EVALUATION OF LIGHTNING ARRESTOR BY USING MATLAB

DISSERTATION

Submitted in partial fulfillment of the requirement for the award of the degree of

MASTER OF TECHNOLOGY

IN

(Electrical Engineering)

By

GAURAV SHARMA

Under the Guidance of

Mr. ANSHUL MAHAJAN

LOVELY PROFESSIONAL UNIVERSITY

School of Electrical and Electronics Engineering

Lovely Professional University

Punjab

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CERTIFICATE

This is to certify that the DISSERTATION titled **“EVALUATION OF LIGHTNING ARRESTOR BY USING MATLAB”** that is being submitted by **“GAURAV SHARMA”** is in partial fulfillment of the requirements for the award of **MASTER OF TECHNOLOGY DEGREE IN ELECTRICAL ENGINEERING**, is a record of bonafide work done under my guidance. The contents of this DISSERTATION,is full or in parts, have neither been taken from any other source nor have been submitted to any other institute or University for award of any degree or diploma and the same is certified.

Mr. ANSHUL MAHAJAN

ASSISTANT PROFESSOR

LOVELY PROFESSIONAL UNIVERSITY

DATE:

ABSTRACT

Nowadays, to operate the electrical energy in steady state is the major problem due to the faults or disturbances occur in the power system. The disturbances occur due to on and off of the system, lightning occurrences, or due to the symmetrical and unsymmetrical faults. The magnitude of voltage and current increases as compared to the steady state due to change in circuit conditions i.e. opening and closing of the switches, or occurrence of a natural fault such as lightning, discharge.

Maximum overvoltage across the system is due to the overvoltage which affects the steady state stability of the system and makes the system faulty. When there is overvoltage on the transmission line it rapidly increases the magnitude of voltage and current in the system and disturbs the stability of the system due to which system gets switched off. To protect the system from overvoltage disturbances lightning surge arrestors are used.

In this report we are protecting the system from getting damaged by the overvoltage developed across the system (due to switching or lightning). For analyzing the system we are consider two cases of overvoltage i.e. lightning and switching. In this report we emphasize the impact of protection technique used for protecting the various equipment from overvoltage develop across the system.

All the simulating work is done in MATLAB/Simulink in which we developed different graphical relationship between current, voltage waveforms with respect to time. All the simulation is done by inducing lightning on different points on the transmission line and then comparison is made, then considering the results by using arrestor model and without using arrestor model. In the last we concluded that it is preferable to use arrestor across the line to protect the compensated devices across the system because the arrestor protective device operates immediately in order to remove the heavy overvoltage to pass through the compensated devices.

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GAURAV SHARMA

Reg. No. 11302031

DECLARATION

I GAURAV SHARMA, student of **M.TECH POWER SYSTEMS** under Department of **ELECTRICAL AND ELECTRONICS ENGINEERING** of lovely professional university, Punjab, hereby declare that all the information furnished in this Dissertation report is based on my own intensive research and is genuine.

This Dissertation does to the best of my knowledge; contain part of my work which has been submitted for the award of my degree either of this university or any other university without proper citation.

GAURAV SHARMA

Registration No. 11302031

Date:

TABLE OF CONTENTS

List of Figures Page No.

LIST OF TABLES PAGE NO.

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Overvoltage is one of the major problem occurring in the power system and to minimise this problem many methods, equipment's and techniques have used. It is of two types i.e. lightning and switching. To improve the performance of the power system from lighting several studies has been conducted and many methodologies have been proposed in the technical literature over the last decades. The most important safeguard in electrical power system is to protect overhead high voltages transmission line from lightning strokes. Accurate evaluation of the lightning performance helps to make the system highly efficient. Shield wires and surge arrestors are used for the protection of lines from lightning. Due to the lightning phenomena overvoltage occurs which reduces the reliability of electrical network, leading to interruption and as a consequence increases the transmission line repair cost. To minimize the annual failure of the line overhead ground wires are placed above the phases to intercept lightning strokes[2] . Surge arrestors are the main measures, which are used in order to protect the system against lightning and switching phenomena.

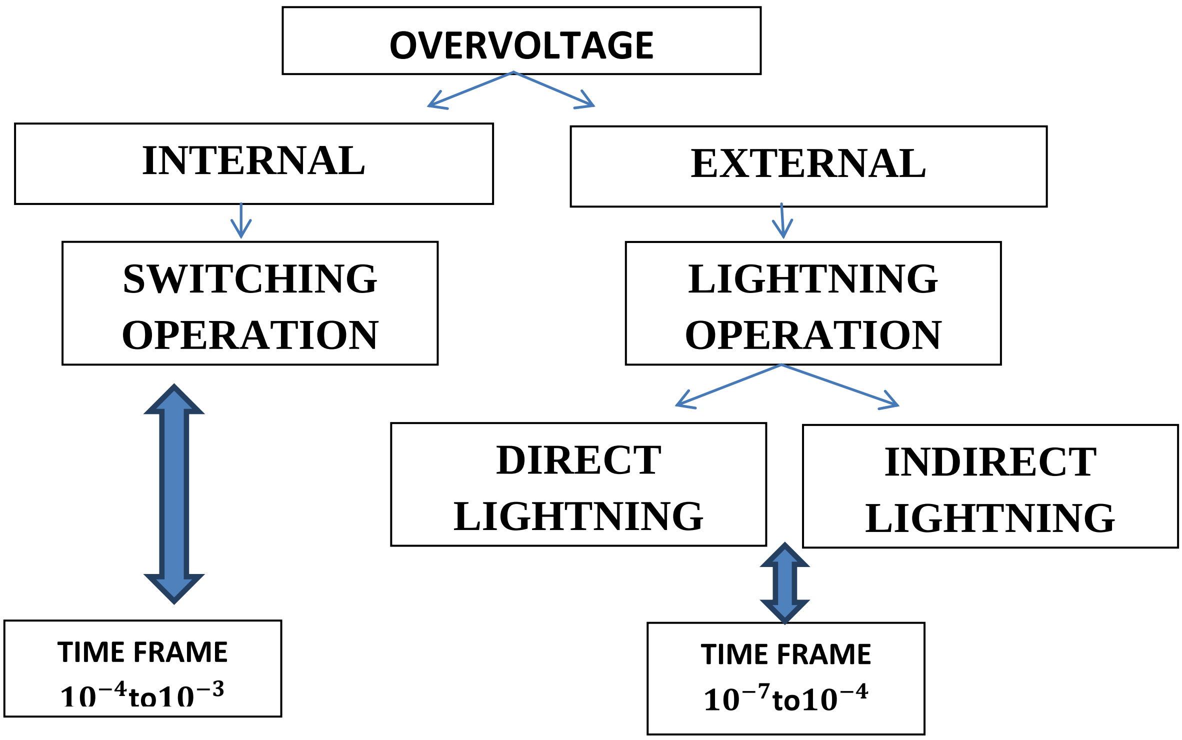
Franklin‟s invention of lightning rod to be protects apparatus from lightning strikes. Till today for more than 200 years, the lightning rod has been used for air terminal of lightning protection systems [6] But lightning rods cannot always function perfectly because they have an unexpected shielding failures, are often due to the improbability of lightning phenomenon. For example, several direct strikes to the transformer substations took place in the power grid of north India. For designing a lightning protection system, the protection angle method, the rolling sphere method and the mesh method are used to evaluate the protection zone of a lightning rod, all of these fall considerations on stochastic behaviours of the lightning process. The effectiveness of lightning rods is investigated by means of dynamic simulation of lightning strikes including stochastic [19].

Over voltages in the power system may be due to the lightning strokes that terminate on or near to power lines such over voltages are known as lightning over voltage or surges. Switching over voltages or surges is due to the certain change in the circuit condition brought about by deliberate or unintentional switching operation[15]. The magnitude of lightning over voltage is essentially independent of system voltage is known as external over voltages.

1.2 OVERVOLTAGE

When the voltage across the system increased to very high value than its normal voltage flowing in the system, the increased voltage which is beyond the upper limit of voltage across the system is known as overvoltage. The overvoltage is one of the most dangerous condition arises across the system. The overvoltage across the system depends on duration that whether it's a transient or a voltage spike or permanent [16]. There are two types of overvoltage occur in the system.

- Natural: - The natural source of overvoltage is lightning.
- Man-made:-Man made source of overvoltage usually caused by switching



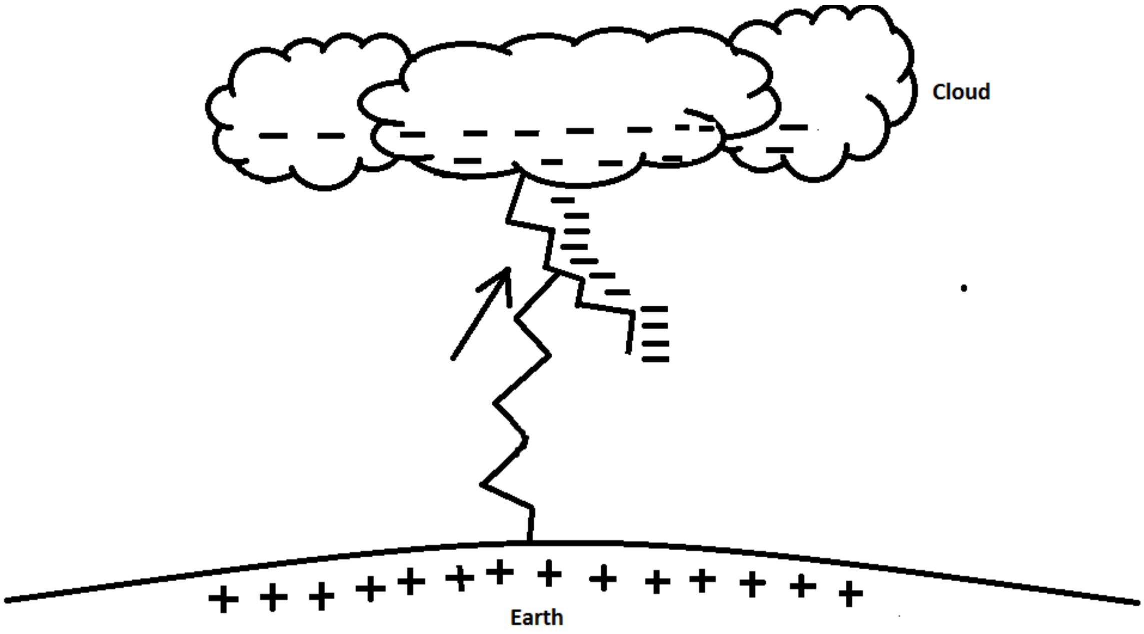
Figureure1.1Basic block diagram of different overvoltage develop across the system

1.3 LIGHTNING OPERATION

Lightning is a phenomenon that occurs in nature. The energy contained in a lightning stroke is very high and it can be tremendously destructive. Lighting strokes are unprotected to electric distribution networks. A single stroke to a distribution line is sufficient to cause a blackout throughout a feeder and to prevent this type of problems power systems are protected with lightning rods, ground wires and lightning arrestors. Overhead high voltage transmission lines and to reduce the failure rate, arrestors are installed between each phase and earth to protect the system [2].

1.3.1 LIGHTNING FORMATION

Lightning formation is the technique which develops, when there is charge separation in the clouds. Lightning is static charges which develop across the system just like a static charge develops when a balloon is rubbed and produce static electricity [6].



Figureure1.2Representation of lightning formulation in the atmosphere

Once a significant charge separation has built up the positive and negative charges seek to reach each other and neutralize. Streamers come up from the ground to form a pathway. Once a pathway is completed a spark forms and neutralizes the charge. As the negative charge races down, the air surrounding gets heat up. The spark is very hot and it rapidly heats the air to create a shock wave [6].This shock wave is known as lightning.

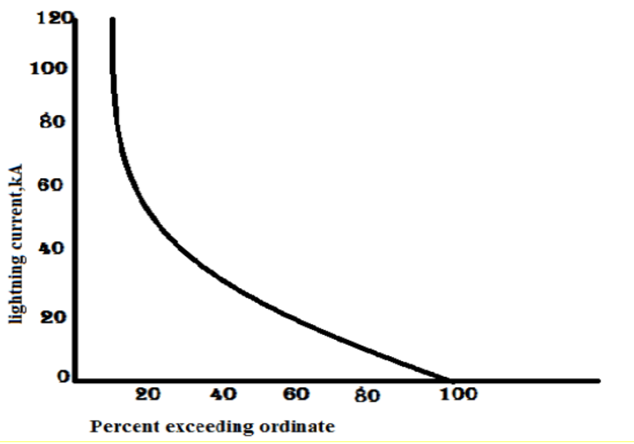
1.3.2 SOME LIGHTNING FACTS

- There are 100 lightning strikes a second happening worldwide.
- There are more than 8lakh lightning bolts per day.
- Lightning flash is about 4.5 Km long but only a centimetre wide
- A lightning strike discharges about 1-10 lakhs joules of energy and produces a current of 30,000 to50,000 amperes.
- A single lightning bolt has as much energy as blowing up a ton of TNT.

1.3.3 CHARACTERISTICS OF LIGHTNING STROKES

Lightning strokes characteristics are studied by investigating a large number of aspects:-

- Lightning strokes are of negative polarity.
- Total surge report occur in the power system are7 to 18% strokes on transmission lines,37% distribution lightning arrestor surges and 12% station lightning arrestor
- Time taken by a lightning stroke may be 1 sec or so.
- A lightning stroke may contain peak current from 1kA to 200kA or so. Figure1.1 shows the distribution of peak value of lightning current.
- The time to first peak is between zero and 10 microseconds. The time to half value on the tail is between 5 and 90 microseconds [6].



Figureure1.3 Represent the characteristics of lightning strokes

1.3.4 OVERVOLTAGE DUE TO LIGHTNING

When the lightning occurs in the system the voltage develops across the system becomes too high. Basically lightning is a natural phenomenon in which voltage value may be high and low energy level. The direct lightning strike on the conductor or roof of the system it will damage the system or equipment being installed in the system. The over voltage develops across the system is more than the 20 times the normal voltage develop across the system which harms the rating of the equipment being installed in the system. The over voltage may be due to direct lightning strokes or may be indirect lightning strokes[6].

1.3.4.1 OVERVOLTAGE DUE TO DIRECT LIGHTNING STROKES

These can be in two forms:

- **When lightning strike the conductor**:- When lightning strikes on the lightning conductor or on the roof of a building which is earthed or grounded, the lightning current goes into the ground through the ground wire. The impedance of the ground and the current flowing through the conductor develops large potential difference, this is overvoltage. This overvoltage then propagates throughout the building all the way through the cables and damaged the equipment present in the system.

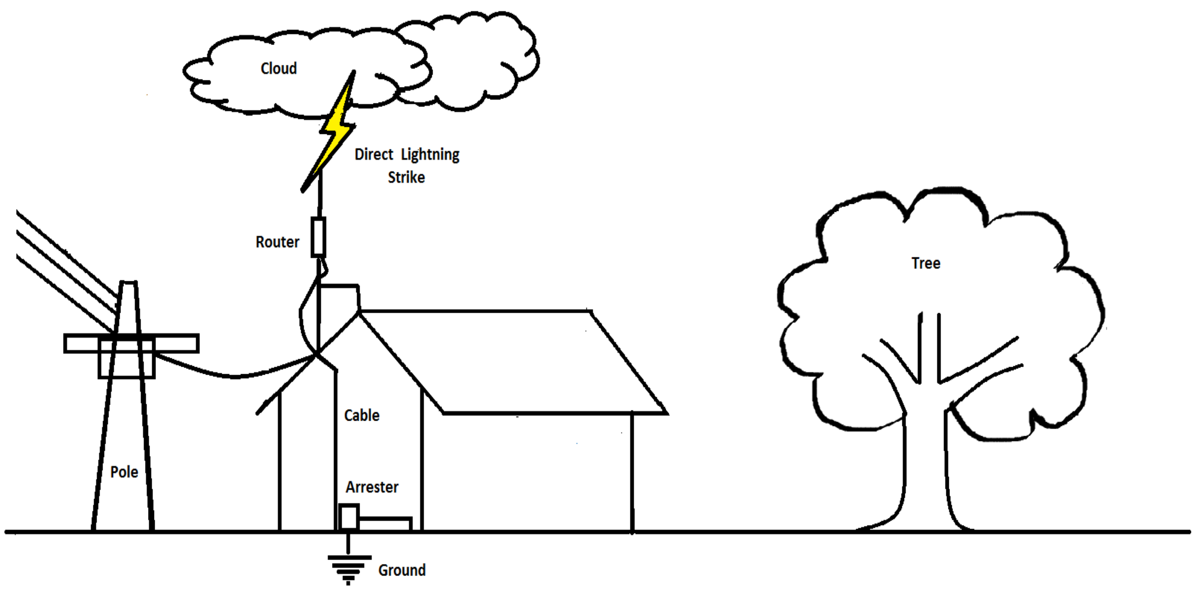


Figure1.4 Direct lightning strike on the roof of the building

- **When lightning strike on line**:-When lightning strikes on overhead low voltage line it conducts high currents which passes into the building creating large overvoltage. The damage caused by over voltage is usually very hazardous and results in explosions [6].

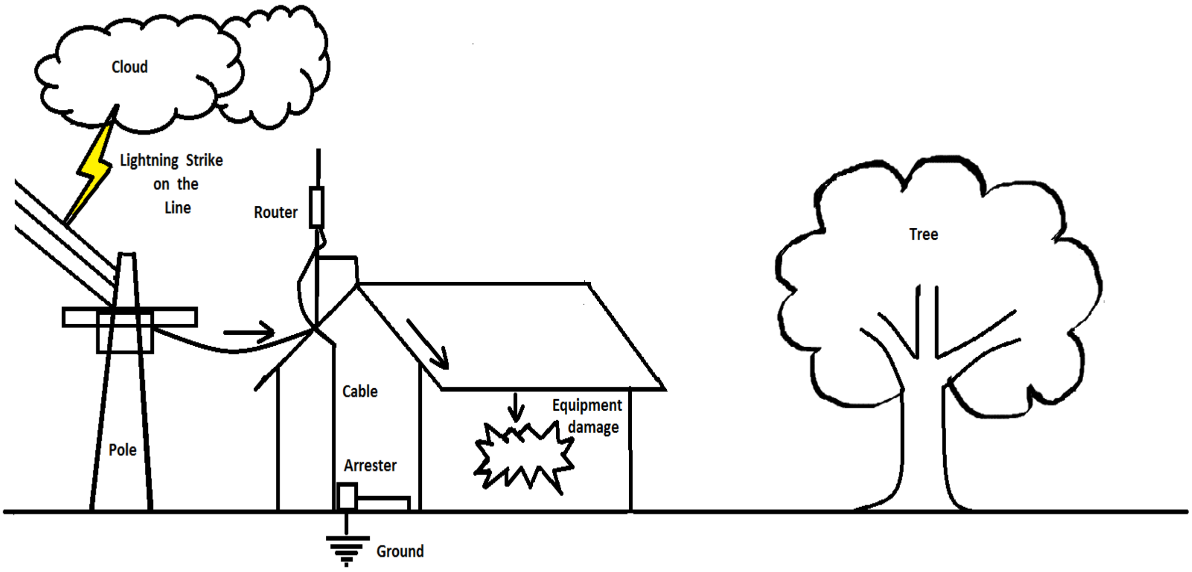


Figure1.5 Direct lightning strike on overhead low voltage line

1.3.4.2 OVERVOLTAGE DUE TO INDIRECT LIGHTNING STROKES

The lightning current generates the electromagnetic field across the system due to which the capacitive and inductive coupling develops the over voltage across the system. Basically over voltage develops when lightning strikes on the conductor or in the building this is due to the higher potential of ground at the point of impact [6]. The energy contained in a lightning stroke is very high and it can be tremendously destructive. Lighting strokes are defenceless to electric distribution networks. A single stroke to a distribution line is sufficient to cause a blackout throughout a feeder and to prevent this type of problems in power systems are protected with lightning rods, ground wires and lightning arrestors. To reduce the failure rate across overhead high voltage transmission lines arrestors are installed between each phase and earth to protect the system

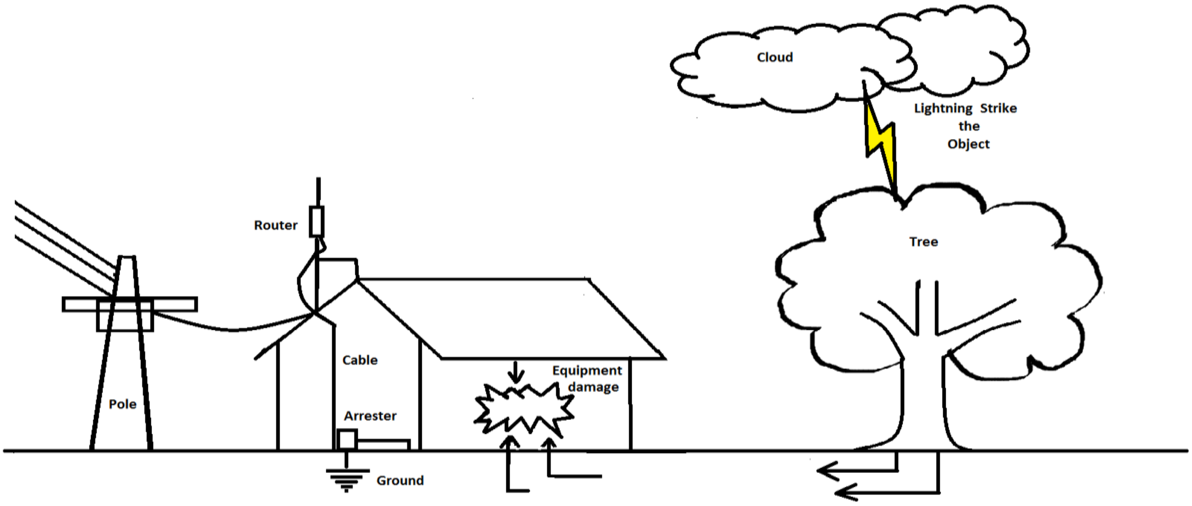


Figure1.6 Overvoltage due to indirect lightning

1.3.5 LINE DESIGN BASED ON DIRECT STROKES

The basic principles to protect system from direct lightning strike are:

- There should be supply with ground wire of sufficient mechanical strength to shield the phase conductors from direct lightning strokes.
- There must be adequate clearance from the phase conductor to the tower so that full effectiveness of the insulating structure can be obtained.
- There must be adequate clearance from the phase conductor and the ground wire especially at mid span so that flashover between phase conductor and ground wire are eliminated
- The tower footing resistance should be as low as economically justified. A tower footing resistance helps in maintaining the tower top voltages to a safe value[3].

1.3.6 PROTECTION AGAINST LIGHTNING

Lightning produces high magnitude of current and voltage in the system. So to protect the electrical equipment from being damaged from lightning stroke following techniques are to be studied:-

- Transmission line protection from direct lightning strokes.
- Substation and power station protection from direct lightning strokes

- Electrical equipment’s protection from travelling waves flowing in the system.

There are different methods adopted for protecting the electrical equipments from lightning strokes. These are specified by the types of the lighting strokes come across the system[17].

Table1.1 Methods adopted for protecting the electrical equipment from lightning strokes

S.No.	Phenomena	Protective Equipment
1	Direct Lightning stroke	Ground wire and Lightning arrestors
2	High Voltage Impulse having a step wave front	Ground wire and lightning arrestor
3	Arcing ground	Neutral earthing
4	Low voltage high frequency oscillations	Condensers or surge absorbers
5	Static over potential	Water jet earthing resistance or earthing choking coils

1.3.7 LIGHTNING ARRESTOR

A lightning arrestor is a device installed near the end of any conductor which is long enough before the conductor lands on electrical equipment. It’s main purpose is to divert lightning-induced transients safely to ground through property changes to its varistor in parallel arrangement to the conductor inside the unit which is also called a surge protection device or transient voltage surge suppressor, they are only designed to protect against electrical transients resulting from the lightning flash, not a direct lightning termination to the conductors [15]. Figure1.7 shows the internal structure of the arrestor. The arrestor consist of spare gap with non-linear resistor combined and then placed it to earth directly. Lightning arrestor due to this property act as insulated during normal operation and it act as conductor when high voltage appear across the system. Figure1.8 is voltage Vs current characteristics of surge arrestor.

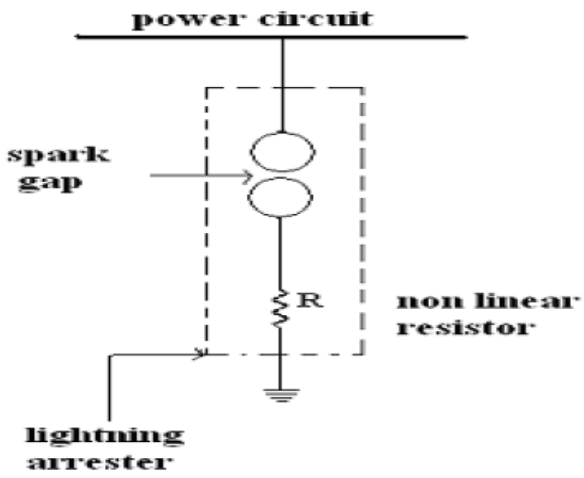


Figure 1.7 Surge arrestor internal structure

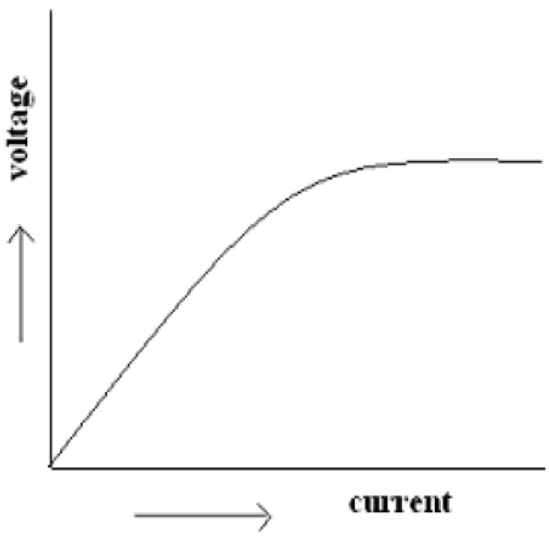


Figure 1.8 The Characteristics of surge arrestor

1.3.8 CALCULATION OF ARRESTOR VOLTAGE AND CURRENT

- **ARRESTOR AT THE END OF A LINE**

An arrestor connected at the end of the line of surge impedance Zc and a wave ef travelling on the line.

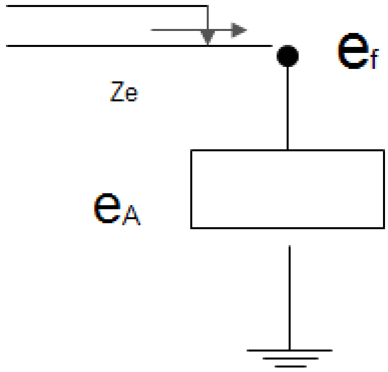


Figure 1.9 Surge arrestor at the end of a line actual circuit

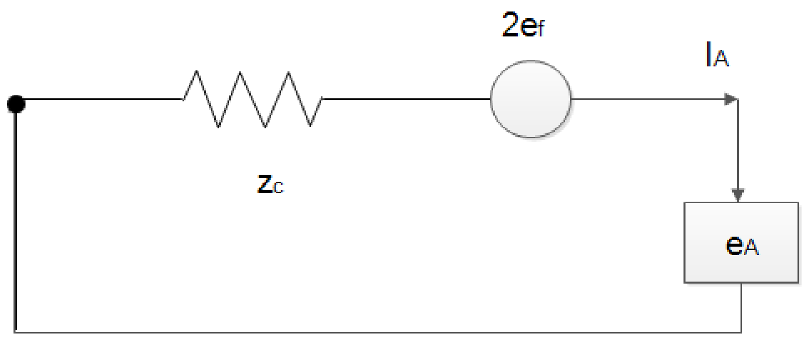


Figure 1.10 Surge arrestor at the end of a line equivalent circuit

Figure1.9 shows the surge arrestor at the junction of a line actual circuit. This is the basic diagram of arrestor installation in parallel to lines for protecting the system from being damaged. Figure1.10 is the equivalent circuit of the actual circuit of arrestor installation for calculating the current present across the arrestor installed in the system.

$$2e_f = e_A + Z_c I_A \text{---------------}1.1$$

$$I_A = k(e_A)^{\alpha} \text{-----------------------}1.2$$

Where e_f =forward voltage, e_A =arrestor voltage, Z_c =surge impedance,

I_A =Arrestor current

- **ARRESTOR AT JUNCTION OF TWO LINES**

Arrestor at the junction of two lines having surge impedances $Z1$ and $z2$

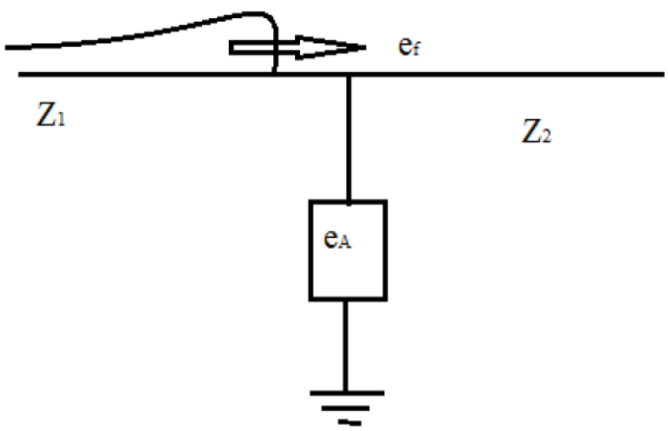


Figure 1.11 Surge arrestor at the junction of two line actual circuit

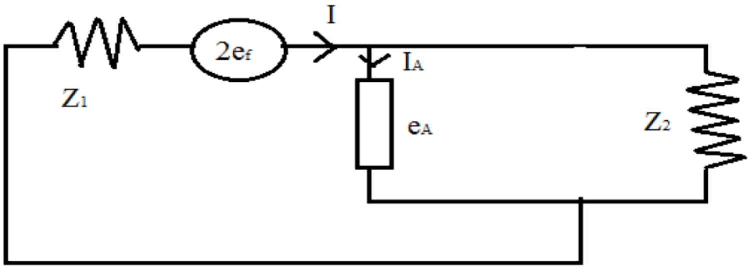


Figure 1.12 Surge arrestor at the junction of two line equivalent circuit

Figure1.11 shows the surge arrestor at the junction of two line actual circuit. This is the basic diagram of arrestor installation in the system between the two lines for protecting the system from being damaged. Figure1.12 is the equivalent circuit of the actual circuit of arrestor installation for calculating the current present across the arrestor installed in the system.

$$2e_f = e_A + Z_1 I \text{-----------------}1.3$$

$$2e_f = e_A + Z_1(I_A + \frac{e_A}{Z_2})\text{---------}1.4$$

$$2e_f = e_A\left(1 + \frac{Z_1}{Z_2}\right) + Z_1 I_A\text{--------}1.5$$

$$I_A = k(e_A)^{\alpha}\text{-----------------------}1.6$$

Where e_f =forward voltage, e_A =arrestor voltage, Z_c =surge impedance,

I_A =Arrestor current, Z_1 =surge impedance of line 1

Z_2 = Surge impedance of line 2

In the above equations the surge impedance plays a very important role in limiting the voltage across the arrestor. If Zc and $Z1$ = 0 i.e. line is absent, the voltage eA is equal to$2ef$. An arrestor as a separate entity does not limit the voltage. It is only through the combination of arrestor characteristics and line surge impedance that we can limit the voltage across the equipment [6].

1.3.9 LIGHTNING PROTECTION OF LOW VOLTAGE INSTALLATION

Lighting can cause huge damage to low voltage installation. These installations include towering buildings, communication lines, equipment's and other similar facilities. Lighting may travel on power lines and enter these installations through power lines.

Lightning protection scheme involves five basic steps:

- It Capture the lightning stroke through an air terminal
- The system Conduct the lightning current to earth through a down conductor
- Scatter energy of lightning stroke allows impedance earthing system
- It avoid earth loops and potential differentials
- It protect the equipment's installed from surge travelling on power lines

1.3.10 EFFECT OF LIGHTNING CURRENT

The following effects are noticed if we select and place wrong arrestor in the system.

- Thermal effects: When there is lightning the system get heated up due to the increase in the current in the system. Sometimes it catches fire when the value of current increases.
- Electrodynamics effects: The attraction and repulsion force present in the system current increases, due to which the wire of the system breaks.
- Combustion effects: The shock waves present in the system are transformed into sound waves which are being heard by us as the sound of thunder. This thunder effect produces combustion effect in the system.

This explains indirect strokes of lightning increase voltage and the breakdown of equipment. This effect ledS to physical and catastrophic failures initiating industrial/domestic fire outbreaks, equipment failure, loss of lives and downtime revenue loss and not only make the system discontinuous but create other losses also.

Hence it is important to understand damage caused due to lightning and provide best protection against lightning hazard using international standards.

1.4 SWITCHING OVERVOLTAGES

Another method of overvoltage occurrence in the system is switching operation. The increase in transmission voltage needs to fulfil the requirement of increase transmission powers, switching surges have become the main factor for designing of insulation for the transmission line. In the meantime the lightning overvoltage which is a source of external overvoltage develops across the system comes as a secondary factor in the transmission line protection [1]. There are two fundamental reasons for this shift in relative importance from lightning surges as higher transmission voltages are called for:

- Over-voltages developed on the transmission line by lightning strokes are only slightly dependent on the power system voltages. As a result of this the magnitude relative to the system peak voltage decrease as later it increase.
- External insulation has breakdown strength lowest under surge whose fronts fall in the range 50-500 micro sec. which is typically for the switching surges develop in the system.

1.4.1 ORIGIN OF SWITCHING OVERVOLTAGES

There are many methods or faults occur in the system due to which the switching operation takes place. The origin of such over-voltages develop across the system cause various type of disturbances in the system and make the system faulty to work in the strong condition.

The various types of switching operations develop across the system are:

- **ENERGIZATION OF TRANSMISSION LINES AND CABLES:-** The specific switching operation occur in this category which makes the system faulty are:

a. Energization of a line that is open circuited at the far end
b. Energization of a line that is terminated by a unloaded transformer
c. Energization of a line through the low voltage side of the transformer

- **RE-ENERGIZATION OF THE LINE:-** Re-energization of the line means the energization of the line carrying charge get trapped by previous line interruptions when high speed recloures are used.

- **LOAD REJECTION:-** This is affected by the circuit breaker opening at the far end of the line. This is also be followed by opening the line at the sending end which is also known as the line dropping operation.

- **SWITCHING ON AND OFF OF THE EQUIPMENTS:-** All switching operations involving an element of the transmission network will produce a switching surge in the system and makes the system faulty. The switching surge develop across the system by:
  a. Switching of high voltage reactors
  b. Switching of transformers that are loaded by a reactor on their tertiary winding.
  c. Switching of transformer at no load.

1.4.2 OTHER SWITCHING OPERATIONS

- Reclosing (energization of a line with trapped charges)
- Energization of a line terminated by an unloaded transformer
- Load rejection at the receiving end of a line
- Load rejection at the receiving end of the line followed by line dropping at the sending end
- Interrupting lines at no-Load of transmission line (line dropping)
- Switching of transformers at no-load
- Initiation of a single phase to earth fault without a switching operation

CHAPTER 2

LITERATURE SURVEY

.1 INTRODUCTION

In the literature survey different topic related to overvoltage protection mainly topics are on the overvoltage due to lightning occurrence in the system and switching operation. In literature survey various journals and conference topic related to the lightning protection and the techniques used by various authors to predict the lightning faults or failure occur due to lightning in the system.

2.2 RELATED WORK

D.RODRIGUEZ SANABRIA, C.RAMOS ROBLS AND L.ORAMA EXCLUSA (2006)

In this paper the author present how ATP/EMPT plays an important role to model lightning strikes and what are the various effect of lightning on power distribution system. Mainly the research is done on the action and development of arrestor used in the system. In this paper the author analyse the effect of lightning strike and multiple lightning strokes are simulated in ATP. The author monitored the effect of direct lightning strike on the substation buses and voltage buses across the system. In this paper the author not only work on ideal system but also simulate the result on worse conditions also.

L.EKONOMOU, I.F.GONOS, I.A.STATHOPULOS (2006)

In this paper the author work on the artificial neural network (ANN) method to develop a model based on the lightning performance of high voltage transmission line in the power system. The main advantage of this system is that the author uses ANN method to simulate the output result by taking actual data. Nowadays ANN method is most economical and efficient method as compare to the other computer technologies. ANN method is being used in the transmission line with similar characteristics as that of the transmission line. This method is used in training and testing procedure for taking desirable results. In this paper the author use the radial basis and feed-forward ANN methods, in which transfer function and structure is calculated for carrying out the desire result accurately. The author compares advantages and disadvantages of the ANN methods and proposed the ANN is best method for the design of the electrical power system.

DALINA JOHARI, TITIK KHAWA ABDUL RAHMAN (2007)

In this paper the author is predicted the lightning occurrence by using ANN method and compare it to the other forecast techniques available in the system. The author uses the historical data and the meter logistic data to make the ANN method efficient to predict the lightning occurrence in the system. The author got successful after teste the data on the different networks. The author got the desired result by using a heuristic technique.

C.A.CHRISTODOULOU, G.PERANTZAKIS, G.E. SPANAKIS AND P.KARAMPELAS (2008)

In this paper the author uses artificial neural network method in which he specially work on the Q-learning algorithm for the high voltage transmission line for evaluating the lightning performance. In this paper the author make result of lightning failure rate without arrestor as well as the probability of arrestor failure. The result of various simulations is done by appropriate tools in the system. The ANN method is best reliable, small size, quick training process and consumes less memory as compare to other system.

YONG WANG, JIN CHANG ZHOA, GUI FANG ZHANG (2008)

In this paper the author model a 10KV transmission line in which he placed surge arrestor. The author also works on the basic surge arrestor principle and its working procedure. The author analyse the result by using different cases and different number of arrestors by using PSCAD. The author concludes that the usage of surge arrestor can reduce the large amount of current flowing in the system and over voltage develop across the line. It is the best economical and effective way to protect the system from being damage by lightning strokes.

XUEWEI ZHANG, LIN DONG, JINLIANG HE, SHUIMIMG CHEN AND ROG ZENG (2009)

In this paper the author did series simulation of single lightning rod. The author shows how we are able to protect the system from being damaged by the lightning so he has done various simulations on various lightning rods and verified that the system is capable to protect the power system from lightning occurrence in the system. The author conclude about the topic that, Interception area of the system is directly proportional to the rod augments height, The upper section of the rod is relatively denser due to the strike distribution, Lightning protection zone are analysis by using different rod height and The protection zone sharper, as the height of the rode increases.

M.A. OMIDIORA (2009)

In this paper the author discussed about the performance of overvoltage develop due to real lightning discharges occurring in distribution power lines equipped with covered conductors. The author evaluates and simulates the results based on real lightning data collected from the Finnish Meteorological Institute (FMI). Evaluation of induced overvoltage from indirect stroke to the line is analysed with MATLAB and various results has been concluded. With the Electromagnetic Transient Program (EMTP), simulations of lightning strokes are performed with different lightning current characteristics and then all cases are considered with the modelling guidelines as specified in some lightning literature. Simulations are made to compared the resulting over-voltages and energy absorptions of surge arrestors for all the analysed cases. The following remarks are drawn from the study:

- The induced voltage due to a lightning stroke to a power line support is more intense than the induced voltage due to a lightning stroke to ground.
- The distortion increases with the change in lightning characteristic does not lead to a significant change in the maximum induced voltage for a lightning stroke to a line support, as was the case for a lightning stroke to ground.
- The induced voltage on the distribution line is higher than the induced voltage on the covered conductor as simulated by the model. This can be very stressful for surge protective devices.

- The rate of rise of lightning current decreases as the arrestor dissipation energy increases.

MICHAEL A.OMIDIORA, MATTI LEHTONEN (2009)

In this paper the author studied the performance of an MV underground cable due to a nearby lightning discharge occurring in the system. The simulation is made with Finite Element Method (FEM). In this paper the author consider the effects of lightning stroke location, resistivity of the soil and underground cable configurations as its primary parameter and carry out the desirable result .The results of the numerical computation show about electric field intensity and potential distribution vary with the factors mentioned above. Estimations of the failure rate of the underground cable are made based on the real lightning statistics. It is expected that the results will provide a good understanding of the need for lightning protection on MV underground cables.

ABDOLAMIR NEKOUBIN (2011)

In this paper the author checked the behaviour of fixed series compensated extra high voltage transmission lines during faults is simulated in the transmission system. While the need for more compact and environmentally robust equipment is required. Use of series capacitors for compensating part of the inductive reactance of long transmission lines increases the power transmission capacity. Emphasis is given on the impact of modern capacitor protection techniques (MOV protection). The author simulates the performance using MATLAB/SIMULINK and results are given for a three phase and a single phase to ground fault. In the last author concluded that during a three phase fault the MOV protection devices operate immediately, in order to remove the capacitor banks from the system. The capacitor is not isolated from the line so its reinsertion is instantaneous. An important result is that as soon as the bypass switch closes the line current is reduced to a value, as if there were no capacitor banks in the system. During single phase fault only protection equipment of faulted phase function whiles the capacitor banks of the other phases remain in the system to maintain stability. And he also concluded that the MOVs' absorption of energy is measured in all phases and the energy is exchanged between the capacitor and the MOV.

M.CHANAKA, KUSUM SHANTHI, RANJIT PERERA (2011)

In this paper the author carried out a case study on 220KV transmission line at hilly area of the Sri Lankan. The author works on the lightning back flash over which lead to the system failure. The author uses the PSCAD software for modelling the system and simulating the result. The author simulates the result by using the lightning arrestor and without using the arrestor. The main objective of the paper is to analysis the back flash over and to analysis the performance of the 220KV line where this system has been installed. In the last the author concluded that we have to install the lightning arrestor across each tower to protect the system from lightning develop across the system. So the author does simulation work by using arrestor and without using arrestor and carry out the various results that how system behaves.

GU DINGXIE, DAI MIN, HE HUIWEN (2011)

In this paper the author worked on the shielding failure flash over across the system in the mountainous area. The shielding angle increased with the ground slope along the line in mountainous area. In this paper the author design a new method and principle for calculating the inrush over voltage to ultra-high voltage and also make a concept of reducing the lightning current and shielding failure and optimize the various result of lightning arrestor to restrict lightning inrush over voltage to the various substation. With the help of this work the author wants to minimise the amount of MOAs used in the system.

G.E.CHATZAROKIS, V.VITA, P.KARAMPALAS AND L.EKNONOMOUS (2011)

In this paper the author uses artificial neural network method in which he specially work on the Q-learning algorithm for the high voltage transmission line for evaluating the lightning performance. In this paper the author make result of lightning failure rate without arrestor as well as the probability of arrestor failure. The result of various simulations is done by appropriate tools in the system. The ANN method is best reliable, small size, quick training process and consumes less memory as compare to other system.

VLADIMIR A.RAKOV (2012)

In this paper the author says that the Traditional lightning parameters needed in engineering applications include lightning peak current, average current rate of rise , maximum current derivative (di/dt), current rise time, current duration, action integral(specific energy) and charge transfer(specific energy), all derivable from direct current measurements. Distributions of these parameters nowadays adopted by lightning protection are largely based on measurements. The author wanted that direct current measurements on instrumented towers were made in other countries. Triggered-lightning experiments have provided considerable insight into natural lightning processes.

JOHN TARILANYO AFO (2013)

In this paper the author studied about the surge diverters and the performance and construction of diverters. The author engrossed that the ZnO arrestor has good performance. The use of arrestor depends upon the life span and efficiency of the diverter used in the system to protect the system. The author concluded that the rainfall in the atmosphere as well as dust particles is the main factors which affect the performance of the system.

2.3 PRESENT WORK

Till now the literature survey of different authors about the lightning occurrence in the system and the different steps taken by them to protect the transmission line from lightning occurrence. By reading all these paper concluded that there is need to design a system which can protect the compensated devices attached with the system to protect the highly sensitive component from overvoltage developed due to lightning and switching.

CHAPTER 3

WORK DONE

3.1 PROBLEM FORMULATION

In our dissertation work, we have done literature survey and then design a new model on lightning arrestor using MATLAB/Simulink. All results and response is carried out in the MATLAB/Simulink and the performance of the system is noted. The main aim of this system is to protect the system from heavy damage caused by the over voltages develop across the system due to lightning and switching, to protect the compensated devices connected across the system.

We are analysing the behaviour of the current and voltage magnitude developed across the transmission model by inserting the overvoltage faults such as switching and lightning. All the simulation work is done by using MATLA/Simulink software in which we develop the graphical representation between voltage vs time and current vs time waveforms across the conductor used in the system. All the simulation work is done by using arrestor and without using arrestor. Then we carried out the results by comparing the two models.

3.2 OBJECTIVES

The objectives of the study of this dissertation work is given as

- The main objective of research work is to protect the compensated devices from being damage from overvoltage occurrence in the system.
- To analyse the performance of the system with or without using arrestor in the system
- To study the use of surge arrestors across the system and to analyse the result and graphical representations of voltage vs time and current vs time waveforms of the conductor affecting the system by using MATLAB/Simulink software.

3.3 TOOLS

The tool required for calculating the desired results is

3.3.1 MATLAB\Simulink

Simulink is a block diagram situation for multi area simulation and Model-Based Scheme. It provisions simulation, automatic code generation, and incessant test and corroboration of embedded systems. Simulink offers a graphical editor, customizable block libraries, and solvers for displaying and simulating dynamic systems. It is united with MATLAB which allowing joining MATLAB algorithms into models and transfer simulation results to MATLAB for further analysis.

Capabilities

- **Building the Model**: - Model ranked subsystems with predefined library blocks.

- **Simulating the Model**:-Simulate the dynamic performance of system and opinion results as the simulation runs.

- **Analysing Simulation Results**:-View simulation consequences and restore the simulation.

- **Managing Projects**:- Easily accomplish files, components, and large amounts of data for projects.

- **Connecting to Hardware**:-Connect model to hardware for real-time testing and embedded system deployment.

3.4 RESEARCH METHODOLOGY

To evaluate the performance of lightning arrestor across the overhead transmission line to protect the system from overvoltage such as lightning and switching develop across the system, we have used the MATLAB/Simulink as the key software for budding the comparison between the models with and without the arrestor present in the system. In our dissertation we construct a 735KV equivalent transmission system by feeding a load through

200 Km transmission line. The line is series compensated at the middle of the transmission line and shunt compensated at the receiving and sending end respectively. A switching as well as lightning fault is applied to the transmission line to carry out the various simulation results regarding the fault develop across the system. We are using MATLAB/Simulink to check the variation of current and voltage develop across the system with respect to time. Through this research methodology we come to know that which system is best suitable in the transmission system and what are the various factors effecting the transmission line caused due to over voltages[1][9].

- The series capacitor and shunt inductor are both protected by metal oxide varistors (MOV). The series capacitor varistor MOV consists of 30 columns protecting the capacitor at 2.5 times its rated voltage (rated voltage is obtained for a 2000 kA line rated current). The corresponding protection voltage (defined at 15 kA = 500 A per column) is 2.5*26.2 *2kA*sqrt(2) = 185 kV.
- The shunt inductor is protected by a 2-column arrester (MOV2) at 1.8 p.u. of nominal phase-to-ground voltage (424.4 kVrms). The corresponding protection voltage (defined at 1 kA or 500A /column) is 1.8*424.4*sqrt(2) = 1080 kV.
- A 3 phase short circuit level of the transmission system is 15000MVA. The line is 40% series compensated by the capacitor and shunt compensated by 330MVar inductor at the load end. The series capacitance and shunt inductor are protected by the metal oxide varistor. The series capacitor varistor MOV1 consist of 30 columns protecting the capacitor at 2.5 times its rated value. The shunt inductor is protected by a 2 column arrestor at 1.8 pu of nominal phase to ground voltage

- **SWITCHING MODEL WITHOUT USING ARRESTOR**

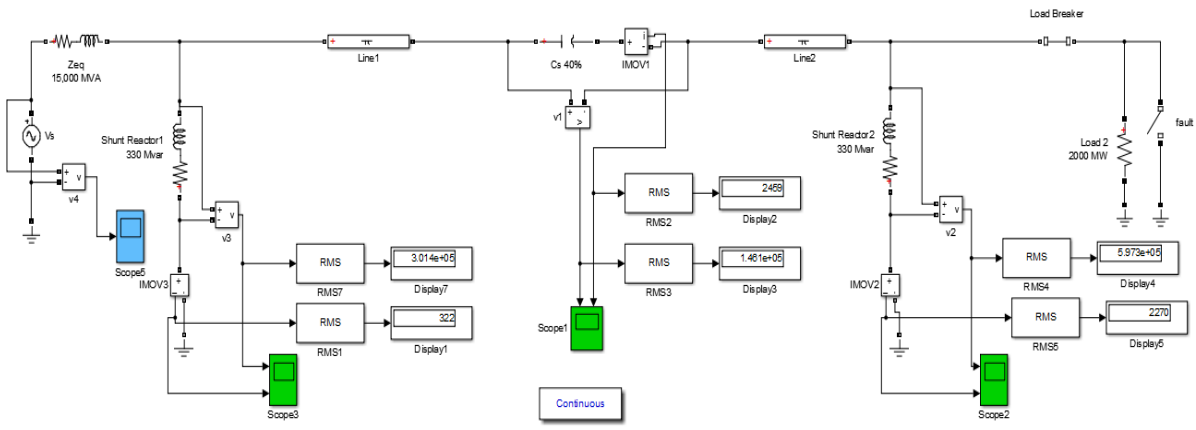


Figure3.1 A single phase MATLAB/Simulink model of switching overvoltage without using arrestor.

In switching overvoltage near the load without using arrestor, the transmission is having only the shunt and series compensated device. The extra high voltage will pass to ground through these devices and will affect the compensation system. Due to the high voltage develop across the system there is large amount of voltage and current flow through the series and shut compensated system which may even burn the compensated devices and damage the whole transmission system.

- ## SWITCHING MODEL BY USING ARRESTOR

In this case we use metal oxide surge arrestor to minimize the current and voltage flow across the compensation line which cause a harmful effect to the transmission line. In this case an earth to ground fault is inserted inside the system which act as switching operation, due to which the overvoltage develop across the system.

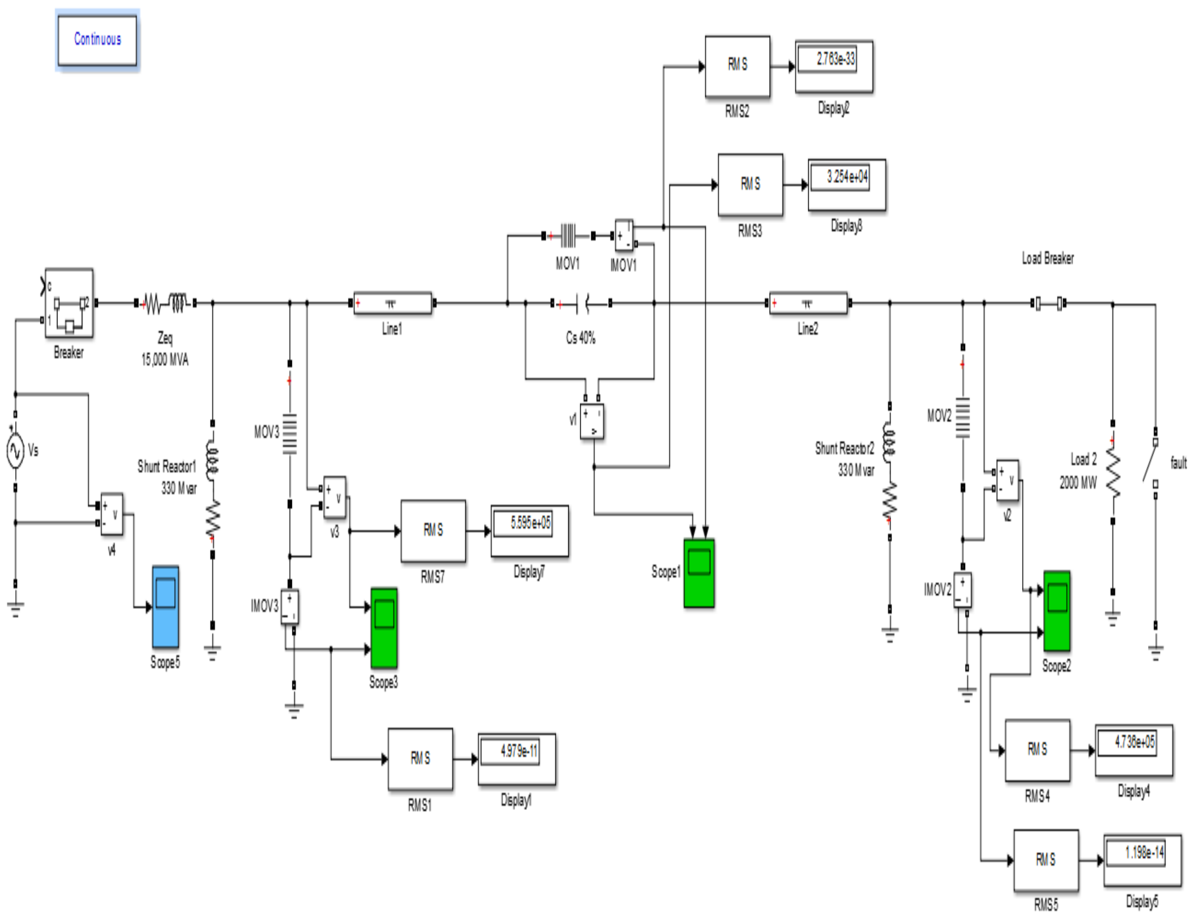


Figure3.2 A single phase MATLAB/Simulink model of switching overvoltage by using arrestor.

- **OCCURANCE OF LIGHTNING BEFORE SERIES CAPACITOR WITHOUT ARRESTOR**

In this case when lightning will fall before the series capacitor on the transmission line there is no arrestor present in parallel to the shunt and series compensated device. All lightning overvoltage will pass though the compensated devices attached across the system.

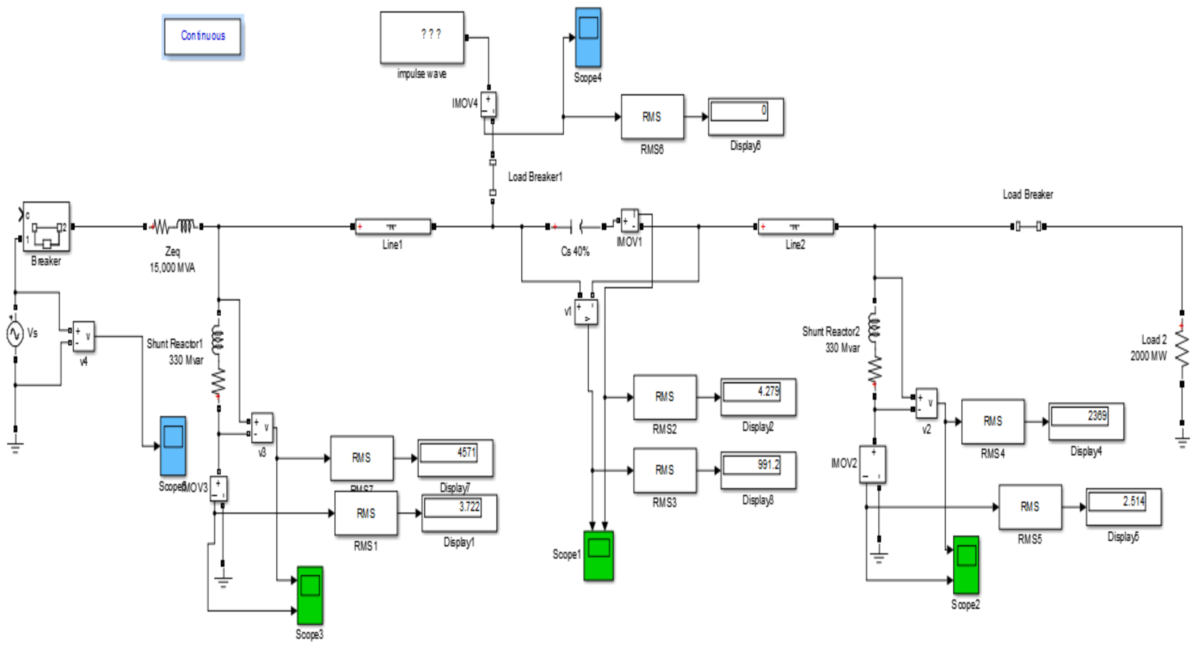


Figure3.3 A single phase MATLAB/Simulink model of lightning overvoltage before series capacitor without using arrestor.

- **OCCURANCE OF LIGHTNING BEFORE SERIES CAPACITOR BY USING ARRESTOR**

In this case when the lightning will fall before the series capacitor, the arrestor installed in parallel to the shunt and series compensation devices protect the system from the heavy voltage develop across the system. When the lightning impulse will fall on the transmission line, the system will produce a back flash to the receiving end and ground the large amount of lightning voltage to the ground and save the system from heavy damage.

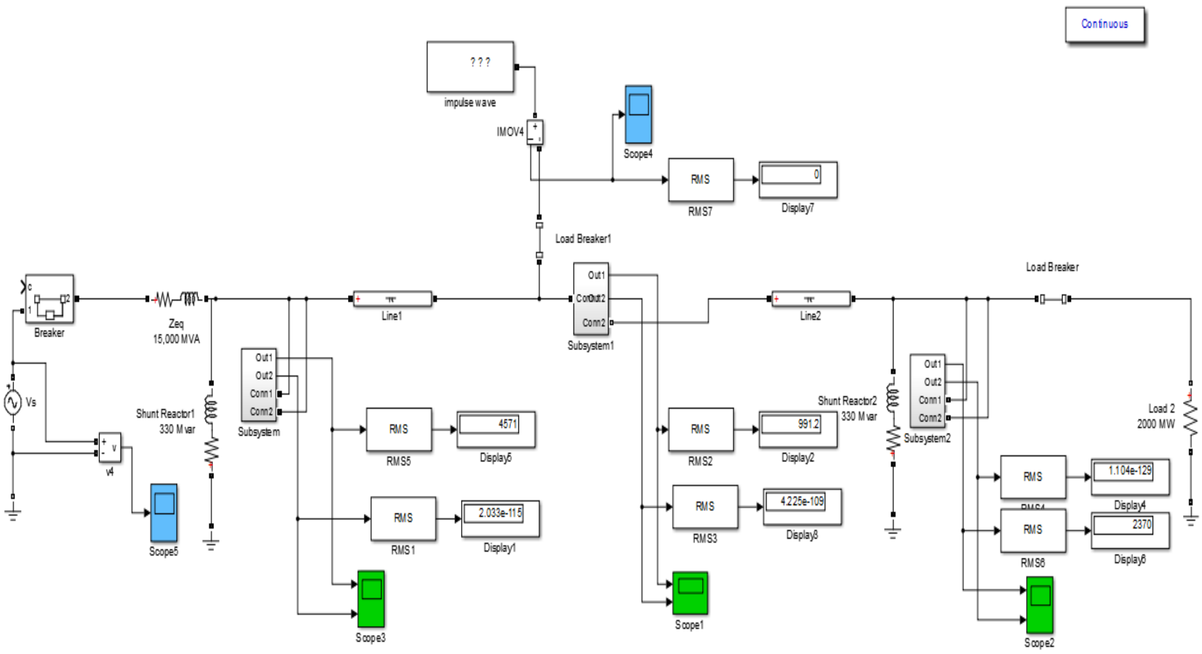


Figure3.4 A single phase MATLAB/Simulink model of Lightning overvoltage before series capacitor by using arrestor.

- **OCCURANCE OF LIGHTNING AFTER SERIES CAPACITOR WITHOUT USING ARRESTOR**

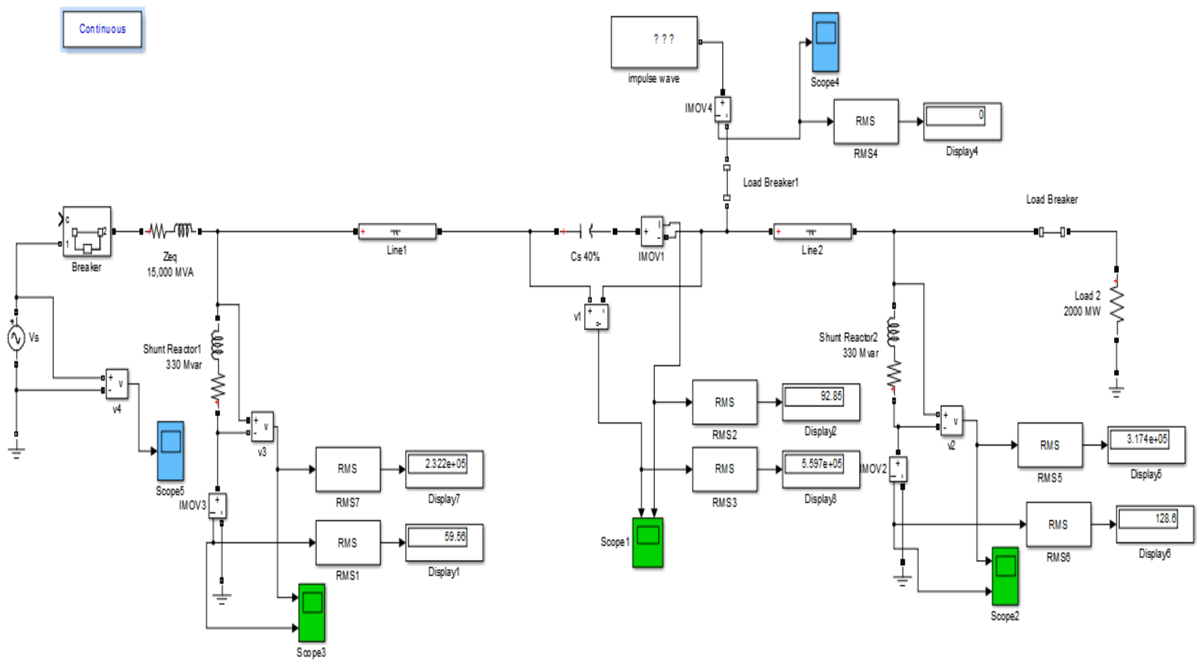


Figure3.5 A single phase MATLAB/Simulink model of lightning overvoltage after series capacitor without using arrestor.

In this case when lightning will fall after series capacitor on the transmission line there is no arrestor present in parallel to the shunt and series compensated device. All lightning overvoltage will pass though the compensated devices attached across the system.

- **OCCURANCE OF LIGHTNING AFTER SERIES CAPACITOR BY USING ARRESTOR**

In this case when the lightning will fall after the series capacitor, the arrestor installed in parallel to the shunt and series compensation devices protect the system from the heavy voltage develop across the system. When the lightning impulse will fall on the transmission line, the system will produce a back flash to the receiving end and ground the large amount of lightning voltage to the ground and save the system from heavy damage.

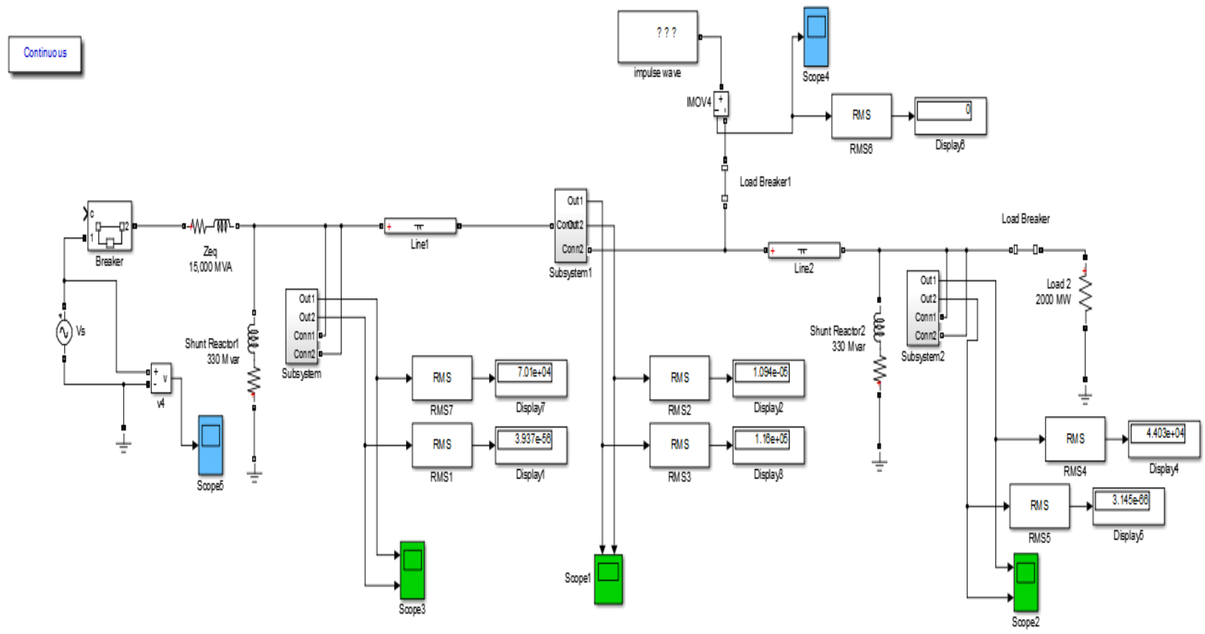


Figure3.6 A single phase MATLAB/Simulink model of Lightning overvoltage after series capacitor by using arrestor

- **SUBSYSTEM USED IN THE SYSTEM**

In our model we have develop the artificial lightning by using the impulse generator. From this experiment we investigated that we can obtain the desired impulse voltages and wave shapes from an impulse voltage generator for high voltages just like the lightning occurrence in the system. The impulse voltage generated by the impulse generator is

$4.831*10^8$ volts which act as external lightning source occurring in the system [1][12]. Impulse voltage generator can be developed by MATLAB Simulink with standard blocks available in Simulink as shown in Fig. 7. The single-stage impulse voltage generator acting as lightning source is simulated with the software. The stage sphere gaps were simulated by the use of switches, as shown. In the case of multistage system, each of the stage capacitors was given an initial charge voltage value, which is equal to 1/n of the total kV test voltage. The values of front and tail resistors, as well as the stage capacitors, are the same as used in the actual impulse generator. The impulse wave forms generated from MATLAB/Simulink model with different front and tail resistor[11][12]

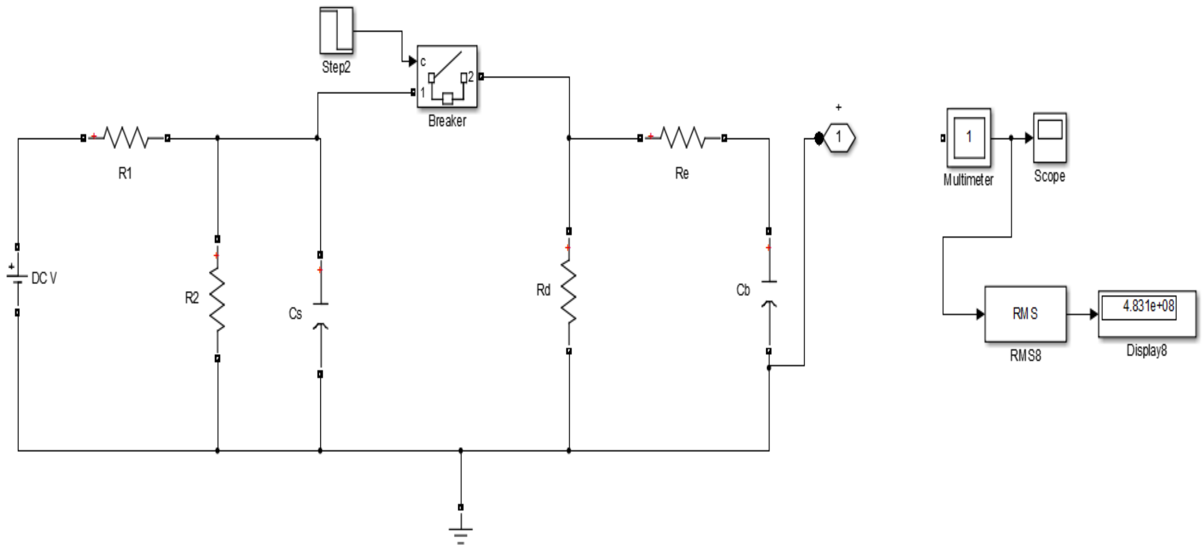


Figure3.7 Simulink model of impulse generator

CHAPTER 4

RESULTS AND DISCUSSION

4.1 BASIC DETAILS OF THE SIMULATIMG MODEL

In our model we have constructed a 735KV equivalent transmission system feed a load through a 200 Km transmission line. The transmission line is series compensated at the middle point and shunt compensated at the sending end and the receiving end of the system. An overvoltage fault is applied to the transmission line. Firstly we apply lightning fault in which we induce the pulse wave in the transmission line of very high value and then calculate the various results. This lightning is fall on the different position on the transmission line to analysis the result of arrestor across the system. Secondly we introduce switching fault near the load terminal. This fault is cleared by load breaker opening. For simplification purpose only one phase of the transmission system is modelled. All parameters correspond to positive sequence

A 3 phase short circuit level of the transmission system is 15000MVA. The line is 40% series compensated by the capacitor and shunt compensated by 330MVar inductor at the load end. The series capacitance and shunt inductor are protected by the metal oxide varistor. The series capacitor varistor MOV1 consist of 30 columns protecting the capacitor at 2.5 times its rated value. The shunt inductor is protected by a 2 column arrestor at 1.8 pu of nominal phase to ground voltage[1][9].

4.2 SUBSYSTEM USED IN THE MODEL

In our model we have develop the artificial lightning by using the impulse generator. From this experiment we investigated that we can obtain the desired impulse voltages and wave shapes from an impulse voltage generator for high voltages just like the lightning occurrence in the system. The impulse voltage generated by the impulse generator is $4.831*10^8$ volts which act as external lightning source occurring in the system [1][12].

An impulse generator essentially consists of a capacitor which is charged to the required voltage and discharged through a circuit. The waveform is the standard 1.2/50μs duration with the peak voltage reached in 1.2μs (T1) and the tail of the wave decaying to a level of 50% of the peak in 50μs (T2).The circuit parameters can be adjusted to give an impulse voltage of the desired shape. Basic circuit of a single stage impulse generator where the capacitor Cs is charged from a dc source until the spark gap G breaks down. The voltage is then impressed upon the object under test of capacitance Cb. The wave shaping resistors Rd and Re control the front and tail of the impulse voltage available across Cb respectively. Overall, the wave shape is determined by the values of the generator capacitance (Cs) and the load capacitance (Cb), and the wave control resistances Rd and Re[11][12].

$$v(t)=\frac{V_0}{C_b\,R_d\,(\alpha-\beta)}\left(e^{-\alpha t}-e^{-\beta t}\right) \text{--------------4.1}$$

$$\text{Where } \alpha=\frac{1}{R_d C_b} \text{----------------------------------4.2}$$

$$\beta=\frac{1}{R_e C_z}\text{---4.3}$$

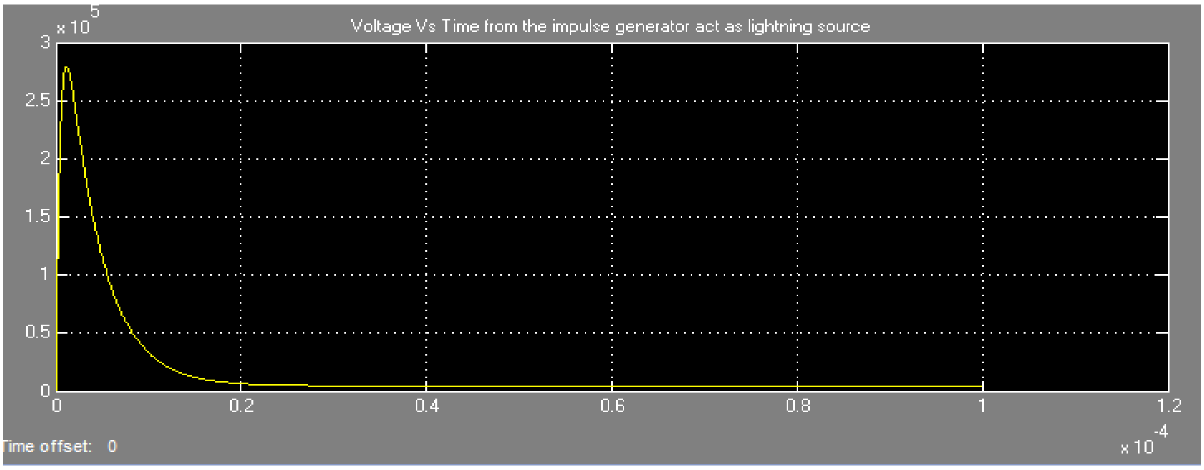


Figure4.1 Represent the Voltage Vs Time wave generated by impulse generator which act as lightning voltage source

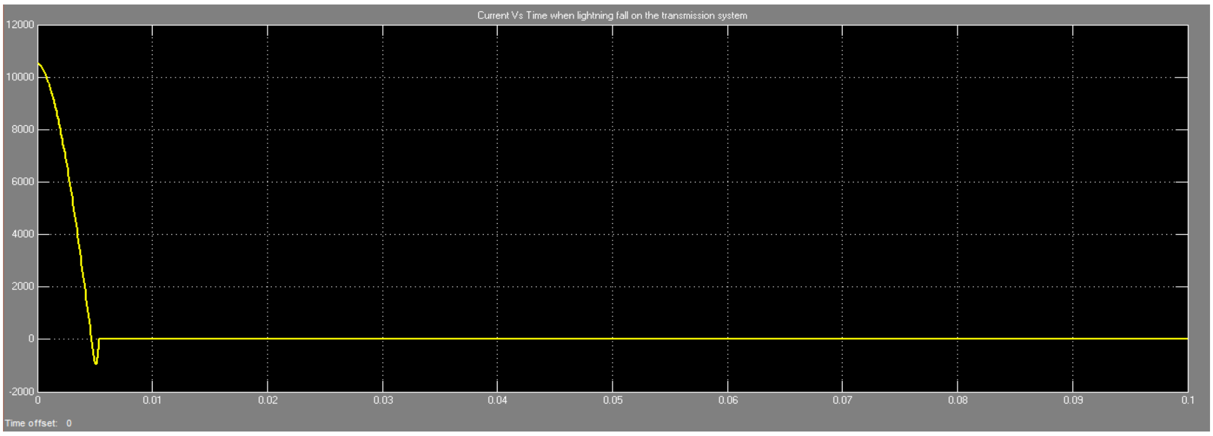


Figure4.2 Represent the Current Vs Time wave generated by impulse generator which act as lightning current source

The graphical representation in figure4.1 and 4.2 are the voltage and current waveform occur by the pulse generator. The RMS value of voltage is 4831 MV occurring in the system which acts as lightning production in the system. These are just a pulse wave produced in the system to make the system faulty due to overvoltage occur in the system just like the occurrence of lightning.

4.3 SIMULATION CRITERIA

The simulation criteria are conducted by creating the model in the MATLAB\Simulink. The variation in voltage and currents occur in the system which show us the different simulations regarding the type of model used for evaluating the lightning arrestors performance in the system. For comparing the simulations regarding the evaluation of arrestor we develop two similar models, one by using arrestor and another without using arrestor. From this we come to know about the performance of arrestor in the system.

4.3.1 SWITCHING OVERVOLTAGE

The increase in transmission voltage needs to fulfil the requirement of increase transmission powers, switching surges have become the main factor for designing of insulation for the transmission line. In the meantime the lightning overvoltage which is a source of external overvoltage develops across the system comes as a secondary factor in the transmission line protection.

In our dissertation we are comparing the two models of transmission line on which switching overvoltage develops. First model is constructed by using the arrestor and second without using arrestor. In these models when switching overvoltage occurs, we see the rate of change of current and voltage develop across the system and the variation result carried out in the system by using arrestor and without using arrestor.

4.3.1.1 SWITCHING OVERVOLTAGE ACROSS COMPENSATION DEVICES

- **WITHOUT USING ARRESTOR**

In this system when there is any switching operation when occur, there is no arrestor present in the system. We have calculated the different values of RMS voltage and current in the sending, midpoint and at the receiving end of the transmission line.

Table 4.1 switching overvoltage without using arrestor

RMS Voltage at sending end (V_{rmss})	RMS Current at sending end (I_{rmss})	RMS Voltage at midpoint (V_{rmsm})	RMS Current at midpoint (I_{rmsm})	RMS Voltage at receiving end (V_{rmsr})	RMS Current at receiving end (I_{rmsr})	Time frame (T)
$6.026e^{04}$	358.4	$6.529e^{04}$	501.5	$1.074e^{05}$	348.6	0.01
$6.026e^{04}$	358.4	$6.529e^{04}$	501.5	$1.074e^{05}$	348.6	0.02
$1.687e^{05}$	192.9	$5.119e^{05}$	7775	8551	330.2	0.03
$6.677e^{04}$	29.18	$3.073e^{05}$	$1.752e^{04}$	$1.89e^{04}$	341.9	0.04
$9.026e^{04}$	60.92	$1.621e^{05}$	$1.771e^{04}$	$2.011e^{04}$	332.6	0.05
$3.496e^{05}$	408.6	$4.944e^{05}$	583.9	$3.679e^{05}$	903.7	0.06
$2.005e^{05}$	376.1	$3.864e^{05}$	1456	$1.159e^{06}$	920	0.07
$3.486e^{05}$	350	$2.463e^{05}$	1508	$4.288e^{05}$	2227	0.08
$3.171e^{05}$	401.5	$3.986e^{05}$	1948	$4.241e^{05}$	1700	0.09
$3.014e^{05}$	322	$1.461e^{05}$	2459	$5.973e^{05}$	2270	0.10

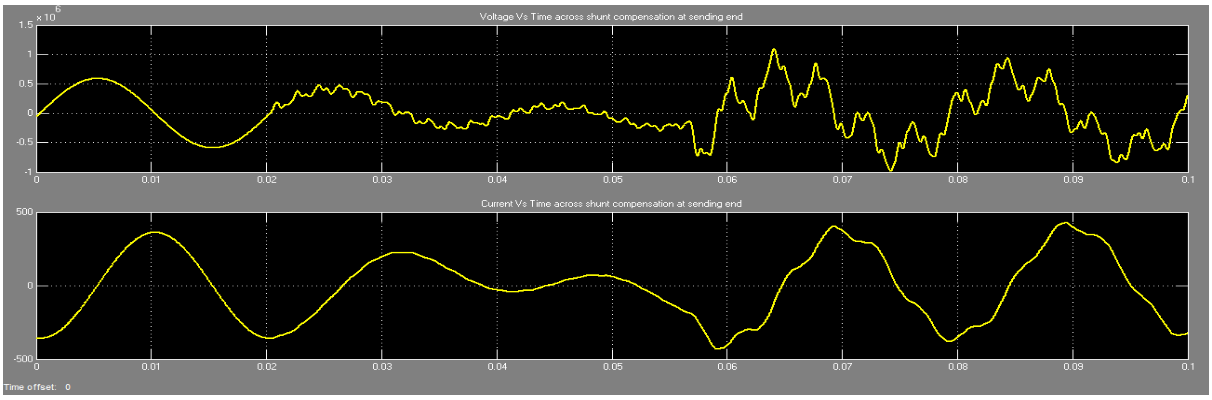


Figure4.3 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the sending end of transmission line, switching overvoltage without using arrestor

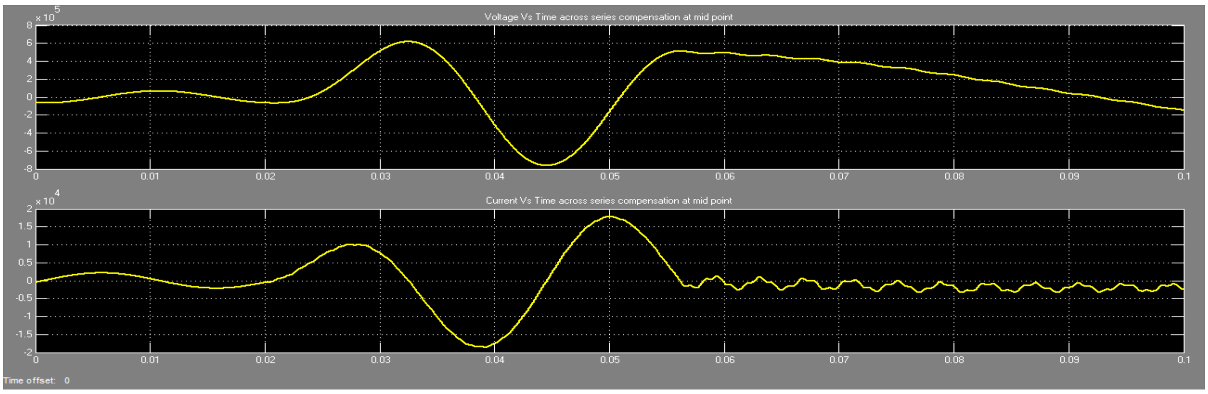


Figure4.4 Voltage Vs Time and Current Vs Time waveform of the series capacitor at the midpoint of transmission line,switching overvoltage without using arrestor

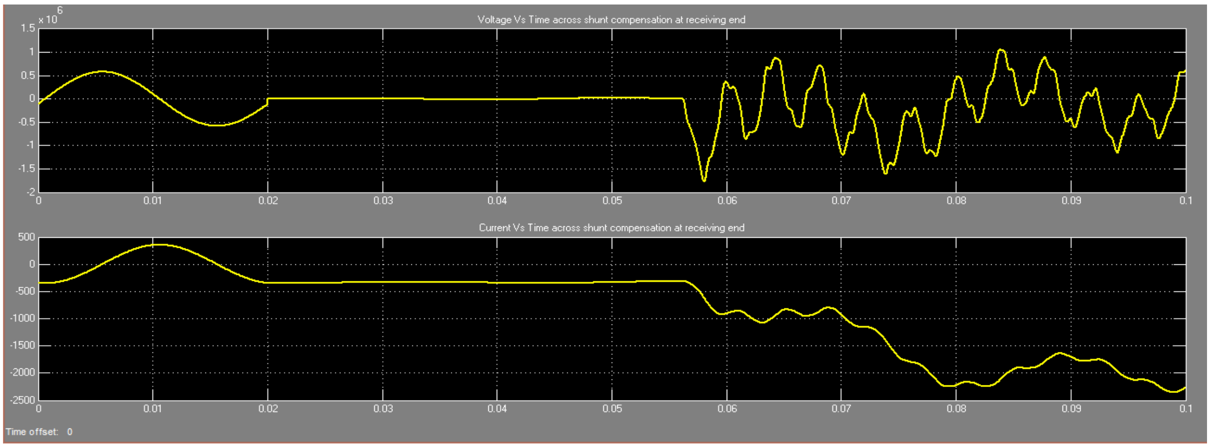


Figure4.5 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the receiving end of transmission line,switching overvoltage without using arrestor

These are the graphical representation of voltage and current waveforms at the sending end, midpoint and the receiving end of the 200 Km transmission line. These waveforms are showing the variation across the compensated devices when there is switching fault occur in the system.

- **BY USING ARRESTOR**

In this system when there is any switching operation when occur, there is arrestor present in the system. We have calculated the different values of RMS voltage and current in the sending, midpoint and at the receiving end of the transmission line.

Table 4.2 Switching overvoltage by using arrestor

RMS Voltage at sending end (V_{rmss})	RMS Current at sending end (I_{rmss})	RMS Voltage at midpoint (V_{rmsm})	RMS Current at midpoint (I_{rmsm})	RMS Voltage at receiving end (V_{rmsr})	RMS Current at receiving end (I_{rmsr})	Time frame (T)
$4.852e^{04}$	$3.971e^{-64}$	$3.985e^{04}$	$6.861e^{-29}$	175.7	0	0.01
$1.085e^{05}$	$1.228e^{-46}$	$2.617e^{04}$	$5.091e^{-38}$	$1.75e^{05}$	$2.866e^{-36}$	0.02
$1.165e^{05}$	$4.121e^{-45}$	$1.785e^{04}$	$2.477e^{-46}$	$1.663e^{05}$	$2.234e^{-37}$	0.03
$4.209e^{05}$	$3.292e^{-17}$	8421	$1.215e^{-62}$	$4.193e^{05}$	$2.734e^{-17}$	0.04
$5.78e^{05}$	$2.551e^{-10}$	1837	$1.064e^{-95}$	$5.337e^{05}$	$4.707e^{-12}$	0.05
$4.018e^{05}$	$3.218e^{-18}$	$1.205e^{04}$	$7.495e^{-55}$	$4.377e^{05}$	$2.331e^{-16}$	0.06
$1.162e^{05}$	$3.775e^{-45}$	$2.1e^{04}$	$8.536e^{-43}$	$1.337e^{05}$	$4.046e^{-42}$	0.07
$1.486e^{05}$	$8.208e^{-40}$	$2.758e^{04}$	$7.049e^{-37}$	$1.662e^{05}$	$2.181e^{-37}$	0.08
$3.607e^{05}$	$1.462e^{-20}$	$3.144e^{04}$	$4.951e^{-34}$	$4.167e^{05}$	$1.993e^{-17}$	0.09
$5.595e^{05}$	$4.979e^{-11}$	$3.254e^{04}$	$2.763e^{-33}$	$4.736e^{05}$	$1.198e^{-14}$	0.10

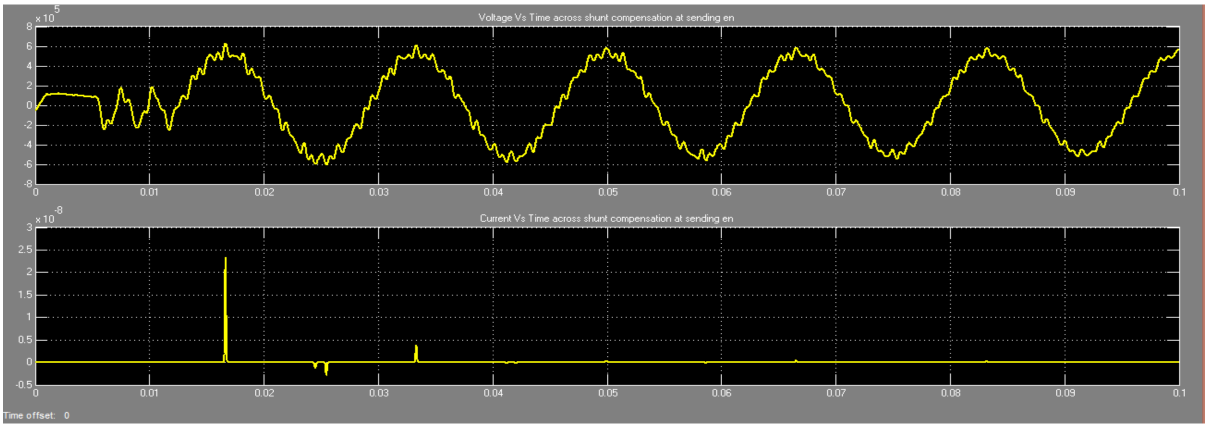


Figure4.6 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the sending end of transmission line, switching overvoltage by using arrestor

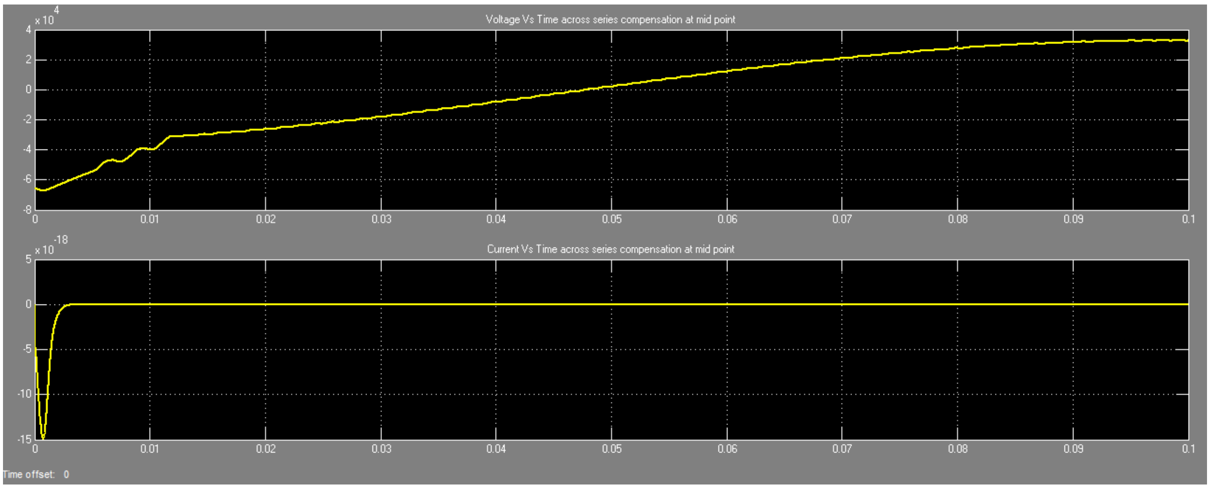


Figure4.7 Voltage Vs Time and Current Vs Time waveform of the series capacitor at the midpoint of transmission line,switching overvoltage by using arrestor

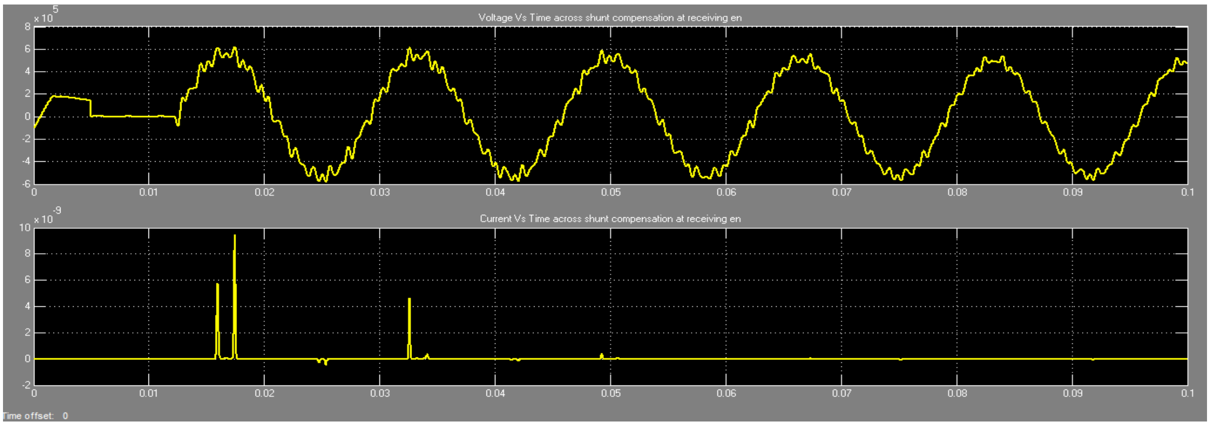


Figure4.8 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the receivingend of transmission line,switching overvoltage by using arrestor

These are the graphical representation of voltage and current waveforms at the sending end, midpoint and the receiving end of the 200 Km transmission line. These waveforms are showing the variation across the arrestor attached in parallel to the compensated devices the voltage and current when there is switching fault occur in the system.

4.3.2 LIGHTNING OVERVOLTAGE

Lighting can change huge damage to low voltage installation. These installations include high rise buildings, communication lines and equipment's and other similar facilities. Lighting may travel on power lines and enter these installations through power lines. So we have constructed a transmission line on which the lightning will fall. Just like the switching case we have built the model by using surge arrestor and without using surge arrestor across the transmission line. For more modification we have inserted the lightning which is produced by impulse generator (subsystem) on the various positions on the transmission line.

For understanding about the effect of lightning occurrence in the system we are considering two cases in which we are falling lightning at different position on the transmission line. After falling the lightning on the transmission line we consider two cases with and without arrestor to analysis the effect of lightning occurrence in the system.

4.3.2.1 OCCURANCE OF LIGHTNING BEFORE SERIES CAPACITOR

- **WITHOUT USING ARRESTOR**

In this system when there is any lightning operation occur before series capacitor, there is no arrestor present in the system. We have calculated the different values of RMS voltage and current in the sending, midpoint and at the receiving end of the transmission line. When there is no arrestor present in the system the voltage and current develop by the lightning will passes through the compensated devices and damage the compensated system attached across the system and make the system faulty.

Table 4.3 Overvoltage before series capacitor without using arrestor

RMS Voltage at sending end (V_{rmss})	**RMS Current at sending end (I_{rmss})**	**RMS Voltage at midpoint (V_{rmsm})**	**RMS Current at midpoint (I_{rmsm})**	**RMS Voltage at receiving end (V_{rmsr})**	**RMS Current at receiving end (I_{rmsr})**	**Time frame (T)**
$2.663e^{04}$	13.36	11.11	1477	4545	6.308	0.01
8195	8.514	15.95	432.1	5029	0.6098	0.02
5071	5.484	2.856	289.6	512.1	3.333	0.03
3229	4.081	3.444	723.8	66.07	3.716	0.04
1727	2.389	3.533	1081	118.6	3.629	0.05
1075	2.857	1.27	1298	2339	0.7514	0.06
1390	0.606	0.0435	1430	2183	1.544	0.07
4097	0.1562	0.1145	1394	4387	1.537	0.08
3788	2.118	1.614	1269	5609	2.029	0.09
4571	3.722	4.279	991.2	2369	2.514	0.10

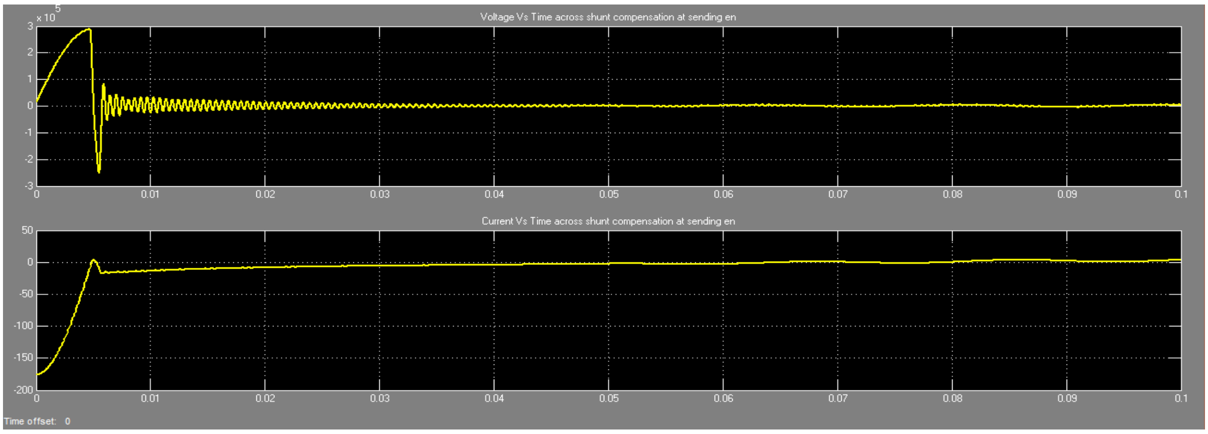


Figure4.9 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the sending end of transmission line,Lightning overvoltage before series capacitor without using arrestor

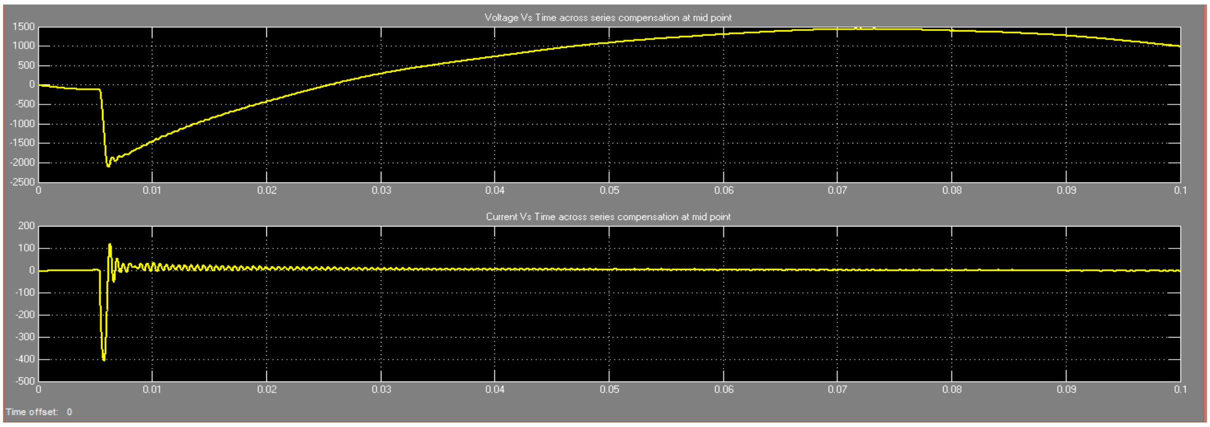


Figure4.10 Voltage Vs Time and Current Vs Time waveform of the series capacitor at the midpoint of transmission line,Lightning overvoltage before series capacitor without using arrestor

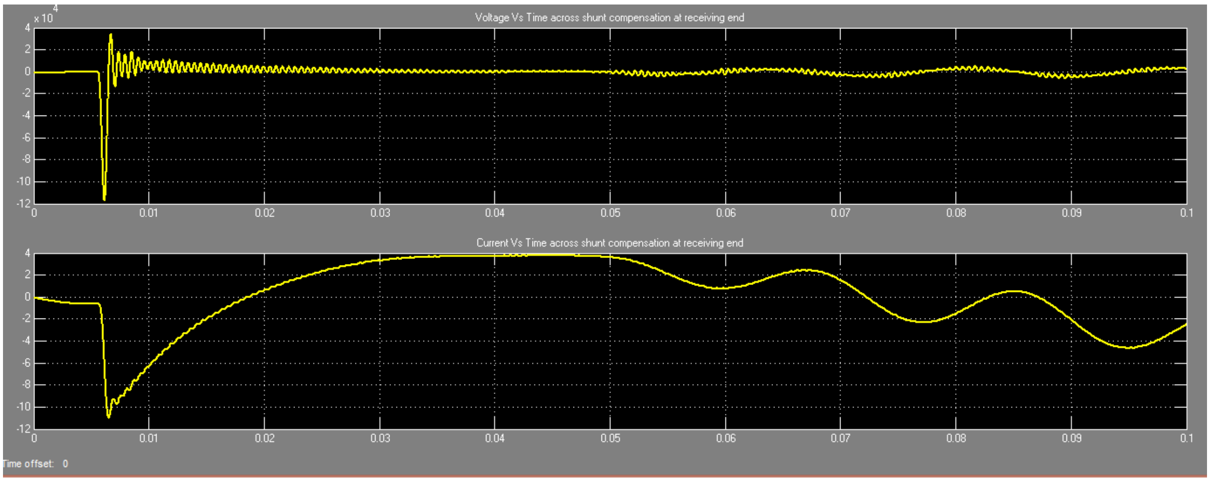


Figure4.11 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the receiving end of transmission line,Lightning overvoltage before series capacitor without using arrestor

These are the graphical representation of voltage and current waveforms at the sending end, midpoint and the receiving end of the 200 Km transmission line. These waveforms are showing the variation across the compensated devices the voltage and current when there is lightning occur in the system before series capacitor attached to the system.

- **BY USING ARRESTOR**

In this system when there is any lightning operation occur before series capacitor, there is arrestor present in the system. We have calculated the different values of RMS voltage and current in the sending, midpoint and at the receiving end of the transmission line.

Table 4.4 Lightning overvoltage before series capacitor by using arrestor

RMS Voltage at sending end (V_{rmss})	RMS Current at sending end (I_{rmss})	RMS Voltage at midpoint (V_{rmsm})	RMS Current at midpoint (I_{rmsm})	RMS Voltage at receiving end (V_{rmsr})	RMS Current at receiving end (I_{rmsr})	Time frame (T)
$2.663\ e^{04}$	$3.804\ e^{-77}$	1477	$1.911e^{-100}$	$1.536e^{-115}$	4546	0.01
8191	$9.367e^{-103}$	432.1	$3.968e^{-127}$	$2.435e^{-113}$	5030	0.02
5071	$3.667e^{-113}$	289.6	$8.02e^{-136}$	0	512.2	0.03
3230	$5.843e^{-123}$	723.8	$6.292e^{-116}$	0	66.03	0.04
1726	$1.429e^{-136}$	1081	$3.217e^{-107}$	0	118.7	0.05
1075	$7.483e^{-147}$	1298	$2.995e^{-103}$	$5.695e^{-130}$	2338	0.06
1391	$3.006e^{-141}$	1430	$3.783e^{-101}$	$1.826e^{-131}$	2183	0.07
4098	$6621e^{-118}$	1394	$1.07e^{-101}$	$2.609e^{-116}$	4387	0.08
3785	$1.626e^{-119}$	1269	$9.775e^{-104}$	$5.771e^{-111}$	5611	0.09
4571	$2.033e^{-115}$	9912	$4.225e^{-109}$	$1.104e^{-129}$	2370	0.10

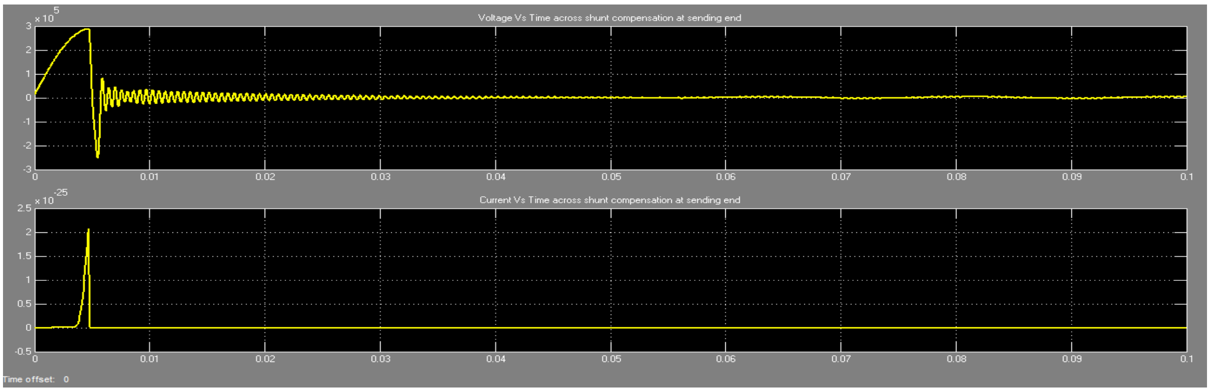


Figure4.12 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the sending end of transmission line,Lightning overvoltage before series capacitor by using arrestor

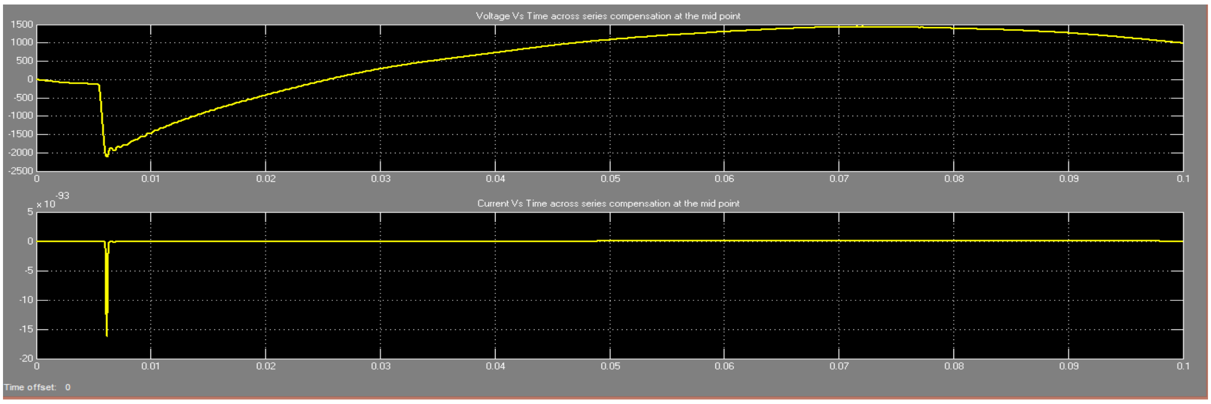


Figure4.13 Voltage Vs Time and Current Vs Time waveform of the series capacitor at the midpoint of transmission line,Lightning overvoltage before series capacitor by using arrestor

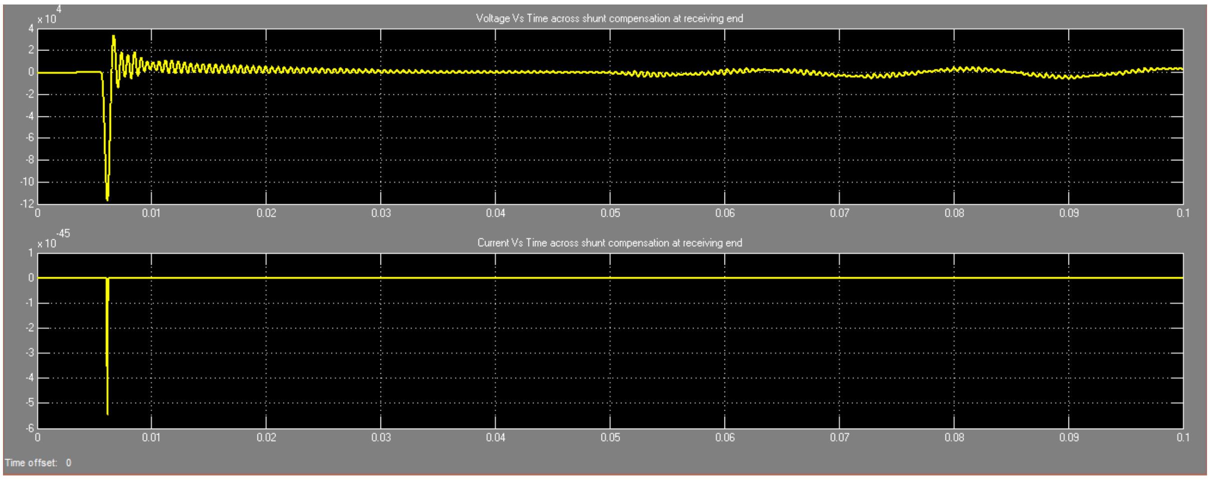


Figure4.14 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the receiving end of transmission line,Lightning overvoltage before series capacitor by using arrestor

These are the graphical representation of voltage and current waveforms at the sending end, midpoint and the receiving end of the 200 Km transmission line. These waveforms are showing the variation across the arrestor attached in parallel to the compensated devices when there is lightning occur in the system before series capacitor attached to the system.

4.3.2.2 OCCURANCE OF LIGHTNING AFTER SERIES CAPACITOR

- **WITHOUT USING ARRESTOR**

In this system when there is any lightning operation occur after series capacitor, there is no arrestor present in the system. We have calculated the different values of RMS voltage and current in the sending, midpoint and at the receiving end of the transmission line.

Table 4.5 Lightning overvoltage after series capacitor without using arrestor

RMS Voltage at sending end (V_{rmss})	RMS Current at sending end (I_{rmss})	RMS Voltage at midpoint (V_{rmsm})	RMS Current at midpoint (I_{rmsm})	RMS Voltage at receiving end (V_{rmsr})	RMS Current at receiving end (I_{rmsr})	Time frame (T)
$4.68e^{05}$	694	652.5	$7.005e^{05}$	$1.517e^{05}$	59.11	0.01
$3.424e^{05}$	1473	1438	$5.931e^{05}$	$2.565e^{05}$	481	0.02
$1.69e^{05}$	1908	1897	$4.259e^{05}$	$2.527e^{05}$	971.6	0.03
$3.05e^{05}$	2070	2053	$2.295e^{05}$	$1.855e^{05}$	1376	0.04
$6.973e^{04}$	2001	1986	$2.841e^{04}$	$9.951e^{04}$	1629	0.05
$1.631e^{05}$	1741	1731	$1.562e^{05}$	9828	1707	0.06
$7.488e^{04}$	1482	1461	$3.141e^{05}$	$2.41e^{05}$	1462	0.07
$2.742e^{05}$	1058	1085	$4.405e^{05}$	$1.62e^{05}$	1622	0.08
$2.496e^{05}$	657.7	615.1	$5.247e^{05}$	$2.647e^{05}$	574.6	0.09
$2.322e^{05}$	59.56	92.85	$5.597e^{05}$	$3.174e^{05}$	128.6	0.10

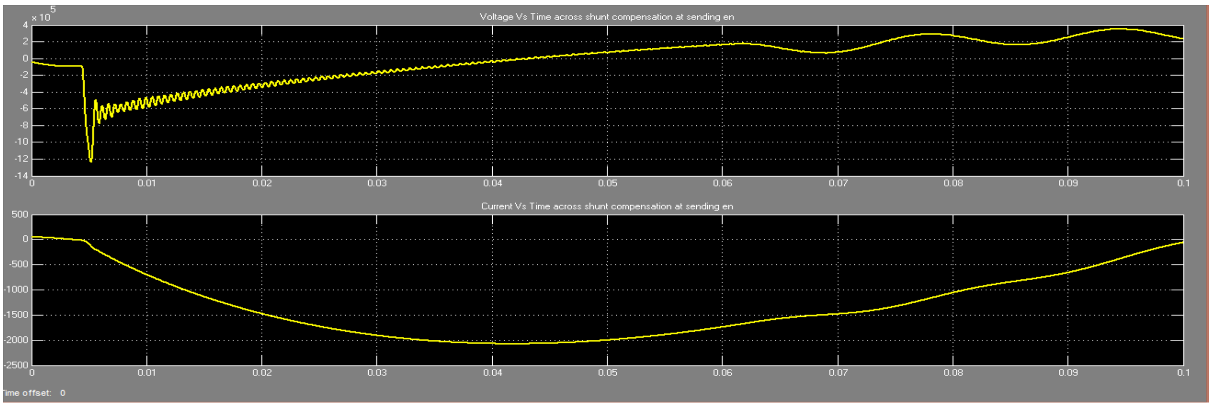


Figure4.15 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the sending end of transmission line,Lightning overvoltage after series capacitor without using arrestor

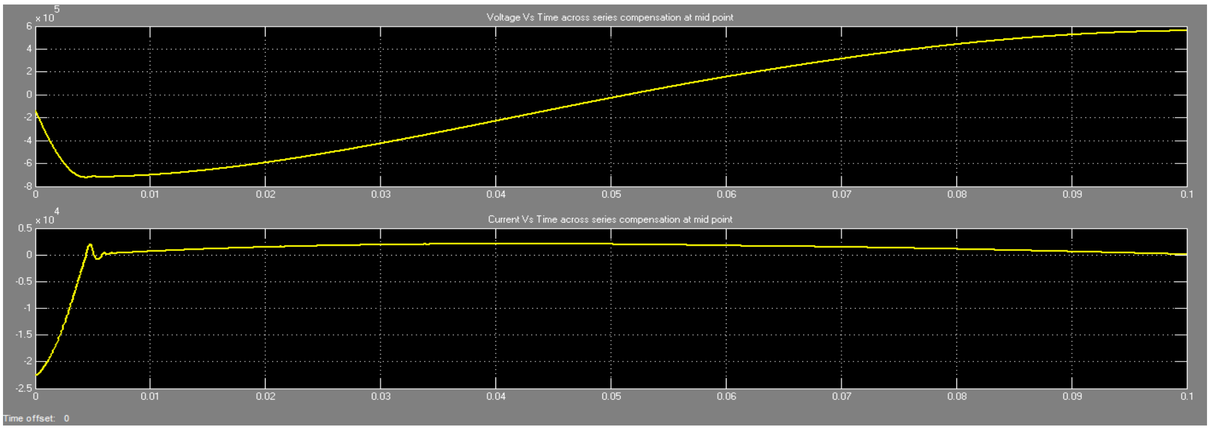


Figure4.16 Voltage Vs Time and Current Vs Time waveform of the series capacitor at the midpoint of transmission line,Lightning overvoltage after series capacitor without using arrestor

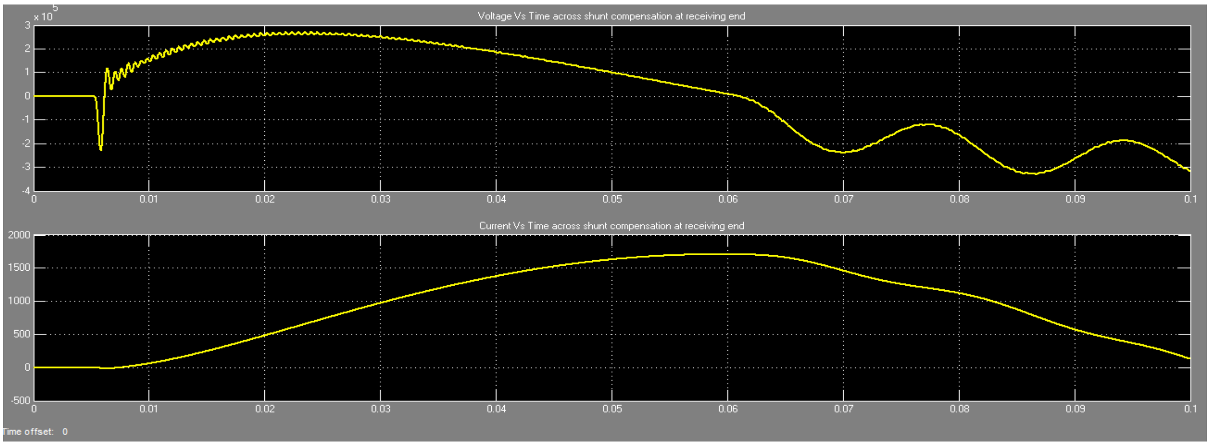


Figure4.17 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the receiving end of transmission line,Lightning overvoltage after series capacitor without using arrestor

These are the graphical representation of voltage and current waveforms at the sending end, midpoint and the receiving end of the 200 Km transmission line. These waveforms are showing the variation across the compensated devices when there is lightning occur in the system after series capacitor attached to the system

- **BY USING ARRESTOR**

In this system when there is any lightning operation occur before series capacitor, there is arrestor present in the system. We have calculated the different values of RMS voltage and current in the sending, midpoint and at the receiving end of the transmission line.

Table 4.6 Lightning overvoltage after series capacitor by using arrestor

RMS Voltage at sending end (V_{rmss})	RMS Current at sending end (I_{rmss})	RMS Voltage at midpoint (V_{rmsm})	RMS Current at midpoint (I_{rmsm})	RMS Voltage at receiving end (V_{rmsr})	RMS Current at receiving end (I_{rmsr})	Time frame (T)
$1.647\ e^{05}$	$1.401e^{-37}$	143	$1.61e^{05}$	$2.61e^{04}$	$1.387e^{-77}$	0.01
$1.091e^{05}$	$1.559e^{-46}$	3.477	$1.494e^{05}$	$4.361e^{04}$	$1.947e^{-66}$	0.02
$5.95e^{04}$	$1.082e^{-59}$	0.0001876	$1.228e^{05}$	$5.914e^{04}$	$7.96e^{-60}$	0.03
$2.955e^{04}$	$6.865e^{-75}$	$1.77e^{-12}$	$8.485e^{04}$	$5.219e^{04}$	$1.547e^{-62}$	0.04
4498	$9.141e^{-116}$	$6.029e^{-28}$	$4.162e^{04}$	$3.72e^{04}$	$6.871e^{-70}$	0.05
$2.02e^{04}$	$3.753e^{-85}$	$1.149e^{-98}$	1603	$1.825e^{04}$	$2.334e^{-85}$	0.06
$3.844e^{04}$	$3.515e^{-69}$	$1.785e^{-28}$	$4.061e^{04}$	2978	$1.017e^{-124}$	0.07
$2.636e^{04}$	$2.269e^{-77}$	$1.615e^{-15}$	$7.376e^{04}$	$4.676e^{04}$	$6.333e^{-65}$	0.08
$4.719e^{04}$	$1.002e^{-64}$	$5.52e^{-09}$	$9.965e^{04}$	$5.051e^{04}$	$3.011e^{-63}$	0.09
$7.01e^{04}$	$3.937e^{-56}$	$1.094e^{-05}$	$1.16e^{05}$	$4.403e^{04}$	$3145e^{-66}$	0.10

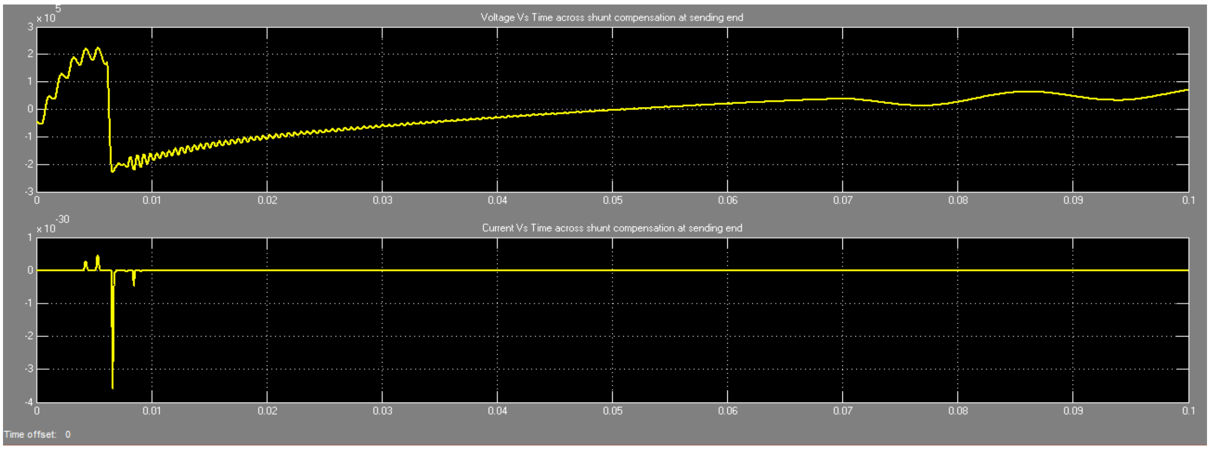


Figure4.18 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the sending end of transmission line,Lightning overvoltage after series capacitor by using arrestor

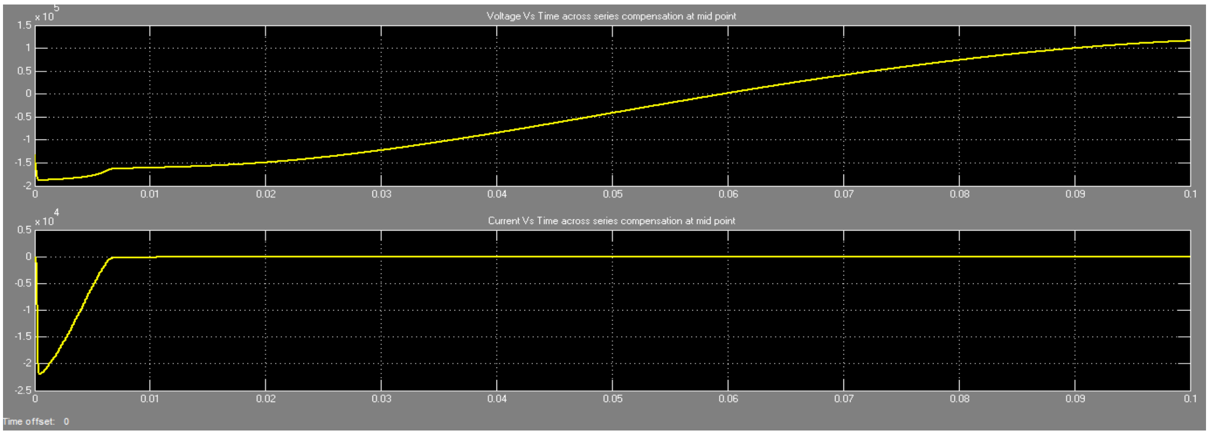


Figure4.19 Voltage Vs Time and Current Vs Time waveform of the series capacitor at the midpoint of transmission line,Lightning overvoltage after series capacitor by using arrestor

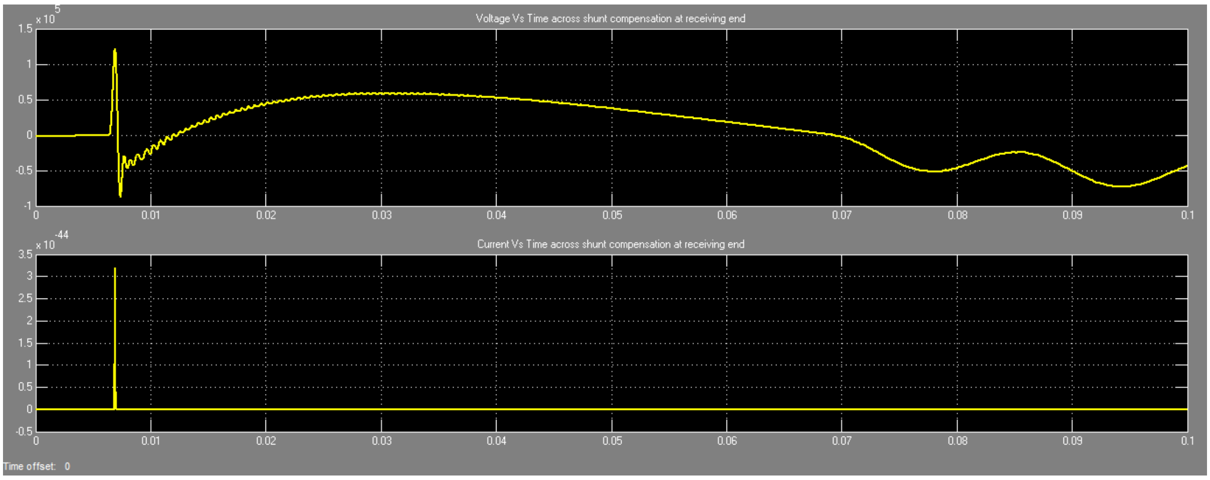


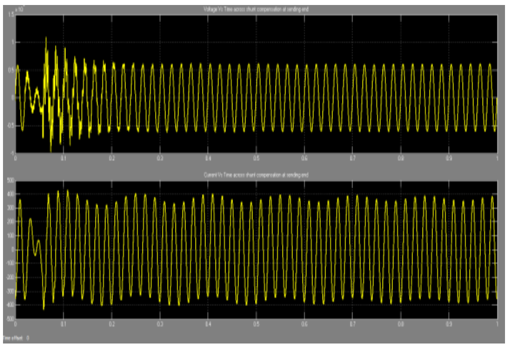
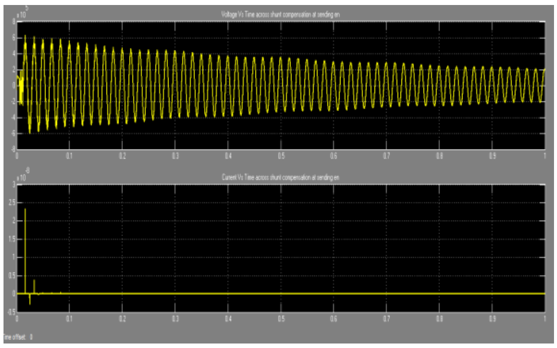
Figure4.20 Voltage Vs Time and Current Vs Time waveform of the shunt reactor at the receiving end of transmission line,Lightning overvoltage after series capacitor by using arrestor

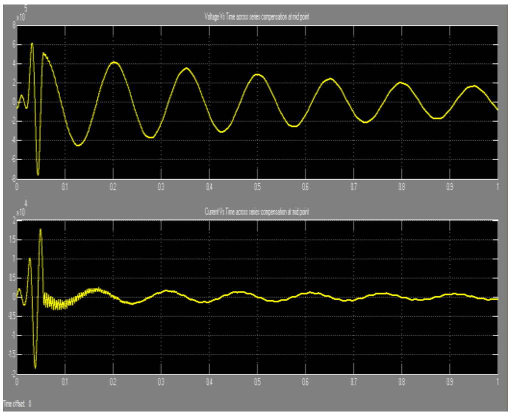
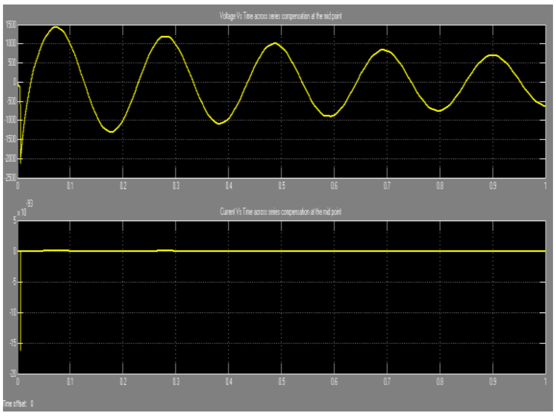
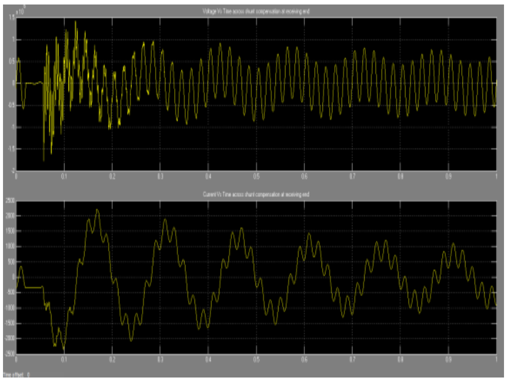
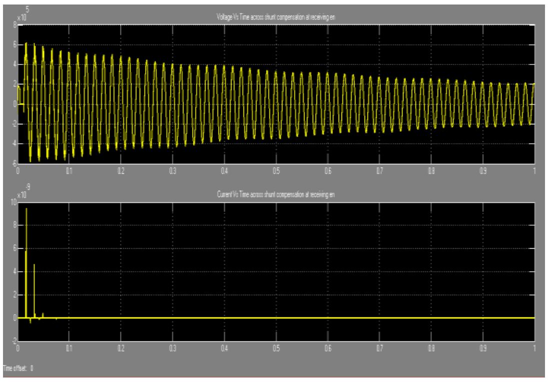
These are the graphical representation of voltage and current waveforms at the sending end, midpoint and the receiving end of the 200 Km transmission line. These waveforms are showing the variation across the arrestor attached in parallel to the compensated devices when there is lightning occur in the system after series capacitor attached to the system

4.4 SIMULATION RESULTS

Case 1- Switching overvoltage across compensation devices

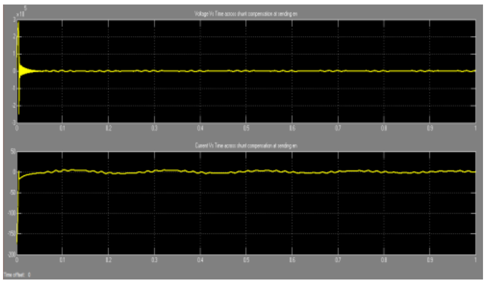
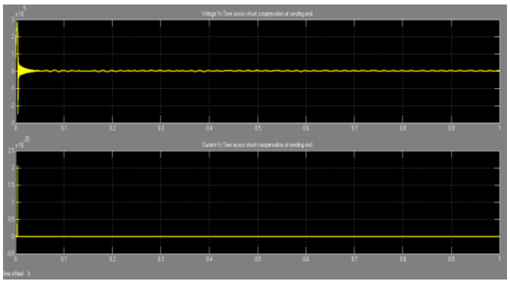
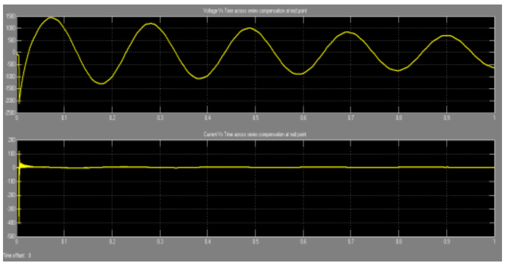
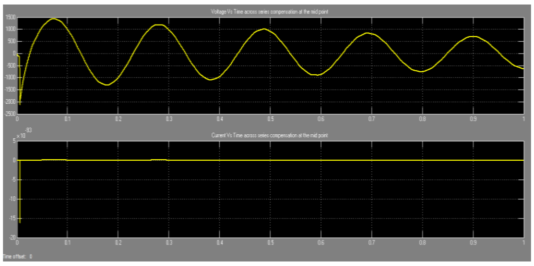
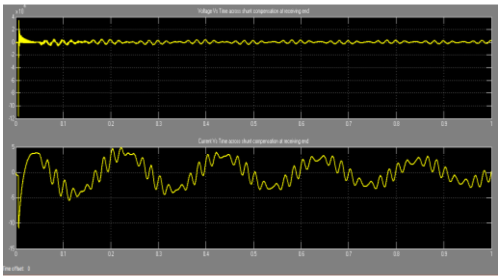
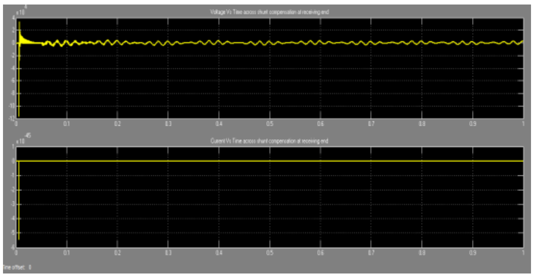
Table4.7 Comparison between Switching overvoltage with arrestor and without arrestor model

S.No	Without Arrestor	With Arrestor
1	**Sending end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmss})= 1.983 e^5V Average RMS Current (I_{rmss})=285.8 A	**Sending end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmss})= 92020 V Average RMS Current (I_{rmss})=3.0489 e^{-11}A

2	**Midpoint Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 2.169 e^{5}V Average RMS Current (I_{rmsm})=4596.29 A	**Midpoint Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 0.21873 e^{5}V Average RMS Current (I_{rmsm})=6.8613 e^{-30}A
3	**Receiving end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 3.239 e^{5}V Average RMS Current (I_{rmsm})=972.3 A	**Receiving end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 2.9239 e^{5}V Average RMS Current (I_{rmsm})= 4.7192 e^{-13}A

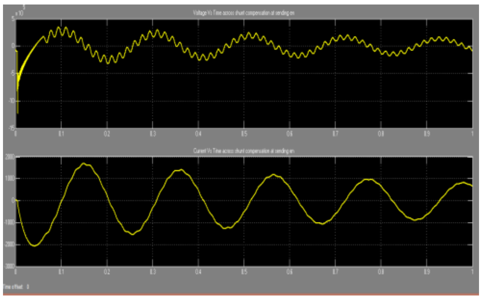
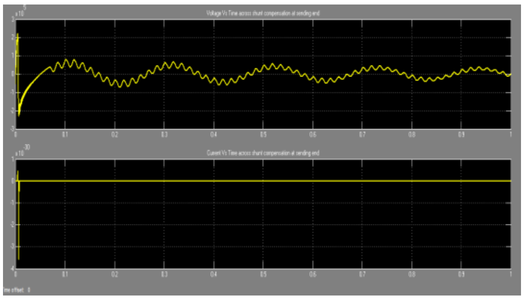
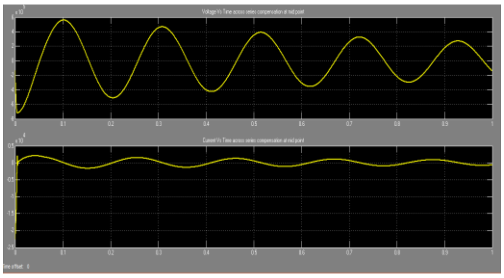
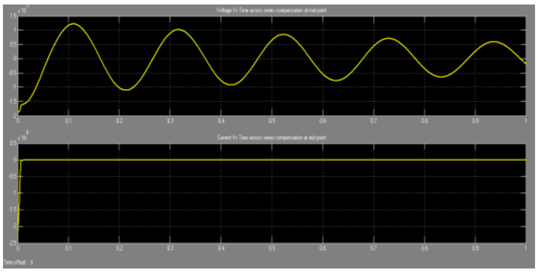
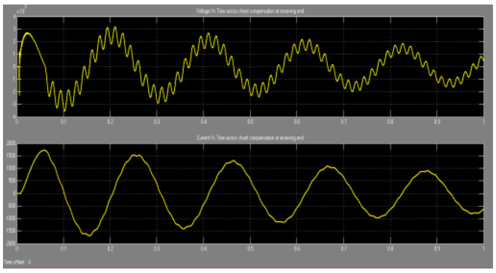
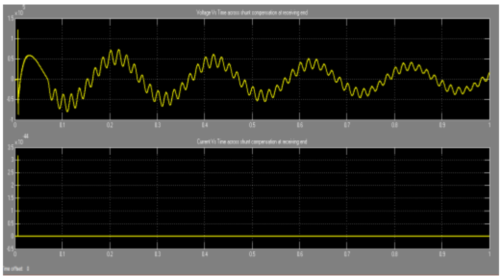
Case 2- Occurrence of lightning before series capacitor

Table4.8 Comparison between lightning overvoltage before series capacitor with arrestor and without arrestor model

S.No	Without Arrestor	With Arrestor
1	**Sending end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmss})= 3314.56V Average RMS Current (I_{rmss})=4.568 A	**Sending end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmss})= 5976.8 V Average RMS Current (I_{rmss})=3.804 e^{-77}A
2	**Midpoint Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 4.4214 V Average RMS Current (I_{rmsm})=1038.57 A	**Midpoint Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 1930.65V Average RMS Current (I_{rmsm})=1.911 e^{-100}A
3	**Receiving end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 2715.77V Average RMS Current (I_{rmsm})=2.5971 A	**Receiving end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 5.771 e^{-111}V Average RMS Current (I_{rmsm})= 2716.193A

Case 3- Occurrence of lightning before series capacitor

Table4.9 Comparison between lightning overvoltage after series capacitor with arrestor and without arrestor model

S.No	Without Arrestor	With Arrestor
1	**Sending end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmss})= 2.3481 e^5V Average RMS Current (I_{rmss})=2863.556A	**Sending end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmss})= 20229 V Average RMS Current (I_{rmss})=9.141 e^{-116}A
2	**Midpoint Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 1474.945V Average RMS Current (I_{rmsm})=847261 A	**Midpoint Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 14.6477V Average RMS Current (I_{rmsm})=85068.70A
3	**Receiving end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 253393.8V Average RMS Current (I_{rmsm})=807.691 A	**Receiving end Voltage Vs Time and Current Vs Time waveforms**  Average RMS Voltage (V_{rmsm})= 38076.8V Average RMS Current (I_{rmsm})= 7.978 e^{-62}A

From all these comparisons we concluded that in case of arrestor models as long as the voltage develops across the compensated devices is above the protective level then all the current is flowing into the MOV. The flow of current is null through compensated devices when the voltage passes below the protective level because the MOV offers a high resistance. But in the absence of arrester model all the high voltage and current will passes through the compensated device which will either turn off the system or damage the whole compensated system because the compensated devices allow the high voltage and current to pass through them as a low resistive path to flow.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

In our dissertation, we have design the model of transmission line on which we evaluated the performance of lightning arrestor installed in the system. All the simulation is carried out in MATLAB/Simulink. We have designed a transmission model in which we have analysed the switching overvoltage occurrence with or without the help of surge arrestor and compared their results and evaluated the performance of arrestor across the line.

We have also analysed the system when lightning overvoltage strikes the system. For simulation of lightning, we used a transfer impulse function block as impulse generator which induces a large voltage across the transmission line just like the occurrences of lightning in the nature (in the Simulink). All the simulations were carried out by inserting the transfer function block at different points on the transmission line and then comparisons were made. Simulation results are compared by using arrestor or without using arrestor model. In the last we concluded that it is preferable to use arrestor across the line to protect the compensated devices across the system because the arrestor protective devices operate immediately in order to remove the heavy overvoltage to pass through the compensated devices. The flow of current is null through compensated devices when the voltage passes below the protective level because the arrestor offers a high resistance.

5.2 FUTURE SCOPE

By considering the various factors corresponding to the lightning and switching overvoltage’s we can use this extra energy for harvesting purposes. This is a very difficult task but not impossible. As we come to know the various parameters on which lightning depends we can develop a control system which can control this extra energy source for harvesting purpose.

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APPENDIX

GLOSSARY OF TERMS

1. **VOLTAGE SURGE**: Any sudden excessive rise in the voltage that may be dangerous to the electrical equipment's of an installation is known as voltage surge.

2. **LIGHTNING**: Lightning is a huge spark which is due to the electrical discharge taking place between the clouds, within the same cloud and between the cloud and ground.

3. **A STROKE LIGHTNING**: A stroke lightning is characterised by the comparatively long time to produce discharge. It strikes the highest and most sharply pointed object in the neighbourhood.

4. **B STROKE LIGHTNING**: B stroke lightning is characterised by its rapidity. It ignores the tall objects and reaches the ground in the random manner. B stroke is most dangerous lightning stroke.

5. **EARTHING SCREEN**: Earthing screen consists of a network of copper conductors, earthed at least on two points, over all the electrical equipment in the substation.

6. **EARTH WIRE**: An earth wire is a form of lightning protection using a conductor or conductors, well-grounded at regular intervals, preferable at each support and attached from support to support above the transmission line.

7. **LIGHTNING ARRESTOR**: Lightning arrestor limits the duration and amplitude of the follow current.

8. **SURGE ABSORBER**: Surge absorber reduces the steepness of the wave front of a particular surge.

ABBREVIATIONS

LFC	:	LOAD FREQUENCY CONTROL
MATLAB	:	MATRIX LABORATORY
PI	:	PROPORTIONAL-INTEGRAL
PID	:	PROPORTIONAL-INTEGRAL-DERIVATIVE
AC	:	ALTERNATING CURRENT
AGC	:	AUTOMATIC GENERATION CONTROL
ACE	:	AREA CONTROL ERROR
HVDC	:	HIGH VOLTAGE DIRECT CURRENT
EHVAC	:	EXTRA HIGH VOLTAGE ALTERNATING CURRENT
HIL	:	HARDWARE-IN-LOOP
SSE	:	STEADY STATE ERROR
MOV	:	METAL OXIDE VARISTOR
TSR	:	TOTAL SURGE REACTOR
ANN	:	ARTIFICIAL NEURAL NETWORK