# INVESTIGATION ON LIGHTNING IMPACT TO NEIGHBORHOOD GROUPS DUE TO THE TELECOMMUNICATION TOWERS

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree

Master of Science

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

May 2012

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# ABSTARCT

The investigation has been conducted to study the hazardous environment created in the neighborhoods in the event of a lightning strike to the Telecommunication tower. This thesis provides comprehensive analysis on the lightning scenarios in 18 communication and broadcasting towers situated in similar and different isokeraunic contours in Sri Lanka.

The results and observation show that most of the damages reported due to the indirect lightning flashes, power line surges and step voltage in the event of lightning strike to the tower. The property damages such as patches and cracks developed in their walls and floors, the damages to electrical and electronic equipment such as electrical switch gears, bulbs, socket outlets, televisions, and radios also reported. The personal injuries were in the form of temporary paralysis due to step potential or electric shock. In one case, the victims were sleeping on floor in his home which is located around 40m away from the tower and also the altitude is low with compared to the tower ground level. In another case the victims were sitting on the chair with legs on the ground in his home which is located around 30m away from the tower and also the altitude is low with compared to the tower ground level. The descriptions indicate that they have been subjected to step potential.



The above scenarios with related to the lightning strikes to telecommunication tower going to explain with the geographical arrangement of tower surround, Earth resistance values measured, tower grounding arrangement, power line lightning protection system and the commercial power distribution to the area by Earth resistance tester, technical theories and simulation software.

The outcome also shows that equipotential bonding of the grounding system, a distributed grounding network including a ring conductor and a suitable system of surge protective devices to radio base stations and neighborhood homes play a much vital role in lightning protection of equipment and safety of neighborhood people compared to the effects of simply achieving a low grounding resistance. However, in the absence of such integrated, distributed and equipotentialized grounding system, a high value of ground resistance will sharply increase the possibility of accidents and damage.

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**ABBREVIATIONS**

| | |
|---|---|
| RBS | Radio Base Station |
| BTS | Base Transmission Station |
| DF | Direction Finder |
| GSM | Global System for Mobile |
| ESE | Early Streamer Emission |
| LPS | Lightning Protection System |
| IEC | International Electrotechnical Commission |
| SRF | Surge Reduction Filter |
| TSG | Transient Spark Gap |
| CVM | Collection Volume Method |
| MW | Micro Wave |
| ODU | Out Door Unit |
| IDU | Indoor Unit |
| TRC | Telecommunication Regulatory Commission |

# CHAPTER 1

# 1.0 INTRODUCTION

## 1.1 Lightning Severity

Lightning is a physical phenomenon that occurs when the clouds acquire charge or become polarized, so that the electric fields of considerable strength are created within the cloud and between the cloud and adjacent masses such as earth and other clouds, [1] When these fields become excessive, to the extent that the dielectric (the air) of intervening space can no longer support the electrical stress, a breakdown or lightning flash occurs; this is usually a high-current discharge.

The usual flash between the cloud and the ground is initiated in the base of the cloud. The initiating discharge, a downward traveling spark, is called the stepped leader. The stepped leader is a low-luminosity traveling spark which moves from the cloud to the ground in rapid steps about 50 yards long, and lasts less than a millionth of a second. The formation of each step of a dart-stepped leader is associated with a charge of a few milli-coulombs and a current of a few kilo-amperes, [2] the visible lightning flash occurs when the stepped leader contacts the ground. The usual stepped leader starts from the cloud without any “knowledge” of what structure or geography are present below. It is thought that the stepped leader is “unaware” of objects beneath it until it is some tens of yards from the eventual strike point. When “awareness” occurs, a traveling spark is initiated from the point to be struck and propagates upward to meet the downward-moving stepped leader, completing the path to ground. When the stepped leader reaches ground, the leader channel first becomes highly luminous at the ground and then at higher altitudes. The bright, visible channel, or so-called return stroke, is formed from the ground up, thus visible lightning moves from the ground to the cloud. In very tall structures the lightning is result of the reverse process. They are initiated by stepped leaders which start at the building top and propagate upward to the cloud.



Lightning strikes are electrical discharges caused by lightning, typically during thunderstorms. Humans can be hit by lightning directly when outdoors. Contrary to popular notion, there is no 'safe' location outdoors. People have been struck in sheds and makeshift shelters. However, shelter is possible within an enclosure of conductive material such as an automobile, which is an example of a crude type of Faraday cage.

Lightning strikes injure humans in several different ways

- Direct strike, which is usually fatal.
- Contact injury, when the person was touching an object that was struck
- Side splash, when current jumped from a nearby object to the victim
- Ground strike, current passing from a strike through the ground into a nearby victim. A strike can cause a difference of potential in the ground (due to resistance to current in the Earth), amounting to several thousand volts per foot.
- Blast injuries, either hearing damage or blunt trauma by being thrown to the ground.

Lightning strikes can produce severe injuries. These severe injuries are not usually caused by thermal burns, since the current is too brief to greatly heat up tissues, instead nerves and muscles may be directly damaged by the high voltage producing holes in their cell membranes, a process called electroporation. In a direct hit the electrical charge strikes the victim first.



If the victim's skin resistance is high enough, much of the current will flash around the skin or clothing to the ground, resulting in a surprisingly benign outcome. Metallic objects in contact with the skin may concentrate the lightning strike, preventing the flashover effect and resulting in more serious injuries. At least two cases have been reported where a lightning strike victim wearing an iPod suffered more serious injuries as a result [3]. However, during a flash the current flowing around the body will generate large magnetic fields, which may induce electrical currents within organs such as the heart. This effect might explain the cases where cardiac arrest followed a lightning strike that produced no external injuries [4].

Splash hits occur when lightning prefers a victim (with lower resistance) over a nearby object that has more resistance, and strikes the victim on its way to ground. Ground strikes, in which the bolt lands near the victim and is conducted throughthe victim and his or her connection to the ground (such as through the feet, due to the voltage gradient in the earth, as discussed above), can cause great damage.

Telephones, modems, computers and other Electrical & electronic devices can be damaged by lightning, as harmful overcurrent can reach them through the phone jack, Ethernet cable, or electricity outlet. A secondary effect of lightning on users of telephone equipment can be hearing damage, as the strike may cause bursts of extremely loud noise. Close strikes can also generate electromagnetic pulses (EMPs) - especially during 'positive' lightning discharges.

In most parts of the world, communication towers are all-metalstructures, which make them prime targets of lightning that may come within their vicinity. During the last few decades, a large number of lightning related accidents and damages have been reported in many countries in connection with communication and broadcasting tower sites (Kithil, 2006; Eriksson and Meal, 1984; Pierce, 1971) [5]. In a tower environment, lightning related hazards may occur at various stages of a lightning strike.



A lightning step leader may attach with an antenna structure, aviation warning light or signal/power cable in the tower, in which case the object which is subjected to the lightning attachment may be severely damaged. There can also be secondary effects, as the item struck by lightning may be detached from the tower or fragmented, giving rise to falling parts that will cause damage to the objects underneath or injuries to the staff at ground level. The lightning current will most probably enter the cables connected to the object struck, and flow into the signal feeding devices or power panels in the BTS causing many other hazards to both equipment and staff.

As the lightning current flow to the ground level through any possible path, melting or burning of materials and side flashing to nearby objects or antenna structures in the tower itself, may occur depending on the resistance and impedance of the path taken by the current. The lightning current, which usually shows a rapidly varying double exponential waveform with sub-microsecond to microsecond scale rise time, gives rise to a large electromagnetic field in the proximity which may induce large voltage impulses in the nearby electrical systems. Such voltage pulses may also damage the equipment.

Once the lightning current reaches the ground level, a low impedance path should be provided to that to be dissipated into earth within a very short period. In the absence of such path the current may take surface routes in the form of arcs and/or enter into electrical networks through the electrical grounding system (or even by insulation breakdown between the path of the lightning current and the electrical system). Such cases may lead to severe injuries or even death of the staff in the site and also cause heavy equipment damage and triggering of fire/explosions, etc.

## 1.2 Lightning Statistics for Sri Lanka

Over 4000 lightning cloud-to-ground flashes were recorded for 38 days during Northeast and Southwest monsoon thunderstorms. The observed maximum hourly rate during this period was found to be 104 flashes/hour. The Northeast monsoon produced over 884 cloud-to-ground flashes with a peak lightning rate of 96 flashes per hour whereas Southwest monsoon produced 3,294 flashes with a peak rate of 104 flashes per hour. Relative lightning maxima were observed over South of Baticoloa and over Ratnapura region. From the total number of flashes observed, 2.6% were positive flashes. The spatial distributions of positive flashes are not distributed uniformly over Sri Lanka. The mean peak current of 38 kA was observed for negative flashes that occur within 10 km and 250 km from the DF stations which agree with the previously reported values for tropical regions. The same for positive flashes is 32 kA. The two station DF network used in this study is accurate up to 10 km in localizing Cloud-ground flashes within any part of Sri Lanka [2].



A histogram of the lightning activity occurred in a duty-cycle of 24 hours is shown in Figure 1.1. Data are extracted from days where stations have recorded lightning activities without any interruptions. The time interval of maximum occurrence for diurnal distribution is between 1400 and 1900 hours [2].

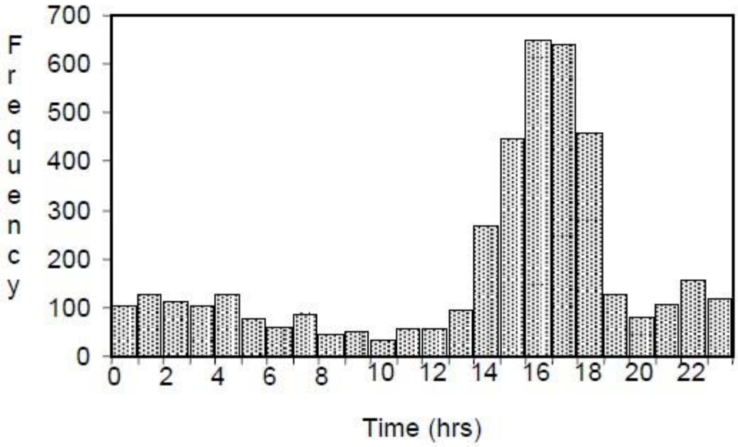



Figure 1.1: Frequency of cloud-to-ground lightning flashes vs. time of the day. Data are taken from days where stations have recorded lightning activities without any interruptions

*(Source:* A. B. Weerasekera1, D. U. J. Sonnadara1,*, I. M. K. Fernando1, J.P. Liyanage2, R. Lelwala1 and T. R. Ariyaratne, "Activity of cloud-to-ground lightning observed in Sri Lanka and in surrounding area of the Indian Ocean".)

A spatial distribution of lightning activities observed for Northeast and Southwest monsoon thunderstorms are shown in Figure 1.2. During the Northeast thunderstorms, a relative maximum was observed over the Ratnapura area. During the Southwest monsoon thunderstorms, relative maxima were observed over South of Baticaloa area and Ratnapura area. The heaviest activity of values exceeding 198 cloud-to-ground flashes per 28×28 km2 was recorded close to Ratnapura for the whole season. According to the Figures, the lightning activity is low in the north of Sri Lanka and in the south-east regions of the island close to the sea.

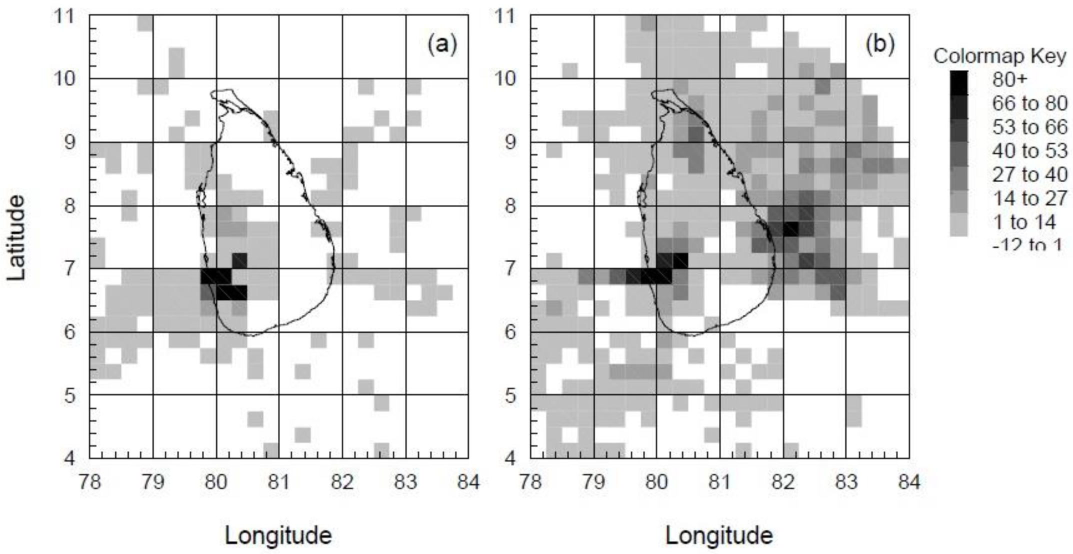



Figure 1.2: A scatter plot of reconstructed lightning flashes together with a map of Sri Lanka superimposed. (a) Flashes observed for Northeast monsoon (b) Flashes observed for Southwest monsoon.

(*Source:* A. B. Weerasekera1, D. U. J. Sonnadara1,*, I. M. K. Fernando1, J.P. Liyanage2, R. Lelwala1 and T. R. Ariyaratne, “Activity of cloud-to-ground lightning observed in Sri Lanka and in surrounding area of the Indian Ocean”.)



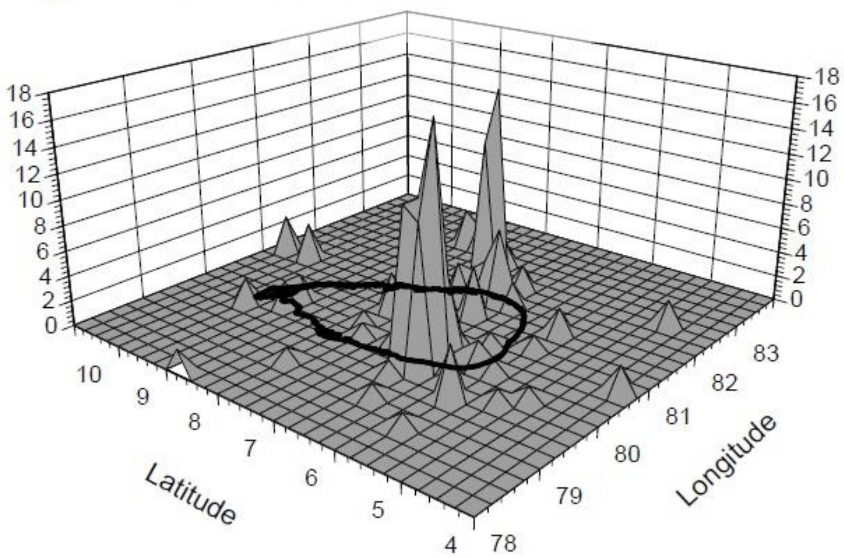



Figure 1.3: Spatial distribution of positive flashes

(*Source:* A. B. Weerasekera1, D. U. J. Sonnadara1,*, I. M. K. Fernando1, J.P. Liyanage2, R. Lelwala1 and T. R. Ariyaratne, “Activity of cloud-to-ground lightning observed in Sri Lanka and in surrounding area of the Indian Ocean”.)

Spatial distribution of the positive flashes is shown on a 3D surface map. The Figure 1.3 shows that the geographical distribution of the positive flashes is not uniform. Most of the positive flashes are concentrated in the same areas where heavy lightning activity was observed. For the present data set, average peak current values observed for negative flashes within 20 km to 120 km distance from the DF stations is 27 kA whereas for positive flashes the same is 34 kA [2].

Knowledge of the frequency of occurrence of lightning strokes is of utmost importance in the design of protection against lightning. The frequency of occurrence is defined as the flashes occurring per unit area per year. However, this cannot be measured very easily without very sophisticated equipment. This information is difficult to obtain. However, the keraunic level at any location can be quite easily determined. The keraunic level is defined as the number of days in the year on which thunder is heard. It does not even distinguish between whether lightning was heard only once during the day or whether there was a long thunderstorm. Fortunately, it has been found by experience that the keraunic level is linearly related to the number of flashes per unit area per year [6]. In fact it happens to be about twice the number of flashes/square mile/year. By assuming this relationship to hold good throughout the world, it is now possible to obtain the frequency of occurrence of lightning in any given region quite easily. The isokeraunic level map, which shows contours of equal keraunic level, for Sri Lanka is shown in Figure 1.4.




Figure 1.4: Isokeraunic Level map of Sri Lanka.

*(Source:* J R Lucas 2001, "High Voltage Engineering")

Figure 1.5 shows the Telecommunication tower distribution throughout the Sri Lanka in one of mobile telecom network. Therefor we can see that most of the towers in network are under risk of lightning in the areas of Rathnapura, Horana, Galle, Ambalangoda, Kaduwela, Gampaha, Ampara, etc as per the research conducted by Department of Physics, University of Colombo, Sri Lanka and Department of Surveying Sciences, Sabaragamuwa University of Sri Lanka

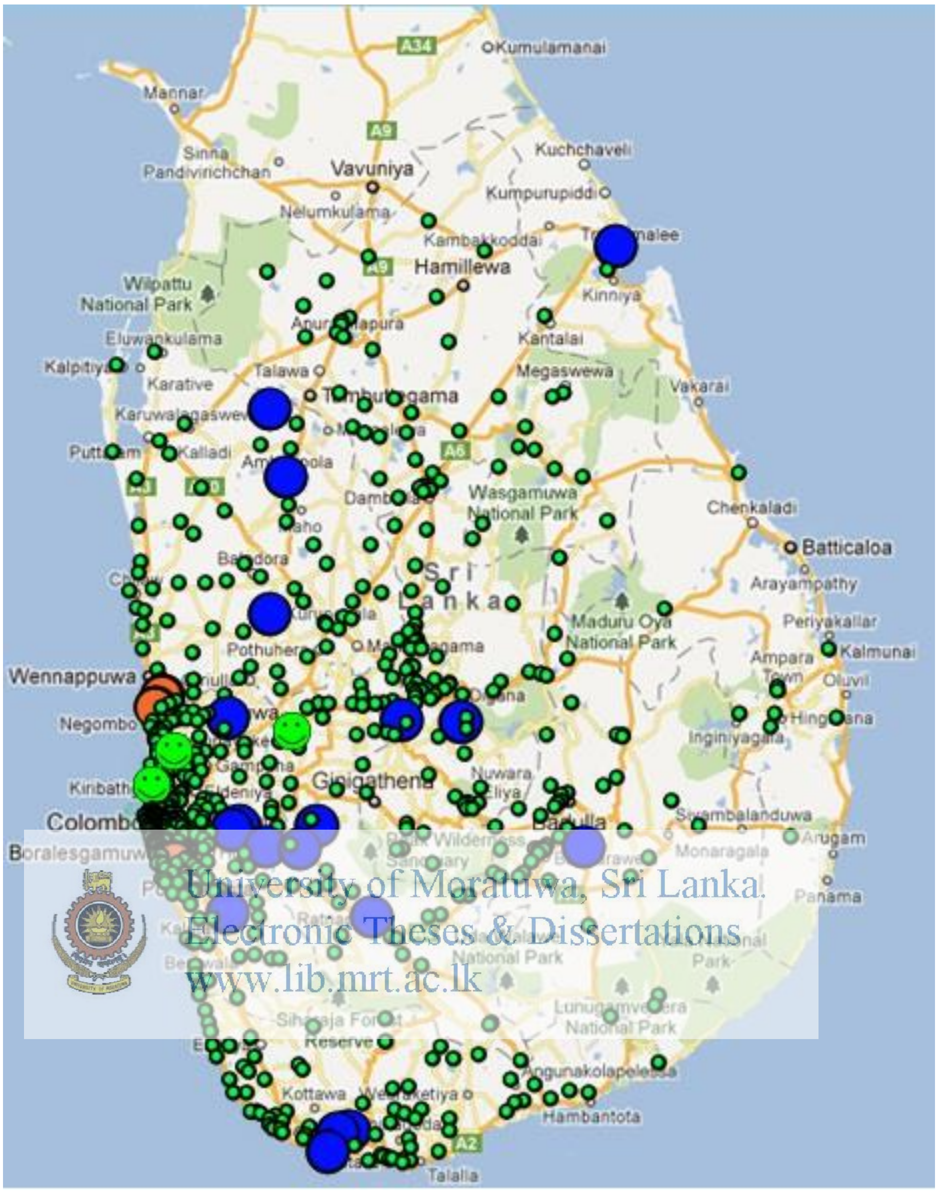





Figure 1.5: Tower distribution in Sri Lanka

*(Source:* Network Operation center data base, Etislat Lanka (pvt) Ltd)

## 1.3 Lightning Interaction with Telecommunication Towers

It has been observed that very tall towers, usually more than 100 m, is capable of initiating lightning from thunderclouds under certain conditions by launching an upward leader from the tower top all the way to the overhead cloud. Height of the tower, topography of the place where the tower is situated, the background electric field just before launching of the leader from tower top, and meteorological conditions (height of charged cloud) are some of the factors that are known to influence the lightning initiation from towers [7].

During a lightning strike to communication tower stroke currents are shared by the tower and by the shields of the cables along the tower. The currents in the tower proceed towards the grounding system (possibly a combination of counterpoises or ring conductors or ground rods or grounding grids) connected to tower legs' foundation [8].

### 1.3.1 Direct and Indirect effect of Lightning strike on Structures

If we consider the network each and every tower installed with an Air terminal on the top of the telecommunication tower to intercept with lightning stepped leader. Generally, Air Terminal covers all antenna structures in the tower within a cone of vortex angle 45 [5]. There is no any damage reported to the tower mounted equipment from the direct lightning strikes or from any bypass. But we have observed few incidents where some of lightning flashes strike to the neighborhood structures such as homes and plantations. These incidents have been investigated by using collection volume method and other lightning cases reported in the world.



A new methodology, the Collection Volume Method, is given for the placement of lightning rods or air terminals for the protection of tower structures against lightning. The calculations of the attractive radii also depend on the upward leader inception criterion employed, in the present case a critical breakdown field of 3 MV/mover an effective space charge or corona radius of 0.3 m, both taken from laboratory experiments of previous investigations [14]. The attractive radius computations involve three-dimensional calculations of the electrostatic field on the surface and immediately around the structure, i.e. the degree of electric field intensification created by the penetration of the structure into the ambient field of the thunderstorm.
In This method proposed a striking distance model that depended on the structure parameters as well as the prospective peak stroke current. In particular, this model took into account the electric field intensification factor, Ki , of a grounded structure of height H. Ki is the ratio of the intensified electric field at the structure top to the value E0 of the ambient field. Hence, the basic electrogeometric model was improved with a more physical basis, since [14].

$$d_s = f(I_p, K_i)$$

CVM considered the approach of a linearly charged downward leader or downward leader branch and evaluated the electric field strength developed at the top of the structure and at the ground below the leader, as shown in Figure.1.6. When the ambient electric field is of sufficient strength, i.e., downward leader sufficiently close to the structure, an upward leader will be initiated from the structure. The distance of the downward leader at this point is commonly used to define the striking distance $d_s$.

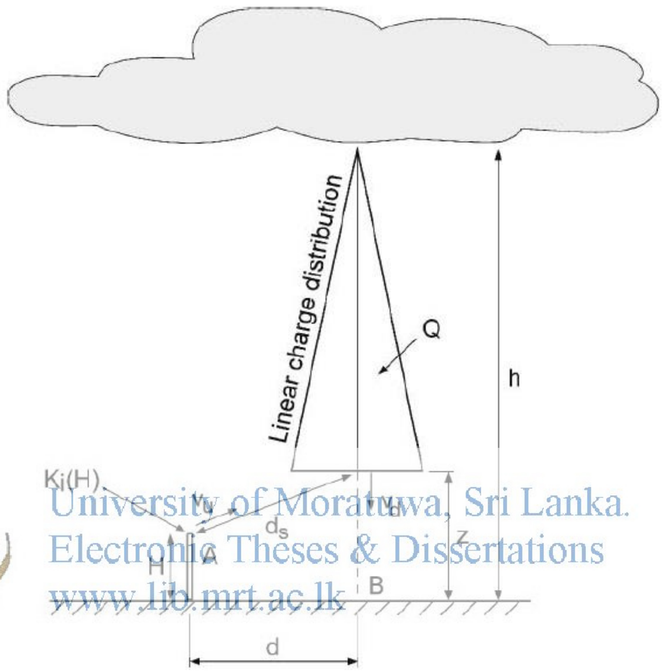





Figure 1.6: Model of downward leader approach to a structure at some arbitrary lateral distance d.

*(Source:* F. D'Alessandro, J.R. Gumley," A Collection Volume Methoda for the placement of air terminals for the protection of structures against lightning," ERICO Lightning Technologies, G.P.O. Box 536, Hobart, Tasmania 7001, Australia Received 25 May 2000; received in revised form 14 November 2000; accepted 28 November 2000)

The upward leader inception field $E_m$ for the structure tip and the ground is 3.1 MV/m under standard atmospheric conditions [14]. Depending on the lateral displacement of the downward leader, at some stage the electric field at the structure tip (A), over the critical radius, or at the ground below (B), will exceed $E_m$, yielding an upward leader and a potential attachment point. Clearly, the electric field intensification factor of the structure determines which of these occurs first and for what displacement of the downward leader.

$$I_p = 29.4Q^{0.7}$$
$$E_A = \frac{Q}{\pi\varepsilon d^2(h/d - z/d)^2}\left[\frac{(h/d - z/d)}{\{1 + (z/d)^2\}^{0.5}} + \sinh^{-1}\left(\frac{z}{d}\right) - \sinh^{-1}\left(\frac{h}{d}\right)\right]$$

$$E_B = \frac{Q}{\pi\varepsilon(h - z)^2}\left[\left(\frac{h - z}{z}\right) + \ln\left(\frac{z}{h}\right)\right].$$

Using above equations, for a given charge Q on the downward leader, a striking distance surface can be defined above the structure. This involves set of iterative calculations and the result of such calculation shown in below Figure 1.7(a). Also we can show that for a given structure height *H*, the points (*d*, *z*) satisfying below equation trace out a parabolic volume above the structure [14].

$$z = \left[\frac{d^2 + H^2}{2H}\right]$$

Once again, these points are obtained through a set of iterative calculations for different lateral displacements of the downward leader. Hereafter, we refer to this limiting region (*d*, *z*) as the velocity derived boundary. The result of such a calculation is illustrated in Figure 1.7 (b).

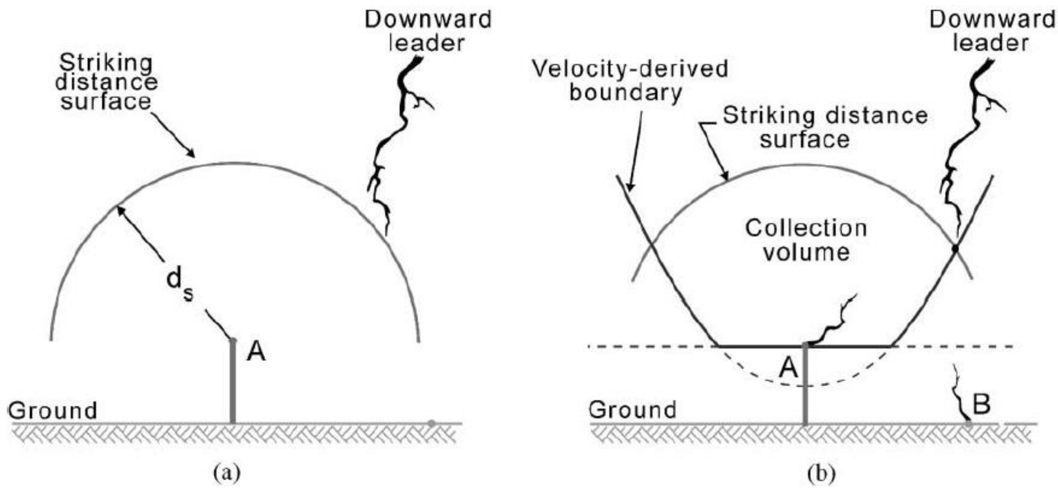



Figure 1.7 (a) Iterative calculations which apply the leader inception criterion give rise to a striking distance surface above the point. (b) Application of a leader propagation and interception criterion leads to a `velocity-derived boundary, completing the `collection volume of the point on the structure.

*(Source:* F. D'Alessandro, J.R. Gumley," A Collection Volume Methoda for the placement of air terminals for the protection of structures against lightning," ERICO Lightning Technologies, G.P.O. Box 536, Hobart, Tasmania 7001, Australia Received 25 May 2000; received in revised form 14 November 2000; accepted 28 November 2000)



The basic model reveals that, even though an upward leader may be initiated from the structure, the flash will still terminate on the ground for lateral distances between the advancing downward leader and the structure which exceed the limiting value d. This propagation-related criterion adds a considerable amount of conservatism to the definition of the capture area of the structure. Hence, a particular structure will only intercept those downward leaders that enter the appropriate collection volume, which is defined by the striking distance surface and the velocity-derived boundary.

The sectional radius of the collection volume for a given downward leader charge (or striking distance surface) is called the attractive radius, Ra, of the structure.

For slender structures, it is possible to derive a generalized relationship between attractive radius ($R_a$), structure height and peak current for a given velocity ratio. For Velocity ratio $K_v$=1,

$R_a = 0.84 I_p^{0.74} H^{0.6}$

Hence, for a given structure, the attractive radius varies on a stroke by stroke basis, depending on the relative stroke intensities (peak currents). If an average attractive radius is required, then it is necessary to compute the `probability weighted attractive radiusa using a frequency distribution of peak currents. Such a calculation weights the attractive radius according to the relative percentage of peak currents in a standard distribution, such as the one shown in Figure 1.8.

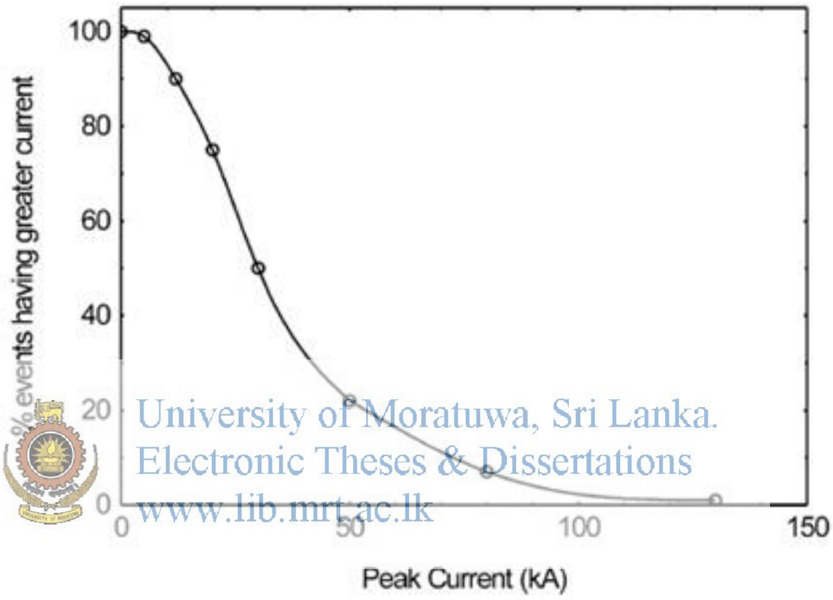





Figure 1.8 Typical cumulative frequency distribution of lightning peak current amplitudes (e.g., as in IEC Standard 1024-1-1: `Protection of structures against lightning)

*(Source:* F. D'Alessandro, J.R. Gumley," A Collection Volume Methoda for the placement of air terminals for the protection of structures against lightning," ERICO Lightning Technologies, G.P.O. Box 536, Hobart, Tasmania 7001, Australia Received 25 May 2000; received in revised form 14 November 2000; accepted 28 November 2000.)

The percentage of positive flashes and average peak lightning current values for negative flashes are found to be 6.4% and 36 kA respectively for the Northeast monsoon period and 1.7% and 40 kA respectively for the Southwest monsoon period for the flashes that struck within 10-250 km range. No significant difference in average peak lightning current values was observed for the negative and positive flashes in both monsoons.

Therefore for the 60m height Telecom tower, the attractive radius is 150m for negative flashes as we consider the areas in southwest region.

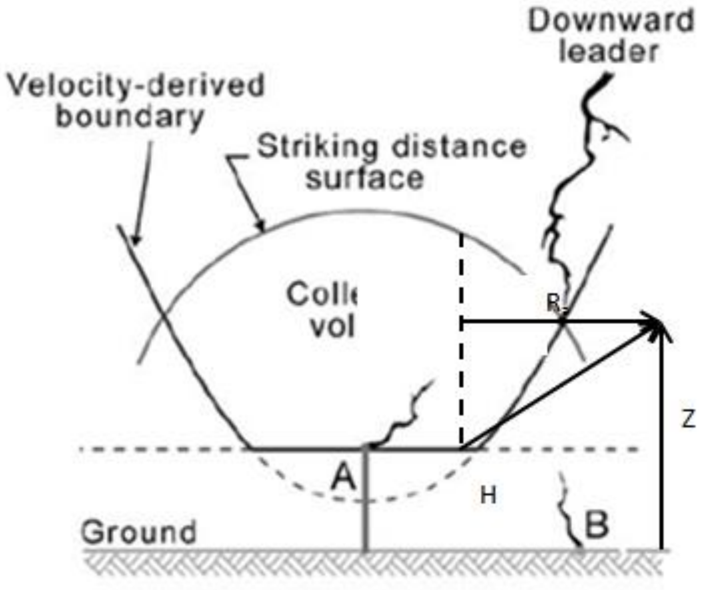



Figure 1.9: Collected volume for 60m height Tower

*(Source:* Author)



Ra=150m, Z = 247.5m

Practical experience has shown that lightning occasionally strikes the:

(i) sides of these structures (hereafter termed `side strikes),

(ii) ground or other lower structures within the so-called shielding zone of the structure.

There are theoretical reasons for believing that only flashes with low currents are likely to penetrate below the upper part of the structure to strike the sides, or sub-structures at a lower level. No lightning protection design is 100% safe and these rare side strikes are usually accepted as part of the `shielding failure rate, e.g., the 2% (maximum) of low energy strikes in a 98% lightning protection design [14]. To reduce the probability of strikes to sub-structures near ground level and within the assumed shielding zone of a tall structure, a derating angle can be applied to the collection volume attractive radius an apparently safe overlap of capture areas in plan view is derated due to the excessive vertical separation of capture areas, as shown in Figure.1.10

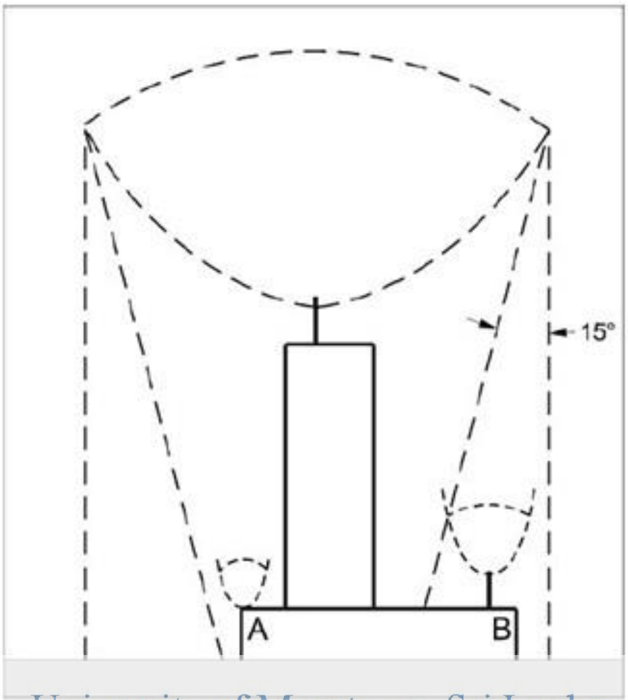





Figure 1.10: Application of collection volume derating to tall structures.

*(Source:* F. D'Alessandro, J.R. Gumley," A Collection Volume Methoda for the placement of air terminals for the protection of structures against lightning," ERICO Lightning Technologies, G.P.O. Box 536, Hobart, Tasmania 7001, Australia Received 25 May 2000; received in revised form 14 November 2000; accepted 28 November 2000.)

The natural collection volume of point A is within the (derated) capture area of the main structure, whilst point B requires additional protection because its volume falls outside the area.

Firstly, it is important to relate the basic CVM theory to the probabilistic nature of lightning strikes. In this way, a risk analysis can be introduced into the lightning protection design. The striking distance surface can be used to assign a protection level according to the statistical risk of bypass of the collection volume. Table 1.1 gives some typical levels of protection based on a standard cumulative frequency distribution of lightning stroke currents such as that shown in Figure. 1.8. Table 1.1 show that 98% of all lightning fishes have a peak stroke current exceeding 6.5 kA. Hence, a collection volume bounded by a striking distance surface derived with a downward leader charge of 0.5 C will, on average, capture 98% of all strikes. The remaining 2% of low-energy strikes will not necessarily bypass the point with the designated collection volume [14]. The direction of approach is crucial a higher risk is associated with an obliquely approaching downward leader (or branch thereof) on the periphery of the collection volume.

Risk analysis and protection levels based on lightning statistics

| Leader charge $Q$ (C) | Peak current $I_p$ (kA) | % strikes $> I_p$ |
|---|---|---|
| 0.5 | 6.5 | 98 |
| 0.9 | 10 | 93 |
| 1.5 | 16 | 88 |

Table 1.1 Risk analysis and protection levels based on lightning statistics

*(Source:* F. D'Alessandro, J.R. Gumley," A Collection Volume Methoda for the placement of air terminals for the protection of structures against lightning," ERICO Lightning Technologies, G.P.O. Box 536, Hobart, Tasmania 7001, Australia Received 25 May 2000; received in revised form 14 November 2000; accepted 28 November 2000)



For easy explanation, we can consider a lightning incident happen in Villaputri Building, downtown Kuala Lumpur in year 2005. This 170 meter high building was installed with two Dynasphere air terminals. The unique feature of this building is that most of the corners are curved instead of angular thus giving the two Dynasphere air terminals the maximum opportunity to collect all lightning strikes that come within their claimed enhanced "collection volumes". However, several bypasses have been observed as shown in below Figure on the curved corners which are not supposed to have any collection volume, thus dispelling the CVM hypothesis [15].

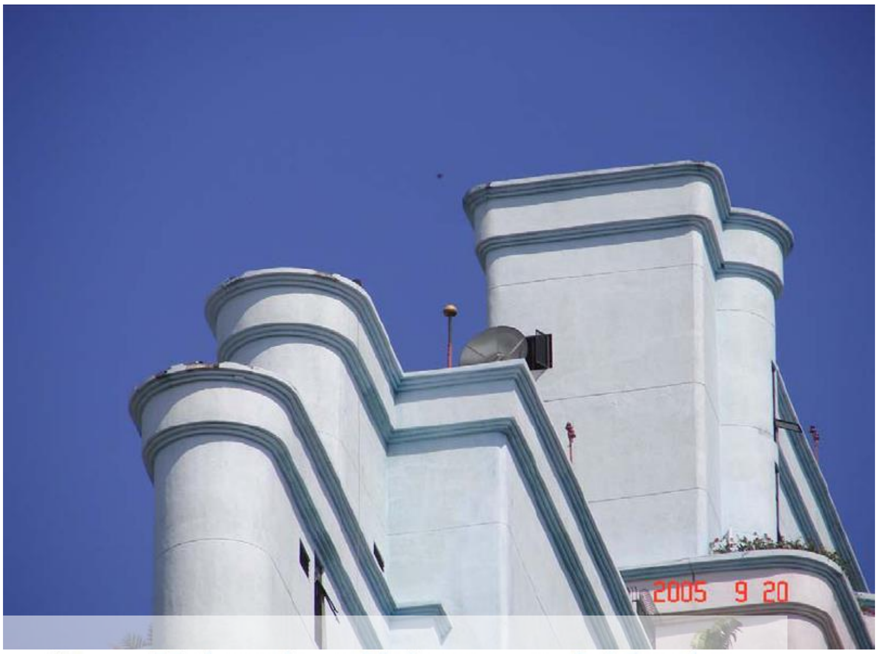





Figure 1.11: A view of the Villaputri building from a different angle. Since the curved edges had been struck by lightning repeatedly, the claimed existence of the collection volume is doubtful.

(*Source:* Z. A. Hartono, I Robiah," CASE STUDIES ON THE COLLECTION VOLUME METHOD,"NF C 17-102. By Z. A. Hartono & I Robiah Senior Members IEEE October 2010 E-mail: zahartono@ieee.org)

### 1.3.2 Step and Touch voltage Distribution around the Telecommunication Base stations

Still not much information concerning the actual values of step and touch voltages that people can be exposed to during lightning strokes is provided [9]. Since the effective area for dissipating the lightning current into the earth can be comparable or greater than the area of the station earthing system, potential gradients at the edges of the earthing network can be very high resulting in large step voltages. This depends also on the soil parameters.

Therefore it is very important to know about the distribution of step, touch and earth potential rise around the telecommunication tower. The step voltage is defined as the potential difference between one's outstretched feet, usually 1m apart. The touch voltage is the potential difference between one's outstretched hand touching an earthed structure and one's feet. The maximum hand-reached distance of 1m is usually assumed. Detail graphic representation of step and touch voltages is presented in Figure 1.12.

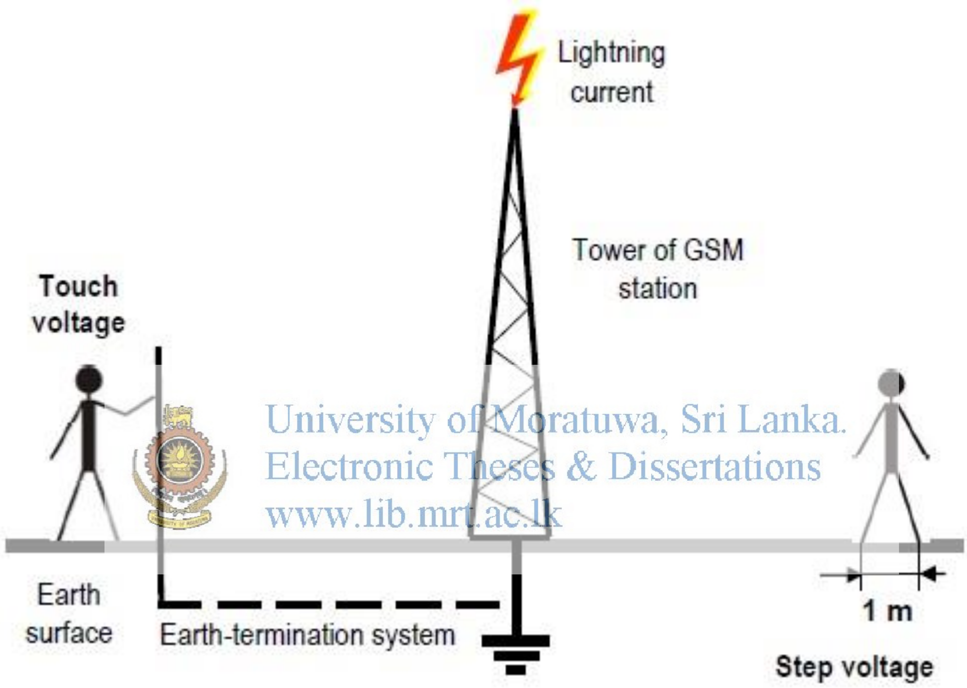




Figure 1.12: Transient step and touch voltages

(*Source*: Renata Markowska, Andrzej Sowa, Jarosław Wiater "Step and Touch Voltage Distributions at GSM Base Station during Direct Lightning Stroke", Bialystok Technical University, Electrical Department Wiejska 45 D, 15-351 Bialystok, Poland.)

The Bialystok Technical University, Electrical Department of Poland has done a research on thin wire model of the GSM base station to show the variation of above parameters. Figure 1.13 shows the thin wire model of the GSM base station.

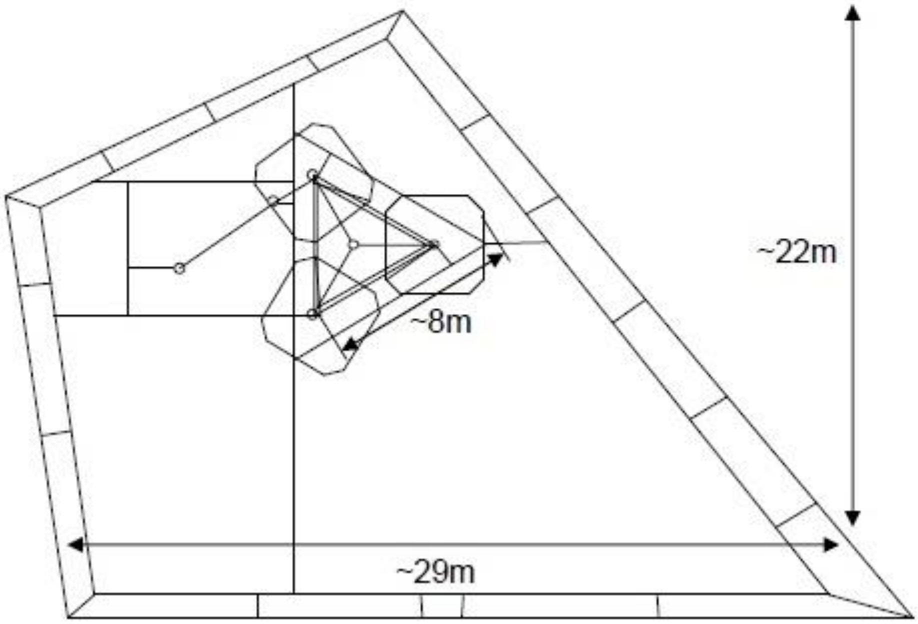



Figure 1.13: Thin wire model of the GSM base station – top view

(*Source*: Renata Markowska, Andrzej Sowa, Jarosław Wiater "Step and Touch Voltage Distributions at GSM Base Station during Direct Lightning Stroke", Bialystok Technical University, Electrical Department Wiejska 45 D, 15-351 Bialystok, Poland.)



It is composed of straight cylindrical conductors with appropriate dimensions and electrical parameters. The station consists of a 60m high communication tower set on an equilateral triangular basis of a side length of 8 m and a small container in close proximity of the tower.

The dimensions of the container are about 3.8 m x 2.5 m x 3 m and the area marked by the station fence corners extends to about 29 m per 22 m as indicated in Figure. The earthing system and other underground structures of the station were modeled in detail. The station earthing system consists of:

- Ring earth electrodes around the tower and the container located at 1.5 m distance from the tower and the container bases;
- Ring earth electrode of the station located 0.5 m away from the fence on its internal side;
- Horizontal earth electrodes that connect the corners of the tower and the container ring electrodes to the ring earth electrode of the station (5 connections). The earthing network is buried at a 60 cm depth.

The distribution of touch voltages around the considered area is quite similar to the distribution of scalar potential, apart from that it is inversed. The minimal values of touch voltages, up to 27 kV can be expected around the tower. In close proximity of the station fence, the touch voltages have nevertheless quite high values - up to about 81 kV and these values increase rapidly outside the station with increasing distance to the station fence. For example, up to 135 kV of touch voltage can be expected within about 2 m distance to the station fence. Close to the fence corners, this distance can be even significantly smaller as for the case of direct touching the structure. The touch voltages calculated in long distances are estimated with the assumption of indirect touching the structure. The maximum values of step voltages - up to 128 kV can be expected around the vertical ground conductors of the station fence, especially close to the corners. Such values of step voltages extend to about 2 m diameters around the ground conductors. Fast decrease of step voltages is observed outside the area enclosed by the fence. It should be pointed out that the distribution of scalar potential as well as step and touch voltages is strongly dependent on soil resistivity and the effective area for a given lightning current shape. Further detailed analysis for these cases could be interesting. The analysis of scalar potential, step and touch voltages in and around a GSM base station during lightning stroke into the communication tower were evaluated using a software package based on electromagnetic field theory. It allows for calculations of relatively complex structures with both underground and aboveground elements in wide frequency range. The calculation results revealed that the lightning transient step and touch voltages in a GSM base station might be very high. In practice dangerous can be voltages occurring outside a station close to the fence: 100 kV of touch voltage and 80– 100 kV of step voltage [9].

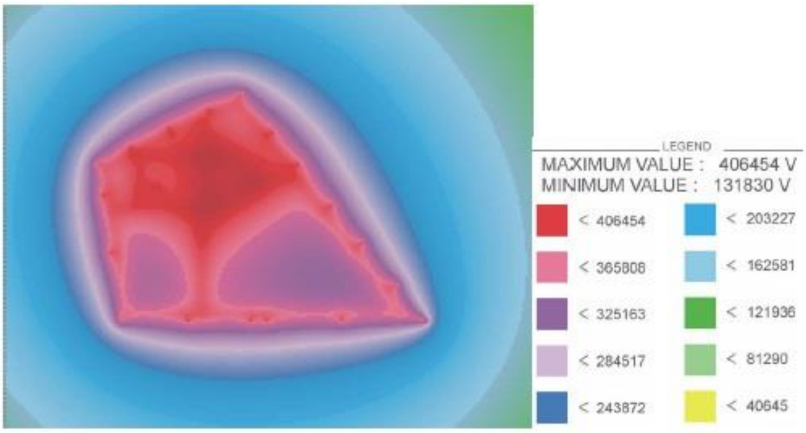



Figure 1.14: Contour plot of the scalar potential distribution in and around the base station

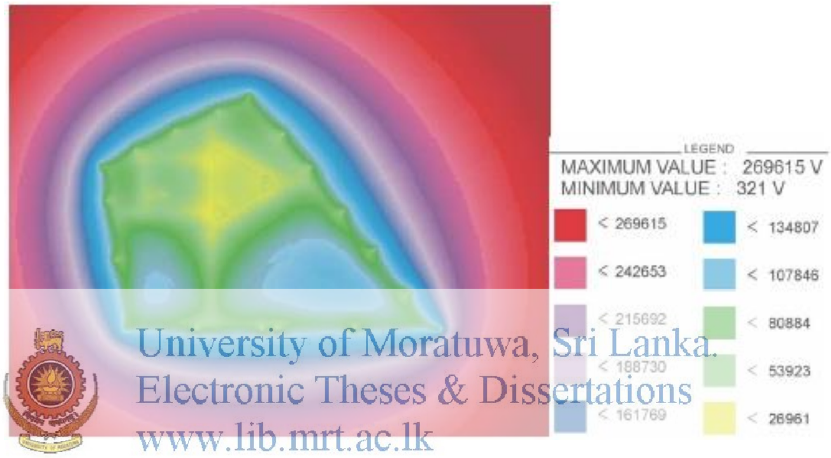





Figure 1.15: Touch voltages in and around the base station

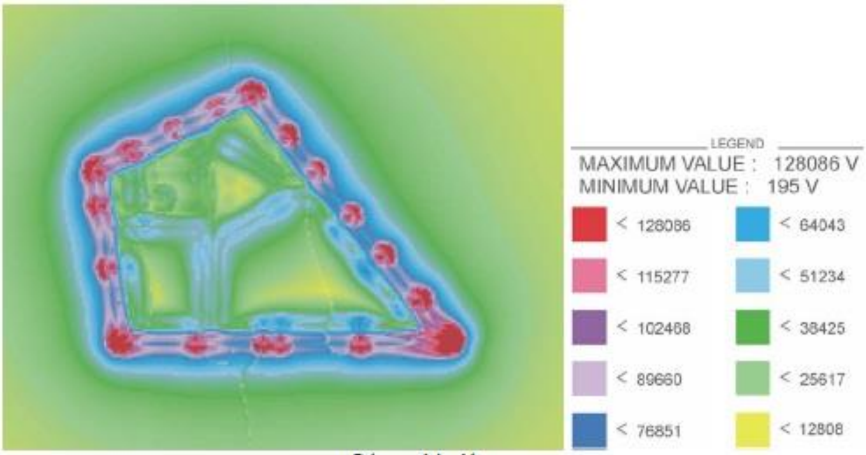



Figure 1.16: Step voltages in and around the base station

(*Source*: Renata Markowska, Andrzej Sowa, Jarosław Wiater "Step and Touch Voltage Distributions at GSM Base Station during Direct Lightning Stroke", Bialystok Technical University, Electrical Department Wiejska 45 D, 15-351 Bialystok, Poland.)

### 1.3.3 Importance of Lightning protection systems

The basic requirements and features of earthing system can be summarized as follows:

- Provides personnel safety and reduces fire hazard during fault conditions by maintaining low or zero potential difference between all conductive elements of a structure;
- Provides low impedance path for lightning current to earth and improves system tolerance to electrostatic energy discharge; Minimizes service interruptions and equipment damage under fault conditions;
- Facilitates equipment operation i.e. signaling with earth return by ensuring low impedance ground reference;
- Reduces radiated and conducted electromagnetic emissions and susceptibility of equipment.

A lightning protection system is a system designed to protect a structure from damage due to lightning strikes by intercepting such strikes and safely passing their extremely high voltage currents to "ground". Most lightning protection systems include a network of lightning rods, metal conductors, and ground electrodes designed to provide a low resistance path to ground for potential strikes. Also this includes the power line surge protectors to protect equipment from power line surges. But even under these conditions, lot of damages to telecom equipment, neighbourhood groups near the RBS have been observed.



In lightning season we can here lot of stories from neighborhood groups regarding lightning strikes and damages. Below mentioned are some of incidents reported near the Telecommunication towers due to the lightning.

“Keselhenawa public protest is getting increase day by day. Today they complained that their trip switches and bulbs were damaged due to yesterday lightening and they say lightening is due to the tower. But equipment in our site was not damaged due to that lightening. They also tell that no such damages were occurred before constructing the tower”

"This tower does not have Cu tape from Air terminal to the ground that is the reason for this kind of damages"

"All neighbors complain that lightning strikes were affected to their houses and some of them were fallen due to unconscious condition occurred due to lightning. One lady complained that she became deaf after the strike. They also complain that all of them have faced a threat as well as their children"

"Lightening surges (fire balls) were thrown away by the tower. They emphasized that they were never experienced such worst conditions before. They told all the problems became after erecting the tower. They showed their strong protest due cause. So it is essential to make an arrangement to minimize future injuries"

In such incidents, neighborhoods people are not allowed RBS maintenance people to visit the sites. There were two incidents that villagers have damaged to the Radio base stations at Akmeemana and Erathna. There are few incidents where, they have written to the Government bodies such as Telecommunication Regulatory Commission of Sri Lanka, Central Environment Authority and Pradeshiya Sabha. Few incidents where they have made police entries. There are few incidents where, they have filed court cases against telecom towers (**Annexure I**).



Therefore government bodies such as Telecommunication Regulatory Commission of Sri Lanka, Central Environment Authority, Pradeshiya Sabha are always monitoring the conditions of lightning protection of telecommunication towers periodically [10]. These government bodies are always handling the complaints with regards to the lightning incidents and try to maintain tower and earthing system in a healthy condition to minimize such damages and complaints. For this purpose they are always coordinating with telecom operators and arrange necessary things to minimize such incidents (**Annexure II**). The earth system evaluation is the main role in investigation of complaints from neighbourhoods. How we evaluate the quality of the grounding system is measuring earth resistance value. If Earth resistance in each tower leg is less than 10 Ohms, then we will conclude that the tower grounding system is in healthy condition and Government authorities are also recommended that. But damages are still remaining. Therefore it is very important to check the accuracy of earth resistance measurement.

### 1.3.3.1 Importance of Earth resistance measurement

The object of an earth electrode system is to provide a low resistance to foreign currents that may cause injury or damage or disrupt equipment. The currents will dissipate safely when properly conducted to earth via the electrode. There are three components to the resistance (Figure. 1.17):

- Resistance of the electrode materials and connections to them
- Contact resistance between the electrode and the soil surrounding it
- Resistance of the surrounding earth.

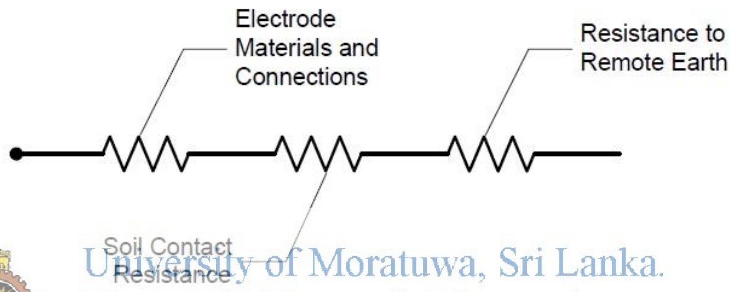





Figure 1.17: Equivalent Resistance Circuit of an Earth electrode System

(*Source*: Whitham D, "Principles and Practice of Earth Electrode Measurements", Reeve 08/01/2008)

The resistance of the electrode materials is purposely made small so their contribution to the total resistance is negligible. Generally, copper materials are used throughout. Ground rods usually are copper-coated steel for strength.

The contact resistance between the electrode and soil is negligible if the electrode materials are clean and unpainted when installed and the earth is packed firmly. Even rusted steel ground rods have little contact resistance because the iron oxide readily soaks up water and has less resistance than most soils (however, rusted ground rods may eventually rust apart in which case their effectiveness is greatly reduced).

Generally, the resistance of the surrounding earth will be the largest of the three components. An earth electrode system buried in the earth radiates current in all directions and eventually dissipates some distance away depending on the soil's resistance to current flow, as indicated by its resistivity.

An earth electrode system consists of all interconnected buried metallic components including ground rods, ground grids, buried metal plates, radial ground systems and buried horizontal wires, water well casings and buried metallic water lines, concrete encased electrodes, and building structural steel.

The earth electrode can be thought of as being surrounding by shells of earth, each of the same thickness (Figure. 1.18) [11]. The shell closest to the electrode has the smallest surface area and offers the greatest resistance. The next shell has larger area and lower resistance, and so on. A distance eventually will be reached where the additional earth shells do not add significantly to the resistance. Earth electrode resistance is measured to remote earth, which is the earth outside the electrode's influence. A larger electrode system requires greater distance before its influence decreases to a negligible level.

Another way of thinking about the earth shells is as parallel resistances. The closest shell has some unit resistance. The next larger shell has more surface area so it is equivalent to several unit resistances in parallel. Each larger shell has smaller equivalent resistance due to more parallel resistances.



The resistance of the surrounding earth depends on the soil resistivity. Soil resistivity is measured in ohm-meters (ohm-m) or ohm-centimeters (ohm-cm) and is the resistance between two opposite faces of a 1 meter or 1 centimeter cube of the soil material. The soil resistivity depends on the type of soil, salt concentration and its moisture content and temperature. Frozen and very dry soils are a good insulators (have high resistivity) and are ineffective with earth electrodes.

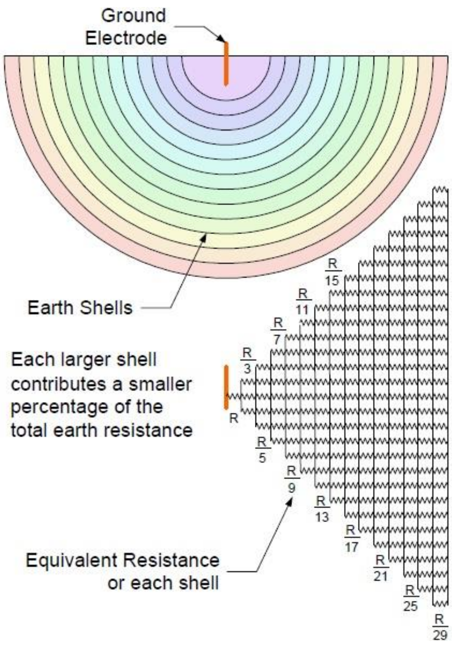



Figure 1.18: Concentric Earth Shells around an Earth electrode

(*Source*: Whitham D, "Principles and Practice of Earth Electrode Measurements", Reeve 08/01/2008)

The current probe also is surrounded by earth shells but with a commensurately smaller influence. It is necessary to locate the current probe far enough away so the influential shells do not overlap as mentioned in Figure 1.19 (b)

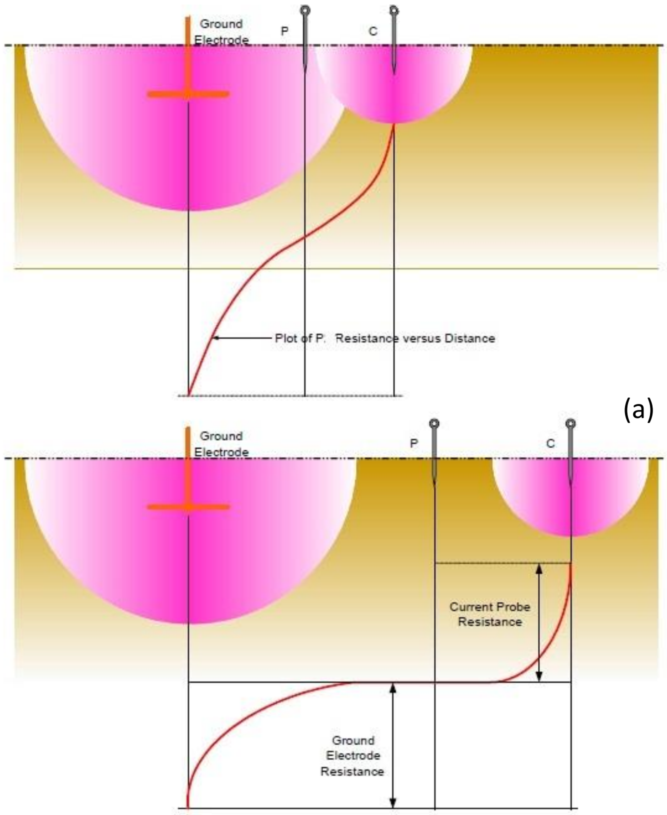



Figure 1.19: (a) Overlapping Shells of Earth (b) Non-Overlapping Shells of Earth

*(Source*: Whitham D, “Principles and Practice of Earth Electrode Measurements”, Reeve 08/01/2008)



Therefore mobile telecom operators are always looking the issues with the existing grounding arrangement and improve grounding system as per the standards & regulations and try to maintain healthy grounding protection systems in their base stations.

# CHAPTER 2

# 2.0 OBJECTIVES AND METHODOLOGY

## 2.1 Objective

Eighteen Telecommunication towers in Sri Lanka have been investigated during 3 and half year period from 2008 May to Dec 2011. As per the experience throughout the period the telecom operator has faced lot of damages to RBS equipment, neighborhoods and lot of complaints received from neighborhoods and Government authorities. At the moment two court cases are being heard with regards to the lightning cases. The objective of this research is to identify the lightning incidents case by case or as a general and propose suitable precautions and strengthen the proposal using geographical arrangement of tower surround, Earth resistance values measured, tower grounding arrangement, power line lightning protection system and the commercial power distribution to the area by measurements, technical theories and simulation software.



## 2.2 Methodology

In this investigation

Check the nature of Tower and the surrounding

- Geographical nature of the tower location
- Lightning density of the area
- Soil condition of the tower location
- Tower height above the sea level
- Nature of other towers located in same area
- Check the neighborhood residence around the tower

Check the nature of damages reported

- Direct lightning strikes
- In Direct lightning strikes
- Power line surges
- Earth potential rise

Check the nature of the lightning protection system

Air termination system

Power line surge protection system

Grounding system arrangement

Taken quantitative measurements of

Earth resistance system

Check the severity of ground potential rise on the power line voltage rises with

Earth resistance

Secondary diverters

Data collection has done through the site surveys to check the nature of the tower locations, lightning protection system and the damages.

The data for the geographical nature of the tower locations and height from the sea level taken by using Google contour maps as shown in Figure 2.1.




Figure 2.1: Contour map

*(Source*: Author)

The grounding measurements has been done using Digital Earth Tester – KYORITSU 4105A. The Fall-of-Potential method (sometimes called the Three-Terminal method) is the most common way to measure earth electrode system resistance, but it requires special procedures when used to measure large electrode systems. This is the method to accurately measure earth resistance in telecommunication towers, where we can find large no of electrodes, wires, plates etc. The arrangement for the earth resistance measurement by using KYORITSU 4105A is shown in Figure 2.2.

This method eliminates many tedious measurements but may not yield good accuracy unless the current and potential probes are outside the electrical influence of the electrode system. But main problem in telecommunication tower measurements is the lack of space to place current and potential electrode outside the electrical influence of the electrode system.

The ground resistance was taken for every possible direction from each tower leg twice (in same direction, with two different potential and current electrode locations where ever possible), where a conductor intended for grounding, enters the earth. The standard distance for the earth to potential electrode has taken as 61.8 % of the earth to current electrode distance [11].



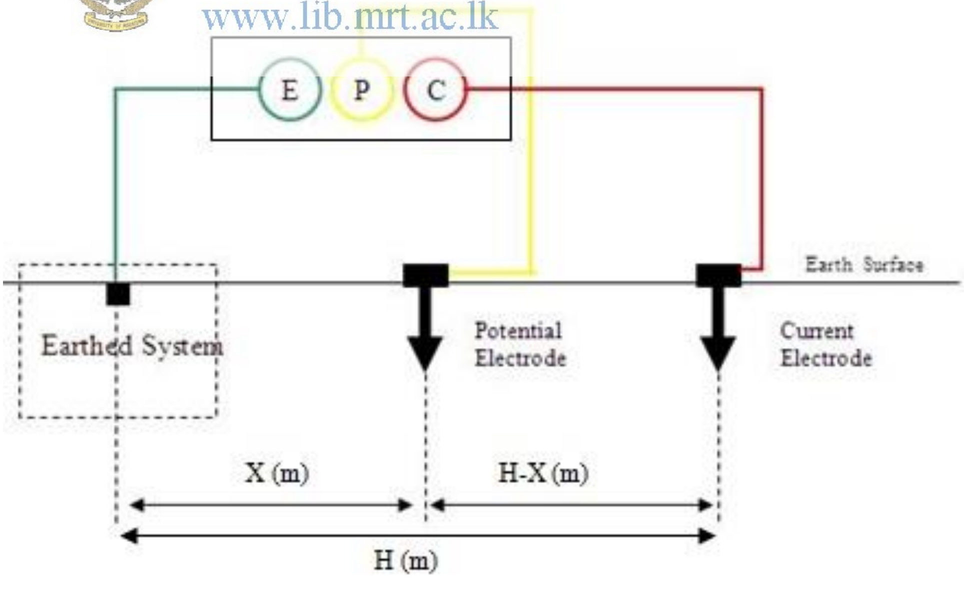



Figure 2.2: Earth resistance measurement arrangement using KYORITSU 4105A.

(*Source*: Author )

The potential and effects of power line damages are quantified and simulated using PSCAD Ver. 4.20 Professional. Models for surge reduction filter, Power line arrangement and surge wave developed using PSCAD.

## CHAPTER 3

# 3.0 OBSERVATIONS AND DATE COLLECTION

This research conducted in high lightning zone in Sri Lanka. Few Telecommunication base stations are selected in Rathnapura, Horana, Galle, Ambalangoda, Kaduwela, Weliweriya, etc for the analysis.

### 3.1 Tower and the surrounding

The 18 towers inspected in this study are all-metal (made of metal re-bars making a steel lattice that stands on concrete platforms), self-supported structures (no guy wires except in four towers) with height of 60m. All the towers are triangular cross-sectioned having 3 legs, they are tapered over the entire height (i.e. legs are inclines to the vertical). The all members of the towers are typically made of painted galvanized steel. The towers are either used for signal transmission in telecommunication or for broadcasting. A structure of a tower is shown in Figure 3.1.



Figure 3.1: Tower Structure

(*Source*: Author)

The sites have been selected so that they are situated in areas different contours of isokeraunic levels different elevations.

Out of 18 sites,

| | |
|---|---|
| 60-80 isokeraunic level | 7 sites |
| 90-100 isokeraunic level | 6 sites |
| Over 100 isokeraunic level | 5 sites |

If we consider the towers located in Rathnapura region, the iso keraunic level is greater than 100 and also the altitudes of the towers are also higher compared with other sites mentioned in Table 3.5. Also most of the damages and frequency of occur the damages are high in the same region. Most of the tower mounted equipment such as antenna failures are high in same region. One of the remarkable features in the data is that MW antenna failures occur in the site where height greater than 100 m from the sea level at most tower.

### 3.2 Air Termination



The air terminals are typically arranged on the top of the telecommunication tower to intercept with lightning stepped leader. Generally, Air Terminal covers all antenna structures in the tower within a cone of vortex angle 45 [5]. Here we can see the Air terminal type which we have installed on the towers. And no tower installed with ESE lightning rods. Tin plated solid round conductors which is having 10mm diameter are using for the air termination and that is in accordance with the IEC 62305-3 (2006). See **Annexure III.**

Figure 3.2: Air Terminal system

(*Source*: Author )

### 3.3 Down Conductor

The term ''down conductor'' is used to refer any metallic part that is specifically installed to drive lightning current from top of the tower to ground level.



In order to reduce the probability of damage due to lightning current flowing in the LPS, the down-conductors shall be arranged in such a way that from the point of strike to earth:

a) several parallel current paths exist;

b) the length of the current paths is kept to a minimum;

c) equipotential bonding to conducting parts of the structure

Some of our base stations do not have CU down conductor from air terminal to the ground. This is because; it cannot be protecting form steeling. Therefore, Stainless steel tower structure itself use as the down conductor (3 legs behave like 3 down conductors) which having average of 800 $mm^2$ cross section. The tower structure connected to the ring earth by using CU tape at the bottom of the tower. All three legs are connected to the ring earth as shown in Figure 3.3.

Figure 3.3: Tower structure connected to the ring earth

*(Source*: Author )

Out of 18 sites, 10 sites having separate 25mmx3mm (75 $mm^2$) copper down conductor from air terminal to ring earth while same structure grounding also exists. Therefore the down conductor system in accordance with the IEC 62305-3 (2006). See **Annexure III**



Also one tower leg contains around 6 joints and those are arranged in order to make good contact between each other. Therefore we have not observed more than 0.1 Ohm resistance in between them.

Figure 3.4: Tower leg joint

*(Source*: Author)

### 3.4 Grounding System

Typical grounding conductor arrangement observed is shown in Figure 3.5. That is a basic crow foot arrangement. There are two earth rings. One is through the tower legs and one is around equipment cabin. The earth electrode using for the grounding system is solid round and having 16mm diameter and it is in accordance with the IEC 62305-3 (2006). See **Annexure IV**

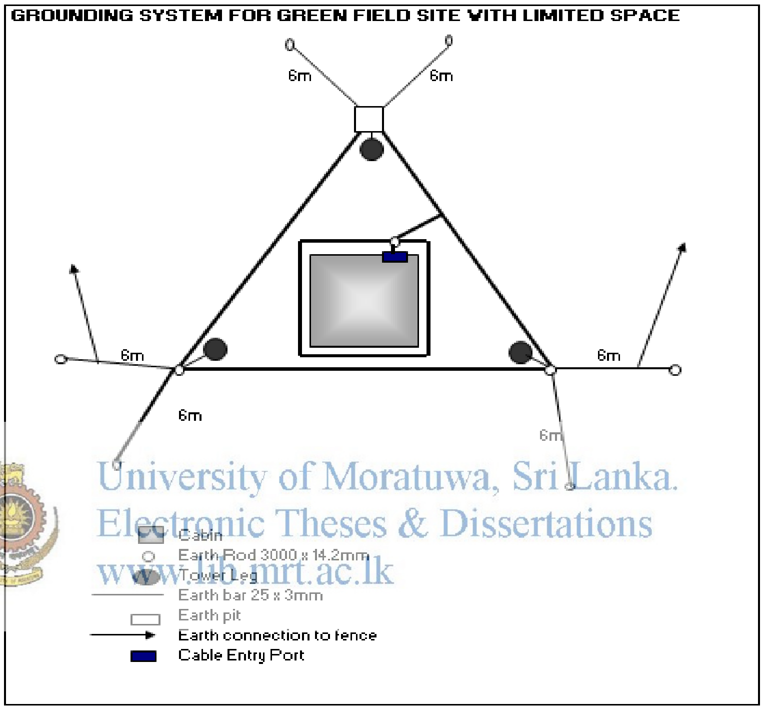




Figure 3.5: Grounding system for green field site with limited space

*(Source*: Author )

Earth resistance will be measured after this installation. If measured earth resistance is more than 10 ohms, further improvement will be done to reduce earth resistance. But for a particular site we cannot find the exact locations where earth rods are buried, as several improvements may take place since the tower erection date.

### 3.5 Earth Resistance Measurements

A remarkable feature in this regards is that the measured resistance values of the towers located in rocky area seems very high even after the several earth resistance improvements. Also we can see the measured values for three legs are entirely different to each other.

Earth resistance is measured in some telecommunication tower using fall of potential method and there we can find lot of issues with the measurements. Keselhenawa, Moragahakanda and Erathna sites earth resistance measurements have done to get clear picture about the issues.

In Kehelhenawa measurements, the current electrode can be placed at maximum of 16m away from the system earth. But 61.8% rules tell the earth resistance as 3.02 ohms at one leg and 16.57 Ohms at another leg. Table 3.2 shows the Earth resistance measurements data and Figure 3.6 shows the fall of potential curves for Keselhenawa Radio base station.



| **Earth measurement (Ohms)** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Distance X(m)** | **Leg 1** | **Leg 2** | **Leg 3** | **Distance X(m)** | **Leg 1** | **Leg 2** | **Leg 3** |
| 0.1 | | | | 9 | 1.9 | 10.5 | |
| 0.2 | | | | 9.5 | 2.2 | 13.8 | |
| 0.4 | | | | 10 | 3.02 | 16.5 | |
| 0.7 | | | | 11 | 4.57 | 24 | |
| 1 | 0.71 | 0.35 | | 12 | 4.89 | 29.6 | |
| 3 | 1.05 | 0.66 | | 12.5 | 5.34 | | |
| 5 | 0.87 | 1.85 | | 13 | 7.55 | | |
| 5.5 | 0.9 | 2.7 | | 13.5 | | | |
| 6 | 1 | 2.9 | | 14 | | | |
| 6.5 | 1.2 | 2.3 | | 14.5 | | | |
| 7 | 1.03 | 2.43 | | 15 | | | |
| 7.5 | 1.2 | 4.1 | | 15.5 | | | |
| 8 | 1.5 | 5.5 | | 16 | | | |
| 8.5 | 1.7 | 7 | | | | | |

Table 3.2: Earth measurements Keselhenawa Radio base station

(*Source*: Author )

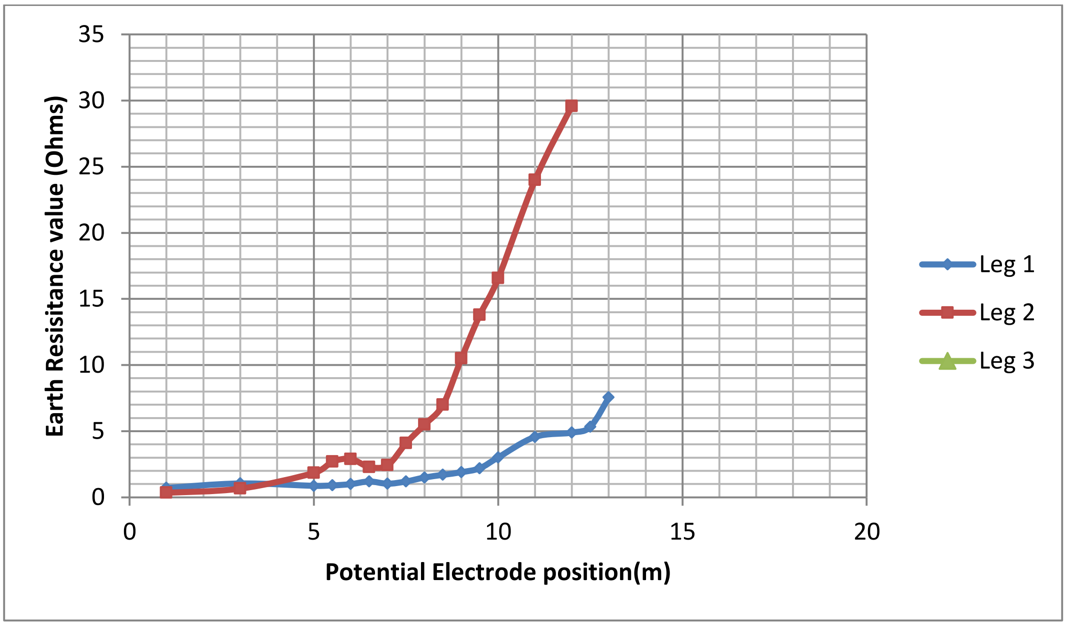



Figure 3.6: Fall of potential curves for Keselhenawa Radio base station

(*Source*: Author)



Below table and Figure shows the same thing done in Moragahakanda radio base station. In this case also current electrode can be placed at maximum of 16m away from the system earth. In here the earth electrode resistance can be estimated by examining the curves or field data at the 61.8% point as it shows the Non-Overlapping behavior. 14 Ohms is the figure shows as per the 61.8% rule. Table 3.3 shows the Earth resistance measurements data and Figure 3.7 shows the fall of potential curves for Moragahakanda Radio base station.

| | Earth measurement (Ohms) | | |
|---|---|---|---|
| Distance X(m) | Leg 1 | Leg 2 | Leg 3 |
| 0.1 | | 1.79 | |
| 0.2 | | 1.85 | |
| 0.4 | | 1.99 | |
| 0.7 | | 2.28 | |
| 1 | 0.98 | 2.27 | 1.46 |
| 3 | 1.22 | 2.44 | 6.64 |
| 5 | 5.5 | 2.12 | 8.72 |
| 7 | 10.96 | 4.3 | 10.95 |
| 8 | 10.5 | 6 | 12.8 |
| 9 | 11 | 12 | 13 |
| 10 | 14.78 | 13.47 | 13.35 |
| 11 | 15.58 | 13.7 | 14.15 |
| 12 | 16.51 | 15 | 15.2 |
| 13 | 17.37 | 17.42 | 16.17 |
| 14 | 18.12 | 21.2 | 17.15 |
| 15 | 19.03 | 26.5 | |
| 15.5 | | | |
| 16 | | | |

Table 3.3: Earth measurements Moragahakanda Radio base station

*(Source:* Author)

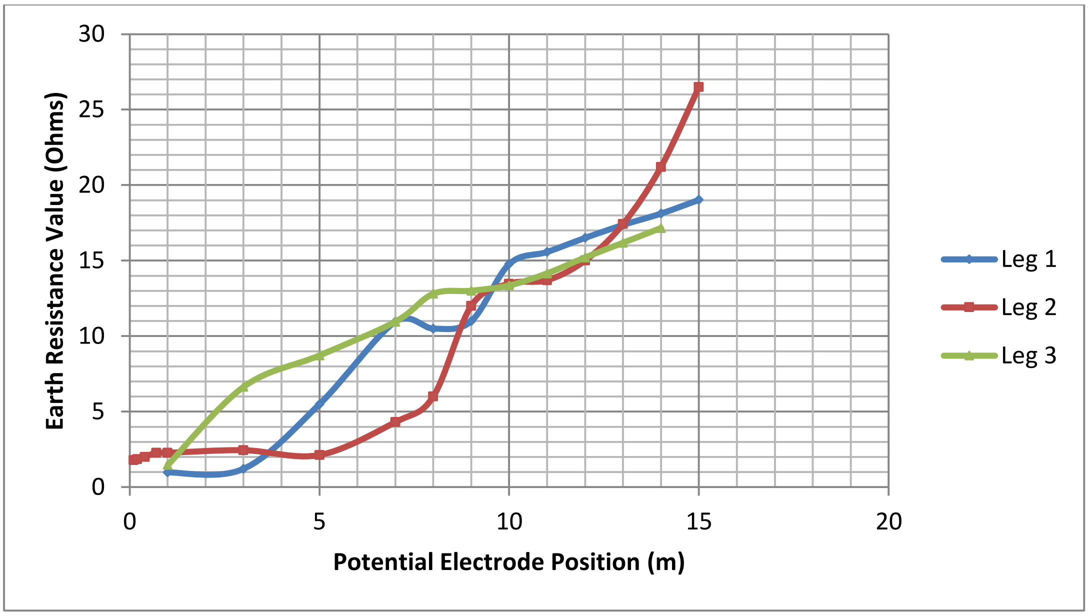



Figure 3.7: Fall of potential curves for Moragahakanda Radio base station

*(Source*: Author )

The table 3.4 and Figure 3.8 shown the results of earth measurement done in Erathna Radio base station. There we have managed to keep distance between earth system and current electrode. But we can see an irregular behavior in between potential electrode distance 25m to 35m. But totally we can see a non-overlapping behavior and conclude that the earth resistance value is around 30Ω. Table 3.4 shows the Earth resistance measurements data and Figure 3.8 shows the fall of potential curves for Keselhenawa Radio base station.

| Distance X(m) | Leg 1 | Distance X(m) | Leg 1 | Distance X(m) | Leg 1 | Distance X(m) | Leg 1 |
|---|---|---|---|---|---|---|---|
| 15 | 16.5 | 28 | 43.2 | 40.5 | 29.2 | 52 | 39.3 |
| 15.5 | 19.5 | 28.5 | 37.6 | 41 | 29.6 | 52.5 | 39.1 |
| 16 | 20.2 | 29 | 34.5 | 41.5 | 29.7 | 53 | 42 |
| 16.5 | 17.8 | 29.5 | 31.1 | 42 | 30.2 | 53.5 | 44.2 |
| 17 | 18.5 | 30 | 25.5 | 42.5 | 30.1 | 54 | 45.6 |
| 17.5 | 17.7 | 31.5 | 30.9 | 43 | 30 | 54.5 | 47.4 |
| 18 | 17.4 | 32 | 31.8 | 43.5 | 31.7 | 55 | 50.32 |
| 18.5 | 17.4 | 32.5 | 32 | 44 | 30.1 | 55.5 | 52.33 |
| 19 | 17.7 | 33 | 31 | 44.5 | 31 | 56 | 54.5 |
| 19.5 | 17.4 | 33.5 | 32.5 | 45 | 30 | 56.5 | 55.2 |
| 20 | 17.9 | 34 | 26.6 | 45.5 | 29.9 | 57 | 56.6 |
| 20.5 | 18.8 | 34.5 | 26.7 | 46 | 30.05 | 57.5 | 60.2 |
| 21 | 17.8 | 35 | 26.8 | 46.5 | 31 | 58 | 63.1 |
| 21.5 | 22 | 35.5 | 27.2 | 47 | 31.5 | 58.5 | 63.4 |
| 22 | 20.2 | 36 | 27.5 | 47.5 | 31.7 | 59 | 65.2 |
| 22.5 | 63.6 | 36.5 | 28.9 | 48 | 32.4 | 59.5 | 65.2 |
| 23 | 22.4 | 37 | 29.4 | 48.5 | 32.2 | 60 | 68.4 |
| 23.5 | 60.8 | 37.5 | 29.5 | 49 | 32.4 | | |
| 24 | 31.8 | 38 | 28.5 | 49.5 | 33.3 | | |
| 24.5 | 32 | 38.5 | 28.4 | 50 | 35.2 | | |
| 25 | 41.5 | 39 | 28.6 | 50.5 | 35 | | |
| 25.5 | 38.7 | 39.5 | 29 | 51 | 37.02 | | |
| 26 | 36 | 40 | 29 | 51.5 | 38.22 | | |

Table 3.4: Earth measurements Erathna Radio base station

(*Source*: Author)

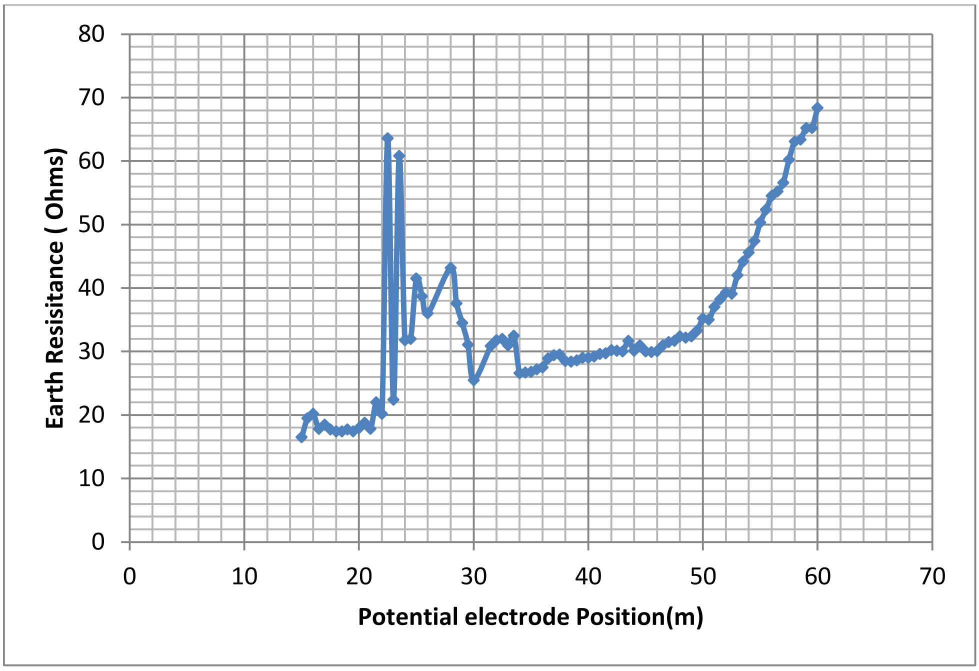



Figure 3.8: Fall of potential curves for Erathna Radio base station

*(Source*: Author )



### 3.6 Power line Surge Protection system

In Sri Lanka we follow power distribution system as TT system. The system having one point of the source of energy earthed and the exposed-conductive-parts of the installation connected to independent earthed electrodes.

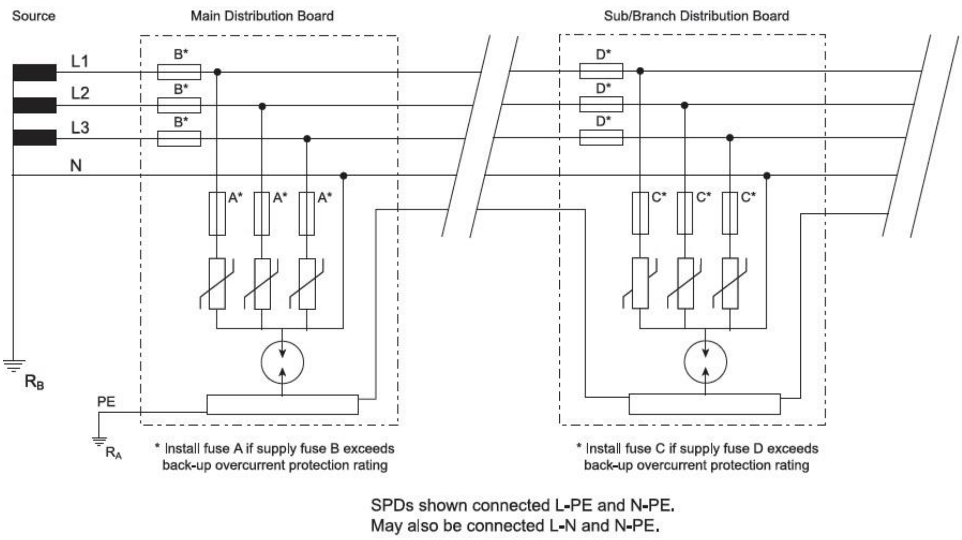



Figure 3.9: Power Distribution Systems and SPD Installation

*(Source*: ERICO Lightning Technologies)

The Surge Reduction Filter (SRF) installed as the power line protector in radio base station is shown in Figure 3.10. It compromise with two TSG in Line to Neutral and Neutral to earth in power line side. Then there is a low pass LC filter at the load end.

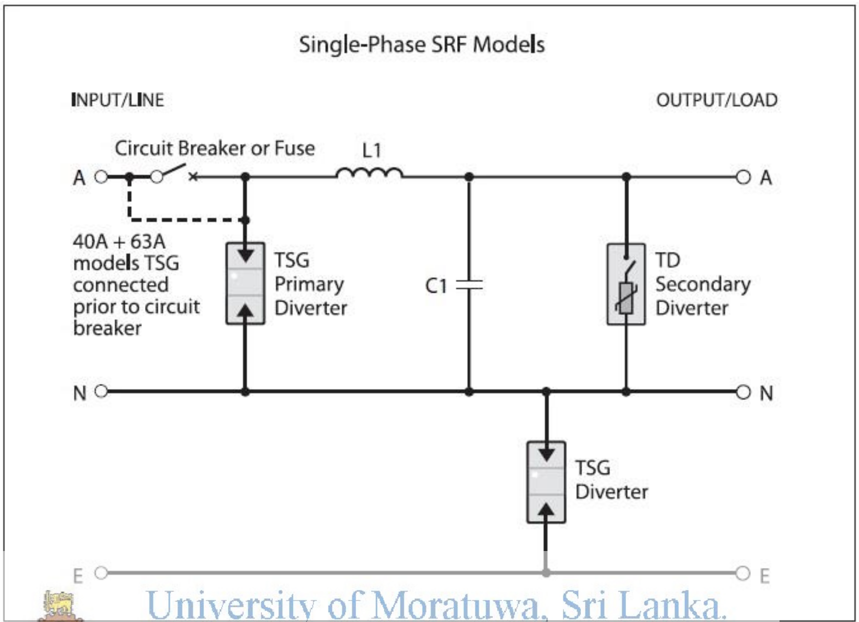





Figure 3.10: SRF 140 Surge reduction filter installed for the power line
(*Source*: ERICO Lightning Technologies)

The cabling and earth wires connected to the filter input is always be run separately, with a minimum clearance of 300 mm between them and all other cables or sensitive equipment as shown in Figure 3.11.

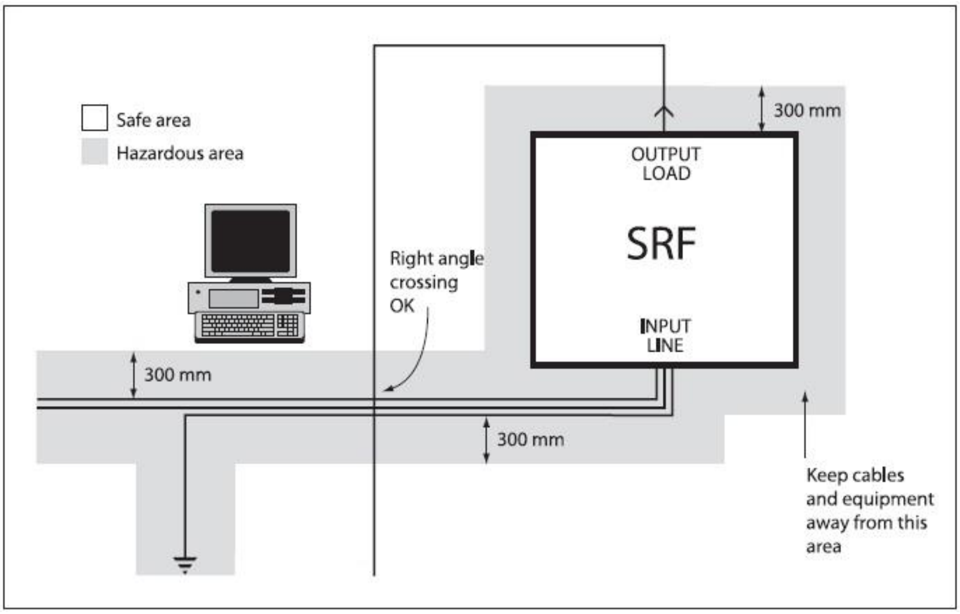



Figure 3.11: Maintaining clearance between input and other cabling

*(Source*: ERICO Lightning Technologies)

The input cable and earth wire will carry the transient energy, while the "protected" output cable, can be considered to be a "clean filtered" supply. By separating these cables, any incoming transients will not be induced from the input cables onto nearby "clean" cables. This clearance will reduce the possibility of arc-over from input to output cables. Where cables need to run closer together due to space restrictions, input and output cables should cross at right angles and not be installed parallel to each other. Cabling has sized in accordance with all relevant wiring standards to ensure that the full load current can be safely supplied. All cabling or busbars have connected to the protection equipment should be securely anchored to prevent undue stress being applied to the input/output terminals.



The earths for all site equipment have integrated (preferably deploying a single point earthing approach) and an equipotential earth plane has created. The effectiveness of an SRF is intimately related to the impedance presented by the earthing system to which it is connected. A low impedance route to the earth is required (less than 10Ω). This can be achieved by ensuring that the earth electrode system at the site presents low surge impedance with respect to the ground. Additionally, the interconnecting cabling must be of adequate cross sectional area and be routed to provide as short and direct a path as is practical. The earth conductor for the SRF should be sized according to local regulations but with a minimum size of 6 mm2 and we have at least 16mm2 in each and every base station and always maintained limit the cable length to less than 5 meters.

With this configuration, we do not have experienced any side flashes during last three years.


Figure 3.12: Equipotential bonding inside the Equipment cabin

(*Source*: Author )



**3.7 Electrical & Electronic Equipment and Other damages**

Sites were selected on the basis where most of the lightning damages were reported during April/May 2011. Below shown are the reported damages in last three and half years.

- Equipment cabin rectifier damages
- Outdoor units of the Microwave antenna
- Indoor units of the Microwave antenna
- Meter cubical burst
- Generator control modules, battery chargers, Magnetic contactors etc.
- Electric Energy meter burnt
- Earth terminals for most of socket outlets get burnt
- Wall cracked
- Earth terminals of the Power DBs also got burnt

- Shock felt on their bodies
- Computers and routers
- CRT TV
- Radios
- Refrigerators
- Electrical switch gears
- Bulbs
- Human faint

We observed that there are lots of electrical and electronic equipment damages after the lightning incidents. This is not only for the telecom equipment, but also for the neighbourhoods electrical and electronic equipment. Also we have observed that there are some incidents where the Tower mounted equipment such as Microwave Antenna Outdoor unit and indoor units of them also got failed.



Figure 3.13: MW Outdoor and Indoor units connected through IF cable

*(Source*: Author)

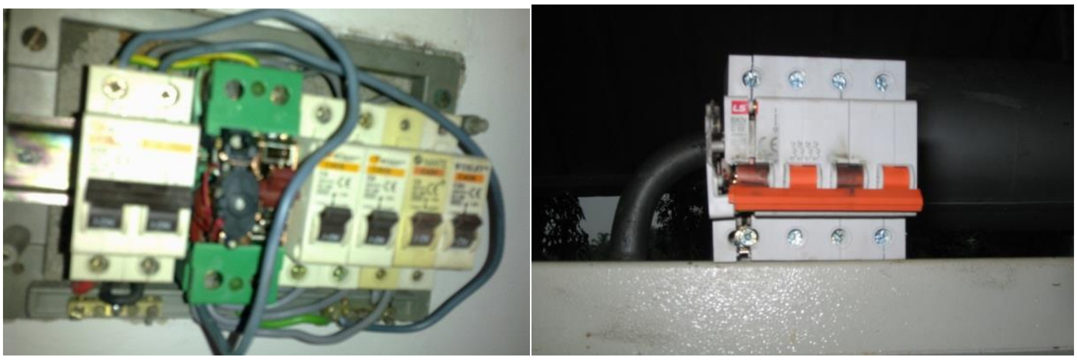


Figure 3.14: MCB damages reported in homes located near the Madampegama Radio Base station

*(Source*: Author )



Figure3.15: Electrical Bulbs and Holder damages repoted in homes near the Madampegama Site

*(Source*: Author )

Figure 3.16: ADSL router damaged in home near the Thihariya site

*(Source*: Author)

Figure 3.17: Computer damaged in home near the Thihariya site

*(Source*: Author)



Figure 3.18: Energy meter and cable damages reported near the Keselhenawa telecommunication tower

*(Source*: Author)

Figure 3.19: Neutral to earth surge arrester damaged in Magalle radio base station

*(Source*: Author )

Figure 3.20: wall damages reported in homes near the Madampegama telecommunication tower

*(Source*: Author )



Figure 3.21: wall damages reported in homes near the Nakiyadeniya telecommunication tower

*(Source*: Author )

Figure 3.22: wall cracks reported in homes near the Keselhenawa telecommunication tower

*(Source:* Author )

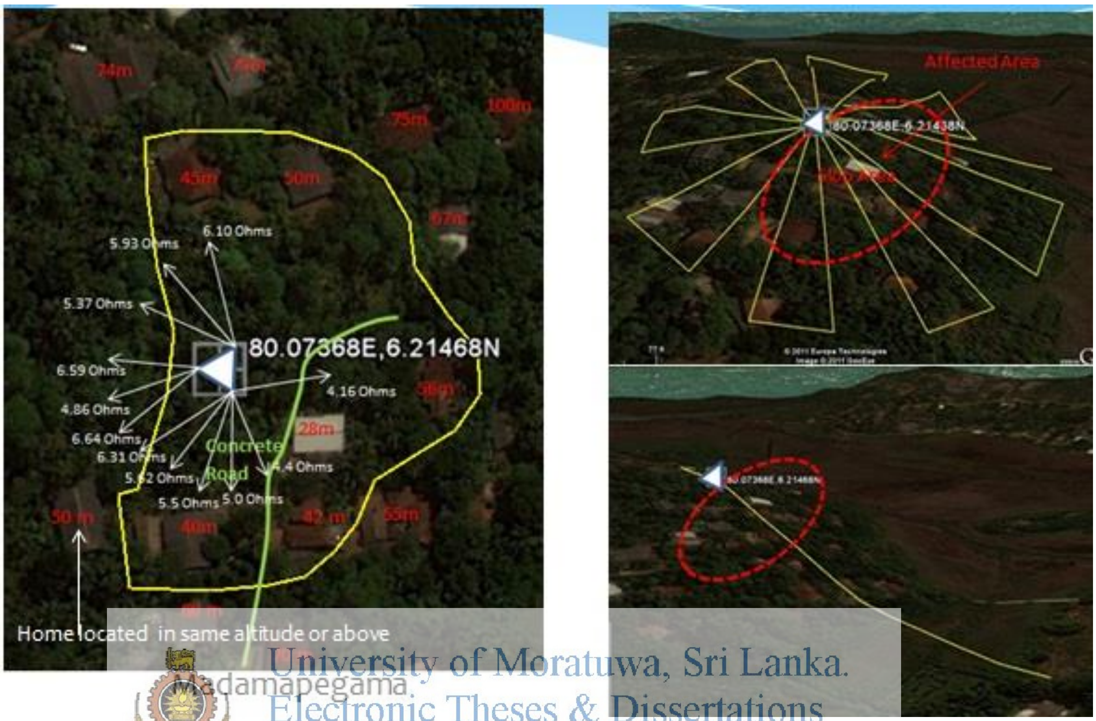
Recently few incidents reported with regrads to the Telecom towers and mobile phones. Below incident reported at Madampegama site in Ambalangoda, when a person sleeping on the ground floor with the mobile phone under his arm in his home after the lightning incident to the Telecom Tower.



Figure 3.23: Human damages reported in home near the Madampegama Telecommunication Tower

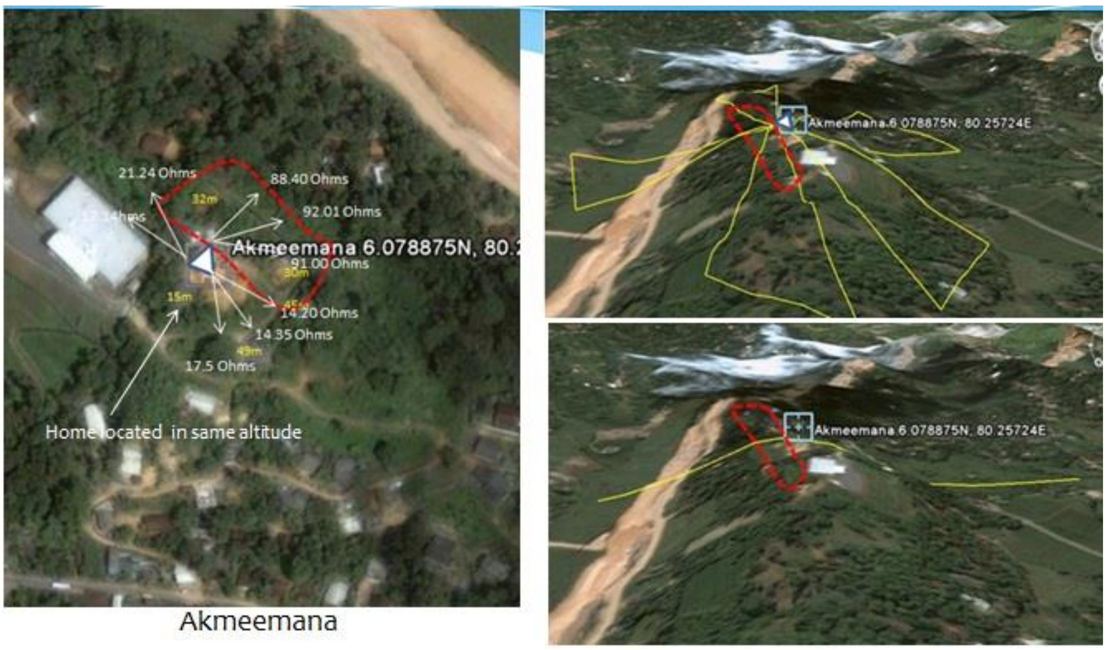
*(Source*: Author)

One remarkable future highlighted throughout this research regarding the reported damages and elevation of those homes with respect to the elevation of the tower. It is highlighted that damages reported in homes where elevation is less than the tower elevation. Four sites selected in Ambalangoda region and check the surrounding earth profile and damages reported. All four sites are in same isokeraunic region.

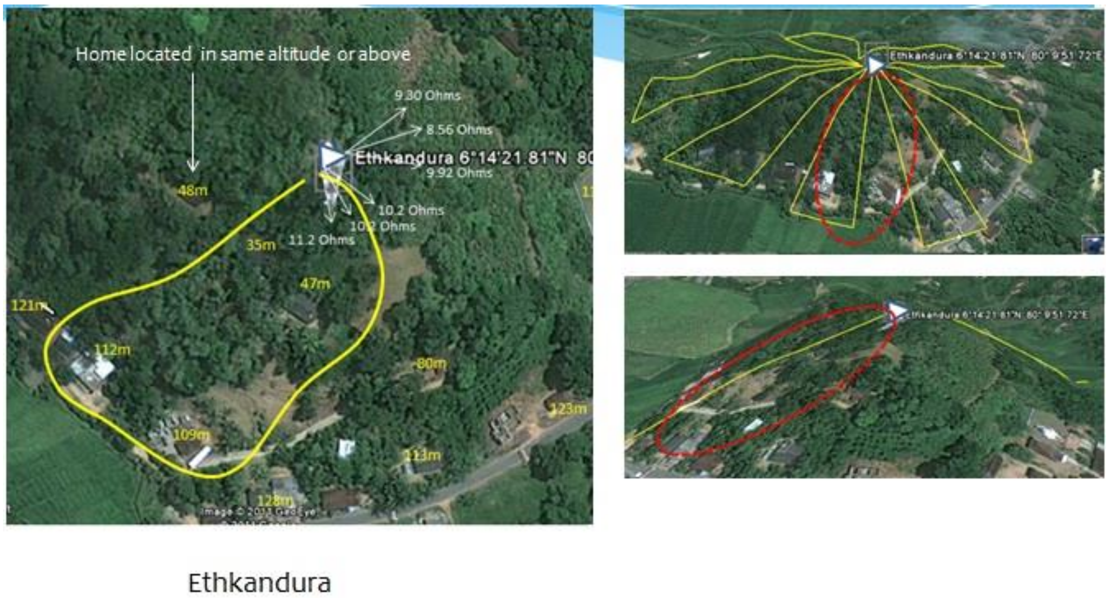





(a)




(b)




(c)




(d)

Figure 3.24: Earth profiles of (a) Madampegama (b) Akmeemana (c) Ethkandura (d) Boossa
*(Source*: Author)

The tower surrounding earth profile of Madampegama, Akmeemana and Ethkandura are rather steep and damages reported only in homes located in same steep area ( Figure 3.24 (a), (b) and (c) ). But the surrounding earth profile of Boossa is rather flat and there were no any damages reported either to Tower equipment or neighbourhoods.

Below table shows the data collected throughout this research.  As per the observation we can categorize site where

- Both Site equipment and neighborhood damages reported
- No damages to Site equipment but neighborhood damages reported
- Site equipment damages reported. No damages to neighborhood.
- No damages to either site equipment or neighborhood

| Site Name | keraunic level | Coordinates | Tower height from sea level | Soil condition | Earth Resistance | Separate Down conductor | Reported Damages | No of neighborhood around the tower 100m | Additional Comments |
|---|---|---|---|---|---|---|---|---|---|
| Thihariya | 60-80 | Lon - 80.06826<br>Lat - 7.128039 | 60-80 m | laterite | 8.0 Ohms<br>14.3 Ohms<br>27.2 Ohms | Yes | ADSL Router<br>Power supplies | 07 | Both Site equipment and neighborhood damages reported |
| Radawana | 60-80 | Lon - 80.10088<br>Lat - 7.039889 | 60-80 m | laterite | 30 Ohms<br>18.4 Ohms<br>9.4 Ohms | Yes | kWh Meter cubicle | 02 | Site equipment damages reported. No damages to neighborhood |
| Pasyala | 60-80 | Lon -80.12715<br>Lat - 7.169372 | 120-140 m | Laterite/Regular | 8.4 Ohms<br>11.50 Ohms<br>9.2 Ohms | No | kWh Meter cubicle damaged<br>ATS panel | 08 | Site equipment damages reported. No damages to neighborhood.<br>Site equipment damages reported before and after CU down conductor removal |

| Site Name | keraunic level | Coordinates | Tower height from sea level | Soil condition | Earth Resistance 3 leg direction | Separate Down conductor | Reported Damages | No of neighborhood around the tower 100m | Additional Comments |
|---|---|---|---|---|---|---|---|---|---|
| Wewldeniya | 60-80 | Lon - 80.14616<br>Lat - 7.185607 | 160-180m | laterite | 6.82 Ohms<br>16.50 Ohms<br>8.45 Ohms | Yes | MW ODU<br>Bulbs | 02 | Both Site equipment and neighborhood damages reported |
| Kirindiwela | 60-80 | Lon - 80.11826<br>Lat - 7.047782 | 90-110 m | Laterite/Regular | 4.80 Ohms<br>8.46 Ohms<br>7.24 Ohms | Yes | No | 15 | No damages to either site equipment or neighborhood |
| Negambo Kattu | 60-80 | Lon - 79.84641<br>Lat - 7.241883 | 60-80m | laterite | 9.60 Ohms<br>13.46 Ohms<br>7.90 Ohms | Yes | ADSL router<br>Power supply<br>CFL Bulbs<br>TV<br>Fan | 24 | No damages to Site equipment But neighborhood damages reported |
| Sandalankawa | 60-80 | Lon - 79.95138<br>Lat - 7.30117 | 60-80m | laterite | 6.30 Ohms<br>7.4 Ohms<br>8.9 Ohms | No | Generator control module<br>TV<br>Bulbs | 24 | Both Site equipment and neighborhood damages reported |
| Agalawatta | 90-100 | Lon - 80.15908<br>Lat - 6.534115 | 120-140m | laterite | 32.0 Ohms<br>34.3 Ohms<br>8.03 Ohms | Yes | Human shock<br>TV<br>kWh meter | 03 | No damages reported after Airtel tower erection nearby area |

| Site Name | keraunic level | Coordinates | Tower height from sea level | Soil condition | Earth Resistance 3 leg direction | Separate Down conductor | Reported Damages | No of neighborhood around the tower 100m | Additional Comments |
|---|---|---|---|---|---|---|---|---|---|
| Ethkandura | 90-100 | Lon - 80.16442<br>Lat - 6.239312 | 100-120m | rocky | 8.56 Ohms<br>10.2 Ohms<br>Cannot measure | No | TV<br>Refrigerator<br>CDMA phone<br>MW IDU<br>MW ODU<br>kWh meter | 08 | This happen before and after CU down conductor removal |
| Nakiyadeniya | 90-100 | Lon -80.33689<br>Lat - 6.137947 | 220-240m | rocky | 86.0 Ohms<br>50.10 Ohms<br>24.0 Ohms | No | Wall Damages<br>TV<br>Radio | | No damages to Site equipment But neighborhood damages reported |
| Akmeema | 90-100 | Lon -80.25724<br>Lat - 6.078875 | 80-100m | rocky | 92.20 Ohms<br>17.14 Ohms<br>14.20 Ohms | Yes | TV<br>DVD players<br>Human shock<br>Switch gears<br>Bulbs<br>Socket outlets | 09 | Both Site equipment and neighborhood damages reported |

| Site Name | keraunic level | Coordinates | Tower height from sea level | Soil condition | Earth Resistance 3 leg direction | Separate Down conductor | Reported Damages | No of neighborhood around the tower 100m | Additional Comments |
|---|---|---|---|---|---|---|---|---|---|
| Boossa | 90-100 | Lon - 80.16785<br>Lat - 6.082915 | 60-80m | laterite | 5.05 Ohms<br>3.78 Ohms<br>5.13 Ohms | No | No | 16 | No damages to either site equipment or neighborhood |
| Galpatha | 90-100 | Lon- 80.0042<br>Lat- 6.63512 | 80-100m | Rocky/iragular | 4.2 Ohms<br>110 Ohms<br>Cannot measure | No | | 05 | |
| Madampegam | 90-100 | Lon- 80.07368<br>Lat- 6.21468 | 80-100m | Laterite/Regular | 6.10 Ohms<br>6.59 Ohms<br>4.44 Ohms | No | TV<br>Fan<br>Computer<br>Human shock<br>Switch gears<br>CFL Bulbs<br>Socket outlets<br>Wall damages<br>Human shock<br>Generator ATS<br>kWh Meter | 26 | Both Site equipment and neighborhood damages reported. Before that the damages reported in the area where another tower located near this area. |

| Site Name | keraunic level | Coordinates | Tower height from sea level | Soil condition | Earth Resistance 3 leg direction | Separate Down conductor | Reported Damages | No of neighborhood around the tower 100m | Additional Comments |
|---|---|---|---|---|---|---|---|---|---|
| Deraniyagala | Over 100 | Lon - 80.32869<br>Lat - 6.919281 | 360-380m | Rocky/ laterite | 7.86 Ohms<br>2.63 Ohms<br>Cannot measure | Yes | Refrigerator<br>TV<br>Switch gears<br>MW IDU<br>MW ODU | 1 | Both Site equipment and neighborhood damages reported |
| Gataheththa | Over 100 | Lon - 80.2277<br>Lat - 6.901372 | 120-140m | Rocky/Regular | 31.50 Ohms<br>32.60 Ohms<br>26.10 Ohms | No | TV<br>Fan<br>MW ODU<br>MW IDU | 06 | Both Site equipment and neighborhood damages reported |
| Parakaduwa | Over 100 | Lon - 80.29496<br>Lat - 6.825613 | 200-220m | Rocky/Regular | 27.30 Ohms<br>36.90 Ohms<br>32.00 Ohms | Yes | Human shock<br>TV<br>Satalite system<br>Kwh Meter<br>MW IDU<br>MW ODU | 06 | Both Site equipment and neighborhood damages reported |

| Site Name | keraunic level | Coordinates | Tower height from sea level | Soil condition | Earth Resistance 3 leg direction | Separate Down conductor | Reported Damages | No of neighborhood around the tower 100m | Additional Comments |
|---|---|---|---|---|---|---|---|---|---|
| Erathna | Over 100 | Lon -80.3711<br>Lat - 6.83 | 320-340m | Rocky | 30.00 Ohms<br>Cannot measure<br>Cannot measure | Yes | MW ODU<br>kWh meter<br>TV<br>Refrigerator | 2 | Both Site equipment and neighborhood damages reported before and after copper down conductor installtion |

Table 3.5: Collected data for lightning incidents

(*Source*: Author)

# 4.0 RESULTS, ANALYSIS AND ACTIONS

## 4.1 Effect of Tower and the Geographical situation

In here we are not considering the areas of Mannar, Anuradhapura, Badulla and Hambantota as there were no major lightning incidents reported. As per the table 3.5, the towers located within the region, where iso keraunic level is greater than 60 are under the risk of lightning strikes and lot of damages reported. Rathnapura region is mostly affected during last 3 years of period. If we consider the tower mounted equipment damages such as Microwave antenna, the damages reported mainly in sites where, tower height is greater than 120m from the sea level.

There are two incident that we observed damages occurrence and non-occurrence with the tower erection. For an example: We have observed frequent lightning damages and complain near Madampegama RBS from the date of tower erection. But there is a tower near the Madampegama RBS with the same tower height and from the 150m of air distance. But elevations of the two tower locations are different and Madampegama Tower is located on around 10-20m higher elevation as you can see in below google maps. The Other operator site is located in mentioned area for more than one year before Madampegama tower erection. But there were no such lightning incidents reported with regards to that tower. Therefore simply we can conclude that erection of tower has considerable effect for lightning incidents and also there is a correlation with the tower elevation from the sea level or effective height. Also it is noted that the area is residential having around 26 homes around 100m of perimeter.


Figure 4.1: Elevation of Madampegama site with respect to other operator site

*(Source*: Author)




Figure 4.2: Contour map -Madampegama site with respect to other operator site

*(Source*: Author )

The other incident is reported near Agalawatta RBS. There was lot of damages reported near Agalawatta RBS. But we have observed that there were no damages reported to this RBS after the other operator tower erection near this are. We can see that the other operator site has same tower height and located from the 125m of air distance. Same as the Madampegama case, the elevations of the two tower locations are different and Agalawatta Tower is located on around 10-20m lower elevation as you can see in below google maps.


Figure 4.3: Elevation of Agalawatta site with respect to other operator site

*(Source*: Author)




Figure 4.4: Contour map -Agalawatta site with respect to other operator site

*(Source*: Author)

The reason for this can be explain using iso keraunic level and tower height from the sea level. Grounded vertical objects produce relatively large electric field enhancement near their upper extremities so that upward-moving connecting leaders from these objects start earlier than from the surrounding ground and therefore, serve to make the object a preferential lightning termination point. With increasing height of an object an increase in the number of lightning discharges is observed with an increasing percentage of upward initiated flashes [12].

### 4.2 Effect of Indirect Flashes

A one of home located in Nakiyadeniya radio base station has damages due to some of side flashes occurred in the tower. This can happen as there may be shielding failure rate, e.g., the 2% (maximum) of low energy strikes in a 98% lightning protection design as shown above [15]. As per the damages it is obvious that the damages are due to CVM by pass.

If we consider the total mountain as one structure height of 250m (above sea level) and we have installed air terminal on the top of mountain. The home can be considered as a point on the structure that is on the lower part of the structure and that point has been damaged due to CVM bypass as similar as lightning incident happen in Villaputri Building, downtown Kuala Lumpur in year 2005.

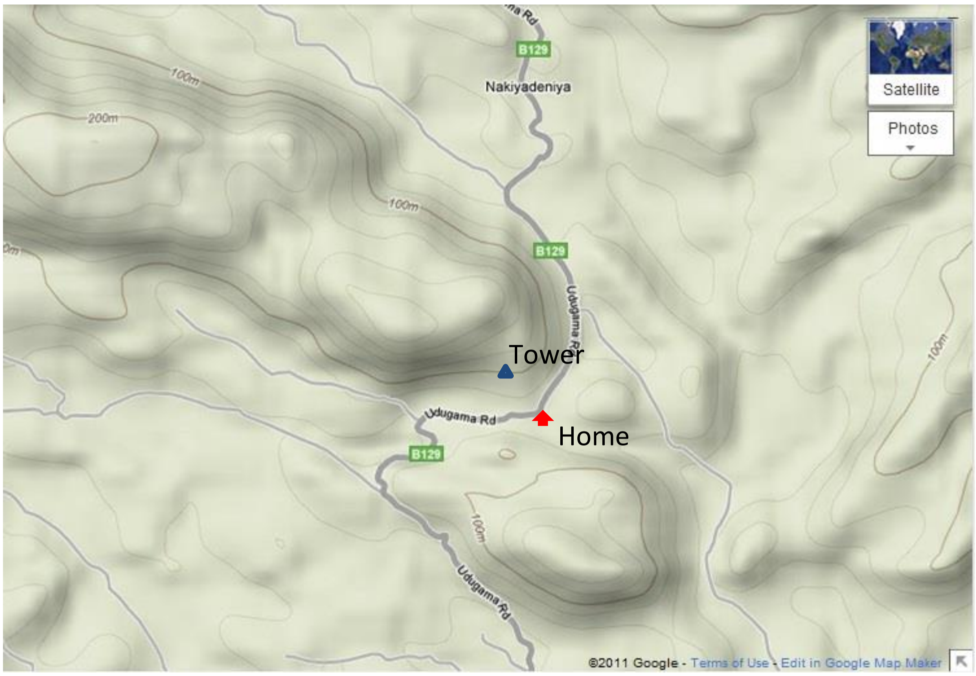



Figure 4.5: Tower location and the home location in Nakiyadeniya lightning incident

*(Source*: Author )



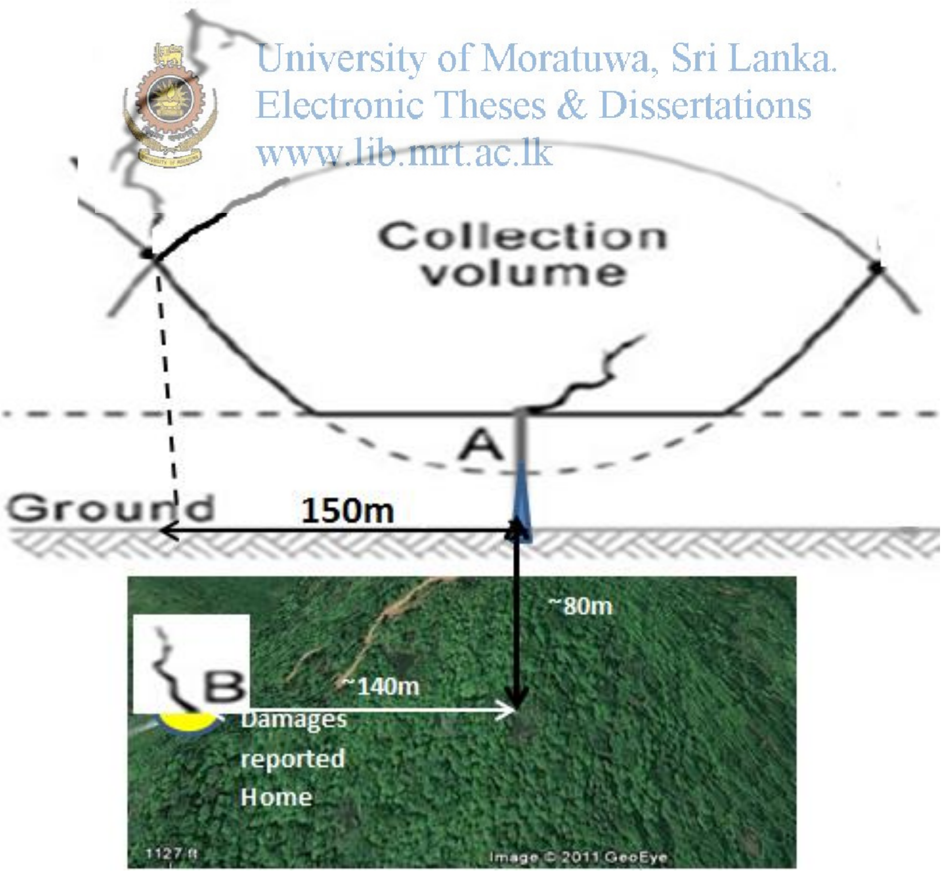



Figure 4.6: Collected volume of the Nakiyadeniya Tower

*(Source*: Author)

Tower Air terminal height with reference to the see level is around 250m and home located around 110m above the see level. Therefore it is obvious that we can expect such bypasses even there lightning protection zone due to a telecommunication tower. In such cases we have taken care of protecting neighborhoods by creating protection zone for them.

The only thing can do is to protect home is to develop a shielding area for the home. Simply we can route the discharge path through the Airterminals that we are going to use for the creation of shielding area.  Then the discharge happen previously through the wall can now be discharge through the Airterminal without damaging any other object.

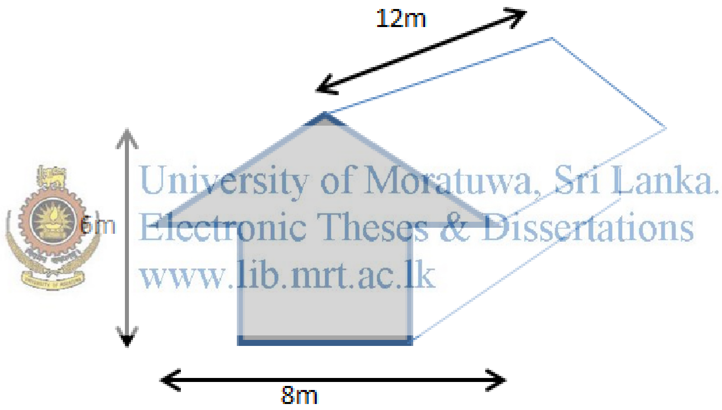




Figure 4.7 Dimensions of the damaged Home

(*Source*: Author)

A lightning rod mounted on 10m GI structure selected for the protection of home. Then for the high risk, we have selected 6.5kA peak current, and then radius of protection is 13m. For more safety we can put 2 lightning rods and have large collected volume.

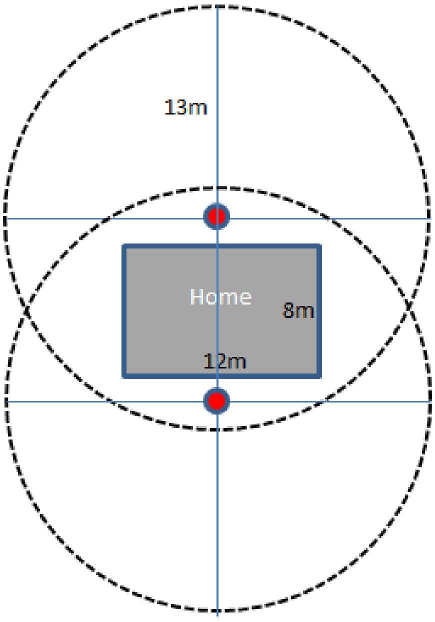



Figure 4.8 Shielding areas proposed around the damaged home

*(Source*: Author)

This system has been implemented on March 2010 and we have no any complaints since the implementation date and it is obvious that the implementations have very effective and fruitful as we have almost passed two year with more than four lightning seasons. The onsite implementations are shown in figure.



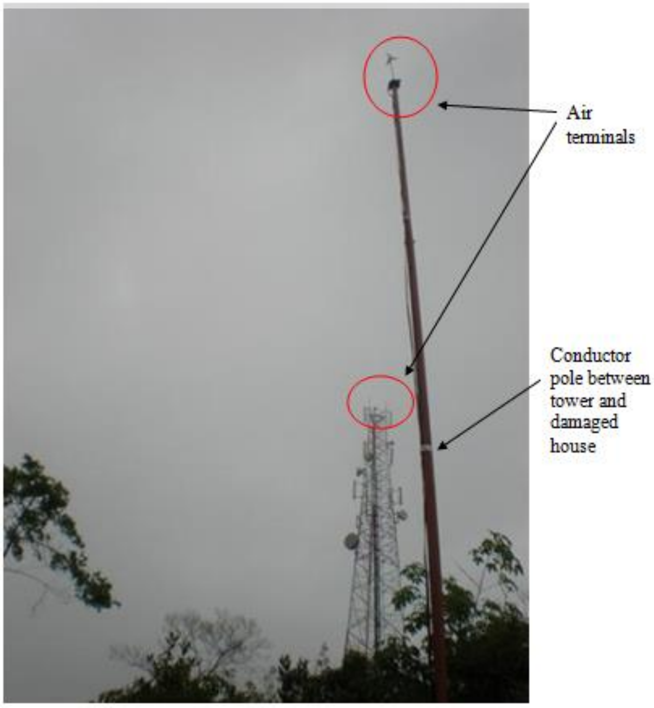



Figure 4.9 Air Terminal installed on tower side near the damaged home

*(Source*: Author )


Figure 4.10 Air Terminal installed on home side

(*Source*: Author)



### 4.3 Effect of Power line surge

During the research, it is observed that the most of the damages reported are due to the power line surges. The way of developing surges on power line need to be discussed in this session. There are few possibilities of happening this. Those can be proposed as follows

- The surge voltage developed due to direct lightning induced on power line
- The surge voltage developed due to the direct lightning stroke to tower and then it return to the power line through the surge reduction filter installed at tower equipment cabin

SRF 140 surge reduction filter using as the power line protector model by using Line to Neutral and Neutral to Ground surge arrester and low pass filter as shown in Figure 4.11.

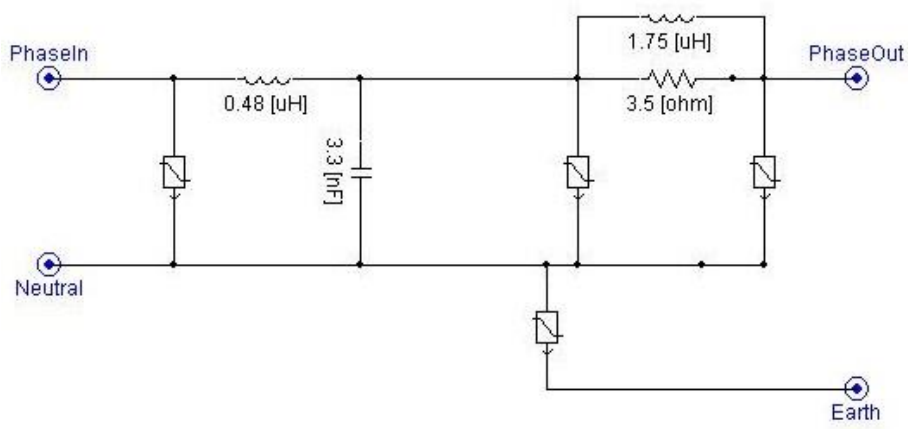



Figure 4.11: Surge reduction filter model

*(Source*: Author)

For the purpose of surge calculations, it is only the heavy current flow during the return stroke that is of importance. During it has been found that the waveform can be represented by a double exponential of the form

$$i = I\,(e^{-\alpha t} - e^{-\beta t})$$



The parameters of the lightning current surge were taken according to the International Standard IEC 61312-1 [12] for the III and IV protection levels as 10/350 μs 10 kA. The Surge generator and wave shown in Figure 4.12 and Figure 4.13 respectively

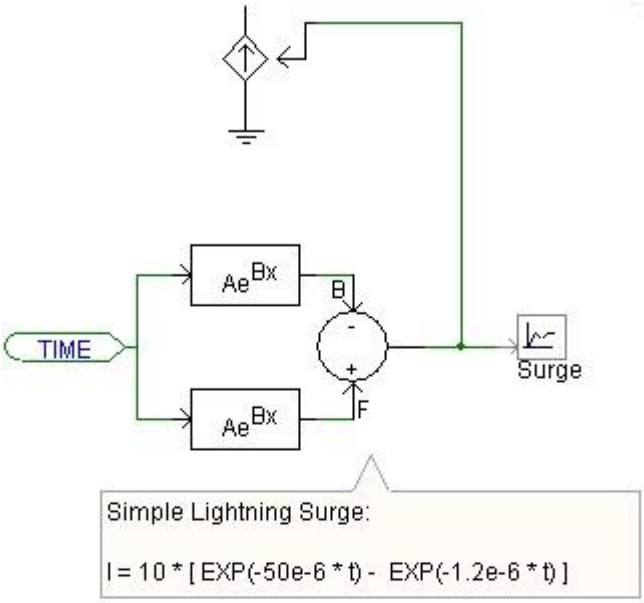



Figure 4.12: Surge Generator

*(Source*: Author)

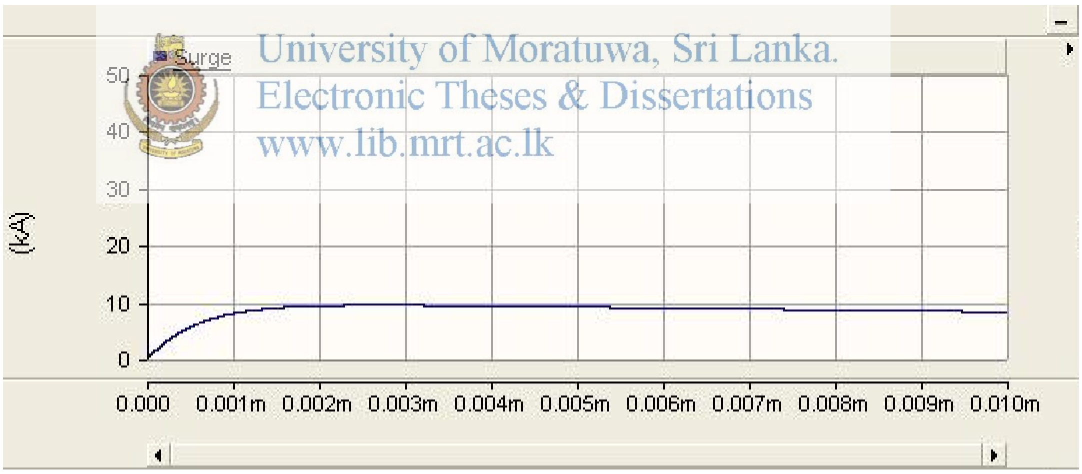





Figure 4.13: Surge wave model

*(Source*: Author)

The power line arrangement, Lightning strike and earth resistance system combine to a one model and demonstrated in Figure 4.14 to show the RBS power line arrangement from the generation end to the load end. The arrangement inside the doted square shows the RBS. The Armourd cable segment from meter cubicle to the SRF and then to the RBS load is shown there.  In one side we can see the neighborhood loads serves from all three feeders from the transformer.

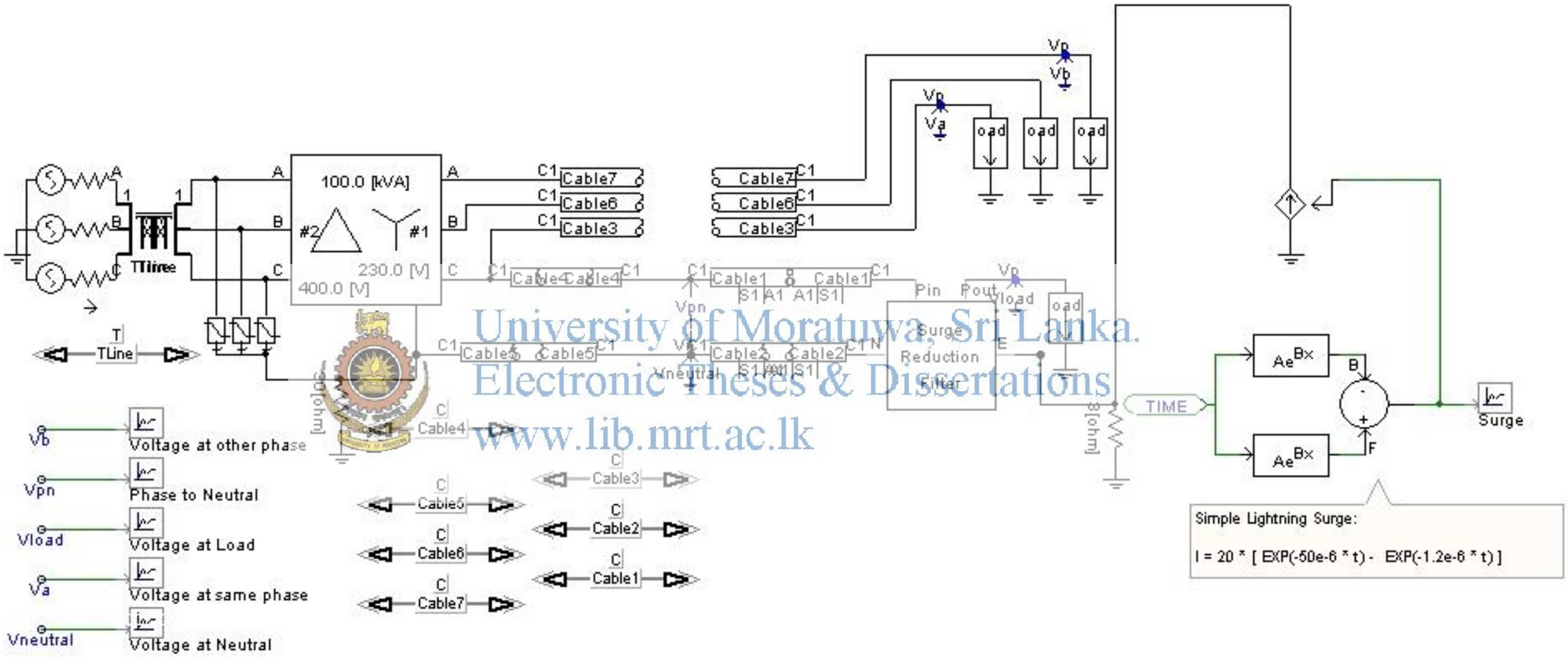





Figure 4.14: Power line model for the telecommunication Radio Base station

*(Source*: Author)

### 4.3.1 Voltage rise with the effect of earth resistance

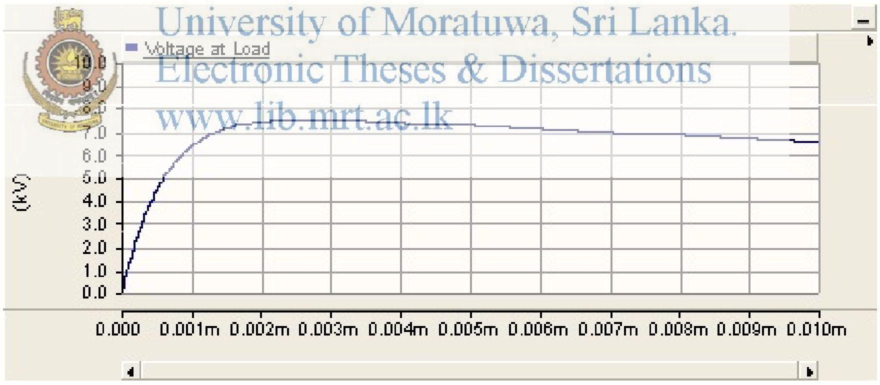
The below simulation are based on the direct lightning stroke to tower and then it return to the power line through the surge reduction filter installed at tower equipment cabin. In here we will look at how potential raise in power lines vary with the tower earth resistance value.

The equivalent resistance for the grounding system is simulated by a resistance as shown in below Figure. The Simulation has done to find the effect on potential rise in phase and neutral in the case of direct lightning strike to the tower

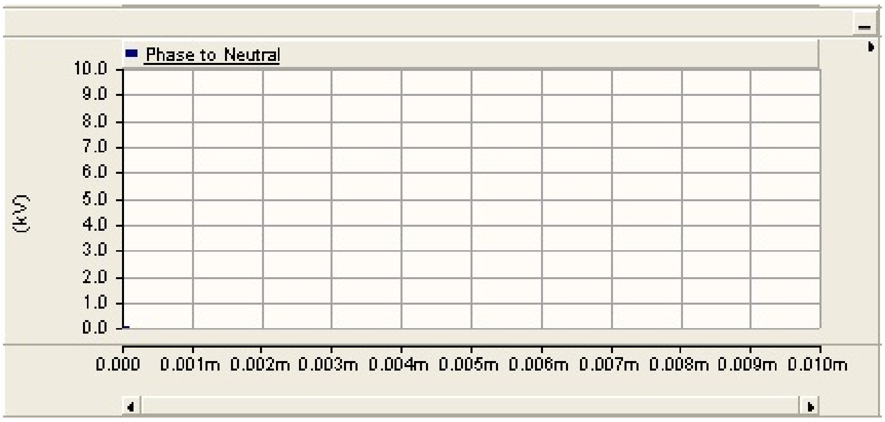
***Voltage variations with 100 Ohms Earth resistance systems***

With the effect of the lightning strike to the tower, we can see around 7.5kV voltage rise at the power input phase to the SRF, Neutral, Power output from the SRF and at Separate phase from the transformer with respect to the ground and there is no voltage difference in Phase to neutral in RBS having 100 Ohms earth resistance system.

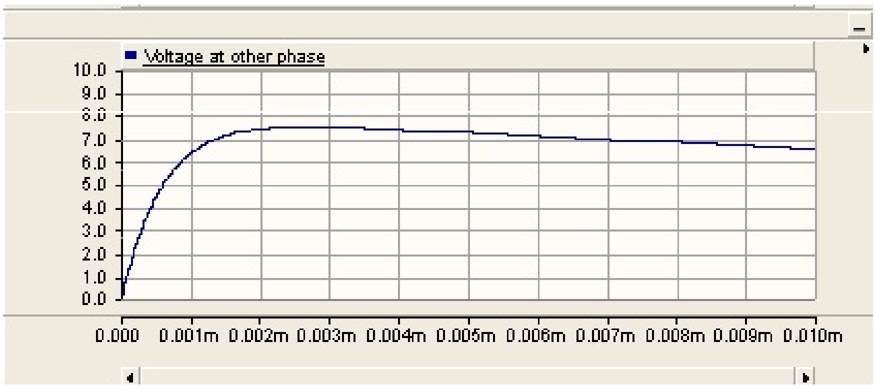




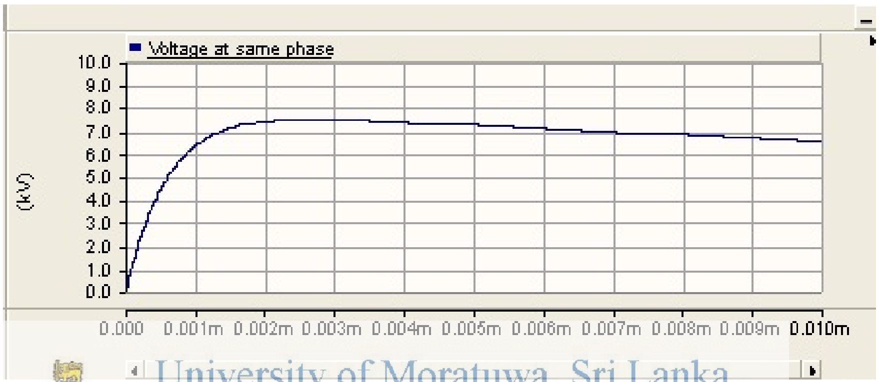

(a)




(b)

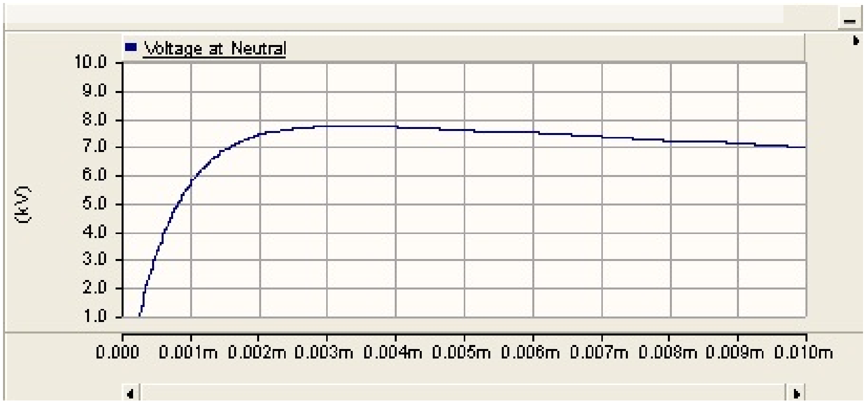



(c)






(d)

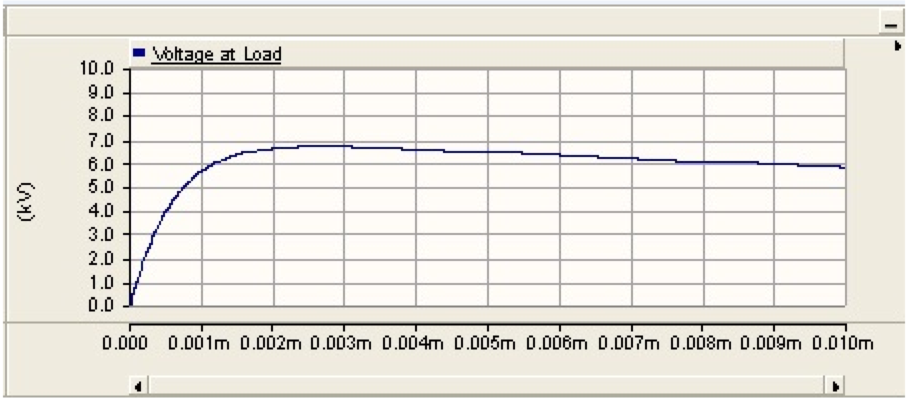



(e)

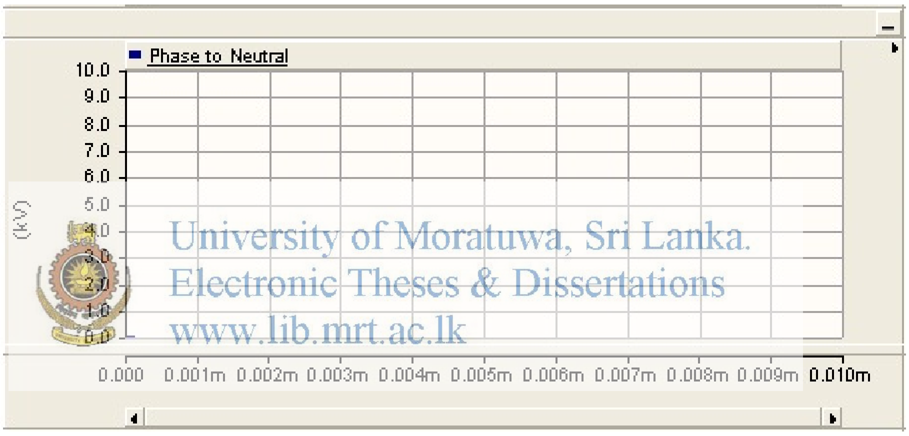
Figure 4.15 Voltage rises in (a) at load (b) Phase to neutral (c) at separate phase (d) Site power input phase (e) at neutral for 100 Ohms earth resistance system

*(Source*: Author)

*Voltage variations with 10 Ohms Earth resistance systems*

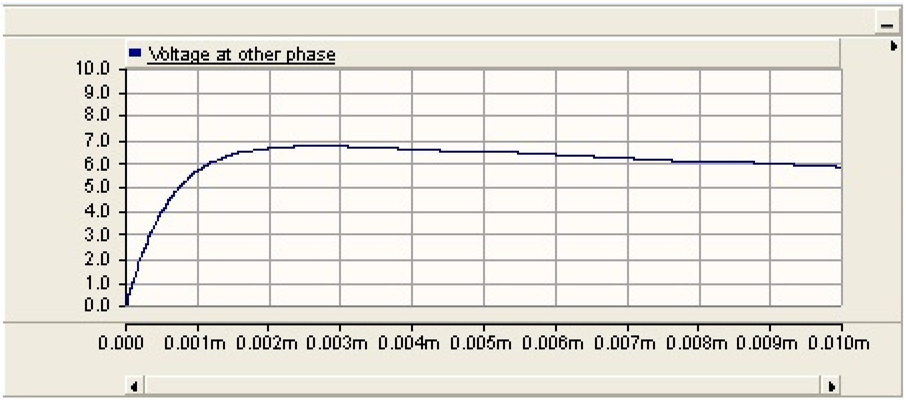



(a)

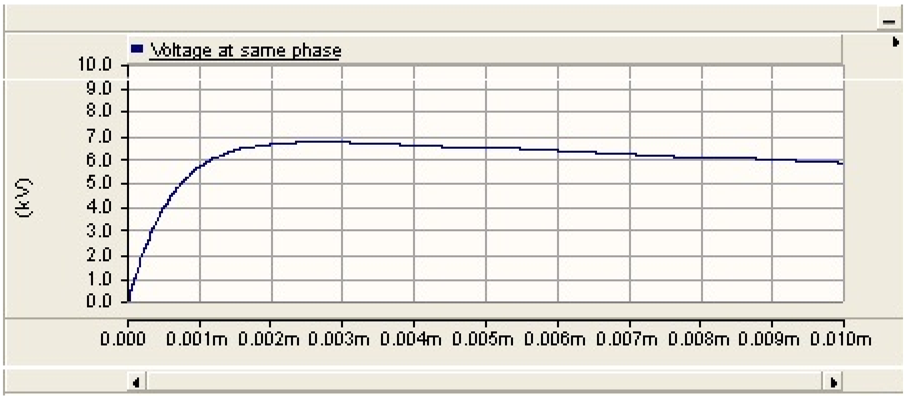




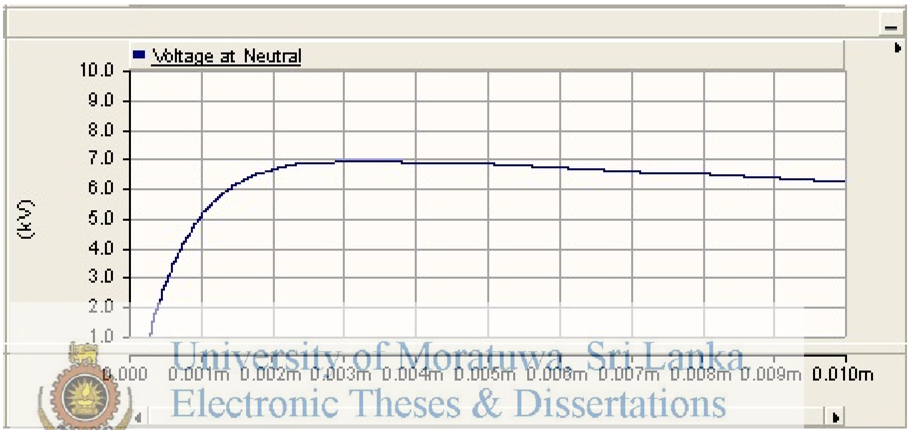

(b)




(c)




(d)





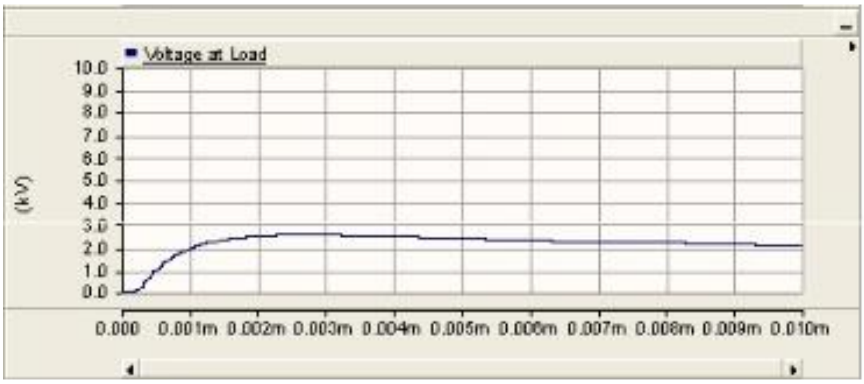

(e)

Figure 4.16 Voltage rises in (a) at load (b) Phase to neutral (c) at separate phase (d) Site power input phase (e) at neutral for 10 Ohms earth resistance system

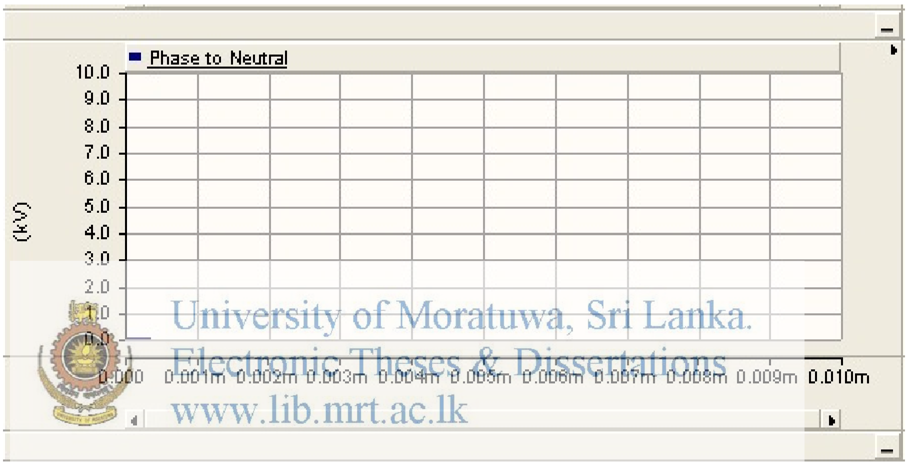
*(Source*: Author)

With the effect of the lightning strike to the tower, we can see around 7 kV voltage rise in power input phase to the SRF, Neutral, Power output from the SRF, Separate phase from the transformer with respect to the ground and there is no and voltage difference in Phase to neutral. This is not a considerable reduction in voltage rise compared with 100 Ohms earth resistance system.

*Voltage variations with 1 Ohms Earth resistance systems*

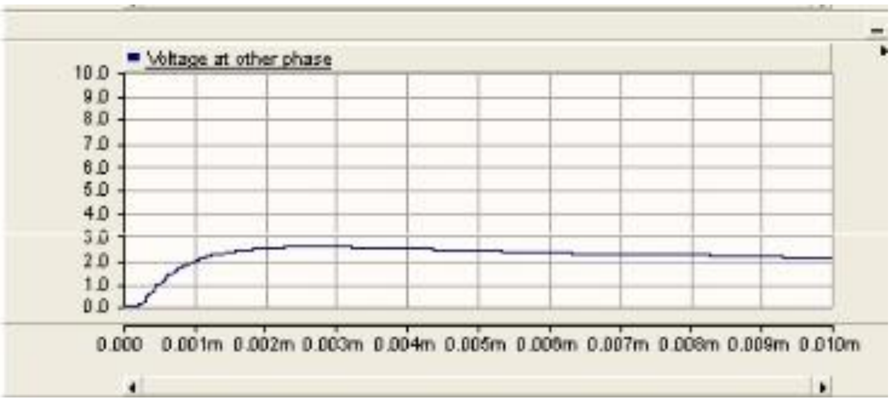



(a)

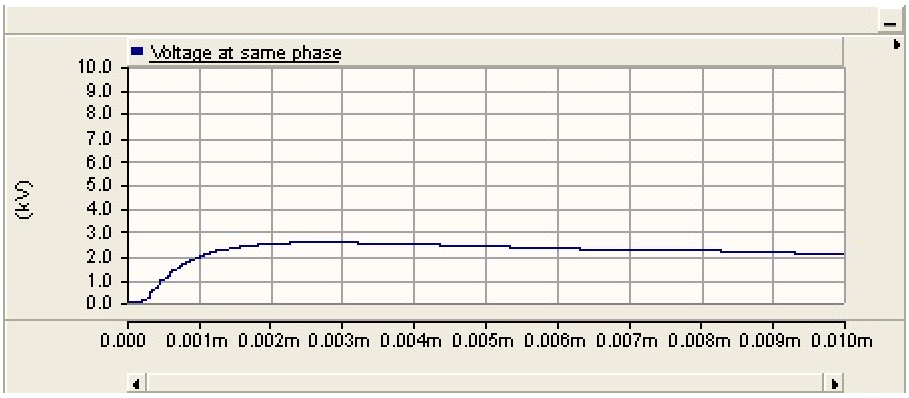




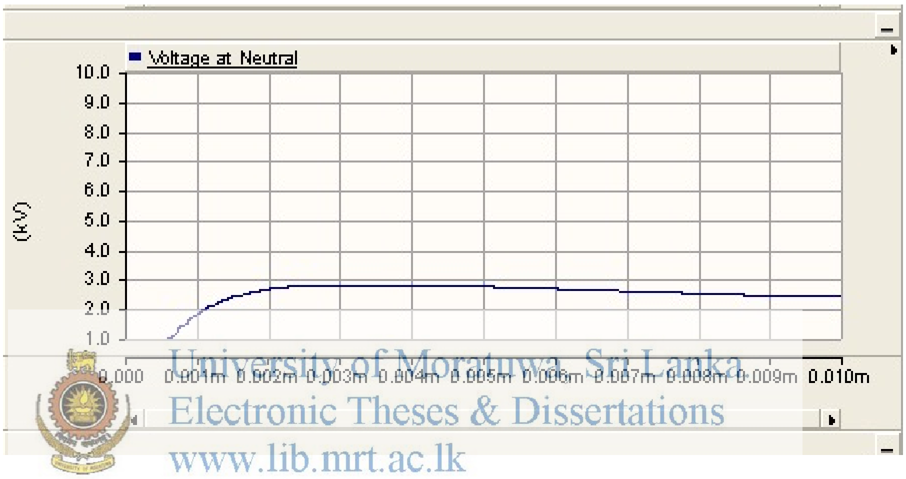

(b)




(c)




(d)






(e)

Figure 4.17 Voltage rises in (a) at load (b) Phase to neutral (c) at separate phase (d) Site power input phase (e) at neutral for 10 Ohms earth resistance system

*(Source*: Author)

With the effect of the lightning strike to the tower, we can see around 2.5 kV voltage rise in power input phase to the SRF, Neutral, Power output from the SRF, Separate phase from the transformer with respect to the ground and there is no and voltage difference in Phase to neutral. This is a considerably low value compared with 100 Ohms and 10 Ohms earth resistance system.

By considering the simulation results we can see that the considerably high voltage built up in power lines not only in RBS power in, but also in other transformer feeders. This will cause to lot of electrical equipment damages. During the research data collection, we can see that the earth resistance values in most of the sites are greater than 5 Ohms. With this we can see there may a possibility of more than 7kV voltage rise in electrical systems with respect to the earth. This is basically high value compared with BIL of electrical items and therefore will cause to equipment failures.

### 4.3.2 Voltage rise with the effect of Secondary sure arresters

Throughout these 3 years of period we have observed lot of electrical equipment damages in neighborhood homes. As a regulation and a habit, we have been installing secondary surge arrester of 20kA class B and we have experienced a good result from that. In such sites we do not have any evidence in damages after the surge arrester installation. For this installation it is cost around Rs. 50,000.00 per home. If there is complains from 20 homes, we need to install surge arrester for all homes and it will cost Rs 1M. Therefore to achieve same effect we have installed only one surge arrester set at the RBS meter cubicle (i.e. at the power entry to the site). The simulation results of the secondary surge arrester installation at the meter cubicle is shown below and will discuss about the effect of the arrangement.



***Effect of Phase to Ground secondary surge arrester***

Phase to ground surge arrester with 280V Class B protection level has installed as shown in below Figure. In this case earth system resistance kept at 30 Ohms fix.

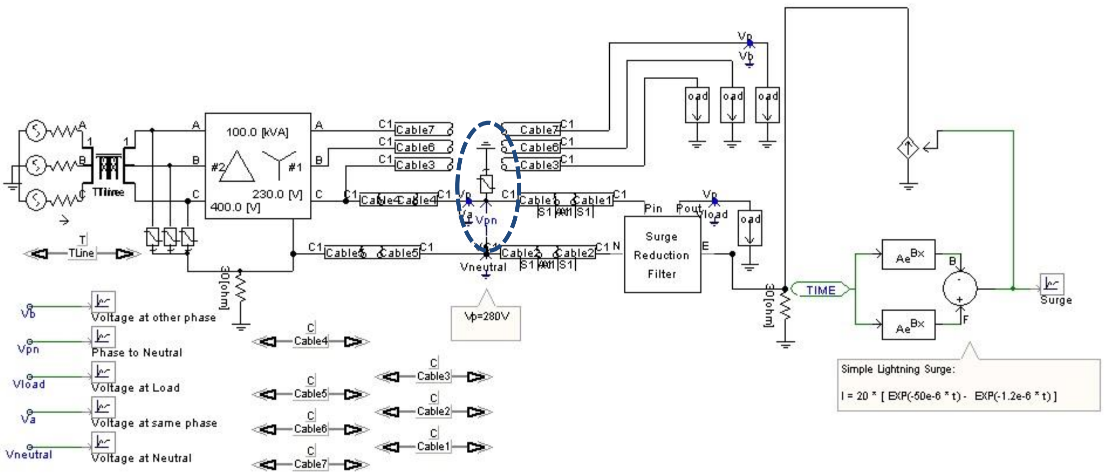
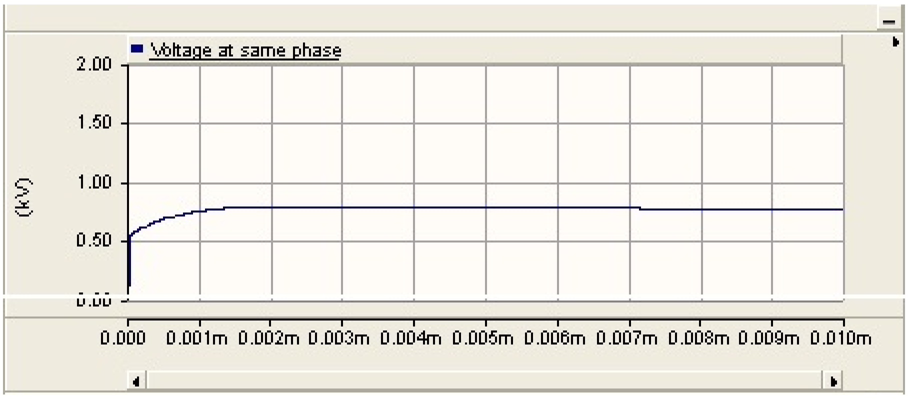


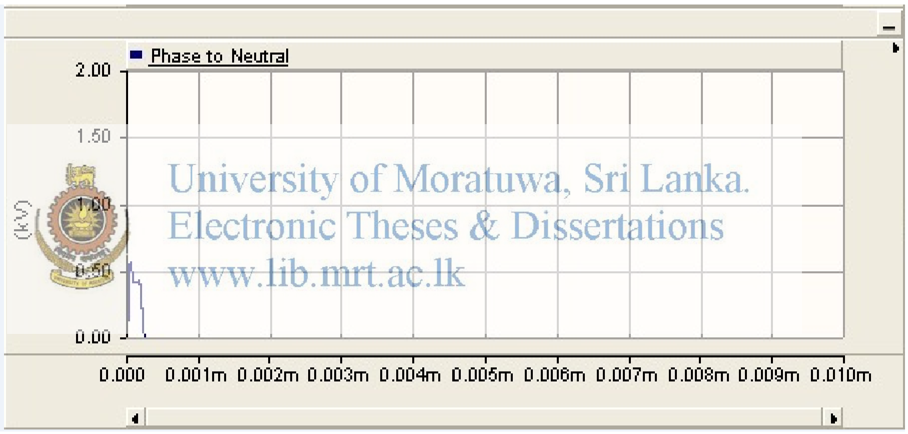

Figure 4.18 Phase to Ground secondary surge arrester

(*Source*: Author)

In this simulation we can see the voltage around phase get dropped to around 0.75kV as shown in Figure (a), (d) and (e). At neutral it is around 1.25kV as shown in Figure (c). A remarkable feature in phase to neutral is that at the beginning we can see a voltage spike and then it became to zero as shown in Figure (b). Therefore we can see that the phase to ground surge arrester works effectively to reduce voltage rise due to the lightning surges.

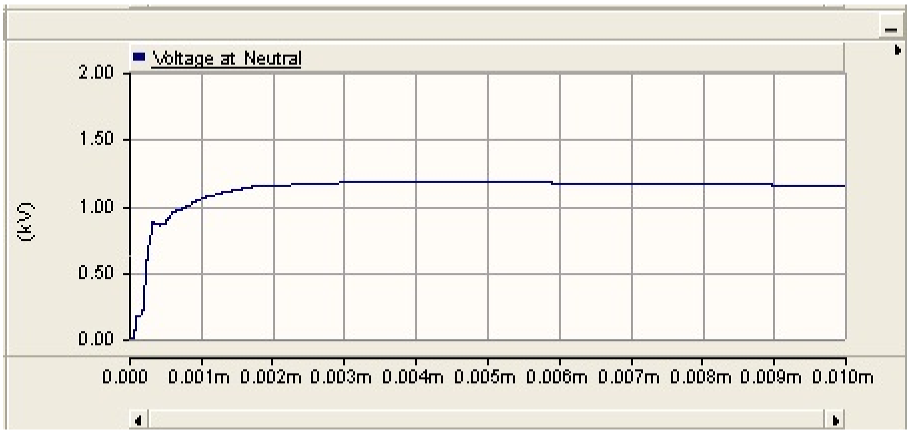



(a)

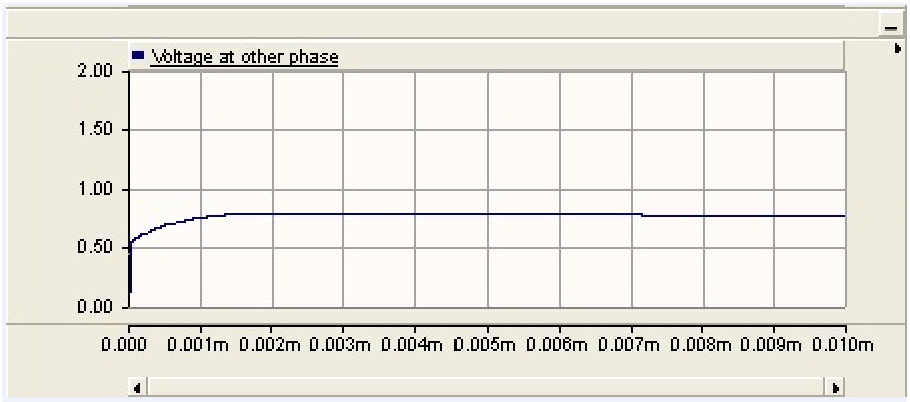




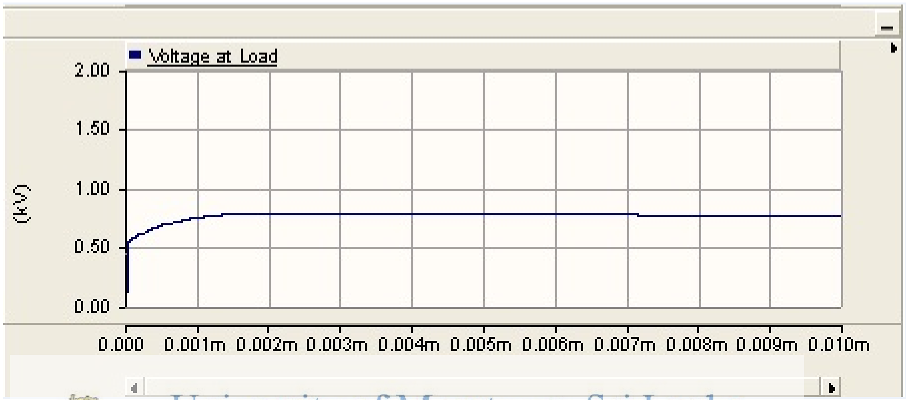

(b)




(c)




(d)




(e)



Figure 4.19 Voltage rises in (a) at same phase (b) phase to neutral (c) at neutral (d) at separate phase (e) at load - for secondary surge arrester installation at phase to ground

(*Source*: Author)

***Effect of Neutral to Ground secondary surge arrester***

Neutral to ground surge arrester with 280V Class B protection level has installed as shown in below Figure. In this case earth system resistance kept at 30 Ohms fix.

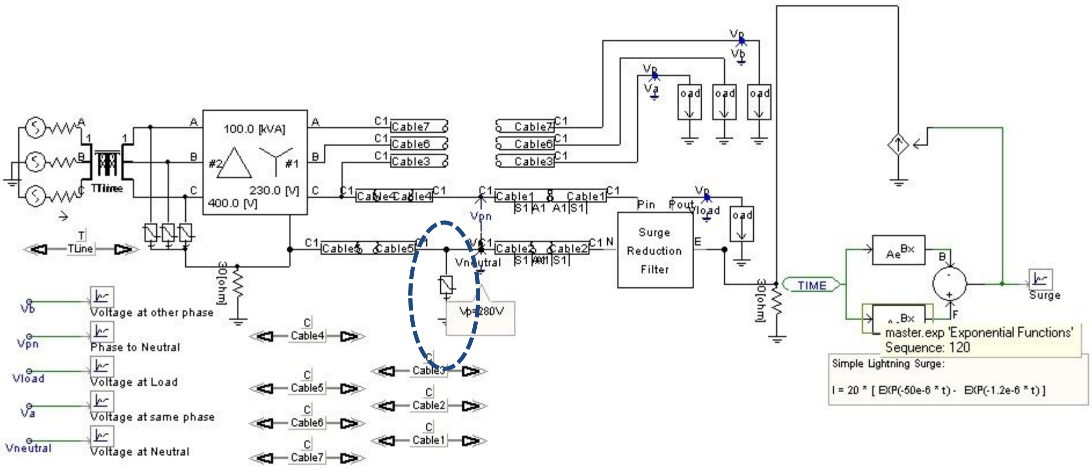
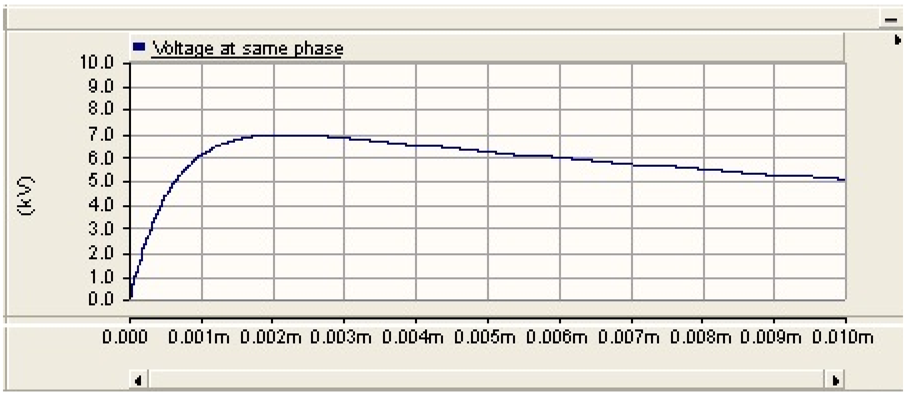


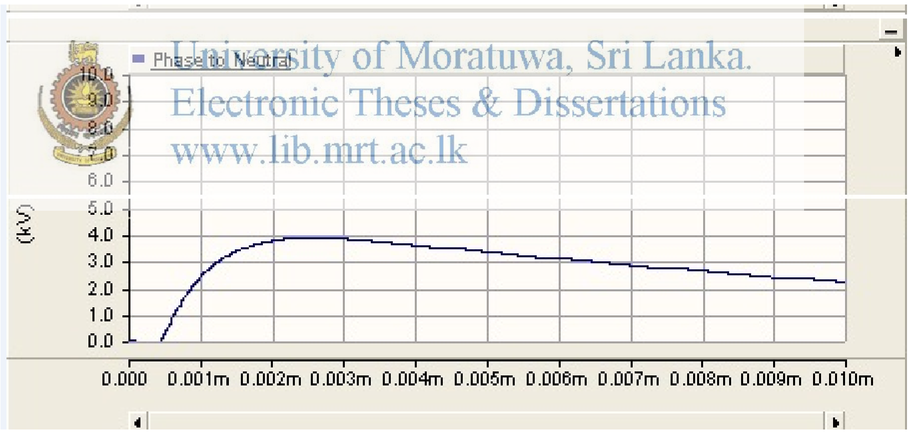

Figure 4.20 Neutral to Ground secondary surge arrester

(*Source*: Author)

In here we cannot see considerable effect due to the surge arrester installation at Neutral to ground. We can see the voltage around phase get dropped to around 7 kV as shown in Figure (a), (d) and (e). There is no any voltage rise at neutral as shown in Figure (c). But we can see phase to neutral voltage rise drop to around 4kV as shown in Figure (d). Therefore we can see that the phase to ground surge arrester does works effectively to reduce voltage rise due to the lightning surges.

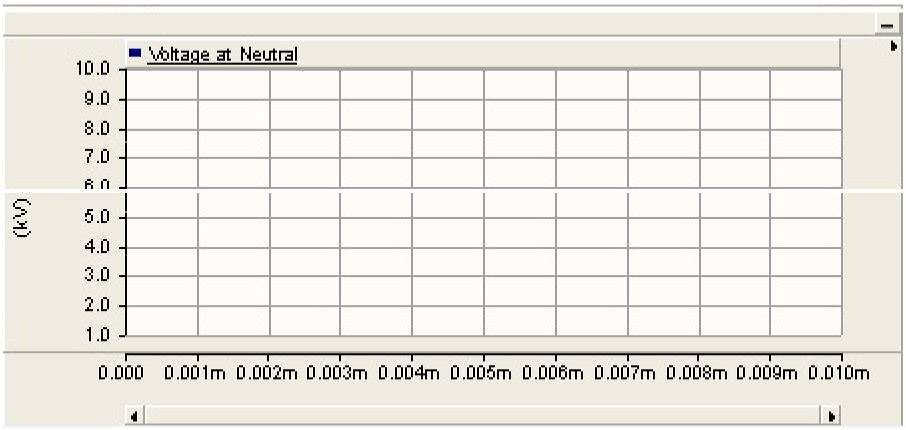



(a)

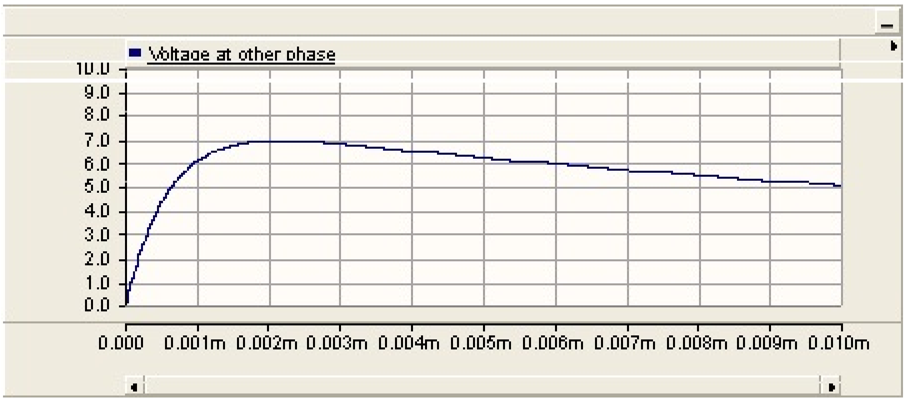




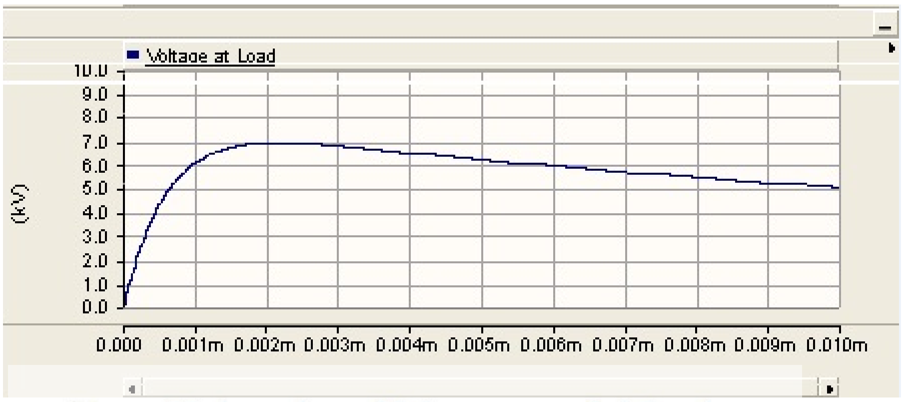

(b)




(c)




(d)




(e)



Figure 4.21 Voltage rises in (a) at same phase (b) phase to neutral (c) at neutral (d) at separate phase (e) at load - for secondary surge arrester installation at Neutral to ground

*(Source*: Author)

***Combine Effect of Phase to Neutral and Neutral to Ground secondary surge arresters***

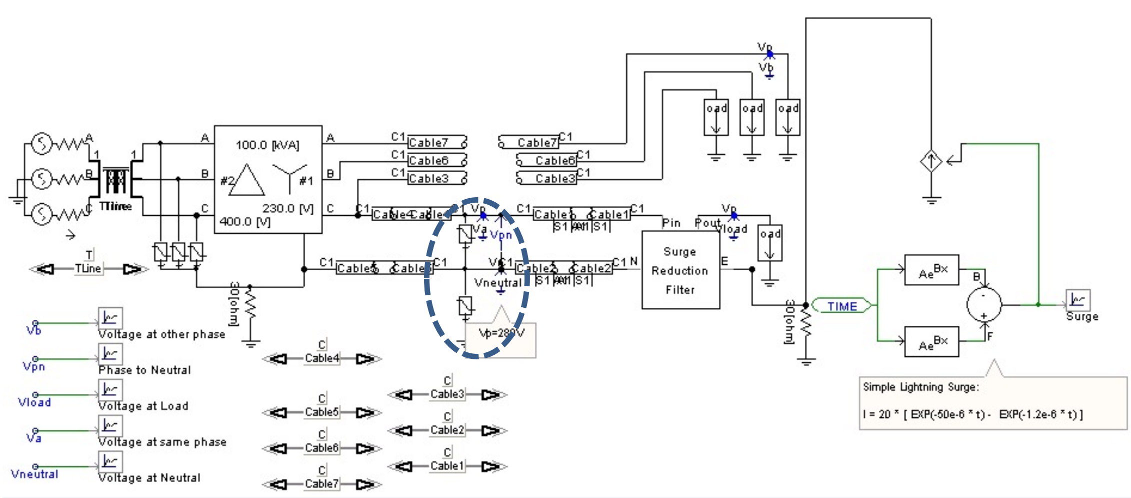
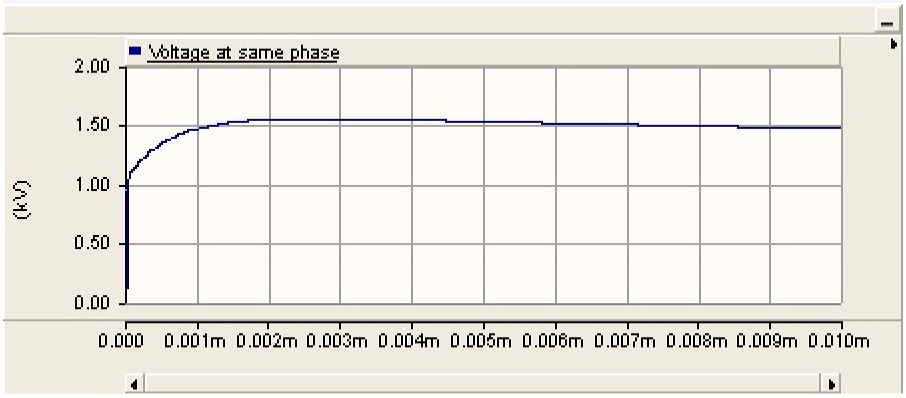


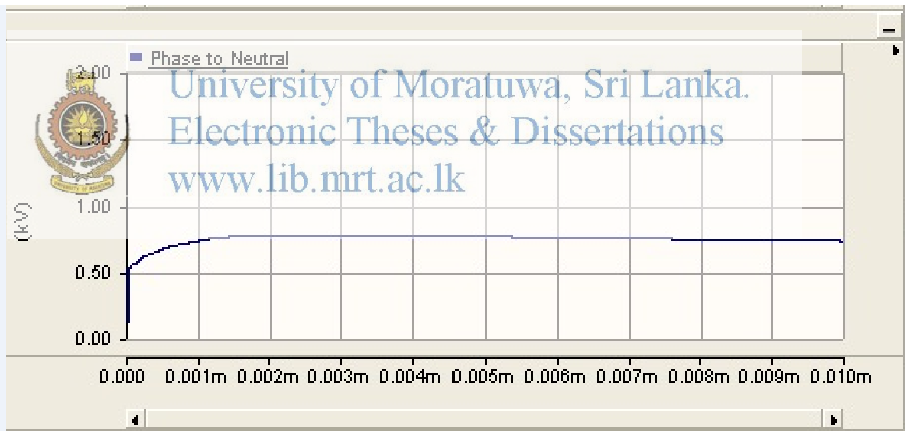

Figure 4.22 Phase to Neutral and Neutral to Ground secondary surge arrester

*(Source*: Author)

This arrester configuration is also effectively drop the voltage rises. We can see the voltage around phases get dropped to around 1.5 kV as shown in Figure (a), (d) and (e). But we can see phase to neutral and neutral to ground voltage rise, drop to around 0.75kV as shown in Figure (b) and (c). Therefore we can see that the phase to ground surge arrester works effectively to reduce voltage rise due to the lightning surges. But this not good configuration compared with phase to ground arrester configuration.

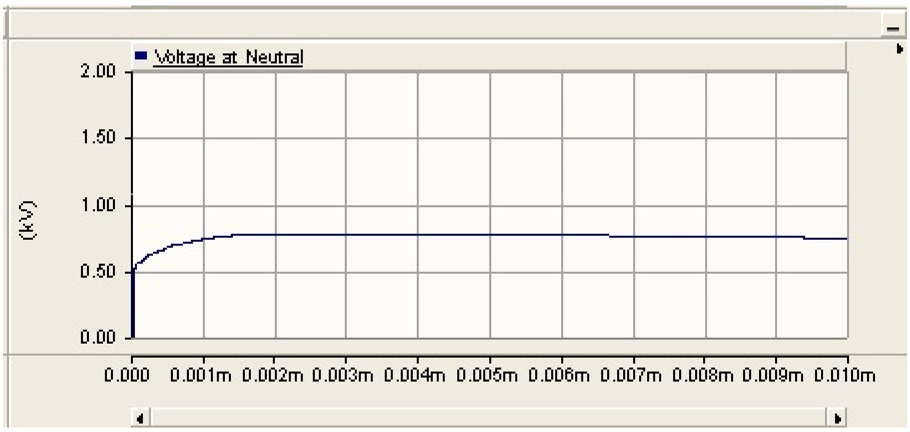



(a)

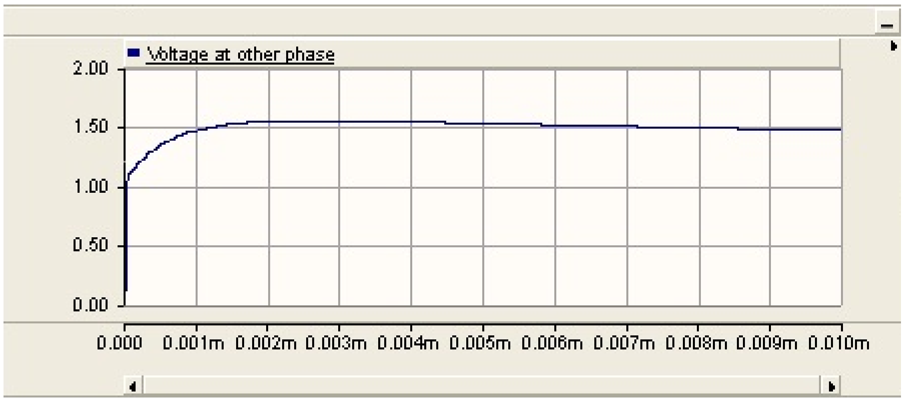




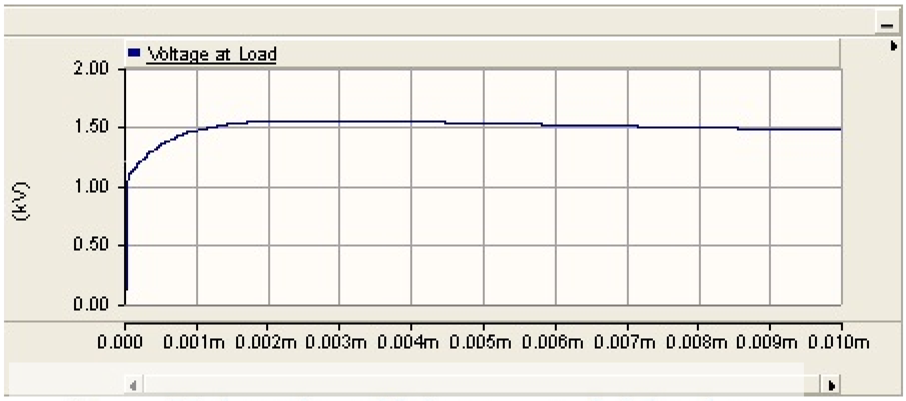

(b)




(c)




(d)






(e)

Figure 4.23 Voltage rises in (a) at same phase (b) phase to neutral (c) at neutral (d) at separate phase (e) at load - for secondary surge arrester installation at Phase to Neutral and Neutral to ground

*(Source*: Author)

***Combine Effect of Phase to Ground and Neutral to Ground secondary surge arresters***

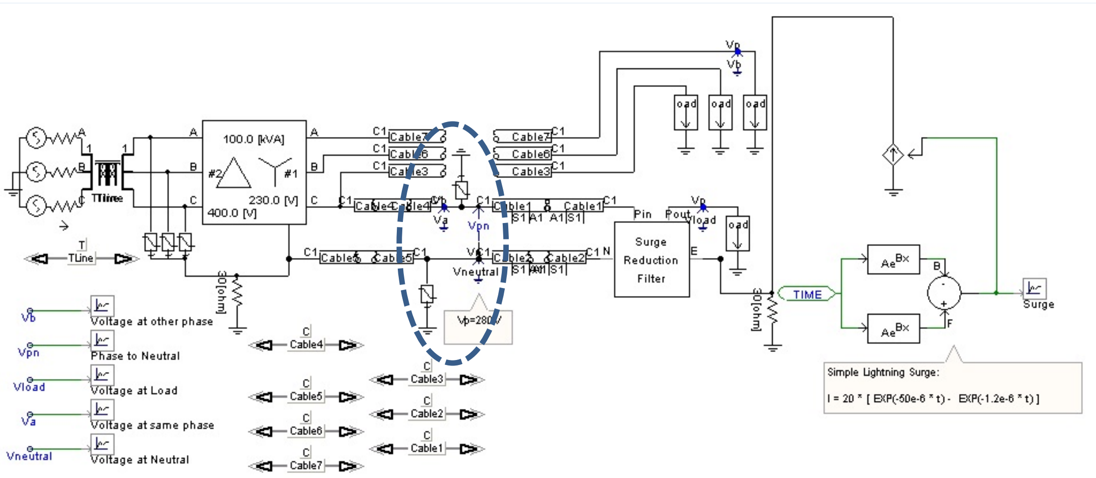
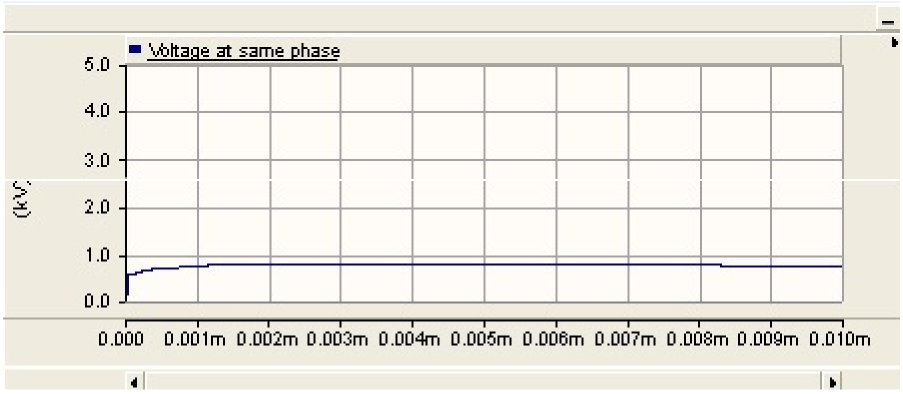
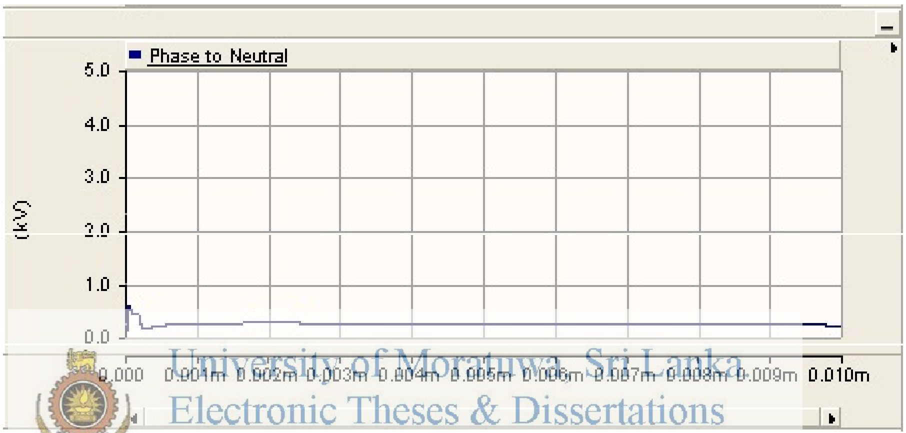



Figure 4.24 Phase to Ground and Neutral to Ground secondary surge arrester

*(Source*: Author)

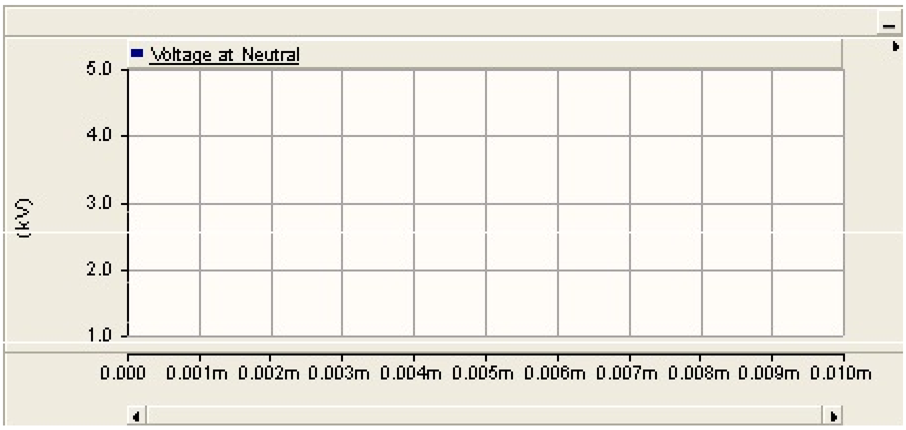

Voltage at same phase
5.0
4.0
3.0
2.0
1.0
0.0
(kV)
0.000 0.001m 0.002m 0.003m 0.004m 0.005m 0.006m 0.007m 0.008m 0.009m 0.010m

(a)

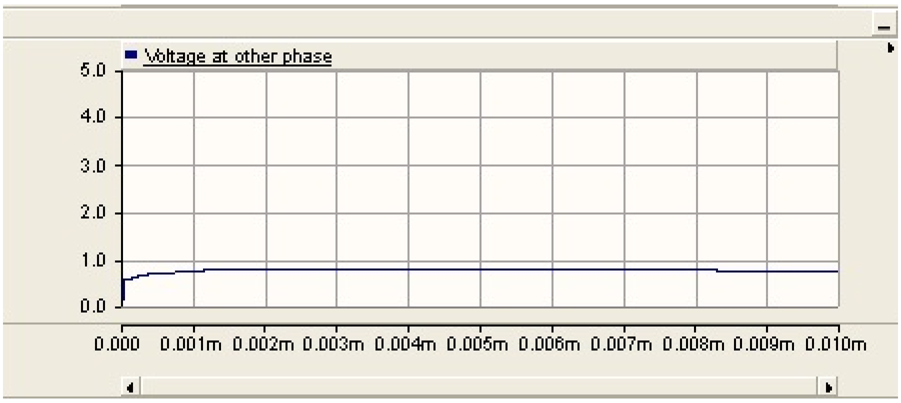

Phase to Neutral
5.0
4.0
3.0
2.0
1.0
0.0
(kV)
0.000 0.001m 0.002m 0.003m 0.004m 0.005m 0.006m 0.007m 0.008m 0.009m 0.010m



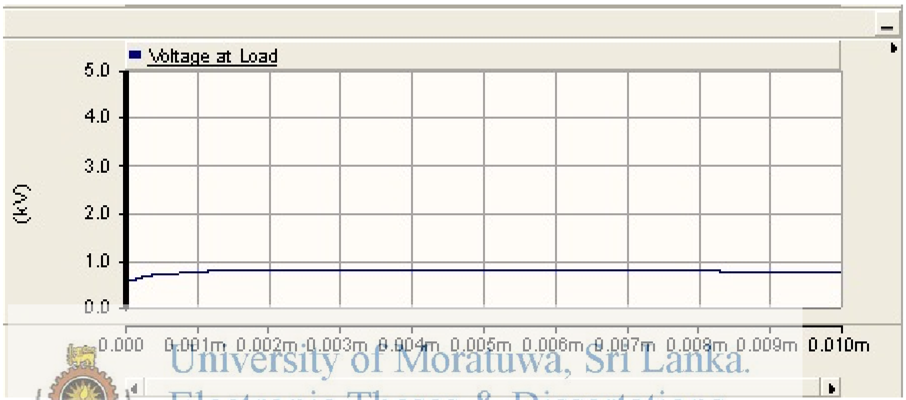
(b)


Voltage at Neutral
5.0
4.0
3.0
2.0
1.0
(kV)
0.000 0.001m 0.002m 0.003m 0.004m 0.005m 0.006m 0.007m 0.008m 0.009m 0.010m

(c)




(d)






(e)

Figure 4.25 Voltage rises in (a) at same phase (b) phase to neutral (c) at neutral (d) at separate phase (e) at load - for secondary surge arrester installation at Phase to Ground and Neutral to ground

*(Source*: Author)

This configuration is very effective compared with both other configuration proposed under Figure 4.20 and 4.22. This arrester configuration is also effectively drop the voltage rises. We can see the voltage around phases get dropped to around 0.75 kV as shown in Figure (a), (d) and (e). There is no any voltage rise at neutral as shown in Figure (c). But we can see phase to neutral voltage rise drop to around 0.25kV as shown in Figure (b).

If a lightning stroke hits a power line or voltage rise on power line, the only way to protect it is using a lightning arrester. The lightning arrester is a non-linear device that acts as an open circuit to low potentials, but conducts electrical current at very high potentials. When lightning strikes a line protected with a Lightning arrester, the non-linear resistance draws the current to ground. One of the most common lightning arresters is the MOV (metal oxide varistor) lightning arrester, [16]. The MOV has a piece of metal oxide that is joined to the power and grounding line by a pair of semiconductors. The semiconductors have a variable resistance dependent on voltage. When the voltage level in the power line is at the rated voltage for the arrester, the electrons in the semiconductors flow in a way that creates a very high resistance. If the voltage level in the power line exceeds the arrester rated voltage, the electrons behave differently and create a low resistance path that conducts the injected lightning current to the ground system.

But as we can see throughout the simulation results, we have to use them in effective configuration so that only we can reduce the power line damages effectively. Therefore Combine Effect of Phase to Ground and Neutral to Ground secondary surge arresters is suit for the installation near meter cubical (i.e. power input to the RBS) so that we can effectively reduce voltage rise and reduce the damages to both RBS electrical equipment and neighborhood electrical equipment.



This system has been implemented in few sites and we have no any complaints since the implementation date and it is obvious that the implementations have very effective and fruitful as we have almost passed more than two year with more than four lightning seasons. The onsite implementations are shown in Figure

**4.4 Effect of Base Band arrester Installation for transmission equipment**

Past experience shows that lot of tower mounted transmission equipment and indoor transmission equipment damages due to the lightning 3 years before.

This has happened due to the voltage different between the tower structure and the coaxial cable. Irrespective of the resistance, the inductance alone will contribute to a very high potential difference between the coaxial cable and the tower structures which are essentially at ground potential. But as per the past experience we do not have noticed and spark-over through insulation breakdown.

As a preventive action we have installed base band arrester to both end of the transmission path of all microwave antenna link in the network.

(a) (b)

Figure 4.26: Base band arrester installation (a) at ODU mounted on tower structure (b) at IDU mounted in equipment cabin

*(Source*: Author)

We have observed ODU and IDU failure rate after the installation during last three years and it has successes 100%. The MW links located in high iso keraunic level areas such as Rathnapura get hanged, but no equipment failure reported. This has been happed due to exceed of no of hits can be managed by the arrester.



**4.5 Accuracy of measurements of Earth resistance system**

In most of the telecom towers, the measured earth resistance values are in accurate due to overlapping shells of earth due to low space to place current and potential electrode outside the electrical influence of the electrode system. If we look at the detailed earth resistance test carry out for Keselhenawa (Figure 3.6) and Erathna (Figure 3.8) we can clearly see the effect of overlapping shells. We can experience this effect in every RBS due to the unavailability of space to place current and potential electrode outside the electrical influence of the electrode system, irregular shape in earth profile

It can be shown that the actual electrode resistance is measured when the potential probe is located 61.8% of the distance between the center of the electrode and the current probe [11]. But if we consider the total radio base station network it is very difficult to find non-overlapping earth shelf. Sometimes we cannot find where the berried earth electrodes are. If we look at Table 4.1, we can have different values for earth resistance for different current electrode distances. Therefore it is a question that available space for current electrode will give the accurate earth resistance or not. Therefore finalizing the earth resistance for a particular site is somewhat difficult due to the limited space between earth electrode and current electrode.

With regards to the earth resistance measurements, the available distance from earth point to the current electrode position is different in leg to leg and site to site as per the space availability for the measurements. To see the effect, the earth resistance values were measured for different distance in Madampegama sites. Table 4.1 show the earth resistance value measured for different potential and current electrode distances.

| E-P distance (m)<br>( 62% of the E-C distance) | E-C Distance (m) | Earth Resistance value<br>(Ohms) |
|---|---|---|
| 18.6 | 30 | 8.6 |
| 15.5 | 25 | 8.9 |
| 12.4 | 20 | 6.1 |
| 9.3 | 15 | 5.4 |
| 6.2 | 10 | 2.8 |

Table 4.1: Earth resistance measurements for different potential and current electrode distances

*(Source*: Author)

## CHAPTER 5

## 5.0 DISCUSSION

There are two incident that we observed damages occurrence and non-occurrence with the tower erection. To account for the observations of increased lightning activity to tower of moderate height (less than 100m) on high mountains a so called " effective height" being larger than the physical height of the object is assign to the structure [13]. The effective height accounts for the additional field enhancement at the tower top due to the presence of the mountain.

A new methodology, the Collection Volume Method, is given for the placement of lightning rods or air terminals for the protection of tower structures against lightning. In this concept it is define particular area where object within that area get protected through the same volume. But there may be shielding failure rate and there may be possibility of by passing CVM. This can be handling only case by case. Therefore it is important to identify such incidents and need to take precautions before it gets worsen.



If we look at the Table 3.5, we can see MW antenna mounted on the tower structure got failed in both site types where separate copper down conductor available site and non-available sites within same iso keuranic level and with fairly same earth resistance system. But we cannot figure out any arcing marks on the equipment. This is because the down conductor termination and tower footing integrated. As per the observations we can see there is no any effect of having separate copper down conductor. For an example, if we consider Getaheththa, Erathna and Parakaduwa, it is very clear that there is no considerable effect of installation of separate copper down conductor installation.

It is also noted that the measured earth resistance values are very high in hard rock areas where high resistivity exist and it is difficult to carry out grounding system improvement. In some cases the access to the nearest large mass of soil required a metal extension for more than 100 m. Therefore copper tapes were extended parallel from the tower site to this location. We have done such two improvements to the Nakiyadeniya and Galapatha sites. Please see the figure 5.1.




Figure 5.1: Extended Copper tape for the nearest mass of soil

(*Source:* Author)

It has identified that power line surges have developed in neighbourhood due to the direct lightning stroke to tower and then it return to the power line through the surge reduction filter installed at tower equipment cabin and it is obvious in simulation results rather than the direct lightning induced on power line.

If we compare the Potential rise in power line with the earth resistance value, to have effective reduction in potential rise in power lines, it is needed to achieve earth system resistance below 1 ohm. This is not a practically achievable value and it can be seen from measured earth resistance values in 18 sites. But it is very clear that we can achieve this using secondary surge arrester installation at meter cubical. But as we can see throughout the simulation results, we have to use them in effective configuration so that only we can reduce the power line damages effectively. Therefore Combine Effect of Phase to Ground and Neutral to Ground secondary surge arresters is suit for the installation near meter cubical (i.e. power input to the RBS) so that we can effectively reduce voltage rise and reduce the damages to both RBS electrical equipment and neighborhood electrical equipment.

It is also obvious that we cannot have a standard value for earth resistance value for a particular site, The Earth resistance data measured in Table 3.5 also taken as per the availability of space and the measured distances are different to each other. Therefore it is difficult to get idea about earth resistance value and compare it with another site.

In some sites we cannot find regular earth profile. Some sites are constructed on rocks. Some sites are constructed on mountains and surrounded by forests which cannot be access. Therefore it is sometimes even too difficult arrange apparatus to measure earth resistance. Therefore measuring the accurate earth resistance is questionable.

# CHAPTER 6

## 6.0 CONCCLUTION AND RECOMENDATIONS

All inspected towers are maintained as per the “Guidelines on Antenna Structures” provided by Telecommunications Regulatory Commission of Sri Lanka Colombo. The materials, dimensions and installation arrangement of the Air termination, down conductor and grounding system are as per the IEC 62305-3 (2006).

With the observed data we do not have strong evidence to make any conclusive remarks regarding the necessity of a separate down conductor for the protection against lightning strikes. The tower structure itself seems sufficient of providing safe passage to lightning current.

Also there may be possibility of happening CVM by passes as reported in theories and practical cases. Therefore it is recommended not to using magnetic devices such as mobile phone during lightning, near the telecommunication towers. There are some evidences as mentioned in observations of lightning damages regarding mobile phone usage during lightning.



In the stage of tower erection, we do the basic crow foot grounding system. That is a standard design irrespective of tower location, keraunic level, soil condition etc. And further improvement done after any complain or damages reported. Therefore it is recommended to design the best suited grounding system, for a given tower site. Our analysis show that at tower sites on extremely high resistive grounds; rocks and sandy soil, the transient equipotentialization is more suitable for the safety of people and protection of equipment instead of attempting to achieve low ground resistance. Therefore ring conductor also recommended in such sites earth electrode (type B arrangement) should preferably be buried at a depth of at least 0.5 m for bare solid rock [17]. For the rocky areas we can use earth mesh with chemical compound that reduce the earth resistivity to arrange distributed earth as shown in Figure 6.1

Figure 6.1: Distributed earth with copper earth mesh

*(Source*: Author)

Throughout the research we were discussed about space restriction for the earth resistance improvement. So that we recommended to use chemical ground rods and it provide low impedance earth to effective dissipate and electrical fault currents. This is ideal in situations where space is restricted and normal lightning earths such as radial and grid type systems cannot be installed.



Figure 6.2: Chemical rod installation in space restricted places

*(Source*: Author)

It is recommended to install base band surge arresters (air gap arrester) in all MW links installed and replace it at least once in three year. For the towers located in high keraunic level regions, it is recommended to replace it once a year. These recommendations are based on the facts collected during the research.

We also emphasize some careless practices repeated by neighbors. As per the observed data all most all the neighborhood equipment damages were due to careless practices of using electrical equipment. The people forget to remove power cables from the power socket outlet when they are not using the electrical equipment such as televisions, radios etc. Therefore it is recommended to remove power cables from power socket especially during lightning and night. Therefore it is better to arrange awareness programs to the neighborhoods regarding the effects of lightning and safety precautions to minimize the effects.

In some areas we cannot protect lightning protection systems installed in RBS from theft. This kind of behaviors are also cause to lot of lightning damages to RBS equipment as well as equipment damages in neighborhoods.

It was clear that there may be a voltage rises in power line due to direct strike to the tower with the RBS power line surge protection system. To minimize the damages we recommended installing secondary surge arrester with proper rating at the power entrances (at meter cubical) of the RBS. The effective configuration proposed is phase to ground and neutral to ground arrangement as simulated in Figure 4.24.



Simulation results shows that reduction of earth resistance has no much influence on reduction of voltage rises in power lines. But reduction of earth resistance very much important for make proper path for the lightning discharge.

The way of earth resistance measurement also should be addressed. The readings taken for the earth resistance value in RBS are questionable. We cannot recommend the way of measuring earth resistance in towers. There are some practical reasons and restrictions to have accurate reading. Therefore it is time to thinking of an effective way of measuring accurate earth resistance in telecommunication towers.

In results and analysis, we have observed a relationship between the geography of site location and the lightning damages. It is just an observation and need a further analysis to scientifically prove it.

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# Annexures

**Annexure I**
**A Letter from a society**

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උක්ත කරුණ සම්බන්ධයෙන් ඔබ වෙත කෙරුණු දැනුම් දීම අනුව ඔබ ආයතනයේ නිළධාරීන් විසින් ස්ථානීය පරීක්ෂාවක් කර තිබේ මෙකී අවස්ථාවට එටිසලාට් සමාගමේ නිළධාරීන්ද සහභාගිවී සිටියහ එකී ස්ථානීය පරීක්ෂණය 2011.03.28 දින සිදුවිය එකී ස්ථානීය පරීක්ෂාවෙන් අනතුරුව පහත සඳහන් සමථ යෝජනා ඉදිරිපත් විය

01) විදුලි උත්පාදක යන්ත්‍රය (ජෙනරේටරය) ක්‍රියාත්මකවීමේදී පරිසරයට නිකුත්වන ශබ්දය ප්‍රදේශ වාසීන්ට ඉසිලිය නොහැකි කරදරයක් සිදුවන බව නිගමනය කොට මාස 05 ක කාලයක් තුළ අදාල විදුලි උත්පාදක යන්ත්‍රය ඉවත්කොට නව විදුලි උත්පාදක යන්ත්‍රයක් සවි කිරීමට යෝජනාවී තිබේ එහෙත් තාවකාලිකව විදුලි උත්පාදක යන්ත්‍රයක් දැනටමත් සවි කොට තිබේ

02) විනය විරෝධී කටයුතුවල නිරතවෙමින් සමාජ ගැටලු ඇති කල එම ස්ථානයේ සේවය කල ආරක්ෂක භටයා අප්‍රේල් පළමුවැනි [illegible] එම ස්ථානයෙන් [illegible]

03) සම්[illegible] [illegible] ඇතුලත කුලුනට සම්බන්ධ කරමින් [illegible] දීමට එකඟ විය

කෙසේ [illegible] පොදු කරදරය [illegible] ප්‍රදේශ වාසීන් අත්විඳිමින් සිටින අතර ඒ හේතු කොට ගෙන මෙකී පොදු කරදරයට පාත්‍ර වන ගේහිමියන්ගේ ගැටලු වලට විසඳුමක් එකී ස්ථානීය පරීක්ෂණයේදී ලබා දීමට සූදානමක් නැති බව අපට පැහැදිලිව සිබේ එනම් අකුණු සන්නායක සවිකල පසු වර්ෂා කාලයේදී අකුණු සැර වැදී ක්‍රියා විරහිත වන විදුලි භාණ්ඩවල වගකීම ඔවුන් භාර නොගනී නමුත් වර්ෂා කාලයේදී කොතරම් ප්‍රබල අකුණු සැරක් එයිදැයි නිගමනය කල නොහැකිය එසේම අකුණු සැරින් නිවෙස් බේරුනද මනුෂ්‍ය ජිවිත අකුණු සැරින් විනාශ වුවහොත් එහි වගකීම දරන්නෝ කවුද යන්න එසේම මෙම කුලුනින් සිදුවන සෞඛ්‍ය ගැටලු මේවා තවමත් ප්‍රදේශ වාසීන්ට ප්‍රශ්නාර්ථයකි ඉහත හේතු කරුණු කොට මෙකී ප්‍රදේශය ජනාකීර්ණ ප්‍රදේශයක් වීම හේතු කොට ගෙන ඇතිවී ඇති පොදු කරදරය, පාරිසරික බලපෑම්, සෞඛ්‍ය හේතුහා ජිවිත ආරක්ෂාව හේතු කොට ගෙන මෙකී සම්ප්‍රේෂණ කුලුන වහාම මෙකී ස්ථානයෙන් ඉවත් කිරීමට කටයුතු කරන ලෙස ඉල්ලා සිටිමු එසේම මෙම ලිපියට පිළිතුරු හා ඔබ ආයතනය ස්ථානීය පරීක්ෂණයේදී පැමිණි නිගමනයන්ද අපට ලිඛිතව ඉදිරිපත් කරන ලෙස කාරුණිකව ඉල්ලා සිටිමු

ස්තුතියි!

මෙයට, විශ්වාසී

නිදහස් මාධ්‍යවේදී
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1 වන [illegible] කොටුවැම්ම පාර
ඇතුල් කෝට්ටේ, [illegible]
දු: ක. 0112-883116, 0112-882998
0718108397, 0776513141

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පිටපත්

01) අධ්‍යක්ෂක තුමා- මධ්‍යම පරිසර අධිකාරිය 02) එටිසලාට් සමාගම 03) නගරාධිපතිනිය- කෝට්ටේ මහ නගර සභාව

NO:31/14, 1ST LANE, RAMPART RD, KOTTE. TELL: 011-2883116,011-2882998, FAX 011-2883116 . Mobil: 071-8108397 , 0773990973

**Annexure II**
**A Letter from TRC**

Telecommunications Regulatory Commission of Sri Lanka

TRC/NW/ESK/11/01 24.05.2011

Mr. D. Palitha Herath
Regional Manager-Network Operations
Etisalat Lanka (Pvt) Ltd
3rd Floor, Mukthar Plaza
78, Grandpass Road
Colombo 14

Dear Sir,

Katubemma – Kotte (Etisalat RBS Site)



This is further to the inspection carried out by TRC on 28.[illegible].2011.

Please take early action to attend to the following proposals to minimize the neighborhood resident concerns.

(a) Replace the existing generator with a sound proof generator.
(b) Install surge diverters and other necessary preventive measures to avoid complaints.

Please treat this very much urgent and essential.

Yours faithfully

TELECOMMUNICATIONS REGULATORY COMMISSION OF SRI LANKA

W. D. De Alwis
Deputy Director - Networks

## Annexure III

**Material, configuration and minimum cross-sectional are of air-termination conductor, air-termination rods and down-conductor**

| Material | Configuration | Minimum cross-sectional area mm² | Comments [10] |
|---|---|---|---|
| Copper | Solid tape | 50 [8] | 2 mm min. thickness |
| | Solid round [7] | 50 [8] | 8 mm diameter |
| | Stranded | 50 [8] | 1,7 mm min. diameter of each strand |
| | Solid round [3], [4] | 200 [8] | 16 mm diameter |
| Tin plated copper [1] | Solid tape | 50 [8] | 2 mm min. thickness |
| | Solid round [7] | 50 [8] | 8 mm diameter |
| | Stranded | 50 [8] | 1,7 mm min. diameter of each strand |
| Aluminium | Solid tape | 70 | 3 mm min. thickness |
| | Solid round | 50 [8] | 8 mm diameter |
| | Stranded | 50 [8] | 1,7 mm min. diameter of each strand |
| Aluminium alloy | Solid tape | 50 [8] | 2,5 mm min. thickness |
| | Solid round | 50 | 8 mm diameter |
| | Stranded | 50 [8] | 1,7 mm min. diameter of each strand |
| | Solid round [3] | 200 [8] | 16 mm diameter |
| Hot dipped galvanized steel [2] | Solid tape | 50 [8] | 2,5 mm min. thickness |
| | Solid round [9] | 50 | 8 mm diameter |
| | Stranded | 50 [8] | 1,7 mm min. diameter of each strand |
| | Solid round [3], [4], [9] | 200 [8] | 16 mm diameter |
| Stainless steel [5] | Solid tape [6] | 50 [8] | 2 mm min. thickness |
| | Solid round [6] | 50 | 8 mm diameter |
| | Stranded | 70 [8] | 1,7 mm min. diameter of each strand |
| | Solid round [3], [4] | 200 [8] | 16 mm diameter |

1) Hot dipped or electroplated minimum thickness coating of 1 μm.

2) The coating should be smooth, continuous and free from flux stains with a minimum thickness coating of 50 μm.

3) Applicable for air-termination rods only. For applications where mechanical stress such as wind loading is not critical, a 10 mm diameter, 1 m long maximum air-termination rod with an additional fixing may be used.

4) Applicable to earth lead-in rods only.

5) Chromium ≥ 16 %, nickel ≥ 8 %, carbon ≤ 0,07 %.

6) For stainless steel embedded in concrete, and/or in direct contact with flammable material, the minimum sizes should be increased to 78 mm² (10 mm diameter) for solid round and 75 mm² (3 mm minimum thickness) for solid tape.

7) 50 mm² (8 mm diameter) may be reduced to 28 mm² (6 mm diameter) in certain applications where mechanical strength is not an essential requirement. Consideration should, in this case, be given to reducing the spacing of the fasteners.

8) If thermal and mechanical considerations are important, these dimensions can be increased to 60 mm² for solid tape and to 78 mm² for solid round.

9) The minimum cross-section to avoid melting is 16 mm² (copper), 25 mm² (aluminium), 50 mm² (steel) and 50 mm² (stainless steel) for a specific energy of 10 000 kJ/Ω. For further information see Annex E.

10) Thickness, width and diameter are defined at ±10 %.

## Annexure IV
## Material, configuration and minimum dimension of each electrodes

| Material | Configuration | Minimum dimensions | | | Comments |
|---|---|---|---|---|---|
| | | Earth rod Ø mm | Earth conductor | Earth plate mm | |
| Copper | Stranded [3] | | 50 $mm^2$ | | 1,7 mm min. diameter of each strand |
| | Solid round [3] | | 50 $mm^2$ | | 8 mm diameter |
| | Solid tape [3] | | 50 $mm^2$ | | 2 mm min. thickness |
| | Solid round | 15 [8] | | | |
| | Pipe | 20 | | | 2 mm min. wall thickness |
| | Solid plate | | | 500 x 500 | 2 mm min. thickness |
| | Lattice plate | | | 600 x 600 | 25 mm x 2 mm section Minimum length of lattice configuration: 4,8 m |
| Steel | Galvanized solid round [1] [2] | 16 [9] | 10 mm diameter | | |
| | Galvanized pipe [1] [2] | 25 | | | 2 mm min. wall thickness |
| | Galvanized solid tape [1] | | 90 $mm^2$ | | 3 mm min. thickness |
| | Galvanized solid plate [1] | | | 500 x 500 | 3 mm min. thickness |
| | Galvanized lattice plate [1] | | | 600 x 600 | 30 mm x 3 mm section |
| | Copper coated solid round [4] | 14 | | | 250 µm minimum radial Copper coating 99,9 % copper content |
| | Bare solid round [5] | | 10 mm diameter | | |
| | Bare or galvanized solid tape [5] [6] | | 75 $mm^2$ | | 3 mm min. thickness |
| | Galvanized stranded [5] [6] | | 70 $mm^2$ | | 1,7 mm min. diameter of each strand |
| | Galvanized cross profile [1] | 50 x 50 x 3 | | | |
| Stainless steel [7] | Solid round | 15 | 10 mm diameter | | |
| | Solid tape | | 100 $mm^2$ | | 2 mm min. thick |

1) The coating shall be smooth, continuous and free from flux stains with a minimum thickness of 50 µm for round and 70 µm for flat material.
2) Threads shall be machined prior to galvanizing.
3) May also be tin-plated.
4) The copper should be intrinsically bonded to the steel.
5) Only allowed when completely embedded in concrete.
6) Only allowed when correctly connected together at least every 5 m with the natural reinforcement steel of the earth touching part of the foundation.
7) Chromium ≥ 16 %, nickel ≥ 5 %, molybdenum ≥ 2 %, carbon ≤ 0,08 %.
8) In some countries 12 mm is allowed.
9) Earth lead in rods are used in some countries to connect the down-conductor to the point where it enters the ground.