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].

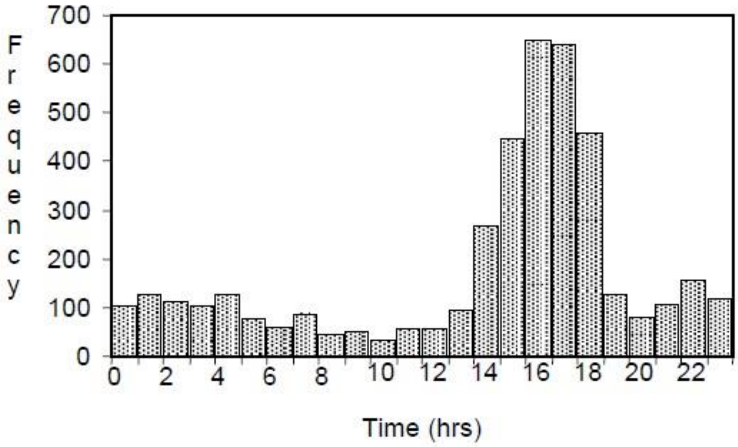

Figure 1.1: Frequency of cloud-to-ground lightning flashes vs. time of the day. Data are taken from days where stations have recorded lightning activities without any interruptions

(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.

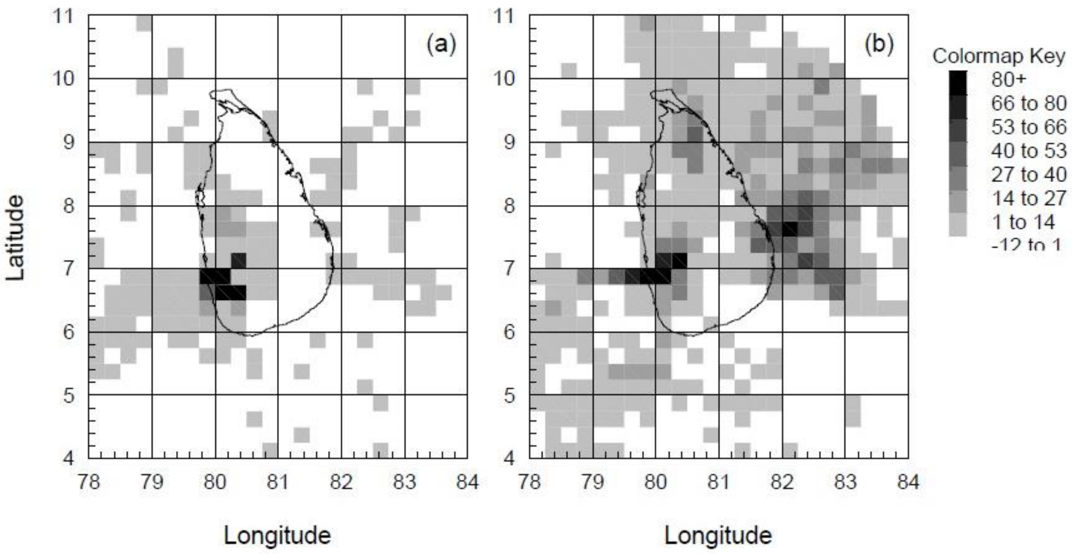

Figure 1.2: A scatter plot of reconstructed lightning flashes together with a map of Sri Lanka superimposed. (a) Flashes observed for Northeast monsoon (b) Flashes observed for Southwest monsoon.

(*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".)

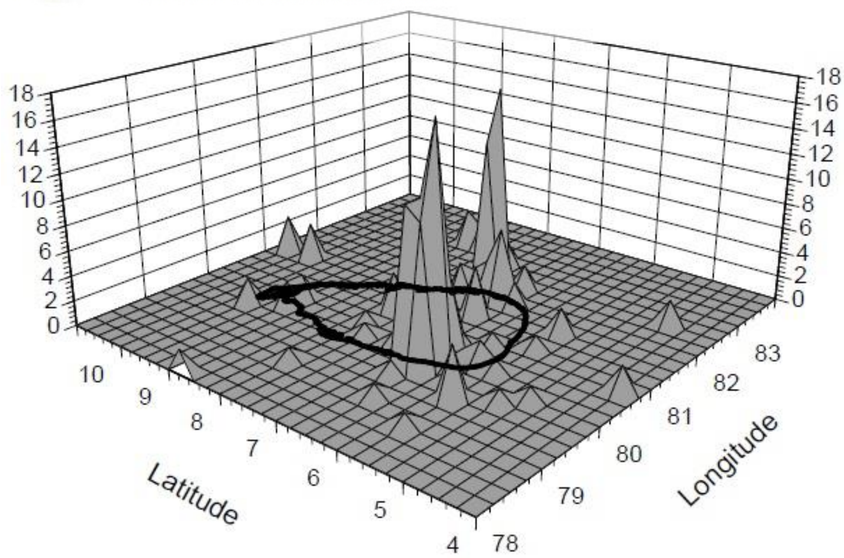

Figure 1.3: Spatial distribution of positive flashes

(*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

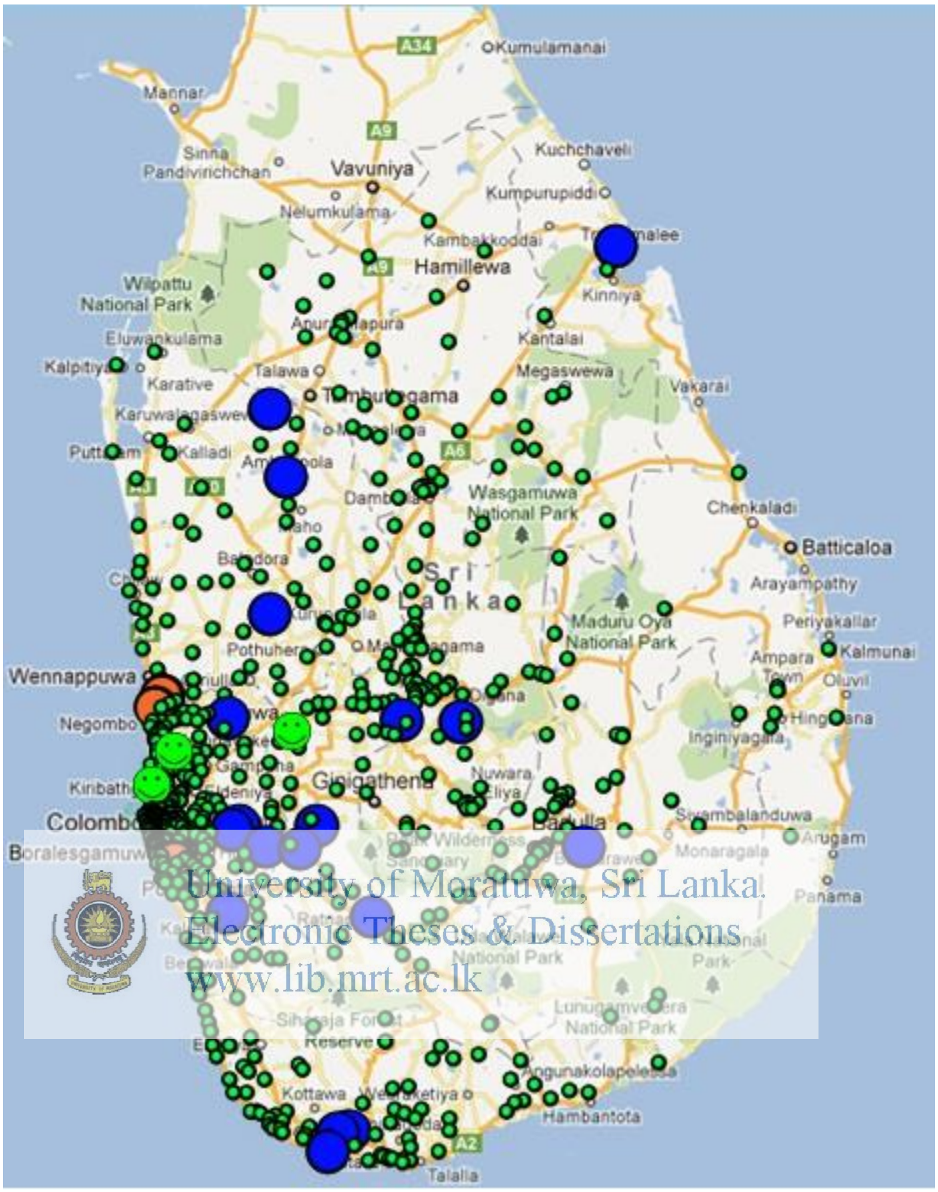

Figure 1.5: Tower distribution in Sri Lanka

(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.

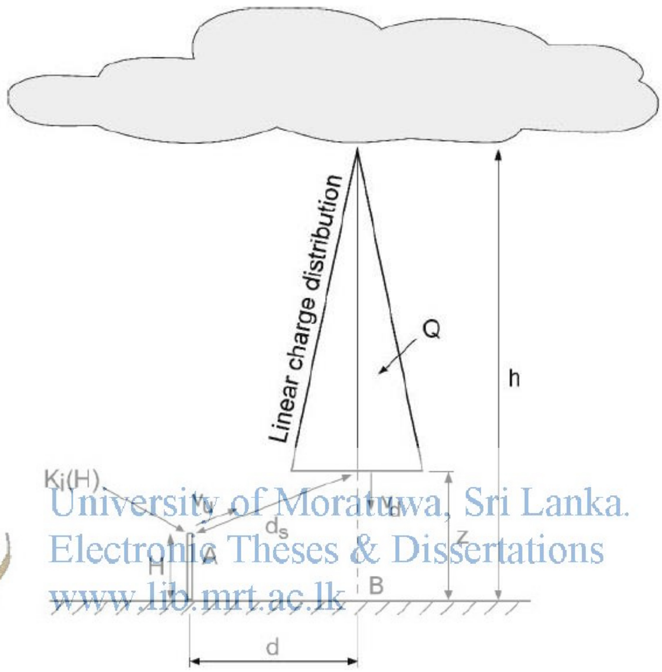

Figure 1.6: Model of downward leader approach to a structure at some arbitrary lateral distance d.

(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).

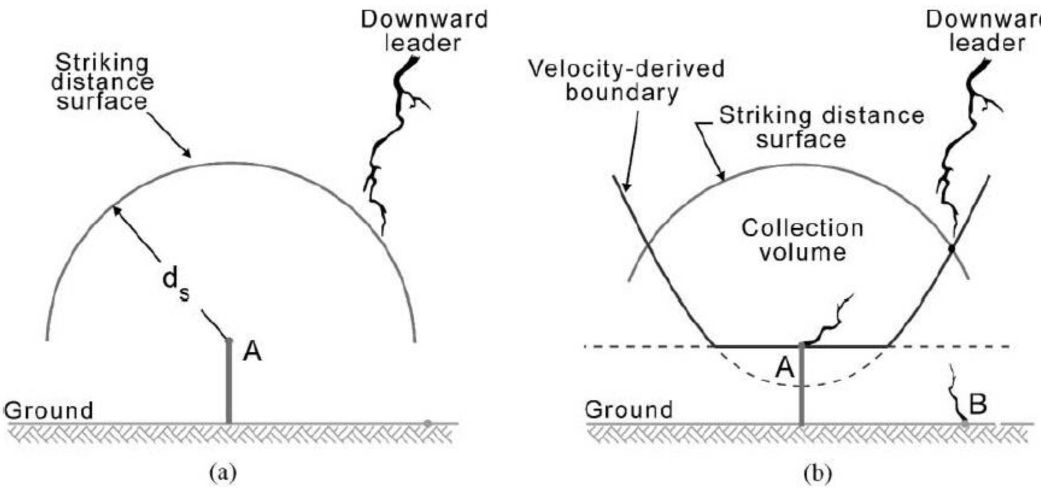

Figure 1.7 (a) Iterative calculations which apply the leader inception criterion give rise to a striking distance surface above the point. (b) Application of a leader propagation and interception criterion leads to a `velocity-derived boundary, completing the `collection volume of the point on the structure.

(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.

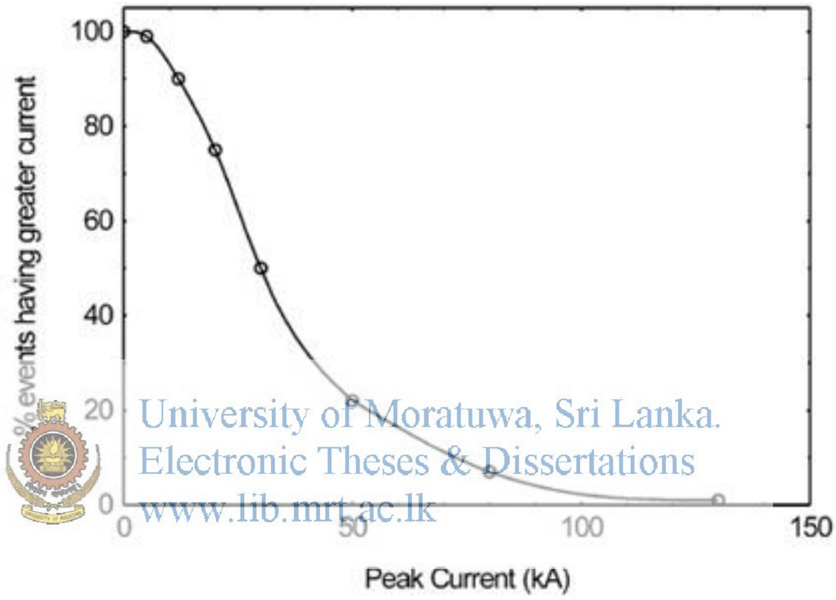

Figure 1.8 Typical cumulative frequency distribution of lightning peak current amplitudes (e.g., as in IEC Standard 1024-1-1: `Protection of structures against lightning)

(*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.

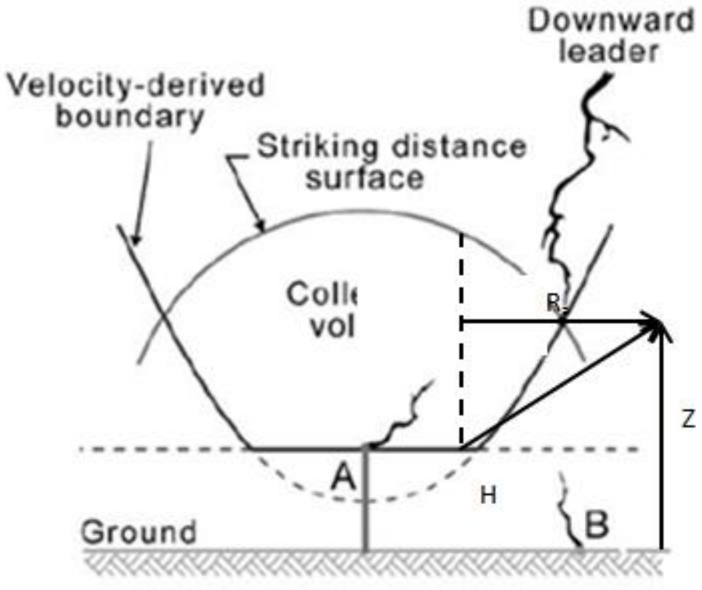

Figure 1.9: Collected volume for 60m height Tower

(*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

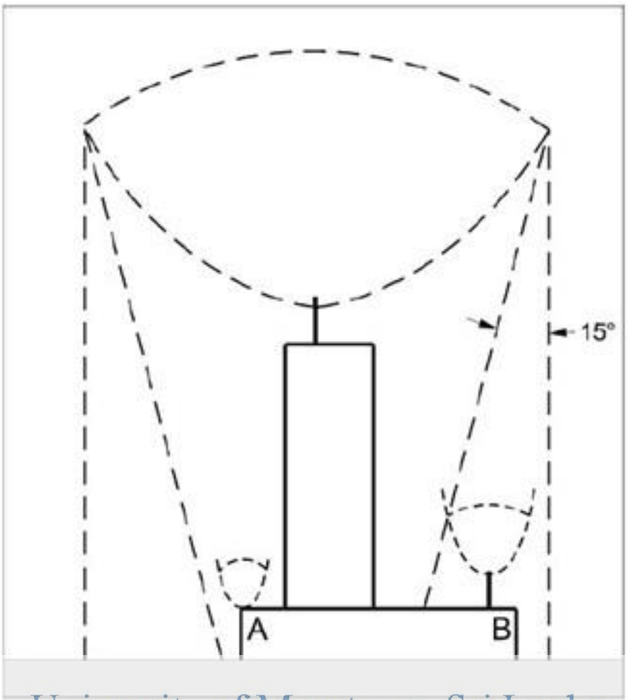

Figure 1.10: Application of collection volume derating to tall structures.

(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].

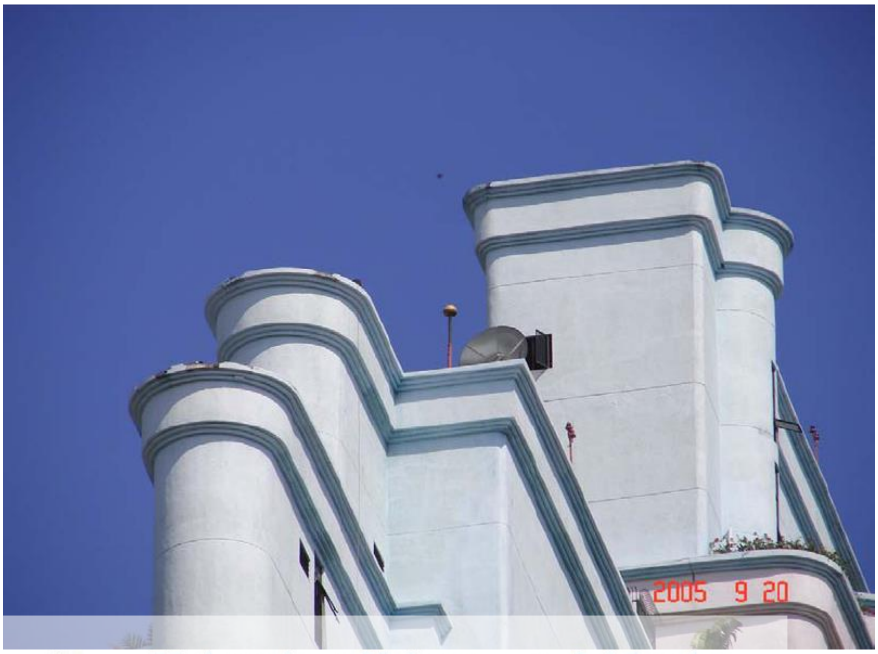

Figure 1.11: A view of the Villaputri building from a different angle. Since the curved edges had been struck by lightning repeatedly, the claimed existence of the collection volume is doubtful.

(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.

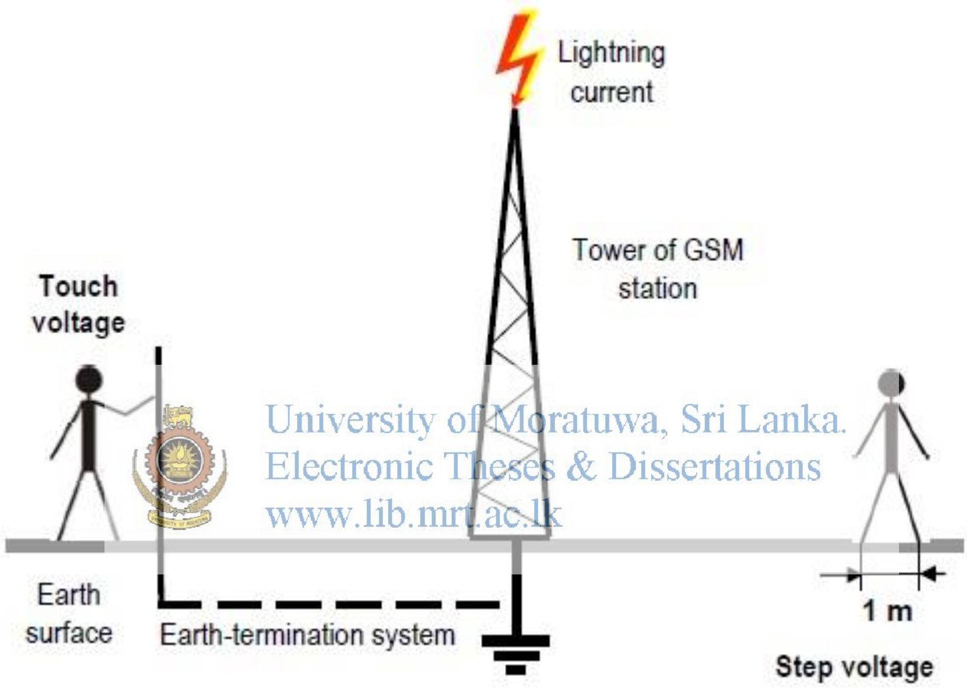

Figure 1.12: Transient step and touch voltages

(*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.

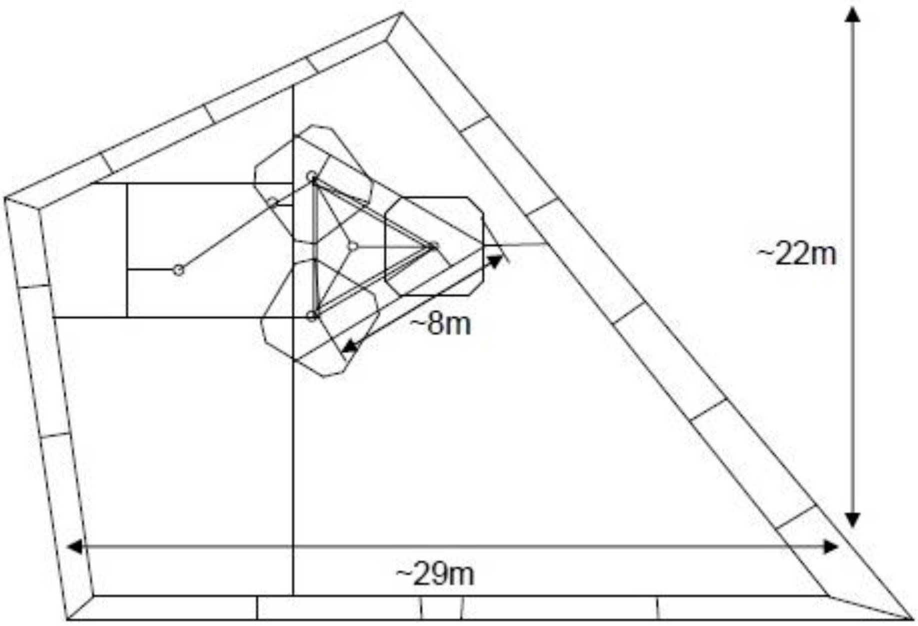

Figure 1.13: Thin wire model of the GSM base station – top view

(*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].

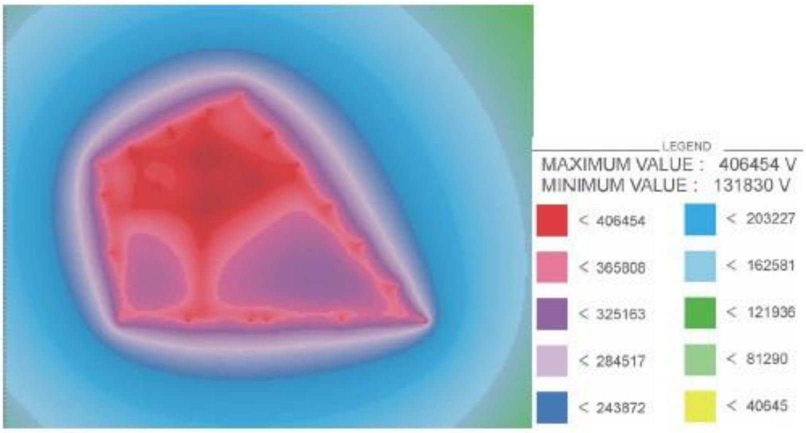

Figure 1.14: Contour plot of the scalar potential distribution in and around the base station

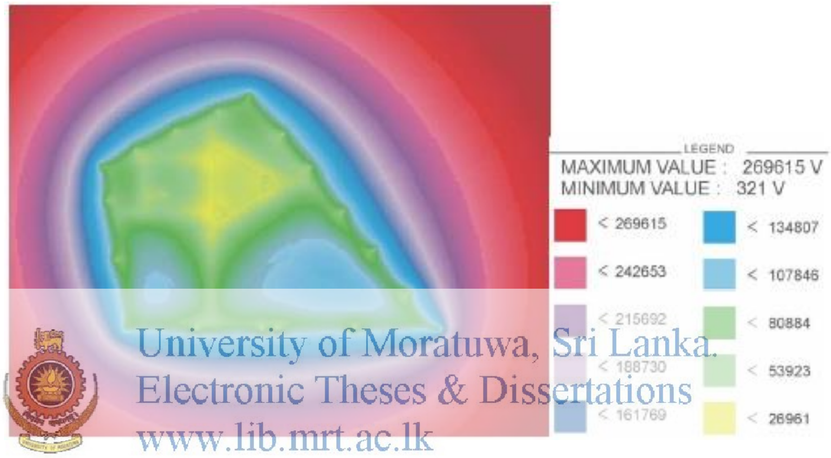

Figure 1.15: Touch voltages in and around the base station

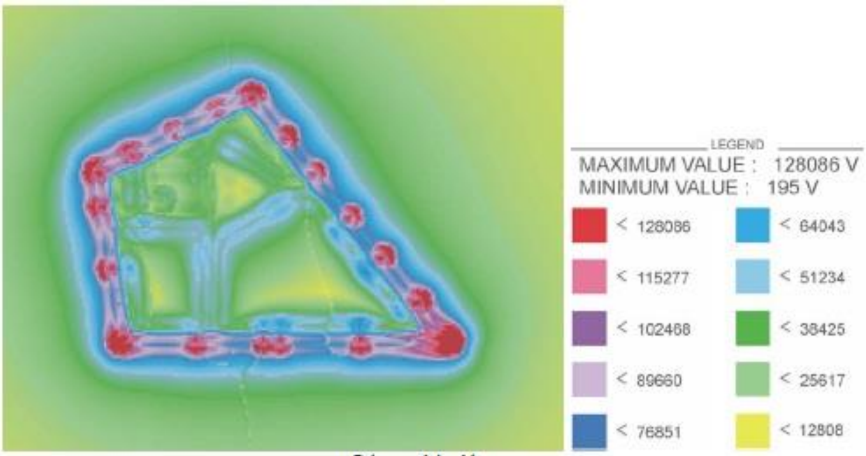

Figure 1.16: Step voltages in and around the base station

(*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.

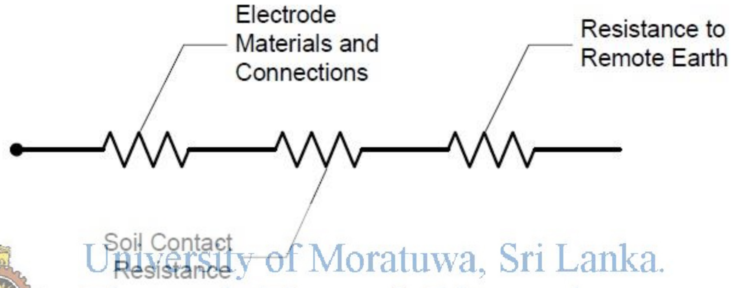

Figure 1.17: Equivalent Resistance Circuit of an Earth electrode System

(*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.

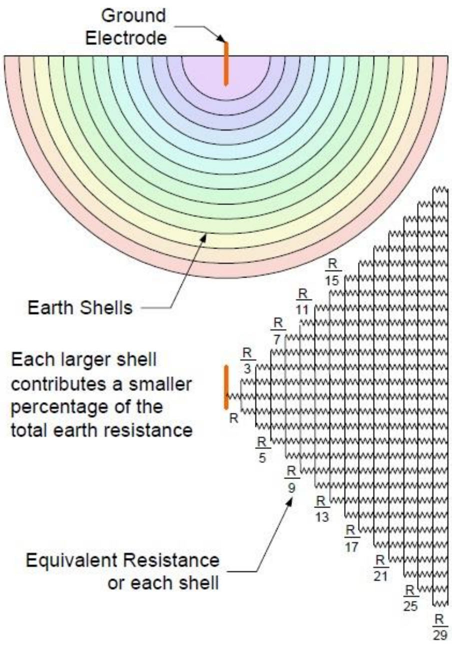

Figure 1.18: Concentric Earth Shells around an Earth electrode

(*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)

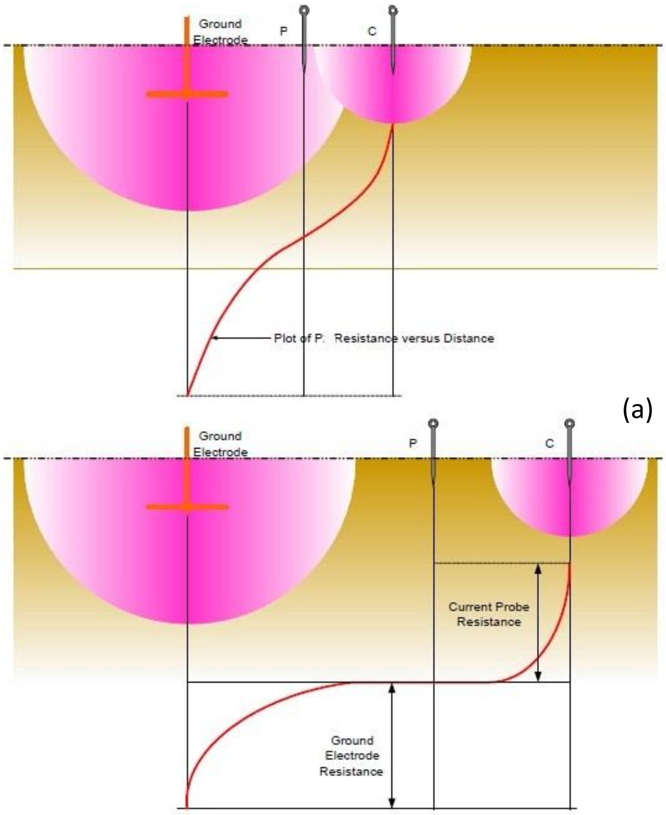

Figure 1.19: (a) Overlapping Shells of Earth (b) Non-Overlapping Shells of Earth

(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.