SIMULATION OF HADDAD SURGE ARRESTER MODEL ON A 132KV OVERHEAD TRANSMISSION LINE FOR BACK FLASHOVER ANALYSIS USING ALTENATIVE TRANSIENT PROGRAM (ATP)

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A project report submitted in partial

Fulfillment of the requirement for the award of the

Master of Electric Power

Faculty of Electrical and Electronics Engineering

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JANUARY 2015

DECLARATION

I hereby declare that the work in this project report is my own except for quotations and summaries which have been duly acknowledged

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ACKNOWLEDGEMENT

First and foremost, a special gratitude towards Allah Almighty for the time and strength given to me in order to complete my dissertation papert successfully. Secondly, I would like to give a warm thanks to my family for all their continuous support and motivations. Which enable me to me to complete my study remarkably. Furthermore, I would also express my appreciation to my beloved supervisor Dr Muhammad Saufi Bin Kamarudin whose encouragement, knowledge in simulation and suggestion contributed to the coordinate of my study. Lastly, sincere thanks also goes to my team members whom are doing similar study as mine for their suggestion that helped me to assemble all the parts of this study.

ABSTRACT

Lightning is a major problem in a transmission line system. Lightning which occurs around the world will give a huge effect on electrical transmission system and also on distribution system division. Lightning-strike commonly generated in two different ways. One of the ways is direct strike to a wire shield (tower top) and another way is shielding failure. A direct-strike to the wire shield generates back flashover as a result of voltage on insulator string magnitude is equal or exceeds the critical flashover voltage (CFO). Therefore, the insulation of surge arrester on transmission line is the way to reducing and finally solving the back flashover problem.

This study modelled a 132kV overhead transmission line for back flashover pattern by using ATP/EMTP software before and after implement the Haddad Surge Arrester Model. This study also analyzed and compares the performance of Haddad Surge Arrester Model with ABB Surge Arrester when four different magnitude lightning strike current is injected. From this study, it show that the Haddad Surge Arrester Model has archived the target to protect the transmission line system.

ABSTRAK

Kilat adalah satu masalah yang besar dalam sistem talian penghantaran. Kilat berlaku di seluruh dunia yang akan memberi kesan yang besar dalam sistem penghantaran elektrik dan juga sistem bahagian pengedaran. Serangan kilat biasanya terhasil dalam dua cara, yang merupakan serangan terus ke wayar perisai (menara atas) dan kegagalan melindungi. Sambaran seecara lansung menghasilkan "back flashover", "back flashover" ini berlaku apabila voltan pada tali penebat adalah sama atau melebihi voltan "flashover" kritikal (CFO). Oleh itu, untuk mengatasi dan memperbaiki masalah "back flashover" ini pemasangan penangkap lonjakan adalah cara yang terbaik.

Kajian ini membina sistem penghantaran 132kV talian atas bagi melihat kesan "back flashover" terhadap kilat sebelum dan selepas menggunakan penangkap lonjakan Haddad dengan menggunakan perisisan ATP/EMTP. Kajian ini turut mengkaji dan membuat perbandingan terhadap pencapaian penangkap lonjakan Haddad dengan penangkap lonjakan ABB apabila empat magnitud pancaran kilat diberikan. Dapatan kajian menunjukkan penangkap lonjakan Haddad dapat mencapai tujuan bagi memberi perlindungan kepada sistem penghantaran talian atas.

CONTENTS

LIST OF FIGURE

LIST OF TABLE

CHAPTER 1

INTRODUCTION

1.1 Background of project (Motivation)

Temporary over voltage in transmission line system is actually causes from the lightning. The lightning will causes the travelling waves to the different connection on both sides of transmission line. The over voltage is harmful to line insulators and other devices connected to the transmission line [1]. The effect of lightning is depending upon the surges size and the equipment sensitivity. High magnitude surges can cause damage to many type of component. The other cause of lightning is reducing equipment lifetime, damaging the components resulting in equipment and system downtime which may lead to other problems, such as losses in production and also losses of good business opportunities. As a protection of equipment in power system and substation it is essential to investigate a lightning surge for a reliable operation of a power system, because the lightning surge over voltage is dominant factor for the insulation design of power system.

Back flashover normally occurs when the lightning-strike to the tower or the overhead ground wire. Currents ware forced by lightning to flow down the tower and out on the ground wires. Therefore, a voltage is generated across the line insulation. Then, flashover will happen when the generated voltage is equal or exceed the line critical flashover voltage (CFO). The estimation back flashover rate are important to design the transmission line tower. In order to reduce this back flashover problem surge arrester need to be implement on the overhead transmission line. The various types of surge arrester model will have different effects and advantages. Hence, by using ATP/EMTP package surge arrester will give more accurate result in analyzing various types of surge arrester and also in deferring the back flash lightning withstanding level.

1.2 The Objectives

The main objective of the project is:

1) To study and redesign the 132kV overhead transmission-line model circuit using ATP-EMTP software.
2) To analyse the Haddad Surge Arrestor Model circuit performance when 10kA, 20kA, 34.5kA and 40kA lightning strikes is injected.
3) To investigate the back flashover voltage pattern when four lightning current magnitudes are injected to a transmission-tower top.

1.3 Scope of Study

The main scope of this project is to develop the 132kV overhead transmission line model (Bergeron tower model) by using ATP/EMTP. There are a few types of surge arrester model that is used on 132kV transmission line to reduce damage due to lightning. This study will only focus on Haddad surge arrester model. How would Haddad surge arrester model act upon 10kA,20kA,34.5kA and 40kA lightning strikes is what will be analyses in this study. Furthermore, the comparison between 132kV overhead transmission line during lightning strikes with and without Haddad surge arrester model will also be show in this study.

1.4 Problem Statement

Lightning occurs in all over the world, normally lightning was damage the substation equipment's by producing back flashover and shielding failure when the lightning strike to the overhead line tower either direct or indirect. In order to protect the line and equipment from lightning over voltage, implementation of surge arrester in transmission line is very important. Either back flashover or shielding failure, the arrester avoid the lightning-strike by control over voltage across the insulator string.

Lightning strike on shield wire or top of the tower will produce back flashover, where the resultant voltage across the line insulator is equal or exceed the critical flashover voltage (CFO) to cause a flashover from the tower to the line conductors. This back flashover can cause damage to the expensive substation equipment's. For that reason, the implementation of surge arrester on transmission line will ensure the safety of the equipment's against line lightning over voltage. Nowadays, surge arrester has been implemented on transmission line but they're still less efficient. Therefore, by using ATP/EMTP package software to model and select the various types of surge arrester need to develop for improving the efficiency.

1.5 Report Outline

Chapter 1: Describes the background of project and elaborates all of the objectives, problem statement, scope and lastly this part that is report outline.

Chapter 2: Literature review, including description of transmission line, tower model, lightning phenomenon, back flashover, transmission line system, model of tower, surge arrester, model of surge arrester and the implementation of surge arrester in transmission line tower model.

Chapter 3: Describes the methodology on how to model transmission line tower by using ATP-EMTP package software. Methodology chart is also included.

Chapter 4: Describes on modelling 132kV overhead transmission line tower by using package software ATP-EMTP. Model surge arrester with the same software then implemented to that tower.

Chapter 5: In this chapter, after modelling transmission line and surge arrester all this was tested by simulation via ATP-EMTP software. Then was analyze and discuss the result to make a conclusion.

Chapter 6: Discuss and conclude all the result from the simulation and also do a recommendation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Lightning strike comes about every day in the world. The lightning strike towards the surface on earth has been estimated at 100 times every second. Thus, almost every governments suffer major loses because of this phenomenon every year [2, 7]. Malaysia is the highest lightning activities in the world that was reported by United State National Lightning Safety Institution. The average thunder day level for Malaysia's capital Kuala Lumpur within 180 - 260 days per annum [3].

Malaysia was categorized as prone to high lightning and thunderstorm activities because Malaysia lies near the equator [3]. Malaysia's electric power provider, Tenaga Nasional Berhad (TNB) have been recorded that Thunderstorms have been suspected to have caused between 50% and 60 % of the transient tripping in the transmission and distribution networks. Therefore, installation of surge arrester on a transmission line as a protection is good to be implemented.

2.2 Lightning Phenomenon

2.2.1 Lightning Form

Lightning happens when have an attraction between positive charges (protons) in the ground and the negative charges (electrons) in the bottom of the cloud. The insulating properties of air have been overcome by the accumulation of electric charges. When this condition occurs, a stream of negative charges pours down towards a high point where charges have clustered due to the pull of the thunderhead. Therefore protons and electrons met together that made a connection. Lightning will appear and hear a thunder at that point. Therefore, that's how lightning is formed [2, 5, 7].

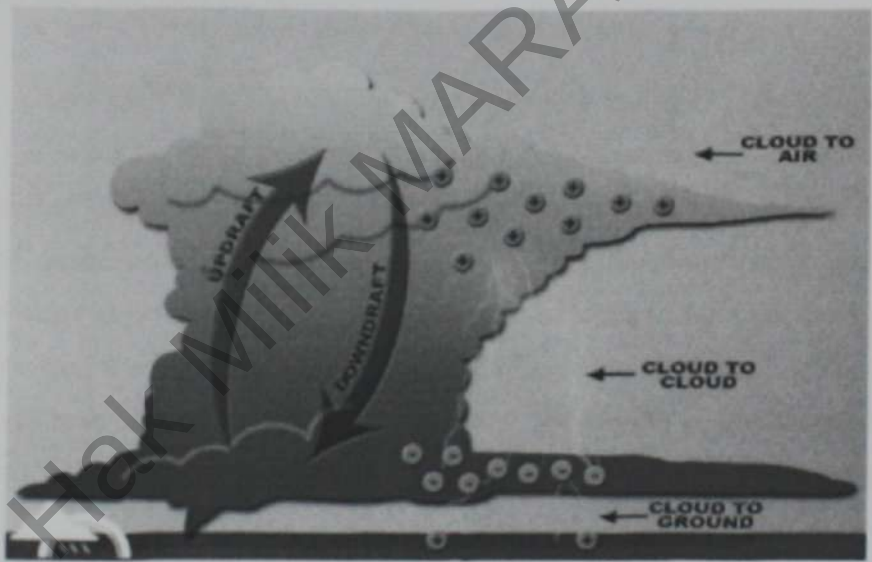


Figure 2.1: Interaction of protons and electrons [2]

2.2.2 Classification of lightning

Flash, negative lightning (-C2G), and positive lightning (+C2G) is the three different type of lightning strike. C2G is stands for cloud to ground discharge. Thus, current flow will be the main input of the lightning strike. The value is between -180 kA and 180 kA. The level of lightning current can be classified in low, medium or high class [4].

Table 2.1: Strike Level Definition

Class	Range
Low	-60kA, +60kA
Medium	[-120kA,-60kA] and [+60kA,120kA]
High	[-180kA,-120kA] and [+120kA,+180kA]

2.2.3 Lightning and transmission line

Enormous overvoltage between ground and the line produced when a large electric charge deposit on the transmission line, after lightning makes a direct hit on the transmission line. The flashover occurs when the electric strength of air is immediately exceeded. The line discharges itself and the overvoltage disappears in typically less than 50μs [5, 9].

A very high local overvoltage produced since the local charge accumulates on the line when lightning strike the overhead ground wire that shields the line. This concentrated charge immediately divides into two waves that swiftly move in opposite directions at close to the speed of light (300m/μs). The height of the impulse wave represents the magnitude of the surge voltage that exist from point to point between the line and ground. The peak voltage (corresponding to the crest of the wave) may attain one or two million volts. Wave front is concentrated over a distance of about 300m, while wave tail may stretch out over several kilometers [5, 6]

As the wave travels along the line, the I^2R and corona losses gradually cause it to flatten out, and the peak of the surge voltage decreases. Should the wave encounter the line insulator, the insulator, the latter will briefly subjected to a violent overvoltage. The overvoltage period is for the time it takes for the wave to sweep past the insulator. The voltage rises from its nominal value to several hundred kilovolts in about 1μs, corresponding to the length of wave front. If the insulator cannot withstand this overvoltage, it will flash over, and the resulting follow-through current will cause the circuit breakers to trip. On the other hand, if the insulator does not fail, the wave will continue to travel along the line until it eventually encounter a substation. The windings of transformer, synchronous condenser, and reactor are seriously damaged when they flash over to ground. Expensive repairs and even more costly shut downs are incurred while the apparatus is out of service. The overvoltage may also damage circuit breaker, switches, insulators and relay that make up a substation [5, 11].

To reduce the impulse voltage on station apparatus, lightning arresters must be installed on all coming lines. Lightning arresters are designed to clip off all voltage peaks that exceed a specified level voltage [5].

2.2.4 Three possibility discharge paths that can cause surges on line

First is the induced voltage, developed when the capacitance between the earth and the leader is discharged quickly. Second discharge is the back flashover. This back flashover occurs when discharge path capacitance between lightning head and the earth conductor. Last but not least, the third discharge is the shielding failure. This third discharge is when the capacitance discharge between the phase conductor and the leader core. J .Rohan Lucas [6] point out all this possibility and well described in their book. Therefore the figure below shows all the discharge

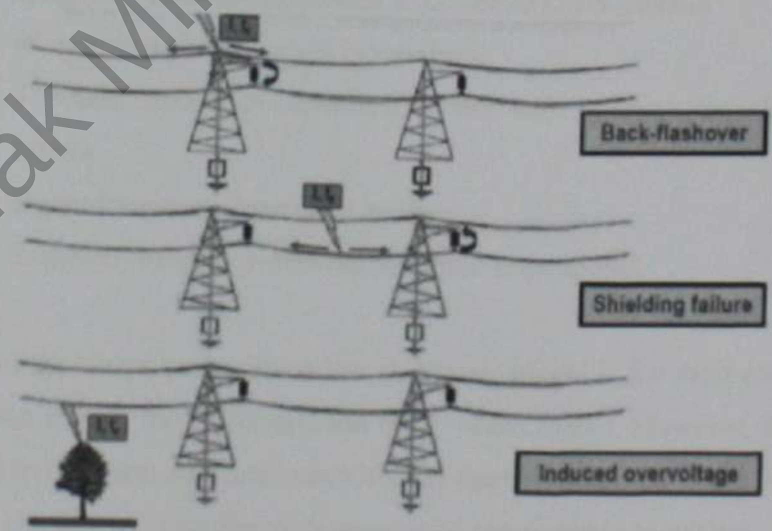


Figure 2.2: Three Possible Discharge Paths [19]

2.2.5 Back flashover

Flashover from the tower to the phase conductor occurs when the lightning strikes at the top of the tower or shield wire. A stroke that so terminates force currents flow down the tower and out on the ground wires. Thus voltages are built up across the line insulation. Flashover occurs, when these voltages equal or exceed the line CFO [5, 11]. Therefore it's good to improve the performance of overhead transmission line by implementing surge arrester as a protection. The actual placement of the surge arrester on the transmission line will be influenced to reduce the back flashover rate.

2.3 Transmission Line System and Tower Model

2.3.1 Transmission Line System

There are several models of transmission line that have been used offers by ATP-EMTP package software:

i. Bergeron: constant-parameter K.C. Lee or Clark models
ii. PI: nominal PI-equivalent (short lines)
iii. J. Marti: frequency-dependent model with constant transformation matrix
iv. Noda: frequency-dependent model
v. Semlyen: frequency-dependent simple fitted model

Three of the above transmission line and tower model is the most commonly used is Bergeron model, the PI model, and the J. Marti model. However, the most suitable model to represent overhead transmission lines in Malaysia is the Bergeron model that the shield wire is similar with phase wire connected to tower top.

LU Zhiwei and LI Dachuan [9] state that, this model (Bergeron model) is actually based on distributed LC parameter travelling wave line model with lumped resistance. In power system transient fault analysis the model that's commonly used is the time-domain Bergeron model. Then, represented by L and C elements of a PI section and also approximate equivalent by means of an infinite number of PI sections, except that the resistance is lumped [1/2 in the middle of the line, ¼ at each end].

The Bergeron model mostly is based on LC-parameter travelling waves and described by the following two values:

The Surge Impedance, $Z_c = \sqrt{\frac{L}{C}}$ (1)

The Phase Velocity, $v = \frac{1}{\sqrt{LC}}$ (2)

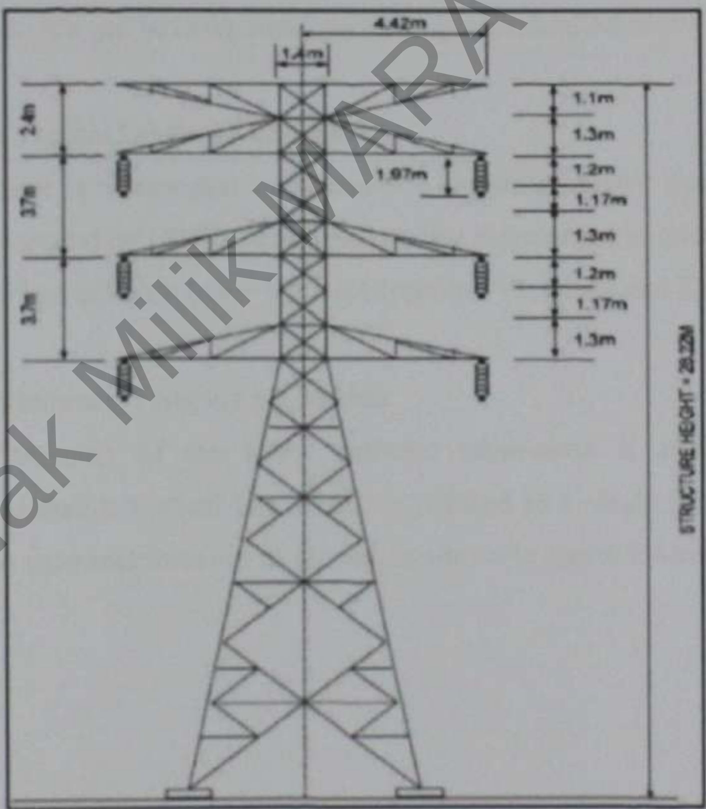


Figure 2.3: Tower configuration of 132kV transmission line system [9]

2.3.2 Tower Model

Juan A. Martinez, Ferley Castro-Aranda [10, 11] point out, several multi-phase untransposed distributes a parameter line spans on both sides of impact represent a transmission line. Frequency dependent or a constant parameter model, either one of these can be made as a representation of the transmission line. A line termination is needed on each side of the above model to prevent reflection that could affect the simulated over voltages. At each sides, surely can be achieved by adding along enough line section. Phase voltages at the instant at which the lightning stroke impacts the line deduced by randomly determining the phase voltage reference angle.

By using a theoretical approach and the experimental work, a tower model has been developed. It's can be categories into three groups detailed below:

1. Single Vertical Lossless Line Models
   The tower is represented by means of a simple geometric form. The model recommended by CIGRE was based on that represented in reference of travel time of transmission tower by WA Chisholm, YL Chow and KD Srivastava.

2. Multiconductor Vertical Line Models
   Each segment of the tower between cross-arms is represented as a multiconductor vertical line, which is reduced to a single phase line whose section increases from top to ground, as shown in figure 2.4 below.

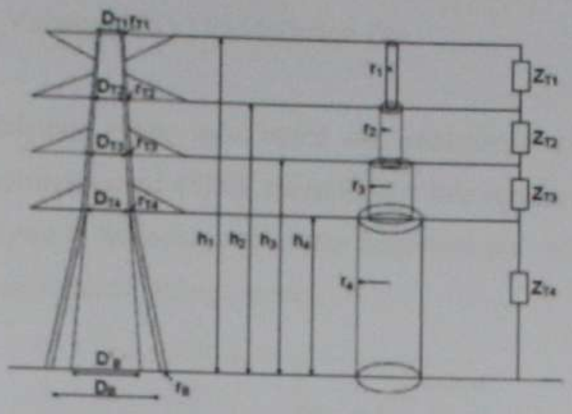


Figure 2.4: Multiconductor vertical line model [10]

The tower shown in figure 2.5 includes the effect of bracings (represented lossless lines in parallel to main legs) and cross-arm (represented as lossless line branched at junction points).

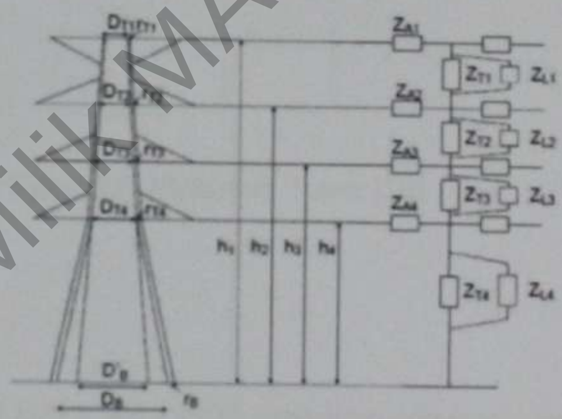


Figure 2.5: Multiconductor vertical line model, including bracings and cross-arm [10]

3. Multistory Model

The tower section between the cross-arms, represented in four sections. Lossless line in series with a parallel R-L circuit included for each section which include for attenuation of the travelling waves. In spite of the fact that, all the parameters of this model were initially deduced from experimental results. The approach was originally developed for representing tower of Ultra High Voltage (UHV) transmission line.

Multistory tower was based on transmission line of 500kV. In Malaysia normally used 132kV transmission line tower. A real transmission line tower need to be include all of the important part which is a cross-arms model and an insulator-strings model.

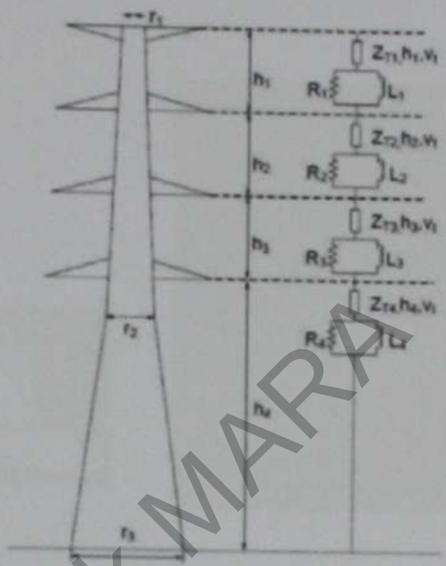


Figure 2.6: Multistory Tower [10]

2.3.3 Cross-Arms

Most of transmission line 132kV and 275kV, cross-arms commonly made up of hard wood. Usually, use of cross-arms is to supports transmission line and the towers.

$$Z_{AK} = 60\ln\left(\frac{2h}{r_A}\right) \qquad (3)$$

Where

h = height of the cross-arms

r_A = radius of the cross arms

2.3.4 Insulator String

Insulator string used as a mechanical protection (mechanical insulator) system between live conductor and the pole. Which are made up of porcelain, glass or composite materials. The characteristics of solid insulators is high mechanical strength, high electric strength, high insulation resistance, free from impurities and moisture, air and gas free (decrease the dielectric strength) and can withstand the flashover phenomenon.

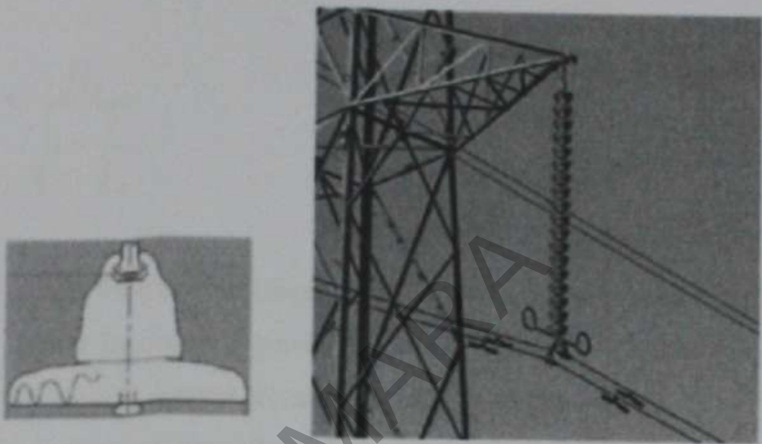


Figure 2.7: Insulator Disc and Insulator String

2.3.5 Tower- Footing Resistance and soil ionization

2.3.5.1 Tower- Footing Resistance

In modelling transmission line tower, the tower footing resistance is one of the main parts for model of tower [10]. Lightning flashover rates is determined by rating of tower footing resistance, this is because the tower footing resistance is an extremely important parameter for flashover rates and it can be calculate by using formula shows:

$$R_T = \frac{R_o}{\sqrt{1 + \frac{I}{I_g}}} \quad (4)$$

Where:

R_o = Tower footing resistance at low current and low frequency, ohm

R_T = Tower footing resistance

I_g = the limiting current through the footing impedance, A

I = the lightning current through the footing impedance, A

2.3.5.2 Soil Ionization

The limiting current is a function of soil ionization and is given by:

$$I_g = \frac{E_o \rho}{R_o^2} \quad (5)$$

Where:

ρ = soil sensivity, ohm-m

E_o = soil ionazitation gradient (400kV/m)

2.3.6 Tower Surge Impedance

The tower surge impedance is deeply related to their geometric shapes. However, the existence of complex transmission line structures it is not easy to compute its surge impedance. Furthermore, the variety of structures, with different shapes and sizes makes impossible to have a general equation, which encompasses all the cases. In this way were developed equations obtained from simple geometric shapes, as cylinders and cones representing various types of tower. The surge impedance was calculated by formula from cylindrical tower (geometric):

$$Z_{Pole} = 60\ln\left(\frac{2\sqrt{2}Hc}{r_c}\right) - 60 \qquad (6)$$

Where

Hc is the average height of the poles (m)

r_c is the radius of the base of the poles (m)

2.4 Lightning Source

Lightning strike model of Heidler type in ATP/EMTP software is represented by current source that parallel with resistance. Lightning path impedance is the parallel resistance of the lightning strike model.

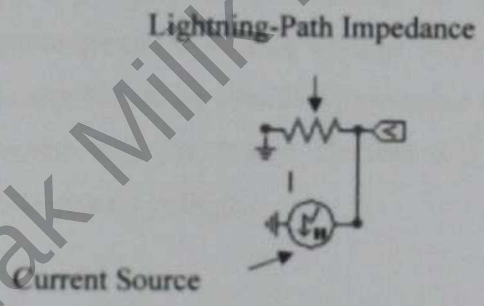


Figure 2.8: Lightning Strike, Heidler Model

2.5 Surge Arrester

The equipment of a transmission line will be protected by Surge arrester (Lightning arresters). Surge arrester installation of the transmission line will give more security to the overvoltage. The effectiveness of an arrester to limit an overvoltage will depend on the rate of rise of the overvoltage wave. Since the critical flashover voltage (CFO) was exceeded the insulation failure will occurs. Means that flashover and back flashover discharge cause a fault to the system. It is important to explain the ability of electrical equipment to withstand surge is not easily defined and depends on the exposure time. Therefore it is good to implement surge arrester on the transmission line.

Selecting an appropriate arrester requires knowledge about the system and specific application parameters such as:

- Maximum system voltage and grounding type (effectively grounded, impedance grounded, ungrounded)
- Insulation level of protected equipment and desired Margin of Protection
- Possible durations and levels of power frequency overvoltages
- Lengths of conductor that will carry switched loads
- Mechanical loads placed on the arrester
- Available line-to-ground fault current
- Environmental conditions and severity of site pollution

The primary factor in determining the correct arrester voltage is its Continuous line-to-ground Operating Voltage rating (Uc or COV). When selecting the appropriate arrester for an effectively grounded neutral system, it is desirable to choose an arrester with the lowest Uc that will meet or exceed the system's maximum line-to-ground voltage.

2.6 Model proposed by Haddad Et Al

The proposed equivalent circuit is shown in figure 2.9. It comprises two series sections; one to represent the resistance of zinc oxide grains (R_{grain}) and the self-inductance (L_{body}) due to the physical size of the arrester body and a parallel network to represent the properties of the intergranular layers. One branch of the network carries the high amplitude discharge current, so that the ranch has a highly non-linear resistance R_{lg} and a low value inductance L_{c1}. The second branch has a linear resistance R_c and a higher value inductance L_{c2} to account for the delay in low-current fronts and the multiple–current path concept. A capacitive element C_{lg} to represent the arrester shunt capacitance was also included in the equivalent network. [13]. The simulation of the model resulted in an excellent fit to experiment conducted in the laboratory despite that the model parameters are determined experimentally which is sometimes difficult to achieve [14].

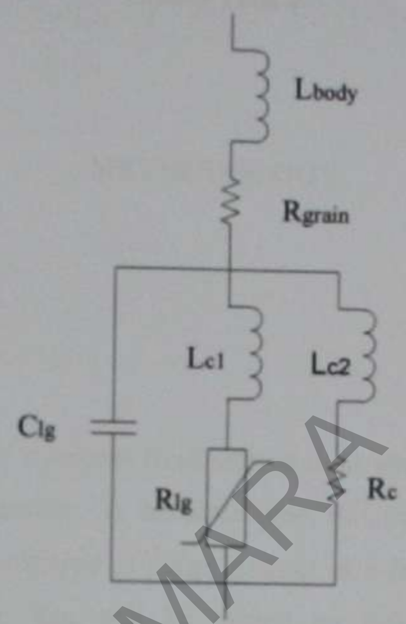


Figure 2.9 : Proposed ZnO equivalent circuit for multiple current-path representation [13].

Table 2.2: Parameters for the IEEE Model [13]

Parameter	Value (SI unit)
L_{body}	1 (μH)
R_{gain}	1.1 (Ω)
L_{c1}	0.01 (μH)
L_{c2}	75 (μH)
Clg	1.5 (pF)
Rlg	*f(I,V)*
R_c	100 (Ω)

CHAPTER 3

METHODOLOGY

3.1 Introduction

On this chapter the 132kV overhead transmission lines was developed to be used for back flashover analysis studies. At the same time, this transmission line tower will be used to select a different type of surge arrester as a protection against lightning strike. This transmission line will be design by using ATP-EMTP software. Therefore this chapter will describes all of the step how to develop a transmission line and how to model surge arrester by using ATP-EMTP software.

3.2 Alternate Transient Responds (ATP)

3.2.1 Introduction

ATP is known as Alternative Transient Program is the one of the software that can develop and modelling overhead transmission line. This software used for digital simulation of electromagnetic transient phenomena as well as electromechanical nature in electric power systems. Other than that, ATP has widespread modeling capabilities and additional important features besides the computation of transients.

Below is all of the elements support by ATP:

1. The Simple RLC lumped elements
2. The Nonlinear components (arresters, nonlinear inductors etc.)
3. The Overhead lines (Semlyen, Bergeron,KCLee, JMarti, Noda.)
4. The Saturable transformers
5. The Controllable switches
6. The Various voltage and current sources
7. The Electric machines (synchronous, inductionDC)
8. The TACS (transfer functions, control systems etc.)

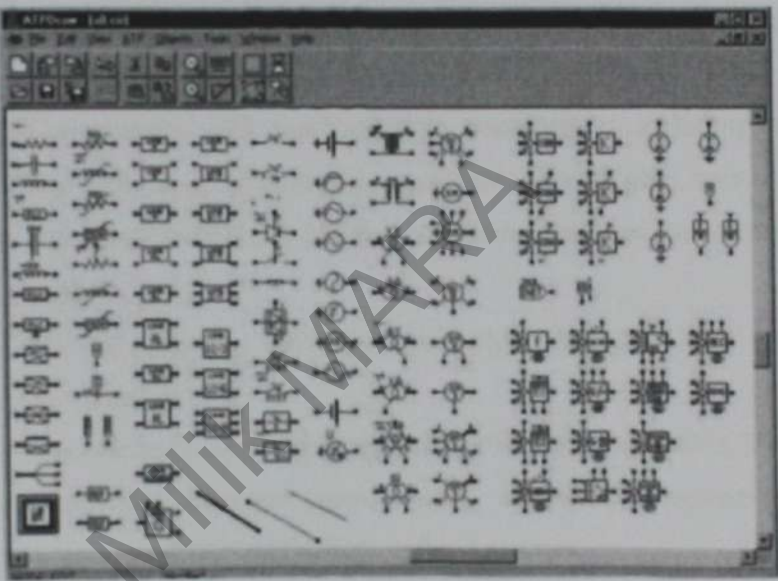


Figure 3.1: Shows all the component in ATP software

3.2.2 Operating Principle and Capabilities of ATP

The ATP program predicts variables of interest within electric power networks as functions of time, typically initiated by some disturbances. Basically, trapezoidal rule of integration is used to solve the differential equations of system components in the time domain. Non-zero initial conditions can be determined either automatically by a steady-state phasor solution or user can be entered for simpler components.

ATP has many models including rotating machines, transformers, surge arresters, transmission lines and cables. Interfacing capability to the program modules TACS (Transient Analysis of Control Systems) and MODELS (a simulation language) enables modeling of control systems and components with nonlinear characteristics such as arcs and corona. Dynamic systems without any electrical network can also be simulated using TACS and MODELS control system modelling.

The ATP program has restored the components in the model-library such as:

a) Nonlinear resistance and inductances, hysteretic inductor, and time-varying resistance
b) Components with nonlinearities: transformers including saturation and hysteresis, surge arresters (gapless and with gap), arcs.
c) Rotating machines: 3-phase synchronous machine, universal machine model.
d) Valves (diodes, thyristors, triacs), TACS/MODELS controlled switches.
e) User-defined electrical components that include MODELS interaction
f) Analytical sources: step, ramp, sinusoidal, exponential surge functions, TACS/MODELS defined sources.
g) Transmission lines and cables with distributed and frequency-dependent parameters.
h) Uncoupled and coupled linear, lumped RLC elements.

3.2.3 Typical ATP-EMTP Applications

ATP-EMTP used around the world for switching and lightning surge analysis, insulation coordination and shaft torsional oscillation studies, protective relay modeling, harmonic and power quality studies, HVDC and FACTS modeling. Typical EMTP studies are:

a) Machine modeling system
b) Lightning overvoltage studies
c) Shaft torsional oscillations
d) Protection device testing
e) Harmonic analysis, network resonances
f) Transient stability, motor startup
g) Very fast transients in GIS and groundings
h) Statistical and systematic overvoltage studies
i) Circuit breaker duty (electric arc), current chopping
j) Ferroresonance
k) Transformer and shunt reactor/capacitor switching
l) FACTS devices: STATCOM, SVC, UPFC, TCSC modelling
m) Power electronic applications
n) Power electronic applications

3.2.4 Characteristics of Plotting Program

These post-processors are interfaced with ATP by the disk files. The results are displayed on a time or frequency domain simulation is their main function. All of the File having extension .pl4, is to stored data from ATP simulation. This program also can be processed either off-line, or on-line. The latter is available only if the operating system provides concurrent PL4-file access for ATP and the postprocessor program.

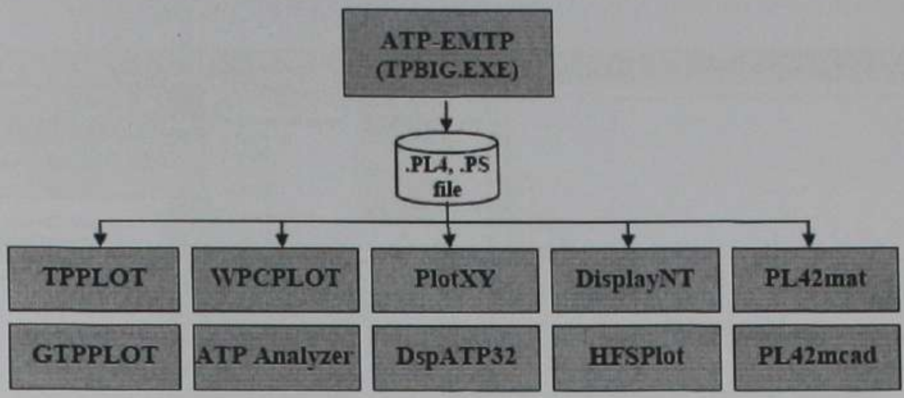


Figure 3.2: Plotting Program in ATP

The common used plotting in ATP programs are PLOTXY and GTPPLOT.

a) PLOTXY – plotting program is design for WIN32. Which is design to make plots in Microsoft Windows environments. Design as easy and fast as possible. Other than that, this program is able to perform some post-processing on the plotted curves, algebraic operations, and computation of the Fourier series coefficients. By using the 32bit code, will provides fastest operation. At the same time, the program has an easy-to use graphical user interface. Up to 3 PL4 or ADF files can be simultaneously held in memory for easy comparison of different data and up to 8 curves per plots versus time, or X-T plots are allowed. Figure 3.3 shows the example of graph by PLOTXY

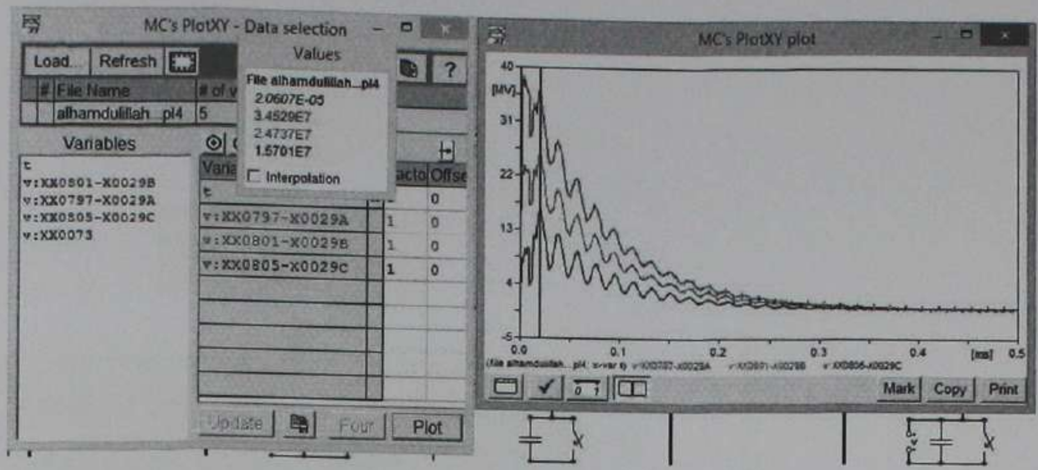


Figure 3.3: Graph by PLOTXY

3.3 Methodology Chart

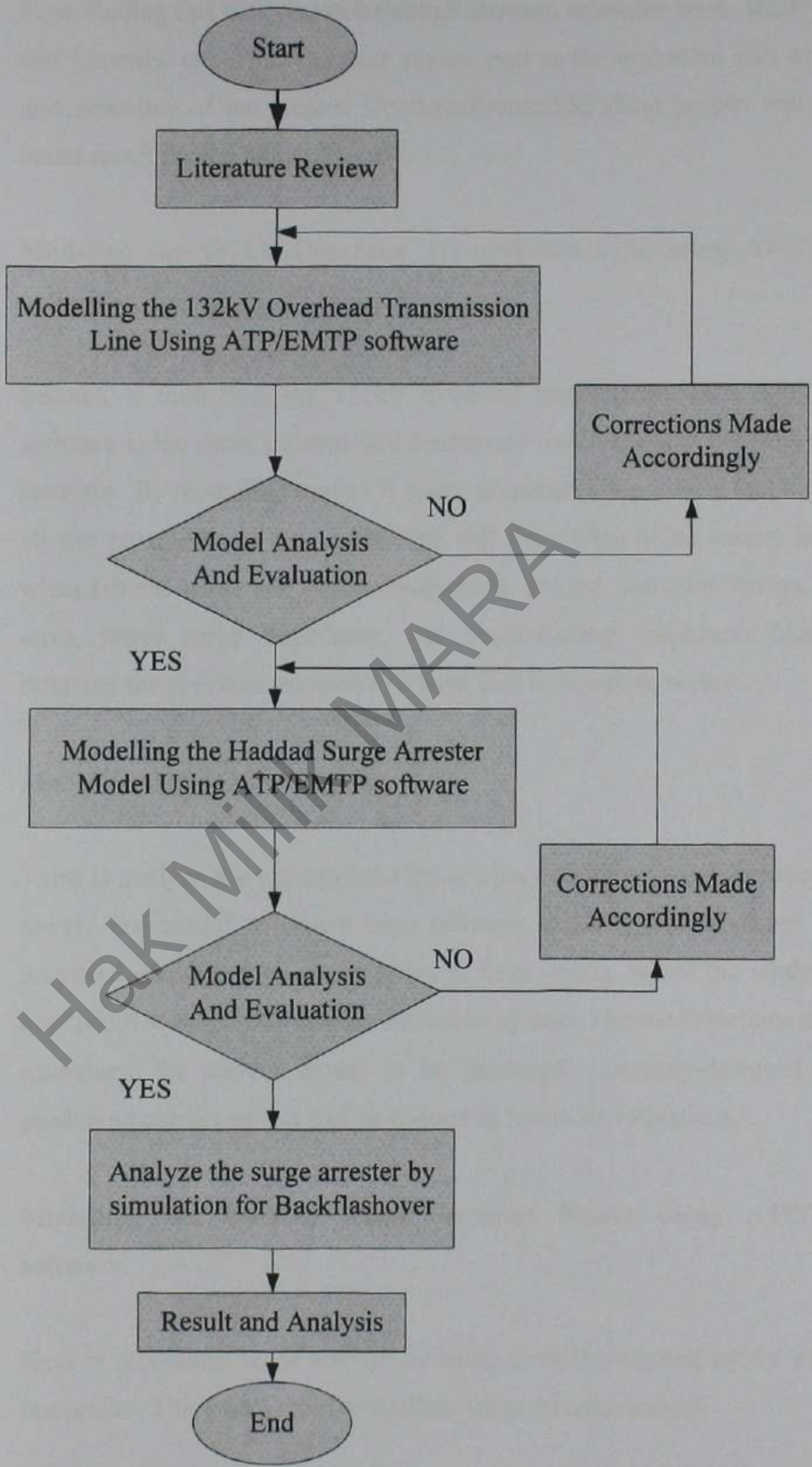


Figure 3.4: Methodology Chart

A. Literature review

First, finding fact data research through internet, reference book, IEEE papers and journals, etc. This literature review part is the important part to better understanding of the project. Good understanding about project will give a better result for the report.

B. Modeling the 132kV Overhead Transmission Line using ATP/EMTP software

Second, is modelling the 132kV overhead transmission line. ATP/EMTP software is the most suitable tool commonly used in power system transient analysis. By modelling seven (7) spans of transmission towers that including all the parameter of the tower. The full transmission-line model includes wires (shield wires and phase conductors), towers, insulator strings, cross-arms, tower surge impedance, and tower-footing resistance. Model by referring the previous research that have find in literature review.

C. Model Analysis and evaluation

Third is analyze the transmission tower after completely done producing the tower. The model will have been referring to IEEE journal/papers whose proposed methods proved compliant to field results. All of the methods are not specified for 132kV transmission line system. The modifications are thus necessary, for correct model to be produced. Correctly-designed model producing correct output will be re-used in future investigations.

D. Modelling the Haddad Surge Arrester Model Using ATP/EMTP software

Next is modelling surge arrester by using models proposed by the previous researcher. The model that are Haddad Surge Arrester model.

E. Model Analysis and evaluation

Therefore after done modelling, Now state of analysis the functionality of Haddad surge arrester model.

F. Analyze the surge arrester by simulation for back flashover analysis

Now, each surge arrester will be observed their performance on the transmission line when flashover occurs on the transmission line. Test one by one, all the data recorded.

G. Result and Analysis

All the data from the simulation result before will be discuss and to make a conclusion and recommendation.

CHAPTER 4

MODELLING OF 132KV OVERHEAD TRANSMISSION LINES AND SURGE ARRESTER

4.1 Introduction

Developed and model the overhead transmission line of 132kV and design Haddad surge arrester Model by using ATP-EMTP software.

4.2 Transmission Line and Tower Model

A model overhead transmission line of 132kV with a height of 28.22 meters (m) normally used in Malaysia. A double circuit vertical phase conductor configuration with two ground wires is usually used. For double circuit line the phase conductors are arranged differently for each circuit. Seven towers were modelled by using ATP-EMTP program as show in figure 4.1. First circuit, blue phase is arranged at the top follow by red and yellow. Second circuit the positions of the phase conductors are yellow, blue and red. The full model is shown in Appendix B.

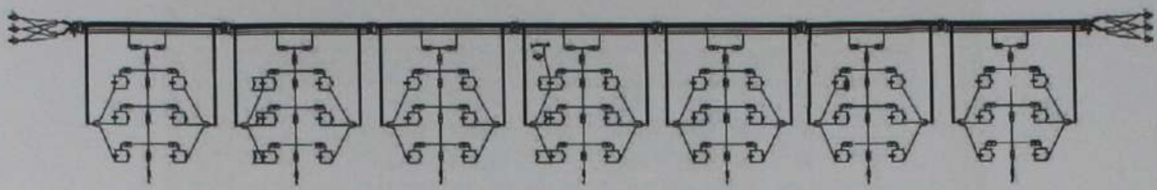


Figure 4.1: Seven Towers Model

4.2.1 Multistory Tower Model (Bergeron model)

The model of the tower that wants to develop is the Bergeron model that is basic of distributed LC-parameter travelling wave line model with lumped resistance. This Bergeron model describes in chapter 2 (literature review).

The 132kV overhead transmission line system has been chosen for the Bergeron model type, with the applicable height of 28.22m and was fixed by TNB transmission. Figure 4.2 shows all of the parameters and the elements to model a tower need to be setup in ATP/EMTP software.

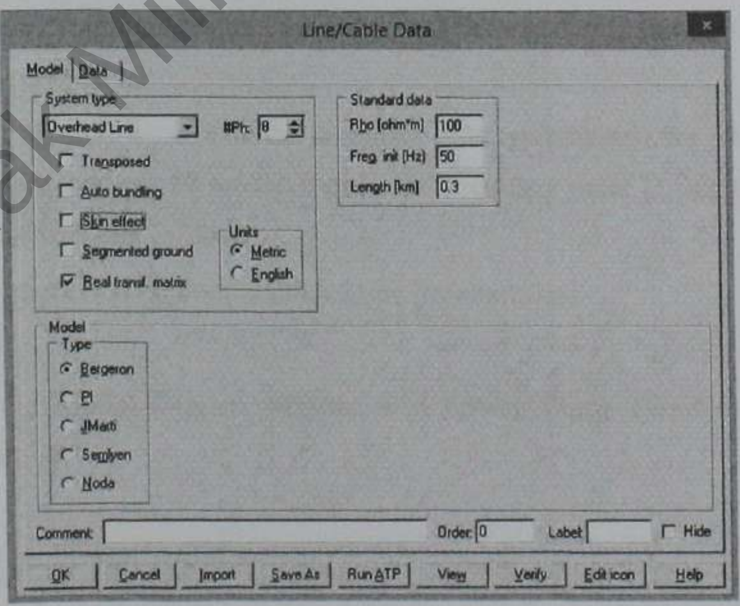
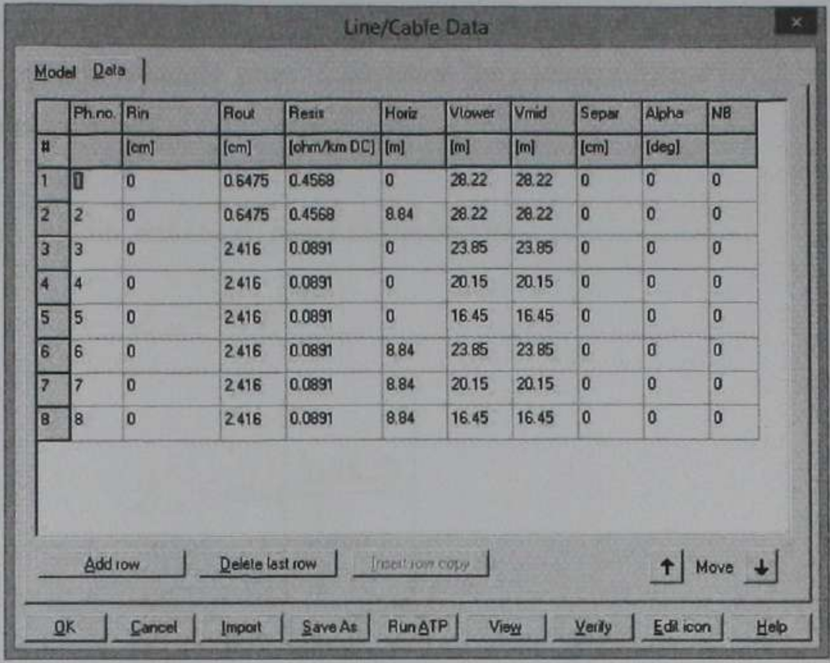


Figure 4.2: Model for Line/Cable data



	Ph.no.	Rin	Rout	Resis	Horiz	Vtower	Vmid	Separ	Alpha	NB
#		[cm]	[cm]	[ohm/km DC]	[m]	[m]	[m]	[cm]	[deg]	
1	1	0	0.6475	0.4568	0	28.22	28.22	0	0	0
2	2	0	0.6475	0.4568	8.84	28.22	28.22	0	0	0
3	3	0	2.416	0.0891	0	23.85	23.85	0	0	0
4	4	0	2.416	0.0891	0	20.15	20.15	0	0	0
5	5	0	2.416	0.0891	0	16.45	16.45	0	0	0
6	6	0	2.416	0.0891	8.84	23.85	23.85	0	0	0
7	7	0	2.416	0.0891	8.84	20.15	20.15	0	0	0
8	8	0	2.416	0.0891	8.84	16.45	16.45	0	0	0

Figure 4.3: Data for transmission line tower

Based on figure 4.3 above, the data comes from LCC module. This type considered real transfer matrix of conductor and the imaginary part from matrix transformation is neglected. The selected Bergeron model is based on constant parameter of K. C. Lee, or Clark model. Standard data for this system type includes:

- **Rho** – ground resistivity (ohm) of homogeneous earth [Carson's theory]
- **Freq. init** – frequency at which line parameters are calculated [Bergeron and PI models], or lower-frequency point [J. Marti, Noda, and Semlyen model]
- **Length**- is length of overhead line [m/km/miles]

4.2.2 Cross-Arm Model (Upper, Middle, and Lower Phase Conductor with Shield Wire)

Cross arms model in ATP-EMTP is expressed basically by wave impedance and calculated via the formula described in chapter 2 (literature review). The arm width at the junction point, for upper, middle, and lower, phase of conductor is the same, and the three conductors have the same wave-impedance value. While the width of arms at junction point for shield wire is different from conductor's width, resulting in a different wave-impedance value. Calculation for wave impedance of shield wire and phase conductor are:

1. Upper, middle, and lower, phase of conductor

$$Z_{AK} = 60\ln\left(\frac{2h}{r_A}\right)$$

$$Z_{AK} = 60\ln\left(\frac{2x28.22}{\frac{1}{4}x1.3}\right)$$

$$Z_{AK} = 309.426\Omega$$

2. Shield wire

$$Z_{AK} = 60\ln\left(\frac{2h}{r_A}\right)$$

$$Z_{AK} = 60\ln\left(\frac{2x28.22}{\frac{1}{4}x1.1}\right)$$

$$Z_{AK} = 319.45\Omega$$

Figure 4.4 shows the data that used for cross arms.

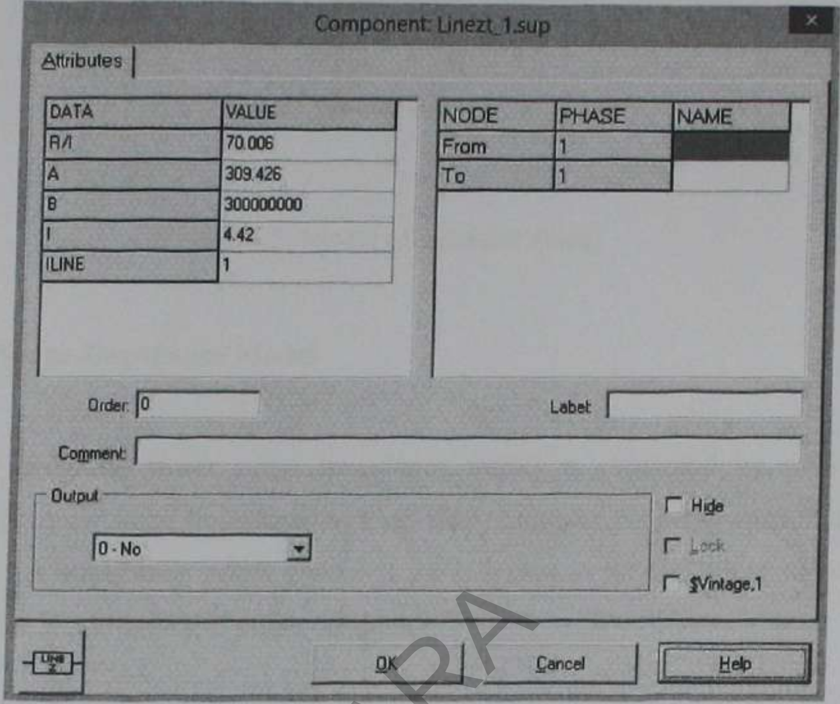


Figure 4.4: Data for the cross-arms impedance

Details of input parameter for cross-arms impedance (LINEZT_1 - Distributed parameters, sigle phase) model, explained as follow:

- R/l = Resistance pr. length in [Ohm/length]
- ILINE = 1: A=Modal surge impedance in [ohm] Z=sqrt(L'/C')
- ILINE = 1: B=propagation velocity in [length/sec.] v=1/sqrt(C'*L')
- L = length of line (>0 for transposed lines

4.2.3 Insulator-String

Insulator string used as a mechanical protection (mechanical insulator) system between live conductor and the pole. This insulator string in ATP program is design by using capacitor parallel with voltage-dependent flashover switches connected between phase and tower [15] Figure 4.5 shows the model of insulator string.

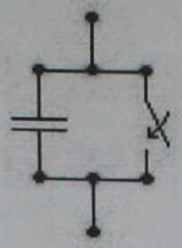


Figure 4.5: Model of insulator string

4.2.4 Tower Surge-Impedance Model

In ATP-EMTP program, tower surge impedance model is expressed by wave impedance . This tower surge impedance is most likely same as the cross-arms, but it's different at the impedance value. Below is the calculation for the tower surge impedance of both shield wire and phase conductor.

$$Z_{Pole} = 60\ln\left(\frac{2\sqrt{2}Hc}{r_c}\right) - 60$$

$$Z_{Pole} = 60\ln\left(\frac{2\sqrt{2}(28.22)}{4.42}\right) - 60$$

$$Z_{Pole} = 113.62\Omega$$

Figure 4.6 shows how to set the value of Tower Surge-Impedance Model in component line setup of ATP/EMTP software.

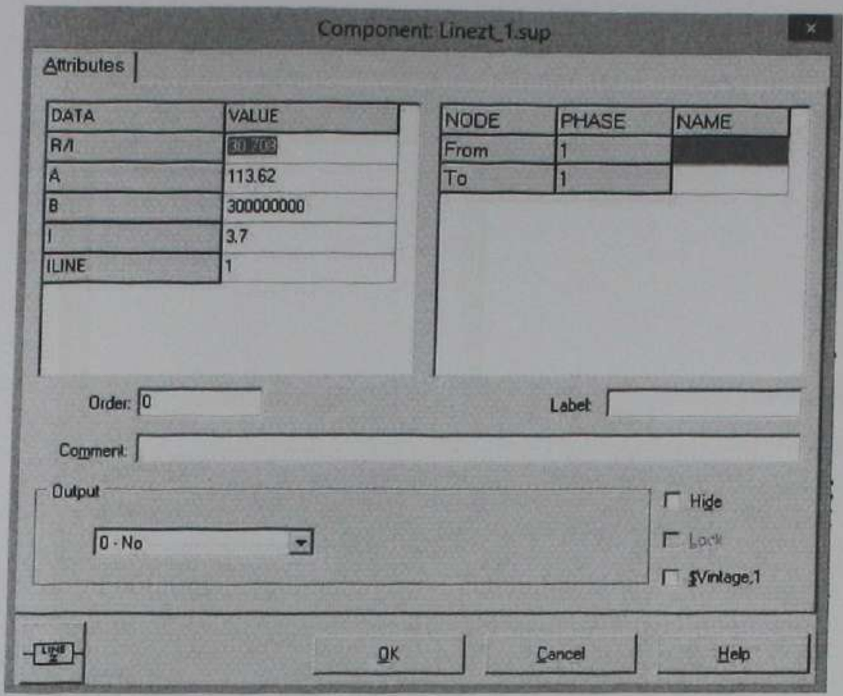


Figure 4.6: Model of tower surge impedance

4.2.5 Tower-Footing Resistance Model

Tower footing resistance is the one of important parameter that need to be consider in modelling transmission line. Therefore, the tower footing resistance, R_0 need to design properly with a suitable value and it is represented by a resistor (in ATP-EMTP). For 132kV overhead transmission line commonly the value of R_0 10 Ω (ohm) or less as shows in figure 4.7.

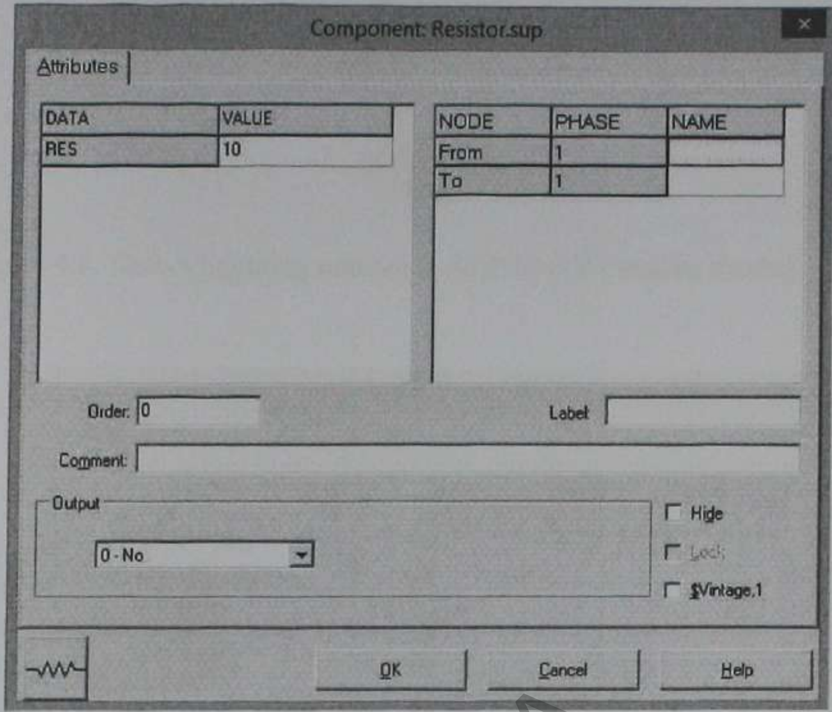


Figure 4.7: Tower Footing Resistance (10 Ω)

4.3 Lightning Source

Lightning voltage/current sources in ATP-EMTP program are:

- Two exponentials surge source
- Heidler surge source
- 1-phase metal oxide varistor
- 3-phase metal oxide varistor
- Zener's diode

There a five sources of lightning for ATP-EMTP program. The selected source is heidler surge source. This is modeled as an impulse current parallel with lightning-path impedance. The selected resistance value is 400 Ω [16]. Figure 4.8 shows its configuration.

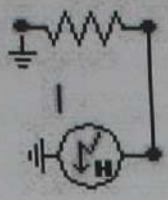


Figure 4.8: Shows lightning sources in ATP-EMTP (heidler model)

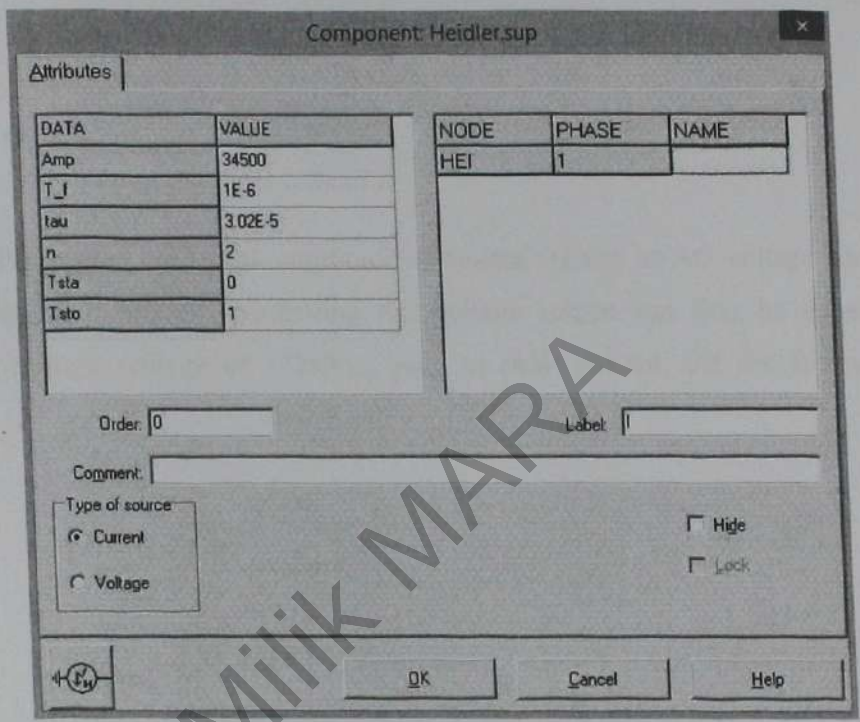


Figure 4.9: Data for heidler surge sources model

Details of input parameter of the heidler-type lightning source (HEIDLER - Surge function. Heidler type. TYPE 15):

U/I	=	0: Voltage source ; -1: Current source.
Amp	=	Multiplicative number in [A] or [V] of the function. Does not represent peak value of surge.
T_f	=	The front duration in [sec]. Interval between t=0 to the time of the function peak.
Tau	=	The stroke duration in [sec]. Interval between t=0 and the point on the tail where the function amplitude has

fallen to 37% of its peak value.

N = Factor influencing the rate of rise of the function.

Increased n increases the maximum steepnes.

Tsta = Starting time in [sec.]. Source value zero for T<Tsta.

Tsto = Ending time in [sec]. Source value zero for T>Tsto.

HEI = Positive node of exponential surge function.

Negative node is grounded.

= Amp * (t/T_f)^n/(1+(t/T_f)^n)*exp(-t/tau)

4.4 AC Voltage Source

ATP-EMTP program used peak amplitude of system voltage as AC voltage source for the simulation process. Modelling AC voltage source can thus be done by converting system voltage of $132kV_{L\text{-}L\ (RMS)}$ to peak voltage, via the following equation:

$$V_{peak} = \frac{\sqrt{2}}{\sqrt{3}}\left[V_{L-L(RMS)}\right]$$

$$V_{peak} = \frac{\sqrt{2}}{\sqrt{3}}\left[132kV\right]$$

$$V_{peak} = 107777.5V$$

This figure shows input data for AC voltage source used for this simulation.

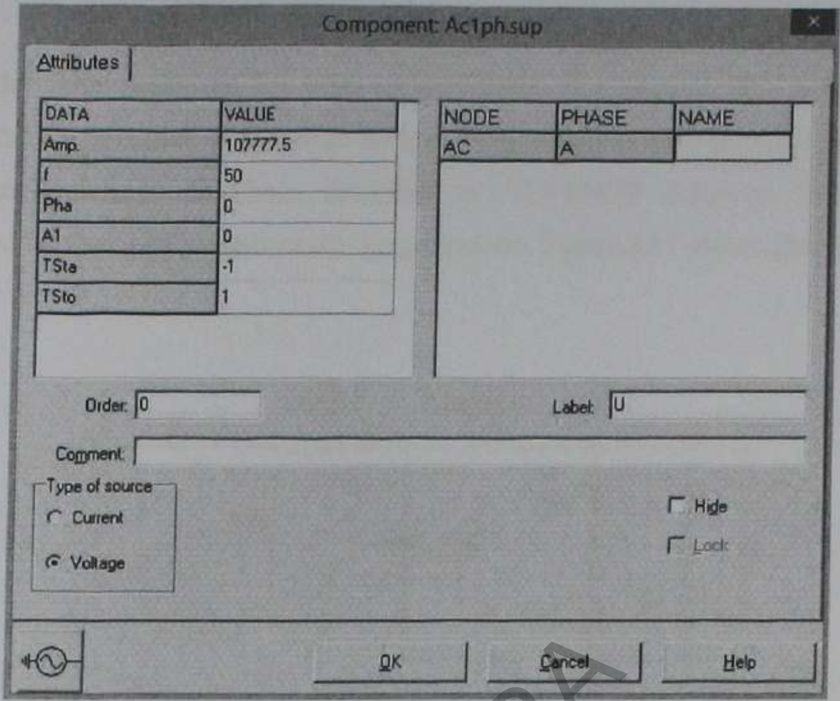


Figure 4.10: Input data AC voltage source

The details AC voltage source parameter [AC1PH - Steady-state (cosine) function].

- U/I = 0: Voltage source. ; -1: Current source.
- Amp = The peak value in [A] or [V] of the function.
- F = Frequence in [Hz].(In Malaysia 50Hz ± 2%.)
- Pha = shift in degrees or seconds depending on A1.
- Tsta = Starting time in [sec.]. Source value zero for T<Tsta.
- Tsto = Ending time in [sec]. Source value zero for T>Tsto.
- AC = Positive node of cosine function.
  Negative node is grounded.

4.5 Surge Arrester Model

All of the value parameter has been showed before in chapter 2. This is the design circuit for performance of the surge arrester from the lightning injected. All value of nonlinear resistance has been describes in ATP-EMTP software. This model proposed by their analysis about this surge arrester. Figure 4.11 shows Haddad Surge Arrester circuit.

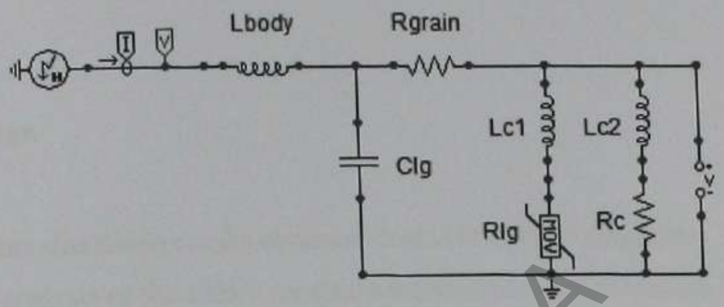


Figure 4.11: Surge Arrester Haddad Model

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

This chapter presents simulation results obtained from ATP-EMTP simulation. They are based on back flashover analysis of the 132kV overhead transmission-line modelled. The first part is comparison of simulation on the Haddad surge arrester model by injecting several value of current from a datasheet ABB manufacturer and the second part of this chapter mainly discusses and analyses simulation results obtained from four magnitudes of lightning current injected into the top tower of the transmission line. Back flashover voltage occurring across insulator strings at each phase is studied. Complete analysis and discussion on waveforms obtained from simulation results are presented in this chapter.

5.2 Part 1: Simulation of surge arrester for each injected lightning

The surge arrester model circuit will be injected with lightning current and analyzed. The effect of surge arrester is analyzed as the surge arrester is installed on the transmission line tower. The error percentage of the surge arrester are calculated, it is thus compared the simulation results with datasheets from ABB manufacturer. The simulations must be done by using the readings datasheets from ABB. The reason is to compare the results with Haddad surge arrester model.

5.2.1 Simulation of surge arrester based on ABB datasheets

Table 5.1 shows the maximum Residual Voltage for ABB Surge Arrester with the rated value of 120kV Continuous Operating Voltage (U_r) and 98kV maximum Continuous Operating voltage (MCOV). Appendix A shows the detail of ABB Surge Arrester datasheet.

Table 5.1: ABB datasheets for transmission line arrester rated of 120 kV [17].

Rated voltage (U_r - kV_{rms})	Max. residual voltage with current wave			
	5 kA kV_{peak}	10 kA kV_{peak}	20 kA kV_{peak}	40 kA kV_{peak}
120	260	273	299	328

a) Lightning current = 10kA front and tail time of 8/20 µs

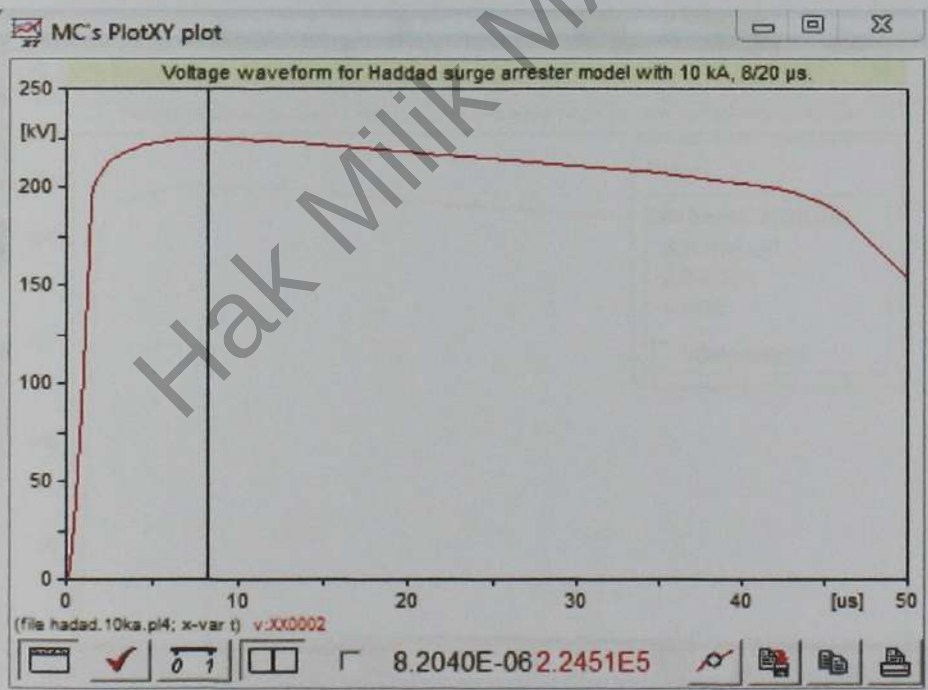


Figure 5.1: Voltage waveform for Haddad surge arrester model with 10 kA, 8/20 µs.

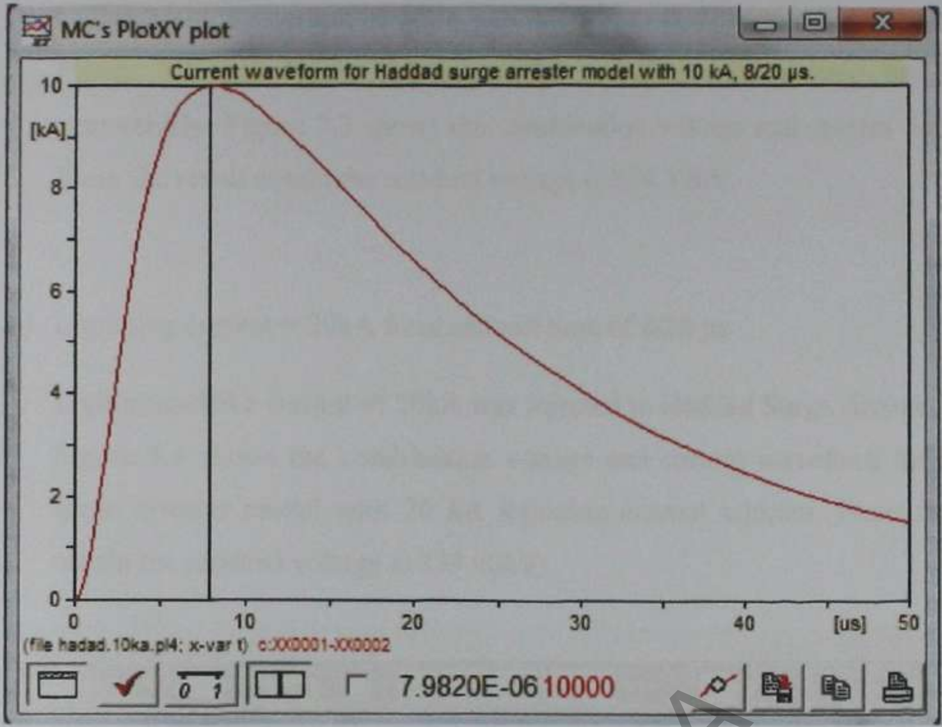


Figure 5.1: Current waveform for Haddad surge arrester model with 10 kA, 8/20 µs.

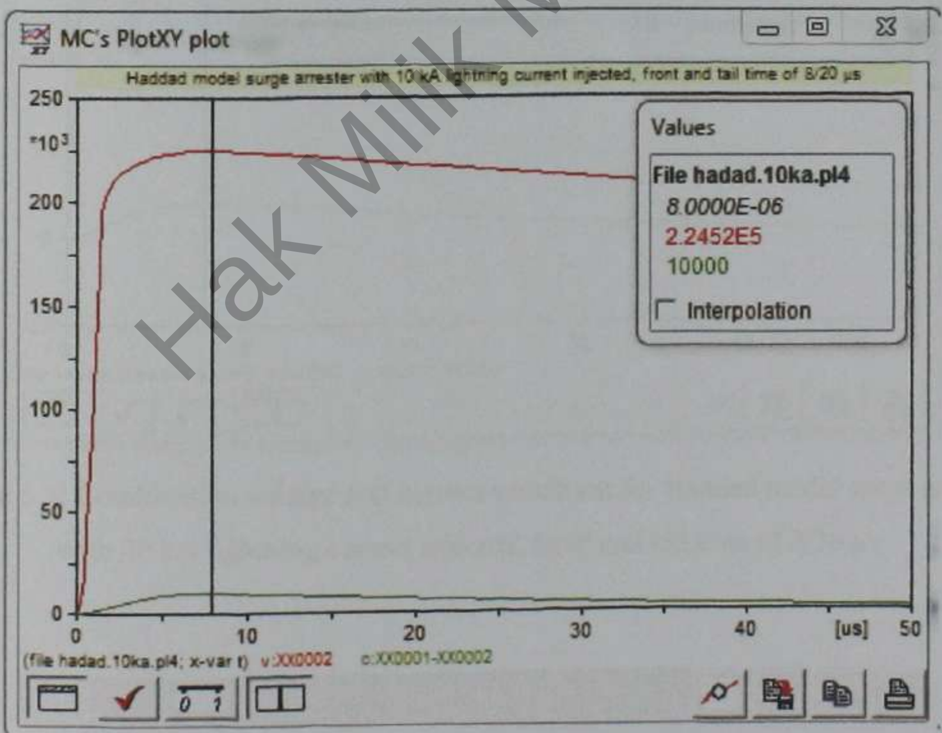


Figure 5.2: Combination voltage and current waveform for Haddad surge arrester model with 10 kA lightning current injected, front and tail time of 8/20 µs.

Lightning-strike current of 10kA was injected to Haddad Surge Arrester Model. Figure 5.1 and Figure 5.2 show the waveform for voltage and current respectively. Figure 5.3 shows the combination voltage and current waveform. From the result obtain the residual voltage is 224.52kV.

b) Lightning current = 20kA front and tail time of 8/20 μs

Lightning-strike current of 20kA was injected to Haddad Surge Arrester Model. Figure 5.4 shows the combination voltage and current waveform for Haddad surge arrester model with 20 kA lightning current injected. From the result obtain the residual voltage is 239.90kV.

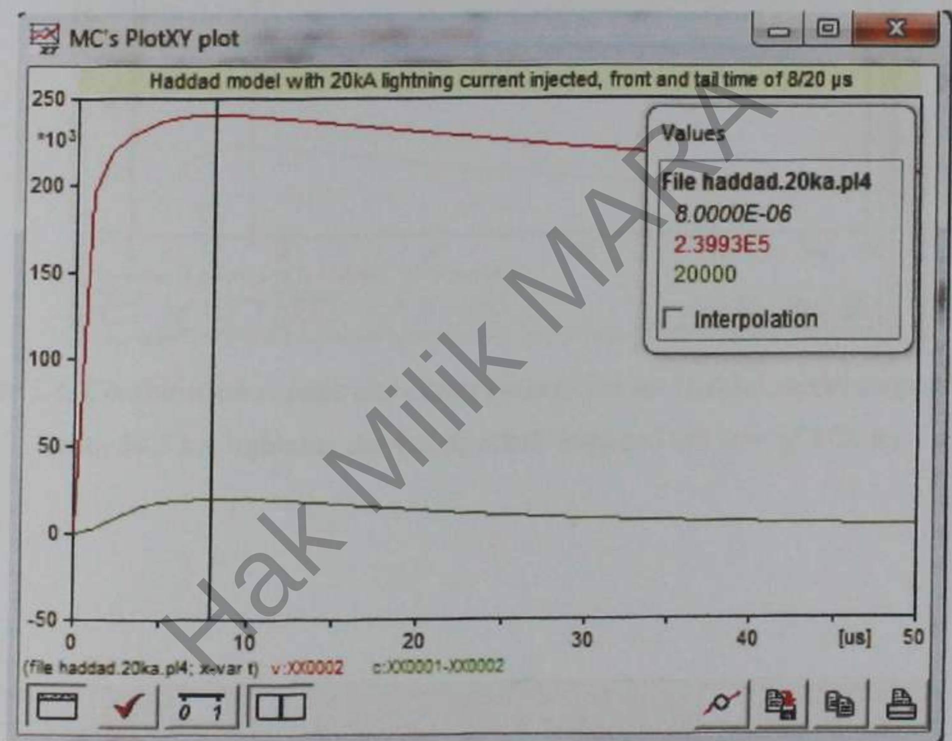


Figure 5.3: Combination voltage and current waveform for Haddad model surge arrester with 20 kA lightning current injected, front and tail time of 8/20 μs.

c) Lightning current = 34.5kA front and tail time of 8/20 μs

Lightning-strike current of 34.5kA was injected to Haddad Surge Arrester Model. Figure 5.5 shows the combination voltage and current waveform for Haddad surge arrester model with 34.5kA lightning current injected. From the result obtain the residual voltage is 259.14kV.

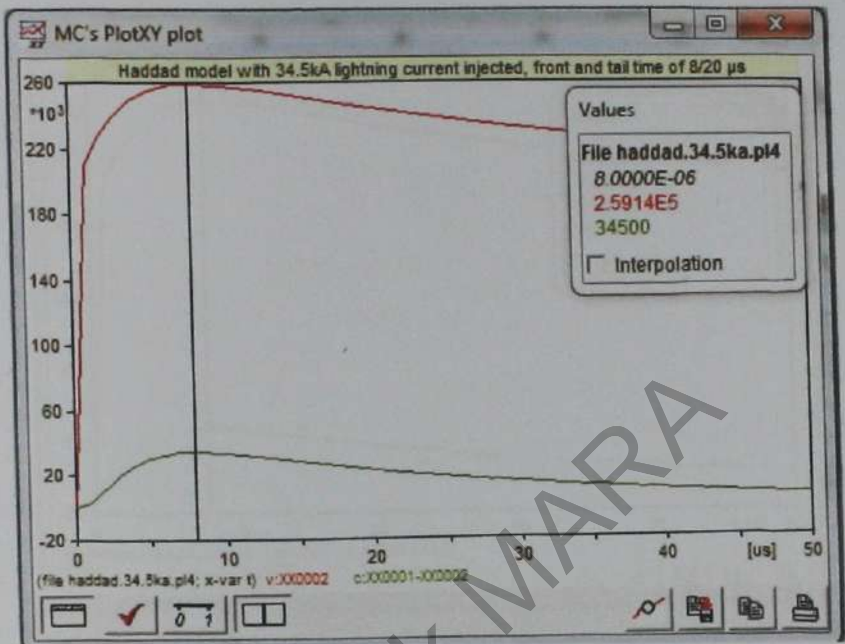


Figure 5.4: Combination voltage and current waveform for Haddad model surge arrester with 34.5 kA lightning current injected, front and tail time of 8/20 μs.

d) Lightning current = 40kA front and tail time of 8/20 μs

Lightning-strike current of 40kA was injected to Haddad Surge Arrester Model. Figure 5.6 shows the combination voltage and current waveform for Haddad surge arrester model with 40kA lightning current injected. From the result obtain the residual voltage is 266.06kV.

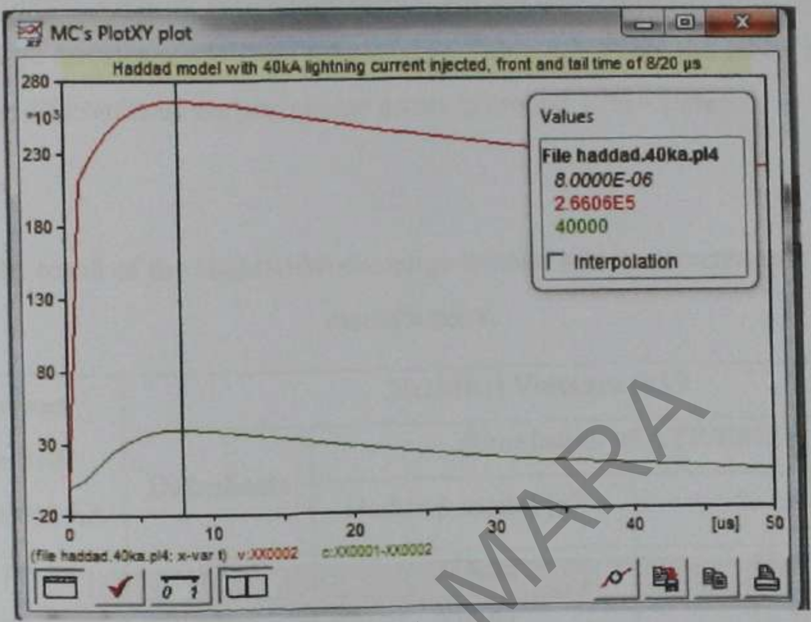


Figure 5.5: Combination voltage and current waveform for Haddad model with 40kA lightning current injected, front and tail time of 8/20 μs.

d) Comparison between the Haddad Surge Arrester Model with ABB manufacturer surge arrester.

Figure 5.3 to Figure 5.6, was simulated by ATP/EMTP software then it shows that the difference between Haddad of surge arrester model (based on ABB manufacturer). The Haddad surge arrester model was simulated and it gives a different value of percentage errors. All the data collected from the simulation surge arrester model was tabulated in Table 5.2. From the table, it shows that the difference of the percentage errors is around 17% - 20%.

Table 5.2: The result of the Haddad Model surge arrester and its percentage errors of ABB manufacturer.

Current injected (lightning) kA	**Residual Voltages (kV)**		
	Datasheets	**Simulation of ATP/EMTP**	
		Haddad model (kV)	**% errors**
10	273	224.52	17.76%
20	299	239.93	19.76%
40	328	266.06	18.88%

5.3 Part 2: Simulation of wave before and after installation surge arrester of on the transmission line

The modelled 132kV overhead transmission line with seven towers was used for lightning-surge simulation. The towers were modelled in Simple Transmission Line Model (see previous chapter). Figure 5.1 shows the model for a part of the simulation circuit. Appendix C is a full diagram of the model.

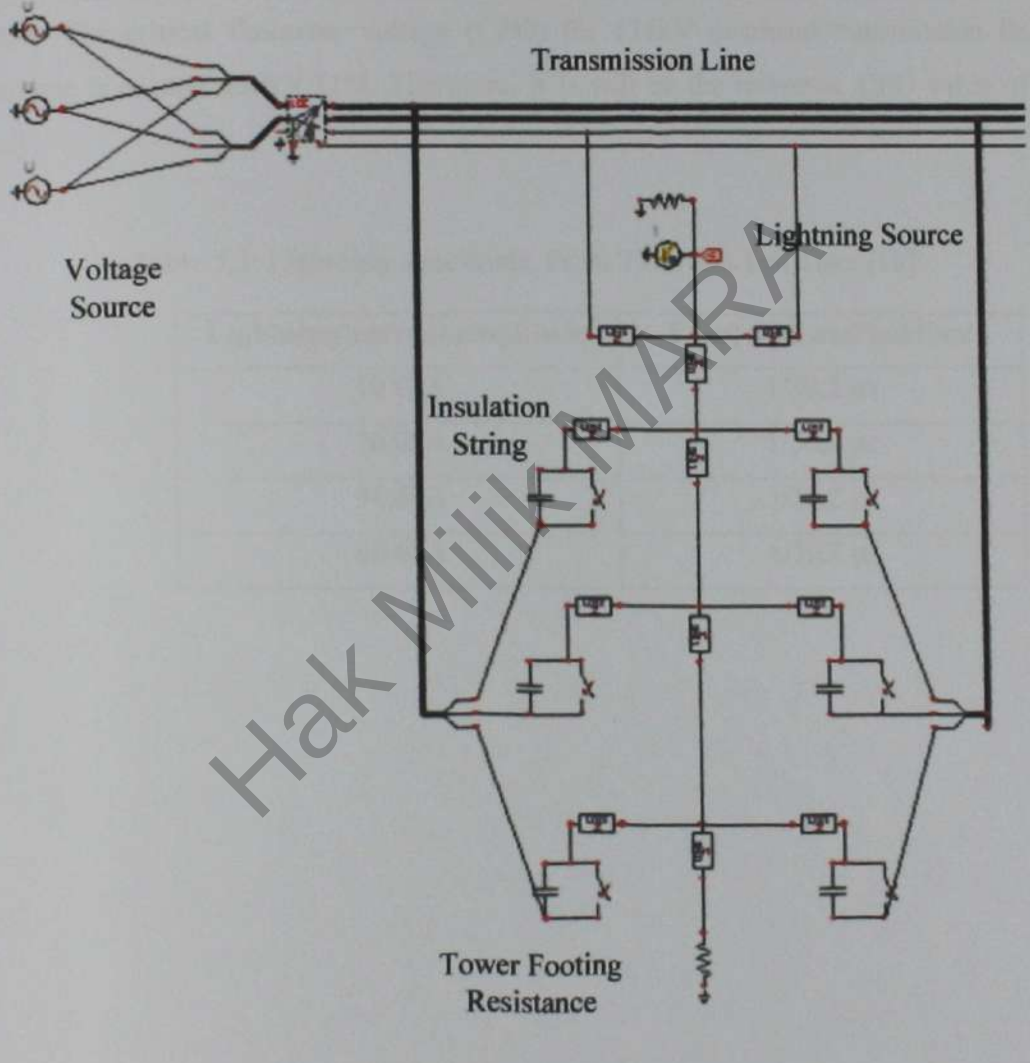


Figure 5.6: Close up of the transmission line.

In this study, four amplitudes of lightning current (positive polarity) were used to perform back flashover analysis on the modelled circuit. The simulation is based basically on lightning activities in Malaysia which has an average lightning current of 34.5kA [18]. The value of lightning current injected to the circuit is according to the readings on datasheets from the manufacturer which are 10kA, 20kA, and 40kA. In order to analyze reduction of the back flashover phenomenon after installing surge arrester on the transmission line tower, a suitable value of current injection is 10kA, 20kA , 34.5kA and 40kA. Thus, this value will be used to show either the surge arrester is protecting the transmission line tower form back flashover phenomenon. The front time and tail time use are declared in the table below. The critical flashover voltage (CFO) for 132kV overhead transmission line in Malaysia is around 650kV [18]. Therefore, it is will be the reference CFO value of this study.

Table 5.3: Lightning Amplitude, Front Time and Tail Time [18].

Lightning current amplitude	**Front time and tail time**
10.0kA	1/30.2 μs
20.0kA	1/30.2 μs
34.5kA	1/30.2 μs
40.0kA	1/30.2 μs

5.3.1 Wave before install surge arrester on the transmission line.

a) Lightning current = 10kA front and tail time of 1/30.2 μs

Lightning-strike current of 10kA was injected into the top tower. Figure 5.8 shows the waveforms for voltages obtained across insulator strings at each phase. Figure 5.9 is a close-up of the waveforms.

Figure 5.7: Wave before install arrester with injected current of 10kA.

Figure 5.8: Close-up before install surge arrester with injected current of 10kA.

Table 5.4: Table of residual voltage with injected current of 10 kA.

Phase /level	Residual Voltage (kV)	Flashover
Phase A (Upper)	695.37 kV	Y
Phase B (Middle)	418.39 kV	N
Phase C (lower)	67.611 kV	N

Y : Flashover N : No Flashover

b) Lightning current = 20kA front and tail time of 1/30.2 μs

Lightning-strike current of 20kA was injected into the top tower. Figure 5.10 shows the waveforms for voltages obtained across insulator strings at each phase. Figure 5.11 is a close-up of the waveforms.

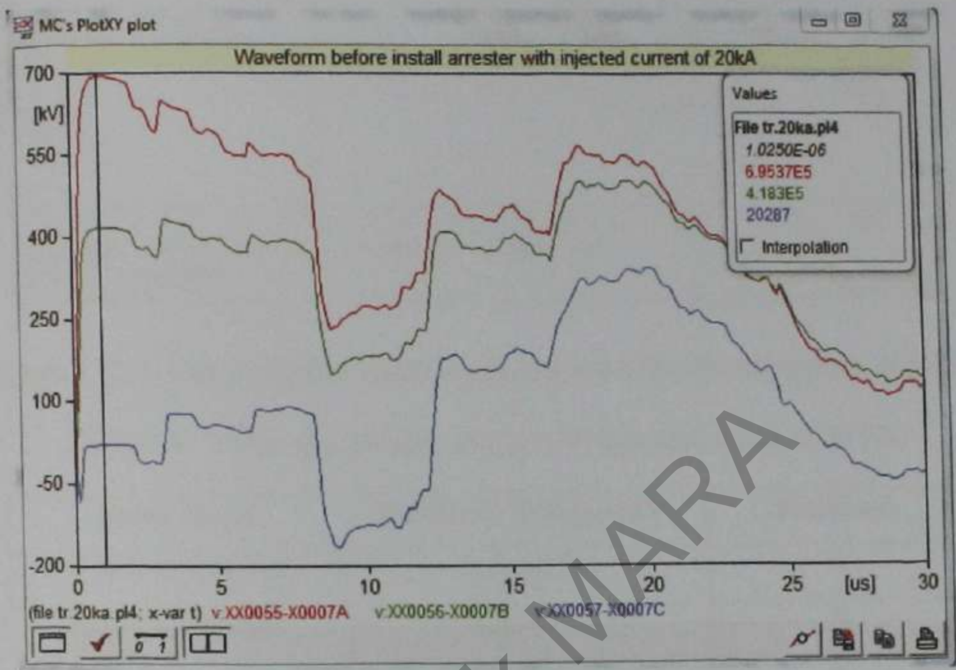


Figure 5.9: Waveform before install arrester with injected current of 20kA.

Figure 5.10: Close-up before install surge arrester with injected current of 20kA.

Table 5.5: Table of residual voltage with injected current of 20 kA.

Phase /level	**Residual Voltage (kV)**	**Flashover**
Phase A (Upper)	695.24 kV	Y
Phase B (Middle)	418.19 kV	N
Phase C (lower)	20.255 kV	N

Y : Flashover N : No Flashover

c) Lightning current = 34.5kA front and tail time of 1/30.2 μs

Lightning-strike current of 34.5kA was injected into the top tower. Figure 5.12 shows the waveforms for voltages obtained across insulator strings at each phase. Figure 5.13 is a close-up of the waveforms.

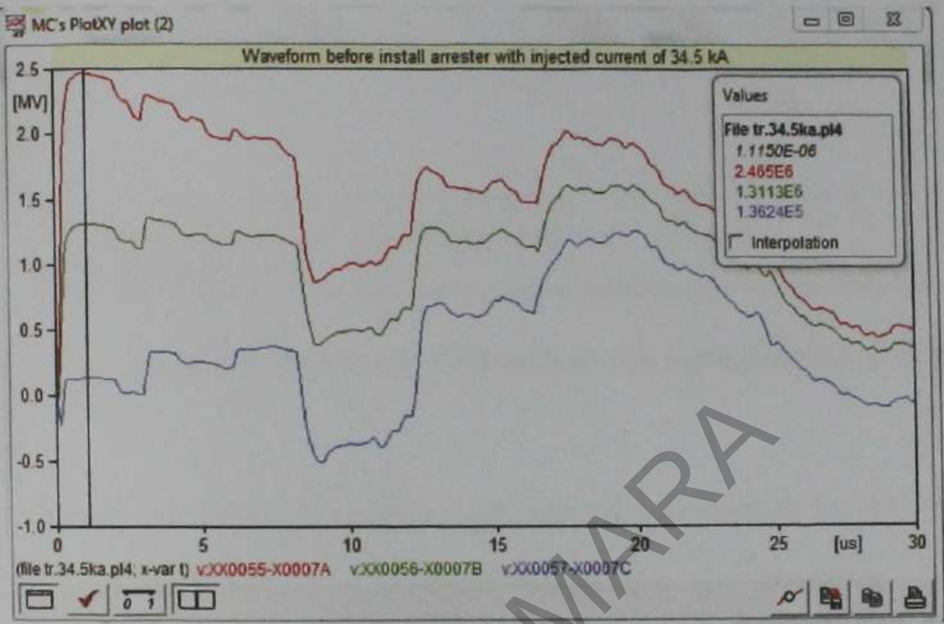


Figure 5.11: Waveform before install arrester with injected current of 34.5 kA.

c) Lightning current = 34.5kA front and tail time of 1/30.2 μs

Lightning-strike current of 34.5kA was injected into the top tower. Figure 5.12 shows the waveforms for voltages obtained across insulator strings at each phase. Figure 5.13 is a close-up of the waveforms.

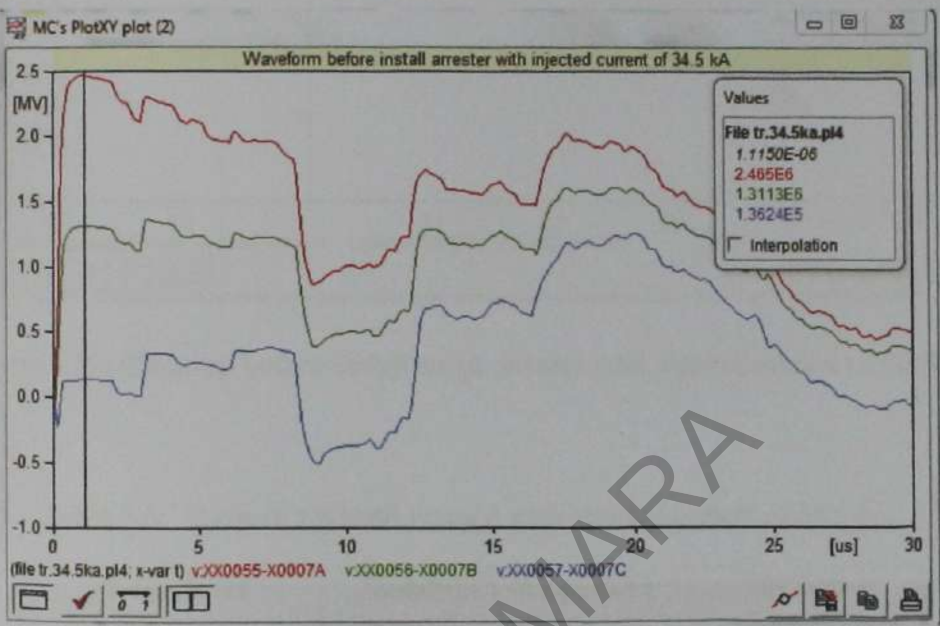


Figure 5.11: Waveform before install arrester with injected current of 34.5 kA.

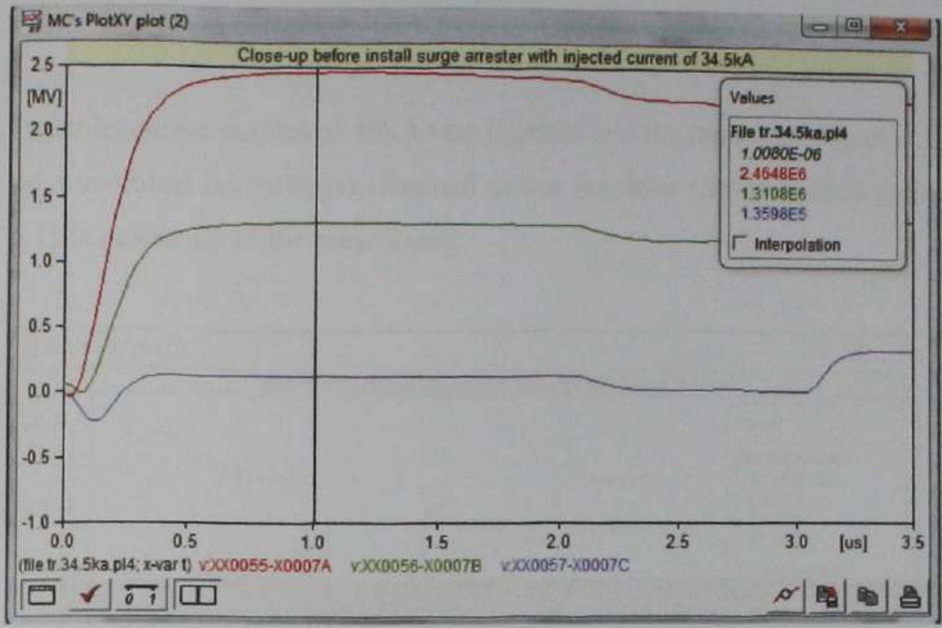


Figure 5.12: Close-up before install surge arrester with injected current of 34.5kA.

Table 5.6: Table of residual voltage with injected current of 34.5 kA.

Phase /level	Residual Voltage (kV)	Flashover
Phase A (Upper)	2464.8 kV	Y
Phase B (Middle)	1310.8 kV	Y
Phase C (lower)	135.98 kV	N

Y : Flashover N : No Flashover

d) Lightning current = 40kA front and tail time of 1/30.2 μs

Lightning-strike current of 40kA was injected into the top tower. Figure 5.14 shows the waveforms for voltages obtained across insulator strings at each phase. Figure 5.15 is a close-up of the waveforms.

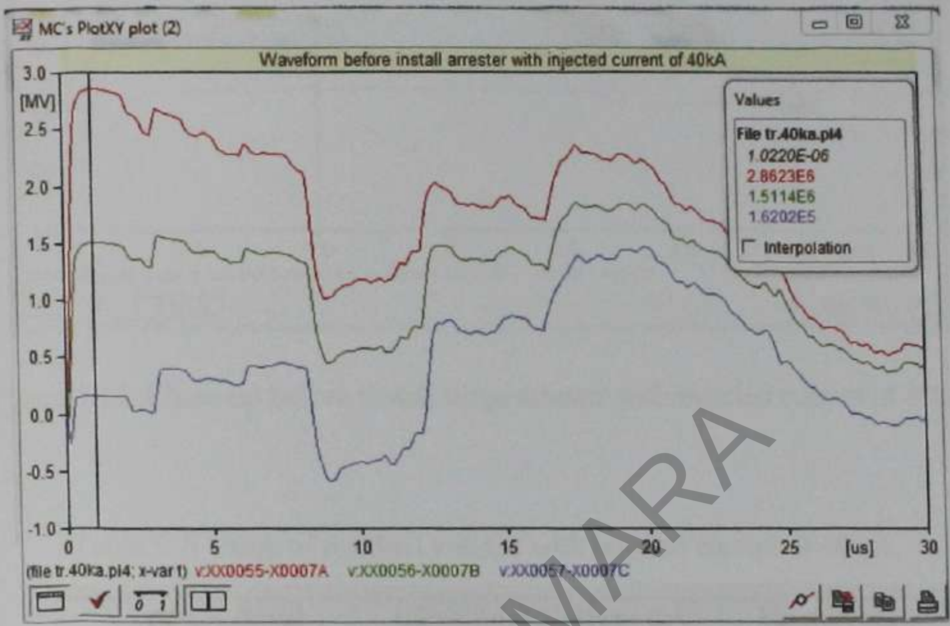


Figure 5.13: Wave before install arrester with injected current of 40 kA.

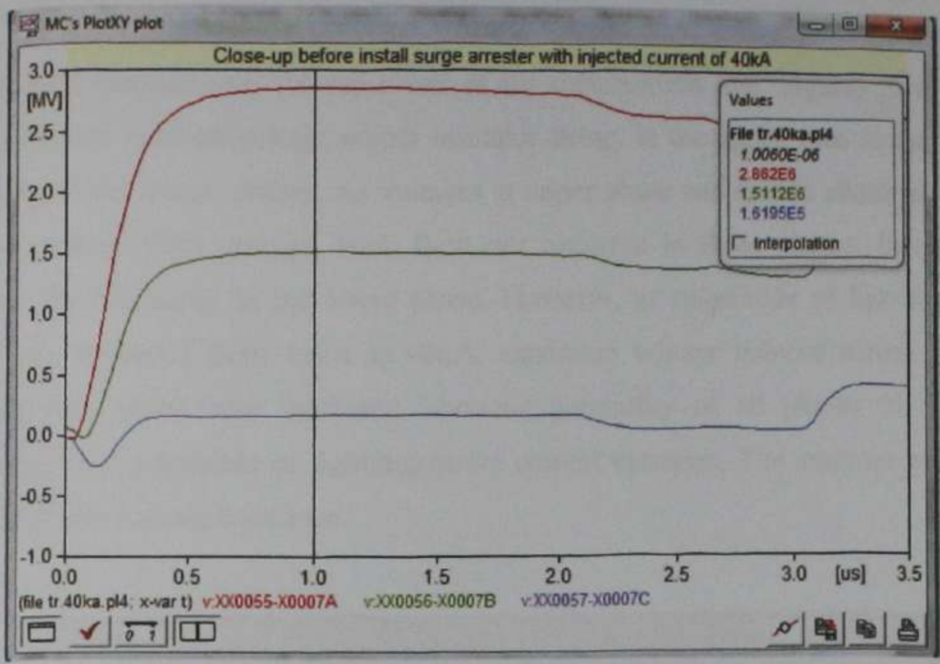


Figure 5.14: Close-up before install surge arrester with injected current of 40kA.

Table 5.7: Table of residual voltage with injected current of 40 kA.

Phase /level	Residual Voltage (kV)	Flashover
Phase A (Upper)	2862.0	Y
Phase B (Middle)	1511.2	Y
Phase C (lower)	161.95	N

Y : Flashover N : No Flashover

Figures 5.8 to 5.15 show amplitudes of induced voltage across insulator strings when lightning-strike current is injected into the top of the middle of transmission-tower before install surge arrester.

According to Figures 5.8 and 5.9 maximum voltage induced across the insulator string is observed in the upper phase, followed by in the middle phase, and then in the lower phase, at 1µs front time. According to the CFO determined for this analysis (650kV), voltage at only the upper and the middle phases exceeds 650kV; back flashover thus occurred only in the two phases [18].

The same phenomena occurred when 20kA, 34.5kA, and 40kA lightning-strike currents were injected into the top tower of the transmission line. Figures 5.10 to 5.15 show maximum induced voltage across insulator string, in the upper, then in the middle, and finally in the lower, phases. As voltages at upper phase and middle phase are greater than the defined CFO voltage, back flashover occurred in those phases. In all cases, flashover did not occur in the lower phase. However, as magnitude of lightning-strike current was increased from 10kA to 40kA, maximum voltage induced across insulator string in each phase also increased, showing possibility of all phases to flashover increasing when magnitude of lightning-strike current increases. The analyses were done with 10Ω tower-footing resistance.

5.3.2 Wave after install surge arrester on the transmission line.

When a lightning strike hits the earth wire, the current dissipation involves an increase to the tower top voltage and eventually the flashover of one or several insulators can take place. In this study the phase angle were not be consider because the surge arrester were installed in parallel with the insulation strings. Appendix D shows that surge arrester connection to the 132kv Transmission line.

a) Lightning-strike current of 10kA was injected into the top tower. Figure 5.16 shows the waveforms for voltages obtained across insulator strings at each phase. Figure 5.17 is a close-up of the waveforms.

Figure 5.15: Wave after install arrester with injected current of 10kA.

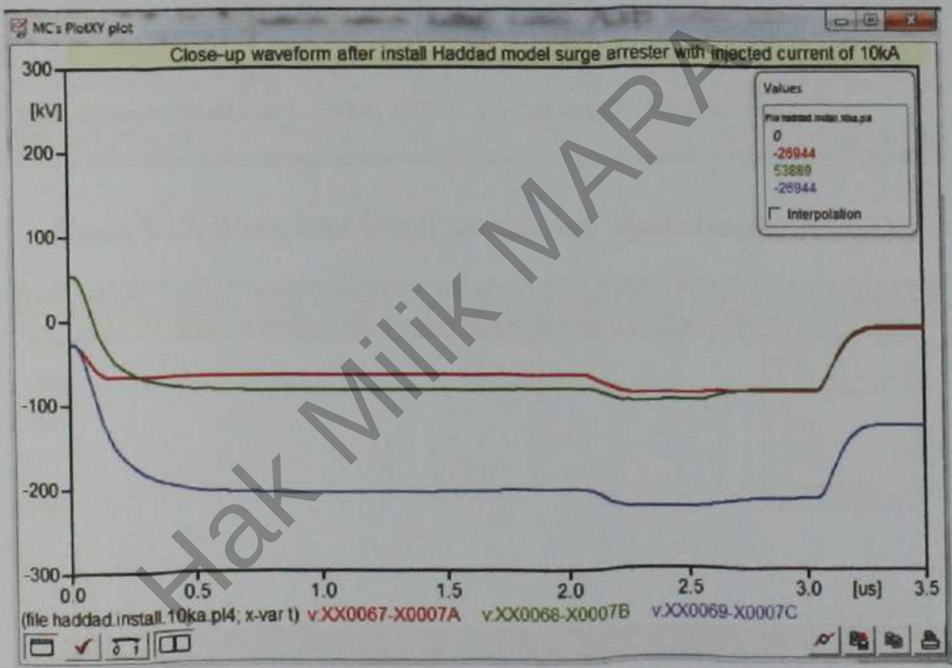


Figure 5.16: Close-up waveform after install Haddad model surge arrester with injected of 10kA.

b) Lightning-strike current of 20kA was injected into the top tower. Figure 5.18 shows the waveforms for voltages obtained across insulator strings at each phase. Figure 5.19 is a close-up of the waveforms.

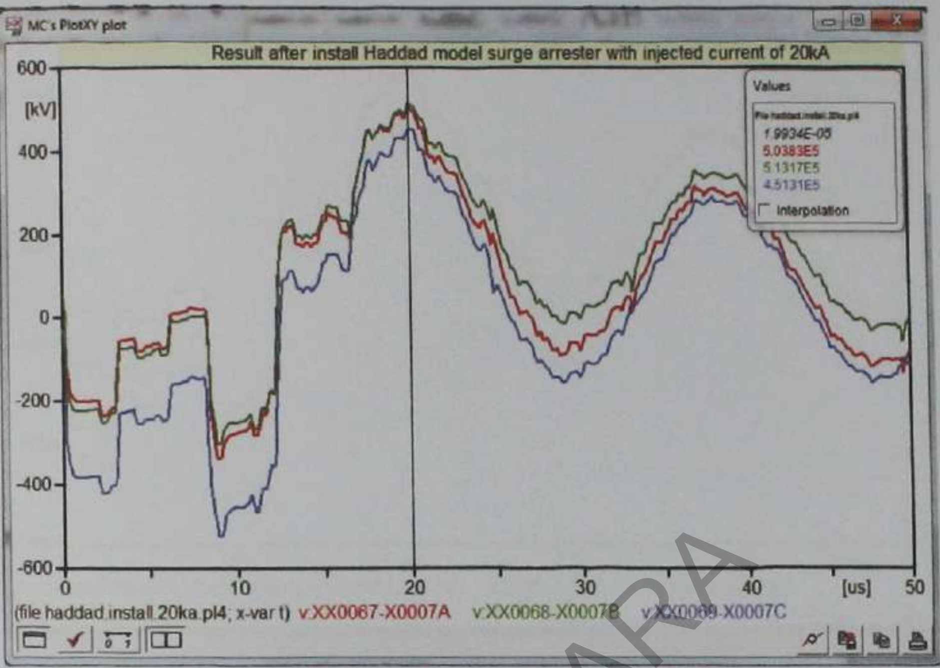


Figure 5.17: Wave after install arrester with injected current of 20kA.

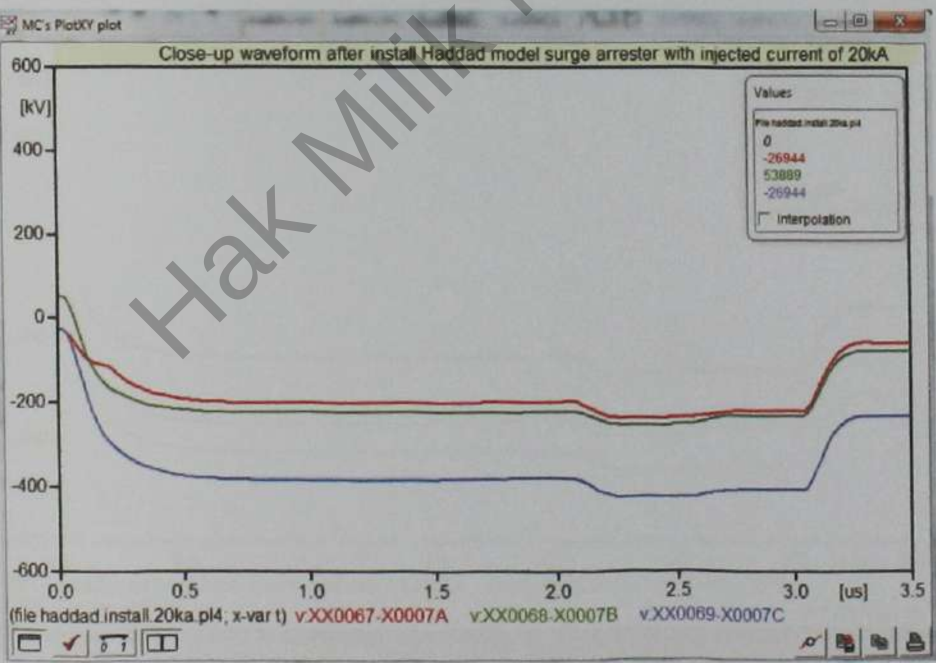


Figure 5.18: Close-up waveform after install Haddad model surge arrester with injected of 20kA.

c) Lightning-strike current of 34.5kA was injected into the top tower. Figure 5.20 shows the waveforms for voltages obtained across insulator strings at each phase. Figure 5.21 is a close-up of the waveforms.

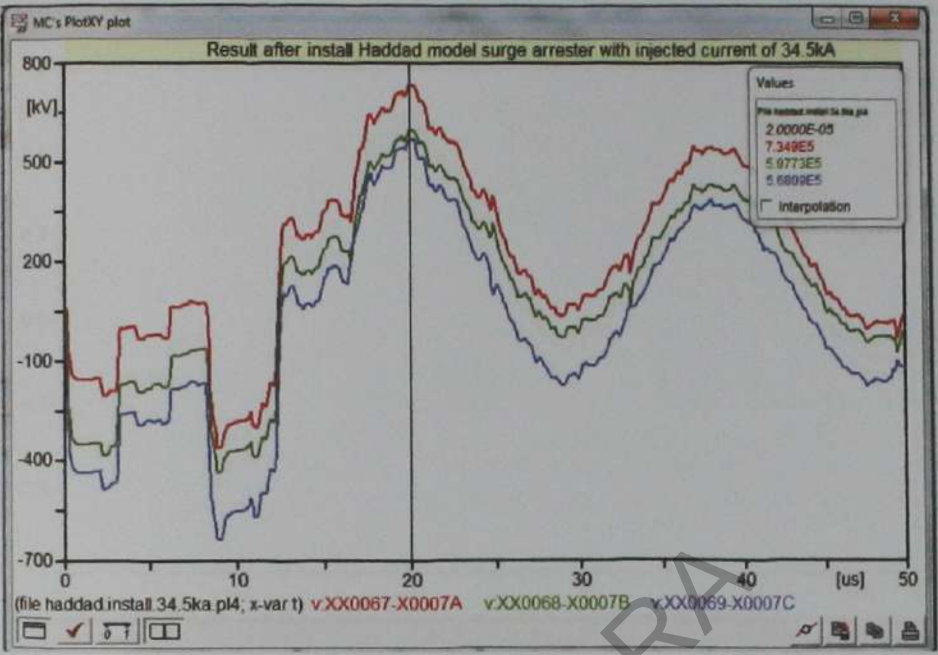


Figure 5.19: Wave after install arrester with injected current of 34.5 kA.

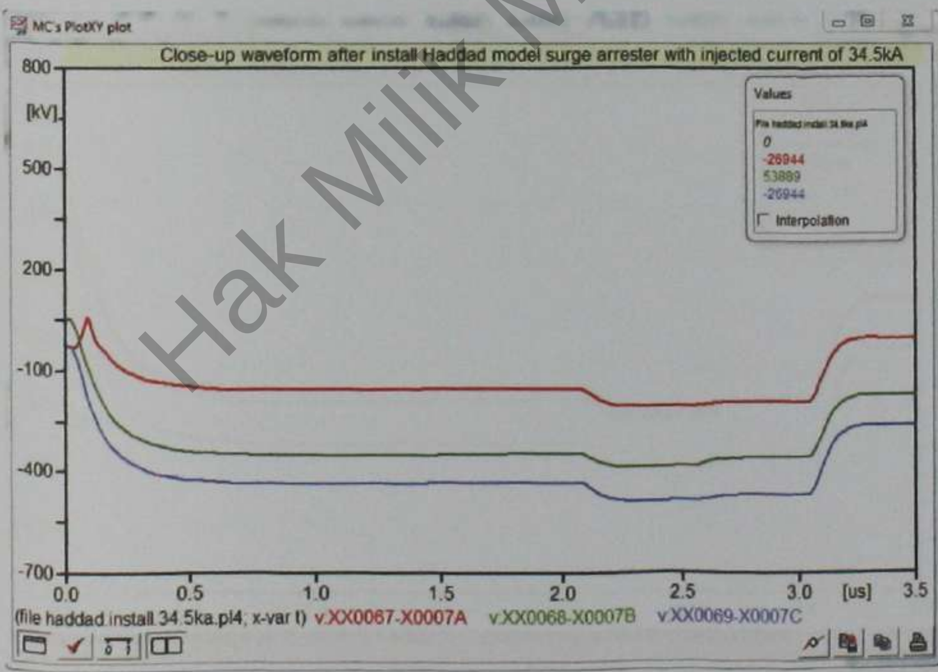


Figure 5.20: Close-up waveform after install Haddad model surge arrester with injected of 20kA.

d) Lightning-strike current of 40kA was injected into the top tower. Figure 5.22 shows the waveforms for voltages obtained across insulator strings at each phase. Figure 5.24 is a close-up of the waveforms.

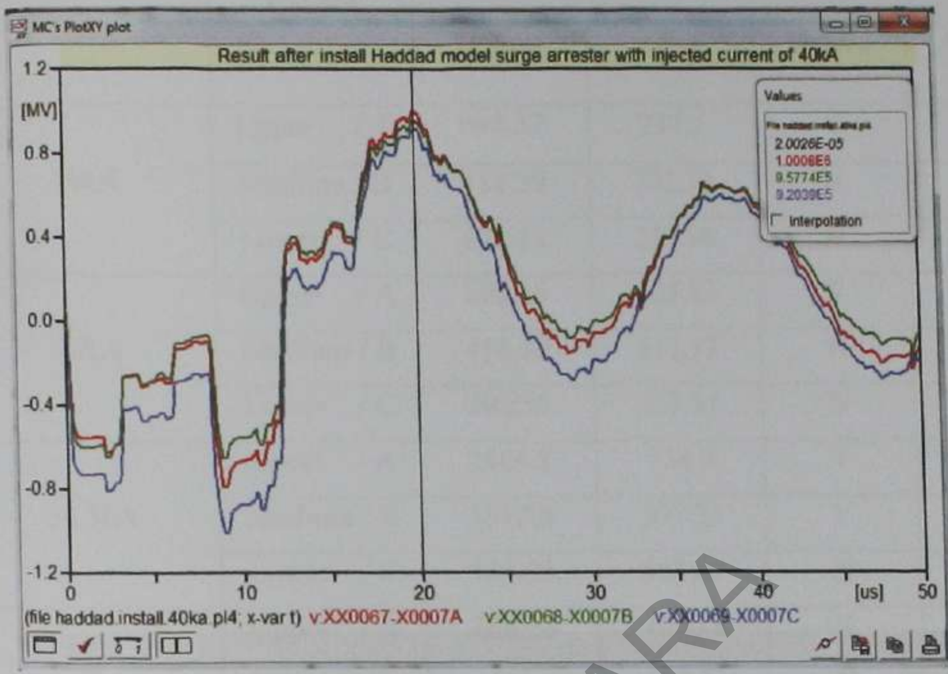


Figure 5.21: Wave after install arrester with injected current of 40kA.

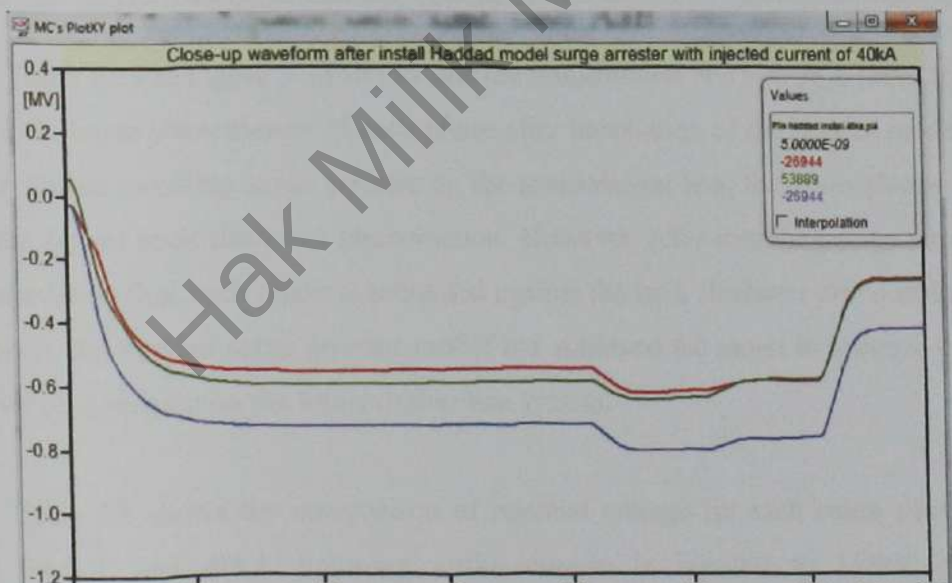


Figure 5.22: Close-up waveform after install Haddad model surge arrester with injected of 20kA.

Table 5.8: Table of residual voltage for each phases for a different lightning current injected.

Current injected (kA)	Phases	Residual voltage (kV)		Flashover	
		Before	After	Before	After
10kA	Upper / A	695.37	237.1	Y	N
	Medium / B	418.39	283.32	N	N
	Lower / C	67.611	213.99	N	N
20kA	Upper / A	695.24	503.83	Y	N
	Medium / B	418.19	513.17	N	N
	Lower / C	20.255	451.31	N	N
34.5kA	Upper / A	2464.8	734.9	Y	Y
	Medium / B	1310.8	597.73	Y	N
	Lower / C	135.98	568.09	N	N
40kA	Upper / A	2862.0	1000.8	Y	Y
	Medium / B	1511.2	957.74	Y	Y
	Lower / C	161.95	920.39	N	Y

Figure 5.16 to Figure 5.23 shows that the transmission line system is protected from the back flashover phenomenon of each phase after installation of the Haddad model surge arrester. Before installing surge arrester on the transmission line, the lower phases are not protected against back flashover phenomenon. However, after installing surge arrester on the transmission line, each phase is protected against the back flashover phenomenon. As a conclusion, the Haddad surge arrester model has achieved the target to improve the back flashover phenomenon on the transmission line system.

Table 5.8 shows the comparison of residual voltage for each phase when 10kA, 20kA, 34.5kA and 40kA lightning strike current is injected to 132kV overhead transmission line before and after installing Haddad Surge Arrester Model. From the simulation results obtained Haddad surge arrester can reduce back flashover effect at the overhead transmission line system.

5.4 Analysis and discussion

This study has completely achieved the first objective, which is redesigned the 132kV transmission line system consists of seven towers. This Bergeron tower model is the most common and suitable model used in the Malaysia transmission line system. This study focuses on the surge arrester whether it can protect the transmission line against back flashover phenomenon the lightning strikes the top of the tower.

The Haddad surge arrester Model circuit has been developed using the ATP/EMTP software. Later, a comparison was made between simulation results that were obtained from simulations that are using values that stated on two different datasheets from ABB manufacture.

The comparison was done between four different surge arrester with three different values of lightning current injection (10kA, 20kA, 34.5kA and 40kA). These prove the Haddad surge arrester model can be implemented on the 132 kV transmission line systems, in order to protect the transmission line from back flashover phenomenon.

The Simulation is done before installing the surge arrester on the transmission line system in order to record at what phase the back flashover occurs. Then, once again the simulation is done, but this time the surge arrester is installed on the transmission line. Finally, the data was compared. The result shows that the surge arrester reduces the back flashover phenomenon, and its protection cover all the phases against the injected lightning current.

As a conclusion, Haddad model was reducing surge at the 132kV transmission line system. In addition, this model showed it can protect the transmission line from damage, by reducing surge voltage during lightning occurring.

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CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter will briefly describes all of the work that has been done, including the entire methods taken, results and the conclusion from the study. The contribution and also the recommendation for this study will also be included

6.2 Conclusion

The study of a transmission line tower of 132kV by using ATP-EMTP software package was successfully done. This transmission line was designed and modeled by referring to the Bergeron model tower that is suitable as for the lightning environment in Malaysia. The effect of surge arrester for reducing the back flashover phenomenon has been analyzed. The value is standardizes consecutively to observe the effect of different types of surge arrester performance.

The results obtained are focusing more on the performance of Haddad surge arrester model in order to protect the transmission line from back flashover occurring in any phases. The installation of the surge arrester has actually shown a positive result as in reducing a back flashover phenomenon on the insulator-string. The surge voltage that cause by lightning is reduced by installing a surge arrester.

As a conclusion, the Haddad surge arrester model was selected to be implemented on the 132 kV transmission line systems, and the simulation shows that the surge arrester can diminish the surge voltage that is produced by the lightning current. Each phase is protected by the surge voltage, so there is no back flashover occurs at any phase of the transmission line. For that reason, all the equipment's either on the transmission line system or on distribution system is protected against this back flashover phenomenon.

6.3 Recommendations

The model circuit of surge arrester and 132kV overhead transmission line system need more improvements to give a better simulation result:

a) Other software package should be tried to develop a model circuit of the overhead transmission line tower.
b) The study about surge arrester model should be continued. After that, may be another model circuit of surge arrester could be proposed to be implemented on the Transmission line system.
c) Further study about the characteristics of the MOV arrester must be conducted in order to build the surge arrester with the best performance.

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APPENDIX A:

ABB Surge Arresters “High Voltage Surge Arresters Zinc Oxide Surge Arrester PEXLIM P-X.” , Product information , Buyer´s Guide.

EXLIM P

Guaranteed protective data 36 - 170 kV

Max. system voltage	Rated voltage	Max. continuous operating voltage 1)		TOV capability 2)		Max. residual voltage with current wave						
		as per IEC	as per ANSI/IEEE			30/60 µs			8/20 µs			
U_m	U_r	U_c	MCOV	1 s	10 s	1 kA	2 kA	3 kA	5 kA	10 kA	20 kA	40 kA
kV_{rms}	kV_{rms}	kV_{rms}	kV_{rms}	kV_{rms}	kV_{rms}	kV_{peak}	kV_{peak}	kV_{peak}	kV_{peak}	kV_{peak}	kV_{peak}	kV_{peak}
36 3)	30	24.0	24.4	34.8	33.0	58.5	60.7	62.2	64.9	68.3	74.8	81.9
	33	26.4	26.7	38.2	36.3	64.4	66.7	68.4	71.4	75.1	82.3	90.1
	36	28.8	29.0	41.7	39.6	70.2	72.8	74.6	77.9	81.9	89.7	98.3
	39	31.2	31.5	45.2	42.9	76.1	78.8	80.8	84.3	88.8	97.2	107
52	42	34	34.0	48.7	46.2	81.9	84.9	87.0	90.8	95.6	105	115
	48	38	39.0	55.6	52.8	93.6	97.0	99.4	104	110	120	132
	54	43	43.0	62.6	59.4	106	110	112	117	123	135	148
	60	48	48.0	69.6	66.0	117	122	125	130	137	150	164
72	54	43	43.0	62.6	59.4	106	110	112	117	123	135	148
	60	48	48.0	69.6	66.0	117	122	125	130	137	150	164
	66	53	53.4	76.5	72.6	129	134	137	143	151	165	181
	72	58	58.0	83.5	79.2	141	146	150	156	164	180	197
	75	60	60.7	87.0	82.5	147	152	156	163	171	187	205
	78	62	63.1	90.4	85.8	153	158	162	169	178	195	213
	84	67	68.0	97.4	92.4	164	170	174	182	192	210	230
100	84	67	68.0	97.4	92.4	164	170	174	182	192	210	230
	90	72	72.0	104	99.0	176	182	187	195	205	225	246
	96	77	77.0	111	105	188	194	199	208	219	240	263
123	90	72	72.0	104	99.0	176	182	187	195	205	225	246
	96	77	77.0	111	105	188	194	199	208	219	240	263
	108	78	84.0	125	118	211	219	224	234	246	270	295
	120	78	98.0	139	132	234	243	249	260	273	299	328
	132	78	106	153	145	258	267	274	286	301	329	361
	138	78	111	160	151	270	279	286	299	314	344	377
145	108	86	86.0	125	118	211	219	224	234	246	270	295
	120	92	98.0	139	132	234	243	249	260	273	299	328
	132	92	106	153	145	258	267	274	286	301	329	361
	138	92	111	160	151	270	279	286	299	314	344	377
	144	92	115	167	158	281	291	299	312	328	359	394
170	132	106	106	153	145	258	267	274	286	301	329	361
	144	108	115	167	158	281	291	299	312	328	359	394
	150	108	121	174	165	293	304	311	325	342	374	410
	162	108	131	187	178	316	328	336	351	369	404	443
	168	108	131	194	184	328	340	348	364	383	419	459

1) The continuous operating voltages U_c (as per IEC) and MCOV (as per ANSI) differ only due to deviations in type test procedures.
U_c has to be considered only when the actual system voltage is higher than the tabulated.
Any arrester with Uc higher than or equal to the actual system voltage divided by √3 can be selected.

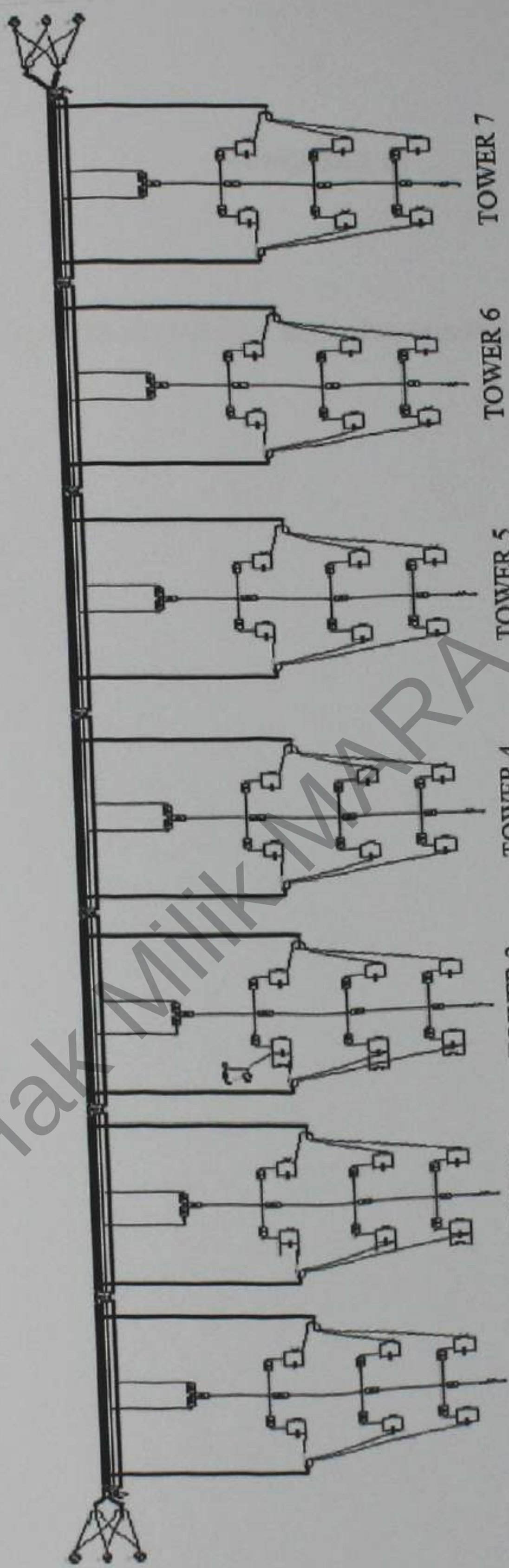
2) With prior duty equal to the maximum single-impulse energy stress (7.0 kJ/kV (U_r)).

3) Arresters for system voltages 36 kV or below can be supplied, on request, when the order also includes arresters for higher system voltages.

Arresters with lower or higher rated voltages may be available on request for special applications.

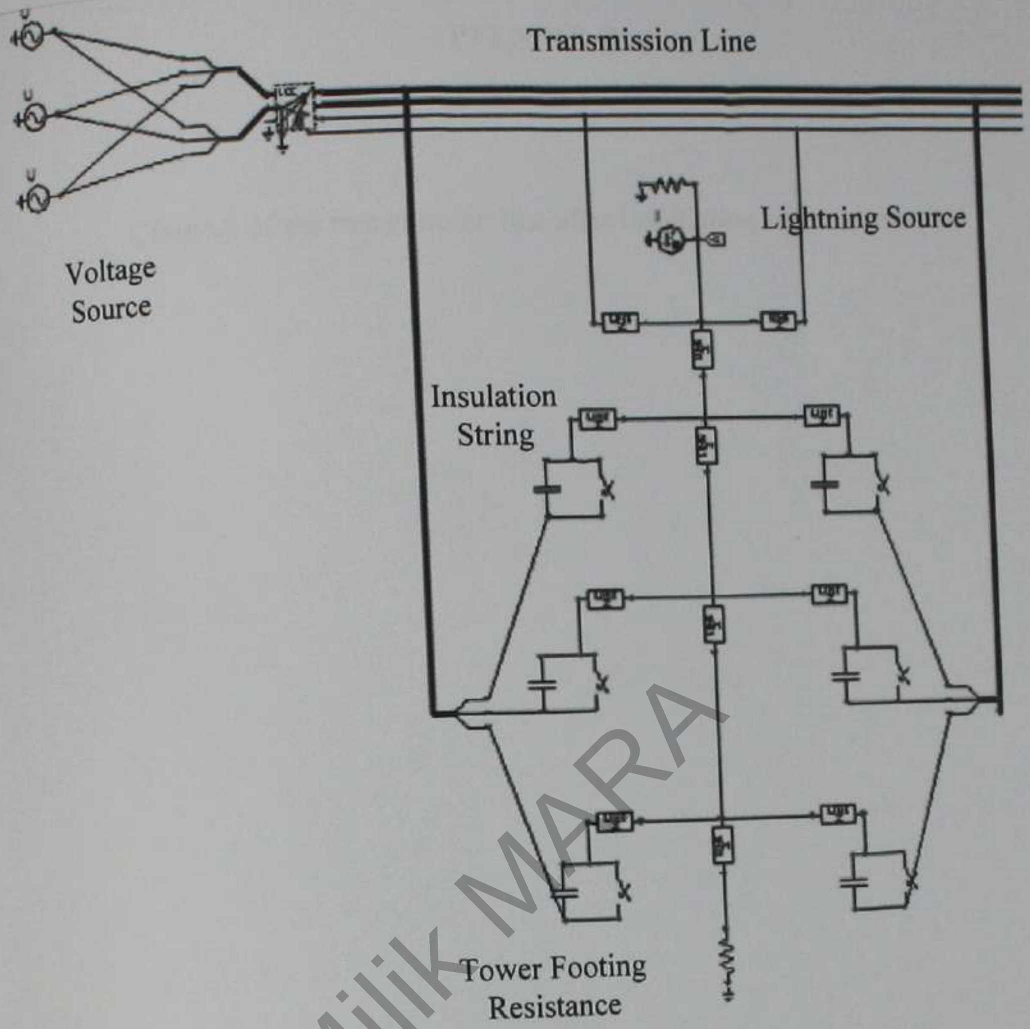
APPENDIX B:

Full diagram of 132kV Overhead Transmission lines Model designed in ATP-EMTP Software


TOWER 1
TOWER 2
TOWER 3
TOWER 4
TOWER 5
TOWER 6
TOWER 7

APPENDIX C:

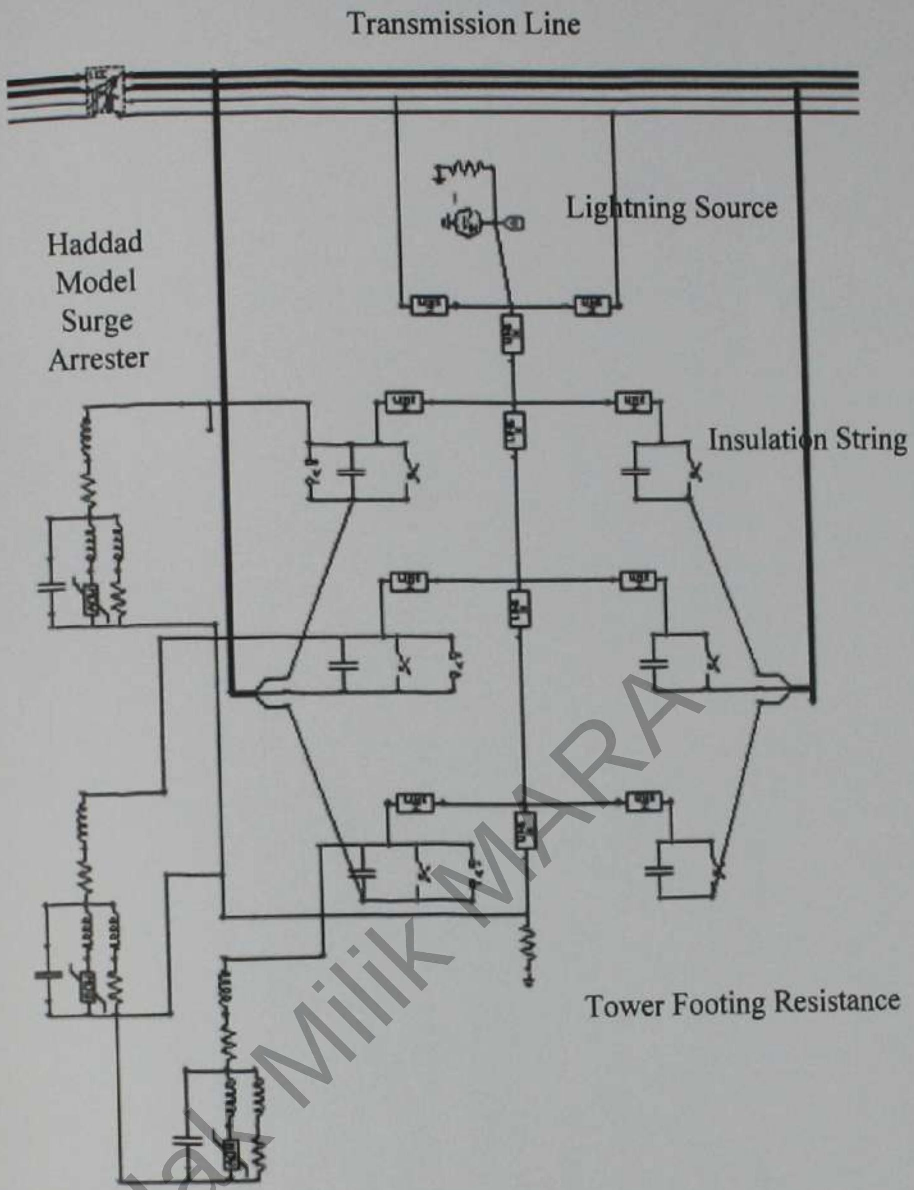
Close up of the transmission line before installation surge arrester



Transmission Line
Lightning Source
Voltage
Source
Insulation
String
Tower Footing
Resistance

APPENDIX D:

Close up of the transmission line after installation surge arrester


Transmission Line
Lightning Source
Haddad Model Surge Arrester
Insulation String
Tower Footing Resistance