THE STUDY OF SAFETY DISTANCE BETWEEN TOWER AND SATELLITE DISH FOR LIGHTNING PROTECTION SCHEME USING ROLLING SPHERE METHOD

By

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FINAL PROJECT REPORT

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CERTIFICATION OF APPROVAL

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Approved:

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TRONOH, PERAK

May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Mohamad Akhmal Bin Ahmad Daud

ABSTRACT

The development of a computer program for the evaluation of lightning safety distance between the tower and satellite dish is written in M-File MATLAB simulation software. The 3-Dimensional illustrative graphics model is used in order to have better understanding on how lightning protection system (LPS) works. The study of physical length of grounding electrode use on the tower is found to be significantly affecting the grounding system performances. The performances of grounding system are depending on magnitude of lightning strikes current being dispersed and the settling time for lightning strikes current is completely dispersed. The grounding system performances is studied by using lightning current impulse (LCI) generator, simulated in OrCad PSpice simulation software. It is found that the optimum length of vertical lightning rod in LPS should be the same with the striking distance. There is no significant improvement is found in lightning safety distance if the length of vertical lightning rod is higher than striking distance. The lightning strikes peak current that have larger magnitude than the withstand insulation level of specified object should cause no physical damage. It is because the lightning safety distance will also increase whenever the lightning strikes peak current become bigger. It is also found that the lower grounding impedance will produce higher magnitude of dispersed peak current and faster settling time.

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In the name of Allah, the Most Gracious and the Most Merciful

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LIST OF ABBREVIATIONS

LPS	Lightning Protection System
IEC	International Electrotechnical Commission
LCI	Lightning Current Impulse
Z_A	Grounding Impedance
I_s	Lightning Strikes Peak Current
S	Striking Distance
h_1	Height of Lightning Rod
h_2	Height of Object
R_g	Total Horizontal Lightning Safety Radius
R_o	Lightning Object Safety Radius
ρ	Resistivity
l	Length of Grounding Electrode
r	Radius of Grounding Electrode
t	Depth of Grounding Electrode

CHAPTER 1

INTRODUCTION

The LPS relies upon the application of some of electricity and the physics of electrical discharges. It is needed in order to protect the electrical and electronic equipment that require a protection against the lightning strikes, including telecommunication systems at the station.

1.1 Background of Research

The concept of striking distance is essential in the design of lightning protection systems (LPS) for earthed structures. According to the idea of Electro-Geometric Method, a downward leader stroke is considered to propagate randomly and uncontrollably at the beginning of lightning stroke [1]. As a charge of a cloud is transferred along the downward leader, the electric field on the surface of a grounded object increases. Finally, at a striking distance, the critical electric field for breakdown of air at the surface of the grounded object is reached, and an upward streamer starts from the object to meet the leader stroke. Since the electric field at the tip of a structure is mainly influenced by the downward leader propagation and charge distribution in the leader channel, and the charge is related to the return stroke current, it was believed that the striking distance is a function of the lightning current [2].

Natural lightning surge waveform has been compared to standard impulse waveform as evidence that there have a similarity between them [3]. The standard impulse waveform could be used to test the strength of electrical equipment against the lightning. Therefore designing and simulating the impulse generator is important in order to understand the lightning characteristics. The peak value of potential energy created by lightning stroke can be seen in simulation result. Hence, the study of grounding system performances is very significant in order to make a good one lightning protection systems (LPS).

1.2 Problem Statements

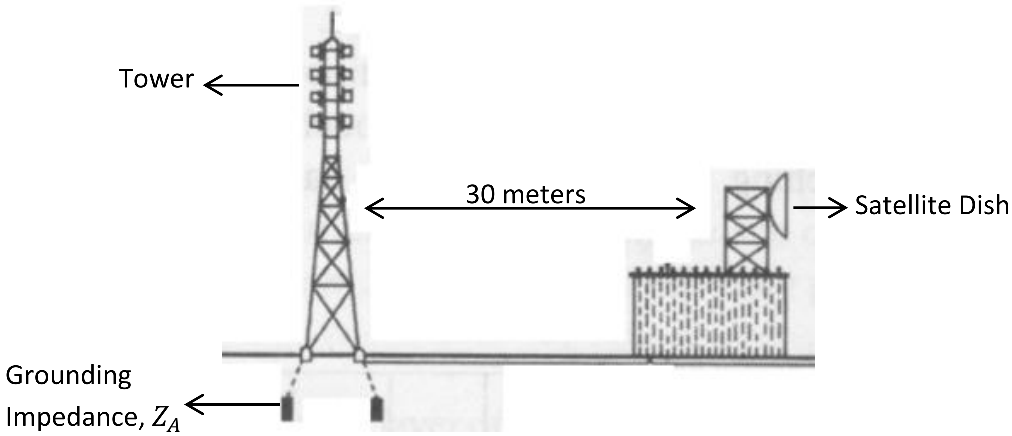


Figure 1: Existing telecommunication block arrangement [4]

Figure 1 shows the distance from communication tower to satellite dish of 30 meters. This distance is found to be unsafe which requires protection against lightning. A station having lattice tower is not necessary to provide down-conductors from the air termination system to earth termination system because the cross sectional area of the support structure is usually adequate [5]. The communication tower has been pointed as a lightning rod and it should protect the satellite dish from any harmful accident possibly occurred when lightning strikes. The new lightning safety distance according to level 1 type of standard lightning protection in between communication tower and satellite dish will be determined in this project.

The grounding impedance, Z_A are deliberately inserted at the end point of conductor normally in ground, to limit the fault current to an acceptable level. Theoretically, when grounding impedance Z_A becomes bigger more fault current will regulate in the tower. In this case, a communication tower has the grounding impedance of 15 Ω, which is too high. The value of grounding impedance is usually recommended to be below 10 Ω and 1 Ω, according to the typical level of the local soil resistivity [6]. Therefore in this project, the grounding impedance value will be varied in order to study the effects of grounding system in terms of how much lightning strikes energy can be dispersed.

1.3 Objectives

1) To develop a computer program of 3-Dimensional illustrative graphics model lightning protection system using Matlab M-File
2) To study a new telecommunication block arrangement that will provide a lightning protection zone for the satellite dish
3) To investigate the relationship between the grounding system performances and grounding impedance

1.4 Challenges

The first challenge in this project is to review various studies in the LPS. It has lot of methods and parameters which require consideration. There is no system or mean of protection that can guarantee absolute security over the particular object that needed a protection against lightning strikes. The lightning protection systems will be dependent on the scale of the precautions adopted. The probability of lightning protection

The second challenge is to create the current impulse generator circuit. There are several conditions that need to be complied, so then the output waveforms yield in this project will fulfill the requirement of IEC 61000-4-5-Surge Standard for current impulse standard criteria. The grounding system performance is based on the physical dimension of electrode and resistivity value on which type of soil or water that it has been buried. The fundamental concept and theory of grounding impedance is needed to be understood first before further study about the grounding system performances being analyzed.

1.5 Significant of Project

The significant of the project is to protect the satellite dish from any physical damages, including high thermal temperature and electrodynamics stresses caused by lightning strikes. The satellite dish is very important equipment in the station due to its function as a signal broadcaster. At the time when satellite dish is down, there will no signal being transmitted and the quality services are in bad reputation. By having a level 1 type of LPS, the satellite dish can be protected so that continuous services are provided.

1.6 Contribution

This project will help reduce the potential of property damage caused by lightning strikes. Hence, cost saving in terms of repairing and fixing the properties can be optimized.

1.7 Scope of research

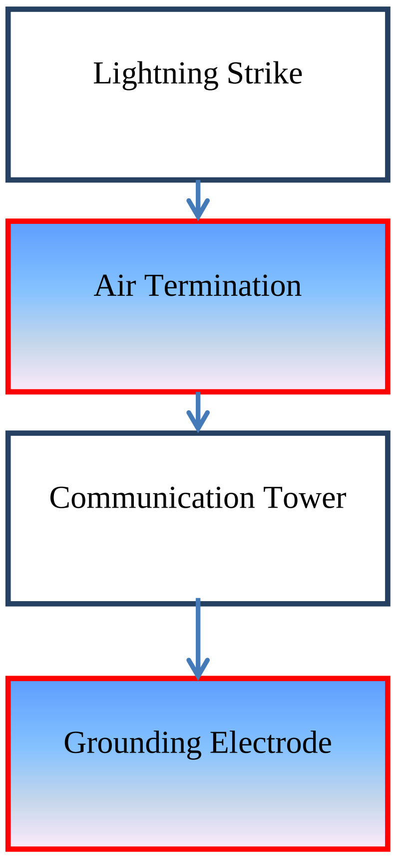


Figure 2: Scope of project

Figure 2 shows the scope of the project. The air termination is the area of lightning protection zone, which protects the property against any potential disaster created during lightning discharging phenomenon. Here, a model concept called "Rolling Sphere Method

(RSM)" is used to determine the protective zone operating under vertical rod lightning system. Also, there are other models that can be applied such as Protection Angle,Electro-Geometrical and Mesh Method.

Table 1: List of technique models for lightning protection systems

Method	Design Approach	Application
Protection Angle [7]	• protection zone of a vertical conductor is viewed as a cone • Protective angle of the cone was assumed to have range between 30^{o} and 45^{o}, formalized by Wagner and colleagues	• The electricity supplier company uses this concept at grounding conductors (on top of phase conductor) to protect the phase conductors in transmission lines
Electro-Geometrical [8]	• Long horizontal conductors located at certain height above ground level • Lightning strikes will be attracted to the horizontal conductor based on attractive radius concept.	
Mesh [9]	• Encase the building in a Faraday cage since it is the best procedure to protect from lightning strikes	• The military uses this technology for protection of defense equipment from electromagnetic pulse attacks
Rolling Sphere [10]	• Directly related to the Electro-Geometrical Method • Vertical conductor rod has a safety region with radius equal to striking distance.	• Power transmission lines • Buildings, 90 % termination on corners

Table 1 shows a list of various methods that can be applied in order to build and design one lightning protection systems. Protection Angle and Electro-Geometrical methods are used in lightning protection systems application where external conductor of wire needed. As for the Mesh method, it is too expensive and not suitable as alternative for practical implementation. In RSM technique, a single vertical cylinder conductor is used to attract the lightning strikes and channel it to the ground. By then, any specific area that requires protection can be achieved. Therefore, the Rolling Sphere Method is chosen for this project.

The rod grounding electrode is to create a channel for lightning strikes to earth. The grounding electrode physical dimensions will influent the value of grounding impedance. In this project, the length of electrode and the resistivity of soil or water where it is buried are the concerned parameters in order to produce grounding impedance lower than the 10 Ω; as recommended by general concept of LPS. The grounding impedance effects towards the performance of lightning grounding system will also be studied.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the theoretical part about designing a lightning protection system will be discussed. The rolling sphere method (RSM) working concept, lightning current impulse (LCI) generator and grounding impedance are the main concern subject in this project.

2.1 Rolling Sphere Method Concept

In 1977, Lee developed a simplified technique for applying the electromagnetic theory to the shielding of buildings and industrial plants. Orrell extended the technique to specifically cover the protection of electric substations. The technique developed by Lee has come to be known as the rolling sphere method [11].

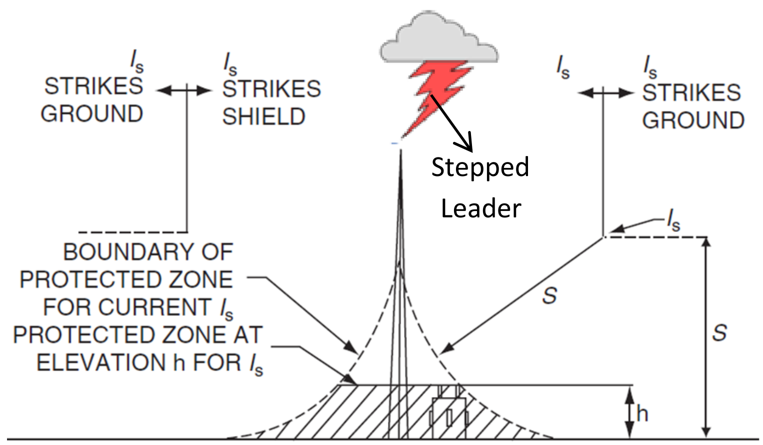


Figure 3: Protective zone of a vertical lightning rod from elevation view [12]

In Figure 3 the air terminal of a grounded structure is located in such a way that when a sphere with a striking distance is rolled around the structure, it should touch only the conductors of the lightning protection. The striking distance will be determined by a certain lightning strikes peak current, I_s.

The striking distance, S can be calculated by using formulae developed by E.R Love also known as given by Eq. (1):

$$S = 10 I_s^{\ 0.65} \text{ (meters)} \tag{1}$$

Where:

I_s= lightning strikes peak current (kA)

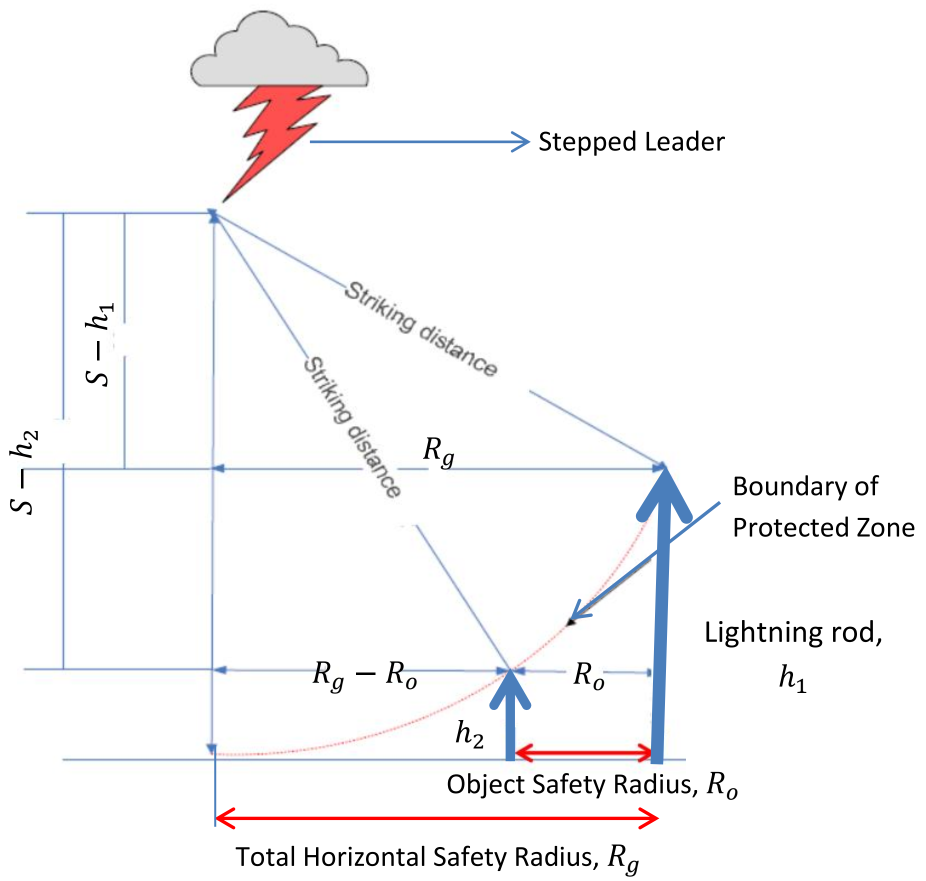


Figure 4: Configuration of lightning protection systems design [13]

Figure 4 shows the safety radius covered by single vertical lightning rod in the lightning protection systems, LPS. The lightning rod, h_1 will protect effectively against the lightning strikes in a circular space around it, where the diameter of the space being twice the height of h_1.

The total horizontal safety radius from lightning rod, R_g in meters is given by Eq. (2):

$$R_g = \sqrt{2Sh_1 - {h_1}^2} \qquad (2)$$

Where:

h_1= height of lightning rod

S = striking distance

Meanwhile for the object safety radius, R_o in meters is given by Eq. (3):

$$R_o = R_g \left[1 - \sqrt{2Sh_2 - {h_2}^2 / 2Sh_1 - {h_1}^2} \right] \qquad (3)$$

Where:

R_g = total horizontal safety radius on the ground

h_1= height of lightning rod

h_2= height of object

S = striking distance

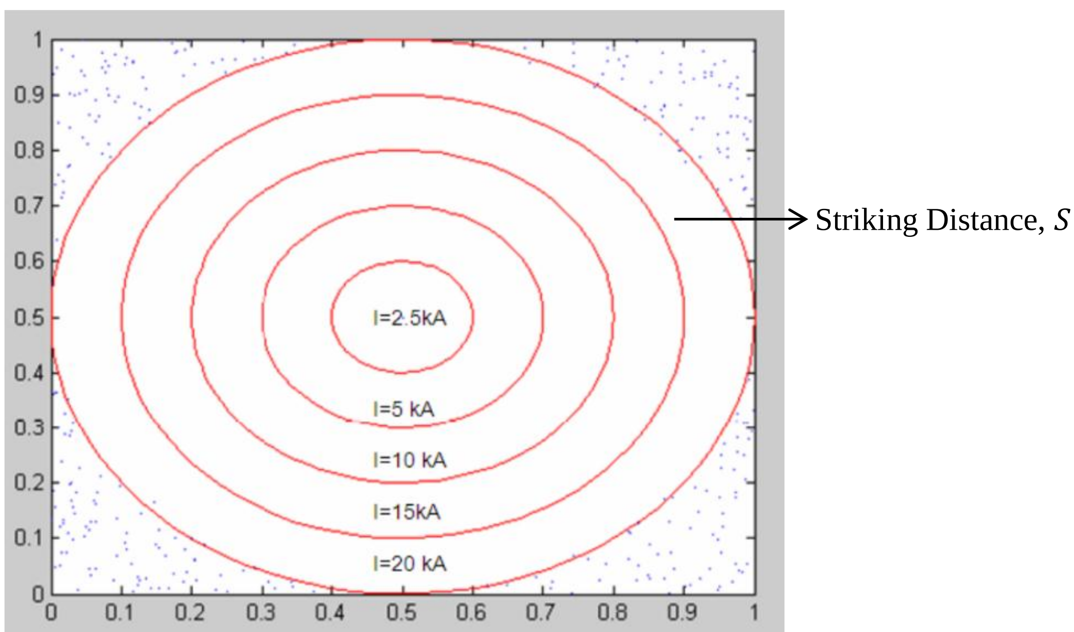


Figure 5: Relationship between the lightning strikes peak current and striking distance [14]

Figure 5 shows the relationship between the striking distance, S and lightning strikes peak current, I_S produced by Noor Shahida in 2008 [14]. Based on this study, any stepped leader associated with a prospective peak return stroke current larger than I_S will be associated with a rolling sphere of larger radius; such a stepped leader will not be able to penetrate the lightning protection systems. Therefore, to make the lightning protection systems become more sensitive structure, a smaller sphere radius should be used.

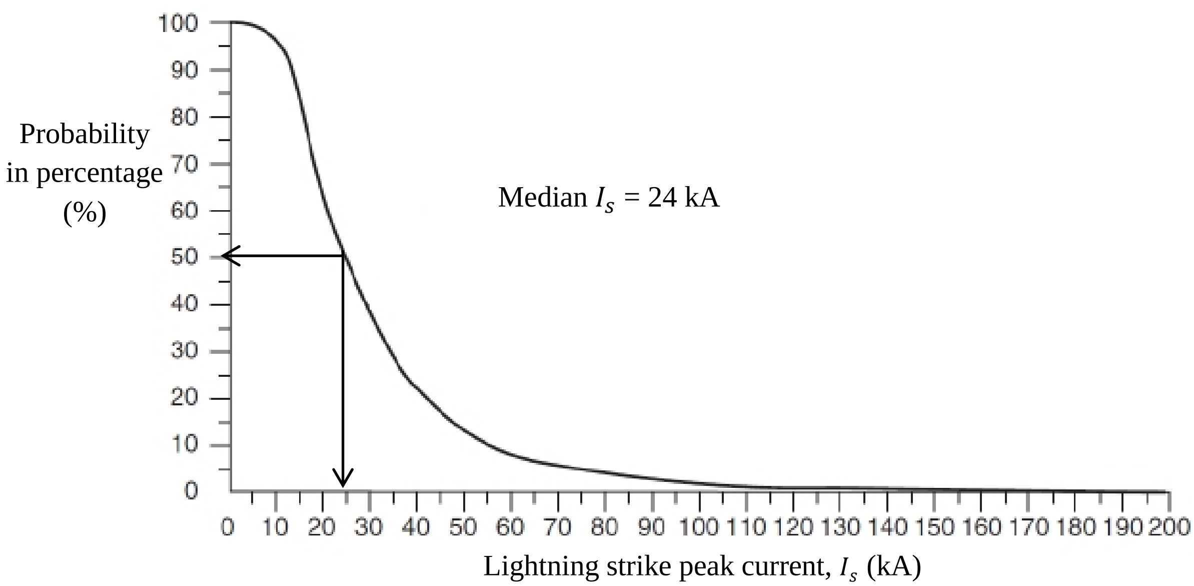


Figure 6: Probability peak current of natural lightning strike [15]

Figure 6 shows the probabilities for natural lightning on Earth. Since the striking distance, S and lightning strikes peak current, I_S are related, the distribution of stroke current magnitudes is required to be identified. In 1989, Mousa has shown that a median I_S of 24 kA for strokes to flat ground. These mean that, certainly I_S with the magnitude lower than 24 kA will occur because the probability percentage is bigger than 50 % [16].

The probability that certain peak current will be exceeded in any stroke is given by the following Eq. (4):

$$P(I) = \left[1 \Big/ 1 + \left[I_s / 24 ^{2.6} \right] \right] \tag{4}$$

Where:

I_s= lightning strikes peak current (kA)

Table 2: IEC 61024-1 lightning protection standard [17]

Maximum Current Exceeding the Peak Value (I_s)	Protection Level	Interception Efficiency
2.9kA	I	99%
5.4kA	II	97%
10.1kA	III	91%
15.7kA	IV	84%

Table 2 shows a lightning protection standard based on International Electrotechnical Commission (IEC 61024-1), where the protection levels can be interpreted as Level 1, Level 2, Level 3 and Level 4. A structure lightning protection systems based on level will not allow a return stroke peak current larger than 2.9 kA, 5.4 kA, 10.1 kA and 15.7 kA respectively to penetrate the protective zone. Here, the rolling sphere method can be used to determine the area of space protected by a structure.

2.2 High Current Impulse Generator

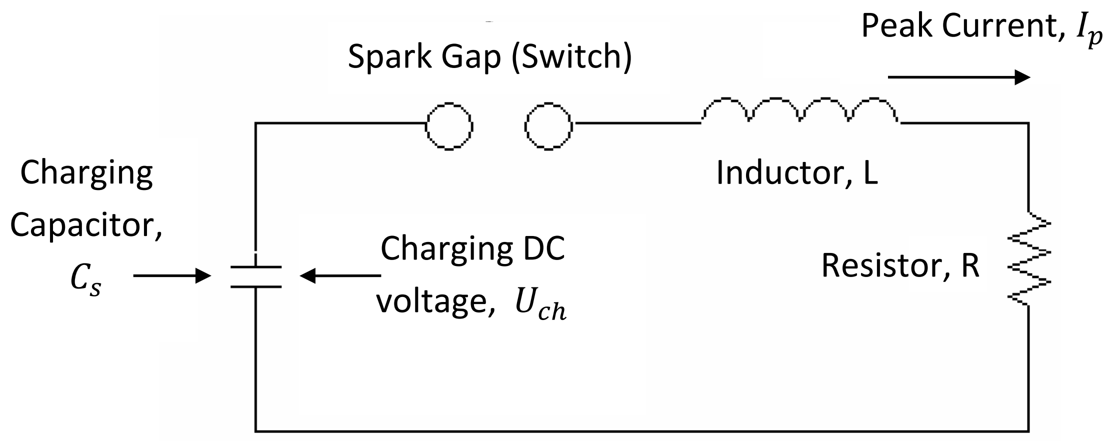


Figure 7: R-L-C Lightning Current Impulse Generator circuit [18]

Figure 7 shows a circuit diagram in creating a high current impulse generator. This impulse generator can be used in order to understand lightning waveform characteristics behavior. It is determined that configuration of 10/350 µs impulse generator circuit will give an exactly the same waveform characteristics with natural lightning phenomena.

Initially, the surge capacitor, C_s will be charged slowly with High DC Voltage source up to the charging voltage, U_{ch}. When the C_s is fully charged, it will discharge through the spark gap switch, inductor L and resistor, R. The phenomena of energy from C_s being discharges through R-L impedance is where the peak current, I_p is generated. The current waveform yield in this circuit is representing the real natural lightning phenomena.

In 2004, Michael Gamlin has implemented the study of long duration current impulse for surge arrestor stress withstands capabilities [19]. The lightning current impulse (LCI) was designed with the combination of voltage impulse generator and current impulse generator altogether in order to get the long duration of current impulse.

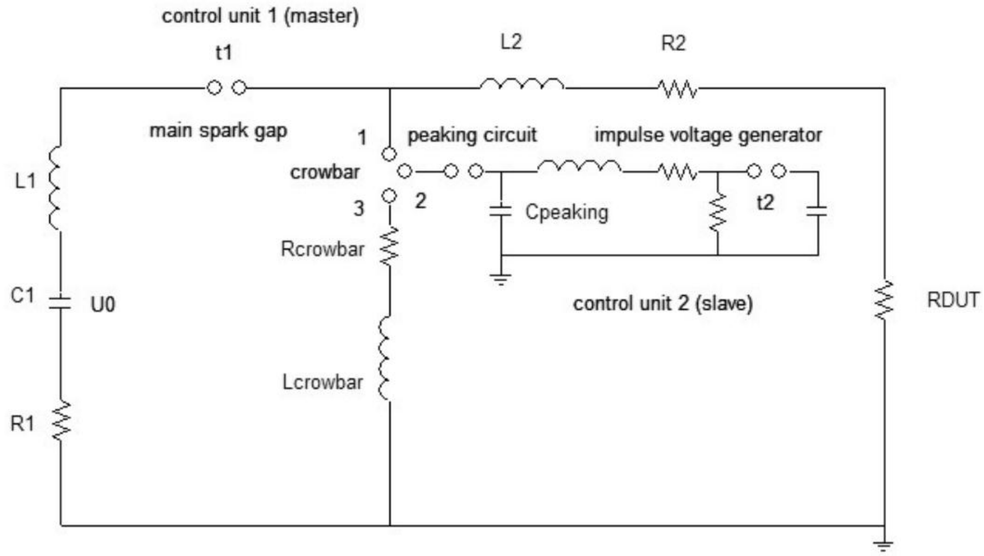


Figure 8: Lightning Current Impulse Generator circuit diagram for longer duration [19]

Figure 8 shows about the long duration circuit diagram of lightning current impulse (LCI). It was invented purposely to give more stress to the surge arrestor during the capabilities withstand testing. However in this project, only the current impulse generator will be simulated.

Table 3: IEC 61312-1 (Annex C): High Energy Portion

Parameters	Unit	Protection Level			Tolerance (%)
		Level 1	Level 2	Level 3-4	
Peak Current, I_p	kilo Ampere (kA)	200	150	100	± 10
Specific Energy, $W/_R$	Mega Joule per Ohm $\left(MJ/_\Omega\right)$	10	5.6	2.5	± 35
Time for half of Peak Current, I_p	micro seconds (µs)	N/A			± 10

Table 3 provides a limitation values for the 10/350 µs standard waveforms according to IEC 61312-1 (Annex C): High Energy Portion parameters. In this project, the level 1 type of protection will be chosen because it is the highest class of lightning safety level protection.

Based on this information, lightning current impulse generator circuit parameters can be determined.

In order to find the R-L-C circuit parameters for lightning current impulse generator with critically damped, there are two conditions that must be followed. According to IEC 61312-1 (Annex C): High Energy Portion, the two conditions are peak current, I_p, and specific energy, ${}^{W}/_{R}$.

In order to find the peak current, I_p in kilo Amperes is given by Eq. (5):

$$I_p = 0.736 \times {}^{U_{ch}}/_{R} \quad (5)$$

Where:

U_{ch} = Charging voltage

R = Resistance

The specific energy, ${}^{W}/_{R}$ in Mega Joule per Ohm is given by Eq. (6):

$$ {}^{W}/_{R} = \left(\sqrt{{}^{C_s}/_{L}}\right) \times \left({U_{ch}}^2 \times {}^{C_s}/_{4}\right) \quad (6)$$

Where:

C_s = Charging capacitance

L = Inductance

U_{ch} = Charging voltage

Meanwhile the ratio value that should be complied between inductance L and surge capacitance C_s is given by Eq. (7):

$$L/_{C_s} = \left(R^2/_{4} \right) \quad (7)$$

Where:

L = Inductance

R = Resistance

C_s = Charging capacitance

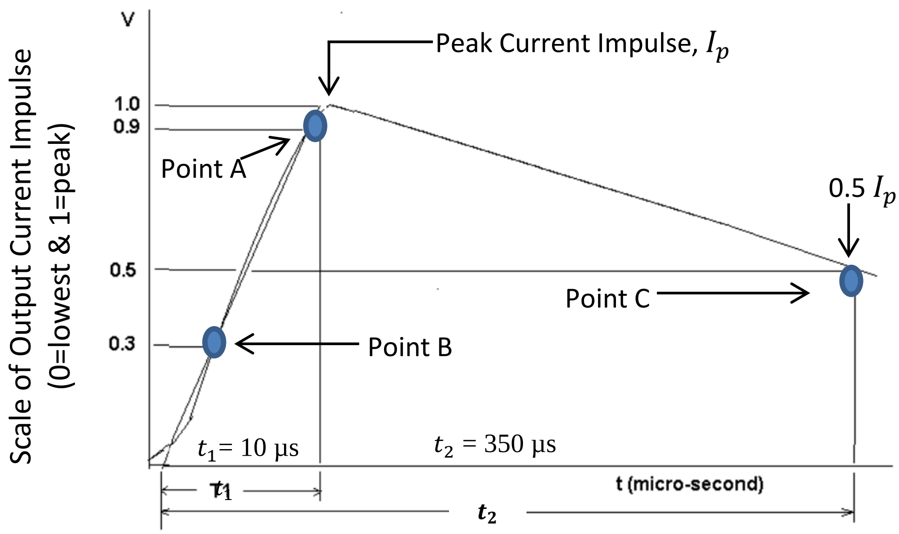


Figure 9: IEC 61000-4-5-Surge Standard for Current Impulse [20]

In Figure 9, it describes the standard lightning waveform of scale 10/350 µs. The peak values, I_p in waveform will represent the highest magnitude current of lightning strikes. The t_1 will represent the value of wave front. Then, t_2 represents the value of wave tail. The effect of grounding impedance corresponding to the peak current return stroke can be determined by using this concept.

Table 4: Reading table for IEC 61000-4-5-Surge Standard [21]

Criteria	Time	Current Measurement Point (Figure 9)	Label
Front	10 μs	A-B	t_1
Tail	350 μs	C	t_2

Table 4 is used as a reference of standard lightning impulse waveform, shown in Figure 9. The results based on simulation multistage equivalent circuit should follow accordingly to these standard specifications.

2.3 Grounding Impedance

In 2012, Jong-Hyuk Choi and Bok-Hee Lee have produced a research paper that describes about the grounding impedance. This is very important criteria to be considered in order to produce the lightning protection systems (LPS). The best grounding system performances will disperse the injected current in larger magnitude scale [22].

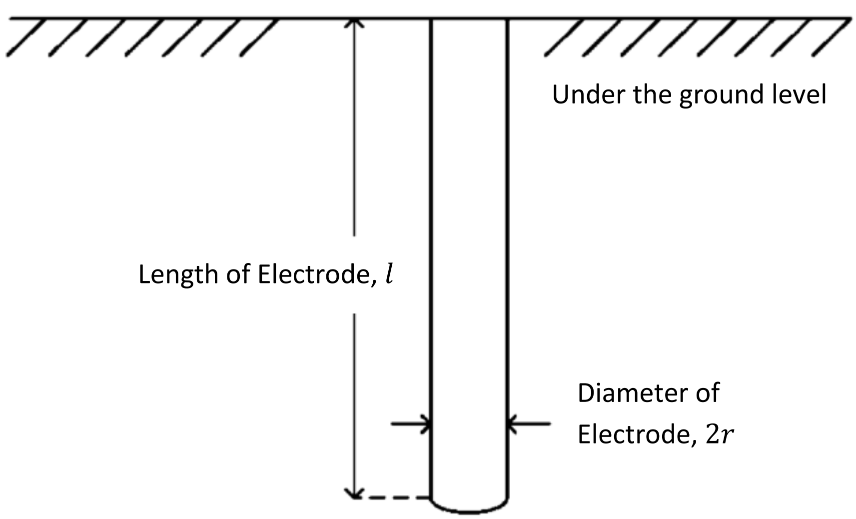


Figure 10: The grounding electrode [23]

Figure 10 shows the type of grounding electrode used in this project. The grounding impedance was being measured by using a technique of dipole-dipole method. Significantly, the grounding impedance will be affected by soil resistivity where the electrode is buried. However, there is other criteria that can be influenced the grounding impedance. The two others criteria that can alter the grounding impedance are length of grounding system electrode and also the depth of electrode been buried.

The grounding impedance Z_A can be calculated by using Eq. (8):

$$Z_A = \left(\rho\ \left[\ln\left({2l}/{\sqrt{2rt}}\right) - 1\right]\right) \Big/ \pi l \qquad (8)$$

Where:

ρ = resistivity of soil or water

l = length of electrode

r = radius of electrode

t = depth of electrode is buried

In 1999, Elvis R. Sverko has come out with the data of resistivity values that involved with several types of soil and water. The relationship between the grounding impedance, Z_A and soil or water resistivity, ρ is proportionally increased [24].

Table 5: The resistivity value of soil and water

Type of soil or water	Resistivity ($\Omega.\mathrm{m}$)
Clay	100
Groundwater, well, spring water	150
Sandy clay, cultivated soil	300
Rain water	1300

Table 5 shows about the resistivity value for each type of soil and water. Based on this data, the grounding impedance, Z_A can be calculated. Hence, the analysis of grounding system performances based on current dissipation can be analyzed.

2.4 Summary of Related Issues

Table 6: Summary of related issues

Year	Author	Title	Design Approach	Description
1999	Elvis R. Sverko [24]	External Lightning Protection System	The resistivity of soil and water	Data collection for resistivity values measurement from various type of soil and water
2004	Michael Gamlin [19]	Current impulse Testing	Rectangular Current Impulse	Real implementation of current impulse system of the Shanghai Metrology Institute delivered by the Haefely AG
2006	P.Y. Okyere [2]	Evaluation of Rolling Sphere Method Using Leader Potential Concept: A Case Study	Empirical formulae for striking distance using leader potential concept	A case study of lightning protection design and demonstrated how low grounding impedance could be used to mitigate Ground Potential Rise (GPR)
2008	NoorShahida BT Jamoshid [14]	Lightning Simulation Study On Line Surge Arrester And Protection Design Of Simple Structures	Empirical formulae for striking distance using Mousa and Srivastava invented in 1988	Simple lightning protection structure by using vertical rod that covers the total horizontal (ground) area.

2010	Ahmed A. Hossam-Eldin and AbdallaBadrAbdalla [25]	New Concept for Lightning Protection of Ships: The Leader Potential Concept Method	Empirical formulae for striking distance using Leader Potential Concept Method 'LPCM'	Revealed that the LPCM method has the lowest possible cost for a lightning protective scheme.
2012	Jong-Hyuk Choi and Bok-Hee Lee [22]	An Analysis Of Conventional Grounding Impedance Based On The Impulsive Current Distribution Of A Horizontal Electrode	Evaluate grounding system performances	In low frequency, the ground current dissipation rate is proportional to the soil resistivity
2012	Akihiro Ametani, Tomohiro Chikaraa, Hiroshi Morii, and Takashi Kubo [23]	Impedance Characteristics Of Grounding Electrodes On Earth Surface	Evaluate grounding system performances	Based on grounding electrode dimension and method of it is being buried

Table 6 describes the summary of related issues in this project. For the striking distance, varieties of empirical formulae can be used. In this project, the formulae developed by E.R Love which is mostly used for lightning protection systems (LPS) will be used in order to determine the striking distance. The equivalent circuit for lightning current impulse (LCI) generator can be used in order to represent the natural lightning strikes. Hence, the study of relationship between grounding impedance and lightning grounding system performances can be analyzed.

CHAPTER 3

METHODOLOGY

In this chapter, the method approach of designing a lightning protection system will be discussed. The two improvement criteria in this project are the air and earth termination system. The project will be implemented in the simulation computer program.

3.1 Block Diagram

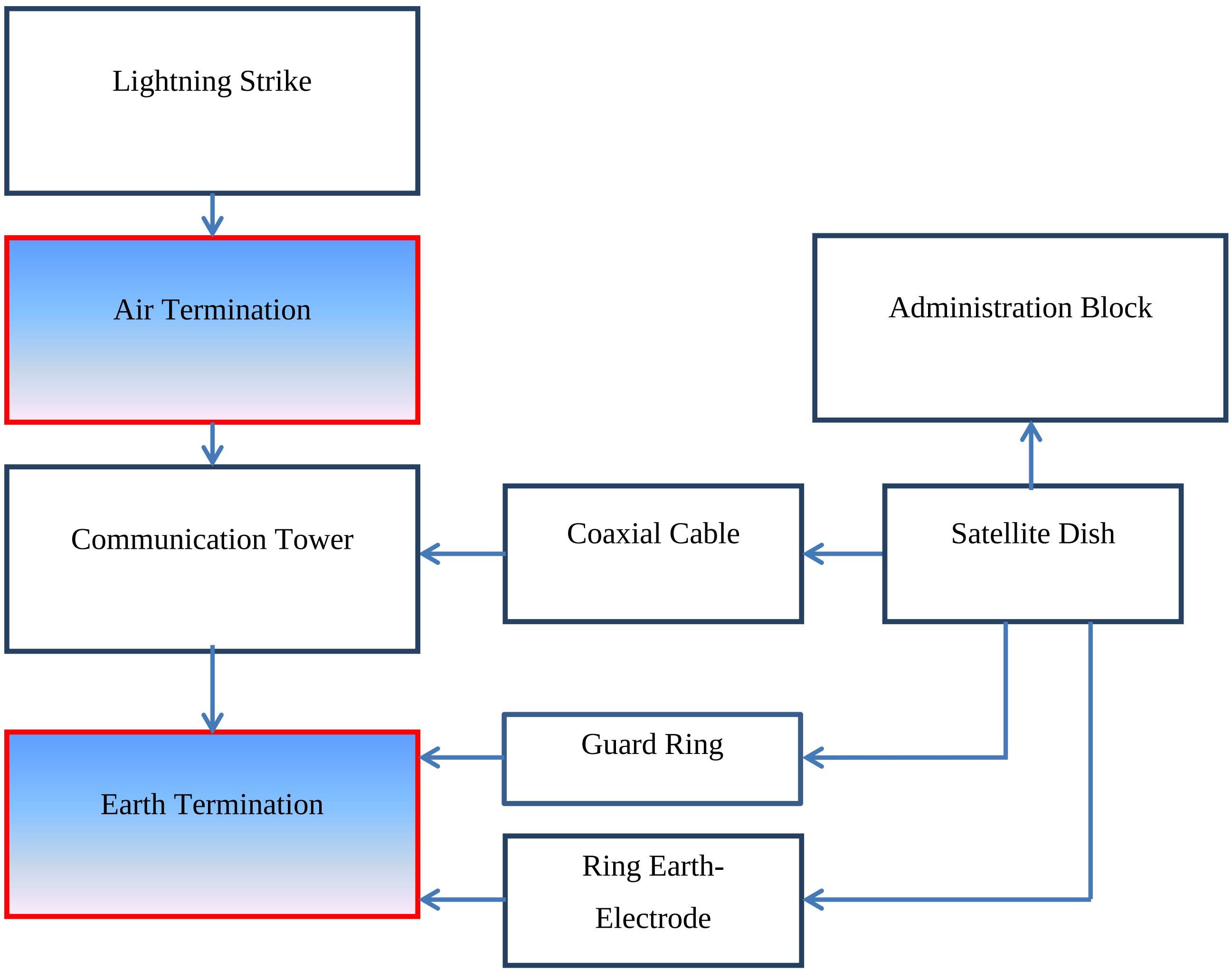


Figure 11: Block diagram of the project

Figure 11 describes the block diagram of the project. Mainly, the air termination and the grounding electrode are the focus areas of study. For the air termination system, RSM concept will be used in order to investigate the lightning safety distance between communication tower and satellite dish against the lightning strikes. The grounding system effectiveness will be depending on the grounding impedance values.

3.2 Flow Chart

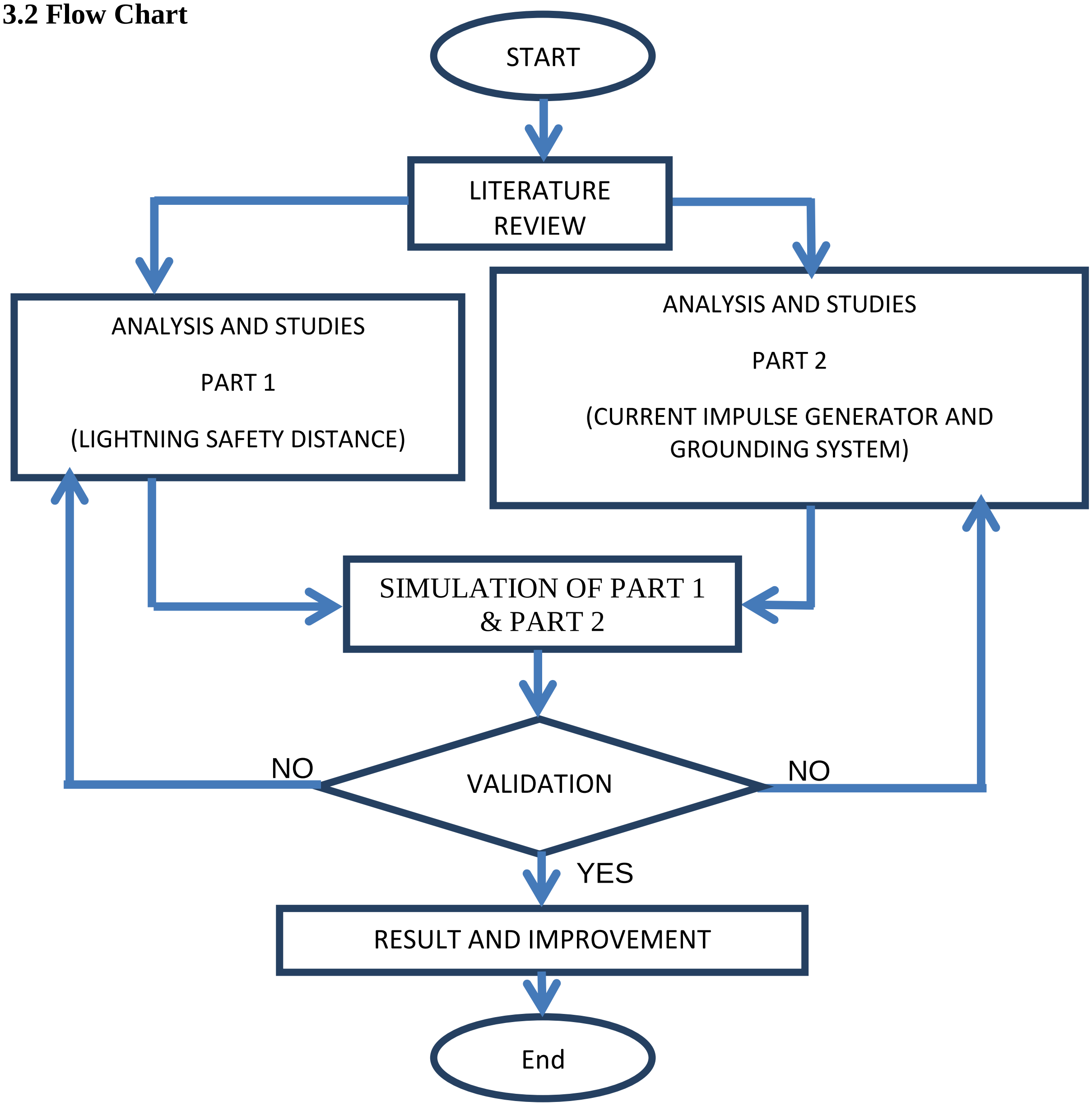


Figure 12: Flow chart of the project

Figure 12 describes the process flow in this project. The first objective of the project is to determine the lightning safety distance. The RSM concept will be used in order to find the lightning safety distance. The two input parameters will be investigated in order to study their relationship with the lightning safety distance. The two input parameters are lightning peak current and the length of vertical lightning rod. For the second part of the project is to study about the grounding system performances based on the grounding impedance values being inserted in the lightning current impulse equivalent circuit. The type of soil or water and the length of electrode are the input parameters that will be investigated in order to study their relationship with the grounding system performances.

3.2.1 Lightning Safety Distance

Table 7: Set of parameters that will be used to analyze the lightning safety distance

	ACTUAL CASE	CASE #1	CASE #2	CASE #3
Object's dimension (meters)	h_2 = 2.0 l_2 = 2.0 w_2 = 2.0	h_2 = 1.4 l_2 = 20.0 w_2 = 14.0	h_2 = 3.6 l_2 = 14.0 w_2 = 8.0	h_2 = 2.5 l_2 = 0.5 w_2 = 0.5
Height of lightning rod, h_1 (meters)	Tower = 20.0	High = 37.1 Medium = 19.9 Low = 15. 7	High = 67.6 Medium = 19.9 Low = 8.0	High = 3.7 Medium = 2.8 Low = 2.6
Lightning strikes peak current, I_s (kA)	2.9	High = 11.6 Medium = 2.9 Low = 0.7		
Minimum object safety distance required, R_o (meters)	1.41	12.20	8.10	0.35
Real application	Telecommunication Station	Residential College Building and Parking Lot	Single Stories House (Melaka)	CCTV at V5 Cafeteria

Table 7 shows the set of case study simulated in this project. The lightning strikes peak current, I_s and height of lightning rod, h_1 will be varied in order to understand their relationship with the total horizontal safety distance on the ground, R_g and the object safety distance, R_o. By understanding all these variations of parameter, the new lightning safety distance for satellite dish will be determined.

The Eq. (1), Eq. (2), and Eq. (3) will be used in order to find the new lightning safety distance for satellite dish. Based on all these theories, the script of programming will be built in M-File Matlab software. The program should be designed in the way of the user needs to key in the necessary inputs data before the result of lightning safety distance can be simulated.

The requirement input parameters that the user needs to key in before the result of safety distance can be simulated are:

1) The lightning strike peak current, based on IEC 61024-1 Lightning Protection Standard
2) The height of vertical rod
3) The dimension of object needs to be protected; including height, width and length of the object

For the dimension of object, this project is referring to the satellite dish. The user needs to identify the height of object and the total area of object on the ground. This data is critically needed in order to simulate the lightning safety distance. The lightning safety distance calculation in Eq. (2) and Eq. (3) have involved only with the input parameters of height of the object and height of the vertical lightning rod. The length and width of the object are not considered in the equation. Therefore the base area of the object (total object area on the ground) will be considered into account, in order to build one lightning protection system.

Table 8: Real case scenario

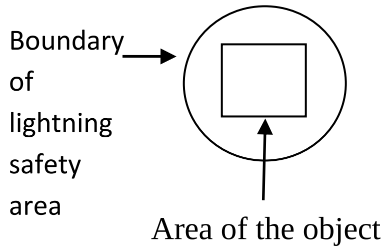
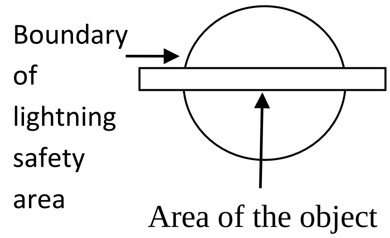
Criteria	Condition 1	Condition 2
Top view of lightning protection illustration		
Radius of safety distance	5 meter	5 meter
Length of the object	4 meters	1 meters
Width of the object	4 meter	16 meter
Area of the object	$16\ meters^2$	$16\ meters^2$
Result	Yes, the object will be protected because it is located inside the boundary of lightning safety area	No, the object will not be protected because it is located beyond than the limit boundary of lightning safety area

Table 8 shows as an example of scenario for the safety area of lightning protection systems from the top view. The argument here is although in both scenario indicates that the area of the object are the same, it does not mean conclusively that the lightning protection system will be working. Since the lightning safety distance of lightning protection systems is in the form of radius, the dimension of the object needs to be considered as well in the simulation.

In this project, the level 1 type of lightning protection based on International Electrotechnical Commission (IEC 61024-1) where the maximum return stroke peak current of 2.9 kA is chosen. It is because the level 1 type of lightning protection has 99 % of interception efficiency. Hence, it can be reduced the risk of potential that might appear and cause a failure to the lightning protection system during the lightning strikes. The result in the first part should give a protective zone distance between communication tower and satellite dish.

3.2.2 Grounding System Performances

In the second part, since the natural lightning has similarity in its characteristic waveform with current impulse generator, the equivalent circuit can be developed. The equivalent circuit output results need to be followed the IEC 61000-4-5-Surge Standard for current impulse. Therefore, all criteria that have been mentioned in a standard waveform must be satisfied.

In order to understand better about natural lightning waveform characteristic, a current impulse generator will be simulated. By using Eq. (5), Eq. (6) and Eq. (7) the lightning current impulses (LCI) generator with the level 1 type of protection equivalent circuit parameters can be calculated.

Table 9: R-L-C circuit parameters for LCI generator

Criteria	Formulae	Ratio	Result
Resistor, R	$R = 0.736 \times U_{ch}/I_p$	N/A	$R = 0.368\ \Omega$
Surge capacitor, C_s	$W/R = \left(\sqrt{C_s/L}\right) \times \left(U_{ch}{}^2 \times C_s/4\right)$	$L/C_S = 0.033856$	$C_s = 0.736\ mF$
Inductor, L			$L = 0.025\ mH$

Table 9 shows the R-L-C circuit parameters for LCI generator. For the level 1 type of lightning protection, the value of peak current, I_p is 200 kA. Meanwhile the charging voltage, U_{ch} is 100 kV. By using the Eq. (5), the resistance value for LCI generator equivalent circuit is 0.368 Ω. The specific energy, W/R for level 1 type of lightning protection is 10 MJ/Ω. The value of the surge capacitance, C_s and inductor, L can be calculated by using Eq. (6) and Eq. (7). The surge capacitance C_s and inductor, L are $0.736\ mF$ and $0.025\ mH$ respectively.

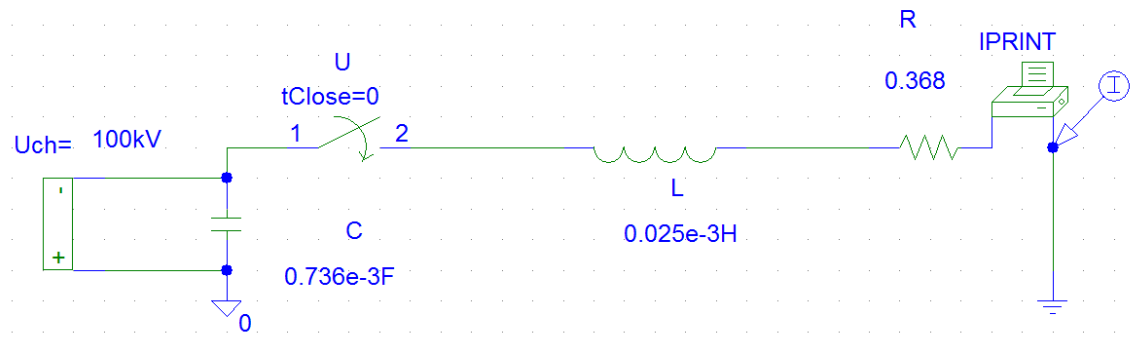


Figure 13: Lightning Current Impulse generator

Figure 13 shows the equivalent circuit diagram of lightning current impulse generator in order to produce a similar natural lightning waveform according to IEC 61000-4-5-Surge Standard for current impulse. All circuit components were assembled in PSpice simulation software with respectively calculated parameter values.

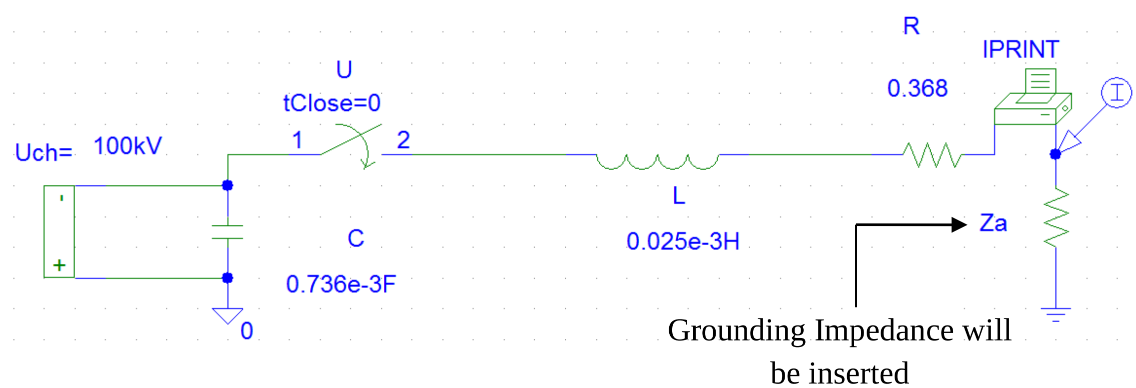


Figure 14: The place where the Grounding Impedance will be placed

Figure 14 shows the new circuit configuration of lightning current impulse (LCI) generator with grounding impedance, Z_A. The grounding system performances will be based on:

1) The value of lightning peak current being dispersed, the higher the better
2) The settling time, t_s for lightning current being completely dispersed, the faster the better

In order to find the grounding impedance, Z_A the Eq. (8) will be used. The general principle of lightning protection system for grounding impedance, Z_A is recommended to be smaller than the 10 Ω. The length of electrode, l and the soil or water resistivity, ρ are the concerned parameters in order to produce grounding impedance lower than 10 Ω. The effects between length of electrode and resistivity towards the performances of grounding system will be conducted. Listed below are the constant parameter criteria and their values that will be used in this project:

1) Radius of electrode, r $(meters)$ is 0.004 meters
2) Depth of electrode is buried, t $(meters)$ is 0.5 meters

Meanwhile, for each type of soil or water resistivity, there will be three differences length of electrode, l that will be used in this project. In scale of high, medium and low length of electrode, the values for this parameter are 350 meters, 100 meters and 10 meters respectively.

The Grounding Impedance, Z_A values can be calculated based on Eq. (8). An example of grounding impedance, Z_A calculation with using the clay type of resistivity and 350 meters length of electrode is shown below:

$$Z_A = \left(\rho \left[\ln\left({2l}/{\sqrt{2 \times 0.004 \times 0.5}}\right) - 1\right]\right)/{\pi l} \quad (8)$$

$$Z_A = (31.831 \times [\ln(31.623 \times 350) - 1])/{350}$$

$$Z_A = 0.756\ \Omega$$

Table 10: Grounding Impedance, values

Type of soil or water	Resistivity, ρ (Ω.m)	Grounding Impedance, Z_A (Ω)		
		Low	Medium	High
Clay	100	15.140	2.247	0.756
Groundwater, well, spring water	150	22.710	3.370	1.134
Sandy clay, cultivated soil	300	45.421	6.741	2.268
Rain water	1300	196.823	29.210	9.827

Table 10 shows the values of grounding impedance, Z_A used in this project. All the figures of grounding impedance, Z_A is based on the Eq. (8). The high grounding electrode setting is deliberately been adjusted in order to make the grounding impedance, Z_A become smaller than the 10 **Ω** (as recommended by general concept of LPS). Each value of grounding impedance, Z_A will be inserted in the circuit diagram in Figure 14. The final conclusion in this project will determine which type of length of electrode setting is the best for grounding system.

3.3 Gantt Chart

3.3.1 FYP 1

Table 11: Gantt chart of the Final Year Project 1

No.	Details\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic: Lightning protection														
2	Preliminary Research Work: Research on literatures related to the topic														
3	Extended Proposal Submission														
4	Proposal Defense (Presentation)														
5	FYP 1 Draft Report Submission														
6	FYP 1 Interim Report Submission														

In Table 11, it describes about project's timeline so then progress can be made accordingly. Research on literatures review has to be continued until the end of the Final Year Project. Based on this timeline, all document requested by Electrical and Electronics FYP Coordinator need to be prepared earlier than due date. The final draft report of Extended Proposal and Interim Report need to be endorsed during the submission.

3.3.2 FYP 2

Table 12: Gantt chart of the Final Year Project 2

No.	Details\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Progress Report from FYP 1															
2	Research on literatures related to the topic and Final Result															
3	Technical and Final Report Submission															
4	VIVA (Final Presentation)															

In Table 12, it describes about project’s timeline so then progress can be made accordingly. The progress report (from FYP1) needs to be submitted in week 8th for Final Year Project 2. However, the study and research on literature review that related to the project title need to be continued until the end of project in week 13th. The technical and final report submission due date is in week 14th. Therefore, the project need to be finished earlier so then the report can be finished sooner than the submission due date.

3.4 Simulation Software

To carry out the project, MATLAB R2011a software version will be used to simulate a graphical model of protective lightning zone area. By using M-file programming script, all the mathematics theory will be included for calculation of effective safety area. Then, the graphical form of 3-Dimensional Rolling Sphere Method (RSM) concept can be observed.

The lightning current impulse generator can create the same waveform characteristics as what the natural lightning have. The analysis for grounding system performances affected by the values of grounding impedance will be simulated by using Orcad PSpice 9.1 software version. The grounding system performances criteria are the magnitude of lightning peak current being dispersed and the settling time.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, the results and discussion based on the simulation computer program will be discussed. The new safety distance between the tower and satellite dish will be demonstrated by using 3-Dimensional illustrative graphics model.

4.1 Part 1: Lightning Protection Area Based On Rolling Sphere Method Concept

By using Matlab 2011 simulation software, all equations from Eq. (1) until Eq. (3) which form an algorithm were included in the programming script M-File. The simulation programming file was designed where it requires the users to fill in all the requirements data needed in order to construct a basic lightning protection system (LPS). All the parameters are required in order to ensure that the specific object is safely being protected during lightning strikes. The lightning protection system will be illustrated by using the technique of 3-Dimensional graphical simulation.

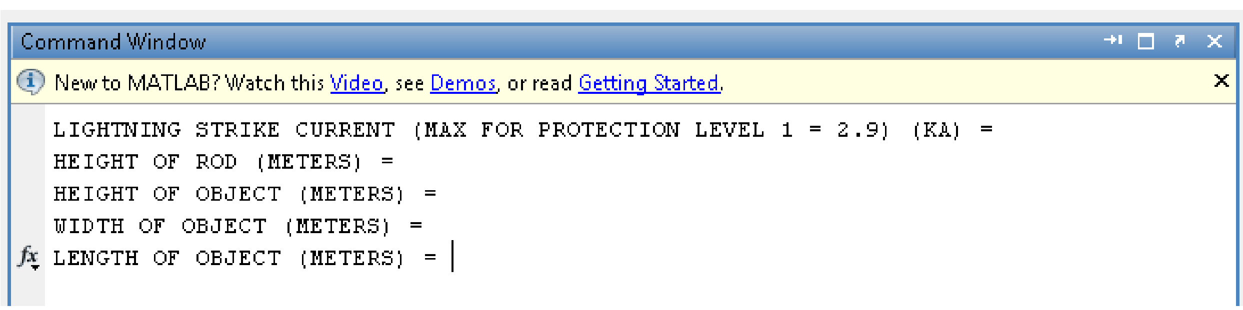


Figure 15: User needs to fill in the requirement parameters

Figure 15 shows all the requirements criteria needed in order to build one lightning protection system. The script of programming in M-File, requires some input data before any calculation can be made. For the lightning peak current, the input parameter should be in kilo (10^3) amperes unit. Based on the IEC 61024-1 lightning protection standard, the maximum input value of lightning peak current is 2.9 kA in order to construct the level 1 type of lightning protection system. However, the users can still fill in the lightning peak current parameter values larger than 2.9 kA. For the object volume dimension parameters, the users need to key in the value numbers of height of object, width of object and height of object. The heights of lightning rod used to build one lightning protection system, to be filled in for this simulation. For the object volume dimension and height of lightning rod, all parameters are in unit meter.

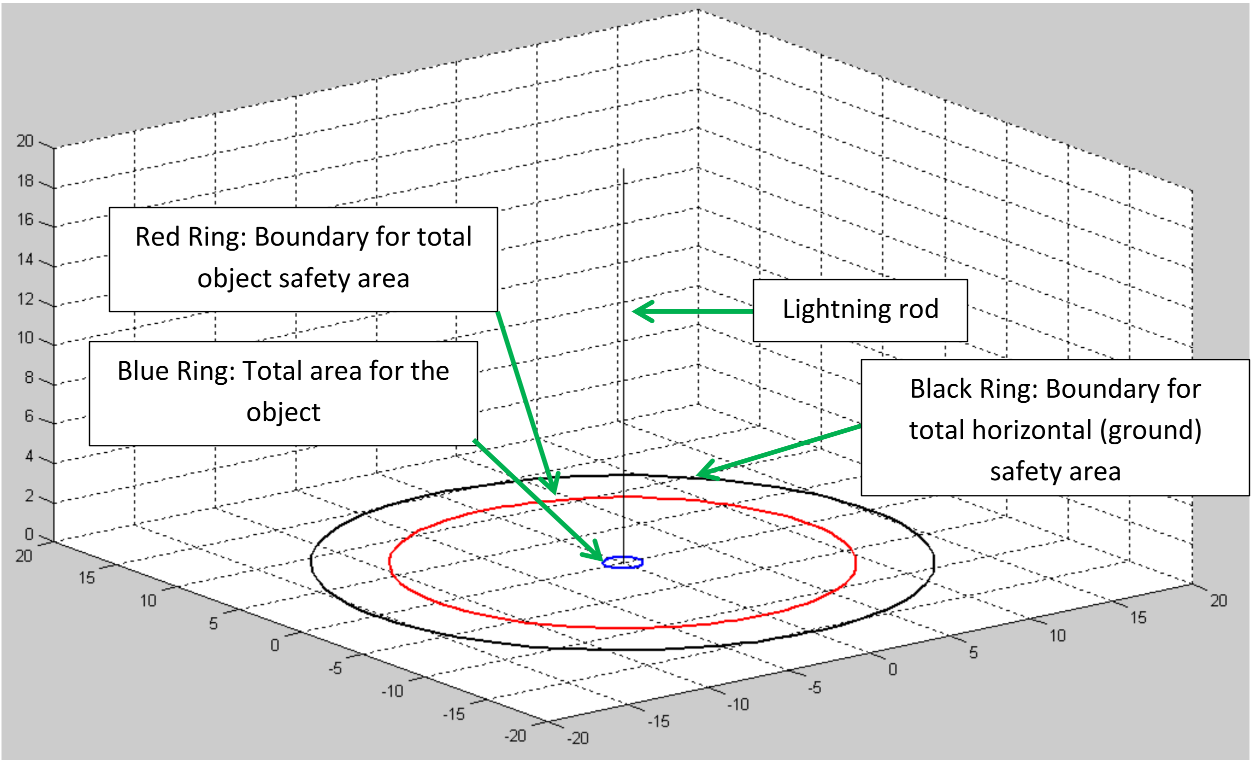


Figure 16: Graphical form of 3-Dimensional Rolling Sphere Method

Figure 16 shows the 3-Dimensional graphical simulation of lighting protection systems illustration derived from the RSM concept. The limit boundary of distance from one single vertical lightning rod based on RSM concept can be seen in this graphical simulation. In order to ensure that the lightning protection system is working successfully, the sequences of boundaries have been layout in the form of ring color. In order to ensure that the lightning protection system is working successfully, the arrangement of ring color sequences should follow exactly like in Figure 16.

Firstly the black ring boundary should have bigger area if compared with red ring boundary. That means if the red ring boundary is located outside from the black ring boundary in this graphical simulation, then the lightning protection system will not be working successfully. Secondly, the blue ring boundary should not be wider than red ring boundary. If the blue ring area is wider than red ring area, the lightning protection system will fail and the specified object is not being protected by the lightning rod.

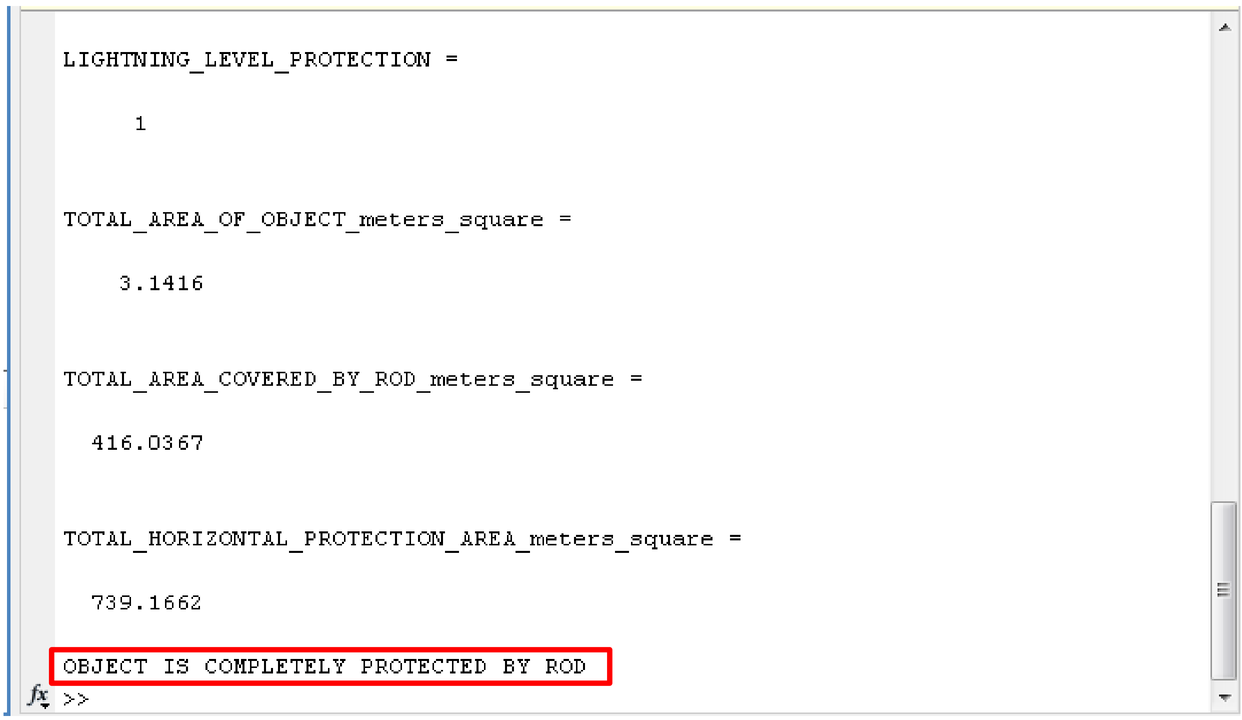


Figure 17: Final simulation result

Figure 17 shows the final simulation result in form of value numbers as an output for the lightning protection system. From this information, the users can determine whether or not all the input parameters are able to protect the specific object against the lightning strikes based on RSM concept.

From this final output simulation, there are two conditions need to be fulfilled in order to ensure that the input settings will be protected the specific object against the lightning strikes.

1) The total horizontal ground protection safety area (Black Ring) is wider than the total safety area covered by the lightning rod (Red Ring)
2) The total safety area covered by the lightning rod (Red Ring) is wider than the object total area (Blue Ring)

In the lightning protection system, the lightning safety distance is significantly important criteria. It can be influenced by using a different value numbers of the lightning peak current and also the height of lightning rod itself. Therefore, these two types of criteria that can influence the lightning safety distance will be varied in order to understand the concept of lightning protection system.

4.1.1 The Effect Of Lightning Peak Current Magnitude Towards The Lightning Safety Distance

The result of lightning safety distance for the specific object can be simulated in this project in 3-Dimensional graphical illustration. The difference parameter values of lightning peak current magnitude should be affected the lightning safety distance.

4.1.1.1 The Medium Lightning Peak Current Magnitude

Table 13: Simulation result based on medium lightning strikes peak current magnitude

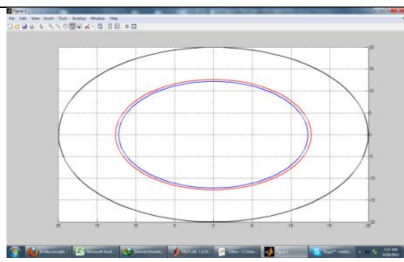
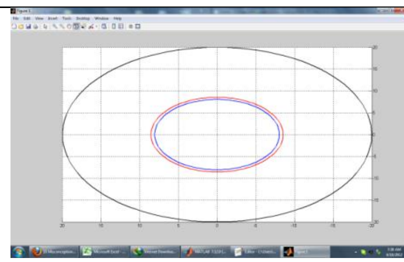
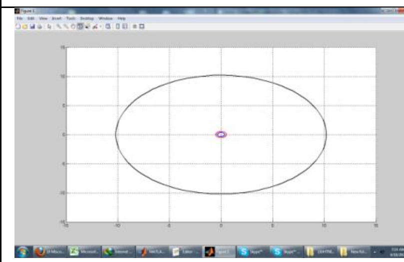
	CASE #1: Between V5B Residential College Building and Parking Lot Minimum Object Safety Distance, R_o Required = 12.20 meters	CASE #2: Single Stories House in Melaka Minimum Object Safety Distance, R_o Required = 8.10 meters	CASE #3: Walking area CCTV at V5 Cafeteria Minimum Object Safety Distance, R_o Required = 0.35 meters
Result for lightning peak current (manipulate parameter) is: MEDIUM I_s = 11.6kA	 Object Safety Distance, R_o=12.6311 meters	 Object Safety Distance, R_o=8.5377 meters	 Object Safety Distance, R_o=0.5231 meters
Lightning protection system is working successfully	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.

Table 13 shows the result for the lighting peak current, I_s input parameters is 2.9 kA also known as MEDIUM I_s. As being stated before, the condition of lightning protection system will be working successfully if the total horizontal ground protection safety area (Black Ring) is wider than the total safety area covered by the lightning rod (Red Ring) and the total safety area covered by the lightning rod (Red Ring) is wider than the object total area (Blue Ring). The graphical simulation in Table 13 has shown that the object safety distance, R_o is wider than the minimum object safety distance required. Therefore, the lightning protection system is in the condition where it will be protected the specific object with safely.

4.1.1.2 The Higher Lightning Peak Current Magnitude

Table 14: Simulation result based on high lightning strikes peak current magnitude

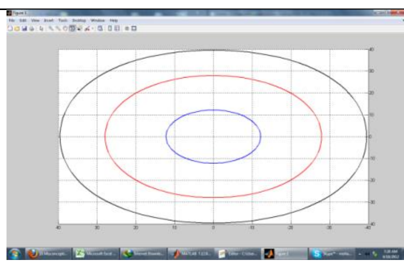
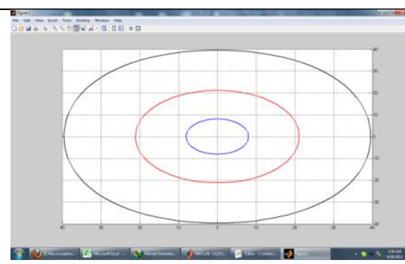
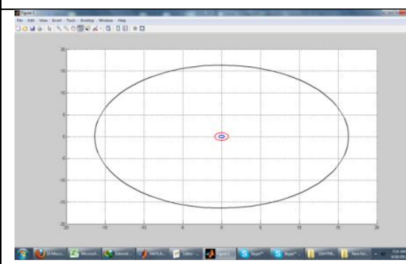
	CASE #1: Between V5B Residential College Building and Parking Lot Minimum Object Safety Distance, R_o Required = 12.20 meters	CASE #2: Single Stories House in Melaka Minimum Object Safety Distance, R_o Required = 8.10 meters	CASE #3: Walking area CCTV at V5 Cafeteria Minimum Object Safety Distance, R_o Required = 0.35 meters
Result for lightning peak current (manipulate parameter) is: HIGH =11.6 kA	 Object Safety Distance, R_o=27.8678 meters	 Object Safety Distance, R_o=21.0479 meters	 Object Safety Distance, R_o=0.8770 meters
Lightning protection system is working successfully	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.

Table 14 shows the result for the lighting peak current, I_s input parameters is 11.6 kA also known as HIGH I_s. As being stated before, the condition of lightning protection system will be working successfully if the total horizontal ground protection safety area (Black Ring) is wider than the total safety area covered by the lightning rod (Red Ring) and the total safety area covered by the lightning rod (Red Ring) is wider than the object total area (Blue Ring). The graphical simulation in Table 14 has shown that the object safety distance, R_o is wider than the minimum object safety distance required. Therefore, the lightning protection system is in the condition where it will be protected the specific object with safely.

From the results information that have been tabulated in the Table 14, the understanding of relationship between the lightning safety distance and lightning peak current magnitude was discovered. In this situation, the lightning protection system is successfully working if the lightning strikes peak current magnitude is larger than the initial setting of lightning strikes peak current parameter (MEDIUM I_s).

4.1.1.3 The Lower Lightning Peak Current Magnitude

Table 15: Simulation result based on low lightning strikes peak current magnitude

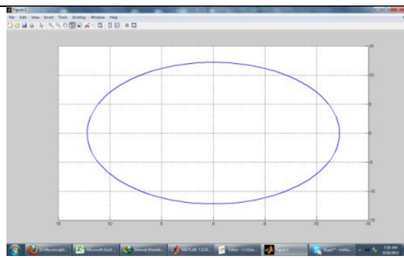
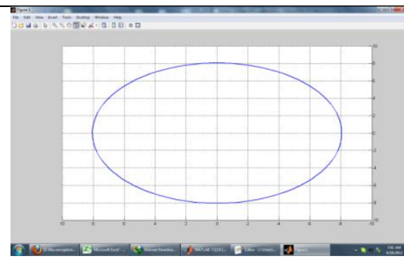
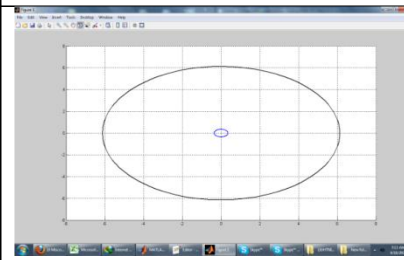
	CASE #1: Between V5B Residential College Building and Parking Lot Minimum Object Safety Distance, R_o Required = 12.20 meters	CASE #2: Single Stories House in Melaka Minimum Object Safety Distance, R_o Required = 8.10 meters	CASE #3: Walking area CCTV at V5 Cafeteria Minimum Object Safety Distance, R_o Required = 0.35 meters
Result for lightning peak current (manipulate parameter) is: LOW = 0.725 kA	 Object Safety Distance, R_o=3.4312 meters	 Object Safety Distance, R_o=1.2868 meters	 Object Safety Distance, R_o=0.2679 meters
Lightning protection system is working successfully	No, because the object safety distance, R_o is smaller than the minimum object safety distance required.	No, because the object safety distance, R_o is smaller than the minimum object safety distance required.	No, because the object safety distance, R_o is smaller than the minimum object safety distance required.

Table 15 shows the result for the lighting peak current, I_s input parameters is 0.725 kA also known as LOW I_s. As being stated before, the condition of lightning protection system will not be working successfully if the total horizontal ground protection safety area (Black Ring) is smaller than the total safety area covered by the lightning rod (Red Ring) and the total safety area covered by the lightning rod (Red Ring) is smaller than the object total area (Blue Ring). The graphical simulation in Table 15 has shown that the object safety distance, R_o is smaller than the minimum object safety distance required. Therefore, the lightning protection system is not in the condition where it will be protected the specific object with safely.

In another word to explain this is when the lightning strikes peak current magnitude is smaller than the initial setting of lightning strikes peak current parameter (MEDIUM I_s), the lightning protection system (LPS) will not be working.

Therefore any lightning strikes peak current is smaller than MEDIUM I_s magnitude, the lightning protection system will not be able to provide the protection for the specified object. However, if the value of MEDIUM I_s was selected based on the withstand insulation level of specified object, LOW I_s should cause no damage to the equipment.

4.1.2 The Effect Of Length Of Vertical Lightning Rod Towards The Lightning Safety Distance

The result of lightning safety distance for the specific object can be simulated in this project in 3-Dimensional graphical illustration. The difference parameter values of vertical lightning rod should be affected the lightning safety distance.

4.1.2.1 The Medium Length Of Vertical Lightning Rod

Table 16: Simulation result based on medium length of vertical lightning rod

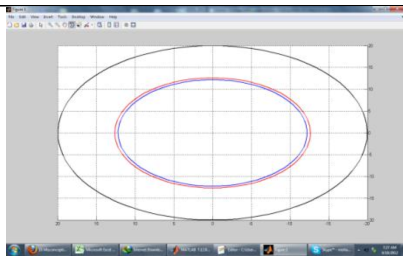
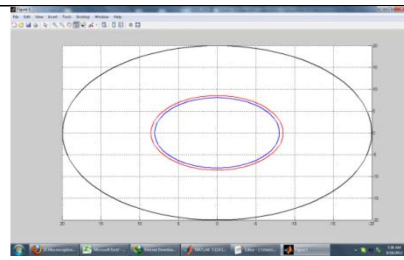
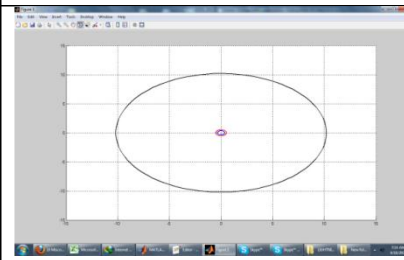
	CASE #1: Between V5B Residential College Building and Parking Lot Minimum Object Safety Distance, R_o Required = 12.20 meters	CASE #2: Single Stories House in Melaka Minimum Object Safety Distance, R_o Required = 8.10 meters	CASE #3: Walking area CCTV at V5 Cafeteria Minimum Object Safety Distance, R_o Required = 0.35 meters
Result for length of vertical lightning rod (manipulate parameter) is: MEDIUM	 Object Safety Distance, R_o=12.6311 meters	 Object Safety Distance, R_o=8.5377 meters	 Object Safety Distance, R_o=0.5231
Lightning protection system is working successfully	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.

Table 16 shows the result for the length of vertical lightning rod, h_1 with input parameters is 19.9 meters for CASE #1 and CASE #2 and 2.8 meters for CASE #3 also known as MEDIUM h_1. As being stated before, the condition of lightning protection system will be working successfully if the total horizontal ground protection safety area (Black Ring) is wider than the total safety area covered by the lightning rod (Red Ring) and the total safety area covered by the lightning rod (Red Ring) is wider than the object total area (Blue Ring). The graphical simulation in Table 16 has shown that the object safety distance, R_o is wider than the minimum object safety distance required. Therefore, the lightning protection system is in the condition where it will be protected the specific object with safely.

4.1.2.2 The Higher Length Of Vertical Lightning Rod

Table 17: Simulation result based on high length of vertical lightning rod

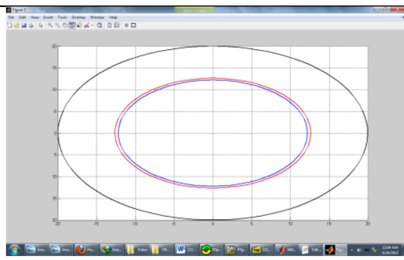
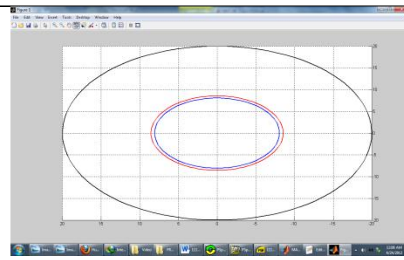
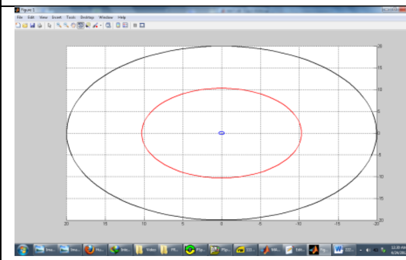
	CASE #1: Between V5B Residential College Building and Parking Lot Minimum Object Safety Distance, R_o Required = 12.20 meters	CASE #2: Single Stories House in Melaka Minimum Object Safety Distance, R_o Required = 8.10 meters	CASE #3: Walking area CCTV at V5 Cafeteria Minimum Object Safety Distance, R_o Required = 0.35 meters
Result for length of vertical lightning rod (manipulate parameter) is: HIGH	 Object Safety Distance, R_o=12.6312 meters	 Object Safety Distance, R_o=8.5379meters	 Object Safety Distance, R_o= 1.9054 meters
Lightning protection system is working successfully	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.	Yes, because the object safety distance, R_o is wider than the minimum object safety distance required.

Table 17 shows the result for the length of vertical lightning rod, h_1 with input parameters is 37.1 meters for CASE #1, 67.6 meters for CASE #2 and 3.7 meters for CASE #3 also known as HIGH h_1. As being stated before, the condition of lightning protection system will be working successfully if the total horizontal ground protection safety area (Black Ring) is wider than the total safety area covered by the lightning rod (Red Ring) and the total safety area covered by the lightning rod (Red Ring) is wider than the object total area (Blue Ring). The graphical simulation in Table 17 has shown that the object safety distance, R_o is wider than the minimum object safety distance required. Therefore, the lightning protection system is in the condition where it will be protected the specific object with safely.

From the results information that have been tabulated in the Table 17, the understanding of relationship between the lightning safety distance and the length of vertical lightning rod was discovered. In this situation, the lightning protection system is successfully working if the length of vertical lightning rod, h_1 is longer than the initial setting of the length of vertical lightning rod parameter (MEDIUM h_1) at the first places when the users has designed it.

The maximum distance of protection provided by the length of vertical lightning rod, h_1 is supposedly equal with the length of striking distance, S. In another way to explain this, if the length of vertical lightning rod, h_1 is longer than the values of striking distance, S, then the maximum values of total horizontal ground protection safety area is remained equal with the length of striking distance, S.

4.1.2.3 The Lower Length Of Vertical Lightning Rod

Table 18: Simulation result based on low length of vertical lightning rod

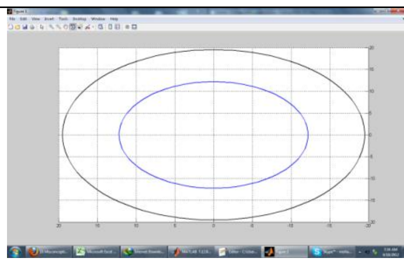
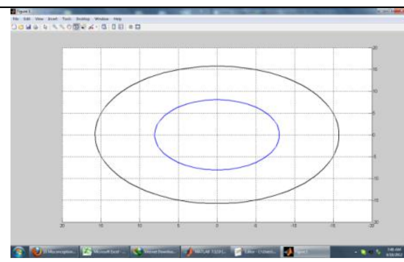
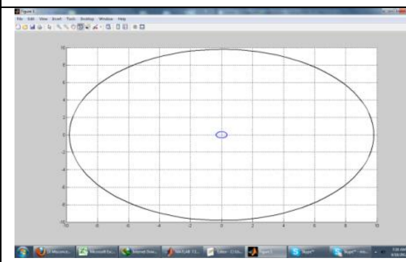
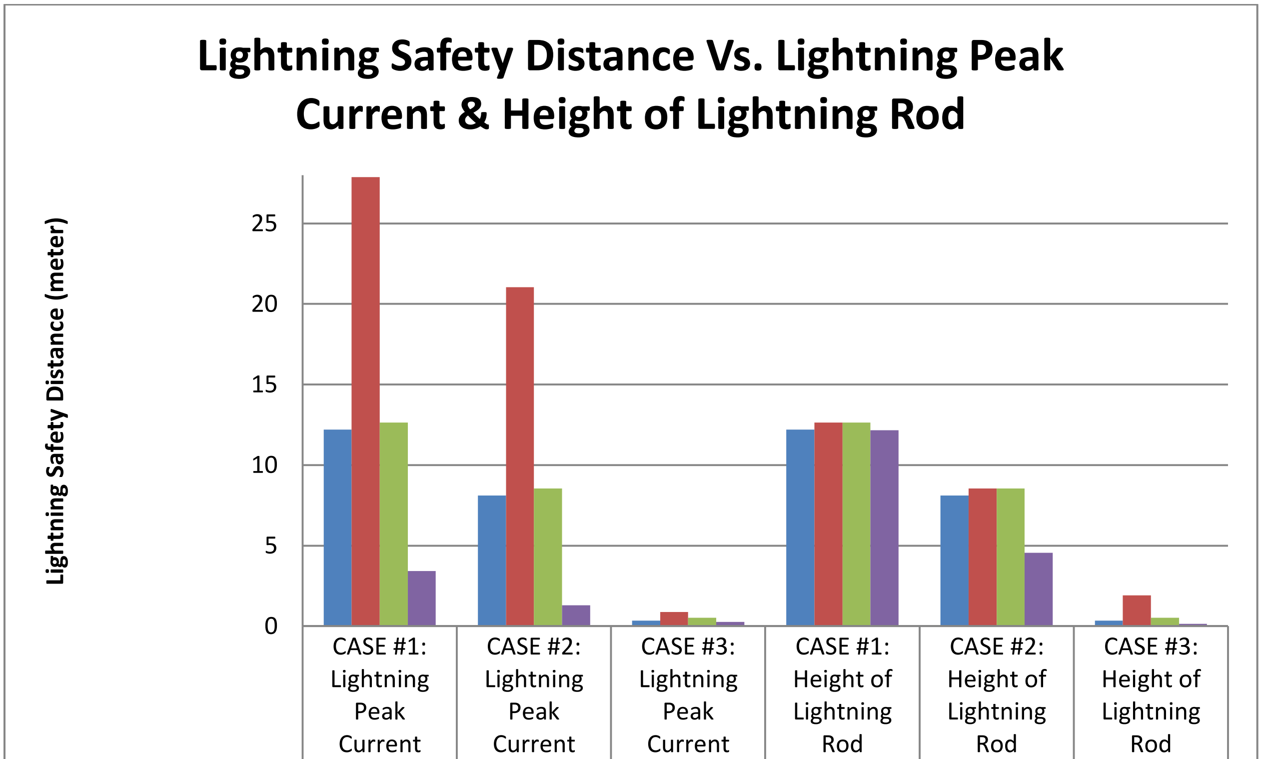
	CASE #1: Between V5B Residential College Building and Parking Lot Minimum Object Safety Distance, R_o Required = 12.20 meters	CASE #2: Single Stories House in Melaka Minimum Object Safety Distance, R_o Required = 8.10 meters	CASE #3: Walking area CCTV at V5 Cafeteria Minimum Object Safety Distance, R_o Required = 0.35 meters
Result for length of vertical lightning rod (manipulate parameter) is: LOW	 Object Safety Distance, R_o=12.1678 meters	 Object Safety Distance, R_o=4.5487 meters	 Object Safety Distance, R_o=0.1431 meters
Lightning protection system is working successfully	No, because the object safety distance, R_o is smaller than the minimum object safety distance required.	No, because the object safety distance, R_o is smaller than the minimum object safety distance required.	No, because the object safety distance, R_o is smaller than the minimum object safety distance required.

Table 18 shows the result for the length of vertical lightning rod, h_1 with input parameters is 15.7 meters for CASE #1, 8.0 meters for CASE #2 and 2.58 meters for CASE #3 also known as LOW h_1. As stated before, the condition of lightning protection system will not be working successfully if the total horizontal ground protection safety area (Black Ring) is smaller than the total safety area covered by the lightning rod (Red Ring) and the total safety area covered by the lightning rod (Red Ring) is smaller than the object total area (Blue Ring). The graphical simulation in Table 18 has shown that the object safety distance, R_o is smaller than the minimum object safety distance required. Therefore, the lightning protection system is not in the condition where it will be protected the specific object with safely.

In another word to explain this is when the length of vertical lightning rod, h_1 is smaller than the length of striking distance, S and the height of object, h_2, the lightning protection system (LPS) will not be working. Therefore if the length of vertical lightning rod, h_1 is smaller than the length of striking distance, S and the height of object, h_2, the lightning protection system will not be able to provide the protection to the specified object.

4.1.3 Comprehensive Relationship Between Running Parameter And Lightning Safety Distance



	CASE #1: Lightning Peak Current	CASE #2: Lightning Peak Current	CASE #3: Lightning Peak Current	CASE #1: Height of Lightning Rod	CASE #2: Height of Lightning Rod	CASE #3: Height of Lightning Rod
MIN REQUIREMENT	12.2	8.1	0.35	12.2	8.1	0.35
HIGH	27.8678	21.0479	0.877	12.6312	8.5379	1.9054
MEDIUM	12.6311	8.5377	0.5231	12.6311	8.5377	0.5231
LOW	3.4312	1.2868	0.2679	12.1678	4.5487	0.1431

Figure 18: Lightning safety distance vs. lightning peak current and height of lightning rod

Figure 18 shows the relationship among the lightning safety distance, R_o, lightning strikes peak current, I_s and lightning rod, h_1. The distance of R_o will increase when the lightning strikes is larger than the medium current I_s for all cases. For an example Case #1, the R_o of high current I_s (11.6 kA) is 27.8678 meters while for the medium current I_s (2.9 kA) is 12.6311 meters. The result shows that the R_o of high current I_s is wider than the medium current I_s. Therefore, LPS is in the condition where it will be protected the specific object with safely. In another hand, the distance of $R_o$will decrease when the lightning strikes is smaller than the medium current I_s for all cases. For an example Case #1, the R_o of low current I_s (0.7 kA) is 3.4312 meters while for the medium current I_s (2.9 kA) is 12.6311 meters. The result shows that the R_o of low current I_s is smaller than the medium current I_s. In this situation, LPS is not in the condition where it will be protected the specific object with safely. However, if the value of medium current I_s was selected based on the withstand insulation level of specified object, low current I_s should cause no damage to the equipment.

The distance of R_o is not having a significant improvement when the lightning rod is longer than the medium length of h_1 for Case #1 and Case #2. For an example Case #1, the R_o of high lightning rod (37.1 meters) is 12.6312 meters while for the medium lightning rod (19.9 meters) is 12.6311 meters. The small differences value of R_o between the high lightning rod and medium lightning rod result shows that maximum effective height of lightning rod is should be the same with striking distance. For the Case #3 the high lightning rod used is 3.7 meters, while the striking distance is 20 meters. Therefore the R_o will keep on increasing until the height of lightning rod used is same with striking distance. It is because the maximum effective height of lightning rod should be same with the striking distance. The distance of R_o is smaller when the lightning rod is lower than the medium length of h_1 for all cases. For an example Case #1, the R_o of low lightning rod (37.1 meters) is 12.1678 meters while for the medium lightning rod (19.9 meters) is 12.6311 meters. Therefore the LPS will not be working safely since the R_o for low lightning rod is smaller than the minimum safety distance required.

4.1.4 Existing Lightning Protection Scheme At Telecommunication Station

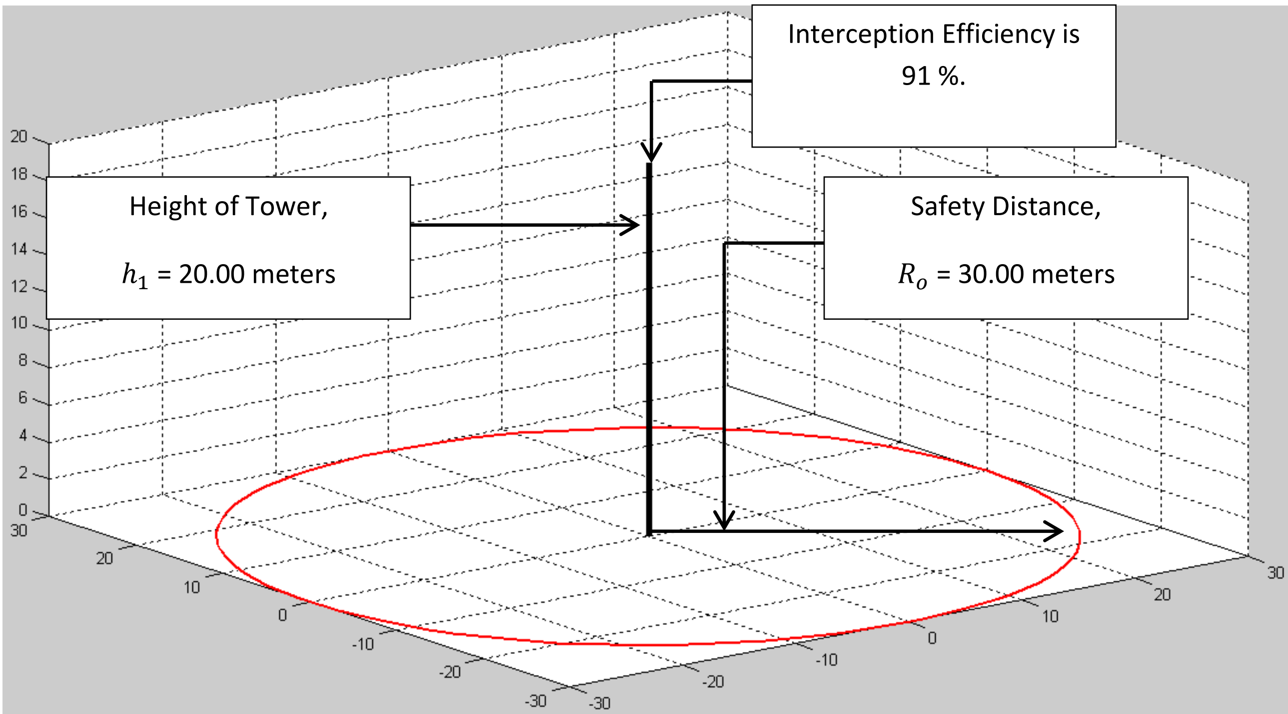


Figure 19: 3-Dimensional for current protection scheme

Figure 19 shows the current lightning safety distance of satellite dish, based on level 3 lightning protection system. For this lightning protection scheme based on the IEC 61024-1 lightning protection standard, the interception efficiency is 91 %. The interception efficiency can be improved by using the level 1 type of lightning protection system. The current safety distance at the telecommunication station is 30 meters. It is found to be unsafe for the satellite dish protection. It is because the total horizontal ground protection safety area (Black Ring) is not presented in the graphical simulation. Yet, the maximum distances of total safety area covered by the lightning rod (Red Ring) is supposedly 20 meters for the level 1 type of lightning protection standard.

4.1.5 Improved Lightning Protection Scheme

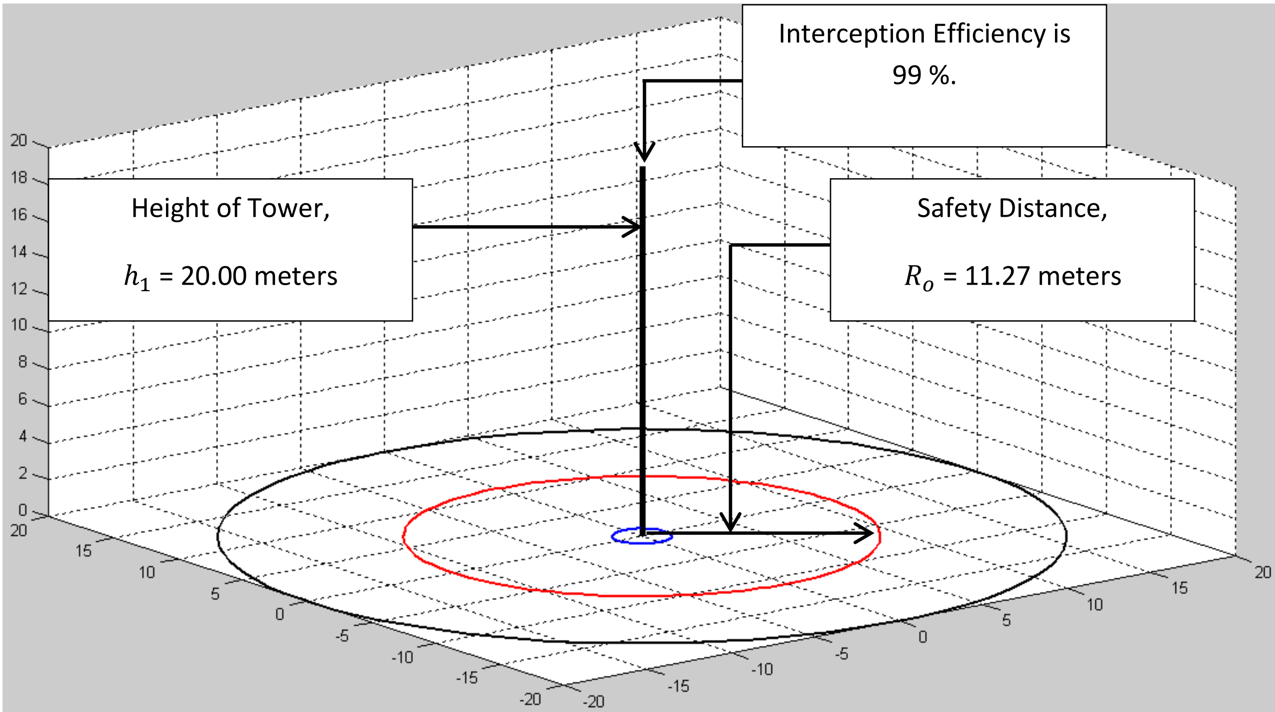


Figure 20: 3-Dimensional for improved protection scheme

Figure 20 shows the improved safety distance of satellite dish, based on level 1 lightning protection system. The improved lightning safety distance for the satellite dish is 11.27 meters. It has closer distance with the tower of 20 meters height, compared to the current setting. The improved safety distance is reduced by 62.43 % from its original length. Based on this improvement, the tower has been equipped with the 99 % of interception efficiency of lightning level protection. The new lightning systems protection scheme is found to be safe for the satellite dish protection.

It is because the condition of lightning protection system will be working successfully if the total horizontal ground protection safety area (Black Ring) is wider than the total safety area covered by the lightning rod (Red Ring) and the total safety area covered by the lightning rod (Red Ring) is wider than the object total area (Blue Ring).

4.2 Part 2: Grounding System Analysis

The result of grounding system performances based on the magnitude of lightning peak current being dispersed and the settling time for lightning current being completely dispersed criteria can be simulated. But firstly, the lightning current impulse generator need to be verified so then all the standard waveform characteristics are fulfilling the requirement of IEC 61000-4-5-Surge Standard for current impulse.

4.2.1: Lightning Current Impulse Generator

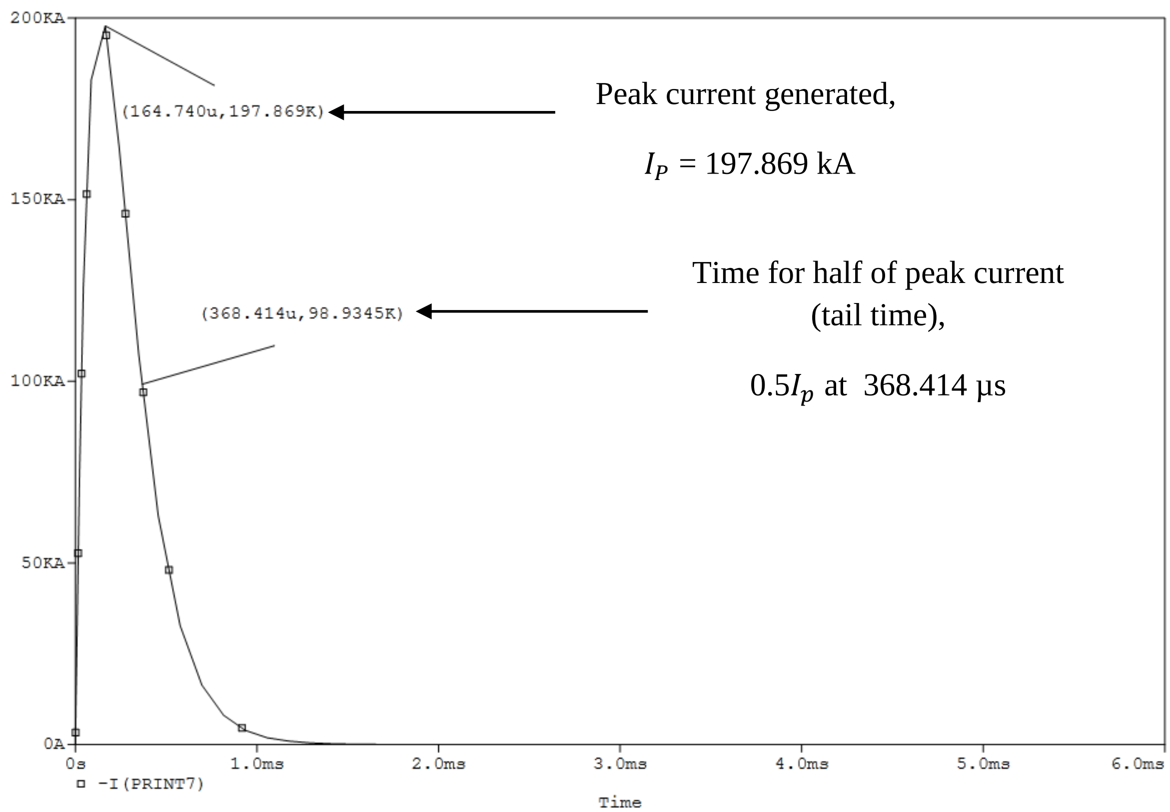


Figure 21: 10/350 µs current impulse waveform

Figure 21 shows the result for simulation circuit of 10/350 µs lightning current impulse waveform. The lightning current impulse has generated the peak magnitude current of 197.869 kA and the time for half of peak magnitude current (tail time) is at 368.414 µs. Before the analysis of grounding system performances can be conducted, the simulated waveform needs to fulfill the requirement of standard lightning waveform in IEC 61000-4-5-Surge Standard for current impulse. According to IEC Surge Standard, at the tail time (350 μs); the amplitude of current impulse waveform is one-half of peak current produced.

In addition, according to IEC 61000-4-5-Surge Standard for current impulse the allowable tolerance for peak current, I_p is $\pm$10 %. In this project, the level 1 type of protection for 10/350 μs current impulse waveform has been selected where the peak current, I_p is 200 kA. That means the peak current values for the simulated waveform is supposedly in the range of between 220 kA and 180 kA. The generated lightning peak current is 197.869 kA, so then one of the requirement criteria of standard waveform has been fulfilled.

Then, according to IEC 61000-4-5-Surge Standard for current impulse the allowable tolerance for specific energy, $W/_R$ is $\pm$35 %. In this project, the level 1 type of protection for 10/350 μs current impulse waveform has been selected where the specific energy, $W/_R$ is 10 $MJ/_\Omega$. That means the peak current values for the simulated waveform is supposedly in the range of between 13.5 $MJ/_\Omega$ and 6.5 $MJ/_\Omega$.

Table 19: Checking the standard waveform of current impulse generator

Criteria	Theory	Simulated Waveform	Different in Percentage	Allowable Tolerance in Percentage	IEC Surge Standard
Peak Current, I_p	200 kA	197.869 kA	-1.066 %	± 10 %	Yes
Time for half of Peak Current, $0.5I_p$	98.9345 kA at 350.000 µs	98.9345 kA at 368.414 µs	+5.261 %	± 10 %	Yes
Specific Energy, $W/_R$	10 $MJ/_\Omega$	9.984 $MJ/_\Omega$	-0.160 %	± 35 %.	Yes

Table 19 shows the standard waveform requirement criteria that have to be fulfilled by the lightning current impulse generator. As a result, all types of requirement criteria provided by the IEC 61000-4-5-Surge Standard for current impulse have been fulfilled. The percentage of allowable tolerance also does not exceed from the limit provided by the IEC 61000-4-5-Surge Standard for current impulse.

4.2.3 Comparison of Grounding System Performances Based On Grounding Impedance

The comparative result of the grounding system performances influence by the grounding impedance values need to be analyzed. The current grounding impedance value at the telecommunication station is 15 Ω. Meanwhile, the recommended values of grounding impedance by the general principle of lightning protection system should be smaller than 10 Ω. Therefore, the grounding impedance that has values smaller than the 15 Ω should give the better grounding system performances.

4.2.3.1 Existing Grounding Impedance At Telecommunication Station (15 Ω)

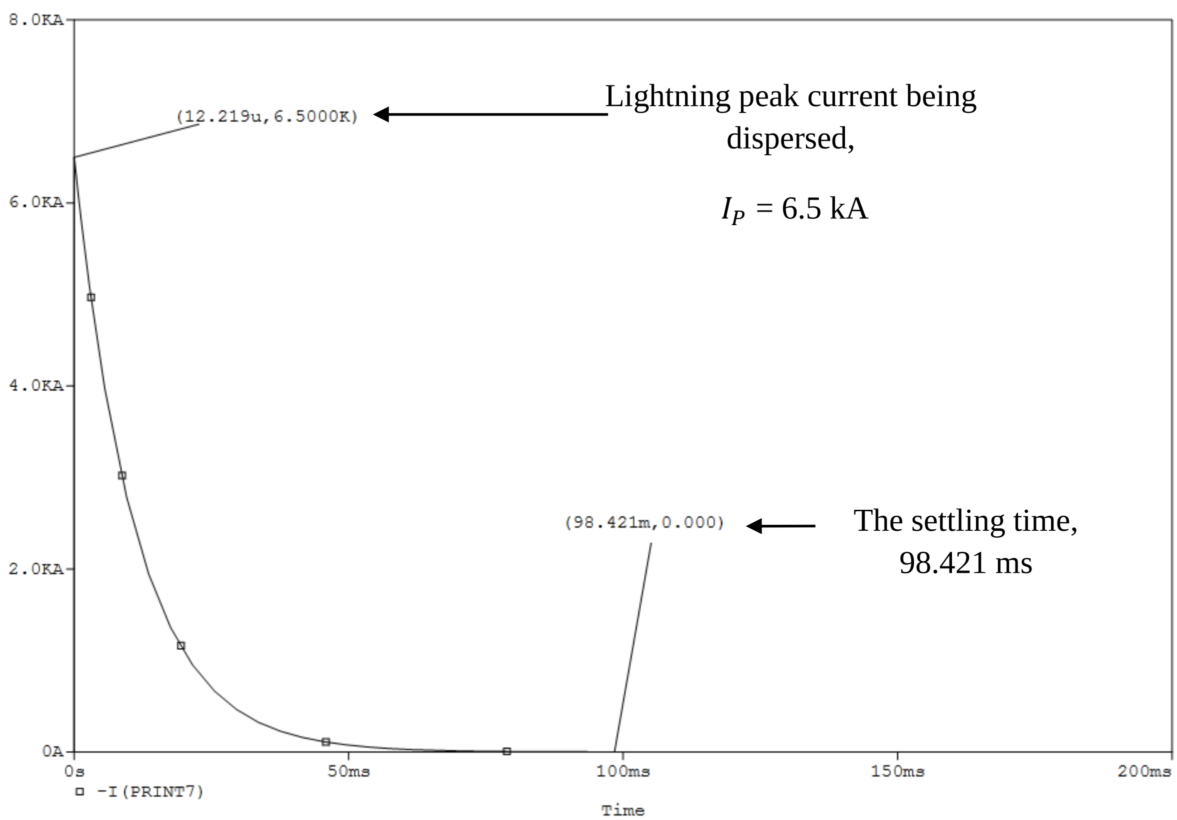


Figure 22: Magnitude of peak current being dispersed by using 15 Ohm of grounding impedance

Figure 22 shows the magnitude of current being dispersed by using 15 Ω grounding impedance, Z_A. The simulated waveform is based on lightning current impulse (LCI) equivalent circuit generator with the grounding impedance. This is an example for simulated waveform yielded by using the LCI equivalent circuit generator with additional component of grounding impedance, Z_A. The simulated waveform is indicating that the amount of peak current being dispersed is 6.5 kA. In addition, the settling time, t_s for 15 Ω grounding impedance, Z_A is 98.421 ms. The best performance of grounding system will create a huge amount of peak current being dispersed and shorter settling time.

4.2.3.2 Lower Grounding Impedance (0.004 Ω)

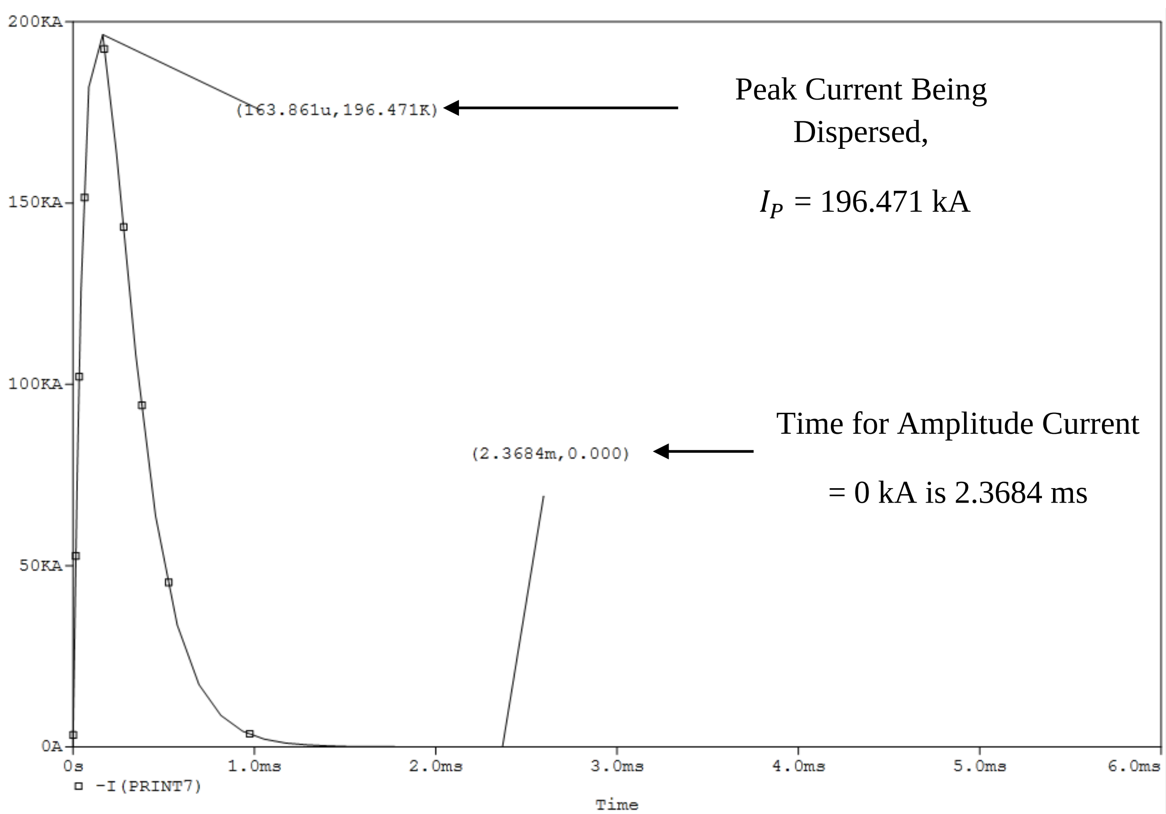


Figure 23: Magnitude of peak current being dispersed by using 0.004 Ohm of grounding impedance

Figure 23 shows the magnitude of dispersed current by using $0.004\,\Omega$ grounding impedance, Z_A. The simulated waveform is based on lightning current impulse (LCI) equivalent circuit generator with the grounding impedance. This is an example for simulated waveform yielded by using the LCI equivalent circuit generator with additional component of grounding impedance, Z_A. The simulated waveform is indicating that the amount of dispersed peak current is 196.471 kA. In addition, the settling time, t_s for $0.004\,\Omega$ grounding impedance, Z_A is 2.3684 ms. The best performance of grounding system will create a huge amount of dispersed peak current and shorter settling time.

4.2.4: The Full Result For Grounding System Performances

Table 20: The full result of the project

Type of soil or water	Resistivity, ρ (Ω.m)	length of electrode, l (meters)								
		Low = 10 meters			Medium = 100 meters			High = 350 meters		
		Grounding Impedance, Z_A (Ω)	Lightning Peak Current Being Dispersed, (kA)	Settling Time, (ms)	Grounding Impedance, Z_A (Ω)	Lightning Peak Current Being Dispersed, (kA)	Settling Time, (ms)	Grounding Impedance, Z_A (Ω)	Lightning Peak Current Being Dispersed, (kA)	Settling Time, (ms)
Clay	100	15.140	6.441	96.842	2.247	37.431	19.388	0.756	82.285	9.072
Groundwater, well, spring water	150	22.710	4.330	139.175	3.370	26.397	26.735	1.134	63.348	11.633
Sandy clay, cultivated soil	300	45.421	2.187	258.763	6.741	14.008	49.388	2.268	37.141	19.592
Rain water	1300	196.823	0.507	897.959	29.210	3.380	172.956	9.827	9.782	68.776

Table 20 shows the comprehensive result of the project that includes the criteria of grounding system performances. As mentioned earlier that the grounding system is best when it has higher amount dispersed of peak current and shorter settling time will give the best result. For each type of soil or water resistivity, there will be three differences length of electrode, l used. In scale of high, medium and low length of electrode, the values for this parameter are 350 meters, 100 meters and 10 meters respectively.

For an example, with the constant resistivity of the rain water, the grounding impedance, Z_A is decreasing when the length of electrode, l become higher. For the low, medium and high length of electrode setting, the grounding impedance values are 196.823 Ω, 29.210 Ω and 9.827 Ω respectively. Therefore for the resistivity of rain water, in order to make the grounding impedance become less than 10 Ω (as recommended by general principle of lightning protection system), the high length of electrode setting will be used. In all cases, when the length of electrode becomes longer, the grounding impedance decreases.

For high length of electrode, the magnitude of lightning dispersed peak current is 9.782 kA. Meanwhile the low and medium length of electrode setting produced smaller magnitude of lightning dispersed peak current which are 0.507 kA and 3.380 kA respectively. The comparisons of grounding system performances have shown that the high length of electrode setting is the best. It is because the magnitude of lightning dispersed peak current is higher than the other setting. In all cases of item, when the length of electrode is become longer, the magnitude of lightning dispersed peak current will be higher.

For the high length of electrode setting, the settling time for dispersed lightning current is 68.776 ms. Meanwhile the low and medium length of electrode setting produced higher settling time which are 897.959 ms and 172.956 ms respectively. The comparisons of grounding system performances have shown that the high length of electrode setting is the best. It is because the settling time for completely dispersed lightning current is faster than the other setting. In all cases of item, when the length of electrode becomes longer, the settling time for completely dispersed lightning current will be faster.

For the lower constant resistivity of item like the clay, groundwater well and spring water, and sandy clay and cultivated soil, the grounding impedance values are already below than 10 Ω (as recommended by general principle of lightning protection system) by using medium length of electrode setting. The grounding impedance values for the resistivity of clay, groundwater well and spring water, and sandy clay and cultivated soil are 2.247 Ω, 3.370 Ω and 6.741 Ω respectively. Therefore for the lower constant resistivity of items, the medium length of electrode setting is already enough in order to produce grounding impedance values smaller than the 10 Ω. In all cases, when the constant resistivity of item becomes larger, the grounding impedance will increase.

Further discussion will be explained in the form of graph analysis. The relationship between the resistivity of item and the length of electrode toward the effectiveness of grounding system performance will be analyzed.

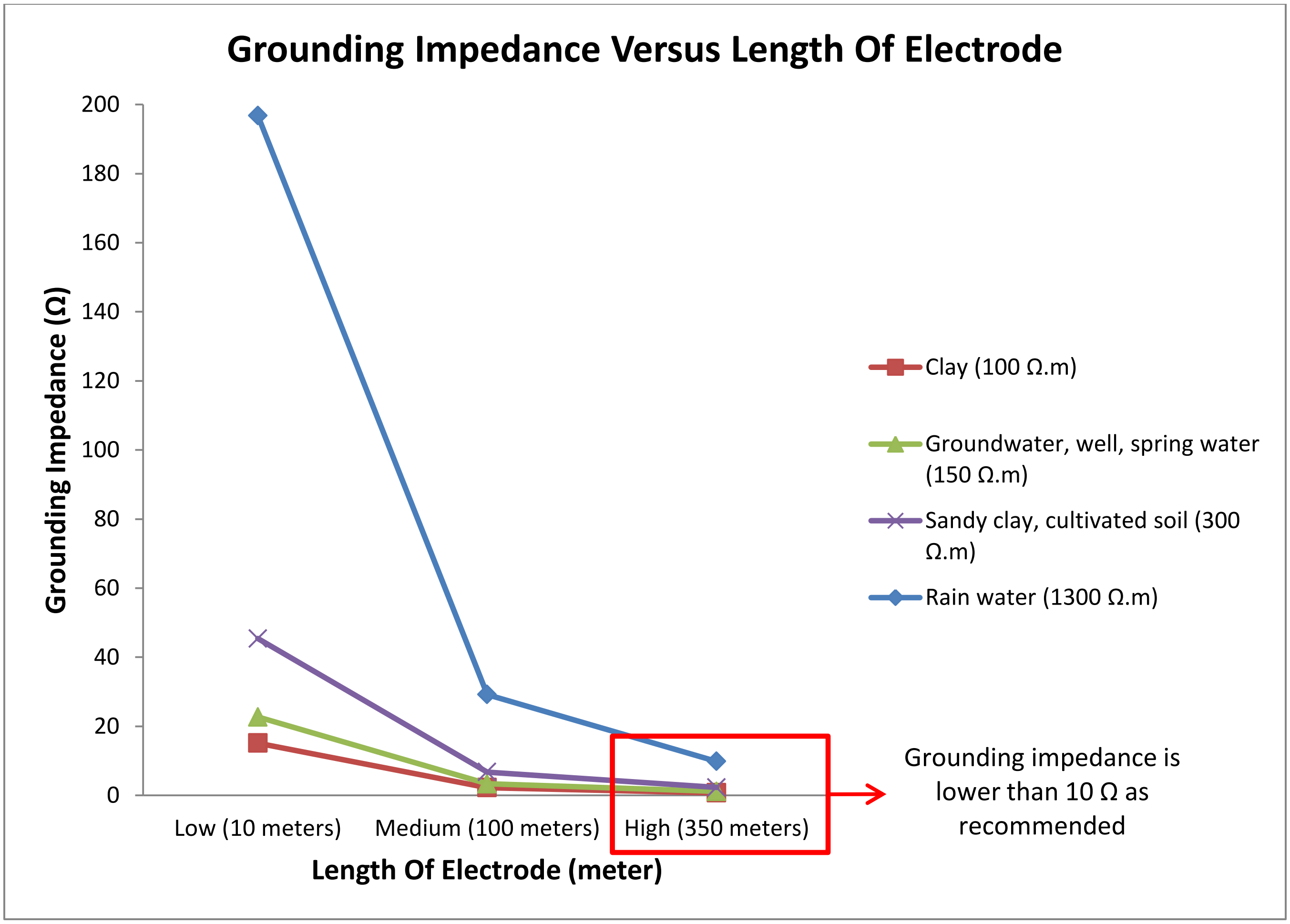


Figure 24: Grounding impedance versus length of electrode

Figure 24 shows that the relationship between the grounding impedance and length of electrode. The resistivity (Ω.m) value is depending on the type of soil or water. In order to design the grounding impedance smaller than the 10 Ω (as recommended by the general principle of lightning protection system), the length of electrode should be increased. The high length of electrode (350 meters) settings is successfully able to produce the grounding impedance value smaller than the 10 Ω for all types of item provided in the analysis. Meanwhile, the low length of electrode (10 meters) and the medium length of electrode (100 meters) setting have failed to produce the grounding impedance value smaller than the 10 Ω. Therefore, the longer distance of length of electrode will make the grounding impedance become smaller.

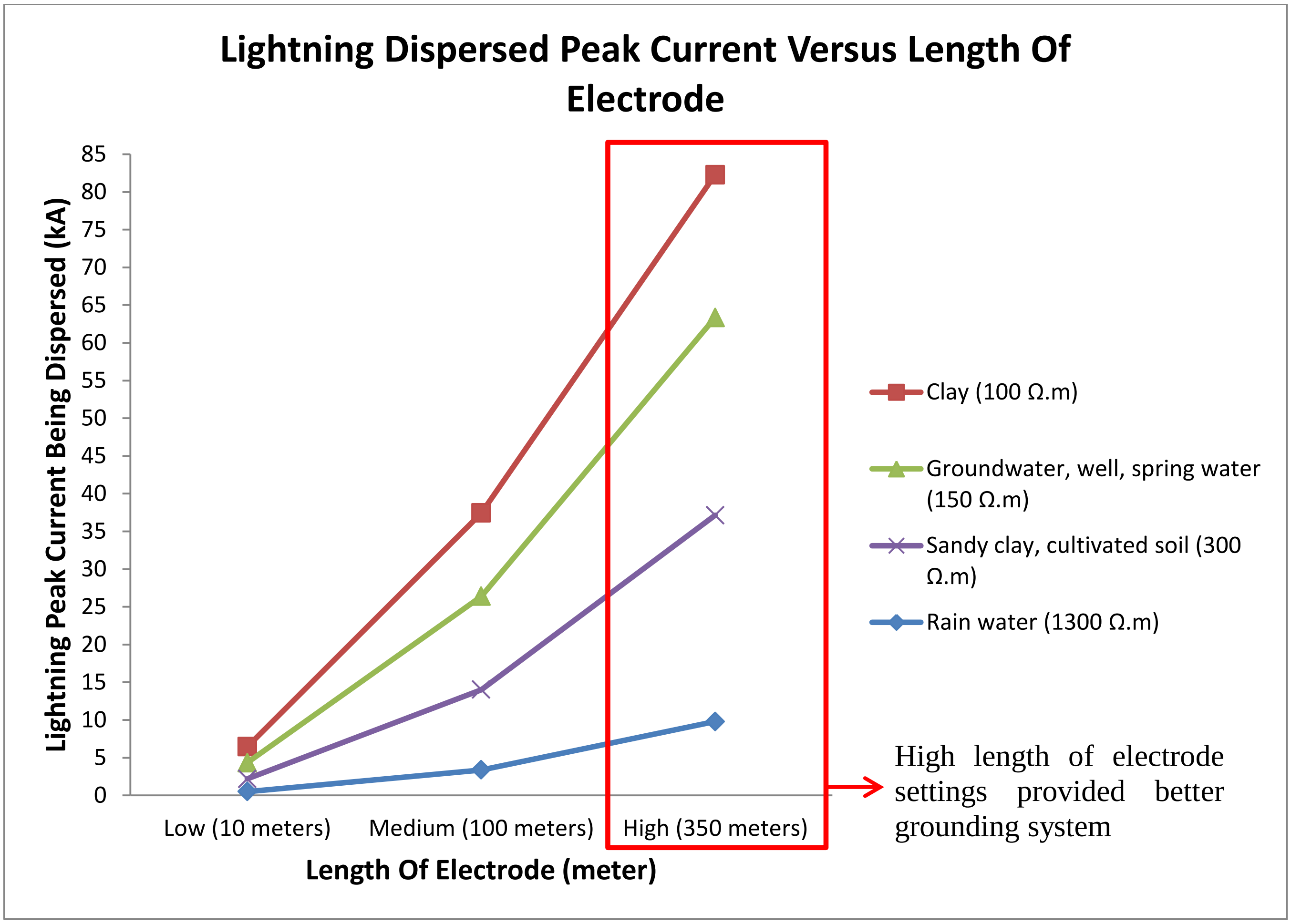


Figure 25: Lightning peak current being dispersed versus length of electrode

Figure 25 shows that the relationship between the lightning dispersed peak current and length of electrode. The resistivity (Ω.m) value is depending on the type of soil or water. The highest magnitude of lightning dispersed peak current for all types of item provided in the analysis is provided by the high length of electrode (350 meters) settings. The lowest magnitude of the lightning dispersed peak current is provided by the low length of electrode (10 meters) settings. Therefore, the amount of magnitude of the lightning dispersed peak current is proportionally increased with the length of electrode. Hence, the lower value of grounding impedance will make the amount of magnitude of the lightning dispersed peak current higher. In another word, the lower value of grounding impedance will make the grounding system better.

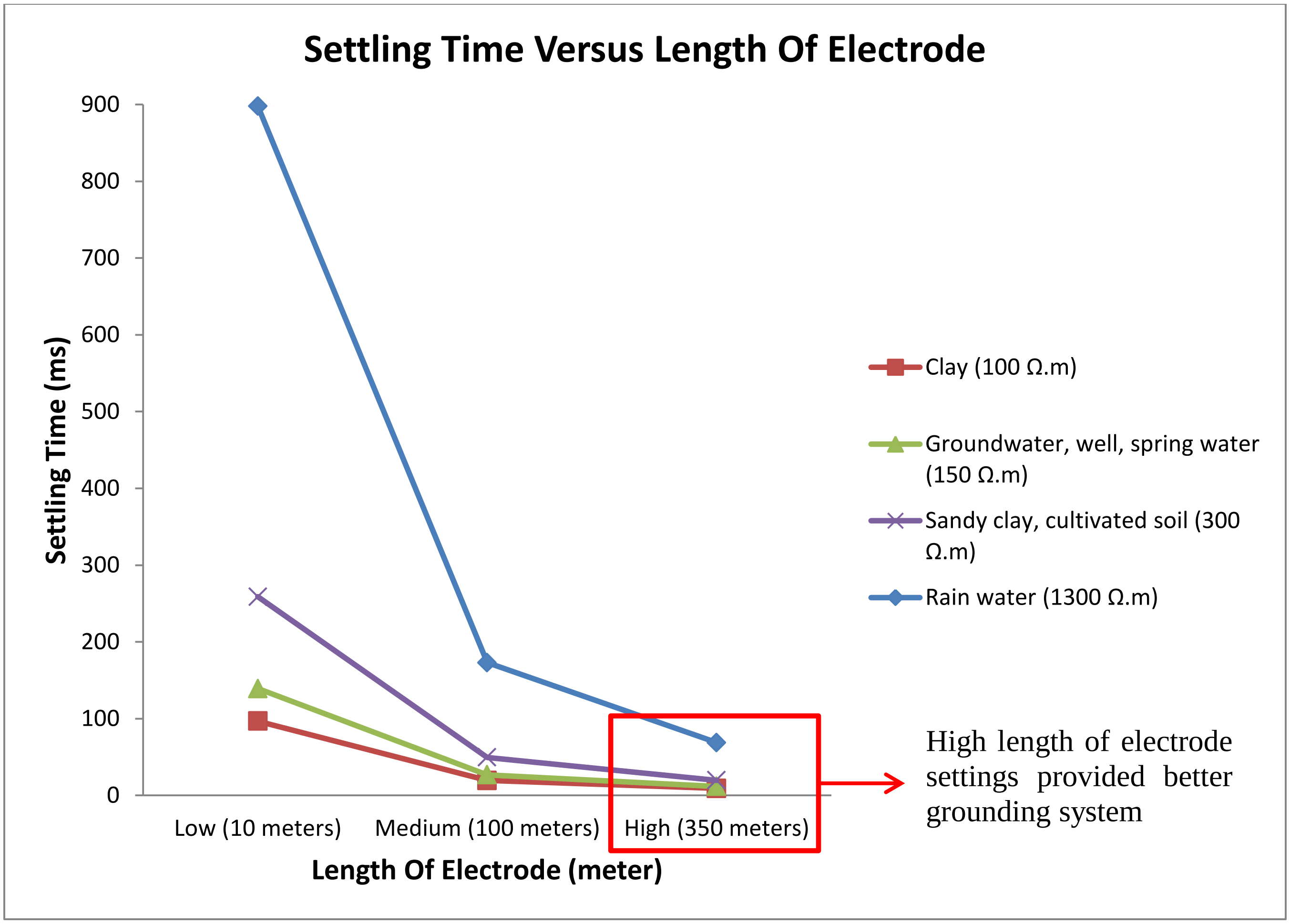


Figure 26: Settling time versus length of electrode

Figure 26 shows that the relationship between the settling time and length of electrode. The resistivity (Ω.m) value is depending on the type of soil or water. For all types of item provided in the analysis, the settling time for completely dispersed lightning current will become faster when the high length of electrode (350 meters) settings is used. The settling time for completely dispersed lightning current will become slower when the low length of electrode (10 meters) settings is used. Therefore, the settling time for completely dispersed lightning current is proportionally inversed with the length of electrode. Hence, the lower value of grounding impedance will make the settling time for completely dispersed lightning current faster. In another word, the lower value of grounding impedance will make the grounding system better.

From the result, in order to produce the grounding impedance smaller than 10 Ω (as recommended by the general principle of lightning protection system), the resistivity of items and the length of electrode need to be considered. The lower grounding impedance will make the grounding system performances better. It is because when the lower grounding impedance is used, the magnitude of dispersed lightning peak current becomes higher. Also, the smaller grounding impedance will make the settling time for completely dispersed lightning current becomes faster.

CHAPTER 5

CONCLUSION

This project has produced the result based on the simulation about the lightning protection system based on International Electrotechnical Commission (IEC 61024-1) standard. The results can be summarized as follows:

1) In general concept of lightning protection system, the lightning vertical rod optimum length is should be the same with the striking distance.
2) The striking distance will become extending when the magnitude peak current of lightning strikes get bigger. This will influence the lightning safety distance to become larger and the specific object remains safely.
3) The lower grounding impedance can be produced by having lengthier distance of grounding electrode and lower resistivity in the soil or water. Hence, the lower grounding impedance can make the grounding system performances become better.

The new LPS configuration is designed with the improvement of lightning interception efficiency increase to 8 %. The maximum boundary of new LPS configuration is based on the maximum distance of striking distance. It is found that the new lightning safety distance between tower and satellite dish with level 1 type of lightning protection should be reduced by 62.43 % from the existing distance. The grounding impedance that has been reduced to 99.97 % will improve the lightning peak current being dispersed by 96.69 %. Meanwhile, the settling time for totally dispersed lightning strikes current will improve by 97.59 %.

However, the new LPS configuration needs to be tested first in order to ensure that it is successfully working. The evaluation can be conducted by using smaller scales of the real application of model in the high voltage laboratory with appropriate equipment. The area of intercepting the lightning stepped leader current might become wider if the height of vertical lightning rod is higher than the striking distance. Therefore, the evaluation on those criteria should be discovered.

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APPENDIX A:

M-File Matlab Programming For Lightning Safety Distance In Part 1

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%input data prompt
ip=input('LIGHTNING STRIKES PEAK CURRENT (FOR PROTECTION LEVEL 1 <=2.9)
(KA) = ');%strike current
h1=input('HEIGHT OF ROD (METERS) = ');%height of rod
h2=input('HEIGHT OF OBJECT (METERS) = ');%high of object
width=input('WIDTH OF OBJECT (METERS) = ');%width of object
length=input('LENGTH OF OBJECT (METERS) = ');%length of object
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%lightning rod
r=0;
[X,Y,Z] = cylinder(r);
X=X;
Y=Y;
h=h1-1;
z=Z+h;
z(1,:)=z(1,:)-h
surf(X,Y,z,'LineWidth',4)
hold
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%output level protection
if ip<=2.9
LIGHTNING_LEVEL_PROTECTION = 1;
display(LIGHTNING_LEVEL_PROTECTION);
elseif ip<=5.4
LIGHTNING_LEVEL_PROTECTION = 2;
display(LIGHTNING_LEVEL_PROTECTION);
elseif ip<=10.1
LIGHTNING_LEVEL_PROTECTION = 3;
display(LIGHTNING_LEVEL_PROTECTION);
elseif ip<=15.7;
```

```
LIGHTNING_LEVEL_PROTECTION = 4;
display(LIGHTNING_LEVEL_PROTECTION);
else
LIGHTNING_LEVEL_PROTECTION = N/A;
display(LIGHTNING_LEVEL_PROTECTION);
end
s=10*(ip^0.65);
display(s);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if h1>s
s_meters=10*(ip^0.65);
AH2= (s_meters*2*h2)-(h2^2);
AH1= s_meters^2;
AH= 1-((AH2/AH1)^0.5);
TOTAL_HORIZONTAL_PROTECTION=s_meters;
SAFETY_RADIUS_FOR_OBJECT=TOTAL_HORIZONTAL_PROTECTION*AH;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%start simulation
a=0; % coordinate x for rod
b=0;% coordinate y for rod
[lat,lon] =
SCIRCLE1(a,b,SAFETY_RADIUS_FOR_OBJECT);%%%%%%%%%%%%%%%%%%%%Ro
[lat3,lon3] =
SCIRCLE1(a,b,TOTAL_HORIZONTAL_PROTECTION);%%%%%%%%%%%%%%%%%Rg
plot(lat3,lon3,'black','LineWidth',2)
display(TOTAL_HORIZONTAL_PROTECTION);
display(SAFETY_RADIUS_FOR_OBJECT);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%total area of object
a=0; % coordinate x for rod
```

```
b=0;% coordinate y for rod
width1=width/2;
length1=length/2;
RADIUS_OF_OBJECT=((width1^2)+(length1^2))^0.5;
[lat2,lon2] = SCIRCLE1(a,b,RADIUS_OF_OBJECT);
plot(lat2,lon2,'','LineWidth',2)
display(RADIUS_OF_OBJECT);
if TOTAL_HORIZONTAL_PROTECTION > SAFETY_RADIUS_FOR_OBJECT
if SAFETY_RADIUS_FOR_OBJECT > RADIUS_OF_OBJECT
%data for circle
plot(lat,lon,'r','LineWidth',2)
disp('OBJECT IS COMPLETELY PROTECTED BY ROD');
else
%data for circle
plot(0)
disp('SYSTEM FAILED')
end
else
%data for circle
plot(0)
disp('SYSTEM FAILED')
end
else if h1<=STRIKING_DISTANCE
s_meters=10*(ip^0.65);
AH2= (s_meters*2*h2)-(h2^2);
AH1= (s_meters*2*h1)-(h1^2);
AH= 1-((AH2/AH1)^0.5);
```

```
TOTAL_HORIZONTAL_PROTECTION=AH1^0.5;
SAFETY_RADIUS_FOR_OBJECT=TOTAL_HORIZONTAL_PROTECTION*AH;
%start simulation
a=0; % coordinate x for rod
b=0;% coordinate y for rod
[lat,lon] = SCIRCLE1(a,b,SAFETY_RADIUS_FOR_OBJECT);
[lat3,lon3] = SCIRCLE1(a,b,TOTAL_HORIZONTAL_PROTECTION);
plot(lat3,lon3,'black','LineWidth',2)
display(TOTAL_HORIZONTAL_PROTECTION);
display(SAFETY_RADIUS_FOR_OBJECT);
%total area of object
a=0; % coordinate x for rod
b=0;% coordinate y for rod
width1=width/2;
length1=length/2;
RADIUS_OF_OBJECT=((width1^2)+(length1^2))^0.5;
[lat2,lon2] = SCIRCLE1(a,b,RADIUS_OF_OBJECT);
plot(lat2,lon2,'','LineWidth',2)
display(RADIUS_OF_OBJECT);
if TOTAL_HORIZONTAL_PROTECTION > SAFETY_RADIUS_FOR_OBJECT
if SAFETY_RADIUS_FOR_OBJECT > RADIUS_OF_OBJECT
%data for circle
plot(lat,lon,'r','LineWidth',2)
disp('OBJECT IS COMPLETELY PROTECTED BY ROD');
else
%data for circle
plot(0)
```

```
disp('SYSTEM FAILED')
end
else
%data for circle
plot(0)
disp('SYSTEM FAILED')
end
end
```