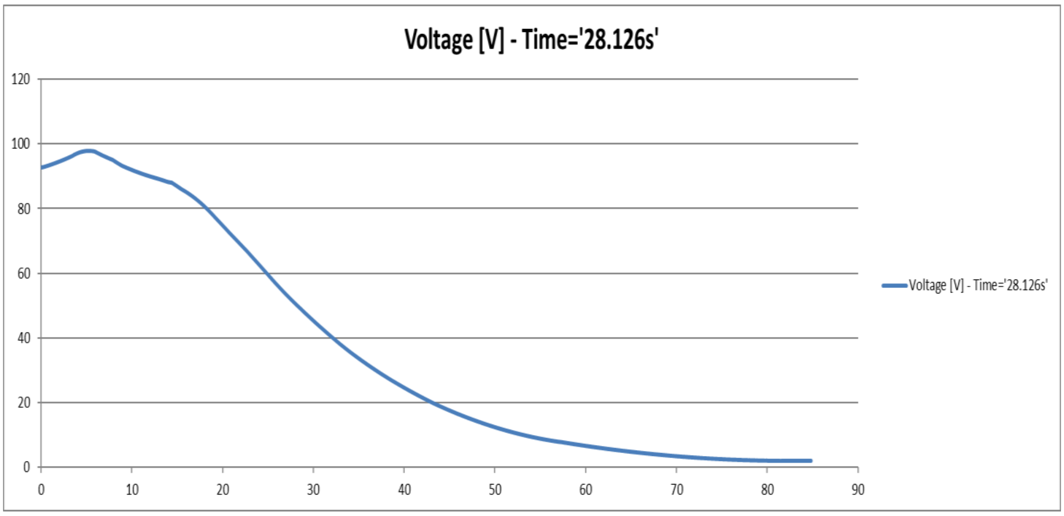


Figure 3.14 voltage curve of Atalugama site from center to a corner.

Figure 3.15 shows the inverted voltage curve of the above. The curve inverted by deducting spontaneous value from the maximum voltage. The inverted voltage curve and the measured earth resistance curve against the distance from the center of Atalugama site gets the same shape as per the figure 3.15.

This proves that the inverted voltage curve and earth resistance curves have the same shape and that uses for the analysis in the chapter 4 ,5 and 6.

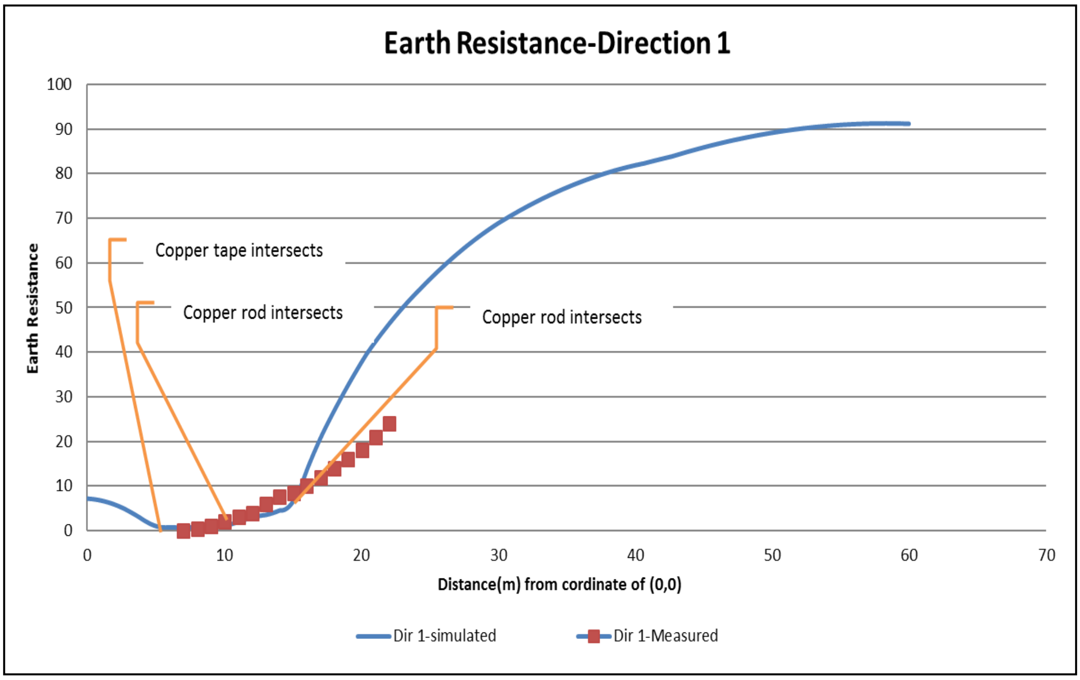


Figure 3.15 Inverted voltage curve and masured earth resistance curve.

3.6. Identification of reasons in deviated earth resistance

Validate model using measurements for a site showing irregular behavior of earth resistance and identification of reason in deviated Earth resistance.Analysis continued on different dirrecions which has measured earth resstance and soil resistivity.With the values obtained from the measurement,it can be proved simumlated values are correct.Upon the verification this can be used for accurate earth resistance estimation and to comment on the behavior of the earth resistance.

4. Theoretical Analysis

4.1. Introduction

Based on the informtion and calculations obtained from Raddoluwa , Atalugama and Matugama sites, theoratical analysis is done.

4.2. Raddoluwa Site -Technical Analysis

Raddoluwa site details are as below. As per the figure 4.1 soil resistivity varies within the range of 251.2 Ωm to 502.4 Ωm.Top soil layer is clay mixed loam soil. The earthing system is equality distributed and the terrain is almost flat.

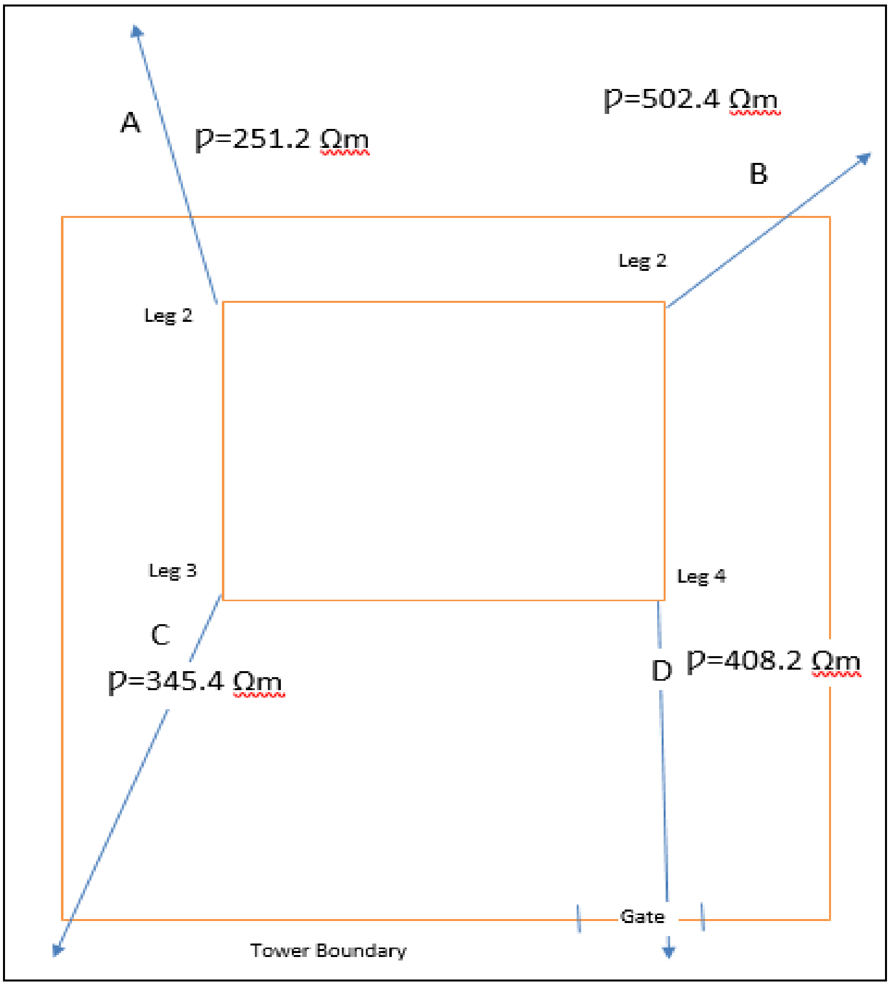


Figure 4.1 Site details of Raddoluwa base station

4.2.1. Calculation of ER in each leg of the antenna structure.

Below parameters are used for the calculation.

Parameters			
Symbol	Description	Unit	Value
L	Copper ROD length	m	3
d	Copper ROD diameter	m	0.016
n	Number of copper rods in parallel	each	8
L	Buried Length of the electrode in m	m	40
h	Buried depth of the electrode in m	m	0.6
d	Diameter of the electrode in m	m	0.004887

Calculated Earth Resistance of Leg A-

Leg A		
Item	Value	Unit
Earth Resistivity	251.2	Ωm
$R_{g(\text{Total Earth resistance of single rod})}$	84.18	Ω
Reduction of ER with Parallel rods	6	times
$R_{g\ (\text{Total Earth resistance of Parallel rods})}$	14.03	Ω
$R_{g\ (\text{Total Earth resistance of Copper tapes})}$	13.98	Ω
Mutual Resistance	0	Ω
Total estimated resistance (neglecting mutual resistance)	7.00	Ω
With the use of GEM-Earth resistance	5.25	Ω

Table 4.1 Earth Resistance of Leg A

Calculated Earth Resistance of Leg B-

Leg B		
Item	Value	Unit
Earth Resistivity	502.4	Ωm
R_g (Total Earth resistance of single rod)	168.35	Ω
Reduction of ER with Parallel rods	6	times
R_g (Total Earth resistance of Parallel rods)	28.06	Ω
R_g (Total Earth resistance of Copper tapes)	27.96	Ω
Mutual Resistance	0	Ω
Total estimated resistance (neglecting mutual resistance)	14.01	Ω
With the use of GEM-Earth resistance	10.50	Ω

Table 4.2 Earth Resistance of Leg B

Calculated Earth Resistance of Leg C-

Leg C		
Item	Value	Unit
Earth Resistivity	345.4	Ωm
R_g(Total Earth resistance of single rod)	115.74	Ω
Reduction of ER with Parallel rods	6	times
R_g(Total Earth resistance of Parallel rods)	19.29	Ω
R_g(Total Earth resistance of Copper tapes)	19.23	Ω
Mutual Resistance	0	Ω
Total estimated resistance (neglecting mutual resistance)	9.63	Ω
With the use of GEM-Earth resistance	7.22	Ω

Table 4.3 Earth Resistance of Leg C

Calculated Earth Resistance of Leg D -

Leg D		
Item	Value	Unit
Earth Resistivity	408.2	Ωm
$R_{g(\text{Total Earth resistance of single rod})}$	136.79	Ω
Reduction of ER with Parallel rods	6	times
$R_{g(\text{Total Earth resistance of Parallel rods})}$	22.80	Ω
$R_{g(\text{Total Earth resistance of Copper tapes})}$	22.72	Ω
Mutual Resistance	0	Ω
Total estimated resistance (neglecting mutual resistance)	11.38	Ω
With the use of GEM-Earth resistance	8.53	Ω

Table 4.4 Earth Resistance of Leg D

4.2.2. Measured earth resistanc of Raddoluwa site.

Earth resistance measured by keeping 10m span between earth electrodes.Moved the middle current probe around 10 meters and taken the value where the point of earth resistance value is stable.Figure 4.2 shows the directional behavior of mesured earth resistance.

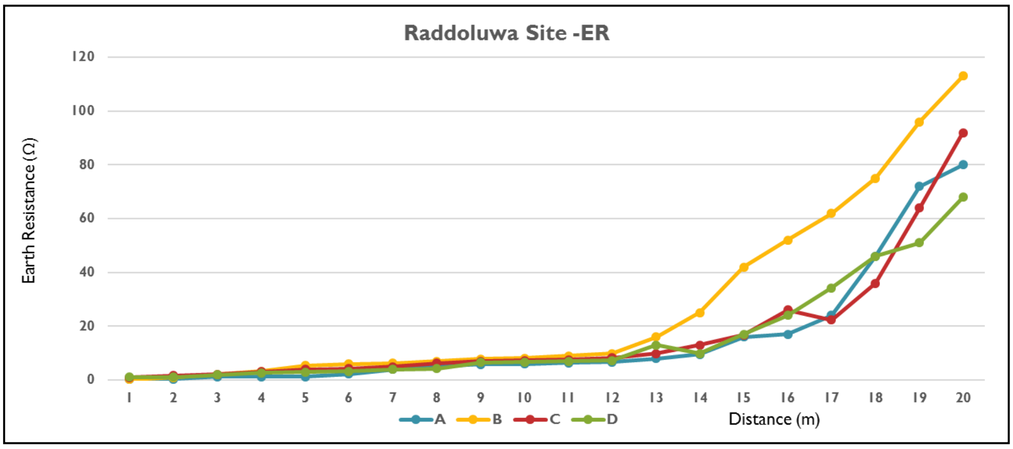


Figure 4.2 Measured ER of raddoluwa Site

The formation of calculated values and measured values were verified via the Ansys Maxwel software as per the figure 4.3. Figure 4.3 shows a symmetrically distributed voltage profile since the soil is homogenous and no elevation.

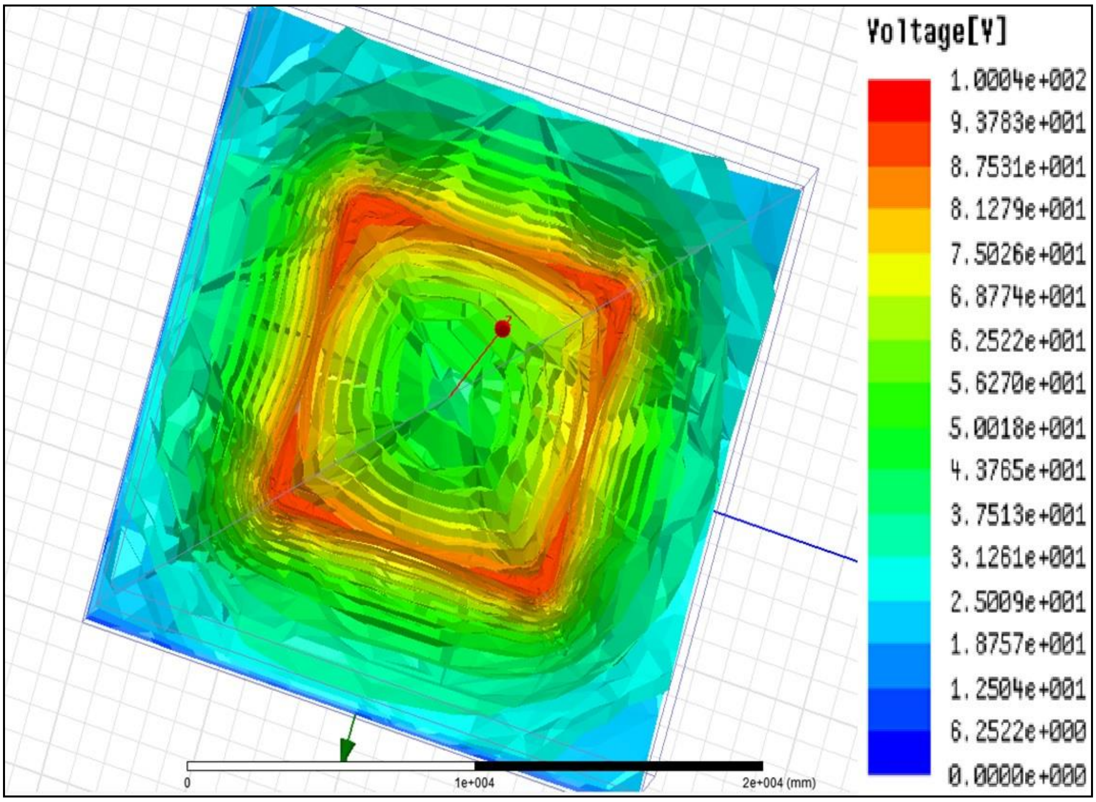


Figure 4.3 Voltage distribution of the Raddoluwa site

4.3. Matugama Site -Technical Analysis

Key feature of the Matugama site is having elevated soil formation. One side of the site is sloped a lot. This site was complained for several lightning issues from neighbors. Soil type also varies considerably from leg to leg of the antenna structure. Figure 4.4 shows the soil resistivity around each tower leg. Variation in soil can be verified from the measured soil resistivity which varies from 1300 Ωm to 2100 Ωm.

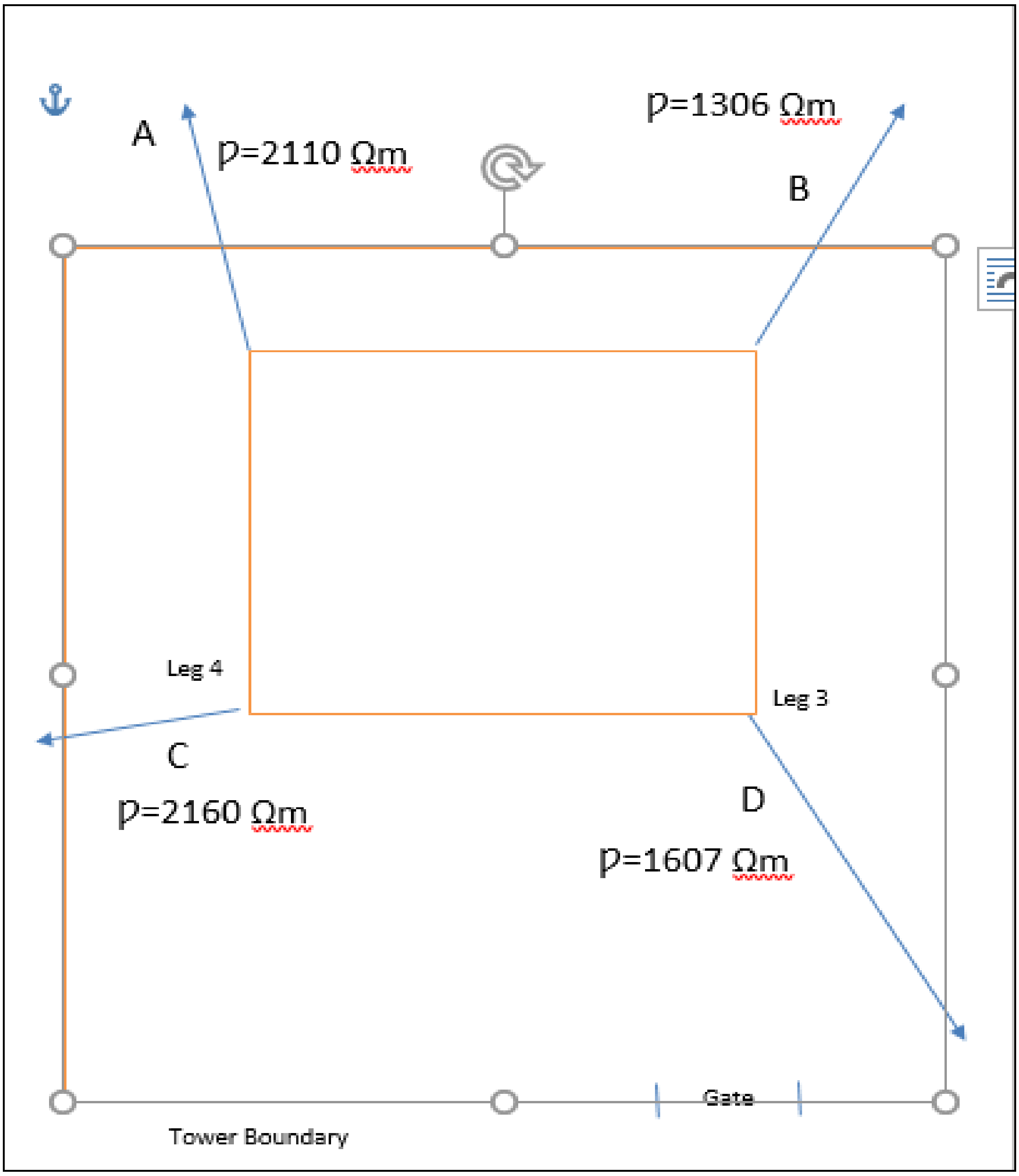


Figure 4.4 Site details of Matugama base station

Vertically also there are two layers of soil. Beneath 2m from the top soil layer there exist hard rock layer. Due to this hard rock, it's difficult to do the installation of earthing system and lot of restrictions to enhance the earth resistance value of the site. Apart from this restriction the elevated soil formation creates scattered earth resistance values for the site.

4.3.1. Summary of calculated and measured ER of Matugama Site

As per the table 4.5 it can be observed that there is considerable amount of variation in measured and calculated earth resistance values.The elevational difference of min and max is 2.0 m. There are several reasons for this variation and the reasons for this variation to be discussed in detail under the chapter six.

Direction	Measured ER(Ω)	Soil resistivity(Ωm)	Calculated ER(Ω)	Variation
A	26.7	2110.08	53	-99%
B	38	1306.24	5	87%
C	19	2160.32	40	-111%
D	46	1607.68	8	83%

Table 4.5 comparison of Calculated and measured ER

4.4. Atalugama Site -Technical Analysis

Atalugama is a Base station which locates in Kalutara district. Soil type deviates significantly from leg to leg and legs are located on different elevations. This three-legged antenna structure constructed on a soil layer where the soil resistivity varies within 50 Ωm to 1944 Ωm.

Figure 4.5 shows the details of the site and figure 4.6 shows the actual earthing arrangement of the site. Leg number two and three of the antenna structure are in the same elevation and the leg number one is located 3m above the leg 2 and 3. Within the span of 20m, there are residential houses and few times the antenna structure subjected to neighbor complains due to lightning.

To the left side of the base station there is a concrete road and that prevents of earthing upgrades on that area. At the time of tower construction there wasn't this concrete road and most of the earthing installation has been done under the concrete road.

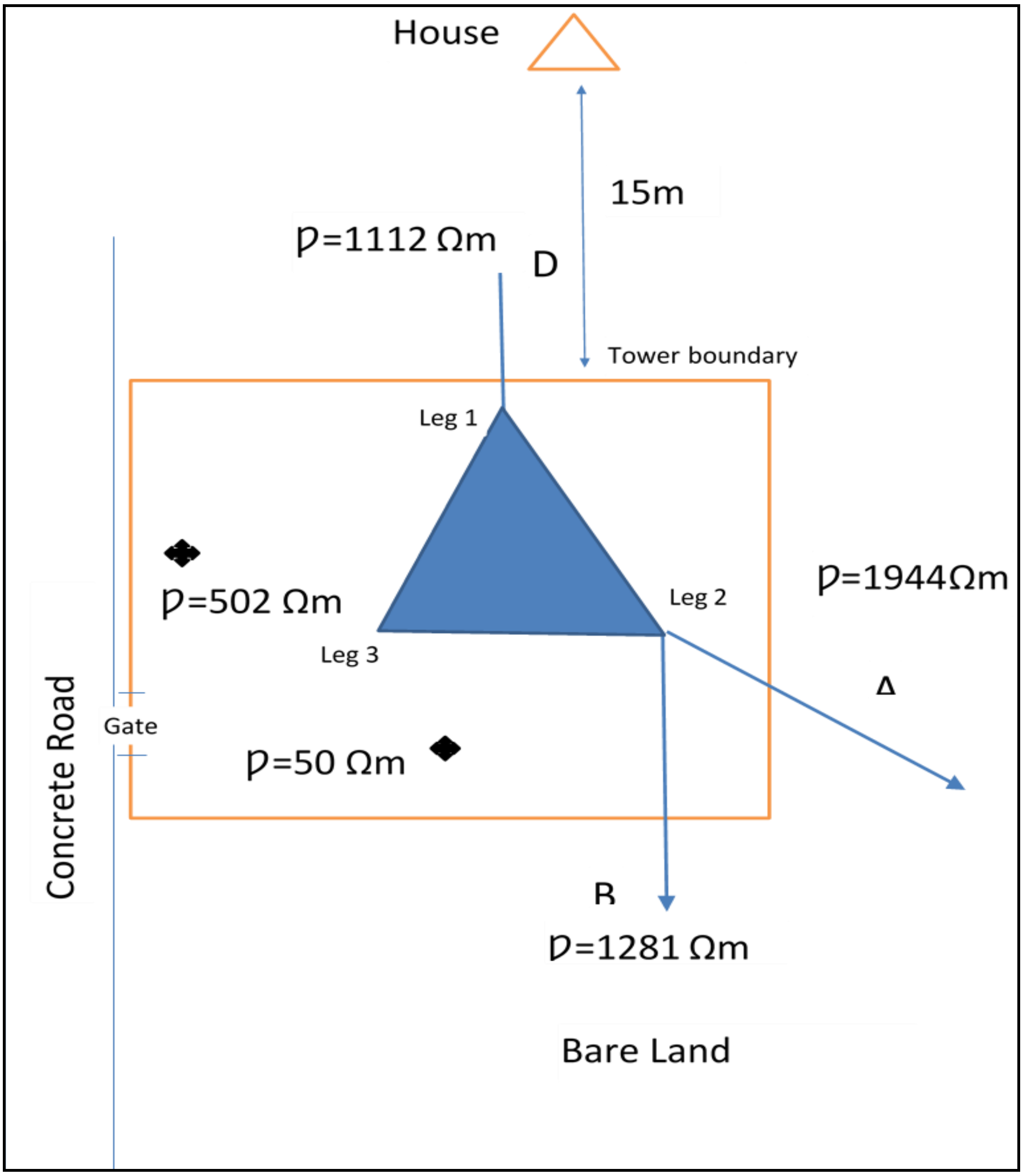
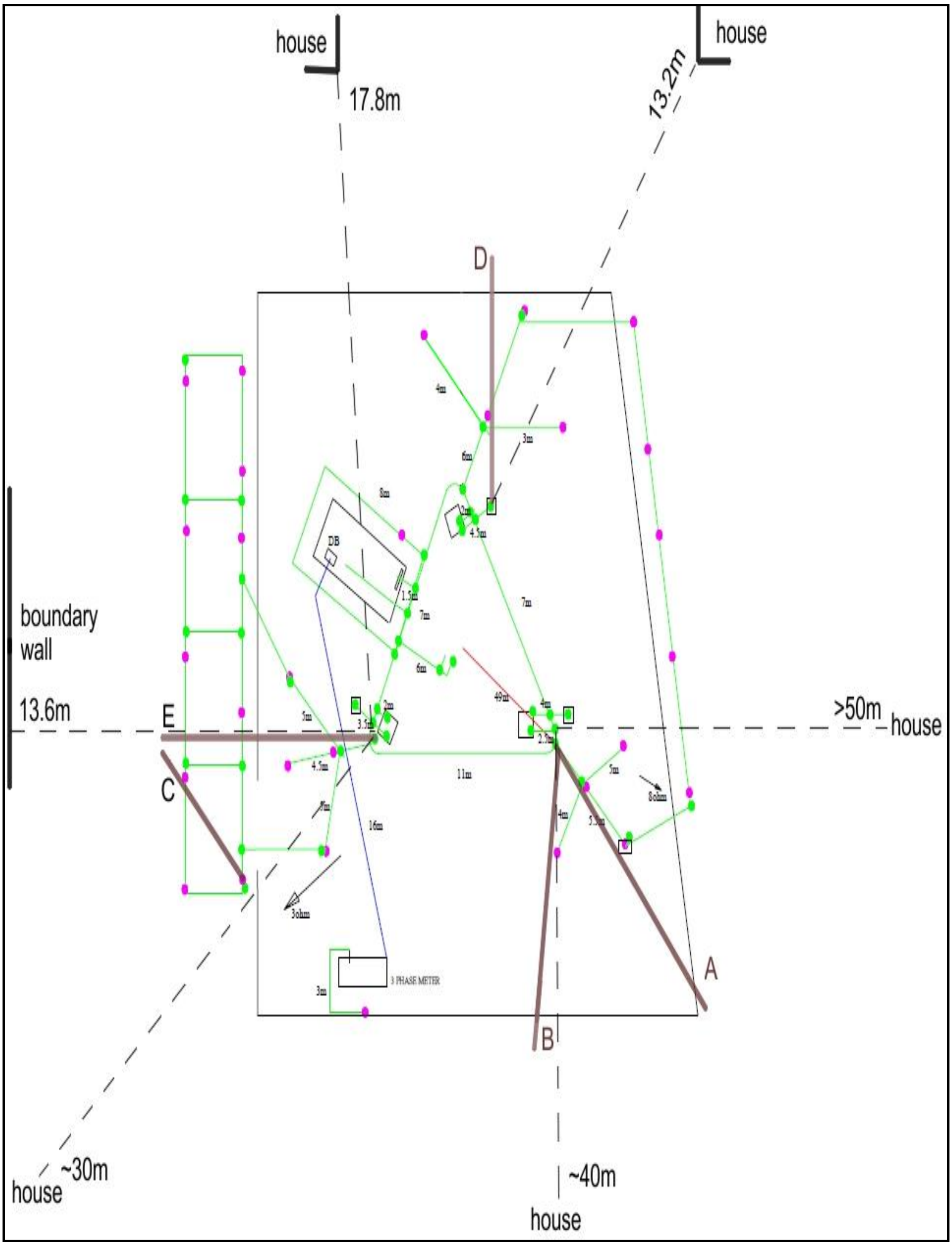


Figure 4.5 Site details of Atalugama base station

Measured earth resistances of the antenna structure along the directions of A, C and D are 27Ω ,15Ω and 12Ω respectively. Figure 4.7 shows the earth resistance against the distance. Final measured earth resistance has been selected at the distance of 10m from the tower leg which stabilizes the ER values. Toward the direction, B, it's not possible to take reading due to the high slope of the site and that has been eliminated.



5Figure 4.6 Site details of Atalugama base station [14]

4.4.1. Calculation of ER of the Atalugama Base station.

Calculated Earth Resistance of Leg A-

Parameters used-Direction A

Parameters-Direction A			
Symbol	Description	Unit	Value
ρ	Earth Resistivity	Ωm	1944
L	Copper ROD length	m	3
d	Copper ROD diameter	m	0.016
n	Number of copper rods in parallel	each	4
L	Buried Length of the electrode in m	m	50
h	Buried depth of the electrode in m	m	0.001
d	Diameter of the electrode in m	m	0.004887

Leg A		
Item	Value	Unit
$R_{g(\text{Total Earth resistance of single rod})}$	651.43	Ω
Parallel rods	3	times
$R_{g(\text{Total Earth resistance of Parallel rods})}$	217.14	Ω
$R_{g(\text{Total Earth resistance of Copper tapes})}$	128.93	Ω
Mutual Resistance	0	Ω
Total estimated resistance (neglecting mutual resistance)	80.90	Ω
With the use of GEM-	60.67	Ω

Table 4.6 Earth Resistance of Leg A

Calculated Earth Resistance of Leg C-

Parameters-Direction C			
Symbol	Description	Unit	Value
ρ	Earth Resistivity	Ωm	502
L	Copper ROD length	m	1.2
d	Copper ROD diameter	m	0.016
n	Number of copper rods in parallel	each	16
L	Buried Length of the electrode in m	m	40
h	Buried depth of the electrode in m	m	0.6
d	Diameter of the electrode in m	m	0.004887

Leg C		
Item	Value	Unit
$R_{g(\text{Total Earth resistance of single rod})}$	359.51	Ω
Parallel rods	12	times
$R_{g(\text{Total Earth resistance of Parallel rods})}$	29.96	Ω
$R_{g(\text{Total Earth resistance of Copper tapes})}$	27.94	Ω
Mutual Resistance	0	Ω
Total estimated resistance (neglecting mutual resistance)	14.46	Ω
With the use of GEM-	10.84	Ω

Table 4.7 Earth Resistance of Leg C

Calculated Earth Resistance of Leg D -

Parameters- Direction D			
Symbol	Description	Unit	Value
ρ	Earth Resistivity	Ωm	1112.8
L	Copper ROD length	m	1.6
d	Copper ROD diameter	m	0.016
n	Number of copper rods in parallel	each	12
L	Buried Length of the electrode in m	m	20
h	Buried depth of the electrode in m	m	0.6
d	Diameter of the electrode in m	m	0.004887

Leg D		
Item	Value	Unit
$R_{g(\text{Total Earth resistance of single rod})}$	629.57	Ω
Parallel rods	9	times
$R_{g(\text{Total Earth resistance of Parallel rods})}$	69.95	Ω
$R_{g(\text{Total Earth resistance of Copper tapes})}$	111.60	Ω
Mutual Resistance	0	Ω
Total estimated resistance (neglecting mutual resistance)	43.00	Ω
With the use of GEM-	32.25	Ω

Table 4.8 Earth Resistance of Leg D -measured earth resistanc of Atalugama site.

Earth resistance measured by keeping 10m span between earth electrodes.Moved the middle current probe around 10 meters and taken the value at the point of earth resistance where its stable. Figure 4.7 shows the directional behavior of mesured earth resistance.

Earth resistance of the direction B restricted only for two points due to high slope. Therefore, Earth resistance of direction D has been omitted.

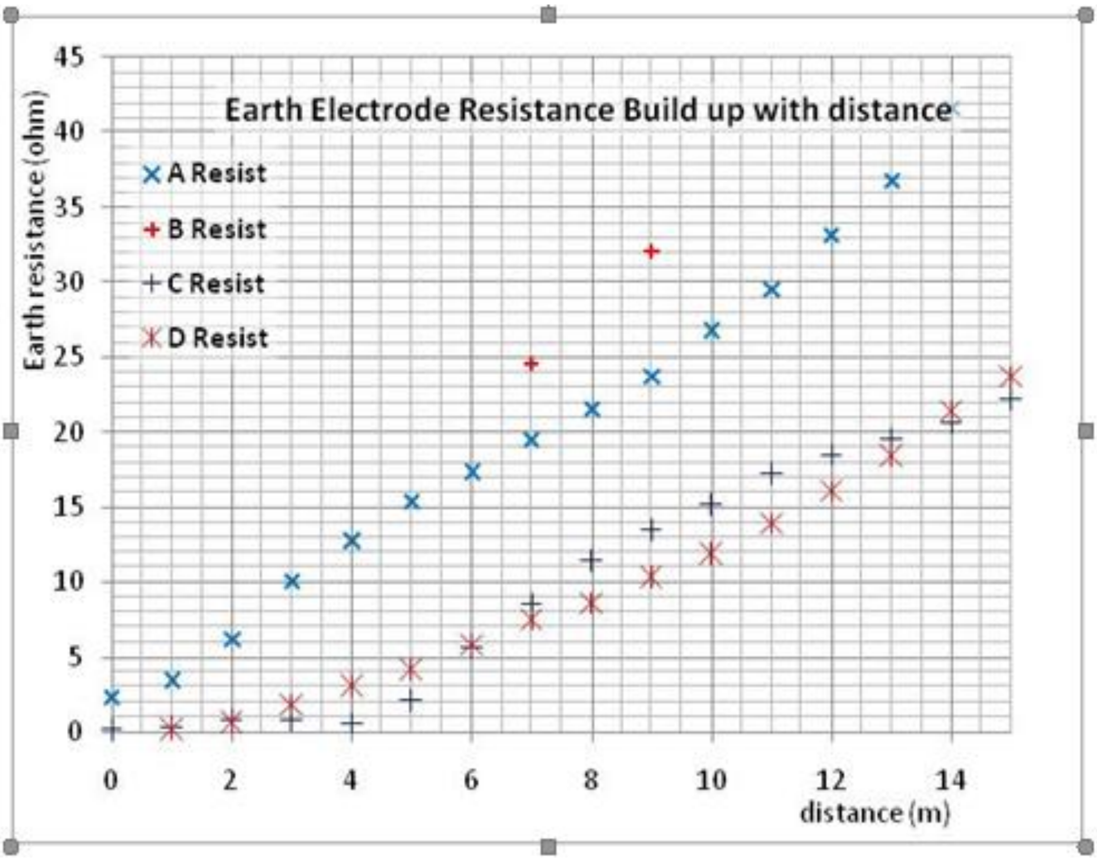


Figure 4.7 Measured earth resistance of Ataluigama base station [14]

4.4.2. Simulated earth resistance profile of Atalugama Site.

Simulation has done for the earth resistance under the Atalugama site. Actual earthing system modelled in the Ansys Maxwell and figure 4.8 shows the actual earthing distribution of Atalugama site. To make the simulation simpler, used vertical and horizontal copper tape arrangement.

Simulation has been done for all eight sites as per the figure 4.8. But for comparison, only selected three directions same as “A”, “C” and “D”. Simulated voltage of the Atalugama site inverted and with that it obtained a curve which is same as the measured value curve. Vertical nudges of the curve vary with respect to the measured earth resistance curve. But the shape of both measured and simulated curves are almost the same.

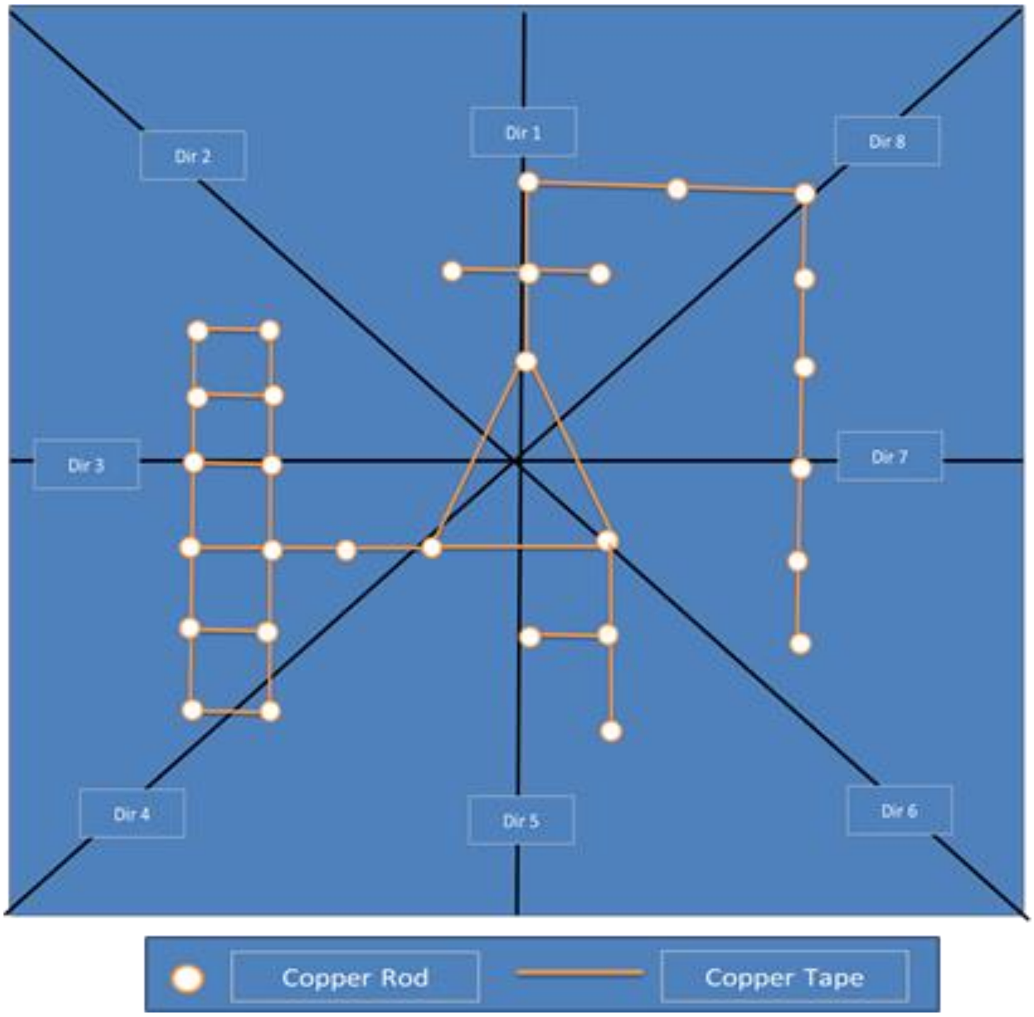


Figure 4.8 Simulated Earthing arrangment of Atalugama site

5. RESULT VALIDATION

With the calculations, measurement of Atalugama and Raddoluwa sites, it can be validated the results generated from simulation via Ansys Maxwell.

5.1. Summary of calculated and measured ER of Raddoluwa Site

As per the table 5.1 it can be observed the calculated earth resistance and the measured earth resistances are marginally the same. The highest deviation is 30% in the leg B. The lesser variation among calculated and measured earth resistance is due to the soil distribution and due to the formation of soil. The terrain of Raddoluwa site is mostly a flat terrain with same soil structure. Soil resistivity doesn't vary a lot in Raddoluwa site. But when the soil type and the elevation differs significantly the calculated values and measured values become more contradictory. This will be discussed with facts and figure in this chapter by considering Matugama and Atalugama sites as examples

Direction	Measured ER(Ω)	Soil resistivity(Ωm)	Calculated ER(Ω)	Variation
A	6	251.2	5.25	12%
B	8.1	502.4	10.5	-30%
C	7.2	345.4	7.22	0%
D	6.7	408.2	8.53	-27%

Table 5.1 comparison of Calculated and measured ER-Raddoluwa Site

5.2 Summary of calculated and measured ER of Atalugama Site

Direction	Measured	Soil	Calculated ER(Ω)	Variation
A	27	1944	60.67	-125%
C	15	502	10.84	28%
D	12	1112.816	32.25	-169%

Table 5.2 Comparison of measured and calculated ER-Atalugama Site

As per the table 5.2 towards the direction A and D it can be observed significant variation. The main cause of this variation is the differed elevation of tower legs and the different soil types.

5.2.1 Comparison of simulated and measured ER along direction A

Figure 5.1 shows the similar formation of earth resistance curves from measured values and simulated values with a rightward shifting of 8m.The vertices of the curves are due to the intersection of either copper rod or copper tape. It can observe beyond the 50m distance the earth resistance gets stabilize. Simulated inverse voltage profile shows earth resistance value even at the 0 distance and measured values don't reflect such. The reason to this is, when measuring tower leg is considered as electrode and normally it starts from 4m-8m from the center of antenna structure.

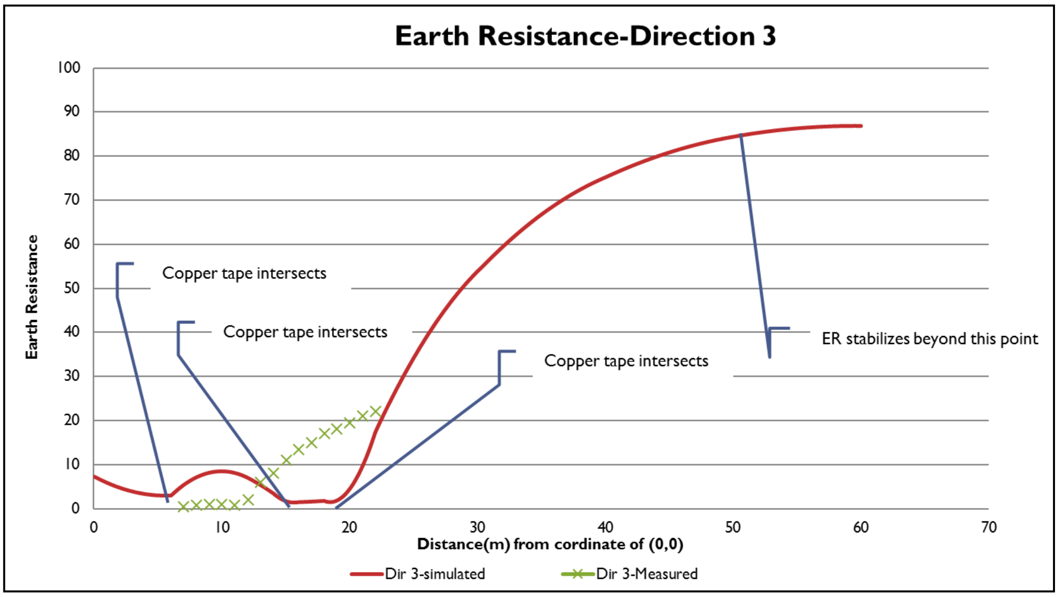


Figure 5.1 Simulation: inverted voltage profile of Atalugama site-Dir A

5.2.2 Comparison of simulated and measured ER along direction D

During the first 15 meter from the antenna structure tower leg, Earth resistance keeps as very like the measured values. Beyond the 15m point, Earth resistance of measured and simulated get bit outward relationship.

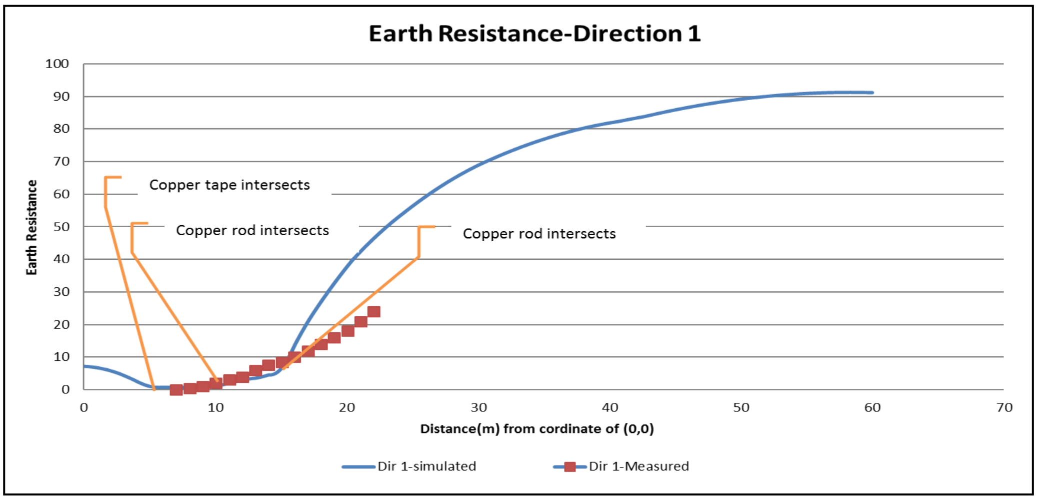


Figure 5.2 Simulation: inverted voltage profile of Atalugama site-Dir D

The measured and simulated earth resistance curve shapes are almost same as per the figure 5.3. There is a 2 m rightward shift from the measure ER.It can be observed that beyond the 50m line from tower leg, Earthing resistance gets stabilize.

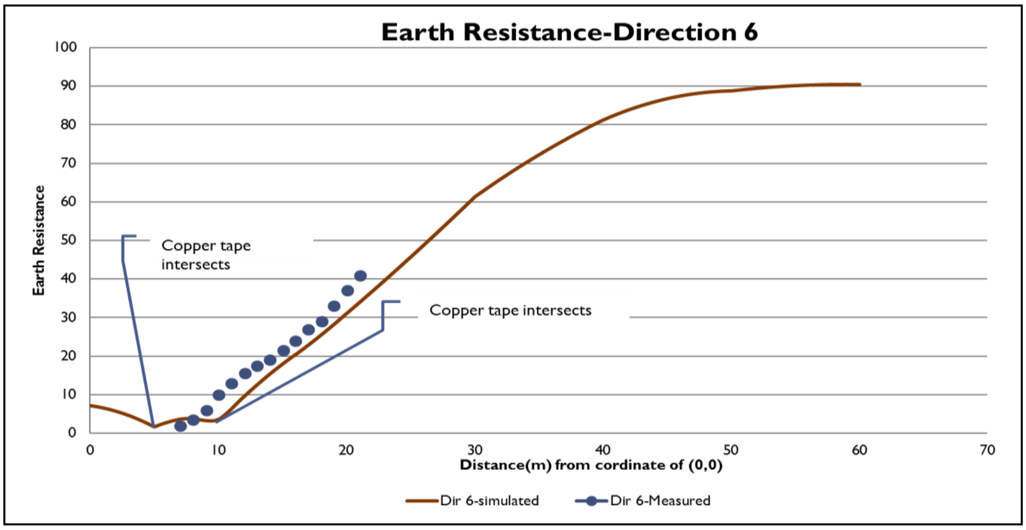


Figure 5.3 Simulation: inverted voltage profile of Atalugama site-Dir C

6. ANALYSIS OF RESULTS

6.1. Simulation of ER for different scenarios

Two scenarios defined as below to do a simulation.The purpose of the simulation is to fgure out the impact of the tower leg spacing and spacing of earthing system.

Scenario 1

Soil resistivity -100 Ωm
Dimension of Boundary -240m*240m*45m
Radius of Copper rod: 0.016 m
Height of the copper rod- 3.0m
Cross section of copper tape- 0.025m*.003m
Span of tower legs-10m
Span of copper rods-5m

Scenario 1

Soil resistivity -100 Ωm
Dimension of Boundary -240m*240m*45m
Radius of Copper rod: 0.016 m
Height of the copper rod- 3.0m
Cross section of copper tape- 0.025m*.003m
Span of tower legs-15m
Span of copper rods-7.5m

Simulation has done for a hypothetical earthing arrangment under aforesaid scenarios.Figure 6.1 and 6.3 graphically illustrate the arrangement of two earthing systems.Figure 6.2 and 6.4 conclude the voltage ditribution of the erathing arrangment.As per the voltage distribution it can be clearely obseved the distribution of voltage profile is symetrical. The reason is the symmetry of the earthing arrangement.But the voltage profile of two scenarios are different from each other.In terms of shape of the voltage profile,both are the same.As per the figure 6.5 derived inverted voltage curve towards the direction 1 and direction 2.Since the eathing arrangment is symmetrical,not considered the other directions.

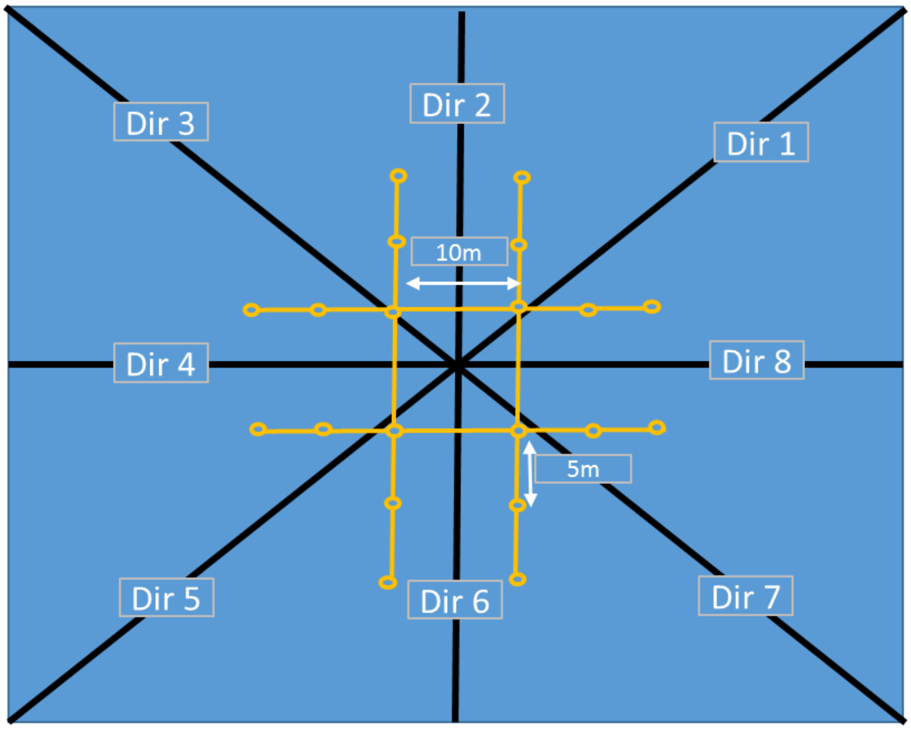


Figure 6.1 Earthing arrangement for the scenario 1

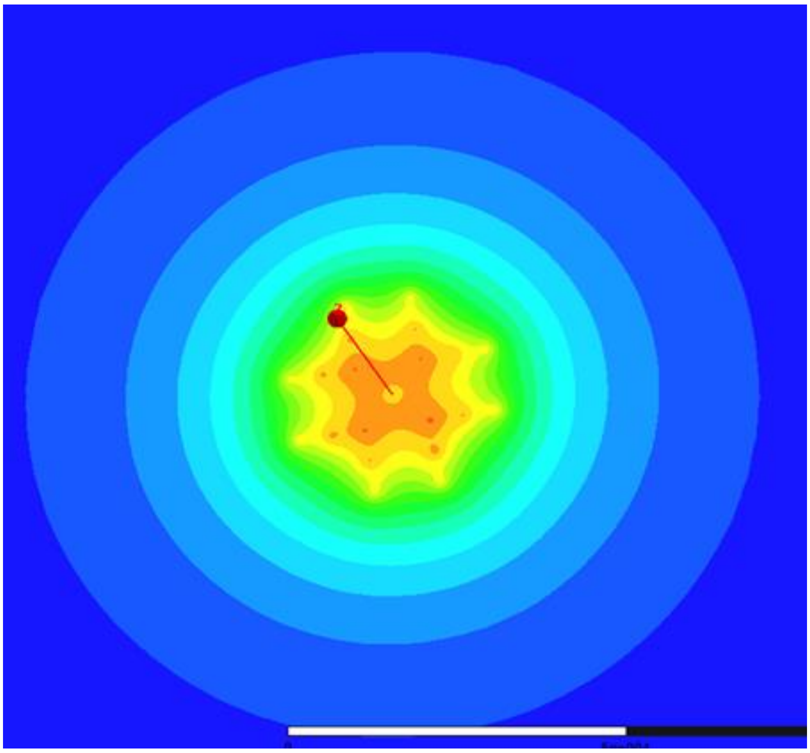


Figure 6.2 voltage distribution of scenario 1

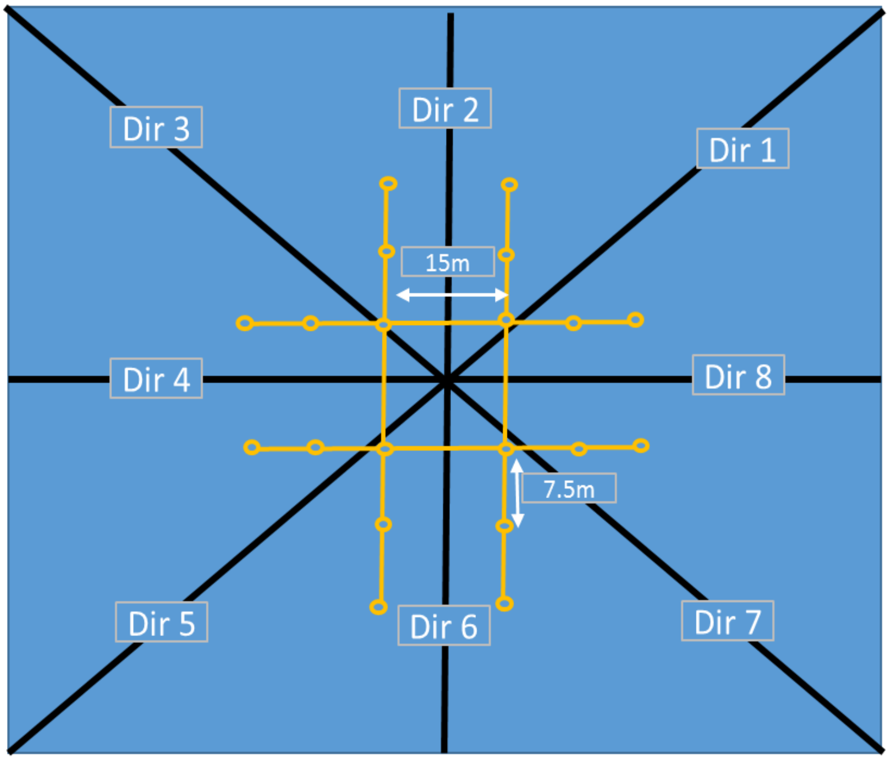


Figure 6.3 Earthing arrangement for the scenario 2

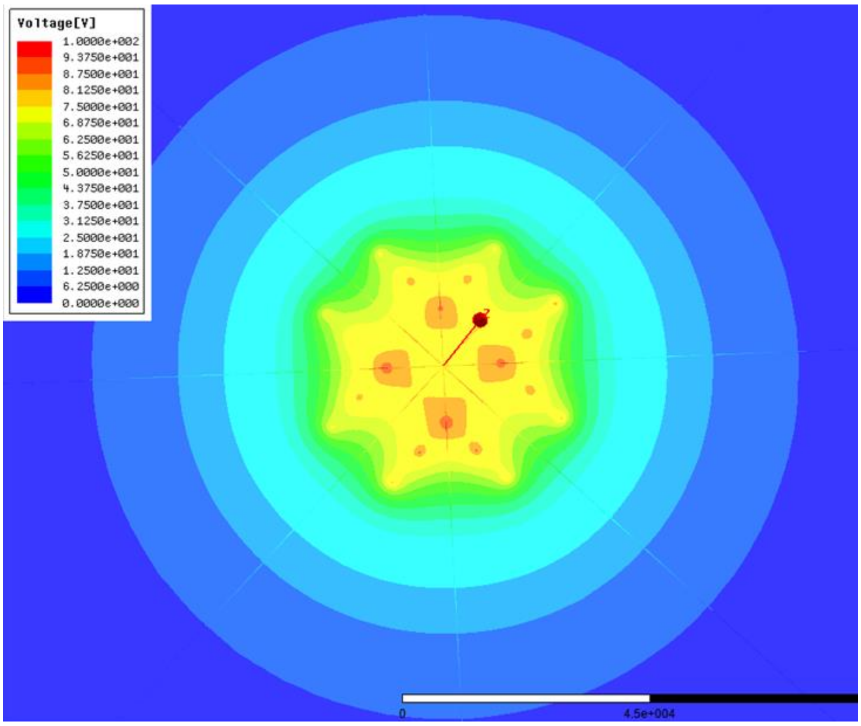


Figure 6.4 voltage distribution of scenario 2

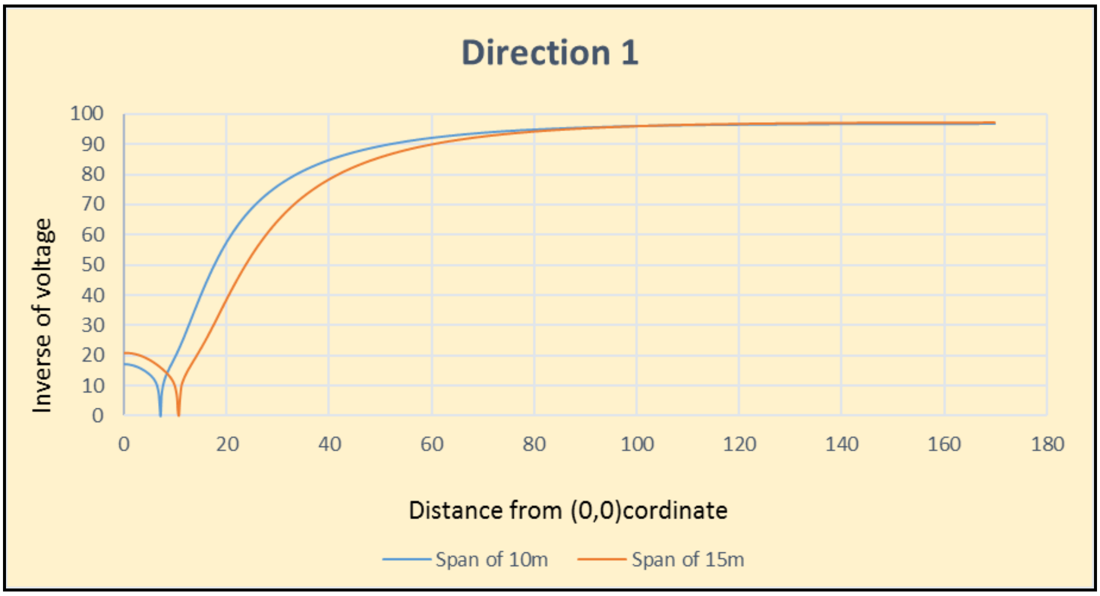


Figure 6.5 Simulation: inverse voltage profile in direction 1

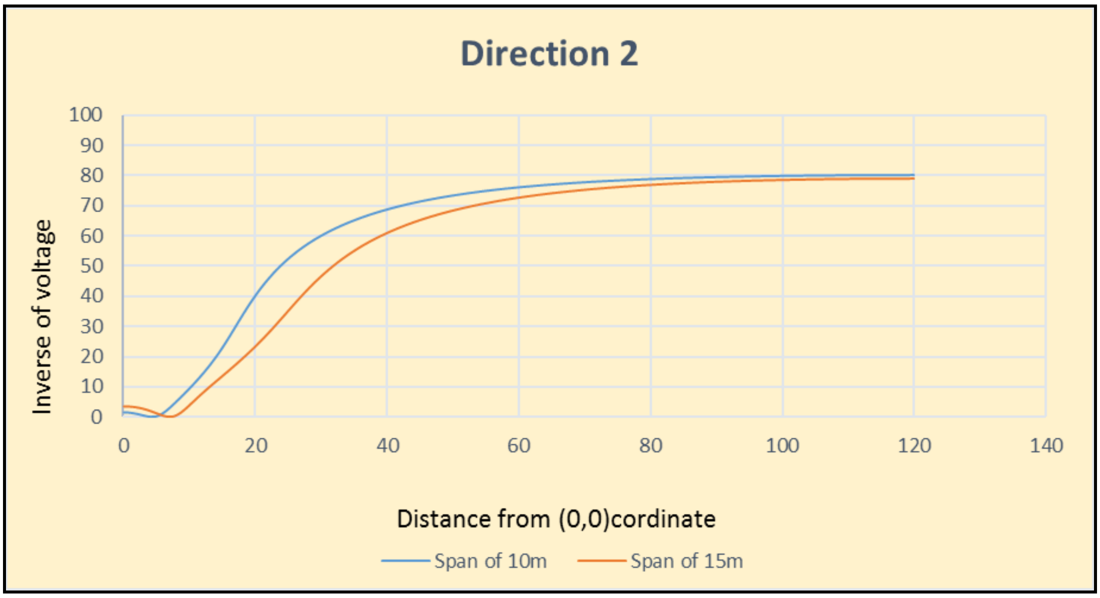


Figure 6.6 Simulation: inverse voltage profile in direction 2

As per the figure 6.5 and 6.6 it can be observed earth resistance value get stabilizes beyond the distance of 120m from the center of the antenna structure.

Currently as a practice to measure earth resistance, the extreme probe keep 20m away from the electrode. But as per the simulation, to get more accurate and effective earth resistance it's recommended to measure earth resistance by keeping the extreme peg at least 120m away from the electrode.

6.2. Directional deviations in apparent ER

6.2.1 Soil resistivity

Soil resistivity is a key parameter of deciding the earth resistance.Simulation has done while keeping all other parameters same other than the soil resitivity.Split the tower area into four imaginary parts and given differnet soil resistivity for each quadrant as per figure 6.7.

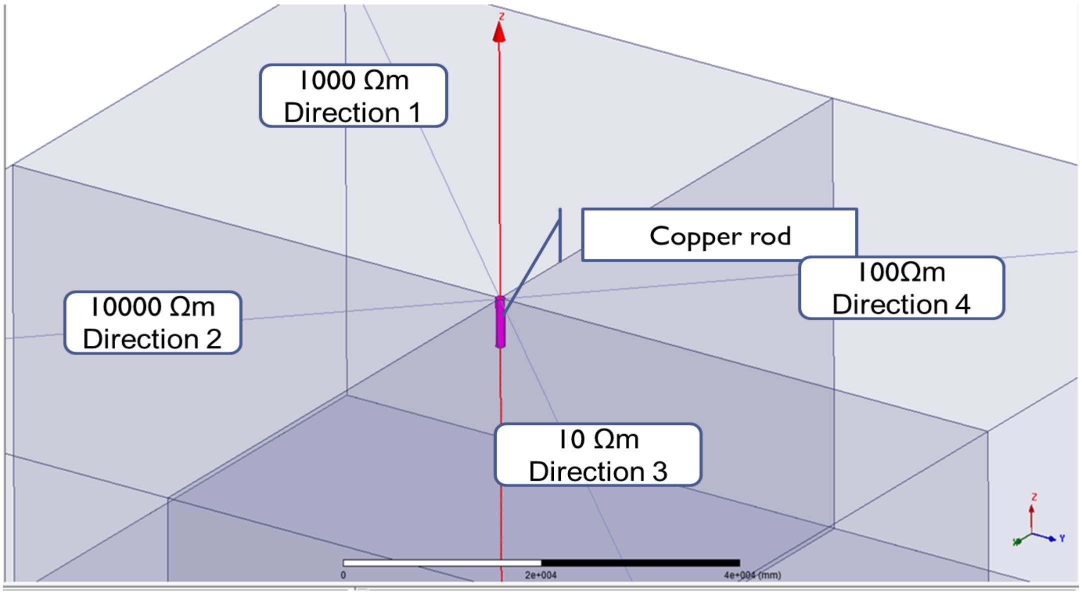


Figure 6.7 differed soil resistivity of quadrants

Voltage profile of each direction examined and all the voltage curves (figure 6.8) are almost identical though the soil resistivity changes. But the current density curves (figure 6.9) are deviated from each other. That proves earth resistance varies based upon the soil resistivity variation.

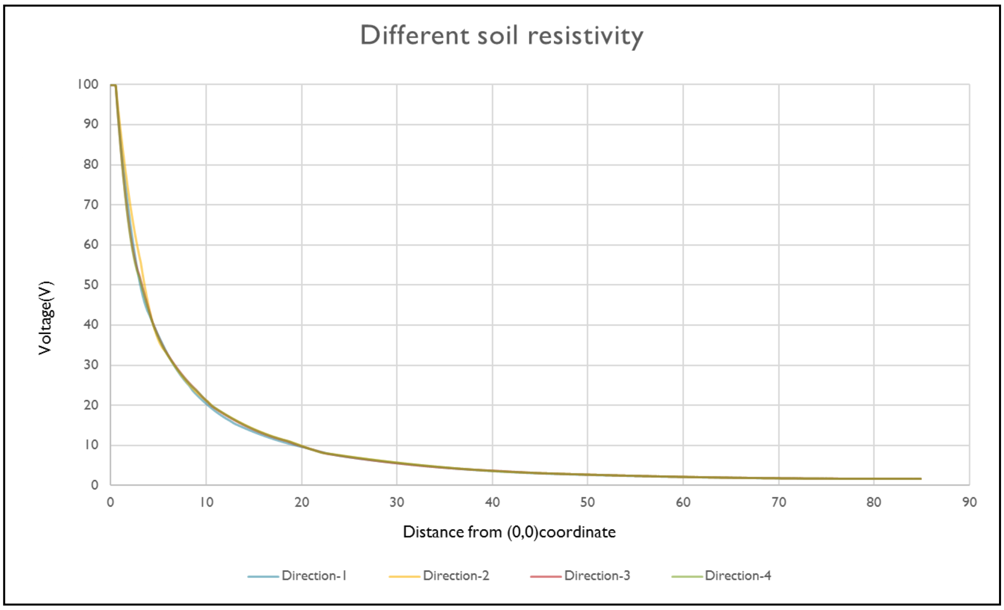


Figure 6.8 voltage profiles of different soil resistivities

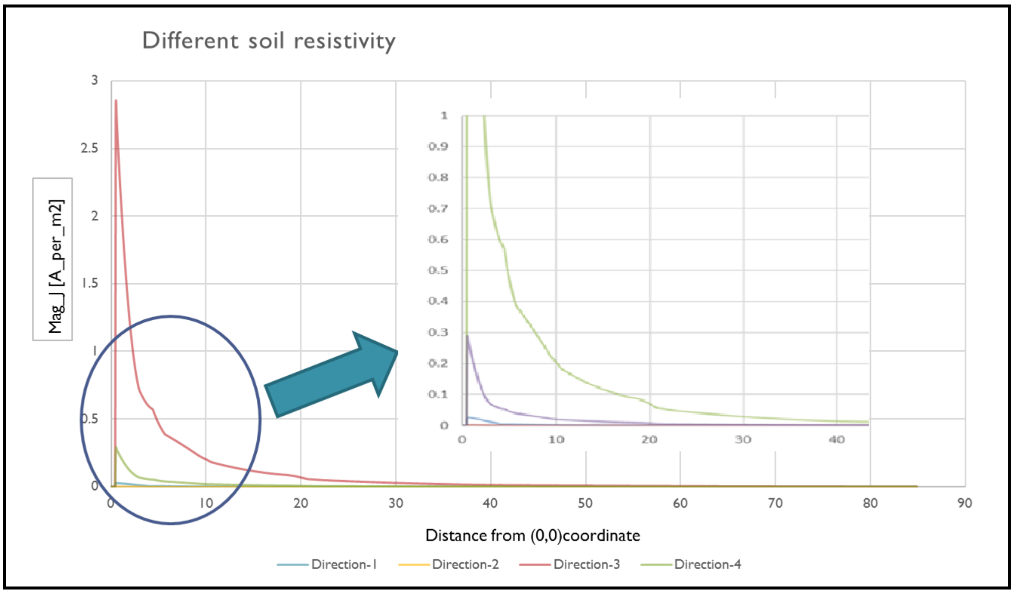


Figure 6.9 current density profiles of different soil resistivities

6.2.2 Comparative elevation of the soil layer

In the initial stage of selecting problamatic sites,different elevation is one key common feature observed. So, by keeping all other parameters same, changed only the elevation of tower area (figure 6.10).

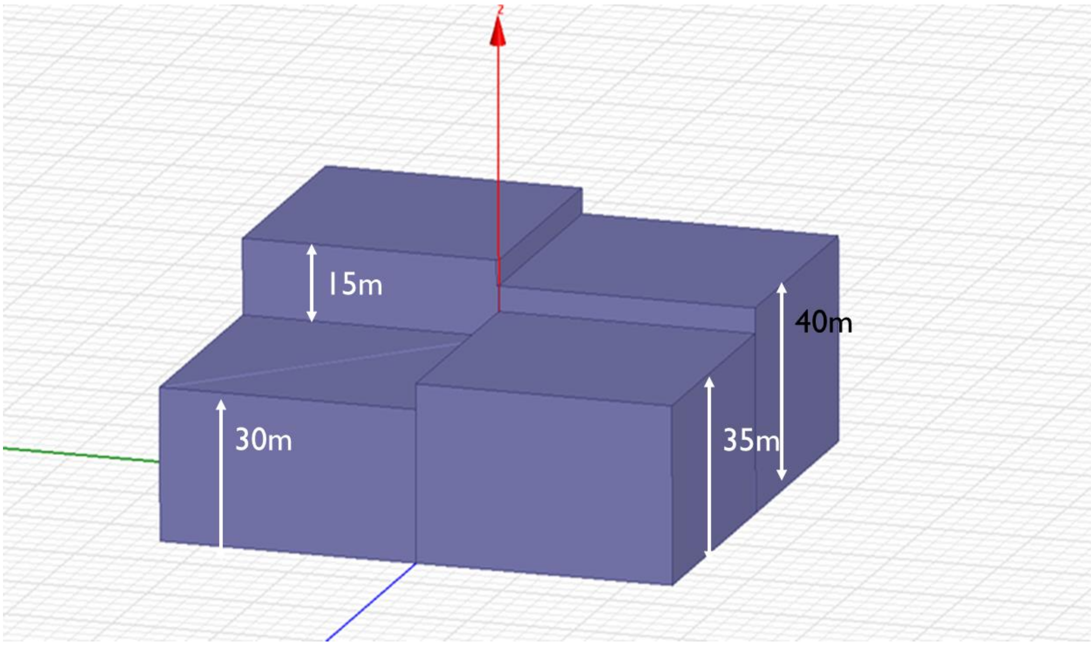


Figure 6.10 different elevation of each quadrant

As per the figure 6.11 it can be observed deviated voltage curves due to the different level of elevation. With this it implies elevation of antenna structure is a key parameter to get directionally deviated earth resistance.

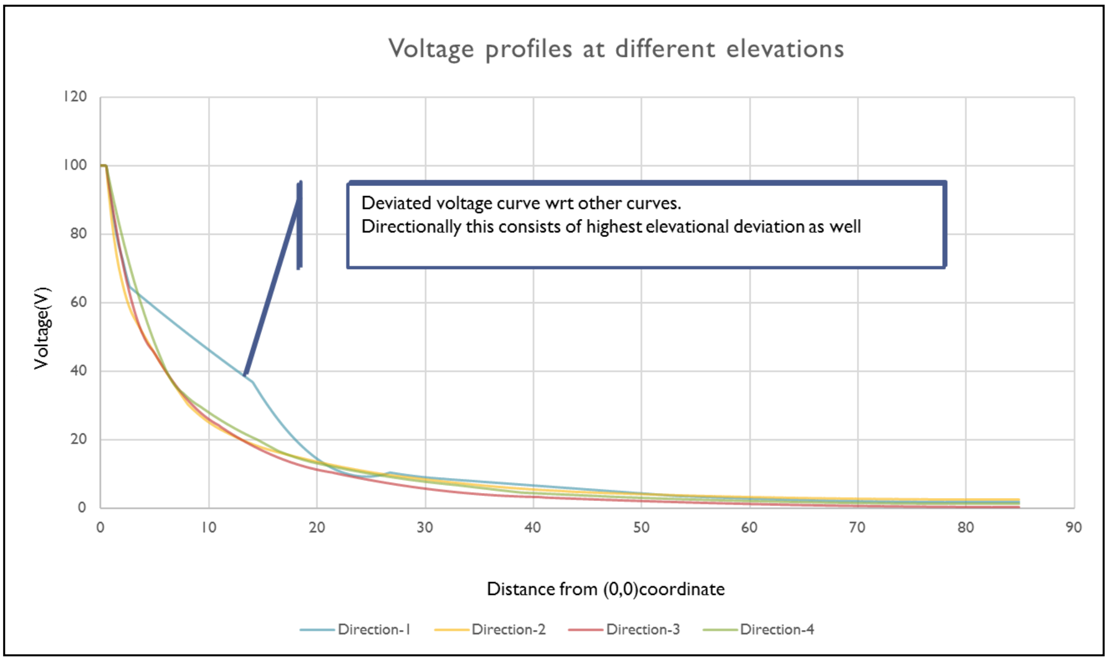


Figure 6.11 voltage curves for different elevations

Practically there are more than one soil layer vertically. But when we measure the earth resistance we dig the peg only for 15 cm. But beneath that, there are different soil layers with different soil resistivity. Therefor by keeping all parameters same changed the vertical soil resistivity as per the figure 6.12.

Top soil layer is 10Ωm and going down soil resistivity increases.

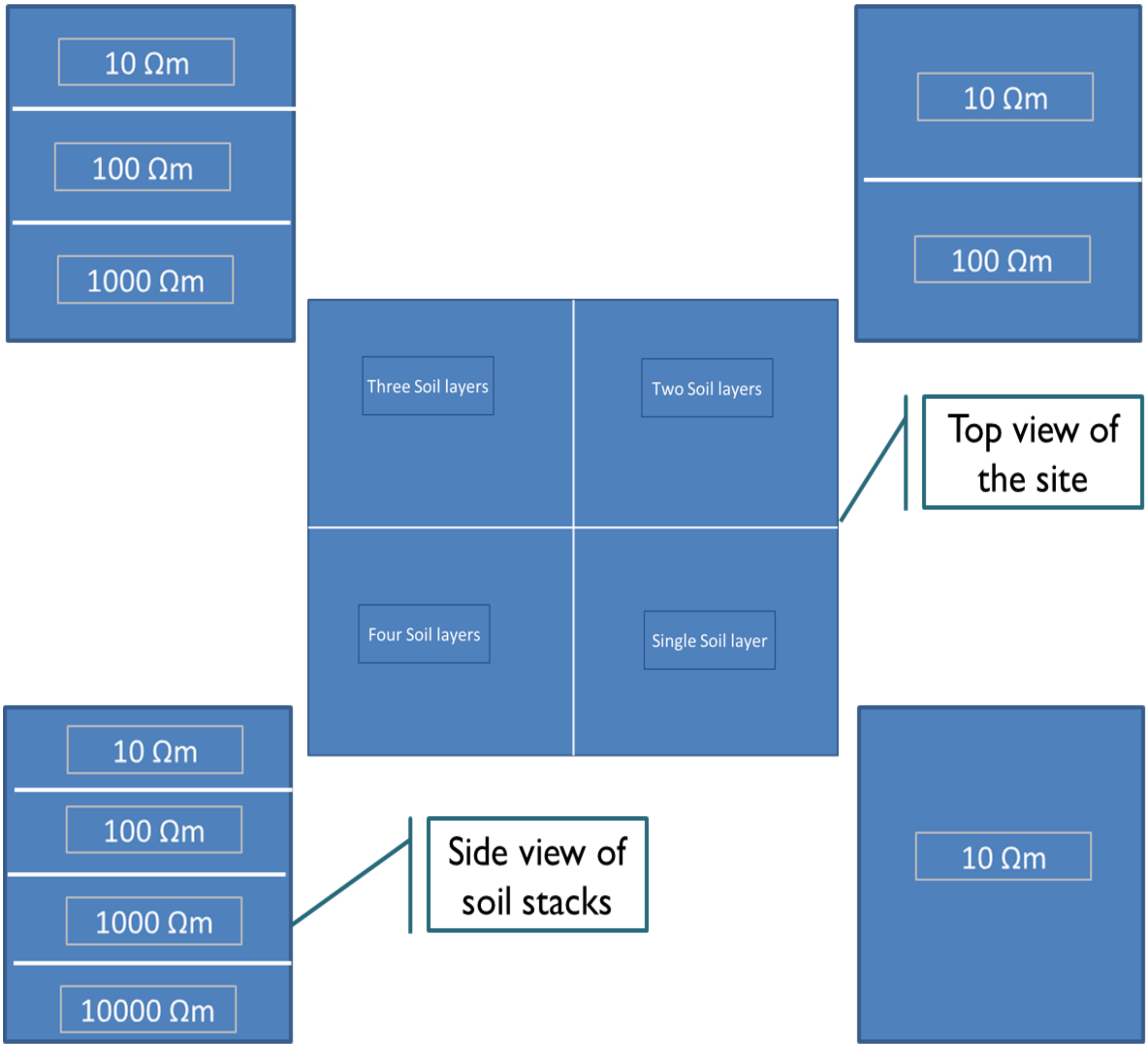


Figure 6.12 vertical soil stacks in quadrants

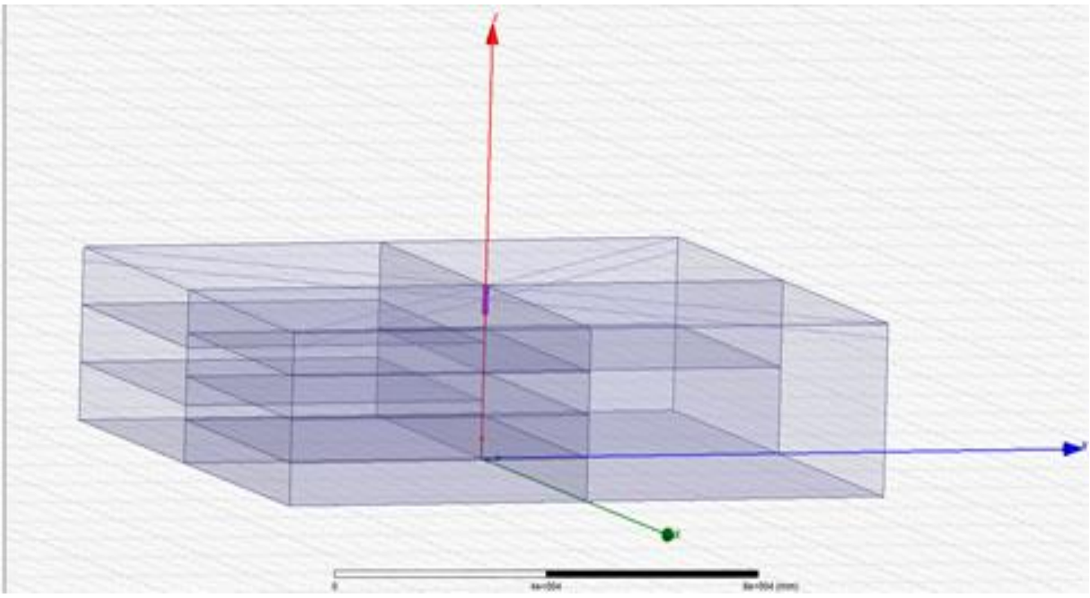


Figure 6.13 Ansys Maxwell simulation for different vertical soil resistivities

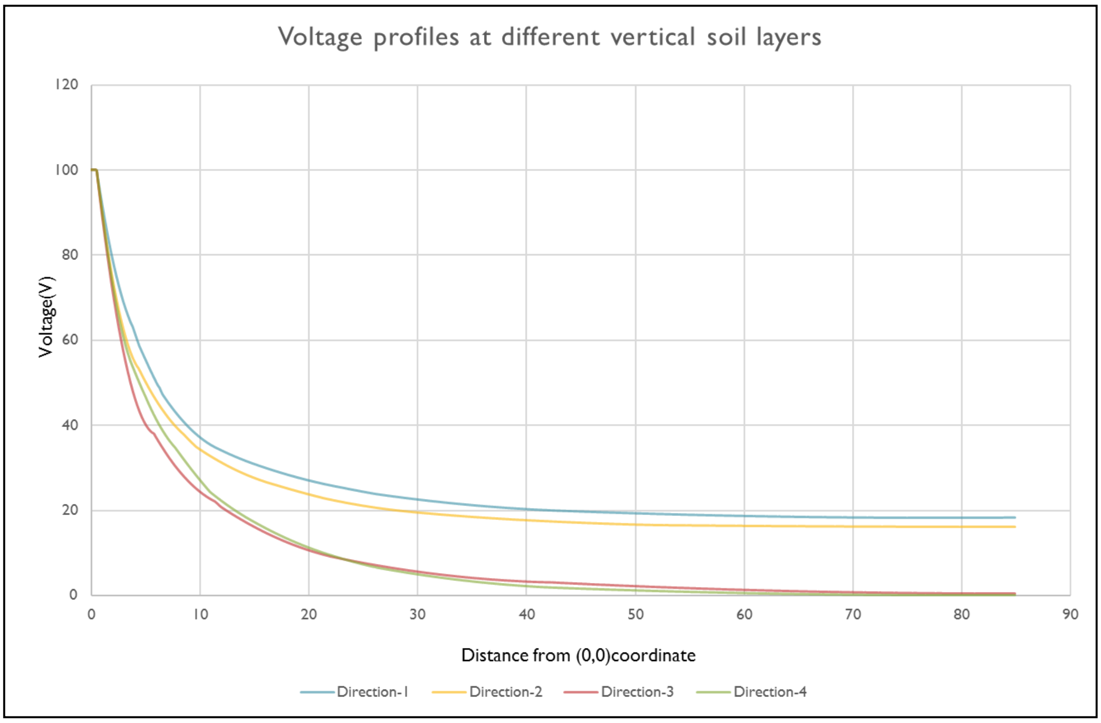


Figure 6.14 directional voltage profiles of each quadrant

When the vertical soil levels get changes the voltage profiles also change accordingly.Therefore having different soil layers is another key reason for getting deviated earth resistance in different directions.

7. CONCLUSIONS AND RECOMMENDATION

7.1 Summary of Conclusions of study

Conclusions of this study, the main resons for the directional deviation of the earth resisitance (ER) and the recommendation to measure ER with more accuracy are presented in following sections.

7.1.1 Reasons for deviated ER values

Directional deviations in apparent earth electrode resistance (ER) in earthing of antenna structures have been studied using Ansys Maxwell software and are shown to be dependent on the soil resistivity, the comparative elevation of the soil layer and on the different types of vertical soil layers. Estimated deviations in ER values have been verified in this thesis.

Verification of Simulated Soil Resistance

The result verification concludes that the deviation of simulated earth resistance against the mesured earth resistance is within the average of 35% deviation upto the distance of 20 m.The main reason of such deviation is the existing copper tapes and rods in the earthing system for which no proper earthing layout plan is available.Prior to improve in the estimate with the current work, the deviation between legs amounted to 107.3% in this particular site.

Effect of Placement of Measuring Electrodes

The study has shown that the placement of the electrodes has a great effect on the value of ER in non-homogeneous soils. For a typical problematic site, when measurements were taken at with the electrodes at 5m (potential electrode) and 10m (current electrode) the apparent ER had values of y Ω and while when the distances were increased to 10m and 20m the corresponding value was 2.8y Ω. The variation is around 280%. Since the earthing structure is large with legs 10m apart, such measurements due not yield the true ER value.

Reasons for deviated ER values, which have been verified in this thesis, and are detailed in the following sub-sections.

Soil Resistivity

Due to requirements of high coverage, antenna structures are often located on the top of a hill on rocky areas where the soil type sometimes differs in different direction. When the soil resistivity varies, the apparent ER values in different directions measured by the normal three-electrode configuration appear to be different., and one main reason for getting extreme deviations in directional ER . A typical study has shown that with.the resistivity varying by a factor of 3 in the three directions (i.e. 502 Ωm to 1944 Ωm), the apparent earth resistance in the three directions varies by 505% (i.e. 10.05Ω, 32.8Ω and 60.83Ω).

Comparative elevation of the soil layer

Base stations are not always located on flat ground. They are sometimes located on sloping land where the legs are located at different heights. In such cases, the study has shown that although other parameters remain the same, the apparent ER values get deviated a lot. A typical study with difference in elevations of the 4 tower legs of 2m has maximum deviation of measured values by 142% Therefore, another key reason for deviated ER value in directionally is the discontinuities in the soil layer.

Different types of vertical soil layers

The soil on which antenna structures are located are generally not homogeneous. When there exist different soil layers, both horizontal and vertical, the directional ER value get changed. Typical studies involving with four horizontal soil layers from 10Ωm to 10000Ωm have shown that the apparent ER varies by 800% as the highest deviation.

7.1.2 Recommendation for ER measurement

The study has shown that the placement of the electrodes has a great effect on the value of ER in non-homogeneous soils. Thus, it is recommended that map of earth electrodes must be accurately maintained and the furthermost electrode in each direction must be ended with an earthing pit to avoid the presence of earthing tapes and electrodes interfering with the measurement. The study also shows that for an antenna structure, the measurement of ER should be taken around 110 m away from the earthing pit. But considering the practical ability its recommended to measure at least by 80m away from the aforesaid earthing pits. The study has clearly shown that stabilization of values occurs beyond the distance of 120m from the center of antenna structure. Also its essential to avoid directions where additional earth electrodes have been driven when measuring ER.If the additional electrode intersects,the reading will give a false reading which is not the actual site ER.Measurements at the normal 10m or 20m distance from the electrode does not give true ER value.

7.2 Limitation of the study

The software used is not tailor made for earth resistance simulations. Ansys Maxwell is an electromagnetic simulation package. No specific software to use for earth resistance simulation in the market. Therefore, earth resistance is a derived value from voltages.

With the available resources, it's not possible to analyze on soil layer formation of sites. The current practice is to dig a hole and get a rough idea about the soil types which is not accurate.

It's hard to find the actual earthing arrangement drawings of sites. Most of the sites are upgraded in earthing arrangement and that makes things more complicated. Measurement of earth resistance is another main issue due to the hard terrains. Restrictions are there to reach other premises to get earth resistance measurement. Also, no way to measure earth resistance of sites which locate on rock since inability to dig pegs.

Furthermore, as the sites are located all over the country, there can be places where we have the access difficulties. Most of the problematic sites are in hard terrains which is very hard to reach and stay.

7.3 Recommendations for future work

This study covers the theoretical analysis on why it gets different earth resistance on different directions. As the future study this should be extended to develop a method to estimate earth resistance while having measured earth resistance values away from 120m from electrode. The existing method of measurement is not accurate since it doesn’t measure the earth resistance away from 120 m from electrode and practically it’s hard to go beyond that distance.

Also, it’s a burning issue of not having as-built earthing arrangement drawing and the drawings which are available are not accurate. Simulation methodology to estimate points of vertical rods and horizontal tapes will be very handful.

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