COMPARATIVE STUDY OF HIGH VOLTAGE DIRECT CURRENT AND HIGH VOLTAGE ALTERNATING CURRENT FOR POWER TRANSMISSION SYSTEM IN MALAYSIA

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A project report submitted in partial fulfillment of the requirements for the award of

Master of Engineering (Electrical)

Lee Kong Chian Faculty of Engineering and Science

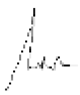
University Tunku Abdul Rahman

15 March 2023

DECLARATION

I hereby state that every aspect of this project report, with the exception of quotations and sources that have been properly recognized, is my own original work. I further declare that it has not been submitted for any other degree or award at UTAR or other universities in the past or concurrently.

Signature:



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ABSTRACT

COMPARATIVE STUDY OF HVDC AND HVAC FOR POWER TRANSMISSION SYSTEM IN MALAYSIA

Chandra Kumar Ponmudi

A high Voltage Direct Current (HVDC) power system is used for direct current transmission of bulk power over long distances. By comparison to AC transmission lines, HVDC lines are more economical and efficient. HVDC has been used for interconnections between AC networks that have different frequencies. Over the past 100 years, AC transmission is more popular and well developed due to the easier and cheaper voltage conversion technology by using transformer. Voltage conversion of DC current is more complicated and expensive. As the technologies and engineer solution for dc transmission is getting mature, HVDC power transmission system is getting popular and widely used especially for super high voltage transmission over extremely long distance. The recent form of HVDC transmission uses expertise established comprehensively in 1930s in Sweden and in Germany. Initial profit-making systems comprised one in the Soviet Union in 1951 between Moscow and Kashira, and a 100kV, 20MW system between Gotland and mainland Sweden in 1954. Earlier to the Chinese project of 2019, the extensive HVDC connection in the world was the Rio Madeira link in Brazil, which consists of two bipoles of 600kV, 3150MW each, linking Porto Velho in the state of Rondônia to the Sao Paulo area with a distance of more than 2,500km. The purpose of this study is to discuss what HVDC is, how HVDC can be integrated with today's power transmission system, methods, and solutions of integration of HVDC with HVAC transmission system, the advantages of application of HVDC over HVAC and current application of HVDC in Malaysia.

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CHAPTER 1

INTRODUCTION

This chapter presents the knowledge related with this project, problem statement, and project objective.

1.1 Project Background

The existing global distribution system configuration can no longer sustain consumer's requirements for energy consumption and environmental safety such as power supply consistency and quality in distribution services. This is due to dispersed generation access, changes in domestic application and electricity methods, the acceptance of electric automobiles, and the increase of well-regulated load. These requirements will lead to ongoing changes in the outline of the outdated distribution network. Alternatively, DC power sharing network as a substitute for AC power supply network brings benefits in terms of control, configure and transmission capacity. HVDC have the capacity to moderate power and operational loss at the same time maintains high reliability (Hafeez and Khan, 2019).

Energy is crucial for a nation's ability to thrive economically without falling into poverty. Electricity can be produced using natural energy sources such oil, coal, gas, wind, sun, and hydropower. These resources typically exist far from urban areas. As a result, it has been discovered that high voltage transmission lines (HVTLs) can effectively carry electric power across vast distances from the generation station to the customer. High phase order (HPO), high voltage direct current (HVDC), high voltage alternating current (HVAC), extra high voltage alternating current (EHVAC) and composite AC/DC transmission lines are the numerous types of electric power conduction systems.

Traditionally, the components of the electric power system that are concerned are generation, transmission, and distribution. The primary purpose of the generation activity is to produce or transform energy resources into electric power. Electricity is transferred during transmission operations from the generation location to the supply station. Next, the supply process focuses on getting the electricity to the end users. Direct current (DC) waveforms are initially used for the generation, transmission, and distribution of electricity. DC creates the first electric power transmission cable. In the subject of DC, the essential ideas of Ohm, Ampere, Galvani, Oersted and Volt, were learned.

The first electric central station (DC) in the world was developed and erected in Pearl Street, New York, in 1882 by Thomas Edison (1857–1931). Even though DC existed in the beginning, it was later supplanted by alternating current (AC) for greater purposes. This is because electric technologies like transformers, induction motors, and polyphase circuits became available starting in 1890. For the transmission and induction engine that operated exclusively with AC in the market, the transformer is very simple and straightforward to adjust the voltage level. As a result, AC has significantly benefited both residential and commercial spaces. However, AC has some limitations for long transmission distances, which headed to the usage of DC in power transmission developments.

Over the past few decades, HVAC has emerged as a powerful power transfer technology. HVAC is less important than HVDC in light of the rising need for electricity. Due to the restriction on reactive power, AC power cable are not recommended for usage over lengthy spaces, might result in significant power losses in the transmission system. HVDC, however, eliminates this problem because it is built to send enormous amounts of electrical energy across great spaces with little energy loss. HVDC has conductors that can transport more electricity per unit than HVAC. As a result, pylons and cables have a lower profile, saving money and land.
Further to increase the steadiness and dependability of the system, HVDC can also be applied with varying frequencies between grid systems. It is obvious that HVDC is superior to HVAC because of its useful, financial, and eco-friendly advantages.

A comparison of the HVAC and HVDC transmission systems is done in this project. This study compares and contrasts HVAC and HVDC transmission systems in terms of design concept, component, technology, benefit, and cost. Additionally, this project's main objective is to assess Malaysia's potential for implementing an HVDC conduction structure by examining the eenrgy consumption, method design, costs, and environmental effects.

1.2 Problem Statement

Technically, HVDC is the solution for transmission line and long-distance utilization over existing HVAC system. This come with varies advantages such as lack of transmission line capacitive or reactive charging effects, lower DC transmission losses or costs compared with HVAC. Specifically, HVDC reduced transmission losses, line-resistive losses and eliminating the potential for costly, ultrafast and AC line-reactive compensators (Joseph et al., 2018).

Moreover, DC transmission may be employed for very lengthy transmission spaces of more than 3000 km with fewer cables and conductors and makes full use of the transmission capacity of the lines up to their thermal limits (Langwasser et al., 2021) .This lowers the cross-sectional area required for DC cables and thus, the transmission cost.

However, the high-priced rectifier and inverter stations for AC/DC and DC/AC conversion, which are not required in the HVAC application, greatly increase the overall HVDC transmission cost (Wang et al., 2021). That is, the fixed cost of DC transmission such as stations and equipment. One the other hand, line costs and losses are significantly skewed in favor of DC. As a result, a breakeven distance for both technologies is established, after which DC transmission becomes more cost-effective (Rouzbehi, 2018). HVDC breakeven distance estimates vary, but typical values for overhead lines are between 300 and 800 km, and offshore/underground cable linkages are between 50 and 100 km (Regar, 2019). Based on disclosed project pipelines, operating HVDC capacity has significantly beyond 200 GW as of 2017 and is likely to surpass 400 GW by 2022 (Cheah-Mane et al., 2017). Market demand and technological advancement will determine the future of power system. In term of Conversion of HVAC to DC Operation**,** switching to DC is primarily advantageous in terms of maximizing conductor utilization, boosting transmitted power capacity, and reducing the corona effect (Rouzbehi, 2018). Converting to DC operation required the installation of full-capacity HVDC converter stations on both ends, as well as the alteration of transmission pylon heads and insulators to put up DC requests (Zhang and Kuffel, 2017).

1.3 Project Objectives

The aim of this assignment is:

i. To analyze, examine and define the rightness to initiate HVDC transmission system in Malaysia.

1.4 Chapter Conclusion

This chapter has discussed on the background of HVDC based on the latest researches and problem statements. The project objectives associate with the problem statement is clearly described.

CHAPTER 2
LITERATURE REVIEW

This chapter discuss the reviews on HVAC and HVDC in terms of components, types, transmission of construction, design features, cost of transmission and HVDC and HVDC project in Malaysia.

2.1 History of HVDC

Both HVAC and HVDC lines can be used to transmit substantial amounts of energy. Generally, HVAC has been the primary transmission expertise, owing to the initial progress of AC transformers, which permitted for higher voltage AC transmission over stretched distances with lesser damages, resolving the "War of Currents" between Edison and Tesla in Tesla's favour (Chetty, 2011). Nevertheless, the subsequent discovery of mercury arc valves and well-known acceptance by the 1930s prepared the path for DC to come back to transmission business, as they enabled for higher DC voltages to be transferred (Hafeez and Khan, 2019).
After years of testing, ABB developed the first viable HVDC link in Sweden in 1954. The Gotland 1 link was 98 kilometres long and carried 20MW at 100 kV (Cheng, 2021). However, with the introduction of thyristor valves in the 1960s, the use of HVDC transmissionprogressed even further, solving various limitations of its predecessors. The major benefits were reduced thyristor weight and space constraints, as well as improved effectiveness, power concentration and control tractability. As a result, thyristor-based lines rapidly became the dominant HVDC technology .However HVDC marketplace evolution from mercury-arc to thyristor switchingvalves is not much discussed by author Xue and Yang in his book (Xue and Yang, 2018). Thereare huge gaps between introduction of thyristor in 1960s and latest development of HVDC (Cheng, 2021). These gaps encourage more research and development on HVDC transmission system especially in Malaysia.

On the other side of coin, Insulated-Gate Bipolar Transistor (IGBT) valves were developed in the 1980s (Xue and Yang, 2018), and they were presented to the HVDC industry by the late 1990s (Hafeez and Khan, 2019). IGBT valves still widely use in the market and providing the necessary support to HVDC system and contributing to the advancement of HVDC as one of the most reliable method in Malaysia.

2.2 Introduction of HVAC Transmission System

Power plants and other types of generating stations produce electrical power, which is then transmitted through a convoluted system made up of transformers, transmission lines, and energy substations. Transmission networks connect electricity generating stations to electricity substations, and electric power distribution networks connect substations to consumers. In order to deliver AC electricity to more consumers, it is also connected to numerous generators. The traditional power system is depicted in Figure 2.1 as consisting of a producing station, transmission lines, a step-up and step –down transformer.

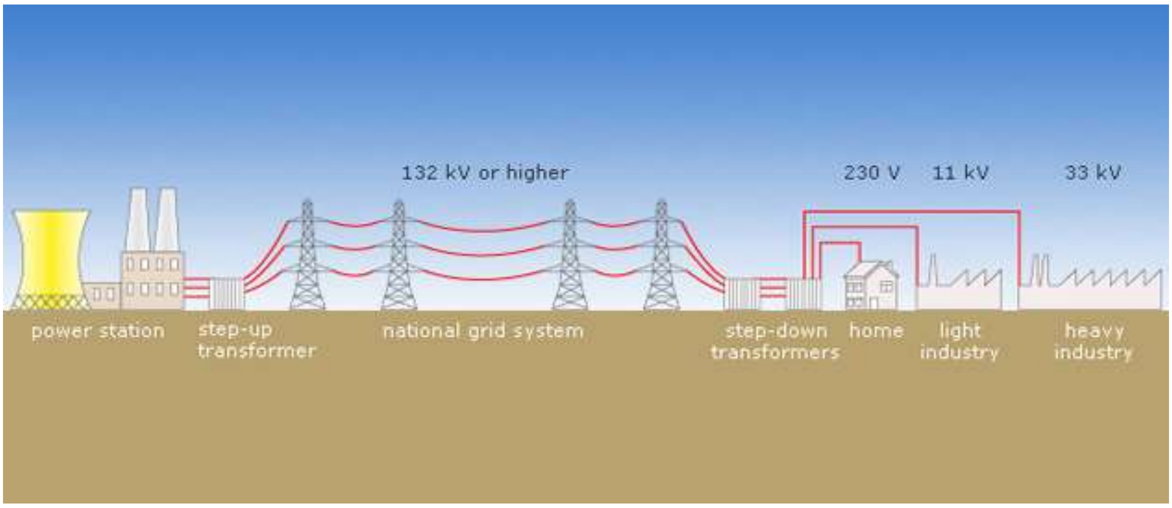

Figure 2.1: Power Structure of Electrical system.

Transmission of power utilizing AC was very common in the early days of the electric power industry. This is because AC electricity can convert low voltages to high voltages with ease. In addition to offering greater power transmission through a conductor, increased voltages have decreased power losses than low voltages. High voltages can, however, result in certain induction losses. The electromagnetic field produced surrounding the wire is greater at higher voltages. More wires are needed to fix this.

The transmission and distribution components of the HVAC system are involved. The model of the HVAC transmission system is shown in Figure 2.2.It is shown increased up to 132 kV and then decreased to 230V. 230V is finally delivered to the residential area. Transformers can alter the voltage when the capacitors and inductors AC waveforms are in phase. It may result in power losses and poorer efficiency in the transmission system if the current is impacted by inductance and varying loads.

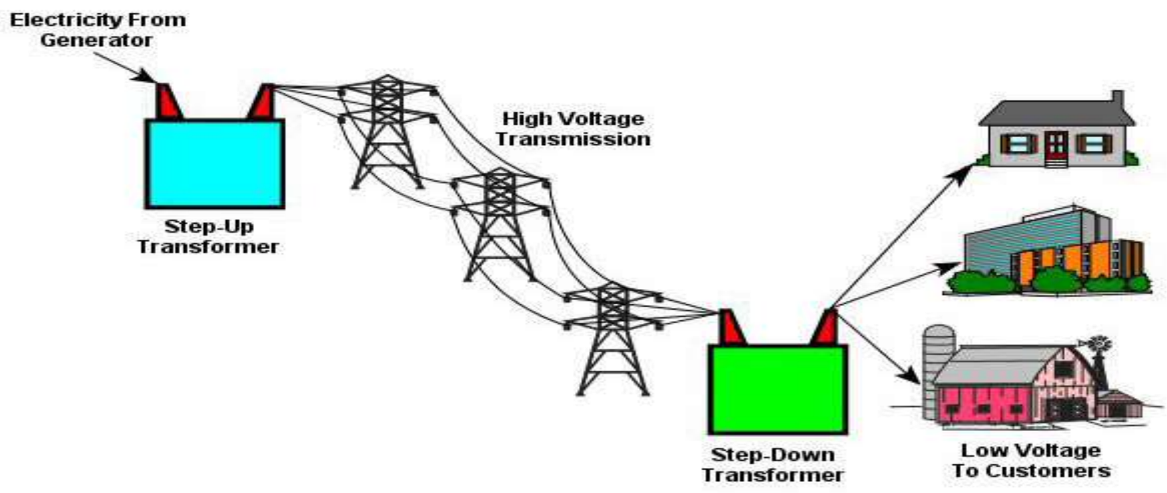

Figure 2.2: Transmission System of HVAC

AC Substation components such as transformer shunt capacitor banks, bus bars, voltages controllers, switchgear, cables, lightning arrestors and cables are illustrated in Figure 2.3.

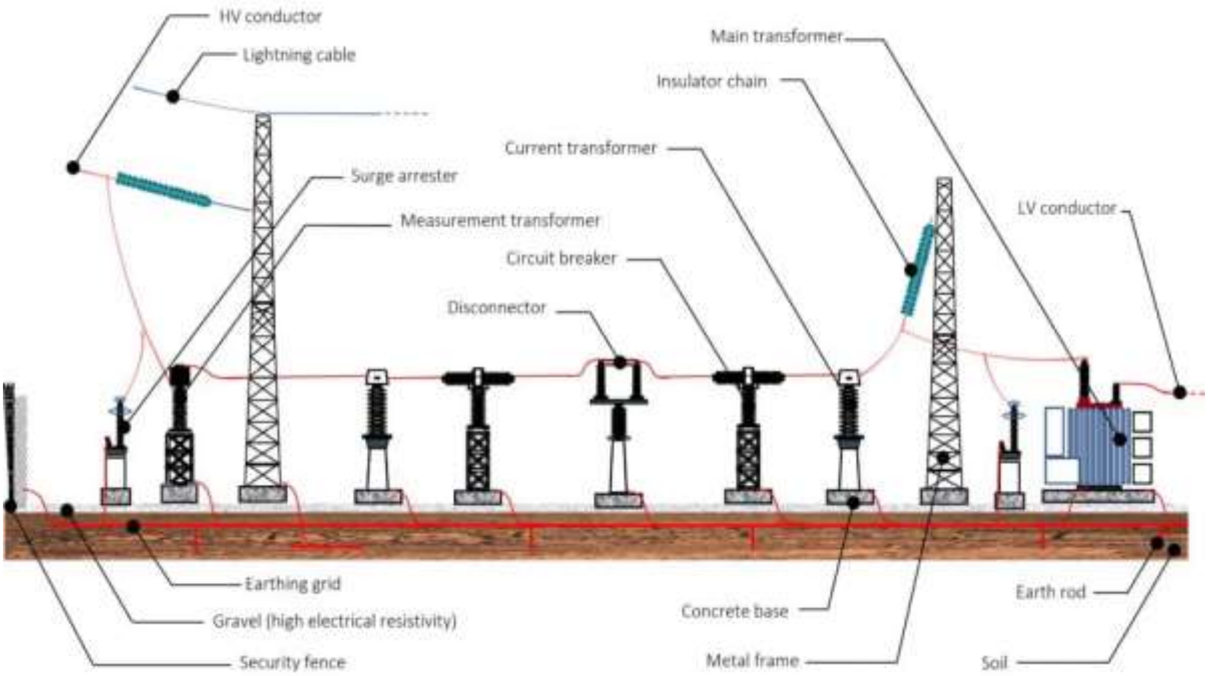

Figure 2.3: AC Substation Components

2.3 Introduction of HVDC Transmission System

The benefits of HVDC technology have been further realized since it has characteristic which make it especially attractive in certain transmission applications. The number of HVDC project committed or under consideration globally has increased in recent years reflecting a renewed interest in this field proven technology. New HVDC converter designs and improvements in conventional HVDC design have contributed to this HVDC for transmission networks.

2.4 Components of HVDC

The HVDC system primarily employs DC power and is capable of doing so between unsynchronized AC systems. As a result, the HVDC transmission system is separated into three basic components: transmission lines; a converter station for converting AC to DC (rectifier); and a second converter station for converting DC to AC again (inverter). A HVDC transmission system's design must take into account a number of crucial factors. The converter, reactive power sources, harmonic filters, smoothing reactors, AC breakers electrodes, and DC outlines make up the majority of the system. Figure 2.4 provides an outlines of HVDC transmission system so that the major parts may be seen.

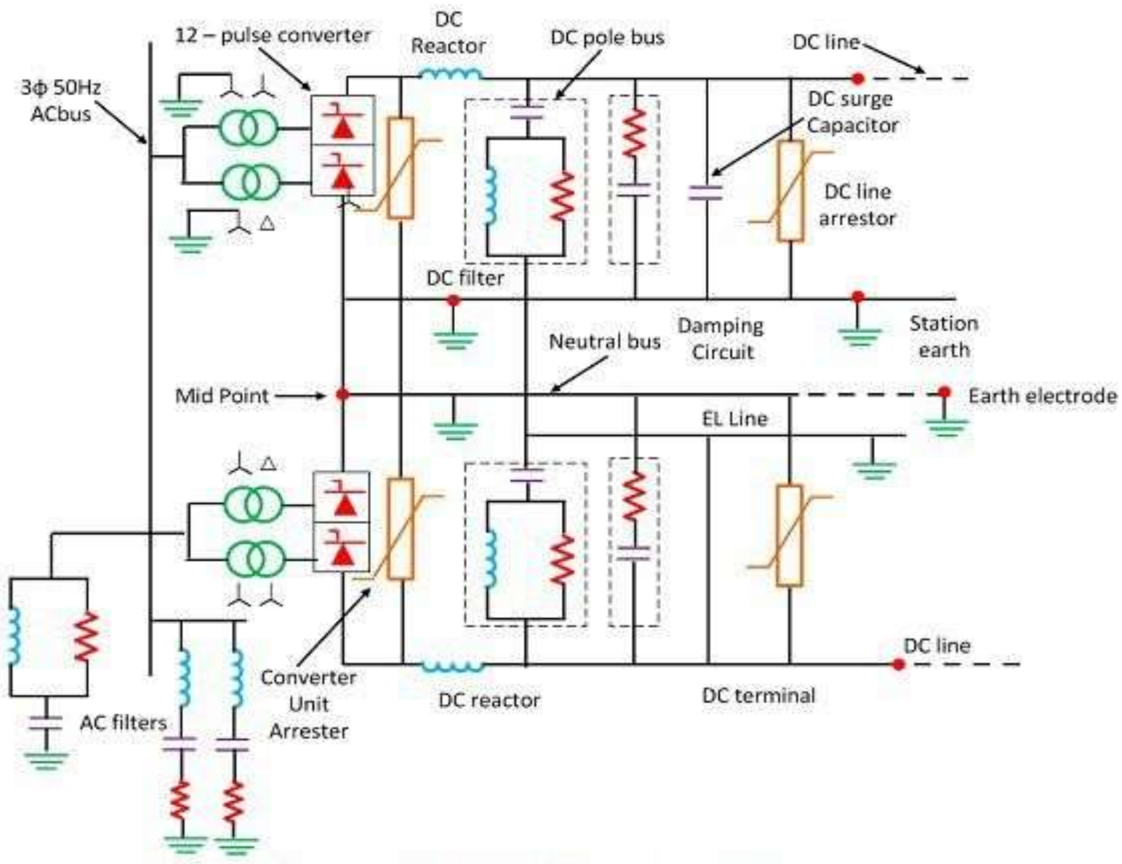

Figure 2.4: Diagram of HVDC Transmission System

2.4.1 Converters

Converters used to adjust power parameters such as current, voltage and frequency. In the HVDC transmission system, the rectifier converter stations, which use thyristor technology, converts AC to DC, and the inverter converter station, which converts DC to AC, are two different converter stations. Transformers and valve bridges were also included in the converters. The valve bridges are interconnected using a 6 or 12 pulse arrangement. Since the transformers are not earthed, the DC system can secure ground as its referral point.

Figure 2.5: HVDC Converter

2.4.2 Smoothing Reactors

Figure 2.6 depicts the HVDC's smoothing reactor. The HVDC smoothing reactor can be built with an oil-insulated core or with an air core. Smoothing reactor and converter are connected in sequence. Smoothing reactors' primary purposes are:

- To reduce DC's ripple currents.
- To reduce the DC line's fault currents.
- To lessen the DC line's harmonic voltage and current.
- To prevent an inverter commutation failure.
- To prevent current interruptions for consumers.

Figure 2.6: HVDC Smoothing Reactors

2.4.3 Harmonic Filters

In general, AC harmonics happen in an AC system, whereas DC harmonics happen in DC lines. The generators and capacitors may overheat as a result of these harmonics. Moreover, disrupt the communication networks. DC and AC filters are implemented in the HVDC system to reduce harmonics. Through the use of AC filters, harmonic frequencies are supplied with low impedances, resulting in AC harmonic currents that pass over the earth. There are altered and hampered filters available. To effectively control the converters, reactive power can also be provided via an AC harmonic filter. The DC filters are used to direct DC harmonics away from DC lines and toward ground. Such a filter doesn't need reactive power, just like a DC line doesn't need it. Figure 2.7 depicts the AC filter's surface area.

Figure 2.7: Harmonic Filter Area of AC

2.4.4 Reactive Power Source

At stable condition, the amount of reactive power needed by converter is about equal to the amount of active power transmitted. During transitory conditions, the reactive power consumption may increase. In addition, shunt capacitors are another source of extra supply.

Figure 2.8: Reactive Power Source

2.4.5 Electrodes

The conductors used to establish a assembly to the earth for neutral are called rods. Reduced current densities and outward voltage gradients are the duties of electrodes.

Figure 2.9: Electrode lines of HVDC

2.4.6 Alternative Circuit Breakers

AC circuit breakers are useful in eliminating transformer problems and preventing the DC links from operating continually. However, a converter can fix a DC issue. The valve hall is normally where the AC circuit breakers are housed, as depicted in Figure 2.10.

Figure 2.10: Alternative Circuit Breakers

2.4.7 Layout of HVDC Transmission System

The configuration of the HVDC transmission system is shown in Figure 2.11. It comprises of a converter building, an AC switchyard, and a DC switchyard. Shunt capacitors are situated next to the AC filters, which are situated close to the AC switchyard.

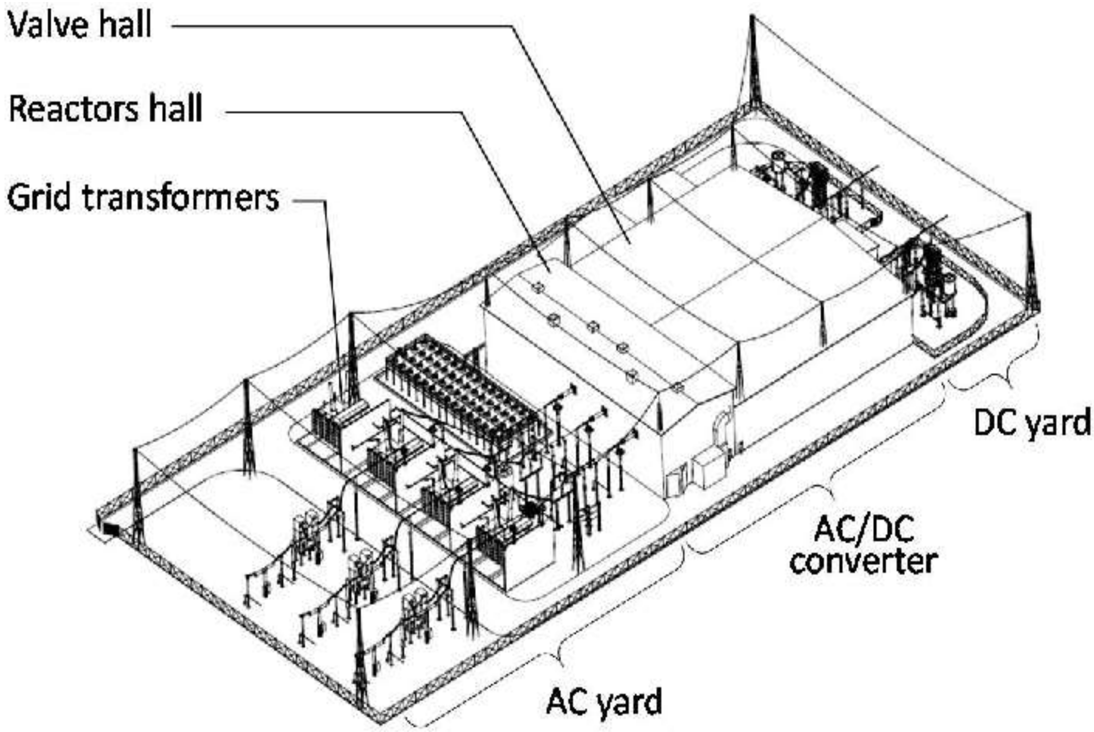

Figure 2.11 HVDC Transmission System Layout

2.5 Types of HVDC Transmission System

The HVDC transmission system in the electric energy industry can be designed in a few different ways to suit the needs of cost, flexibility, and operation. There are various ways to link the HVDC system. HVDC links are classified into several types and each links will be discussed accordingly.

2.5.1 Monopolar HVDC system

A solo pole line is employed in the monopolar HVDC system to divide the two converter stations. The current's path is fully returned by land or sea. Furthermore, the undersea cables for the transmission system can be connected using this monopolar configuration. In Monopolar HVDC system (figure 2.12) single connection of rectifier is joined to earth or grounded. Second connection is joined to a transmission line and without metallic electrode, current flows thru the ground electrodes between two stations. Since one terminal of the converters is connected to earth, the return conductor not required being fully insulated, thus making it less expensive but earth return subject to electrochemical deterioration once buried for long term such as metal pipelines. This link has several drawbacks because it uses earth as return path and not a popular option currently.

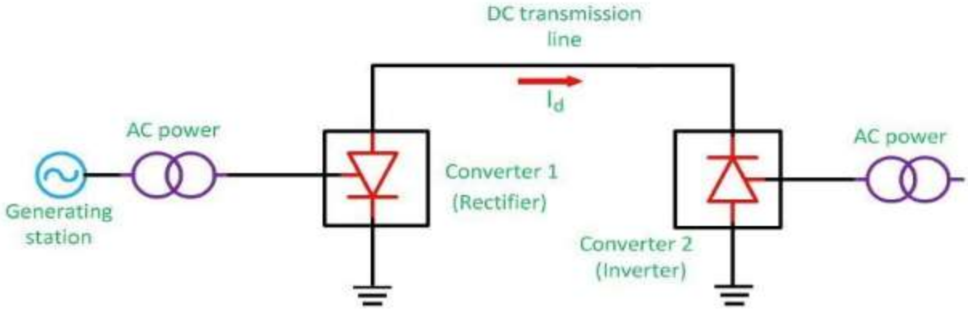

Figure 2.12 Monopolar HVDC system

2.5.2 Bipolar HVDC System

Bipolar HVDC systems are two monopolar systems connected in parallel. Positive and negative conductors make up a bipolar system's two conductors. With the ground return, each system can be operated independently as a single unit. Since one pole is positive and the other is negative, the currents that happened at both poles are identical. As a result, the ground current is either zero or fluctuates by no more than 1%. The most significant advantage of the bipolar links is that if any of their links stop operating, the link is converted into monopolar mode due to the ground return system and still continues to transmit power. One of the obvious disadvantages of this type is that conductors must be fully insulated for full voltage, resulting in higher transmission costing compared to monopolar .Nevertheless bipolar system is the most frequently used in the market.

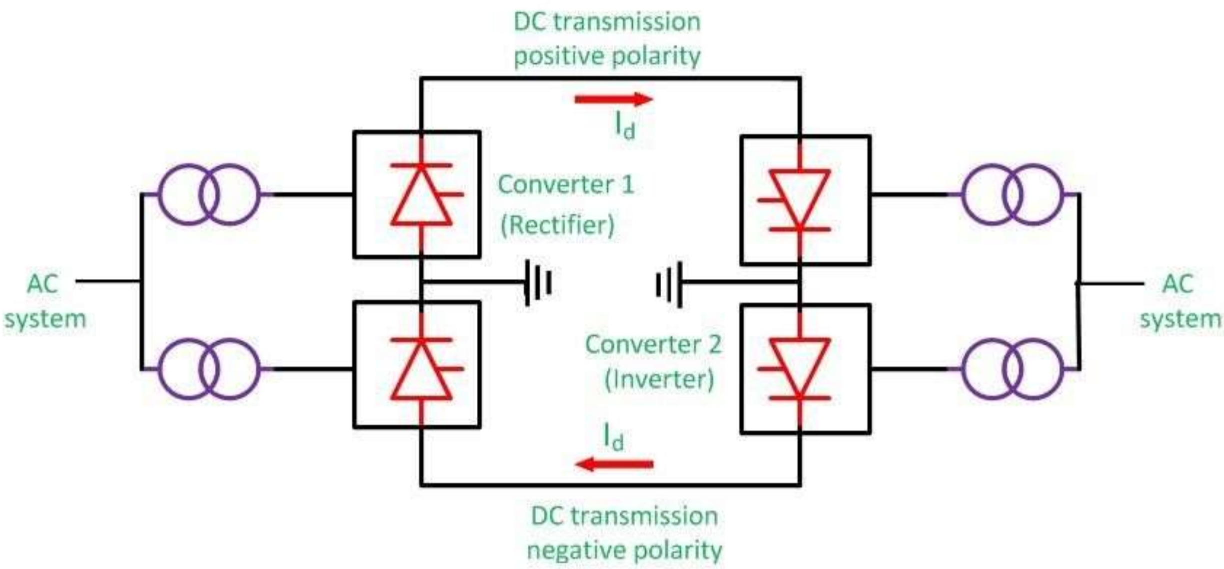

Figure 2.13: Bipolar HVDC System

2.5.4 Back to Back HVDC System

Back to back HVDC system (Figure 2.14) refers to the HVDC system that transfers electricity at the same location that able the interconnection of two asynchronous ac networks. HVDC system takes electrical power in an AC system and convert it into high-voltage DC using a converter station .It than transmits the DC to a remote system and converted back again to AC by next HVDC converter station. The design of the system demonstrated that two converters may be fitted side by side without a lengthy DC line in the power distribution system. Typically, two neighboring asynchronous AC systems are used to connect back-to-back HVDC systems. The frequency range between 50 Hz and 60 Hz is provided by these two connections between AC systems. Back to Back system, improves the voltage regulation, system stability and overall efficiency in the system.

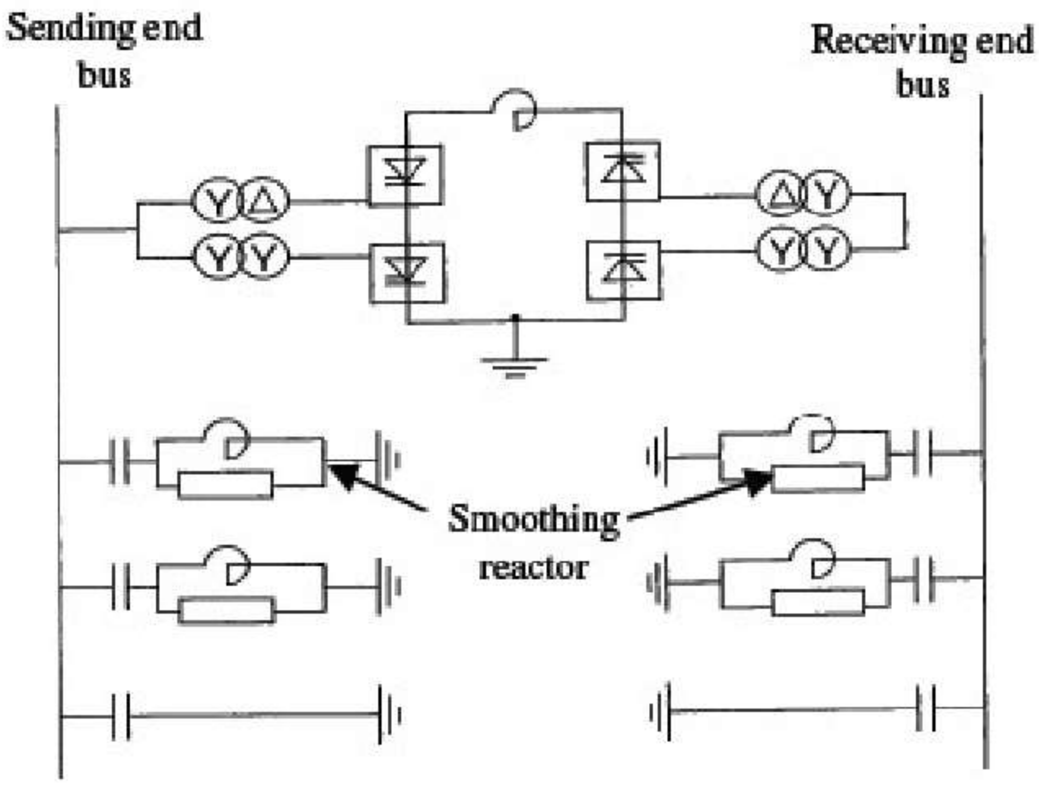

Figure 2.14: Back to Back HVDC System

2.6 Types of Connectors

It consists of both alternative tools used for the HVDC transmission system, depending on converter design. Line Commutated Converter (LCC) and Voltage Source Converter are what they are (VSC).

2.6.1 Line Commutated Converter (LCC)

Mercury valves were the primary component of the HVDC transmission system throughout the early stages of converter technology research. The main problem with mercury-arc technology is an ark-back defect that harmed the converter valve's rectifying ability and consequently led to further problems. In order to solve these issues, a novel thyristor valve technology has been discovered. Line commutated converters are converters with mercury valve bases or thyristor valve bases (LCC). LCC-HVDC converters typically consist of full wave and three phase bridge circuits. Then, in order to do away with similar contacts and reduce the quantity of sequence contacts for thyristors at individually valve, greater current and voltage thyristors are produced (Toledo, P. F. D., 2003). In addition, there are no LCC-HVDC linkages useful to converters on offshore substations, and the majority of LCC-HVDC links utilise undersea cables. The LCC-HVDC transmission system includes, as illustrated in Figure 2.15, thyristor valves, AC and DC filters, capacitor banks, smoothing reactors, converter transformers, DC cables, and secondary control sets. Since the LCC-HVDC technology has been so effective, there are high hopes for it to continue to advance.

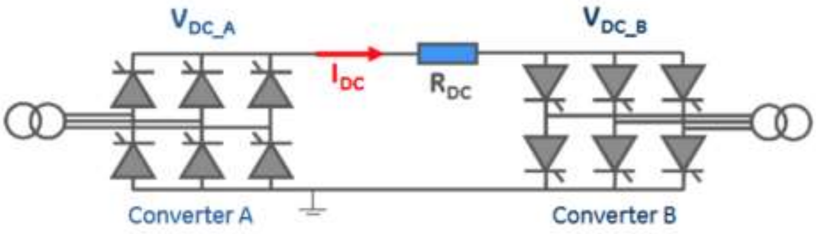

Figure 2.15: Line Commutated Convertor

2.6.2 Voltage Source Converter (VSC)

A comparatively fresh converter technology for HVDC transmission systems is the voltage-source converter (VSC). The VSC has been extensively employed for power transmission systems since the expansion of Insulated Gate Bipolar Transistor (IGBT).

In 1999, Sweden's Gotland island saw the commissioning of the first VSC-HVDC system in the world. Self-commutating switches used in voltage-source converters can be readily switched on or off (Toledo, P. F. D., 2003). This demonstrated thyristor valve able only be switched off by reversed voltage. The converters have been divided into three categories for HVDC applications: dual-level, triple-level, and integrated multilevel converters. The capacity to operate in four quadrants, the complex plan, and larger power losses when likened to LCC are the main characteristics of VSC. Figure 2.16 depicts the VSC-HVDC system's circuit diagram.

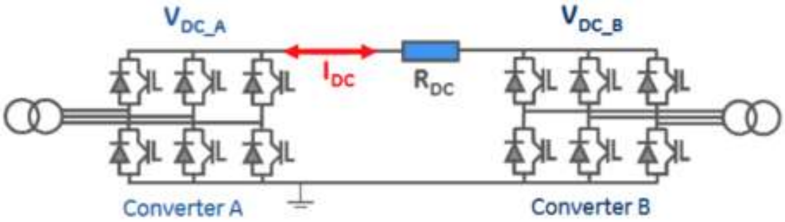

Figure 2.16: Voltage Source Converter

2.7 Comparison of HVDC Converters

A comparison of the LCC-based and VSC-based HVDC transmission systems is presented in Table 2.1.

Table 2.1: Comparison of LCC and VSC

	LCC-based HVDC	**VSC-based HVDC**
Power Capability	Up to 8000MW.	Up to 1400MW.
Overload Capability	Good, continuous and short time.	None.
AC System Requirement	Strong existing network is required	Able to work into fragile AC systems or no AC system.

Reactive Power	Change by switching ac harmonic filters.	Control by the converter.
Harmonic Performance	Converter created alteration reduced by ac and dc filters.	minimal harmonic distortion. No filters necessary.
Losses	0.8 %	1.0 %
Land Take	Huge site,	50 to 70% of LCC rating

2.8 Comparison of AC and DC Transmissions

Either AC or DC must be used to convey the electrical power. Each system has its own benefits and drawbacks. Therefore, a comparison study is done to determine which system is superior for sending electrical power across longer distances.

2.8.1 Advantages of HVDC Transmission System

1. Both AC and DC link have distinct capabilities for transmitting power; DC transmits greater power per conductor and only need two conductors, AC required three conductors to transmitting power.

2. Lower Space and Smaller Tower Size: Compared to an AC transmission of equal power, the DC insulation level is lower. Additionally, compared to an AC line that needs three conductors, a DC line only needs two. Therefore, the tower's mechanical and electrical design features made it smaller. In addition, the DC transmission line resulted in a reduction in the amount of area needed and the number of transmission towers from two to one.

3. Greater capacity for cables: In comparison to an overhead line, a breakdown cable occurs due to stimulation rather than an external flashover. The absence of ionic mobility is the primary cause. The DC cable is able to deliver greater active power over longer distances without receiving constant current charges.

4. Absent of skin effect: Under AC conditions, the conductor does not always receive the same amount of current. These circumstances show that the conductor cross-section is not fully utilised since the current concentration is higher in the outside area (skin effect). However, in steady DC conditions, there are no skin effects and a constant current is given to the conductor, allowing the metal to be used more effectively.

5. Less radio interference and corona: For a particular conductor diameter and applied voltage, corona effects are reduced as frequency is increased. As a result, DC experiences less radio interference. Due to fewer utilisation of conductors, transmission line costs are also lowered.

2.8 Construction of HVDC Transmission System

From the start of the contract to the completion, it takes a long time to establish a transmission system. LCC-HVDC system construction typically takes three years, while VSC-HVDC system building typically takes one year. The construction procedure for HVDC transmission is covered in this section.

2.8.1 Improvement of the Staging Area

The staging area was well-organized and utilized as storing before work began. To avoid disruptions or incidents during the movement of materials or the construction of the transmission tower, a staging area was created. The equipment, building supplies, fuels, and some chemical components can all be stored in the staging area. Additionally, depending on where the staging area is located, blasting agents may also be stored. Every 15 miles, there is a staging area where materials or fuels can be used right away.

2.8.2 Establish Access

Every transmission construction requires the construction of a new access road. It is crucial to continue running the transmission line's building and maintenance projects. In addition, cleaning the areas is crucial for the structures.

2.8.3 Tower Construction

The area of land needed to build a tower is roughly 100 feet by 200 feet. Dissimilar tower types need dissimilar sized of plots. The land required for a lattice tower is roughly 80k square feet. However, 32k square feet of plot required for the structure of the Monopole Post.

2.8.4 Substation Construction

A substation would take between six and nine months to build. About 435k ft^2 of land is required for the substation.

2.8.5 Conductor Stringing

To prevent damage to the conductor surface, the conductor wires should be installed either underground or atop of a tower. During the stringing operation, conductor cables are pulled by a vehicle with a mounted spool to avoid the need for additional land for tower building. Due to the deviation that happened at the diversion tower, the line's path can be drastically altered.

2.9 Design Features of HVDC

There are a few things that can be taken into consideration while designing a transmission system to lessen the environmental effects of its construction and operation.

2.9.1 Route Selection

The main strategy in minimize the effects of the HVDC transmission system is route selection. The following route selection considerations must be taken into consideration in order to minimize the system's effects:-

- Wetlands and delicate natural habitat should be avoided.
- Avoid delicate regions like untouched land and public parks.
- Avoid using farmland.
- Avoidance of historical structures
- Avoid going into neighbourhoods.

2.9.2 Transmission Line Design

A few elements, including materials, the quantity of electrodes, the type of erections, the form of Cables and route pointers, must be taken into account while planning a transmission line. The following elements can also lessen transmission line effects:

Tower design: The primary factor in transmission tower design correlated to the type of tower erected to build the transmission system. The conduction pylon was selected and built to be high, and the above power cables sustain and resist heavy winds. The two main types of transmission towers are depicted in Figure 2.18 and 2.19.

Figure 2.18: Lattice Power Transmission Tower

Figure 2.19: Monopolar Power Transmission Tower

Phase to ground clearances: This refers to the procedure of closing the gaps between the conductors. It might entail making room for other electric lines to pass between the lien and them.Features of the specific mitigation strategy: Other design factors can still be used to mitigate the effects of the transmission line. For instance, using ball markers and flappers can prevent a conflict between a bird and an airplane.

2.10 Price of Transmission

The price of a transmission system depends on a number of variables, including the converter type, component type, transmission tower type, and power capacity. When compared to AC transmission, DC transmission requires fewer conductor cables ,two for a DC circuit and three for a three-phase AC circuit. As a result, it was made abundantly evident that HVDC transmission is less expensive than HVAC transmission. Although HVDC transmission does not require HVAC transmission, converter stations are expensive. Figure 2.20 depicts the so-called break-even distance at a particular length. It is evident from the figure that HVDC transmission lines are significantly less expensive than HVAC transmission outlines. For overhead lines, the break-even point is roughly 300-600 km, and for undersea lines, it is 50 -100km.

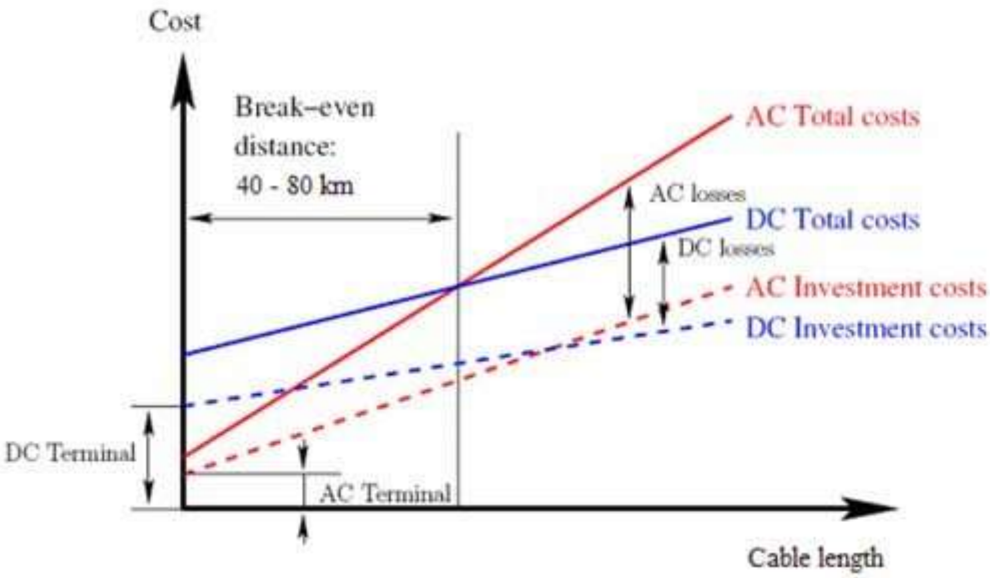

Figure 2.20: HVAC VS HVDC Transmission Cost

2.11 HVDC Transmission System in Malaysia

The 300/600 MW HVDC system between Thailand and Malaysia is the region's earliest HVDC interconnection. This HVDC interconnection project was initially slated to go into effect between Malaysia and Thailand in 1997. After that, work on the project began in

February 2000 and was finished in September 2001.The HVDC system is linked as 300 kV monopolar above transmission lines thru a 300 MW rated power, as seen in Figure 2.21. According to Figure 2.22, power is transmitted over a 110 km distance from a converter station in Gurun, Kedah to Khlong Ngae, Thailand. A contract to establish this HVDC interconnection project is signed on 15th August 1997, by both power provider from Thailand and Malaysia. (Halirni Abdullah, M., 2003).

The goals are:

- Distribute the turning standby among the EGAT AC and TNB systems.
- Achieve additional cost-effective power interchange among the two nations
- Support in an emergency to any AC network.
- Voltage control for both AC networks with reactive power support.

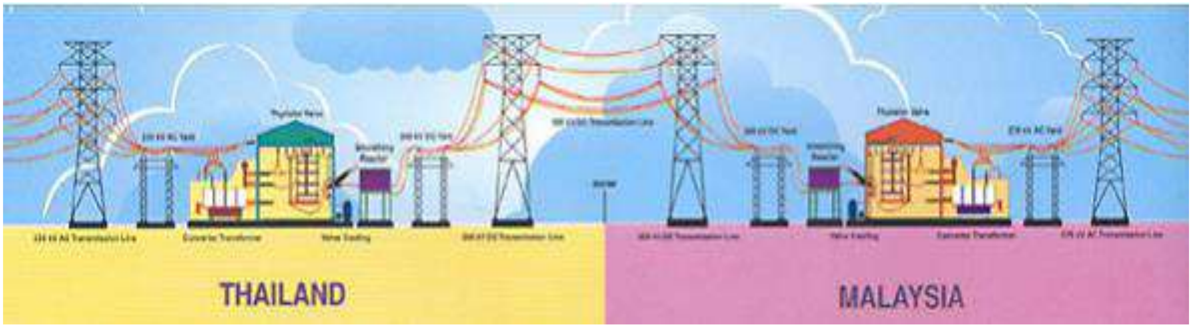

Figure 2.21 Malaysia – Thailand HVDC System

Figure 2.22 Malaysia – Thailand Interconnection of HVDC System

2.12 Technical assessment of HVDC vs HVAC

DC transmission was employed for very extended transmission distances of more than 3000 km (Shah and Barnes, 2018. It similarly uses less cables and conductors and makes complete use of the transmission capacity of the lines up to their current limits. Hence lowers the cross-sectional area required for DC cables and subsequently transmission cost (Obradovic et al., 2021).

In addition , some applications need the deployment of dependable HVDC stations as the only alternative for linking two asynchronous AC power systems in diverse nations (Chetty and Ijumba, 2011) or inside the similar nation, as in Japan (both 50/ 60 Hz systems) and the United States (asynchronous 60 Hz systems) (Chetty and Ijumba, 2013).

In summary, it is safe to argue that utilisation of HVDC transmission above extended distances has significant practical benefits. Due to the absence of transmission line capacitive or reactivecharging effects, DC transmission prices are substantially lesser than HVAC. This reduces HVDC transmission harms and eliminating the potential for costly ultrafast (Benato and Gardan, 2022). This finding by Benato and Gardan have contributed to more research on HVDC transmission for cost saving and development of morerobust yet cost effective solution in transmitting huge amount of power over long distance.

2.13 Chapter Conclusion

In brief, HVAC and HVDC transmission system have been reviewed. It plays major role in power transmission system. In order to utilize HVDC transmission system in Malaysia, few elements such as components, types, transmission of construction, design features, cost of transmission and technical assessment of HVAC and HVDC reviewed.

CHAPTER 3
METHODOLOGY

Based on the context, layout, design elements, and components involved, an actual case study chosen for an HVDC transmission system from china, Xiangjiaba-Shanghai HVDC transmission system to compare with an HVAC system from India , 765 kV HVAC transmission line between Raichur and Solapur in India. Alternatively, mathlab Simulink simulation is run for each transmission system to evaluate the impact of vital parameter to the system.

3.1 Background of Real Case Study-China

3.1.1 HVDC Transmission System

Due to the obvious swift economic expansion of China, needs for energy are rising. The 800 kV Xiangjiaba–Shanghai HVDC transmission system was constructed in China and has a 6400 MW capacity. State Grid Corporation of China (SGCC) has ordered it to transport the hydropower from Xiangjiaba Dam to Shanghai. SGCC is a pilot state holding company with state authorization for investments with a focus on building and managing power systems. The Xiangjiaba-Shanghai HVDC transmission system surpassed all other HVDC transmission systems in terms of both power and length in July 2010. However, the 800 kV Jinping-Sunan HVDC with a rate of 7200 MW took over the power capacity record in December 2012, and the Rio-Madeira HVDC in Brazil took over the distance record in 2013

Figure 3.1: HVDC Transmission System of Xiangjiaba – Shanghai

3.1.2 Layout of HVDC Transmission System

The system connects Shanghai's Fulong converter station with Fengxia converter station utilizing a bipolar type connection. The so-called rectifier at the Fulong converter station is about 10 kilometres south of the Xiangjiaba hydroelectric dam. The assembly between the Fulong converter station and the generating stations is made using four 500kV AC wires. The Fengxia converter station, also known as an inverter, is situated around 45 kilometers from Shanghai's city Centre. Three 500 kV AC wires in Shanghai connect it to Nanhui station. Figure 3.2 shows the power system's organizational structure.

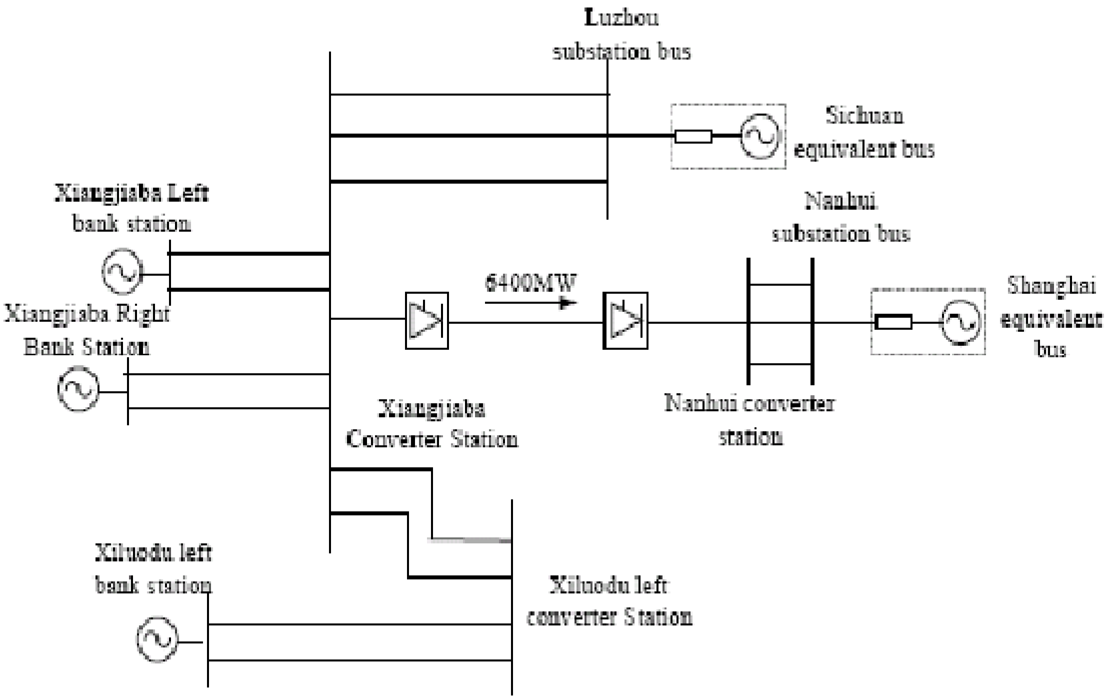

Figure 3.2: Xiangjiaba – Shanghai DC Transmission Power System Layout

3.1.3 Design Features of HVDC Transmission System

At the Fulong converter station, the bipolar HVDC system is providing energy with an output of 6400 MW and a DC voltage of 800 kV. Two 400 kV twelve-pulse bridges are connected in sequence to create the pole voltage. The transmission system can conduct the highest amount of electricity without the need for further cooling. The structure will spontaneously switch to the de-icing to dissolve the ice on the pole lines when high current in the converter occurs. The converters are arranged with 12 pulses and attached in equivalent in each post. At 400 kV, each post will be running. Two 400 kV convert stations are linked in sequence in Figure 3.3

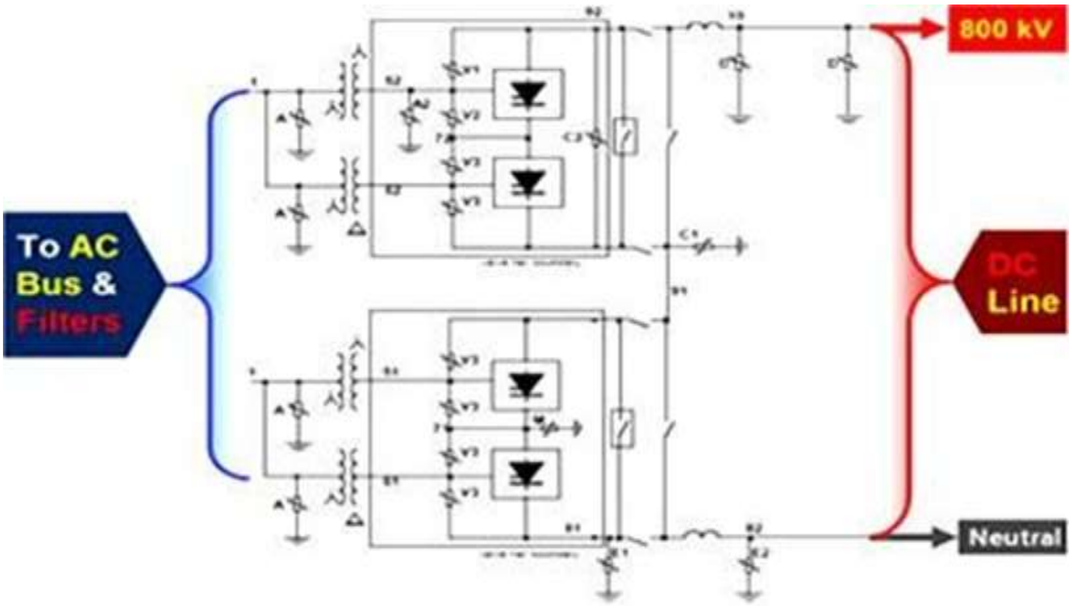

Figure 3.3: Bipolar Station Arrangement

3.1.4 Main components of HVDC Transmission System .

3.1.4.1 Thyristor Valves

Six inch YST130 type thyristors were used in the design of the thyristor valves. Each valve contains 56 thyristor components. These thyristors have been extensively used in HVDC needing high current as a result of earlier research. It remained the earliest development utilizing six-inch thyristors for HVDC transmissions. Figure 3.4 showing thyristor valves in HVDC transmission system in China.

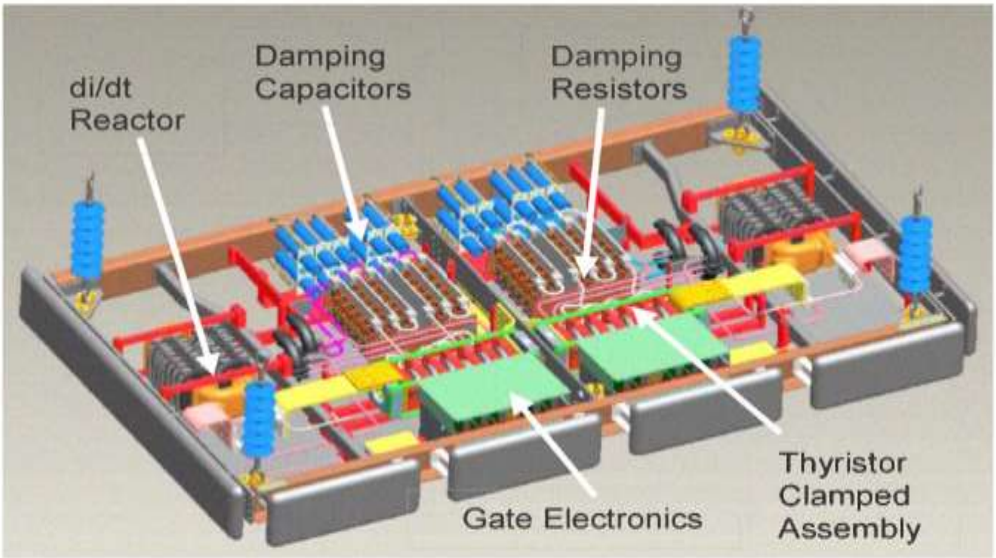

Figure 3.4: Thyristor Valves

3.1.4.2 Convertor Transformers

The transformers of the Xiangjiaba-Shanghai HVDC Transmission System are single phase with two windings. Either Sweden or China manufactures the transformers. Figure 3.5 showing convertor transformers.

Figure 3.5: Convertor Transformers

3.1.4.3 Smooth Reactors

The type of smoothing reactors utilized air as the insulator. Two smooth reactor units are put on the 800 kV voltage side, and two further components are connected on the neutral voltage side.

3.2 Background of Real Case Study-India

3.2.1 HVAC Transmission System in India.

Power Grid Corporation of India Ltd. has turned on the 765 kV HVAC transmission line between Raichur and Solapur in India. According to Figure 3.6, this HVAC transmission line was put into service in December 2013 and spans a distance of 208 kilometres from Raichur in Karnataka to Solapur in Maharashtra. The line is put into action as part of a plan for synchronous interconnection between the Southern and Western regions. With a total power capacity of 235 GW, this link has made India's power system single biggest synchronous running networks in the domain. The objective of "One Nation - One Grid - One Frequency" was subsequently accomplished.

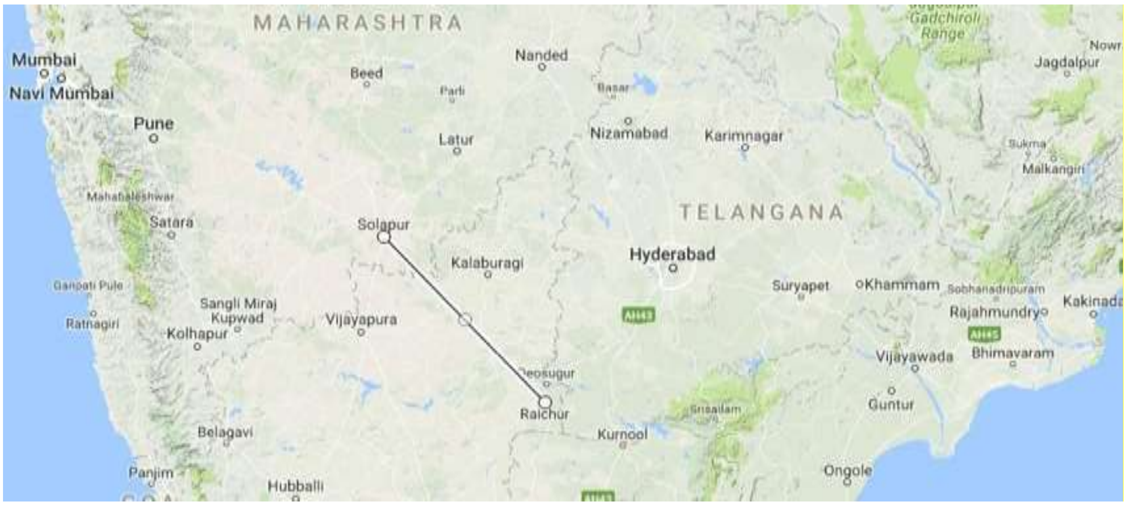

Figure 3.6: HVAC Transmission System of Raichur – Solapur

3.2.2 Layout of HVAC Transmission System

The distribution system and the transmission system are the two components of the HVAC transmission system between Raichur and Solapur. Each system has two stages that can be separated. The primary transmission comes first, followed by the secondary transmission, as indicated in Figure 3.7. Three-phase power generation and transmission are used.

The electrical energy is produced at 220 kV in a energy plant for primary transmission. Then, the producing voltage is raised to 765 kV. In order to reduce energy losses when transferring electrical energy , the voltage is increased. At a receiving station, the voltage is then decreased to 400 kV. The RS is linked to substations close to the city for secondary transmission. At the substation, the transformer is decrease the voltage to 11 kV. This voltage is then used by the primary supply, often known as the primary distribution, to deliver to larger users like industrials. The 415 V stepped down voltage is finally being transmitted to additional users by the secondary distribution system.

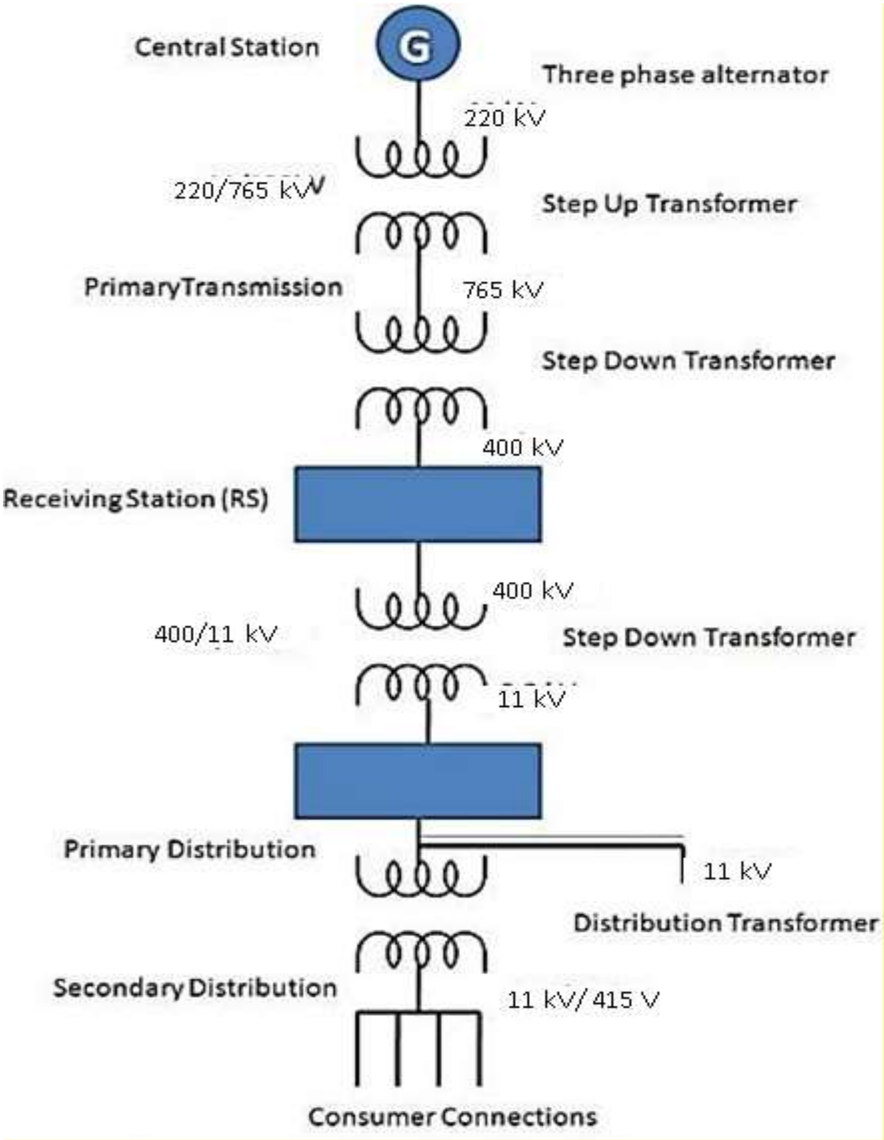

Figure 3.7: Raichur – Solapur AC Transmission Power System Layout

3.2.3 Design Features of HVAC Transmission System in India

The transmission lines in the Raichur-Solapur HVAC system are single 765 kV circuits. As a result, a wider area of land roughly 200 feet is needed for this 765 kV transmission line. Additionally, this transmission line makes extensive use of high tension insulators with two corona rings.

3.2.4. Main components of HVAC Transmission System in India

3.2.4.1 Generators

Subsequently, a main part of the power structure is the generator. It converts mechanical energy into electrical energy and is of the synchronous type. Stator and rotor compose up a generator. The stationary component with conductors inserted into its slots called the stator .Meanwhile the rotor rotates inside the stator while mounted on the shaft.

3.2.4.2. Transformers

Transformers are typically utilized in substations. It has the ability to adjust the system voltage. Whereby, only when the power is transferred at the producing end can the voltage be increased, and all following substations must gradually step down the voltage until it reaches the working voltage level.

3.2.4.3 Transmission Line

A conductor called a transmission line is used to move electricity from a generation facility to a distribution network.

3.2.4.4 Bus Bars

Bus bars are utilized to directly join transmission cables that are running at the identical voltage. Either copper or aluminum is used to manufacture these bus bars.

3.3 Comparison of both India (HVAC) and China (HVDC) transmission system.

The Xiangjiaba-Shanghai HVDC transmission line may transport power over a distance of 2000 km from Shanghai in eastern China to Xiangjiaba in southwest China. Alternatively, 800 kV DC voltage is used to reduce transmission losses. In comparison to local power supply with energy-mix, the CO2 p.a. is reduced by up to 44 million metric tonnes using green hydro power generation and minimal energy losses of HVDC transmission system.

Siemens Energy has installed 10 DC converters for the lines at the Fulong converter station. Additionally, Siemens works with XPR to install the towers and connectors based on six-inch thyristor valves.

On the other hand, the Raichur –Sholapur 765kV single –circuit transmission line is the highest voltage transmission line in India. In term of high voltage direct current (HVDC) lines, India is forming links with Extreme high voltage of straight 800kV.An Exceptional feature of india’s energy transmission to set up extra high voltage power transmission links 1,200kV, the maximum voltage level anyplace in the world. Both huge power transmission systems have been discussed in details and table 3.1 lists down both system parameters.

Table 3.1: Details of India and China power transmission system.

Customer	State Grid Corporation of China and XD Xi’an Power Rectifier Works (XPR)	Power Grid Corporation of India Ltd.
Project name	Xiangjiaba	Raichur -Solapur
Location	Xiangjiaba to Shanghai	Raichur to Solapur
Type of plant	Long-distance transmission, 2070 km	208km
Power rating	6400 MW, bipolar	235GW
Voltages levels	± 800 kV DC, 525 kV AC	765kV AC

3.4 Simulation of HVAC Transmission System

A simulation model for a three-phase HVAC transmission system with a 1680 MW power rating is shown in Figure 3.8 and 3.9. The frequency is 50 Hz, and the voltage level is 500 kV. A power plant's generated electricity travels 300 kilometers along transmission lines to a substation. To improve the power quality and capacity, each line incorporates a shunt capacitor acting as a series compensator. This compensator aids in minimizing active and reactive power losses while maximizing transmission power. At the substation, 1650 MW of power will be delivered during the last phase.

Figure 3.8: HVAC Transmission Simulation Model

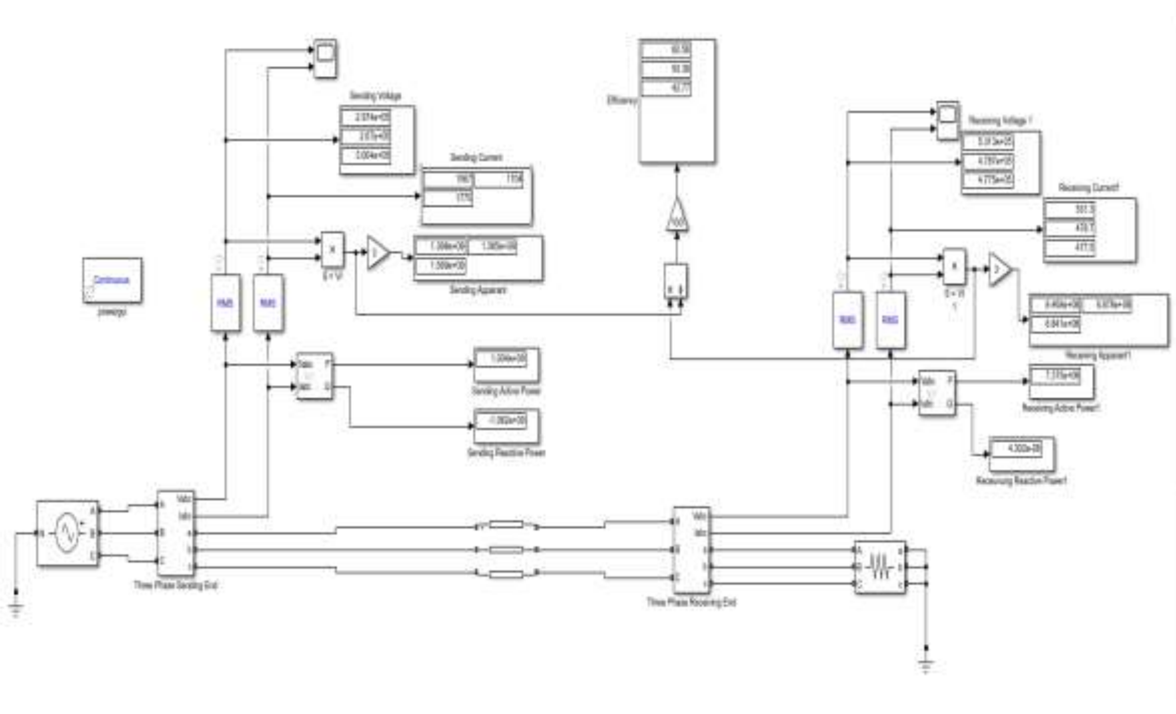

Figure 3.9: HVAC Matlab Simulink Model

3.5 Simulation of HVDC Transmission System

Figure 3.10 illustrates a simulation model for an HVDC transmission system using a thyristor converter with a 12-pulse configuration. The electricity is then rated at 1680 MW, with a 500 kV voltage level and a 50 Hz frequency. A power plant's generated electricity travels 300 kilometres along transmission lines to a substation. Two universal bridges are used to connect the rectifier and inverter in series. Finally, 0.9 H of smoothing reactors is put in close proximity to the converters. To reduce fault current and prevent resonance in DC circuits, smoothing reactors are used. Finally, the substation will receive 1645 MW of power. Figure 3.11 showing HVDC Matlab Simulink Model.

Figure 3.10: HVDC Transmission Simulation Model

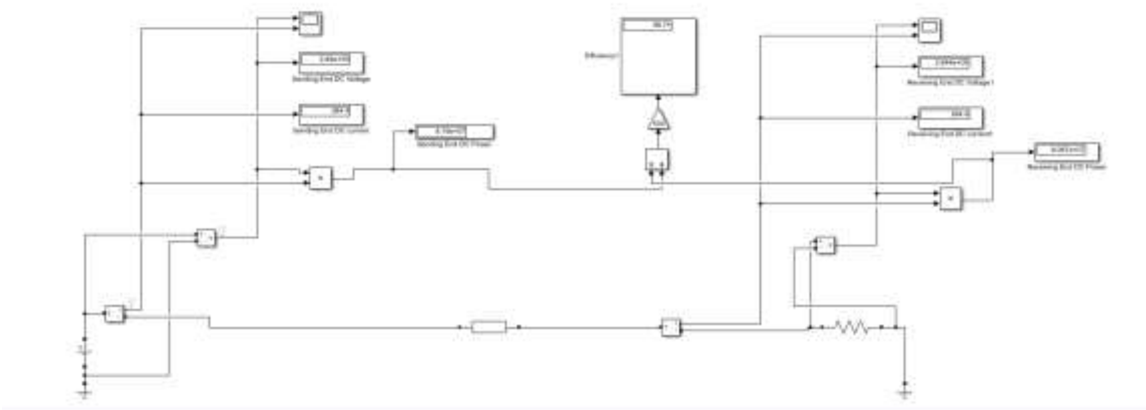

Figure 3.11: HVDC Matlab Simulink Model

3.6 Short Circuit Current in HVAC and HVDC Transmission Systems

Electric errors can occur from time to time when a lot of current is flowing through a different path. This results in unstable power, catastrophic damage to equipment, injuries to humans, and even potential fatalities. The proportion of symmetrical defects in transmission lines is around 5%. (Mizanur Rahman, Md. et al, 2014).

Determining the outcome of the asymmetrical fault gets more challenging if some phases are affected. This is because not all phases can be used with the simplistic assumption of equal current magnitude. There are three different types of asymmetric faults: double link to earth fault, link to earth fault, and line to line fault. When both links come into contact with one another, a link-to-link fault occurs. A link to earth fault occurs where a line meets the earth. Lightning strikes or other storm-related damage are simple ways to trigger it. When two links are shorted to earth, a double line to ground fault occurs. Storm damage is typically to reason.

When a fault in the transmission system is detected, the short circuit current, similarly identified as fault current, occurs. A high level fault current or a strong current flowing through a circuit can damage equipment powered by current by destroying the insulating system and causing power surges. The gadgets are also charged to control the electric shock sent across the body. Depending on the type of the fault current, electric shock can also be fatal.

As a result, a simulation is run for the HVAC and HVDC transmission systems to relate and examine the consequences of the fault current. For better analysis and outcomes, both systems use the same settings.

3.7 Chapter Conclusion

This chapter briefly discussed based on the context, layout, design elements, components involved and actual case study for an HVDC and HVAC transmission system. Nevertheless, each simulation test and transmission type been explained.

CHAPTER 4
RESULT AND DISCUSSION

This chapter discusses the result of the simulated model with statistical result. Then, comparison between the data collected from the simulation discussed.

4.1 Design Aspects for Transmission Lines

Electrical and mechanical aspects are crucial areas that can influence a transmission system's cost when designing AC and DC transmission lines.

The voltage level, power capacity, and number of parallel circuits can all be evaluated in order to assess the transmission system's cost. The transmission lines for 500 kV DC and 800 kV AC are shown in Figure 4.1.

A transmission system's conductor designs are crucial from a mechanical perspective. The number of conductors employed, which will be covered in section 4.4, can impact the cost of transmission. Table 4.1 displays the power capacity (MW) and Right of Way (RoW) in meters (M) of the transmission lines utilized in the HVAC in India and HVDC in China.

Transmission Line	800kV AC	500kV DC
Capacity (MW)	2000	3000
RoW(m)	85	50

Table 4.1: Transmission Line of AC and DC

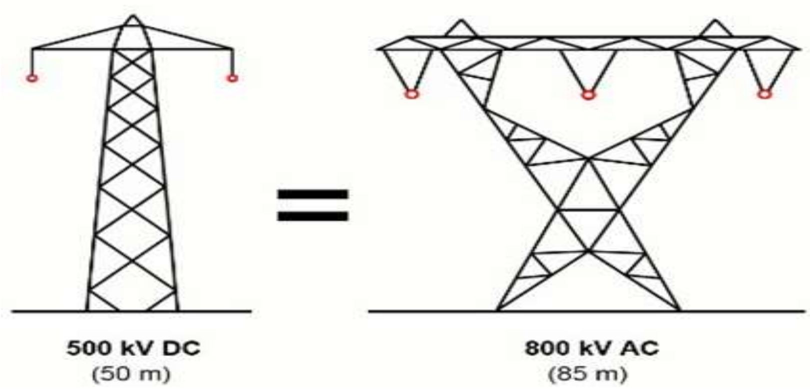

Figure 4.1: 800kV AC and 500kV DC Transmission Lines

4.2 Quantity of Lines in Parallel

The quantity of conductors required determines how many lines can be linked in parallel. One of the elements influencing the number of lines used is corona noise. The quantity of lines needed when using HVAC or HVDC at different voltage levels was displayed in Table 4.2.

Table 4.2: Required Lines for HVAC and HVDC

		Cond. diameter	**Thermal limit (line)**	**Thermal limit (s/s)**	**SIL**	**1.5 x SIL**	**Required no. of lines**	
	kV	mm	GW	GW	GW	GW	8GW	12GW
HVAC	800	5 x 35	7.5	5.5	2.5	3.8	4	5
	1000	8 x 35	15.0	6.9	4.3	6.5	3	3
HVDC	±600	3 x 50	8.0	5.8	n.a.	n.a.	2	3
	±800	5 x 50	17.7	5.8	n.a.	n.a.	2	3

Figure 4.2 provides evidence for the efficiency of HVDC transmission lines at advanced voltage points.

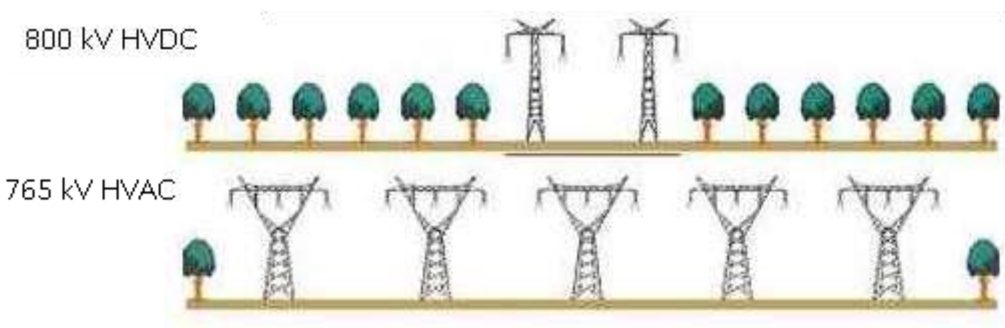

Figure 4.2: 800kV HVDC and 765kV HVAC Transmission Towers RoW

4.3 Line Losses

Power losses can have an impact on the cost of the transmission system in addition to the conductor designs for HVAC and HVDC. To determine the conductor cross section in HVAC lines, resistive losses occurred. The AC corona losses must be taken into account for a better conductor bundle design. When it's raining, there are more corona losses.

In order to determine the conductor cross section, resistive losses occur in HVDC lines similarly to HVAC lines. As DC corona losses are lower than AC corona losses, conductor design is less of a concern. In Figure 4.3, power losses in DC and AC lines are illustrated. It is obvious that in weather-related losses, HVDC lines suffer less than HVAC lines.

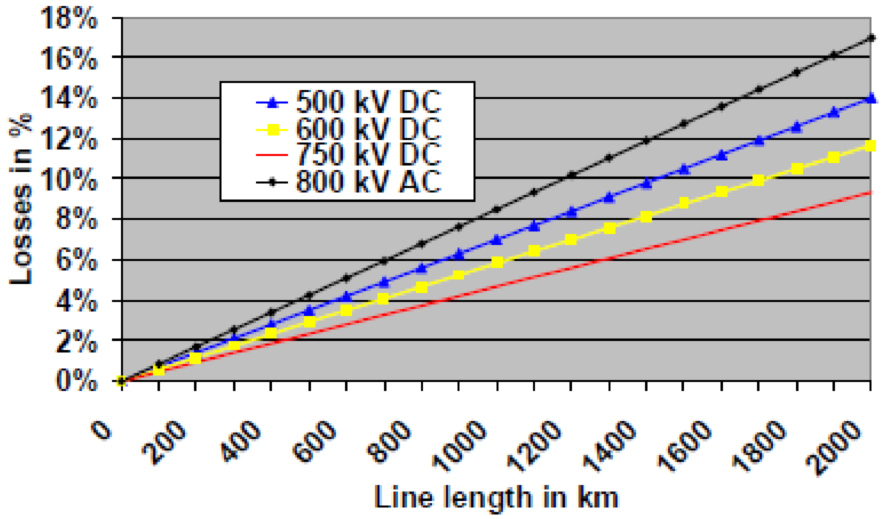

Figure 4.3: AC and DC Power Losses

4.4 Conductor Burden on Tower

Literature review clearly shows HVDC transmission uses fewer wires than HVAC transmission. According to Figure 4.4, the amount of HVDC conductors used at the same voltage level is almost half that of HVAC conductors.

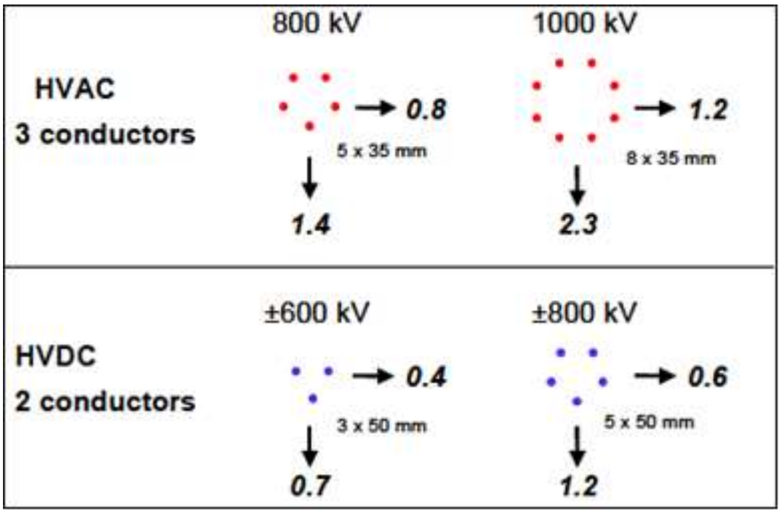

Figure 4.4: AC and DC Towers Total Conductor Load

4.5 Differences between HVDC China and HVAC India

The technical viability, environmental impact, and economic features of HVAC in India and HVDC in China are evaluated in Table 4.3.

Table 4.3: Contrast between HVDC in China and HVAC in India

Characteristic	**Item**	**HVAC**	**HVDC**
Technical Feasibility	System Connection	Synchronous	Asynchronous
	Power Flow Control	Difficult	Easy & Fast
	Topping of Power Connection	Simple & Easy	Difficult & Costly
	Short Circuit Limitation	Not Effective	Effective
	Power Transmission Capability	Low	High
	Distance	Limited	No Limitation
	Reactive Power Control	Not Available	Available
	Frequency Control	Not Available	Available
	Cable Losses	Higher	Lower
	Cable Installation	Complex	Relatively Simple
	Offshore Experience	Mature	Less Mature

	Black Start Capability	Yes	No
Environmental Impact	Visual Impact	High	Low
	Right of Way Requirements	High	Low
	Pollution Effect	Relatively Less	More Pronounced
Economic Aspects	Cables Installation Cost	High	Low
	Substation Installation Cost	Low	High

4.6 Simulation Results

4.6.1 Single line to Ground Fault

Figure 4.5 showing fault current (kA) over time in HVAC transmission system. Highest fault current of 37 kA is recorded as per figure 4.5. Where else only 29kA of fault current recorded in HVDC transmission system for single line to ground fault as shown in Figure 4.6.

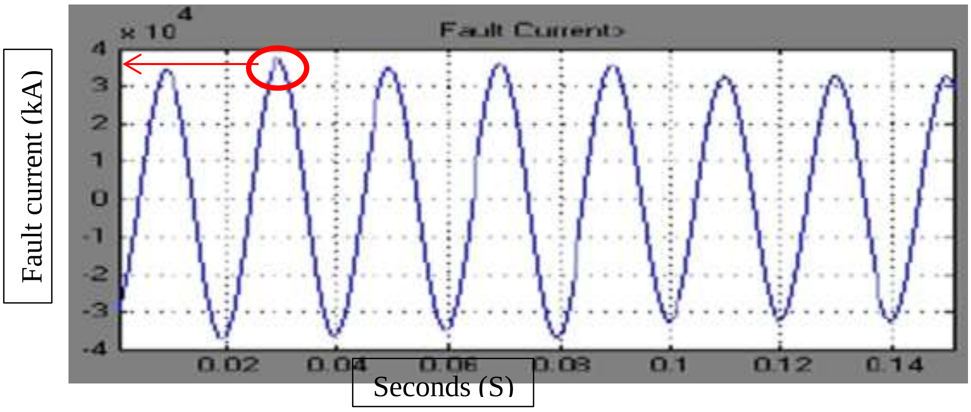

Figure 4.5: HVAC - Single Line to Ground Fault Current

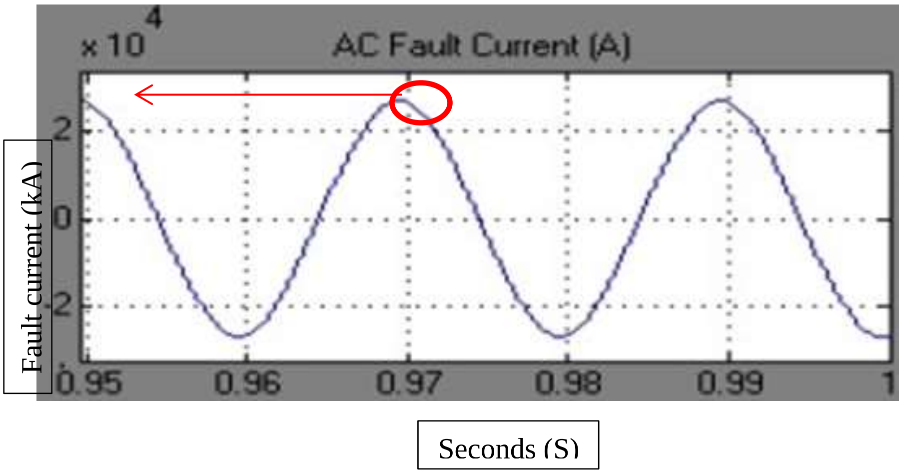

Figure 4.6: HVDC - Single Line to Ground Fault Current

4.6.2 Line to line Fault

Asymmetrical faults can also be in line-to-line configurations. It is abundantly apparent from the results that the fault current in the HVAC transmission system is excessive, 34 kA as indicating in Figure 4.7. However, under the same circumstances, the fault current at the HVDC transmission system is lower, 20 kA as illustrated in Figure 4.8.

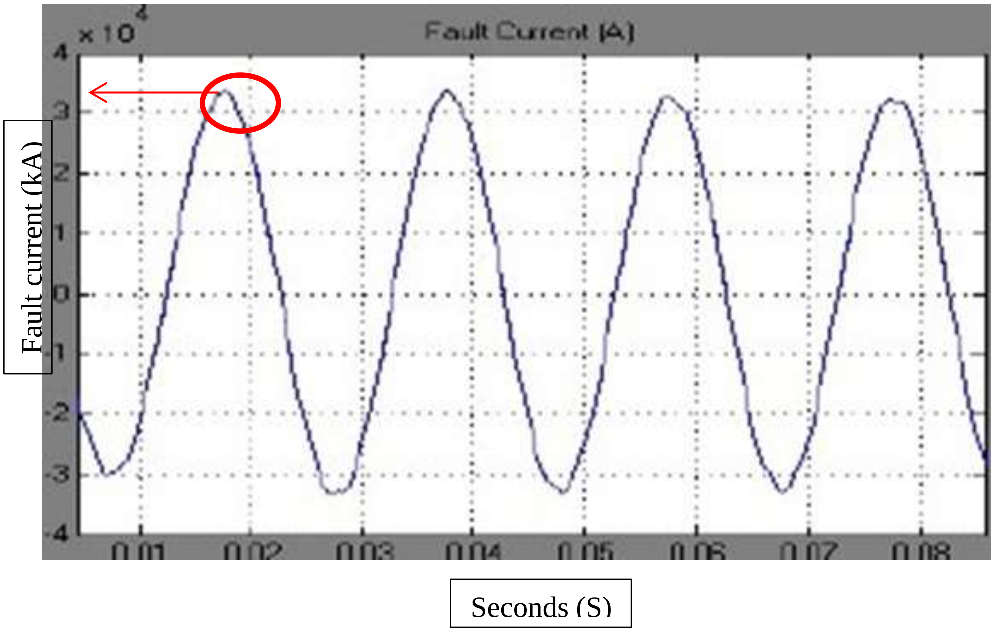

Figure 4.7: HVAC System - Line to Line Fault Current

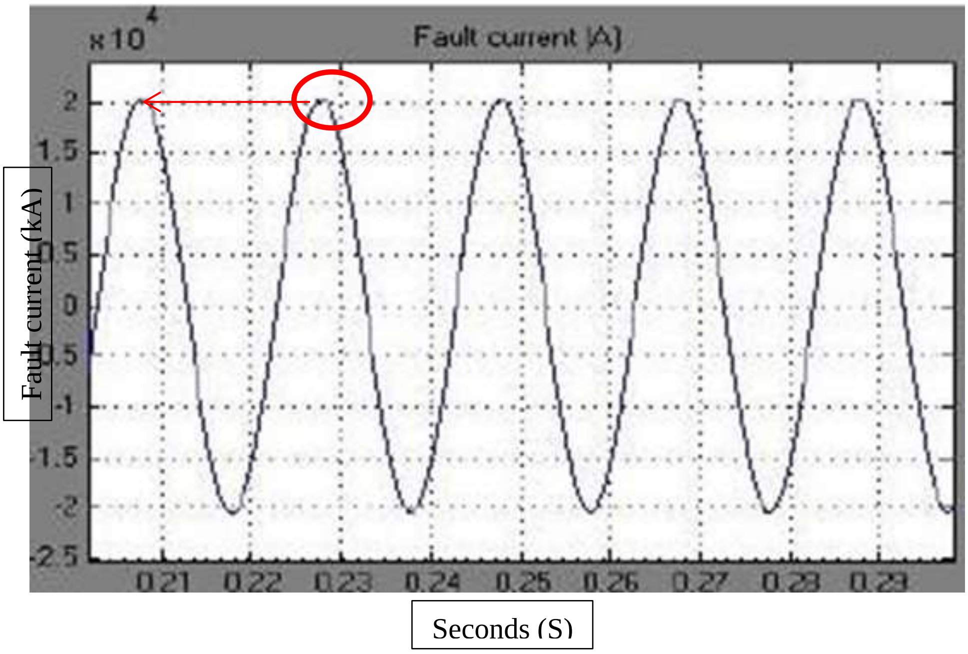

Figure 4.8: HVDC System - Line to Line Fault Current

4.6.3 Fault in Transmission Line

Figure 4.9 indicating the transmission line fault for the HVAC transmission system is roughly 12 kA. The transmission line part of the fault occurred, but the reception end part of the fault for a single link to earth occurred. The transmission line fault for an HVDC transmission system occurs in the DC transmission line part. Comparing the two circuits, Figure 4.9 shows that the HVAC transmission system's fault, 12 kA is more than that of the HVDC transmission system ,700 A as indicating in Figure 4.10.

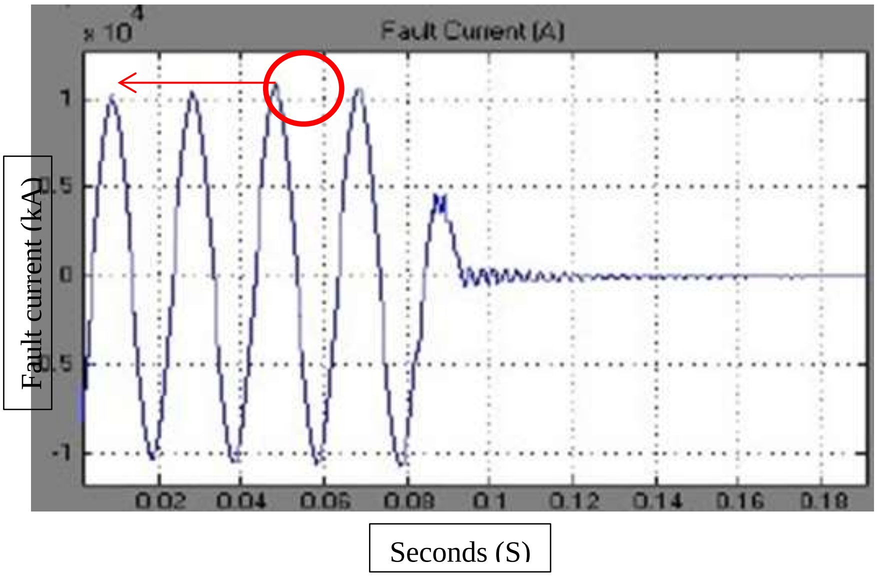

Figure 4.9: HVAC System - Fault Current at Transmission Line

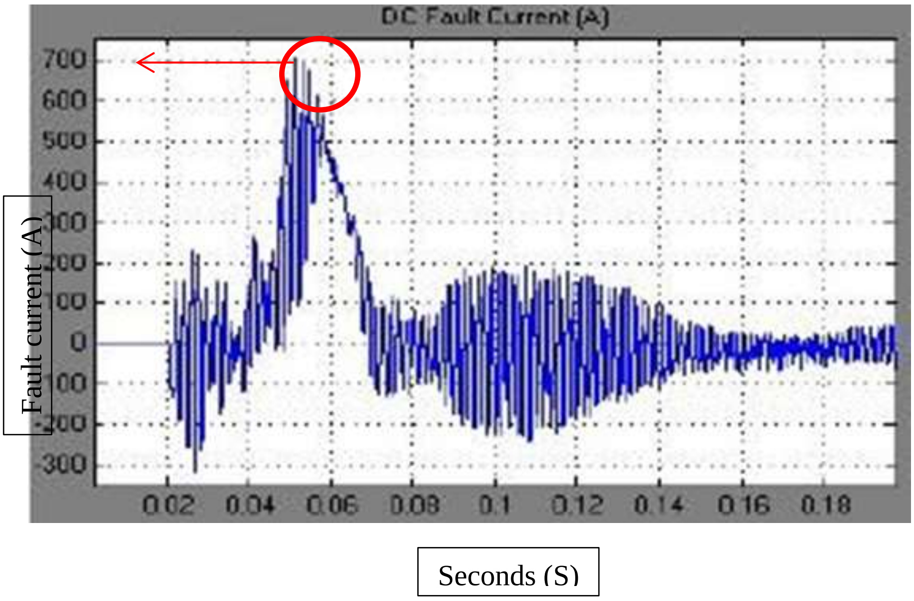

Figure 4.9: HVDC System - Fault Current at Transmission Line

4.7 Comparison of Fault Current

Fault current is the flow of abnormal current through an improper path due to electric faults which causes massive damages .In HVAC transmission system, fault current due to electric faults is too large which affects the overall power system including –receiving &sending end bus, transmission system, load and even also the Power Generation unit. HVDC transmission system dramatically reduces these effects, as the fault current due to electric faults is much lower and only affects the individual faulty section of the overall transmission system. Table 4.4 compares the fault current of the HVAC and HVDC systems with various failure types. The findings demonstrated that whereas HVDC transmission systems are less susceptible to the impacts of fault current, HVAC transmission systems are more susceptible.

Table 4.4: Fault Current Comparison between HVAC and HVDC Systems

Fault	**HVAC (Max. Value)**	**HVDC (Max. Value)**
Single line to ground	37 kA	29 kA
Line to line	34 kA	20 kA
Transmission line	12 kA	0.7 kA

4.8 Malaysia Conditions

Malaysia is a tropical nation with agricultural farmland and abundant sunlight that is created constantly. Agriculture initially has a significant impact on a nation's economy. However, the industrial activity has been more heavily concentrated on boosting the economy. Within twenty years, Malaysia's agriculturally based economy was effectively transformed into an industrial one according to the "Malaysia Incorporated" model. The need for electricity has grown over the past few decades due to the economy's rapid expansion.

Tenaga Nasional Berhad provides Malaysia's electric energy needs (TNB). The TNB annual report states that in 2016, the maximum energy demand was estimated to be 17,788 MW, and it is predicted to be 274 TW in 2030. The annual increase in energy request is about 3.5 percent. Large power plants are being constructed and put into operation to meet the demand for electric energy. Gas, coal, and water are the primary natural resources used by the majority of power plants. 12,013.4 MW of installed generating capacity in total. It consists of 2,347 MW of hydropower, 5,694.9 MW of gas power, and 3971.6 MW of coal power.

A new and longer transmission line must be built as the power capacity is raised. This might raise the price and place more restrictions on rights-of-way (ROW). As a result, the issues can be solved by highly efficient technologies like HVDC transmission. The HVDC transmission system offers a number of advantages, including lower investment costs, minimum usage of land and reduced environmental effects. The HVDC transmission system must be implemented with great significant in Malaysia.

State governments in Malaysia have authority over and control over land matters. The owners of commercial land must be compensated in order to construct the HVDC transmission. When the landowners cannot be identified or the site is leased, cons Malaysia included a lot of mountains, rivers, and rain forests. The biggest difficulty in constructing the HVDC project was moving the large machinery. The equipment and materials must be transported over rough terrain by land and by helicopter. As a result, if the tools and materials are handled improperly, they could be harmed. Due to the rising market value, thefts of copper bars, steel components, and aluminum conductors are also frequent today. Construction of HVDC transmission may be delayed. Construction will also be hampered by newly developed areas, such as a new airport, industry, or roads.

Similarly, local power corporation is enforcing the requirement that all transmission-related parts be purchased from or produced by local producers. The insulator must be imported, though. One major problem is that local businesses find it challenging to meet transmission tower regulations. They might offer components that are the incorrect size, thickness, or strength.

4.9 Chapter Conclusion

This chapter presented result of the simulated model with statistical result that proves that HVDC transmission line is preferred to be implemented in Malaysia compared to HVAC with the reasonable costing. A further study on the cost of HVAC and HVDC is suggested.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

This chapter concludes the outcome of the study in conjunction with the objectives of the study and discusses the contributions and recommendations for future improvement.

5.1 Project Conclusion

The majority of the transmission and distribution networks were built using AC in the early days of the electric power system. This is because simple and dependable transformers make it easy to shift voltage levels. It was a robust technology that has been in use for a while. However, there are numerous drawbacks to AC that make it theoretically impossible to utilize for extended distances. One of the problems that can lead to the HVAC transmission system being unstable is the lack of reactive compensations. Therefore, it is suggested to use traditional AC technology in the transmission system employed to increase the efficiency and stability of the HVDC transmission system. The installation of the converters in the HVDC transmission system is therefore more expensive. In contrast to HVAC transmission systems, HVDC transmission systems offer greater advantages. The following are additional conclusions that are discussed:

5.1.1 HVDC and HVAC Transmission break-even distances

The distance that shows the investment and savings is the break-even distance. For overhead lines, the breakeven distance between AC and DC lines is approximately from 300km to 800 km; for undersea lines, it is approximately 50 km to 100km. Over a longer distance, HVDC transmission is much less expensive than HVAC transmission. The conductor specifications for AC and DC lines are to blame for this. Only two conductors are needed for a DC line, compared to three for an AC line.

5.1.2 Current in short circuit

The most frequent problem in an electric power system is short circuit current, also referred to as fault current. The lines could become heated or melt due to the high currents from short circuits. It can also create an arc to harm system components. Additionally, overheating can damage other equipment and compromise the stability of the power system. The HVDC transmission system, is more stable since the converters do not cause short circuit current. Power can be transmitted smoothly through the system without raising short circuit levels.

5.1.3 Environment-Related Aspects

Every year, the public becomes more and more concerned about environmental issues like the electric magnetic field (EMF). While AC lines produce an alternating magnetic field, DC lines provide a stationary magnetic field. The alternating magnetic fields, as opposed to stationary magnetic fields, can cause body currents. There are thus greater restrictions while installing AC transmission lines. HVDC is preferred to be used for transmitting power over long distances from 300km to 800km. Both HVAC and HVDC power transmission solutions have been applied all over the world nowadays. Both transmission methods have their own advantages and disadvantages that are being taken into consideration when a decision is made of choosing one of them by the proficient personals. Technically, HVDC is the solution for transmission line and long-distance utilization over existing HVAC system. The efficiency for HVDC overtakes HVAC of 51.23% with 98.74 % respectively for longer transmission line over 300km. This come with varies advantages such as absence of transmission line capacitive or reactive charging effects, lower DC transmission losses or costs compared with HVAC. HVDC reduced transmission losses, line-resistive losses and eliminating the potential for expensive, ultrafast and AC line-reactive compensators (Joseph et al., 2018). Moreover, DC transmission may be employed for very long transmission distances of more than 3000 km with fewer cables and conductors (Langwasser et al., 2021). This lowers the cross-sectional area required for DC cables and, consequently, the transmission cost. However, the high-priced rectifier and inverter stations for AC/DC and DC/AC conversion, which are not required in the HVAC application, greatly increase the overall HVDC transmission cost (Wang et al., 2021). That is, the fixed cost of DC transmission such as stations and equipment. One the other hand, line charges and sufferers are significantly tilted in favor of DC. As a result, a breakeven distance for both expertise is established, afterward which

DC transmission becomes more cost-effective (Rouzbehi and Shariati , 2018). HVDC breakeven distance estimates vary, but overhead lines are between 300 and 800 km, and offshore/underground cable linkages are between 50 and 100 km (Regar and Srivastava, 2019). Based on disclosed project pipelines, global commissioned; operating HVDC capacity has significantly beyond 200 GW as of 2017 and is likely to surpass 400 GW by 2022 (Cheah- Mane et al., 2017). Market demand and technological advancement will determine future growth of HVDC to be more effective and efficient solution for Malaysian power industry.

5.2 Project Benefits

The results of this study clearly prove that HVDC technologies are more advantageous for the transmission and distribution of electrical power. Below is a list of the top advantages of HVDC transmission systems in brief:

- There are no restrictions on transmission distances.
- A tower of the same size can transfer more electricity.
- HVDC converters help lower short circuit current.
- Rapid reactive and active power control.
- Less disruption of the environment.

5.3 Future Recommendations

One of the recommendations is to keep using the 500kv to 1000 kV higher voltage HVDC transmission system. It is clear that for long distances, more than 300km, 500kv to 1000 kV HVDC lines are superior to 500kv to 1000 kV HVAC lines while having an equal power capacity. In Malaysia, the backbone is up to 500kV currently and projected to dramatically double up in 25 years to cater future demands. HVDC transmission system is applicable ,on high potential to explore and implemented in stages .The United Nations Power Grids Document and the Feasibility Report on European Grids both stated that it is not feasible to implement 1000 kV HVAC transmission systems over current power grids in the near future. HVDC power grids should be kept up to date, and the power capability at various voltage stages should be increased. Aside from that, adding an offshore grid can boost the efficiency of HVDC transmission. Offshore grids like wind farms produce better wind energy market prices. Additionally, given the rising cost of fossil fuels, the HVDC transmission may be less expensive if the oil and gas power plant is erected from shore.

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