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Examination of Gas Active Arc Extinguishing and Lightning Protection for Transmission Lines

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Abstract

The study investigated the gas active arc extinguishing and lightning protection for transmission lines. Lightning is one of the most significant sources of over voltages in overhead transmission lines. The lightning over voltages could lead to failure of the devices connected to the transmission line. Fundamental constraint on the reliability of an electrical power transmission system is the effectiveness of its protective system. The role of the protective system is to safeguard transmission system components from the effects of electrical overstress. Shield wire and surge arresters are an important means of lightning protection in transmission and distribution systems. Therefore, it is necessary to analyze the influence of over voltages caused due to lighting. The requirements of system security for lightning protection technology reach the high standard that lightning strike tripping and wire breakage are not allowed. Both the power supply side and the demand side have very high requirements for lightning protection of transmission lines, but the lightning accident rate remains high. This situation poses a great threat to the reliability and safety of power network, it is urgent to solve this problem. The gas active interrupter principle is put forward. From two latitudes of lightning overvoltage and power frequency over current, the effective control of lightning accident rate caused by large probability and multiple lightning strike is realized. This paper is aimed at evaluation of protection level of transmission line by using gas active arc extinguishing, shield wire and line surge arresters against lightning overvoltage. When lightning strikes, the internal short gap of the main body and the air gap break down, and the lightning arc enters the arc-extinguishing body through the breakdown channel. Arc is compressed by force to form internal and external gradients temperature in order to produce jet airflow. Jet airflow acts on the subsequent power frequency follow current arc, a model coupling an arc and a compressed jet airflow in a multi-fracture compression airflow arc-extinguishing structure is established and simulated. The increase in voltage due to lightning are investigated by using the MATLAB software. Direct and induced, types of lightning strokes are considered. The model of a 33kV three-phase overhead power transmission line is developed considering the RL circuit. The simulations are performed based on time domain analysis. Also, numerical analysis is made for 133kV tower structure transmitting power over 220km from 132 KV Sub-transmission Lines in port Harcourt region. Based on the simulation study this research study gas active arc extinguishing and lightning protection for transmission lines, are very important in computer application like Electromagnetic Transient Propagation (EMTP) and Power System Computer Aided Design (PSCAD) which are used in future study. These soft wares provide an alternative way to bring the precise result in study of lightning protection level of high voltage transmission line.

Keywords: protection, lightning, transmission lines, faults type, relay communication, Arch-flash

1. Introduction

1.1 Background to the Study

Lightning protection of overhead lines by multiple sparks over gaps has a long history. Transmission lines have become links between power networks and users, and the safe and stable operation of these lines directly affects the power supply reliability of the power grid. Due to the low insulation level of Transmission lines, the probability of influences from direct lightning and induced lightning is high, which makes lightning flashover occur. Hence, lightning protection for Transmission lines urgently needs to be developed. At present, installing a metal oxide arrester (MOA) to limit the potential difference between the ends of an insulator is a main lightning protection measure used for Transmission lines. However, due to inherent problems, such as a delay in the initial response and layer affecting thermal dissipation, the application of this measure for the lightning protection of Transmission lines is restricted. On the other hand, Lightning is the sudden draining of electrical charge built up in low cloud systems. It may involve another cloud system (which is not of much interest to us in this course) or ground (which is). The flow of charge creates a steep fronted current waveform lasting for several tens of microseconds (Belko & G. V. Podporkin, 2016).

A direct lightning strike on a human body or livestock can result in death or serious injury. Lightning can cause destruction of a living organism, such as a tree. It can damage building parts through which the lightning surge is conducted to the ground. It can even place personnel within a building at risk because of very high potential differences between different parts of a building that carry the lightning surge. Even the flow of lightning surges in the ground can cause electrocution due to high potential differences between different points in the soil carrying the surge currents. Lightning strikes on electrical installations (which include overhead conductors of power and communication lines) can cause current and voltage surges. A nearby strike to the ground can cause such problems by coupling into electrical circuits. A surge may consist of a single spike or multiple diminishing spikes and unless properly protected against, can cause failure of insulation in electrical wiring or devices due to excessive voltage. A surge traveling through electrical power supply network can damage sensitive electronic equipment. A proper understanding of the mechanism of lightning and its effects is, therefore, essential for planning protection against lightning strikes so that no damage is caused to personnel, buildings and electrical installations.

Lightning is a significant cause of temporary and permanent power outages; due to the abnormal stresses it puts on the Transmission lines. Studies from China, Japan, and Malaysia indicate that lightning is a major cause of power outages, with 40–70% of the total number of outages caused by lightning. In Thailand, statistics from the Metropolitan Electricity Authority (MEA), 2014 report 5000 outages per year with an unknown cause that may be the result of lightning hitting the system. Therefore, lightning protection is an important consideration in the design of Transmission lines. There are many techniques that are considered efficient ways of decreasing the frequency of outages, due to lightning strike; these include using overhead ground wires and surge arresters, which are the most common form of lightning protection used to increase the reliability of the Transmission system. Overhead ground wires are installed above the phase conductor to intercept lightning strikes and conduct the current to the ground; arresters are fixed between the phase conductor and the ground.

To reduce the damage from the power frequency follow current of Transmission lines, a multi-fracture compression airflow arc-extinguishing structure is Proposed in this study. The structure is mainly composed of a compression tube, a metal electrode, and metal connection fittings, and the multifracture compression airflow arc-extinguishing body is formed by the combination of packaging and insulation fittings. The body and the air gap are parallel to both ends of the insulator. When lightning strikes, the internal short gap of the main body and the air gap break down, and the lightning arc enters the arc-extinguishing body through the breakdown channel. In the structure, the arc is compressed by force to form internal and external gradients of temperature and to produce jet airflow. The jet airflow acts on the subsequent power frequency follow current arc, which is suppressed and extinguished.

The need to adopt the gas active arc extinguishing is necessitated because bolts of lightning comprise extremely high currents. They can cause a large voltage drop and a large rise in potential, even in well-earthed buildings or systems, despite low earthing resistances. This can then result in a galvanic, inductive or capacitive coupling of surge voltages within the circuits of electrical or electronic facilities. Any insulation will also be penetrated. So, in reality, there are no electrical isolation methods which provide reliable protection against surge voltages. Analogue converters, relays or op to modules are important for separating potentials, but they are definitely not surge protection components. A natural lightning strike consists of a main discharge and a time-shifted post discharge. The strength of this second discharge is usually far below the energy level of the main discharge. Both discharges, however, have enough power to cause significant damage (M. A. Araújo, R. A. Flauzino, R. A. Altafim, O. E. Batista & L. A. Moraes, 2015).

1.2 Statements of Problem

In Nigeria, lightning and thunder strikes are one of the main causes of power outages. Lightning strikes to the phase conductor result in high arrester energy and the possibility that the arrester will fail. On the power supply side, the disturbance caused by lightning tripping and wire breakage increases with the expansion of power system. Moreover, the increase of capacity leads to the increase of short-circuit current, the difficulty of arc-extinguishing of circuit breaker, and the distortion of transformer winding caused by large electric force. On the power demand side, the important loads such as petrochemical industry, high-speed railway, aerospace, smelting, high-precision machining and so on have increased. A large number of loads, such as computers, electronic control systems and motor groups, have replaced the simple loads of lighting, etc. The requirements of system security for lightning protection technology reach the high standard that lightning strike tripping and wire breakage are not allowed. Both the power supply side and the demand side have very high requirements for lightning protection of transmission lines, but the lightning accident rate remains high. This situation poses a great threat to the reliability and safety of the power network, so it is urgent to solve this problem. The voltage across the insulator, and the arrester energy absorbed due to the lightning, need to be analyzed for different grounding distances of the overhead ground wire, ground resistance, lightning impact positions, and lightning current waveforms. In this objective reality, the gas active extinguishing principle is put forward. From two latitudes of lightning overvoltage and power frequency over current, the effective control of lightning accident rate caused by large probability and multiple lightning strike is realized.

1.3 Aims and Objectives of the Study

The study is aimed at examining gas active arc extinguishing and lightning protection for transmission lines.

Its specific objectives are:

1) To investigate lightning as the main cause of supply disruption in overhead Transmission lines in Nigeria.
2) To evaluate the effect of a lightning strike to transmission lines in Nigeria.
3) To highlight the several methods of decreasing the outage rate caused by lightning strikes directly to Transmission lines in Nigeria.
4) To identity the various ways for lightening protection for transmission lines.
5) To ascertain the need for the adoption of lightning protection as an important consideration in the design of Transmission lines.

1.4 Significance of the Study

This study introduces the impulse flashover that transmission line causes when there is thunderbolt, causes line insulator flashover, then produces very large power frequency continued flow, damages insulator string and gold utensil, causes line accident. Traditional "blocking type" lightning protection mode, due to its limitation, cannot solve the problem of lightning at all.

Hence the study proposes the use of a multi-fracture compression airflow arc-extinguishing structure.

The study will It be significant to the power holding company in Nigeria to adopt lightning protection as an important consideration in the design of Transmission lines as it will highlight the need for the company to adopt the gas active arc extinguishing technology in the protection of transmission lines.

This study is of paramount importance because not only will it add to already existing body of knowledge on protection of transmission lines, but it will afford Electrical engineers the avenue of appreciating the dynamic and relevance of the need for gas active arc extinguishing and lightening protection for transmission lines in Nigeria.

The study will also be of immense benefit to research students in that it will serve as reference material for further study on the topic or related topics.

1.5 Scope of the Study

The study will focus on examining angas active arc extinguishing and lightening protection for transmission lines. The study will limit its findings to overhead transmission lines. The study will highlight the several methods of decreasing the outage rate caused by lightning strikes directly to Transmission lines in Nigeria, as well as highlighting the need for the adoption of lightning protection as an important consideration in the design of Transmission lines.

2. Literature Review

2.1 Conceptual Clarification

2.1.1 Overview of Transmission Lines in Nigeria

The first power interconnection in Nigeria was 132kV link constructed in 1962 between Logos and Ibadan. By 1968 the first National grid structure emerged with the construction of the Kainji hydro station which supplied power via a 330kV, primary radial type transmission network into the three 132kV sub system then existing in the Western, Northern and Eastern parts of the country. The 330kV and 132kV systems were initially run by two separate bodies- Niger Dams Authority (NDA) and Electricity Corporation of Nigeria (ECN) respectively. Central control for the 330kV network was coordinated from Kainji power supply control room. While the 132kV network was run by load dispatcher located at Ijora power supply Lagos. These two bodies were merged formally into single power utility known as NEPA in 1972, thus ushering in centralized regulation and coordination of the entire rapidly growing 330kV and 132kV National network. Presently, the radial transmission grid (330kV and 132kV) is managed by the Transmission Company of Nigeria (TCN), with the responsibility of undertaking the system operation and market settlement functions, respectively. These networks are characterised by many disturbances, which cause various hindrances and outages. The current transmission system in Nigeria comprises 5523.8km of 330kV, 6801.49km of 132kV, 32No 330/132kV substations with total installed transformation capacity of 7688MVA. 105No. 132/33/11kV substations with total installed transformation capacity of 9130MVA. The average available capacity on 330/132kV is 7364MVA and 8448MVA on 132/33kV. The Nigeria 330kV transmission grid is characterized by high power losses due to the very long transmission lines. Power losses result in lower power availability to the consumers, leading to inadequate power to operate their appliances. Increased power demand pushes the power transmission network to its upper limits and beyond, resulting to shortening of the life span of the network or total collapse. Before the unbundling of the Nigeria existing power network, it comprised 11,000km transmission lines (330kV), it was faced with so many problems such as; Inability to effectively dispatch generated energy to meet the load demand, large number of uncompleted transmission line projects, reinforcement and expansion projects in the power industry, poor voltage profile in most of northern part of the grid, inability of the existing transmission lines to wheel more than 4000MW of power at present, operational problems, voltage frequency control (M. S. Banjamin, M. S. Savi´c, & Z. M. Stojkovi´c, 2015; Chen, S. Gu, J. He, & B. Yin, 2010).

The transmission system in Nigeria Power System does not cover every part of the country. It currently has the capacity to transmit a maximum of about 4,000MW and it is technically fragile and radial in nature thus very sensitive to major disturbances. This show that if the generation sector is to run at full production, the transmission grid will not have the capacity to handle the produced power reliably. In summary, the major problems identified are: (i). It is funded solely by the Federal government, whose resource allocation cannot adequately meet all the requirements; (ii). It is yet to cover many parts of the country; (iii). Its current maximum electricity wheeling capacity is 4,000MW, which is awfully below the required national needs; (iv). Some sections of the grid are outdated with inadequate redundancies as opposed to the required national needs; (v). The Federal government lacks the required fund to regularly expand, update, modernize and maintain the network; (vi). There is regular vandalization of the lines, associated with low level of surveillance and security on all electrical infrastructure; (vii). The technologies used generally deliver very poor voltage stability and profiles; (viii). There is a high prevalence of inadequate working tools and vehicles for operating and maintaining the network; (ix). There is serious lack of required modern technologies for communication and monitoring; (x). The transformers deployed are overloaded in most service areas; (xi). In adequate of spare-parts for urgent maintenance; and (xii). Poor technical staff recruitment, capacity building and training programme. Power Holding Company of Nigeria, in attempt to solve these problems, resulted in its unbundling. Thus, the Nigeria 330kV integrated network intends to improve the grid stability and creates an effective interconnection. It is anticipated to increase transmission strength because of the very high demand on the existing and aging infrastructure by building more power stations and transmission lines, through the Independent Power Projects. The reformed Nigeria power system grid was initiated with system security on the mind of the players, the post reformed grid provided remedies to the inadequacies associated with the pre-reform grid network. The existing grid lacks the technical adequacy to handle huge electric power injection and meet the future system performance criteria. The grid interconnects these stations with fifty two buses and sixty four transmission lines of either dual or single circuit lines and has four control centres (one national control centre at Osogbo and three supplementary control centres at Benin, Shiroro and Egbin). The Nigerian 28-bus 330kV transmission system consist of ten generating stations, twenty-three load stations and thirty-two transmission lines. The single line diagram of system, Figure 1, shows that the system is divided into three major regions: North, South-East and South-West regions. North is connected to South by a triple circuit line between Jebba and Osogbo, while West is linked to the East through one transmission line from Osogbo to Benin and a double circuit line from Ikeja to Benin. It has only one major loop system involving Benin – Ikeja West – Ayede – Osogbo and Benin. The absence of loops accounts mainly for the weak and unreliable power system in the country.

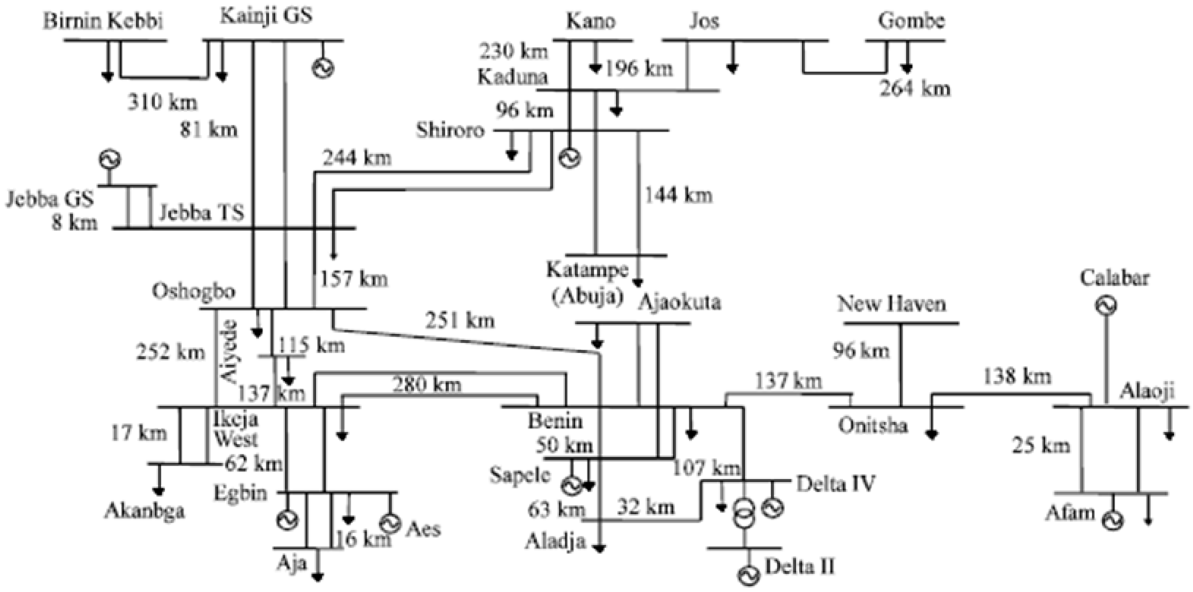


Figure 1. One-line Diagram of Nigeria 330kV Transmission Network as at 1999

2.1.2 Concept of Lightning

Lightning is an electrical discharge caused by imbalances between storm clouds and the ground, or within the clouds themselves. Most lightning occurs within the clouds. "Sheet lightning" describes a distant bolt that lights up an entire cloud base. Other visible bolts may appear as bead, ribbon, or rocket lightning. During a storm, colliding particles of rain, ice, or snow inside storm clouds increase the imbalance between storm clouds and the ground, and often negatively charge the lower reaches of storm clouds. Objects on the ground, like steeples, trees, and the Earth itself, become positively charged creating an imbalance that nature seeks to remedy by passing current between the two charges. Lightning is extremely hot a flash can heat the air around it to temperatures five times hotter than the sun's surface. This heat causes surrounding air to rapidly expand and vibrate, which creates the pealing thunder we hear a short time after seeing a lightning flash.

Cloud-to-ground lightning bolts are a common phenomenon about 100 strike Earth's surface every single second, yet their power is extraordinary. Each bolt can contain up to one billion volts of electricity. A typical cloud-to-ground lightning bolt begins when a step-like series of negative charges, called a stepped leader, races downward from the bottom of a storm cloud toward the Earth along a channel at about 200,000 mph (300,000 kph). Each of these segments is about 150 feet (46 meters) long. When the lowermost step comes within 150 feet (46 meters) of a positively charged object, it is met by a climbing surge of positive electricity, called a streamer, which can rise up through a building, a tree, or even a person. When the two connect, an electrical current flows as negative charges fly down the channel towards earth and a visible flash of lightning streaks upward at some 200,000,000 mph (300,000,000 kph), transferring electricity as lightning in the process. Some types of lightning, including the most common types, never leave the clouds but travel between differently charged areas within or between clouds. Other rare forms can be sparked by extreme forest fires, volcanic eruptions, and snowstorms. Ball lightning, a small, charged sphere that floats, glows, and bounces along oblivious to the laws of gravity or physics, still puzzles scientists. About one to 20 cloud-to-ground lightning bolts is "positive lightning," a type that originates in the positively charged tops of storm clouds. These strikes reverse the charge flow of typical lightning bolts and are far stronger and more destructive. Positive lightning can stretch across the sky and strike "out of the blue" more than 10 miles from the storm cloud where it was born.

Lightning is not only spectacular, it's dangerous. About 2,000 people are killed worldwide by lightning each year. Hundreds more survive strikes but suffer from a variety of lasting symptoms, including memory loss, dizziness, weakness, numbness, and other life-altering ailments. Strikes can cause cardiac arrest and severe burns, but 9 of every 10 people survive. The average American has about a 1 in 5,000 chance of being struck by lightning during a lifetime. Lightning's extreme heat will vaporize the water inside a tree, creating steam that may blow the tree apart. Cars are havens from lightning but not for the reason that most believe. Tires conduct current, as do metal frames that carry a charge harmlessly to the ground. Many houses are grounded by rods and other protection that conduct a lightning bolt's electricity harmlessly to the ground. Homes may also be inadvertently grounded by plumbing, gutters, or other materials. Grounded buildings offer protection, but occupants who touch running water or use a landline phone may be shocked by conducted electricity (Z. G. Datsios, P. N. Mikropoulos & T. E. Tsovilis, 2014).

2.2 Transmission Line Faults

Fault detection can be classified based on either detection by signal model (periodic signals, stochastic signals, non-stationary signals) or model-based approach. In this work, the model-based approach based on parameter estimation is employed for fault detection. Signal model-based fault detection methods are especially used for detecting machine vibration, imbalance or bearing faults, knocking etc. where the measured signals of processes show oscillations that are either of harmonic or stochastic nature or both. Also signals from many other sensors, like electrical current, position, speed, force, flow and pressure, may show oscillations with a variety of higher frequencies than the usual process dynamic responses. The extraction of fault-relevant signal characteristics can, in many cases, be restricted to the amplitudes or amplitude densities within a certain bandwidth of the signal using band pass filters. The parametric signal models which allow the main frequencies and their amplitudes to be directly estimated and which are especially sensitive to small frequency changes can also be used. Model-based methods of fault detection use the relationship between several measured variables to extract information on possible changes caused by faults. These relations are mostly analytical in the form of process model equations but can also be causalities. The two methods of fault diagnosis are: classification method (without structural knowledge) and inference method (with structural knowledge). Classification methods are used when structural knowledge is available between the symptom and fault. These methods include Bayes classifier (based on the statistical Transmission of the symptoms), decision trees (based on series of questions to be answered for the cause of fault), polynomial classifier (functional approximation of the classes based on particular fault), geometric classifier (based on the determination of the membership class of a data point from its distance to reference point) and neural network classifier. When the basic relationship between faults and symptoms is partially or fully known in the form of causal relations, the inference method of fault diagnosis is employed. Fault tree is an inference method of fault diagnosis apart from neural network and fuzzy based techniques. The symptoms and events are considered as binary variables and the condition part of the rules are evaluated by Boolean equations. However, the fault tree is not a popular method because of the continuous nature of fault and symptoms (Li, H. Cong, Q. Sun, J. Xing & Q. Chen, 2014).

Transmission system line faults are the most common faults, triggered by falling trees, lightning strikes or insulator string flashover and 85-87% of power system faults are occurring in the transmission lines. Most of the transmission system faults occurs on overhead lines, due to their inherent characteristics of being exposed to atmospheric conditions. Faults occur in the power system of various causes. For example, lightning strike can overload the system's components and result in a breakdown of the insulation in overhead lines. The impedance of source connections is often very low, resulting in large currents flowing during faults. The energy contained in a fault current can quickly create excessive heating or forces to components and can result in divesting explosions of equipment. Short-circuit causes, over short interruptions with voltage dips damage the grid and creating major disturbances and cost. Faults occur in many different forms depending on the fault type and the algorithm for calculating distance to fault will therefore vary. Faults on transmission overhead lines are in majority temporary single phase to ground, arcing faults (Li, J. Wang, X. Zhou, S. Huang & Z. Xia, 2019).

2.2.1 Fault Types

A power system fault can either be shunted, series or combination of both type, shunt fault providing a current flow between two or more phases, or to earth. Shunt faults occurs through a breakdown of insulation between the phases, or earth. Shunt faults often occur in two different ways; abrupt changes of the lines voltage and current characteristic, due to lighting strike, birds, and threes or similar; or slowly deterioration of the lines insulation. Slow deterioration of insulation will gradually create poor components and worn material that will age over time. Sometimes the difference between slow changes and abrupt faults is not strictly clear. It's possible to talk about faults that occur suddenly, but have evolved over longer period of time. Failure like this is typical faults that are caused by phases to phase merging, due to strong wind. When a fault occurs, the fault current will increase in magnitude, the total amplitude of fault current during a fault depends upon a variety of factors, such as fault type, network, fault resistance, failure causes load currents, short circuit levels etc. Typical shunt faults are presented below:

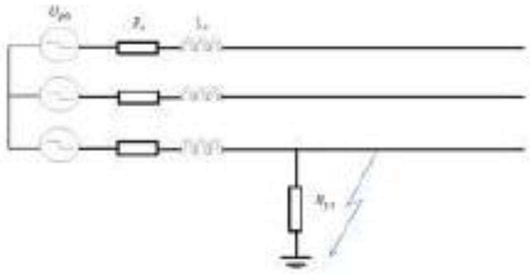


Figure 1.1 (l-g) fault

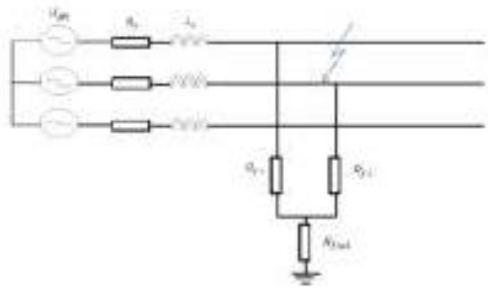


Figure2.2: (l-l-g) fault

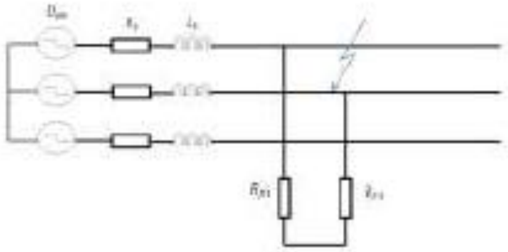


Figure2.2 (L-L) fault

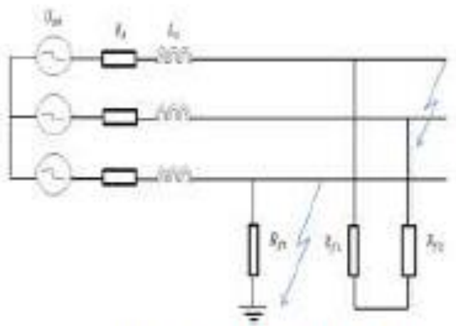


Figure 2.3 (L-L) fault

Fault in which the balanced state of the network is called unsymmetrical or unbalanced faults. The most common faults are single-to-line to ground faults line-to-line faults and double-line to-line faults. All of these are unbalanced fault or asymmetric fault (Li, J. Wang, X. Zhou, S. Huang, R. Yan & Z. Xia, 2020).

2.2.1.1 Common Fault on a Transmission Line

- **Line-to-line fault** – short circuit between lines caused by physical contact between two lines 10-15% of all fault in the system line-to-line faults (For example, broken conductor or strong wind).

- **Line-to-ground fault** – short circuit between one phase and ground caused by physical contact, 75-80% are line-to-ground fault. (Ex. lightning and external factors).

- **Line-to-line-to ground fault** – short circuit of two line and ground, and 5-10% are line line-to line to ground faults. (Ex. external factors)

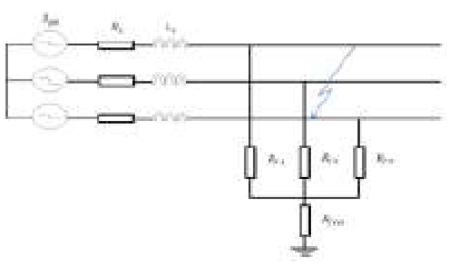


Figure 2 4 (L-L-L-G) fault

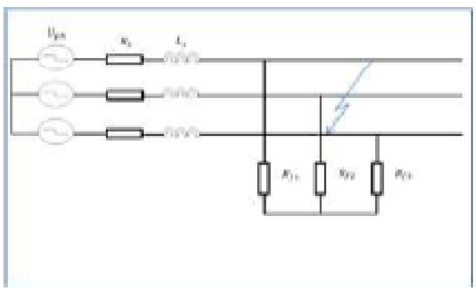


Figure 2. 5 (L-L-L) fault

A three-phase symmetrical fault is caused by application of three equal impedances to the three phases, as shown in figure. Balanced faults are categorized in two fault types called solid or a bolted fault. These faults can be of two types: Line-to-line-to-line ground fault or without ground. Since all the three phases are affected, the system remains balanced. A balanced fault in the transmission system is very uncommon and only 5 % of the system fault is three phases fault.

Series faults represent open conductor and take place when unbalanced series impedance conditions of the lines are present. Two examples of series fault are when the system holds one or two broken lines, or impedance inserted in one or two lines. In the real world a series faults takes place, for example, when circuit breakers control the lines and do not open all three phases, in this case, one or two phases of the line may be open while the other/s is closed. Series faults are characterized by increase of voltage and frequency and fall in current in the faulted phases.

Table 1. Types of faults

Types of faults	Symbol	% Occurrence	Severity
Line to Ground	L-G	75-80%	Very less severe
Line to Line	L-L	10-15%	Less severe
Double Line to Ground	L-L-G	5-10%	Severe
Three phase	3-Φ	2-5%	Very severe

2.2.1.2 Broken Conductor Fault

Other faults like broken conductor faults are series faults which involve a break in one or two of the three conductors of a three phase power system. In this case, the fault is an unsymmetrical series fault and thus, the theory of symmetrical components was revisited. A series fault is an abnormal condition, since the impedance in the three phases is not equal when one or two phases of a balanced overhead three-phase line open it creates unbalance in the system and may result in high unbalanced currents and voltages. Such condition usually occurs when the conductor of a transmission line is broken or damaged. Broken conductor faults are usually caused by variable weather condition and climate influences to the power grid. Conductor icing is a comprehensive physical phenomenon determined by meteoric all factors, temperature fluctuation, humidity, wind and other weather factors. A known physical phenomenon in when cold weather accumulate ice on the conductor, and when the ice suddenly drops the dynamic effect of the transmission line will cause major electrical and mechanical failure.

Electrical failure between adjacent conductors and the ground led to flashover or electrical shock. From a mechanical view, high amplitude vibrations may break one conductor or more and this will result in large unbalance in the phases.

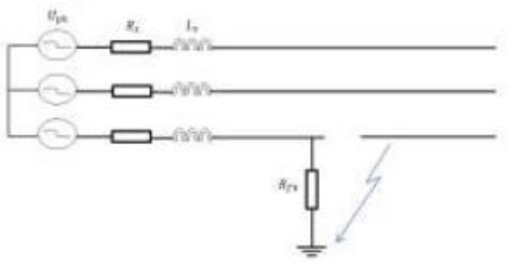


Figure 2. 6 Broken conductor and L-G fault

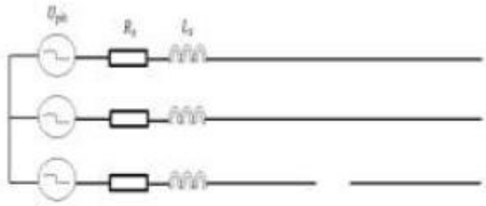


Figure 2. 7 Broken conductor

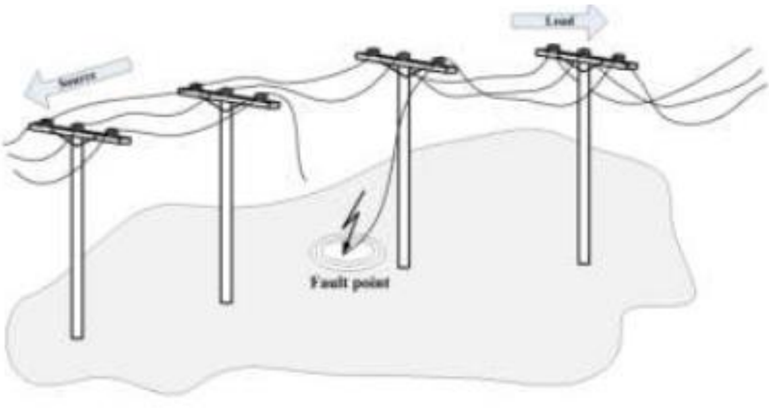


Figure 2.8 Down Conductor fault on overhead line

Strong wind may also create Aeolic harmonics vibration on power transmission lines; these vibrations are associated with great tension on the conductors, which can lead to broken conductors. This phenomenon, where the conductors come in contact with one another during strong wind or other external forces, is called conductor clashing.

2.2.1.3 Arcing Faults

At a high voltage flashover in voltage magnitude, an arcing fault may occur and cause fault situation on the transmission grid. An arcing fault can be considered as a current dependent resistance with three zones. Area closes the adjacent points can be described as a voltage drop independent of current magnitude, arc is spreading if there is space available. If the flowing current through the arc is high the arcing fault through ionization becomes more powerful and the resistance lower. The fault resistance is much larger in the main part of the arc than in the end points.

An electrical arc is affected by magnetic forces and wind, but also the heat extension during the development of an electrical arc. Because of this, its length will increase over time, and if the condition is right the arc may escalate through the conductors and cause short circuits. In the initial phase of an arc fault the arc's length will be extended, and so over until a disconnection occur. Flashover and arc faults on overhead lines caused by power surges (e.g., Lightning) usually occur over the isolators because the arc distance is shortest at these points. In a short circuit causes the acing resistance is very low compared to the impedances, especially during the fault measurement time of a protective. To calculate the maximum fault, current the acing resistance sets to zero. This is because a nonlinear arc resistance causes a certain harmonic content in the fault current that protective relay must accept.

2.2.1.4 External Faults

Lightning faults and faults caused by trees are the most common faults on overhead lines. In the transmission grid lightning faults are dominate because the overhead line here is more tree secured. Losses in overhead lines are resistive and the created losses can be seen as a series resistance at the overhead lines end points. Current flow in overhead line creates a magnetic field around the conductor in overhead lines is this called line reactance. Reactance between the conductor's phases and to ground creates an electrical field; this can be seen as a capacitance. Lightning's fault usually appears when lightning strikes a phase conductor directly, but there are also other places where a lightning strike can create a fault, depending on the size of earth resistance and lightning's voltage amplitude.

When a lighting fault occurs on an overhead line an arcing will occur over insulators, phases and insulator bracket. If the isolator bracket is connected to ground, a ground fault has occurred. Ground fault can be either single-phase or multiphase fault, depending how many phases involved. Ground fault voltages into a properly grounded network have low value for cases where all three phases are involved; if the ground fault voltage phase voltage reaches a high-level earth fault has occurred. Lighting strike on 400 kV network is virtually all single-phase fault, if there are two or more phase's inductor on the grid the lighting strike usually occurs on all phases at same time. If the voltage is moderate and the insulation strength is higher than normal voltage level, an individual conductor may have been involved. Besides lightning strikes, other types of faults can occur on overhead lines in the transmission system. These external faults may include phase failure, defective insulators or failure due to snow and ice, salt or other contamination.

2.2.2 Protection of Transmission Lines

Transmission lines are a vital part of the electrical Transmission system, as they provide the path to transfer power between generation and load. Transmission lines operate at voltage levels from 69kV to 765kV, and are ideally tightly interconnected for reliable operation. Factors like de-regulated market environment, economics, right-of-way clearance and environmental requirements have pushed utilities to operate transmission lines close to their operating limits. Any fault, if not detected and isolated quickly will cascade into a system wide disturbance causing widespread outages for a tightly interconnected system operating close to its limits. Transmission protection systems are designed to identify the location of faults and isolate only the faulted section. The key challenge to the transmission line protection lies in reliably detecting and isolating faults compromising the security of the system.

The high-level factors influencing line protection include the criticality of the line (in terms of load transfer and system stability), fault clearing time requirements for system stability, line length, the system feeding the line, the configuration of the line (the number of terminals, the physical construction of the line, the presence of parallel lines), the line loading, the types of communications available, and failure modes of various protection equipment. The more detailed factors for transmission line protection directly address dependability and security for a specific application. The protection system selected should provide redundancy to limit the impact of device failure, and backup protection to ensure dependability. Reclosing may be applied to keep the line in service for temporary faults, such as lightning strikes. The maximum load current level will impact the sensitivity of protection functions, and may require adjustment to protection functions settings during certain operating circumstances. Single-pole tripping applications impact the performance requirements of distance elements, differential elements, and communications schemes. The physical construction of the transmission line is also a factor in protection system application. The type of conductor, the size of conductor, and spacing of conductors determines the impedance of the line, and the physical response to short circuit conditions, as well as line charging current. In addition, the number of line terminals determines load and fault current flow, which must be accounted for by the protection system. Parallel lines also impact relaying, as mutual coupling influences the ground current measured by protective relays. The presence of tapped transformers on a line, or reactive compensation devices such as series capacitor banks or shunt reactors, also influences the choice of protection system, and the actual protection device settings.

2.2.2.1 GE Multilin Application

Advantages Before considering using a GE Multilin relay for a specific transmission line protection application, it is important to understand how the relay meets some more general application requirements for simplicity, security, and dependability. GE Multilin relays provide simplicity and security for single pole tripping, dependability for protection communications between line terminals, security for dual-breaker line terminals, and simplicity and dependability of redundant protection schemes.

2.2.2.2 Single-Pole Tripping

Single pole tripping using distance protection is a challenging application. A distance relay must correctly identify a single-phase fault, and trip only the circuit breaker pole for the faulted phase. The relay also must initiate the recloser and breaker failure elements correctly on the fault event. The distance elements protecting the unfaulted phases must maintain security during the open-pole condition and any reclosing attempts. The D90Plus Line Protection System and D60 Line Distance Relay use simple, dedicated control logic for single pole tripping applications. This control logic uses a Phase Selector, Trip Output and Open Pole Detector in conjunction with other elements as shown in the simplified block diagram. The Trip Output is the central logic of single pole tripping. The Trip Output combines information from the Open Pole Detector, Phase Selector, and protection elements to issue a single pole or three pole trips, and also to initiate automatic reclosing and breaker failure. The Phase Selector is the key element for maintaining the security of single pole tripping applications, quickly and accurately identifying the faulted phase or phases based on measured currents and voltages, by looking at the phase angles between the positive sequence, negative-sequence, and zero-sequence components. The Open Pole Detector ensures the relay operates correctly during a single pole trip, placing the relay in an open pole condition when a single pole trip command is issued, or one pole of the circuit breaker is open. The Open Pole Detector asserts on a single pole trip command, before the circuit breaker pole actually opens, to block protection elements that may misoperate under an open pole condition, such as negative sequence elements, undervoltage protection, and phase distance elements associated with the faulted phase (for example, AB and CA elements for an AG fault). The Open Pole Detector also resets and blocks the Phase Selector so the other distance elements may operate for evolving faults. The Open Pole Detector also accounts for line charging current and for weak infeed conditions. Once the Open Pole Detector operates, a further trip will cause the Trip Output to declare a three-pole fault, indicating either an evolving fault condition or a reclose onto a permanent phase to-ground fault. This total logic simplifies the setting of the D60 for single pole tripping, and ensures dependable and secure operation when faced with single line-to-ground faults. The L90 Line Differential Relay and the L60 Line Phase Comparison Relay are both phase-segregated, current only relays. Single pole tripping on these relays does not present any unusual challenges, as each phase of the protection element operates independently of the other unfaulted phases.

2.2.2.3 Communications with Relays

Often transmission lines are protected by using schemes that require communications with relays located at other line terminals. The reliability of the communications obviously impacts the reliability of the protection system. GE Multilin relays include features that maintain reliable operation of the protection communications during power line faults, communications channel delays, communications channel switching, and communications channel dropout. Pilot protection: Pilot protection schemes, such as directional comparison blocking and permissive over-reaching transfer trip, use simple on/off communications between relays. There are many methods to send this signal. The most common method is to use contact closure to an external communication circuit, such as power line carrier, microwave, radio, or fiber optic communications. GE Multilin relays simplify fiber optic communications method by using internal fiber optic communications via Direct I/O, eliminating the need for external communications devices. Direct I/O is a reliable mechanism that is simple to configure, securely transmits digital status points such as tripping or blocking commands between relays via directly connected or multiplexed fiber optic channels. Direct I/O operates within 2ms for high speed communications to the remote line end. Direct I/O is available in any of the transmission line relays by adding an internal communications card. The output of the card can be IEEE C37.94, RS422 or G.703 communications to interface with fiber optic multiplexers, or may be a direct fiber connection to other relays. The communications card can be single-channel or dual-channel, to support point-to-point communications, dual point-to-point communications, or ring communications between up to 16 relays.

Communications is an integral piece of a line differential relay, as the currents from one line terminal must be sent to relays at other line terminals to perform the differential calculation. This requires the use of a digital communications channel, which is commonly a multiplexed channel where channel switching may occur. The analog information must be precisely time synchronized between the line ends for the differential calculation to be correct. Synchronization errors show up as phase angle offset, where identical currents produce phasors with different phase angles, and transient errors, where changes in current are seen at different times at different measurement points. For example, on a 60 Hz system, every 1ms of time shift between terminals introduces a 21.6° phase shift into the measured currents. There are two methods to account for the phase shift between line terminals due to the communications channel delay. One method is to measure the round-trip channel delay, and shift the local current phase by an angle equal to ½ of the round-trip delay time. This method is simple to implement, but creates a transient error when the communications channel is switched. In addition, the differential element will be temporarily blocked when the communications channel switches, or noise in the communications channel causes communications packet loss.

2.2.2.4 Security for Dual-Breaker Terminals

Dual-breaker terminal line terminals, such as breaker-and-a-half and ring bus terminals, are a common design for transmission lines. The standard practice is to sum the currents from each circuit breaker externally by paralleling the CTs, and using this external sum as the line current for protection relays. This practice works well during actual line faults. However, for some external fault events, poor CT performance may lead to improper operation of line protection relays. When current flows through a dual-breaker line terminal, the line current measured by a relay using external summation matches the actual line current only if the two CTs are accurate. The most significant relaying problem is CT saturation in either CT. The current measured by the relay may contain a large error current, which can result in the relay operating due to an incorrect magnitude or direction decision. This incorrect operation may also occur if the linear error current of the CTs due to accuracy class is close to the through current level. These errors appear in the measured phase currents. As a result, relays that calculate the negative sequence and zero sequence currents from the measured phase currents may also see errors.

Distance relays applied at dual-breaker line terminals are vulnerable to mis-operation on external faults. During a close in reverse external fault, the voltage is depressed to a very low level, and the security of the relay is maintained by directional supervision. If one of the lines CTs saturates, the current measured by the relay may increase in magnitude, and be in the opposite direction of the actual fault current, leading to an incorrect operation of the forward distance element for an external fault. The D90Plus Line Protection System and the D60 Line Distance Relay handles the challenge of dual-breaker line terminals by supporting two three-phase current inputs to support breaker failure, overcurrent protection, and metering for each circuit breaker. The relays then mathematically add these currents together to form the total line current used for distance and directional overcurrent relaying. Directly measuring the currents from both circuit breakers allows the use of supervisory logic to prevent the distance element and directional overcurrent elements from operating incorrectly for reverse faults due to CT error. This supervisory logic does not impact the speed or sensitivity of the protection elements, operates during all load conditions, and correctly allows tripping during an evolving external-to-internal fault condition. The dual-breaker line terminal supervisory logic essentially determines if the current flow through each breaker is either forward or reverse. Both currents should be forward for an internal fault, and one current should be forward and one reverse for an external line fault. The supervisory logic uses, on a per-phase basis, a high-set fault detector (FDH), typically set at 2-3 times the nominal rating of the CT, and a directional element for each CT input to declare a forward fault, for each breaker. The logic also uses, on a per-phase basis, a low-set fault detector (FDL), typically set at 1.5-2 times the nominal rating of the CT, and a directional element to declare a reverse fault, for each breaker. Tripping is permitted during all forward faults, even with weak infeed at the dual-breaker terminal. Tripping is blocked for all reverse faults when one breaker sees forward current and one breaker sees reverse current. During an evolving external-to-internal fault, tripping is initially blocked, but when the second fault appears in the forward direction, the block is lifted to permit tripping.

Line differential protection is prone to tripping due to poor CT performance on dual-breaker terminals, as the error current from the CTs is directly translated into a differential current. The only possible solution for traditional line differential relays is to decrease the sensitivity of the differential element, which limits the ability of the differential element to detect low magnitude faults, such as highly resistive faults. The L90 Line Differential Relay supports up to four three-phase current inputs for breaker failure, overcurrent protection, and metering for each circuit breaker. The relay then uses these individual currents to form the differential and restraint currents for the differential protection element.

2.2.2.5 Arc-flash Protection Methods

The impact of an arc-flash incident depends on the energy of the incident. The energy depends on voltage, current, and arcing time, and of course on the distance to arc. System voltage is normally not one of the issues that can be changed. Thus, the practical protection principles are increasing the distance to arc or providing a mechanical barrier between the operator and the arc, and reducing the arcing time or current. Arc-flash protection is usually implemented by separate system using arc flash detectors connected to dedicated arc protection relays. Overcurrent, earth fault etc. protection is carried out by other relays. A comprehensive, selective arc flash protection system comprises of arc flash sensors, light and current slave units collecting data from light sensors and current transformers, and a master unit or several units for final collection of all the data, and tripping the correct breaker, if both light and overcurrent are detected.

2.3 Lightning and Transmission Lines

One of the main causes of accidents and violations in the Transmission networks are a storm surge on overhead lines, causing the pulse overlap destruction of insulators, causing arcing fault, the concomitant damage to equipment outages and lines. However, the rules in force did not provide any special protection against lightning surges overhead lines with bare wires with voltage up to 20 KV, except in cases of protection of individual points of overhead lines or weakened insulation with high requirements for reliability. This state-of-lightning protection of Transmission overhead line was the result of historically established recognition of the inevitability of their storm outages and damage due to the lack of effective and affordable technology. However, with the beginning of mass use in Transmission overhead line conductors protected arose the need for mandatory technical measures to lightning protection. The peculiarity of the problem of lightning protection protected overhead lines is that in the absence of special measures, when lightning insulator overlapping lines, followed by the breakdown of the solid insulation of the wire, which is formed with a high probability of commercial frequency arc is not able to move through the wire (as in bare wires) and burning at the site of the breakdown of the insulation off until the line. This can cause damage to wire insulation, damaged insulators and line wire burnout, as evidenced by experience in operating lines with insulated wires. Because lines with bare wires exposed arc electrodynamic forces able to move one of its ends along the wire, the factor of wire damage due to thermal effects of the arc was not significant and does not affect the formation of the concept of lightning protection of overhead lines. In the case of insulated overhead wires to prevent burnout becomes the main condition in determining the need for mandatory application of any lightning protection measures (Li, J. Wang, X. Zhou, S. Huang, & Z. Xia, 2019).

Some literature suggests that the probability of a direct blow to the wire insulated overhead line missing. To test this hypothesis, we performed experimental studies the probability of a lightning strike in the wire insulated overhead line for different conditions. In the laboratory of ultra-high voltage of the department "electric power transmission" of the national technical university "kharkiv polytechnic institute" was established allowing the large-scale model to simulate overhead line with bare wires or protected. This model makes it possible to perform experiments to determine the probability of a direct lightning strike to insulated overhead line and overhead lines for different geometrical parameters of lines. As a source of high-voltage pulse voltage generator used (gpv), with a maximum voltage of 2.4 mv. One of the main issues in experimental studies of lightning protection of various objects is the question of compliance with the conditions of discharge between a cloud and the earth (lightning) and in the laboratory between. (H. Liao, C. Wu, Wang & W. Xia, 2018)

One such condition is the choice of the form of exposure voltage. Previously, for the initiation of the spark discharge in the air gap used the standardized international electrotechnical commission (iec) lightning overvoltage impulse 1.5 / 40 ms (the length of the of impulse front of 1.5 microseconds pulse length - the time from the beginning of the pulse until the voltage reaches half the maximum value - 40 ms). Currently, the standard form of the pulse slightly changed (1.2 / 50 s) that does not change the fact. In addition to lightning characteristic zigzag channel, due to its stepwise development, and random direction of each stage at a low average discharge voltage - the order of 15 kv / m. To play the random nature of the direction of the discharge in the laboratory must be possible to obtain a lower average discharge voltage, which provides a stepwise development of the spark channel with a sufficiently large with respect to the length of the discharge gap length of the stage leader and therefore the direction of the development of accidental discharge. From this viewpoint justified application of positive polarity voltage pulse with a gently sloping front, at which the average discharge voltage in a sharply non uniform field (such as rod-plane) decreases rapidly with increasing length of the gap. When negative polarity average discharge voltage for a period of rod - plane much more. For short periods (2-3 m) of the discharge voltage in the negative polarity voltage (to 1000 kv / m) is more than twice the discharge voltage at the positive polarity (400 kv / m).

Studies related to the effects of lightning strokes on power lines are of fundamental importance during the stage of tower design, as inadequate choice of the electrical parameters of the tower may lead to high tripping rates. These studies determine clearances and shielding angles of the tower and minimum distances required to bring flashover probability down to acceptable levels. Because of the complexity and random nature of the mechanism of lightning discharges, studies in this field require a Monte Carlo approach to carry out simulations. This method adequately represents the randomness of the variables involved and has been widely used in the literature to solve diverse problems, e.g., solution of simultaneous equations, diffusion of neutrons through materials, determination of probabilistic thermal limits of power lines, to name a few examples. This method, therefore, is adequate for simulating lightning current intensity, wavefront characteristics, incidence angle of the discharge, insulation strength on the tower and location of the stroke.

Two situations may occur, depending on the discharge location relative to the wires composing the transmission line. The first one, named a direct stroke, takes place when a phase conductor is struck directly, in turn producing a voltage increase in that phase. This may lead to a discharge between the phase conductor and the tower, if the insulator strength is exceeded. In this case, the operating voltage maintains the discharge arc, causing a short circuit and consequently a line trip out. This is commonly referred to as a shielding failure. By studying direct strokes, it is possible to obtain an effective shielding by proper Transmission of ground wires. Unlike the first situation, it is very difficult to eliminate trip outs entirely. However, trip out occurrence can be minimized by proper choice of tower clearances, optimization of the coupling parameters between conductors and ground wires, and by improving the tower grounding project.

For the case of indirect strokes, voltage and current traveling waves are generated at the discharge site, propagating along the wires thereafter, until they reach the adjacent towers. This in turn leads to the production of reflected waves, with characteristics determined by the relative values of the surge impedances involved in the process. These traveling waves induce transient voltages on the conductors, having shapes determined by the electric coupling among conductors and ground wires. If the voltage difference between conductor and tower exceeds the insulator strength, a discharge occurs. This phenomenon is called back flashover. It is important to point out that a back flashover is much more likely to occur on insulators than a flashover at midspan, because of the smaller distance between phase conductor and ground at the tower relative to that at midspan. The voltage wave at the tower is called tower top transient voltage and is dependent on the lightning current and associated waveform, location of the stroke, and transmission line parameters. When applied to the insulator string it is given by Eq (1),

$$V_s(t) = (1 - k)V_t + V_n(t) \tag{1}$$

A procedure for reconstructing the spatial waveforms of the lightning return-stroke current base using a numerical-Feld synthesis method and Fourier transform. The combination of these methods is proven to increase the efficacy of lightning detection. Cotton et al, 2014 compared voltage induced by lightning and switching on a 1-km pipeline of parallel overhead transmission line. Although the switching-induced voltage is lower than the lightning-induced voltage, either can cause damage to devices and systems.

Induced currents caused by lightning strikes to the ground near a steel-reinforced concrete building. The relation among the peak values of the induced currents and three main factors, namely, the height of a building, its roof, and the lightning rods used, is studied. It is found that the building's height and several attributes of the lightning rods are the major contributing factors.

A novel lightning current function that is more complex than an ideal lightning current function, but obtains an exact waveform; thus, the novel method can completely replace the ideal model without any impact on the processing time. Sometimes, the analysis by a single method is not comprehensive, so some researches apply various methods to utilize the features of each method in order to obtain the best results; for example, a novel lightning current function by coordination between differential integral equation and Fourier transform, in which the first-order positive sequence of lightning return stroke and the subsequent lightning stroke is analyzed. The results demonstrated that an offered function can be used to analyze every type of lightning return stroke.

The estimated time of the maximum transient current at the horizontal axis of finite-ground electrode, using the coefficient of refection to analyse the conditions of soil and air by combining the Laplace transform and Cauchy residue theorem. Afterwards, because of the development of technologies, many researchers began to apply this development in their research to improve the accuracy and efficiency.

Analyses of lightning events in Switzerland from 1999 to 2007 using Benford'slaw. The results proved that Benford's law is not suitable for determining the analytical characteristics of lightning, because it can only analyse low lightning currents. However, the law is reasonable to locate the position of lightning.

Installed magnetic sensors in the power system using the time detected by sensors to estimate the spread of the field and the discharge. The induced voltage and current at a transformer in a hydroelectric plant using the finite-difference time domain method. Their analysis was based on computer simulation and was used to determine the effect of a 1-kA lightning strike at phase A. It was found that the induced voltage follows the lightning point. When faults occur in the power systems, the characteristic of voltage and current change. Thus, various methodologies that analysed the change in the signal have been used for the protection system.

A method to predict the location of single-line, line-to-line, double-line-to-ground, and three-phase faults that occurred in a transmission network. The observation network was based on 39 buses, and the variable parameters are the resistance and line percentage. The operation of this method is unlike that of the conventional method. The proposed method only requires a phasor measurement unit (PMU). The results showed that fault detection by PMU is highly efficient. In addition, the sub situation theorem and least-square method were also used to estimate the voltage and current before and after the fault occurred.

Moreover, the synchrophasor technology for real-time monitoring of a wide-area system. A study proposed a fault-detection method based on the maximum amplitude of the fault, based on the theoretical and PMU data when the fault occurred, and resolving the condition based on a comparison of the EM when the fault occurred. Te results of the presented method show high efficiency for detecting faults.

Two-terminal transmission system by using the traveling-wave method. The research analysis only used the time of the transient; the polarity and magnitude of the transient were ignored. The real-time analysis has high efficiency for detecting and identifying internal and external faults. Furthermore, the sampling rate and velocity of wave traveling in a line directly affect the detection accuracy.

The fault current by using the discrete wavelet transform (DWT) with consideration of the impact on the mother wavelet, level of wavelet, sampling frequency, and inception angle of faults on the behaviour of wavelet current signals. The result verifies that all these parameters have an impact on the behaviour of signals, especially at the level of the wavelet. Therefore, a suitable issue between a level and signal waveform is necessary for the efficiency of signal analysis.

Furthermore, a method to protect a long transmission line with an installed compensator. This method chose two dissimilar mother wavelets for analysis, which were simulated and processed by PSCAD/EMTDC and MATLAB. The methodology using convolutional sparse autoencoder to detect and classify faults on transmission line has been proposed. The research applied DWT based methodology on high-technology devices for fault protection system. For instance, Korkal, 2015 inserted global position system (GPS) to detect the time of traveling waves and locate fault positions by DWT, the time detected by wireless sensors distributed in the power system to locate the fault areas, based on the coefficient of DWT (V. E. Podporkin, E. S. Pilshikov, Kalakutsky & A. D. Sivaev, 2014).

2.4 Review of Related Literature

The effect of a multi-fracture compression airflow arc-extinguishing structure interrupting the power frequency follow current. He found out that to reduce the damage from the power frequency follow current of Transmission lines, a multi-fracture compression airflow arc-extinguishing structure is studied. The structure is mainly composed of a compression tube, a metal electrode, and metal connection fittings, and the multi fracture compression airflow arc-extinguishing body is formed by the combination of packaging and insulation fittings. The body and the airgap are parallel to both ends of the insulator. When lightning strikes, the internal short gap of the main body and the air gap break down, and the lightning arc enters the arc-extinguishing body through the breakdown channel. In the structure, the arc is compressed by force to form internal and external gradients of temperature and to produce jet airflow. The jet airflow acts on the subsequent power frequency follow current arc, which is suppressed and extinguished. In this paper, a model coupling an arc and a compressed jet airflow in a multi-fracture compression airflow arc-extinguishing structure is established theoretically and simulated by simulation software. Finally, a power frequency follow current interruption test is carried out. The simulation results show that a high-speed airflow of 600 m/s is formed around the fracture at approximately 0.99 ms, and the airflow is proportional to the rate of temperature variation.

The test results show that the power frequency follow current of 1.289 kA is cut off within approximately 3 ms without a reburning phenomenon. The effect of power frequency follow current interruption is obvious in the structure (P. Sarajcev, 2015).

The classification of Lightning and Faults in Transmission Line Systems Using Discrete Wavelet Transform in Thailand. They found out that the electrical energy consumption has been rapidly increasing, following economic and population growth. In order to supply constant power to consumers, reliability is an important factor the electric utility needs to consider. Common disturbances that cause severe damage to transmission and Transmission systems are lightning and faults. The system operator must deal with these two phenomena with speed and accuracy. Thus, this study aims to investigate the differential behaviors of transmission systems when disturbance such as lightning strikes and faults occurs in a 115-kV transmission line. The methodology consists of using the ATP/EMTP program to model the transmission system by the 115-kV Electricity Generating Authority of Thailand (EGAT) and simulate both lightning and fault signals in the system. The discrete wavelet transforms are then applied to obtain the signals in order to evaluate the characteristics and behaviour of both signals in terms of high-frequency components. The obtained data will then be used to construct the fault and lightning classification algorithm based on DWT and travelling wave theory. The proposed algorithm shows the effectiveness in classifying the fault and lightning based on the transmission system that was modelled after the actual system in Thailand. Thus, it can further improve the protection scheme and devices in terms of accuracy and reduce the response time for an operator to address the disturbance and ensure the reliability of the system in the future.

The development of Arc-Guided Protection Devices Against Lightning Breakage of Covered Conductors on Transmission Lines. They found out that the breakage of overhead covered conductors on Transmission lines resulting from the short-circuit arcs caused by lightning flash becomes a challenge as the application of covered conductors increases on Transmission lines. Based on various methodologies and devices developed to avoid the covered conductor breakage in the world, novel arc-guided devices, including arcing protection hardware with barbs, clamping post composite insulator, and barb electrode clamping post porcelain/composite insulator are presented in this paper. Experimental results are also presented to validate these new developed devices. Devices based on the developed technologies have been widely applied on the power grids in China successfully.

The characteristics of arc extinguishing time of a new lighting protection gap for transmission lines. They envisaged the development of a novel arc extinguishing lightning protection gap in pursuit of reducing the lightning trip-out rate and accident rate. In the developed setup, the jetting stream arc extinction lightning protection gap device was used for transmission line. When this transmission line was struck by lightning and the lightning surge was going to break down the gap, the arc extinguishing lightning protection gap immediately jetted out sufficient electronegative gas flow that quickly cut off the arc and effectively prevented the insulator from being damaged by the arc. Furthermore, when the line was attacked by lightning, the generated overvoltage instantaneously broke the gap that was parallel to the insulator string, so that the lightning current was oriented to the earth from the gap. Simultaneously, it triggered the gas generator and generated a high-speed stream, then extinguished the frequency continuous current arc rapidly, thus effectively reducing the rate of line trip to ensure the reliability of power supply. They used a high-speed camera and ordinary camera that automatically captured the process of the jetting stream arc in the extinction lightning protection gap device, while extinguishing the 1kA power frequency arc. The image of the high-speed camera indicated that the power frequency arc of 1kA was quenched in 10 ms before the relay protection action of the test loop, which made that the overhead line lightning flashover, but the circuit breaker did not trip. Thus, a reduction in the rate of lightning trip was observed by the developed setup, and it has an immense potential for application at the transmission lines of China.

The protection of overhead transmission lines from lightning strike. They found out that transmission lines are shielded with protective wires to overcome various kinds of sudden upsurge of high voltage. The aim of the article was to determine the probability of direct lightning strikes in overhead lines with protected wires for different model configurations with the help of experiments. The experimental results have allowed to refute the hypothesis of the absence of direct impacts in protected wires of overhead lines. The studies conducted suggest that lightning defeat of overhead lines with protected wires is substantially lower than those traditional lines (R. Shariatinasab, J. Gholinezhad, K. Sheshyekani & M. R. Alemi, 2016).

3. Methodology

3.1 Experimental Setup

This study will be adopting the multi-fracture compression airflow arc-extinguishing structure. The multi-fracture compression airflow arc-extinguishing structure is arranged in a serrated structure consisting of several compression tubes, in which the outer diameter of the compression tube is 6 mm, the inner diameter is 3 mm, and the length is approximately 20 mm. Each compression tube contains spherical metal electrodes with a diameter of 3 mm. There are corners between the pairwise compression tubes, where multiple fractures are formed in contact with the air. To increase the number of fractures, a t-type compression tube is added between the two compression tubes. A spherical metal electrode is arranged on the left and right sides of the t-type compression tube and the middle part is the jet burner.

The compression tube and the inner spherical metal electrode of the t-type compression tube through the short gap breakdown discharge to form a breakdown channel that is developed according to the structural design. The breakdown channel controls the flow path of the arc plasma. At the corner, to ensure that the arc can enter the next compression tube normally, the joint also adds metal connection members (F. Tossani, F. Napolitano, A. Borghetti, C.A. Nucci, G. P. Lopes, M. L. B. Martinez, et al., 2015).

The arc in the structure is forced to be mechanically compressed, and a pressure gradient is formed in the compression tube and the outer air. Internal and external temperature gradients are formed due to the thermal insulation of the compression tube wall. Hence, a jet airflow is formed at the fracture to act on the arc in the external air. The main body of the multi-fracture compression airflow arc extinguishing device is composed of the multi-fracture compression airflow arc-extinguishing structure, flashover metal, and insulation fittings. The arc-extinguishing main body is connected to the grounding end through the metal fittings. An air gap is formed between the wire and the flashover metal of the main body, which is connected in parallel to the two ends of the insulator.

When lightning strikes, the lightning impact component preferentially breaks the short internal gap of the main body and the air gap to form a discharge channel and avoid ablation of the insulators. The main body action starts at the lightning impulse stage, and the duration of the lightning impulse is generally within tens to hundreds of microseconds. It takes approximately tens of milliseconds for the power frequency follow to reach a steady state. When the main body acts, the power frequency follow in the transient rising stage can be effectively extinguished. This effect ensures that the arc-extinguishing time is much less than the relay protection action time, thus realizing the "lightning strike not tripping" (Wang, J. Liu, G. Wu, Q. Liu & W. Guo, 2015).

3.2 Coupling Model of Arc Compression and Jet Airflow

The arc enters the main structure through the external electrode and exhibits three stages: forcing the arc to compress mechanically, thermal accumulation in the compression tube, and arc extinguishing by jet airflow. A. Forcing the arc to compress mechanically when the arc enters a compression tube, the arc is strongly restricted by the cold channel wall of the compression tube. At this point, the arc cross-sectional area decreases, that is, the arc column radius decreases. However, the arc current remains constant, and the decrease in the arc column radius increases the current density of the arc column center. Hence, the center temperature of the arc is bound to increase. The relationship between the current density and the arc column radius is expressed as follows:

$$\mathrm{j} = \frac{I}{\pi r2} \qquad (2)$$

where j is the current density, I is the current amplitude, and r is the arc radius. If the arc column is considered for numerous small currents, each current is subjected to a self-magnetic compression Lorentz force. These force directions attract each other and point toward the center of the arc column, intensifying the decrease in the arc column radius. The equilibrium equation for the force of the arc column is established as follows:

$$\frac{dp}{dr}+jB\varphi=0 \quad (3)$$

where P is the pressure, j is the current density, and Bφ is the intensity of the magnetic field of the arc column, which is in the tangent direction. The relationship between the intensity of the magnetic field and the current using Ampere's circuital theorem is as follows:

$$B_{\varphi}=\frac{\mu_0}{r}\int_0^r jrdr \quad (4)$$

where μ0 is the vacuum permeability and r is the radial length from the arc axis center. The pressure at the edge of the arc column is set to the pressure P0. By integrating the pressure P from the edge to the inside of the arc column and combining it with Eqs. (2) – (4), by self-magnetic compression, the pressure at radial r is as follows:

$$P(r)=\mu_0\int_{r_0}^{r}\frac{j}{r}\int_0^r jrdr+P_0 \quad (5)$$

Because the arc in the compression tube is restricted by the tube wall, the radius of the arc column ra is small, and the pressure P_0 is large. The arc pressure in the compression tube is much higher than that in the external air, forming internal and external pressure gradients and driving the medium in the arc column to flow from the high pressure to the low pressure.

3.3 Thermal Accumulation in the Tube

High-density thermal accumulation is instantly produced by the arc in the compression tube and a high-temperature thermal source is formed. The thermal transfer form of the arc in the compression tube is mainly convection thermal transfer. According to the energy conservation law, the convection thermal transfer between the inner wall of the compression tube and the arc is equal to the decrease in the internal energy of the arc, and the following results are obtained:

$$hA(T-T_a)=-pCV\frac{dT}{dr} \quad (6)$$

where h is the coefficient of convection thermal transfer, A is the surface area, T is the inner-wall temperature of the compression tube, Ta is the temperature of the arc column, ρ is the density, V is the volume, C is the specific thermal capacity, and τ is the transient time of convection thermal transfer. By introducing the temperature difference θ = T − Ta, the initial condition of transient thermal convection is set as follows: θ0 = T_0 − T_a, where T_0 is the initial temperature of the compression tube inner wall. On combination with Eq. (6), the time is integrated as follows:

$$\int_{\theta_0}^{\theta}\frac{d\theta}{\theta}=-\int_0^r\frac{hA}{\rho VC}d\tau \quad (7)$$

The total convection thermal transfer of the arc from 0 to τ is

$$Q\tau=\int_0^\tau hA(T-T_a)d\tau=\cdot(T-T_a)\int_0^\tau hAexp\left[-\left(\frac{hA}{\rho VC}\right)\tau\right]d\tau=(T-T_a)\rho VC(1-e^{\frac{-hA}{\rho VC}\tau}) \quad (8)$$

3.4 Model of the Jet Airflow Extinguishing the Arc

The arc is extinguished by the jet airflow generated in a compression tube from the energy accumulation of the arc. The combined effect of the dynamic field and electromagnetic field is involved in the process coupling the arc and jet airflow, so it is necessary to establish the relevant simplified governing equations. The mass conservation equation:

$$\frac{\partial(\rho V\rho V_Z}{\partial z}+\frac{1}{r}\frac{\partial(\tau\rho V\tau)}{\partial\tau}=0 \quad (9)$$

The momentum conservation equations: Axial direction:

$$\rho(Vz\frac{\partial V_z}{\partial_z}+V_\tau\frac{\partial V_\tau}{\partial\tau})=-\frac{\partial\rho}{\partial z}+\frac{1}{\tau}\frac{\partial}{\partial\tau}(\mu\tau\frac{\partial V_z}{\partial\tau}) \quad (10)$$

Radial direction:

$$\frac{\partial\rho}{\partial\tau}+j_zB_\emptyset=0 \quad (11)$$

The energy conservation equation:

$$\rho\left(V_z\frac{\partial h}{\partial z}+V_r\frac{\partial h}{\partial r}\right)=\sigma E^2-e_\phi+\frac{1}{r}\frac{\partial}{\partial r}\left(\lambda r\frac{\partial T}{\partial r}\right) \quad (12)$$

The electromagnetic field equations (Maxwell equations):

$$\frac{1}{r}\frac{\partial}{\partial r}\left(rH_{\phi}\right)=j_z. \tag{13}$$

The Ohm's law equation:

$$j=\sigma E \tag{14}$$

The equation of state for gases:

$$P=\rho RT \tag{15}$$

Here, ρ is the density of the medium, V is the flow velocity of the medium, j is the current density of the arc, subscripts r and z represent radial and axial components, respectively, P is the gas pressure, Bφ is the magnetic induction intensity, μ is the coefficient of dynamic viscosity, h is the coupling enthalpy of the gas flow and arc, σE is the term of the Ohm thermal effect, E is the electric field strength, σ is the conductivity, eφ is the thermal balance of the arc column radiation, λ is the coefficient of thermal conductivity, Hφ is the magnetic field intensity, and R is the ideal gas constant.

3.5 Lightning Current Model

The International Council on Large Electric Systems (CIGRE) lightning current waveform was used with a CIGRE type15 current source. The impedance of the lightning strike channel was 400 W parallel to the current source; normally, the time to halve the value, or the tail time, is stable at 77.5 _s. The front time of the lightning current can be calculated from Equations (16) and (17):

$$t_f=\begin{cases}1.77I^{0.188}, 3\le I\le 20\,kA\\ 0.906I^{0.411},\ I>20\,kA\end{cases}$$

$$S_m=\begin{cases}12I^{0.171},\ 3\le I\le 20\,kA\\ 6.5I^{0.376},\ I>20\,kA\end{cases} \tag{16}$$

3.6 Simulation Analysis

This study will be making use of Matlab Simulink in the analysis of gas active arc extinguishing and lightning protection for transmission lines. MATLAB is a well-known and popular general-purpose mathematical program. The MATLAB program is also a suitable tool for the simulation of the effect of Lightning strike and the performance of arc extinguishing structure on transmission lines. Through the simulation, the velocity, temperature, and convective heat flux along the y-axis of the multi-fracture compression flow arc-extinguishing structure are plotted. By testing the power frequency follow current interruption, the interruption effect of the structure is analyzed and the waveforms of voltage and current are plotted. The electrical parameters of the line and the geometrical design for the transmission tower are established as follows:

$$R_i=\Delta R_i * x_i = 2 * Z_t\frac{\ln(\frac{1}{\alpha})}{(h-x)} \tag{17}$$

$$L_i = 2 * \tau * R_i \tag{18}$$

$$\tau=\frac{h}{c_0} \tag{19}$$

Where τ is the time of the travelling lightning wave along the tower height expressed in μs, Ri and Li are the values for resistance and inductance of each (RL) circuit of the tower, h=18 m is the tower height, x is the distance between power distribution line phases $c0$ 300m/μs is the light speed in free space, α = 0.89 is the attenuation coefficients along the tower. For the simulation, lightning-surge current was injected into each phase conductors. Shielding failure voltage across insulator string was measured at each phase, by using probe branch voltage. Flashover occurs when voltage across line insulation is equal to or greater than Critical Flashover Voltage (CFO), which is determined from Basic Insulation Level (BIL) calculated via the equation below:

$$BIL=CFO\left(1-1.28\frac{\sigma_f}{CFO}\right) \tag{20}$$

Where σ_f is coefficient of the variation, known as sigma. For lightning, the sigma is 2% to 3 %. According to ANSI C92 IEEE1313.1, the suggested BIL for 150kV is 650kV, so, with this BIL value and 2% sigma, the CFO is approximately 650kV; this value will be used throughout the analysis.

4. Results and Discussions

4.1 Introduction

In the previous section, the methodology to make the dynamics simulations is presented. However, in order to analyze and study gas active arc extinguishing and lightning protection for transmission lines, different parts of an overhead transmission line such as wires shield wires and phase conductors, towers, grounding, insulator strings and others have to be simulated. Accordingly, a summary of guidelines used in this research not only for the transmission lines representation in lightning studies but also for the representation of different lightning flash features are presented as follows:

The most important factor in lightning surge simulations is related to their magnitude. However, it has been accepted that when a lightning hits a transmission line, it injects current into the power system. As regards the transmission tower, there are two possibilities to simulate this element, the first consists of using inductances-resistances, and the second consists of using distributed parameters impedances, the last one considerers voltage reflections from adjacent towers and from cross arms, thus, in this research the tower is represented as a lossless distribute-parameter transmission line, characterized by their impedance and travel time. For the purpose of this study, the Transmission line will be used as case study. The transmission line used is represented as lumped LC PI model found in Matlab Simulink block. It is Pi-model transmission line with length of 220km from the load. The lightning is assumed to strike tower nearest to the transmission line which 220km from the source and 220km from load to best determine the effectiveness of protective surge arrester that is employed to protect substation equipment. The model consists of three phase AC source of 132kV representing the sending end of the line under study, 2000MW load to represent receiving end of the line under study. Since the line transmits 2000MW power by two double circuit lines, only a single circuit is included under this study as they are identical, AC lighting source of amplitude 10kA in parallel with resistance of 350ohm to represent lightning as the lightning source is current in parallel with surge impedance (M. Yoshida, K. Setoguchi, A. Ishimoto, Asakawa & S. Nakamura, 2016).

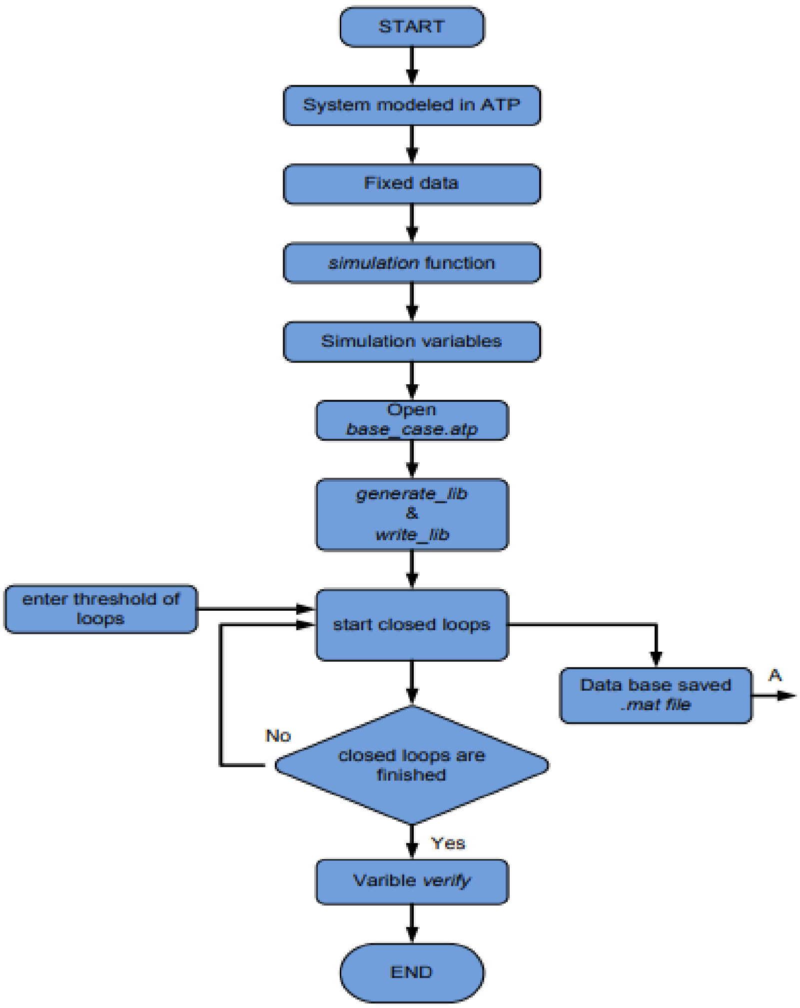


Figure 4.1 Simulation algorithm flowchart

The whole model is constructed in the Simulink environment (MATLAB) and the use of ETAP version 12.6 is used to simulate the case study.

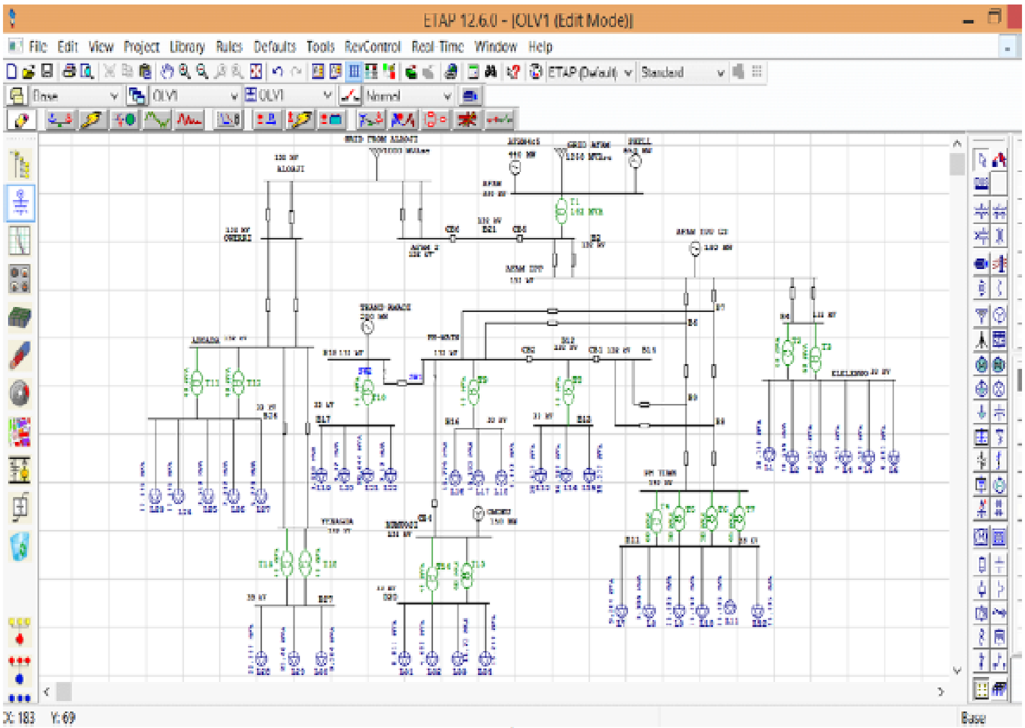


Figure 4.2 The Base-case Network of the 132 KV Sub-transmission Lines for Port Harcourt Sub-region and their Load Capacities

4.1.1 Parameters Used in the Analysis

Table 2. Simulation parameters used

Serial No.	**Quantity**	**Value**
1	Supply Voltage	415V, 50Hz (line-line)
2	Tower height	18M
3	AC lighting source	10KA
4.	CFO	650KV
4	Source Impedance	$R_s = 0.5\ \Omega$, $L_s = 0.1$ Mh
5	DC Capacitor	5000 Uf
6	DC Link Voltage	680V
7	Ripple filter	L_f= 2 mH, C_f = 50 uF
8	Series Transformer	1:1
9	Switching Frequency	20 kHz
10	Load	Three Phase Balanced Linear Load R – Lload (R= 30Ω, L = 0.302H)

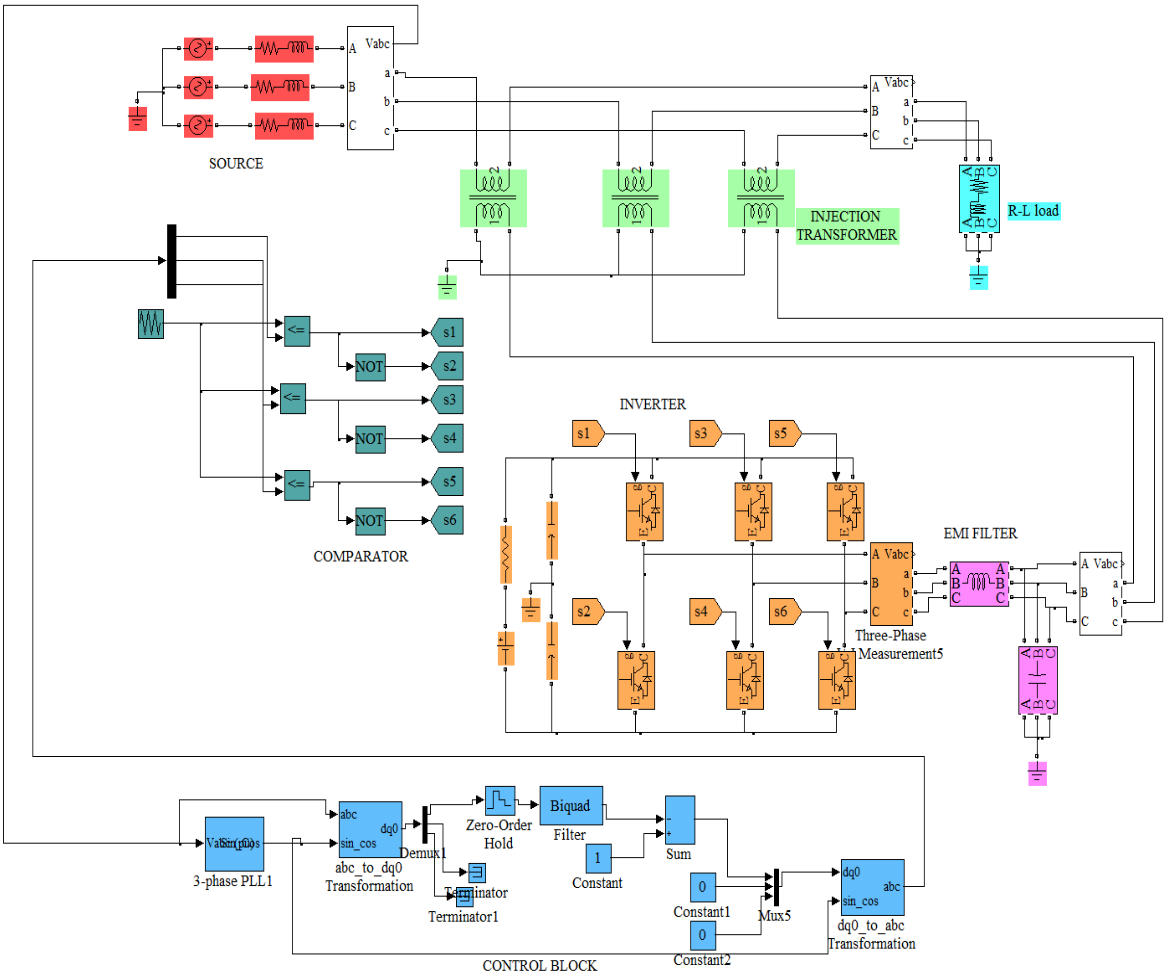


Figure 4.3 Circuit Diagram of MATLAB Simulation

The above figure shows a comprehensive model of DVR designed in the Simulink environment (MATLAB). The model is made up of a control block, comparator, EMI filter, Injection transformer, Inverter, Load, and Source. The source is generated as a result of different supply voltage instability. The inverter is used to convert DC supply to AC supply. The outputs of the inverter enclose fundamental voltage and the voltages of switching frequencies and multiples of switching frequencies. Thus, the EMI filters are eradicated through voltages of switching frequencies and multiples of switching frequencies. The comparators by comparing the sinusoidal signal with a triangular signal are generated by pulses. The injection transformer injects the AC voltage of the inverter to each phase of the line. While the control block generates the reference signals to the PWM inverter.

4.2 Supply Voltages

Case I: Balanced Supply Voltage

The voltage across the load is kept constant for different supply voltage disturbances. Once the rated balanced voltage is applied to the load, the injected voltage by the voltage source converter is zero ideally but supplies very a small voltage to compensate for the drop in the injection transformer.

The subsequent equations correspond to the balanced source voltage.

$$v_{sa} = 338.846 \cdot \sin(wt) \quad (4.1)$$

$$v_{sb} = 338.846 \cdot \sin(wt) \quad (4.2)$$

$$v_{sc} = 338.846 \cdot \sin(wt) \quad (4.3)$$

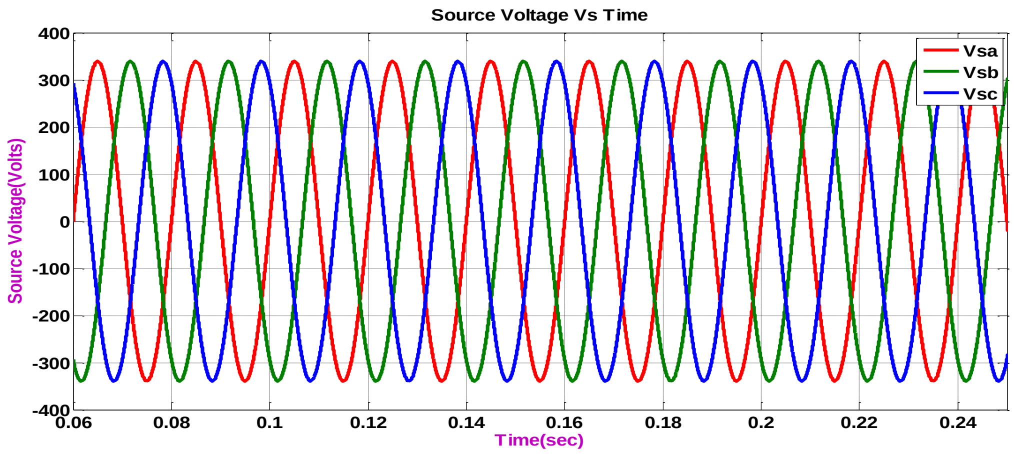


Figure 4.4 Source Voltage for Balanced Supply Voltage

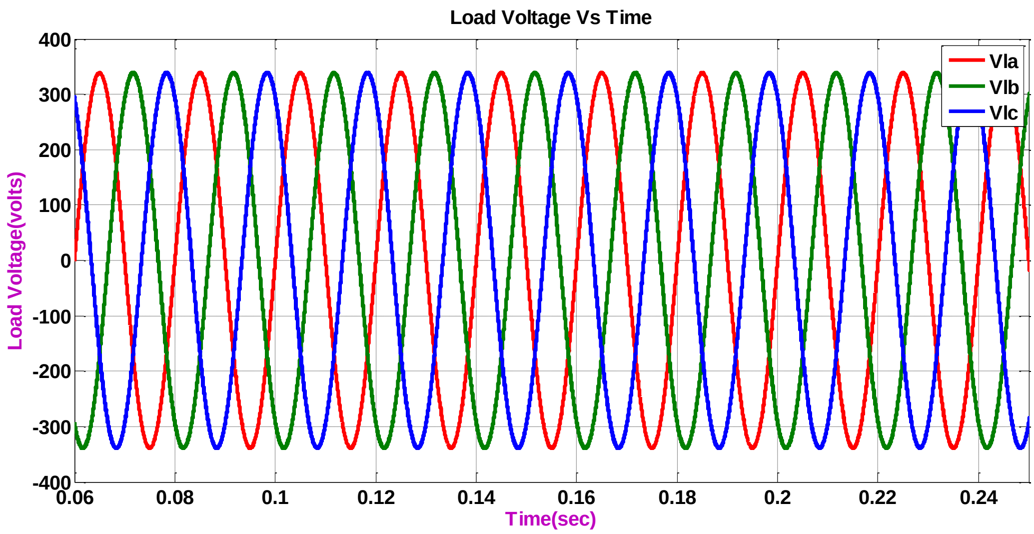
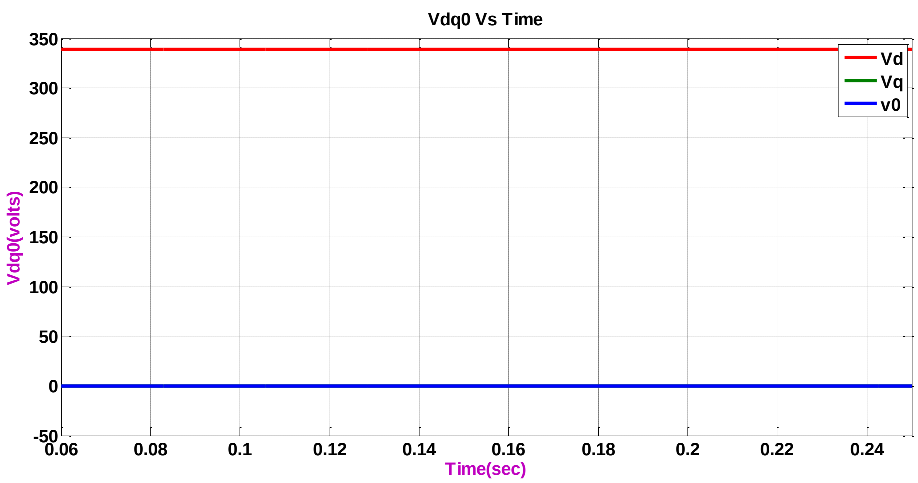
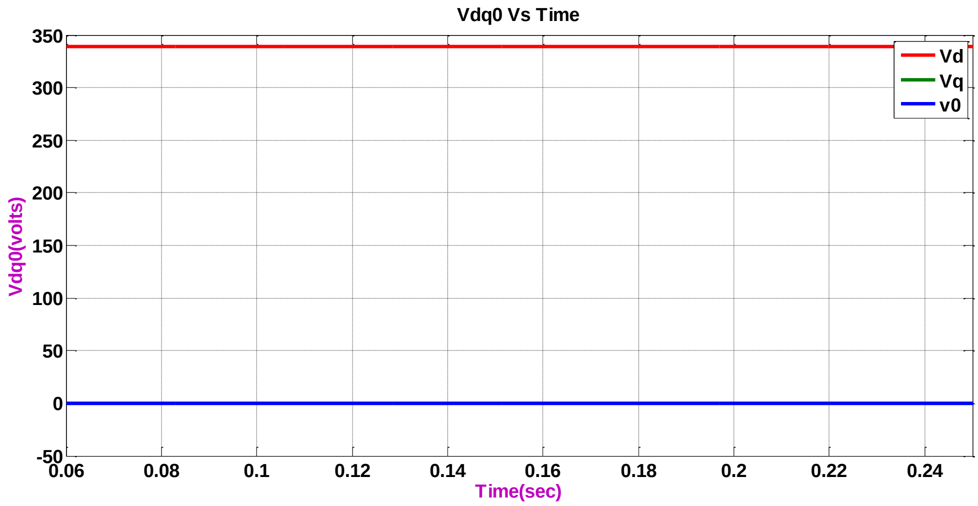


Figure 4.5 Load Voltage for Balanced Supply Voltage



(a)



(b)

Figure 4.6 (a), (b) Direct, Quadrature, and Zero axis voltages

The above figure shows the waveform of Direct, Quadrature, and Zero axis voltages under balanced supply Voltage (simulation is done in Matlab Simulink. The Quadrature and zero axis voltages are of zero voltage after converting the source voltage to a synchronously rotating reference frame (abc to $dq0$). Figure 4.7 shows the waveform of Balanced Sag Source Voltage (simulation is done in Matlab Simulink). The voltage sag is supplied from 0.08 to 0.2 seconds (6 cycles). Figure 4.8 shows the waveform of Load Voltage (simulation is done in Matlab Simulink). The voltage is injected by DVR from 0.08 to 0.2 seconds. From the waveform, it can be observed that the voltage across the load is maintained to rated voltage.

Case II: Balanced Supply Voltage (Sag)

The subsequent equations represent the balanced sag voltage with 20% of sag. The peak value of phase voltage is 338.846V and line to line voltage of 415V.

$$v_{sa} = (338.846 \ * 0.8) \sin(wt) \quad (4.4)$$

$$v_{sb} = (338.846 \ * 0.8) \sin(wt - 120) \quad (4.5)$$

$$v_{sc} = (338.846 \ * 0.8) \sin(wt - 240) \quad (4.6)$$

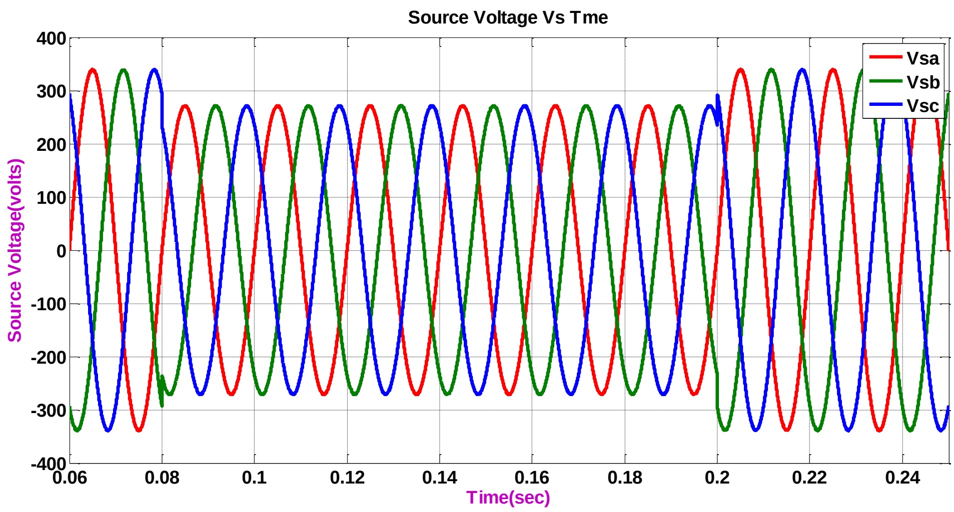
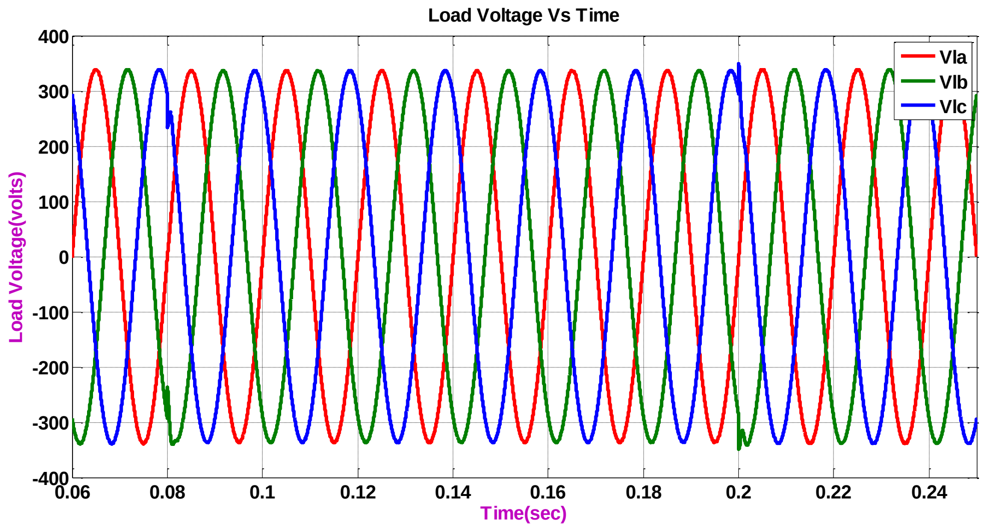
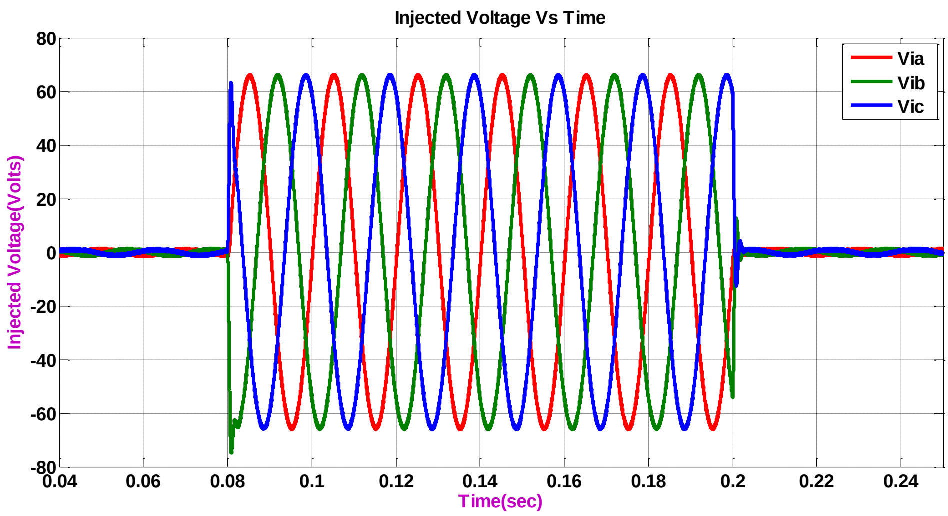


Figure 4.7 Source Voltage for Balanced Supply Voltage (Sag)



(a)



(b)

Figure 4.8 (a), (b) Load voltage for Balanced Supply Voltage (Sag)

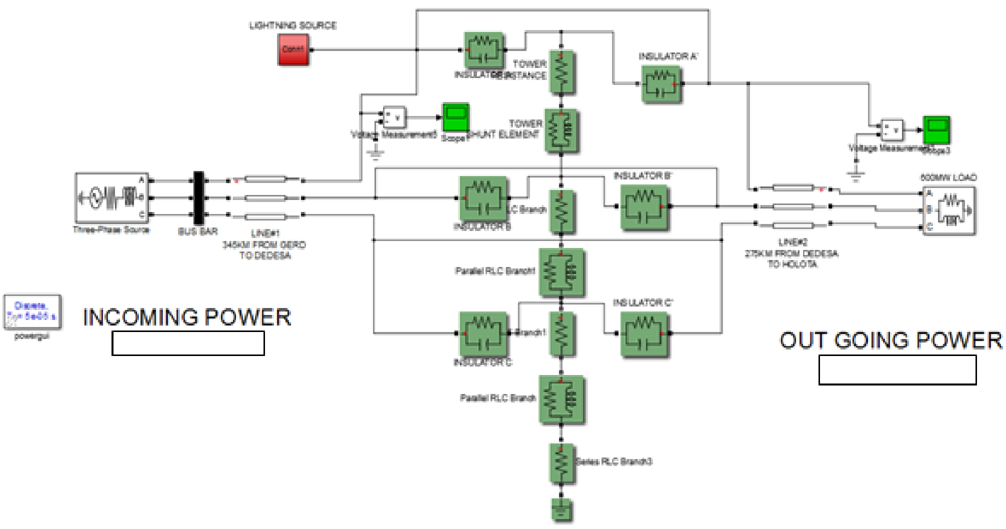


Figure 4.9 HV Tower model in MATLAB for direct stroke

Now let consider the direct stroke case (stroke to phase conductor). In this case the stroke (shown at the top edge the tower entitled as lightning source) is assumed to strike phase conductor.

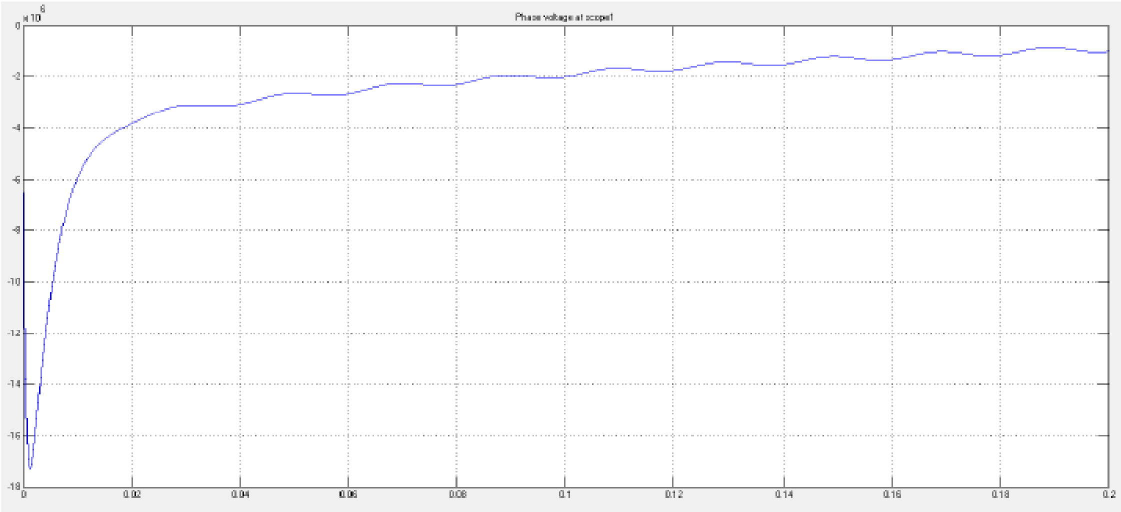


Figure 4.10 Plot of phase voltage at scope 1 under direct stroke

From this result it is easy to see that when lightning strikes phase conductor voltage will go far beyond operating voltage for very short duration of time and then it quickly disappears. In this study lightning source is modeled by using current source of amplitude 20kA in parallel with series RLC branch of 400ohm to represent surge impedance of the tower. When direct stroke occurred the voltage in increased to 17MV and then decayed to about 1MV.

Indirect Stroke

This will happen if the lightning strike shield wire or tower structure.

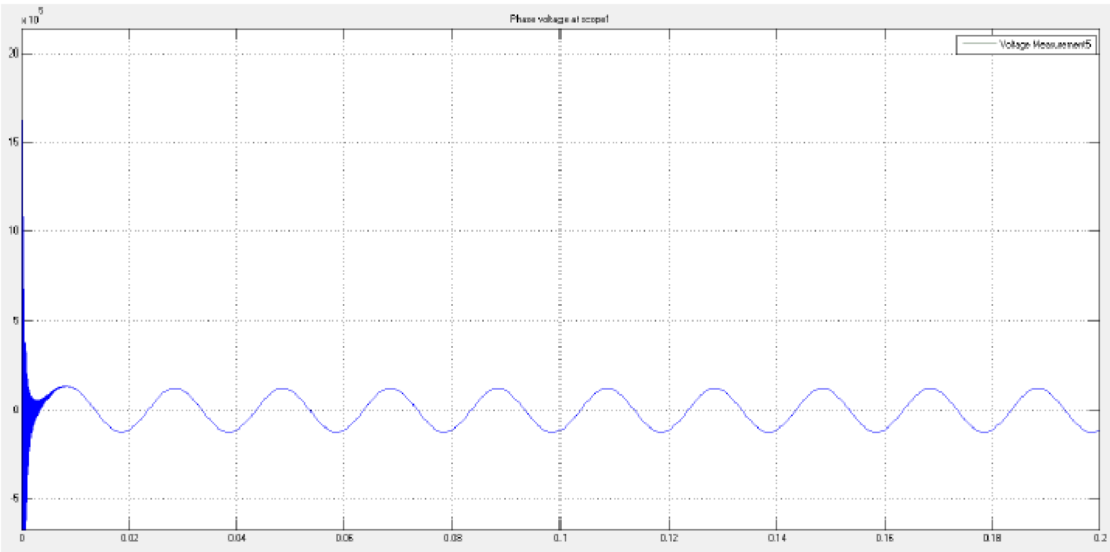


Figure 4.11 Plot of phase voltage at scope 1 under indirect stroke

From this it can be concluded that when lightning stroke happens to shield wire or tower body, operating voltage or phase voltage will be decreased as insulator voltage goes beyond operating voltage there by reducing phase voltage to very small value.

4.3 Transient Simulation of the Transmission Line

The model described in this section illustrates the protection system of series compensated transmission system that represents transmission line transmission line which is protected by MOV. The model represents a three-phase, 50 Hz, 500 kV power system transmitting power from a power plant consisting of sixteen 375 MVA generators to an equivalent system through a 220 km transmission line. The transmission line is split into two 245km and 175km lines connected between buses B1, B2, and B3. To increase the transmission capacity, each line is series compensated by capacitors representing 50% of the line reactance. The line is also shunt compensated by a 330 MVAr shunt reactance. Each series compensation bank is protected by metal-oxide varistors (MOV). The two circuit breakers of line 1 are shown as CB1 and CB2.

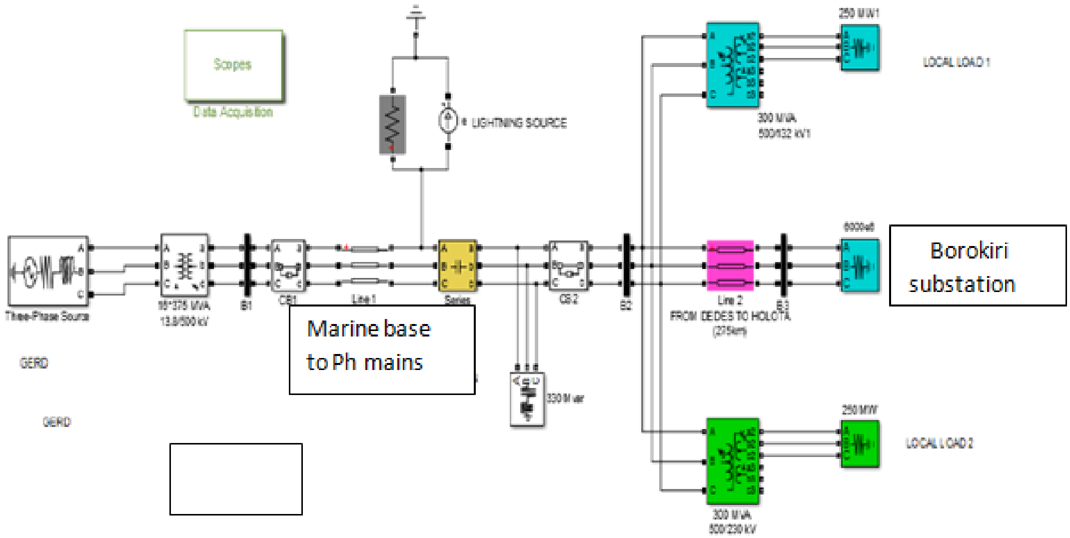


Figure 4.12 MATLAB model for transient analysis

Lightning Transient Simulation

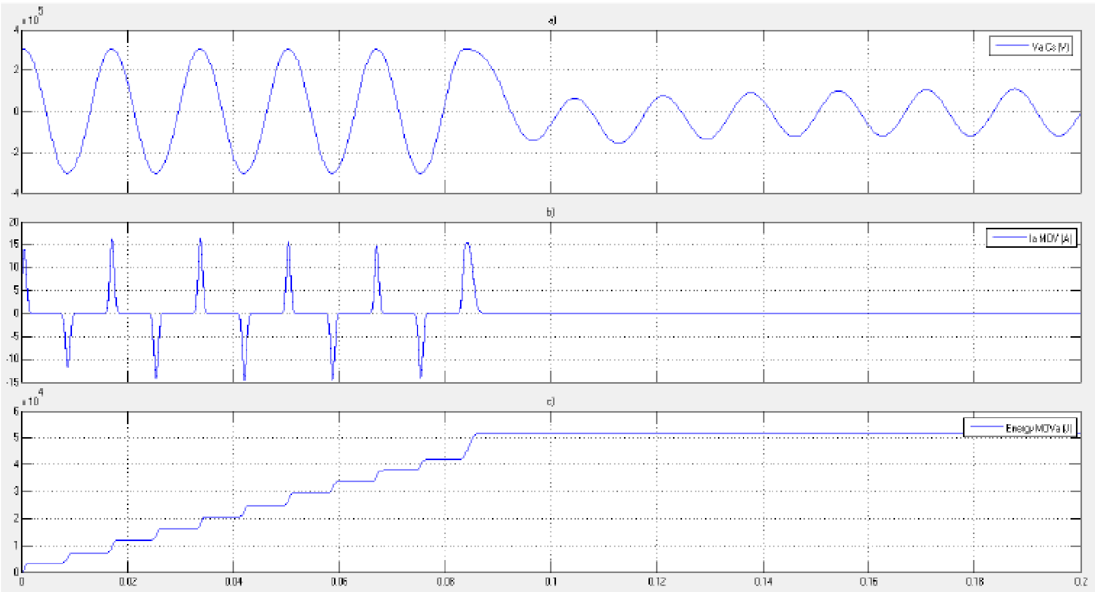


Figure 4.13 Lightning transient simulation result

a. Series capacitor voltage,

b. MOV current

c. MOV energy for lightning study

The simulation starts in steady state.

At the t = 1 cycle, lightning stroke is applied and the fault current reaches 10 kA. During the fault, the MOV conducts at every half cycle and the energy dissipated in the MOV builds up to 5MJ.

At t = 5 cycles the line protection relays open breakers CB1 and CB2 and the energy stays constant. At the breaker opening time, the fault current drops to a small value and the line and series capacitance start to discharge through the fault and the shunt reactance. The fault current extinguishes at the first zero crossing after the opening order given to the fault breaker (t = 6 cycles). Then the series capacitor stops discharging and its voltage oscillate

4.4 Simulation of Transmission Line Protected from Sending and Receiving End by MOV

Below figure shows a 132 kV transmission system with two transmission line arrester placed at the sending end and the receiving end of the line. Over the system a lightning surge of 20 kA was induced, and the resulting simulation was carried out by using MATLAB software. A 132 kV transmission system feeds a load (2000MW) through a 220 km transmission line. The result of the simulation shows the temporary increase in current at MOV which is done by the lightning when 20 kA lightning current is applied. On the other hand, the temporary increase in voltage in each arrester.

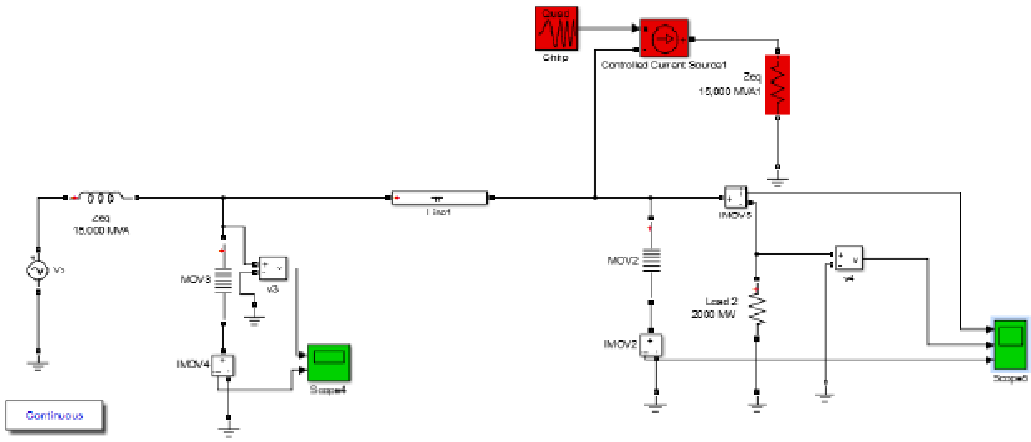


Figure 4.14 Model to simulate TL protected by MOV

Here the generation and load are both protected by metal oxide varistors (MOV). The MOV consists of 30 columns protecting the components at 2.5 times its rated voltage. Hence protection voltage is 2.5*132kV=330kV.

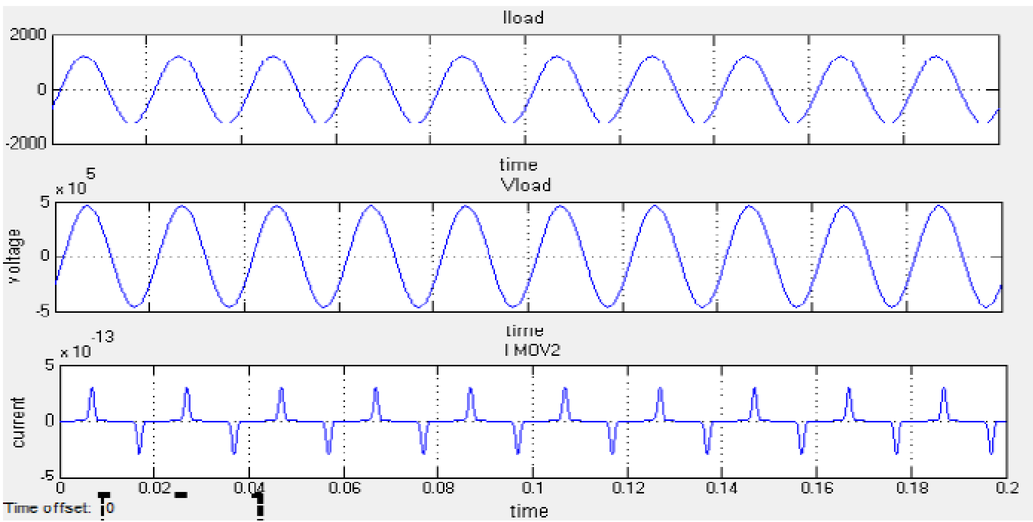


Figure 4.15 Load current, load voltage, and MOV current under normal condition

If stroke happens at receiving end of TL, the resulting current and voltage wave form (without employing MOV Surge arrester) are represented by Fig 4.10. Initially, the current will raises up to 10kA and the voltage will raises up to 4MV.

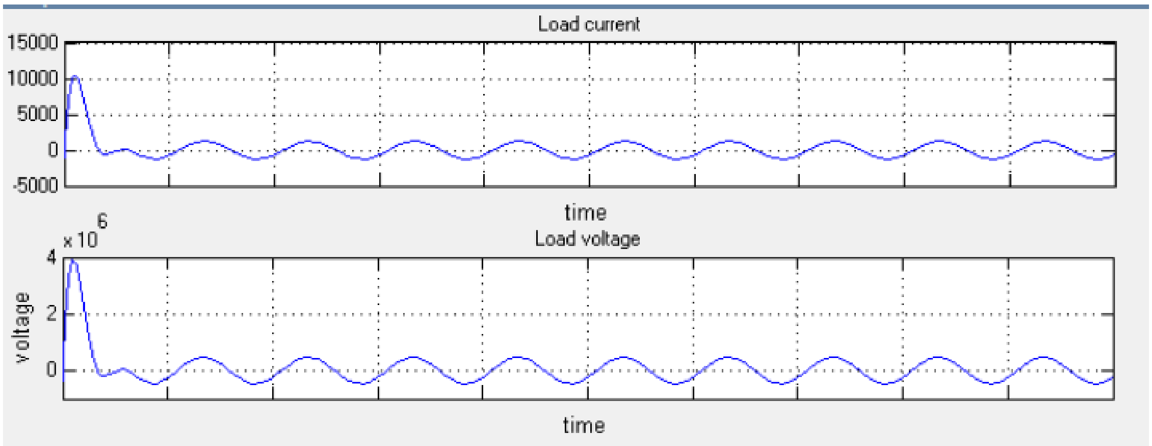


Figure 4.16 Load current, load voltage, and MOV current when lightning strike the line

If MOV Surge arrester is employed to the system at sending and receiving ends, the current and voltage wave forms look like the following. Initially when the current and voltage wave go to high value, the MOV will conduct until the value drops to tolerable value.

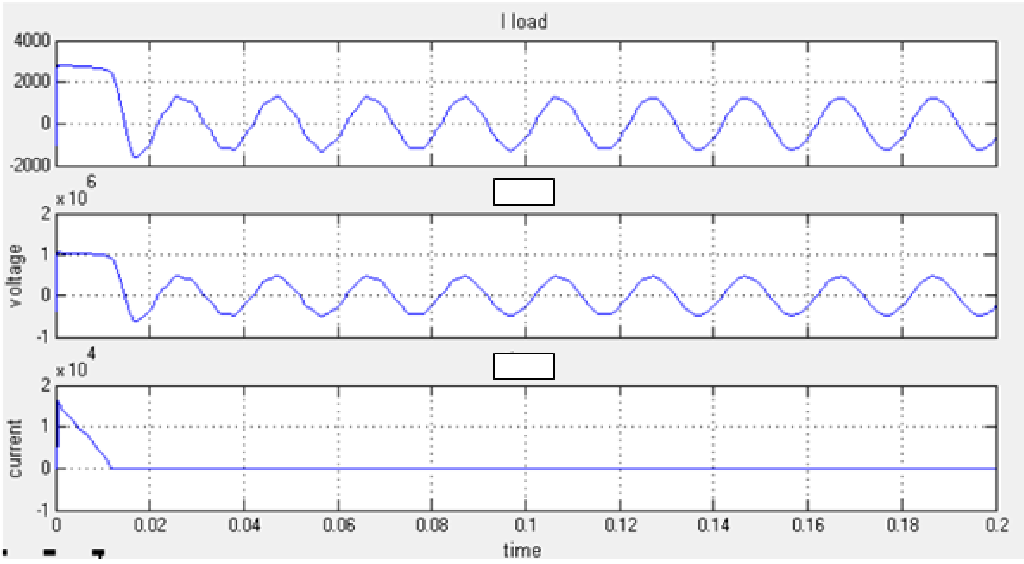


Figure 4.17 Load current, load voltage, and MOV current after employing Surge arrester

5. Conclusion and Recommendations

5.1 Conclusion

An assurance of reliability of work of electric power systems needs detailed analysis of exploitation risks of all devices. Overhead high voltage transmission lines have special meaning in such systems. Among exploitation risks lightning over voltages have the most important influence on insulation coordination and optimization of electric withstand of insulation systems of electric power lines. Especially lightning over voltage, which can be generated in overhead lines, need detailed analysis; because of the risks they pose on the system. They might create danger for insulation systems of transmission lines and electric power substations. This research covers the range of risk problems which concern lightning over voltages in electric power lines, protected by shielding wires and metal oxide surge arresters. Progress in insulation coordination specially follows from the development of possibility of computer simulation of over voltages risks of insulation systems. Therefore, the mathematical Modelling of devices and phenomena which have influence on courses and maximal values of lightning over voltages has special meaning.

The results of computer simulations of lightning over voltages in overhead lines are significantly dependent on mathematical models of towers and earthing systems. The current strokes with large values during lightning strokes to shielding wires flow to the earth through tower with different construction and dimensions. The results of analysis of protection effectiveness of overhead lines by shielding wires based on the c power line model confirms, that phase conductors of overhead lines protected by shielding wires can be risked by directly lightning strokes with small currents. The analysis of lightning over voltages in overhead lines should take into account both over voltages generated during strokes to shielding wires as well as to phase conductors with maximal lightning currents which can be determined on the basis of the line construction analysis. The results of computer simulations of lightning over voltages in overhead lines show that over voltages which create risk to the earth insulations systems of lines and transformers

Lightning studies and analyzes on EPS performance, especially on Transmission Lines are crucial for safe and reliable power supply. In this paper a novel methodology for simulation of lightning strikes is presented. The methodology uses an interface between MATLAB-ATP. Their performance was tested varying the lightning impact point. Thus, data bases considering the transmission line total length are built. As the main contribution of this work, it is related to the building databases for specific conditions, reducing the operation time that some cases can be unnecessary. Only adjusting specific features in the input data, systematic simulations can be automatically developed.

In these conditions the surge arresters work on the beginning and practically linear parts of the current-voltage characteristics and practically have no influence on over voltage courses and their maximal values. The analysis shows that over voltages generated in the phase conductors during lightning strokes to the shielding wires are limited to values which are safe for insulation systems. The analysis also shows that the shielding wires, which are installed in overhead lines in the lightning protection engineering of electric power devices, do not assure the full protection of line phase conductors against direct lightning strokes. Lightning strokes with small currents can stroke to phase conductor in spite of shielding wires. The over voltages generated in this condition which exposures insulation systems of lines and devices in power substations can increase the values of over voltages which are generated during lightning strokes to shielding wires. Over voltages generated during lightning strokes with small values to phase conductor are limited by use of metal oxide surge arresters which are installed on the end of the overhead lines and installed in power substations. The computer simulation of lightning over voltage reveals that shielding wires and surge arresters create the complex overvoltage protection of insulation systems of overhead transmission lines. The maximum value of lightning over voltages to which insulation systems of lines and electric power substations exposed to depends on the construction of overhead lines and parameters and localization of surge arresters. Therefore, the improvement of overvoltage protection systems of overhead transmission lines and power substations is possible.

5.2 Recommendations

Over voltages which are generated during lightning discharges to overhead lines can cause flashover in air insulation systems and can overload equipment connected to it. Flashovers have a significant influence on the courses and maximum values of lightning over voltages. Therefore, based on finding of this research the researcher recommends to divide transmission line in to grades per 100km and employ surge arrester so that the effect of lightning strokes that could arise at far distant from substation cannot cause problem to substation equipment.

5.3 Contribution to Knowledge

This work combines a MOV and gas active arc extinguishing into a hybrid component. Providing a space-saving circuit protection device, the two technologies can be packaged in a familiar MOV radial package, thus providing a drop-in replacement option. Putting a MOV and a gas active arc extinguishing together offers lower leakage over the life of the MOV, resulting in a predictable failure mode and eliminating harmful watt loss heating. With this approach, the line voltage appears largely across the extremely low-leakage under normal operating conditions. This research introduces a lightning protection device, that is simple, the installation is convenient, and when the line is struck by the lightning, lightning current can be leaked into the ground quickly, and simultaneously the high-speed airflow is generated to extinguish power-flow current, so that the transmission lines is effectively protected and the power supply reliability is improved.

5.4 Future Works

Based on the simulation study done in this research to study the gas active arc extinguishing and lightning protection for transmission lines, it is very important if computer soft wares like Electromagnetic Transient Propagation (EMTP) and Power System Computer Aided Design (PSCAD) are used in future study. These soft wares provide an alternative way to bring the precise result in study of lightning protection level of high voltage transmission line. Again, in this research as the line is not energized and as it is new, there is no recorded data about its lightning stroke history. Therefore, all analysis is made by using scientific assumption used by collecting international standards used in lightning protection systems by referring to contractor manual. For future if somebody wants to do research on this transmission line it is important to consider this actual datum.

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