FEASIBILITY STUDIES OF IMPLEMENTATION OF HVDC DISTRIBUTION NETWORK IN MALAYSIA

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A project report submitted in partial fulfillment of the requirements for the award of Master of Engineering (Electrical)

Faculty of Engineering and Science

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DECLARATION

I hereby declare that this project report is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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ABSTRACT

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Chua Ken Tat

In early of electric power distribution, direct current (DC) is the main system for transmitting the power. It was started from the DC generators which designed by Thomas Edison. The DC system is a mature technology but it comes with the drawback of high power losses and voltage drops when transmitting the power through long distances. As technology evolved, the DC is then replaced by alternating current (AC). AC has been widely used to transmit the power for last few decades, since the voltage levels can be easily increased by transformers. Thus, the power losses and voltage drops could be controlled. However, AC has some limitations such as system unstable, voltage drop due to impedances of AC lines and synchronization of machine which can affect the power transmission. In consequence, it brought back with the use of DC in some power transmission projects. HVDC transmission system is the first technology which able to transmit large amount of power through the long distances without losing much power and voltage. Other advantages such as no reactive power compensation, lower investment cost and lesser environment impacts have led the HVDC system more attractive in electric power system. Therefore, a study is carried out to compare and evaluate the design concept, component, technology, benefit and cost between

HVAC and HVDC transmission systems. The study is also focused on the evaluation of suitability to implement HVDC transmission system in Malaysia by investigating the power demand, system configuration, cost and impacts on environment.

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LIST OF ABBREVIATIONS / GLOSSARY

DC	Direct Current
AC	Alternating Current
HVAC	High Voltage Alternating Current
EHVAC	Extra High Voltage Alternating Current
HPO	High Phase Order
HVDC	High Voltage Direct Current
CB	Circuit Breaker
LCC	Line Commutated Converter
VSC	Voltage Source Converter
TNB	Tenaga Nasional Berhad
EGAT	Electricity Generating Authority of Thailand
SGCC	State Grid Corporation of China
RoW	Right of Way
EMF	Electric Magnetic Field
MI	Mass Impregnated

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

In a country, energy plays a major role for an economic growth without suffering the poorness. Natural energy resources such as oil, coil, natural gas, wind, solar and hydropower can be used to generate the electric power. These resources generally occur in faraway from the cities. Hence, high voltage transmission lines (HVTLs) have been found to efficiently transmit the electric power over the long distances from generation station to consumer. The electric power transmission systems are categorized into high voltage alternating current (HVAC), extra high voltage alternating current (EHVAC), high phase order (HPO) HVAC, high voltage direct current (HVDC) and composite AC/DC transmission lines.

Traditionally, generation, transmission and distribution are the activities that concerned in the electric power system. The generation activity mainly used to generate or convert the energy resources into electric power. In transmission activity, the electric power is transmitted from generation station to distribution station. Then, distribution activity is focused on distributing the electric power to consumers. In the beginning, the generation, transmission and distribution of electric power are carried out in direct current (DC) waveform. The first electric power transmission line is developed by DC. The fundamental concept of Volt, Ohm, Ampere, Galvani and Oersted have been discovered in the DC field. Thomas Edison (1857 – 1931) designed and built the world first electric central station (DC) in the Pearl Street, New York on 1882. Even though there is the existence of the first rise of DC, then DC is replaced by alternating current (AC) for better uses. This is due to the supply of electric devices such as transformer, induction motor and polyphase circuits on 1890. The transformer is extremely easy and simple to vary the voltage level for the transmission and the induction motor that worked solely with AC in the industries. Thus, AC has becomes very helpful for industrial and residential areas. However for long transmission distances, AC has some limits which led to use the DC in the power transmission projects. HVAC has becomes the strong technology of power transmission system for the last few decades. With increasing demand for power, the importance of HVAC is lesser as compared to HVDC. This is because of the limitation on reactive power, AC cable lines are not suitable for long distances which can cause the transmission system suffered with higher power losses. But HVDC does not have this issue, it is designed to transmit large amount of electric power through the long distances with low power losses. Each conductor of HVDC able to transfer more power than HVAC. Therefore, the profile of pylons and wiring are reduced, both money and land are saved. HVDC also can apply with different frequency between grid systems in order to improve the stability and reliability of system. From these, it is clear that HVDC is more favorable than HVAC due to its technical, economical and benefit of environmental.

In this project, a comparative study is carried out for HVAC and HVDC transmission systems. This study is to evaluate and compare the design concept, component, technology, benefit and cost between HVAC and HVDC transmission systems. Moreover, this project is focused on evaluation of suitability to implement HVDC transmission system in Malaysia by investigating the power demand, system configuration, cost and impacts on environment.

1.2 Problem Statement and Objectives

Early electric power distribution, the AC generators are located near in the industrial and residential areas. As electric power demand is increasing, the distances between loads and generation station is increased. A long AC transmission line connected with a generator may cause the power system unstable and higher power losses. Thus, the main challenge of transmission is presented to transmit the power over long distances.

With retentive evolution of HVDC technology, HVDC has more effectual to transmit the electric power with low power losses over the long distances. It has been widely used for bulk power transmission on last 40 years. The HVDC transmission system able to improve the system stability and reliability. More advantages such as no reactive power compensation required, able to connect two asynchronous grids, using less land and lower capital cost have make the HVDC became a strong and reliable backbone structure in electric power supply. From this, HVDC transmission system has more advantages than HVAC transmission system.

In Malaysia, the growth of economy is remained favorable. Strong domestic economic fundamentals have allowed the economy to grow. With the strong growth in economy, the demand of electric power will be increased. Tenaga Nasional Berhad (TNB) is the local company that supplies the electric power to consumers. As the power demand is increased, a new and longer transmission lines need to be constructed. Hence, high efficient technology such as HVDC transmission system able to fulfill the power demand.

The objectives of this project are:

1. To evaluate HVAC and HVDC transmission systems.
2. To investigate the system configuration, technical consideration, environmental impact and transmission cost for both HVAC and HVDC.
3. To determine the suitability to implement HVDC transmission system in Malaysia.

1.3 Overview of the Project

Chapter 1: The electrical power transmission system is introduced. Background, structure and technology of AC and DC are also presented in this section. Furthermore, it provides an overview why HVDC transmission system is more advantageous than HVAC transmission system. The objectives and overview of the project are then listed.

Chapter 2: Literature studies for HVAC and HVDC transmission systems. In this section, the background, layout, components, technologies used, costs, advantages and disadvantages are studied and discussed for HVAC and HVDC transmission systems.

Chapter 3: A real case study for HVDC transmission system is selected to compare with a HVAC transmission case study based on the background, layout, design features and components required. Moreover, a simulation is carried out for each transmission system to compare and analyze the fault current effects.

Chapter 4: Comparison results of HVAC and HVDC transmission systems. The simulation results of fault current are discussed in this section. Furthermore, there is an overview of Malaysia conditions to identify the challenges and suitability of HVDC implementation.

Chapter 5: The study is completed by giving some conclusions and recommendations regarding the HVDC transmission system.

CHAPTER 2

LITERATURE REVIEW

2.1 HVAC Transmission System

Electrical power is generated at generating station such as power plant and transmit through a complex system that consists of transformer, transmission line and electricity substation. The connection between generating station and electricity substations are called transmission network and the connection between substations and consumers are known as electric power distribution network. While, the combination of these two networks also known as the power grid or the grid. The electricity grid can be formed by hundreds of transmission lines with length of thousands mile. It is also connected with many generators to transmit the AC power to a larger number of consumers. Figure 2.1 shows the conventional power system consists of generating station, step-up transformer, transmission lines, step-down transformer and loads.

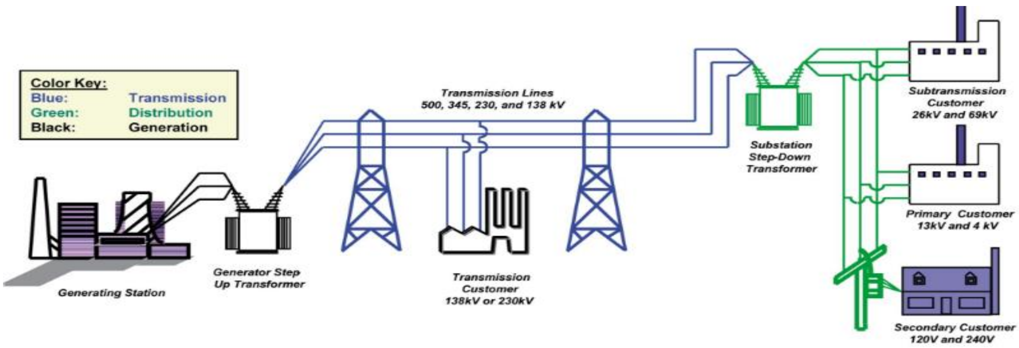

Figure 2.1: Electric Power System.

In early of electric power sector, AC has been widely used in power transmission. This is due to the conversion from low to high voltages can be easily done by AC power. High voltages have lower energy losses than low voltages and provide better power transmission through a conductor. However, the high voltages can cause some losses from the induction. When the voltage is higher, the electromagnetic field generated is larger around the wire. To solve this, more wires are required.

HVAC transmission system involved into two parts which are transmission and distribution. Figure 2.2 shows the model of HVAC transmission system is stepped up to 345 kV and then stepped down to 69 kV. At the end, 220 V is supplied to residential area. The voltage can be changed by transformers when the AC waveform is in sync from capacitors and inductors. If the waveform is affected by the inductance and changing the loads, it may cause the power losses and less efficient in the transmission system.

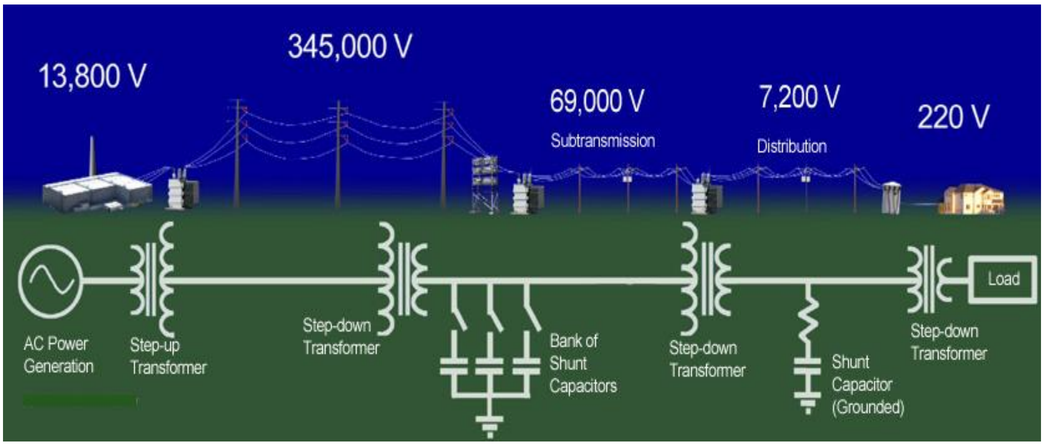

Figure 2.2: HVAC Transmission System.

Figure 2.3 shows the AC substation consists of transformers, bus bars, shunt capacitor banks, switchgear, voltage regulators, wires and lightning arrestors.

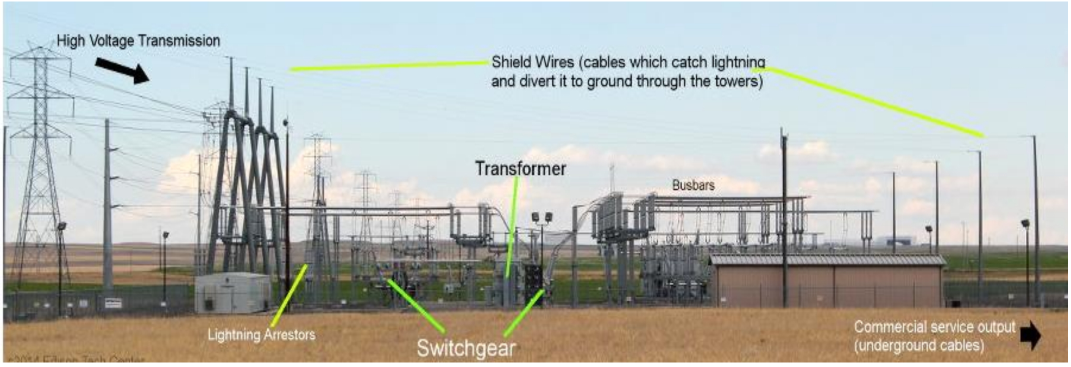

Figure 2.3: Components of AC Substation.

2.2 HVDC Transmission System

DC is the first electric power generator and hence the first power transmission is developed by DC. It requires much effort or skill to transform a DC power to a high voltage and low current form. While, the availability of transformers helped to done this efficiently with AC. A simple transformer easily change the voltage level for the transmission. Also, the improvements of induction motors led to greater appeal and use of AC. Hence, AC became very useful for the domestic and industrial uses. But in some conditions, AC are technically not practicable and economically not best for the long transmission (Meah, K. & Ula, S., 2007).With the fast growth of technology, it has allowed the reliable generation of HVDC for transmission systems and this HVDC recently obtained the new interest due to more price-effective power electronics, advanced of control electronics and the rising need for long power transmission in development of a country.

2.3 Components of HVDC Transmission System

The HVDC system basically uses DC for the power transmission and able to transmit the power between the unsynchronized AC system. Hence, HVDC transmission system is divided into three fundamental parts which are a converter station for AC to DC conversion (rectifier), transmission lines and another converter station to convert back DC to AC (inverter). When design a HVDC transmission system, there are several important components need to be considered. The main components are converter, harmonic filters, reactive power source, smoothing reactor, electrodes, AC circuit breakers and DC lines. Figure 2.4 shows the schematic of HVDC transmission system to identify the main components.

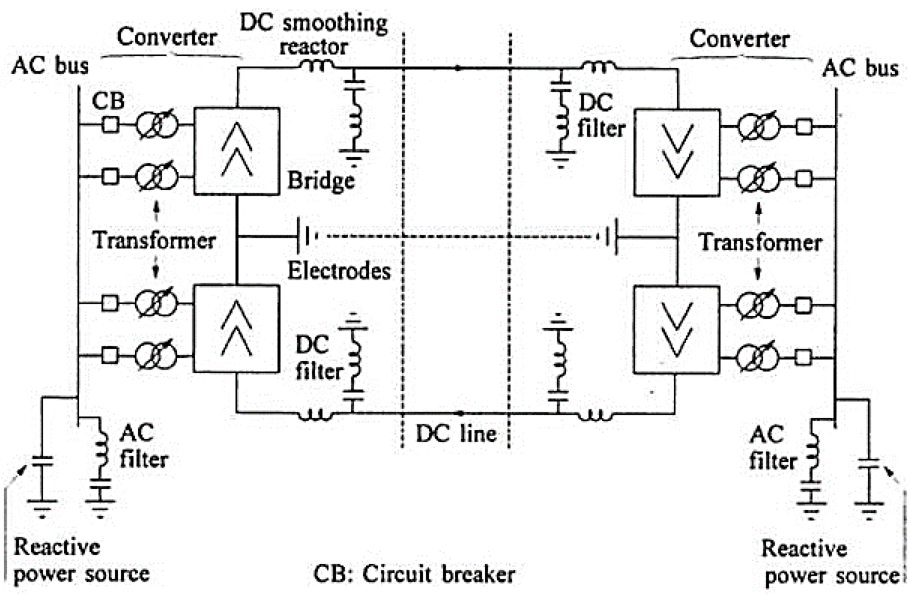

Figure 2.4: Schematic of HVDC Transmission System.

2.3.1 Converters

The power electronic converter usually used to change the power parameters and these parameters can be current, voltage or frequency. In HVDC transmission system, the converter station is installed with thyristor based which convert AC to DC is called rectifier while another converter station which convert DC to AC is called inverter. In additional, the converters contained valve bridges and transformers. The valve bridges are connected in a layout of 6 pulses or 12 pulses. The transformers are not grounded and hence the DC system capable to set its reference to ground.

2.3.2 Smoothing Reactors

The smoothing reactor of HVDC is showed in Figure 2.5. HVDC smoothing reactor can be designed as air core and oil-insulated unit as well. The connection between smoothing reactor and converter is in series. The main functions of smoothing reactors are:

- To smooth the ripple currents in DC.
- To limit the fault currents in the DC line.
- To reduce the harmonic voltage and current in DC line.
- To avoid commutation failure in the inverter.
- To avoid current discontinuous for the loads.

Figure 2.5: HVDC Smoothing Reactor.

2.3.3 Harmonic Filters

Harmonics are generated by HVDC converters in voltage and current. Generally, the AC harmonics are occurred in the AC system, while the DC harmonics are occurred in the DC lines. These harmonics can cause overheating on the capacitors and generators. Also, interfere the telecommunication systems. To minimize the harmonics, AC and DC filters are installed in HVDC system. The AC filters are based on RLC circuit which connects between phase and ground. By using AC filters, the low impedances are supplied to harmonic frequencies and resulting the AC harmonic currents passed through the ground. Both tuned and damped filters can be used. Furthermore, the reactive power can be supplied by AC harmonic filter to manipulate the converters efficiently. Connection between the neutral bus and pole bus is DC filter. The DC filters are applied to divert the DC harmonics to ground and avoid them getting into DC lines. Such a filter does not require reactive power as DC line does not require DC power. Figure 2.6 shows the area of AC filter.

Figure 2.6: AC Harmonic Filter Area.

2.3.4 Reactive Power Source

At steady state condition, the reactive power required by converter is concerning half of the active power transferred. The reactive power consumption may higher at transient condition. Besides that, the additional supply also can be received from shunt capacitors.

2.3.5 Electrodes

Electrodes are the conductors used to make connection to the ground for neutral. The functions of electrodes are reducing the current densities and surface voltage gradients.

2.3.6 AC Circuit Breakers

AC circuit breakers are usefulness to remove the faults in the transformer and prevent the DC links continuously function. But for DC fault, it can be removed by converter. The AC circuit breakers are typically located at valve hall as shown in Figure 2.7.

Figure 2.7: AC Circuit Breakers.

2.3.7 Layout of HVDC Transmission System

Figure 2.8 shows the layout of HVDC transmission system. It consists of AC switchyard, converter building and DC switchyard. The AC filters are located near the AC switchyard and shunt capacitors are located beside the filters.

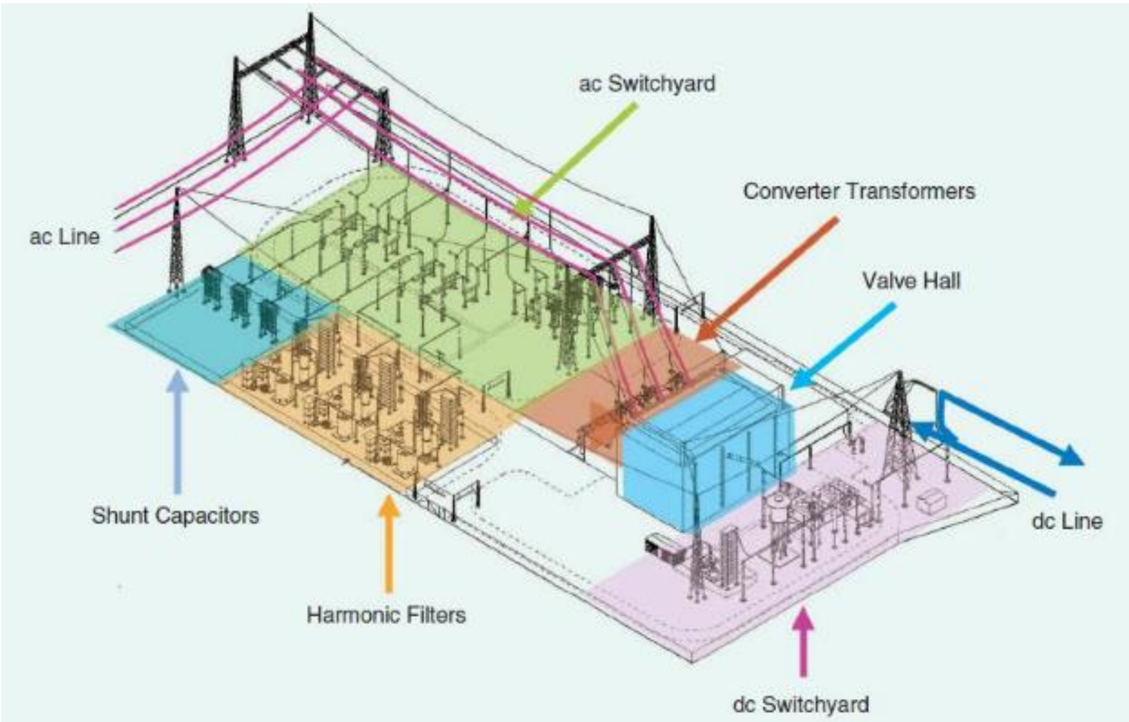

Figure 2.8: Layout of HVDC Transmission System.

2.4 Types of HVDC Transmission System

In electric power sector, the HVDC transmission system can be designed in some ways to support the price, flexibility and operational needs. The HVDC system can be connected in different ways.

2.4.1 Back to Back HVDC System

The electric power transferred by HVDC system at the same place is called back to back system. The structure of the system showed that two converters are installed at the same place without using long DC line in the power transmission system. Normally, the back to back HVDC system is connected with two adjacent asynchronous AC system. These two AC system interconnections are providing the frequency range in between 50 Hz and 60 Hz. Figure 2.9 shows the circuit diagram of back to back HVDC system.

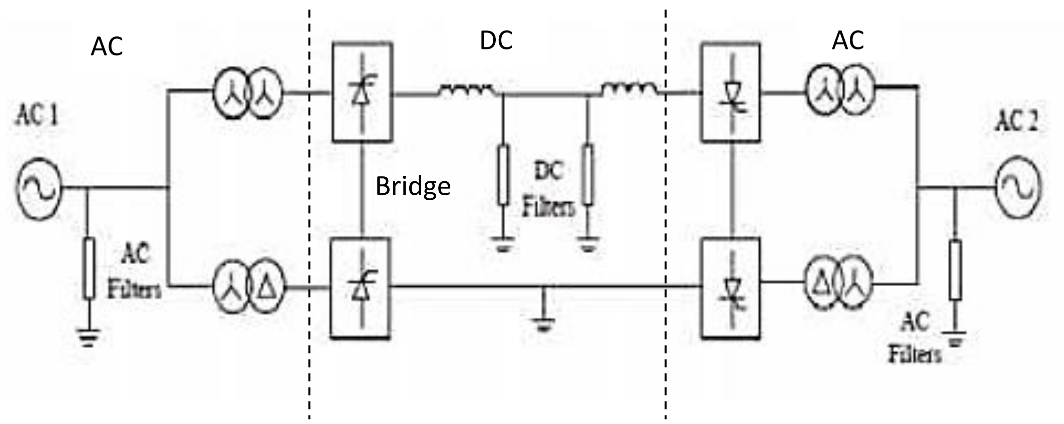

Figure 2.9: Circuit Diagram of Back to Back HVDC System.

2.4.2 Monopolar HVDC System

In Monopolar HVDC system, a single pole line is being used to separate the two converter stations. By either ground or sea, the path of current is fully returned. Moreover, this monopolar configuration can be used to connect the submarine cables for transmission system. Figure 2.10 shows the circuit diagram of monopolar HVDC system.

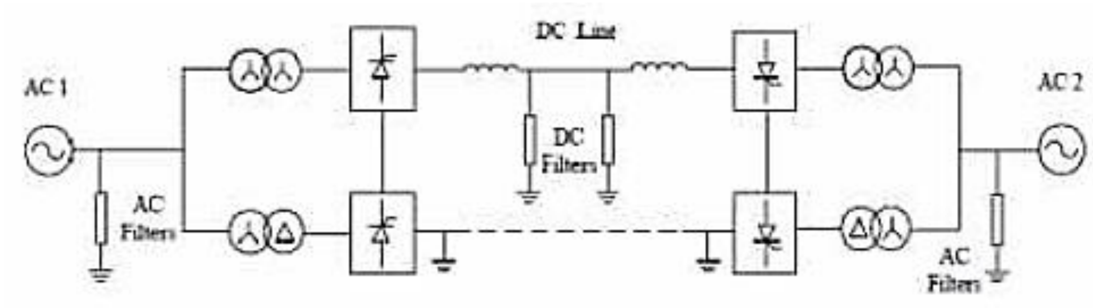

Figure 2.10: Circuit Diagram of Monopolar HVDC System.

2.4.3 Bipolar HVDC System

Two monopolar systems connected in parallel is known as bipolar HVDC system. Bipolar system consists of two conductors which are positive and negative. Each system can be operated separately as an independent system with the ground return. The currents occurred in both poles are same, since one is positive and another is negative. Hence, the ground current is zero or the ground current is within a difference of 1 percent. One of the benefits is that the pole can still proceed for transmitting the power if a fault occurred on another pole. Also, it is the most common use of configuration for HVDC transmission system. Figure 2.11 shows the circuit diagram of bipolar HVDC system.

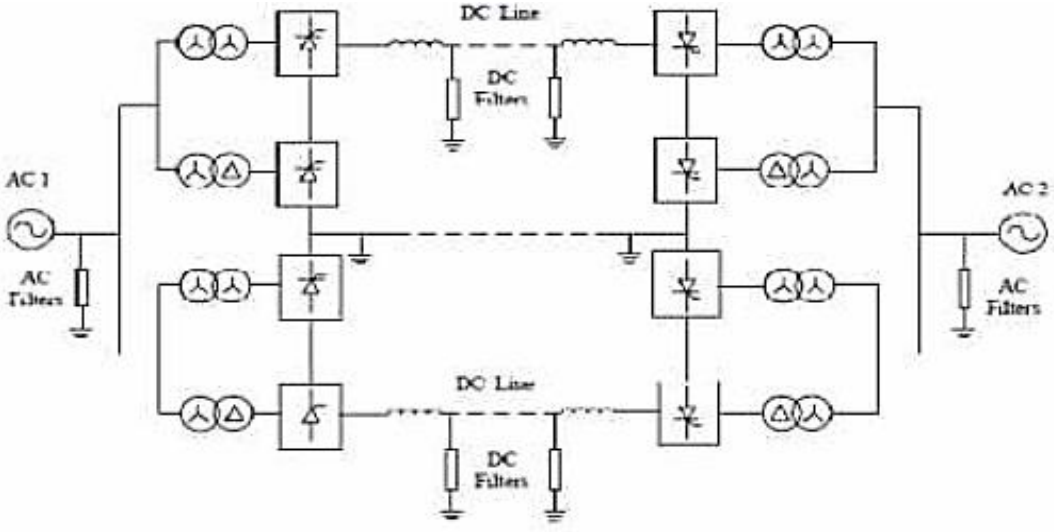

Figure 2.11: Circuit Diagram of Bipolar HVDC System.

2.4.4 Multi-terminal HVDC System

While, the system that involves three or more converter stations is known as multi-terminal HVDC system. They are separated to different location and interconnected through transmission cables or lines. This configuration has offered an effective way to transfer large power and improve stability of the system. Figure 2.12 shows the circuit diagram of Multi-terminal HVDC system.

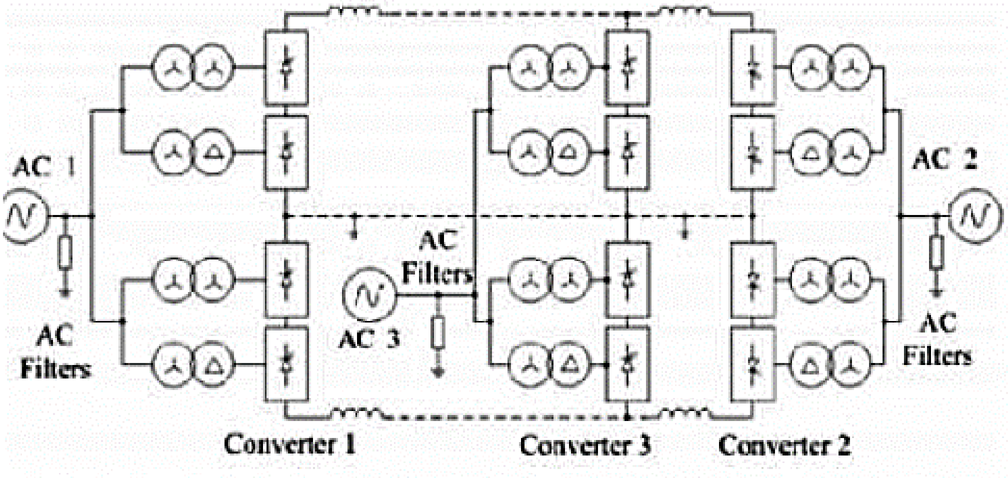

Figure 2.12: Circuit Diagram of Multi-terminal HVDC System

2.5 Types of Converter

Based on converter configuration, it consists of two different technologies used for HVDC transmission system. They are Line Commutated Converter (LCC) and Voltage Source Converter (VSC).

2.5.1 Line Commutated Converter (LCC)

In early research of the converter technology, the HVDC transmission system mainly based on mercury valves. The major drawback of mercury-arc technology is ark-back fault which damaged the rectifying property of the converter valve and consequently caused other issues. Thus, a new thyristor valve technology has been found to overcome these problems. Converter with mercury valve based or thyristor valve based is called line commutated converter (LCC). LCC-HVDC converter generally formed by three phase and full wave bridge circuit. Then, higher current and voltage thyristors is developed to eliminate the parallel connections and minimize the number of series connections for thyristors at each valve (Toledo, P. F. D., 2003). Besides that, most of the LCC-HVDC links are involved using submarine cables and there has no LCC-HVDC link applied to converters on offshore substation. As shown in Figure 2.13, the LCC-HVDC transmission system has the components like thyristor valves, AC filters, DC filters, smoothing reactor, capacitor bank, converter transformer, DC cable and auxiliary power set. The LCC-HVDC is a very successful technology and there are many expectations for LCC–HVDC to grow better.

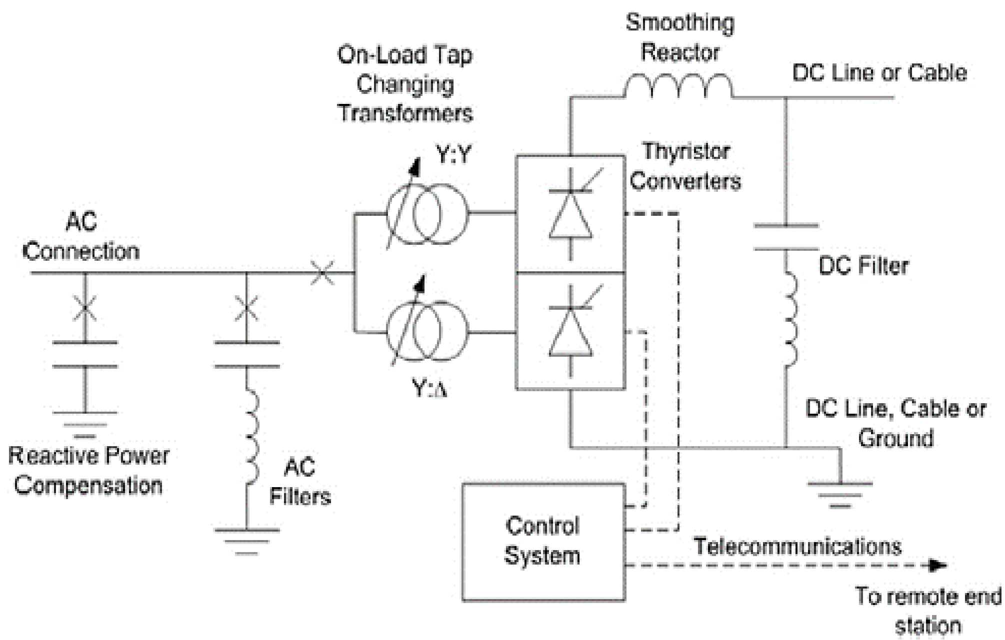

Figure 2.13: LCC – HVDC System

2.5.2 Voltage Source Converter (VSC)

Voltage-source converter (VSC) is a relatively new converter technology for HVDC transmission system. After the development of Insulated Gate Bipolar Transistor (IGBT), the VSC has been widely used for power transmission system. The world first VSC-HVDC system is commissioned in Gotland island of Sweden in year 1999. Voltage-source converter is exploitation self-commutating switches which can be turned on or off easily (Toledo, P. F. D., 2003). This showed that the reversed voltage can solely turns off the thyristor valve. For HVDC applications, the converters have been categorized into three types which are two level converter, three level converter and modular multilevel converter. The major features of VSC are a four-quadrant operation capability, difficult design and higher power losses compared to LCC. The circuit diagram of VSC – HVDC system is showed in Figure 2.14.

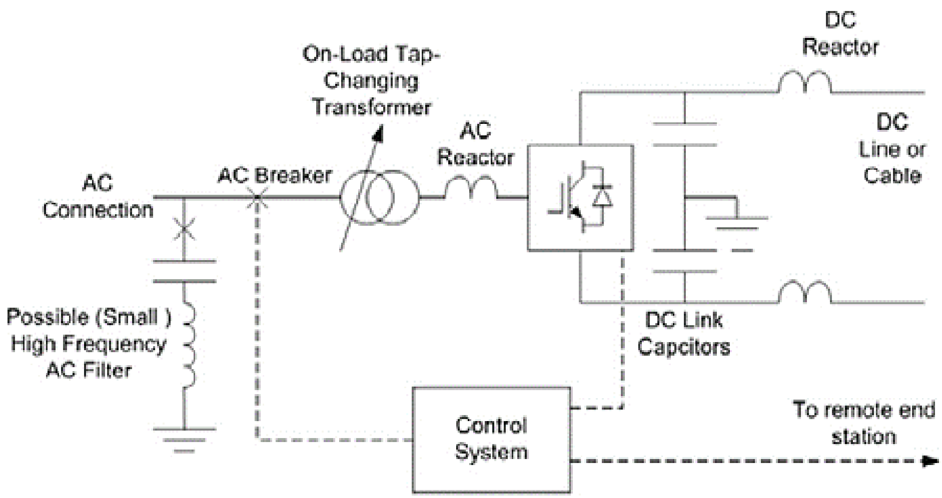

Figure 2.14: VSC – HVDC System.

2.5.3 Comparison of HVDC Converters

Table 2.1 shows a comparison of the LCC based and VSC based for HVDC transmission system.

Table 2.1: Comparison of HVDC Converters.

	LCC-based HVDC	**VSC-based HVDC**
Power Capability	Up to 8000MW.	Up to 1400MW.
Overload Capability	Good, continuous and short time.	None.
AC System Requirements	Strong existing network is required	Can operate into weak AC systems or no AC system.
Reactive Power	Control by switching ac harmonic filters.	Control by the converter.
Harmonic Performance	Convertor generated distortion reduced by ac and dc filters.	Very low harmonic distortion. No filters required.
Losses	0.8 %	1.0 %
Land Take	Large site, dominated by the ac harmonic filters	50 to 70% of LCC equivalent rating
Cable Technology	Mass impregnated (MI) technology only.	Both MI and XLPE technologies are available.

2.6 Comparison of AC and DC Transmissions

The electrical power needs to be transmitted either by AC or DC. Each system has their own advantages and disadvantages. Hence, a comparative study is carried out to decide which is the best system to transmit the electrical power over longer distance.

2.6.1 Advantages of HVDC Transmission System

- **DC transmits more power per conductor:** An AC link and a DC link have different capability to transmit the power. DC is required only two conductors as compared to AC with three conductors as shown in Figure 2.15.

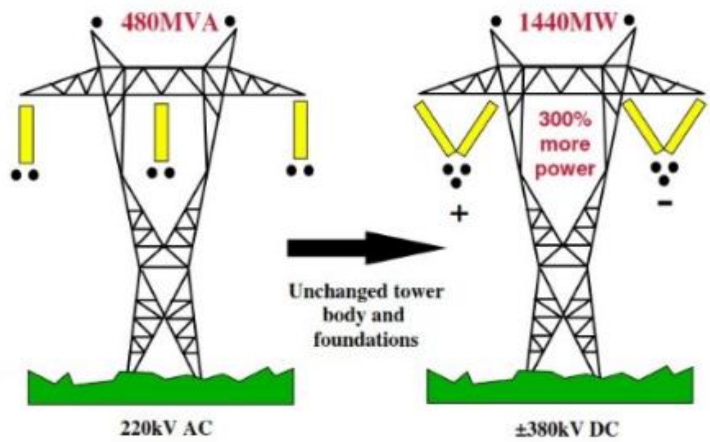

Figure 2.15: Three Conductors AC Tower versus Two Conductors DC Tower.

- **Lower Space and Smaller Tower Size:** The DC insulation level for a similar power transmission is less than the corresponding AC level.

Also, the DC line required only two conductors while three conductors are required for AC. Hence, the electrical and mechanical design aspects brought the tower to become smaller. Besides that, the DC transmission line lead to lower space requirement and the transmission towers have been reduced from two to one transmission. Figure 2.16 shows the tower sizing and land spacing for AC and DC transmission.

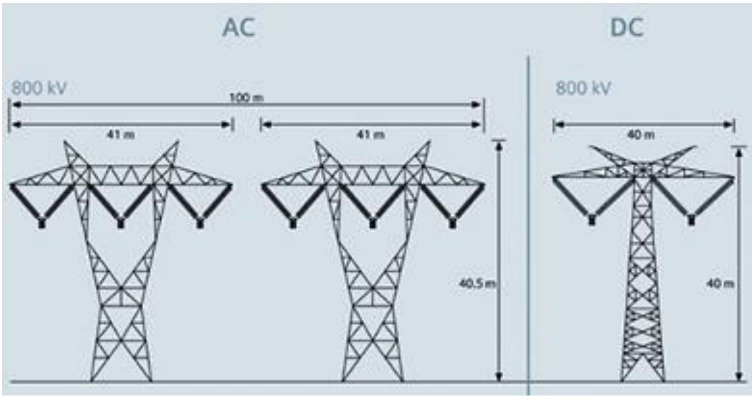

Figure 2.16: AC Transmission Tower versus DC Transmission Tower.

- **Higher capacity available for cables:** In review of the overhead line, the breakdown cable is occurred by stimulate instead of external flashover. The main reason behind is due to the absence of ionic motion. Moreover, the working stress of the DC cable insulation is three times higher than AC (Behravesh, V. & Abbaspour, N., 2012). Without continuous charge of current, the DC cable able to transmit higher active power over the long distance.

- **No skin effect:** Under AC conditions, the current is not constantly distributed over the conductor. From these conditions, it can be seen that the current density is larger in the outer region (skin effect) and end in underutilization of the conductor cross-sectional. However, there are no skin effect under the conditions of stable DC and result a constant current supplied in the conductor that allows the conductor metal to have a better use.

- **Less corona and radio interference:** The corona effects are lower when the frequency increased for a specific conductor diameter and applied voltage. Therefore, the radio interference with DC is lower. The cost of transmission line is also reduced due to lesser use on conductors.

2.6.2 Disadvantages of HVDC Transmission System

- **Expensive converters:** At each end of DC transmission link, an expensive converter station is needed but AC transmission link only needs transformer station.

- **Reactive power requirement:** More reactive power is required for converters during rectification and inversion. Each converter may use up to half of the DC active power. (Behravesh, V. & Abbaspour, N., 2012).

- **Generation of harmonics**: Converters produce much harmonics for both AC and DC sides. Thus, the filters are being used to minimize the number of harmonics transmitted through the AC system. But for DC system, smoothing reactors are installed for same purpose. Subsequently, these components cause the system more expensive.

- **Difficulty of voltage transformation:** In order to transmit higher voltage, the DC transformers need to carry out the voltage transformation on the AC system and avoid the DC system being used alone.

- **Difficulty of high power generation**: Because of some issues of commutation with DC voltage, speed, machines and size are restricted, the power generated by DC is relatively lower.

- **Absence of overload capacity:** Converters have lower overload capability in contrast to transformers.

2.7 Construction of HVDC Transmission System

To build a transmission system, it is required to spend a lot of time from contract date to completion. The construction normally takes about three years for LCC-HVDC system and one year for VSC-HVDC system. In this section, the process of construction for HVDC transmission is discussed.

2.7.1 Development of the Staging Area

Before the construction started, staging area is well prepared and used as a storage. The purpose of developing the staging area is to prevent the disturbances or incidents happen when moving the materials or building the transmission tower. The staging area can be used to store the equipment, building materials, fuels and some chemical materials. Besides that, blasting agents also be stored depend on the location of staging area. The location of staging area is located at every 15 km in order to use the materials or fuels immediately.

2.7.2 Establish Access

New access road is required for every transmission construction. It is essential to keep the construction and maintenance of transmission line continue run. Other than that, the sites clearing is also important for the structures. As shown in Figure 2.17, the specific sites are cleared before the towers and substations being build.

Figure 2.17: Site Preparation for Construction.

2.7.3 Tower Construction

The land required for constructing a tower is approximately area of 100 feet by 200 feet. Different type of tower is requiring different size of land. For lattice tower, the land needed is about 80k square feet. But for monopole tower, 32k square feet of land is needed for construction. Figures 2.18 to 2.23 show the construction process of a transmission tower.

Figure 2.18: Stones being drilled to make the tower foundation footings.

Figure 2.19: Anchor bolts cage is prepared to strengthen the tower.

Figure 2.20: Anchor bolts cage is installed.

Figure 2.21: Another hole being drilled for tower footing.

Figure 2.22: The components of tower are moved by using helicopter.

Figure 2.23: A crane being used to build the tower.

2.7.4 Substation Construction

The construction of a substation would takes around six to nine months. Land needed for substation is about 435k ft^2. Figure 2.24 shows the substation construction.

Figure 2.24: Substation under Construction.

2.7.5 Conductor Stringing

The conductor cables should install at overhead of a tower or underground to avoid damage to the conductor surface. In stringing process, a truck with mounted spool is utilized to pull the conductor cables without using additional land for tower construction. The direction of line can be severely changed due to the deviation occurred at diversion tower.

2.8 Design Features of HVDC Transmission System

By referring the design of transmission system, there are some factors can be considered to reduce the impacts of environment during the construction and operation of transmission system.

2.8.1 Route Selection

Route selection is the major design consideration to reduce the impacts of HVDC transmission system. In general, route selection is highly forced due to the uncertain factors, but to the extended practical, the following route selection factors must be considered which can reduce the impacts of the system:

- To avoid sensitive natural habitat and swampland.
- To avoid sensitive areas such as public park and uncultivated land.
- To avoid of farmland.
- To avoid historic buildings.
- To avoid residential areas.

2.8.2 Transmission Line Design

When designing the transmission line, there are few factors need to be considered such as materials, number of conductors, type of structures, type of wires and line markers. The impacts of transmission line also can be reduced by the following factors:

- **Tower design**: In design of transmission tower, the main consideration is the types of tower used for constructing the transmission system. The transmission tower is chosen and designed to be tall, overhead lines support and withstand the force from strong wind. Figure 2.25 shows the two different types of transmission tower.

Figure 2.25: Typical Power Transmission Towers: Lattice type, Monopole.

- **Phase to ground clearances**: It is the process of removing spacing between the conductors. It may involve to the clearances between the lien and other electric lines.

- **Specific mitigation features**: The transmission line impacts still able to be reduced by other design considerations. For example, the conflict between bird or aircraft can be prevented by utilizing the ball markers and flappers.

2.9 Cost of Transmission System

The cost of transmission system is depending on several factors, such as types of converter, components, types of transmission tower and power capacity. The conductor wires required by DC transmission is lesser than AC transmission, where two conductor wires for DC circuit and three conductor wires for 3 phase AC circuit. Thus, it clearly showed that the cost of HVDC transmission is cheaper than HVAC transmission. However, the converter stations are costly to HVDC transmission which does not need for HVAC transmission. Figure 2.26 shows a specific distance so called break even distance. From the figure, it is clear that the HVDC transmission lines is much cheaper than HVAC transmission lines. The break even distance is about 600km for overhead lines and 50 km for submarine lines.

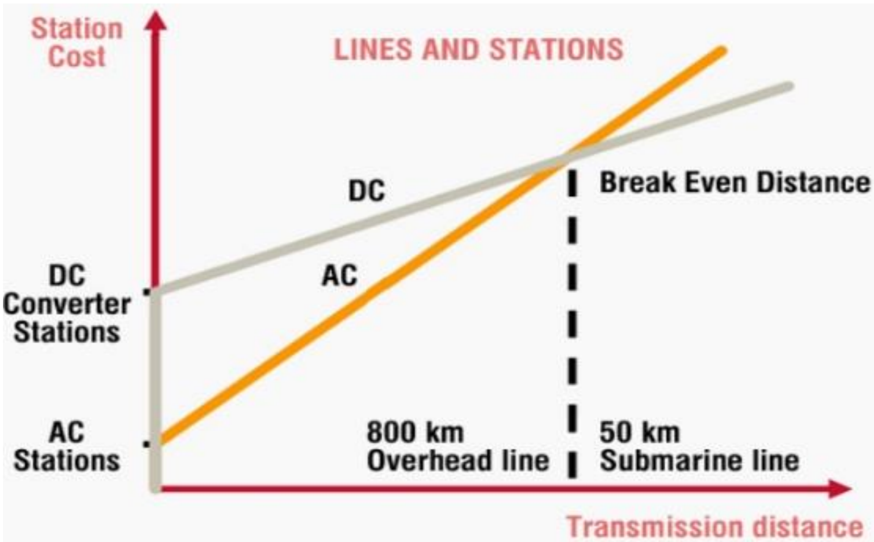

Figure 2.26: Cost of HVAC and HVDC Transmission Lines.

2.9.1 Cost of HVDC Transmission Components

In this section, the cost of HVDC transmission components is studied and discussed. The components cost would be based on LCC-HVDC and VSC-HVDC. One of the challenges of this study is lack of data about the components cost due to the private and confidential. However, an attempt to provide the data as accurate as possible. All the data are referred from references and the prices presented are in Euros, €.

2.9.1.1 Cost of LCC-HVDC Components

In 2002, a LCC – HVDC interconnection is built between Greece and Italy. The system is connected by using submarine cables. According to (Lazaridis, L. P., 2005), the 500 MVA converter stations are cost about 80M Euros and providing a price of 0.08 Euros per VA. To make the data accurate, the price of this case will be used as a reference. The price of submarine DC cables is compared between the year of completion and year 2004, as shown in Table 2.2. Table 2.3 lists the cost of cables per km.

Table 2.2: DC Cable Cost according to Power Capacity.

Cable capacity (MW)	**Project Name**	**Price in year of completion**	**Price in 2004**
600	Sweden-Poland link	€860/km in year 2002.	€900/km

550	Iceland link	€820/km	€724/km
500	Italy-Greece link	€660/km in year 2002.	€700/km
440	Skagerrak 3 link	€170 M	€700/km

Table 2.3: Cable Cost per km for LCC-HVDC Transmission System.

Rated Power for MI cable (MW)	600	500	440	300	250	150
Cost (M€/km)	0.85	0.74	0.67	0.51	0.45	0.32

2.9.1.2 Cost of VSC-HVDC Components

From the ABB technical report, the price of VSC-HVDC converter station is about 0.12 Euros per VA. There are three different power rated of cables used such as 250, 350 and 500 MW. All these cables have approximately rated voltage of 150 kV. The installation cost of the cable will be 100k Euros per km and hence, a pair of cable will be 200k Euros per km. The Table 2.4 shows the cost of cable per km for VSC – HVDC transmission system.

Table 2.4: Cable Cost per km for VSC – HVDC Transmission System.

Rated power for cable (MW)	250	350	500
Cost for each cable pair (M€/km)	0.31	0.45	0.61

2.9.2 Cost Structure of HVDC Transmission System

Other than that, there are many factors can be involved to the cost of HVDC transmission system, such as types of converter station, components, types of transmission tower, power capacity and environment conditions. Figure 2.27 shows the typical cost structure of a converter station, whereby 20% of the cost goes to the valves, 16% of the cost goes to the converter and transformers.

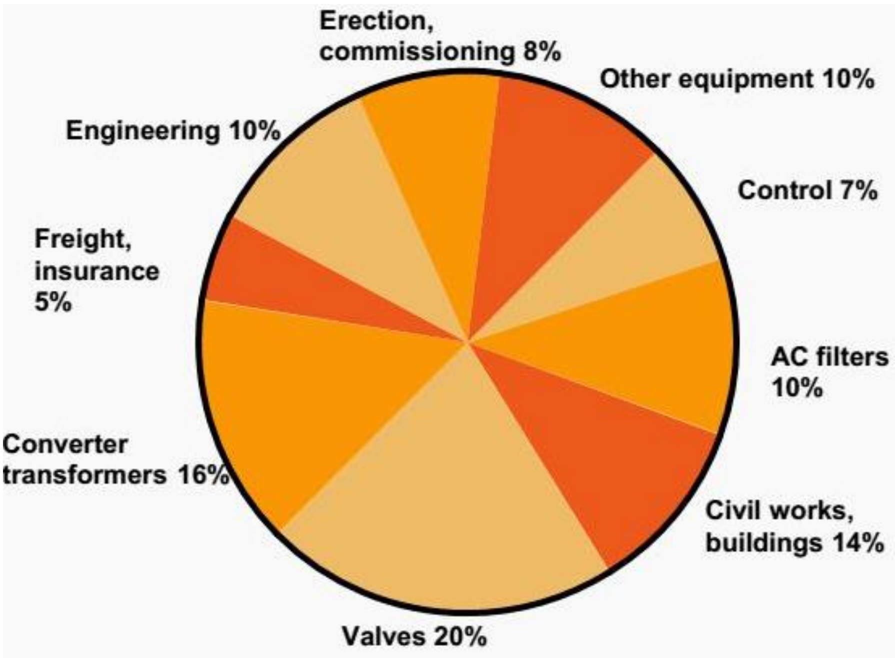

Figure 2.27: Cost Structure of HVDC Transmission System.

2.9.3 Cost of HVAC Components

From the cost of HVDC components, it is clear that the data is divided into two aspects which are the converter station cost and the cable cost.

Although these two aspects are important, but the HVAC components listed for the costing are more extensive. The HVAC components are:

- Transformers.
- Compensators.
- 132 kV, 220 kV and 400 kV three-core, XLPE, submarine cables.
- Cable installation cost.
- Switchgear.

2.9.3.1 Cost of Transformers

From the review of (Lazaridis, L. P., 2005), the cost of transformers is depending on the rated power. As shown in Table 2.5, higher rated power makes the cost of transformers become higher.

Table 2.5: Cost of Transformers.

Rated Power (MVA)	800	722	630	400	300	250	200	180	150	125	100	50
Cost (M€)	5.05	4.68	4.23	3.01	2.44	2.11	1.79	1.66	1.45	1.26	1.07	0.64

2.9.3.2 Cost of Compensators

Compensator is an essential component for every HVAC transmission system. It is giving a fast acting reactive power compensation on the transmission network. The compensation required is depending on the voltage levels and the distances between each end of AC cable. Table 2.6 shows the compensation needed on different voltage level and transmission distance.

Table 2.6: Compensation Needed (MVA) at Each End of Each Cable Installed.

MVA	**Transmission Distance**					
Transmission Voltage	50 km	100 km	150 km	200 km	250 km	300 km
132 kV	33	65	98	130	163	195
220 kV	72	143	214	285	356	-
400 kV	227	453	679	905	-	-

The cost of the compensators is the 2/3 of the price of transformer, as listed in Table 2.7. It is clear that the cost of compensator is increasing if the voltage level and rated power is increasing.

Table 2.7: Cost of Reactive Power Compensators.

132 kV						
Rated power for compensator (MVA)	33	65	98	130	163	195
Cost (M€)	0.31	0.52	0.70	0.86	1.02	1.17

220 kV						
Rated power for compensator(MVA)	72	143	213	285	356	
Cost (M€)	0.55	0.92	1.25	1.55	1.83	
400 kV						
Rated power for compensator(MVA)	227	453	679	906		
Cost (M€)	1.31	2.20	2.98	3.69		

2.9.3.3 Cost of AC cable

With voltage level of 400 kV AC cable, the cost is about 1.96M Euros per km. The installation cost for the HVAC cables will be 100k Euros per km. One of the considerations is that only one cable can be place when installing one path of cable.

2.9.3.4 Cost of Switchgear

Lastly, the switchgear costs are presented in Table 2.8 with four different voltage levels. Switchgear is used as a disconnect circuit breaker to protect and control the equipment in the transmission system.

Table 2.8: Cost of Switchgear.

Rated voltage for switchgear (kV)	33	132	220	400
Cost (M€)	0.06	0.13	0.19	0.31

2.10 HVDC Transmission System in Malaysia

The 300/600 MW Thailand – Malaysia HVDC system is the first HVDC interconnection in ASEAN region. At the beginning, this HVDC interconnection project is planned to implement in between Malaysia and Thailand in 1997. The project is then started on February 2000 and completed on September 2001.

As shown in Figure 2.28, the HVDC system is connected as monopolar 300 kV overhead transmission lines with rated power of 300 MW. Power is transmitted from converter station at Gurun, Kedah to another converter station at Khlong Ngae, Thailand over the distances of 110 km as shown in Figure 2.29.

On 15 August 1997, a contract is signed between TNB and Electricity Generating Authority of Thailand (EGAT) to develop this HVDC interconnection project (Halirni Abdullah, M., 2003). The purposes are:

- To share the spinning reserve between TNB and EGAT AC systems.
- To get more economical power exchange between both countries due to the different daily peak consumption periods.
- Emergency assistance to either AC network.
- Reactive power support (voltage control) to both AC networks.

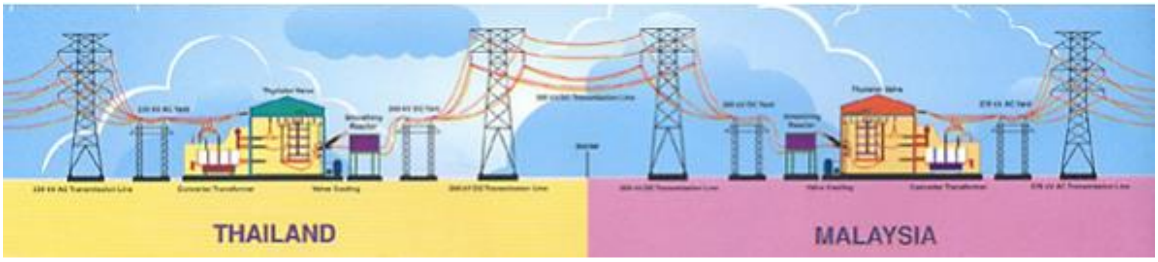

Figure 2.28: Monopolar HVDC System between Malaysia and Thailand.

Figure 2.29: The Thailand – Malaysia Interconnection HVDC System.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, a real case study for HVDC transmission system is selected to compare with a HVAC transmission case study based on the background, layout, design features and components required. Moreover, a simulation is carried out for each transmission system to compare and analyze the fault current effects.

3.2 Background

3.2.1 Xiangjiaba – Shanghai HVDC Transmission System

Countries such as China and India are growing rapidly in their economies and hence, the demand of energy is increasing for both countries. In China, 800 kV Xiangjiaba – Shanghai HVDC transmission system is built and rated for 6400 MW. It is commissioned by State Grid Corporation of China (SGCC) to transmit the hydro power from Xiangjiaba Dam to the Shanghai city. SGCC is state-authorized investment and a pilot state holding company which focus to construct and operate the power grids. In July 2010, Xiangjiaba – Shanghai HVDC system became the most powerful and longest

HVDC transmission system in the world. However, the power capacity record is taken over by the 800 kV Jinping–Sunan HVDC with rate of 7200 MW in December 2012 and distance record is taken over by Rio – Madeira HVDC, Brazil in 2013.

As shown in Figure 3.1, the Xiangjiaba – Shanghai HVDC transmission system able to transmit the power over distances of 2000 km from south west of China to Shanghai on eastern of China. Other than that, the 800 kV DC voltage is operated to minimized the losses from transmission. With eco-friendly hydro power generator and low power losses of HVDC transmission system, the CO2 p.a. is save up to 44 million metric tons compared to local power supply with energy-mix.

In Fulong converter station, there are ten DC converters have been installed for the lines by Siemens Energy. Furthermore, Siemens cooperate with XPR to install the six-inch thyristor valve based towers and connectors. Table 3.1 is clearly listing the information of Xiangjiaba – Shanghai HVDC System.

Table 3.1: Information of Xiangjiaba – Shanghai HVDC System.

Customer	State Grid Corporation of China and XD Xi’an Power Rectifier Works (XPR)
Project name	Xiangjiaba
Location	Xiangjiaba to Shanghai
Type of plant	Long-distance transmission,

	2070 km
Power rating	6400 MW, bipolar
Voltages levels	± 800 kV DC, 525 kV AC
Type of thyristor	Electric-triggered thyristor, 8 kV (6 inches)

Figure 3.1: The Xiangjiaba – Shanghai HVDC Transmission System.

3.2.2 Raichur–Solapur HVAC Transmission System

In India, the 765 kV Raichur – Solapur HVAC transmission system has been energized by Power Grid Corporation of India Ltd. This HVAC transmission system is commissioned on December 2013 and is connected from Raichur in Karnataka to Solapur in Maharashtra with a distance of 208 km as shown in Figure 3.2. The line is implemented under the scheme of synchronous interconnection between Southern Region and Western Region.

With this interconnection, the power system of India has become one of the largest synchronous operating grids in the world with the total power capacity of 235 GW. Subsequently, the goal of ‘One Nation – One Grid – One Frequency’ has been achieved.

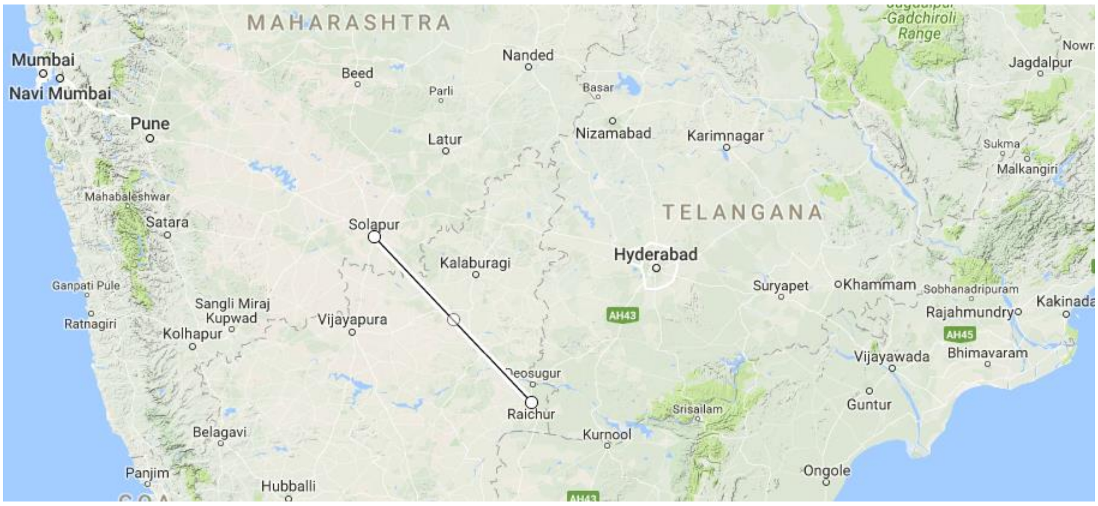

Figure 3.2: The Raichur – Solapur HVAC Transmission System.

3.3 Layout

3.3.1 Layout of the Xiangjiaba – Shanghai HVDC Transmission System

The Xiangjiaba – Shanghai HVDC transmission system will transmit electrical power with lower power losses from Xiangjiaba, Fulong Station, Sichuan Province to Shanghai through a DC line length of 2000 km.

The system is using bipolar type connection which connecting Fulong converter station to Fengxia converter station in Shanghai. The Fulong converter station so called rectifier, is located about 10 km away from the south of Xiangjiaba hydro dam. Four of 500kV AC lines are used to make the connection between Fulong converter station and generation stations.

Meanwhile, the Fengxia converter station so called inverter that located around 45 km from the center of Shanghai. It is linked to the Nanhui station with three of 500 kV AC lines in Shanghai. The layout of power system is illustrated in Figure 3.3.

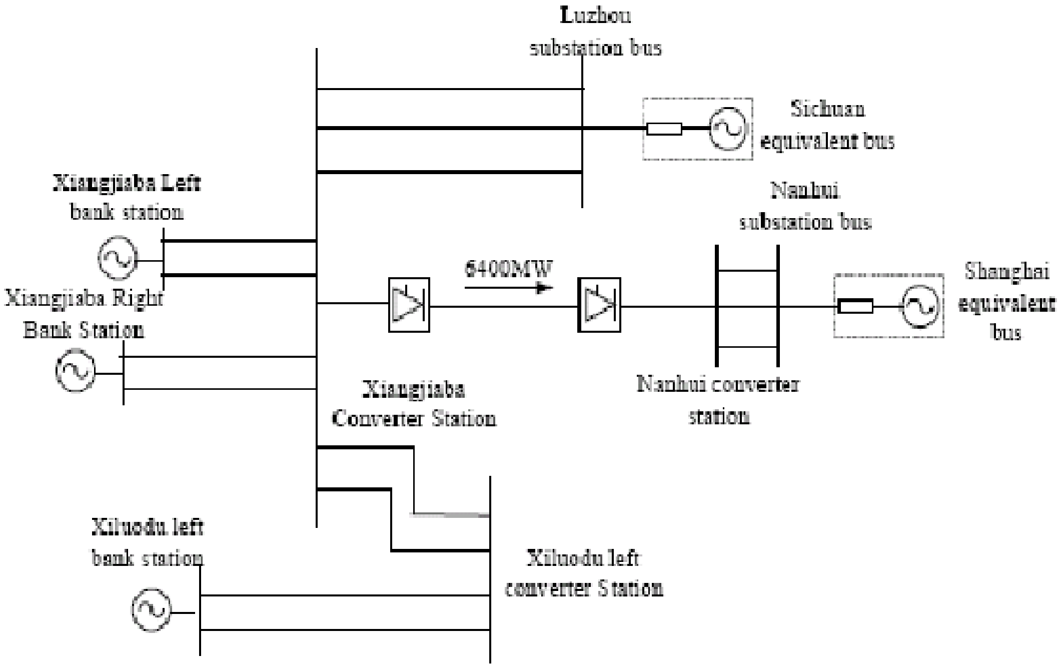

Figure 3.3: Power System Layout for Xiangjiaba – Shanghai HVDC.

3.3.2 Layout of the Raichur – Solapur HVAC Transmission System

The Raichur – Solapur HVAC transmission system is categorized into two parts which are transmission system and distribution system. Each of the system can be divided into two stages. First stage is the primary transmission and next is the secondary transmission as shown in Figure 3.4. The generation and transmission are three phase type.

For primary transmission, the electrical power is generated at 220 kV in a power plant. This generating voltage is then stepped up to 765 kV. The purpose of stepping up the voltage is to minimize the power losses when transmitting the electrical power. After that, the voltage is stepped down to 400 kV at a receiving station (RS).

For secondary transmission, the RS is connected to the substations which located near the city. The transformer is stepping down the voltage to 11 kV at substation. Then, the first distribution also called as primary distribution is using this voltage to supply to bigger consumers like industrials.

At last, secondary distribution system is transmitting the 415 V stepped down voltage to other consumers.

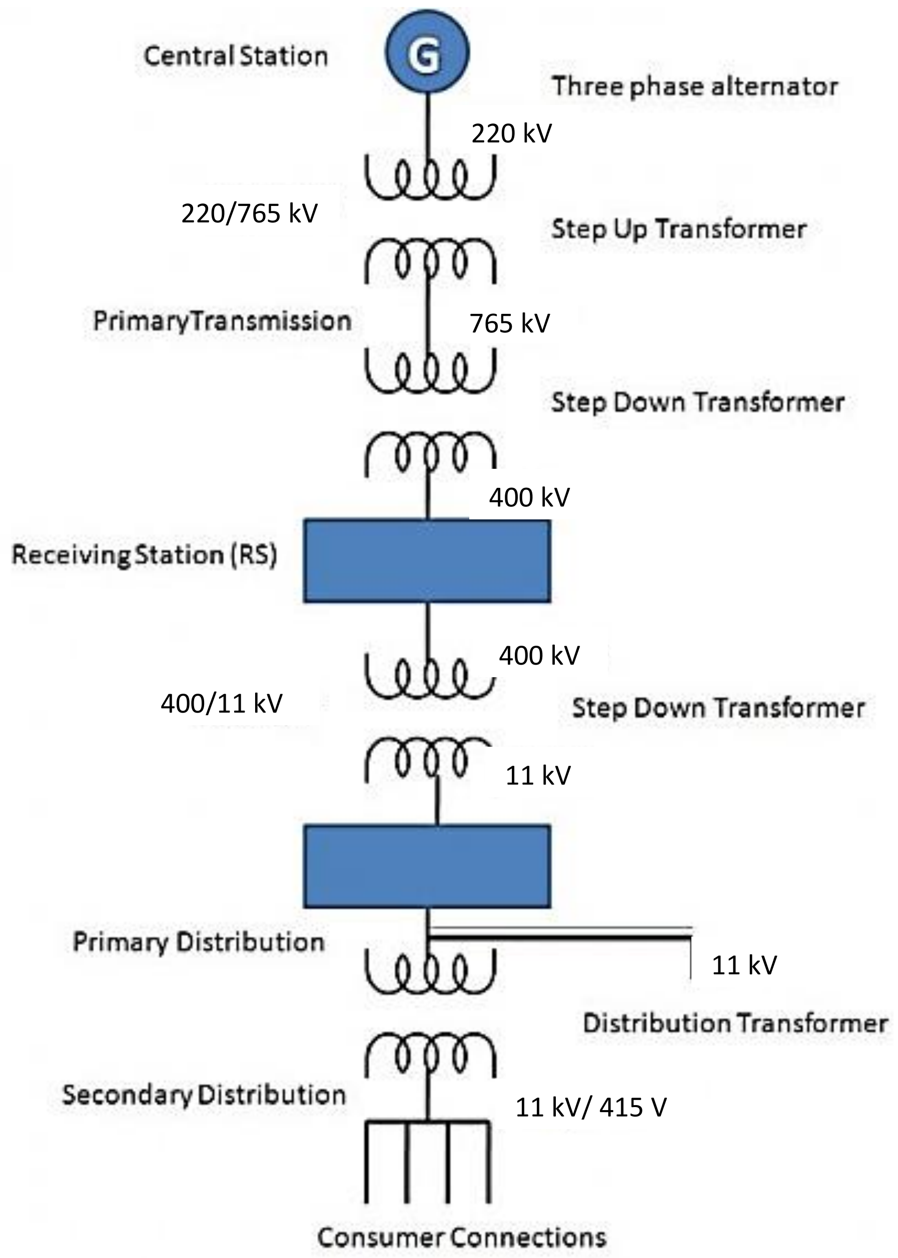

Figure 3.4: Power System Layout for Raichur – Solapur HVAC.

3.4 Design Features

3.4.1 Design Features of the Xiangjiaba – Shanghai HVDC Transmission System

The bipolar HVDC system is supplying the power rated of 6400 MW and DC voltage of 800 kV at Fulong converter station. The pole voltage is achieved by connecting two 400 kV twelve-pulse bridges in series. The transmission system able to transmit maximum rated of power without needless of cooling service. When high current occurred in the converter, the system will automatically operate in de-icing mode that used to melt the ice on the pole lines. The converters used are 12 pulses arrangement which connected in parallel in every station. Each station will be operated at 400 kV. Figure 3.5 shows two 400 kV of convert stations are connected in series.

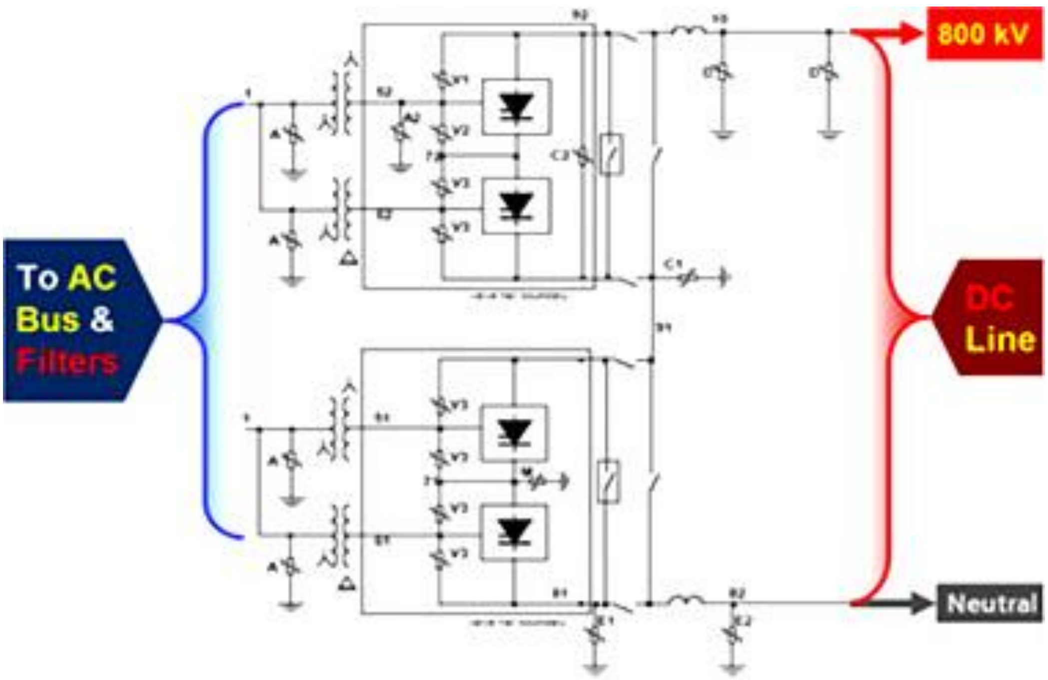

Figure 3.5: Bipolar Station Layout with two 400 kV Converters in Series.

3.4.2 Design Features of the Raichur – Solapur HVAC Transmission System

In Raichur – Solapur HVAC system, the transmission lines are designed by 765 kV single circuit. Thus, larger land space is required for this 765 kV transmission line, approximately width of 200 feet. Besides, high tension insulators are also widely used in this transmission line. Figure 3.6 shows the high tension insulator which designed with two corona rings.

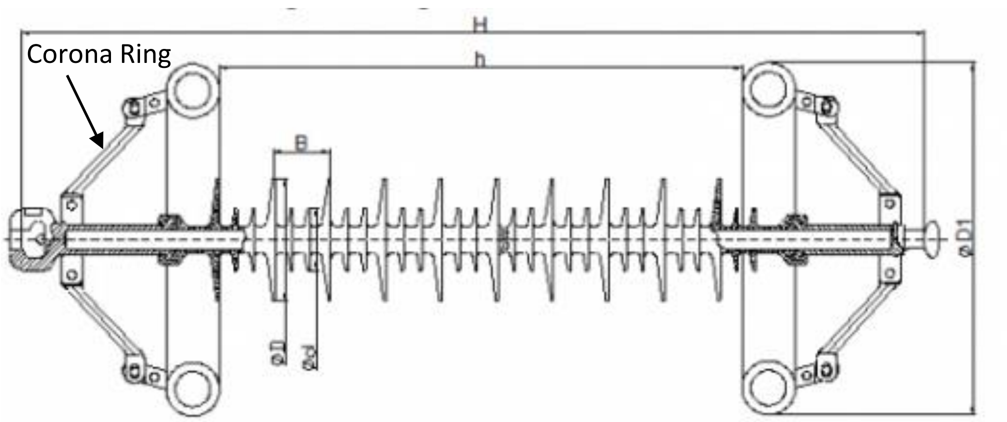

Figure 3.6: High Tension Insulator.

3.5 Main Components

3.5.1 The Xiangjiaba – Shanghai HVDC Transmission System

3.5.1.1 Thyristor Valves

The thyristor valves are designed by six inch YST130 type of thyristors. There are 56 units of thyristors in every valve. From the previous research, these thyristors have been exploited and widely used in the applications with high current. It was the first HVDC transmission project that using six inch thyristors.

3.5.1.2 Converter Transformers

In Xiangjiaba – Shanghai HVDC Transmission System, the transformers are designed in single phase with two windings. The transformers are made either in China or in Sweden.

3.5.1.3 Smooth Reactors

The smoothing reactors used are in air insulated type. There are two units of smooth reactors installed at 800 kV voltage side, while another two units installed in the neutral voltage side.

3.5.2 The Raichur – Solapur HVAC Transmission System

3.5.2.1 Generators

Generator is one of the important components for power system. It is synchronous type and converting the mechanical energy to electrical energy. Generator consists of stator and rotor. The stator is the stationary part that has conductors embedded in the slots. While, the rotor is mounted on the shaft and rotates inside the stator.

3.5.2.2 Transformers

Normally, the transformers are used in the substations. It able to step up or down the system voltage. The voltage can only be stepped up when the power transmitted at the generating end, while the voltage is gradually stepped down to reach finally to working voltage level at all the subsequent substations.

3.5.2.3 Transmission Line

The transmission line is a conductor designed to transmit the electric power from generation station to the distribution system.

3.5.2.4 Bus Bars

Bus bars are used to connect the transmission lines which are operating at same voltage directly. These bus bars are made either by copper or aluminum.

3.6 Short Circuit Current in HVAC and HVDC Transmission Systems

Sometimes, the electric faults are occurred when large amount of current flow through an alternative path. Due to this, the power becomes unstable, a serious damage on equipment, people injured or may cause people to death. In transmission line, the symmetrical faults are approximately 5% (Mizanur Rahman, Md. et al, 2014).

If some phases are affected, the result of the asymmetrical fault becomes more complicated to determine. This is due to the simplifying assumption of equal current magnitude is being not suitable in all phases. Asymmetric faults consist of three types such as line to line fault, line to ground fault and double line to ground fault. Line to line fault is happened when two lines have contacted each other. A line to ground fault is happened between a line and ground. It can be easily caused by lightning or other storm damage. For double line to ground fault, it is happened when two lines are shorted to ground. It is usually caused by storm damage.

The short circuit current also known as fault current is occurred when the fault is detected in transmission system. A heavy current or high level fault current flow through the circuit can destroy the insulation system and cause the power surges the damage equipment that powered by current. Furthermore, the devices are charged to manage the electric shock released to the human body. However, the electric shock also can cause death depends on the nature of the fault current.

Hence, a simulation is carried out for HVAC and HVDC transmission systems to compare and analyze the fault current effects. Both systems are using same parameters to have better analysis and results.

3.6.1 Simulation of HVAC Transmission System

Figure 3.7 shows a simulation model for HVAC transmission system by three phase and power rated of 1680 MW. The voltage level is set at 500 kV with the frequency of 50 Hz. The generated power is transmitted from a power plant to a substation through transmission distances of 300 km. Each line has series compensated by shunt capacitor in order to increase the power quality and power capacity. This compensator helps to reduce the losses from active and reactive power and increase the transmission power to maximum. In final stage, 1650 MW of power will be received at substation.

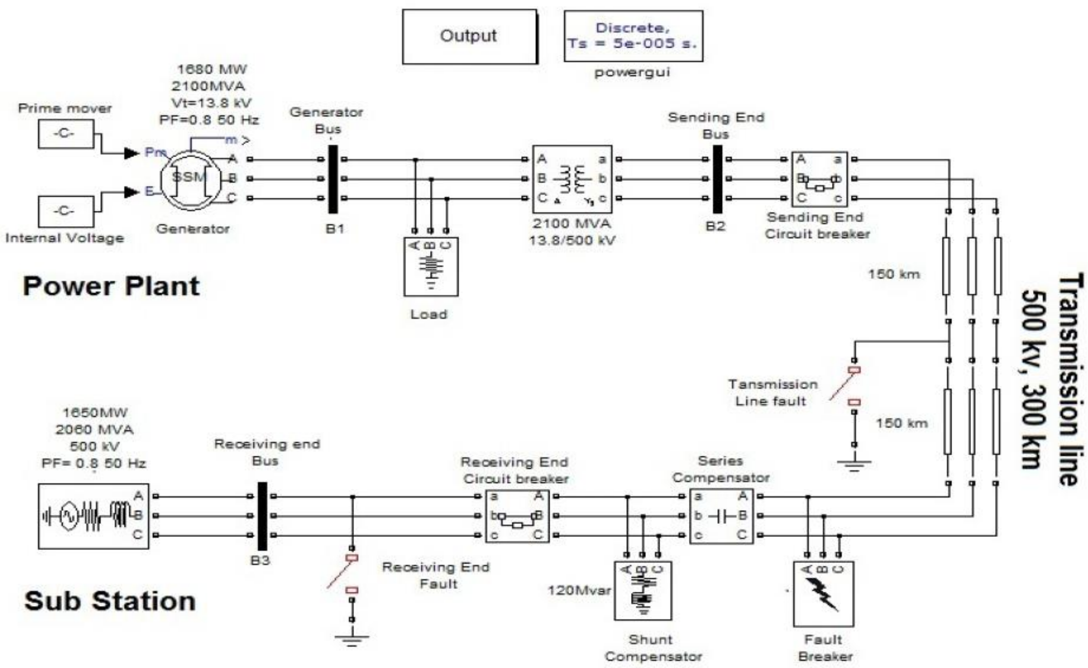

Figure 3.7: Simulation Model of HVAC Transmission System.

3.6.2 Simulation of HVDC Transmission System

Figure 3.8 shows a simulation model for HVDC transmission system by utilizing 12 pulse arrangement of thyristor converter. Then, the power is rated at 1680 MW and the voltage level is set at 500 kV with frequency of 50 Hz. The generated power is transmitted from a power plant to a substation through transmission distances of 300 km. The rectifier and the inverter are connected in series with two universal bridges. 0.9 H of smoothing reactors are then installed near the converters. The smoothing reactors are applied to minimize the fault current and avoid the resonance occurs in DC circuit. At last, 1645 MW of power will be received at substation.

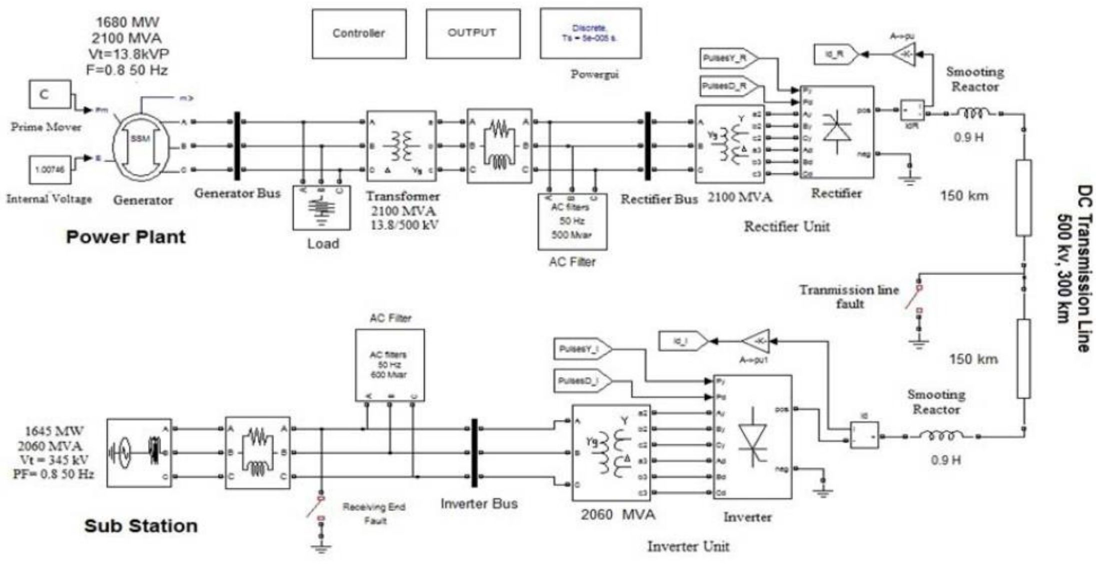

Figure 3.8: Simulation model of HVDC Transmission System.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Design Aspects for Transmission Lines

When designs the AC and DC transmission lines, electrical aspect and mechanical aspect are the important fields which can affect the cost of a transmission system.

By looking at the power capacity, the voltage level and the number of parallel circuits can be determined and used to calculate the cost of transmission system. Figure 4.1 shows the transmission lines for 800 kV AC and 500 kV DC.

For mechanical aspect, the conductor designs play an important role for a transmission system. The number of conductors used can affect the cost of transmission, this will be discussed in section 4.4. The power capacity and RoW of transmission line used in the HVDC China and HVAC India is showed in Table 4.1.

Table 4.1: AC and DC Transmission Line.

Transmission Line	800 kV AC	500 kV DC
Capacity (MW)	2k	3k

RoW (m)	85	50

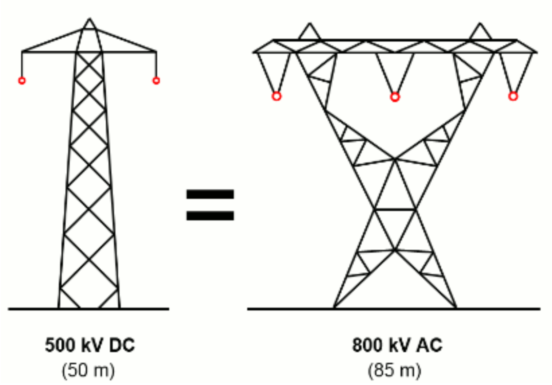

Figure 4.1: Transmission Lines for 800 kV AC and 500 kV DC.

4.2 Number of Lines in Parallel

The number of lines connected in parallel is determined by using the requirement of conductors. The corona noise is one of the factors that affect in selecting the number of line. Table 4.2 showed that the number of lines required when using HVAC or HVDC at different voltage levels.

Table 4.2: Number of Lines required for HVAC and HVDC Systems.

		Cond. diam.	Thermal limit (line)	Thermal limit (s/s)	SIL	1.5 x SIL	Required no. of lines	
	kV	mm	GW	GW	GW	GW	8 GW	12 GW
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

The effectiveness of HVDC transmission lines at higher voltage levels is clearly demonstrated in Figure 4.2.

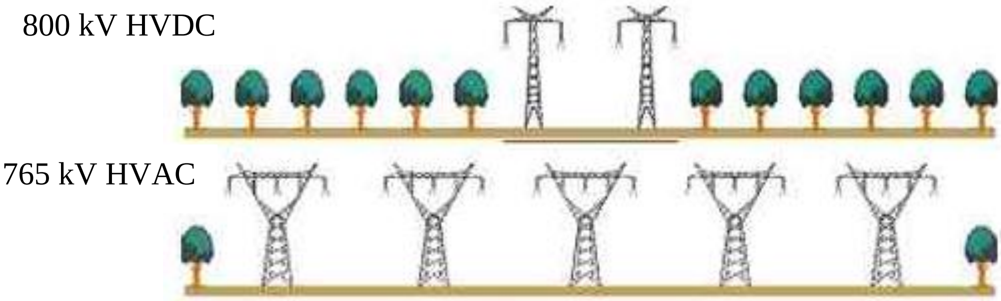

Figure 4.2: RoW for 800 kV HVDC and 765 kV HVAC Transmission Towers.

4.3 Line Losses

Besides the design of conductors for HVAC and HVDC, the cost of the transmission system can be affected by power losses. The resistive losses occurred to identify the cross section of conductor in HVAC lines. In order to get better design of the conductor bundle, the AC corona losses have to be considered. The corona losses are higher during the condition of rain.

For HVDC lines, there are like HVAC lines in which the resistive losses occurred to identify the conductor cross section. DC corona losses are lower compared to AC and hence the concern level of conductor design is lesser. Power losses of DC and AC lines are shown in Figure 4.3. It is clearly seen that the HVDC lines are lesser losses compared to HVAC lines in weather conditions.

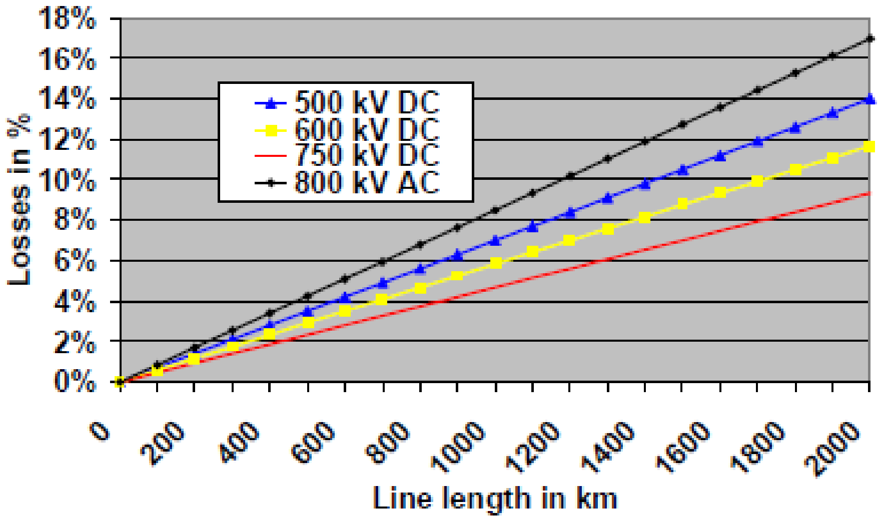

Figure 4.3: Power Losses on AC and DC Lines.

4.4 Conductor Load on Tower

From the literature review, it is clearly showed that the HVDC transmission are utilizing lesser number of conductors compared to HVAC transmission. At the same voltage level, the HVDC conductors used are almost half of the HVAC conductors as shown in Figure 4.4.

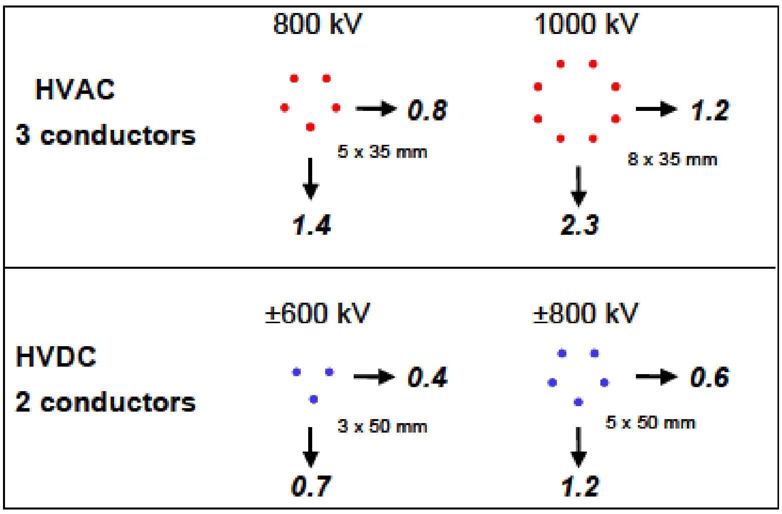

Figure 4.4: Total Conductor Load on AC and DC Towers.

4.5 Comparison between HVDC China and HVAC India

In Table 4.3, the technical feasibility, environmental impact and economic aspects are being be compared between HVAC in India and HVDC in China.

Table 4.3: Comparison between HVDC China and HVAC India.

Characteristic	*Item*	**HVAC**	**HVDC**
Technical Feasibility	*System Connection*	Synchronous	Asynchronous
	Power Flow Control	Difficult	Easy and Fast
	Tapping of Power Connection	Simple and Easy	Difficult and 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

For single line to ground fault, HVAC transmission system (37 kA in Figure 4.5) received higher fault current as compared to HVDC transmission system (29 kA in Figure 4.6).

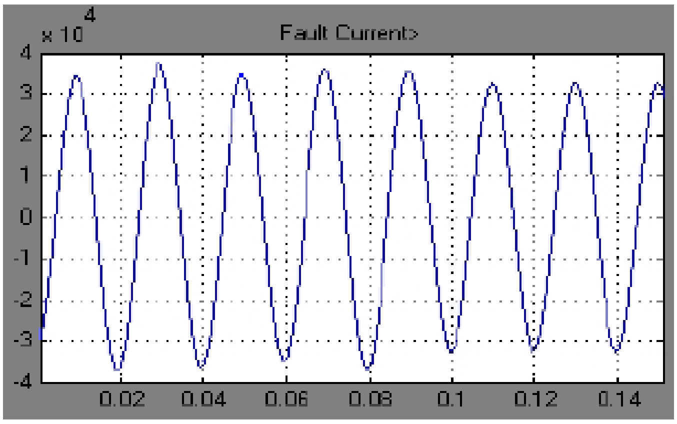

Figure 4.5: Single Line to Ground Fault Current for HVAC System.

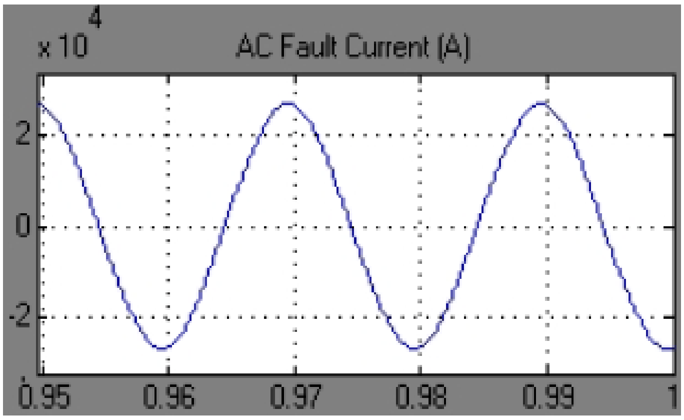

Figure 4.6: Single Line to Ground Fault Current for HVDC System.

4.6.2 Line to line Fault

Line to line fault is another type of asymmetrical fault. At receiving end of HVAC transmission system, the results clearly show the fault current is high (34 kA in Figure 4.7). But under same condition, the fault current is lower (20 kA) at HVDC transmission system as shown in Figure 4.8.

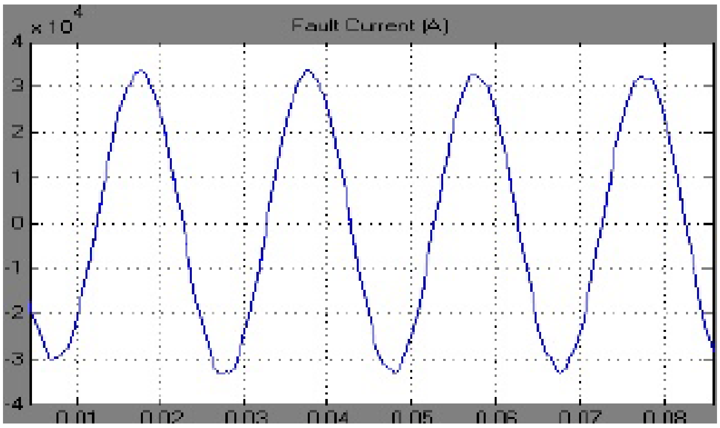

Figure 4.7: Line to Line Fault Current for HVAC System.

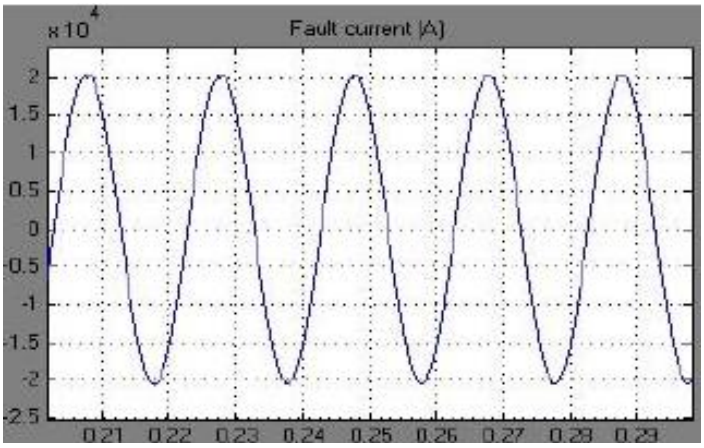

Figure 4.8: Line to Line Fault Current for HVDC System.

4.6.3 Fault in Transmission Line

Referring to the Figure 4.9, the transmission line fault is about 12 kA for HVAC transmission system. The fault is happened at the transmission line part, but the fault is happened at the receiving end part for single line to ground. For HVDC transmission system, the transmission line fault is happened at DC transmission line part. By comparing both system, the fault in HVAC transmission system (12 kA in Figure 4.9) is higher than HVDC transmission system (700 A in Figure 4.10).

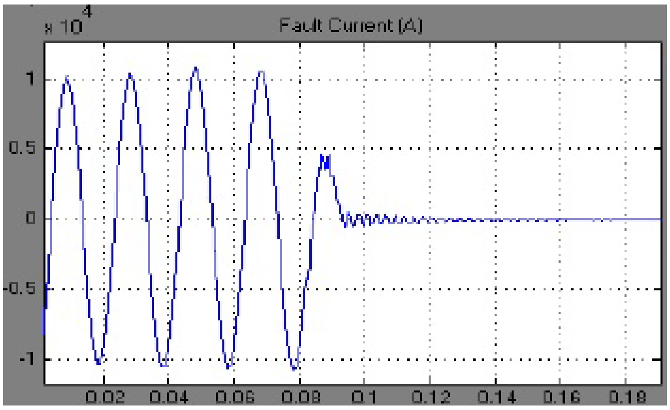

Figure 4.9: Fault Current at Transmission Line for HVAC system

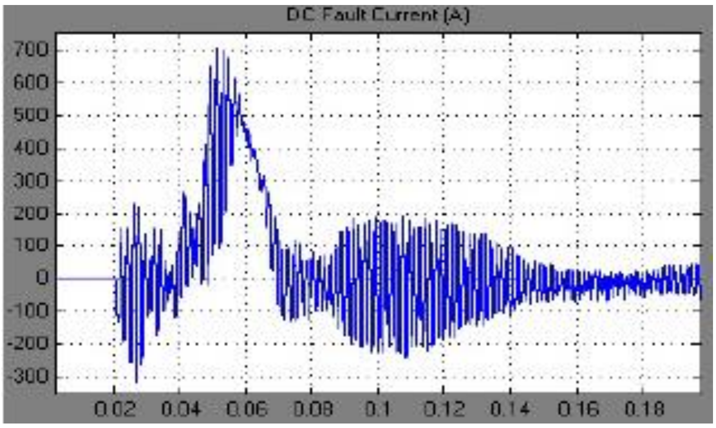

Figure 4.10: Fault Current at Transmission Linefor HVDC system

4.7 Comparison of Fault Current

The comparison of fault current of HVAC and HVDC system is presented in Table 4.4with different fault types. The results showed that the effects of fault current can easily damage the HVAC transmission system but effects are lesser in HVDC transmission system.

Table 4.4: Fault Current Comparison for 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 country with rich of soil and large amount sunlight produced all the time. In the beginning, agriculture plays a major role for the economy of a country. However, the industrial activity has been focused more to improve the economy. The concept of "Malaysia Incorporated" successfully brought Malaysia to change the agricultural based economy to an industrial based within two decades. With the strong growth of economy, the demand of electricity is increased on last few decades.

In Malaysia, the electric energy demands are supplied by Tenaga Nasional Berhad (TNB). According to the TNB annual report, the maximum energy demand is about 17,788 MW in 2016, expected to reach 274 TW in 2030. The energy demand rate is approximately 3.5% rise every year. To fulfill the electric energy demand, large power stations are being built and commissioned. Most of the generation stations are using natural resources like gas, coal and hydro. The total generation capacity installed is 12,013.4 MW. It comprises of 5,694.9 MW gas power stations, 3971.6 MW coal power stations and 2,347 MW hydro power stations.

As the power capacity is increased, a new and longer transmission lines need to be constructed. This may increase the cost and restriction on Rights-of-Way (ROW). Therefore, high efficient technology like HVDC transmission is able to overcome the problems. The HVDC transmission system has lower investment cost, lesser land use, lower power losses, lesser environment impacts and other benefits. However, there are some challenges to implement the HVDC transmission system in Malaysia.

In Malaysia, the land matters are under control and power by the state governments. To build the HVDC transmission, a compensation is required for the commercial land owners. Construction of HVDC transmission can be delayed when the land owners cannot be located or the land under lease. Furthermore, development areas such as new airport, industries or new road will prevent the construction.

Other than that, the local power company is applying a rule that all the components of transmission need to be sourced or made from local manufacturers. However, the insulator is given to be imported. One main issue is the local industries have difficult to meet the requirements of transmission tower. They may provide the wrong size, strength or thickness of the components.

Malaysia involved many rain forests, mountains and rivers. The movement of heavy equipment became the main challenge to build the HVDC project. On rugged terrain, the land and helicopter transports are required to move the equipment and materials. As a consequence, the equipment and materials can be damaged if mishandled. Thefts on copper rods, steel parts, and aluminum conductors are also common today because of the increasing value in the market.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In early of electric power system, most of the transmission and distribution network are formed with AC. This is due to the voltage levels can be easily changed by simple and reliable transformers. It was a strong technology and has been used for few decades. However, AC has some limitations that lead the AC unable to technically use for long distances. The absence of reactive compensations is one of the issues which can cause the HVAC transmission system unstable. Thus, conventional AC technology is preferred to apply in the transmission system. A simple current conversion applied to make the HVDC transmission system more efficient and stable. Due to this, extra costs are needed to install the converters in HVDC transmission system. However, HVDC transmission system provides more benefits compared to HVAC transmission system. More conclusions are discussed and listed as below:

- **Break even distances for HVAC and HVDC transmission:**

  The break-even distance is the distance that indicated the capital cost savings. The breakeven distance between AC and DC lines is around 600 km for overhead lines, while the breakeven distance of submarine lines is around 50 km. The cost of HVDC transmission is significantly lower than HVAC transmission over the longer distance. This is due to the conductor requirements on AC and DC lines. DC line is required only two conductors, but three conductors for AC line.

- **Short Circuit Current:**

Short circuit current as known as fault current, is the common issue in electric power system. The heavy currents from short circuit may cause the lines heating or melting. It also can form the arc to damage elements in the system. In additional, the stability of the power system can be affected and other equipment can be damaged due to over-heating. On the other hand, HVDC transmission system is more stable due to the converters does not contribute to short circuit current. The system is able to transmit the power smoothly without increasing the short circuit levels.

- **Environmental Aspects:**

Environmental issue such as electric magnetic field (EMF) is being concerning of the public every year. The magnetic field produced by DC lines is stationary, but AC lines produce alternating magnetic field. Unlike stationary magnetic fields, the alternating magnetic fields can induce the body currents. Thus, there are more limits to install the AC transmission lines.

- **Benefits:**

From this study, it is clearly showed that the HVDC technologies are more favorable in electrical power transmission and distribution. The benefits of HVDC transmission systems are summarized and listed as below:

- No limitations on the transmission distances.
- More power can be transmitted through same size of tower.
- Short circuit current can be reduced by HVDC converters.
- Fast control of active and reactive power.
- Less environmental disturbances.

5.2 Recommendations

One of the recommendations is to continue implement the HVDC transmission system with higher voltage, 1000 kV. With the similar power capacity, it can be seen that 1000 kV HVDC lines are better than 1000 kV HVAC lines for long distance. According to the Feasibility Report of European Grids and the Power Grids Document of United Nations, 1000 kV HVAC transmission systems overlay the existing power grids would not be achieved in the future. Power grids by HVDC technologies should be maintained and the power capacity with different voltage levels should be improved.

Other than that, the economy of HVDC transmission can be improved by introducing the offshore grid. Offshore grid such as windfarm is respected produce a better market price of the wind energy. Moreover, the HVDC transmission can be cheaper after the oil and gas power plant is installed from shore since the price of fossil fuel is increasing.

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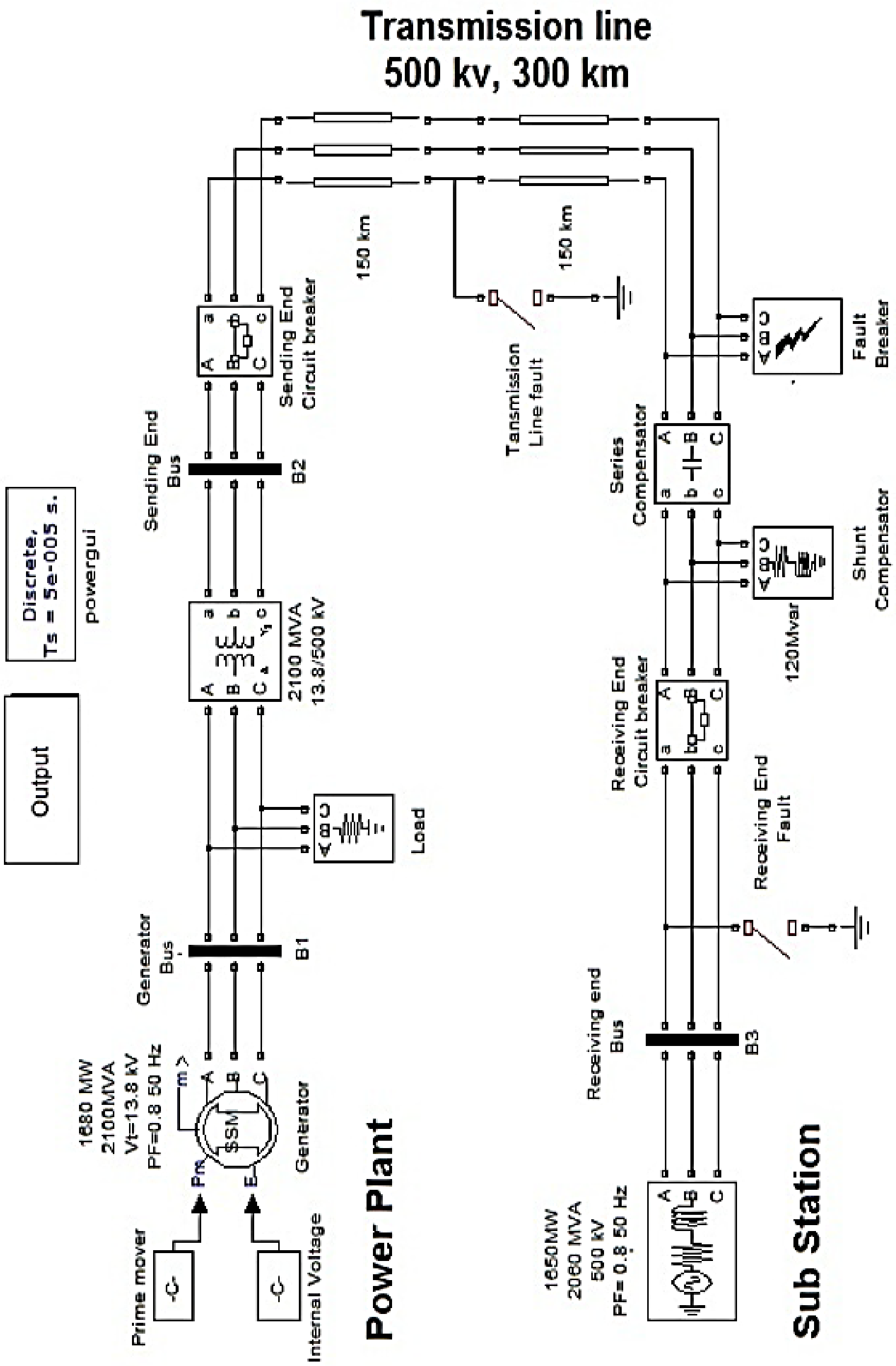
APPENDICES

APPENDIX A – Simulation Model of HVAC Transmission System



APPENDIX B – Simulation Model of HVDC Transmission System