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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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.

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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].

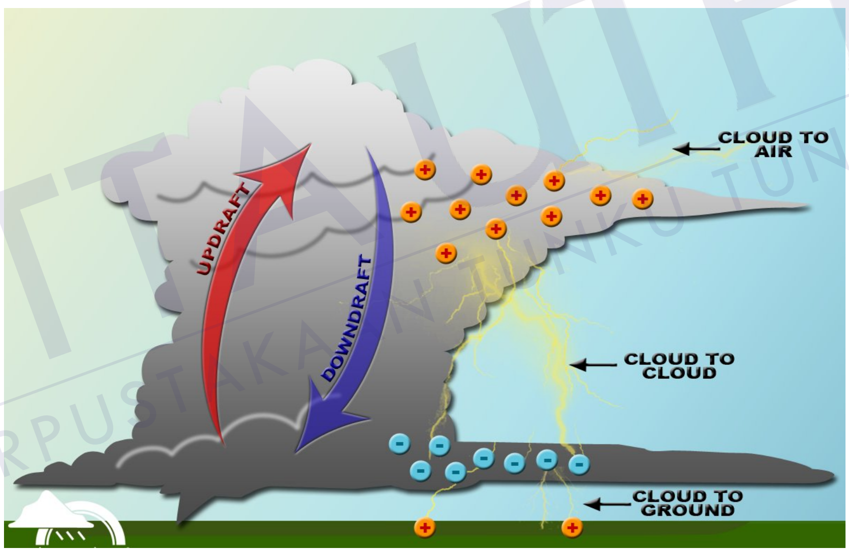

Figure 2.1: Interaction of protons and electrons [2]

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

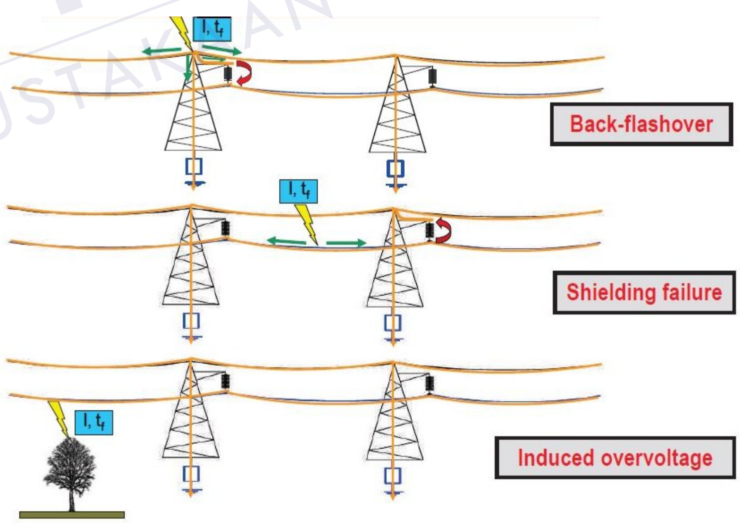

Figure 2.2: Three Possible Discharge Paths [19]

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)

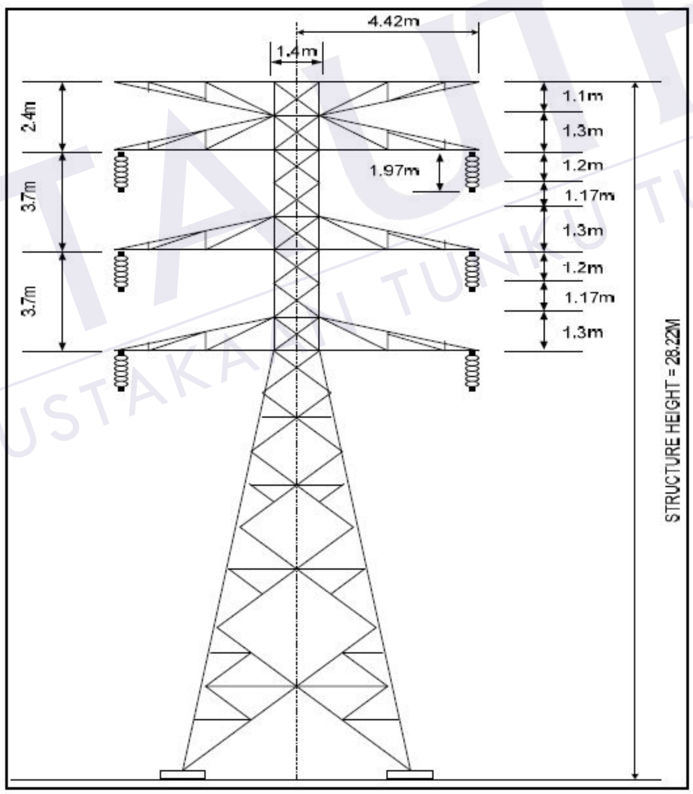

Figure 2.3: Tower configuration of 132kV transmission line system [9]

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.

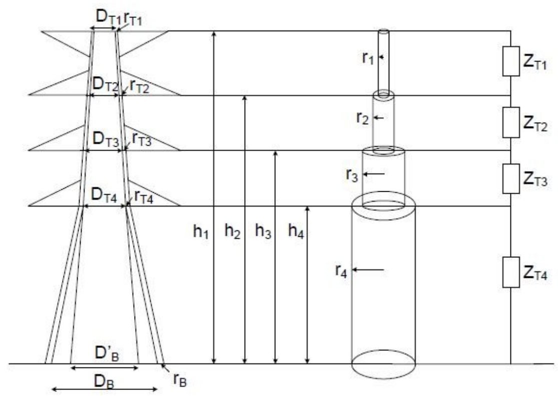

Figure 2.4: Multiconductor vertical line model [10]

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).

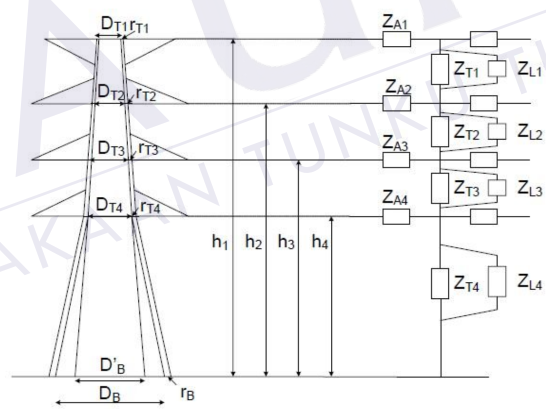

Figure 2.5: Multiconductor vertical line model, including bracings and cross-arm [10]

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.

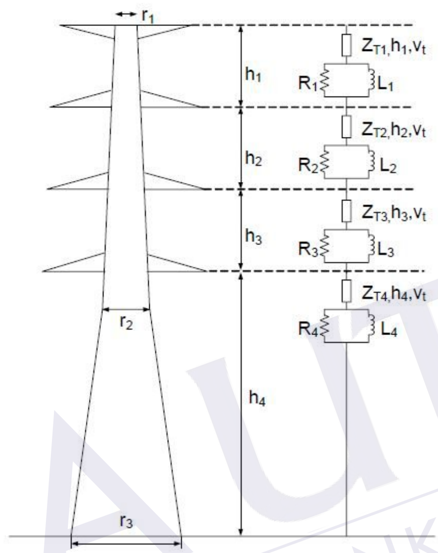

Figure 2.6: Multistory Tower [10]

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.

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

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.

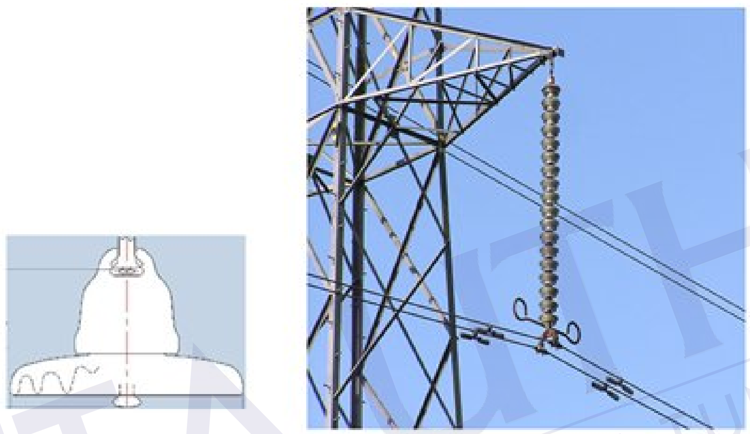

Figure 2.7: Insulator Disc and Insulator String

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:

$$R_T = \frac{R_o}{\sqrt{1+\frac{I}{I_g}}} \tag{4}$$

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:

$$I_g = \frac{E_o \rho}{R_o^2} \tag{5}$$

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):

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

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.

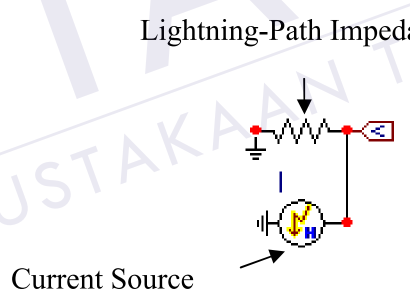

Figure 2.8: Lightning Strike, Heidler Model

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].

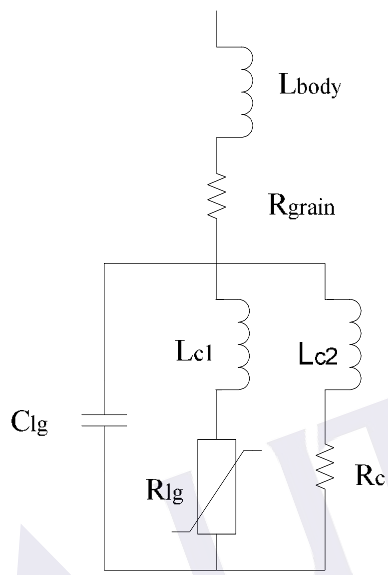

Figure 2.9 : Proposed ZnO equivalent circuit for multiple current-path representation [13].

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.)

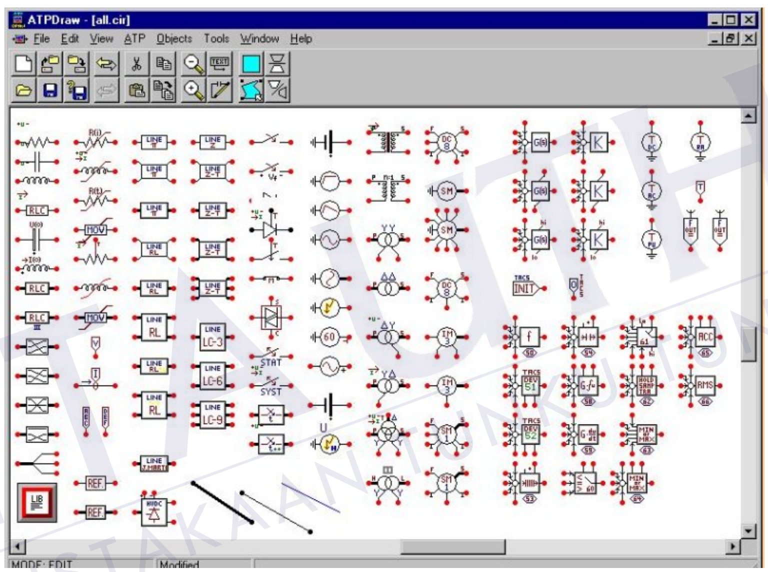

Figure 3.1: Shows all the component in ATP software

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.

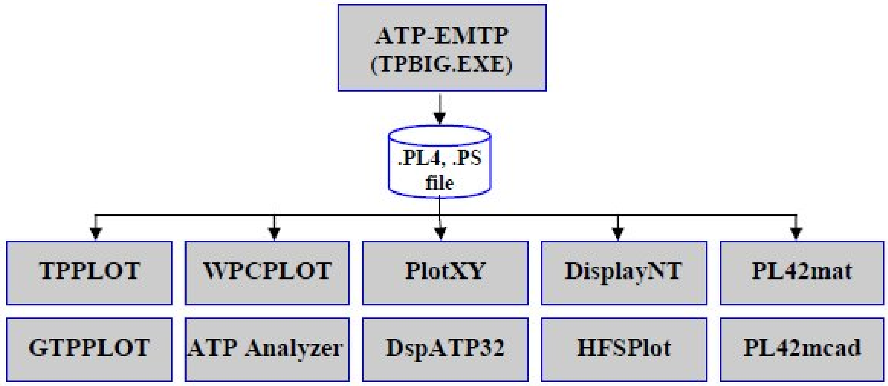

Figure 3.2: Plotting Program in ATP

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

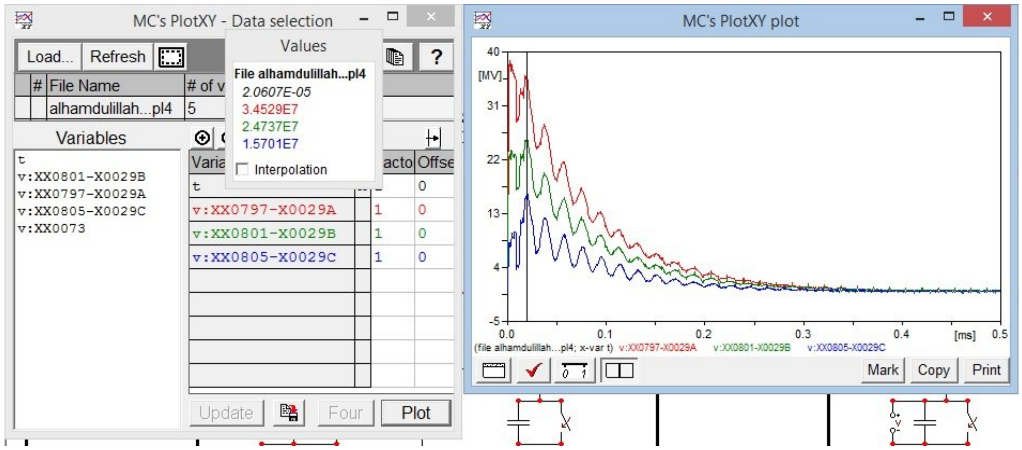

Figure 3.3: Graph by PLOTXY

3.3 Methodology Chart

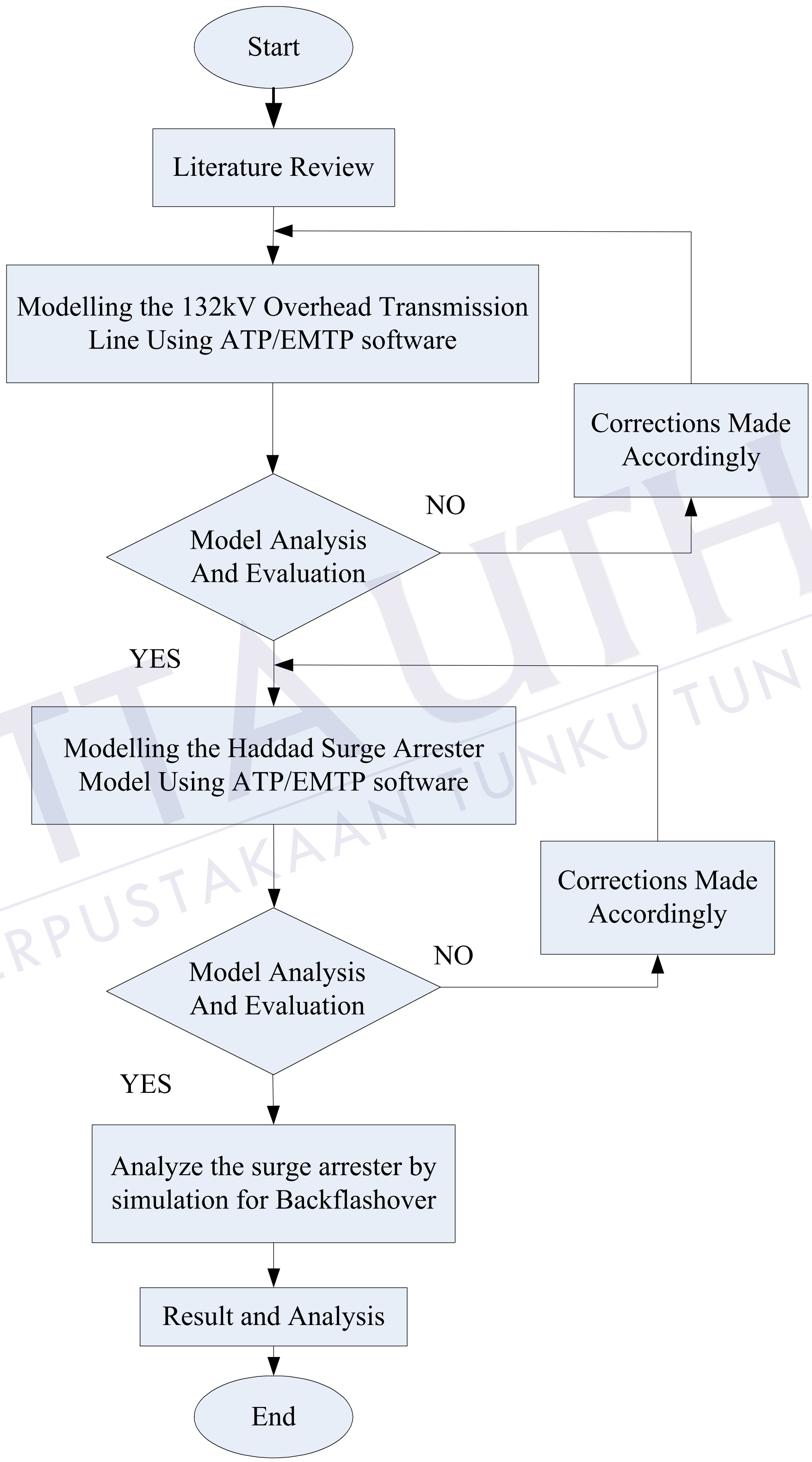

Figure 3.4: Methodology Chart

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