POWER SYSTEM ENHANCEMENT BY SIMULTANEOUS AC- DC POWER TRANSMISSION

Case study (Asella to Segure +15 kV transmission line)

by

Desalegn Bayecha Tufa

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A thesis submitted to

The department of Electrical power and Control Engineering

School of Electrical Engineering and Computing

Presented in Partial Fulfilment of the Requirement for the Degree of Master's in Electrical Power Engineering

Office of Graduate Studies

Adama Science and technology University

Adama, Ethiopia

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APPROVAL SHEET

We, the undersigned, members of the Board of Examiners of the final open defense by Desalegn Bayecha have read and evaluated his study entitled ***"power system enhancement by simultaneous AC- DC power transmission (Case study: Asella to Segure +15 kV transmission line)"*** and examine the candidate. This is, therefore, to certify that the study has been accepted in partial fulfillment of the requirement of the Degree of Masters of Science in Electrical Power and Control Engineering Program (Specialization in Electrical Power Engineering).

Advisor	Signature	Date
__________________	_________	_______________
Chair Person	Signature	Date
_______________	________________	_______________
Internal Examiner	Signature	Date
_______________	________________	_______________
External Examiner	Signature	Date
______________	______________	______________

DECLARATION

I certify that study work titled ***"power system enhancement by simultaneous AC- DC power transmission (Case study: Asella to Segure +15 kV transmission line)"*** is my own work. The study or any part has not been submitted elsewhere for the award of any degree/diploma. Where material has been used from other sources it has been properly acknowledged / referred.

Desalegn Bayecha ______________________________

Student name signature

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Name of major advisor

Dr. Tefera T. Y. (Assistant professor) 13/September/2019

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At the beginning I would like to thank the Almighty and cheerful God for giving me this chance of academic advancement. I would like to take this opportunity to forward my deepest gratitude to my advisor Dr.Tefera Y.T. (Assistant professor) who contributed a lot for my achievement. I would also like to bear my gratitude to employees of EEU & EEP for their friendly and dedicated cooperation.

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ABSTRACT

Due to the increasing of power demand there are requirements for the construction of new transmission lines. But right of way problems are hindering the erection of transmission lines. In transmission line the power flow is much lower than its thermal limit due to the constraints related to stability. So instead of erecting new lines the existing AC lines are modified to simultaneous AC-DC lines to increase their power transfer capability and enhancing the transient stability close to their thermal limits.

This study will give the feasibility of improved power transfer for Asella to Segure +15 kV power transmission by simultaneous AC-DC transmission and analysis the cause of power loss on transmission line. It is possible to convert existing AC transmission line into a simultaneous AC-DC power transmission line without the alterations of conductors, insulator strings and towers structure of original line by using only the converter at sending end and receiving end of transmission. The sending end side converter is used to convert the existing AC voltage into DC voltage and on the receiving end side there is other converter which is used to convert the converted DC voltage sent from sending end to AC voltage. In addition, with the two converter station in this study, four zigzag transformers are added to the system for converting pure AC line into simultaneous AC-DC line. MATLAB Simulink software is used for simulation purpose in the study. The study conducted the simulation analysis considering only transmission line, without including the whole system from generator to infinite bus. The simulation result shows the stability of power system for both existing system and the new system under no fault condition.

Key-Words: - HVAC transmission, HVDC transmission, MATLAB SIMULINK, FACTs, Simultaneous AC-DC power transmission, stability enhancement techniques.

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ACRONYMS AND LIST OF ABBREVIATIONS

AAAC All-aluminum-alloy conductor

AAC All-aluminum conductor

AC Alternate current

ACAR Aluminum conductor, alloy-reinforced

ACSR Aluminum conductor, steel-reinforced

EEP Ethiopian electric power

EEU Ethiopian electric utility

FACTS Flexible AC transmission systems

HVAC High voltage alternate current

HVDC High voltage direct current

IEEE Institute of electrical and electronics engineers

MATLAB Matrix Laboratory

SIL Surge Impedance Loading

SSSC Static synchronous series compensator

SSR Sub synchronous resonance

TCSC Thyristors Controlled Static Series Compensator

TSSC Thyristors Switched Series Capacitor

VDCOL Voltage dependent current order limiter

CHAPTER ONE

INTRODUCTION

1.2 Background

The stability of power system is the great issue of power system planners and operators. Unfortunately, the load impressed on the system fluctuate in random manner. In practical power system there is assumption that the power generated must equal to demand power including losses to ensure constant speed and operation frequency. In case during power transmission from generation terminal to distribution there is a factor that affect the power not to deliver the generated amount of power among this power system instability is one factor. It is therefore completely impossible to accomplish the equilibrium of power generation and demand power due to the stability factor. An excess of real power generation will always manifest this mismatch results in frequency fluctuation which brings system instability.

The demand of electric power having steady growth power is but the availability of power often not available at the increasing load centers and remote locations. On the environmental acceptability, and the economic concerns also giving the availability of energy are the factors which determining all these locations. It is well known that whole world requires the large amount of power with low loss because year by year the growth of all power consumers such as industries, commercial and residential part of the world demanding power for their growth.

The load of the system may change gradually or unconditionally due to sudden switching operation or occurrence of faults followed by tripping of lines, circuit breaker or loads. Here because of stability considerations, it is very difficult to load long high voltage AC transmission lines to their thermal limits as given proper margin which kept against transient instability. Among all the limiting factors that normally set a ceiling on the load carrying capability of a particular transmission line, the major factors mostly influential are thermal limit, voltage drop limit and steady state stability limit [1]. Therefore, power system planners and operators are in continuous search for the effective ways to exploit the full capacity of the existing transmission lines. The necessity of use of the power transmission systems at their highest capacity is increasing day by day due to monotonically increasing demand and limitations of constructing new transmission infrastructures for increasing the transmission capacity of existing transmission line.

The power transfer can be increased through constructing new transmission line and operating it in parallel with the existing transmission system. The effective and quickest solution to solve the power transmission problem is the upgrading of transmission capacity of existing transmission lines. To increase the transmission capacity of AC transmission line series and shunt compensation are commonly used. The main disadvantage of series compensation is sub synchronous resonance which is close to the natural frequencies of mechanical oscillations of power generating equipment. This Sub synchronous resonance may cause the mechanical failure and loss of synchronism of generating unit. Flexible AC transmission systems such as Static synchronous series compensator, Sub synchronous resonance, Thyristors Controlled Static Series Compensator, and Thyristors Switched Series Capacitor are widely used to increase the stability of existing high voltage transmission system and it reduces the risk of SSR to some extent. The other approach to increase the stability of an existing transmission system is the simultaneous AC-DC power transmission system.

In simultaneous AC-DC power transmission system conductors will be allowed to carry alternating current along with the direct current superimposed on it at a time. AC transmission system can be converted to simultaneous AC-DC system without bringing any change in the existing infrastructure of the transmission lines, such as transmission tower, string, insulator.

1.2 Statement of the problem

Pure AC transmission system has different problem on the transmission system such as power instability, corona loss, high fault occurrence and power interruption. The transmission line from Asella to Segure is +15kv transmission line it face power interruption problem and instability problems all the time since it is pure AC transmission thus to enhance the transient stability of this transmission the simultaneous AC-DC transmission system gives the benefit of power transmission instability without constructing separate DC transmission line.

1.3 Objectives

1.3.1 General objective

The main objective of this study is to enhance the transient stability of the transmission line by simultaneous AC-DC power transmission without changing the existing transmission line equipments such as transmission line tower, insulator, power cable, and without altering structure of the transmission line.

1.3.2 Specific objectives

- ✓ To compare existing pure AC transmission system with simultaneous AC-DC power transmission system.
- ✓ To compare existing transmission loss with new proposed system
- ✓ To analyze fault effect of simultaneous AC-DC transmission

- ✓ To analyze stability in terms of critical clearing time for a fault at different locations.

1.4 Methodology

In this study, a methodology or a model based on System dynamic approach has been develop to make more energy available at affordable prices and minimizing power losses to enable all people to use modern energy to meet their basic needs. To slow overall growth of energy consumption through conservation and energy efficiency improvement and to make energy sources more environmentally sustainable.

Data collection: The study has been started from literature review to get the concept behind the study and the secondary data was collected for the study from Asella distribution substation with existing capacity of 25 MVA. Some secondary data has been collected by the direct involvement of the researcher and workers of EEU Asella substation district for the purpose that is intended to be done. During the site survey, the primary data necessary for this study were the average demand, peak demand, power interruption time Kwh purchased and peak load.

Strategy: In order to collect quantitative information at distribution station, observation and document analysis methods employ as alternative techniques of obtaining information on the subject matter. The collected data has been analyzed using excel and MATLAB/Simulink in order to show briefly the collected data before and after analyzed.

Design: Based on the information obtained from this study, Modeling and analyzing the technical details of simultaneous ac-dc transmission system has been done. To find solutions to power stability problems different method used and the opportunities available to enhance integrated approaches on power stability improvements for Asella to Segure transmission line. To achieve this objective both quantitative and qualitative methods have been employed.

1.5 Scope of the study

This studies show the transmission power stability enhancement for pure AC voltage transmission system with the help of converter on both sending and receiving side of transmission system. It will evaluate sending end and receiving end pure AC transmission in comparison with the AC- DC transmission receiving end and sending end voltages and current through Simulink in MATLAB. Additionally, from MATLAB simulation results both active and reactive power changes are shown with comparison of both system the existing one and the simultaneous AC-DC transmission system.

1.6 Significance of the study

Currently in the world the flexible AC transmission system (FACTS) concepts based on applying power electronic technology to existing AC transmission system improve stability to achieve power transmission close to its thermal limit. The other concept of power system stability enhancement is by simultaneous ac-dc power transmission system which is to utilize the advantage of FACTs and parallel ac–dc transmission by loading the line close to its upper thermal limit without affecting the existing transmission line only by adding two converters on both sending and receiving side of transmission line.

This study will be important due to

- ✓ The study gives the feasibility of converting AC line into simultaneous AC-DC power transmission line to get the advantages of parallel AC-DC transmission to enhance power stability
- ✓ Sending end and receiving end voltage and current is analyzed.
- ✓ Real and reactive power was shown.
- ✓ The effect incidents on existing transmission was shown.
- ✓ The result shows the stability of power system when compared with only AC transmission.

1.7 Limitations of this study work are as follows:

a) Some approximations are made in the model development process which gives rise to some errors in the results obtained through the developed model.

b) Even though it is possible to increase the stability by simultaneous ac-dc transmission it is more complex for huge transmission line

c) The analytical model for transient stability analysis of simultaneous AC-DC system is cannot be applicable for multi-machine system.

d) The stability model is applicable only for the 3-phase to ground fault at different locations of simultaneous AC-DC transmission system.

e) AC side and DC side harmonics are not considered in the developed model of simultaneous AC-DC system.

1.8 Organization of the study

There are five chapters in this study and a brief description of all the chapters is presented below.

Chapter One

The introductory chapter of the study consists of introduction, objectives, methodology and organization of the study.

Chapter Two

This chapter mainly presents a brief literature review on different types of power transmission systems along with their merits, demerits and limitations, focusing on the specific goal of this work and an elaborate description is presented on simultaneous AC-DC system. Before going through the simultaneous AC-DC system, this chapter also briefly discusses the existing power transmission system such as HVAC, HVDC systems.

Chapter Three

This chapter deals with the development of analytical model for simultaneous ac-dc system through the existing AC transmission line and data analyzing of the study.

Chapter four

Presents the Simulink model development and result discussion of the thesis in case of pure AC transmission system and the proposed system which is simultaneous AC-DC power transmission.

Chapter five

This chapter discuss the overall conclusion of the study, future work of the study and limitation of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical background of the study

The flexible AC transmission system (FACTS)concepts, based on applying state-of-the-art power electronic technology to existing AC transmission system, improve stability to achieve power transmission close to its thermal limit [4]- [7]. The ability of FACTS controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle and the damping of oscillations at various frequencies below the rated frequency. These constraints cannot be overcome, while maintaining the required system stability, by mechanical means without lowering the useable transmission capacity [5] [10].

In stability point of view, DC link parallel operation with AC transmission line is more beneficial than AC-DC parallel transmission lines. In case of AC-DC parallel system the DC link power flow is highly controllable through converter operation. The effect of controlled DC link on system stability and damping also depends on system operating conditions. A HVDC controller which improves stability at one operating condition may have detrimental effect at other operating conditions. Therefore, an adaptive control mode would be needed for the HVDC controller to improve system stability over a wide range of system performance [5] [7].

Moreover, the transmission of pure AC system is much lower than the thermal limit of the line but for a given percentage of DC mix, what would be the limiting values of the ratios between the current of pure AC system and the thermal limit current of the conductor and between the total AC and DC currents of a simultaneous AC-DC system and the thermal limit current of the conductor, for which the power system stability enhancement by simultaneous AC-DC system is possible, is not yet reported in the literature. The basic proof justifying the simultaneous AC–DC power transmission is explained in an IEEE paper "Simultaneous AC-DC power transmission'', by K. P. Basu and B. H. Khan. In the above reference, simultaneous AC–DC power transmission was first proposed through a single line circuit AC transmission line. In case of Mono-polar DC transmission system there is a ground used as return path. There were certain limitations due to use of ground as return path.

Moreover, the instantaneous value of each conductor voltage with respect to ground becomes higher by the amount of the dc voltage, and more discs are to be added in each insulator string to withstand this increased voltage. However, there was no change in the conductor separation distance, as the line-to line voltage remains unchanged. In this paper, the feasibility study of conversion of a double circuit AC line to composite AC-DC line without altering the original line conductors, tower structures, and insulator strings has been presented.

All the studies conducted on simultaneous AC-DC power transmission system are based on numerical simulation. However, to investigate the behavior of a system comprehensively an appropriate mathematical model is a necessary. This study presents the power system enhancement by simultaneous AC-DC power transmission by simultaneous AC-DC power transmission**.**

2.2 HVAC transmission systems

The main target behind the electric transmission system is the interconnection of the electric energy producing power plants or generating stations with the loads which is most of the time located hundreds of kilometer away. A three-phase AC system is used for most transmission lines. The operating frequency varies from is 60 Hz in the North America and 50 Hz in other continents like Ethiopia. The three-phase system has three phase conductors. The system voltage is defined as the rms voltage between the conductors, also called line-to-line voltage. The voltage between the phase conductor and ground, called line-to-ground voltage, is equal to the line-to-line voltage divided by the square root of three [26].

The main significance of using high-voltage transmission lines is that, high-voltage transmission lines can be used to transport power over long distances much more efficiently than lower-voltage distribution lines for two main reasons. First, high-voltage transmission lines take advantage of the power equation, that is, power is equal to the voltage times current. Therefore, increasing the voltage allows one to decrease the current for the same amount of power. Second, since transport losses are a function of the square of the current flowing in the conductors, increasing the voltage to lower the current drastically reduces transportation losses. Plus, reducing the current allows one to use smaller conductor sizes [25] [6]. The industrial growth mainly depends on the energy availability and requires energy particularly electrical energy for its development. The source of power that mainly includes the natural resources have been depleted to a large extent and thus sources of energy other than Hydro and thermal are required to meet the demand for the rapid rate of consumption. The increasing demand has led to the increase in generation and transmission facilities. Thus high voltages are required for transmission. A simple AC transmission system is presented in figure below where a generating unit evacuates power to an infinite bus through a long transmission lines.

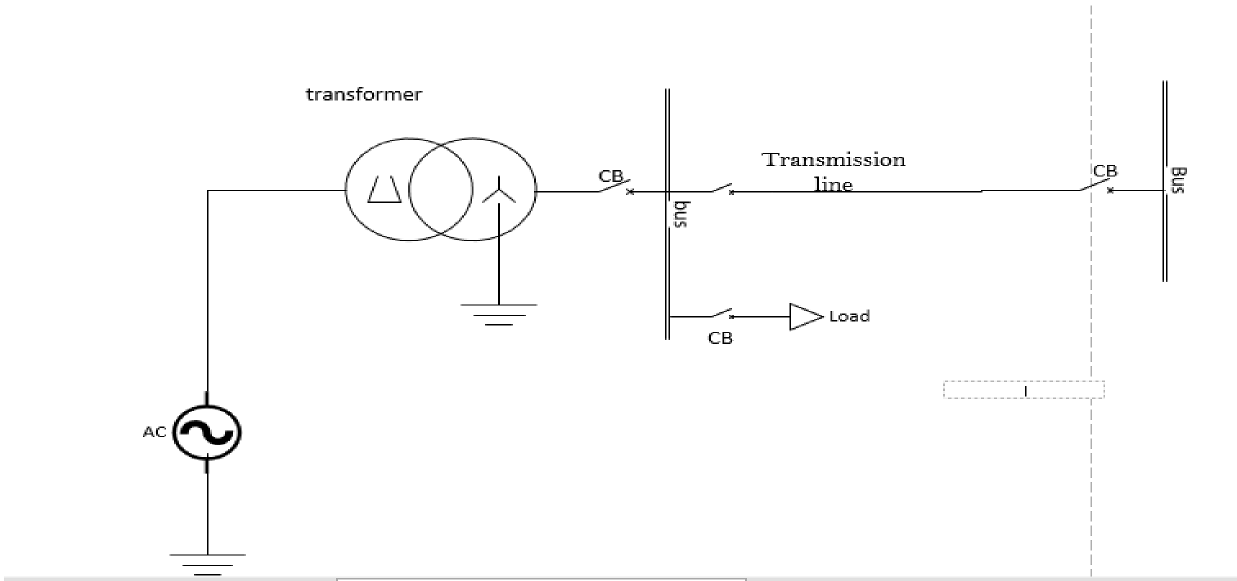


Figure 2. 1: AC power transmission system

High voltage alternating current transmission system is being used from very early times of the electrical power. As we know that there are many different industries and domestic areas too which needs the electric power. In order to cope up with the increasing demand of the era high voltage supply became the necessity for setting up the equilibrium between demand and the supply part. But as we all know, HVAC transmission lines cannot be loaded to their thermal limits, it will not come up with the supply and instability occurs in the voltage. There are certain disadvantages of this system or can be said as the problems which encounters while using the HVAC system for the transmission of electrical power they are as follows [2] [5].

- Under the conductor lines, there is a high volume of electrostatic field.
- There are Corona problems occurring in the system resulting in audible noise.
- There are switching over voltages in AC systems which causes more problems than lightning over voltages.
- In AC transmission, Ferro resonance also occurs in the system in which impedance behaves like resistance.
- Compensation done in the AC transmission system induces sub synchronous resonance.
- There is increment in current density due to increase in the loading of the line using series capacitor.
- In AC systems conductor carries high surface voltage gradient over it.
- Increased Short-Circuit currents

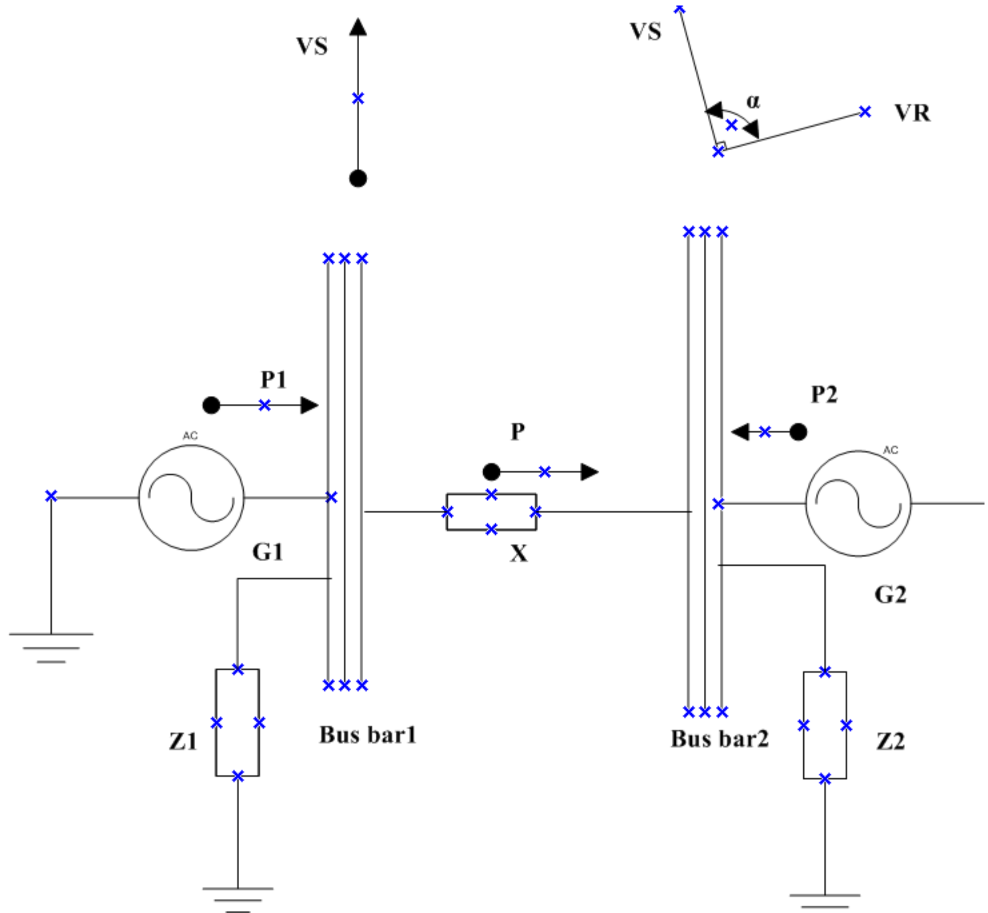


Figure 2. 2 Schematic diagram of AC transmission system

$$P_1 = \frac{V_S{}^2}{Z_1} + P \tag{2.1}$$

$$P_2 = \frac{V_R{}^2}{Z_2} - P \tag{2.2}$$

The real power (MW) flow between two buses is obtained by

$$P = \frac{V_S V_R}{X} sin\alpha \tag{2.3}$$

Where ,P is Real power in MW

V_S is Sending − end voltage

V_R is Receiving − end voltage

X *is* Line impedance between buses

α is Angle delta between bus voltage

2.3 HVAC transmission Line Components

The HVAC power transmission line is one of the major components of an electric power system. Its major function is to transport electric energy, with minimal losses, from the power sources to the load centers, usually separated by long distances. The main purpose of any configuration of transmission tower is to carry the overhead transmission line conductors and earth wires above the ground during design every tower type has to:

- ✓ Withstand all the variety of forces that it is exposed to with regards to the. These forces include normal air loads, extreme wind loads, ice loads, loads during erection and maintenance and the changing of conductor sag when the conductor expands and contracts with normal daily current loads. In some cases, tower designs must with stand loads imposed by extreme conditions such as in earth quake, cyclone and high humidity areas [27].
- ✓ Maintain electrical clearances between live conductors and any earthed body in the vicinity of the tower such that the energized lines do not include any hazardous voltage that could render the operation of the transmission lines dangerous to the environment and the public.
- ✓ Provide a proper a path for earth fault during lightning. Hence, the tower must also exhibit low resistance to ground during transient lighting overvoltage.

The basic components of a transmission line are the supports (towers), insulators, and the conductors. Operation of a transmission line is also dependent on fault detection equipment, voltage control equipment, and the bus arrangement at the terminals. A single transmission circuit is comprised of three phases. Each phase may consist of a single conductor, or each phase may be bundled in that it consists of two or more conductors suspended from the same insulator string.

The latter design is more common, particularly at the high voltage levels, because it minimizes power loss due to corona. Conductors are always bare in order to allow maximum heat dissipation. In addition to the phase conductors, one or two grounded shield wires are also strung along the top of the tower in order to protect the phase conductors from lightning strokes.

Today, almost all conductors utilize aluminum in their construction because aluminum is plentiful, relatively inexpensive, and lightweight. The most common types of conductors are: all-aluminum conductor, all-aluminum-alloy conductor, aluminum conductor, steel-reinforced, and aluminum conductor, alloy-reinforced. Depending on network requirement of power system, the tower may be designed to cater for single three phase circuit, double three-phase circuit, multiple voltages circuits and with direct current transmission either mono polar, bipolar construction. In certain countries, due to land constraints new transmission lines always built on double circuit towers and old single circuits are upgraded to double circuit to optimize the use of land settlement [27].

2.4 High Voltage Direct Current Transmission

In a High Voltage Direct Current Transmission system, electricity is taken from an AC power network, converted to DC in a converter station and transmitted to the receiving point by a transmission line or cable. It is then converted back to AC in another converter station and injected into the receiving AC network. The additional expense of conversion is the main reason that HVDC is normally only used for overhead bulk transmission purposes when the transmission distance is substantial; a good rule of thumb is that HVDC can be considered as a design alternative to AC transmission when the distance is in excess. High voltage direct current transmission enables the power flow to be controlled rapidly and accurately, and improves the performance, efficiency and economy of the connected AC networks. It requires only two conductors rather than three and are therefore less expensive to build due to narrower rights of way and tower requirements [3]. The drawback mainly included the fact that DC power at low voltage was difficult to be transmitted over long distances, hence giving rise to high voltage line carrying alternating current. With the development of high voltage rating values, it was possible to transmit direct current power at very high voltages over long distances, known as the high voltage direct current transmission systems.

2.4.1 Components of HVDC transmission

High voltage direct current transmission has different components from which the followings are well known and described briefly.

i. Converters:

The major components of a high voltage direct current transmission system are converter stations where conversions from AC to DC (Rectifier station) and from DC to AC (Inverter station) are performed. A point to point transmission requires two converter stations. The role of rectifier and inverter stations can be reversed (resulting in power reversals) by suitable converter control.

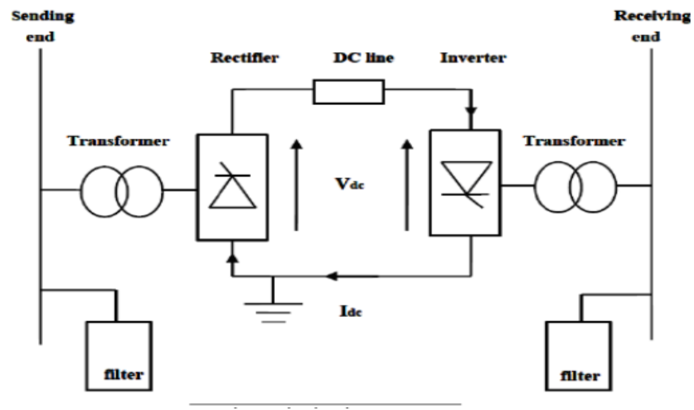


Figure 2. 3 Basic HVDC transmission system converter stations

ii. **Smoothing reactors:** A sufficiently large series reactor is used on direct current side to smooth DC current and also for protection. The reactor is designed as a linear reactor and is connected on the line side, neutral side or at intermediate location. It is an oil filled oil cooled reactor having a large inductance

Smoothing reactors serve the following purposes.

1. They smooth the ripples in the direct current.
2. They decrease the harmonic voltage and current in the DC lines.
3. They limit the fault current in the DC line.
4. Consequent commutation failures in inverters are prevented by smoothing reactors by reducing the rate of rising of the DC line in the bridge when the direct voltage of another series connected voltage collapses.
5. Smoothing reactors reduce the steepness of voltage and current surges from the DC line. Thus, the stresses on the converter valves and valve surge diverters are reduced.

iii. Converter Transformer

The converter transformer converts the AC networks to DC networks or vice versa. They have two sets of three phase windings. The AC side winding is connected to the AC bus bar, and the valve side winding is connected to valve bridge. These windings are connected in star for one transformer and delta to another.

The AC side windings of the two, three phase transformer are connected in stars with their neutrals grounded. The valve side transformer winding is designed to withstand alternating voltage stress and direct voltage stress from valve bridge. There are increases in eddy current losses due to the harmonics current. The magnetization in the core of the converter transformer is because of the following reason

1. The alternating voltage from AC network containing fundamentals and several harmonics.

2. The direct voltage from valve side terminal also has some harmonics.

iv. Harmonic filters

There are three types of filters used which are

a. **AC Filters:** These are passive circuits used to provide how impedance, shunt paths for AC harmonic currents. Both tuned and damped filter arrangements are used.
b. **DC Filters:** These are similar to AC filters and are used for the filtering of DC harmonics.
c. **High Frequency Filters:** These are connected between the converter transformer and the station AC bus to suppress any high frequency currents. Sometimes such filters are provided on high-voltage DC bus connected between the DC filter and DC line and also on the neutral side
d. **Reactive power supplies:** Converter stations require reactive power supply that is dependent on the active power loading. But part of the reactive power requirement is provided by AC filters. In addition, shunt capacitors, synchronous compensator and static VAR systems are used depending on the speed of control desired.

v. **AC circuit breakers** Parallel rather than series operation of converters is likely as it allows certain flexibility in the planned growth of a system. The DC breaker ratings are not likely to exceed the full load ratings as the control intervention is expected to limit the fault current.

2.4.2 Main types of high voltage direct current links

A. Mono polar HVDC link

As the name suggests, monopolar link has only one conductor and return path is provided by permanent earth or sea. The line usually operates with negative polarity with respect to ground so as to reduce corona loss and radio interference.

The earth electrodes are designed for continuous rated current operation and for any overload capacity required in the specific case. The sea or ground return is permanent and of continuous rating. The ground return path has a low resistance and, therefore, low power loss in comparison with a metallic line conductor of economical size and equal length provided the ground electrodes are of proper design. Monopolar line is more ground return saves the cost of the one metallic conductor and losses in it.

Monopolar HVDC links were used only for low power rating and mainly for cable transmission. In some cases, the monopolar lines installed earlier are converted into bipolar systems by adding additional substation pole and transmission pole. Monopolar HVDC line has only the rating equal to half of corresponding bipolar line rating and is; therefore, not economically competitive with ac schemes for s cables longer than 15 km and of power rating of about 250 MW. For such cable transmission high voltage ac scheme is not technically feasible due to economical than a bipolar line because the large charging currents with ac cables beyond thermal limit.

The basic configuration of mono polar link is shown in Figure below; it uses one conductor which may be of positive or negative polarity. The return path is provided by ground. A metallic return may be used in situations where the earth resistivity is too high or possible interference with the underground metallic structures is objectionable.

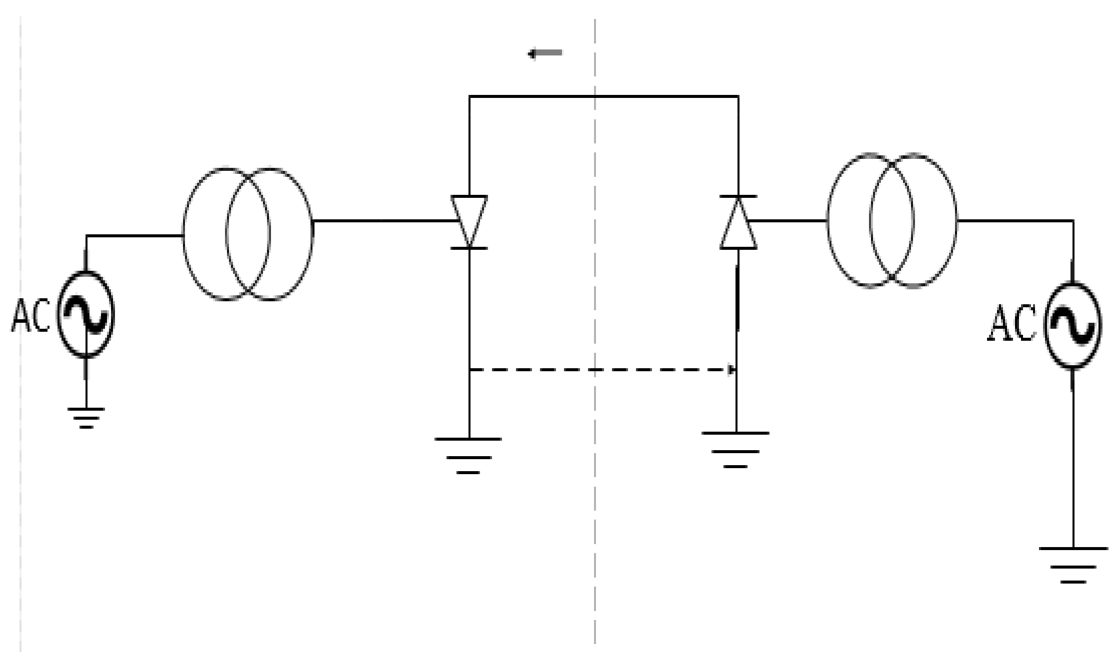


Figure 2. 4 Mono polar HVDC link power transmission system

B. Bipolar HVDC link

This is most widely used DC link for overhead long distance high voltage direct current transmission systems and also for back-to-back HVDC system. This link has two conductors one operating with positive polarity and the other with negative polarity with respect to the earthed tower structure.

There are two converters of equal voltage rating and connected in series at each end of the direct current line. The neutral points, that is the junction between converters may be grounded at one end or at both the ends. If it is grounded at both ends each pole can operate independently. The rated voltage of a bipolar link is expressed as ± 500 V. Power rating of one pole is about half of bipolar power rating. The earth carries only a small out-of-balance current during the normal operation. When the currents in the two conductors are equal, the ground current is zero.

During fault or trouble on one of the lines, the other line along with ground return can supply half of the rated load. Thus continuity of supply is maintained. After taking corrective measures, the system is switched over to normal bipolar operation. Thus the reliability of a bipolar line is equal to that of a double circuit 3-phase line although it has only two conductors instead of 6 for 3-phase line.

In case of fault on one of the poles, the system automatically switches over to monopolar ground return mode supplying 50% of the rated load. Thereafter the system may be changed over to bipolar metallic return mode when the other conductor is used as return conductor.

The bipolar link configuration is shown in Figure below has two conductors, one positive and other negative. Each terminal has two converters of equal rated voltage connected in series on the DC side. The junction between the converters is grounded. Power can flow in both directions as the converters can be operated in both the modes of rectifier and inverter operation.
Bipolar cable is not justified for ratings up to about 500 MW. Recent HVDC cable schemes are bipolar.

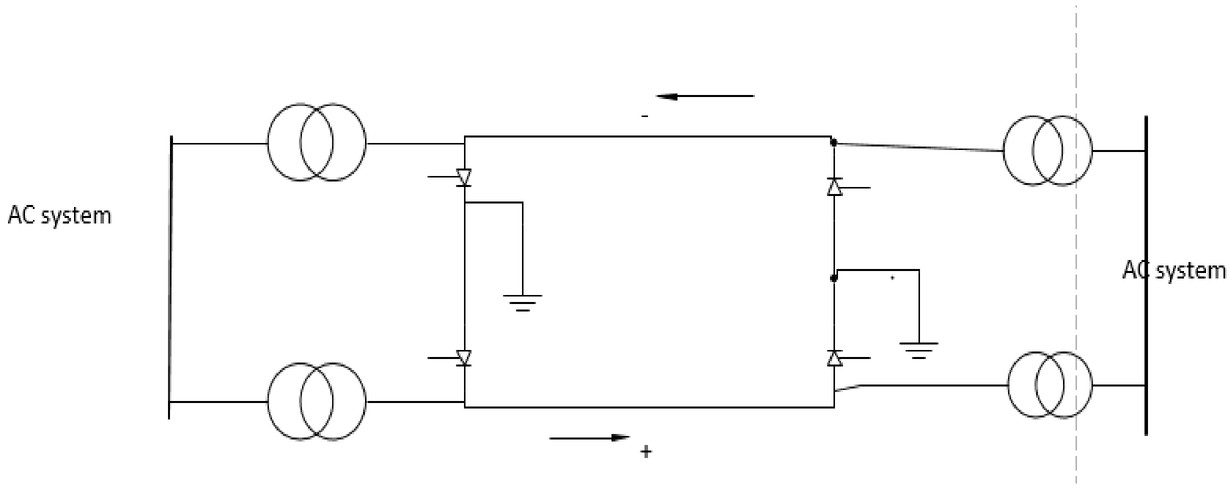


Figure 2. 5 HVDC power transmission system bipolar HVDC link.

C. Homopolar DC Link:

A homopolar link has two or more conductors having the same polarity, usually negative, and always operates with ground as the return conductor. In case of a fault on any one of the conductors, the converter equipment can be reconnected so that the healthy conductor can supply power. Such a scheme is very complicated and is preferred to a bipolar link provided continuous ground return does not pose additional problems.

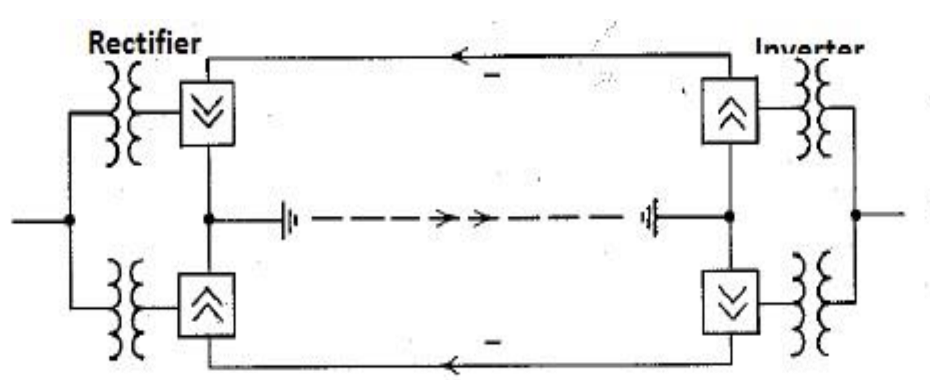


Figure 2. 6 Homopolar DC link

2.4.3 Electrical parameter expression for HVDC

The expression for current, power, voltage and resistance for HVDC system are as follows.

$$I_d = \frac{V_{dor}\cos\alpha \ - V_{doi}\cos\omega}{R_{cr} + R_L + R_{ci}} \tag{2.4}$$

$$P_{dr} = V_{dr} I_d \tag{2.5}$$

$$P_{di} = V_{di} I_d \tag{2.6}$$

$$V_{dr} = V_{dor}\cos\alpha - R_{cr} I_d \tag{2.7}$$

$$V_{di} = V_{doi}\cos\omega + R_{ci} I_d \tag{2.8}$$

$$R_{cr} = \frac{3}{\pi} X_{cr} \tag{2.9}$$

$$R_{ci} = \frac{3}{\pi} X_{ci} \tag{2.10}$$

Where,

Id = Line current in the DC link.

Vdr = DC link voltage at the rectifier end.

Vdi = DC link voltage at the inverter end.

Rcr = Equivalent commutating resistance for the rectifier.

Rci = Equivalent commutating resistance for the inverter.

R_L = Line resistance.

Xcr = commutating reactance for the rectifier.

Xci = commutating reactance for the inverter.

$$V_{dor} = \frac{3\sqrt{2}}{\pi} X_{ci} \tag{2.11}$$

$$V_{d0i} = \frac{3\sqrt{2}}{\pi} X_{cr} \tag{2.12}$$

α =Ignition delay angle.

ω = Extinction advance angle

V_{cr} = Line to line RMS commutating voltage at the rectifier end.

V_{ci} = Line to line RMS commutating voltage at the inverter end.

P_{dr} = Power at the rectifier end.

Pdi = Power at the inverter end.

2.4.4 Advantage of high voltage direct current transmission system

In the recent years concerning major issues such as environmental factors and control, high voltage direct current transmission systems have become desirable for the following reasons:

- Cost of transmission is less, since only two conductors are used for transmission.
- There is no reactive power. So transmission losses are reduced.
- Because of DC transmission, there is no skin effect. So thin conductors can be used. In case of HVAC transmission, the thick conductors must be used to eliminate skin effect.
- Two AC systems having different frequencies can be interconnected using HVDC transmission lines, which is not possible in high voltage alternating current transmission system.
- HVDC uses electronic converters. So Protections, fault clearance can be implemented faster than HVAC.
- Therefore, DC transmission system have improved transient stability.
- Since HVDC requires no charging current and the reactive power, it is preferred in power transmission through cables.
- Unlike HVDC transmission system, high voltage AC induces body currents in the vicinity of the conductors.
- HVDC transmission does not have any dielectric loss heating problems in the insulation of conductors.
- HVDC has minimum audible noise as well as minimum radio, TV interference.
- Due to bipolar transmission the voltage levels are balanced with respect to an earth.
- DC cables used for transmission are cheaper than AC cables.
- In HVDC, line charging and electric resonance do not present which leads to high-efficiency.

2.4.5 Problems associated with HVDC transmission

High cost converting and inverting equipment's are required for HVDC transmission. The cost of installation at the Converter Stations is quite high, required at each end of a DC transmission link, whereas in an AC link only transformer stations are required, so it is uneconomical for low power supply over short distances.

- ✓ Converters control is quite complex.
- ✓ Additional filters are required at various stages of HVDC transmission system to remove higher order harmonics present due to presence of converter in the DC link. So its lead to high installation cost.

2.4.6 Economic distance for HVDC transmission lines

DC lines are cheaper than the AC lines, but the cost of DC terminal equipment is very high as compared to AC terminal cables as shown in the graph below. Thus, the initial cost is high in HVDC transmission system, and it is low in the AC system. An HVDC transmission line costs less than an AC line for the same transmission capacity. Over a certain distance, the so called break-even distance (approx. 600 – 800 km), the HVDC alternative will always provide the lowest cost.

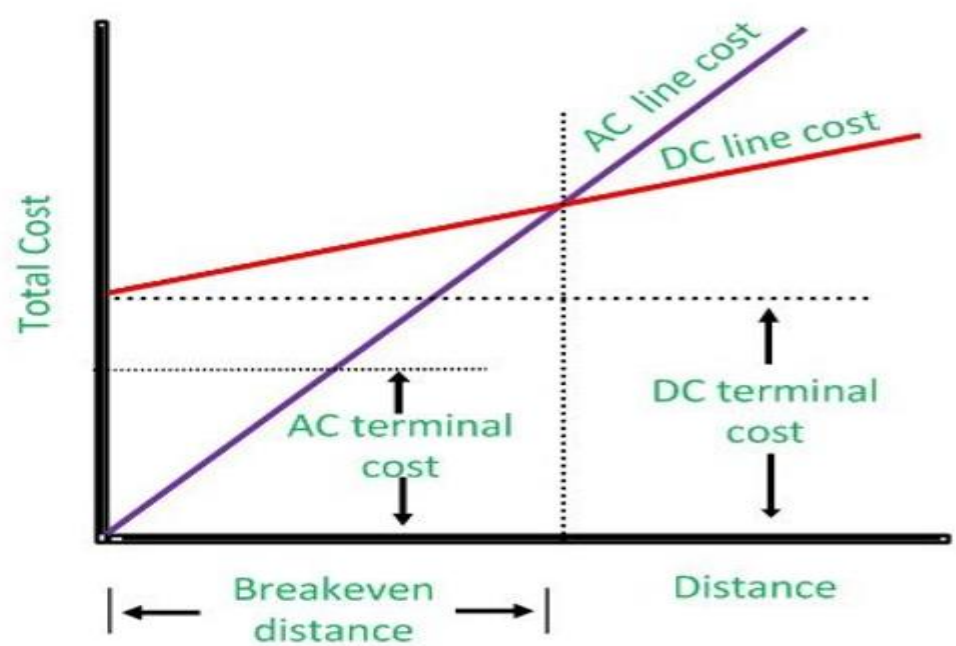


Figure 2. 7 Comparison of cost of AC and DC transmission system [7].

2.5 Simultaneous AC-DC power transmission system

In recent years, energy, environment, right-of-way, and cost problems delayed the construction of both generation facilities and new transmission lines. This has necessitated a change in the traditional power system concepts and practices; better utilization of existing power systems has become imperative.

However, high voltage AC and high voltage DC are the most comfortable mechanism to transfer electrical power for longer distances. In this case of conversion, the line infrastructures are to be changed. Such as, the AC insulators must be replaced by DC insulators, creepage distance and clearing distance must be increased. But, due to the geographical location of the existing line, in many cases, it becomes very difficult to change the line infrastructures. In such cases, for converting the AC transmission line into the pure DC line keeping the line infrastructure unchanged the DC voltage level has to be lowered. To overcome thes concept of power transmission emerging is simultaneous AC-DC power transmission system through double line. In this system conductors will be allowed to carry AC current along with the DC current superimposed at a time. AC transmission system can be converted to simultaneous AC-DC system without bringing any change in the existing infrastructure of the transmission lines.

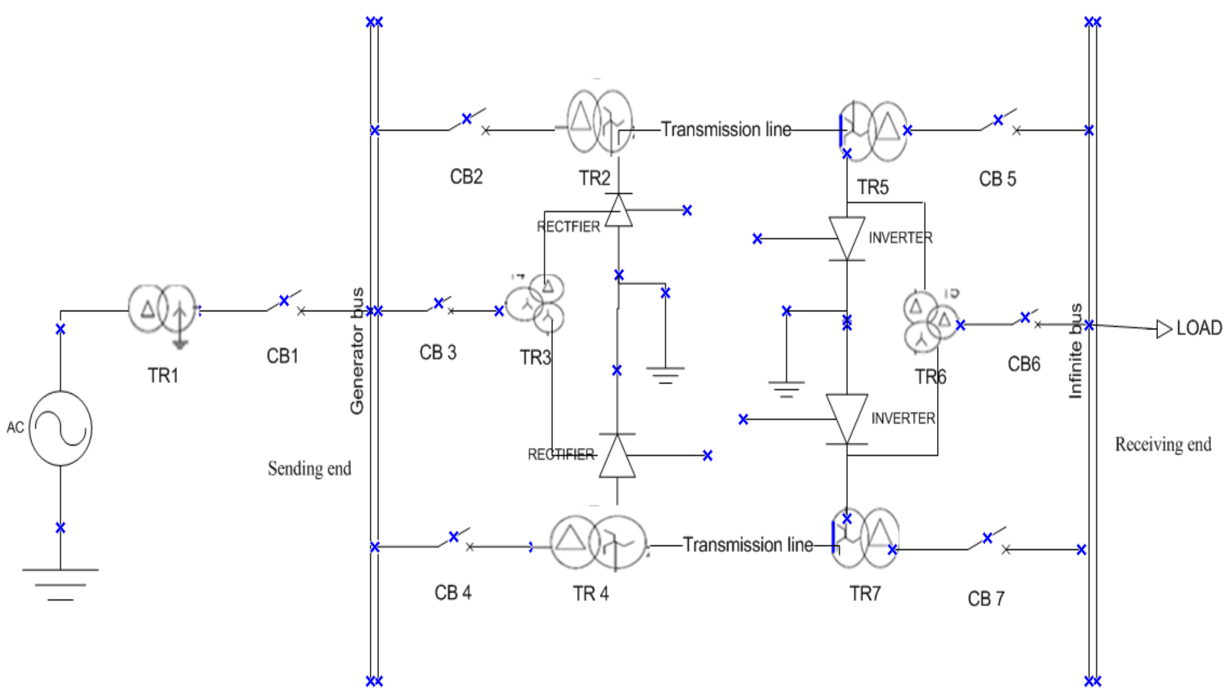


Figure 2. 8 Basic model for composite AC–DC transmission

Figure 2.8 depicts the basic model for simultaneous AC-DC power flow through a dual circuit AC transmission line. Line commutated 12-pulse rectifier bridge is used in conventional HVDC and the DC power is injected to the neutral point of the zigzag connected secondary of sending end transformer and is recovered back to AC again by the line commutated 12-pulse bridge inverter at the receiving end side. The inverter bridge is also connected to the neutral of zigzag connected winding of the receiving end transformer to recover back the DC current to the inverter. The zigzag connections are used at the secondary and primary sides of sending end and receiving end transformers, respectively. The main purpose of the use of zigzag connected winding is to avoid magnetic saturation of transformer core due to DC current. The dual circuit AC transmission line carriers both three-phase AC and DC power. Each conductor of each transmission line carries one third of the total DC current with AC current superimposed. Since the resistance is equal in all the three phases of secondary winding of zigzag transformer and the three conductors of the line, the DC current is equally divided in all the three phases.

The saturation of transformer due to DC current can be removed by using zigzag connected winding at both ends. The fluxes produced by the DC current (Id / 3) flowing through each winding of the core of a zigzag transformer have equal magnitude and opposite in direction and hence cancel each other. At any instant of time the net DC flux becomes zero. Thus, the DC saturation of the core is removed. A reactor $X_d$with higher value is used to reduce harmonics in DC current. In converting existing AC transmission line into AC–DC composite system three factors must be considered; rating of insulator, creepage distance and clearing distance. These factors restrict the magnitude of DC voltage in an AC–DC system lower than 50% of the maximum phase voltage of pure AC system [1].

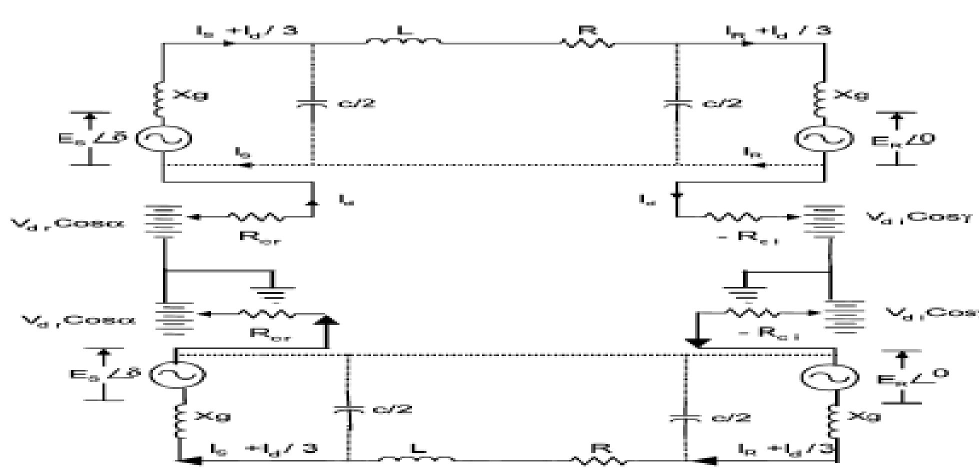


Figure 2. 9 Equivalent circuit diagram

2.6 Transmission line load ability

Load ability of line is defined as the extent of load which can flow through the line without exceeding the limitations. Line load ability is expressed in percentage of surge impedance loading of line. The limiting factor for line loading are: thermal limit, voltage drop limit and steady state stability.

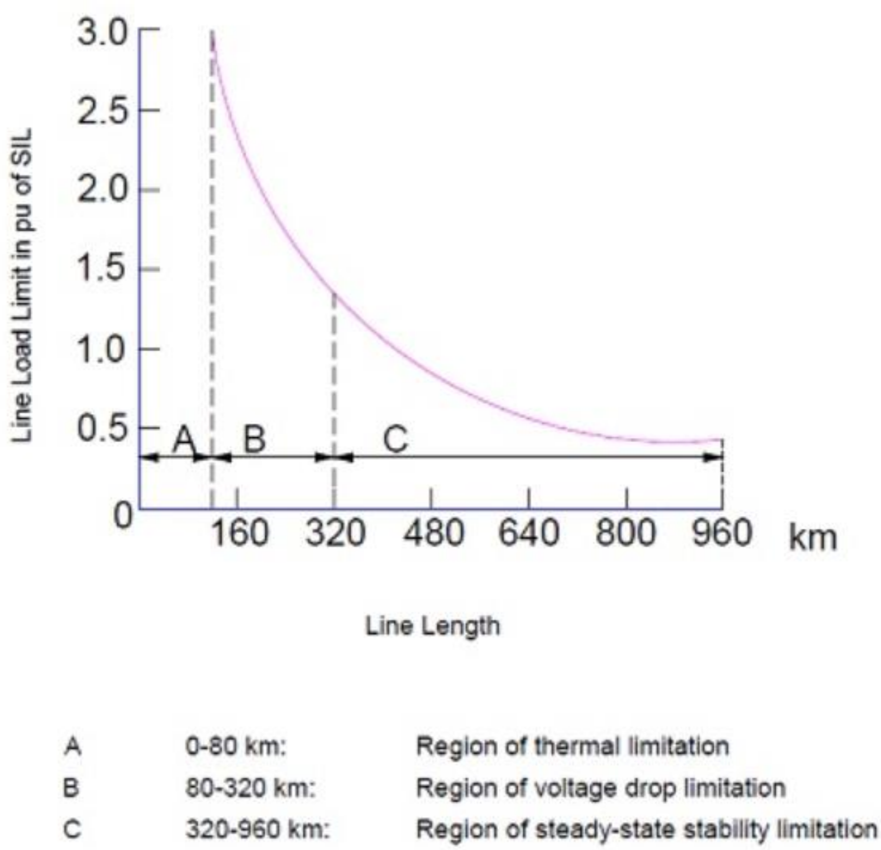


Figure 2. 10 Transmission line load ability curve [6]

2.7 Selection of transmission voltage

The instantaneous value of each conductor voltage with respect to ground becomes more in case of simultaneous ac-dc transmission system by the amount of the dc voltage superimposed on ac and more discs are to be added in each string insulator to withstand this increased dc voltage. However, there is no change required in the conductor separation distance, as the line-to-line voltage remains unaltered. Therefore, tower structure does not need any modification if same conductor is used. Another possibility could be that the original ac voltage of the transmission be reduced as dc voltage is added such that peak voltage with respect to ground remains unchanged. Therefore, there would be no need to modify the towers and insulator strings.

2.8 Economic consideration

To get the advantages of parallel AC–DC transmission in order to improve stability and damping oscillations, the conversion of a double circuit AC line for simultaneous AC–DC power flow has been considered such that no alterations of conductor, insulator string and tower structure of the original line are required. The optimum values of AC phase and DC voltages of the converted line are 1/2 and $1/\sqrt{2}$ times the phase voltage before conversion, respectively. The cost of transmission line includes the investment and operational costs. The investment includes costs of Right of Way, transmission tower, conductors, insulators, labor and terminal equipment. The operational costs include mainly the cost of losses. Additional costs of compensation and its terminal equipment also influences the AC line cost. DC transmission does not require compensation but the terminal equipment costs are increased due to the presence of converters and filters. Replacement of Y-connected transformer in simultaneous AC–DC power transmission with zigzag transformer is not likely to increase the cost, because it transfers only 25% of total power by transformer action. Also, the AC voltage reduces to 50% of the original AC voltage. However, the neutral point of this transformer needs insulation to withstand DC voltage [23].

2.9 Controllability of Power Systems

To illustrate that the power system only has certain variables that can be impacted by control, we have considered here the power-angle curve, shown in Figure below. Although this is a steady-state curve and the implementation of FACTS is primarily for dynamic issues, this illustration demonstrates the point that there are primarily three main variables that can be directly controlled in the power system to impact its performance.

These are:

- Voltage
- Angle
- Impedance

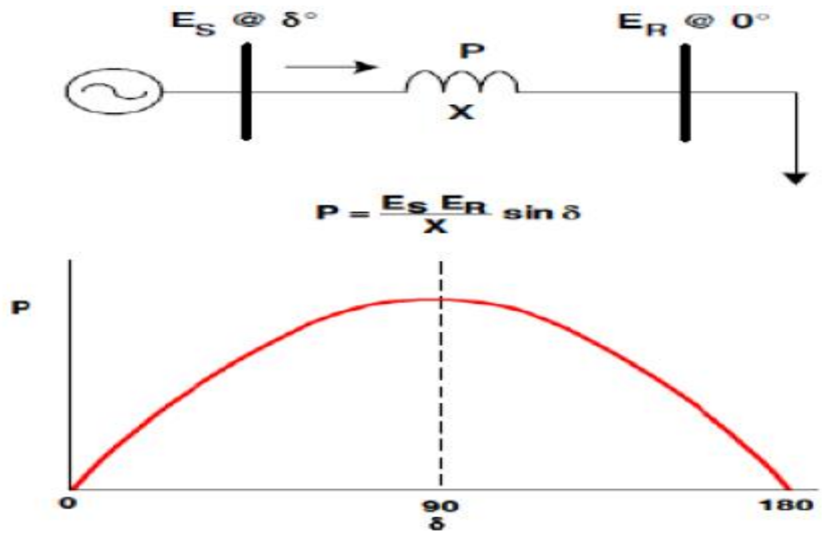


Figure 2. 11: Controllability of power systems

There is a statement that can also infer the point that direct control of power is a fourth variable of controllability in power systems. With the establishment of what variables can be controlled in a power system, the next question is how these variables can be controlled.

2.10 Power system stability

Power system stability involves the study of the dynamics of the power system under disturbances. The stability of the power system implies that its ability to return to normal or stable operation after having been subjected to some form of disturbances.

From the classical point of view power system instability can be seen as loss of synchronism when some synchronous machines going out of step when the system is subjected to a particular disturbance [19].

I. Types of power system stability

A) Steady-state Stability

Steady-state stability relates to the response of synchronous machine to a gradually increasing load. The load is assumed to be applied at a rate which is slow when compared either with the natural frequency of oscillations of the major parts of the system or with the rate of change of field flux in the rotating machine in response to the change in loading. It is basically concerned with the determination of the upper limit of machine loading without losing synchronism, provided the loading is increased gradually. The highest power which can be transferred to the receiving end of the system without affecting the synchronism is termed as Steady State Stability limit.

B) Dynamic Stability

Dynamic stability involves the response to small disturbances that occur on the system, producing oscillations. The system is said to be dynamically stable if the oscillations do not acquire more than certain amplitude and die out quickly. If these oscillations continuously grow in amplitude, the system is dynamically unstable. The source of this type of instability is usually an interconnection between control systems.

C) Transient Stability

Transient stability involves the response to large disturbances, which may cause rather large changes in rotor speeds, power angles and power transfers. Transient stability is a fast phenomenon usually evident within a few second. The index of stability, in case of transient fault, is measured in critical clearing time. That is, the maximum amount of time to clear the fault for which the system will be stable after clearing the fault. In general practice studies related to transient stability in the power system are done over a minimum period equal to the time required for one swing, which approximates to around 1 sec or even less. If the system is found to be stable during this first swing, its assumed that the disturbance will reduce in the subsequent swings, and the system will be stable after that as is the case.

2.11 Power system stability enhancement techniques

I. Flexible AC Transmission Systems (FACTS)

Flexible AC Transmission System is an integrated concept based on power electronic switching converters and dynamic controllers to enhance the system utilization and power transfer capacity as well as the stability, security, reliability and power quality of AC system4 interconnections. It is a collection of thyristors-based controllers, including phase shifters, advanced static VAR compensator, dynamic brake, modulator, series capacitor, load tap changer, fault current limiter and perhaps other that have yet to be invented.

Assuming the line to be lossless and ignoring the effect of line charging, the real power flow (P) is given by,

$$P = \frac{V1V2}{X} \sin(\theta 1 - \theta 2) \tag{2.13}$$

where, X is the series line reactance.

Assuming V1 and V2 to be held constants (through voltage regulators at the two ends), the power injected by the power station determines the flow of power in the line. The difference in the bus angles is automatically adjusted to enable $P = P_{Generated}$).

We may like to control the power flow in an AC transmission line to enhance power transfer capacity or to change power flow under dynamic conditions which is subjected to disturbances such as sudden increase in load, line trip or generator outage to ensure system stability and security. The stability can be affected by growing low frequency, power oscillations which is caused due to generator rotor swings, loss of synchronism and voltage collapse caused by major disturbances. The maximum power (P_{max}) transmitted over a transmission line is given by an expression below.

$$P_{max} = \frac{V1V2}{X} sin\, \delta_{max} \qquad (2.14)$$

where, max angle of (30^o - 40^o) is selected depending on the stability margins and the stiffness of the terminal buses to which the line is connected. For line lengths exceeding a limit, P_{max} is less than the thermal limit on the power transfer determined by the current carrying capacity of the conductors and this is also a function of the ambient temperature. As the line length increases, X increases in a linear fashion and P_{max} reduces as shown in Figure 2.12.below. The series compensation using series connected capacitors increases P_{max} as the compensated value of the series reactance (X_C) is given by

$$X_C = X(1 - K_{se}) \qquad (2.15)$$

where, k_{se} is the degree of series compensation. The maximum value of k_{se} that can be used depends on several factors including the resistance of the conductors. Typically k_{se} does not exceed 0.7[23].

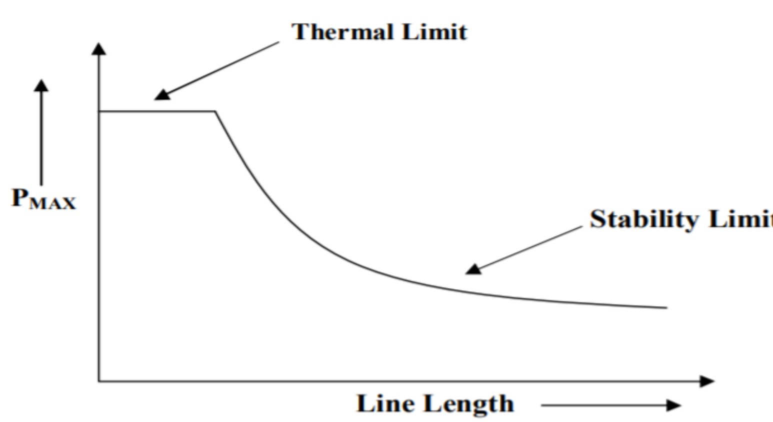


Figure 2. 12 Stability and line length

FACTS technology also tends itself to extending usable transmission limits in a step-by-step manner with incremental investment as and when required. A planner could foresee a progressive scenario of mechanical switching means and enabling FACTS controllers such that the transmission lines will involve a combination of mechanical and FACTS controllers to achieve the objective in an appropriate, staged investment scenario. Control power so that it flows on the desired routes. Power may be controlled by applying a voltage in the midpoint or by applying a voltage in series with the line and in phase quadrature with the current flow or by regulating the magnitude of sending and receiving end voltages. This is more effective than the previous techniques

Parameters controlled by FACTS controllers

FACTS controllers are capable of controlling the following parameters

- ✓ Solve power transfer limit and stability problems
- ✓ Thermal limit
- ✓ Stability limit
- ✓ Small signal stability limit
- ✓ Voltage stability limit
- ✓ Power quality improvement
- ✓ Limit short circuit current

Benefits of FACTS controllers

- ➢ Providing greater flexibility Control of power flow as ordered
- ➢ Increase the voltage stability and enhance the static stability
- ➢ Reduce real power loss and improve the voltage profile
- ➢ Reduce loop flows Reduce reactive power flows
- ➢ Provides secure tie line connections to neighboring utilities
- ➢ To provide controllable compensation to a power system in order to increase the power transmission capability
- ➢ It is possible to maintain constant power flow in a transmission line It is possible to vary the apparent impedance
- ➢ Increase loading capacity of transmission lines.

II. Static synchronous series compensator(SSSC)

The static synchronous series compensator (is a series device of the Flexible AC Transmission Systems family using power electronics to control power flow and improve transient stability on power grids. In place of using capacitor and reactor banks, a SSSC use self-commutated voltage-source switching converters to synthesize a three-phase voltage in quadrature with the line current. The main interest is to use the SSSC for controlling flow of power which is either active and/or reactive power in transmission lines, whereas the SSSC is mainly recommended for damping electromechanical oscillations. Thus, the SSSC control system may be made by a compensation control loop, to accomplish its steady-state function, and by a fast response control, to act during electromechanical transients [9] [11].

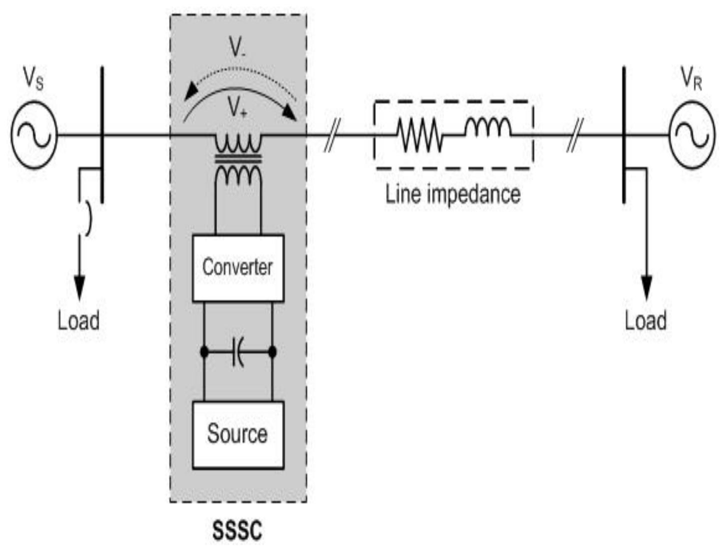
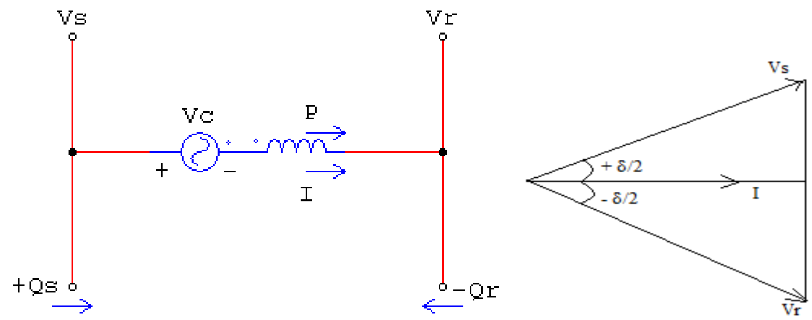


Figure 2. 13 SSSC schematic diagram

It is static synchronous generator operated without an external electric energy source as a series compensator. It is independent of the line current for changing the overall reactive voltage drop. It has energy absorbing devices to increase the dynamic behavior of the system by adding real power to momentarily change in real voltage drop in the line. This type of stability enhancement technique can inject a voltage lagging or leading the current [12].



(a) Single line diagram (b) Phasor diagram

Figure 2. 14 Representation of SSSC in Transmission line

2.12 Stability analysis methods

The methods of determining the stability under transient conditions caused by large disturbances are discussed below.

The dynamics of a synchronous machine is governing by the nonlinear differential equation as,

$$\frac{2H}{\omega_0}\frac{d^2\delta}{dt^2} = (P_m - P_{max} sin\delta) \tag{2.16}$$

Where, P_m = Mechanical power input in per unit

P_{max} = Maximum electrical power output in per unit

δ= Rotor angle in electrical radian

H = Inertia constant in MJ/MVA

t = Time in second

The Equation discussed above is known as swing equation. No closed form solution exists for swing equation. For small disturbance the equation can be linearized but a generalized solution for determining the stability with large disturbance (transient stability) cannot be found.

2.13 Numerical solution of swing equation

In most practical systems, after machine lumping has been done, there are still more than two machines to be considered from the point of view of stability. Therefore, there is no choice but to solve the swing equation by numerical technique on the digital computer. There are several best methods now available for the solution of the swing equation. Among them, point-by-point method of solution is a conventional one which is approximate method like all numerical methods but well tried and well proven method. A brief description of point-by-point method is presented below.

Consider the swing equation as

$$\frac{d^2\delta}{dt^2} = \frac{1}{M}(P_m - P_{max}sin\delta) \tag{2.17}$$

$$= \frac{P_a}{M} \tag{2.18}$$

Where;

$$M = \frac{H}{\pi f} \tag{2.19}$$

$$P_a = P_m - P_{max}sin\delta \tag{2.20}$$

The solution $\delta(t)$uniform throughout. Accelerating power and change in speed which are continuous functions of time are discretized as below:

2 The accelerating power P_a computed at the beginning of an interval is assumed to remain constant from the middle of the preceding interval to the middle of the interval being considered.

3 The angular velocity $\omega = \frac{d\delta}{dt}$ = (over and above synchronous velocity ω_s)is assumed constant throughout any interval, at the value computed for the middle of the interval.

If n is particular interval then at the end of the (n-1) th interval the accelerating power is,

$$P_{a(n-1)} = P_m - P_{max}Psin\delta_{(n-1)} \tag{2.21}$$

The change in velocity caused by the $P_{a(n-1)}$ assume the constant over change in time and represented as follows,

$$\omega_{\left(n-\frac{1}{2}\right)} - \omega_{\left(n-\frac{3}{2}\right)} = \frac{\Delta t}{M}P_{a(n-1)} \tag{2.22}$$

The change in δ during the (n-1) th interval is given as

$$\Delta\delta_{(n-1)} = \delta_{(n-1)} - \delta_{(n-2)}$$

$$= \Delta t\ \omega_{\left(n-\frac{3}{2}\right)} \tag{2.23}$$

The change in δ during the n th interval is given as

$$\Delta\delta_n = \delta_n - \delta_{(n-1)}$$

$$= \Delta t\ \omega_{\left(n-\frac{1}{2}\right)} \tag{2.24}$$

Subtracting equation(2.50) from (2.51) and using equation (2.52), $\Delta\delta_n$ can be expressed as

$$\Delta\delta_n = \Delta\delta_{(n-1)} + \frac{(\Delta t)^2}{M} P_{a(n-1)} \tag{2.25}$$

And the angle at the nth value is written as

$$\delta_n = \delta_{n-1} + \Delta\delta_n \tag{2.26}$$

The process of computation is now repeated to obtained $P_{a(n)}$, $\Delta\delta_{n+1}$, δ_{n+1}, For the first interval, since there is a discontinuity in electrical power the accelerating power is considered as the average value of P_a. The average value of P_a can be written as,

$$P_a\left(0_{average}\right) = P_a(0_-) + P_a(0+) \tag{2.27}$$

Where $P_a(0+)$ is the accelerating power immediately after occurrence of fault and $P_a(0_-)$ is the accelerating power immediately before the fault which is equals to zero.

2.14 Practical approaches to solve the transient stability problem

Equal Area Criterion of Stability:

In this method of stability study it is not necessary to solve the swing equation to determine whether the rotor angle increases indefinitely or oscillates about an equilibrium position. Information regarding the maximum angle excursion (δ_m) and stability limit may be obtained graphically by using power angle diagram. A typical power angle curve of a single machine infinite system is presented in figure 2.15 below [20]. A sudden increase in the mechanical power input from initial value of P_{m0} to P_{m1} is also shown in the figure.

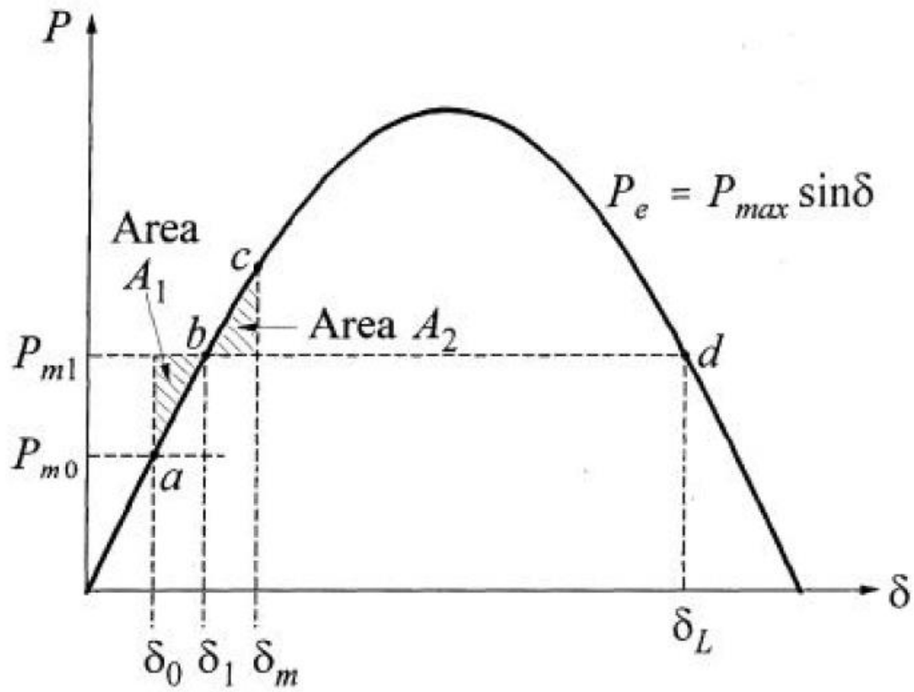


Figure 2. 15 Power-angle variation

As the mechanical power changes the rotor angle cannot change instantly from the initial value δ_0 to δ_1 corresponding to the equilibrium point b at which $P_e = P_{m1}$.The mechanical power is now in excess of the electrical power that causes the rotor to accelerate from the initial operating point toward the new equilibrium point *b*. When the rotor reach at point *b* the accelerating power is zero but the rotor speed is higher than the synchronous speed. Hence, the rotor angle continues to increase. For the values of δ higher than δ_1, the electrical power is greater than mechanical power and the rotor decelerates. The rotor angle oscillates about the new steady state angle δ_1. In practice, there are some sources of positive damping to decay out the oscillation. If the system is to be stable the area under the function *Pm – Pe* plotted against δ is zero in the figure above, this is satisfied when area *A1* is equal to area *A2*. That is, kinetic energy gained by the rotor during acceleration is equal to energy lost during deceleration. This forms the basis for the equal area criterion. The criterion can be used to determine the maximum permissible increase in *Pm*. System stability is maintained only if area *A2* at least equal to area *A1*. If the area *A1* is greater than area *A2* the stability will be lost. The equal area criterion can also be applied for the stability analysis under short-circuit fault. The main limitation of this criterion is that it can be applied only for one or two machine systems but not for multi-machine systems.

2.15 Stability Model

The stability of a power system is its ability to return to normal or stable operation after being subjected to disturbances. Stability is divided into two categories on the basis of the impact of the disturbances which are steady state stability and transient stability. The steady state stability is the stability of the system under condition of gradual or relatively slow change in load. The load is assumed to be applied at a rate which is slow when compared either with the natural frequency of oscillations of the major parts of the system or with the rate of change of field flux in the rotating machine in response to the change in loading. The transient stability refers to the maintenance of stability of a system after sudden and large changes in the network conditions such as faults, sudden large increment of loads. The index of stability, in of transient fault, is measured in critical clearing time (CCT). That is, the maximum amount of time to clear the fault for which the system will be stable after clearing the fault.

2.16 Stability model development for simultaneous AC-DC system

Simultaneous AC-DC power transmission system can improve the stability of the system that has been shown numerically in [23-25]. No mathematical model has yet been found in the literature for stability analysis in case of simultaneous AC-DC system. In this part of the thesis mathematical model is developed for critical clearing time considering same type of fault at the transmission line. Same type of faults at different locations causes different scenario for the circuit operation during fault and post fault condition. In case of 3-phase to ground fault at the load terminal near to the sending end bus the power flow through the transmission line will be zero during fault and after clearing the fault the system will be fully healthy. On the contrary, in case of 3-phase to ground fault at any one of the circuits of double circuit transmission line a small amount of power will flow through the other circuit and after clearing the fault the faulty circuit will be out of service and the system will become healthy with only one circuit until the faulted line circuit breakers are turned on after a minimum dead time. At the outset of the development of the stability model for AC-DC system the pure AC system stability analysis is presented first.

Fault type 1: Three -phase to ground fault near the generator bus at the load terminal.

If a 3-phase to ground fault occurs at point F in Figure above, the power flow through the transmission line will be zero. The power flow through the transmission line can be resumed by isolating the faulted line and the isolation can be performed by tripping the circuit breaker within the faulted line.

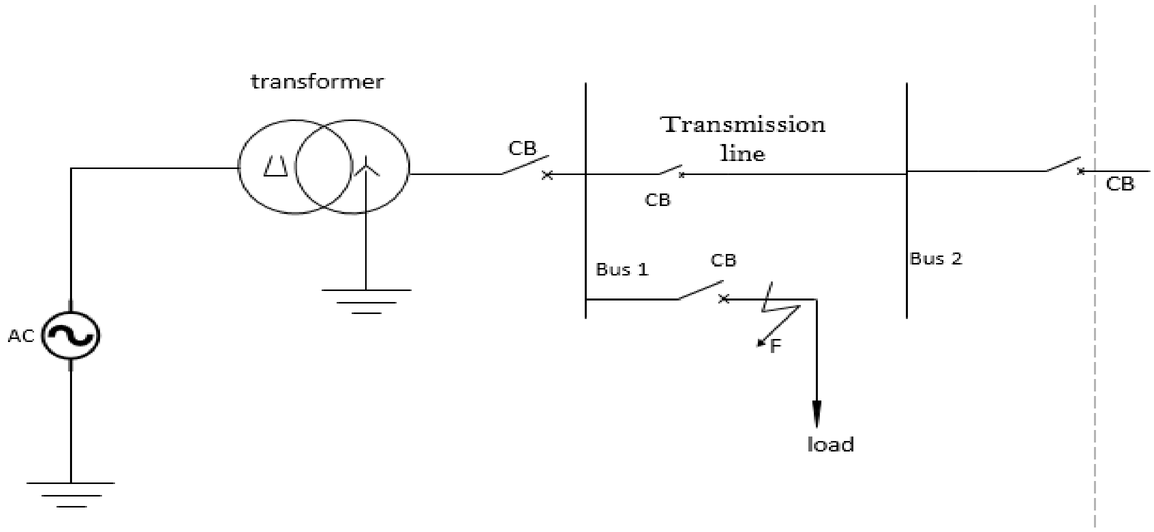


Figure 2. 16 AC Power transmission system with a fault at the load terminal

CHAPTER THREE

DEVELOPMENT OF ANALYTICAL MODEL

3.1 Introduction

The analytical model is developed with a view to analyze the behavior of a system comprehensively. This chapter presents the mathematical model of simultaneous ac-dc transmission system. To develop the model of simultaneous ac-dc transmission system it is considered that the existing AC transmission line is used to transmit both AC and DC through the same line to increase the transient stability limit of the existing line. It may be noted that due to the geographical location of the existing line, in some cases, it becomes very difficult to replace the line to increase power transmission to meet the increasing demand. In such cases, the simultaneous ac-dc transmission is a possible solution. However, for this type of operation the constraints are the maximum voltage and the thermal limit of the conductor. That is, for a given insulator in the transmission pole, the capability of withstanding maximum voltage of that insulator is fixed. Therefore, the summation of the DC voltage and the peak value of AC voltage in simultaneous ac-dc system should not exceed the peak value of pure AC system phase voltage.

The expressions for AC voltage, current and the power equations in terms of A, B, C and D parameters of each line when the resistive drop in transformer winding and in the line conductors due to DC current are neglected can be written as.

Sending end voltage:

$$Vs = AV_R + BI_R \tag{3.1}$$

Sending end current:

$$Is = CV_R + DI_R \tag{3.2}$$

Sending end power:

$$Ps + jQs = \frac{-VsV * R}{B} + \frac{D}{B}\, V_{s2} \tag{3.3}$$

Receiving end power:

$$P_R + jQ_R = \frac{VsV_R}{B} - \frac{A}{B}\, V_{R2} \tag{3.4}$$

Active powers of converters can be computed as

$$P_{dr} = V_{dr}\, I_d \tag{3.5}$$

$$P_{di} = V_{di} I_d \tag{3.6}$$

Reactive powers of converters are,

$$Q_{dr} = P_{dr} \tan\theta_r \tag{3.7}$$

$$Q_{di} = P_{di} \tan\theta_i \tag{3.8}$$

$$\cos\theta r = \frac{[\cos\alpha + \cos(\alpha + \mu r)]}{2} \quad 3.9$$

$$\cos\theta i = \frac{[\cos\Upsilon + \cos(\Upsilon + \mu i)]}{2} \tag{3.1}$$

where μi and μr are commutation angles of inverter and rectifier respectively

The total active and reactive power at both terminal is given as

$$\mathrm{Pst} = \mathrm{Ps} + \mathrm{Pdr} \tag{3.10}$$

$$\mathrm{Prt} = \mathrm{Pr} + \mathrm{Pdi} \tag{3.11}$$

$$\mathrm{Qst} = \mathrm{Qs} + \mathrm{Qdr} \tag{3.12}$$

$$\mathrm{Qrt} = \mathrm{Qr} + \mathrm{Qdi} \tag{3.13}$$

Transmission loss for each line is obtained as

$$P_{loss} = \mathrm{P}_{st} - \mathrm{P}_{rt} \tag{3.14}$$

Expanding the above equation

$$P_{loss} = (P\mathrm{s} + \mathrm{Pdr}) - (\mathrm{Pr} + \mathrm{Pdi}) \tag{3.15}$$

Ia being the rms ac current per conductor at any point of the line, the total rms current per conductor becomes:

$$I_{rms} = \sqrt{{I_a}^2 + (\frac{I_d}{3})^2} \tag{3.16}$$

Power loss,

$$\text{Ploss} \approx 3 * I^2 * \text{R} \tag{(3.17)}$$

Total power in line,

$$P'_{total} = 2M \times SIL \tag{3.18}$$

Where,

M - Multiplying factor whose magnitude decreases with decrease in length of line. We can get value of M from load ability curve.

If the rated conductor current corresponding to its allowable temperature rise is Ith and

$$\text{Ia} = \text{X} * \text{Ith} \tag{3.19}$$

X being less than unity, the dc current becomes:

Allowing I_a to be $I_{threshold}$

$$I_{th} = \sqrt{{I_a}^2 + (\frac{I_d}{3})^2} \tag{3.20}$$

$$I_d = 3\sqrt{{I_{th}}^2 - {I_a}^2} \tag{3.21}$$

The total current I in any conductor is asymmetrical but two natural zero-crossings in each cycle in current wave are obtained for $(Id/3Ia) < 1.414$

The instantaneous value of each conductor voltage with respect to ground becomes the dc voltage Vd with a superimposed sinusoidally varying ac voltages having rms value Vph and the peak value being:

$$Vmax = \sqrt{2}\, V_{ph} = V_d + 1.414\, V_a \tag{3.22}$$

The total power transfer through the composite line

$$P'total = Pac + Pdc \tag{3.23}$$

$$= \frac{3{V_a}^2 Sin\left(\frac{\delta}{2}\right)}{X} + 2V_d I_d \tag{3.24}$$

AC current per phase per circuit of the double circuit line is

$$Ia = \text{V}(\text{Sin}\delta/2)/\text{X} \tag{3.25}$$

$$V_{\text{LL}} = \sqrt{6}\, \text{V}_a \tag{3.26}$$

$$\text{Vd} = \frac{\text{Vph}}{\sqrt{2}} \tag{3.27}$$

$$Va = Vph/2 \tag{3.28}$$

Where,

V_{ph} –Phase voltage V_{LL}- is the line to line voltage

V_a-effective AC and DC voltage

The combined power flow in a simultaneous AC-DC system is,

$$Pcomb = Pac + Pdc \tag{3.29}$$

Where,

P_{comb} = Total combined power flow

P_{ac} = AC power flow

P_{dc} = DC power flow

Due to the introduction of DC, the AC power flow in a simultaneous AC-DC system will be less than that of pure AC system for the same power transmission angle. As the DC power flow is highly controllable, the AC power transmission angle and ultimately the AC power flow in a simultaneous AC-DC system can be controlled by controlling the DC current flow for a given output.

3.2 Evaluation and Analysis of the Existing System

3.2.1 Site Description

Asella is located at the geographical coordinates of $7^0$57'0'' North and $39^0$8'0''East and is 175 km away from Addis Ababa, capital of Ethiopia. It covers an area of about 50.52 sq. km with an elevation of 2430 meters above sea level. The 2007 national census reported total population for Asella 67,269 of whom 33826 were men and 33443 were women.

Figure 3. 1 Geographical Map of case study area

Asella town subjected to a serious epidemic of dysentery during 1953 and a locust invasion in April 1961. In 1957 Asella was the southern end of the national telephone network and by 1960 Asella had one of the ten municipal slaughter houses in Ethiopia further that year a branch of Ethiopian electric light and power authority had begun operation in the town.

3.2.2 Asella Distribution System

There is one feeder line under Asella substations 132 KV feeder line. The energy storage and consumption different form one substation to another substation based on the location, consumer demand, industrial zone, transmission distance and many factors. The imported energy may reduce during the transmission process due to system loss. Asella substation supplies electric power to Asella town and the nearby areas and it receives power via 132kv power lines from power plants Awash. The 132kv is stepped down and distributed by 15 and 33kv feeders.

The Substation consists of 7 outgoing feeders. The nominal voltage of the five feeders is 15 kV and the remaining two feeders is 132kV Adami Tulu outgoing line and transformer 1 line.
The 15kv medium voltage feeders were renamed by the local names of the area they distributed in the town.

Under the feeder line there are different connected load

Feeder 15 KV line consists of

A) Transformer 1 feeder
B) Segure & kersa
C) Iteya
D) Asella town
E) Industry line
F) Tulu dimtu outgoing line

Feeder 132 KV line consists of

A) Awash I incoming line
B) Adami Tulu outgoing line
C) Transformer 1

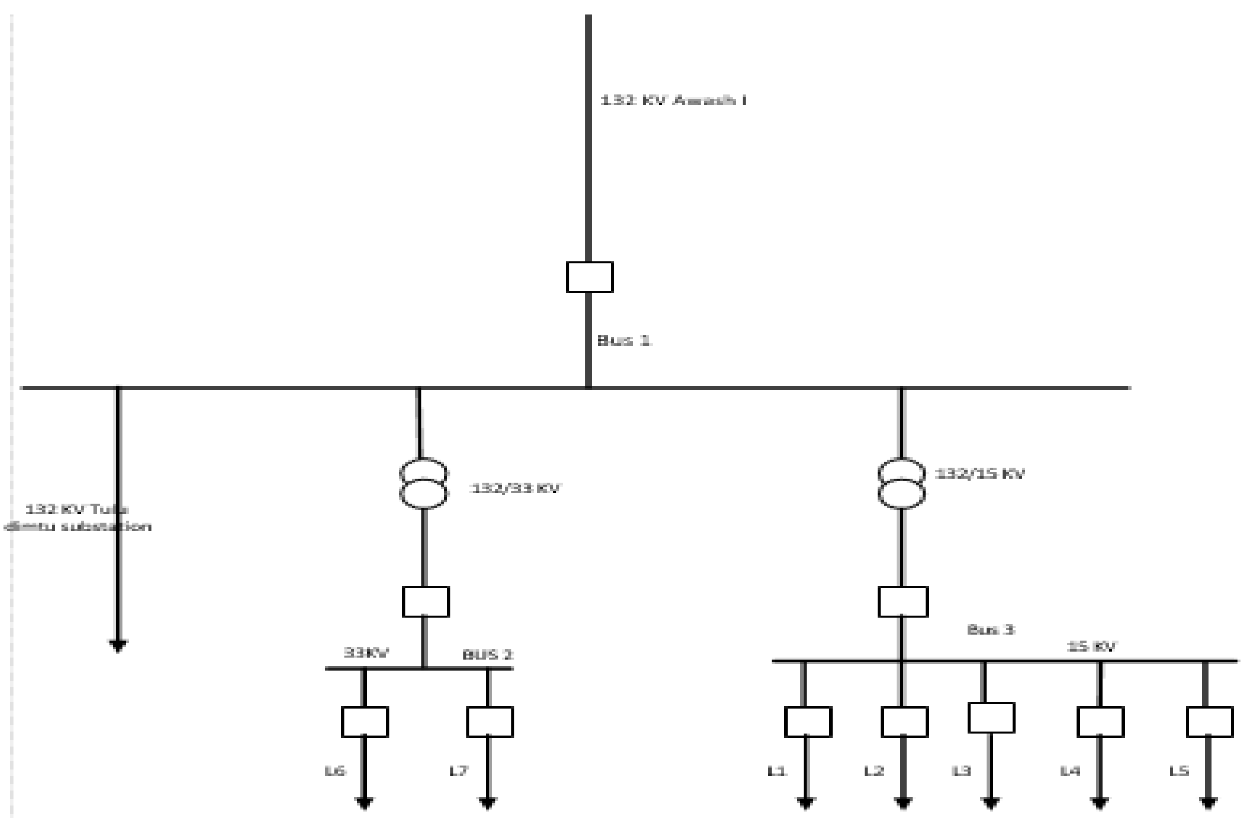


Figure 3. 2 shows distribution feeders' schematic diagram of Asella Substation

LEGEND

Transformer

Circuit Breaker

L1-L7 Out Going Feeders

From the five 15KV feeders, line is serving customers found in the center of the city and is extended to Segure and kersa, which are around 25km away from Asella town. Big hotels, Small and micro industries, banks, most administrative offices, telecommunication BTSs, schools and large number of residential customers get electricity from this feeder. City line is represented by L6 and L3 as depicted in figure below according to the breakers arrangement in the control room Current Transformer (CT) rating of city feeder is 400/5 A. This primary distribution feeder delivers power from the substation to distribution transformers. It begins with the feeder breaker at the distribution substation and exits the substation in a concrete duct bank (feeder get-away) and routed to a nearby pole.

Figure 3. 3 Asella substation control room (source: researcher photograph)

The main primary feeder branches into various primary laterals which in turn separates into several sub laterals to serve all the distribution transformers.

The main feeder and sub feeders before the transformer are three phase three wire circuits and the laterals are three phase four wire or single phase two wire circuits

3.3 Factor affecting existing transmission line stability

In 15 KV line transmission each interruption, interruption duration and loads of each feeder per hour is recorded and the causes of interruptions are described. But to put an appropriate mitigation technique for the stability problem in the case study area; it is critical knowing the causes of interruptions. To know the causes of interruptions data were collected to the employees and longtime daily workers (they are working techniques for longtime as employees of the utility). The site survey was prepared to describe the common causes of interruptions in the selected transmission from years of 2016 GC and 2017 GC.

3.4 Data Analysis

The collected data has been analyzed to identify the stability of existing AC transmission line which are highly affected by power stability problems. As shown figure 3.4, 3.5, 3.6 and 3.7 the data has been analyzed using graphical method.

There are different factors such as environmental conditions like wind, rain and flood and also external agents are involved in the occurrence of faults and failures. Short circuits caused by dielectric breakdown of the insulation system and also when phase to ground fault occurs the circuit breaker may trip or damage, the failures are the termination of the ability of the components to perform its required functions [20].
The components failures normally induce faults and these faults are reflected as defects in the supply voltage. Utilities also use the term incidence to refer the actions implemented to return the systems to normal operation when faults and failures have occurred.

EEU have to do preventive Maintenance (like erection of pole before fall, replace old AC cable before totally damaged, replace damaged light arrester on each transformers etc.). These used to reduce the impact of the faults on the transmission line to minimize losses. Also, fault prediction based on the early identification of symptoms, or incipient faults, leading to the appearance of faults is a topic of interest in power systems and several frameworks are available. The main idea is to exploit the information available related with the causes transmission instability occurred over an important period of time under this study

The figure 3.6 and 3.7 shows causes of failure on transmission line from September 2016 GC-August 2017 GC. Power network disturb due to environmental conditions and plants. In addition to this aging of AC cable in transmission line. Figure 3.4 and 3.5 shows the frequency of power interruption for the year (September 2016 GC –august 2017 GC). Table A.1 and A2 shows that the interruption frequency of relative number of Asella to segure transmission line.

3.5 Major Causes of Interruption in the Existing Transmission System

According to IEEE100-1992, an interruption to service is the isolation of an electrical load from the system supplying that load, resulting from an abnormality in that system. The abnormality in the system can either be a malfunction of a system component, a fault or a system operation due to maintenance or repair. Interruptions, independent from the cause, are generally undesired, as they leave energy un served and customers without service. Most of the time, interruptions occur because the system is reacting to a fault. A fault or short-circuit is defined by IEEE100-1992 as an abnormal connection of relatively low impedance, whether made accidentally or intentionally, between two points of different potential [23], [25].

Over-loading, earth fault and short circuits are the major cause of interruptions in Asella distribution system. These major faults are classified in to two main categories: temporary and permanent faults. Temporary faults account for the majority of faults in distribution systems. Temporary faults can occur for many reasons, but may include tree or animal contact and weather as the main contributors. Temporary faults can be easily solved, with little or no intervention from the system itself. Many are self-clearing, such as a branch or animal contact which burn and fall off, conductors slapping together in severe wind or insulation flashover due to contamination.

Lightning is also a temporary fault. Lightning arrester failure, on the other hand, can become a permanent fault. Other temporary faults are simply cleared once a trip from the substation is issued. Instantaneous reclosing de-energizes the line for a short duration of time, which allows the arc or contact path to disappear, which in turn eliminates the fault path. Once the circuit is re-energized, the system resumes normal operation. Permanent faults, on the other hand, are those that cannot be solved with reclosing action and will not self-clear. Equipment malfunction, cable failure, downed lines or persistent tree contact can all produce permanent faults. It is important to point out, that some tree contact can cause permanent faults, such as a tree falling on a line [23] [25].

There are many principal causes of electrical failure; such as dust and dirt accumulation, moisture, lose connections, and friction of moving parts, aging of conductors, clearance from trees and limbs and structures, equipment over loading, frequency and so on. An effective maintenance program should aim to minimize these effects by keeping equipment clean and dry, keeping connections tight.

3.5.1 Dirt and Dust Accumulation in Switching Stations

During site visit feeder is observed that huge amount of dust was accumulated on coils in transformers and relays, circuit breakers, fuses, isolator switches, etc. This dust accumulation facilitates equipment to failure. EEPCO is not making routine tree and vegetation maintenance on regular cycles to minimize the possible future interruptions. Distribution lines with good clearance experience fewer earthling faults and a significant improvement in electric reliability.

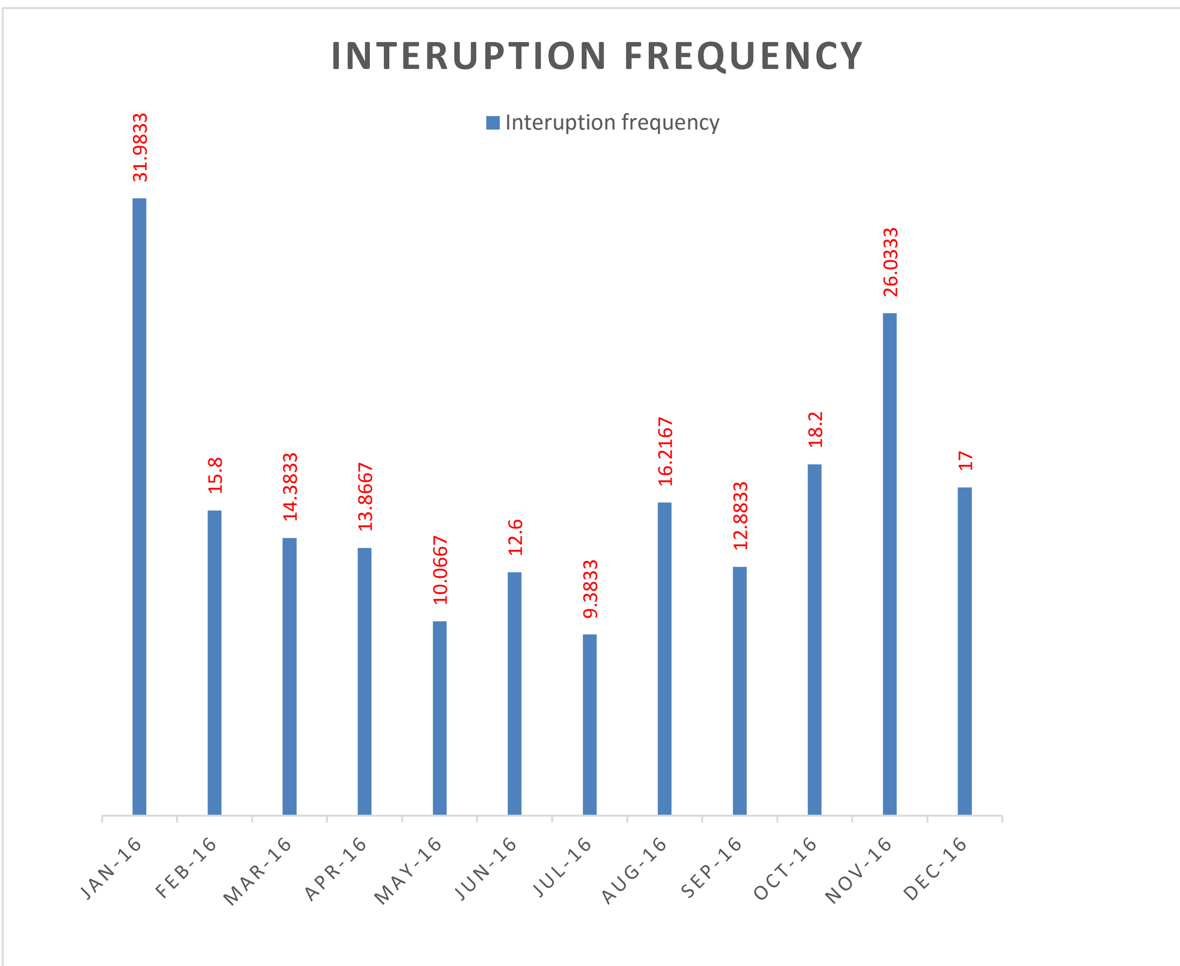


Figure 3.4 Power interruption frequency (source: Asella substation, September, 2016 – August, 2016).

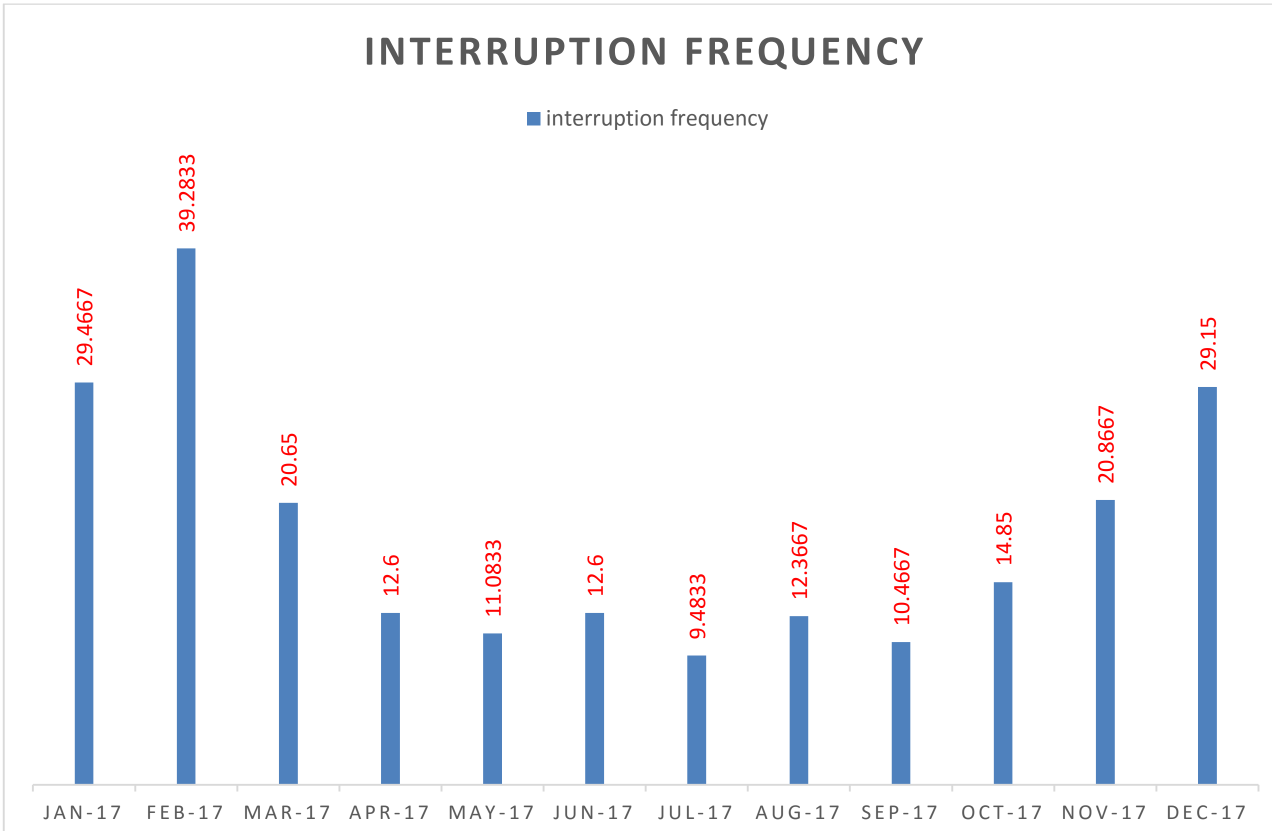


Figure 3.5 Power interruption frequency (source: Asella substation, September, 2017 – August, 2017).

3.5.2 Lightning, Wind, Vehicles and Animals

Lightning often strikes transmission and distribution line towers, utility poles, wires, transformers and other electrical equipment, causing severe damage and loss of power. Lightning is attracted to the most direct path to the ground and usually searches for the highest object to serve as a conductor. Trees struck by lightning may also fall on lines, causing an outage. There are preventive methods to protect lighting to electrical circuits. Some of them are arrestors/ electrodes buried underground. Arrestor is crucial to prevent over voltage flowing into a transformer due to lighting. These transformers may not be sufficiently working at summer/rainy season when lighting is common. So making preventive maintenance and installing all transformers with complete components can sufficiently decrease the rate of power failure/interruption in relation with lighting. Strong winds can swing sagged power lines together and trigger a short circuit. Winds also blow tree limbs or entire trees onto power lines. Severe winds can destroy extensive sections of the lines and utility poles. Animals periodically cause power outages by climbing onto or inside energized equipment. They can cause a short circuit that interrupts the flow of power to customers. The net stations and switching stations can be protected from animals but not the overhead lines what one can do is giving a quick response for the power failure as much as possible. In general, these is the problem in Asella distribution system which cause transmission system instability.

3.5.3 Presence of Moisture and Loose Connection

Moisture and condensation in electrical equipment can cause oxidation, insulation degradation and connection failure. High humidity produces free condensation on the equipment which can result in short circuiting and immediate failure. Electrical connections should be kept tight to recommended values. Creep or cold flow during load cycles is major cause of joint failure. Hardware on all electrical equipment should be checked for looseness resulting from vibration and normal device operation.

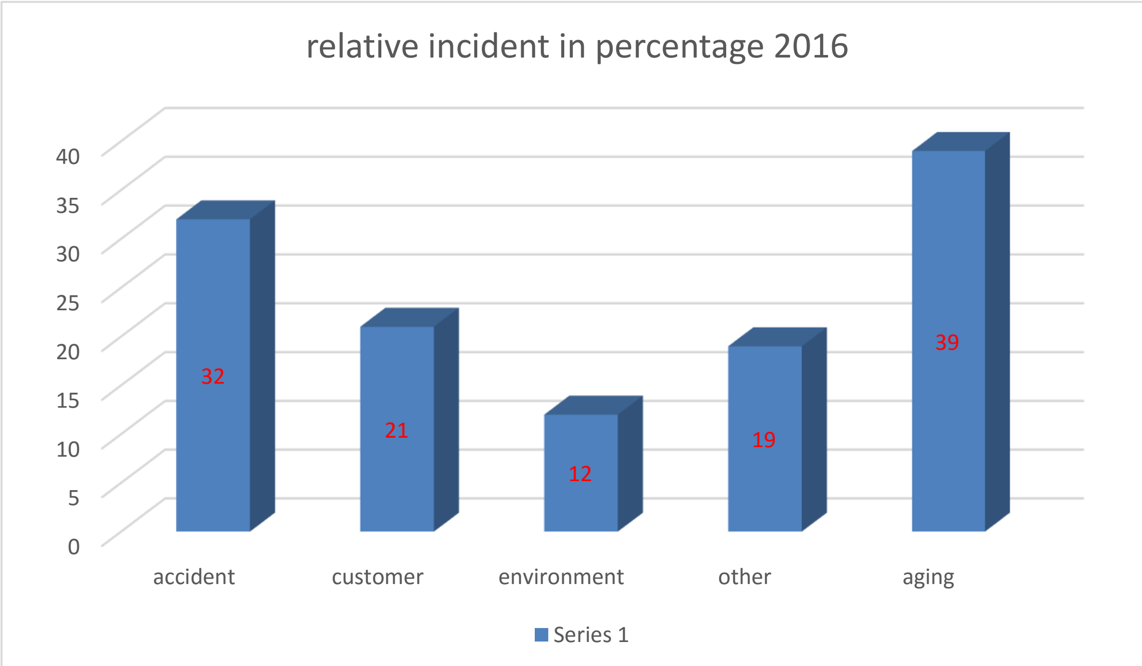


Figure 3.6 Relative incident percentage for 15kv line (source: Asella substation 2016 GC)

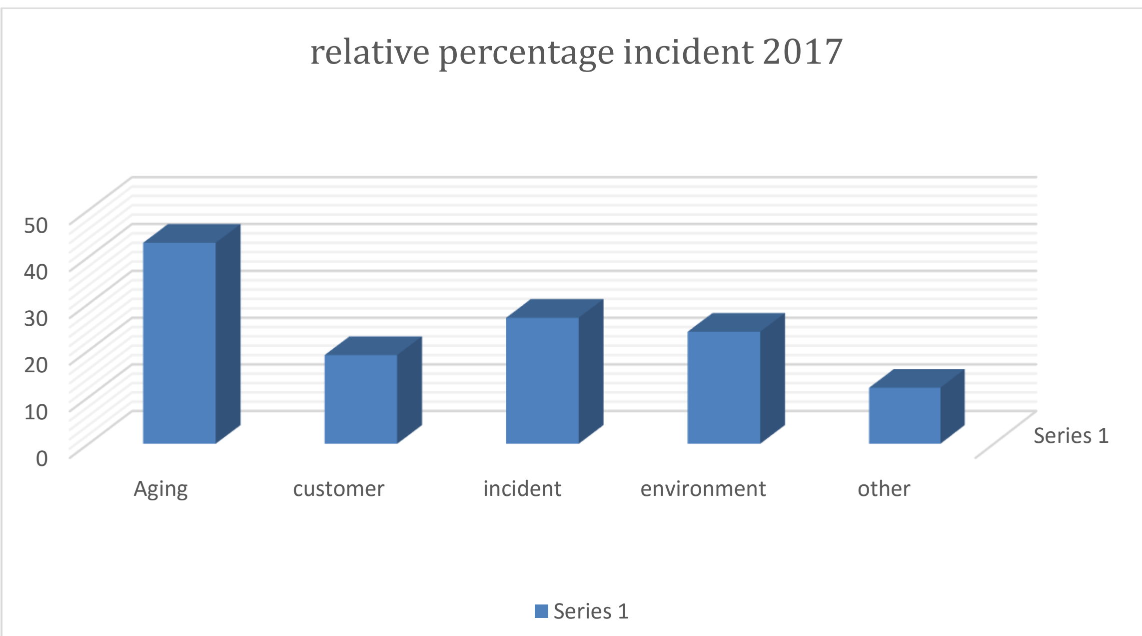


Figure 3.7 Relative incident percentage for 15kv line (source: Asella substation 2017 GC)

15 KV transmission parameter for existing system

Table 3.1: 15 KV line system (source: Asella substation ,2016 GC)

Months	Kwh un purchased in month	Average demand ,KW	Peak demand kw	Peak current
September	25033.2	3395	4800	229
October	89358.8	3443.6	4800	223
November	149899.7	3183.3	4750	249
December	44636.1	3055.9	4400	301
January	40636.1	3432	4300	258
February	18635.2	2350	3643	194
March	16549	3430	3541	260
April	17690	3280	3678	243
May	16855.2	3510	4800	213
June	17238	2500	4800	231
July	19365.2	2320	4769	247
August	33360.6	3408	5200	251

Table 3. 1: 15 KV line parameter for existing system (source: Asella substation ,2017)

Months	Kwh un purchased in month	Average demand ,KW	Peak demand kw	Peak current
September	220474.1	3150	4400	220
October	41128.2	2917.4	3900	223
November	20844.2	3133.3	6400	249
December	36975.55	3543.1	5600	320
January	57270.4	3134.8	5600	311
February	23456	2345	4800	232
March	21134	3457.8	3450	229
April	19867.4	4754.93	4453	235
May	19315.74	3213	4400	302
June	18367.52	3454	4434	231
July	19365.2	2981.8	3800	247
August	93758.3	2963.6	4000	251

CHAPTER FOUR

SIMULATION AND RESULTS

The concept of the power system stability enhancement, in a transmission line is taken to implement the use of simultaneous ac –dc power transmission. The corresponding simulation models of pure AC transmission is developed in MA TLAB / SIMULINK.

4.1 Investigation of pure ac (existing system) transmission line

The function of the electric power system is to supply electrical energy to consumers which is economical as well as reliable. An efficient transmission system has capability to provide the transfer of electrical energy between the point of supply and the delivery. Transmission line performance assessment depends on data collection capabilities and performance metrics to ensure continued grid adequacy and security. The testing of pure AC transmission line device in MA TLAB /SIMULINK model has been discussed in the following sections.

The simulation model for 15kv transmission line is shown in figure below.

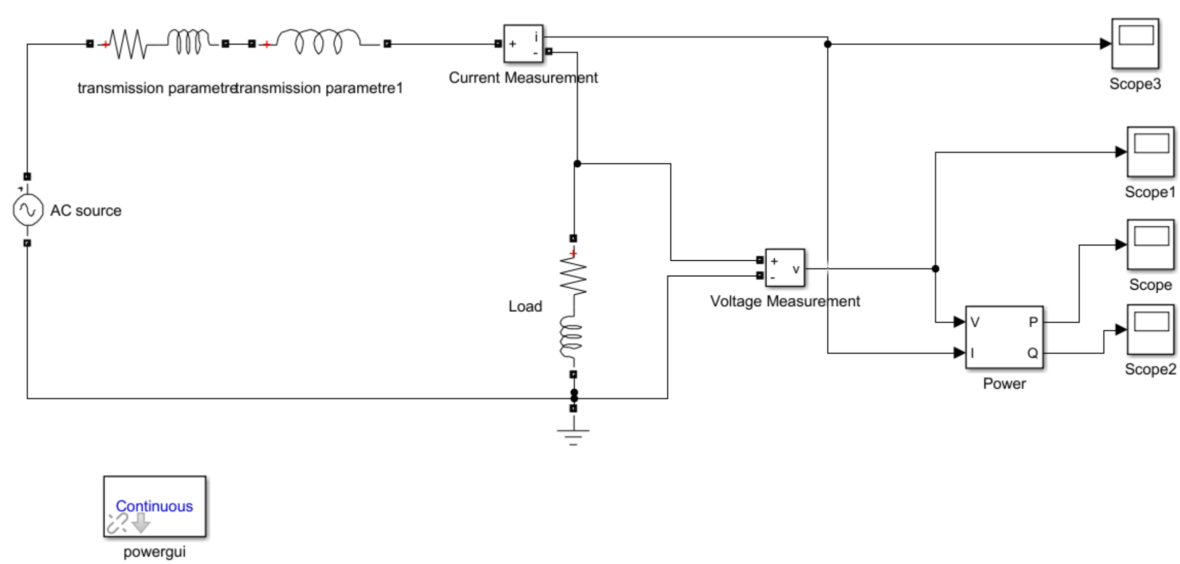


Figure 4. 1 Simulink model of pure AC transmission

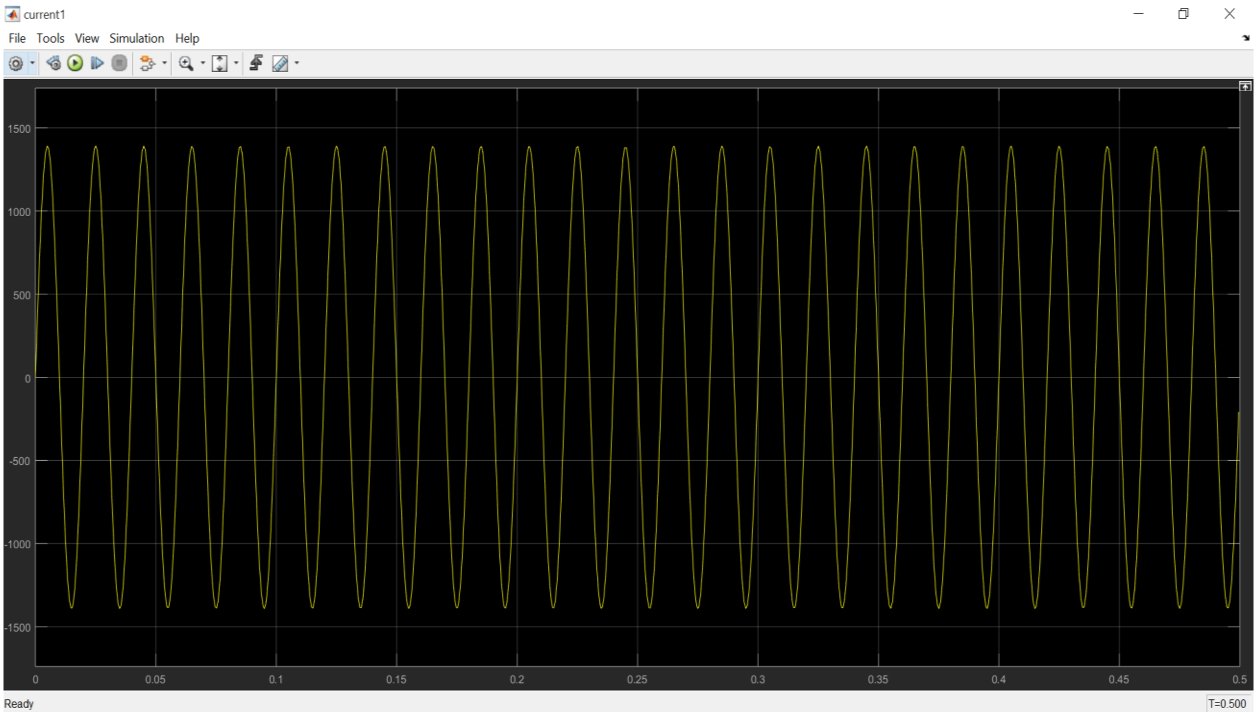


Figure 4. 2 Simulation result of pure AC transmission current

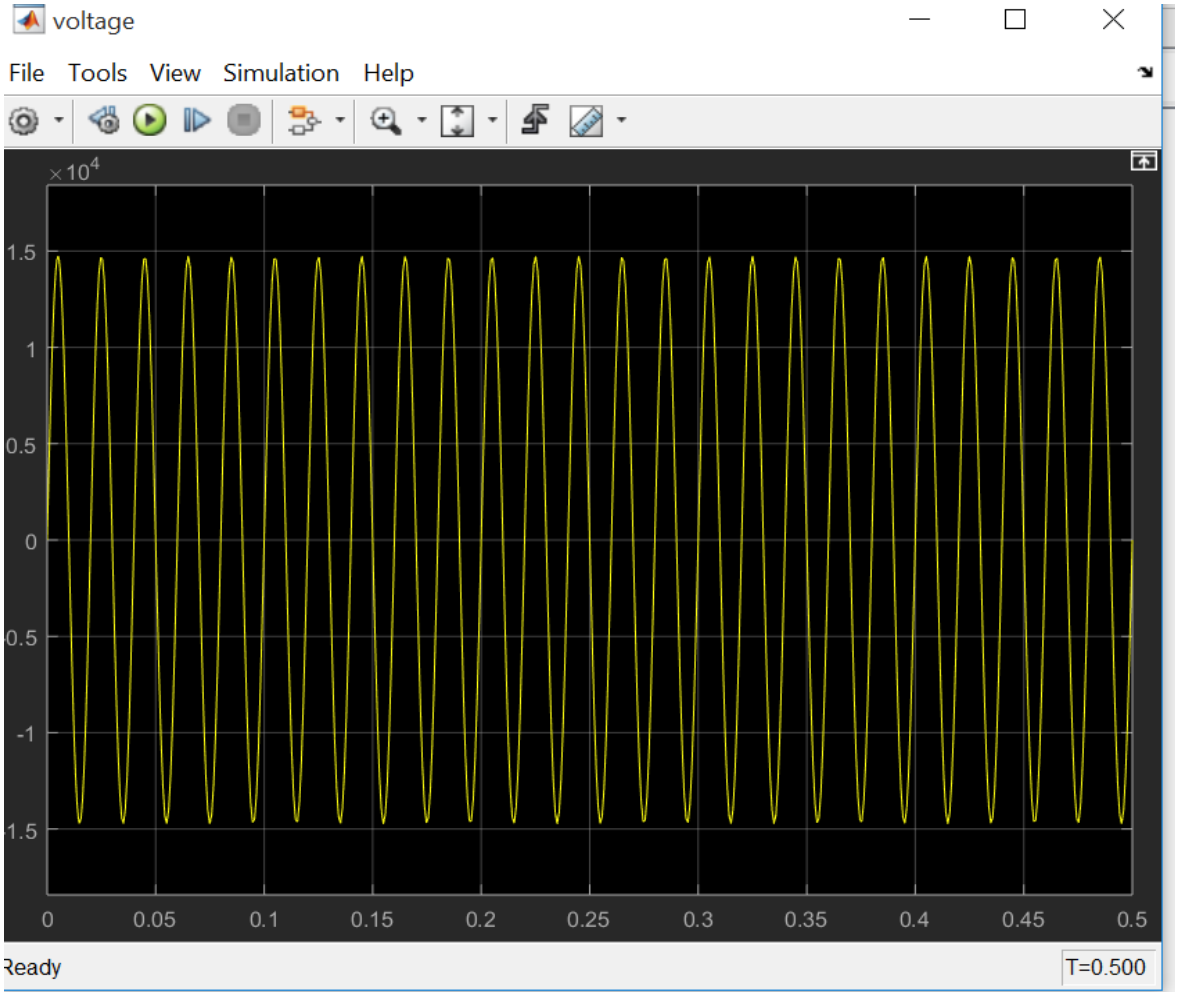


Figure 4. 3 Simulation result of pure AC transmission voltage

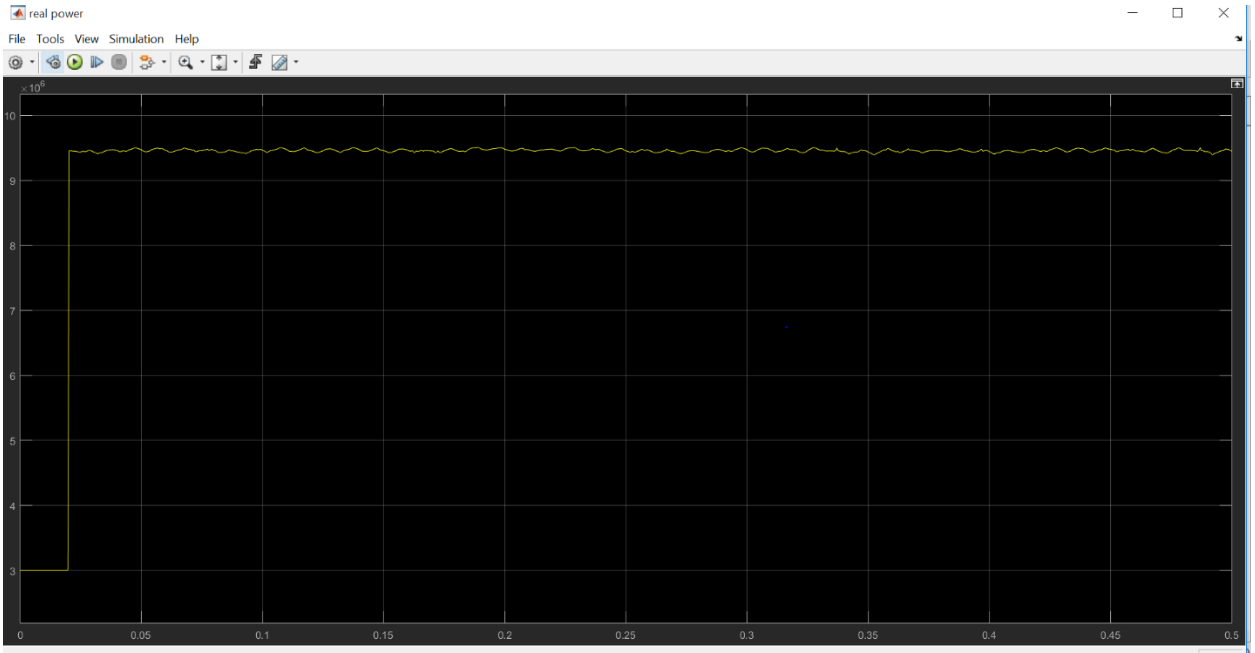


Figure 4. 4 Simulation result of pure AC transmission real power

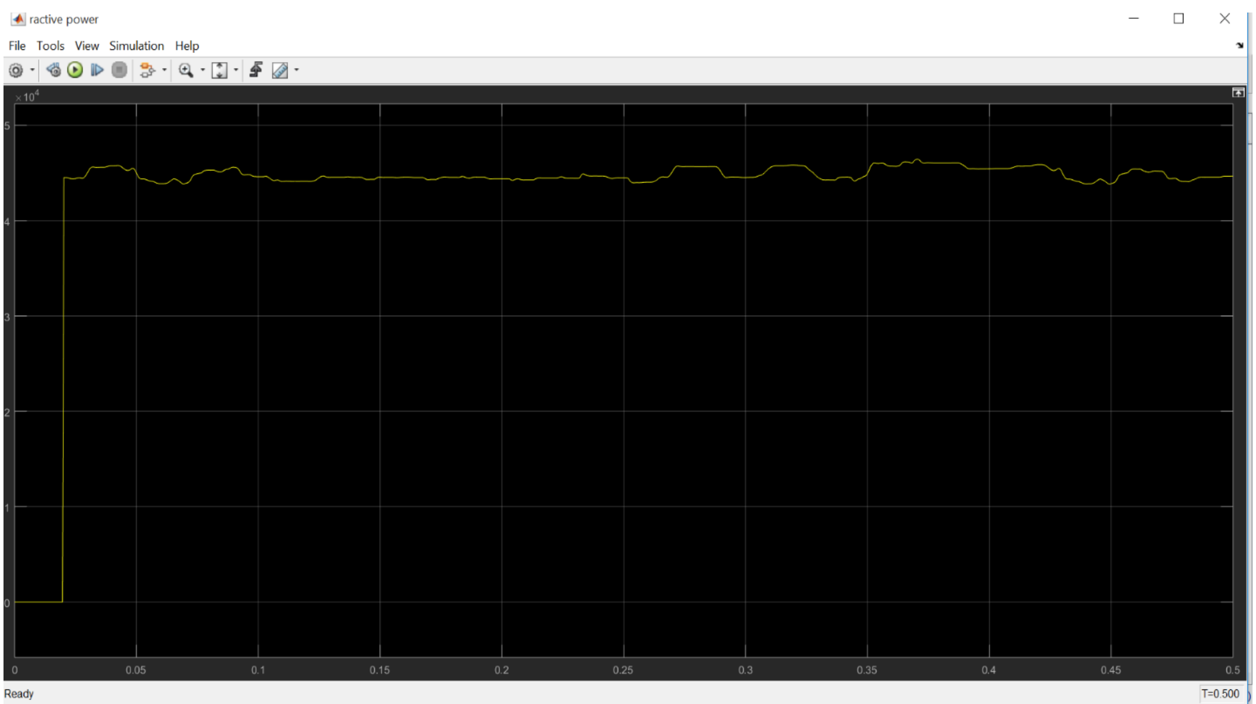


Figure 4. 5 Simulation result of pure AC transmission reactive power

4.2 Investigation of simultaneous ac-dc transmission (proposed system) transmission line

In this study MATLAB/Simulink used to show how simultaneous ac-dc transmission is used to enhance stability of power. The developed configuration of the simultaneous ac-dc transmission is developed and verified for stability analysis by simulating the model using MATLAB/Simulink. MATLAB/Simulink 2016b has been used to model and simulate the proposed system.

Here for the operation of simultaneous AC-DC power flow through a dual circuit AC transmission line we want to add the dc supply with AC supply.

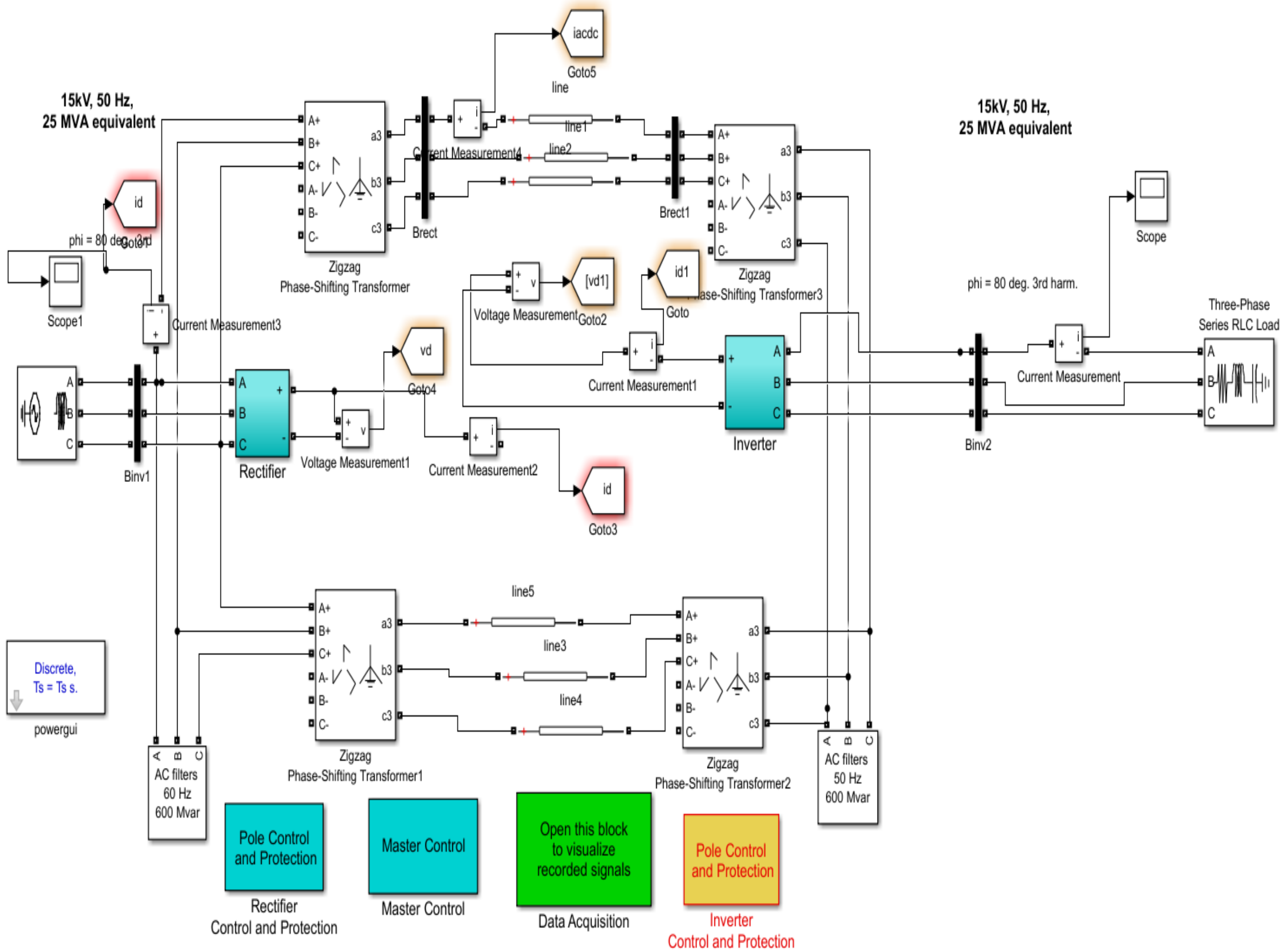


Figure 4. 6 Simulink model of simultaneous AC-DC transmission

The study is based on the comparison between the response under no fault conditions for combined AC and DC transmission (double circuit line) through Simulink in MATLAB.

A comparison between the sending end and receiving end voltages and sending end and receiving end current has been done. The active and reactive power changes during no fault conditions are also observed. I have started with double line AC-DC transmission with two sending end station that is a rectifier station and two receiving end station that is an inverter station making a more reliable and stronger system capable of overcoming any adversities or shortcomings. It is actually designed for a larger chunk of load transfer. It also guarantees continuous supply if one station is interrupted due to internal or external faults. The voltage, current and power profiles are studied during no fault since is found to have better transient response.

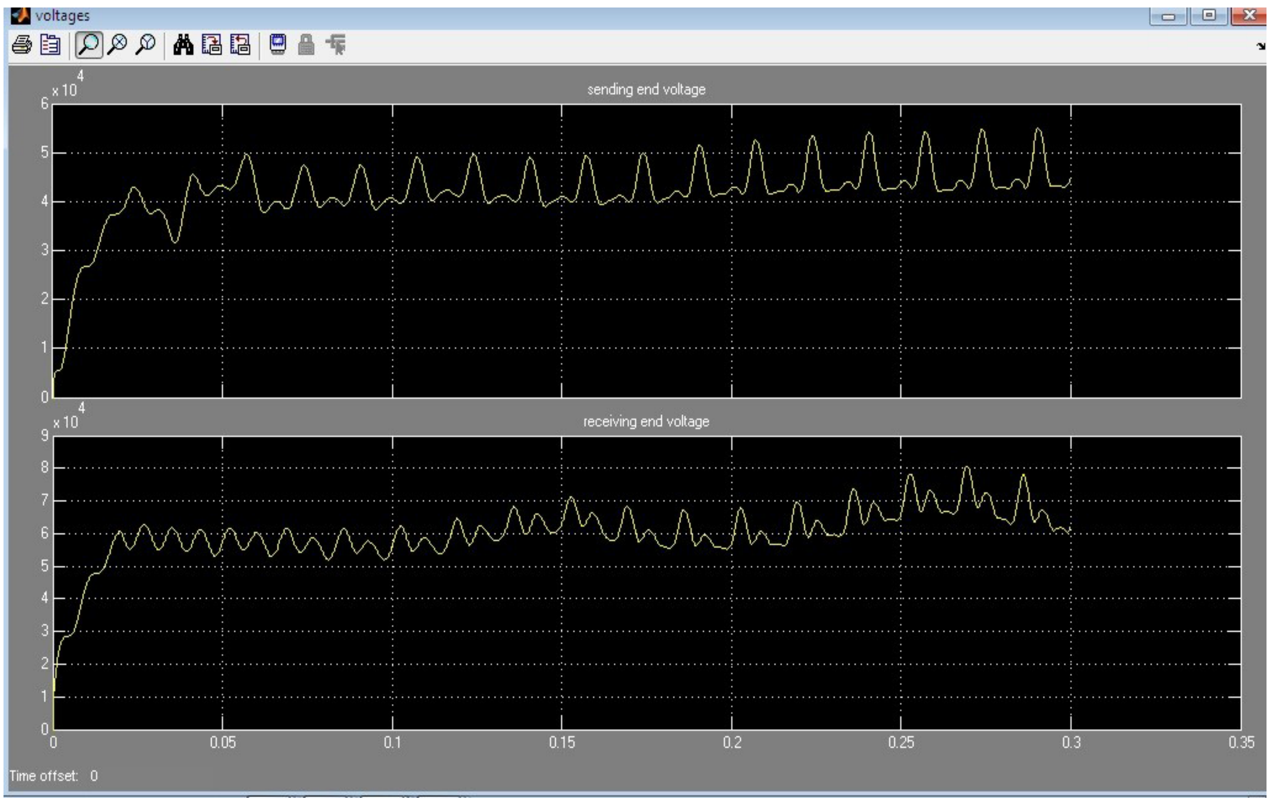


Figure 4. 7 Sending end and receiving end voltage

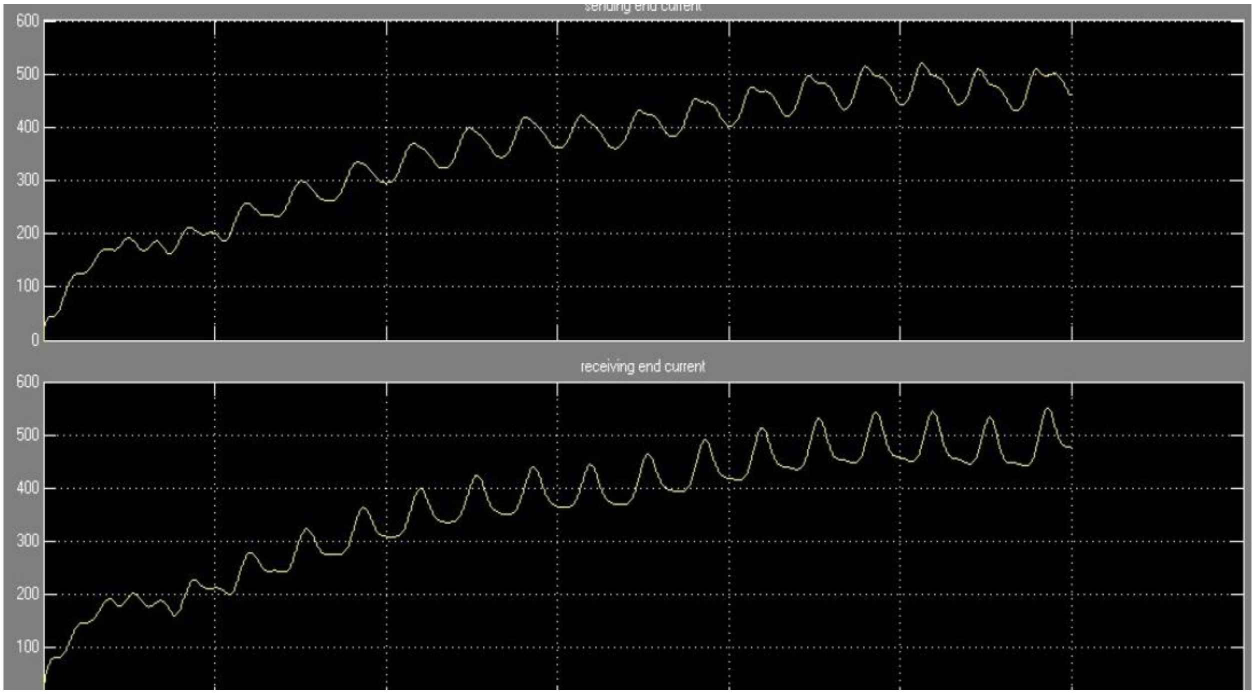


Figure 4. 8 Sending end and receiving end current

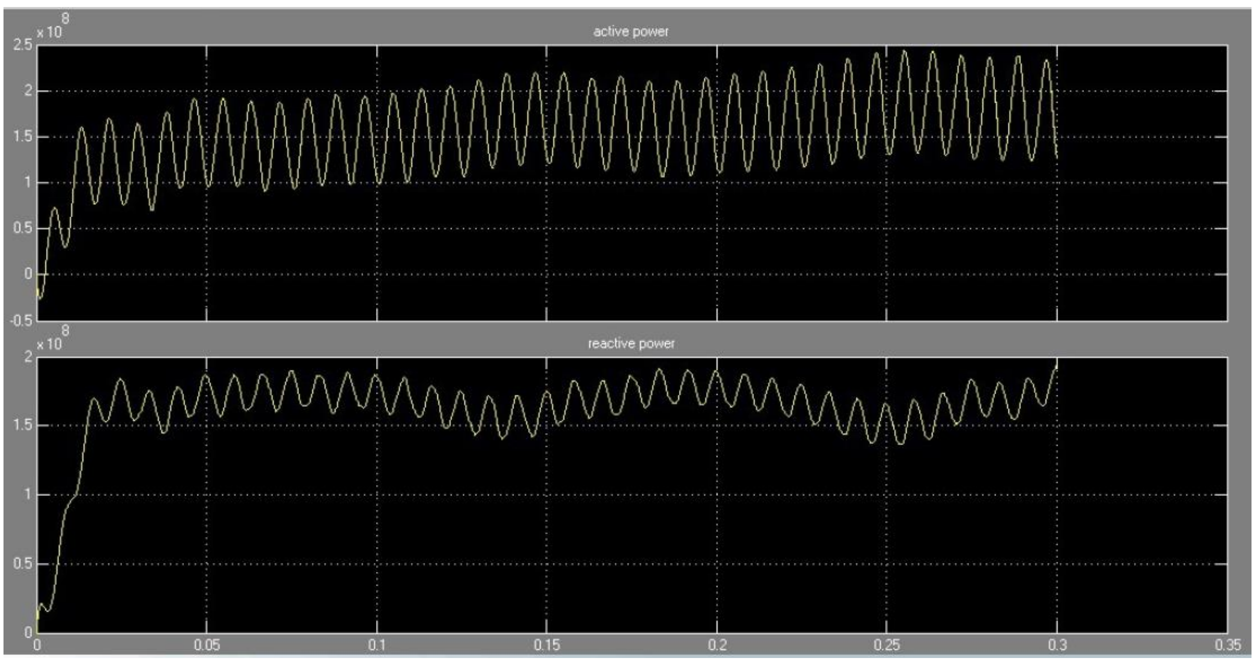


Figure 4. 9 Active and reactive power

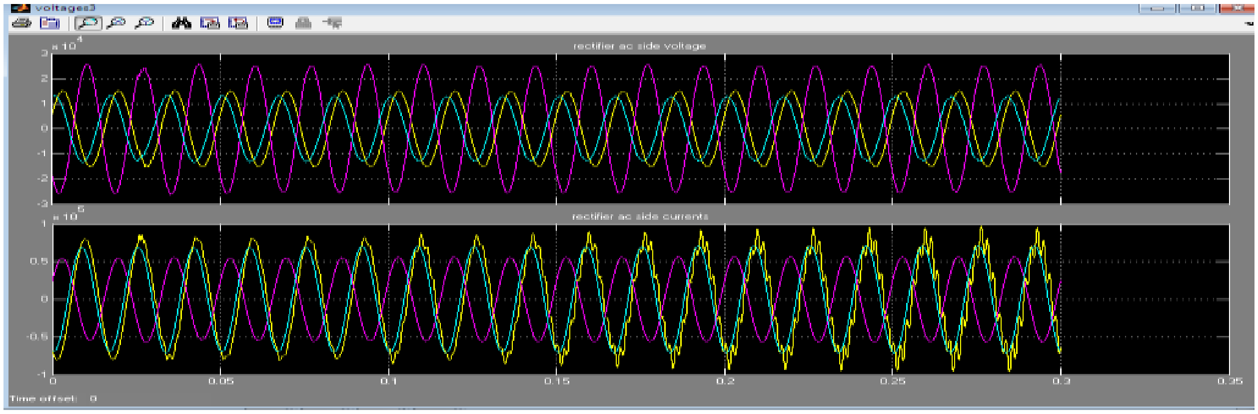


Figure 4. 10 Rectifier Ac Side Voltage, Current

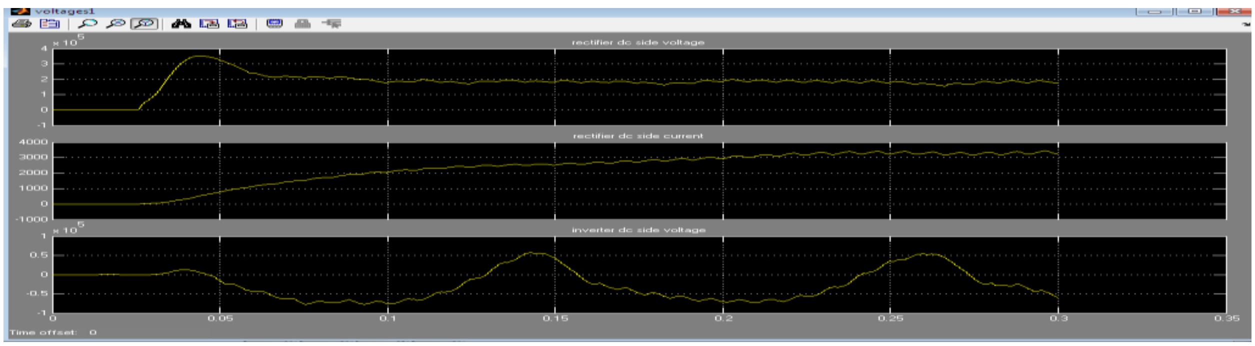


Figure 4. 11 Rectifier DC side (voltage, Current), Inverter dc side voltage

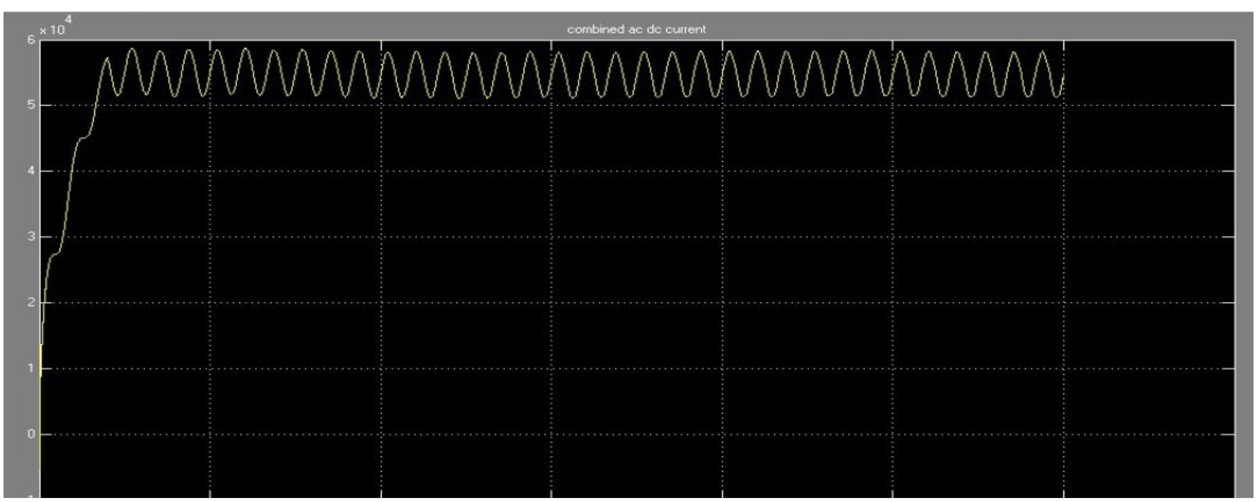


Figure 4. 12 Combined AC-DC current

CHAPTER FIVE

CONCLUSSION AND RECOMMENDATION

5.1 CONCLUSSION

In this study, it is shown that by injecting DC power in AC power transmission lines, we can improve the transmission capacity of the line without altering the existing transmission line. The added DC power flow is not the cause of any transient instability. This study shows the possibility of converting a dual circuit AC line into simultaneous AC-DC power transmission block to improve power transfer as well as to achieve reliability in the power transfer. Simulation studies are being made for the coordinated control and also individually the control of AC and DC power transmitted through the lines. The transmission capacity of the line also increases in the case simultaneous AC-DC power transmission as shown in MATLAB Simulink software. By observing from simulation graph for pure AC transmission the voltage magnitude is 9.754kV, the real power is 3.05e6 and the reactive power is 2.28e6 but in the case of simultaneous AC-DC power transmission this value is boost since it is the combination of both AC and DC value .

The stability is further enhanced because of quicker current control mechanism of HVDC blocks that is the rectifier and inverter blocks. In the control mechanism there is a master control and separately there is inverter and rectifier protection which works on VDCOL control procedures. Whenever the voltage dips on occurrence of a fault the current is restricted so the fault current is also decreased and the most significant thing is that it has very small time constant that is it works very fast.

5.2 RECOMMENDATION

There are so many technique to enhance power system stability which can be enhanced with appropriate software and different methods if implemented correctly. Having this in mind, this study also tried to use the simultaneous AC-DC transmission technique and the MATLAB software is used to show the design implementation of enhancing stability.

This work has been performed for a double circuited set-up. However, this could be extended to other types of systems as well. As is well known faults interrupt power flow in a line and it is mandatory to protect the system from its adverse effects. Therefore, various protection equipment and protection schemes are incorporated. Considering this effect one could employ suitable optimization technique to assess the effect of faults and relevant protection scheme to handle the same. In every transmission line the faults are occurred which interrupts the power supply, to avoid the faulty conditions some protection schemes are used in transmission line. By considering such a drawback in transmission line and with using a solution technique this work can be extended for analyzing the faults effect and different protect schemes suitable to that particular type of transmission.

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APPENDIX_A

Table A. 1 Power interruption frequency (source: Asella substation, Sept, 2016 - August, 2016 GC).

MONTH	**Interruption duration (hour)**
September 2016	12.8833
October 2016	18.2
November 2016	26.0333
December 2016	17
January 2016	31.9833
February 2016	15.8
March 2016	14.3833
April 2016	13.8667
May2016	10.0667
June 2016	12.6
July 2016	9.3833
August 2016	16.2167
Avg. monthly interruption	**16.53472**

Table A. 2: Power interruption frequency (source: Asella substation, Sept, 2017 GC – Aug, 2017 GC).

MONTH	**Interruption duration (hour)**
September-2017	10.4667
October -2017	14.85
November 2017	20.8667
December 2017	29.15
January 2017	29.4667
February 2017	39.2833
March 2017	20.65
April 2017	12.6
May 2017	11.0833
June 2017	12.6
July-2017	9.4833
August -2017	12.3667
Avg.monthly interruption number	**18.57223**

Table A. 3: Parameters of single circuit transmission system [21]

No	**Component**	**Parameters**
1	Transmission line	x = j116.8 (ii) Single circuit. (iii) Three phase (iv) 50 Hz (v) 400 km (vi)345 kV (vii) Thermal limit current = 1.8 Ka
2	Generator	550 MVA, 24 kV, 50 Hz, 30% transient reactance, H = 3.5 s.
3	Generator Transformer	550 MVA, 24/132 kV, 50 Hz, 10% reactance.
4	Transformer (At the sending end of the line)	550 MVA, 132/345 kV, 50 Hz, 8% reactance. (pure AC) 275 MVA, 132/172.5 kV, 50 Hz, 8% reactance. (AC-DC)
5	Transformer (At the receiving end of the line):	550 MVA, 345/132 kV, 50 Hz, 8% reactance. (Pure AC) 275 MVA, 172.5/132 kV, 50 Hz, 8% reactance (AC-DC)
6	DC system	DC system rated voltage 141 kV.

A Single Circuit Power Transmission System

The parameters of different components of the power system considered for the validation of the proposed model through circuit simulations are presented in Table A4.

Table A. 4: Parameters single circuit transmission system for circuit simulation

No	**Components**	**Parameters**
1	Asella-Segure transmission line	(i) z = 0.01755 +j0.3292 (ii) Single circuit. (iii) Three phase (iv) 50 Hz (v) 25 km (vi) 15 kV (vii) Thermal limit current = 1.8 kA Aluminum stranded conductor
2	Transformer (At the sending end of the line)	Delta -star, 25 MVA, 15/33kV, 50 Hz, 16% reactance. (pure AC)
3	Transformer (At the receiving end of the line):	Star –delta 25MVA,33/15 Kv,50Hz 16% reactance
4	DC system	The Rectifier and Inverter are 12-pulse converters using Dc current (rated) = 5.4 kA, Smoothing reactor = 0.5 H, Rectifier firing angle (minimum) = 5degree Inverter Extinction angle (minimum) = 14 degree

APPENDIX_B

Sim Power Systems

Sim Power Systems extends Simulink with tools for modeling and simulating basic electrical circuits and detailed electrical power systems. These tools let model the generation, transmission, distribution, and consumption of electrical power, as well as its conversion into mechanical power. Sim Power Systems is well suited to the development of complex, self-contained power systems, such as those in automobiles, aircraft, manufacturing plants, and power utility applications.

1. Implement sinusoidal voltage source

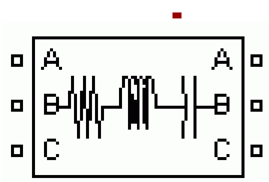
Description:

The AC Voltage Source block implements an ideal AC voltage source. The generated voltage U is described by the following relationship:

Three-Phase Series RLC Branch

2. Implement of three-phase series RLC branch

Description:



The Three-Phase Series RLC Branch block implements three balanced branches consisting each of a resistor, an inductor, or a capacitor or a series combination of these. To eliminate the resistance, inductance, or capacitance of each branch, the R, L, and C values.

Dialog Box and Parameters:

Branch Type: Select the elements you want to include in the branch. The R letter defines the resistor, the L letter defines the inductor, and the C letter defines the inductor.

Resistance R: The branch resistances, in ohms (Ω).

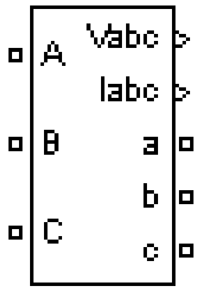
Inductance L: The branch inductances, in henneries (H).

Capacitance C: The branch capacitances, in farads (F).

3. Three-Phase V-I Measurement

Measure three-phase currents and voltages in circuit

Description:



The Three-Phase V-I Measurement block is used to measure three-phase voltages and currents in a circuit. When connected in series with three-phase elements, it returns the three phase-to-ground or phase-to-phase voltages and the three line currents.

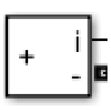
Use a label: If selected, the voltage measurements are sent to a labeled signal. Use from block to read the voltages. The Go to tag from block must correspond to the label specified by the Signal label parameter. If not selected, the voltage measurements are available via the V_{abc} output of the block.

Voltages in pu: If selected, the three-phase voltages are measured in pu. Otherwise they are measured in volts.

Base voltage (V_{rms} phase-phase): The base voltage, in volts RMS, used to convert the measured voltages in pu. The Base voltage (V_{rms} phase-phase) parameter is not visible in the dialog box if Voltages in pu is not selected.

4. Current measurement:

Description:



Select yes if you want to measure the three-phase currents that flow through the block.

Use a label: If selected, the current measurements are sent to a labeled signal. Use from block to read the currents. The Goto tag of from block must correspond to the label specified by the Signal label parameter. If not selected, the current measurements are available via the Iabc output of the block.

Signal label: Specifies a label tag for the current measurements.

Currents in pu: If selected, the three-phase currents are measured in pu. Otherwise they are measured in amperes.

Inputs and Outputs:

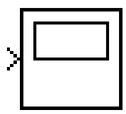
Vabc: The three measured phase-to-ground or phase-to-phase voltages. The Vabc output disappears when the Use a label parameter is selected or when the Voltage measurement menu is set to no.

Iabc: The three measured line currents. The Iabc output disappears when the Use a label parameter is selected or when the Current measurement menu is set to no.

5. Scope

Display signals generated during simulation

Description:



The Scope block displays its input with respect to simulation time.

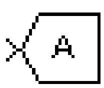
When simulation is started, the Scope windows are not opened, but data is written to connect Scopes. As a result, if we open a Scope after a simulation, the Scope's input signal or signals will be displayed.

If the signal is continuous, the Scope produces a point-to-point plot. If the signal is discrete, the Scope produces a stair-step plot.

6. GOTO

Pass block input to from block

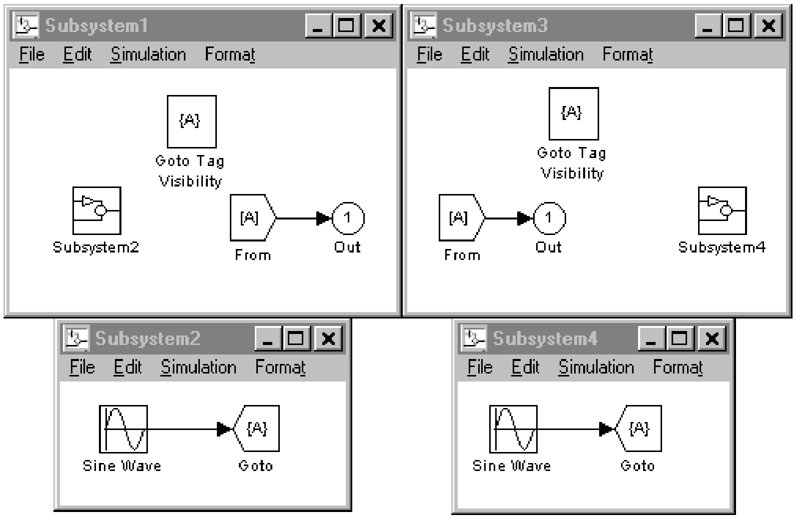
Description:



The Go to block passes its input to its corresponding from blocks. Goto blocks and from blocks are matched by the use of Goto tags, defined in the Tag parameter.

The Tag Visibility parameter determines whether the location of from blocks that access the signal is limited:

Local, the default, means that from and Goto blocks using the same tag must be in the same subsystem. A local tag name is enclosed in brackets ([]).



7. FROM

Accept input from Goto block

Description: