LIGHTNING SURGE ANALYSIS AND PROTECTION SYSTEM DESIGN FOR TYPICAL MOBILE PHONE TOWER

This thesis report submitted to the department of Electrical and Electronic Engineering in partial fulfillment of the degree of Master of Science in Electrical and Electronic Engineering

Md. Zoyheroul Islam
Roll:1503560

Department of Electrical and Electronic Engineering

Khulna University of Engineering & Technology

Supervised By
Dr. Md. Salah Uddin Yusuf
Professor,
Deptartment of EEE, KUET
Khulna-9203, Bangladesh

April 2018

I would like to dedicate this thesis to my loving parents and my beloved wife UMAMA SIDDIQUA . . . . . .

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and acknowledgements. This dissertation contains fewer than 65,000 words including appendices, bibliography, footnotes, tables and equations and has fewer than sixty figures.

Md. Zoyheroul Islam
Roll:1503560
April 2018

Acknowledgements

I am grateful to almighty Allah for kindness and mercy upon me for the successful completion of this thesis. This work carried out under the supervision of **Dr. Md. Salah Uddin Yusuf,** Professor of the Department of Electrical and Electronic Engineering (EEE), Khulna University of Engineering & Technology (KUET), Bangladesh. Without his supervision and guidance on this thesis it was impossible to complete. He showed me the right direction at right time and also provided me with valuable information. I would like to thank him for his support, valuable suggestion and technical instruction throughout this thesis work. I am also grateful to my parents, my wife and respected teachers of the Department for their continuous support to finish such a hardening work.

Abstract

Lightning is not only a serious weather hazard but also it has fascinated and excited humans for as long as they have watched the skies. It has been estimated that the earth is struck by 100 lightning bolts every second. Now a days lightning hazard is an important issue of major interest for the engineers and architects while designing the electric equipment & tall structures. Analyses of lightning surge characteristics deserve much more importance for designing protection scheme for communication tower against lightning. If a return stroke hit upon any metallic structure such as communication tower suited on multi-storied building's roof, the lightning transient over voltage will propagate through the columns, beams and other metallic structures of the building. If proper protection is not provided against lightning, the building, electric equipment and also human being living inside the building will be affected. Obviously this matter has been deserving much more attention for public safety. Modern power and communication system includes many electronic appliances for controlling and information processing purpose. It is essential to operate communication systems utilizing these electronic appliances. In this research the lightning surge response e.g, nature of voltage, current, surge impedance, electric field distribution and effect of direct stroke in another word the lightning surge characteristics on the multi-storied building and communication tower have been analysed. Induced effect of direct stroke on electronic equipment inside the building on different floors has also been analysed. Two different methods are used to analyzed the surge characteristics. Firstly Numerical Electromagnetic Code (NEC-2) is used as simulation tool for finding the surge response. Secondly ATP Draw (Alternative Transient Program) has been used for finding the surge characteristics. In this research IEEE model, Pinceti model and Fernandes-Diaz model of MOV type surge arrester are simulated with ATP-EMTP modified their parameters to determine the optimum values for designing proper protection scheme for the typical mobile phone towers.

Table of contents

List of figures

List of tables

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Lightning is said to be self sustain discharge of electricity between cloud and earth, between clouds or between the charges centers of same cloud. The main effects of lightning are unpredictable power interruptions, Hampers of the communication systems, serious damage to the structures on the ground, imposes a threat to livestock and human beings,collapse of an electrical network due to direct strike etc. A lightning bolt can heat surrounding air to 50000^0 F that's five times hotter than the sun. Each year thousands of properties are damaged or destroyed by lightning. A powerful strike can produce extensive property damage by sparking a fire or surging through electrical circuitary.

Although meteorologists understand the cloud conditions necessary to produce it, lightning cannot be forecasted. At any moment, there are as many as 1800 thunderstorms in progress somewhere on Earth, and each is producing deadly lightning. It has been estimated that the earth is struck by 100 lightning bolts every second. Approximately 400 people survive lightning strikes each year. Now a days lightning hazard is an important issue of major interest for the engineers and architects while designing the electric equipment & tall structures. Analyses of lightning surge characteristics deserve much more importance for designing protecting device and equipment against lightning. If proper protection is not provided against lightning to the communication tower the whole communication may be hampered and also for the multistory building, the electric equipment and people living inside the building will be affected very badly. Obviously this matter has been deserving much more attention for public safety.

1.2 RECENT STATISTICS OF LIGHTNING INJURY

According to the newspaper reports, the youngest person who died from lightning was 13 years old, and the oldest lightning victim was 70 years. In most cases, lightning occurred outdoors in a rural area while the person was performing daily household work or other usual activities. One newspaper reported that 51% of the fatalities were farmers who were working in the fields. After the fatal lightning injury event in May 2016, the Bangladesh government declared lightning a disaster, adding lightning injuries to the country's list of official types of natural disasters, which includes droughts, floods, cyclones, storm surges and riverbank erosion, and earthquakes. In 2016 the government pledged to compensate lightning strike victims and/or their families.

Bangladesh has had a high incidence of preventable deaths from lightning for decades. Data on the period 2005–2016 showed that the highest number of deaths in a single day was in May 2016, when lightning killed 81 people in 26 districts, mostly in the rural north and central Bangladesh. By comparison, lightning deaths between 2005 and 2008 totalled 41. Over the next few years, the number of deaths progressively increased. The English-language Bangladeshi newspaper Daily Star reports that from 2010 to 2016 a total of 645 people died in thunderstorms 14. Another source, the Foundation for Disaster Forum in Bangladesh, reports 1390 deaths due to lightning for the period 2010–2015 (Fig1). Other newspapers have reported that an average of 300 people die every year in Bangladesh due to lightning; however, this is underreporting.

1.3 BACKGROUND AND LITERATURE REVIEW OF THIS RESEARCH

The first theoretical studies of transmission tower surge response was proposed by M. Kawai [1]. Multistory transmission tower model for lightning surge analysis was implemented by M. Ishii [2]. Theoretical work for new derivation was reported by Takahashi [3]. A lot of experimental work done with EMTP such as tower modeling for lightning surge analysis using Electro-Magnetic Transient Program was done by M.E. Almeida [4]. An experimental evaluation of a ultrahigh voltage tower model for lightning surge analysis was done by T. Yamada [5]. Also modeling of a transmission tower for lightning surge analysis was proposed by N. Hara [6]. Numerical electromagnetic field analysis of tower surge response and lightning surge response of tower with shield wire was evaluated by M. Ishii and Y. Baba[7][8].Non Uniform line tower model for lightning transient studies was conducted by J.A Gutirrez [9]. Numerical electromagnetic field analysis of archorn

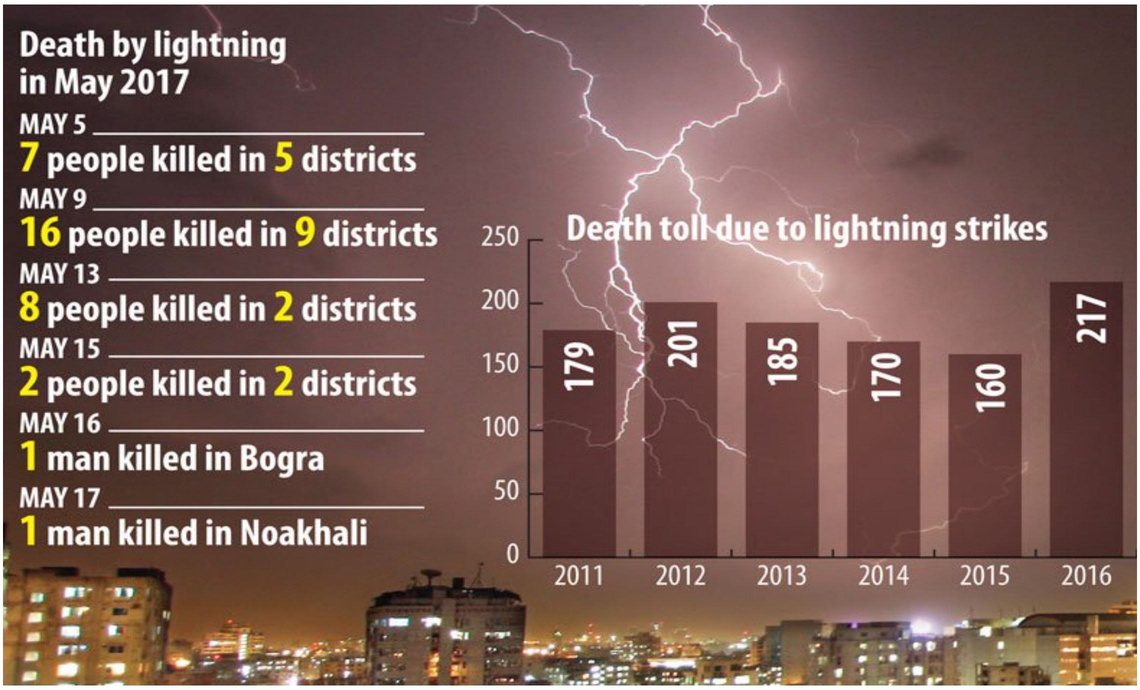


Fig. 1.1 Recent statistics of lightning injury according to the foundation of disaster forum.

voltages during a back-flashover on a 500-kV twin-circuit line was done by T. Mozumi [10]. M. Goni conducted theoretical and experimental investigations of the surge response of a vertical conductor[11]. Analysis and Estimation of Surge Impedance of Tower was done by M. O. Goni [12]. Experimental studies for determining the surge characteristics and recent progress of lightning protection system design have been carried out [13]-[17]. ATP Analysis of Transient Process during Direct Lightning Strike to the telecommunication Tower Asian Transactions on Engineering was conducted by X. Pejtemalli [13]. Recently Lightning Surge Characteristics on Transmission Tower was evaluated by Yusuf et. all [14]. Thus theoretical value of surge impedance agree satisfactory with the experimental and simulation results Lightning and Surge Protection in Photovoltaic Installations was evaluated by J.C.Hernández [15]. Overview of Recent Progress in Lightning Research and Lightning Protection was explored by V.A. Rakov [16]. Effect of Lightning on Building and Its Protection Measures was studied by K.Patel [17]. Empirical formulas of surge impedance for single and multiple vertical cylinder was developed by T. Hara in 1990 [19]. Numerical electromagnetic field analysis on measuring method of tower surge response was conducted in 1999 by Y. Baba and M. Ishii[20]. H. Takahashi derived new method of the surge impedance on the tower model of a vertical conductor by the electromagnetic field theory [21]. Study on lightning damage risk assessment method for power grid conducted by Xiaolan Li[22]. Electrical Transients in Power Systems was analysed by G. Allan[23].

Lightning Performance Analysis of Transmission Lines Using the EMTP and Model of Overhead Transmission Lines for Lightning Studies was developed by J A. Martinez[24]-[25]. Multistory transmission tower model for lightning surge analysis by M. Ishii and T. Hara [26]-[27]. Calculation of Lightning Current Parameters and tower surge impedance by F. Heidler and M A Sargent respectively[28]-[29]. Simulation of Lightning Transients on 110kV Overhead- Cable Transmission Line using ATP- EMTP and Lightning flashover on 77-kV systems: observed voltage bias effects and analysis by K. Fekets and Takamitsu respectively[30]-[31]. Modelling of metal oxide surge arrester, a simplified model for zinc oxide surge arresters and Metal oxide surge arrester model for fast transient simulations was conducted by Pinceti and Fernandez[32]-[34].

1.4 OBJECTIVES OF THIS RESEARCH

The purposes of this research work are to clarify the surge characteristics of a vertical conductor equivalent to real tower structure by analyzing the electromagnetic field around it with the effect of direct and indirect stroke. The objectives of this research including the followings:

- To analyze the lightning surge characteristics and find out the electromagnetic field distribution for transmission towers also find out the induced effect of transient over voltage on electronic equipment inside the multistoried building due to direct strike on tower top.
- To design a typical communication tower suited over a multistoried building and evaluate the surge characteristic such as transient over voltage, current, surge impedance, surge current propagation time at the different portion of the tower and different floor of the building and determine the effect of lightning return stroke (Direct stroke) on the tower.
- To determine out the effect of return stroke to mid span between towers and analyze the dynamic electromagnetic behavior, especially transient response on transmission line, communication tower and multistoried building.
- To compare the simulation result using numerical electromagnetic code (NEC-2) with the recently developed theoretical values and ATP.
- To design surge arrester scheme for saving communicating devices and equipment mounted on tower and the livestock, equipments inside the building.

1.5 THESIS ORGANIZATION

Orientation of this thesis report is described as follows:

- In chapter-1 importance of lightning study and background of this thesis are described.
- Basic theory of lightning mechanism and simulation methodology for analysing surge characteristics are being explained in chapter-2.
- Lightning surge characteristics analysis for typical mobile phone tower and induced effect of lightning on electronic equipment inside multistory building are accumulated in chapter-3.
- Lightning protection system design for typical mobile phone tower is described in chapter-4.
- This thesis is concluded in chapter-5.

Chapter 2

BASIC THEORY AND SIMULATION METHODOLOGY

2.1 INTRODUCTION

An electric discharge between cloud and earth, between clouds or between the different charge centers of same cloud is known as lightning. In other words Lightning is a massive electrostatic discharge between the electrically charged regions within clouds or between a cloud and the surface of a planet. If lightning hits an object on the ground, it is commonly referred to as a strike. Most of the time Lightning strokes hit the towers, conductors or any object in the neighboring of a transmission line. The direct lightning strike can cause collapse of an electrical network, and damage the system equipment. The instantaneous power cut in a large area may bring huge economic losses to the customers. Moreover, sustainable energy technology is applied increasingly in the electrical systems. Solar cells, wind turbines and etc. are usually installed at high positions where the probability of lightning to these devices is very high. The lightning damage increases the maintenance cost and also causes break down of the power supply. For designing proper protection system against lightning measuring of surge characteristics(e.g transient over voltage, current, surge impedance, electromagnetic field distribution etc.) is a vital fact. To analyse surge characteristics on vertical conductor and complex system several methods are available as follows

- Finite Difference Time Domain (FDTD)
- Electromagnetic Transient Program (EMTP)
- Finite Element Method (FEM)
- Numerical electromagnetic Code (NEC)

In this analysis, Firstly NEC-2 is employed as it is a widely used three-dimensional (3-D) electromagnetic modeling code based on the Method of Moments (MoM) in the frequency domain is used to find the surge characteristics for communication tower. Secondly ATP ATPDraw a graphical, mouse-driven preprocessor is a version of the Electromagnetic Transients Program (EMTP) has been employed for carried out the simulation.

2.2 LIGHTNING BASICS

In most cases the mechanism for occurrence of thunder clouds is rising air currents due to the air being heated near the ground by strong sunlight. The air in this rising air current is cooled, and the charge is separated when hail is generated, so the thunder clouds grow large due to the effect of electricity being generated.

Normally, a positive charge accumulates in the top of a thunder cloud and a negative charge accumulates in the bottom, so positively charged static electricity is induced near the ground surface. In this way, a strong electric field is generated between the thunder cloud and the earth, and when this exceeds the insulation capacity of the air, lightning is generated. The charged regions in the atmosphere temporarily equalize themselves through this discharge referred to as a flash. A lightning flash can also be a strike if it involves an object on the ground. Lightning creates light in the form of black body radiation from the very hot plasma created by the electron flow, and sound in the form of thunder. Lightning may be seen and not heard when it occurs at a distance too great for the sound to carry as far as the light from the strike or flash. There are many types of lightning are as follows:

2.2.1 Cloud-to-Ground Lightning

A lightning discharge between cloud and ground initiated by a downward-moving, charged stepped leader is called Cloud-to-Ground (CG) Lightning. CGs may be positive or negative discharge CGs. CGs commonly consist of multiple "return strokes", which are additional pulses of current that illuminate the channel again and again. The first return stroke of a CG is usually the only branched one - the branches usually do not illuminate again in subsequent return strokes.

2.2.2 Ground-to-Cloud Lightning

Ground-to-Cloud lightning (sometimes called Upward-moving lightning) is a discharge between cloud and ground initiated by an upward-moving leader originating from an object on the ground. Ground-to-Cloud (GC) lightning strikes are common on tall towers. GC lightning can also be either positive or negative in polarity. Lightning that demonstrates upward branching is a clear indication of a ground-to-cloud flash, though some upward-moving lightning is branchless below cloud base.

2.2.3 Intra-cloud Lightning

The most common type of discharge - lightning inside a single storm cloud, jumping between different charge regions in the cloud. Intra-cloud lightning is sometimes called sheet lightning because it lights up the sky with a "sheet" of light. All or parts of the actual channel may be obscured inside the cloud, and may or may not be visible to an observer on the ground. Not to be confused with cloud-to-cloud lightning.

2.2.4 Cloud to Cloud Lightning

Lightning discharges may occur between areas of cloud without contacting the ground. When it occurs between two separate clouds it is known as inter-cloud lightning, and when it occurs between areas of differing electric potential within a single cloud it is known as intra-cloud lightning. Intra-cloud lightning is the most frequently occurring type. Not to be confused with common intra-cloud lightning occurring within one storm cloud.

2.2.5 Bolt from the Blue

A bolt from the blue (sometimes called "anvil lightning" or "anvil-to-ground" lightning) is a name given to a cloud-to-ground lightning discharge that strikes far away from its parent thunderstorm. A "bolt from the blue" typically originates in the highest regions of a cumulonimbus cloud, traveling horizontally a good distance away from the thunderstorm before making a vertical descent to earth. Due to the final strike point being a significant distance from the storm (sometimes up to ten miles away), these lightning events can occur at locations with clear "blue" skies overhead - hence the name.

2.3 MECHANISM OF LIGHTNING DISCHARGE

When a charged cloud passes over the earth, it induces equal and opposite charge on the earth below. Fig. 1.7 shows a negatively charged cloud inducing a positive charge on the earth below it. As the charge acquired by the cloud increases, the potential between cloud and earth increases and, therefore, gradient in the air increases. When the potential gradient is sufficient (5 kV/cm to 10 kV/cm) to break down the surrounding air, the lightning stroke starts.

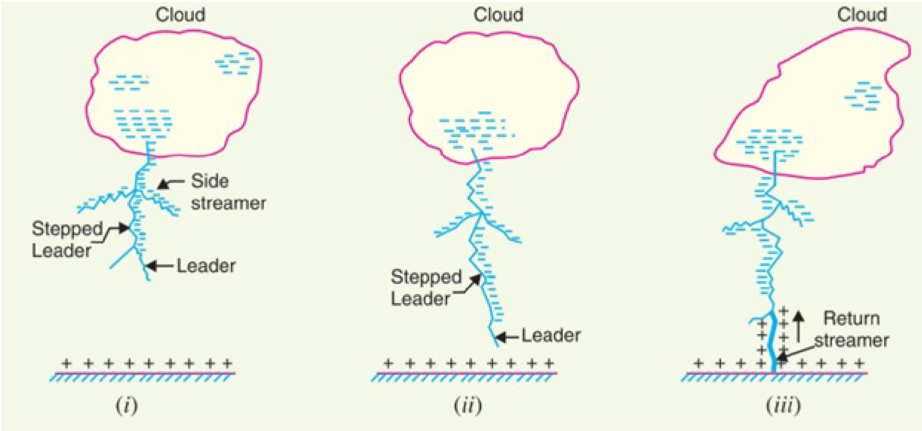


Fig. 2.1 Mechanism of Lightning Discharge.

As soon as the air near the cloud breaks down, a streamer called leader streamer or pilot streamer starts from the cloud towards the earth and carries charge with it as shown in Fig.2.1 (i). The leader streamer will continue its journey towards earth as long as the cloud, from which it originates, feeds enough charge to it to maintain gradient at the tip of leader streamer above the strength of air. If this gradient is not maintained, the leader streamer stops and the charge is dissipated without the formation of a complete stroke. In other words, the leader streamer will not reach the earth. Fig. 2.1(i) shows the leader streamer being unable to reach the earth as gradient at its end cloud not be maintained above the strength of air. It may be noted that current in the leader streamer is low (<100 A) and its velocity of propagation is about 0•05% that of velocity of light. Moreover, the luminosity of leader is also very low .

In many cases, the leader streamer continues its journey towards earth until it makes contact with earth or some object on the earth which is shown in Fig.2.1 (ii). As the leader streamer moves towards earth, it is accompanied by points of luminescence which travel in jumps giving rise to stepped leaders. The velocity of stepped leader exceeds one-sixth of that of light and distance travelled in one step is about 50 m. It may be noted that stepped leaders have sufficient luminosity and give rise to first visual phenomenon of discharge. The path of leader streamer is a path of ionisation and, therefore, of complete breakdown of insulation. As the leader streamer reaches near the earth, a return streamer shoots up from the earth to the cloud which is shown in Fig. 1.7 (iii), following the same path as the main channel of the downward leader. The action can be compared with the closing of a switch between the positive and negative terminals; the downward leader having negative charge and return streamer the positive charge. The approximate time durations of the various components of a lightning stroke are summarized as follows:

Table 2.1 APPROXIMATION TIME DURATION OF LIGHTNING STROKE

Name	Time Duration
Stepped leader	10ms
Return stroke	40ms
period between strokes	40μs
duration of dart leader	1ms

2.4 TYPES OF LIGHTNING STROKE

There are two main ways in which a lightning may strike the power system (e.g. overhead lines, towers, sub-stations etc.), namely: 1. Direct stroke 2. Indirect stroke

2.4.1 Direct Stroke

lightning strike is an electric discharge between the atmosphere and an Earth-bound object.[citation needed] They mostly originate in a cumulonimbus cloud and terminate on the ground, called cloud to ground (CG) lightning. A less common type of strike, called ground to cloud (GC), is upward propagating lightning initiated from a tall grounded object and reaches into the clouds.

The primary conducting channel, the bright coursing light that may be seen and is called a "strike", is only about one inch in diameter, but because of its extreme brilliance, it often looks much larger to the human eye and in photographs. Lightning discharges are typically miles long, but certain types of horizontal discharges can be upwards of tens of miles in length. The entire flash lasts only a fraction of a second. Most of the early formative and propagation stages are much dimmer and not visible to the human eye. In the direct stroke, the lightning discharge (i.e. current path) is directly from the cloud to the subject equipment e.g. an overhead line. The lightning discharge is from the cloud to the subject equipment i.e. an overhead line in this case as shown in Fig. 1.8 .

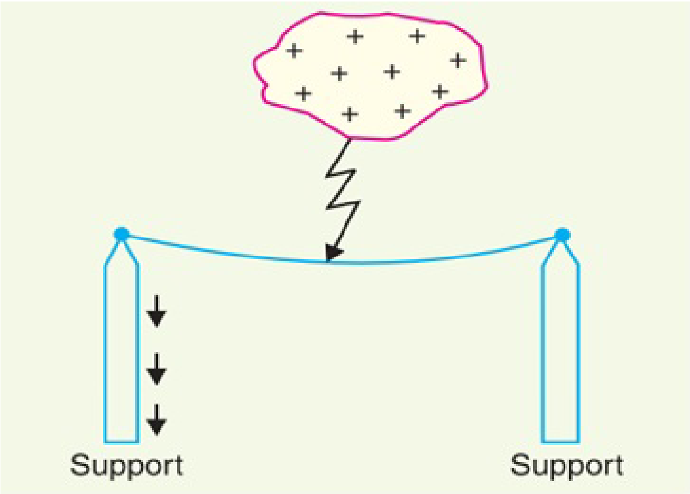


Fig. 2.2 Direct Lightning Stroke.

2.4.2 Indirect Stroke

Indirect strokes result from the electrostatically induced charges on the conductors due to the presence of charged clouds. This is illustrated in Fig. 1.9. A positively charged cloud is above the line and induces a negative charge on the line by electrostatic induction. This negative charge, however, will be only on that portion of the line right under the cloud and the portions of the line away from it will be positively charged as shown in Fig. 1.9.

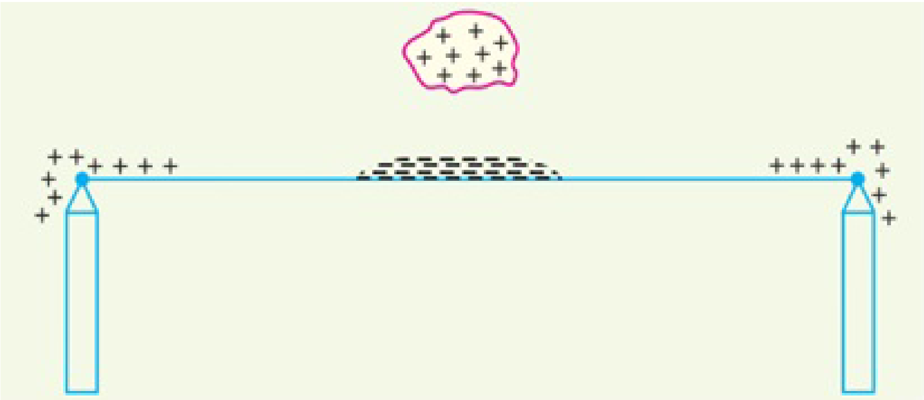


Fig. 2.3 Indirect Lightning Stroke.

2.5 EFFECTS OF LIGHTNING

The time to review possible lightning effects upon a particular asset, facility or structure (AFS) is during the design stage. A Lightning Mitigation Plan is conceived from a Hazard

Design Analysis. Then a Testing and Verification Program can provide certification that the protective measures will function as engineered. Frequently, lightning problems do not receive consideration during the design stage. It remains then for the lightning safety engineer to analyze the effects of lightning during operations and to provide a rationale for safety-through-redesign modifications to the AFS. The intent of this document is to provide the reader with a review of the effects of lightning. The variety of behavior produced by lightning upon AFS can be divided into four areas. Effect of lightning are as follows:

- Unpredictable power interruptions
- Serious damage to the structures on the ground
- Imposes a threat to livestock and human beings
- Collapse of an electrical network due to direct strike
- Hampers of the communication systems

2.6 CONVENTIONAL PROTECTION AGAINST LIGHTNING

These are mainly three main methods generally used for protection against lightning. They are

- Earthing screen.
- Overhead earth wire.
- Lightning arrester or surge dividers.

2.6.1 Earthing Screen

Earthing screen is generally used over electrical sub-station. In this arrangement a net of GI wire is mounted over the sub-station. The GI wires, used for earthing screen are properly grounded through different sub-station structures. This network of grounded GI wire over electrical sub-station, provides very low resistance path to the ground for lightning strokes. This method of high voltage protection is very simple and economic but the main drawback is, it can not protect the system from travelling wave which may reach to the sub-station via different feeders.

2.6.2 Overhead Earth Wire

This method of over voltage protection is similar as earthing screen. The only difference is, an earthing screen is placed over an electrical sub-station, whereas, overhead earthwire is placed over electrical transmission network. One or two stranded GI wires of suitable cross-section are placed over the transmission conductors. These GI wires are properly grounded at each transmission tower. These overhead ground wires or earthwire divert all the lightning strokes to the ground instead of allowing them to strike directly on the transmission conductors.

2.6.3 Lightning Arrester or Surge Dividers

The previously discussed two methods, i.e. earthing screen and over-head earth wire are very suitable for protecting an electrical power system from directed lightning strokes but system from directed lightning strokes but these methods can not provide any protection against high voltage travelling wave which may propagate through the line to the equipment of the sub-station. The lightning arrester is a devices which provides very low impedance path to the ground for high voltage travelling waves. The concept of a lightning arrester is very simple. This device behaves like a nonlinear electrical resistance. The resistance decreases as voltage increases and vice-versa, after a certain level of voltage. The functions of a lightning arrester or surge dividers can be listed as below.

- Under normal voltage level, these devices withstand easily the system voltage as electrical insulator and provide no conducting path to the system current.

- On occurrence of voltage surge in the system, these devices provide very low impedance path for the excess charge of the surge to the ground.

- After conducting the charges of surge, to the ground, the voltage becomes to its normal level. Then lightning arrester regains its insulation properly and prevents regains its insulation property and prevents further conduction of current, to the ground. There are different types of lightning arresters used in power system, such as rod gap arrester, horn gap arrester, multi-gap arrester, expulsion type LA, value type LA.

In addition to these the most commonly used lightning arrester for over voltage protection now-a-days gapless ZnO lightning arrester is also used.

2.7 THEORETICAL FORMULA OF SURGE IMPEDANCES

There is a theoretical formula of surge impedance of a vertical conductor, in case with ground plane and without ground plane [19]. Suppose lightning surge strike on the vertical conductor of height 'h' and radius 'r'. Then the surge current is reflected at the ground of the perfect conductor and returns to the top of the vertical conductor. If current reflectivity and magnetic field reflectivity the formula of which is very close to the well-known empirical formula of Dr. Hara, is obtained as follows:

$$Z = 60\{\ln(h/2r) - 1/4\} = 60\{\ln(2\sqrt{2}h/r) - 1.983\} \tag{2.1}$$

Equation (2.1) gives the surge impedance of the vertical conductor just after the occurrence of the reflection of the traveling wave propagation down from the top of the structure. However if it is considered that $\beta = \gamma_i = \gamma_r = 1$, the potential generated in the vertical conductor at 'h' became,

$V(t) = \frac{c\mu_0 I_0}{2\pi}(ln\frac{(ct+2r)}{2r} - \frac{ct}{2(ct+r)})$

The above equation can be modified by substituting , where 'c' is the velocity of light and assuming $h \gg r$ as

$$Z = 60\{\ln(h/r) - 1/2\} = 60\{\ln(2\sqrt{2}h/r) - 1.540\} \tag{2.2}$$

On the other hand, if there is no ground, the following formula is induced

$V(t) = \int(-E_i \cdot di) = \frac{c\mu_0 I_0}{2\pi}(ln\frac{(ct+2r)}{2r} - \frac{ct}{2(ct+r)})$

substituting $ct = 2h$ and assuming $h \gg r$ as in the above equation, we get

$$Z = 60\{\ln(h/r) - 1/2\} = 60\{\ln(2\sqrt{2}h/r) - 1.540\} \tag{2.3}$$

This formula given by equation (2.2) is same as equation (2.3). Then, we can calculate the surge impedance by these equations and compare with NEC-2 results comparing with and without ground plane case.

2.8 NUMERICAL ELECTROMAGNETIC CODE

NEC-2 code, a standard tool for numerical analysis on electromagnetic field around antennas, can be applied to analysis of lightning transient overvoltages .For practical purposes, the analysis of lightning transients in large conducting structures has mostly been made through modeling the structures by transmission lines. In this approach, the parameters of a transmission line such as the surge impedance, the velocity of the traveling wave etc. need to be determined. This is physically correct if the electromagnetic field around a conductor is in the TEM mode, in that the distribution of the electric field is the same as the electrostatic field. Parameters of the modeled transmission line for parallel conductors or a horizontal conductor above a ground plane can be determined on physical basis. The electromagnetic field around non-parallel conductors or a non-horizontal conductor above a ground plane is not in the TEM mode during transient periods. In modeling such conductor systems by transmission lines, their parameters need to be determined experimentally or hypothetically. Electromagnetic field around a conductor system needs to be solved to produce induced voltages and distribution of currents, which facilitates modeling with equivalent circuits without carrying out experiments. The idea to numerically solve transient electromagnetic field associated with lightning transients is not new. However, it has not been recognized as a practical method, partly because the verification of the accuracy of the result has been difficult, and reproduction of the result by a third party is difficult if a dedicated computer code was developed for the analysis. Numerical Electromagnetics Code is a widely used computer code in analyzing three-dimensional electromagnetic field around antennas and scatters in the frequency domain. The Lawrence Livermore Laboratory developed it and its second version, NEC-2, is publicly released . It was applied to time-domain analysis, combined with Fourier transform, of lightning surge response of a transmission tower, and the accuracy of the computed result was verified through comparison with an experiment . Thus its effectiveness in the application to time-domain analysis of lightning transients of a conductor system was demonstrated. NEC solves integral equations at the boundary numerically by the method of moments. The basic theory of NEC and methods to obtain the code is described below.

2.8.1 Electric Field Integral Equation

NEC allows to use both the electric-field integral equation and the magnetic-field integral equation. The former is suited for analysis of thin-wire structures, while the latter is suitable for structures having large smooth surfaces. The former can be used to analyze voluminous structures by representing surfaces with wire grids. In the application to time-domain analysis, the modeling by using thin wires has been employed throughout. The following description on the basic theory of NEC is extract from the program description The basic electric-field integral equation at the surface of a thin conducting wire in the axial direction is reduced to the following scalar equation 2.4 under the restriction of the boundary condition 2.5 in the axial direction. These equations are for a single angular frequency ω

$$-\hat{s}.E_{inc}(r) = \frac{-j\eta}{4\pi k}\int_L I(\acute{s})(\hat{s}.\hat{\acute{s}} - \frac{\delta^2}{\delta_s \delta_{\acute{s}}})g(r,\acute{r})d\acute{s} \tag{2.4}$$

$$E_{scat}(r) + E_{inc}(r) = 0 \tag{2.5}$$

where
$g(r,\acute{r}) = exp(-jk|r - r\acute{r}|)/|r - \acute{r}|$
$k = \omega\sqrt{\mu_0\varepsilon_0}, \eta = \sqrt{\mu_0/\varepsilon_0}$ //

s is the distance parameter along the wire axis at r, and $\hat{s}$ is the unit vector tangent to the wire axis at r. E_{inc} is the incident field and E_{scat} is the scattered field. The current I is represented by a filament on the wire axis. Equation 2.4 is easily extended to lossy conductors by modifying the boundary condition from equation 2.5 to//

$$\hat{s}.[E_{scat}(r) + E_{inc}(r)] = Z_L(s)I(S) \tag{2.6}$$

where $Z_L(s)$ is the impedance per unit length at s.

2.8.2 Modeling Guidelines of Time-Domain Analysis

The composition of short cylindrical segments of any conductor system can be analyzed by NEC-2. A cylindrical segment is defined by the coordinates of its two end points and its radius. Modeling with cylindrical segments involves both geometrical and electrical factors. Geometrically, the segments should follow the paths of conductors as closely as possible, using a piece-wise linear fit on curves. The main electrical consideration is on the segment length Δ L relative to the wavelength λ, and $10^3\lambda < \Delta L < 0.1\lambda$ is recommended. The radius of segment, a, should be much less than $\lambda/2\Pi$ and $\Delta L/8$. For example, in the analysis of a high voltage measuring system , $a/\Delta L < 1/120$ was necessary to obtain consistent results. If segments are electrically connected at their ends, the identical coordinates should be used. The angle of the intersection of segments should be as large as possible, for an acute angle may results in less accuracy. Abrupt changes of segment length should be also avoided. NEC-2 allows lumped circuit elements to be incorporated into the model by simply defining the impedance of any given segments.

2.8.3 Example of Input Data

For this example, the vertical conductor of 0.6 m in height is divided into 12 segments of 0.05 m. The input data deck must begin with comment lines ‘CM’. The comment lines are

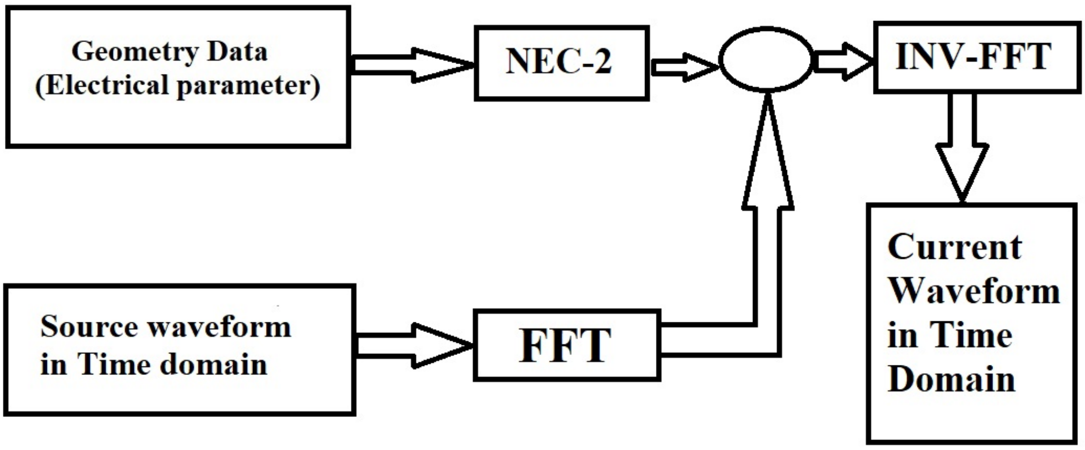


Fig. 2.4 Solution flow of transient analysis in the time domain using NEC-2 and FFT.

terminated by ‘CE’. A line starting with ‘GW’ represents a cylindrical straight wire. The number next to ‘GW’ is a tag number assigned to all segments of the wire. The one next to it is the number of segments into which the wire is divided. The decimal numbers next to them are the coordinates of the wire ends and the radius of the wire (x1, y1, z1, x2, y2, z2, a). Note that the unit is in meters . The following two lines, ‘GE 1’ and ‘GN 1’, indicate a perfectly conducting ground exists at $z = 0$, i.e. by these commands, images below ground are generated.

The 11th and 12th lines beginning with ‘LD’ specify the impedance loading. The 11th line indicates that the 40th segment of the set of segments whose tag number is 4 is loaded by resistance of 510Ω . Similarly, the 12th line indicates that 1st segment of the set of segments having tag number of 2 is loaded by 10kΩ . In the line starting with ‘FR’, the frequency range is specified as 7.813 MHz to 2000 MHz with the linear increment step of 7.813 MHz In the line of ‘EX’, the excitation for the structure is specified. In this case, a voltage source generating 5 V is inserted into the 40th segment of the set of segments having tag number of 4. By the line beginning with ‘PT’, currents for the 1st segment of the set of segments whose tag number is 1 are printed. The last two commands, ‘XQ’ and ‘EN’, are commands of program execution and end, respectively.

2.9 ALTERNATE TRANSIENT PROGRAM(ATP)

ATPDraw for Windows is a graphical, mouse-driven preprocessor to the ATP version of the Electromagnetic Transients Program (EMTP). In ATPDraw the user can construct the digital

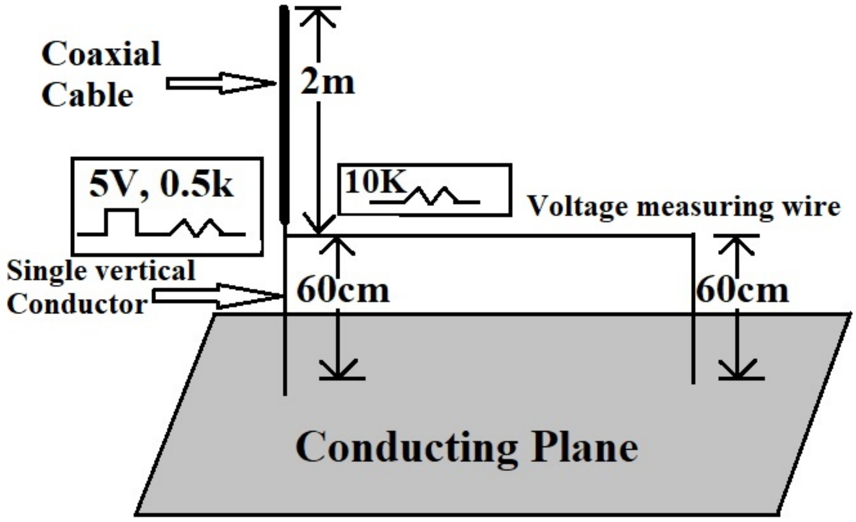


Fig. 2.5 An impulse voltage measuring system of 60 cm vertical conductor.

```
CM  MOBILE PHONE TOWER ON ROOF
CM  Vertically applied source
CM     N=512  DT= 0.267E-06 SEC
CE  PERFECTLY CONDUCTING GROUND
GW 01 020     000      000      020      000      000      000       0.03
GW 02 020     000      010      020      000      010      000       0.03
GW 03 020     015      010      020      015      010      000       0.03
GW 04 020     015      000      020      015      000      000       0.03
GW 05 010     000      010      020      000      000      020       0.03
GW 06 015     000      000      020      015      000      020       0.03
GW 07 010     015      000      020      015      010      020       0.03
GW 08 015     000      010      020      015      010      020       0.03
GW 09 010     000      010      010      000      000      010       0.03
GE  1
GN  1
LD  4  01   20   20     00015
LD  4  02   20   20     00015
LD  4  03   20   20     00015
LD  4  04   20   20     00015
LD  4  02   01   01     10000
FR  0  257            20.0E+6    20.0E+6
EX  0   17  01  00    10.0E+3       0.0
PT  0   02  01
XQ
EN
```

Fig. 2.6 A sample input data for Fig 2.2 using NEC-2.

model of the circuit to be simulated using the mouse and selecting predefined components from an extensive palette, interactively. Then ATPDraw generates the input file for the ATP simulation in the appropriate format based on "what you see is what you get". Circuit node naming is administrated by ATPDraw, thus the user needs to give a name only to nodes having special interest. ATPDraw has a standard Windows layout and offers a large Windows help file system. All kinds of standard circuit editing facilities (copy/paste, grouping, rotate/flip, export/import, undo/redo)are available. Other facilities in ATPDraw are: built-in editor for ATP-file editing, text viewer for displaying the output LIS-file of ATP, automatic LI S-file checking with special trigger strings to detect simulation errors, support of Windows clipboard and metafile export. ATPDraw supports multiple circuit modeling that makes possible to work on more circuits simultaneously and copy information between the circuits. ATPDraw is most valuable to new users of ATP-EMTP and is an excellent tool for educational purposes. However, the possibility of multi-layer modeling makes ATPDraw a powerful front-end processor for professionals in analysis of electric power system transients, as well. Version 3.6 and above of AT PDraw for 9x/NTx/2000/XP Windows platforms are written in Borland Delphi 6.0. From version 5.3 CodeGear Delphi 2007 is used. This version uses the html help file system supported in Windows XP/ Windows-10.

2.9.1 Operating Principle 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 they can be entered by the user 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 modeling.

Symmetrical or unsymmetrical disturbances are allowed, such as faults, lightning surges and several kind of switching operations including commutation of valves. Frequency-domain harmonic analysis using harmonic current injection method (HARMONIC FREQUENCY SCAN) and calculation of the frequency response of phasor networks using FREQUENCY SCAN feature is also supported. The model-library of ATP at present consists of the following components:

- Uncoupled and coupled linear, lumped R,L,C elements.
- Transmission lines and cables with distributed and frequency-dependent parameters.
- Nonlinear resistances and inductances, hysteretic inductor, time-varying resistance, TACS/MODELS controlled resistance.
- Components with nonlinearities: transformers including saturation and hysteresis, surge arresters (gapless and with gap), arcs.
- Ordinary switches, time-dependent and voltage-dependent switches, statistical switching (Monte-Carlo studies).
- Valves (diodes, thyristors, triacs), TACS/MODELS controlled switches.
- Analytical sources: step, ramp, sinusoidal, exponential surge functions, TACS/MODELS defined sources.
- Rotating machines: 3-phase synchronous machine, universal machine model.
- User-defined electrical components that include MODELS interaction.

2.9.2 Integrated Simulation Modules in ATP

MODELS in ATP is a general-purpose description language supported by an extensive set of simulation tools for the representation and study of time-variant systems.

- The description of each model is enabled using free-format, keyword-driven syntax of local context and that is largely self-documenting.
- MODELS in ATP allows the description of arbitrary user-defined control and circuit components, providing a simple interface for connecting other programs/models to ATP.
- As a general-purpose programmable tool, MODELS can be used for processing simulation results either in the frequency domain or in the time domain.

TACS is a simulation module for time-domain analysis of control systems. It was originally developed for the simulation of HVDC converter controls. For TACS, a block diagram representation of control systems is used. TACS can be used for the simulation of

- HVDC converter controls

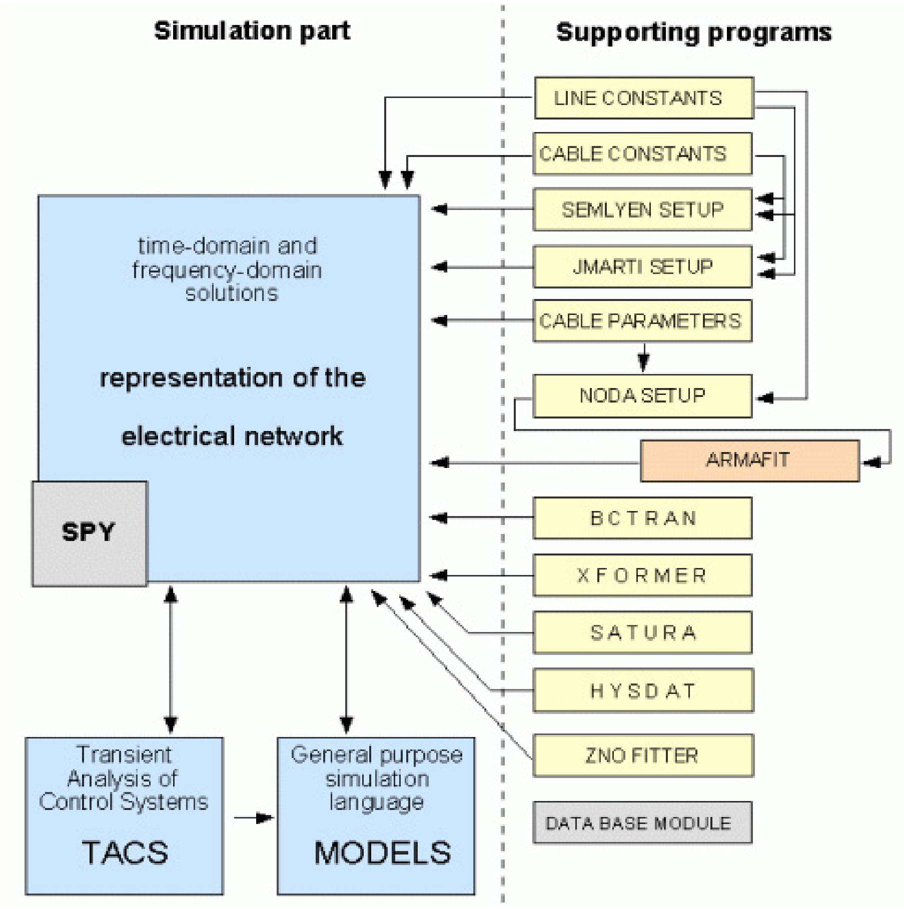


Fig. 2.7 Supporting routines in ATP.

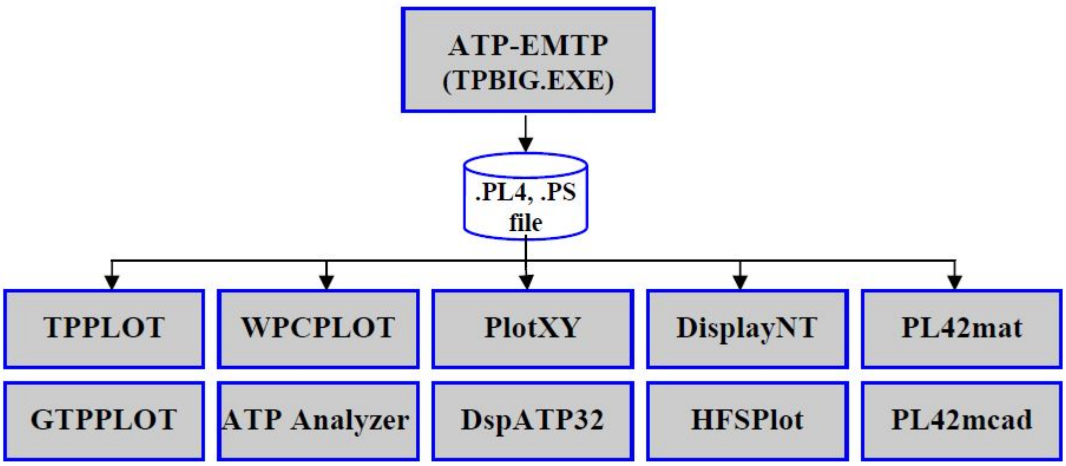


Fig. 2.8 Plotting programs for ATP.

- Excitation systems of synchronous machines
- power electronics and drives
- electric arcs (circuit breaker and fault arcs).

Interface between electrical network and TACS is established by exchange of signals such as node voltage, switch current, switch status, time-varying resistance, voltage- and current sources. Supporting routines are integrated utilities inside the program that support the users in conversion between manufacturers' data format and the one required by the program, or to calculate electrical parameters of lines and cables from geometrical and material data. Supporting modules in ATP are:

- Calculation of electrical parameters of overhead lines and cables using program modules LINE CONSTANTS, CABLE CONSTANTS and CABLE PARAMETERS. Generation of frequency-dependent line model input data (Semlyen, J.Marti, Noda line models).
- Calculation of model data for transformers (XFORMER, BCTRAN).
- Saturation and hysteresis curve conversion.
- Data Base Modularization (for INCLUDE usage).

2.9.3 Program Capabilities

ATP-EMTP tables are dimensioned dynamically at the start of execution to satisfy the needs of users and their hardware (e.g., RAM). No absolute limits have ever been observed, and the standard version has limits that average more than 20 times default table sizes. Today, the largest simulations are being performed using Intel-based PC's. The following table shows maximum limits for standard program distribution.

- Busses 6000
- Sources 900
- Branches 10000
- Nonlinear elements 2250
- Switches 1200
- Synchronous machines 90

2.9.4 Main Characteristics of Plotting Programs for ATP

These post-processors are interfaced with ATP via disk files and their main function is to display the results of a time- or frequency domain simulation. ATP simulation data are stored in a file having extension .pl4, and it can be processed either off-line, or on-line. The latter (i.e. to display results while the simulation proceeds) is available only if the operating system provides concurrent PL4-file access for ATP and the postprocessor program.

ATP Analyzer is a Windows based program intended for observing and analyzing analog signals and discrete channel data associated power generation, transmission and distribution systems. The programis capable of reading and displaying analog signals produced by ATP as type PL4 output file data, industry standard COMTRADE file and analog and digital data produced from protective relays and fault recorder equipment, analog signals from table ASCII text data, and audio wave files. A total of 254 signals can be managed. Signals can be displayed in time domain in multiple overlay charts. One or more signals can be displayed as a function of another on an X versus Y chart. Up to three signals can be displayed simultaneously in the frequency domain as harmonics or as a broad frequency spectrum. Charts may be printed and copied to the Windows clipborard. The program can process the data for harmonic content and store processed data in a Windows Access Data base.

- Developer: Bonneville Power Administration, USA.
- Licensing: Distributed at no cost to the licensed ATP users.
- Distribution: EEUG annual CD distribution, EEUG, JAUG secure Web sites.

GTPPLOT is a plotting program for processing PL4 output of ATP. It is compiled with the GNU FORTRAN, and makes use of the graphical package DISLIN. The program is available for DOSdjgpp extender, Windows 32, and Linux. GTPPLOT can read widenn, formatted PL4-files FREQUENCY SCAN PL4 output, as well. GTPPLOT has no graphical interface, the user must use the keyboard for all the input commands. GTPPLOT is able to process graphics files with up to 1000000 points and up to 1000 variables. The program can plot up to 20 curves end export the graphics in nine different formats: HP-GL, CGM, WMF, PCX, PostScript, PNG, WMF, JAVA and GNUPLOT. For FS and HFS runs the plot can be bar charts. The data can be exported as widenn PL4, COMTRADE, Matlab, MathCad and Mathematica files. Furthermore, the program calculates lot of Power Quality Indexes from data, can be used for FOURIER analysis, turbine shaft loss of life estimation. Various simple math operations with variables, as integration, derivation, RMS, power, energy, I2T are also supported. GTPPLOT can be used to generate KIZILCAY F-DEPENDENT elements from

FREQUENCY SCAN PL4 output, as well. GTPPLOT has no graphical interface, the user must use the keyboard for all the input commands.

2.9.5 Typical EMTP Applications

ATP-EMTP is used world-wide 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:

- Lightning overvoltage studies
- Switching transients and faults
- Statistical and systematic overvoltage studies
- Very fast transients in GIS and groundings
- Machine modeling
- Transient stability, motor startup
- Shaft torsional oscillations
- Transformer and shunt reactor/capacitor switching
- Ferroresonance
- Power electronic applications
- Circuit breaker duty (electric arc), current chopping
- FACTS devices: STATCOM, SVC, UPFC, TCSC modeling
- Harmonic analysis, network resonances
- Protection device testing

Chapter 3

SURGE CHARACTERISTICS ANALYSIS FOR COMMUNICATION TOWERS USING NEC-2

3.1 INTRODUCTION

In this chapter, lightning surges characteristics on a telecommunication tower is analyzed by using NEC-2. Then the effects of the measuring methods and the arrangements of the measuring wires on the tower surge impedance are studied by the NEC-2. For the present analysis, NEC-2 is employed as it is a widely used three-dimensional (3-D) electromagnetic modeling code based on the MoM in the frequency domain. It is particularly effective in analyzing the electromagnetic response of antennas or of other metallic structures composed of thin wires. A vertical conductor system needs to be decomposed into thin wire elements, and the position, orientation and the radius of each element constitute the input data, along with the description of the source and frequency to be analyzed. In analysis, all the elements in the systems are treated as perfect conductors. To solve the time varying electromagnetic response, Fourier transform and inverse Fourier transform are used. The study in this research precedes the work done to obtain the surge characteristics of an earth-wired tower as well as phase conductors of the tower struck by lightning in case of direct and indirect stroke.

3.2 LIGHTNING ON MOBILE PHONE TOWER

Mobile tower is a great threat for Bangladeshi people. Specially in city area it is a great concern for public health . Due to great demand of mobile phone in BD various mobile operator have built up their network through antenna all over the country. Grameen Phone, BanglaLink, Rabi, Citycell , TeleTalk, Airtel are major mobile carriers in Bangladesh. All of those companies have set up their mobile antenna over the roof of houses or institutions without considering the minimum distance from the people's living area. They never followed the international strategy to do it. In developed countries it is established by keeping minimum distance from the residential area, but in BD specially in Dhaka city no operator cared this important and sensitive point. From the tower electro magnetic wave is coming out continuously which badly effect on public health. It can be cause of cancer, heart diseases , high per tension, headache or an other diseases. The symptoms of those diseases can be appeared after 10-20 years later.

Lightning is another major issue for the towers it is well known the direct lightning stroke always hit the top point of the earth surface. As the towers are installed over the roof of the multistoried building so that tower top point can make easily the discharge path for leader streamer.

If lightning strike hit the tower over the roof of building it can cause serious hamper for the building structure, can destroy wiring system of the building. Electric devices such television, fridge, computer can be damaged due to lightning overvoltage and it can also be a serious threat for the people lives inside building if proper lightning protection system is provided. In this research a typical tower model over building roof is considered and lightning surge characteristics on the tower and building is analyzed by Numerical Electromagnetic Code(NEC-2).NEC-2 is widely used three-dimensional (3-D) electromagnetic modelling code based on the Method of Moments(MoM) in frequency domain, and is particularly effective in analyzing the electromagnetic response of vertical structure. A vertical conductor system needs to be decomposed into thin wire elements, and the position, orientation and the radius of each element constitute the input data, along with the description of the source and frequency to be analyzed. In the analysis, all the elements in the systems are treated as perfect conductors. To solve the time varying electromagnetic response, Fourier transform and inverse Fourier transform are used. The study in this paper precedes the work done to obtain the surge characteristics of typical mobile phone tower over multistoried building roof struck by lightning with the help of NEC-2.

3.3 MODELING GUIDELINE

A conductor system to be analyzed by NEC-2 should be modeled by the composition of short cylindrical segments. A cylindrical segment is defined by the coordinates of its two end points and its radius. Modeling with cylindrical segments involves both geometrical

(a)

(b)

Fig. 3.1 Typical network coverage tower strike by lightning installed over roof of building(Location: Khulna, Bangladesh) and electrical factors. Geometrically, the segments should follow the paths of conductors as closely as possible, using a piece-wise linear fit on curves. The main electrical consideration is on the segment length L relative to the wavelength , and $10^{-3} < L < 0.1$is recommended. The radius of segment, a, should be much less than =2 and L=8. For example, in the analysis of a high voltage measuring system [22], $a/L < 1/120$ was necessary to obtain consistent results. If segments are electrically connected at their ends, the identical coordinates should be used.

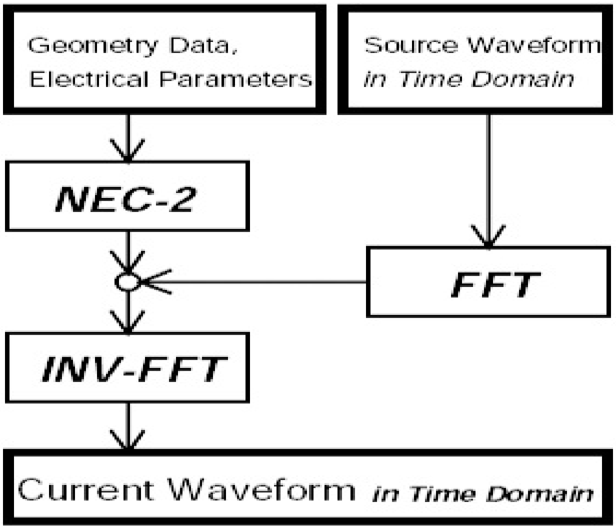


Fig. 3.2 Simulation Diagram of Transient analysis in the time domain NEC-2 and FFT.

The angle of the intersection of segments should be as large as possible, for an acute angle may results in less accuracy. Abrupt changes of segment length should be also avoided. NEC-2 allows lumped circuit elements to be incorporated into the model by simply defining the impedance of any given segments. Application to Time-Domain Analysis NEC-2 is a computer code in the frequency domain, therefore, to obtain the response of a system in the time domain, Fourier transform and inverse Fourier transform are used. For Fourier transform, FFT is employed. The flow of solution is shown in Fig 3.12. Careful considerations should be taken in determining the time step t and duration of analysis T (or the highest frequency f_{high} and the lowest frequency flow in the analysis) in the Fourier transform of the input waveform of the source. The frequencies of the output must be coincided with the frequencies analyzed by NEC-2.

3.4 PROPOSED MODEL FOR ANALYSIS

In Bangladesh, telecommunication utility companies hire multi-storied buildings roof to install their network coverage tower. In this research a typical mobile phone network area coverage tower over the buildings roof is considered.

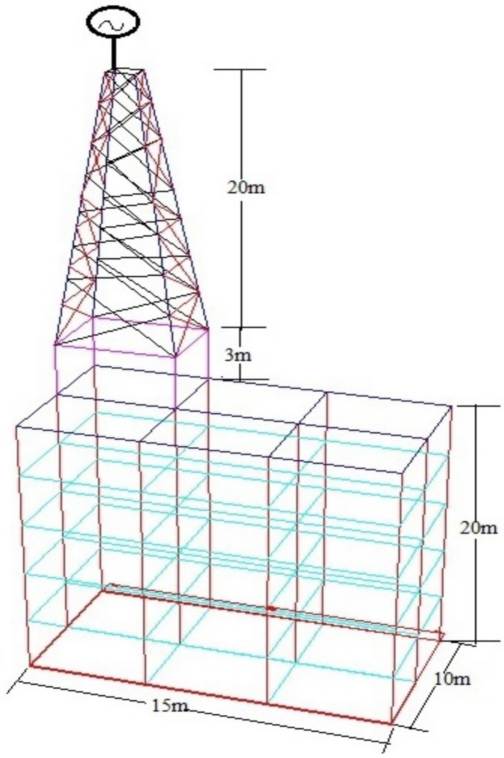
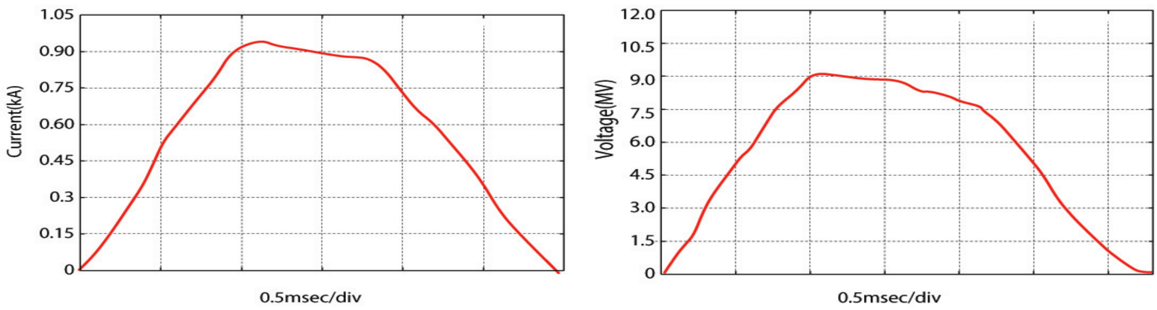


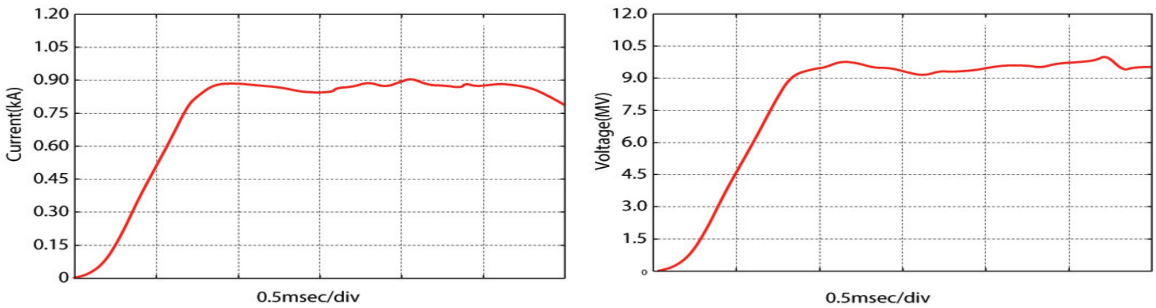
Fig. 3.3 3-D structure of a mobile phone tower over a 5-stored building.

Here a 20m long 4-pole tower is being installed over a five stored buildings roof. The building is 15m in length and 10m in width. A lead wire of 2m height is considered at the top of the tower to give a pulse of 10MV at the top point of the tower by pulse generator. All the segments of the structure is considered as perfectly conductive. Radius of the conductors is being taken 0.005m and segment length is 1m, which is satisfied all conditions of analyzing surge of cylindrical structure by NEC-2. As it is a long structure frequency is taken 20MHz and for 50 steps lower frequency is taken 0.3MHz which are satisfy all the conditions of NEC-2. At the last segment of all columns of the building 15 ground resistance is considered and to obtain current at the top of the tower and every floor of the building 10kΩ resistance is considered for measuring voltage induced at different segment of the structure.



(a) Current (b) Voltage

Fig. 3.4 Current and voltage waveform at the top segment of the tower.



(a) Current (b) Voltage

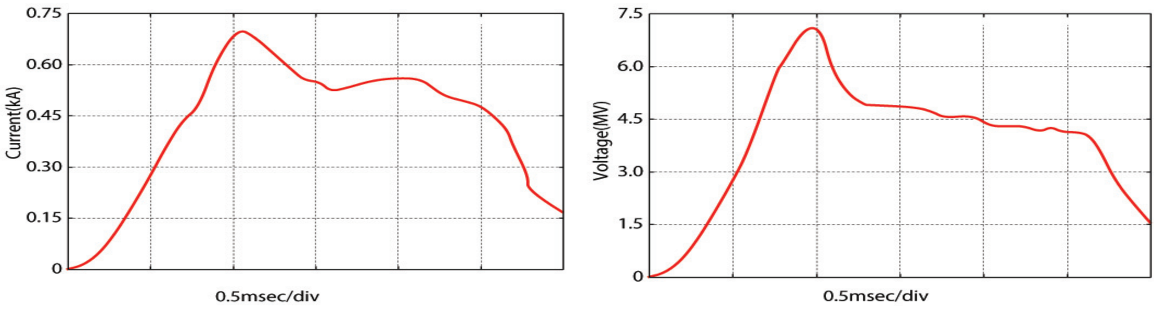
Fig. 3.5 Current and voltage waveform of the 4th floor of the building.

3.5 SIMULATION OF TOWER SUITED OVER THE BUILDING BY NEC-2

Fig. 3.4(a) shows the current at the top of the tower and Fig.3.4(b) shows the voltage induced across the 10kΩ loading. A pulse of 10MV is injected at the top of the tower along with a current lead wire of 2m height as the same diameter of the tower segments.

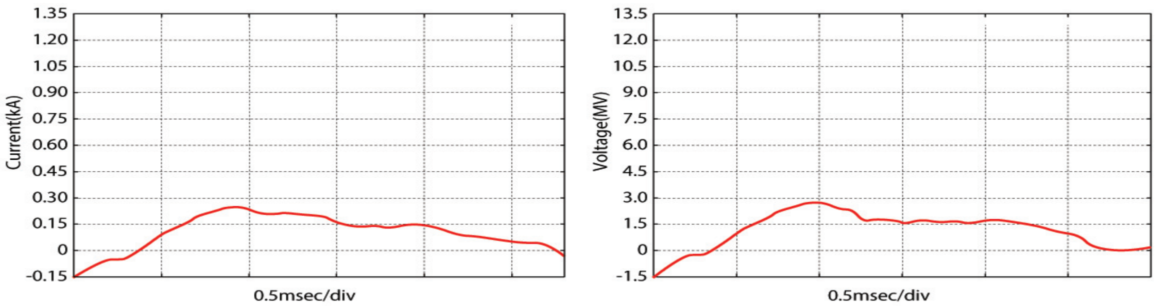
In this simulation a ramp of 1 sec is used for analysis, the Fig.3.4 shows that at the time of 1.1sec the current is reached to the pick and there is a very small delay time as the length of current lead wire is 2m and current propagate at the velocity of light.

The total considered length of conductor in the geometry is 398m so that total reflection time is needed 2.65sec and from the figure it has been seen that current reflection time is needed 2.9sec. In Fig. 3.5(a) maximum current at the 4th floor of the building is found 880A which is less than the current of the top point of the tower and voltage is found 9.5MV at pick point. In Fig.3.6(a) shows current at the 3rd floor and Fig.3.6(b) shows the induced voltage at the 3rd floor. In Fig.3.7(a) shows current at the 2nd floor and Fig.3.7(b) shows the induced voltage at the 2nd floor. In Fig.3.8(a) shows current at the 3rd floor and Fig.3.8(b)



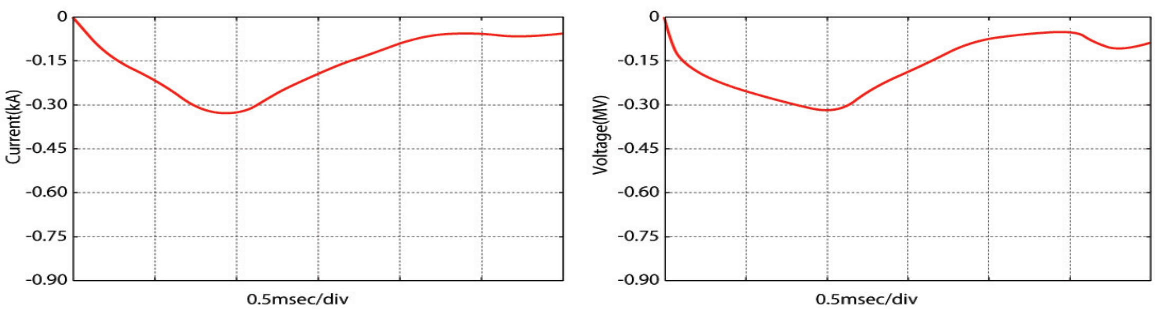
(a) Current (b) Voltage

Fig. 3.6 Current and voltage waveform of the 3rd floor of the building.



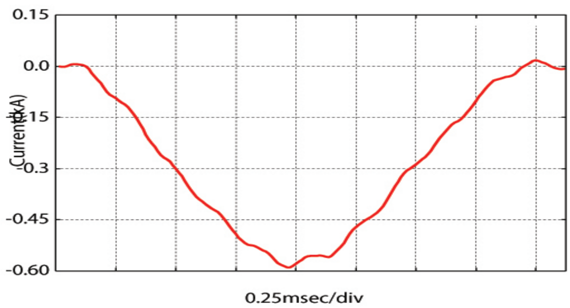
(a) Current (b) Voltage

Fig. 3.7 Current and voltage waveform of the 2nd floor of the building.

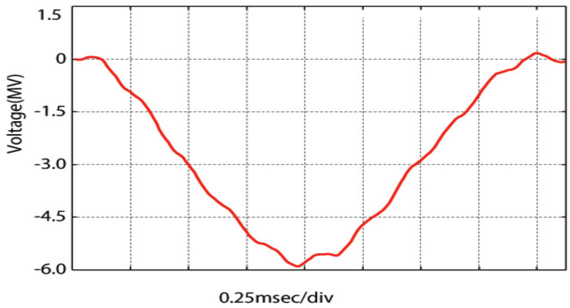


(a) Current (b) Voltage

Fig. 3.8 Current and voltage waveform of the 1st floor of the building.



(a) Current



(b) Voltage

Fig. 3.9 Current and voltage waveform of the ground floor of the building.

shows the induced voltage at the 1st floor.In Fig.3.9(a) shows current at the 3rd floor and Fig.3.9(b) shows the induced voltage at the ground floor.

3.6 COMPARISON OF SURGE IMPEDANCE FOR THE DIFFERENT SECTIONS

For the measurement of voltage 10kΩ resistance has been considered and voltage waveforms have been found. Surge impedances for the tower and for the building are found from the current and voltage wave form of different segments of the structure. The top segment of the tower and the five floors of the building are simulated. The results are included at TABLE I.

Table 3.1 COMPARISON OF CURRENT VOLTAGE AND SURGE IMPEDANCE OF THE STRUCTURE.

Segment	Current(kA)	Voltage(MV)	Surge Impedance(Ω)
Tower top	0.95	9.0	9473
4th floor	0.88	9.2	10450
3rd floor	0.60	7.0	10290
2nd floor	0.23	2.7	11730
1st floor	0.30	3.2	9690
Ground floor	0.58	5.9	10170

From figures and table obtained by simulation, current, voltage and surge impedance at tower and building are found. Direction of current is negative at 2nd, 1st and ground floor due to reflection of current from the other side of the building as the parameters are found from the simulation of at that side of the building on which tower is installed. As the structure is considered perfectly conductive so it must follow KVL and KCL so that it can be said that the simulation result is near accurate. It is well known that communication tower is harmful for building structure, human being and livestock near it for it's radiation. From this analysis it is very much clear that if tower over any building has no proper surge protecting system it can be caused serious damage of the building structure and also caused destruction of wiring system of the building. Electric equipment inside the building can be damaged if any connection from supply phase and much more cause of human death. As a huge amount of voltage injected by lightning stroke so that some amount of voltage are induced on electric device without any connection from supply phase that can also cause of damaging of the devices. So this analysis will be helpful for designing proper surge protecting devices for mobile phone tower on buildings roof to ensure the service continuity and protection of sophisticated equipments.

3.7 INDUCED EFFECT OF LIGHTNING SURGE SIMULATION OF A MULTI-STOREY BUILDING

In this work a 5-storied building has been considered which is stroked by lightning 3-D model of the building is shown in Fig.3.10. The building height is 20m, length is 15m and width is 10m all the columns and beams of the building are considered fully conductive. A lead wire is considered as breakdown path whose height is 3m. At the top of the lead wire a pulse of 10MV is injected by pulse generator. For the easiest calculation and satisfying all the conditions of analyzing surge of cylindrical structure by NEC-2 the radius of all the conducting paths, columns and beams are considered as 0.005m and the length of each segment is 1m. The high frequency f_{high} is taken as 20MHz and for 50 steps f_{low} considered 0.3MHz. 10Ω ground resistance is considered at the last segment of all the columns.

To observe and calculate the induced effect of lightning transient over voltage on electronic equipment a metallic structure is considered inside the 4^{th} floor of the building which is directly not connected to any column or beam of the building. For the simplicity of calculation a $1m \times 1m \times 1m$ structure is included in geometry. Fig.3.11 shows the structure and Fig.3.12 shows waveform of transient voltage induced on the metallic structure. Highest positive pick found around 20V at 1μsec and highest negative pick found 20V at 2.1μsec. It has been seen from the curve that there is no voltage induced after 4μsec from the injection time.

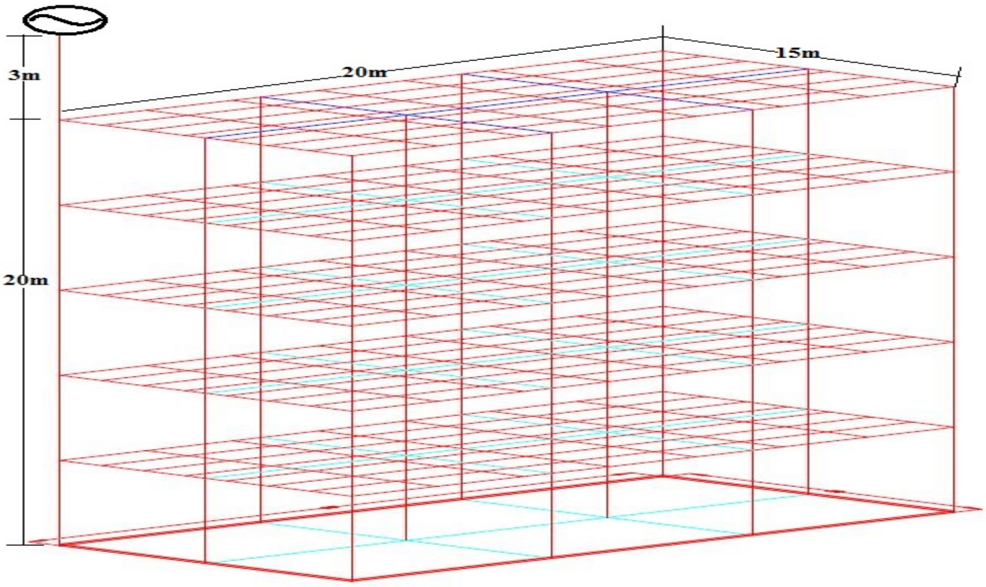


Fig. 3.10 3-D structure of a multistoried building.

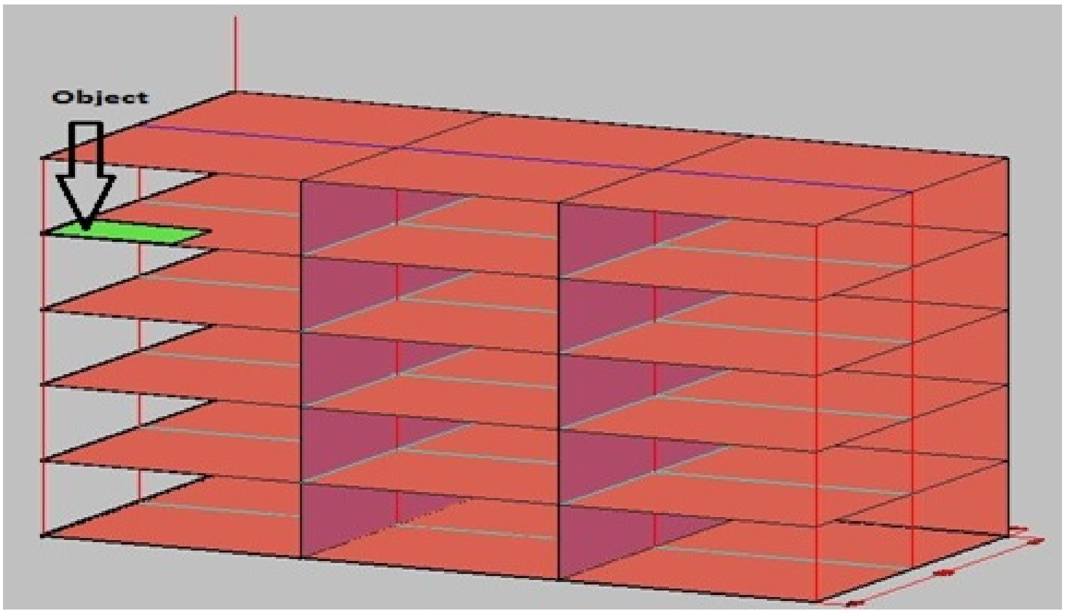


Fig. 3.11 Mettalic object inside the building on 4^{th} floor.

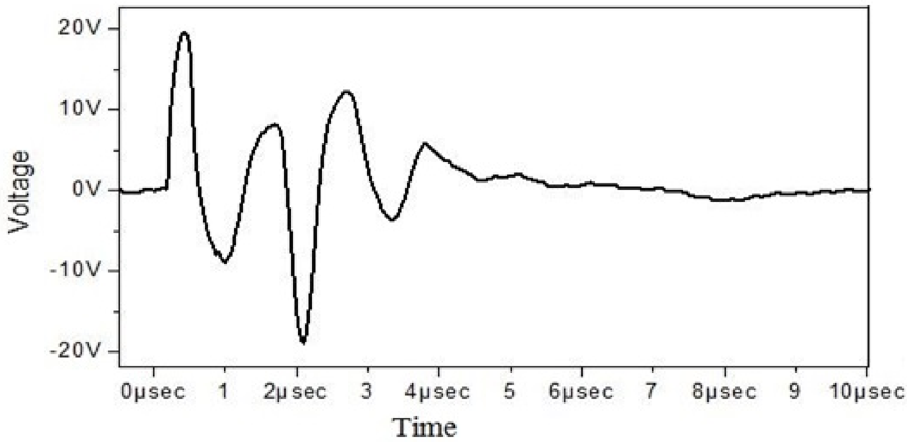


Fig. 3.12 Waveform of induced voltage on a metallic body inside the building.

Table 3.2 COMPARISON BETWEEN DIRECT AND INDUCED VOLTAGE AT DIFFERENT FLOOR OF THE BUILDING.

Corresponding Floor	Direct strike voltage(MV)	Induced Voltage(V)
Ground floor	-3.95	-9.3
1st floor	-2.9	-6.8
2nd floor	4.1	11.2
3rd floor	7.6	16.5
4th floor	9.0	20

Chapter 4

PROTECTION SYSTEM DESIGN FOR TYPICAL MOBILE PHONE TOWER USING ATP

4.1 INTRODUCTION

Lightning surge is one of the common causes of sparking and over current damage of electronic device mounted on tall telecommunication towers. If any communication tower stroked by lightning the equipment connected to the communication system can be damaged. Metal Oxide Varestor (MOV) type surge arrester are used for protecting the line insulations and equipment of the power system connected to the transmission tower so MOV type protection scheme also might be employed for protecting communication tower. To simulate the dynamic properties of MOV type arrester several types of models are proposed. In this research IEEE model, Pinceti model and Fernandes model of MOV type surge arrester are simulated by ATP-EMTP with modification of parameters. Before employed them into communication tower a 900m single line of 132kv with three tower are designed and simulated with ATP-EMTP program and evaluate the performance of different models of lightning arrester for protecting the towers and transmission line from direct and indirect strike. Obtaining the results from transmission tower analysis a Metal Oxide Verestor(MOV) type protection scheme is employed for the proposed typical mobile phone tower. Two exponential current-dependent resistor are used into parallel parallel combination for bypassing the surge current from the tower body.

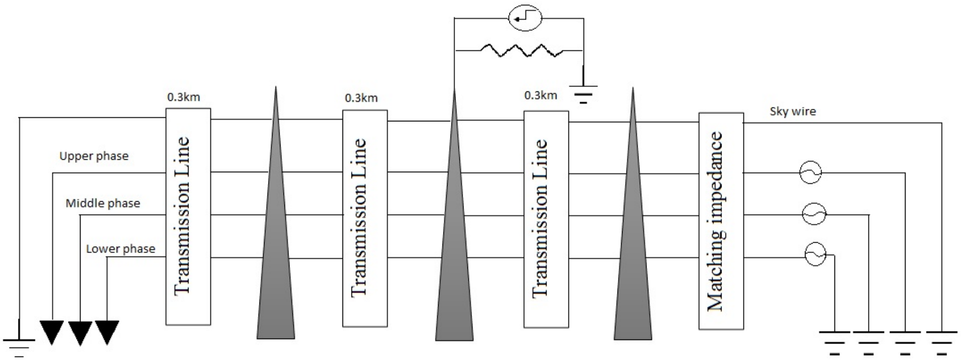


Fig. 4.1 Model of 900m single line transmission line with three tower.

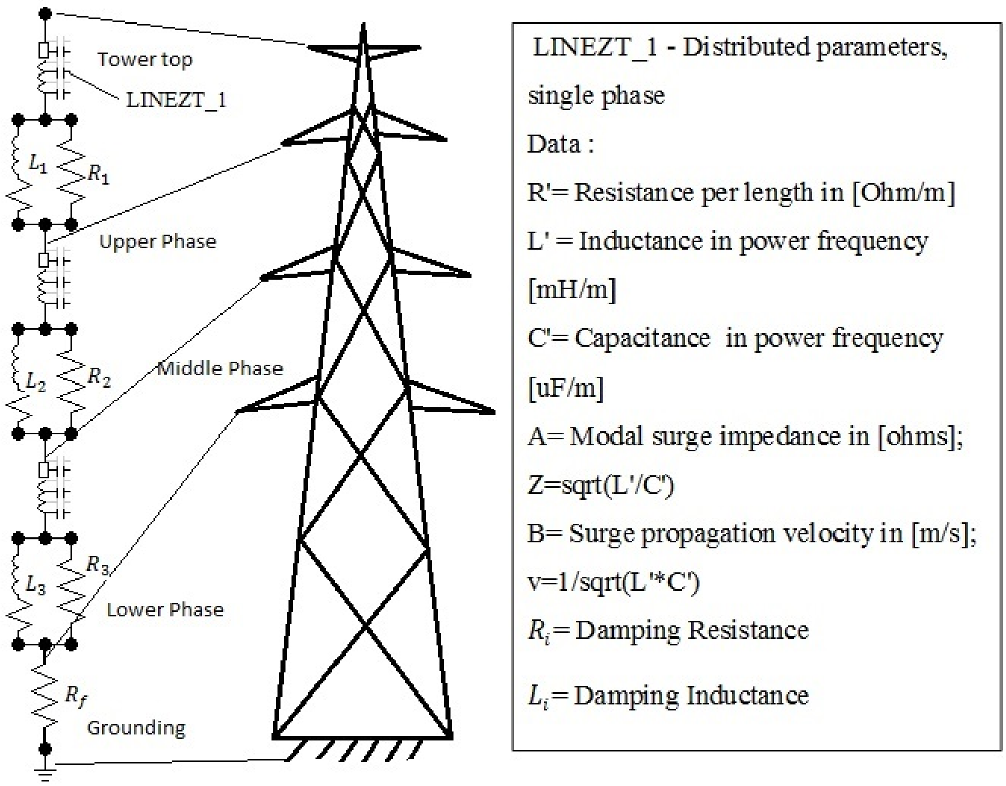


Fig. 4.2 Parameters of multi-storey tower.

4.2 MODELING OF TRANSMISSION LINE

In this portion of research a 132kv three phase line with overhead ground wire was modelled with three towers which are apart 300m from each other. Phase wires and ground wire are explicitly modelled between the towers where three tower spans were used. Line termination at each side of the model was to avoid any reflection that might affect the simulated high-voltages around the point of impact [25]. This has been done by terminating the phase conductors with AC operation voltages, and by grounding the sky wire. Fig.4.1 shows the span of three towers with line termination of the model.

4.2.1 Parameters of Transmission Tower

There are different types models of transmission tower proposed by the researchers at last few years. One of the more well-known models is the multistory model designed by Masaru Ishii in 1991 [26]. A multistory tower model basically is a composition of distributed parameter lines with parallel RL circuits and has been recommended by the Japanese Guideline of insulation design/coordination against lightning [24]. In Japan and other countries this model is widely used for analyzing lightning-surge characteristics. Fig.4.2 shows the proposed multistory tower model. However, the design of the multistory tower model was based on high voltage transmission line. Thus, multistory tower model is not relevant to Mal -voltage transmission line system (such as 132kV and 230kV). Based on the investigation done by Takamitsu[31], a simple distributed line model is adequate enough to represent a low-voltage transmission line model in ATP-EMTP software. Therefore, this model has been used for designing the transmission tower for this work.

4.3 MOV TYPE SURGE ARRESTER MODEL ANALYSED WITH ATP

The dynamic models of surge arrester are very important for insulation coordination and reliability studies of several models in power system at different voltage levels, are proposed to represent the frequency depended characteristic of MOV type surge arresters. IEEE, Fernandez, Pinceti and Popov models are the established models of surge arresters. Frequency-dependent characteristic of arrester have been simulated by IEEE, Pinceti and Fernandez models which are used in this work for designing proper protection scheme of transmission tower. The equivalent ATP model has been drawn for all the models and find the voltage and current across the MOV. For determining the performance of the three models the time of bypassing surge has been found from the matlab figure which were generated by compilation of the ATP circuit of each.

4.3.1 IEEE Model

Fig.4.4.a shows the surge arrester model proposed by the IEEE Working Group 3.4.11 [32]. It has two nonlinear elements known as A_0 and A_1 separated by $R_1 - L$ filter. A capacitor gives the external capacitance related with the height of the arrester. The stability can be improved by adding an inductance L_0 (connected in parallel with resistance R_0). For the fast rising current, the impedance of RL filter becomes more significant which means current passes through the non-linear branch A_0. So, A_0 has a higher voltage than A_1. The model of arrester will generate higher voltages which then match the dynamic behaviour of metal oxide surge arrester. This equivalent ATP model is shown in fig.4.4.b. Current and voltage waveform of A_0 and A_1 varistor are shown in fig.4.4.c.

Equations (1-5) show the parameter and V-I characteristic of varistor given in ref. [32]. The A_0 and A_0 nonlinear characteristic of V-I characteristic is shown in fig.4.4.d.

On the contrary, during fast surges, the impedance of the filter becomes significant, and causes a current distribution between the two branches. For precision sake, the current through the branch A_0 rises when the front duration decreases. Since A_0 resistance is greater than A_1 resistance for any given current, the faster the current surge, the higher the residual voltage. This is because high frequency current are forced by the L_1 inductance to flow more in the A_0 resistance than in the A_1 resistance.

$$L_0 = \frac{0.2d}{n} \mu H \tag{4.1}$$

$$R_0 = \frac{100d}{n} \Omega \tag{4.2}$$

$$L = \frac{15d}{n} \mu H \tag{4.3}$$

$$R_1 = \frac{65d}{n} \Omega \tag{4.4}$$

$$C = \frac{100d}{n} pF \tag{4.5}$$

Where;
n = Total number of parallel columns in metal-oxide (MO) disks.

d = Length of arrester columns in metre (m).
The inductance L_0 in the model represents the inductance associated with magnetic fields in the immediate vicinity of the arrester. The resistor R_0 is used to stabilize the numerical integration where the model is implemented on a digital computer program. The capacitance C represents the terminal-to-terminal capacitance of the arrester.

The efforts of the working group in trying to match model results to the laboratory test data have indicated that these formulas do not always give the best parameters for the frequency dependent model. However, they do provide a good starting point for picking the parameters. An investigation was made by the working group into which parameters of the model had the most impact on the results. To accomplish this, a model based on the preceeding formulas was set up on the Electromagnetic Transients Program. (Ikmo et al., 1996)

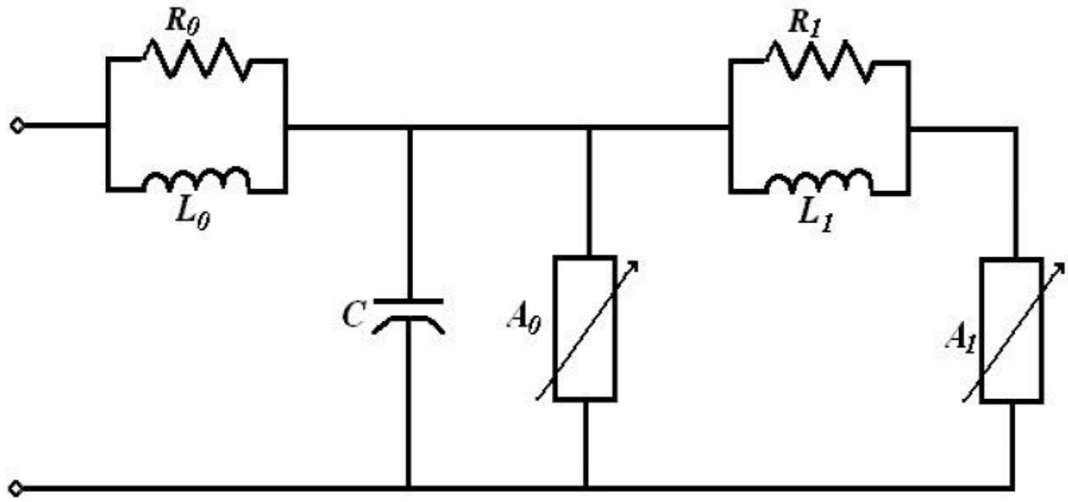
4.3.2 Pinceti Model

Pinceti model is related to IEEE model which is shown in Fig.5.a but a few modifications are done in Pinceti model [33]. The difference is that no capacitance between the one terminal to other terminal and nonlinear resistance A_0. R is replaced by nearly about 1MΩ resistance. The higher value of R is used to avoid numerical oscillation.Inductances L_0 and L_1 are calculated using equation (6, 7). In fig.4.5.b the ATP equivalent of Pinceti model is shown. The ATP equivalent circuit has been simulated hence voltage and current waveform of A_0 and A_1 varistor are shown in fig.4.5.c.

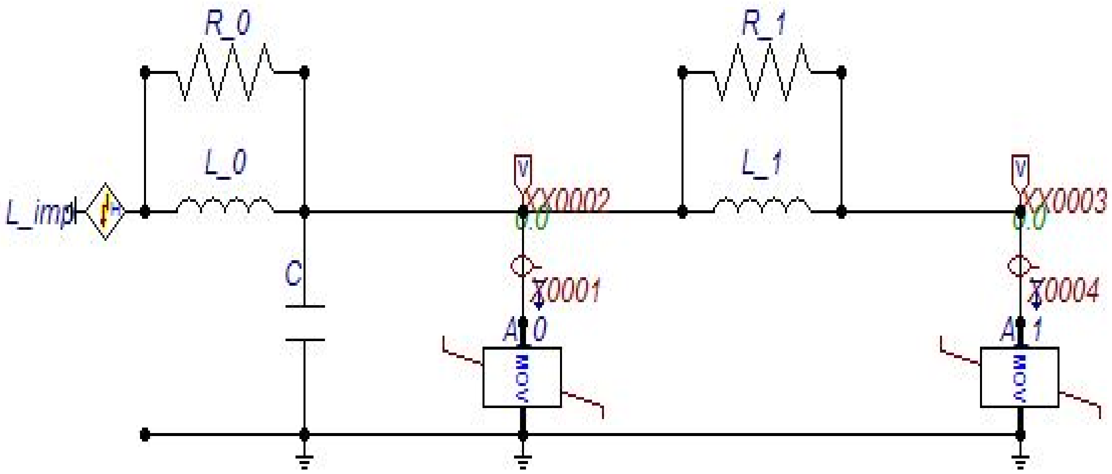
$$L_0 = \frac{1}{12} . \frac{V_{r\frac{1}{T_2}} - V_{r\frac{8}{20}}}{V_{\frac{8}{20}}} V_n \mu H \tag{4.6}$$

$$L_1 = \frac{1}{4} . \frac{V_{r\frac{1}{T_2}} - V_{r\frac{8}{20}}}{V_{\frac{8}{20}}} V_n \mu H \tag{4.7}$$

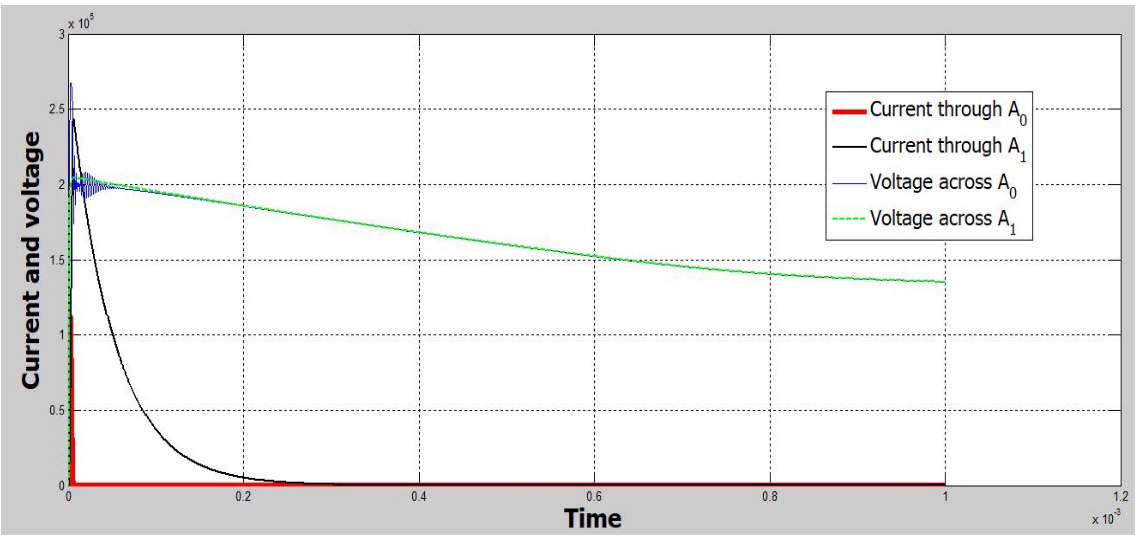
The equations (6) and (7) are based on the fact that parameters L_0 and L_1 are related to the roles that these elements have in the model. In other words, since the function of the inductive elements is to characterize the model behaviour with respect to fast surges, it seemed logical to define these elements by means of data related to arrester behaviour during fast surges.



(a) surge arrester model proposed by the IEEE Working Group 3.4.11.

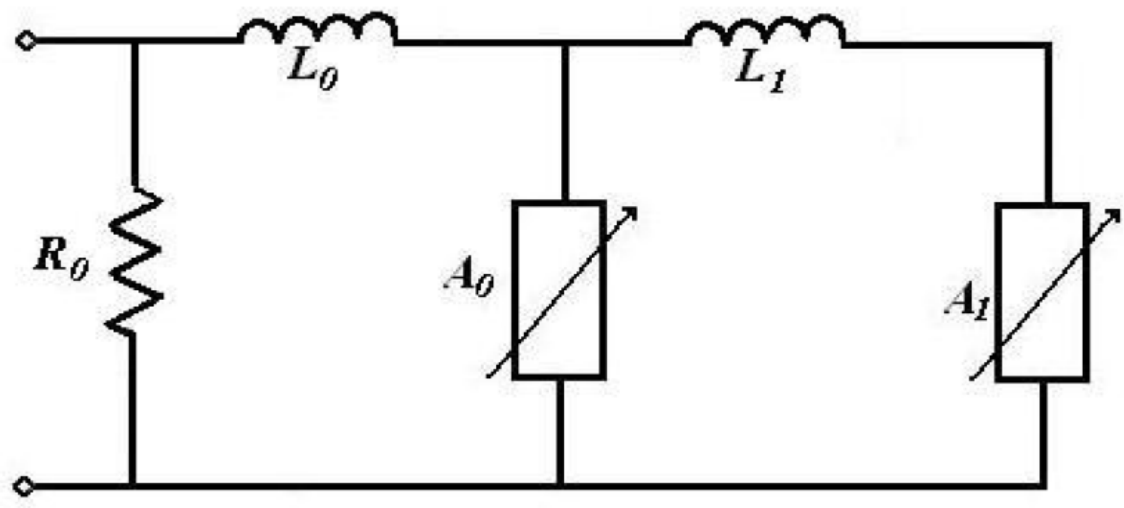


(b) ATP equivalent circuit of IEEE model.

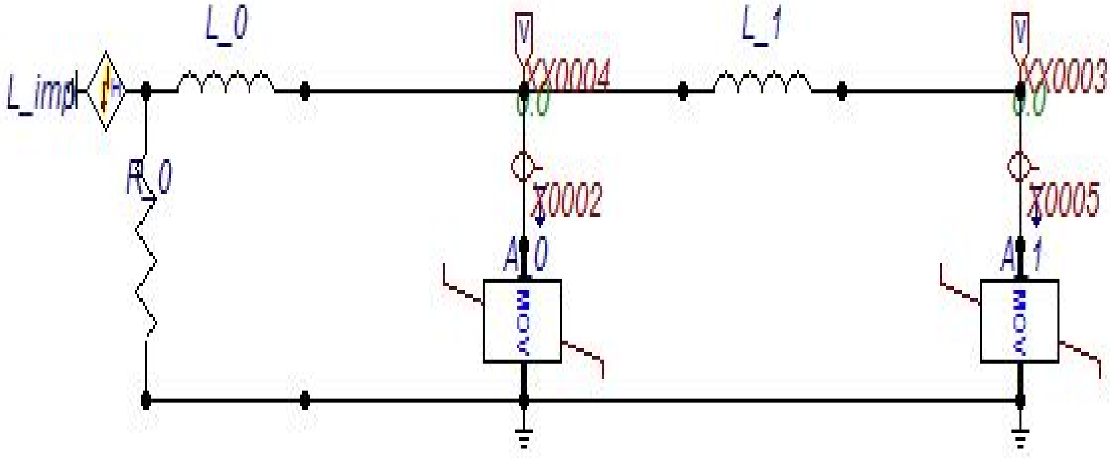


(c) Current and voltage waveform of A_0 and A_1 varistor of IEEE model

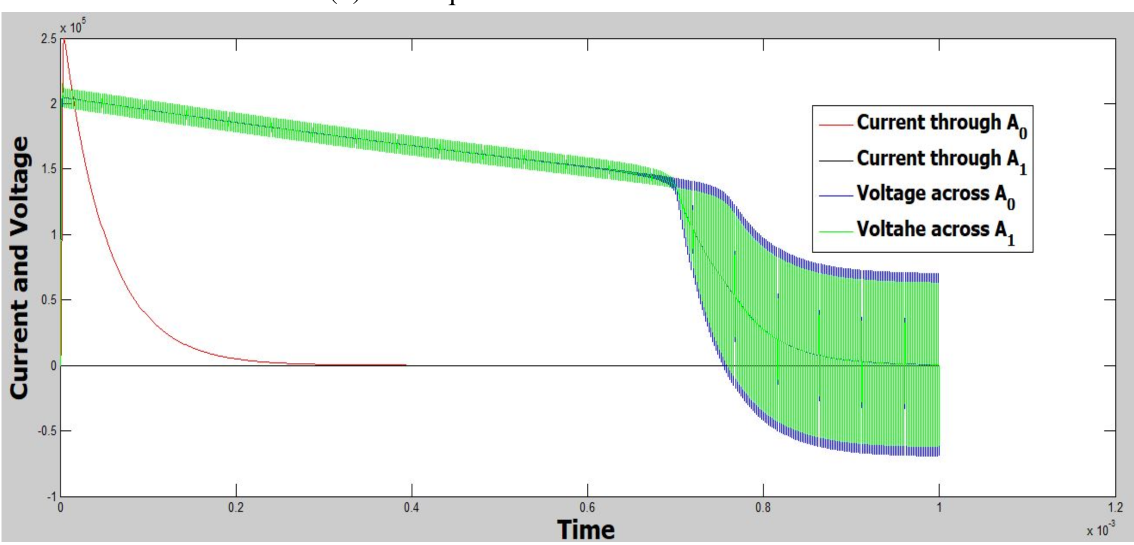
Fig. 4.3 IEEE model with its ATP equivalent circuit and simulation results.



(a) Pinceti model of surge arrester.



(b) ATP equivalent circuit of Pinceti model.



(c) Current and voltage waveform of A_0 and A_1 varistor of Pinceti model

Fig. 4.4 Pinceti model with its ATP equivalent circuit and simulation results.

4.3.3 Fernandez and Diaz model

Fernandez and Diaz model is also based on the IEEE model. In Fernandez and Diaz model A_0 and A_1 are separated by L_1 and L_0 is neglected. This figure is shown in fig4.6.a. Capacitance is included in this model and it represents terminal to terminal capacitance of arrester [34]. The advantage of this model is that it does not need the iterative procedure. V-I (curve) characteristic for A_0 and A_1 are calculated using manufacturer's datasheet. For the resistance, it is assume as 1MΩ to avoid numerical oscillation or to limit the current in circuit. In Fig.4.6.b ATP equivalent circuit three models are shown. The simulation result of ATP equivalent circuit of the model is shown in Fig.4.6.c. Computation of parameter for procedure is given in ref. [34]. The model of arrester will generate higher voltages which then match the dynamic behaviour of metal oxide surge arrester. In Table-1 the initial computed parameters for the above three models are shown, the optimum parameter values obtained using the genetic algorithm[35]. Inductance L_1 and capacitor is given as:

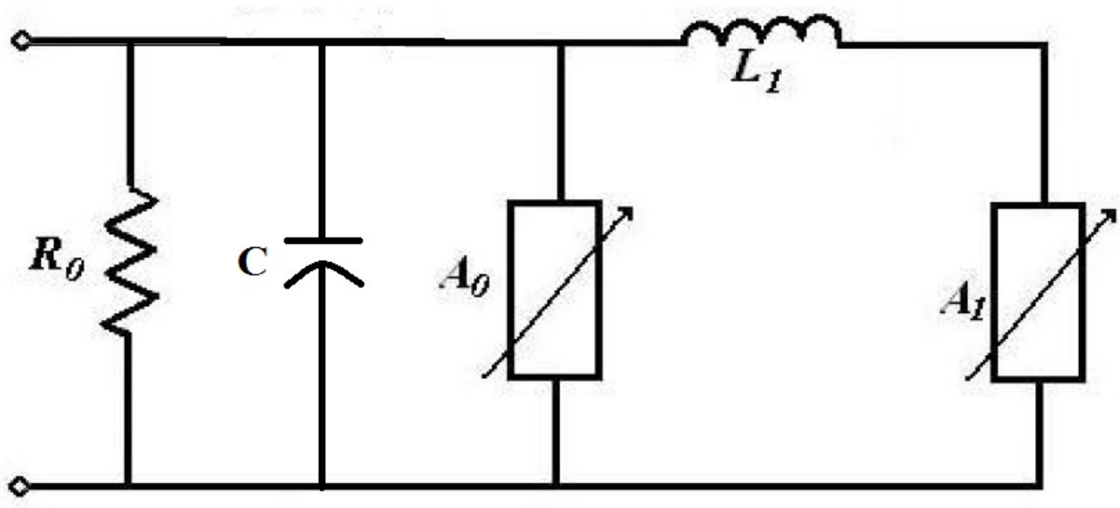
$$L_0 = \frac{1}{5} \cdot \frac{V_{r\frac{1}{20}} - V_{\frac{30}{60}}}{V_{\frac{8}{20}}} V_n \mu H \tag{4.8}$$

$$L_1 = \frac{1}{55} \cdot \frac{V_{r\frac{8}{20}} - V_{\frac{30}{60}}}{V_{\frac{8}{20}}} V_n pF \tag{4.9}$$

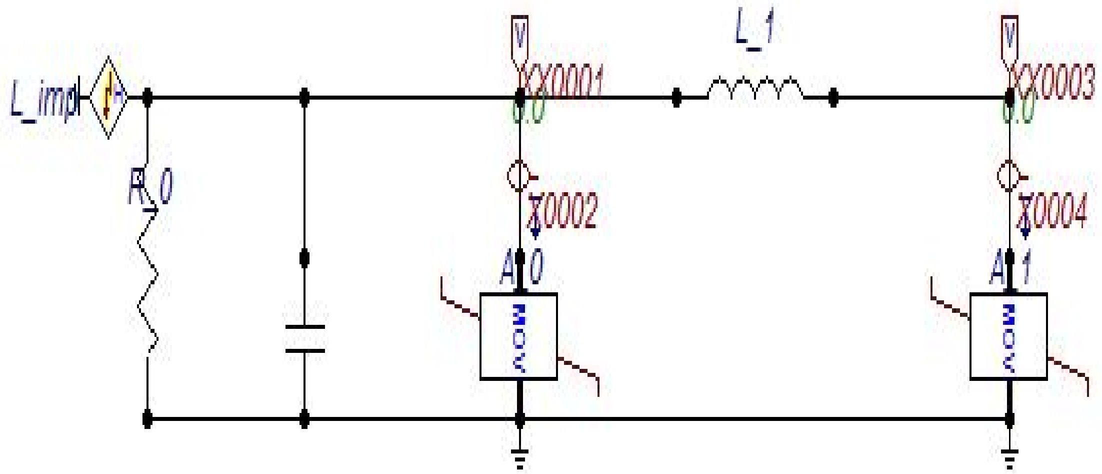
Where;
V_n= Arrester rated voltage.
$V_{r_{8/20}}$ = Residual voltage at 10kA current surge.
$V_{30/60}$ = Residual voltage at 1kA.

Table 4.1 PARAMETERS OF SURGE ARRESTER MODELS

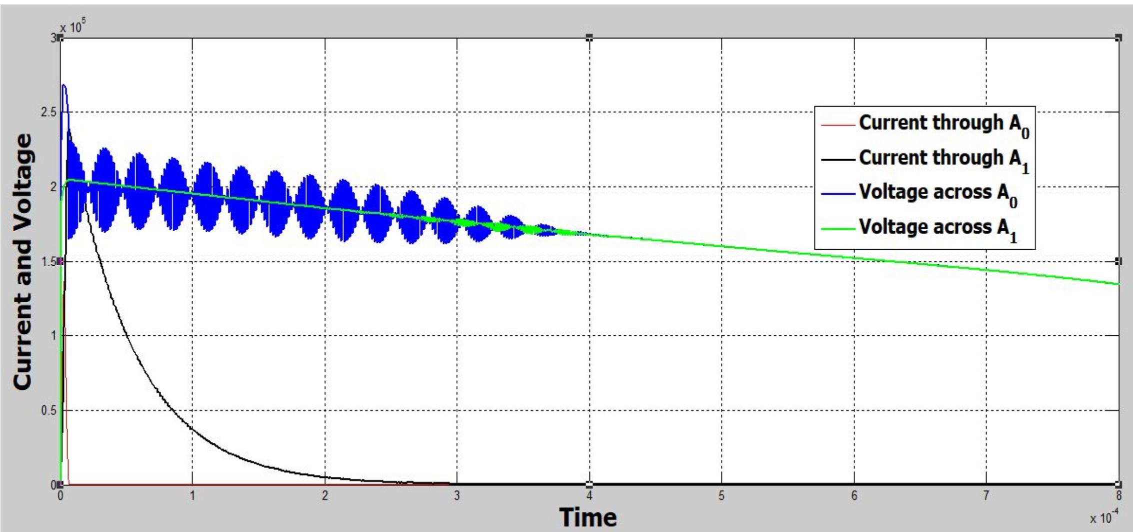
Name of the model	$R_0(\Omega)$	$R_1(\Omega)$	$L_0(\mu H)$	$L_0(\mu H)$	C(pF)
IEEE model	25.43	17.85	0.278	1.017	967.21
Pinceti model	0.895×10^6	-	0.376	0.0435	-
Fernandez-Diaz model	1.465×10^6	-	-	1.371	675.5



(a) Fernandez and Diaz model of surge arrester.



(b) ATP equivalent circuit of Fernandez and Diaz model.



(c) Current and voltage waveform of A_0 and A_1 varistor of Fernandez and Diaz model

Fig. 4.5 Fernandez and Diaz model with its ATP equivalent circuit and simulation results.

4.4 SIMULATION OF DIFFERENT TYPE OF LIGHTNING ARRESTER MODELS WITH ATP

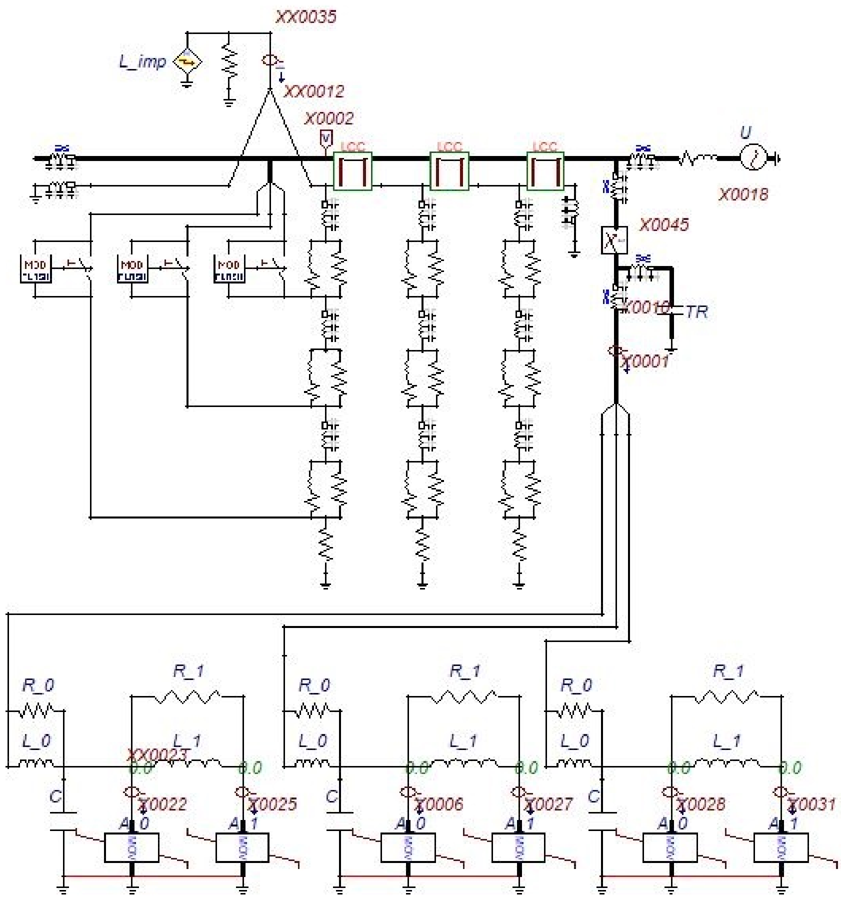
4.4.1 Simulation with IEEE model

In Fig.4.6.a it is shown that the transmission line is protected with the lightning arrester designed according to IEEE model of MOV type surge arrester. The performance of the surge arrester can be evaluated from the Fig.4.7.b and Fig.4.6.c. From the Fig.4.6.b the waveform of surge current of A_0 varistor of ABC phase is found maximum amplitude of surge current found 100kA at phase A at the time of 5μsec. For the A_1 varistor the maximum amplitude of surge current is found 160kA for phase A at 7.5 μ sec. For B and C phase maximum amplitude have found at 100kA at 6μ sec and 70kA at 6.5 μ sec respectively. The surge propagation along the tower structure has been taken into account in this model by representing the vertical pylon sections as single-phase constant parameter transmission lines. The R-L branches below the tower model simulate the tower grounding impedance. The front of wave flashover characteristic of the line insulators plays a significant role in such a back-flashover study. It can be simulated quite easily using a MODELS object - like the Flash of this example-, which controls a TACS/MODELS controlled switch. The influence of the power frequency voltage on the back-flashover probability can't be neglected either at this voltage level.

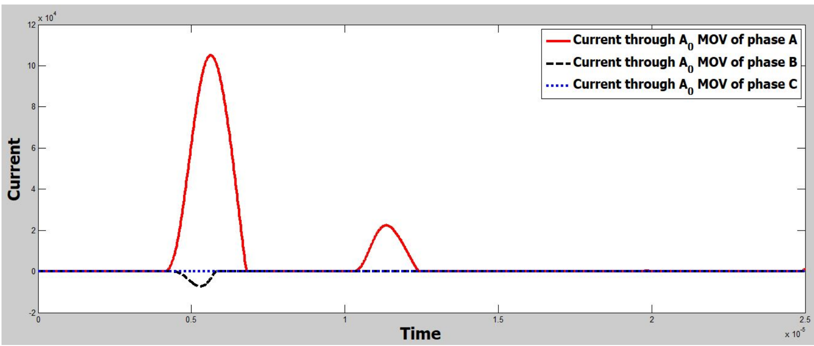
Lightning arrester is modeled by MOV-Type 92 component [36]. The used lightning arrester was identical ABB Surge arrester POLIM-D, distribu-tion class heavy duty, designed and tested accord- ing to IEC 60099-4. The thermal stability of the MO-surge arrester is proved in the operating duty test with the application of one high current im- pulse $I_{hc} = 100kA$, which gives an energy input of 3.6 $kJ/kV(UC)$and its characteristics were taken from manufacturer datasheets [37].

4.4.2 Simulation with Pinceti-Gianettoni Model

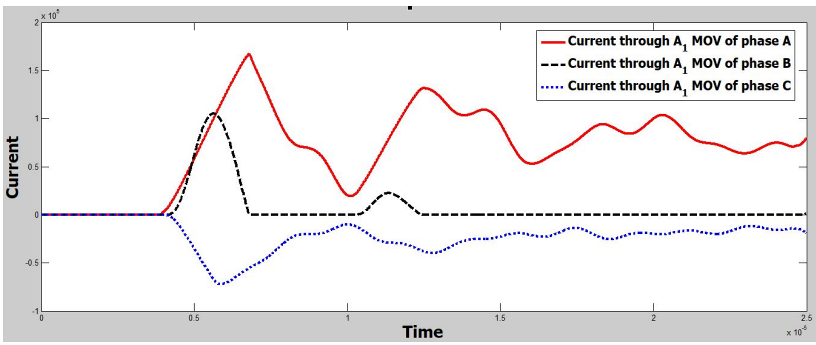
The model in Fig.4.5a (Pinceti model) has been proposed by Pinceti-Gianettoni. This model is based on IEEE model with some differences. The capacitance is eliminated, since its effect on model behavior is neg- ligible. Resistance R (about 1 MΩ) replaced between the input terminals, only to avoid numerical troubles. Resistance R_0 stabilizes the numerical oscillations and the nonlinear resistors A_0 and A_0 can be estimated by using the curves shown in Fig.4.4d. The transmission line is protected with the lightning arrester designed according to Pinceti-Gianettoni model of MOV type surge arrester shown in Fig.4.7.a. For Pinceti-Gianettoni model the only 6A current at 6 μsec for phase A and for remaining two



(a) ATP equivalent circuit of the transmission system protected with MOV type surge arrester modeled according to IEEE model.



(b) Current waveform of the A_0 varistor of IEEE model.



(c) Current waveform of the A_1 varistor of IEEE model

Fig. 4.6 ATP equivalent circuit and simulation result of the transmission system protected with MOV type surge arrester modeled according to IEEE model.

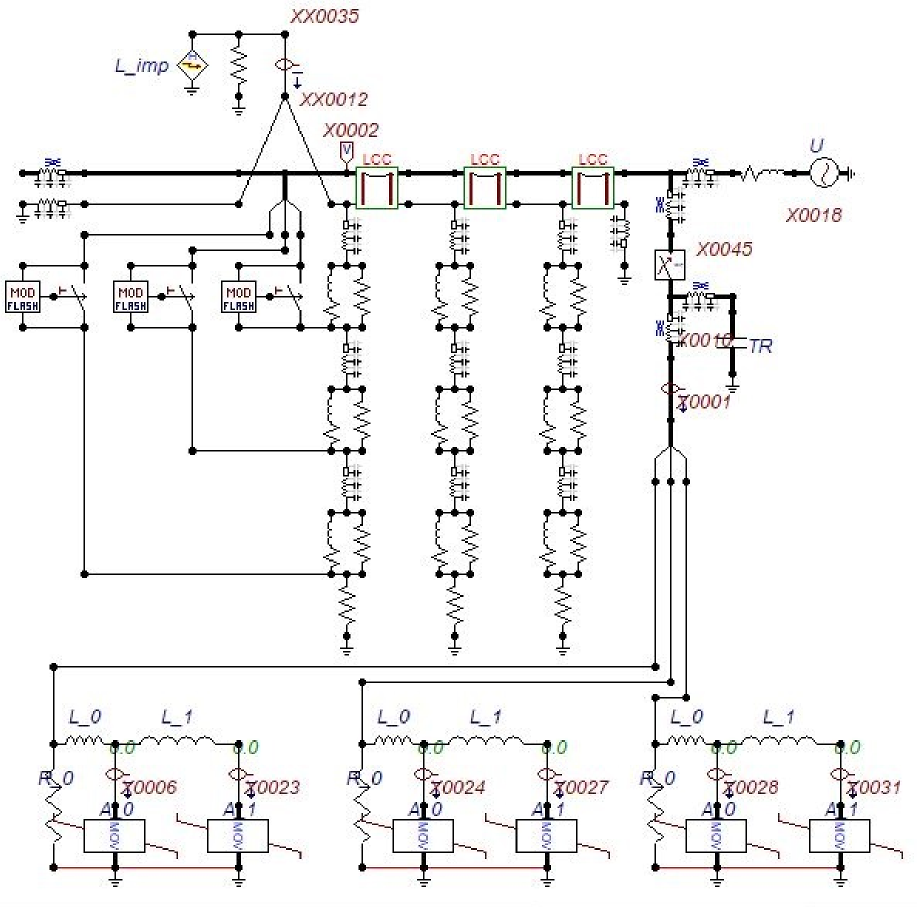
phase the amplitude of surge current is very small at A_0 varistor which is shown in Fig.4.7.b. For A_1 varistor maximum 200kA amplitude of surge current is found at phase A and for phase B and C the surge current amplitude is negative 60KA at 7 µsec and 50kA at 6.5 µsec respectively shown in Fig.4.7.c.

4.4.3 Fernandez-Diaz model Model

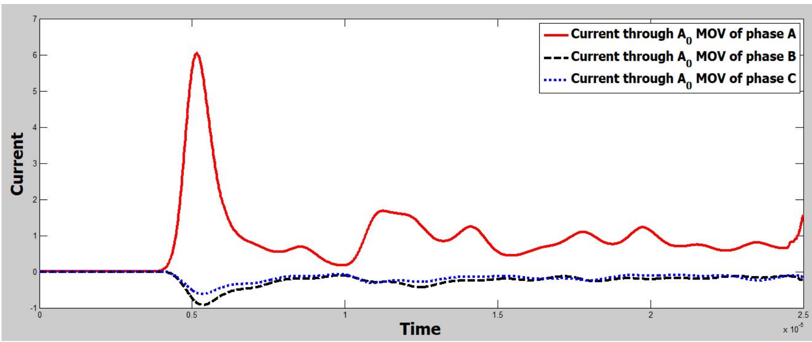
A_0 MOV and A_1 MOV are separated by L_1 and the capacitor represents terminal to terminal capacitance of the MOV. In Fig.4.8.a it is shown that the transmission line is protected with the lightning arrester designed according to Fernandez-Diaz model of MOV type surge arrester. From Fig.4.8.b it is observed that amplitude of surge current is 130kA at 6 μsec and 22kA surge current amplitude at 12 μ sec at phase A. For phase B and C amplitude of surge currents are found 18kA at 6 μ sec and 8kA at 6 μ sec respectively and also the harmonics for B and C phase can be ignored as compared with phase A. Fig.4.8.c shows the surge current waveform of A_1 varistor. At phase A maximum amplitude found 150kA at 7.5 μ sec, for phase B and C surge current amplitude found 60kA at 5 μ sec and 50kA at 5 μ sec.

4.5 PERFORMANCE EVALUATION OF THREE TYPES OF LIGHTNING ARRESTER FROM ATP RESULTS

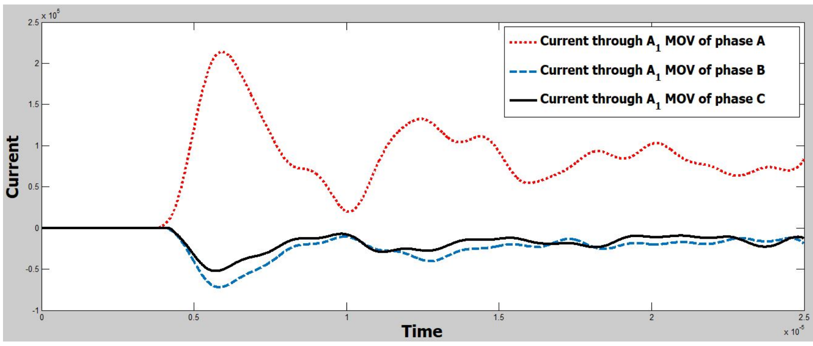
It was carrying out a comparative study among the results provided by the IEEE model, Pinceti model and Fernandez models. In TABLE II are given the computed peak value of the surge current for each model also computed duration and front time of the surge current waveforms. For the simplicity of calculating peak value the harmonics of the phase B and C are not considered. From the above figures it has been cleared that surge current is maximum at upper phase so different arrester at different phase is not necessary for comparison of different arrester performance at different phase. In this work a 132kV single line transmission system with three towers was developed in order optimum surge arrester equivalent circuit model parameters to be determined for designing proper protection scheme for the power network. ATP-EMTP circuit for three most popular MOV type surge arrester model were developed and evaluated their performance. From the simulation result the characteristics of parameter identification for high current impulses can be easily evaluated also. All the models can reproduce the property of metal oxide arresters precisely. In pinceti model, nine parameters must be estimated and in IEEE model, eleven parameters must be estimated, so Pinceti's convergence speed is faster than IEEE and Fernandez model. From the above figure it can also be clearly estimated that Pinceti's model is more faster and when



(a) ATP equivalent circuit of the transmission system protected with MOV type surge arrester modeled according to Pinceti model.

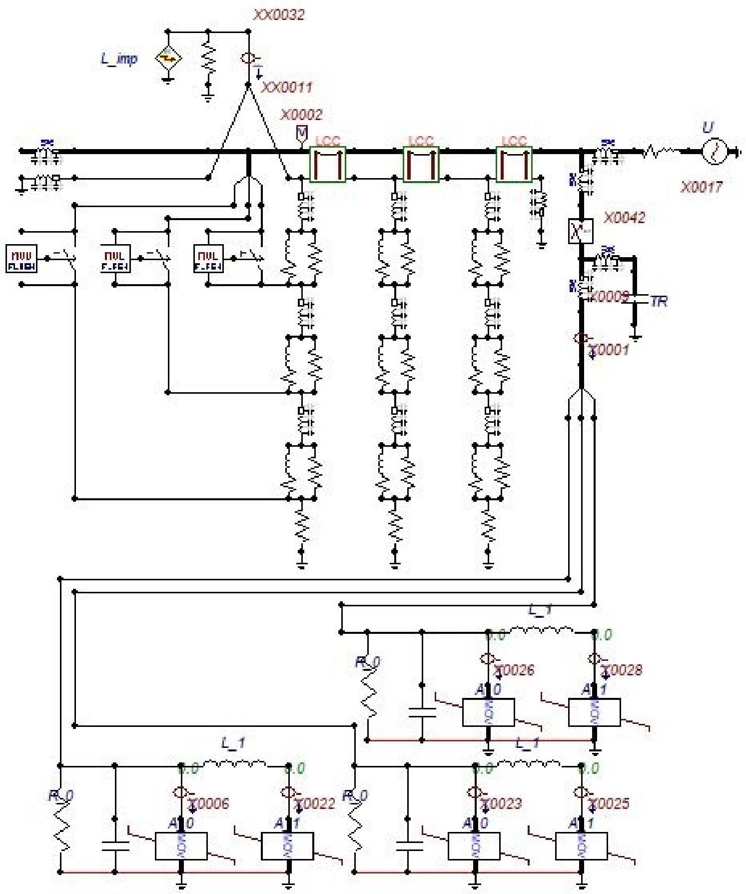


(b) Current waveform of the A_0 varistor of Pinceti model.

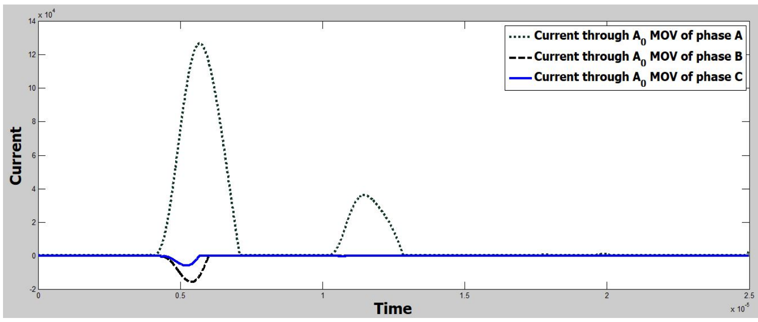


(c) Current waveform of the A_1 varistor of Pinceti model

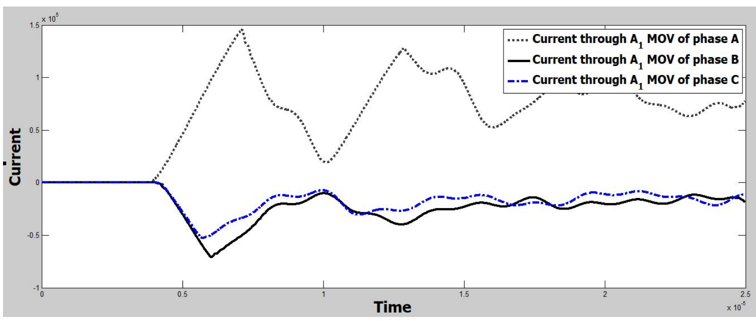
Fig. 4.7 ATP equivalent circuit and simulation result of the transmission system protected with MOV type surge arrester modeled according to Pinceti model.



(a) ATP equivalent circuit of the transmission system protected with MOV type surge arrester modeled according to Fernandez-Diaz model.



(b) Current waveform of the A_0 varistor of Fernandez-Diaz model.



(c) Current waveform of the A_1 varistor of Fernandez-Diaz model

Fig. 4.8 ATP equivalent circuit and simulation result of the transmission system protected with MOV type surge arrester modeled according to Fernandez-Diaz model.

the amplitude of current is higher then the surge arrester exhibit shorter time to peak than at higher amplitude. From the current wave form of across the two MOV it is clear that at higher amplitude of current, the MOV type surge arrester exhibit shorter time to peak than at higher amplitude. From the output of simulation and perception the Pinceti model gives profoundly agreeable results will all dynamic properties and show the shortest quenching time contrasted with IEEE and Fernandez model.

Table 4.2 PERFORMANCE EVALUATION OF THREE TYPES OF ARRESTER MODEL FROM THE MAXIMUM AMPLITUDE OF SURGE CURRENT

Models	Maximum surge current amplitude at phase A		Maximum surge current amplitude at phase B		Maximum surge current amplitude at phase C	
	A_0 MOV	A_1 MOV	A_0 MOV	A_1 MOV	A_0 MOV	A_1 MOV
IEEE model	100kA	160kA	-10kA	100kA	0kA	70kA
Pinceti model	6A	200kA	-1A	60kA	-0.5A	50kA
Fernandez-Diaz model	130kA	150kA	18kA	60kA	8kA	50kA

Table 4.3 PERFORMANCE EVALUATION OF THREE TYPES OF ARRESTER MODEL FROM MAXIMUM DISCHARGE TIME

Models	Maximum discharge time of surge current at phase A		Maximum discharge time of surge current at phase B		Maximum discharge time of surge current at phase C	
	A_0 MOV	A_1 MOV	A_0 MOV	A_1 MOV	A_0 MOV	A_1 MOV
IEEE model	5μsec	6 μsec	2.5 μsec	2 μsec	0 μsec	4 μsec
Pinceti model	3 μsec	5 μsec	2 μsec	3 μsec	1 μsec	3 μsec
Fernandez-Diaz model	5 μsec	6 μsec	2 μsec	4 μsec	1.25 μsec	3 μsec

4.6 DESIGN PARAMETERS OF SURGE ARRESTER ACCORDING TO PENCETI MODEL

4.6.1 Metal Oxide Varistor

Name : MOV - exponential current-dependent resistor. TYPE 92.
Card : BRANCH
Data : V_{ref}= Reference voltage in [V] for single block.
Use an arbitrary well conditioned value around rated voltage.
V_{ref} for A_0 =200KV
V_{ref} for A_1 =150KV

V_{flash}= Flashover voltage in pu. of Vref.
Use a negative number for no gap. V_{zero}= Initial voltage in [V]. Optional.
COL= Multiplicative factor for COEF. Number of arrester columns.
Single branch of blocks : COL=0,1 or BLANK.
Two branches in parallel: COL=2.
SER= Number of blocks in series in each branch.
Used to scale Vref.
ErrLim= Fitting tolerance in pu.
Node : From= Start node of nonlinear resistor. (3-phase)
To = End node of nonlinear resistor. (3-phase)
Points: It's possible to enter 29 points on the current/voltage characteristic.
Do no specify the (0, 0) point!!
A least square method fitting in the log-log domain is performed to fit the characteristic points to the exponential formulation:
$i = p * (u/V_{ref})^q$ split up in required segments accordning to ErrLim. RuleBook: V.E. + XIX-I.

4.6.2 Series Inductor

Name : $IND_R P$
Card : BRANCH
Data : L= Inductance in mH if Xopt.=0
Inductance in Ohms if Xopt.=power frequency Xopt. is set in menu: ATP, Settings/Simulation.
$L_0 = 0.000376 mH$
$L_1 = 4.35 \times 10^{-5} mH$

Kp= Factor for the parallel resistance in ohms;
$Rp = Kp * 2 * L/DELTAT forXOPT = 0$
$Rp = Kp * X/(DELTAT * PI * POWFREQ)$ for XOPT=POWFREQ
Typical range for Kp is 5-10 (typical: Kp=7.5).
Node : From= Start node of inductor
To = End node of inductor
RuleBook: IV.A, see also TheoryBook 2.2.2. The parallel resistance will damp numerical oscillations caused by step changes in the reactor voltage.

4.6.3 Shunt Resistor

Name : RESISTOR
Card : BRANCH
Data : RES = Resistance in Ohm
R_0=895kΩ Node : From= Start node of resistor
To = End node of resistor RuleBook: IV.A

4.7 SIMULATION OF LIGHTNING SURGE CURRENT AND PROTECTION SYSTEM DESIGN FOR MOBILE PHONE TOWER

The telecommunication sector has seen major advances in the past few decades. Cellular mobile systems, personal communication systems , and in particular wireless local area networks have gone through a phenomenal growth. The phenomenal rapid growth in mobile wireless communications in recent years has spurred the development of new modulation methods, forward error control coding, voice and video compression techniques, and signal processing technologies. The goal is to make best use of the limited amount of available spectrum more efficiently. Minimize the impact of interference and fading. These reasons have been the principal reasons behind recent advances in wireless technologies.

Cell towers are made of steel and have lightning conductors on top, therefore direct lightning hits may not be very common. High induced currents could result due to high lightning currents through the cell tower structure. Since, lots of communication traffic will be interrupted if any of the RF device deployed on the cell tower is damaged, it is therefore, essential to have a very robust surge protection. Replacement of the damaged surge protection device is not simple since some of the cell towers are hundreds of feet tall and will require

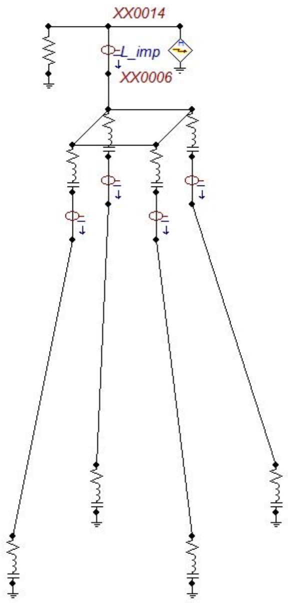


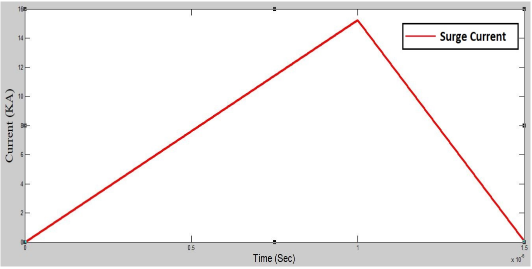
Fig. 4.9 Equivalent ATP circuit of a 4-pole Cell tower.

specialized equipment which could cause long delays in restoring the services. For simplicity of simulation a 4-pole steel tower is considered and equivalent ATP circuit has been drawn in ATP draw. In Fig.4.9 the equivalent ATP model of the tower has been shown. The ground resistance or footing resistance, inductance, capacitance of the tower are considered 5 Ω, 0.053mA and 1.18μF per pole. Fig.10a shows the Surge current waveform of the lightning rod at the tower top fed by HEIDLER type surge current injector and in Fig.10b shows the pole current of the tower.

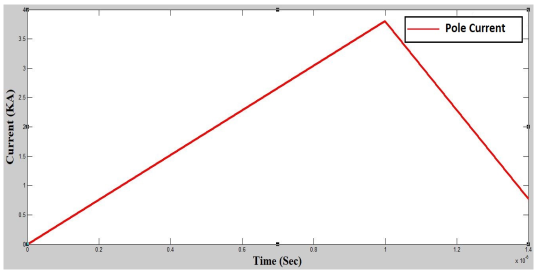
4.7.1 Simulation of ATP equivalent circuit of the mobile phone tower protected by MOV type surge arrester

Following surge protection technologies could be deployed in the FTTA surge protection:

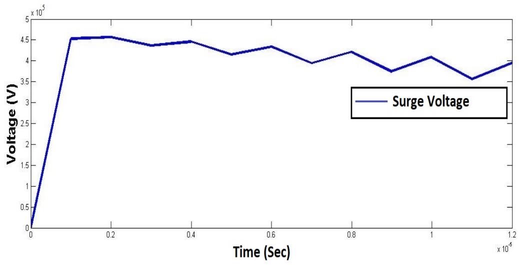
- Metal Oxide Varistor (MOV): Seem to be the most commonly used surge protection elements in the FTTA applications. MOVs are not too expensive and can absorb reasonably high surge energies.
- Spark Gaps: mostly are use in conjunction with MOVs as their break over voltages are high. Spark Gaps can handle lots of surge energy.
- Gas discharge tubes: A single Gas Discharge Tube may continue to conduct after the surge event is over due to hold over properties. However, array of multiple GDTs, can



(a) Current through lead wire



(b) Current through tower pole



(c) Surge voltage at the mid span of the tower

Fig. 4.10 Surge Current and voltage waveform.

be used to handle high surge capability and high break over voltage. Cost and size of such device could become large.

There are two fail-safe modes that a MOV based surge protector can be designed.

- Fail-Open mode: In this mode, the protector will disconnect itself from the line being protected. The service to the connected equipment will continue with a risk of equipment being damaged from subsequent surge event that might take place before the defective surge protector is replaced. Relay alarm contacts provisioned with such protectors will send alarm that the protector needs to be replaced.
- Fail-Short mode: In this mode, the protector will fail in a short to ground condition. This mode of failure though a rare possibility, if the design is robust enough, still could happen. With this, the protector will short the power supply voltage powering the Remote Radio Units to ground and will interrupt service till some one disconnects the device from the circuit.

In Fig.4.11 ATP equivalent circuit of the four pole mobile phone tower protected with MOV type surge arrester has been shown. There are two exponential current-dependent resistor namely A_0 and A_1 are being used in the surge arrester. The reference voltage in volt for single block is used an arbitrary well conditioned value around rated voltage which is considered 150KV and 200KV for A_0 and A_1 varistor respectively. In Fig.4.12.a the current

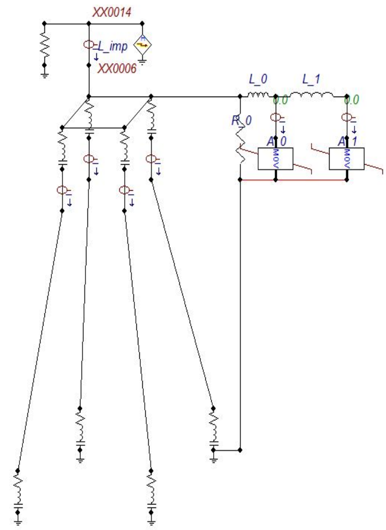
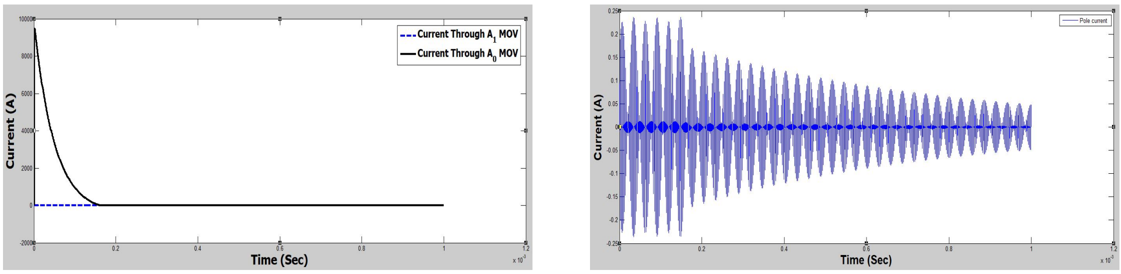


Fig. 4.11 ATP Equivalent circuit of the tower protected by MOV type surge arrester.



(a) Current through the two MOVs

(b) Current through the tower pole

Fig. 4.12 Current waveform through the MOVs and tower pole after being protected.

through the A_0 and A_1 varistor are shown and finally in Fig.12.b current through the tower pole after mitigating the surge current.

4.8 COMPARISON OF SURGE IMPEDANCE

Different mathematical formulas and analytical values of surge impedance of communication tower including high voltage transmission and distribution tower are presented. Those values and formulas have been utilized since 1934. Recently, the surge impedance of communication tower under the influence of direct and indirect lightning hit has drawn a lot of attention. Such value of lightning surge impedance and its associated parameters are becoming important factors for the protection system design in substation as well as low voltage communication equipments including home appliances. A number of tower models have been proposed, but most of them are not general, i.e., a tower model shows a good agreement with a specific case

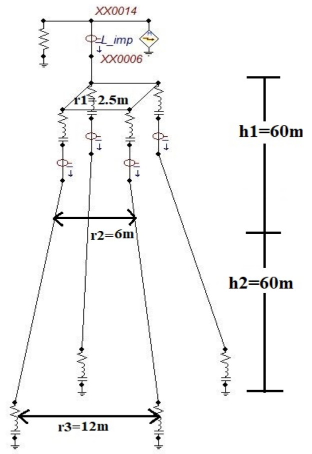


Fig. 4.13 Proposed tower model compared with IEEE model of communication and transmission tower.

explained in the paper where the model is proposed. The following IEEE/CIGRE formula of the tower surge impedance is well known and is widely adopted in a lightning surge simulation. The mobile phone tower has been considered here similar to the IEEE/CIGRE model and found the value of surge impedance form theoretical formula and both NEC-2 and ATP simulation.

$$Z = 60 \ln[cot 0.5 tan^{-1} \frac{R}{h}]\Omega \tag{4.10}$$

where R $= \frac{(r_1 h_1 + r_2 h + r_3 h_2)}{h}$ is the equivalent radius of the tower represented by a truncated cone,

$h = h_1 + h_2$, and r_1, r_2, r_3 tower top, midsection and base radii [m], h_1 height from the midsection to top [m], h_2 height from base to midsection [m] have been shown in Fig16.

Table 4.4 COMPARISON OF SURGE IMPEDANCE FOUND FROM DIFFERENT METHOD

Method	Surge impedance	Deviation with IEEE standard
IEEE formula	149Ω	0%
ATP	126.7Ω	15.5%
NEC-2	125Ω	16.6%

Chapter 5

CONCLUSION

5.1 CONCLUSION

The lightning surge characteristics of transmission and telecommunication towers strike by lightning are explained clearly and the tower footing resistance is considered 15 ohm which is within the range of characteristics impedance.Time to reach maximum peak point of surge current is 6 microsecond which is also within the range. The effect of return stroke to mid span between towers and the dynamic electromagnetic behavior, especially transient response on transmission line, communication tower and multistoried building have been carried out successfully with NEC-2 and ATP simulation.The maximum induced effect of lightning surge on any electronic equipment located inside any multistory building is found 0.0002% of the actual value. ATP-EMTP circuit developed for three most popular MOV type surge arrester models and evaluated their performance by installed them into 132kv line with three transmission towers and finally determined the parameters for surge arrester of mobile phone tower.For designing proper protection system for mobile phone and power transmission tower surge impedance is a very important parameter which is the ratio of voltage and current at any point along an infinitely long line. The term SIL or natural power is a measure of power delivered by a transmission line when terminated by surge impedance. In this analysis surge impedance has been calculated from IEEE formula and considered as standard. For both ATP and NEC-2 analysis surge impedance have been calculated for mid span of the mobile phone tower. For ATP analysis deviation of surge impedance from its IEEE standard value has been found 15.5% and for NEC-2 it has been found 16.6%.

From simulation results the Pinceti's model is more faster for the proposed communication tower. Finally it can be concluded that the proposed model of surge arrester will ensure the protection and safety of the communicating devices.

5.2 DIRECTION FOR FUTURE RESEARCH

- ATP simulation of 132kv grid substation and design proper protection against lightning surge and transient over voltage.
- Design an ATP equivalent model of a wind farm for analysing the surge characteristics and determine the parameters of surge protective device for wind power farm.
- Analyse the effect of lightning on solar power station and design protection for solar panels and solar power plants.
- Determine the probability and effect of lightning surge on air craft also design protection system for air crafts from effect of direct lightning strike.
- Determine the probability and effect of lightning surge on large war ship also design protection system for war ships from effect of direct and indirect lightning strike.

References

[1] M. Kawai, "Studies of the surge response on a transmission line tower, IEEE Trans"., PAS-83, pp. 30-34, 1964.

[2] M. Ishii, et. all., "Multistory transmission tower model for lightning surge analysis", IEEE Trans. On Power Del., vol. 6, no. 3,pp. 1327-1335,1991.

[3] H. Takahashi, "New derivation method of the surge impedance on the tower model of a vertical conductor by the electromagnetic field theory",Trans. IEE Japan, vol.113-B, no.9 pp.1029-1036, Sep. 1993.

[4] M.E. Almeida, et. all., "Tower modeling for lightning surge analysis using Electro-Magnetic Transient Program", IEE Proc.-Gener, Transm. Distrib.", Vol. 141, No.6, November 1994.

[5] T. Yamada, et all., "Experimental evaluation of a UHV tower model for lightning surge analysis", IEEE Trans. On Power Delivery, Vol. 10, No. 1.1995.

[6] N. Hara, and Yamamoto, "Modeling of a transmission tower for lightning surge analysis", IEE Proc. Generation, Transmission. Distribution" Vol. 143, No.3, May 1996.

[7] M. Ishii, Y. Baba, "Numerical electromagnetic field analysis of tower surge response", IEEE Transaction on Power Delivery", vol. 12, no. 1, pp. 483-488, January 1997.

[8] Y. Baba, M. Ishii, "Numerical electromagnetic field analysis on lightning surge response of tower with shield wire", IEEE Transaction on Power Delivery, vol. 15, no.3, pp. 1010-1015, July 2000.

[9] J.A. Gutirrez R., P. Moreno, J.L. Naredo, L. Guardado, "Non Uniform line tower model for lightning transient studies", 4th Int. Conference on Power Systems Transients IPST01, Rio de Janeiro, Brazil, 2001.

[10] T. Mozumi, "Numerical electromagnetic field analysis of archorn voltages during a back- flashover on a 500-kV twin-circuit line", IEEE Transaction on Power Delivery, vol. 18, no.1, pp. 207-213, January 2003.

[11] Md. Osman Goni, Hideomi Takahashi, "Theoretical and Experimental Investigations of the Surge Response of a Vertical Conductor", Aces journal, vol.18, no.1, March 2003.

[12] M. O. Goni and A. Ametani, "Analysis and Estimation of Surge Impedance of Tower", Aces journal, vol. 24, no.1, February 2009.

[13] X. Pejtemalli, P. Cipo and A. Mucka, "ATP Analysis of Transient Process during Direct Lightning Strike to the telecommunication Tower", Asian Transactions on Engineering (ATE ISSN: 2221-4267) Volume 05 Issue 03 June 2013.

[14] M. S.Yusuf, M. Ahmad, M. A. Rashid and M.O. Goni, "Analysis of Lightning Surge Characteristics on Transmission Tower", Engineering Letter 23 : $1, EL_2 3_0 1_0 5$, 17 February 2015.

[15] Jesus C. Hernandez, Pedro G. Vidal, and Francisco Jurado, "Lightning and Surge Protection in Photovoltaic Installation", IEEE Transaction on Power Delivery, vol. 23, no. 4, October 2008.

[16] Vladimir A. Rakov, Fellow, IEEE, and Farhad Rachidi, "Overview of Recent Progress in Lightning Research and Lightning Protection", IEEE Transactions on Electromagnetic Compatibility, vol. 51, no. 3, august 2009.

[17] Kunal Patel, "Effect of Lightning on Building and Its Protection Measures", (IJEAT) ISSN: 2249 8958, Volume-2, Issue-6 2013.

[18] Gomes, C., M.A.F. Hussain, and K.U.M.A.R. Abeysinghe, "Lightning accidents and awareness in South Asia: Experience in Sri Lanka and Bangladesh", 28th Intl. Conf. on Lightning Protection, Kanazawa, Japan, 2006.

[19] T. Hara, O. Yamamoto, M. Hayashi, and C. Uenosono, "Empirical formulas of surge impedance for single and multiple vertical cylinder", Trans. of IEE of Japan, vol. 110-B, no. 2, pp.129 137 (in Japanese), Feb. 1990.

[20] Y. Baba and M. Ishii, "Numerical electromagnetic field analysis on measuring method of tower surge response", IEEE Trans. PWRD, vol.14, pp.630-635, no.2 Apr. 1999.

[21] H. Takahashi, E. kaneko, K. Yokokura, K. Nojima, T. Shiori, and I. Ohshima, "New Derivation method of the surge impedance on the tower model of a vertical conductor by the electromagnetic field theory (Part 3: Introduction of confined gauge potential and experimental analysis)",(in Japanese), Proc. of IEE of Japan, vol. 1, pp. 229-234, 1995.

[22] Xiaolan Li, Jiahong Chen, Chun Zhao, Shanqiang Gu, "Study of Lightning Damage Risk Assessment Method for Power Grid", Energy and Power Engineering , 2013, 5, 1478-1483

[23] GREENWOOD, Allan. "Electrical Transients in Power Systems", New York: John Wiley and Sons, 1991. ISBN 978-0471620587.

[24] J. A Martinez, F. Castro- Aranda, "Lightning Performance Analysis of Transmission Lines Using the EMTP", Power Engineering Society General Meeting, IEEE. pp. 295 300, Vol. 1(2003).

[25] Juan A. Martinez- Velasco and Ferley Castro- Aranda. (June 19-23, 2005), "Modeling of Overhead Transmission Lines for Lightning Studies", International Conference on Power System Transients(IPST'05) in Montreal, Canada.

[26] M. Ishii, T. Kawamura, T. Kouno, E. Ohsaki, K. Shiokawa, K. Murotani, T. Higuchi. (1991), "Multistory transmission tower model for lightning surge analysis. IEEE Transactions on Power Delivery", Vol: 6. Issue: 3. Page(s): 1327- 1335.

[27] T. Hara, O. Yamamoto. (1996), "Modeling of a transmission tower for lightning surge analysis", IEEE Proceedings on Generation, Transmission and Distribution. Volume: 143. Issue: 3. pp. 283-289.

[28] F. Heidler, J.M. Cvetic, B.V. Stanic. (1999), "Calculation of Lightning Current Parameters. IEEE Transactions on Power Delivery", Volume: 14. Issue: 2. pp. 399- 404.

[29] M.A. Sargent, M. Darveniza. (May, 1969), "Tower Surge Impedance. IEEE Transactions on Power Apparatus and Systems", Vol: PAS-88. Issue: 5, Part-1.

[30] K. Fekete, S. Nikolovski, G. Knezevic, M. Stojkov, Z. Kovac. (2010),"Simulation of Lightning Transients on 110kV Overhead- Cable Transmission Line using ATP- EMTP", MELECON 2010- 2010 15 th IEEE Mediterranean Electrotechnical Conference. pp. 856-861.

[31] Takamitsu Ito, Toshiaki Ueda, Hideto Watanabe, Toshihisa Funabashi, and Akihiro Ametani. (2003), "Lightning flashover on 77-kV systems: observed voltage bias effects and analysis", IEEE Transactions on Power Delivery, Vol: 18, Issue: 2, pp. 545 550.

[32] IEEE Working Group 3.4.11, "Modelling of metal oxide surge arrester", IEEE Trans. On Power Delivery, vol.7, No 1, pp. 302-309,1992.

[33] PINCETI, P. and GIANNETTONI, M. (1999), "A simplified model for zinc oxide surge arresters", Power Delivery, IEEE Transactions on, 14(2), 393-398.

[34] FERNANDEZ, F. and DIAZ, R. (2001, June). "Metal oxide surge arrester model for fast transient simulations", In The Int. Conf. on Power System Transients.

[35] P.F. Evangelides, C.A. Christodoulou, I.F. Gonos, I.A. Stathopulos, "PARAMETERS' SELECTION FOR METAL OXIDE SURGE ARRESTERS MODELS USING GENETIC ALGORITHM", 30th International Conference on Lightning Protection - ICLP 2010 (Cagliari, Italy - September 13th -17th, 2010).

[36] Leuven EMTP Center. Alternative Transients Program: Rule Book . Heverlee: EMTP, 1987.

[37] High Voltage Products: Surge Arrester. In: ABB Switzerland Ltd. [online]. 2013. Available at: http://www.abb.com/product/us/ 9AAC710009.aspx.

[38] P. C. A. Mota, M. L. R. Chaves, J. R. Camacho, "Power Line Tower Lightning Surge Impedance Computation, a Comparison of Analytical and Finite Element Methods". International Conference on Renewable Energies and Power Quality (ICREPQ,2012).

[39] Slavko Vujevic,"Dangerous Voltages due to Direct Lightning Strike into the Communication Tower", Journal of communications software and systems, vol. 3, no. 1, march 2007.

[40] M. A. Abd-Allah , T. Elyan and Eman Belal, "Back flashover Analysis for Egyptian 500kV and 220kV Transmission towers", International Journal of Scientific and Research Publications, Volume 6, Issue 4, April 2016, ISSN 2250-3153.