FAST TRANSIENT SIMULATION OF SCHMIDT SURGE ARRESTER MODEL ON A TRANSMISSION LINE USING ATP

MOHD HANAFI BIN MOHD ESA

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Universiti Tun Hussein Onn Malaysia

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ABSTRACT

Overvoltage transients are considered as major disturbance in high-voltage transmission line systems. It will affect the transmission lines system such as power supply disruptions, damage to equipment and will indirectly endanger human life. Surge arrester is equipment that can be used to overcome this problem where it works by diverting the surge current to ground and protect the transmission line. This study is intended to generate simulated data to study the characteristics of the Schmidt surge arrester. The method used for this study is to develop a Schmidt surge arrester and transmission line system using Alternative Transient Program (ATP) version Electromagnetic Transients Program (EMTP) software. Transmission tower model used in this simulation is double circuit multi-story 132kV while the lightning model used is 10kA current amplitude with current wave 8/20µs. Analysis carried out with lightning stroke hit on the transmission lines while surge arrester installed at transmission tower with a variety of configurations to determine optimum protection performance. The results of this study can be improved in the future by carried out with practical study methods and make comparisons.

ABSTRAK

Voltan lampau dianggap sebagai satu gangguan utama di dalam sistem talian penghantaran voltan tinggi. Ianya boleh memberikan kesan buruk terhadap sistem talian penghantaran seperti gangguan bekalan kuasa, kerosakan kepada peralatan dan secara tidak langsung akan membahayakan nyawa manusia. Penangkap kilat adalah peralatan yang boleh digunakan untuk mengatasi masalah ini di mana ianya berfungsi dengan mengalihkan arus lampau ke tanah dan akan melindungi talian penghantaran. Tujuan kajian ini adalah untuk menghasilkan data simulasi dan mengkaji ciri-ciri penangkap kilat model Schmidt. Kaedah yang digunakan untuk kajian ini adalah dengan membangunkan penangkap kilat model Schmidt dan sebuah sistem talian penghantaran menggunakan perisian *Alternative Transient Program (ATP) version Electromagnetic Transients Program (EMTP).* Model menara penghantaran yang digunakan di dalam simulasi ini adalah jenis litar berkembar berbilang tingkat 132kV manakala model kilat yang digunakan adalah amplitud arus 10kA dengan gelombang arus 8/20μs. Analisis dijalankan dengan memberikan sumber kilat pada talian penghantaran manakala penangkap kilat model Schmidt dipasang pada menara penghantaran dengan pelbagai konfigurasi untuk mendapatkan prestasi perlindungan optimum. Hasil kajian ini boleh ditingkatkan pada masa akan datang dengan menjalankan kaedah kajian secara praktikal dan dibuat perbandingan.

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LIST OF ABBREVIATIONS

ATP	-	Alternative Transient Program
EMTP	-	Electromagnetic Transient Program
MOV	-	Metal oxide varistor
VI	-	Voltage-current
IEEE	-	Institute of electrical and electronics engineers
SiC	-	Silicon carbide arresters
TNB	-	Tenaga Nasional Berhad
MPPS-MCCA	-	Pahlawan substation - Malacca substation
ACSR	-	Aluminium conductor shield reinforced
MCOV	-	Maximum continuous operating voltage
BIL	-	Basic insulation level
CFO	-	Critical flashover voltage

CHAPTER 1

INTRODUCTION

1.1 Introduction

High overvoltage transients are considered as major disturbance in high voltage transmission line systems. Overvoltage effects on the transmission line not only cause losses to the energy provider due to faulty equipment, but also to end users due to the power outage.

Surge arrester is a protective device which is used to overcome the phenomenon of overvoltage. It is also known as metal oxide varistor (MOV) which is an essential aid to protect electrical power system components'. Valuable equipment can be protected against lightning and switching overvoltage. The characteristics of surge arrester are extremely high resistance during normal operation and a very low resistance during transient overvoltage [1].

Until today many studies or researches have been done to get the best model that can accurately represent surge arrester. Each model was created to obtain the residual voltages from a simulation that approaching the actual value of surge arrester. Previous researchers have done the studies to compare between several models such as Schmidt model, IEEE recommended model, Kim model, Pinceti model, Haddad model, Fernandez model, and Tominaga model by using 3kV GE Tranquell arrester [1].

This project will focus on the study of the Schmidt surge arrester model which is introduced by Walter Schmidt in 1987 [2]. The improvement of this study is to install Schmidt surge arrester at transmission line tower with three different types of configurations. The results of this study will determine the method of installation can provide optimum protection performance. The modelling for this research will

develop by using ATP-EMTP software which is famous tools for power system transient analysis studies.

1.2 Problem statement

In a power system, the most important component is the protection system. The purpose of the protection system is not only to protect power system equipment but also to protect the human as end users, wildlife and the environment. Protection system covers the entire power system starting from generation, transmission, distribution and load.

Major disturbance in high voltage systems is overvoltage transient. Overvoltage occurs because of switching operations of nearby circuit breakers or as a result of lightning strokes [3]. This project will focus on protection system using surge arrester at a transmission line caused by lightning.

Model selection of surge arrester should be made to meet the standard required for a surge arrester. The difficulty in modelling surge arrester is the estimation of its parameter that suit with the manufactures data and specifications. Each model of surge arrester has its own circuit and the selection of appropriate parameters can produce a good result for a surge arrester model. The objective of this project is to compare the residual voltage and percentage of error between Schmidt surge arrester with the proposed surge arrester model.

1.3 Objectives

The objectives of this study are:

i. To develop Schmidt surge arrester using ATP-EMTP software.
ii. To build an overhead medium transmission line modelling via ATP-EMTP software.
iii. To obtain the optimum configuration and performance of Schmidt surge arrester in the transmission line.

1.4 Scopes

The scopes of this study are:

i. The simulation is performed with the Alternative Transient Program (ATP) version of the Electromagnetic Transient Program (EMTP).
ii. Overvoltage analysis only on lightning stroke current wave 8/20μs.
    a. System exposure : Medium transmission line
    b. Current references: 10kA.
    c. Lightning condition: Direct strike to tower and to phase conductor.
iii. The models of surge arrester are Schmidt.
iv. Studies only to metal oxide surge arrester (MOV).

1.5 Outline of dissertation

The thesis is organized in the following manner.

Chapter 1: The important part which describes the problem and objectives of this research.

Chapter 2: Literature review which includes the overvoltage due to lightning strikes phenomenon, transmission tower, and main points for this study, surge arrester.

Chapter 3: Describes on the methodologies used and process to develop complete transmission line system by using ATP-EMTP software.

Chapter 4: Describes the flow analysis of Schmidt surge arrester performance at transmission line tower to prevent overvoltage. This chapter also discusses the results of analysis.

Chapter 5: General conclusion and recommendation.

CHAPTER 2

SURGE ARRESTER FOR LIGHTNING PROTECTION: A REVIEW

2.1 Surge

Surge in general is a transient wave of current, voltage or power in an electric circuit. It can increase the current or voltage at least ten percent in a few microseconds. Although the surge duration is short, voltage can reach amplitudes of thousand volts. The unstable of sine wave during surge happen to the system is shown in Figure 2.1. Surge can occur with internal and external sources.

The most recognize external source of surge generated is lightning. The lightning surge is the phenomenon when it charged is transferred to a power system and can cause damage. The lightning surge can be determined by two ways on a power system. Direct contact of a lightning to a power system facility or indirectly from the nearby strike to earth that induces an electrical surge onto communications systems.

Internal source or also known as switching surge is generally occurring in the operation of a circuit breaker and switching process whether due to intentional or unintentional operation. Switching surges is not larger as externally generated surge however they occur more frequently in daily operations. This surge exists because of the inductance and capacitance principle in the power system. Whether this component was added or removed, it caused the unstable on the power system.

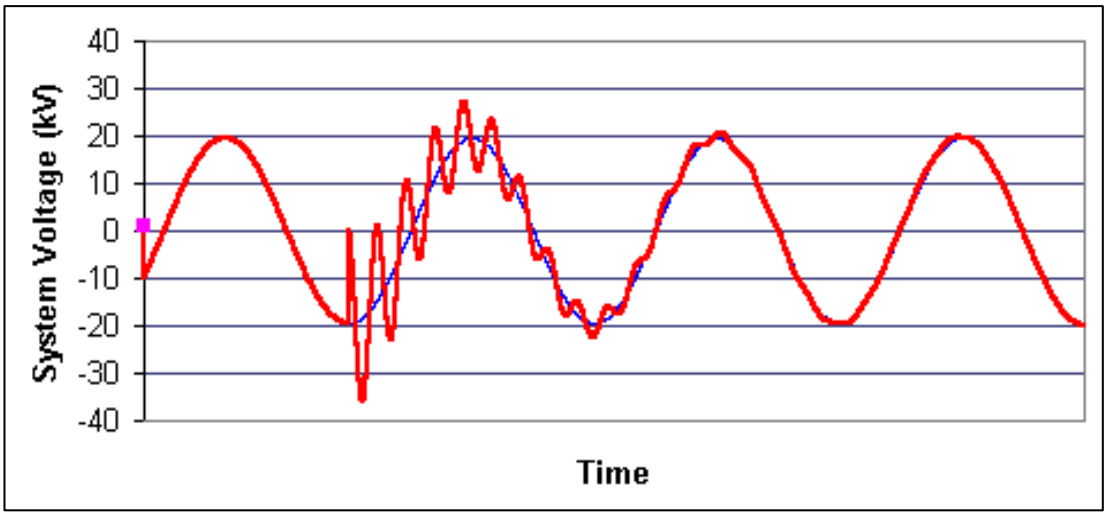

Figure 2.1 : Surge effects on power system [4]

2.2 Lightning

Lightning is an electric discharge in the form of a spark or flash originating in a charged cloud. Generally a cloud consists of a positive charge and a negative charge. The negative charge will acts as lightning because the ground or earth will neutral it by positive charges. Figure 2.2 shows a cloud located above an overhead transmission line [5].

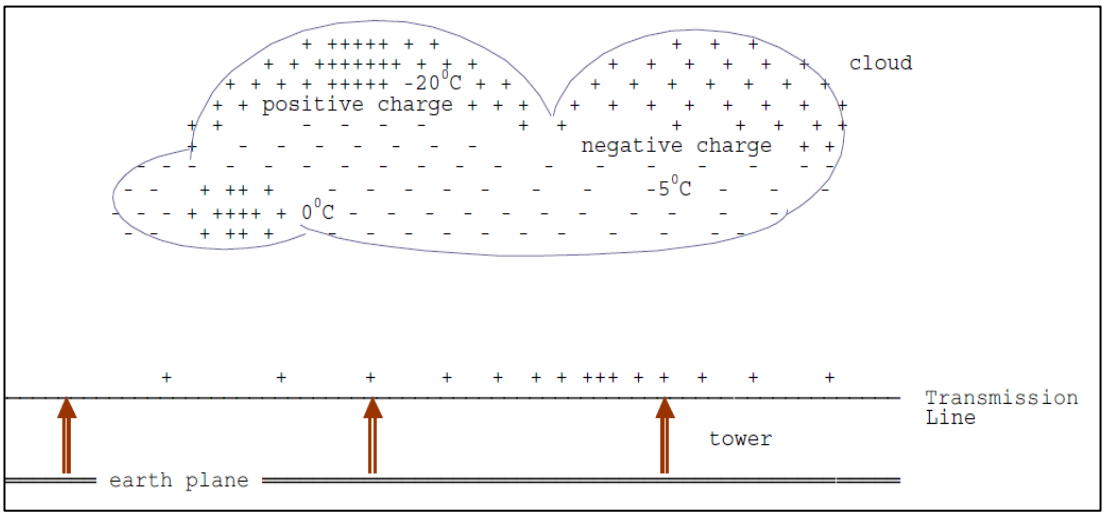

Figure 2.2 : Charges induced on transmission line [5]

2.2.1 Lightning problem in transmission line

Lightning surges on high voltage transmission lines have always been a very troublesome source of disturbance. The negative charges at the bottom of the cloud induce charges of opposite polarity on the transmission line. Three possible discharge paths that can cause surges on line are [5]:

i. The first discharge path is from leader core of lightning strike to earth. Not a significant factor in lightning performance of systems above 66kV however causes considerable trouble on lower voltage systems.

ii. The second discharge path is between lightning head and earth conductor. The resulting travelling wave comes down the tower. Raising potential of the tower top to a point where the difference in voltage across the insulation is sufficient to cause flashover from the tower back to the conductor. This type of stroke is called back flashover.

iii. The third type of discharge is between leader core and phase conductor. Then developing a surge impedance voltage across the insulator string. This type of strike is known as direct stroke to phase conductor.

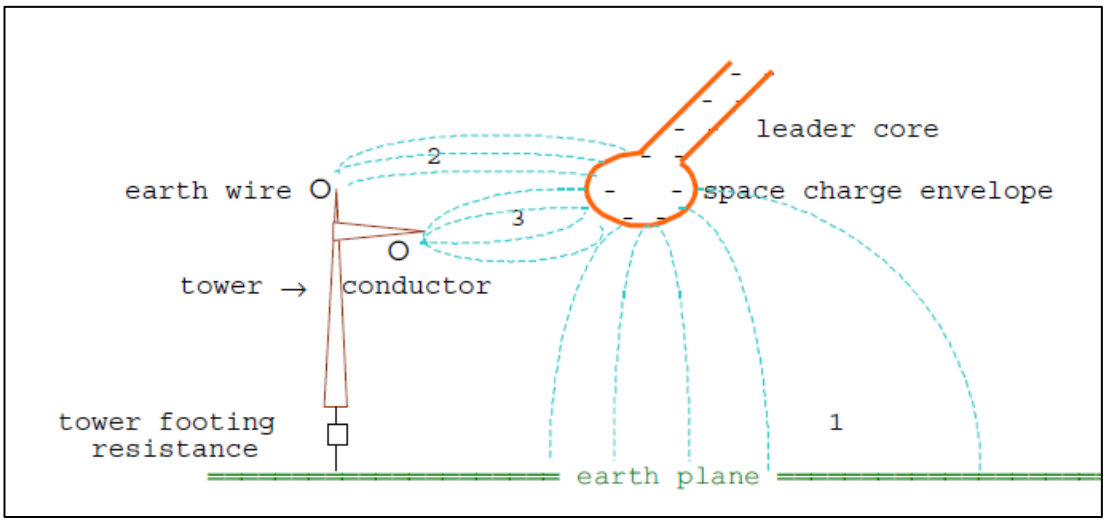

Figure 2.3 : Lightning strike to transmission line [5]

The modelling of lightning phenomena has become important to power system stability. A study of the lightning effects involves two steps, predict what may happen on a lightning strike and recommend solutions for improvement. This is possible by using specialized software that simulates the lightning phenomena as shown in Figure 2.4. Another is a technical and economic studies of insulation coordination taking into account the cost of installations, maintenance and service disruptions.

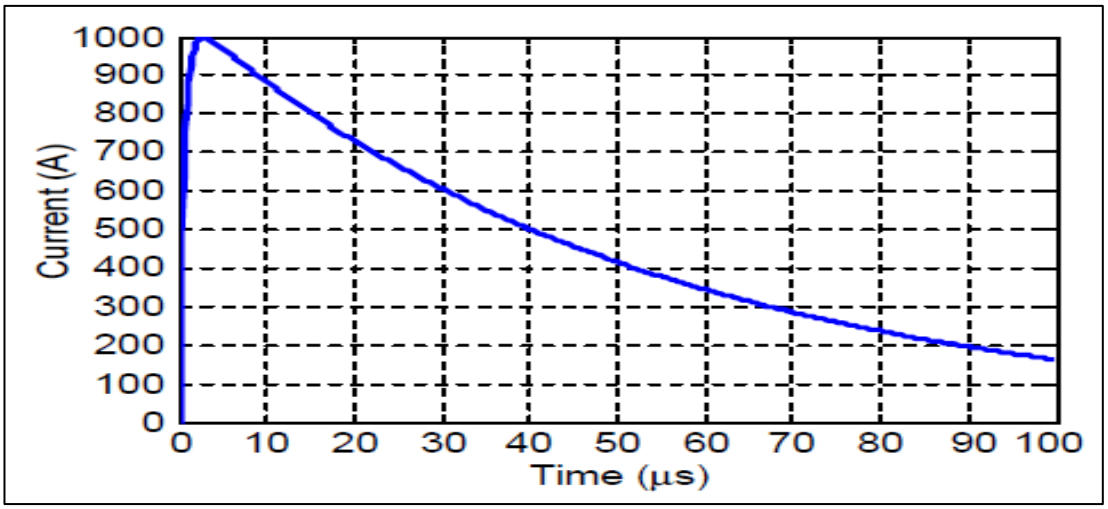

Figure 2.4 : Typical lightning strike waveform [6]

2.3 Transmission tower

Modelling of transmission towers is an essential part of the travelling wave analysis of lightning surges in overhead power transmission lines. Most of accidents that occur on transmission lines are caused by lightning strikes on transmission towers. In order to prevent these accidents, the accurate evaluation of the lightning performance of transmission lines is necessary [7].

To perform the analysis of overvoltage due to lightning is not a simple thing. This is because it requires advance and accurate system. In addition, many parameters that needs to be taken into account especially during lightning strikes to the transmission tower. However, based on previous studies, the actual data collected can also be used for simulation purposes, the data recorded during the occurrence of lightning strikes on transmission towers or may involve laboratory experiments.

The lightning response of a transmission line tower is an electromagnetic phenomenon; the representation of a tower is usually made in circuit term. There are some reasons to support this approach such as representation can be implemented in general purpose simulation tools, e.g ATP-EMTP like programs, and it is easy to understand by the practical engineer [8].

Several tower models have been develop over the years, they were develop using a theoretical approach or based on an experimental works. In recent years, theories proposed by researchers abound, on modelling of transmission tower. One of the more well-known models is the multi-story model designed by Masaru Ishii [9]. A multi-story tower model basically is composed of distributed parameter lines with parallel RL circuits. This model is widely used for lightning surge analysis in Malaysia [10]. Figure 2.5 shows the multi-story tower model.

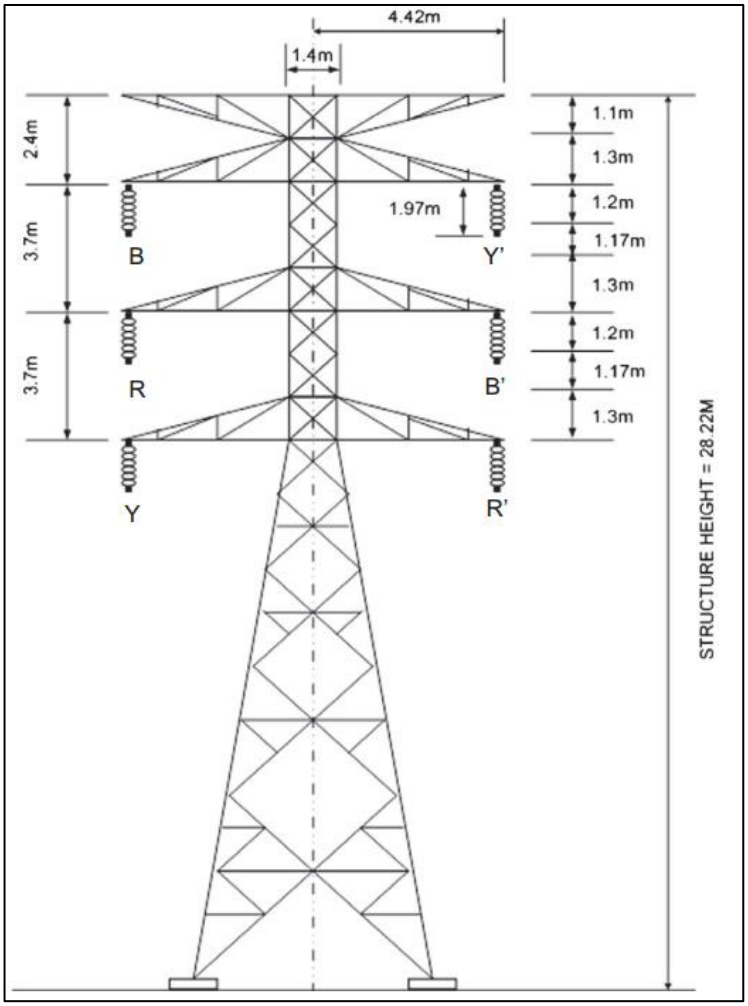

Figure 2.5 : 132kV transmission line multistory model [11]

2.4 Surge arrester

Surge arrester by most definitions is a device used in power systems above 1000V to protect equipment from lightning and switching surges. It is a protective device for limiting surge voltage on equipment by diverting surge current and returning the device to its original condition. It is capable of repeating its function and it has the ratings of protection depends on the system. Figure 2.6 shows the location of surge arrester at the transmission line.

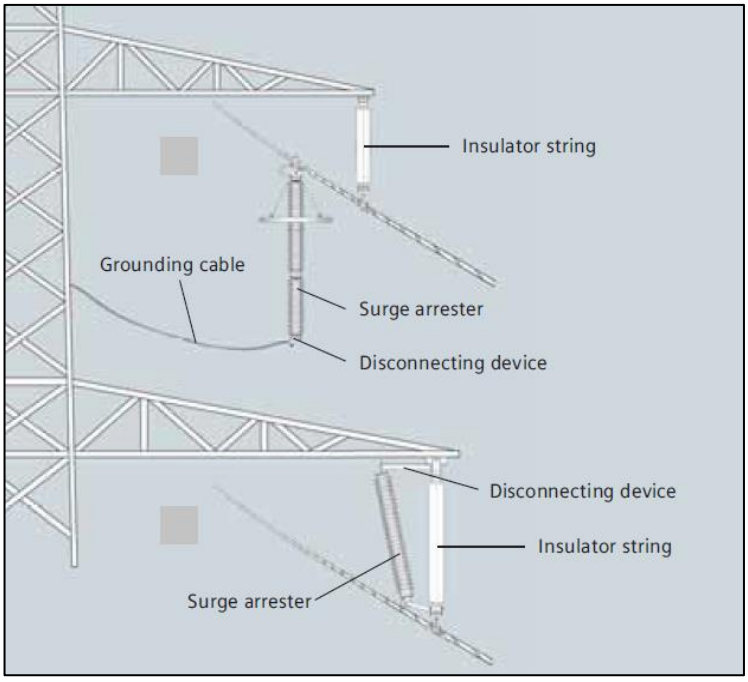

Figure 2.6 : Transmission lines arrester [12]

2.4.1 Types of surge arrester

There are two types of surge arrester is generally known to be used as power system protection. From the mid-1950s through the late 1970s, gapped silicon carbide arresters (SiC) represented the state of the overvoltage surge protection through high voltage transmission line. With the development of metal oxide technology in the mid late 1070s, manufactures replaces the traditional silicon carbide gap design with a gapless metal oxide varistor (MOV) having improved performance characteristics [13].

Silicon carbide arrester is very high resistance to low voltage and very low resistance to high voltage. Its use a non-linear resistance that made of bonded silicon carbide and placed in series with the gaps. The gap function is to isolate the resistor from normal voltage and provide a high limiting voltage. However after many researches was done shows that 50% of silicon carbide arrester cannot meet original protection characteristics. The other problems are moisture contamination and gaps changing characteristics. Figure 2.7 shows silicon carbide arrester (SiC) diagram.

The metal oxide varistor (MOV) material used in modern high voltage surge arrester has a highly non-linear voltage versus current characteristics. Experience has shown that most failures of silicon carbide arrester occur because gap spark over. These failures have been reduced by using metal oxide surge arrester, by moisture ingress or contamination, to a level low enough to permit repetitive spark over at or near the normal operating voltage. The advantages of metal oxide arrester are simple in construction which improves the overall quality such as increase energy absorption capability and easier to maintenance especially to clear arc [14]. Figure 2.8 shows metal oxide varistor (MOV) diagram.

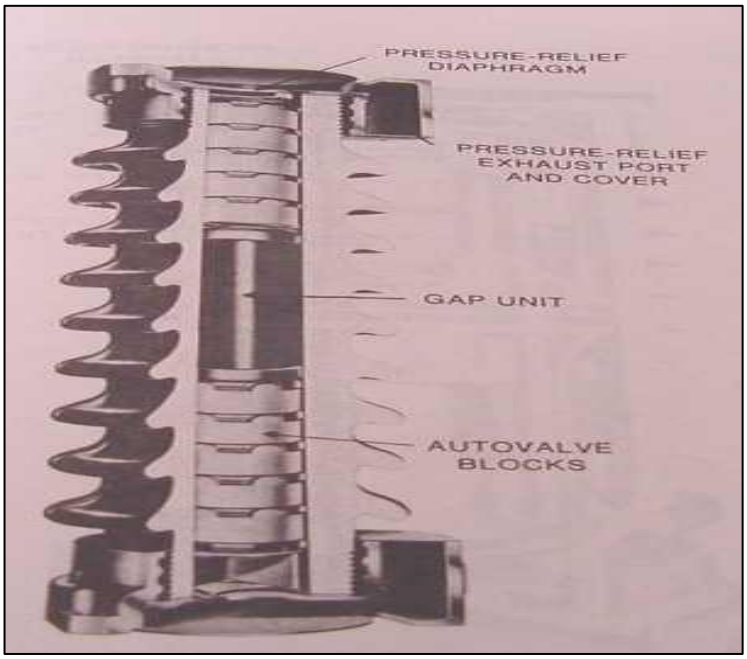

Figure 2.7 : Silicon-carbide arresters (SiC)

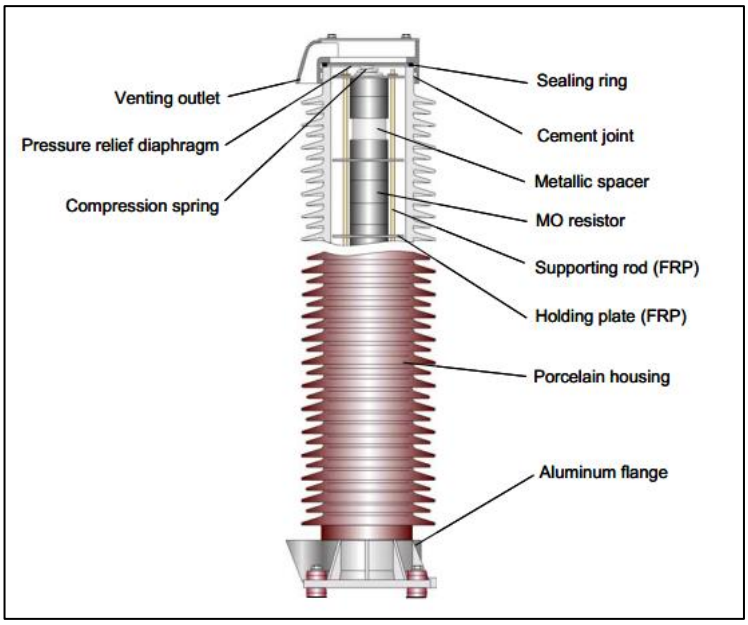

Figure 2.8 : Metal-oxide varistor (MOV) [15]

2.4.2 Function of arrester component

Components in the arrester have its own function. Each of these functions complements each other to make arrester works perfectly in protecting the power system. Figure 2.9 shows physically typical arrester construction.

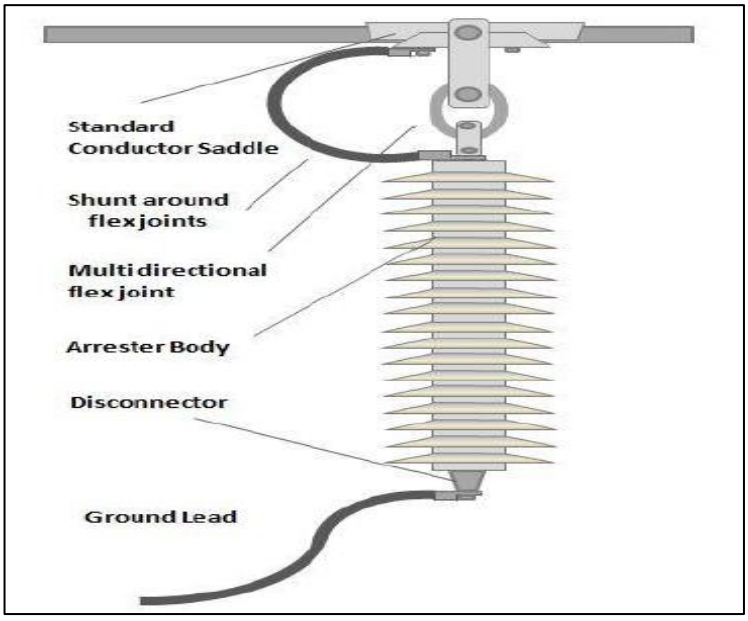

Figure 2.9 : Arrester construction [15]

The functions of every component are as follows [15]:

i. Saddle clamp – this component is use to connect the conductor to the insulators.
ii. Multidirectional flex joint – this joint eliminates mechanical stress due to the motion of the conductor.
iii. Shunt – function as current carrying component from the conductor to the arrester.
iv. Arrester body – this component is electrically specified to conduct whether lightning or switching surge.
v. Disconnector – this component used if the failure to the arrester. It operates when arrester becomes a short circuit and it isolates the arrester from earth.
vi. Ground lead – this component is connected between the arrester and the tower ground to ensure that the ground lead did not make any contact with the other phase.

2.4.3 Principle operation of surge arrester

Metal oxide varistor (MOV) contains one or more varistor with various diameters and heights. Varistor are made of ceramic of non-linear voltage current characteristics. Ceramic is zinc oxide with a mixture of other metal oxide such as bismuth, cobalt, manganese and aluminium [16]. The structure of varistor mass is in the shape of close packed grains as shown in Figure 2.11. By magnifying the metal oxide arrester disc 5000 times, metal oxide grains can be discerned. Each metal oxide varistor (MOV) with a 35mm diameter and a 35mm height contains about 28 billion metal oxide grains. The metal oxide grains and their junctions act as electronic switches that turn on and off to divert the lightning around the equipment and safe from damage.

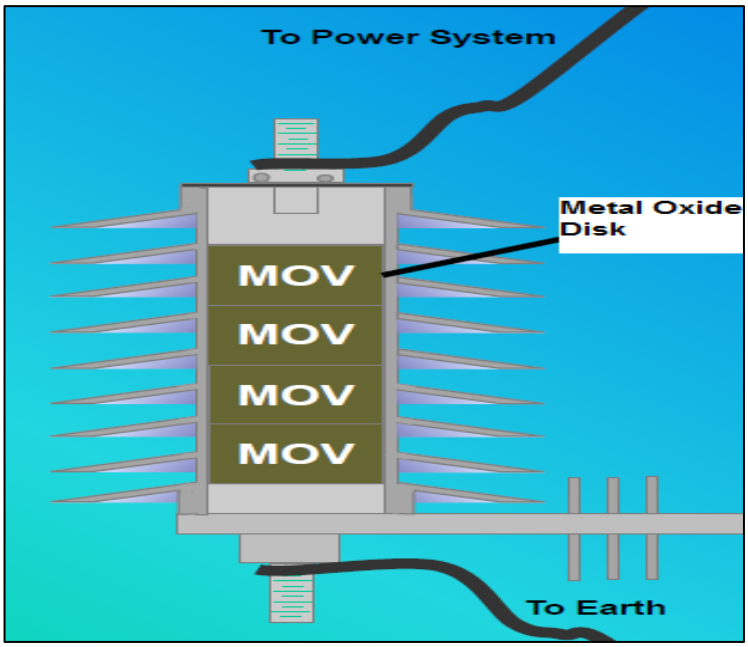

Figure 2.10 : Arrangement metal oxide disk [17]

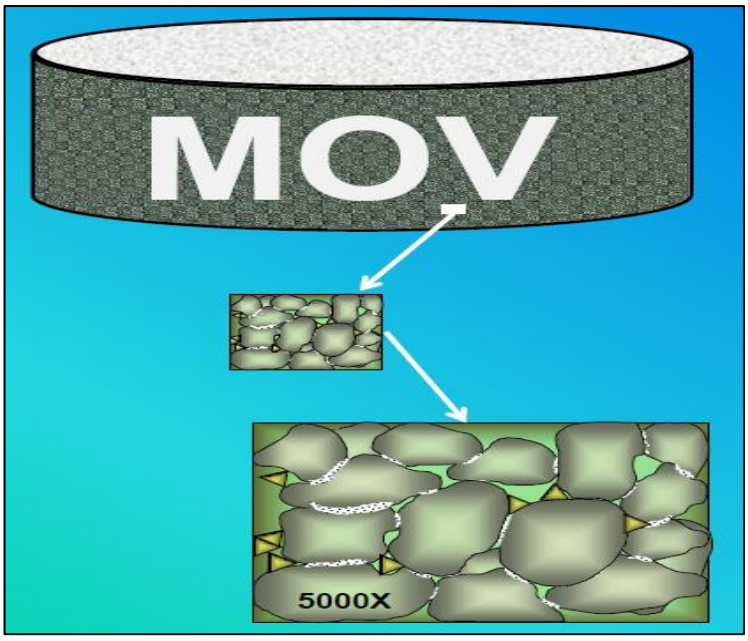

Figure 2.11 : Metal-oxide grains [17]

At normal condition the metal oxide disk is an insulator and will not conduct the current however during overvoltage caused by lightning it becomes a conductor. If surge arrester not installed in a transmission line, the surge current travels down the shield line and down the nearest pole down conductor. If the voltage along this

down conductor increase to a levels that exceeds the withstand level of the line insulator so the insulator may back flash as shown in Figure 2.12.

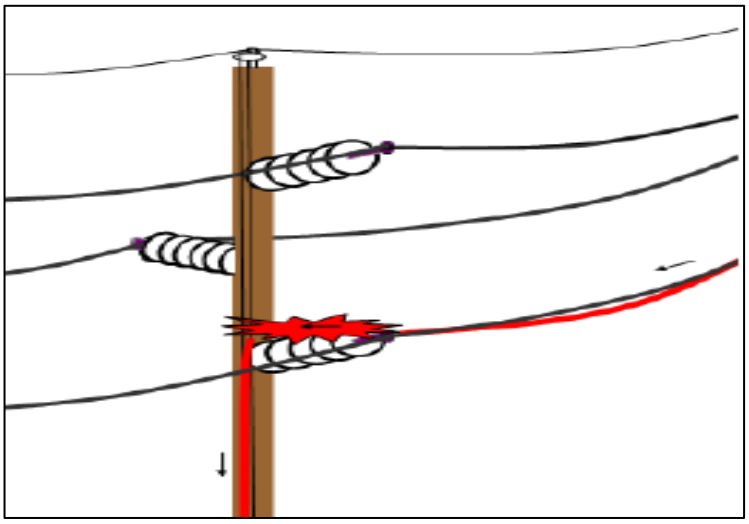

Figure 2.12 : Transmission line without surge arrester installed [15]

With a surge arrester installed in this phase, the surge current uneventfully transferred onto the phase conductor as shown in Figure 2.13. Surge arrester will divert the surge current to ground and protect equipment electrically in parallel with it. This resulted no ionizing arc is produced so there in no overvoltage phenomenon was happen.

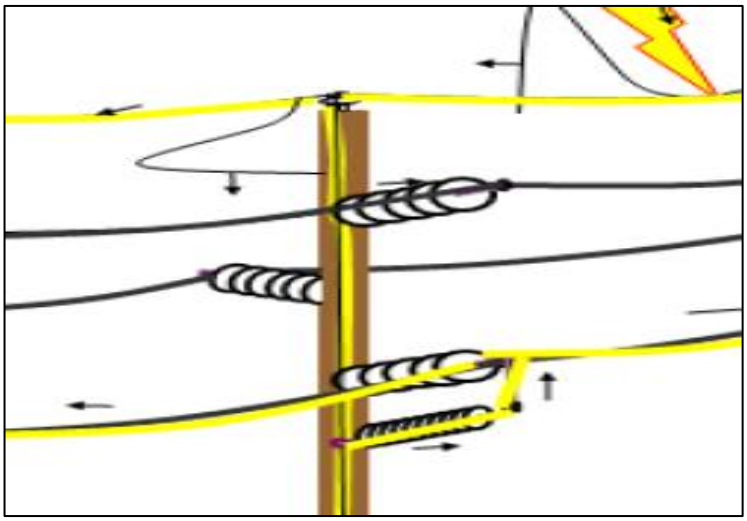

Figure 2.13 : Transmission line with surge arrester installed [15]

2.5 Metal oxide varistor V-I curve

Varistors or variable resistors are voltage-dependent resistors with bidirectional and symmetrical V-I characteristics. Metal oxide varistors (MOV) are primarily made of Zinc Oxide. When varistors are exposed to over voltage transient or surge, the varistors switch from standby state (nearly open circuits) to clamping state (highly conductive state). The major function is to protect equipments from being damaged by over voltage transient. The varistors electrical characteristics, V-I curve are normally expressed in the Figure 2.14.

At leakage region the V-I curve shows a linear relationship. The varistor is in high resistance mode and shows as an open circuit. In normal operation, the V-I curve of a varistor can be described by power law:

$$I = KVa \qquad (2.1)$$

Where:

K is a constant and defines the degree of nonlinearity. At high current, the varistor is in low resistance mode and shows as a short circuit [18].

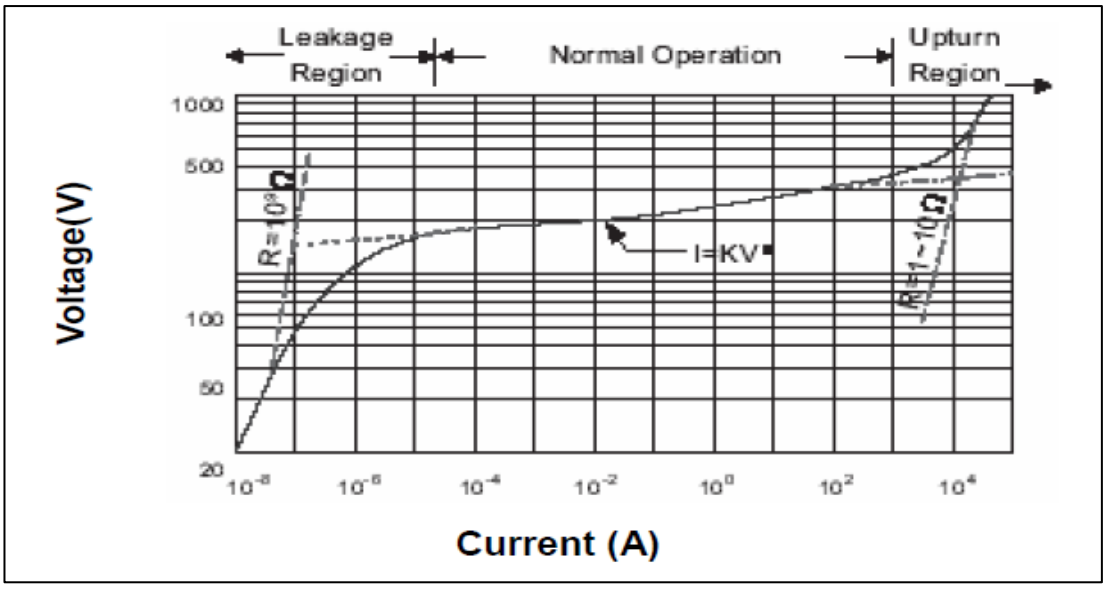

Figure 2.14 : Metal oxide varistor V-I Curve [18]

2.6 Schmidt surge arrester model

Schmidt surge arrester model was introduced by Walter Schmidt in 1987. This model recommended and approved by the IEEE Surge Protective Device Committee of Power Engineering Society for presentation at the IEEE/PES 1988 Winter Meeting, New York. The model for an arrester block shown in Figure 2.15.

This circuit is able to describe the observed phenomena. The turn-on element A in the equivalent circuit is evaluated from the results of the measurements obtained with the RLC circuit. The other parameters were evaluated from independent measurement or from results described in the literature. The elements R and L are attributed to the ZnO grain, whereas the other elements are related to the grain boundaries. An inductance of 1μH/m was assumed. The capacitance C of the arrester block depends on the steepness of the applied transient and was measured as about 0.8 nF for high di/dt and about 1.5 nF for low values of di/dt [2].

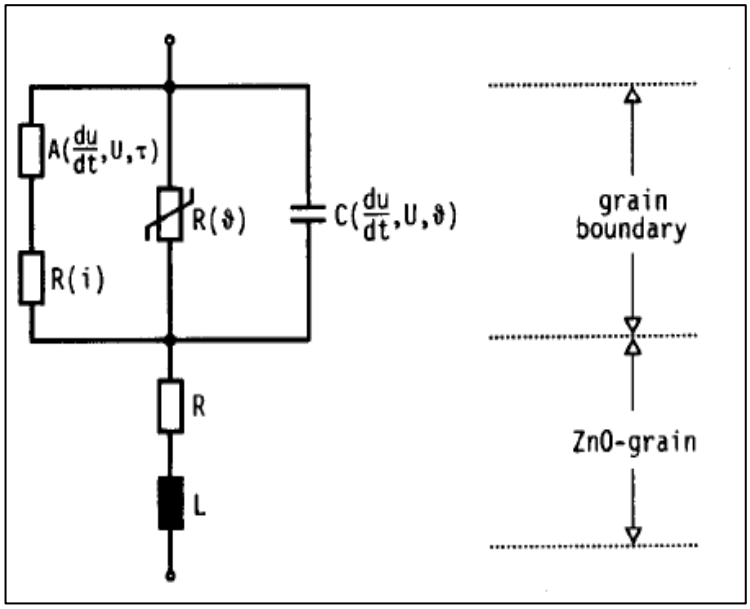

Figure 2.15 : Model proposed by Walter Schmidt [2]

2.7 Critical flashover voltage (CFO)

The lightning critical flashover voltage (CFO) is the crest value of a standard lightning impulse for which the insulation exhibits 50% probability of withstand. It is used in the insulation coordination studies to describe the lightning impulse strength of high voltage insulators [19]. CFO is related with Basic Insulation Level (BIL) and the relationship among CFO and BIL given by the equation below.

$$\text{BIL} = CFO\ (1 - 1.28\frac{\sigma f}{CFO}) \qquad (2.2)$$

Where:

σf is coefficient of the variation, known as sigma. For lightning, the sigma is 2% to 3% [20]. Statistical Basic Insulation Levels (BIL) is the crest values of a standard lightning impulse for which the insulation exhibits a 90% probability of withstand (or a 10% probability of failure) under specified conditions applicable specifically to self-restoring insulation [19].

CHAPTER 3

SIMULATION ON LIGHTNING PROTECTION WITH SURGE ARRESTER MODEL IN ATP

3.1 Introduction

Generally methodology defines methods and necessary steps to completion of a project. This chapter describes the software used and project methodology flow chart.

3.2 Flow chart of methodology

Flow chart of methodology is a research planning from a beginning until complete. It will describe the steps have been taken to ensure successful completion of the project.

i. Literature Review – During this process all the relevant literature collected through either search the internet, reference books, IEEE papers and journals, etc. It is a most important process which will determine the direction of research.

ii. Modelling the 132kV overhead transmission line using ATP-EMTP program - The next step is modelling the 132kV overhead transmission line by using ATP-EMTP program. All information gathered during the literature review used to develop an appropriate transmission line.

iii. Modelling Schmidt Surge Arrester - Modelling Schmidt surge arrester by using ATP-EMTP program. All information gathered during the literature review used to develop an appropriate transmission line.

iv. Model Analysis and Evaluation – Both transmission line and surge arrester modelling have been referred to the IEEE journal and papers proposed the methods. This is a difficult process because it requires a high understanding in a model that is developed can operate exactly as in the literature review. Modifications were made to repeat until successful.

v. Perform Lightning Strike Analysis on the Model – Once the model for the transmission line and surge arrester is assumed correct, lightning analysis will be conducted. Lightning source injected to transmission line conductor and do observation via PLOTXY and WPCPLOT application. This process is done repeatedly by changing the parameters of research whether the surge arrester specification from different manufacturers, change the lightning strikes location and etc. to get a better understanding.

vi. Result and Analysis of the Waveform - This part analyses the waveform obtained from simulation results, and discusses the results.

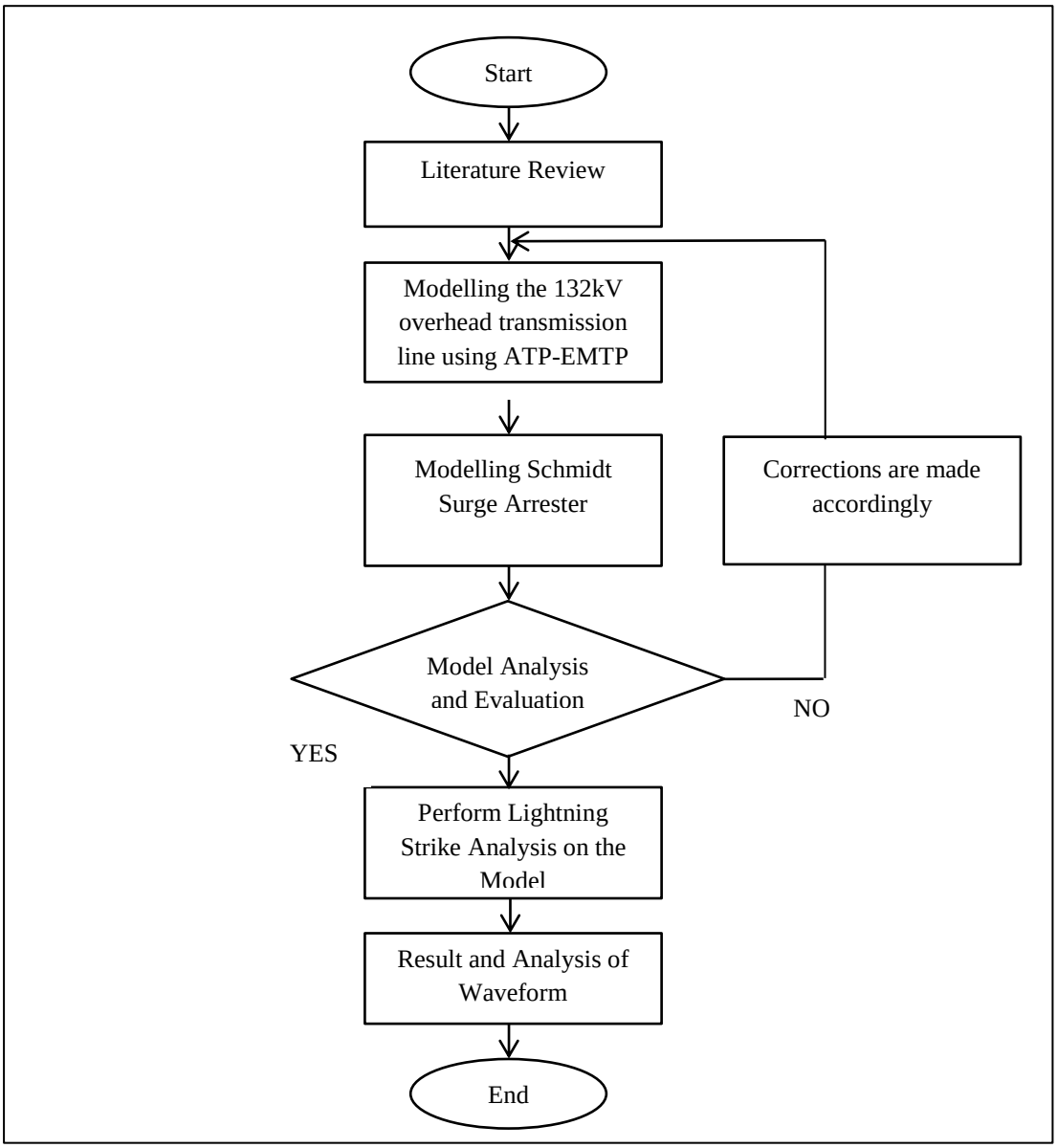

Figure 3.1 : Flow chart of methodology

3.3 Alternative Transient Program (ATP) version Electromagnetic Transients Program (EMTP)

ATP is the royalty free version of the Electromagnetic Transients Program (EMTP). It can simulate phenomena such as lightning occurring in electric power system. This program also suitable for modelling the overhead transmission line and it will be used in this research. It is a full-feature transient analysis program initially developed for electrical power systems simulation. It appeared in early 1984 by Drs. W. Scott

Meyer and Tsu-Huei Liu (both Co-Chairmen of the Canadian/American EMTP User Group) contributing to its development.

3.3.1 ATP Draw

ATPDraw is an application that allows user to create the electrical circuit to be simulated. It will generate the input file for ATP simulation in the appropriate simulation format. Usually, ATPDraw controls the naming process for the circuit node. The user needs to give a name to the nodes of special interest.

ATPDraw has a standard Windows layout, supports multiple documents, and offers a large Windows help file system that explains the basic rules (which helps users use ATPDraw). Generally, it provides standard component that can be used to create both single-phase and three-phase systems.

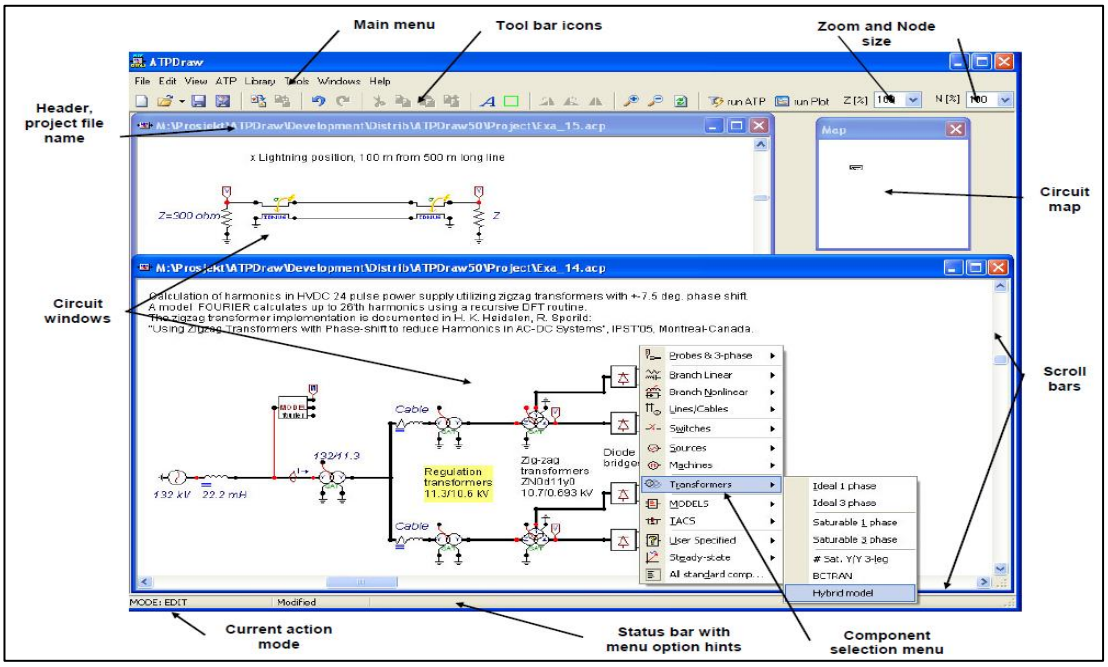

Figure 3.2 : ATP Draw main window [21]

3.4 ATP Plotting

The main function of ATP Plotting is to display simulation results in time-domain or frequency-domain. Data from ATP simulation are stored in a file having an extension .pl4. For example the create file name as *hanafi.atp* in ATPDraw and save it. Automatically it will create another file named *hanafi.pl4* and stored it in ATPDraw folder. The user just reloads .pl4 file and plotting the graph.

Processing can be off-line or on-line. The latter displays results while simulation is proceeding, and is available only if the operating system provides concurrent PL4-file access for ATP and the postprocessor program. Although there are many ATP plotting programs, this study will use two types of programs which are Plot XY and WPCPlot.

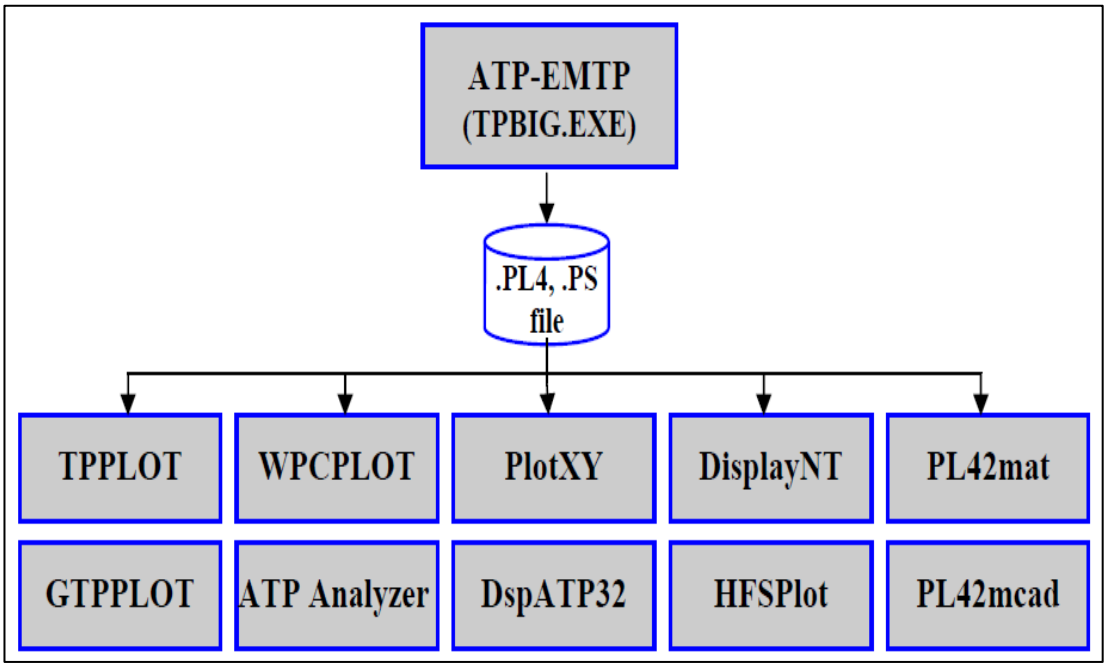

Figure 3.3 : Plotting program for ATP [21]

3.4.1 Plot XY

PlotXY is a support application originally designed for ATP-EMTP software. It's purposely designed to make plotting works in Microsoft Windows environments. It can do a plotted curve, algebraic operation, computation of Fourier series

coefficients, etc. This application can load up to 3 of .pl4 files can be simultaneously held in memory for easy comparison of various data, and up to 8 curves per plots versus time or X-Y plots are allowed. It has automatic axis scaling, can plot with two independent vertical axes, and provides easy tools for factors, offsets, and zoom support, and a graphical cursor to see values in numerical format. Figure 3.4 below are examples of plotting via PLOTXY.

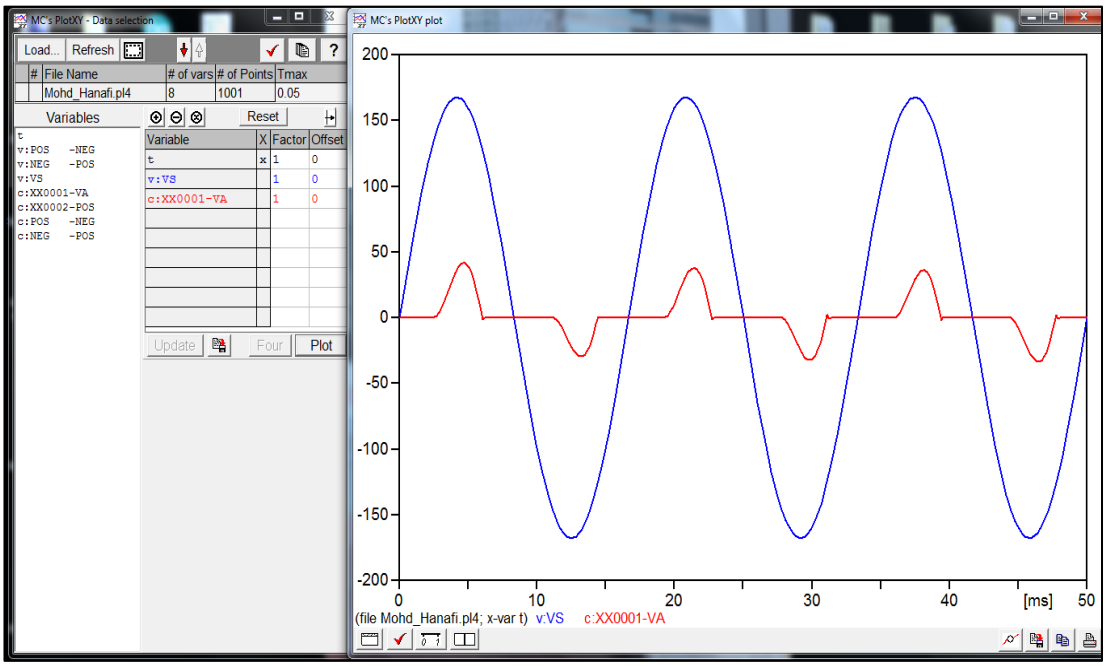

Figure 3.4 : Window for PLOTXY

3.4.2 WPC PLOT

WPCPlot is a graphical output program for ATP-EMTP running under Microsoft Windows 95/98/NT/2000/XP/7. The program is capable of processing PL4-files of C-like and formatted types maximum 6 variables in the same diagram are allowed. Zooming, redraw features and a readout facility obtain instantaneous values of plotting curves are provided. Screen plots can be copied to clipboard or save as color or monochrome bitmap image file. Figure 3.5 below are examples of plotting via WPCPLOT.

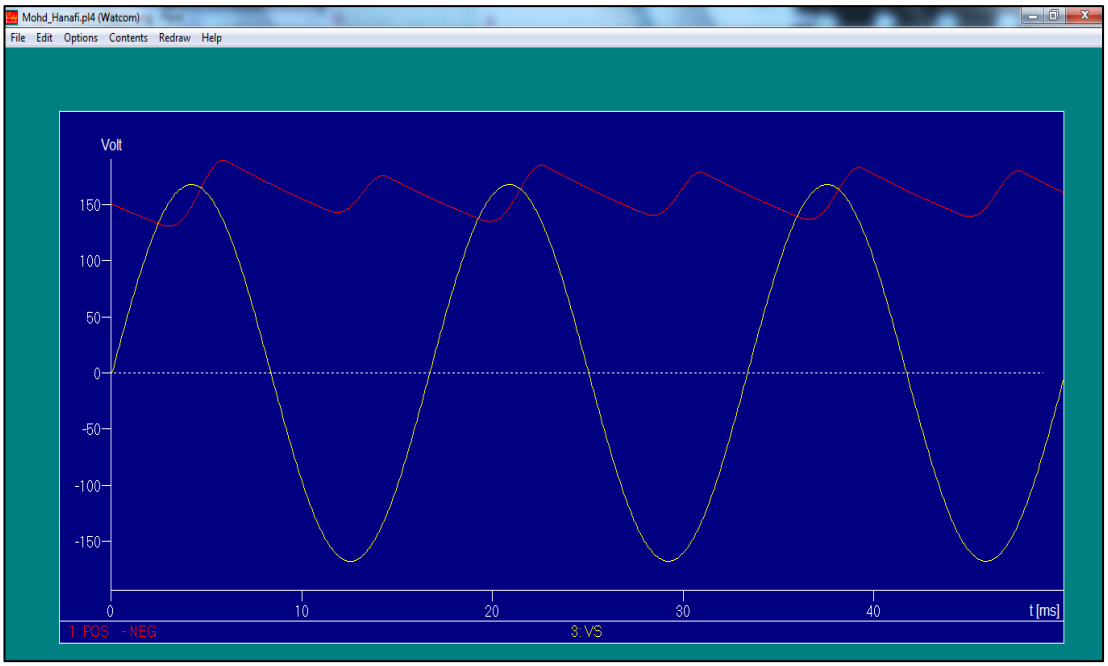

Figure 3.5 : Window for WPCPLOT

3.5 Model development using ATP Draw

To carry out research on surge arresters performance, some segments should be develop using ATP program such as transmission lines tower, surge arrester and lightning. Each segment must be developed using the ATP correctly. It must take into account the parameters and actual data to produce accurate findings. Several previous studies have been used as a source of reference for this study, as discussed in Chapter 2.

3.5.1 Modelling of lightning stroke

Lightning is one of the most significant sources of overvoltage in overhead transmission lines. The lightning stroke is modelled by a current source parallel with resistance which represents the lightning path impedance as show in Figure 3.6. There are various types of lightning source in the ATP such as Cigre-type, Standler-type, Surge-type and Heidler-type. Heidler type will be used for this study and resistance taken as 400Ω as derived by Bewley [22]. Figure 3.7 shows the dialog box of the Heidler-type surge model.

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