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COMPARISON OF HVDC AND HVAC TRANSMISSION SYSTEMS

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ABSTRACT

COMPARISON OF HVDC AND HVAC TRANSMISSION SYSTEMS

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Power transmission mainly depends on the Alternating Current in various fields of life. Especially (AC) is commonly used in the short and medium distances, but that the process of power transfer may face several problems when it's affirmative for power transmission to the distal distances. So these problems and obstacles necessitate to search new ideas and find alternative solutions. Because the truth is that relying on the system stream of (AC) accompanies many problems for the power transmission and also difficult to control, as well as increasing the cost transmission system. In this study, we have put forth advantages and disadvantages of them by making comparison of HVDC and HVAC transmission systems. Power losses have been calculated in both systems by considering different transmission line distances. In addition, the voltage variation between both sending and receiving sides has been found for each of two systems considering different transmission line distances. All tests that have been performed for putting forth disadvantage and advantage of the high voltage transmission systems have been done by the systems working under normal and abnormal situations. As a result of studies, HVAC transmission systems in short and medium distances, HVDC have been proven to be advantageous in case of long distances.

Key words: HVAC power transmission system, HVDC power transmission system.

ÖZET

YÜKSEK GERİLİM DC VE YÜKSEK GERİLİM AC İLETİM SİSTEMLERİNİN KARŞILAŞTIRILMASI

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Hayatın çeşitli alanlarında güç iletimi ağırlıklı olarak alternatif akıma (AC) bağlıdır. Özellikle AC yaygın olarak kısa ve orta mesafelerde kullanılmaktadır, ancak AC iletim sistemleri uzak mesafelere güç iletimi için olumlu olduğunda güç transfer süreci birkaç sorunlarla karşı karşıya kalabilir. Bu nedenle, bu problemler ve engeller yeni fikirlerin araştırılmasını ve alternatif çözümlerin bulunmasını gerektirmektedir. Çünkü gerçek şu ki güç iletimi için AC sistem akışına dayalı olmak bir çok problemlere eşlik eder ve kontrolü de zordur, ilaveten iletim sistem maliyetini artırmaktadır. Bu çalışmada, yüksek gerilim doğru akım (YGDA) ve yüksek gerilim alternatif akım (YGAA) iletim sistemlerinin karşılaştırmasını yaparak avantajlarını ve dezavantajlarını ortaya koyduk. Farklı iletim hattı mesafesi ele alınarak her iki sistemdeki güç kayıpları hesaplandı. Ayrıca, gönderici ve alıcı tarafları arasındaki gerilim değişimleri her iki sistem için farklı iletim hattı mesafeleri dikkate alınarak bulundu. Yüksek gerilim iletim sistemlerinin dezavantaj ve avantajını ortaya koymak için gerçekleştirilen tüm testler sistemlerin normal ve anormal durumlarda çalışması ile yapıldı. Yapılan çalışmalar neticesinde, kısa ve orta mesafelerde YGAA sistemlerin, uzak mesafelerde ise YGDA sistemlerin avantajlı olduğu ortaya koyuldu

AnahtarKelimeler: YGAA güç iletim sistemi, YGDA güç iletim sistemi.

Dedicated to

"To Beloved parents, my dear wife, my brothers and sisters"

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TABLE OF CONTENTS

Pages

LIST OF FIGURES

Pages

LIST OF TABLES

Pages

LIST OF SYMBOLS / ABBREVIATIONS

HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
AC	Alternating current
DC	Direct current
VSC	Voltage Source Converter
VSC-HVDC	Voltage Source Converter based HVDC
CSC-HVDC	Current Source Converter based HVDC
CSC	Current Source Converter
PWM	Pulse Width Modulation
IGBT	Insulated gate bipolar transistor
NPC	Neutral Point Clamped
GTO	Gate Turn-Off Thyristors
LCC	Line-Commutated Current
UHVDC	Ultra High Voltage Direct Current
LCC-HVDC	Line-Commutated Current High Voltage Direct Current
PM	Pulse Modulation
MMC	Modular Multilevel Converter
MW	Mega Watt

Kv	Kilo Volt
Ka	Kilo Amper
ABB	Swedish-Swiss multinational corporation
RoW	Right Of Way
STATCOM	Static synchronous compensator
SVC	Static Var compensator
V	Volt
A	Amper
Rms	Root-mean-square
XLPE	Cross-Linked Polyethylene
δ	Relative Stage Shift
P12	Dynamic power flow
Eac	Compensation transport voltage
MIC	Mass-Impregnated Cable
XL	Inductance transmission line
XC	Capacitance transmission line
Zth	Thevenin proportional impedance
SCR	Short circuit ratio
Pdc	Power direct current

ESCR	Effective short circuit ratio
VDOCL	Voltage dependent order current limit
HVAC	High Voltage Alternating Current
p.u	per unit
P ac	AC power
sec	second
C	Capacitor

CHAPTER 1
INTRODUCTION

1.1 Introduction

As economic an accomplishment and population growing, the electricity utilization of each land also increases speedily. The expansion of transmission system and power generation should also increase intact to cover the electricity demand.The outcome, the whole power system will experience more difficulty in operation and stability, like increased power losses, higher inherent of frequency and voltage insecurity, power flow control, interconnection, power fluctuation, collapse proscription and so on. Over the last decade, to transmit power to long distances High Voltage Direct Current (HVDC) technology has been widely applied. The (HVDC) transmission line technology, more efficient and can transfer bulk power with less electrical losses compared to high voltage alternating current (HVAC) transmission system [1]. The lower transmission cost, means higher efficiency, lower cost. HVDC system can improve stability, enhanced accuracy system, permits the laborer idealistic control over power flows in overall system [2]. The transmission lines in HVDC technique need narrower pathway, utilize minimal mainland when compared to than AC transmission lines. The dominant benefits of HVDC transmission lines are their efficient, lower power is lost as it is transferred and there is no required reactive power Compensation over the transmission lines. Because direct current influx firmly during the lines without fluctuating path many times each second and through the complete conductor in lieu of at the surface, typically the direct current transmission system mislay less power than AC transmission system. In addition to raising and widening the present (AC) grids, there will be a rise, demand to construction “electricity highways”, creating a huge and dependable backbone structure, electricity providing. The direct current system is relevant when Into account a lengthy distance covering networks. So far, HVDC transmission system has fundamentally been used in Submarine applications, for transmitting power.

HVDC has confirmed the benefits over the HVAC transition system as it has extremely minimal corona loss, need less dielectric, and lower voltage falling. The cost of Insulators, cables and conductors, light towers Poles are low so the system is inexpensive. Extreme significantly, the connotation of skin effect, insulation losses, telecommunication signal intervention, Inductance and twister, stabilization and synchronizing troubles are not originating in HVDC transmission system. [3] HVDC system based on its work on three main parts to perform the function for the transmit of electrical power to the long-haul. (1) Converting system to convert AC to DC (2) the transport unit or transmission lines (3) second converter system to convert DC to AC. HVDC technology can be arranged in numerous trends on the foundation of expense, operational necessity, and pliability. The most straightforward one is the back-to-back correlation, and it has two converters on the exact location and there is no transition line. This class of link is utilized as interns tie amidst two various frequency operations transmissions systems. The mono-polar link connect two converters, terminal by an individual conductor line and ground or sea is utilized like turning track. The HVDC bipolar-link is more commonly used in practical applications, where duet converter terminals are linked by bipolar (±) conductors and every jointer has its have earth regress. The multi- stations HVDC have more than two converters, terminal, it could be linked to one of two ways either format (series) or in parallel.

1.2 Motivation and Objective of the Thesis

The purpose of this dissertation is to examine the influence of HVDC technology on the transmission system precision. The utilize of HVDC system in the transmission system will impact the reliability of the system. The HVDC will have various effects on the transmission system.At the time of the proposal, the site of the HVDC in the transmission system should be strictly elected, both HVDC and HVAC systems are modeled and simulated in the MATLAB/ SIMULINK environment hence the observation. The main focus of the thesis is to:

- To evaluate and study the voltage variations for each system separately and compare it to each other.

- Calculating the percentage of power losses to distinguish the difference between both systems.

- The project Focuses on studying different transmission systems to transfer power.

- Evaluate the influence and performance of HVDC technology of the transmission system based on survey cases and the length of lines.

- Finally, understanding the operating principles of HVDC transmission systems.

1.3 Problem formulation and Contribution of the Thesis

An efficient and reliable transport of bulk energy over a long distance is a great challenge. Charging current puts a limitation to the power transmission through underground cable and undersea cable over a long distance. Problems in interconnection of asynchronous grids with the existing power grids due to frequency and voltage levels not suitable for grid connection. An efficient and stable operation of the AC system during and post disturbance conditions are a great challenge for an AC transmission system. For the above problem, it is needed to have an HVDC transmission. Which provides a greater flexibility and control of power flow through a DC transmission line and hence stability.

Now a day’s power system based on an AC transmission work at high risk as it operates at the bottleneck in stability margins. Even a small disturbance can challenge transient stability and voltage stability limits. If the system can’t restore itself within a certain time it leads to collapse of complete power system. Hence, as a solution to the above problem VSC-HVDC with an efficient control strategy which is capable of controlling the active power and reactive power independently. HVDC technology can capable of changing its working point instantly within its capability curve, hence the dynamic stability. The influence of HVDC technology is a very wide topic, It involves technical, as well as economical issues. The technical problem includes regular running, operation over alarms or contingency situations, and responds to mistake in the system, but also deformation and electromagnetic domains due to direct current lines. To provide the required goal to add more stability to the power system.

1.4 General outline of the Thesis (Thesis Scope)

This thesis studies the impacts of HVDC technology in transmission system and its application in the power system to transfer power to different distances, also comparing the analysis between HVDC and HVAC system. This project is organized into six chapters:

Chapter 1: This chapter gives a simple detail of the work, including objective and the contribution of the thesis and the organization of the project.

Chapter 2: This chapter explains the literature related to the work and the place of this work in the literature.

Chapter3: This chapter offers a general information about the HVDC system and explains the principle of the HVDC in details.

Chapter 4: This chapter explains the principle of the HVDC and HVAC systems and the comparison between both systems to address various technical aspects.

Chapter 5: This chapter represents the simulation studies and the discussion of the results.

Chapter 6: This chapter contains conclusion and suggestions for future work.

CHAPTER 2
LITERATURE SURVEY

2.1 Introduction

Many researches have focused on HVDC technology on the power system and the effects on the overall system, literature review from different sources reveal the following thoughts about HVDC technology,which is efficient, fast and freelance control over both active and reactive power and improves the transit stability. Basically, it greatly enhances the voltage stability and keeps the system from collapsing due to lack of reactive power. This chapter establishes a comprehension, up to date literature survey.

2.2 Related Work in the Literature

Orkuþing (2001) presented a paper conference about the high voltage direct current (plus) system, is well proper to subtend the new markets and its request and the purpose of transmitting power for long distance, these research statement interesting operating achievement, which appearance that HVDC (plus) is a certain technology. As a result the HVDC Light is a direct current transit system that has a significant interest in enforcing in competitive shops. These benefits contain its integrated design lead to short- term transmission times, and consolidated terminals and cables, reducing naturally minimize environmental effects and controllability giving endurances to agree the power requirement and or to control the voltage in the electrical grid. These dependability means that HVDC Light preparations can be confirmed speedily in response to competitive shopper signs [4].

Cuiqing Du (2003) he searched with the control of voltage source converters (VSC-HVDC) system, the utilize of (VSC-HVDC) in the inactive manufacturing system and the system styling with various voltage levels.The purpose of the this research is to estimate the possibility and determination of the utilize of direct current system delivery industrial field power systems. In this thesis, we address the technical comparison of a real as provided distribution system and deck provide a distribution system is completed depending on the disturbance situations on the grid side and motor starting on the consumer side. The impact of the current restrictions on the achievement is thoughtful. It is Clearly shown that VSC-HVDC utilized in industrial systems, which can to relieve voltage falls. This research fulfillments the usefulness and harms of employing VSC-HVDC to supply big industrial investiture. Through this inquiry current restriction is comprise and its impact on VSC-HVDC's a capability to lessen voltage drops is evaluated during disturbance situations and during motor starting [5].

Osama Swaitti (2007) from the survey presented that the system stability of the exam system is enhanced with the preamble of HVDC by either increment HVDC road to the system or by the alteration of some AC lines by HVDC. It is also shown that the influence be based on the place of the HVDC system, installing. The performance of the system improves when you add HVDC technique to a large extent due to the increase in transport capacity by means of a critical transition. Which this technique named HVDC is generally better at maintaining voltage stability compared to the AC system for the transfer of power. This is one of the reasons that notes on this technique, where it has a special significance to improve the system, when the exchange high voltage alternating current with high voltage direct current system. The HVDC system designed to perform the balance and controllers of the reactive power on both sides of converters stations on request to preserve the station voltage at its group level freelance of the real power through the HVDC system. Lastly, the outcome system indicator for every HVDC status have been compared with the essential status so as to quantify the influence of HVDC lines. The HVDC system inclusion in the system has support the stationary portion of the voltage stability and hence improves the operational system’s situation, which consequently minimized the number of consumer side failures [6].

Kala Meah (2007) showed and presented a comparison valuation of HVDC and HVAC transmission power systems. HVDC system artificial ability tot transmits giant power through lengthened distances. Practically, Compared to assess HVDC transmission and air conditioning systems. HVDC makes it possible to transport bulk power over long distances. Technically, the command and control are more difficult on the AC system due to lack of stability of the frequency compared to DC power system for the transfer of electric power. In this research lastly researcher arrived to many important main points following as, HVDC transmission does not own the stability issue because of non-existence of the frequency, and so, no distance restriction,Long distances are practically unreachable by HVAC line without interpose reactive power reparations, The HVDC has depress impact on the human and the environment in genericlly,which compel to become the HVDC sympathetic with environment.The cost and expenditure per unit length of a HVDC system minimal than HVAC system of the himself power capability and identical stiffness, but the cost of the stations equipment of a HVDC line is a lot higher than that of the HVAC system.[7]

Mai H. Nguyen, Tapan K. Saha, Mehdi Eghbal (2010) presented a comparative case for three different distance transmission technology due to voltage stability issues. Between bipolar type system, hybrid high voltage DC (HVDC) and High Voltage AC (HVAC) system are compared in phrases of voltage stabilization and point of shake off (break down). Every situation is discussed and tested with various distances of transmission lines and in different unsecured situations. The effects of HVDC control manner and parameters on grid voltage stability are likewise tested. The influences of HVAC and HVDC grids of the system output have been Evaluated.showed the bipolar HVDC is established to be premiums for the others and the hybrid HVDC is the undesired election in terms of system output no matter how distant the transmission line was. The bipolar HVDC was low susceptible to the abnormal situation in the system compared to the other chosen. The steadiness was superior preserved when the faults happened either in other regions or at the grid itself.Finally, as results concluded the hybrid selection is the much costly one and has the worst achievement on system constant voltage stability improvement [8].

SHU ZHOU (2010) presented the (VSC-HVDC) becomes a promising system for grid connection. The VSC-HVDC provides a number of potential advantages over the conventional HVDC, like as fast and freelance control of reactive and active power, no restriction on multiple infeeds. Therefore, VSC-HVDC will likely to be widely used in the future transmission networks. In this thesis, a three-terminal MTDC system was investigated using simulations and experiments. The MTDC system with its control was implemented in PSCAD/EMTDC. The control strategy developed through simulation was verified using experiments. The results of

PSCAD/EMTDC simulation and laboratory demonstration were then compared. The system is able to recover to the normal operation status automatically when subjected to an AC balanced fault (three phase fault) and unbalanced fault (single phase fault) on the grid. [9]

GUSTAVO PINARES CCORIMANYA (2010) he showed, the running of multi-stations VSC-HVDC grids are scrutinized. The main interest of an HVDC link is the capability for transmitting bulk power through tall distances and the possibility of the commerce power among various AC systems. Due to the advantage in the utilization of immaculate power sources, far away from consuming position, the concept of utilizing an HVDC system has become global in the last decades. A control designing, to evenness the power in the HVDC system, has been suggested in this dissertation. In finally, three phases of work can observe. Firstly, a shortly understood of purposed control planning in the literature has been loaded out with the goal of conception the issue of power flow problems and balancing in the DC station. Secondly, the designing and modeling of VSC-HVDC and its specialized controller has been performed jointly with the resolved control strategy and the frequency organizing sketch. Lastly, simulations to examine the proposed control designing of the DC system together with an AC system have been completed [10].

Ana - Irina Stan, Daniel - Ioan Stroe (2010) over this thesis presented for modeling and controlling of the VSC depending on HVDC technique are investigated and described. Two different control ways able of controlling such systems are suggested. Both expanding control strategies are performed in the dq concurrent reference edge. Orderly to analysis both stable state and unstable situation of the improved VSC-based HVDC transmission system all study courses are carried out utilize MATLAB/Simulink. The goal and results of this project showed was to investigate and examination the behavior of the VSC- based HVDC transmission lines [11].

Toru Tanaka, Toshimistu Tanaka, Yosuke Nozaki (2011) examined the impacts of device parameters on a (HVDC) power feeding system when a fuse calamity. We then utilize a pure fuse sample which we have formed, to simulate voltages and currents when a fuse blows and estimate the hazards that another Information and Communications Technology (ICT) tools will flop, or that fuses in the tools will also blow. By studying these results we conclude that, use a fuse-simulation model to discused the impacts of system parameters on the performance characteristics of the system when fuses blow in HVDC power supply systems, which have been receiving much rconcern eventually.When studing and analysis of different three histrionic system parameters, is called the capacitance of the CBOX, the inductance of the CBOX, and the insertion capacitance on the other ICT equipment,wher we put under vision that discontinuity of the other ICT equipment and other fuses blowing will slant to happen in the following situations: The CBOX capacitance is tiny, CBOX inductance is big. The idea of research tested here can be utilized to structure secure systems, participating to the prevalence of HVDC power supply systems [12].

Tatjana Kalitjuka (2011) This thesis examed the implementing of possibility designing and control planning for the DC-link of VSC, with the aim of resemble the effect of such modeling and control on the dynamics of the conversion station. The control technique depends on the immovable notion of vector control is accomplished. The essential mission is guidance toward accomplishment of more dependable DC-link dynamics with smaller wanted capacitance. The control algorithm depends on Offset the power between inverter and rectifier through the DC-connect with the minimal value of DC voltages the divergences. DC- connect voltage regulation is accomplished via investigation a control based on the energy stocked in the DC-connect capacitor. In this thesis two ways of DC-link voltage control were examined, first method is based on reference voltage for voltage control, and the second method is by using energy of the DC-link capacitor as a reference for voltage control. Setting methods of the system were also discussed. Further implementing of the control designing and setting bases are needful for enhancement the controller performance of HVDC technology [13].

Jicheng Yu (2013) reviews previous works on embedded HVDC, proposes a dynamic embedded HVDC model by PSCAD program, and compares the transient stability performance among AC, DC and embedded HVDC. The test results indicate that by installing the embedded HVDC, AC network transient stability performance has been largely improved. Therefore the thesis designs a novel frequency control topology for embedded HVDC. According to the dynamic performance test results, when the embedded HVDC system equipped with a frequency control, the system transient stability will be improved further. Embedded HVDC, like FACTS, is effective equipments which supply additional control through the AC grid in which they are fixation. This gain in flexibility comes at the expense of complexity. Depending on the underlying HVDC technology, different technical issues arise, along with different features and performances. Hence, each project leads to different choices, such as: static power dispatch on hybrid AC/DC transmission corridors; design of an automatic system security control; Contribution to voltage or reactive support; system stability enhancement for transient stability and recovery; power oscillation damping; supplementary controls activated under specific conditions; etc. [14].

MARTIAL GIRANEZA (2013) In this research HVDC technology, namely VSC-HVDC is used as an interface for connecting independent power providers units to the grid. VSC-HVDC has various advantages such as short-circuit contribution and freelance control of useful and harmful power. VSC-HVDC advantages are used for a safe integration of IPPs and make them participate in grid stabilization. MATLAB/Simulink simulations of different grid connected, through VSC-HVDC system, IPPs technologies models are performed. HVDC, now is mostly utilized for the transmit a large amount of power through tall distances and for the interconnection of not matching networks. Along with the expansion of the HVDC, the development of power request, In parallel with the expansion of the population rate in the future. Besides the ongoing increasing of power demand, the reforms in electricity market have led to the liberalization and the incorporation of Independent power providers in power system operation. For each IPP technology model, system model performances are studied and dynamic responses during the disturbance are analyzed in the MATLAB / Simulink program. The simulation results show that the model satisfy the standard imposed by the regulating authority in terms of power quality and grid support. Also the results show the effect of the VSC-HVDC in preventing faults propagation from grid to integrate IPPs units. The use of VSC-HVDC system as an interface for the integration of three IPPs considered in this thesis, it has been observed that despite the difference in their technologies all those IPPs behaves similar during the normal working conditions and that they are able to support the grid during fault [15].

MOHAPATRA BIKASH KUMAR SAHOO during (2014) presented the study to achieve a control strategy used for HVDC transmission to improve the transient and voltage stability of the power system. Transient instability caused by a system faults overcome due to the rapid power work back ability of the VSC-HVDC transition. Technology mentioned above prevents the system from ephemeral shakiness by its instant power reversal ability. The voltage support capability of the VSC system helps to protect the system from voltage collapse, hence losing of synchronism can be avoided. A grid connected back to back VSC-HVDC modeled in the MATLAB / Simulink environment and a current mode control strategy was implemented. The simulation was done to have an observation of a faster and independent control of real and reactive power. HVDC is an efficient technology for bulk power transfer and provides a reactive power support to fault location and hence voltage stability. It reduces the chance of voltage collapse at generating ends [16][11].

MIZANUR RAHMAN, FAZEL RABBI,KHURSHEDUL (2014) this paper presented Comparisons between HVDC and HVAC transmission systems, and study the faults effects, also analysis the results from MATLAB simulation.By observing the finally results was found lower fault current,better performance and higher security relibilty is explained for HVDC technology system.this is done under'line to line' faults and single to ground' faults for both systems.for beteer evaluation, both simulation parameters are kept at himself distance.Where it shows us the result based on cases,values of fault current in HVDC transmission system is much smaller than HVAC transmission system [17][7].

D T Oyedokun, K A Folly, A V Ubisse, L C Azimoh (2010) thus seeks to highlight some of the issues that may be faced in terms of power system stability. One of the issues that we face is the existing HVAC transmission lines that may be present along some of the proposed HVDC corridors. In this research, transient stability of the wall system with four generating plants will be considered. The distance of the HVAC line will be fixed at 500 km, while the HVDC line length will be considered from 100 km to 3000 km. From the simulation output, the results show that the stability of the system after an HVDC transmission line fault is improved with the use of longer HVDC transmission line in symmetrical with an HVAC transmission line. However, the stability of the system after a 3- phase fault on the HVAC transmission line is not improved with the longer HVDC transmission system. It was also observed that terminal voltage dip of generator is reduced with increasing the length of HVDC transmission line [18].

C. Nguyen-Mau, K. Rudion, Z. A. Styczynski (2014) approached and investigate when applying the (VSC- HVDC) and discussed main benefits of stability enhancement in the power system, that occurs when applying HVDC techniques. Due to the advantages of fast and decoupled power flow control, this system or transmission technology can be used to dampen the fluctuation of the load nook of the generator after disturbance. This feature of VSC HVDC should be useful for the Vietnamese power system, which has many problems in operation, maintenance and protection due to the fast rate of its development. Firstly, a review of VSC HVDC technology is introduced. Secondly, the improvement of power system stability. The simulation results reveal that, due to the capability of speedy and freelance active and reactive power control, HVDC system in general can extremely support the stability improve of the grid. This technology has high potential if it would be applied to the power system [19].

CHAPTER 3
HVDC TRANSMISSION SYSTEM CONCEPT AND BACKGROUND IN POWER SYSTEM

3.1 HVDC Transmission System Background

The first step to produce electricity commercially borne, carried out by (Thomas Alva Edison) as DC power system. However, the DC power sending over lengthy distances was uneasy due to the lower voltage characteristic of the direct current power system. The alternating power system was a superior alternate at that time. After the huge growth of the power electronic industry and fundamentally due to the evolution of high voltage valves, it became favorable to transfer direct current power over tall distances and the idea of HVDC technology system became visional as a transmission alternative [20].

It was many years ago the first Hewitt’s mercury-steam HVDC valve is presented in 1901 [20]. so, only after the successful assignment of the first tradeinal implementation of mercury-arc depend on HVDC transmission connect or link between the main land in Sweden and Gotland in 1954, the HVDC transmission system It has become the main alternative to the electric power transmission, especially in long-distance.The HVDC technology systems have been widely applied as bulk power transmission over lengthy distances, interconnecting two With a (different frequency) or asynchronous systems, and power transmission through submarine cables [21].

In 1970s the concept of the DC transmission system was revolting alternate with the preface of thyristor depend converter. Once again in the venture of the connecting island on got land and Swedish mainland this recently insert in technology was utilized. The thyristor based converter was the private technique system utilized for direct current power transition system and is recognized as a current source converter (CSC-HVDC) [22], [23].

3.1.1 Preface of High Voltage Direct Current (HVDC) System

High Voltage Direct Current (HVDC) technique of transmission system has been researched and developed for many years, and it was essentially depend on thyristors and more newly on completely controlled semiconductors like Insulated Gate Bipolar Transistors (IGBT) and Gate Turn-Off Thyristors (GTO) [24,25,26]. In 1930s, mercury arc rectifiers were invented, which was a milestone of HVDC transmission systems. The first HVDC system project of the world was accomplished in 1941, by feeding DC energy by an underground cable through the Distance with a length of 115 km to the city of Berlin. However, due to the World War II, this HVDC link had never been used.

In order to send large amounts of electric power over long distances, you should consider using HVDC transmission system. Because it is considered one of modern electronic technology upon which to send the electrical power required. In the HVDC power system is relying on several ways to send electrical power, which uses an overhead transmission line and cables (underground and submarine) as a path for the transfer of power. HVDC transmission utilized the first time in 1954 in the undersea cable connection between the island of Gotland (Sweden) and Sweden.

The HVDC transmission technology is widely it is known as being beneficial for lengthy distance bulk power delivery, asynchronous interconnections and tall submarine cable passageway [20, 26, 27]. Usefulness of HVDC links include:

- The power flow on an HVDC link is fully controllable – rapid and precise.
  The automatic controller could assortment the magnitude and trend of the power flow in the link unheeding of the interconnected AC system situations.
- The connection of the HVDC transmission system link is asynchronous.
  The two different voltage system that linked with the HVDC system can be controlled separately. Also, it is no necessity for the same frequency of the AC systems.
- Flaws and fluctuations don’t transfer across HVDC interconnected systems.
- HVDC system can be transmit electrical power economically and efficiently over longer distances than AC lines or cables.

The conventional HVDC transmits system is based on Line-Commutated current source Converters (LCC) with thyristor valves, which can only work with the AC current lagging the voltage so the diversion requests reactive power [27]. In the past years the nearby, Voltage Source Converter (VSC) established HVDC technology have been advanced.VSC, s technology has been utilized for lower power driver enforcement. With the development of semiconductor switches, the VSC technology has been used in higher power transmission projects, up to 1200 MW and ±500 kV [28]. The main highlight of the VSC technology is that it can fast control both active and reactive power separately [27]. Many manufactures are developing their own products such as ABB's HVDC Light, Siemens' HVDC Plus and Alstom Grid's HVDC Extra [26]. Nevertheless, there are still some issues to overcome such as high switching losses.

Figure 3.1 ±500 kv HVDC transmission lines [27]

3.2 Applications of HVDC transmission

Due to a large number of usefulness of the HVDC transmission system, the application of HVDC has been spread over the world the last decades. Several applications of HVDC technology appeal, its possibility utilizes. Those are transmission lines through undersea and underground cables where loading current put a restriction to alternating current transmission system.

It supplies a frugal way of interconnecting of two systems or more have a different frequency grid, and the ability to be accomplished without transmission line by using back to back connection of converters station configuration.HVDC technology system is an alternative way of transmitting the power in the AC transmission system, when bulk power transmitted through the lengthy distances and is economical compared to HVAC transmission in accordance with technical issues [29],[30].

The HVDC transmission system having the high-efficiency control the power flow, is important and makes it distinctive, and that is the main reason for preferring the preference HVDC transmission system over HVAC transmission system for the transfer of electrical power. It mitigates issues such as unorganized power flow through AC ties So creating problems and disturbances in the grid, and the outcome is causing instability and Overload due to the abnormal situations in the system [29].

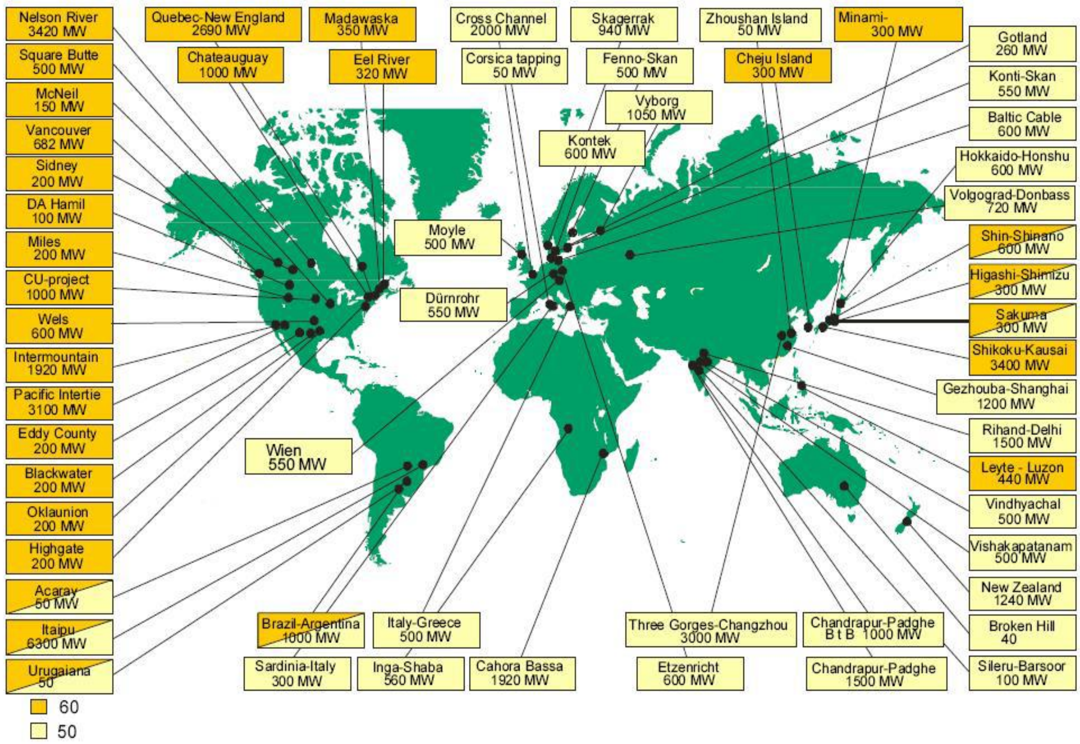

Figure 3.2 shows HVDC projects around the world by power capacity and frequency [31]

3.3 Configurations of HVDC System

Many different types of HVDC configurations are exist. Power system uses four main arrangements can be accomplished by VSCs and CSC converter topology.

I. Monopolar HVDC configuration system

Figure 3.3 illustrates a monopolar HVDC system. In order to interconnect two converters, single pole line is utilized in this configuration. Where they could use one of them positive or negative polarity lines.Corona losses can be minimized by using a negative polarity line. The ground is utilized to regress current. Furthermore, submarine connections for many transmission systems utilized monopolar configuration.

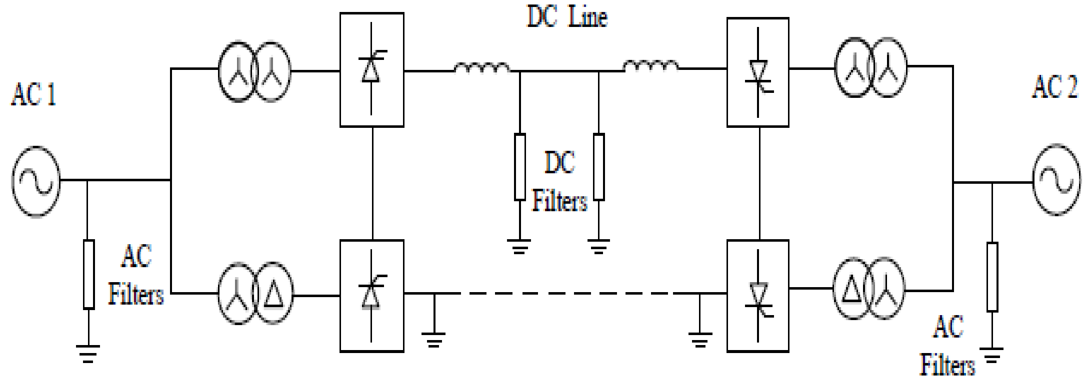

Figure 3.3 Monopolar configuration

II. Back-to-back HVDC configuration system

Back to back HVDC System can be utilized to connect a different frequency grid.In order to interconnect different frequencies of system we can use back to back HVDC system. Configuration commonly placed on the same site, also consist of two converter stations, and there is no long-distance power transmission in the DC link. Figure 3.4 shows the back-to-back HVDC system.

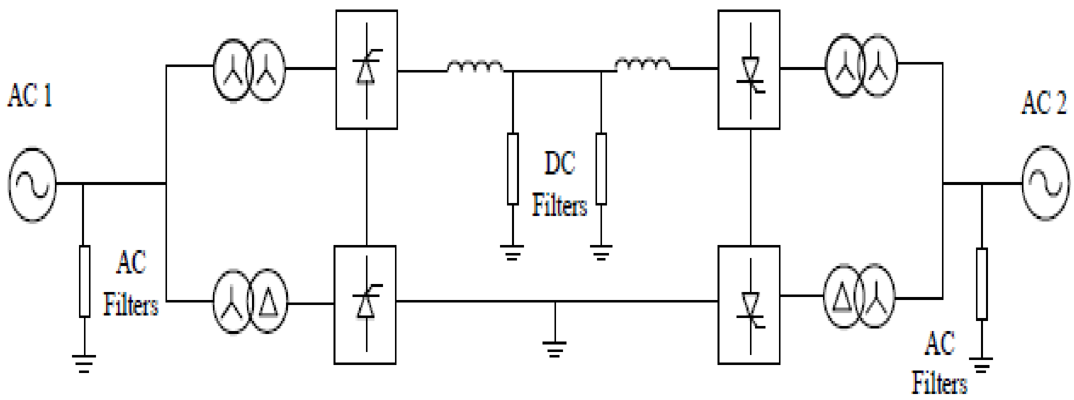

Figure 3.4 back to back configuration

III. Bipolar HVDC system

Figure 3.5 shows the Bipolar HVDC system, which is the most usually utilized configurations. Most overhead line HVDC transmission systems utilize the bipolar configuration [26].

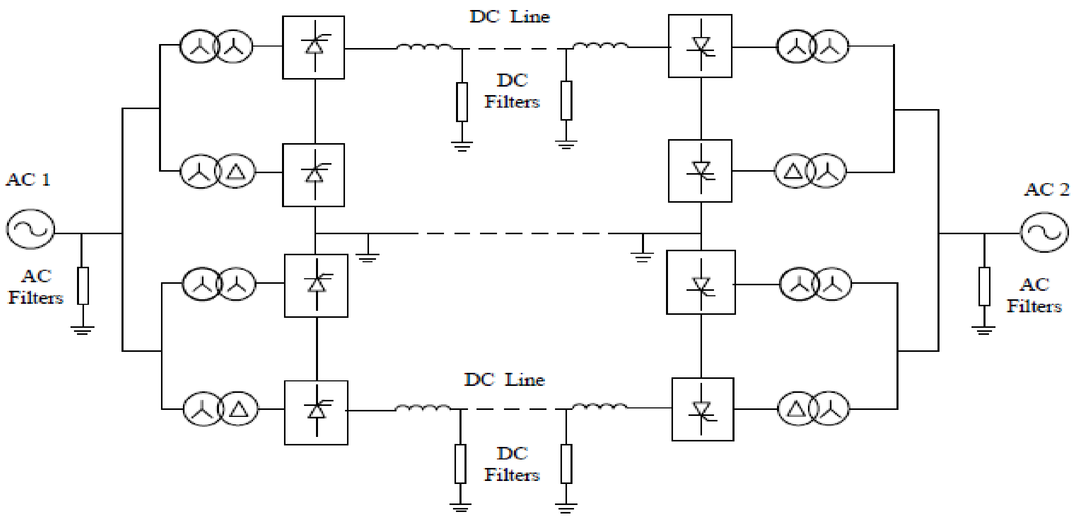

Figure 3.5 Bipolar configuration

IV. Multiterminal system

Figure 3.6 illustrates a mult_station HVDC configuration supplied a pathway for interconnecting three or extra converter stations. The three or extra HVDC converter terminals are detached by place and interconnected throughout cables or transmission lines. Some of them are operating as inverters and some as rectifiers.

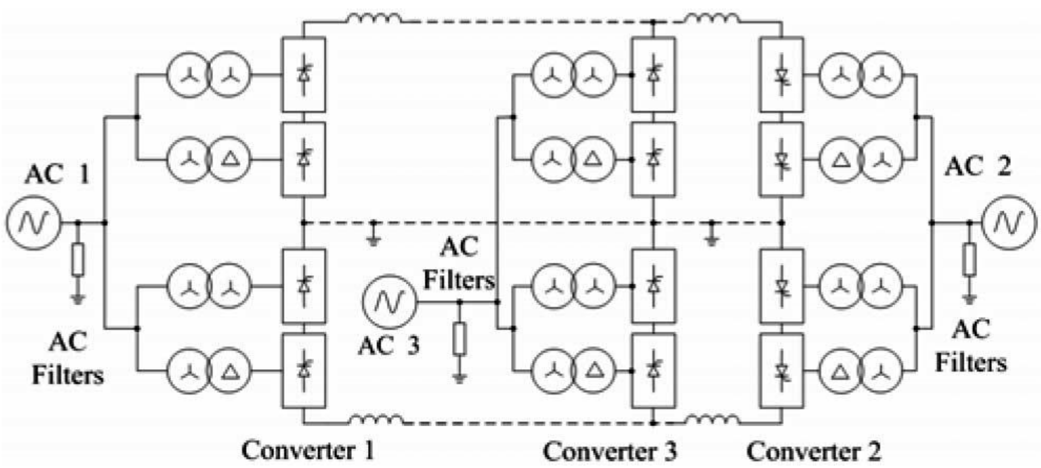

Figure 3.6 Multi- Terminal configuration [20]

3.4 Classification of HVDC transmission

Alternate stations categorized into two types with pertinent to high power enforcement [32].

3.4.1 LCC-HVDC

Line Commutated Converters-HVDC transmission is also called conventional HVDC. Typically, it is suitable for high power applications. The world's highest HVDC transmission voltage rating project is Xiangjiaba - Shanghai ±800 kv UHVDC transmission in China. Also, it is one of the longest overhead line transmission projects in the world, the length of which is 2071 km [33].

The Figure 3.7 shows an LCC-HVDC with the components of LCC converter. Converter station and thyristor valve are included. Also, the transformers, reactive equipment, AC filters and smoothing reactor are shown in this figure.

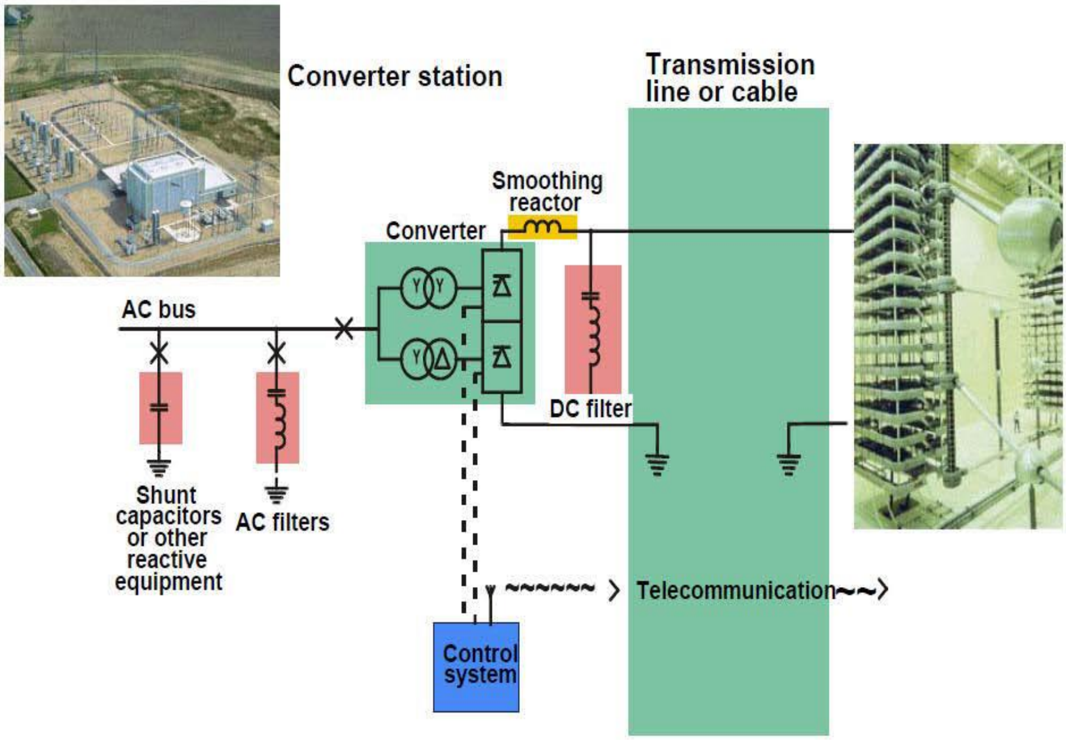

Figure 3.7 LCC-HVDC (converter station and thyristor valve) [28]

3.4.2 Components of LCC-HVDC

LCC-HVDC transmission system consists of a converter, transformer, AC breaker, AC filter, capacitor bank, smoothing reactor and DC filter. The various basic components are described as follows:

3.4.2.1 Line-Commutated Current Source Converter

The converter is a fundamental part of HVDC system. It uses power electronic converters to achieve the power transformation from AC to DC (rectifier) at the sending terminal and from DC to AC (inverter) at the receiving terminus. The conventional HVDC system technology is based on the current source converters (CSCs) with line-commutated thyristor switches. Line-Commutated Current Source work at lagging power factor for the burn of the adapter or converter. Therefore, it requires a large amount of reactive power compensation.

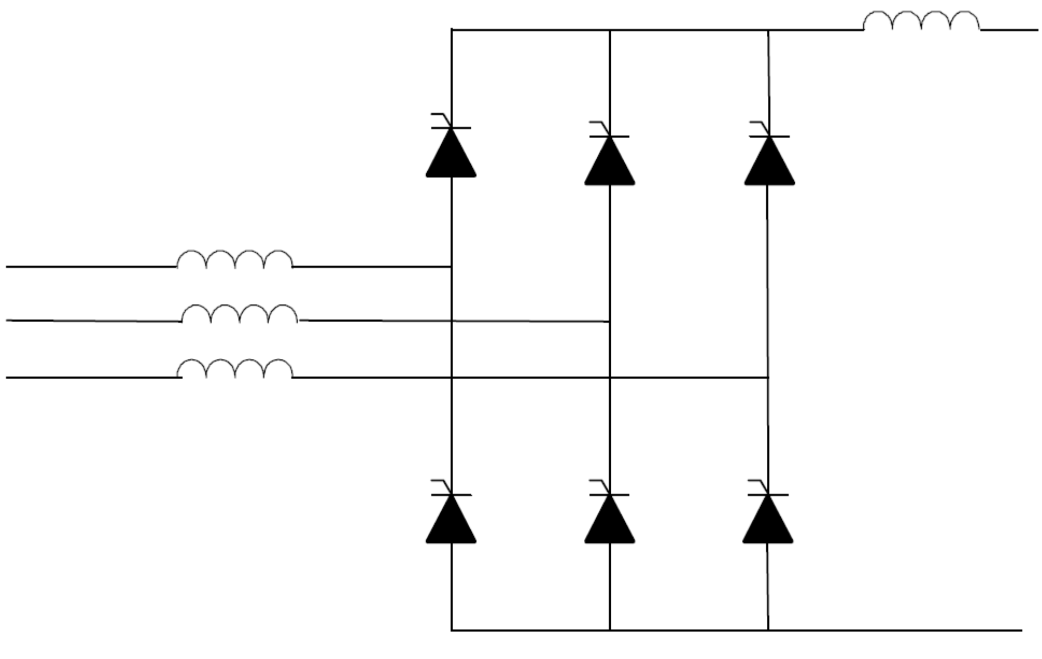

Figure 3.8 Configuration of a basic 6 pulse thyristor valve

The basic converter unit of conventional HVDC is a six pulse valve, shown in Figure 3.8. It is for both conversions, i.e. rectification and inversion. Even though one thyristors is shown in the figure, in real applications a number of thyristors are connected in series and parallel to form a valve as shown in Figure 3.9

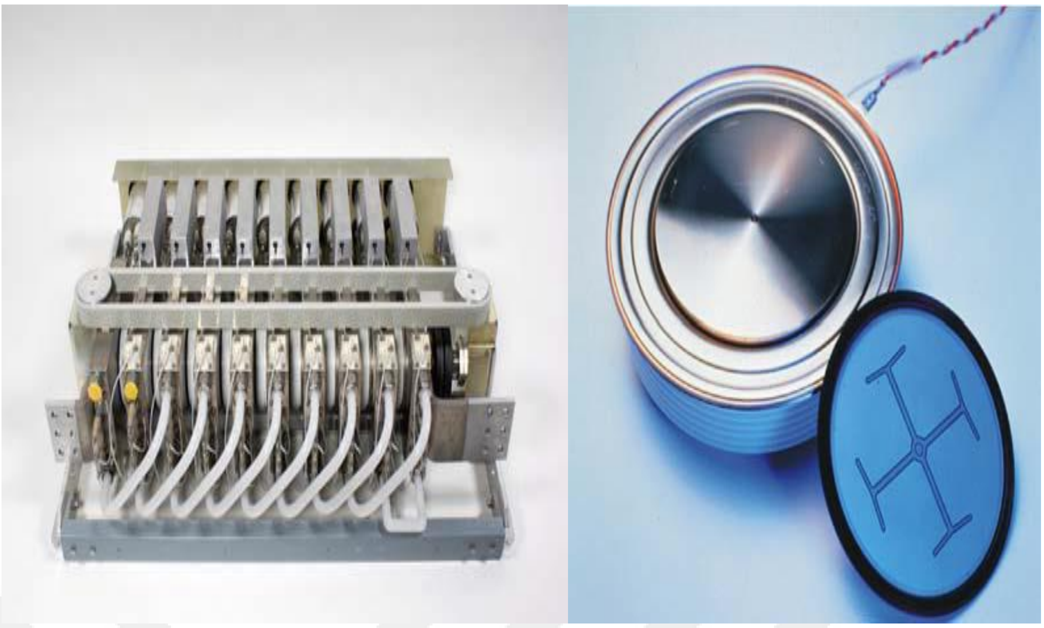

Figure 3.9 Modern thyristor and front view of HVDC thyristor module [34]

Thyristors are switched on by a pulse. Thyristors cease to conduct when the current inflow throughout them decreases to zero.Therefore the (inverter) and (rectifier) stations have a requirement to be connected to a reliable AC system. Furthermore, LCC-HVDC system requires reactive power so as to operate. The amount of reactive power required varies according to the amount of active power transferred. Therefore, additional components such as switched capacitor banks or Static Var Compensator (SVC) are generally employed to supply the reactive power [20,26,27].

As the current only follows from anode to cathode through a thyristor shown in Figure 3.8, in order to reverse the power inflow, the voltage polarity of the converter stations should be reversed. Due to switching the voltage polarity, the transient phenomenon appears in the cable. Therefore, the cables used in LCC-HVDC transmission system requires a higher insulation capability than VSC cables [35].

3.4.3 AC Breaker

AC breaker is utilized to depose the HVDC system from AC system whenever there is a fault in the HVDC system. AC breaker should be estimated to tote full load current and cut off the fault current. The expected location of AC breaker is in the interface between the HVDC systems and AC busbar.

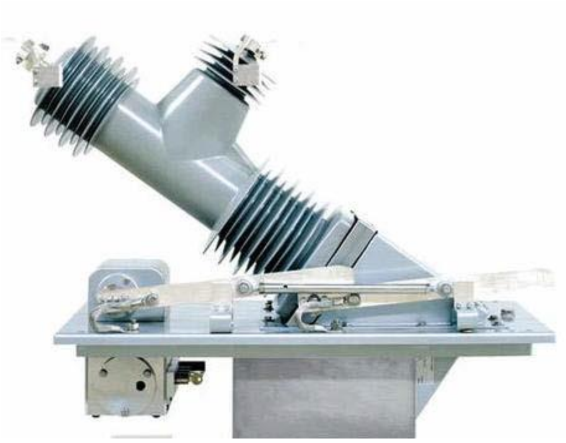

Figure 3.10 AC system breaker [36]

3.4.4 AC Filters and Capacitor Bank

The converter stations produce current and voltage harmonics at both terminal sides of the conversion system.Like harmonic overheat the dynamo and annoys the connection system. A double tuned AC filter is utilized to remove the voltage and current harmonics On the AC side. However, the reactive power sources like asynchronous compensator or capacitor bank are installed to supply the reactive power to power consultation.

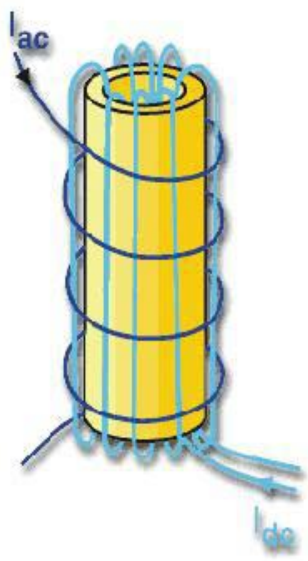

Figure 3.11 AC filter [36]

3.4.5 Converter Transformer

The voltage output of the AC system to be provides to the DC system is by converter transformer. As well supplied a separation between DC and AC system.

3.4.6 Smoothing Reactor and DC Filters

The smoothing reactor shapes an integral component, simultaneously with the DC filter, you must limit the current flowing to the rapid rise into the converter in order to protect the converter valve and prevent failure in the process of commutation.

Figure 3.12 Smoothing Reactor and DC-filter with capacitor in HVDC [36].

3.4.7 VSC-HVDC transmission

Classical HVDC converters can be defined as a current source converter. Prosperity of high frequency completely controlled Keys such(DSPs) and (IGBT) for generation of suitable switching modality provides an attitude for effective oversight of power inflow through voltage source converter (VSC) [37] [38].

Forced-commutated VSC uses gate turn-off Thyristors (GTOs) or generality industrial situations insulated gate bipolar transistors (IGBTs). It is fully-instituted technology system for medium power levels, up to now, newly the projects ranged between 300–400MW power level [36]. The simplest configuration of the classical and modern system is shown in Figure3.13 a-b.

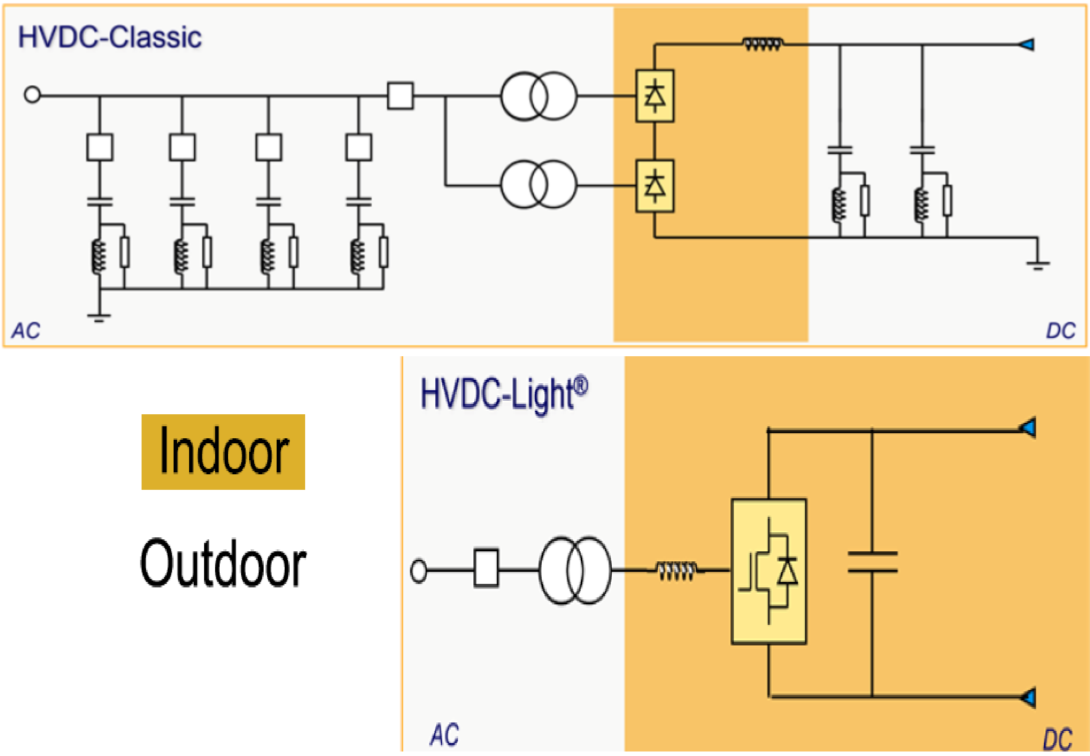

Figure 3.13 (a- b) HVDC classical and HVDC light

The Benefits of voltage source converter (VSC) over current source converter (CSC) are:

1) It provides a separate control of active and reactive power interchange between voltage source converters with AC national grid.
2) When the faults in transmission lines. No hazard of commutation weakness occurs due to disturbances in power system.
3) The VSC is a device that can generate a stable 3-pH, voltage as synchronous generators, hence is beneficial for exhausting starter.
4) VSC can control and domination of the reactive power at converter stations to have coveted AC voltage waveform. It won't have any unuseful or reactive power request such as line commutated converters.

5) These features and scientific qualities that we mentioned above that makes us prefer to use VSC in a lot of applications.
6) Black start capability and dynamic voltage control of VSC enables to provide from remote sites without any native generation [39], [40].

7) Control of AC voltage of power system and reactive power provides an amelioration in a dependable power flow transmit and grid steadiness [37].

VSC-HVDC technology, it contains:

1. AC filter.
2. Transformer.
3. Phase reactor.
4. DC link capacitor.
5. Voltage source converter.

3.4.7.1 Filters in the (AC) side:

Harmonics in the AC system generate losses, overheating, interference in a transmission line, insufficiency of running, over voltage due to ringing and insecurity in the control system. For these reasons, filters are needful to filter out unfavorable harmonics and the elimination of problems and disorders caused by harmonics in the power system. Filters contributor in voltage source converter is inexpensive as compared to traditional HVDC as PWM technicality minimizes the harmonic content to a mighty extent. It’s done as a high pass filter, and linked between converter and transformer which intercept the harmonics to get into the AC system [41].

3.4.7.2 Transformer:

The transformer is useful for maintaining the voltage level in secondary in reasonable and technical demands. The short circuit current level depends on the reactance of the transformer,when we want to reduce the effect of short circuit current should be firstly minimize the reactance of the transformer. It acts is such as a fencing between DC and AC side. A two winding transformer can be utilized for the converter.

3.4.7.3 Phase reactors:

Phase reactors confined the alter in the current pathway through the IGBT switches. It has benefits such as forbidding high frequency harmonics in AC line current as is acts such as a low pass filter. It supplies a decoupled control of active and reactive power by controlling current through it and the limits short circuit current [41].

3.4.7.4 Converter (VSC):

The HVDC converters are an HVDC system's heart. VSC-HVDC system operating in back to back mode. They perform the conversion from AC to DC such as (rectifier) at the sending end and from DC to AC like (inverter) at the receiving end. A converter that is utilized possible a two level, three levels or multilevel converters. For two level voltage source converter it is necessary to have a six pulse generator for triggering six switches every switch contains an IGBT and an anti-parallel diode and it generates two voltage levels on AC side [35]. In three level converter there are consist of a twelve pulse generator is needed for triggering IGBTs, because the converter are 12 switches and twelve pulse generators. However, a relatively low harmonic contents is famed in three level converters [38].

3.4.7.4.1 Three level VSC with capacitive DC side voltage divider:

Three level VSC shown in the Figure 3.14 is a three level (NPC) with capacitive voltage Splitter at its DC aspect. The overall terminal voltage in the DC station partitioned into two equalize half by utilizing selfsame capacitors. The shown in Figure 3.14 when connected two AC systems by back to back configuration mode, the system allows to interchange power between them. In another meaning to the system operating as bidirectional power interchange between two areas. But in three level status NPC provides from a 12 pulse diode bridge rectifier on DC side does not prop for bidirectional power inflow.

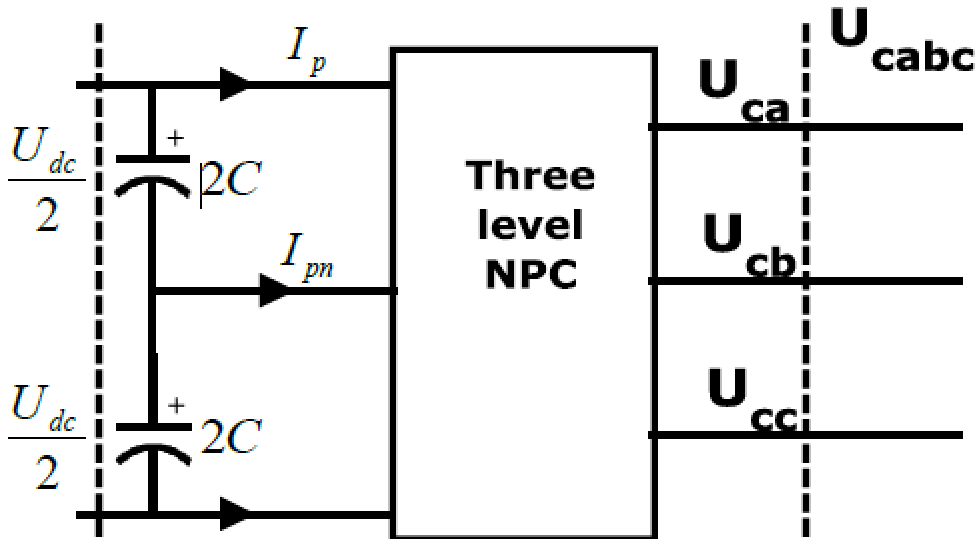

Figure 3.14 three level VSC

Even after pure DC voltage is preserved at fixed standard levels, but voltage driftage happen in both stable case and passing case condition due to homogeneous in gating pulse commands for switches and allowances of the converter. Big third harmonic components in midpoint current which outcomes in a minimal order voltage harmonic at the converter in the AC side [38].

3.4.7.5 DC link capacitor:

In VSC transmission system the DC link capacitor is an important component, operate such as a fixed voltage source. It is beneficial for preserving DC link voltage close to its coveted standard level. It won't permit the alteration of polarity of DC bus. DC link capacitor decides the passing reaction of the system. Hence deciding the value of the DC link capacitor is a challenging assignment. As the current with harmonics generated from PWM switching of IGBTs, flowing to capacitor generates a voltage ripple at DC side. From steady state operation as it driving to DC over voltage can't be finding the rate of capacitors. It is influential to consider the passing over voltage constraint when selecting the DC capacitor range [41].

Time constant τ defines the time wanted the value of DC capacitor required to charge capacitor from an initial value (zero) to its desirable range of DC voltage level of nominal manifest power of the converter is

$$\tau = \frac{1}{2} C \frac{Vdc^2}{Sn} \tag{3.1}$$

Where Vdc is the DC link voltage and Sn is the nominal manifest power. τ is the time constant to charge the capacitor from zero to its ultimate DC voltage level [38], [41], [42].

3.4.7.6 DC cable:

Extruded polymeric isolations are utilized specially to supply resistive to the DC voltage, Whereas AC (XLPE) cables are not lineal utilized for HVDC application due to a phenomenon called splay charges. The electric field produced by the DC voltage reason the splay charges to movement and focus at an assured locus of the insulation, resulting in declining. Private XLPE cables are advanced to avert problem caused due to splay charge. A fast alteration in polarity change reasons a high exertion in insulation. As in VSC-HVDC polarity inversion is not wanted, cables can be utilized. Cables with ± 320 kv DC are currently obtainable [42].

3.5 Topologies, and manufacturers

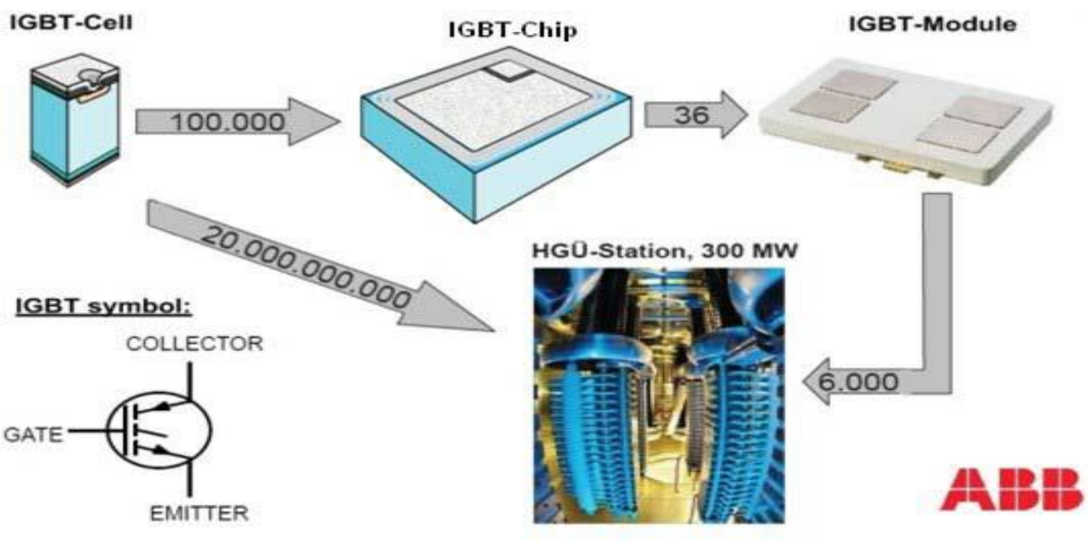

Figure 3.15 IGBT symbol and representation of a valve from IGBT cells [43]

A VSC-HVDC transmission system uses self-commutated semiconductor component for commutation. The Insulated-Gate Bipolar Transistor (IGBT) is the typical semiconductor used for VSC. The first-generation of IGBT was applied in industry in 1980s. However, due to the slow speed of switching on and off, they have been gradually replaced by the second-generation IGBT in 1990s. The second-generation IGBT shows the very best performance for the high voltage and current. With the small size of the IGBT-Cell (around 1 cm2), many of them are connected in parallel to form IGBT chips. Then a number of IGBT-Chip are connected to form IGBT-Module, which is able to withstand current up to 2.4ka with blocking voltage up to 6.5kv. In Figure 3.16, it shows the valve consists of 20 billion IGBT-Cells. A conventional two-level three-phase topology is illustrated in Figure. 3.16 Even though one IGBT with anti-parallel diodes is shown in each box, in real applications, a number of IGBTs is connected in series to form a valve. Therefore, the DC bus voltage level is increased.

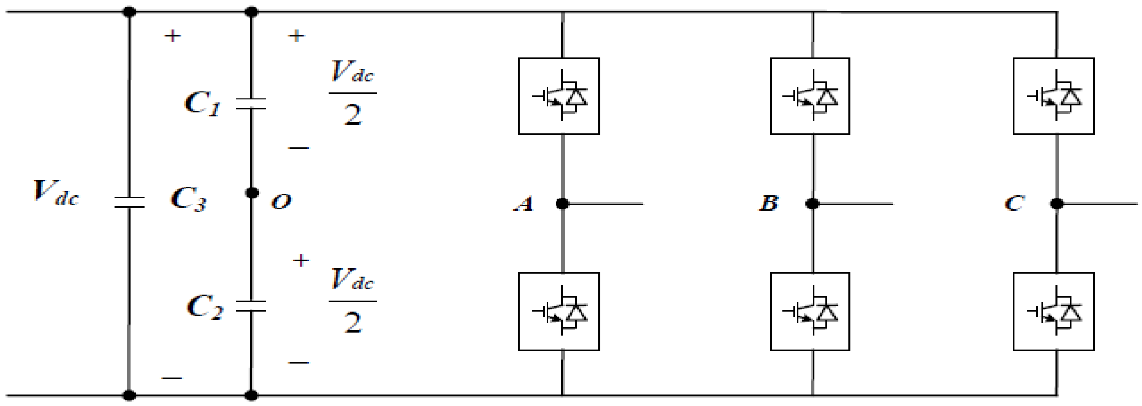

Figure 3.16 Conventional two-level three-phase VSC topology

HVDC Light was introduced by ABB in 1997 at first. It first implemented for the project in Gotland, Sweden in 1999. HVDC Light is based on the topology shown in Figure 3.16 [35] [43]. It uses a carrier-based PWM (sinusoidal) control method to control the gate switching frequency of the IGBT. Due to the requirement of reducing harmonics, the special PWM control methods named optimum frequency-PWM was developed. Within this method, the switching frequency is not fixed, however, it is varied (from1 kHz to 2 kHz) with the current. For instance, the switching frequency reduces while the current increases. It is to reduce the casualties across the converter valves while eliminating the harmonics. Because the series connected IGBTs necessity to be switched at the selfsame time accurately, it is required to measure the voltage over each IGBT. Based on the measured voltage, a control signal is provided to the gate of each IGBT in converter valve to decide the working state of the IGBT. It is for controlling the IGBT switch-on or switch-off. Due to the above reasons, ABB developed a patented control system for monitoring the states of IGBTs.

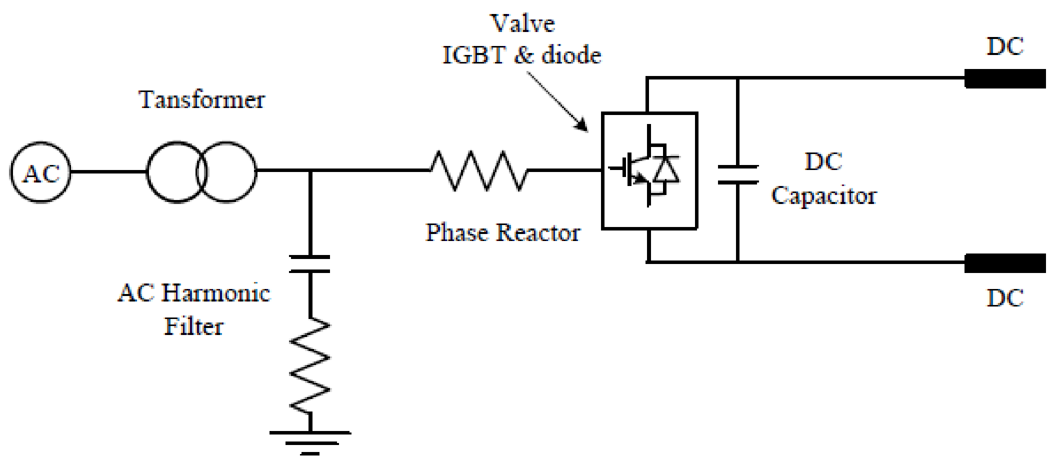

Figure 3.17 Scheme of typical configuration of VSC terminal

The Figure 3.17 shows the typical configuration of VSC terminal, which is also applied in ABB’s HVDC Light. The essential component of the VSC converter valve contains a series-connected IGBTs with anti-parallel diodes. With the snubber capacitors (C1 and C2 show in Figure 3.16) connected in parallel, each IGBT, the over voltage in IGBT valves is able to avoid efficiently. The phase reactors, which connected with converter valve, are one of the significant components in a voltage source converter-based transmission system. They permit continuous and separately control of useful and un-useful power. They decrease the harmonic current produced by the converter. As well, the phase reactors are felicitous to limit the short circuit current of the IGBT valves. Therefore, the AC system connected with valves is isolated by the phase reactors. AC harmonic filters between the phase reactor and the transformer are destined to minimize the harmonics.

It averts the DC voltage stresses and harmful harmonics created by converter valves influential the transformers running.

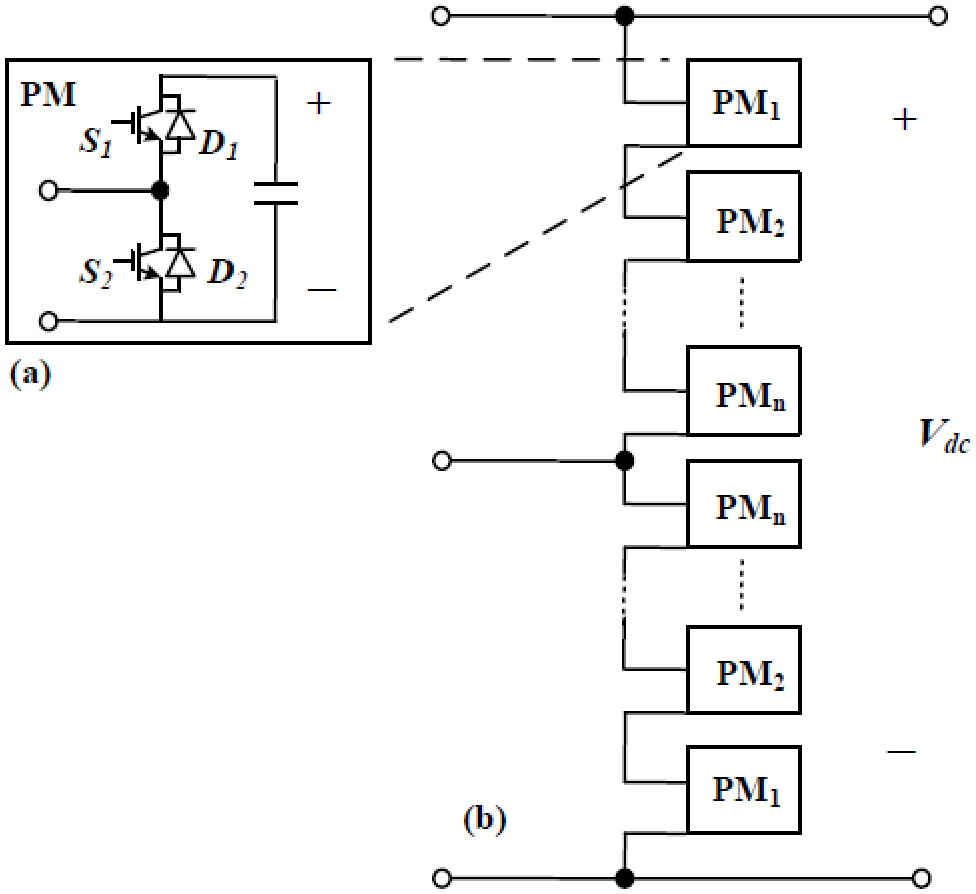

Figure 3.18 MMC topology (a) structure of power module (b) Phase unit [44]

In recent years, Siemens developed HVDC Plus technology, including the advanced multilevel approach [44]. The basic design of the technology is based on the Modular Multilevel Converter (MMC). The topology is shown in Figure 3.18. It uses the half-bridge cascaded connections for each power modular (PM). There is an independent Small capacitor of each PM, which forms a half bridge rectifier. The converter output voltage has been maximized by extra modules connected in series. By controlling turn-on or turn-off of each PM at given instant, more small voltage steps are created, which then built the step-wise AC waveform. Due to the modular nature of this converter topology, it is suitable for applications operating on a different voltage level. In [45], different power level projects have been introduced and the relevant control schemes have been proposed based on this topology.Comparitvly, of conventional 2-level or 3-level converter technology, HVDC Plus based on MMC shows the benefits involving lower switching damages and lower level of high frequency-noise because of lower switching frequency. The first project based HVDC Plus technology has been commissioned in 2010. The 400 MW, 88 kilometer project is called Trans Bay Cable and links San Francisco and Pittsburg. The other projects named HelWin1, BorWin2, SylWin1 and INELFE which are also based on HVDC plus technology will be commissioned in Germany and France-Spain respectively from 2013 to 2014.

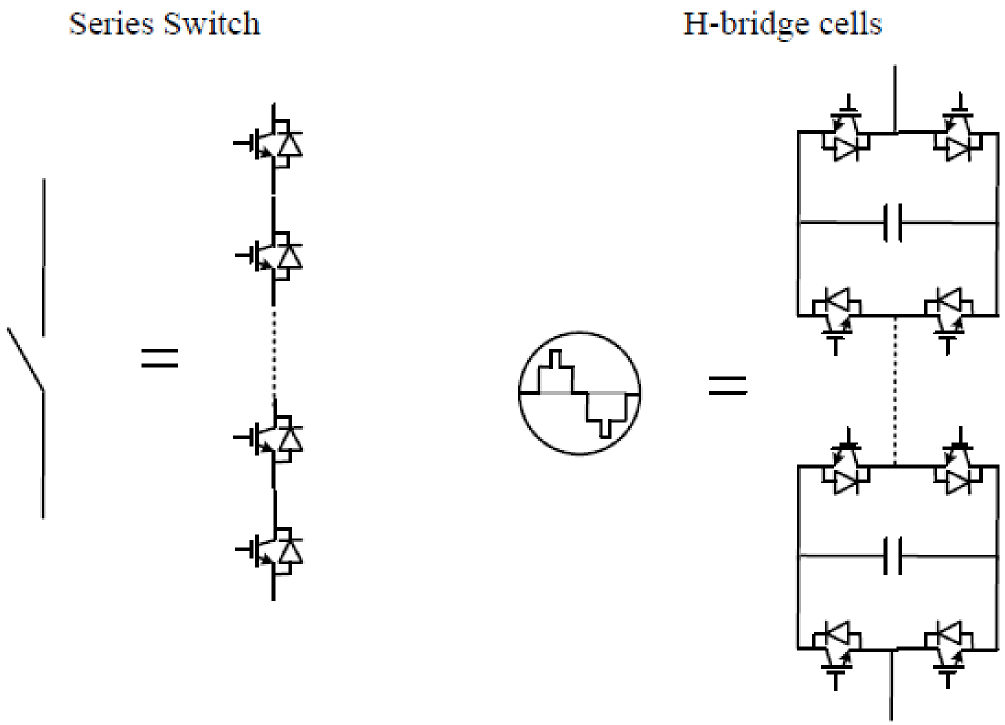

Figure 3.19 Blocks of hybrid converters [46]

Besides ABB and Siemens, Alstom Grid is also a strong manufacture in this area. Their own HVDC solution - HVDC extra is being developed for a long time [26]. Last year, Alstom Grid introduced their latest converter structure called New Hybrid Multi Level (VSC). Based on the specific topology, the system is able to operate within lower losses and also maintains the ability to deal with DC-side faults [47]. As shown in Figure 3.19, the fundamental blocks of the new topology are series switch and H-bridge cells. In Figure 3.20, it shows the topology consists of series switch and H-bridge cells. It reserves the advantage of 2-level converter, which minimizes the total number of semiconductors. A lot of H-bridge cells series connected for constructing the requested converter voltage. It works identically to an LCC-CSC because of the series of IGBTs, called series switch. In each phase, the soft series switch lineal the current to the upper or lower. For instance, while the series switch is closed, the converter voltage was constructed by its H-bridges cells and increasing or decreasing several teeny voltages leads to the DC-bus voltage. The AC phase current surpasses into either the negative or positive DC station and, simultaneously with the two other phase currents, make a DC current with a 6-pulse ripple [47]. Moreover, based on this topology, the system is able to operate within very high efficiency. The simulation results show the Semiconductor losses is only 1.02% in 20 MW power simulation case [47]. Besides the advantage of high efficiency, it is able to control current flow into faults on the DC side of the circuit because the converter based on H-bridge cells, which is full-bridge cell. And also it has the potential to provide reactive power to the AC network during this type of the fault [46].

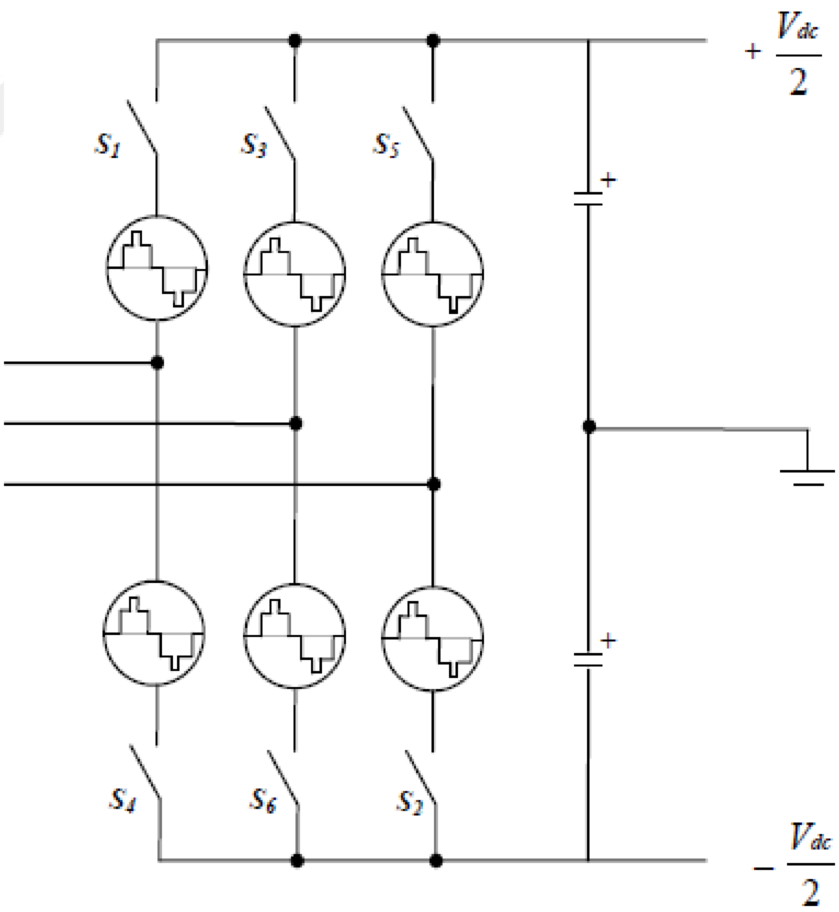

Figure 3.20 Representation of a single phase converter [46]

3.6 Direct Current Transmission Line System

Direct current (DC) transmission lines could be portion of complete high voltage direct current (HVDC) system transmission convene either within a turn key bundle or as unattached contrasted stand-alone clause, subsequently merged into a high voltage direct current (HVDC) system. As an model shown in Figure 3.21.

Figure 3.21 DC transmission line tower 300-kV

3.6.1 Transmission Towers

The transmission tower is the name of the system utilized in the world to transmit the power between two zone and more. The electrical towers structure be lengthy, commonly the electrical towers the are utilized in high-voltage alternating current (AC) and direct current (DC) systems to assistance an over head power line.Direct current (DC) transmission lines system are mechanically prepared as it is exercise for normal alternating current (AC) transmission lines system, the essential varations are, insulation styling, electric power requirements and arrangement of electrical conductor.The transmission tower come in a broad variety of shapes and sizes.

3.6.1.1 Types of tower

The types of the transmission towers categorized into various uses depend on the basis of current:

1. HVAC TRANSMISSION TOWER.

2. HVDC TRANSMISSION TOWER.

3.6.1.1.1 HVAC TOWERS

HVAC towers in electrical power systems are utilized for high voltage ranges starting from (66 kv and above) and extra-high voltage (110 kv and above , most often 138 or 230 kv and above in modern systems) AC transmission lines. The towers are generally steel lattices or trusses, also designed to carry three (or multiples of three) conductors and the insulators are either glass or porcelain discs.

3.6.1.1.2 HVDC TOWERS

The HVDC transmission line system is either bipolar or monopolar systems. Can be used one conductor only with ground return towers in single pole high voltage direct current (HVDC) system in the transmitting region. However, one conductor on each side of the tower is used by bipolar systems in high voltage direct current transmission lines. Additionally, for expansion in future and conversion to another type of transmission line system such as a two-pole system, towers is designed with those requirements to transmit the power in case of two-pole system, installed the conductors in both sides of the tower for protect due to mechanical reasons.

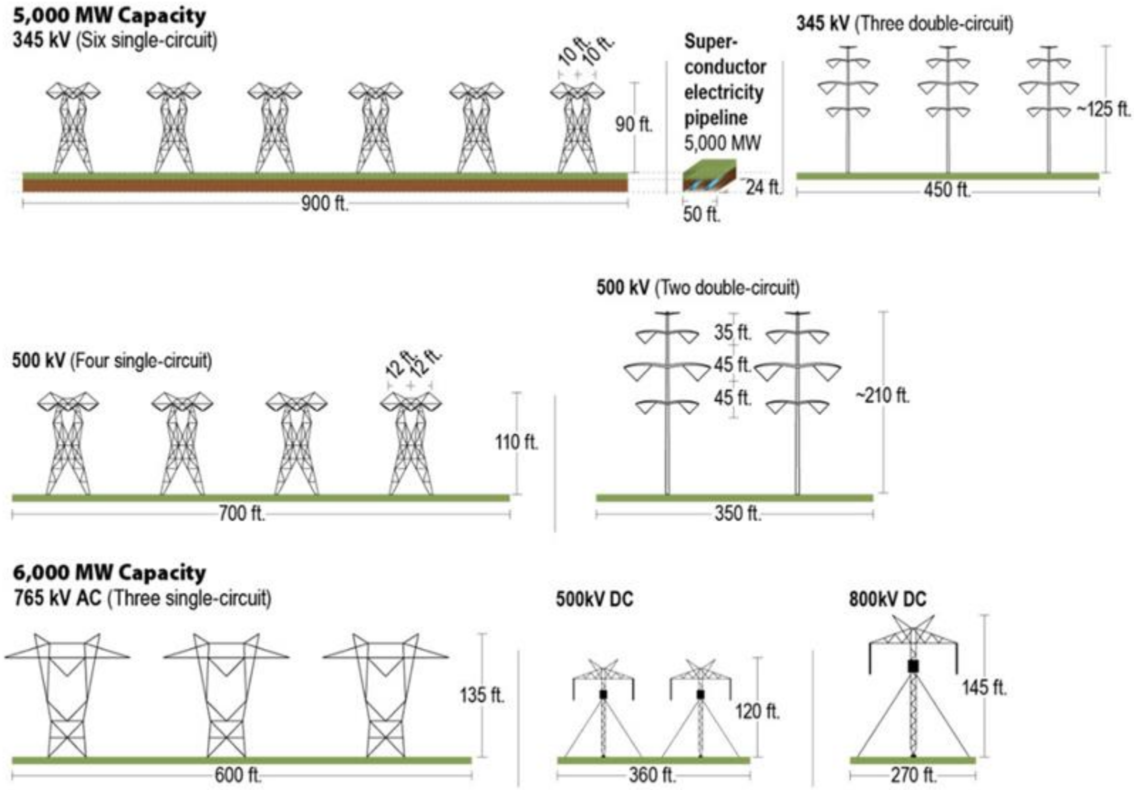

Figure 3.22 a tower types configuration

3.6.1.2 Insulations in DC transmission line

The most crucial part is the insulation styling and therefore this theme is depicting extra detailed below, The proper insulation design for DC transmission line system, is the most intrinsic topic for a peaceful employment during the life time of the DC grow plant.

3.6.1.2.1 Types of Insulators in DC system

There are three various types of insulators serviceable for DC transmission lines, they are categorized by Long-rod porcelain type, pin and cap type, and Composite long-rod type.

Tall-Rod Porcelain Type

The advantage of this type they are:

■ Long- period trail/track record and have well mechanical ferocity.

■ perforation-evidence.

■ Good self-purifying capability, minimal intermediate mineral accessories.

■ Due to caps on both insulator ends not subjected to pin corrosion because

Of low track current density, moderate price.

The main drawback of this type is due to the hulking of the separation of the heavy equipment disc. Which may cause many of the problems of lack of durability under abnormal conditions and in the end, cause failure.

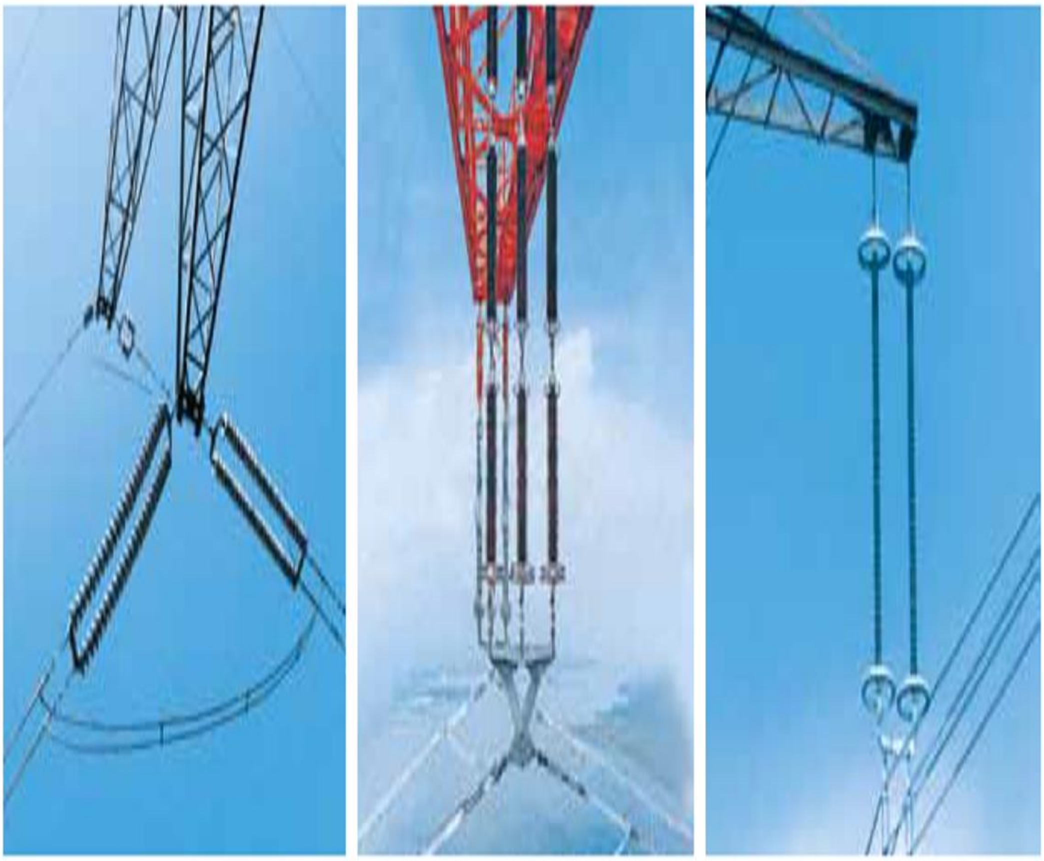

Figure 3.23 Comparison of insulator in transmission line

Cap and Pin Type

The advantage of this type they are

■ has a proper mechanical strength.

■Elasticity within the insulator series.

■ Subversion-proof.

The disadvantage of this type can be described as follows:

■ extremely hulking strings. And very expensive.

■ miserable self-purgation capability.

■ Capability wastage, a hardness that is result abrasion of nail in contaminated regions reasoned due to the altitude path current intensity (This is where the case is of great importance in transportation DC power lines).

■ High RIV and corona level. And many intermediate metal parts.

■ For DC transmission line accomplishment, private, awning design and porcelain material necessary, because the Insulator not hole-evidence.

Composite Long-Rod Type

The advantage of this type they are:

■ handful of insulators in one chain.

■ extremely light – comfortable processing during building and maintenance, logistic features in zones with unrest incoming.

■ Very good self- purifying demeanor – hydrophobicity of the exterior, which shows features of minimal seepage space.

■ having a perfect corona behavior and RIV.

■Very good immovability versus sabotage.

■ One of the important specifications for this type insulators string have shorter length compared to other types.

The Negative Aspects of composite Long-Rod Type, Can thus write them in below:

■ comparatively stumpy track record in DC transmission line application.

■ Minimal tracking resistance versus flash-over. Through the corona rings we can enhance resistance to the desirable limit.

3.6.2 Direct Current (DC) Cables

3.6.2.1 Various Direct Current (DC) Cables Used In HVDC System Transmission Lines

A significant application of high voltage direct current (HVDC) technology is transition lines systems passageway submarine. Therefore, high voltage direct current (HVDC) is the best system for distances exceeding 80 kilometers to the most, especially in the long-distance power transmission. In the sea transition applications section, private cable appropriate for direct current (DC) current and voltage is desired for the operating system. Where cabling is used in applications that range from several hundred to more than a thousand megawatts.

3.6.2.2 Cable Types in HVDC System

For HVDC sea cables there are various kinds obtainable.

1. Oil-Filled Cable

When we compare this type of cables with to another type means (mass-impregnated) cables,conductor isolated by a sheet impregnated and a lower-viscosity oil and amalgamate a tall it udinal channel to allow oil inflow through the cable length.Oil-saturated cables are appropriate for direct current (DC) and alternating cureent (AC) voltages.For DC voltages up to 600 Kv direct current (DC) and big submarine profundity.Due to the wanted oil inflow in cable, the sending line extension are however restricted less than 110 kilo meters and the hazard of oil infiltration or loss into climate situation is constantly topic to debate.

2. Mass-Impregnated Cable

Mass-Impregnated Cable is utilized globally in the high voltage direct current (HVDC) system in the generality of the HVDC system. It is made up of several various strata as it is shown in the below in Figure (3.23).The conductor is construct of stranding copper strata of pieces concerning a centric orbicular rod.Indoor layers are of carbon-stuffed sheets where as the external layer consists of copper-knitted fabrics.The conductor is wrapped by resin-fattened sheets and oil to increase the protection of cable.The completely impregnated cable is then lead-sheathed to protect it from external influences and circumference far from the isolation.The recent stratum of cable is anti-abrasion safeguard which consisting projectile polyethylene. Cable Protection of permanent deformation resulting from the load through the cable, where used tapes Welding galvanized covers polypropylene layers. Capacity of mass-impregnated cables is confined by the conductor overheat, which results in low overload abilities. The innovation in now possible for voltages up to 500 KV and a transmission capacity of up to 800 MW in one link with synthesis profundities of up to 1100 m for submarine application and generally limitless transmission length.

3.6.2.3 HVDC Cables Growth In The Future

The majority of the study and development accomplished for modern cable sorts is finished with the protective material (insulation material). These include:

A – Lapped Thin Film Insulation

As secluding material a lapped non-impregnated slim PP film is used As an option of the impregnated materials. The test process for the cable isolated are accomplished. This class of link can manage up to 60 % higher electrical efforts in running, making it favorable for lengthly distance and remote ocean links. Also, the cable arrangements they are another extent of expansion technically. In transmission line system, for the monopolar arrangement system, either the entryway was the (ground return) or a second connection. The cable quintessence is the established styling for a mass-impregnated cable and the arrival conductor is harmed outside the lead sheath. The first solution constantly encourages environmental worries whereas the second one has an excessive effect on the expense and costs for the total transmission system planner. Because of this feature, a modern cable was progressing with a coordinated return conductor. The conduit shapes likewise area of the equiponderante arm ourselves, together with the level steel wire layer on the outside of the arrival conveyor dielectric.

B - Cross-Linked Polyethylene (XLPE) Type

To prevent further faults and side effects of cables. however, to defeat the negative part of the aforementioned cable types,Where through numerous experiments show us that this type of cable.The dielectric substance is appropriate for a conductor temperature of 85°C and a short-circuit temperature of 245°C.The conductor is the segmented copper conductor separated by libeller cross-linked polyethylene layers.In addition, the more uses and the essential application for Cross-Linked Polyethylene cables the offshore industry and the mainland installation, cross-linked polyethylene type with extruded isolation material for high voltage direct current (HVDC) transmission line systems of lower transmission limits are under development.

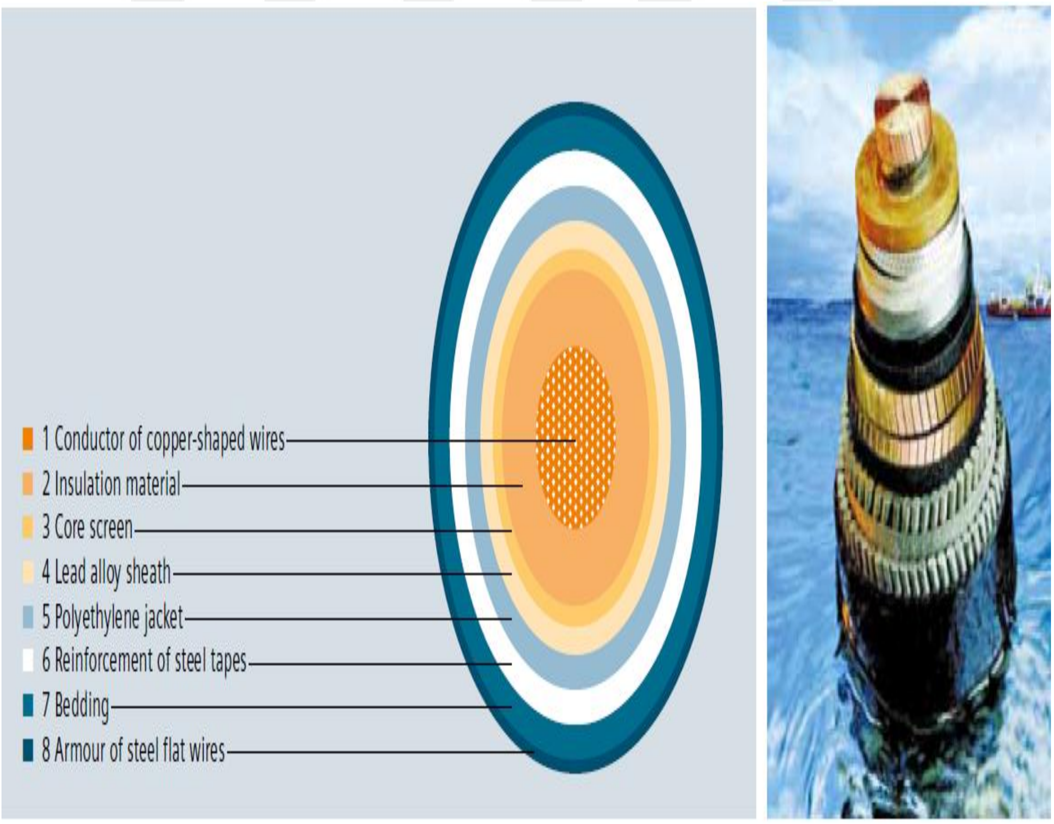

Figure 3.24 Mass-impregnated cable

CHAPTER 4
COMPARISON BETWEEN HVAC AND HVDC TRANSMISSION SYSTEM

4.1 Introduction

The HVDC transmissions can be compared with the HVAC transmission basically from two points of view. From the transmission cost point of view and from the technical point of view respectively. Analyzing the two systems regarding the transmission costs, the next advantages of HVDC transmission systems over the HVAC transmission systems can be found.

1. Considering comparative protecting prerequisites for top voltage levels, a DC line link will convey the same measure of power with two conductors as an AC line link with three conductors, in this way, for the same power level, an HVDC transmission system will require little Right-of-Way, more straightforward towers furthermore the conductor and protector expenses will be lessened, in correlation with an established HVAC transmission.

2. The transmission line losses (conductor misfortunes) they have diminished by around 66% when the DC choice is utilized rather than the AC one.

3. However, the disadvantage of the HVDC transmissions regarding the costs comes from the use of the converters and letters.

4. Furthermore, when an HVDC transmission is used, the absence of the skin effect can be noticed and also the dielectric and corona losses are kept at low level, thus the efficiency of the transmission is increased.

As a conclusion, it can be said that the HVAC transmissions are more economical than HVDC transmissions when used for small distances. Once the breakeven distance is reached the DC alternative becomes more economical fact which may be observed from Figure (4.1). .

In the case of the overhead lines the breakeven distance can change between 300 to 800 km, relying on the transmission line expenses while, if a cable system is used for sending the electrical power between two zones the breakeven of transmission line length vary between 30 and 60 km. The typical breakeven distance from overhead lines is 500 km [48].

Analyzing the two transmission systems, from the technical point of view, the HVDC transmissions overcome some of the problems which are usually associated with the AC transmissions. Thus, the stability limits are overcome when an HVDC transmission is used due to the fact that the power loading ability of direct current transmission lines is not affected by the transmission length between sites. In the case of the HVAC power system the amount of electrical power transmits in the alternating current lines depends on the phase angle which increases with the distance and thus the power transfer is limited.

The second problem which is solved by using the DC transmission instead of the AC transmission is the line charging. In the case of an HVAC transmission, line compensation (using STATCOMs, SVCs etc.) is used in order to solve the line charging issue, while in the case of direct current transmission lines like compensation is not required [48]. Due to this issue, in the case of HVAC transmission the breakeven distance is reduced to 60 km [49]. Moreover, an Asynchronous connection of two alternating current transmission systems can be realized using the HVDC technology. On the other hand the early use of HVDC transmission systems was limited due to several factors like: rising Expensive of converters, generation of harmonics, complexity of the controls, the disability to utilize a transformer to change voltage standards etc. [48]. However, over the time, many of these above presented issues were solved except the disability to utilize a transformer to change voltage standards. As a conclusion of this comparison, it can be said that the HVDC transmission technology is attractive and advantageous for long power transmissions, bulk power delivery, long submarine power crossing and also asynchronous interconnections [49].

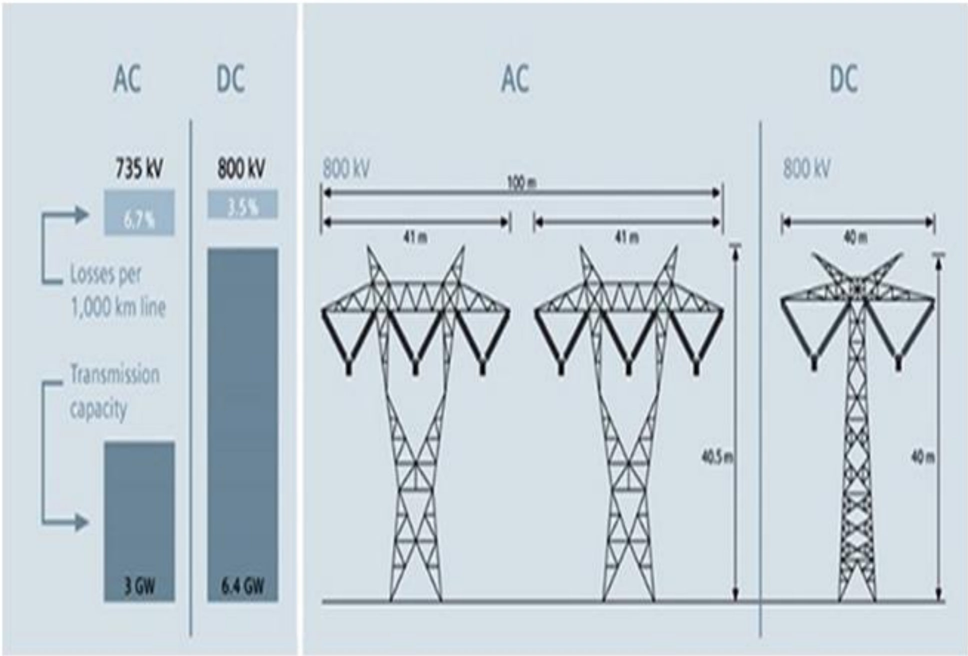

Figure 4.1 compares of DC and AC transmission line power capacity

■ UHVDC more than 50% reduction in right-of-way requirements.

■ UHVDC a significant reduction in transmission loss requirements.

■ HVDC it is considered more practical for long-distance, bulk power delivery.

■ When taken HVDC technology,to transfer power must take into account the technical and economic together.

4.2 Comparison of Alternating Current and Direct Current transmission line system.

To comprehend this energizing development of the high voltage direct current transmission line system, In the last five decades an examination with traditional alternating Current transmission lines framework is done. In the accompanying subdivisions an examination between the Alternating Current and Direct Current transmission line considering diverse perspectives, for example, transmission costs, specialized contemplations, unwavering quality, and accessibility of every transmission innovation.

4.2.1 Comparison Transmission Costs between AC and DC Power System

The expense of any electrical transmission line system, typically incorporates the expense of the primary segments, for example, (RoW) which is the measure of scene may be involved amid establishments of towers, protectors, conductors, and station types of gear notwithstanding the operational costs, for example, the misfortunes in the lines in general. In any case, for giving running limitation of both transmission lines in direct current and alternating current systems, the DC lines can convey as more electrical energy with two conductors as the alternating current transmission line system with three conductors of the same girth. Additionally, the direct current transmission lines demanded less foundations than the alternating current transmission lines which will subsequently decrease expense of the direct current transmission line establishment. In Figure (4.2), a correlation of Right-of-way for direct current and alternating current transition lines is displayed [50]. The direct current transmission line system, the misfortunes will be lessened to around 66% of the practically identical AC transmission lines. Both the corona and skin impacts have a tendency to be lower if there should arise an occurrence of DC transmission line, which will thusly diminish the transmission misfortunes. Figure (4.2) communicates the aggregate expense of the alternating current and direct current transmission lines as for the separation [50].

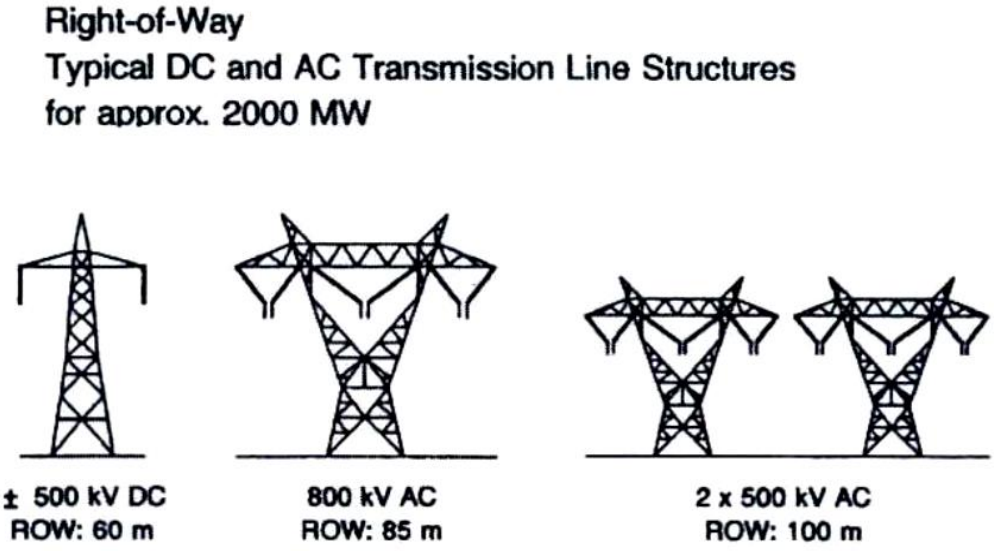

Figure 4.2 Comparison of RoW for AC and DC transmission systems [50]

4.2.2 A Technical Comparison

The quick and whole controllability of the high voltage direct current transmission line system makes conceivable to adjusting the movable electrical power in a snappy and legitimate way. In this way, they significantly affect the soundness of the related alternating current (AC) power system. All the more critically, an appropriate and tough configuration of the high voltage direct current (HVDC) controls is fundamental to guarantee attractive execution of the general AC/DC systems [50] [31]. More about high voltage direct current (HVDC) sways on the framework soundness is clarified in the following segments.

4.2.2.1 Stability confines of power transmission system

In the study of a simple model AC transmission line as shown in Figure (4.3), the alternating current power control through the line of the posting end to the less than desirable end relies on upon the point distinction between the transport voltages (load edge). The surmised electrical mathematical statement that speaks to the transmitted electrical power from the sending side to the less than desirable level in the receiving side, given by this equation at below (4.1).

$$P_{12} = \frac{V_1 V_2}{X_1} \mathrm{Sin}\,(\delta_1 - \delta_2). \qquad 4.1$$

(V) Is the key (Rms) voltage, (X_1) is the arrangement resistance of the simple transmission line, The (V_1) and (V_2) demonstrate sending and receiving end individually and (δ_1) – (δ_2) is the relative voltage stage shift.

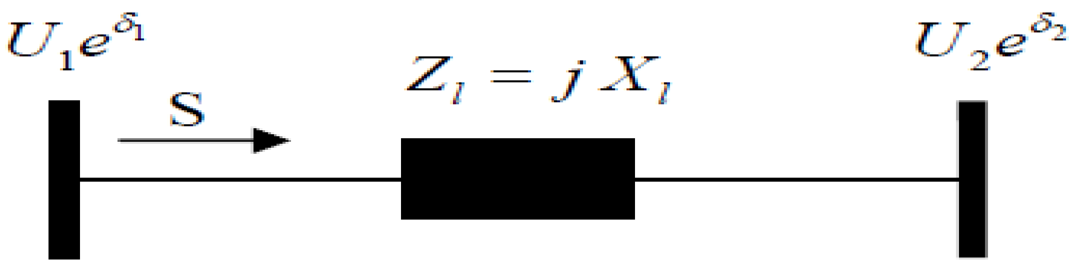

Figure 4.3 simple model AC transmission line

For a specific electrical power exchange level, this point distinction shall increment with separation. Furthermore, the aggregate sum of electrical power can be exchanged will be constrained by the thought of consistent situation and passing dependability. Any unsettling influences in powerful stream will bring about burden angle fluctuations. For reasons related to the stability of the system, the load angle must be preserved at generally low values beneath typical working conditions [27].A consequence of solidness restricts, a parallel alternating current transmission line and in addition some other, exchanging stations, for example, static compensators, synchronous condensers, and arrangement capacitors and ought to be utilized to bolster voltage file in system and to keep away from insecurity that may come after issues on hold [22].

The system load is relatively small probability, the alternating current transmission line transferred the reactive power, this impact could bring about overvoltages in the transmission line system and a few transports in generally in the power system. Shunt reactors are associated with keeping the terminal voltage in the points of confinement. Many of the accounts differs from the functional when taking into consideration the long and short transmission lines in the power system. Be that as it may, the short line model has been utilized as a part of its approximated power mathematical statement with a specific end goal to streamline and outline the clarifications.

Figure (4.4) demonstrates the power conveying ability of an alternating current transmission line which is conversely corresponding to the transmission line length. Conversely, under consistent state situations the inductance and capacitance of the direct current transmission lines have no consequences for the transmission line length. In this manner, the above challenges won't originate from there should arise an occurrence of DC transmission lines. Additionally, there will be no requirement for middle of the road exchanging stations (compensating equipments) with the exception of the converter stations to feeding the considerable receptive force which is expected to keep up a legitimate running of the system equipments [22].

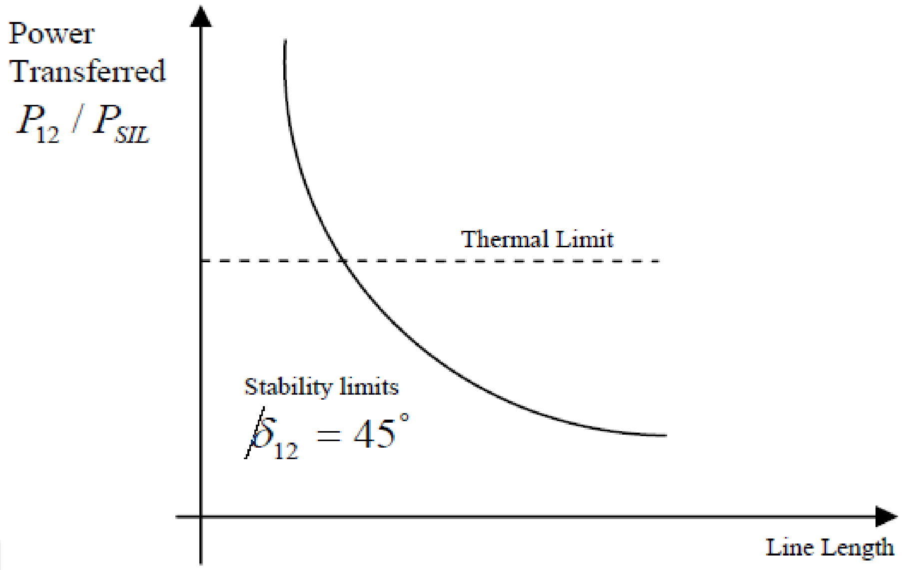

Figure 4.4 Outline of thermal and soundness limits in AC lines [23]

4.2.2.2 Voltage Control

Because of the transmission line loading and voltage falling, the voltage control of an alternating current transmission line is convoluted. The voltage profile of the alternating current transmission lines is generally level, for various loading levels the voltage is constantly swinging and a decent power type it ought to be preserved in a satisfactory level [27]. To keep up the voltage fixed constantly on both sides sending and receiving, responsive power reparations is required, As especially in the case of the latest expansion in new transmission lines. The increased load on the transmission line may eventually lead to reduced voltage sides, especially at the tip of consumers, When you do not take a spin voltage system into consideration and compensate it in the end it affects the entire sela, rather adversely affect the performance of the operation and the exchange of electric power between the systems, see mathematical statement (4.1). Additionally, if there should be an occurrence of alternating current transmission line the reactive power remuneration will increment as the transmission line expanded. Then again, the classical high voltage direct current station expends reactive power which is evaluated to associate with 50% of the aggregate dynamic sending power and no transmission line consumption is required for the direct current transmission lines. In the event of high voltage direct current light (modern system) there will be no reactive consumption utilizations by the converter terminals. Thus, the high voltage direct current transmission line system may be more appropriate than the alternating current transmission line system, especially for tall transmission lines operating with a high voltage level.

4.2.2.3 Reactive Compensation in AC systems

In alternating current transmission lines with a tall transition lines the issue of transmission line loading, soundness confinement and voltage level variety will enlarge. These issues are disposed of by electrical power compensation equipments arrangement. For example, transmission line remuneration is utilized to raise the exchangeability of the alternating current transmission lines as appeared in the figure (4.5). For instance, expressing the approximate symmetrical circuit of the alternating current transmission line system as a simple model in Figure (4.5), with a specific end goal to expand the exchange limit of the transmission line, the general reactance of the transmission line is diminished by including the arrangement capacitance (Xc). The mathematical statement (4.2) portrays the dynamic power flow (P_{12}) between the line closes. The electrical power inflow is expanded when the estimation of (Xl − Xc) is diminished. However, due to as far as possible, and particularly the main swing issues in the transmission system after substantial Disturbances hanging in the balance, the additional estimation of (Xc) will have a specific point of confinement. ($\frac{P_{12}}{Psil}$) Is the real power transmission between the AC line ends which is the ratio between the transmitted power in (MW). (p_{12}) and the surge impedance loading(psil) where the line inductance and capacitance are balanced.[4]

$$P_{12} = \frac{V_1 V_2}{Xl - Xc} \text{Sin}(S_1 - S_2) \qquad (4.2)$$

Figure 4.5 alternating current transmission line system simple model

Shunt remuneration equipments utilized to keep up the voltage at standard value inside of specific points of confinement in the overall power transmission system. Figure (4.6), it delineates the voltage profile as for the transition line separation with and without shunt remuneration over the transmission line. Be consideration after effect of the reparations (compensations), the expense of alternating current transmission line system will increment the quantity of remuneration supplies increment. High voltage direct current transmission systems compensations over the transmission line is not necessary. In any case, as already specified the converter terminal expend receptive power and that would be repaid at both sides of transmission line in sending and receiving terminals. Also, there is no reactive power on the direct current sending line system, accordingly, there are minimal specialized breaking points to the transmission separation contrasted with alternating current transmission line system [41].

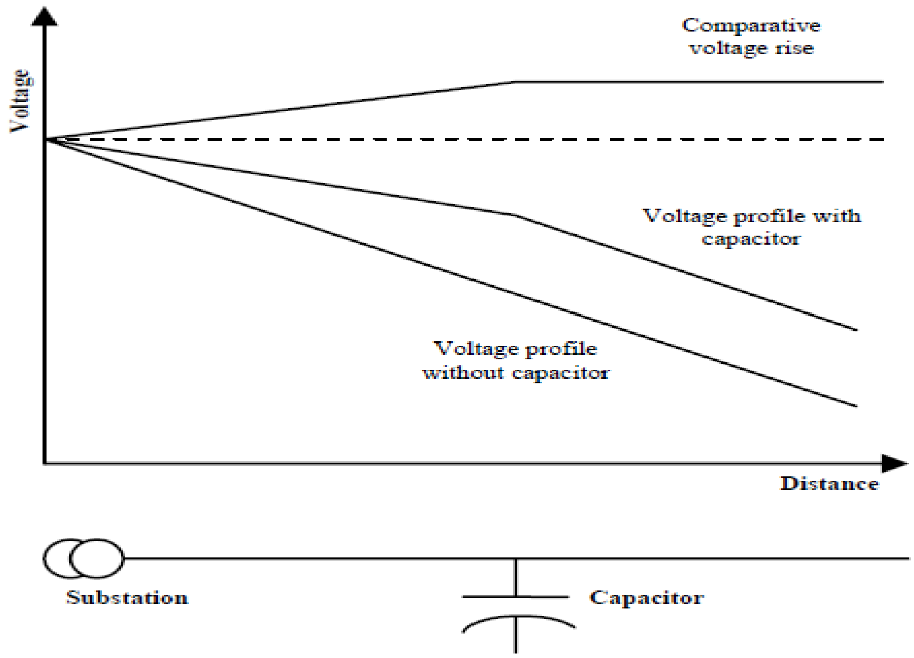

Figure 4.6 Effect of shunt capacitors on voltage profile [41]

4.3 HVDC Technology System Using to Improve the Performance of the AC System

Connecting two alternating current power systems utilizing alternating current balance transmission lines will demand the programmed modern controllers of both transmission power systems, or the two systems with each other to be composed utilizing the tie line power and frequency.Be that as it may, the connected AC power systems with modern control, coordinate yet subject to several practical issues, for example, [27]:

Electrical equipment affected by fluctuations in the growing frequency in the system and her negative

Flaws level issue.

Problems that occur because of faults move from one system to the other via the Transmission line.

Utilizing the direct current (DC) transmission line system as a tie line would wipe out the vast majority of the said issues. The direct current transmission line is less sensitive to the frequency and it would interconnect two different frequency systems and separate the system troubles [27] [31].

4.3.1 Control of High Voltage Direct Current (HVDC) System

A solid control framework for high voltage direct current transmission lines is especially prescribed and it will improve the dynamic execution of the alternating current transmission line systems. There are numerous realizations that make the prompting for an additional control of direct current transmission lines, some they are:

They have a good, affordable damping system, resulting vibration due to technical problems.

Improve the stability in the alternating current power system due to abnormal situations.

Control reactive power fluctuation and frequency of system.

Numerous abnormal state controls are utilized as a part of practice, yet the control target of each relies on upon the related AC system qualities. Every control system that has been utilized has a tendency to be a unique for that power transmission system. Until now no endeavor has been made to build up a generic and the enhanced control way that suits overall power systems [31]. In the coming sub areas a writing audit is done in view of some past studies.

4.3.2 Power Stability Enhancement

High voltage direct current transmission lines are very manageable, and also conceivable to exploit this trademark to improve the transient stability of the alternating current transmission line in the overall power system. After a particular unsettling influence in the transmission line system, the high voltage direct current power system can be controlled in a way like that the direct current power system can be sloped here and there rapidly to return the poise between power capacity and demands on sending and receiving sides of the alternating current transmission power system.In some circumstance inclining up the power system is important for help power system solidness and should possible by method for a transient over-loading abilities of the high voltage direct current transmission system considering The warm limit of the rectifiers. Notwithstanding, in the present day high voltage direct current technology, rectifiers are over evaluated and intended to be over-loaded for quite a while [31] [47]. Controlling the high voltage direct current converters to give compensation power feeding into the system and voltage backing can be valuable to expand transient stability. In any case, it ought to be seen that the established high voltage direct current based on thyristor can not give receptive power, despite what might be expected, it expends reactive power. Modern high voltage direct current system advances, For this, technical reason can be tapped and used in the transmission system electric power.

4.3.3 AC System Durability and Its Impact on the AC/DC Interconnections

The alternate and direct current power system incorporation can to a great degree affected by quality of alternating current grid with respect to the high voltage direct current transmission system limit. Failure of alternating current power system can sometimes can be due to its resistance to high or low idle. The quality of the direct current and alternating current power system can be calculated by its short current ratio, which is proportioned between the short current mega volt ampere (apparent power) of the alternating current power system contrasted with the direct current converter megawatt estimate. As in mathematical statement 4.3 [31].

$$SCR = \frac{Ssc}{Pdc} \quad (4.3)$$

The Short circuit mega volt amper of the alternating current power system is shown in below:

$$Ssc = \frac{E^2ac}{Zth} \quad (4.4)$$

Where (Eac) is the compensation transport voltage at evaluating direct current power system and (Zth) is Thevenin proportional impedance of the alternating current power system transmission line. The short ratio of any power system shows naturally the quality of the alternating current transmission line system. A record he is called powerful or effective short circuit has been acquainted with Indicator the alternating current power system quality considering the impacts of the HVDC types of gear which is associated with the alternating current side [31]. Likewise, the high voltage direct current system control assumes a crucial part in the alternating current to direct current association marvels and it should be refereed to accomplish a decent level of alternating current power system quality [31].The short out proportion or short circuit ratio (SCR) gives only the AC system quality considering the (DC)transmission (Pdc) while the compelling, effective short circuit ratio (ESCR) considers the impacts of the high voltage direct current power system types of gear.

The alternating current(AC) power system quality can be ordered of being high if the effective short circuit ratio (ESCR) the are more noteworthy that three, or Low if the effective short circuit ratio (ESCR) is some between two and three3 and lower if the effective short circuit ratio (ESCR) less that 2. Additionally, associating the high voltage direct current to the less alternating current power system with low effective short circuit ratio (ESCR) will adversely affect the alternating current power system.

1. Harmonic reverberation because of the parallel reverberation between alternating current capacitor filters in the system and the alternating current power system at minimal symphonious.Moreover, disposing of the low-arrange harmonic reverberation is imperative keeping in mind the end goal to diminish transient over Teminal voltages [31].

2. Voltage unsteadiness which is connected with the stacking sensitivities of the high voltage direct current (HVDC) system. Case in point, an expansion of the immediate

current will be trailed by a collapse of rotating voltage which will create the voltage control and recuperation from aggravations troublesome and the high voltage direct current control of power system may add to voltage unsteadiness by reacting to the exchanging voltage diminishment prompting a dynamic breakdown of voltage in the end.

3. Voltage flashers, is the advent because of the consistent exchanging of reactors and the capacitor devices installed in the transmission system bringing on inadmissible transient voltage flashers.

The already specified issues connected with the frail AC systems can be eased by utilizing static var compensator (SVCs) moreover with a rough high voltage direct current controller that can adjust the receptive power in light of voltage fluctuations [31].

Besides, the over-voltage issues related to the high voltage direct current transmission systems have been examined in [48]. Distinctive causes have been analyzed, for example, flashover on the direct current link at various locations (center, initially, and end), the outcomes demonstrated that the high voltage direct current recoups rapidly from like overvoltage issues. A criterion flashover with a (16) kilo amperes that hit the direct current transmission line between (100 to 120)Km from the rectifier terminal will achieve over-voltage issues. Besides, in [48] various types of over-voltage causes have been explored, for example, high voltage direct current transmission line flaws, ground flaws, converter terminal direct current part valve short circuits. Notwithstanding, the suggested control system, it's simple for the high voltage direct current connection to recoup from issues. Conversely, if such lightning happened on account of alternating current transmission lines the best path to ease like blames is to separate the line immediately after the lightning, which may Impactsly affect the other alternating current transmission lines and parts in the overall power system, for example, electrical transformers, and electrical generators over-burdening which will hence bring about fell stumbling of the segments.

4.4 Rapid Rebuttal to System Faults

The high voltage direct current technology system is influenced by various kinds of faults through running process. For example, the deficiencies or faults occurred in the direct current (DC) links, modifiers, and in the alternating current power system may take the high voltage direct current HVDC terminal out of running if not moves are made to obvious them inside of adequate time. With that, a large portion of the flaws in the direct current power transmission system is either itself reset or reset over appropriate activities from the converter ruling, which is not the situation in the alternating current power system, the issues are ordinarily reset by a method for transfers that trek out the alternating current transmission system. However, the converter of high voltage direct current system is vital and assumes an indispensable part in the acceptable reaction of high voltage direct current lines to the shortcomings on both direct current and alternating current parts of transmission system [31].

4.4.1 Faults in the Direct Current System (DC)

The majority of the issues in the direct current side of high voltage direct current system are pole to-ground deficiencies. Bipolar deficiencies are uncommon because of the want of high power to unite the two poles posts. The direct current transmission line issues own a minimum unwanted effect on the alternating current power system than an alternating current shortcoming in light of the fact that losing one shaft will simply hinder the power exchange on that pole while the other pole is for all intents and purposes uninfluenced [31].

The high voltage direct current controller can reset the flaws on the direct current transmission line by two way first one by ordinary control activity and other way utilizing the quick acting line insurance. Any faults occurred on the falls direct current transmission line will quickly bring about the rectifier current to increment because he is sustaining a lower impedance deficiency and the inverter current to diminish, Therefore, this situation, the rectifier control it will work to lessen the immediate voltage and convey back the current to its acceptable range. Nonetheless, the typical control activity has a tendency to return the framework case.In the quick acting assurance control, extra control is utilized to lessen the fault current levels to standard values and recuperation voltage.

It must be specified that, aggregate time for flaw recuperation falls between (150) to (250) Millisecond if the fault is transitory and the reset is effective. The recuperation time is higher for direct current transmission line is associated with the powerless AC power system. The programmer restarts of the high voltage direct current link system is not permitted because of the way that, the greater part of the high voltage direct current link flaws are lasting faults [31]. Different sorts of flaws worth talking about are converter flaws, like a sort of faults may want the valve bunch or the entire shaft to be shutting. The valve bunch fault will want the whole post to stop sending of power, taking after by the current decrease to minimum value relatively zero, which regularly takes under (30) Millisecond [31].

4.4.2 Faults in the Alternating Current System (AC)

The direct current (DC) power system has a quick reaction characteristic to the transient unsettling influences that may occur in the alternating current power system. The high voltage direct current controller obtains a ride along any aggravations in the alternating current power system by either lessening the dynamic power, incidentally or collapse till the alternating current power system recuperates totally. Recuperation from alternating current power system faults the main goal of the principal arranged objectives of high voltage direct current controller. Numerous sorts of alternating current power system faults may occur on the alternating current side of converters stations.

Consider the HVDC schematic in Figure (4.7). The HVDC reaction to three stage flaw happened at a remote spot in the AC system from the rectifier side can be condensed as take after:

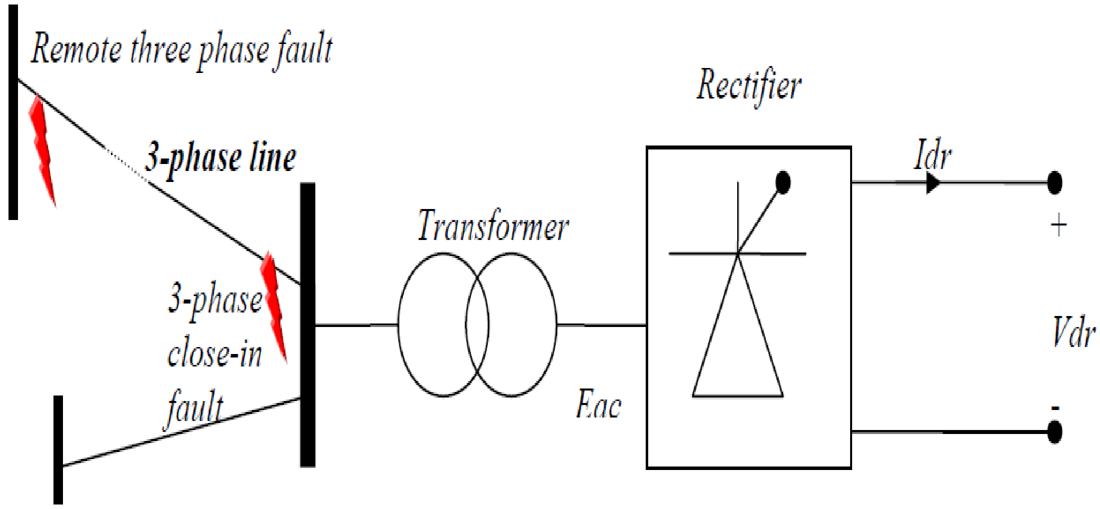

Figure 4.7 schematic diagram of the rectifier side of high voltage direct current technology

As already specified, the length of fault clearing (recuperating term) relies on upon the alternating current network quality (150 to 250 ms) and it may latest more if the direct current link associated with frail alternating current grid power system. Then again, if three phase shortcoming occurred in the alternating current side station near the transformer as appeared in Figure (4.7) , the recompense voltage falling will be huge which will be occurred the collapse of the high voltage direct current power system incidentally under the direct current voltage till the flaw is reset.The high voltage direct current transmission system will obtain ride through with no undeniable impacts, on the grounds that the normal replacement voltage will be greater than the instance of outlying (3ph) error.If there should be an occurrence of a noteworthy fall in the transmmiting voltage, the high voltage direct current control,in generally the performance of power system's response will be like that for remote 3ph- faults.

If there should be an occurrence of inverter side's shortcomings, for example, remote 3-ph alternating current flaws as appeared in Figure (4.8) , the outcome will be a little voltage down at the inverter station side and at the same time an expansion in the direct current happens. The rectifier station and inverter station controllers will react to the progressions to return the power system condition to the normal operation. In the event that the low rotating terminal voltage proceeds with, the tap changers or transformer will be enacted to return the converter firing angle in both stations also the direct voltage to an acceptable value. Then again, for a noteworthy voltage down, the sending voltage will descent, which brings about an interim recompense disappointment at the inverter side station. Furthermore, the subsequent reactive power increment after the fault will drive the high voltage direct current control system to diminish the direct current keeping in mind the end goal to decrease the measure of retained reactive power amid the fault reset procedure [31].

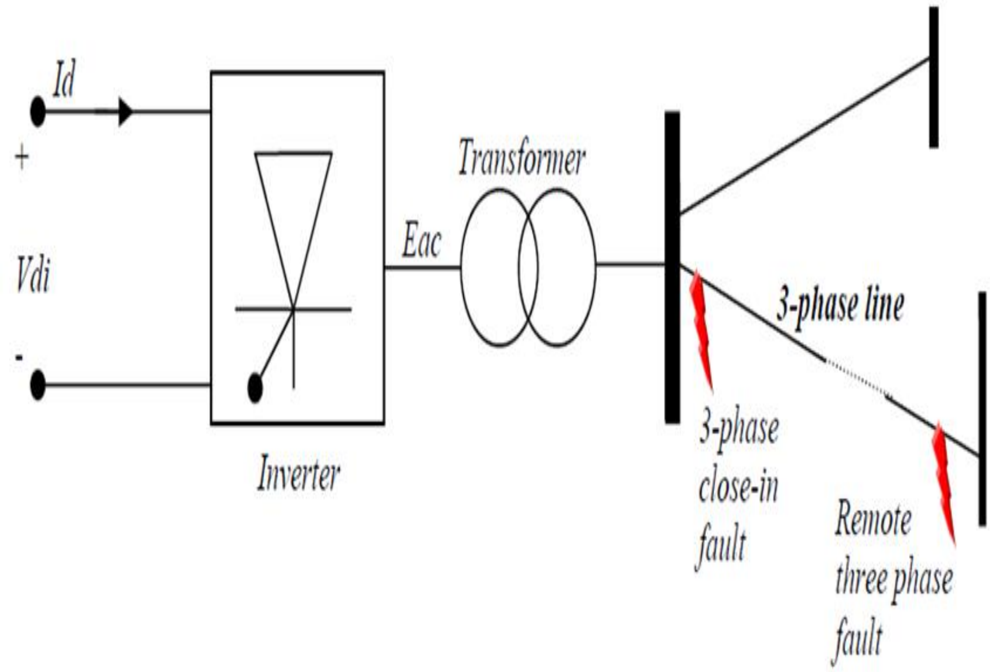

Figure 4.8 HVDC graphical from the inverter side station

4.4.3 Alternating current power System Fault retrieval

The recuperation process from alternating current transmission power system faults relies emphasis on the quality of the alternating current power system, next any unsettling influence on the power system, the general power system execution will rely unequivocally on the alternating current to direct current power system cooperation as said some time recently, and additionally the converter control technique and its related reaction alterations. Notwithstanding, it ought to be specified again that the recuperation operation next any alternating current power system flaw would be speedier if there should be an occurrence of solid AC power system in general, while the feeble AC system may experience issues in giving adequate reactive power to the high voltage direct current link which make the recuperation prepare long-term.

It will take the direct current power system around 150 ms to 550 ms to recuperate to 85% of its pre-flaw control and the reality of the situation will become obvious eventually rely on upon the DC and AC system qualities and also the control technique of the HVDC system. Numerous components impact the recuperation rate, for example, the impedance of the direct current transmission links, direct current reactor equipment, thunderous symphonious frequency of transmission line system and the converter transformer attributes [31]. Moreover, the voltage-subordinate current request boundary assumes an indispensable part in deciding the recuperation from electrical faults. The control module in the direct current power system is in charge of constraining the current mostly amid the antagonistic faults on either the direct current or alternating current side of the direct current power system and subsequently confines the reactive power utilizations amid the faults. Case in point, amid the unsettling influences on either the direct current or the alternating current parts of stations, the unexpected voltage decrease will expand the value of ingested Unuseful power by the high voltage direct current link which subsequently create the recuperation time of the system longer. However, utilizing the VDCOL control procedure will restrict the present as a component of both systems.Accordingly, furnishing the high voltage direct current with a strong and propelled control technique will help the direct current transmission power system recuperation and create it speedier.

CHAPTER 5
SIMULATION STUDIES

5.1 General

The production of electricity takes place in a power plant. Before the power is transmitted, the voltage level of the power should be raised by the transformer. Electric power is Proportionate to the product of voltage and current this is the reason why power transmission voltage levels are used to reduce power transmission losses.

5.2 HVAC Transmission System Model

The simulation model in Figure (5.1) represents an HVAC transmission system model, transmitting 2100 MVA (60 Hz, 13.8 kv) power from a power plant consisting of a six machines and three buses has been simulated in the SOFTWARE environment. The transmission line distances increased and varied from (300 to 1200) km, in order to consider more cases or situations in the work. Also the disturbance applied the faults at the midsection or the midpoint of the line in order to create a single-ground fault to see the comparison and impact of fault in the system as the results, The power plants have been supplied to the system at bus B1, B3 and B2 one major load center of nearly 1000 MW is modeled using a dynamic load model where the load absorbed the active & reactive power as a function of the system voltage. And taking those cases, depending on the distances in the same case for HVAC and HVDC system models [51].

The Simulation model of HVAC transmission system consists of the following parameters, that was his statement through a table (1), (2), (3) and (4).

Table 5.1 Parameters of synchronous machine model.

Parameters	Value
Nominal power, line-to-line voltage, frequency [Pn(VA) Vn(Vrms) fn (Hz)]	[2100e6 13800 60]
Inertia, damping factor and pairs of poles [H(sec) Kd(pu_T/pu_w) pu]	[Inf, 0, 2]
Internal impedance [R(pu) X(pu)]	[0.22/15 0.22]
Initial conditions [dw(%) th(deg) ia,ib,ic(pu) pha,phb,phc(deg)]	[0 1.43122 0.716215 0.716215 0.716215 -3.34575 -123.346 116.654]
Sample time (-1 for inherited)	-1

Table 5.2 Parameters of (AC) Transmission Line System.

Parameters	Value
Number of phases [N]:	[3]
((Frequency used (Hz))	[60]
Resistance per unit length (Ohms/km)	[0.3864]
Inductance per unit length (H/km) [NxN [matrix] or [l1 l0 l0m	[4.1264e-3 0.9337e-3]
Capacitance per unit length (F/km) [NxN matrix] or [c1 c0 c0m]	[7.751e-9 12.74e -9]

Table 5.3 Parameters of three Phase Transformer model (2100MVA)

Parameters	Value
Nominal power and frequency Pn (VA) , fn (Hz)	[2100e6 , 60]
Winding 1 parameters V1 Ph-Ph (Vrms) , R1(pu) , L1 (p.u)	[13.8e3 0.002 0.08]
Winding 2 parameters [V2 Ph-Ph (Vrms) , R2(p.u) , L2 (p.u)	[735e3 0.002 0.08]
Magnetization resistance Rm (p.u)	500
Magnetization inductance Lm (p.u)	500

Table 5.4 Parameters of Three-phase voltage source in series with RL branch.

Parameters	Value
Phase-to-phase rms voltage (V):	[(735e3)*1]
Phase angle of phase A (degrees):	[-2.0892]
Frequency (Hz):	[60]
3-phase short-circuit level at base voltage (VA):	[30000e6]
X/R ratio:	[10]
Base voltage (Vrms ph-ph):	[735e3]

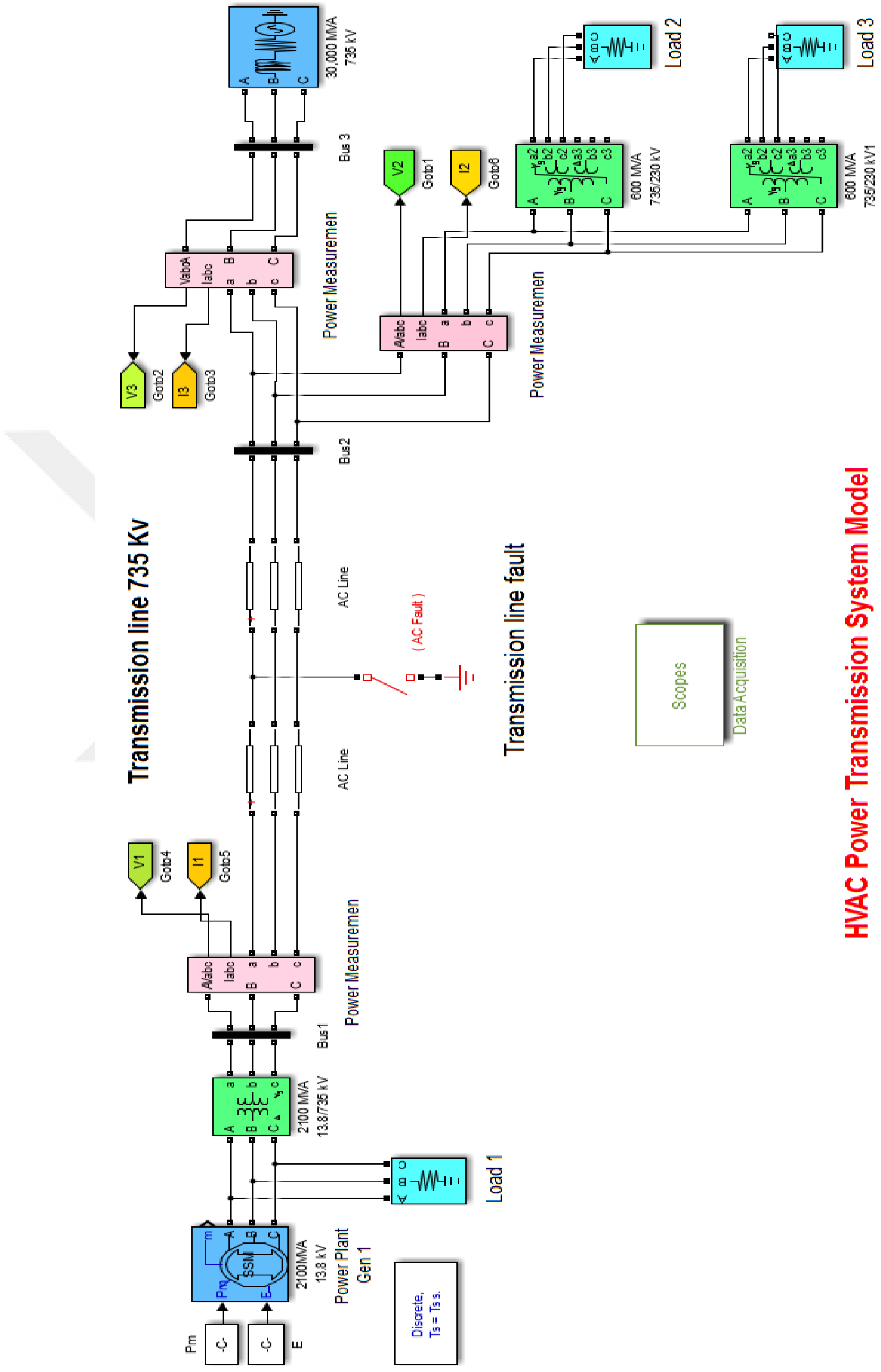

Figure 5.1 HVAC Power Transmission System

5.3 HVDC Transmission System Model.

Now, technological feasibility has been proved in HVDC power transmission system with the improvement of Power electronics devices [52][53]. These devices make the efficient conversion from AC to DC and thus are the main component of any HVDC power transmission system. Figure (5.2) represents the simulation model of (HVDC) transmission system. The system consists of two main sources, like as in AC. Passes through the DC transmission line, where they are changing the distance line from (300 to 1200) km, The System consists of two parts are important, which is a basic job to change electric power from AC to DC and vice versa. Figures (5.1) and (5.2) shows the simulation model of both HVAC and HVDC power transmission system sequentially. For the best analysis and observation of cases influence, the parameters for both simulations were kept same.

The Simulation model of HVDC transmission system consists of the following parameters, that was his statement through a table (5), (6) and (7).

Table 5.5 Parameters of Power Electronic Device (Universal Bridge) in HVDC System

Parameters	Value
Number of bridge arms:	[3]
Snubber resistance Rs (Ohms)	[2000]
Snubber capacitance Cs (F)	[0.1e-6]
Power Electronic device	Thyristors
Ron (Ohms)	[1e-3]
Forward voltage Vf (V)	0
Lon (H)	0

Table 5.6 Parameters of (DC) Transmission Line System in HVDC

Parameters	Units
Number of phases [N]:	[1]
((Frequency used (Hz))	[60]
Resistance per unit length (Ohms/km)	[0.015]
Inductance per unit length (H/km) [[NxN matrix] or [l1 l0 l0m	[0.792 e-3]
Capacitance per unit length (F/km) [NxN matrix] or [c1 c0 c0m]	[14.4e-9]

Table 5.7 Parameters of three Phase Transformer model (1200MVA)

Parameters	Value
Nominal power and frequency Pn (VA) , fn (Hz)	[1200e6 , 60]
Winding 1 parameters V1 Ph-Ph (Vrms) , R1(pu) , L1 (p.u)	[735e3*0.9 0.0025 0]
Winding 2 parameters [V2 Ph-Ph (Vrms) , R2(p.u) , L2 (p.u)	[200e3 0.0025 0.24]
Winding 3 parameters [V2 Ph-Ph (Vrms) , R2(p.u) , L2 (p.u)	[200e3 0.0025 0.24]
Magnetization resistance Rm (p.u)	500
Magnetization inductance Lm (p.u)	500

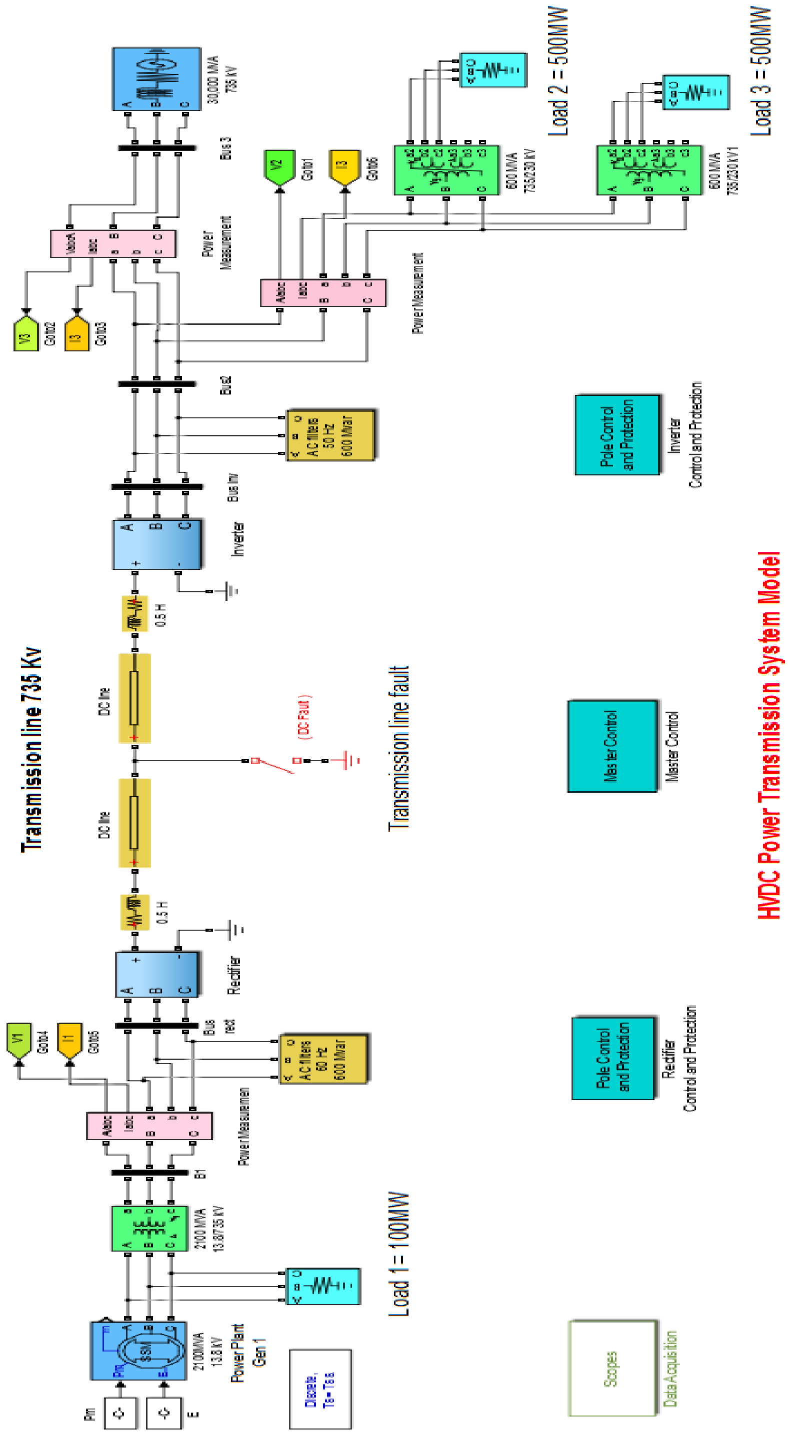

Figure 5.2 HVDC Power Transmission System

5.4 Simulation Studies

The system model in Figure 5.1 and 5.2 is tested under various in three case studies. A Study cases when the length of transmission line considered (300 to 1200)km for both systems (HVAC) and (HVDC) also kept the all parameters at the same value for evaluating. Also the tested investigation during faults duration (0.80 to 0.85) Sec, when applied the single to ground faults of transmission line in midpoint.

The simulation results are obtained in two cases (6steps):

5.4.1 Case Study 1: Test Transmission System under normal conditions:

The system model in Figures (5.1) and (5.2) is tested under normal condition.

5.4.1.1:Test of transmission System under normal conditions through (300) Km:

Figure (5.3) shows the terminal voltage at (B1) and (B2) in HVAC system. It can be seen the terminal voltage (V1) was 0.998 p.u. and (V2) 0.987 p.u. Then the voltage (V1) oscillated between 0.998 p.u. and 0.989 p.u. In figure (5.3) that shows the effect of length of line is different when compared to another length, however the largest dip in terminal voltage was experienced at (300) km, while the largest oscillations occur at (1200) km from the beginning. The time taken for the terminal voltage (V1) and (V2) to settle was 0.13 seconds, which is found to be the differences across all transmission lines.

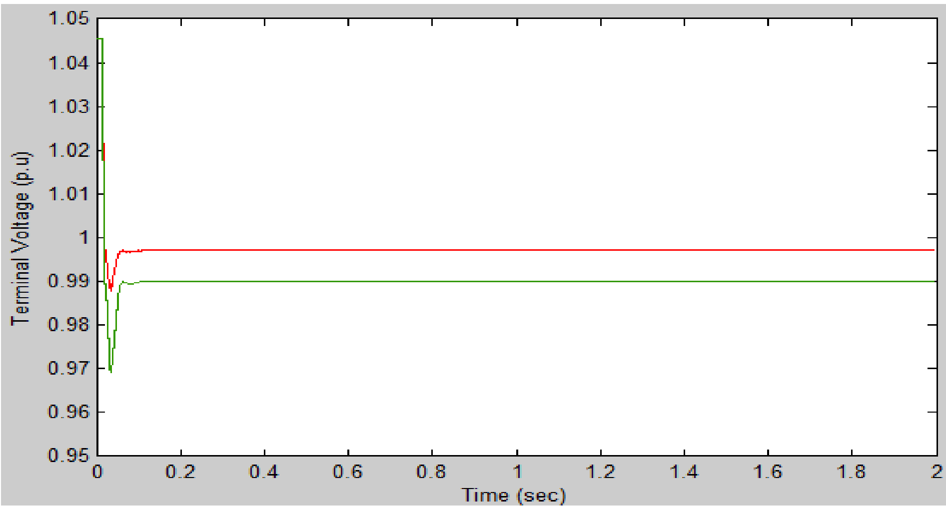

Figure 5.3 (HVAC system): Bus voltage at bus 1-2

Figure (5.4) shows the terminal voltage at (B1) and (B2) in HVDC system. From figure (5.4), it can be seen that the oscillations of (V1) and (V2) starting from the beginning and ends in a time of approximately 0.34 second, and then show the stability of qualitatively. Where we see that the voltage, variation between (V1) and (V2) in particular at this distance of the DC system, shows us most difference when compared to their counterparts AC system. When we see in shape and having a ripple reason due to the work of the system in the transfer that occur from converting AC to DC current and vice versa. We must not forget that normalize the effect of capacitances along the line in the extent of their impact on the system compared to the AC–DC system.

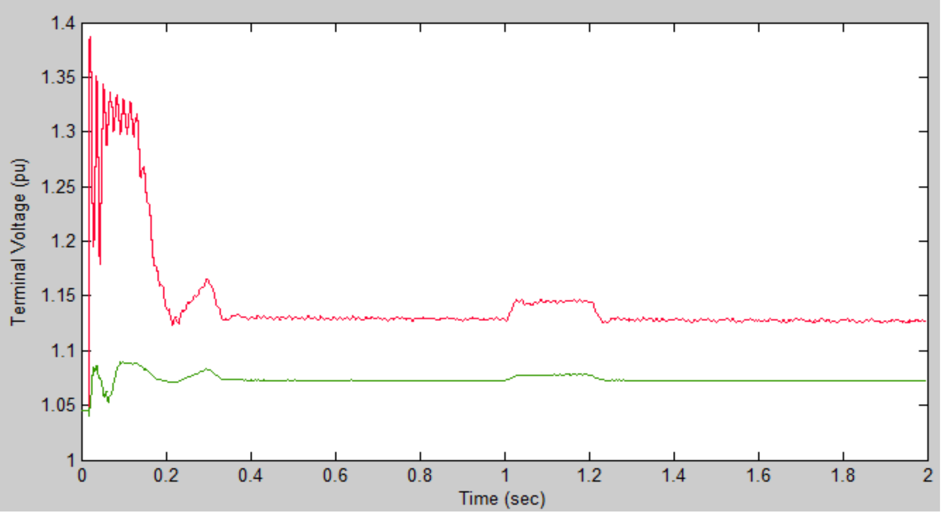

Figure 5.4 (HVDC system): Bus voltage at bus 1-2

Figure (5.5) shows the active power in bus 1, 2 and 3 in (HVAC) transmission system. At steady state active power (P2) is (976.4) MW, (P1) about (1467)MW and (P3) about (-520) MW.It shows us in the figure below the differences between each active power producing and disbursed. We conclude from these curves that the power losses in transmission system, it depends on the length of line and specifications of the transmission system also the load type. An interview with the increasing length of line, it increases respectively, with the losses of power in a transmission line.

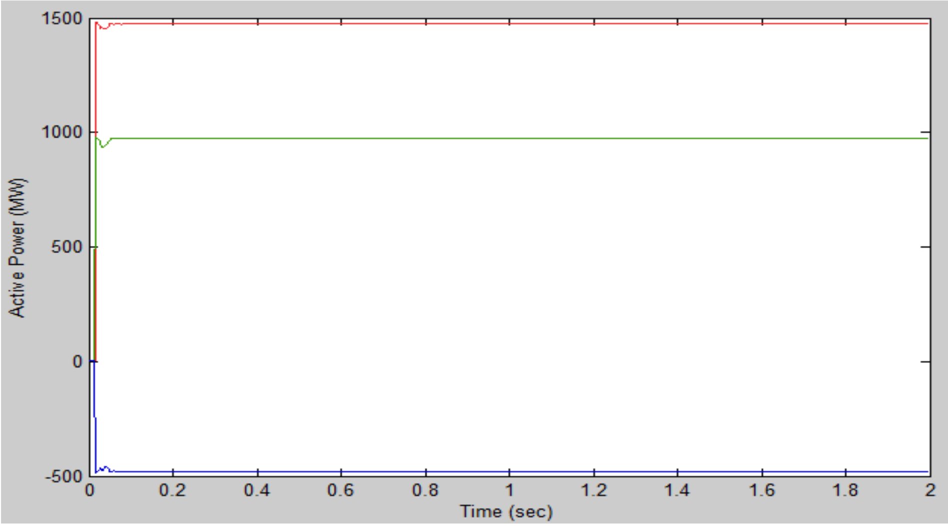

Figure 5.5 (HVAC system):Active power at bus 1-2-3

Figure (5.6) shows the active power in bus 1, 2 and 3 in (HVDC) transmission system. At steady state active power (P2) is (1131) MW, (P1) about (955.9) MW and (P3) about (226.2) MW. Where a conclusion can be summarized here. The transfer of electric power by (HVDC) system in short distances impractical when compared with counterpart (HVAC) system. Because the losses in conventional systems are too high and the cost of the transmission system in general is expensive. Therefore order is preferred AC over DC transmission systems for power transfer, especially in the short and medium distances.

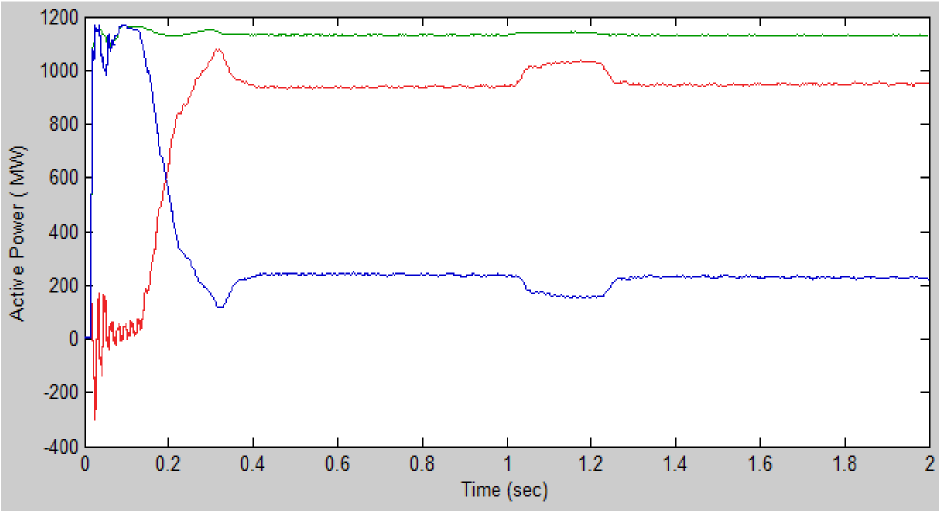

Figure 5.6 (HVDC system): Active power at bus 1-2-3

5.4.1.2: Test of transmission System under normal conditions through (600) Km:

Figure (5.7) shows the terminal voltage at bus 1 and 2 in (HVAC) system, where we could see that the oscillation increases with the increase of the transmission system along the line. Notes through a shape that the time of stability - oriented increased compared to the same system, but different distance in case of (300) km. This is proof that the length of the line for any transmission system determines the importance of selecting the transmission system and how take advantage of its applications.

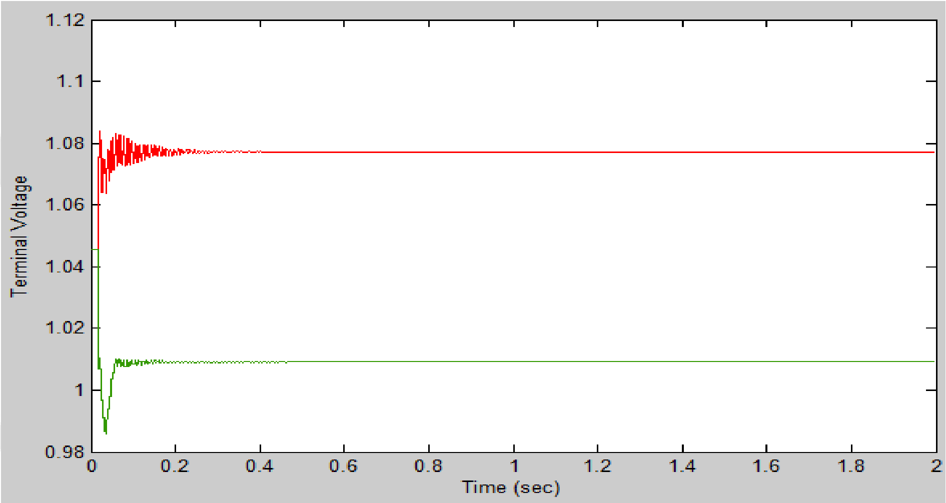

Figure 5.7 (HVAC system): Bus voltage at bus 1-2

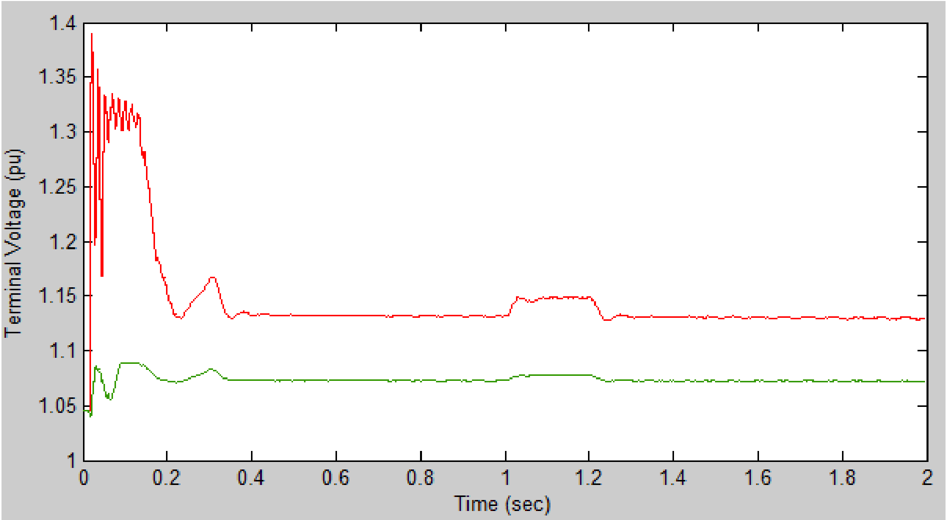

Figure 5.8 (HVDC system): Bus voltage at bus 1-2

Figure (5.8) shows the terminal voltage at bus 1 and 2 in (HVDC) system, initially the value of the V1 is more than 1p.u. After (0.34) seconds voltage being stability and be worth 1.07 p.u. The most important thing in the DC system, which shows us the figures (5.4) and (5.8), the distances positively affect the voltage terminals from sides and vice versa AC transmission system. Therefore, the voltage variations between (V1) and (V2) it is little changed are near close to some of the same values for varied distances. So are this very important property in the (HVDC) transmission system. Which can be proved comparatively to figs. (5.7) and (5.8) For the transmission system in both (HVAC) and (HVDC) for a distance of 600 km, as shown above in figures.

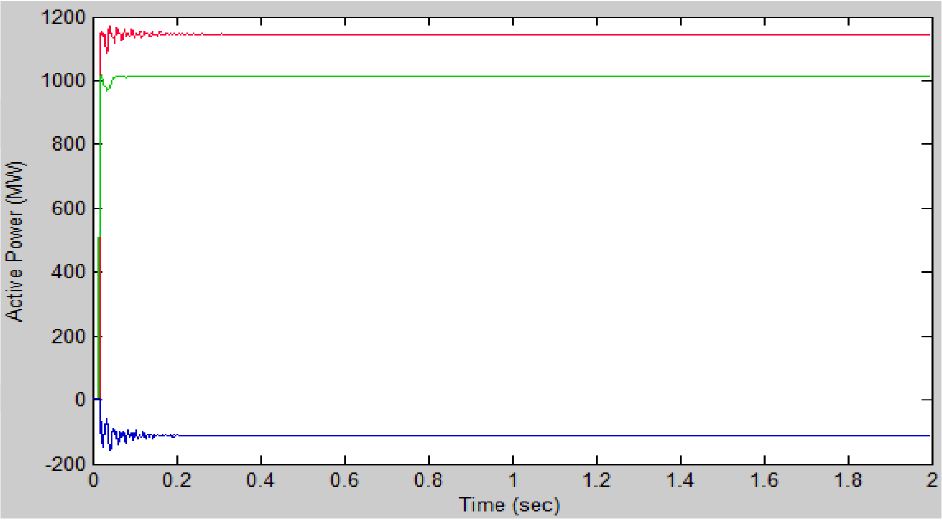

Figure 5.9 (HVAC system): Active power at bus 1-2-3

Figure (5.9) shows the active power in bus 1, 2 and 3 in (HVAC) transmission system. At steady state active power (P2) is (1014) MW, (P1) about (1145) MW and (P3) about (112) MW. From figure (5.9), it can be seen that the oscillation of active power in bus (1-2-3) increased as the length of transmission line (HVAC) increases respectively. After (0.21) Sec, it’s moving towards stability and consistency. When comparing the productive, active power and load power shows us the percentage of power losses in transmission system in general. Clearly shows us that the length of transmission line plays a key role in determining the percentage of power losses.

Figure (5.10) shows the active power in bus 1, 2 and 3 in (HVDC) transmission system. When we observe the figure a below clearly see that the difference between two cases the system running at (300) km and (600) km. At the table (5.11),(5.12)

Shows that the difference between (P1) and (P3) be a little this proof that the length of the transmission line in (HVDC) system is unlimited, and the reason this prefers (DC) system for long distances on the (AC) system. And the conversion from (AC) to (DC) and vice versa in the (HVDC) transmission system be the greatest loss in the system.

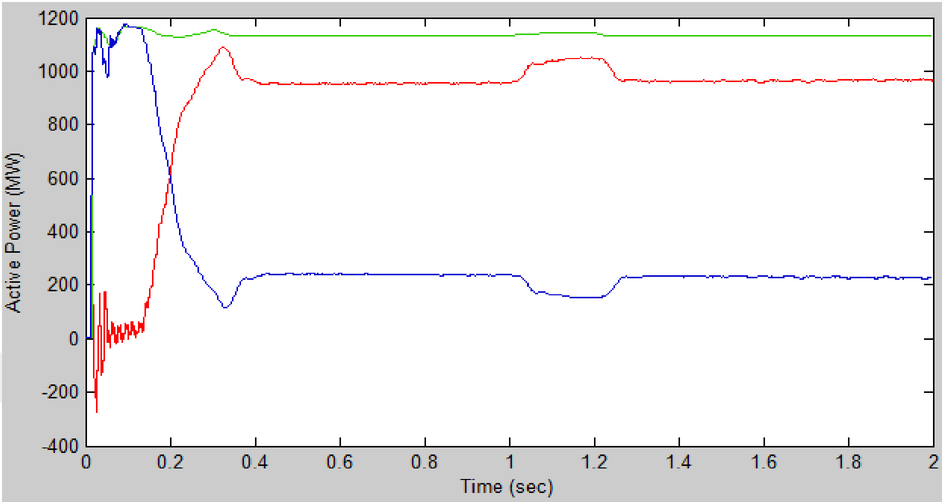

Figure 5.10 (HVDC system): Active power at bus 1-2-3

5.4.1.3: Test of transmission System under normal conditions through (1200) Km:

Fig (5.11) shows the terminal voltage at bus 1 and 2 in (HVAC) system, when the system running under the distance (1200) km and normal conditions. See in figure increasing fluctuation wave starts from the beginning and ends at (0.062) Sec, and then goes to the fundamental value. Through this it is clear that the distance describes the behavior of the systems work, unlike the (HVDC) system, which does not play the main role of the distance of the transmission system. The sense that the other (AC) system depends on the distance, (DC) system is not linked to a factor of line length.

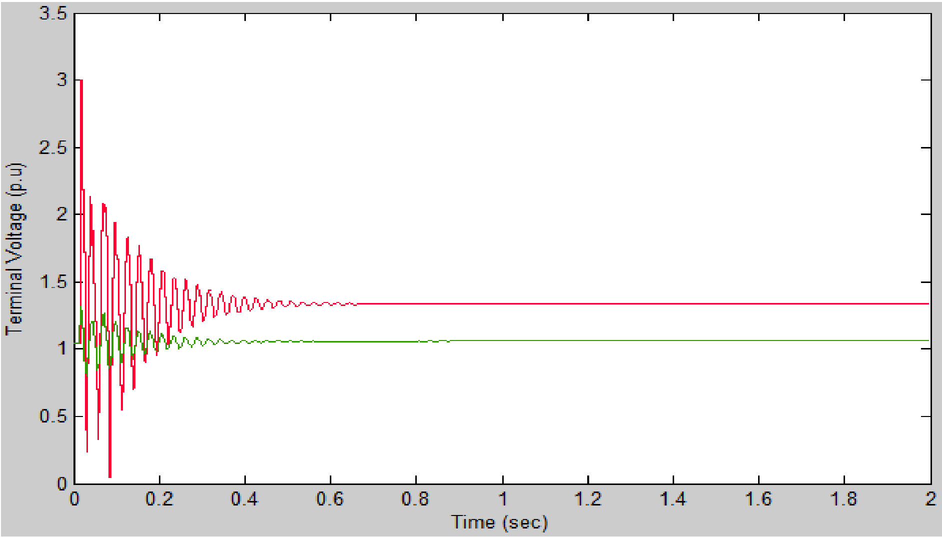

Figure (5.11): (HVAC system): Bus voltage at bus 1-2

Figure (5.12) shows the terminal voltage at bus 1 and 2 in (HVDC) system, initially the value of the voltage is more than 1p.u. After (0.36) seconds voltage being stability and be worth 1.07 p.u. The effect of the length of transmission system. When we compare all the shapes in different distances to see the level of sending voltage and receiving voltage, it is approximately the same values. At the end of the conclusion of the different cases in (HVDC) transmission system, we get to that fact that the distance is unlimited in (DC) system.

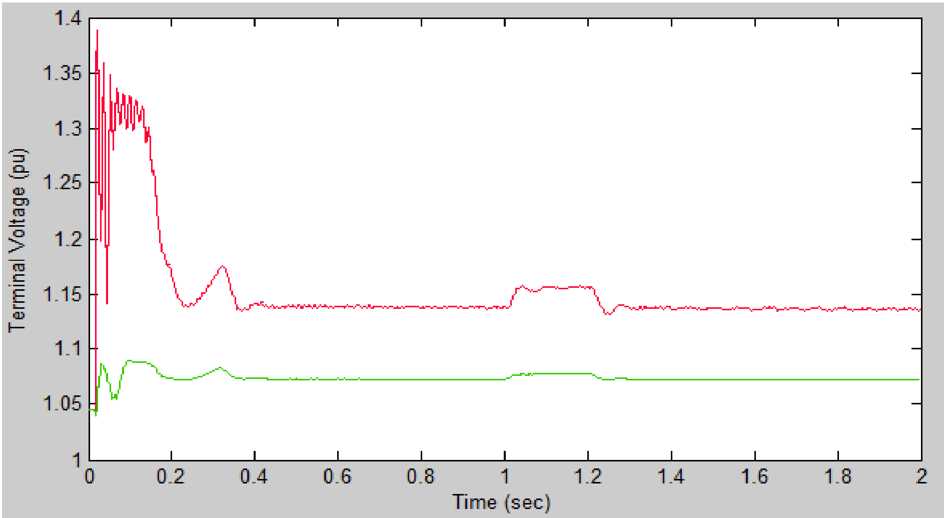

Figure 5.12 (HVDC system): Bus voltage at bus 1-2

Figure (5.13) shows the active power in bus 1, 2 and 3 in (HVAC) transmission system. We conclude from the below figure. That with the increasing length of the transmission line, power losses increase proportionally with that as we can see from the previous cases mentioned or different distances. When transfer electric power. At the beginning of the system works, the system oscillates until approximately (0.97) Sec. After this time is heading toward him stability. Finally, analysis of shape notes the different oscillation for a system with a length of transmission line, where the length of the line effects negatively on the performance of the system.

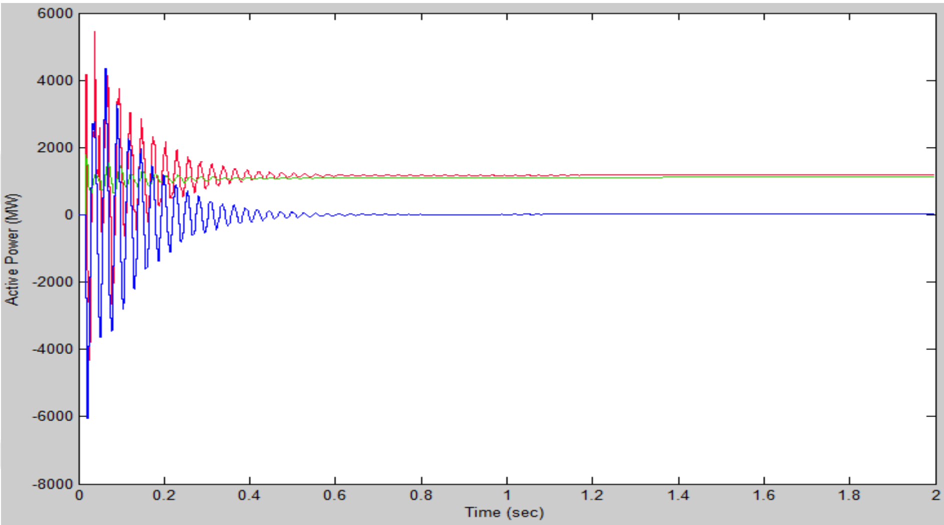

Figure 5.13 (HVAC system): Active power at bus 1-2-3

Figure (5.14) shows the active power in bus 1, 2 and 3 in (HVDC) transmission system. It shows us in the figure, that the active power (P1) generated (994.9)MW, (P2) or load bus (1132)MW, and (P3) (227.7) MW. After (0.4) second the system goes to the stability and operates correctly. But at (1.05) second the value of (P3) downed to under approximately (200)MW, and after (1.23) second returns to stable case. Also (P1) at the same time of operation it brings value to about (1100)MW. And then after this fluctuation the system back to normal state. However, note through all these changes in the operation of the system, does not affect negatively on the active power supplied to consumers.

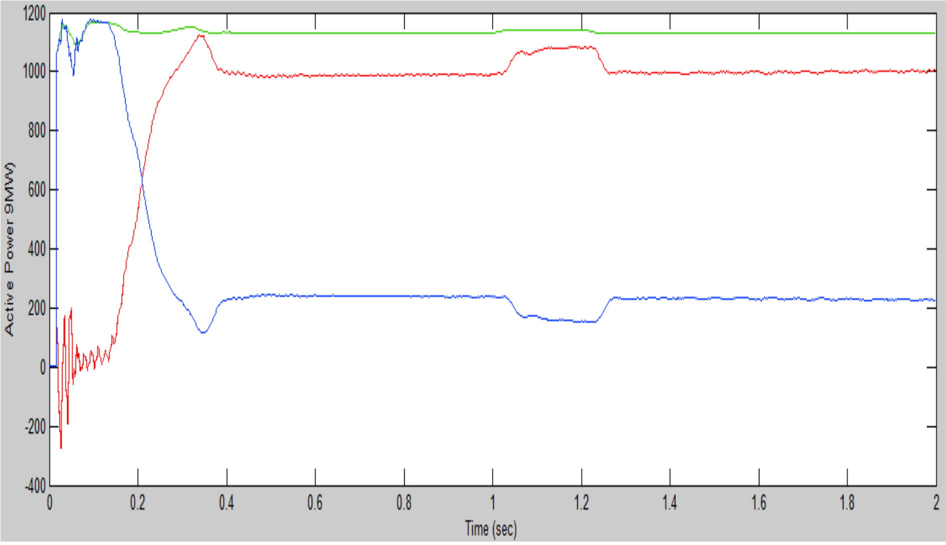

Figure 5.14 (HVDC system): Active power at bus 1-2-3

5.4.2 Case Study 2: Test Transmission System under Abnormal conditions:

The system model in Figures (5.1) and (5.2) is tested under abnormal conditions. The tested investigation during faults duration (0.80 to 0.85) Sec, a (S-G) fault was initiated on 50% of the (HVAC) and (HVDC) transmission line.

5.4.2.1: Test of transmission System under Abnormal conditions through (300) Km:

Figure (5.15) shows the terminal voltage at bus 1 and 2 in (HVAC) system. It can be seen that before the fault, the V1 at the bus was 0.998 p.u. During the fault, the voltage decreased to 0.86 p.u. After the descent rises to 1.03 p.u and oscillated after the arrival of the at 0.98 second returns to the starting situation, Where the influence of faults position is more influential on (V1). Because at the time of faults between (0.80 to 0.85) Sec the value of (V2) becomes about (0.93) p.u. We conclude from figure (5.15) that after 0.98 second the system returns to a normal situation. Then the voltage (V1) oscillated between 1.03 p.u and 0.86 p.u before settling to initial value.

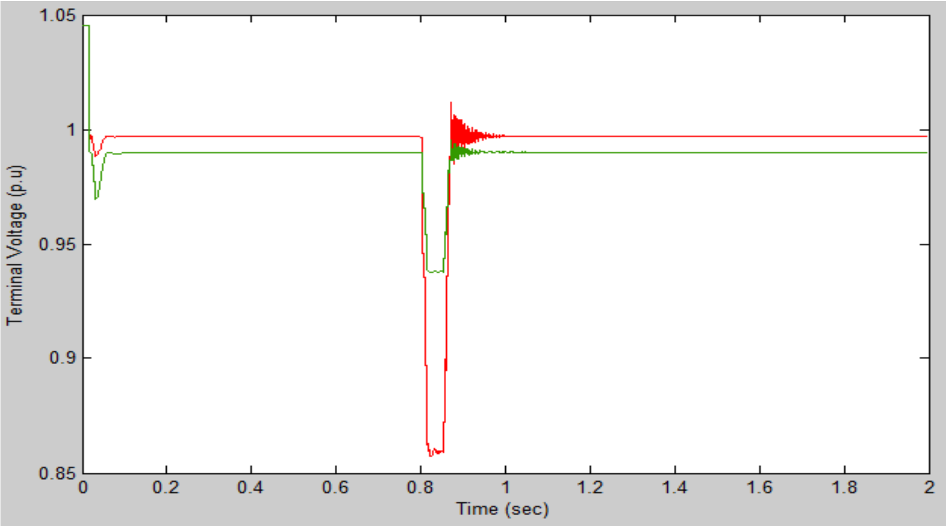

Figure 5.15 (HVAC system): Bus voltage at bus 1-2 under fault

Figure (5.16) shows the terminal voltage at bus 1 and 2 in (HVDC) system. From this figure, it can be seen that the effect of the DC fault (internal fault) on the terminal voltage at bus1, more impact compared to terminal voltage at bus2. Because of fault occurrence at (0.80 to 0.85) second, the effect of faults continues until 1.33 second, and then up to the stability. The second conclusion of shape, when we compare figs. 5.15 and 5.16, we see that the effect of faults to be more influential in the (HVDC) system on his (HVAC), evidenced by the time of the return of the system to its normal state after clearing the faults.

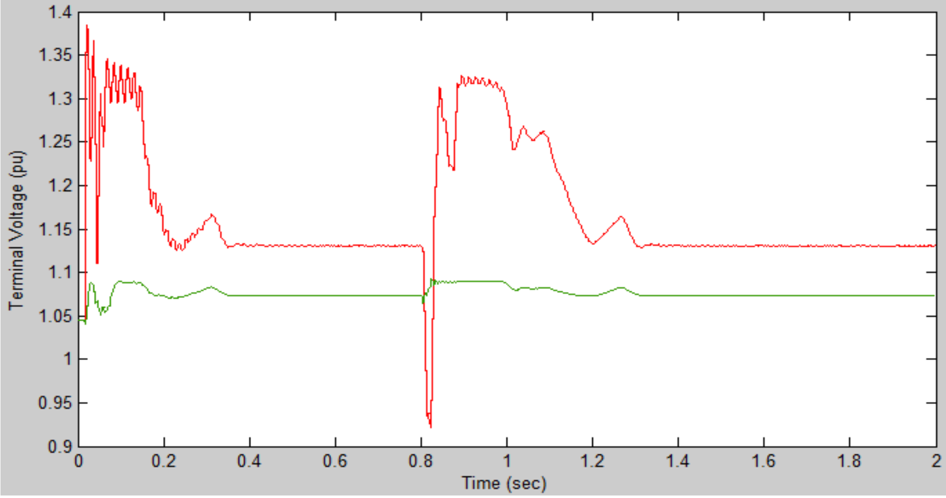

Figure 5.16 (HVDC system): Bus voltage at bus 1-2 under fault

Figure (5.17)shows the active power (P1-P2-P3) in (HVAC) transmission system, a (S-G) fault was initiated on 50% of the (HVAC) transmission line for 50 ms. It can be seen that (P1) oscillated between (1765)MW and(1250)MW during the fault time, after the fault was cleared. The amplitude of the active power (P1) reached to the steady state, its noted from the figure, weaken the impact of the fault on the bus 2 compared to bus 1and 3. From this it is clear that the place of faults and time of occurrence, affects the performance of the transmission system in general.

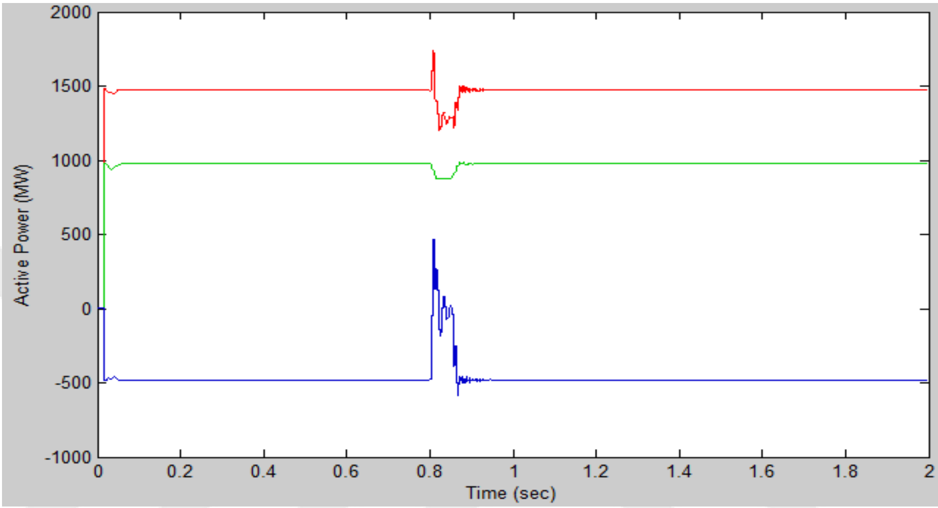

Figure 5.17 (HVAC system): Active power at bus 1-2-3under fault

Figure (5.18) shows the active power (P1, P2) and (P3) in (HVDC) transmission system, where we see the moment of occurrence of fault, and gradually begins descent of the active power (P1) to zero and after the clear of faults at (1.38) sec back to normal situations. It is when we compare figure (5.17) and (5.18) we see that the effect of fault current in the (DC) transmission system is more powerful than the (AC) transmission system. The reason due to the rise of fault current passing in the rectifire system. After the fault, specifically at (1.38) second, the system back to the normal situation as it was before.

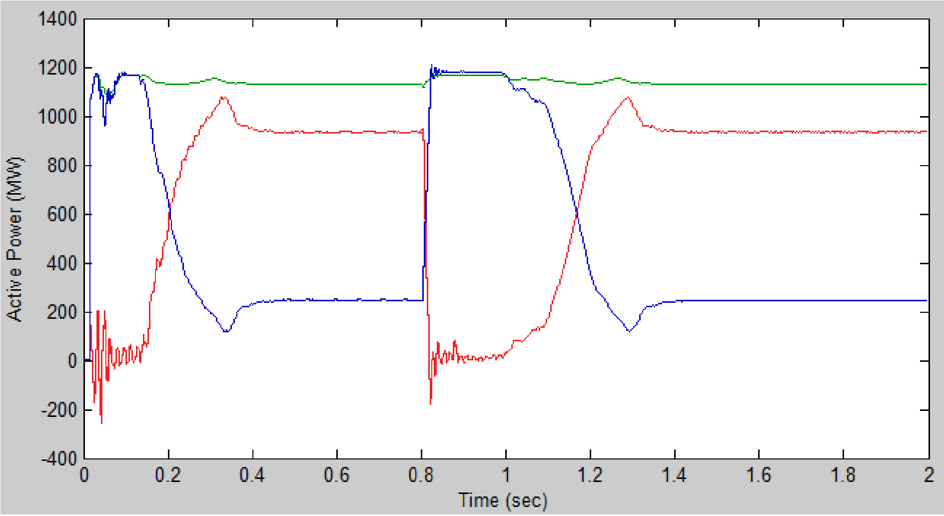

Figure 5.18 (HVDC system): Active power at bus 1-2-3under fault

5.4.2.2: Test of transmission System under Abnormal conditions through (600) Km:

Figure (5.19) shows the terminal voltage at bus 1 and 2 in (HVAC) system. It can be seen that before the fault, the (V1) at bus was 1.079 p.u. During the fault, the voltage (V1) decreased to 0.955 p.u. And the voltage (V2) decreased to 0.97 p.u. It is clear from this figure when compared to the figure (5.15). We can see the impact of the length of transmission line on the system performance in general. Where the system returns at (1.21) seconds, but in figure (5.15) the system in (0.98) seconds back to a normal situation. This is proof of the distance of the system performance when working as (AC) transmission system for transfer power.

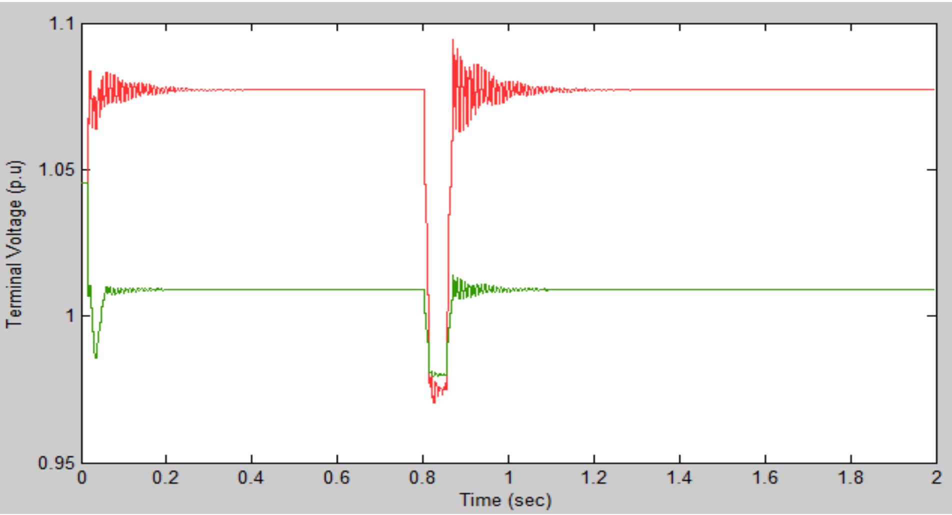

Figure 5.19 (HVAC system): Bus voltage at bus 1-2 under fault

Figure (5.20) shows the terminal voltage at bus 1 and 2 in (HVDC) system. When we see a figure (5.20) and compares to figure(5.16), it can be concluded several important points. First, before the fault occurrence will be the performance of the system in the two cases in different distances, where he works in the same performance. Second, in the moment of the fault and to its end, be the systems work in the same performance at various distances of transmission lines. Finally, we get to that point through the above, features of a (DC) transmission system not constrained the length of line and it does not support it. This is the most important reason to build (HVDC) transmission system to transfer the electric power. Especially for long distances.

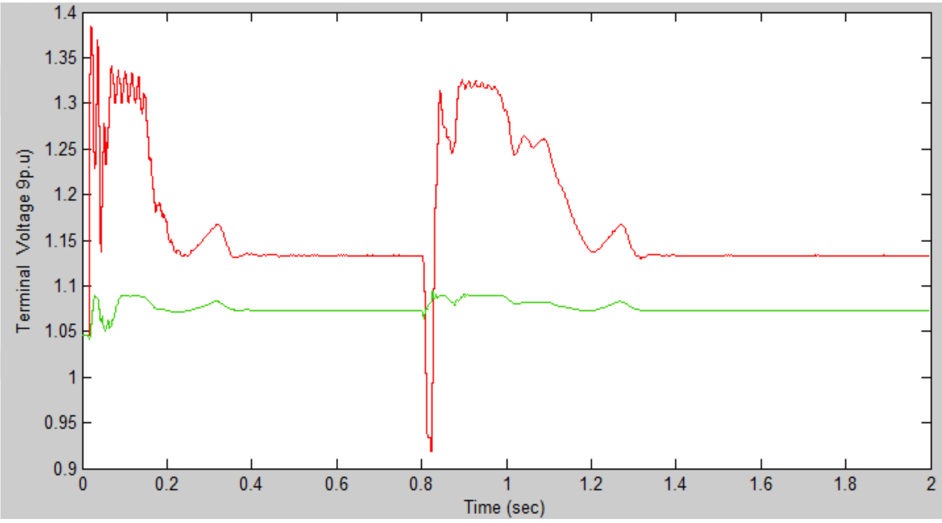

Figure 5.20 (HVDC system): Bus voltage at bus 1-2 under fault

Figure (5.21) shows the active power (P1, P3) generated on bus (1-3) and power delivered to the load (P2). At steady state, P1 about (1146) MW, P2 about (987)MW and P3 (-125)MW. At the time of the fault (0.80 to 0.85) Sec, the active (P1) increased from (1145)MW to about (1385)MW to compensate for the reduction due to fault occurred in transmitted of power. After the fault was cleared, the active power (P1) oscillated between (1385) MW and (985) MW before reaching its pre-fault value of (1145)MW. Therefore, we believe that from figure (5.21) the stability duration of the system is also depends on the transmission line length, especially on the (HVAC) system.

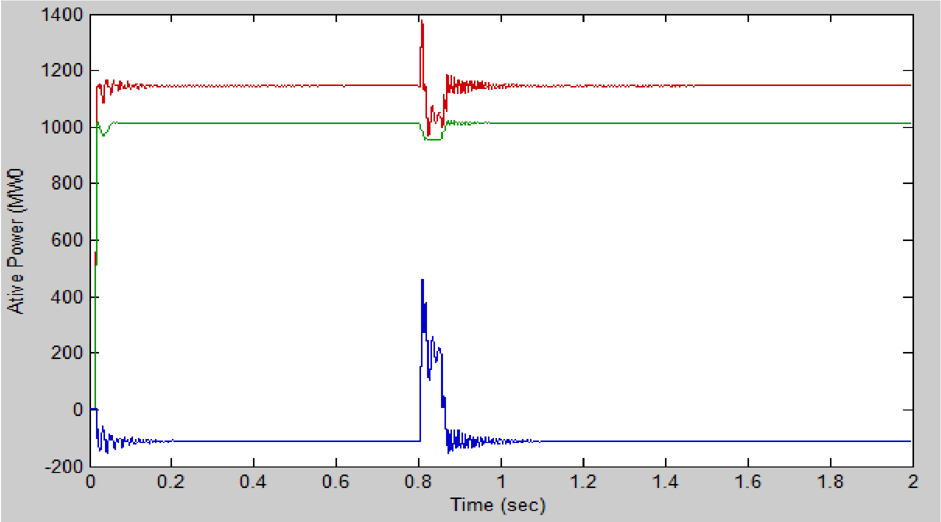

Figure 5.21 (HVAC system): Active power at bus 1-2-3under fault

Figure (5.22) shows the active power (P1, P2) and (P3) in (HVDC) transmission system, in the figure below analysis, we see a slight difference, in this case, when compared to the figure (5.21). For as we know that the distance in the (DC) system does not play a major role affects the performance of the system. In the match figures (5.21) and (5.22). We see that the active power (P2) stabilized at 1132 MW, and active power (P2) in figure (5.21) stabilized at 1131 MW. Also, both (P1) and (P3) in two cases are almost has the rounded values. The recent observation that can be monitored, the stability time of the system, differ very mild when compared.

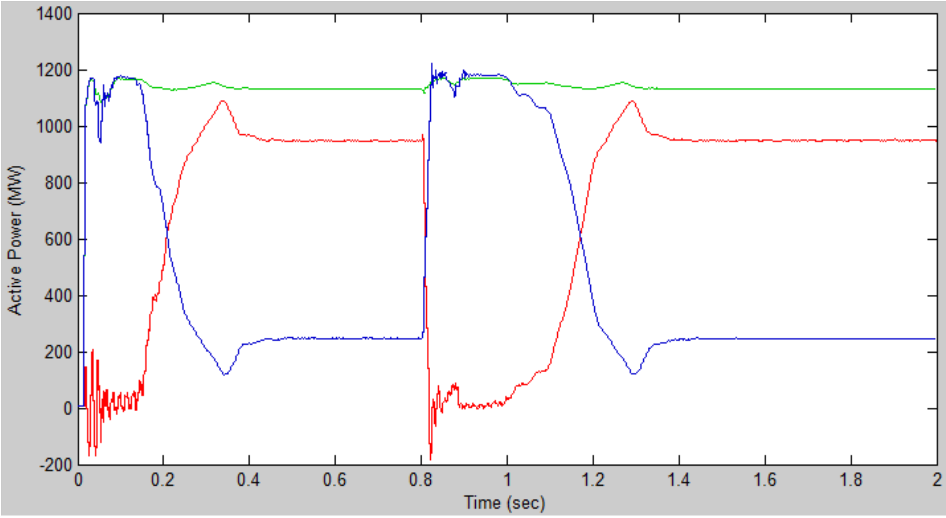

Figure 5.22 (HVDC system): Active power at bus 1-2-3under fault

5.4.2.3: Test of transmission System under Abnormal conditions through (1200) Km:

Figure (5.23) shows the terminal voltage (V1) and (V2) at bus 1 and 2 in (HVAC) system. Where we see the shape of a large fluctuation in the system operation at the beginning, until (0.58) Sec. This is clear to us from the effect of line length on the performance of the system. After occurrence the fault at a time (0.80 to 0.85) second, where the fading influence of fault quickly and precisely at (1.18) second. At the end of the conclusion we see the effect more on the (V1) comparing (V2). The reason is due to the site of the occurrence of faults as well as the length of the transmission lines.

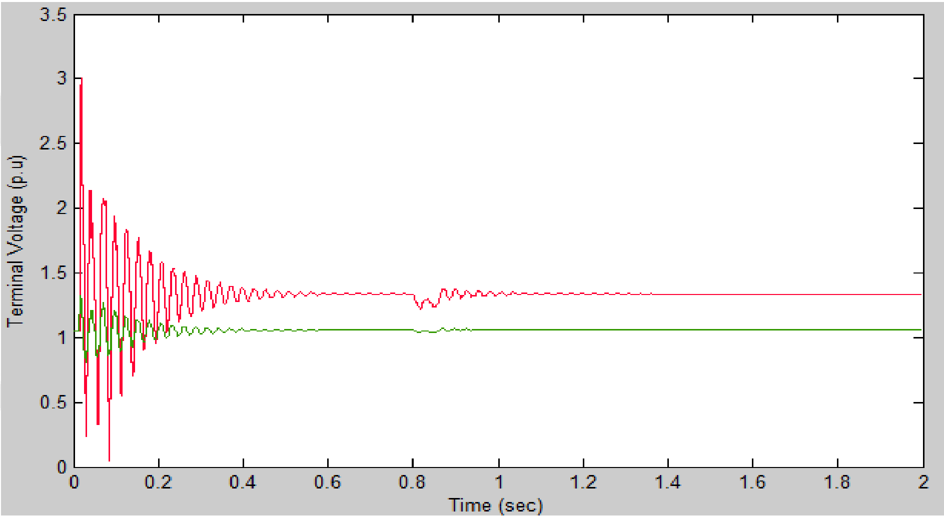

Figure 5.23 (HVAC system): Bus voltage at bus 1-2 under fault

Figure (5.24) shows the terminal voltage (V1) and (V2) at bus 1 and 2 in (HVDC) system under abnormal condition. Where we see the figure (5.24), that show us the voltage (V1) and (V2) values shown in table (5.12), the voltage variations between two sides of sending and receiving be comparable to each other in terms of values in all distances in (HVDC) transmission system. All this has been previously described in different cases under different distances along the transmission system. At the moment of faults, start the voltage (V1) descent gradually to a lower value, and up to almost (0.90) p.u. After clearing the faults, stays the voltage (V1) rise to (1.32) p.u and the gradually after (1.38) second back to a normal state that it was before the fault occurrence.

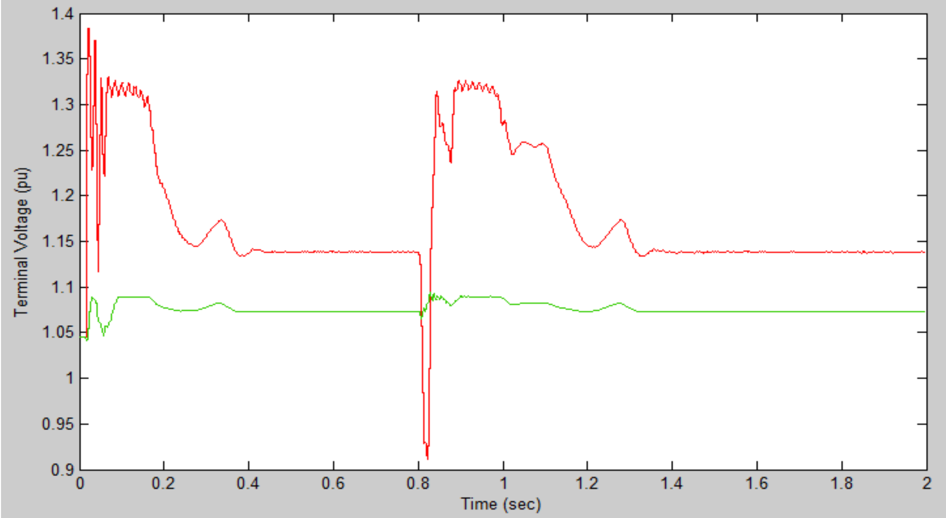

Figure 5.24 (HVDC system): Bus voltage at bus 1-2 under fault

Figure (5.25) shows the active power (P1, P3) generated on bus (1,3) and power delivered to the load (P2) in (HVAC) under fault conditions. At steady state active power (P2) is (1119) MW, (P1) about (1176) MW and (P3) about (19.4) MW. At the moment of occurrence the faults, increasing the power to higher values, as shown in the figure above. When comparing the values as illustrated in a table number (5.8), (5.9) and (5.10). Clearly sees the differences in the power losses in the system, which in turn respect to the transmission line length of the system in general. From this conclude that the power losses are directly proportional to the length of the transmission system.

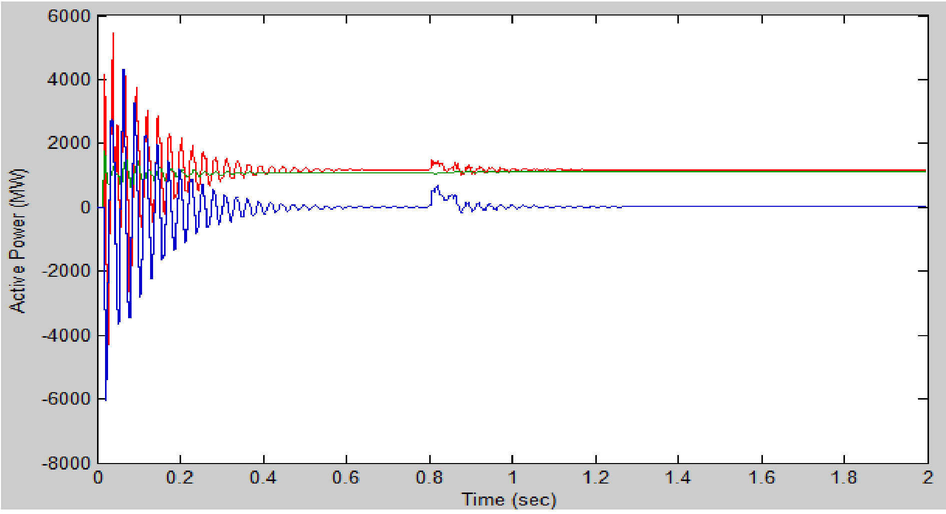

Figure 5.25 (HVAC system): Active power at bus 1-2-3under fault

Figure (5.26) shows the active power (P1, P2) and (P3) in (HVDC) transmission system under abnormal operation, when we compare the previous cases, we can see that the difference in the power generated and load power the values is not great at all distance transmission line, when the length of line (300) km, (P1) = (955.9) MW. In the 600 km, (P1) = (963.6) MW. And last resort in this case (P1) = (994.9) MW. This shows that the effect of the length of the transmission line slightly on the proportion of power loss of the entire system. Thus the preferred choice of things (DC) system on the (AC) system for transmission electrical power in the distal distances.

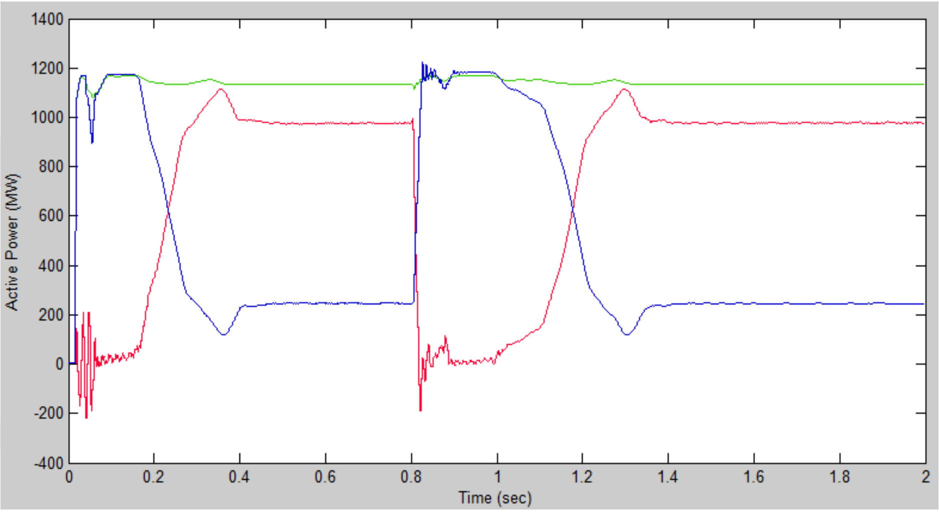

Figure 5.26 (HVDC system): Active power at bus 1-2-3under fault

The following table number (5.8), (5.9) and (5.10) shows a summary of the results of all cases that have been studied with different distance in an HVAC transmission system under normal conditions, when changing the distance of transmission line, from this table we conclude the following shows from the tables below:

Table 5.8 Voltage Profiles and Active Power in (HVAC) System at (300) km

No of Bus	Bus Voltage Per unit	Active power MW
1	0.998	1475
2	0.987	976.4
3	0.987	-481.5

Table 5.9 Voltage Profiles and Active Power in (HVAC) System at (600) km.

No of Bus	Bus Voltage Per unit	Active power MW
1	1.079	1145
2	1.009	1014
3	1.009	-111.5

Table 5.10 Voltage Profiles and Active Power in (HVAC) System at (1200) km.

No of Bus	Bus Voltage (p.u)	Active power MW
1	1.36	1272
2	1.08	1160
3	1.08	-2.04

The following table number (5.11), (5.12), (5.13) and (5.14) shows a summary of the results of all cases that have been studied with different distance in an HVDC transmission system under normal conditions, when changing the distance of transmission line, from these tables we conclude the following shows from the tables below:

Table 5.11 Voltage Profiles and Active Power in (HVDC) System at (300) km.

No of Bus	Bus Voltage Per unit	Active power MW
1	1.112	955.9
2	1.073	1131
3	1.073	226.2

Table 5.12 Voltage Profiles and Active Power in (HVDC) System at (600) km.

No of Bus	Bus Voltage Per unit	Active power MW
1	1.113	963.6
2	1.070	1132
3	1.070	229

Table 5.13 Voltage Profiles and Active Power in (HVDC) System at (1200) km.

No of Bus	Bus Voltage Per unit	Active power MW
1	1.114	994.9
2	1.068	1132
3	1.068	227.7

Table 5.14 Comparison between HVAC and HVDC Voltage Variations

Transmission model	300 (KM)	600 (KM)	1200 (KM)
HVAC system	0.011	0.072	0.33
HVDC system	0.038	0.043	0.0505

The following table number (5.15), (5.16) and (5.17) shows a summary of comparing between HVAC and HVDC, when changing the distance of transmission line from (300 to 1200) km, under normal conditions, in order to calculate the power losses of the transmission system in both (HVAC) and (HVDC), they are shown from the tables below:

Table 5.15 comparisons between HVAC and HVDC in normal case at (300) km.

Transmission model	P1 (MW)	P2 (MW)	P3 (MW)	Power losses (MW)
HVAC system	1475	976.4	-481.5	17.1
HVDC system	955.9	1131	226.2	41.1

Table 5.16 comparisons between HVAC and HVDC in normal case at (600) km

Transmission model	P1 (MW)	P2 (MW)	P3 (MW)	Power losses (MW)
HVAC system	1145	1014	-111.5	19.5
HVDC system	963.6	1132	229	60.4

Table 5.17 comparisons between HVAC and HVDC in normal case at (1200) km

Transmission model	P1 (MW)	P2 (MW)	P3 (MW)	Power losses (MW)
HVAC system	1272	1160	-2.04	114.04
HVDC system	994.9	1132	227.7	80.6

As mentioned previously, through studying and explaining the cases, for different types of tests and all tables. A figures as explained below, by flow charts (1) and (2), to prove the difference between both systems. The first one shows the percentage of power losses.

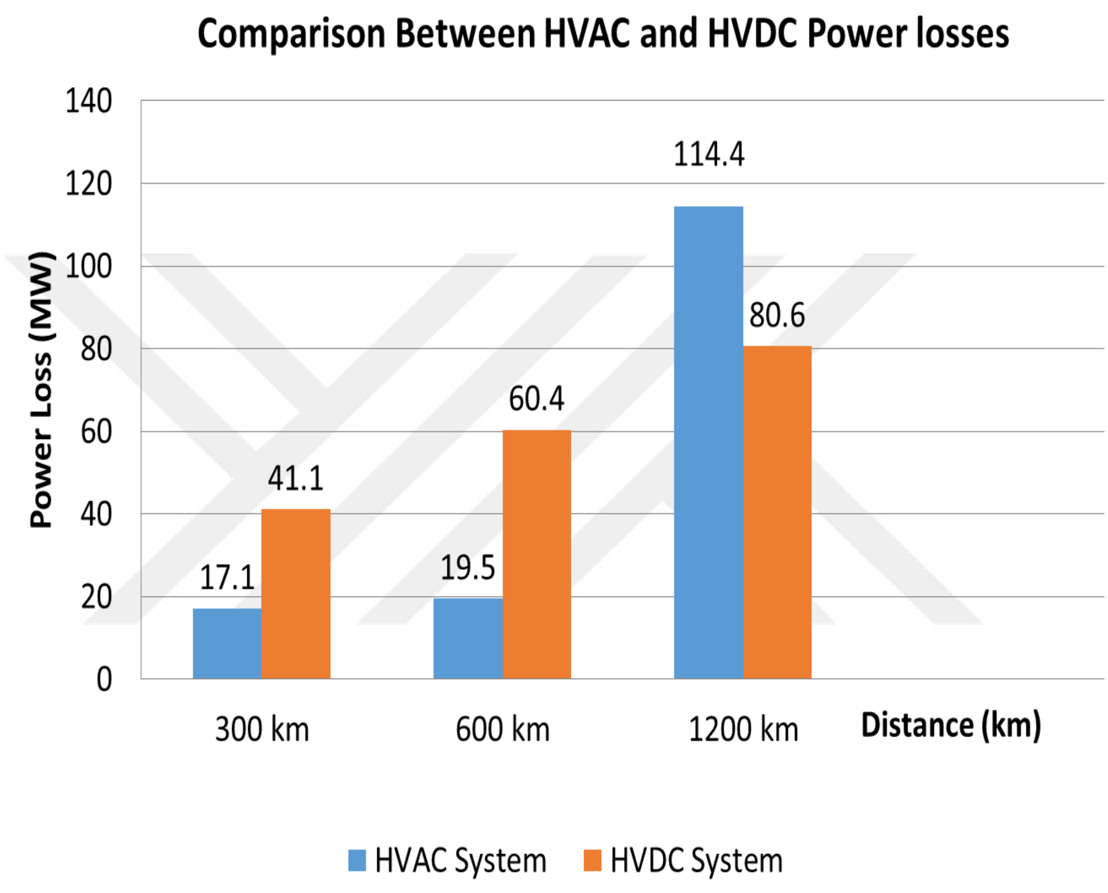

Figure 5.27 Comparison between HVAC and HVDC

And the second one, shows the voltage variation from (200 to 1200) km. As shown in the figure below:

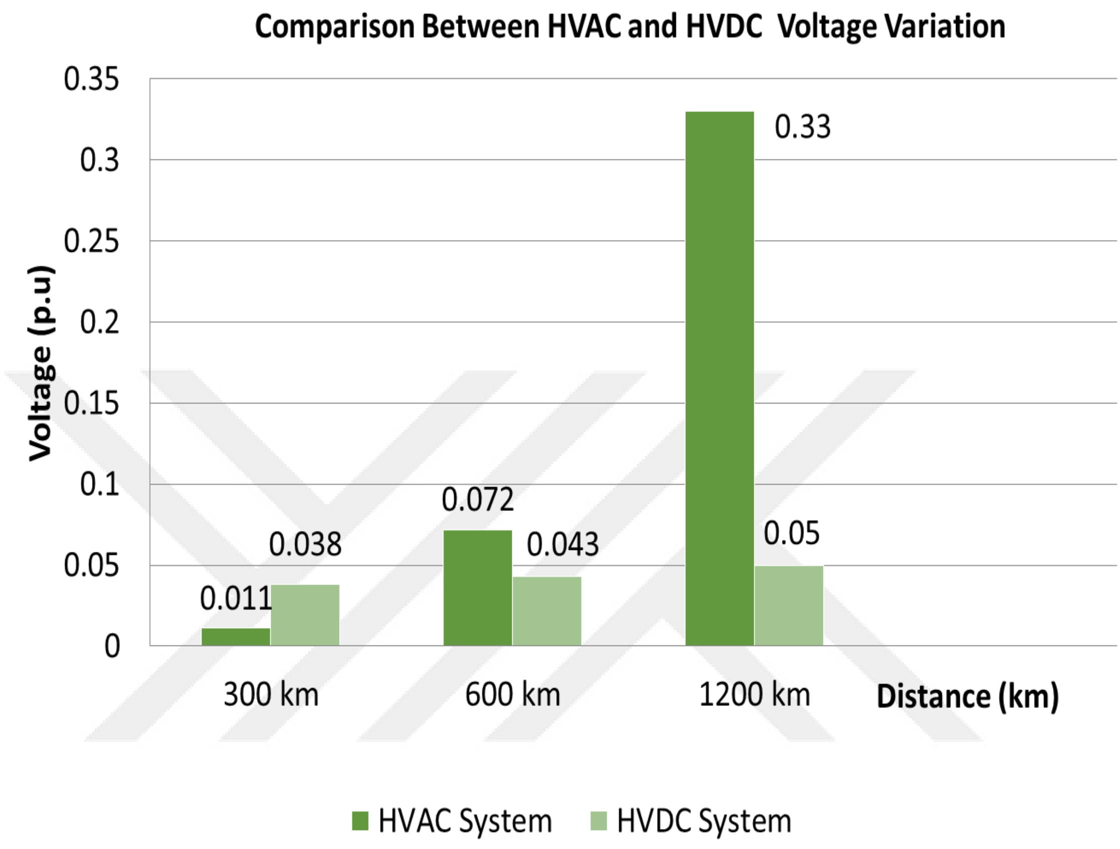

Figure 5.28 Comparison between HVAC and HVDC

CHAPTER 6
CONCLUSION AND SUGGESTIONS FOR FUTURE WORK

6.1 CONCLUSION

Long distances are technically unreachable by HVAC line without intermediate reactive compensations. The frequency and the intermediate reactive components cause stability problems in the AC line. On the other hand HVDC transmission does not have the stability problem because of absence of the frequency, and thus, no distance limitation. The cost per unit length of an HVDC line lower than that of an HVAC line of the same power capability and comparable reliability, This thesis shows a comparison between HVAC and HVDC power transmission system and calculate the transmission power losses. Also calculate and compare bus voltage variations between both transmission systems. This is done under normal and abnormal conditions to apply ‘Single line to ground’ fault at the midsection or the midpoint of the transmission line for both HVAC and HVDC systems. For better analysis and comparison, both simulation environments are kept same and the length varying from (300 to 1200) Km.

At the end of thesis reached to several important points, by highlighting and focus on the work from the first, study the effects of varying the distance in the both systems and the comparison between them. And second one applies the faults and study their effects. Through all the tests to conclude from these are summarized below:

1. The AC transmission system performs better in the short and medium distances, since the power losses are less than the DC transmission system.

2. The bus voltage variations in the DC transmission system, is less than AC system and more stable when compared to the AC transmission system.

3. The power losses in the AC transmission system, is more when compared with DC system, especially in the long distances, as shown by figures and table (5.15) (5.16) and (5.17).

4. Effect of transmission length is more significant on the AC transmission system when Compared to the DC transmission system. This is because in the DC system, the length of transmission line is not limited.

5. The impact of conversion systems from DC to AC and vice versa. It is very Effectively at increases the power losses in the DC transmission system.

6.2 Suggestions for Future Work

1. Study the impacts of fault current and voltage terminal for all types of symmetric, asymmetric faults in different sections (sending end, receiving end, and transmission line) can be analyzed.
2. Study and comparison of HVAC and HVDC transmission systems in economic terms and the effects of environmental factors on systems in the future.
3. Simulation model to enhance the stability of power system in HVDC and HVAC transmission systems using another designed and comparison between them and focus on the efficiency and performance of the systems.
4. Application and use of (VSC) and (CSC) in HVDC conversion, and the difference between them with the HVAC transmission system.

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APPENDIX - A

Table (A) Loads Profiles of the transmission system

Transmission model	Load 1 (MW)	Load 2 (MW)	Load 3 (MW)
HVAC system	100	500	500
HVDC system	100	500	500

Fault type and time duration to apply for investigation the process:

1- AC Fault on HVAC transmission line (single to ground faults).
2- DC fault on HVDC transmission line (Pole to ground faults).
3- The time period of fault occurred is from (0.8 to 0.85) seconds.

Power losses and bus voltage variation calculation procedures:

1- P losses = P sends – P receiving.
2- P sending = P1 and P3.
3- P loads = receiving power.
4- V drop = V sends – V receivers.

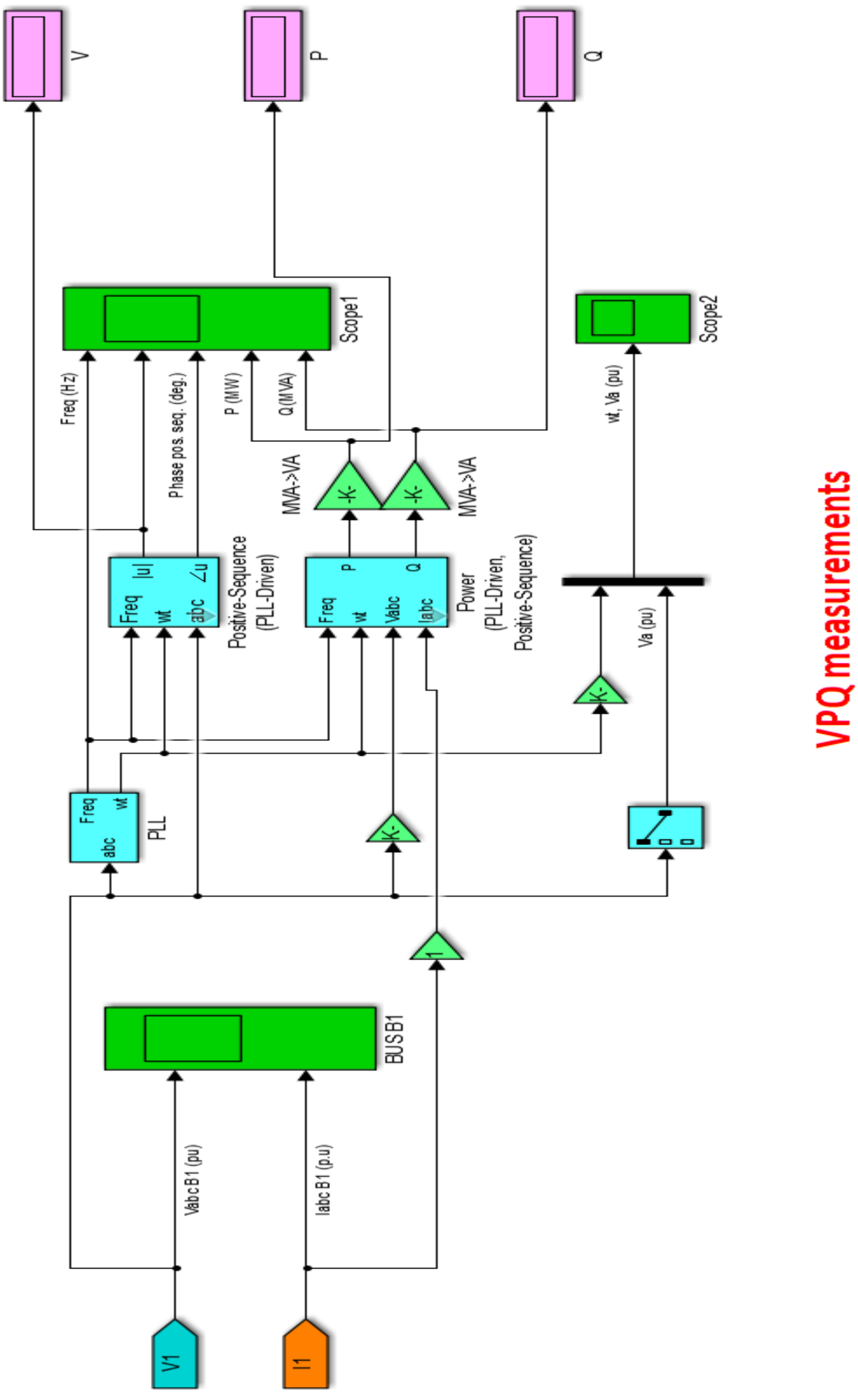

Figure A-1 Under Mask Block of PVQ measurement

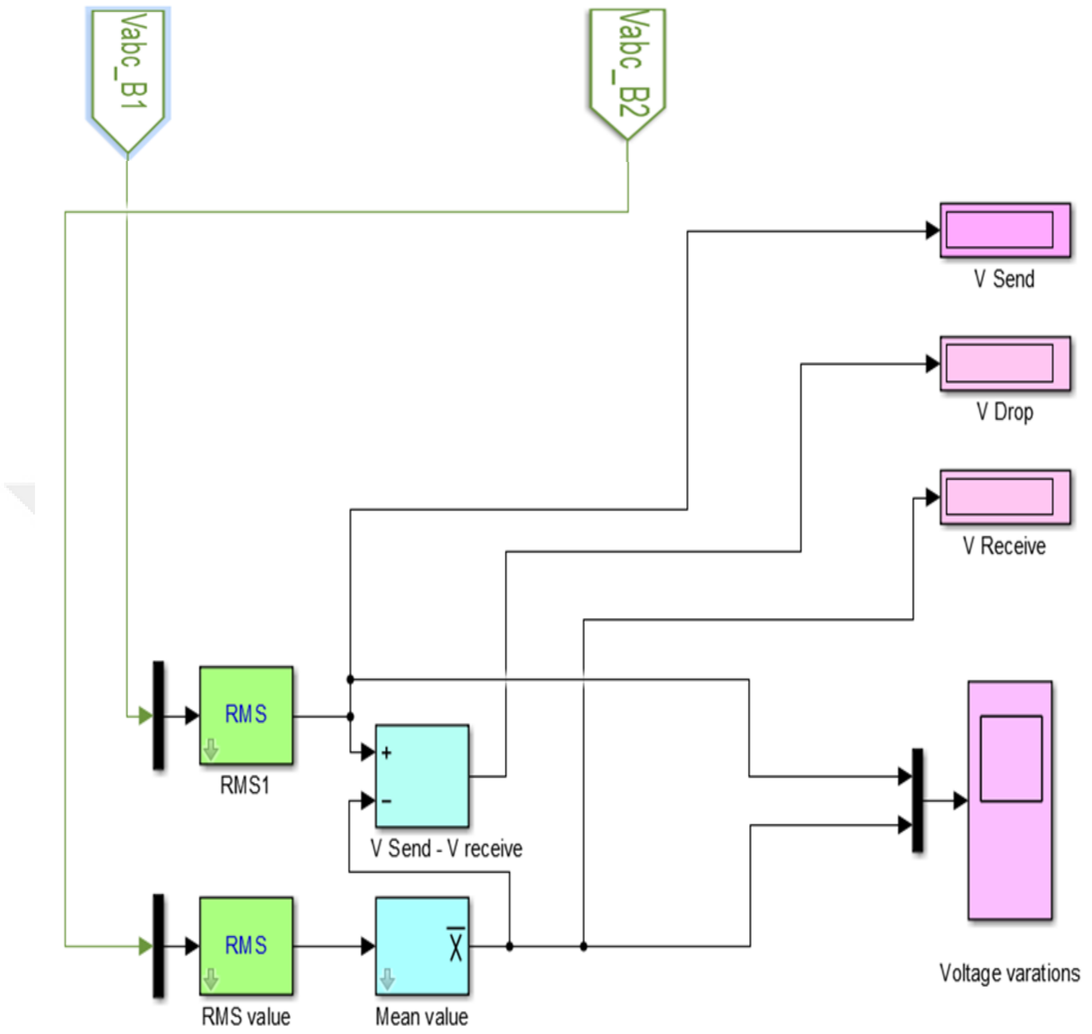

Figure A-2 Under Mask Block of Voltage variation calculations

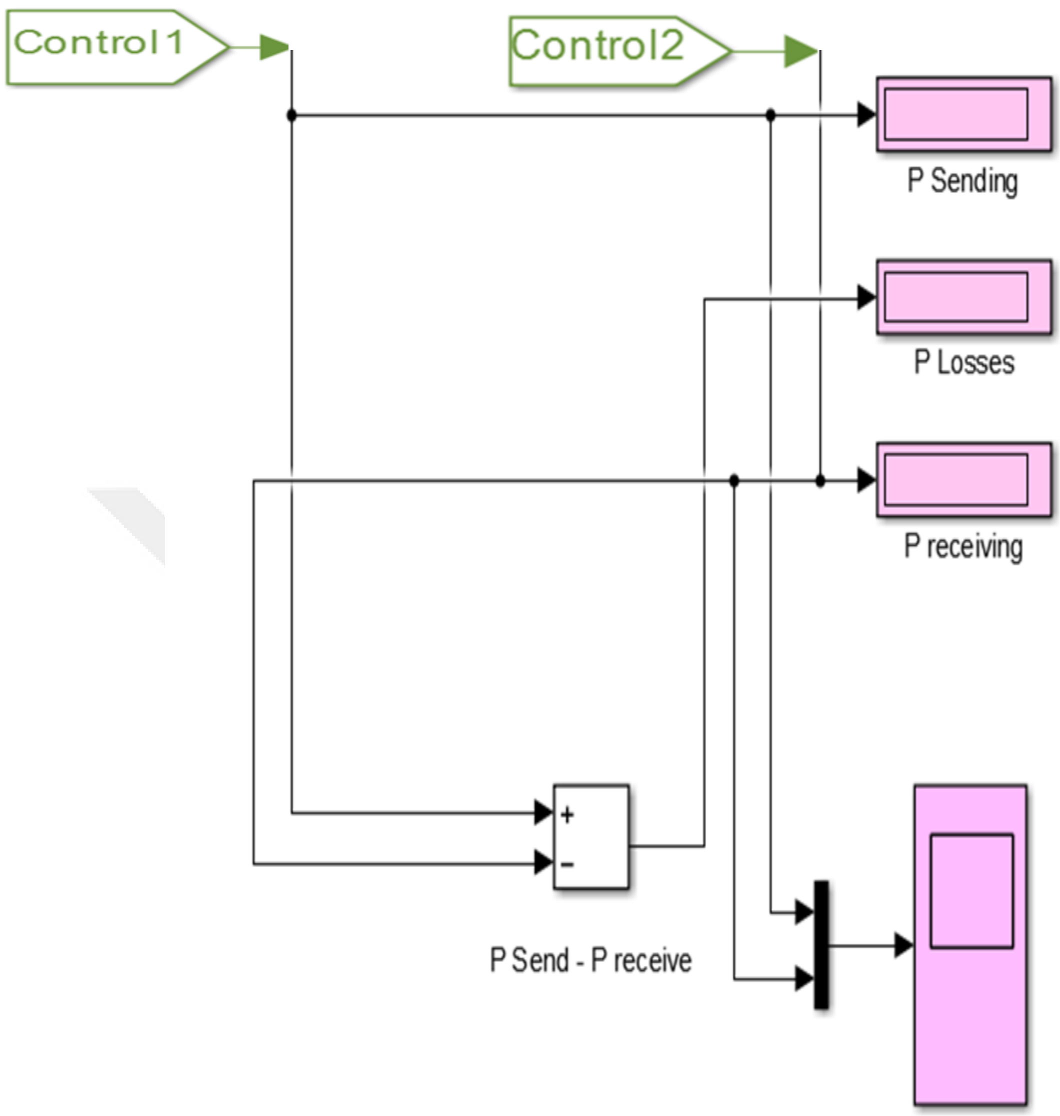

Figure A-3 Block Diagram of power loss measurement