DEVELOPMENT OF A SOFTWARE TO DESIGN LIGHTNING PROTECTION SYSTEM ON TRANSMISSION LINE

By

NUR SYAHIRAH BINTI NAZRI

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Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

_____

(Dr. Mohd Fakhizan bin Romlie)

Project Supervisor

Universiti Teknologi PETRONAS

Tronoh, Perak

September 2015

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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NUR SYAHIRAH BINTI NAZRI

ABSTRACT

Lightning Protection System (LPS) is a system to protect equipment, building, power plant, or transmission line from a lightning strike. Transmission line on the other hand is a line carrying high voltage AC current from a generating power plant to a distribution subsystem. A LPS on transmission line act to protect the transmission line from lightning strike which can result in flashover. But not many people are familiar with the design of LPS on transmission line. Therefore, the purpose of this project is to develop a software that will help ease the designing for installation of LPS on transmission line. Some literature review were done before the development of the software started. The main reference for this project is IEEE Std 1243 – 1997: Guide for Improving Lightning Performance of Transmission Line and IEEE Std C62.22: Guide for the Application of Surge Arrester for AC System. After all the parameters and data for the designing of LPS is gathered, next step is selecting a suitable tool for the development of the software. The best tool chosen that has all the criteria needed including a user-friendly tool is Microsoft Office Excel 2013. The software contains all the collected parameters, data, and equation needed for the calculation in designing a LPS on transmission line. There are several main parts in designing LPS for transmission line which are the grounding, shielding angle, and the selection of suitable surge arrester. The shielding angle calculation helps for the direct strike of the lightning and the surge arrester helps for the indirect strike of the lightning on transmission line. On the other hand, grounding helps to reduce the effect of flashover occurs on the tower by directing the over-voltages on the transmission line to the ground. User will insert some data into the software and click on the button provided for automatic calculation and result. The reliability of the calculation from the software is checked and ensured to be 100% correct.

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

LPS   Lightning Protection System

IEEE   Institute of Electrical & Electronics Engineering

OHGW   Overhead Ground Wire

CHAPTER 1: INTRODUCTION

1.1   Background of Study

Lightning is a deadly natural phenomenon that known for its beauty and hazards to mankind. Lightning is a high voltage discharge that could happen in the clouds, between two clouds, or even between the clouds and the ground (earth). Primarily, lightning can occurs when warm air masses are mixed and collide with cold air masses, thus results in atmospheric disturbances. Lightning is mostly produced by cumulonimbus clouds.

Statistic shows that South East Asia is among the most occurrences of lightning flash, which includes Malaysia. There are several factors that affect lightning frequency in particular regions. Some of them are:

- Ground elevation,
- Latitude,
- Prevailing wind current,
- Humidity,

The effects of lightning strike are known for its cruelty. If a lightning strikes a tree, it may vaporize the tree sap which causes a steam explosion and thus blow out the tree. Besides that, if a lightning strikes the earth's ground in which case, it hit the soil; it may melt the soil and form fulgurites. Humans or animals that get stroke by a lightning may suffer from severe internal injuries and body system damage.
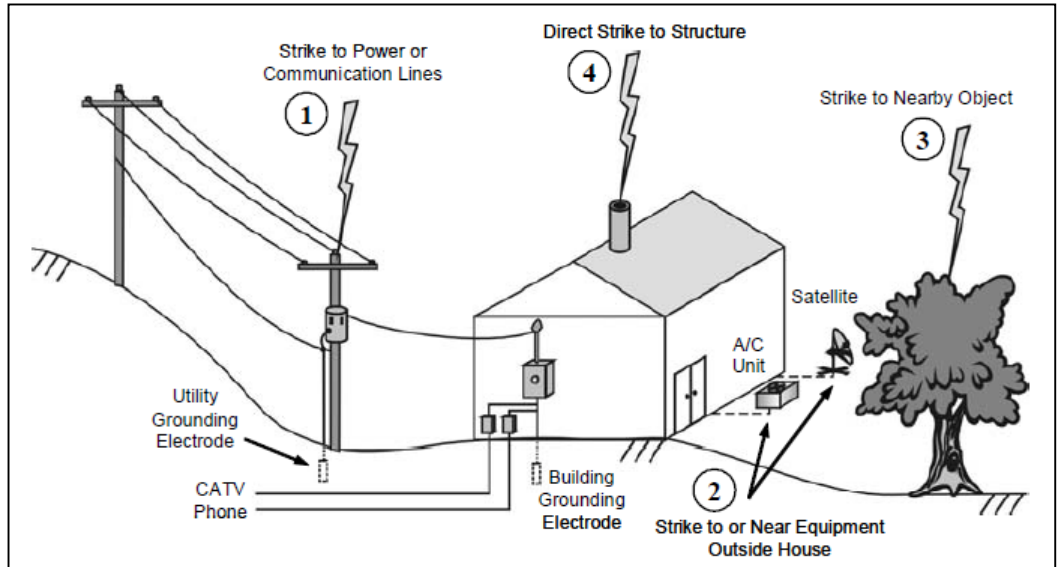
Figure 1. Damages of lightning strikes to objects [13]

Lightning Protection System (LPS) is a system designed specifically to protect equipments, building, plants, and even transmission lines from the lightning strike as it may results in fire or active lightning current. There are several standards available for different types of equipment and conditions. For this project, the focus will be mainly on the lightning protection systems for the transmission lines

The lightning incidents on transmission line are not a new case for all power distributors. With the modernization of nowadays world, the transmission line is often built and construct in an urban area which can attract the lightning flash. Tenaga Nasional Berhad (TNB) itself said that transient tripping in its transmission and distribution network due to lightning strike range about 50 to 60 percent [2]. The most common use of lightning protection system on a transmission line is the surge arrester and lightning rod.
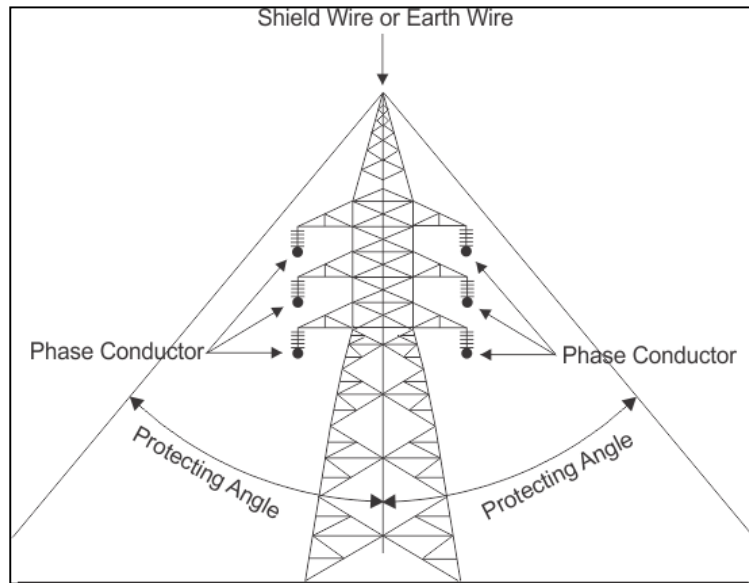
Figure 2. Lightning Protection System on Transmission Line [9]

1.2　　Problem Statement

Malaysia is a country located on the equator of the earth and has a tropical rainforest climate. Because of this, Malaysia has always been strike by lightning. Malaysia Meteorological Service state that thunderstorm in Malaysia occurs around 200 days per year. High voltage transmission line does not excluded from being the victim of the lightning strike. When a lightning strike the transmission line, a flashover will occur which results in the line failure.

There are two reasons a failure can occur from the lightning strike which are from the direct strike and the indirect strike. The direct strike occurs when a lightning flash directly strike a transmission tower and cause flashover. The indirect strike occurs when the lightning flash strike on the line of the transmission tower which causes surge in the line voltage and thus, causes a flashover. Every time a failure occurs on the transmission line, the maintenance cost is highly expensive because of the equipment, the dangers, and also the accessibility of the area especially the terrain of a hillsides.

Therefore, avoiding a transmission line failure due to lightning flash would be a better and significant way. To do that, a lightning protection system is installed on the transmission line tower. For a direct strike, overhead ground wire (OHGW) on the top of the tower should be installed. For an indirect strike, a surge arrester should be installed on the transmission line tower to help reduce the effects of voltage surge by channelling it to the ground.

Before those two method can be installed, a thorough calculation and observation on the surrounding of the installation area should be checked. Several calculations should be made by following to the standards made by several organizations such as National Fire Protection Association (NFPA) and Institute of Electrical and Electronics Engineers (IEEE). But, to read through all the available standards will take a lot of time and too much parameters and equations to be noted. Therefore, a lightning protection system on transmission line software is designed to help lessen the burden. All the parameters and equations will be kept inside the software and user only have to enter several important data before any results of the design can be executed.

1.3   Objectives and Scope of Study

The objective of this project is to design a software that will help in designing a Lightning Protection System for the transmission lines. The users will be asked to enter several data before information or suggestion on the design can be executed. Besides that, this project also intends to help lessen the user burden to read through all the parameters and equation according to the standards by collect, gather and keep all those information into the software. Therefore, a shorter time is needed to design a lightning protection system on high voltage transmission line.

CHAPTER 2: LITERATURE REVIEW

Lightning protection systems are first invented and pioneered by Benjamin Franklin which is known as the lightning rod. The main function of the lightning protection system is to capture and divert lightning current safely from a structure and bring it safely to be discharge to the ground.

The decisions to install a protection system are based on the follows:

- The area whether it is urban or open field,
- The average density of ground flash,
- Total cost loss during a breakdown period,
- Total cost of maintenance,
- Insurance company's requirements.

There are four POINT Enhanced Lightning Protection Systems which are Structural Lightning Protection System, Lightning Protection on Power Line point-of-entry, Lightning Protection on Communication and Signal Line point-of-entry, and Lightning Protection at the point-of-use of critical electronic equipment. Structural Lightning Protection System is where the protection system is in a structural flow. When a lightning strikes, it will reach the air terminal and then flows through the down conductor to the grounding system of the building.

Meanwhile, the Power Line point-of-entry protection is where it uses external wiring which will capture most of the lightning currents and releases them to the grounding system of the building. Advantages of this protection is that it can limits the lightning voltages entering the building and hence, reducing the damage to the equipments. Communication and Signal Line point-of-entry protection uses the same principal as Power Line point-of-entry protection systems. On the other hands, the last enhanced

lightning protection systems are point-of-use of critical electronics equipments. This system functions as the last steps of protection for most of the electronics equipments such as air conditioners, gate control systems and others.

In a transmission line, lightning itself has been a major problem for the interruptions of power. Tenaga Nasiaonal Berhad, TNB is among the main power utility in Malaysia. Lightning strike has causes approximately 50 to 60 percent of transient tripping in TNB's transmission and distribution lines. Normally, when choosing a routing line, designer tends to choose lines through a valley, on top of a mountain, or at the side of a mountain. These routes may be exposes to the lightning strikes mainly due to two reasons which are the exposure of a line to the lightning and the soil sensitivity itself. There are several factors that affect lightning exposure on a transmission line which are structure height, soil resistivity, shielding angle, and also the insulation. Lightning incident on transmission line can causes by a direct strike or indirect strike. Direct strike occurs when a lightning flash strikes on the transmission tower or pole, while indirect strike occurs when a lightning flash strikes on the transmission line.

2.1   Structure Height

The transmission line tower's structure affects the line road of a transmission line. If a tower height is increased, there are two effects which are more flashes will occur at higher tower, and the shielding characteristic especially at the overhead conductor changes.

i)   Mean Conductor Height

To get the mean conductor height, Hg, it can be computed from the profile Drawings or by using estimation for preliminary purpose.

$$Hg = Hgt - \left(\frac{2}{3}\right)(Sc)$$

Hgt = height of conductor at the tower,

Sc = sag of the conductor,

For rolling profile;

$$Hgr = Hgt$$

For Mountaneous profile;

$$Hgm = 2Hgt$$

For all cases;

$$Hg = Hp + \Delta$$

ii) Mean Spacing

Apart from that, the mean spacing between the shield wire and the phase conductor can be calculated approximately from a preliminary outline.

$$C = \frac{U\ (50\%)}{145m}$$

U (50%) = critical impulse flashover voltage of the insulation (kV)
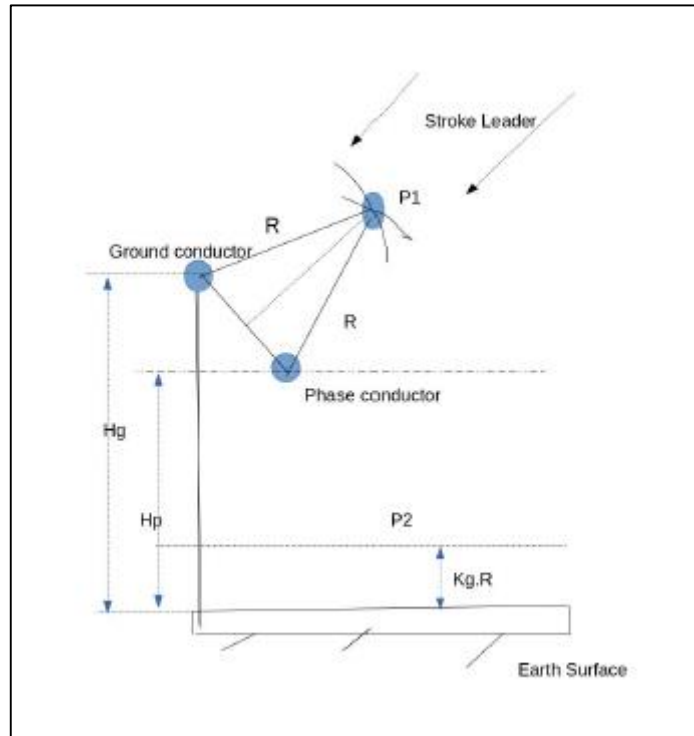
Figure 3. Analytical model of transmission line

iii)   The Striking Distance

Striking distance that will be use is the value of the prospective current to earth

$$R = 10Ip^{0.65}$$

$$Ioc = \frac{2.2\ U\ (50\%)}{Zck\ A}$$

Zc = conductor's surge impedance in the presence of the shield wires (ohm)

According to transmission line protective theory, both Ground wire and Phase conductor yields protective arc around them which cuts one another in space at terminating point. This termination point could be a phase conductor, a ground wire, the ground or the metal tower. To determine the termination point, an electro-geometrical model theory is used with a known striking distance.

$$r = A.i^b$$

$$r = \text{striking distance (m)}$$

where A and b are constants.

iv)   Co-ordinates of Point P1 and P2
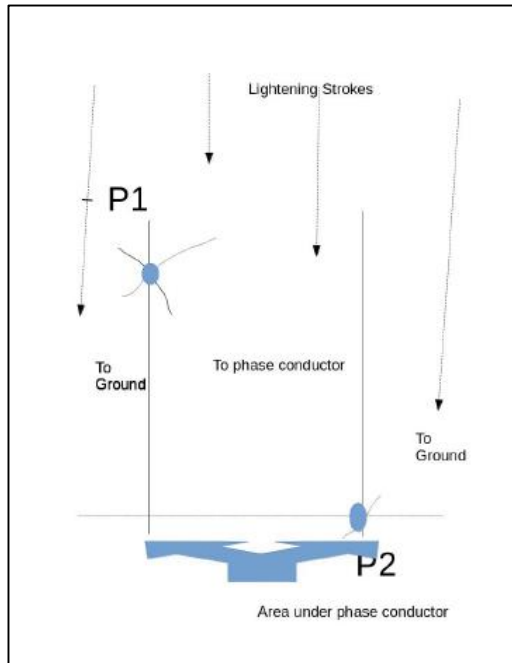
Figure 4. Area of region showing immerging lightning stroke

Based on figure above, it shows the various striking position of leader. There are two points which are P1; the phase conductor and P2; area under phase conductor. If the lightning stroke flash and strike before point P1, it will goes to the ground wire and hence the transmission line is saved. The same goes if the lightning strikes area after point P2 where the flash will goes to the ground and the transmission line is saved. But, if the lightning strikes between points P1 and P2, it will immerges directly to the phase conductor and hence damaging the transmission line.

v)   Flashover

The equation for the flash collection rate is as below:

$$N_s = N_g \left(\frac{28\,h^{0.6} + b}{10}\right)$$

h = height of the tower, m

b = Overhead ground wire (OHGW) separation distance, m

N_g = Ground flash density (GFD), flashes/km^2/year

N_s = flashes/100 km/year

$N_g = 0.04\,T_d^{\,1.25}$

$N_g = 0.04\,T_h^{\,1.1}$

T_d = thunderstorm frequency, days/year

T_h = thunderstorms frequency, hours/year

2.2   Soil Resistivity

The second factor is soil resistivity. A high amount of voltages are generated on the ground when a lightning strikes the structure or overhead ground wire. The higher the structure footing impedance, the higher the voltage, thus more lightning outage for every lightning exposure. In order to achieve the right footing impedance, the line design must specify the size and type of the ground electrode used. These will depend on the soil conductivities at the installation site. A rocky terrain which is usually found at the top of a mountain or the hill side has high footing impedances. In order to decrease the value,

the grounding should be improved. This can be done by using radial-crowfoot or large ring installation.

2.3   Shielding

Shielding is mainly made from shield wire and sometimes from static wire. The function is to shield and protect the phase conductor from a direct lightning flash. The shielding angle in determined by the placement of the overhead ground wire. The lower the height of transmission line, the lower the value of the shielding angle.
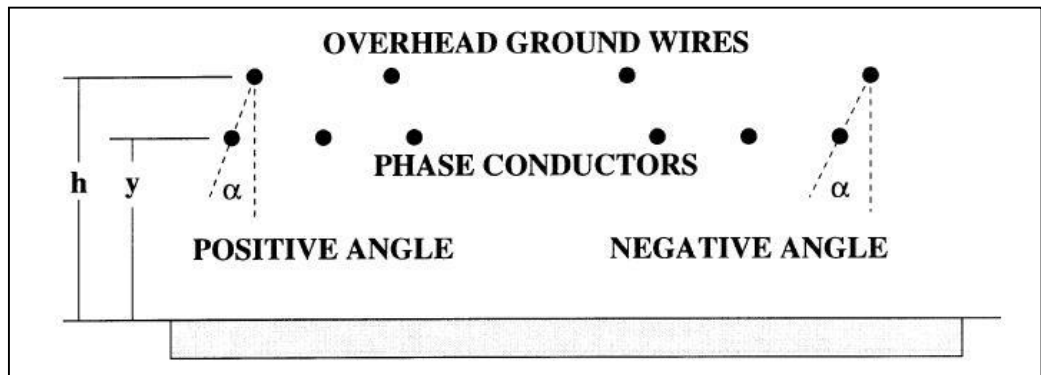
Figure 5. Shielding angle [4]

The overhead ground wire should be strong enough to withstand the high amount of current whenever a lightning stroke occurs. The factors that influence the size of the overhead ground wire are the value of current for every lightning flash, the system fault current and the possibility of supporting a fiber optic cable.

Table 1. DC resistance of typical Overhead Ground Wire [4]

Diameter	Description	Resistance (Ω/km)
7.9 mm (0.31 in)	Galvanized steel	4.7
9.5 mm (0.37 in)	Galvanized steel	4.0
12.7 mm (0.50 in)	Galvanized steel	2.5
7.8 mm (0.31 in)	7 #10 aluminum-clad steel	2.3
9.8 mm (0.39 in)	7 #10 aluminum-clad steel	1.5
11.0 mm (0.43 in)	7 #10 aluminum-clad steel	1.2
14.0 mm (0.55 in)	4/0 American Wire Gage (AWG) (6/1) Aluminum conductor, steel rein-forced (ACSR)	0.26
18.3 mm (0.72 in)	336 kcmil (26/7) ACSR	0.17

Calculations for analytical model structure is as below:

$$\Delta = Hg - Hp$$

Hg = height of ground wire from earth,

Hp = height of phase conductor from the earth

To calculate co-ordinates, geometrical methods in triangle ABC is applied.

$$AB = Hg - Hp$$

$$BC = \Delta\tan(\theta)$$

where θ is the shielding angle between the phase conductor and the ground wire. Thus, by using Pythagoras theorem,

$$AC = \sqrt{\Delta^2 + (\Delta^2 tan^2(\theta))} = \Delta\sec(\theta)$$

Therefore, the co-ordinates of the phase conductor and ground wire are

$$A(0,Hg)$$

and,

C(Δtan(θ),Hp)
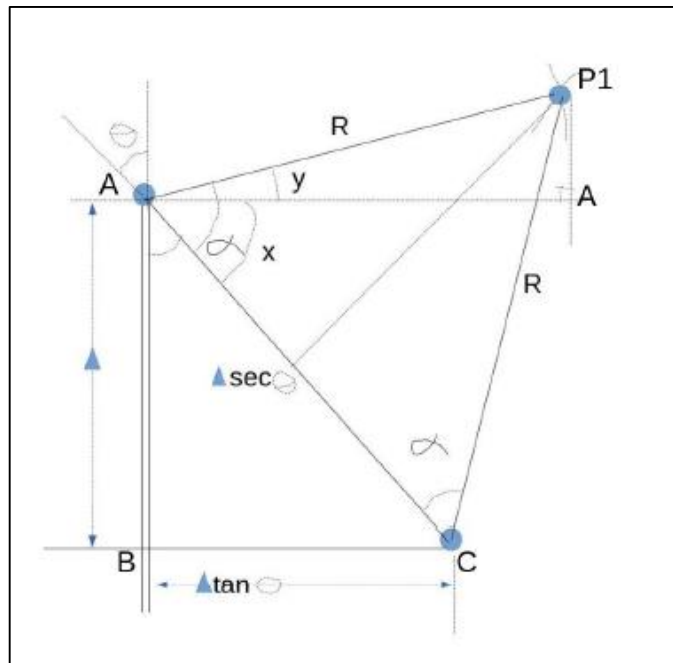
Figure 6. Co-ordinate P1

To find co-ordinates P1 based on figure above,

$$\alpha = \angle y + \angle X$$

$$cos(\alpha) = \frac{(\Delta/2 * sec(\Theta))}{R}$$

$$therefore...\alpha = cos^{-1}(\frac{(\Delta/2 * sec(\Theta))}{R})$$

$$\alpha = y + x$$

$$\alpha = 90 - (\Theta - y)$$

$$\alpha = cos^{-1}(\frac{(\Delta/2 * sec(\Theta))}{R}) = (90 - (\Theta - y))$$

$$(\frac{(\Delta/2 * sec(\Theta))}{R}) = cos(90 - (\Theta - y))$$

$$(\frac{(\Delta/2 * sec(\Theta))}{R}) = sin(\Theta - y))$$

$$sin^{-1}(\frac{(\Delta/2 * sec(\Theta))}{R}) = (\Theta - y))$$

$$y = (\Theta - sin^{-1}(\frac{(\Delta/2 * sec(\Theta))}{R}))$$

Therefore, value of P1 is:

$$P1(R\cos(\theta), Hp + R\sin(\theta))$$

To find co-ordinates P2 by using generalized circle equation,

$$(x - x1)^2 + (y - y1)^2 = R^2$$
$$y = KgR$$
$$y1 = Hp$$
$$x1 = (\Delta \tan(\Theta))$$

Therefore, value of P2 is:

$$P2(\sqrt{R^2 - (KgR - Hp)} + (\Delta \tan(\theta)), KgR)$$

2.4   Insulation

The insulator may experience flashover due to lightning. There are two types of flashover which are backflash and shielding failure. A backflash is where interception of lightning flash by the tower. Meanwhile the shielding failure happen when a direct lightning flash hit the phase conductor. Besides that, there are other three main reasons that affect the flashover of a insulation which are the voltage waveshapes, the insulator characteristics, and the power frequency component of the insulator.

2.5   Lightning Surge Arrester
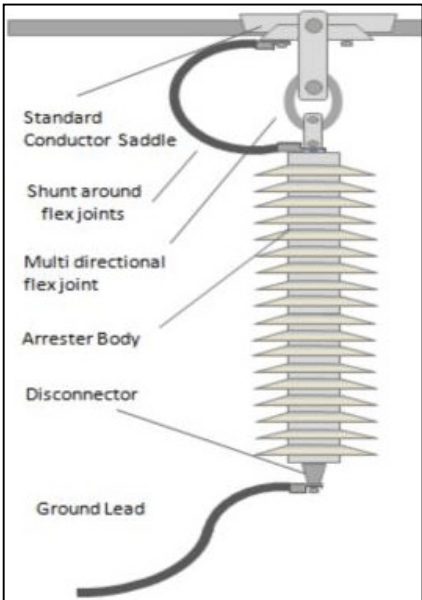
Figure 7. Lightning Surge Arrester [20]

Figure 8. Lightning Surge Arrester
on Transmission Line

Surge arrester is a common insulator used in transmission line to capture and reduce the damage due to lightning strike on a transmission line. To choose the right surge arrester, some aspect has to take into account such as the voltage of the transmission line.
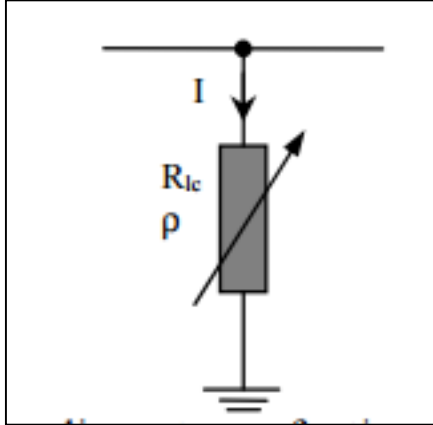
Figure 9. Model for Non-Linear Tower Footing
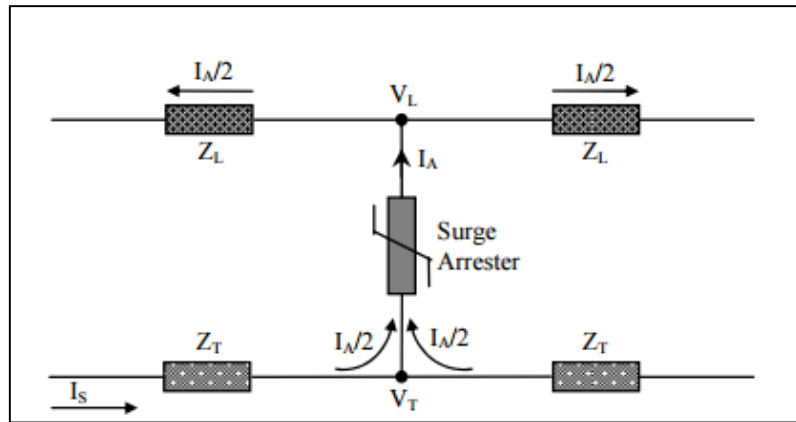
Figure 10. Equivalent circuit of an arrester

$$V_T = (I_S - \tfrac{I_A}{2}) - Z_T$$

$$VL = \left(\tfrac{I_A}{2}\right) - Z_L$$

Z_T = Tower surge impedance,

Z_L = Line surge impedance,

I_S = Stroke current,

I_A = Arrester current

Based on Figure 6 and Figure 7 respectively, it shows a non-linear tower footing model and the arrester's equivalent circuit. A different model will be used for different voltages of lightning strike on the transmission line. There are two parameters influence on the designing of the arrester which are lightning stroke parameter and the line parameter. Table 2 shows the arrester failure on 35 km line.

Table 2. Failure Performance of Arrester in 35 km Line (per year basis)

Direct strikes per year = 3.704 Arrester failure per year = 0.128			
Arrester Failure by Phase			
Phase	Direct Strikes	Failure From		
		Shield Strikes	Phase Strikes	All Strikes
A_1	0.269	0.000	0.065	0.065
B_1	0.000	0.000	0.000	0.000
C_1	0.000	0.000	0.000	0.000
C_2	0.269	0.000	0.065	0.065
B_2	0.000	0.000	0.000	0.000
A_2	0.000	0.000	0.000	0.000

CHAPTER 3: METHODOLOGY

Throughout this project execution, there are three phase of methods done which are literature review, data collection, and lastly, design and simulation.

3.1 Literature Review

1. Standards Review

- All the materials are obtained from the internets.
- Consist of different standards and modifications done by scholars.

2. Search through internet about relevant standards of lightning protection system on transmission lines

- Research papers are obtained from the internet
- Research papers are obtained from IEEE and DirectScience website

3. Review on the incidents regarding lightning on transmission lines

- Some research and reading are done through the internet.

3.2 Data Collection

1. Identify the types and status of transmission line (the locations, height), calculations, formulae and the parameters to design the software.

- Some readings are done through the internet
- Readings through the standards
  - i)   IEEE Std 1243 – 1997

    ii) IEEE Std 1410 – 2010

    iii) NFPA 780

- Consult with the supervisor

2. Identify the suitable lightning protection system to be used

- Analysis is done based on the data obtained through the readings from the journals
- Consult with the supervisor

3.3 Develop the tools by using Visual Basic Application in Microsoft Excel

The designing of the lightning protection system for transmission line software is done entirely by using Visual Basic Application (VBA) in Microsoft Office Excel. Before the development is started, all the information regarding the designing which includes the calculations, formula, and parameters is gather and collected first. All the formula and calculations use for the software is obtain from the IEEE Standards and its reliability is ensure.

Then, a first draft of the software is made. The software is divided into parts of different sheets according to their functions. Users need to enter several data into the software. To execute the results, user needs to click on the button provided and the results will be shown on the blue coloured boxes. The results of the automatic calculation is compared with a manual calculation to ensure its reliability and accurateness.

3.4   Project Flow

```
        ┌─────────────────────────────────┐
        │   Confirmation of Project Title  │
        └─────────────────────────────────┘
                        │
                        ▼
   ┌───────────────────────────────────────────┐
   │  Comparison and classification of different standards │
   │   and functions on lightning protection system  │
   └───────────────────────────────────────────┘
                        │
                        ▼
   ┌───────────────────────────────────────────┐
   │  Understanding on Lightning Protection System for  │
   │            Transmission Line              │
   └───────────────────────────────────────────┘
                        │
                        ▼
   ┌───────────────────────────────────────────┐
   │     Developing a prototype on Lightning     │  ◄──┐
   │          Protection System              │      │
   └───────────────────────────────────────────┘      │
                        │                          │ NO
                        ▼                          │
              ◇ Testing and Troubleshooting       │
                on the prototype  ────────────────┘
                        │
                        │ YES
                        ▼
        ┌─────────────────────────────────┐
        │    Prototype is ready to be use  │
        └─────────────────────────────────┘
```
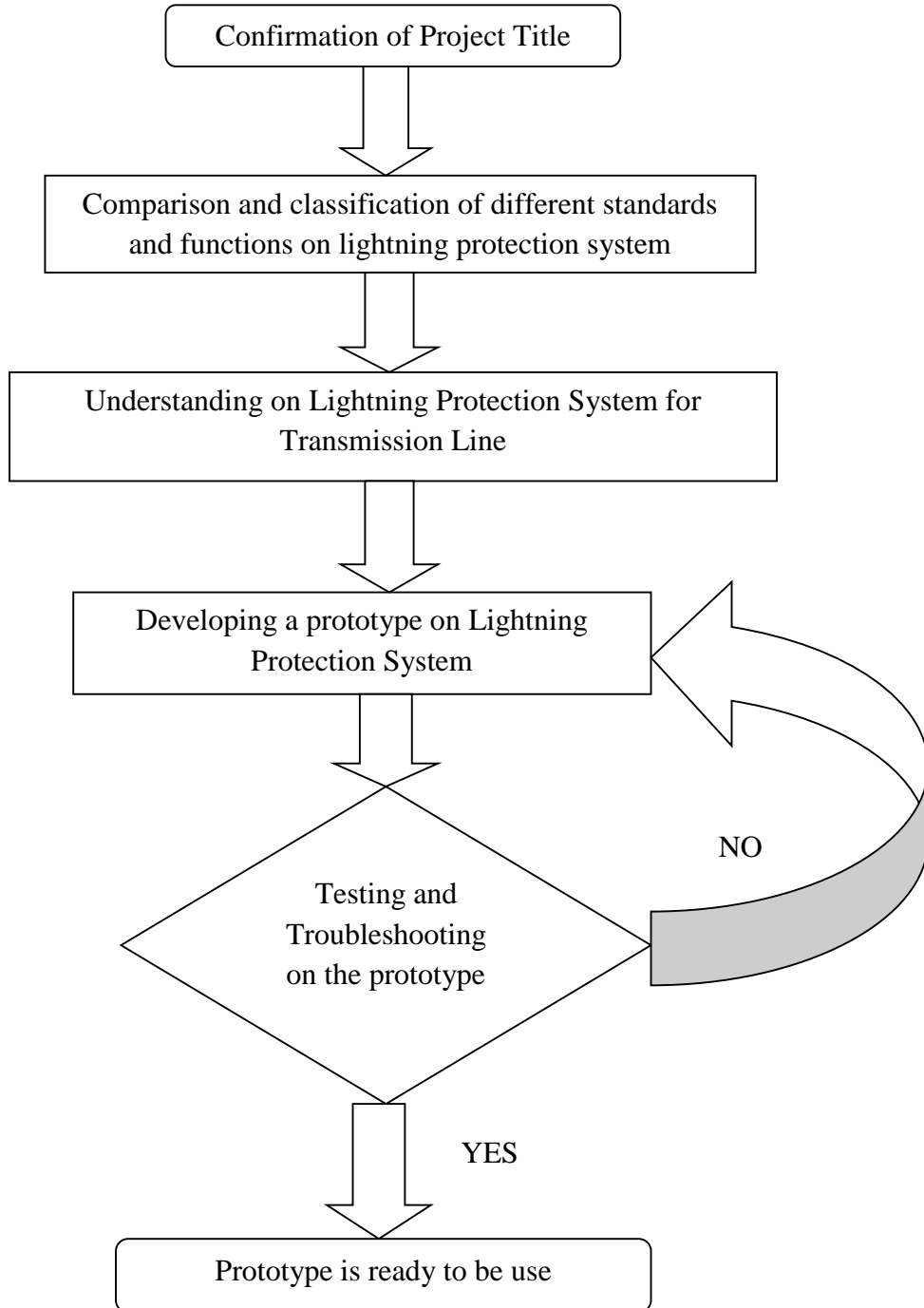
3.5   Flow Chart of the Software

```
                        ┌─────────┐
                        │  Start  │
                        └────┬────┘
                             ▼
        ┌────────────────────────────────────────┐
        │ Calculate Flash Collection Rate        │
        └──────┬─────────────────────────────────┘
               │
               ▼
        ┌────────────────────────────────────────┐
        │ Calculate the lightning performance    │
        └────────────────────────────────────────┘

 ┌──────────────────────────────┐   ┌──────────────────────────────────┐
 │ Calculate the striking distance │  │ Calculate the critical current value │
 └──────────────────────────────┘   └──────────────────────────────────┘

        ┌────────────────────────────────────────┐
        │ Calculate the shielding angle          │
        └────────────────────────────────────────┘

                  ◇ Calculate
                    Ground/Comp          Good
                    osite Line      ──────────►  ┌──────────────────────────┐
                    Performance                  │ No supplemental grounding │
                                                 └──────────────────────────┘

  Poor  ──►  ┌──────────────────────────────────────┐
             │ Supplemental grounding / Counterpoise │
             └──────────────────────────────────────┘

                  ◇ Area with complex      No
                    grounding        ──────────►  ┌──────────────────┐
                                                  │ No complex footing │
                                                  └──────────────────┘

                                 Yes  ──────────► ┌─────────────────┐
                                                  │ Complex footing │
                                                  └─────────────────┘

                  ◇ Bad grounding (Low        No
                    footing impedance/high  ──────────► ┌────────────────────────────┐
                    soil resistivity)                   │ No special grounding effect │
                                                        └────────────────────────────┘

 ┌──────────────────────────────────────────┐       ┌──────────────────────────┐
 │ Select nominal Line-to-Line voltage and mVA │ ──► │ Special grounding effect │
 └──────────────────────────────────────────┘       └──────────────────────────┘
                     │                                   Yes
                     ▼
        ┌────────────────────────────┐
        │ Select class of arrester   │
        └────────────────────────────┘
                     │
                     ▼
  ┌─────────────────────────────────────────────┐
  │ Class arrester characteristics from IEEE Std C62.22 │
  └─────────────────────────────────────────────┘
                     │
                     ▼
                ┌─────────┐
                │  Stop   │
                └─────────┘
```
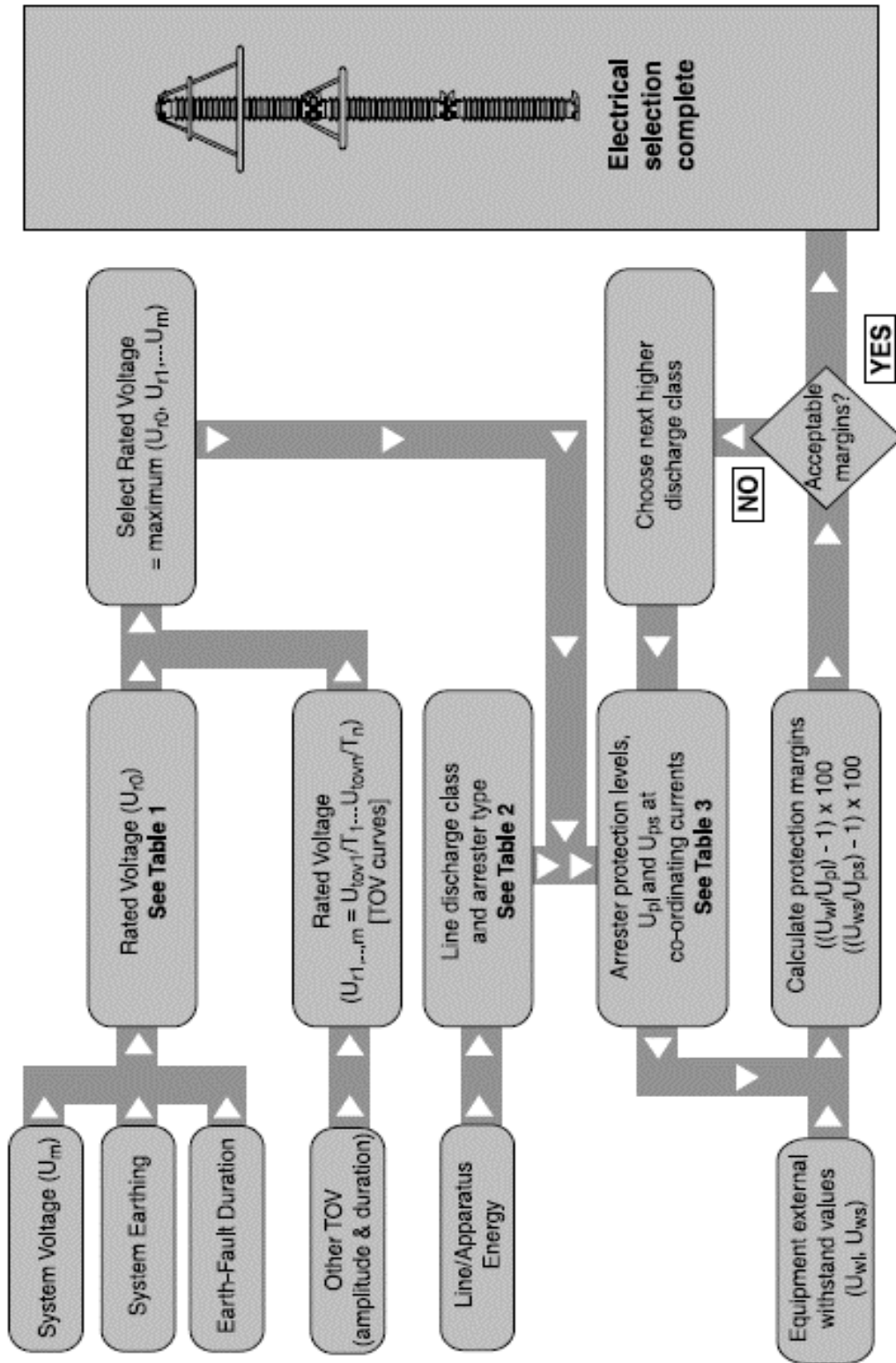
3.6 Flow Diagram for Choosing the Surge Arrester

Figure 11. Flow Diagram in Selecting Surge Arrester [1]

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Construct a designing software using Microsoft Excel
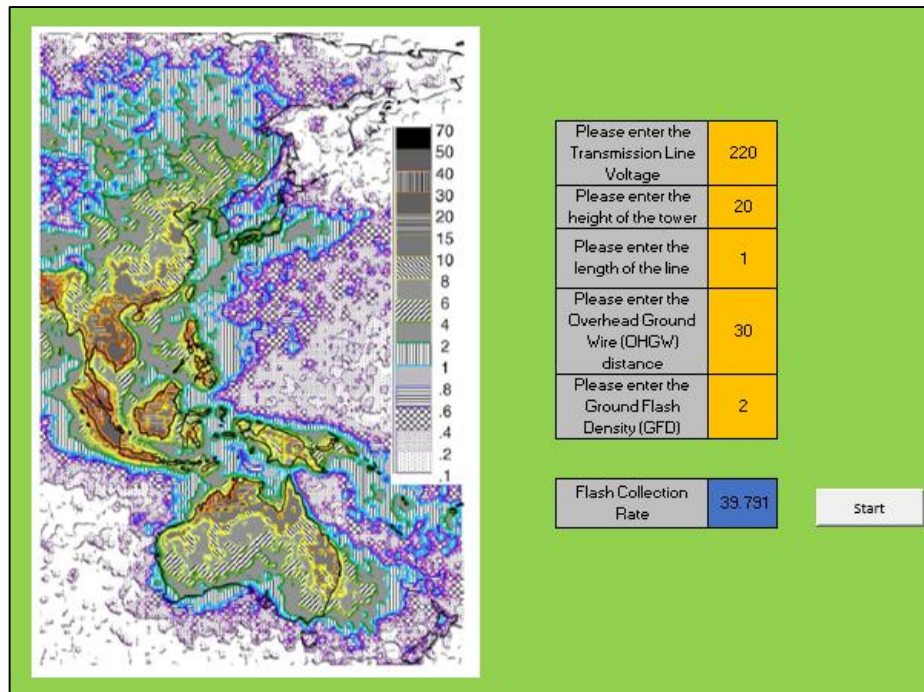
4.1.1 Flash Collection Rate

Figure 12. Flash collection rate worksheet screenshot

The orange coloured box is to be filled by the user and the blue coloured box is the calculated results. For the first step, user needs to fill in the transmission line voltage, height of the tower, length of the line, Overhead Ground Wire (OHGW) distance, and the ground flash density. The value of the ground flash density can be obtained from the keraunic map on the left side of the table.

The ground flash density is the average number of the lightning flashes for every kilometer square in a year for a geographic region. For every geographic region, the number of lightning activity varies. The value of ground flash density is averaged for over ten years. The flash collection rate is the number of lightning flashes for every 100 km in a year. It is depends on the height of the tower, the OHGW separation and the ground

flash density. If the tower height is increased by 20%, the flash collection rate would increase by 12%.

4.1.2   Stroke current analysis
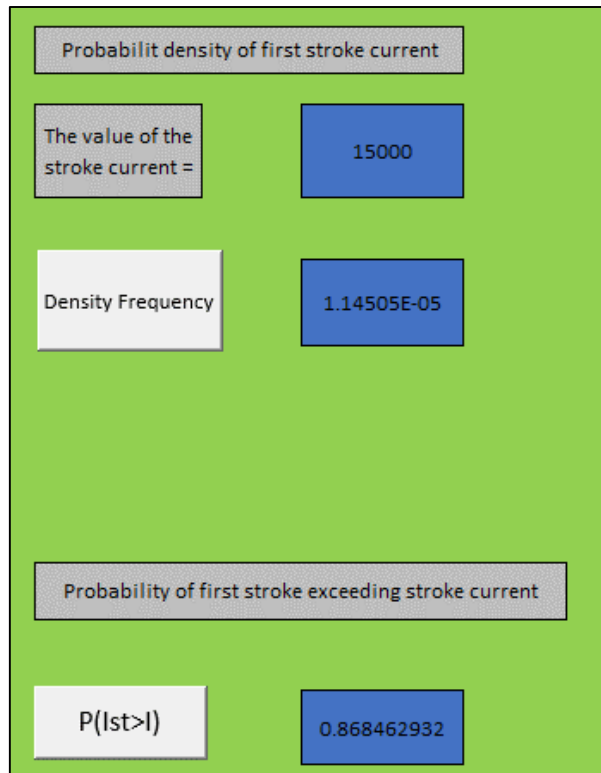
Figure 13. Lightning first stroke analysis worksheet screenshot

Based on Figure 17 above, it show the worksheet of the current stroke distribution analysis. The first one is the probability density of first stroke current and the second is the cumulative probability of the first stroke current will exceeds the normal stroke current. The value and calculation for the probability density of first stroke current is measured by a pair of log-normal distributions.

The statistical analysis above is needed for the calculations of the striking distance for the electro-geomatic model (EGM). As the stroke current increase, the conductor

striking and the ground striking distance will also increase and the exposed distance will decrease. To calculate the value of the data analysis, user need to click on the "Density Frequensy" button for the analysis of probability density of first stroke current and click on the "P(1st>I)" button for the analysis of first stroke current exceeding the normal stroke current.

4.1.3 Striking distance

Figure 14. Striking distance analysis worksheet screenshot

The Figure 18 above shows the calculation for the conductor striking distance as well as the ground striking distance. In this calculation, the conductor striking distance is

assume equal with the striking distance to the shield wire. The equation use for the calculation of striking distance are;

$$r_c = 10 I^{0.65}$$

$$r_g = \begin{cases} [3.6 + 1.7 \ln(43 - y_c)] I^{0.65} & y_c < 40 \text{ m} \\ 5.5 I^{0.65} & y_c \geq 40 \text{ m} \end{cases}$$

where,

    rc   is the conductor striking distance,

    rg   is the ground striking distance,

    and yc is the average conductor height

4.1.4 Shielding angle

Critical Current required for flashover, Ic

Please enter the CFO (Critical Flash Over) voltage value	2
Please enter the conductor radius (m)	3
Please enter the corona radius of the conductor at a gradient of 1500 kV/m (m)	4
The average height of conductor	14

Figure 15. Critical current worksheet screenshot

The critical current analysis is done to know the minimum current required for flashover to occur. This is because, a shielding failure may not causes a flashover at a higher transmission line. Figure 19 above shows the data needed to calculate the critical current. The value is then will be compute to get the shielding angle required for the lightning protection system. The equation used for the calculation is;

$$I_c = \frac{2CFO}{Z_{surge}}$$

$$Z_{surge} = 60\sqrt{\ln\frac{2h}{r}\ln\frac{2h}{R_C}}$$

where,   Zsurge = conductor surge impedance under corona,

        h   = conductor height (m),

        r   = conductor radius (m).

        Rc   = corona radius of the conductor at a gradient of 1500kV/m (m),

        CFO   = critical flashover voltage

Value of conductor surge impedance under corona	260.782
Value of Critical Current (kA)	15.3385
Probability of stroke current exceed Critical Current	1
The Shielding Angle value (degree)	23

Calc Shielding angle

Figure 16. Shielding angle calculation worksheet screenshot

Figure 20 above shows the extended calculation of Figure 19. From the data inserted in Figure 19, an automatic calculation is done and the values in the blue coloured boxes is shown. To do this, user must click on the "Calc Shielding Angle" button as in Figure 20.

4.1.5 Grounding System

A portion of the stroke current will travel and discharge down the tower to the earth when a lightning stroke contact with the tower. The rest will passes along the Overhead Ground Wire (OHGW). The tower current will flow to earth through the impedance of the tower footing. Thus, the resultant voltage drop depends on the value of footing impedance confronted by the current. Therefore, the footing impedance is an important factor to determine lightning performance on an area. To calculate the line performance, equation below is used;

$$T = \frac{\sum T_n L_n}{\sum L_n}$$

where,

T   = total outage rate

L_n = length of line section n with homogenous resistance

T_n = outage rate computed for line section n

First of all, the total outage rate on the area will be calculated. If the rate is not satisfying, a supplemental grounding is used. The common and most used grounding electrode is a driven rod. There are several method to reduce the resistance are increasing the rod radius, increasing the length of the rod, or increasing the number of rods in parallel. The resistance for the supplemental grounding can be calculated as below;

$$R = \frac{\rho}{2\pi s} \ln\left(\frac{2s}{r}\right)$$

where,

R = resistance,

P = earth resistivity (Ω.m),

s = length of the rod in contact with the earth (m),

r = radius of the rod (m).

The electrode will act as a rod with greater apparent diameter if they are closely spaced compared with their length and there will be a small reduction in resistance. The combined resistance will decrease with the increasing of rod spacing. Moreover, the resistance will be reduced in inversely proportional with the number of rod if the rod spacing are larger than the rod length.

Another method to improve grounding performance is by installing counterpoise. Counterpoise is a method in which conductor is buried in the earth parallel to or can be at an angle to the line conductor. Among the most used arrangement is one or more radial wires spreading out from each base of the tower whether it is single, multiple continuous wires from tower to tower, or combination of both radial and continuous wires. The resistance for the counterpoise can be calculated as below;

$$R = \frac{\rho}{\pi s}\left(\ln\left(\frac{2s}{\sqrt{4rd}}\right) - 1\right)$$

where,

r = radius of the wire (m),

d = burial depth (m),

s = length of the counterpoise (m) and s >> d.

The grounding resistance would decrease by 9 percent if the depth of the burial is increasing from 0.5 m to 1.5 m. the inductive effect can be reduced by 15 percent if a thin, wide strap cross-section wire is choose rather than a large circular wire. It also can increase the exposed surface area.

On the other hand, a complex grounding method is recommended for tower with a complex grounding which consist of complex network of driven rods or surrounded by semiconductor materials. The equation used is as below;

$$R_{hemisphere} = \frac{\rho}{2\pi s}$$

$$R_f = \rho/(2\pi s)\ \ln(Cs^2/A).$$

For eq. 7, C = 4π, for eq. 9, C = $2\pi e$,

Where e = 2.178 (exponential constant).

4.1.6 Selection of Surge Arrester

Table 3 and Table 4 above shows the summary of the suggested Maximum Continuous Operating Voltage IEEE (MCOV) and Continuous Operating Voltages IEC (Uc) ratings. MCOV ratings is the maximum designed root mean square or rms value for the power frequency voltage. It can be applied continuously between the terminals of an arrester.

On the other hand, the Uc is a designated permissible rms value of power frequency voltage that can be applied between the arrester terminals.

Table 3. IEEE MCOV (Maximum Continuous Operating Voltages IEC) suggested ratings [19]

Typical IEEE System Voltages				Suggested IEEE Arrester MCOV Rating			
Nom Line to Line Voltage	Max Line to Line Voltage	Max Line to Grnd Voltage		Solid Multi-grounded Systems (4 wire)	Uni-grounded Systems (3 wire)	Impedance grounded, Ungrounded and Delta Systems	Transmission Line Arresters for Lightning Protection Only
kV rms	kV rms	kV rms		MCOV	MCOV [*]	MCOV [*]	
2.40	2.52	1.46				2.55	
4.16	4.37	2.52		2.55	5.1	5.1	
4.80	5.04	2.91				5.1	
6.90	7.25	4.19				7.65	
8.32	8.74	5.05		5.1	7.65		
12.0	12.6	7.28		7.65	10.2		
12.5	13.1	7.57		7.65	12.7 [7.65]		
13.2	13.9	8.01		8.4	12.7 [8.4]		
13.8	14.5	8.38		8.4	12.7 [8.4]	15.3 [8.4]	15.3
20.8	21.8	12.6		12.7	15.3 [12.7]		21
22.9	24.0	13.9		15.3	19.5 [15.3]		22-24
23.0	24.2	14.0		15.3-17		24.4 [15.3]	22-24
24.9	26.2	15.1		15.3	22 [15.3]		24-29
27.6	29.0	16.8		17	24.4 [17]		24-29
34.5	36.2	20.9		22	29 [22]	36-39 [22]	29-36
46.0	48.3	27.9			29	39	29-39
69.0	72.5	41.9			42-48	53-67	48-67
115.0	121	69.8			70-76	84-98	76-98
138.0	145	83.8			84-98	106-115	98-115
161.0	169	98			98-115	115-131	115-131
230.0	242	140			140-152	182-190	152-190
345.0	362	209			209-245	230-289	245-289
500.0	525	303			318-452		>452
765.0	800	462			462-490		>490

[*] MCOV rating of a Gapped MOV arrester

Table 4. Suggested Uc (Continouos Operating Voltages) for IEC System [19]

Typical IEC System Voltages				Suggested Uc for IEC Systems		
Nominal Line to Line Voltage	Typical Max Line to Line Voltage	Max Line to Grnd Voltage		Solidly Earthed Neutral at the Source Transformer	Impedance Earthed, Isolated and Delta Systems	Transmission Line Arresters for Lightning Protection Only
kV rms	kV rms	kV rms		Uc	Uc	
3.3	3.7	2.1		2.4	4.0	
6.6	7.3	4.2		4.8	7.2	
10.0	11.5	6.6		7.2	12	
11.0	12.0	6.9		9.6	12	12
16.4	18.0	10.4		12	18	18
22.0	24.0	13.9		16.8-24	24	24
33.0	36.3	21.0		24-36	36	36
47.0	52	30.1		33-43	53	43-53
66.0	72	41.6		43-58	72	58-72
91.0	100	57.8		66-77	102	77-102
110	123	71.1		77-86	125	86-125
132	145	83.8		96-115	145	115-145
155	170	98.3		110-125	170	125-170
220	245	142		154-188	245	188-245
275	300	173		182-192	300	192-300
330	362	209		221-230	360	230-360
400	420	243		269-288	420	288-420
500	550	318		420-440	550	440-550

CHAPTER 5: CONCLUSION AND RECOMMENDATION

Some literature reviews and studies has been done on the lightning protection systems mainly focusing on the transmission lines. There are several aspect effecting the lightning flash frequency on certain areas which are the structure or transmission tower height, the soil resistivity at the place, the shielding angle of the overhead ground wire, and also the insulation of the transmission tower. The main component of the lightning protection system in transmission line is the grounding, shielding angle, and the surge arrester. Shielding angle act as a protective shield to guard and shield the transmission line especially on the tower from a direct strike. Surge arrester act to reduce the backflash of the current and also the shielding failure of the transmission line. A good grounding can help in reducing the impact of flashover on transmission line.

For further recommendation, the details about the suitable surge arrester can be done by referring to the IEEE Std C62.22.

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APPENDICES I

Mon May 18														
WEEK NUM (SIP)	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
MONTH	MAY		JUN					JUL				AUG		
(MON) DAY	18	25	01	08	15	22	29	06	13	20	27	03	10	17
1.0 PROJECT IDENTIFICATION														
1.1 Conformation of Project Title	▰													
1.2 Identifying the Objective and Scope	▰	▰												
2.0 LITERATURE REVIEW PREPARATION														
2.1 Collecting Reading Material	▰													
2.2 Reading on Past Literature Review and Project Report	▰	▰	▰											
2.3 Reading on Lightning Protection System		▰	▰											
2.4 Reading on PETRONAS Technical Standard (PTS)			▰	▰										
2.5 Reading on National Fire Protection Association (NFPA)				▰	▰									
2.6 Reading on IEEE Standard 142-2007					▰	▰								
2.7 Drafting of Literature Value				▰	▰	▰								
2.8 Submit Extended Proposal							■							
3.0 PROJECT EXECUTION														
3.1 Collecting Data				▰	▰	▰								
3.2 Analysing Data				▰	▰	▰								
3.3 Designing Coding and Programme				▰	▰	▰	▰	▰						
3.4 Programme Troubleshooting				▰	▰	▰	▰	▰						
4.0 PROJECT PRESENTATION														
4.1 Proposal Defense								■						
5.0 REPORT PREPARATION														
5.1 Report Writing								▰	▰	▰	▰	▰	▰	
5.2 Submit Draft Report to SV												▰	▰	
5.3 Submitting Draft Report													■	
5.0 REPORT COMPILATION														
5.1 Finalizing Report													▰	▰
5.2 Submitting Report for SV Approval													▰	▰
5.3 Submitting Final Report														■

Figure 17. Final Year Project I Gantt Chart

APPENDICES II
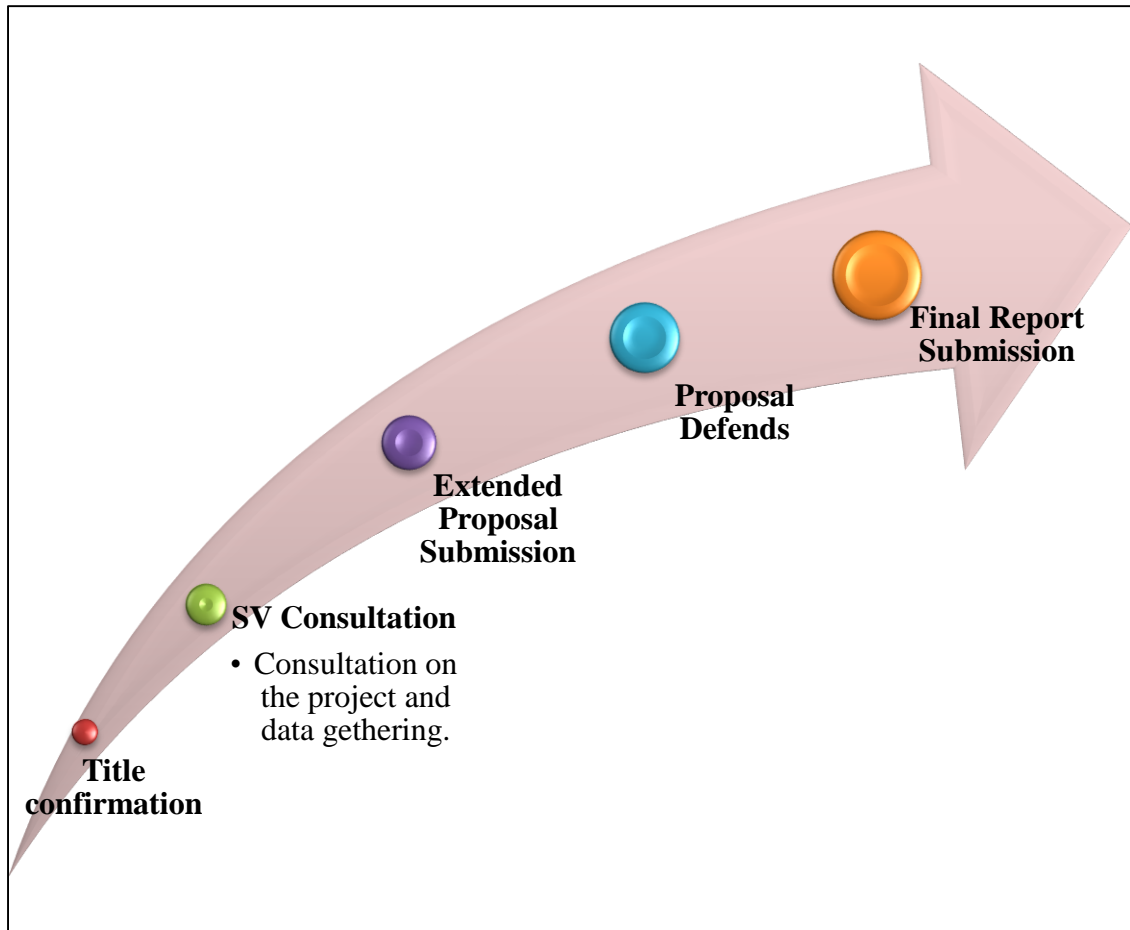

Figure 18. Final Year Project II Key Milestones

APPENDICES III

i. On Sheet "Data"

_____

Sub Data()

Sheets("Data").Select

Range("Flash_Collection_Rate") = Range("Ground_Flash_Density") * (((28) * ((Range("Tower_Height")) ^ 0.6) + Range("Data_OHGW")) / 10)

End Sub

Sub UserForm_Density_Freq()

UserForm1.Show

End Sub

Sub Prob_Stroke_Curr()

a = 31000

b = Range("Stroke_Curr").Value 'Stroke current value in kA

i = b / (10 ^ 3) 'Stroke current value in A

If i < 2 Or i > 200 Then

  MsgBox ("The value is out of limit. Sorry")

  Range("Prob_Stroke_Curr") = "Null"

Else

  Range("Prob_Stroke_Curr") = 1 / (1 + ((b / a) ^ 2.6))

End If

End Sub

Sub Striking_Dist()

i = Range("Stroke_Curr").Value

Range("R_cond") = 10 * (i ^ 0.65)

```vba
If Range("Cond_Height").Value < 40 Then

    yc = Range("Cond_Height").Value

    Range("R_Ground") = (3.6 + (1.7 * Application.Ln(43 - yc))) * (i ^ 0.65)

Else

    Range("R_Ground") = 5.5 * (i ^ 0.65)

End If

End Sub
```

```vba
Sub Cond_Height()

a = MsgBox("Do you know the height of the conductor?", _

vbYesNo)

If a = vbYes Then

    Range("Cond_Height") = InputBox("Please enter the height of the conductor in meter", "Conductor Height", "in meter")

Else

    b = InputBox("Please enter the height of the midspan sag in meter", "Midspan sag height", "in meter")

    Range("Cond_Height") = Range("Tower_Height") - ((2 / 3) * b)

End If

End Sub
```

ii. On sheet "Tower Grounding"

```vb
Sub Grounding()
"""Measure composite line performance"""""
n = Range("no_of_sect").Value
c = 0   'a constant variable
d = 0   'a constant variable
For i = 1 To n
c = e
d = f
Ln = InputBox("Please enter the length of line for section " & i & " with homogeneous resistance in meter", "Length of line section")
    If Ln = vbNullString Then Exit Sub
Tn = InputBox("Please enter the outage rate computed for line section " & i, "Line Section Outage Rate")
    If Tn = vbNullString Then Exit Sub
a = Ln * Tn     'product of Ln and Tn
b = Ln * 1
e = c + a       'summation of "a"
f = d + b       'summation of "b"
Next i
Range("Tot_Outage_rate") = e / f


If Range("Rate_OK") = "yes" Then
Range("rod_res") = "Null"
Range("steady_res") = "Null"
ElseIf Range("Rate_OK") = "no" Then     'supplemental grounding
Exit Sub
End If
```

```
End Sub
```

```
Sub Supplemental_Grounding()

p = Range("earth_res").Value

s = Range("length_rod_ground").Value

r = Range("rad_rod_ground").Value

Range("rod_res") = (p / ((2 * Application.Pi * s)) * Application.Ln(2 * s / r))

End Sub
```

```
Sub counterpoise()

r = Range("wire_rad").Value

d = Range("burial_depth").Value

s = Range("counterp_length").Value

p = Range("earth_res").Value

Range("steady_res") = (p / (Application.Pi * s)) * ((Application.Ln(2 * s / ((4 * r * d) ^
0.5))) - 1)

End Sub
```

```
Sub Complex_Grounding()

'''Calculation of general resistance'''''

p = Range("earth_res").Value

rad = Range("hemis_rad").Value

'a = area

'd or l = length

Range("hemis_res") = p / (2 * Application.Pi * rad)

j = Range("hemis_res")

'''''Calculation of complex low resistance'''''

If Range("electrode_type") = "Wide frame hemisphere" Then

s = Range("hemis_rad").Value

a = 2 * Application.Pi * s * s
```

ElseIf Range("electrode_type") = "Solid electrode rod" Then

s = Range("hemis_rad").Value

r = InputBox("Please enter the length of the rod, (m)", "Solid electrode rod")

If r = vbNullString Then Exit Sub

a = 2 * Application.Pi * s * r

ElseIf Range("electrode_type") = "Radial wire" Then

s = InputBox("Please enter the surface array of radial wire, (m)", "Radial wire")

If s = vbNullString Then Exit Sub

a = Application.Pi * s * s

ElseIf Range("electrode_type") = "Crowfoot wire" Then

s = InputBox("Please enter the crowfoot wire length, (m)", "Crowfoot wire")

If s = vbNullString Then Exit Sub

a = Application.Pi * s * s

ElseIf Range("electrode_type") = "Circular disk" Then

s = InputBox("Please enter the circular disk radius, (m)", "Circular disk")

If s = vbNullString Then Exit Sub

a = Application.Pi * s * s

ElseIf Range("electrode_type") = "2-Vertical-rod electrodes" Then

d = InputBox("Please enter the distance of electrodes separation, (m)", "2-Vertical-rod electrodes")

If d = vbNullString Then Exit Sub

l = InputBox("Please enter the length of the electrodes, (m)", "2-Vertical-rod electrodes")

If l = vbNullString Then Exit Sub

s = ((d * d / 4) + l * l) ^ 0.5

a = 2 * d * l

ElseIf Range("electrode_type") = "A vertical plate" Then

l = InputBox("Please enter the depth of the vertical plate, (m)", "A vertical plate depth")

If l = vbNullString Then Exit Sub

d = InputBox("Please enter the length of the electrodes, (m)", "A vertical plate length")

If d = vbNullString Then Exit Sub

s = ((d * d / 4) + l * l) ^ 0.5

a = 2 * d * l

ElseIf Range("electrode_type") = "4-Vertical-rod electrode or equivalent" Then

d = InputBox("Please enter the distance of electrodes separation, (m)", "4-Vertical-rod electrodes")

If d = vbNullString Then Exit Sub

l = InputBox("Please enter the length of the electrodes, (m)", "4-Vertical-rod electrodes")

If l = vbNullString Then Exit Sub

s = ((d * d / 2) + l * l) ^ 0.5

a = d * d + 4 * d * l

ElseIf Range("electrode_type") = "Equivalently a block" Then

l = InputBox("Please enter the depth of the block, (m)", "A block")

If l = vbNullString Then Exit Sub

d = InputBox("Please enter the length of the block's side, (m)", "A block")

If d = vbNullString Then Exit Sub

s = ((d * d / 2) + l * l) ^ 0.5

a = d * d + 4 * d * l

End If

Range("complex_low_res") = j * Application.Ln((2 * Application.Pi * Exp(1) * s * s) / a)

End Sub

iii. On sheet "Surge Arrester"

```
Sub Surge_Arrester()

nom_LL = Range("nom_LL_volt")

If nom_LL = 13.8 Then

    Range("max_LL_volt") = "14.5"

    Range("max_LG_volt") = "8.38"

    Range("sugg_MCOV") = "15.3"

ElseIf nom_LL = 20.8 Then

    Range("max_LL_volt") = "21.8"

    Range("max_LG_volt") = "12.6"

    Range("sugg_MCOV") = "21"

ElseIf nom_LL = 22.9 Then

    Range("max_LL_volt") = "24.0"

    Range("max_LG_volt") = "13.9"

    Range("sugg_MCOV") = "22 - 24"

ElseIf nom_LL = 23# Then

    Range("max_LL_volt") = "24.2"

    Range("max_LG_volt") = "14.0"

    Range("sugg_MCOV") = "22 - 24"

ElseIf nom_LL = 24.9 Then

    Range("max_LL_volt") = "26.2"

    Range("max_LG_volt") = "15.1"

    Range("sugg_MCOV") = "24 - 29"

ElseIf nom_LL = 27.6 Then

    Range("max_LL_volt") = "29.0"

    Range("max_LG_volt") = "16.8"

    Range("sugg_MCOV") = "24 - 29"
```

```
ElseIf nom_LL = 34.5 Then

    Range("max_LL_volt") = "36.2"

    Range("max_LG_volt") = "20.9"

    Range("sugg_MCOV") = "29 - 36"

ElseIf nom_LL = 46# Then

    Range("max_LL_volt") = "48.3"

    Range("max_LG_volt") = "27.9"

    Range("sugg_MCOV") = "29 - 39"

ElseIf nom_LL = 69# Then

    Range("max_LL_volt") = "72.5"

    Range("max_LG_volt") = "41.9"

    Range("sugg_MCOV") = "48 - 67"

ElseIf nom_LL = 115# Then

    Range("max_LL_volt") = "121.0"

    Range("max_LG_volt") = "69.8"

    Range("sugg_MCOV") = "76 - 98"

ElseIf nom_LL = 138# Then

    Range("max_LL_volt") = "145.0"

    Range("max_LG_volt") = "83.8"

    Range("sugg_MCOV") = "98 - 115"

ElseIf nom_LL = 161# Then

    Range("max_LL_volt") = "169"

    Range("max_LG_volt") = "98.0"

    Range("sugg_MCOV") = "115 - 131"

ElseIf nom_LL = 230# Then

    Range("max_LL_volt") = "242"

    Range("max_LG_volt") = "140"
```

```
        Range("sugg_MCOV") = "152 - 190"

ElseIf nom_LL = 345# Then

        Range("max_LL_volt") = "362"

        Range("max_LG_volt") = "209"

        Range("sugg_MCOV") = "245 - 289"

ElseIf nom_LL = 500# Then

        Range("max_LL_volt") = "525"

        Range("max_LG_volt") = "303"

        Range("sugg_MCOV") = ">452"

ElseIf nom_LL = 765# Then

        Range("max_LL_volt") = "800.0"

        Range("max_LG_volt") = "462.0"

        Range("sugg_MCOV") = ">490"

End If

End Sub
```

iv. On Module 1

Sub freq_stroke_current1()

"if I<20kA

"a=I'

"b=sigma ln

"I=stroke current

a = 61100

b = 1.33

j = InputBox("Please enter the stroke current (kA)", "Stroke Current Value", "Below 20 kA") 'SW = Start Week

Do While j >= 20

   MsgBox ("Please enter a value below 20 kA")

   j = InputBox("Please enter the stroke current (kA)", "Stroke Current Value", "Below 20 kA") 'SW = Start Week

Loop

i = j * 10 ^ 3

Range("Stroke_Curr") = i

If i = vbNullString Then Exit Sub

Range("dens_1st_stroke_curr") = (1 / ((Sqr(2 * Application.Pi)) * b * i)) * (Exp((-(Application.Ln(i / a)) ^ 2) / (2 * (b ^ 2))))

End Sub

Sub freq_stroke_current2()

"if I>20kA

"a=I'

"b=sigma ln

a = 33300

b = 0.605

j = InputBox("Please enter the stroke current (kA)", "Stroke Current Value", "Above 20 kA") 'SW = Start Week

Do While j < 20

   MsgBox ("Please enter a value above 20 kA")

   j = InputBox("Please enter the stroke current (kA)", "Stroke Current Value", "Below 20 kA") 'SW = Start Week

Loop

i = j * 10 ^ 3

Range("Stroke_Curr") = i

If i = vbNullString Then Exit Sub

Range("dens_1st_stroke_curr") = (1 / ((Sqr(2 * Application.Pi)) * b * i)) * (Exp((-(Application.Ln(i / a)) ^ 2) / (2 * (b ^ 2))))

End Sub

Sub Critical_Curr()

'Sheets Shielding Angle

Sheets("Shielding Angle").Select

a = Range("CFO") * 10 ^ 3

Range("Cond_height_SA") = Sheets("Data").Range("Cond_Height").Value

Range("Z_surge") = 60 * ((Application.Ln(2 * Range("Cond_height_SA") / Range("Cond_rad"))) * (Application.Ln(2 * Range("Cond_height_SA") / Range("Corona_rad"))))

Range("Critical_Curr") = 2 * a / Range("Z_surge")

Range("Prob_Is_more_Ic") = 1 / (1 + ((Range("Critical_Curr") / 12000) ^ 2.7))

"""""""""Shielding angle Calculation"""""""""

""EGM MODEL

x = Application.Degrees(Application.Asin(Sheets("Data").Range("R_Ground") - ((Range("Shield_Height") + Range("Cond_Height_SA")) / (2 * 10 * ((Range("Critical_Curr")) ^ 0.65)))))

If Range("hill?") = "Yes" Then

Range("Shield_Angle") = x - Range("hill_deg")

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Else

Range("Shield_Angle") = x

End If

End Sub
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