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Modelling and Designing HVDC Transmission Line Using Controlled Rectifier and Voltage Source Inverter

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Abstract: ***Linear analysis, simulation, and experimental results are used to verify the stability of the control algorithm across a range of operating conditions. Finally, expressions for "harmonic impedance" of the system are derived to study the effects of supply voltage distortion on the harmonic performance of the system. Many grid connected power electronic systems use a voltage source inverter (VSI) connected to the supply network through a filter. This filter, typically a series inductance (smoothing reactor), acts to reduce the switching harmonics entering the distribution network. An alternative filter is a Resistor Capacitor Inductor (RCL) network, which can achieve reduced levels of harmonic distortion at lower switching frequencies and with less inductance, and therefore has potential benefits for higher power applications. For the schematic simulated diagram which is forwarded in this paper, it is likely possible to transmitted high power very close to their limit with negligible reactance and susceptance. The systematic diagram consists of a 12 pulse bridge rectifier, dc links, pulse width modulated (PWM), voltage source inverter (VSI) and converter transformers. This paper gives the feasibility converting a double circuit AC line into composite AC-DC transmission line given the advantage of stability improvement, damping oscillation and reactive power compensation for AC weak buses. Simulation and experimental studies using MATLAB Simulink model are carried out for the coordinated control as well as independent control of AC and DC power transmissions.***

Keywords: HVDC, HVAC, Converter transformer, Harmonics, Smoothing reactor, Filter

1. Introduction

1.1 Electric Power Transmission

Electric power system is the system of equipment's and controls dedicated to the generation, transmission and consumption of electric power. Electric energy is the most suitable form of energy for transmission and distribution. Due to this important behavior it is being intensively utilized as a means of energy transfer this intern results in the appearance of huge electric power transmission system. Electric power transmission system plays the role of transporting energy for a wide range of distances ranging from few kilometers up to hundreds even thousands KM. they connect energy generating parts and energy consuming parts of a power system. These transmission systems operate under carefully designed and controlled conditions in order to achieve the energy tasks.[1]

1.2 Historical Background of HVDC

Beginning with a brief historical perspective on the development of High Voltage Direct Current (HVDC) Transmission systems, this paper presents an overview of the status of HVDC systems in the world today. It then reviews the underlying technology of HVDC systems, and discusses the HVDC systems from a design and modelling points of view. The paper then discusses the recent developments in HVDC technologies. The paper also presents an economic and financial comparison (cost analysis) of HVDC system with those of an AC system; and provides a brief review of reference installations of HVDC systems. The paper concludes with a brief set of guidelines for choosing HVDC systems in today's electricity system development. It has been widely documented in the history of the electricity industry, that the first commercial electricity generated (by Thomas Alva Edison) was direct current (DC) electrical power. The first electricity transmission systems were also direct current systems. However, DC power at low voltage could not be transmitted over long distances, thus giving rise to high voltage alternating current (HVAC) electrical systems. Nevertheless, with the development of high voltage valves, it was possible to once again transmit DC power at high voltages and over long distances, giving rise to HVDC transmission systems.

The development of power semiconductors, in particular IGETs, has led to a limited transmission of HVDC power based on Voltage Source Converters (VSCs). Compared to traditional HVDC, the VSC-based HVDC systems have many advantages, such as, independent control of active and reactive power, dynamic voltage support at the converter bus for enhancing stability possibility to feed to weak AC systems or even passive loads, reversal of power without changing the polarity of dc voltage (advantageous in multi terminal dc systems) and no requirement of fast communication between the two converter stations. High voltage direct current (HVDC) technology has characteristics that make it particularly desirable for some transmission applications. HVDC transmission is generally accepted as being beneficial for long-distance, bulk power supply, asynchronous interconnections and long-distance submarine cable crossings. New converter designs have broadened the potential range of HVDC transmission to include applications for underground, offshore, economic replacement of reliability-must-run generation, and voltage stabilization. HVDC techniques are used in the power grid in situations where high voltage alternating current (HVAC) techniques actually cannot be used or have significant drawbacks. If long distances need to be bridged, HVAC cables can no longer be used due to high capacitive currents.From a certain cable length forward, the capacitive current is so high when opposed to the current to be transmitted that it is no longer possible to use the AC voltage. This break-even point depends on several factors, but at present it is about 30 km for submarine cables and about 500 km for overhead lines.[2]

Alternating current is well established for industrial and domestic use, but for long transmission lines, AC still has some drawbacks that have contributed to the use of DC transmission in some projects. Currents and voltage limits are two significant considerations for the high voltage transmission line.The conductor's AC resistance is greater than its DC resistance due to the skin effect and, finally, the AC transmission loss is greater. Switching surges are extreme transient over high voltage voltages for the high voltage transmission line.In the case of AC transmission, the peak values are two to three times the usual crest voltage, but the DC voltage is 1.7 times the normal voltage. The HVDC transmission has less corona and radio interference than the HVAC transmission line. The HVAC overhead lines generate and consume the reactive power, which is series problem The line reactance is proportional to the length of the line and thus the power per circuit of the operating voltage is limited by the steady state stability, which is inversely proportional to the length of the line. Due to stability, the load angle is held at a relatively low valve under normal operating conditions (approximately 300) because the power flow disturbance affects the load angle very quickly.In an uncompensated line, the angle of the phase varies with the distance. When the lines are operating at natural load and the distance is reduced. On the other hand, DC transmission has no reactivity problem, no stability problem, and thus no distance restriction. In AC, the phase angle between the sending end and the receiving end should not exceed 300 at full load for transient stability.The change in phase angle at natural line load is therefore 0.60 per KM. However, DC is still more desirable for long transmission than AC due to its fiscal, technological and environmental advantages. Economic considerations call for a certain minimum transmission distance (break-even distance) before HVDC can be considered competitive on a strictly cost-effective basis.Estimates for beak-even span overhead lines about 500KM with a large variance of this value depending on the size of the power transfer and the range of line and equipment costs.[3]

2. Literature Review

Most of the researches and scholars have done comparison of HVDC and HVAC transmission system based on cost and technical performance criteria. Some of studies performed in the area of HVDC and HVAC comparisons are described below.

Kala Meah, et al [4] made study on comparative evaluation of HVDC and HVAC transmission systems based on economic and environmental aspect and they have found out that the cost per unit length of HVDC line is lower than that of an HVAC line of the same power capability and comparable reliability, but the cost of the terminal equipment of HVDC line has much higher than that of HVAC line. The breakeven distance of overhead line between AC and DC line was in the range from 500km to 800km. In general, the HVDC has less effect on the human and the natural environment.

M.P Bahram, et al [5] made a study on HVDC transmission and compared with HVAC based on economic comparison of capital costs and losses for different AC and DC transmission alternatives and obtained that the savings in line costs offsets the higher converter station costs due to narrow Row, smaller transmission towers and lower line losses than with AC lines of comparable capacity. They have found that the rough approximation of the savings in the construction was 30%. In their study they showed that the long distance AC transmission lines usually required intermediate switching stations and reactive power compensations and thus increased the substation costs for AC transmission to the point where it is comparable to that of HVDC transmission. Finally, they showed that the breakeven distance was a typical valve of 500km.

Michael Behrman P.E et al [6] made a study on HVDC as economical complements to AC transmission and they have found out that the HVDC line is more economical for longer distances (≥400km) and higher ratings of power (≥2000MW) . Lars wienerset al [7] made a study on HVDC and HVAC transmission systems based on cost and environmental effects and concluded that the breakeven distance calculated was around 500km. On their study they showed that the relative cost of HVDC transmission was reduced and become cheaper in current dollars compared with the situation 20 years ago. This was due to continuing innovation technological development made. On the environmental aspect they showed that the corona losses of HVDC line were much less sensitive to variations for weather condition compared with HVAC lines.

3. General Block Diagram

The configuration shown in figure 1 mainly consists of ac filters, transformer, converters, phase reactors, dc filters, circuit breakers and capacitors. The overall HVDC block diagram can be depicted as follows:[8]

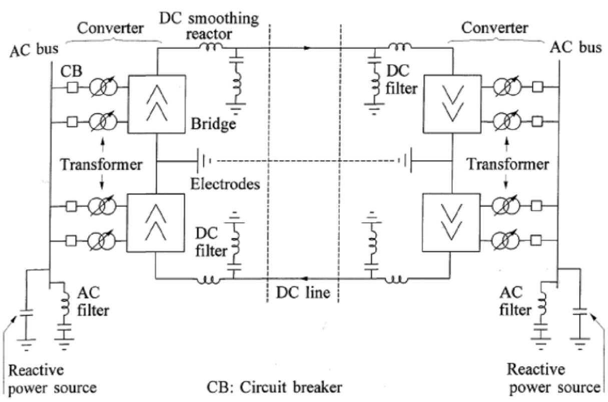

Figure 1: General HVDC link Block Diagram

4. System Design Description

A 300MW (±250kV) force commutated VSC is used to transmit dc power from a 400kV, 2000MVA, 50Hz system to another load system. The rectifier and the inverter are connected through a 321km line (i.e. distributed parameter line) and two 8mH phase reactors. The sinusoidal pulse width modulation switching uses a frequency 27 times the fundamental frequency (1350Hz). A converter transformer(Yg/Y/D) is used to permit the optimal voltage transformation.

4.1 Design Procedure

The design for the circuit chosen by our group with the help of ECE faculty members and graduate students along with the references listed in this paper to achieve an optimal device which met all given requirements. We referred back to past project regarding HVDC transmission and conversion for general ideas on the components required for successful closed-loop operation. The rectifier and inverter are the three level of VSC that use the IGBT/THYRISOR module available in the MATLAB/Simulink/ Simpower system.

MATLAB software, particularly Simulink, MATLAB's graphical interface is an Environment for designing and modeling systems, was used to model various aspects of the proposed power generation and transmission system. MATLAB version 2016, equipped with the SimPower Systems block set, is the software used.

5. Simulation Results

5.1 Rectifier (AC/DC Conversion)

A device which converts an AC input in to corresponding DC output signal. Its simulated diagram is depicted as follows. [9]

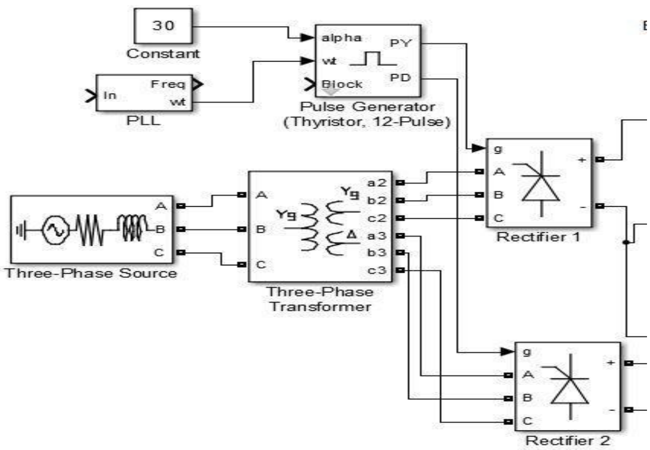

Figure 2: Block diagram of AC/DC conversion

The simulated result of the above rectifier is shown in the MATLAB Simulink model as follows;

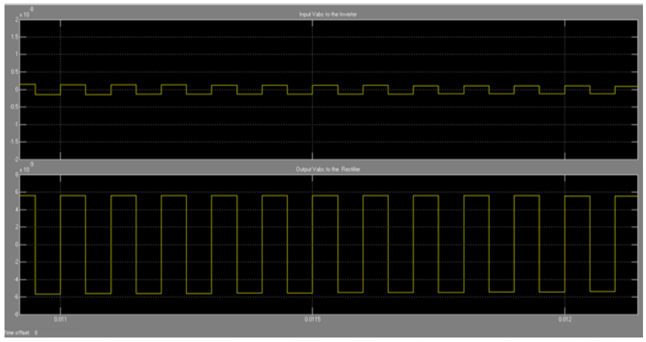

Figure 3: Input Vabc to the Inverter and output Vabc of the Rectifier, respectively

As we have seen the above simulated diagram in fig.3.3, it is clearly seen that at the end of a rectifier converter we have noticed a 12 pulse pulsating DC. However, this pulsating DC travels a long journey of 210km through the DC transmission link and, prior to the inverter side we have got somewhat approximate reduced harmonic DC; this is due to smoothing reactor and DC filters. Here point to be noted that we have not obtained a pure DC due to various environmental factors. But the distortion and other undesirable factors are highly reduced and it is ready for inversion in order to generate the original AC signal.

5.2 DC/AC Conversion (Inverter)

Inversion (DC to AC conversion) is done by using reverse application of the rectification. The output of the rectifier is the input for the Inverter after transmission. The final output of Inverter is the first input of rectifier with some harmonics and this harmonic will have removed by attached AC filter on the AC side. [9]

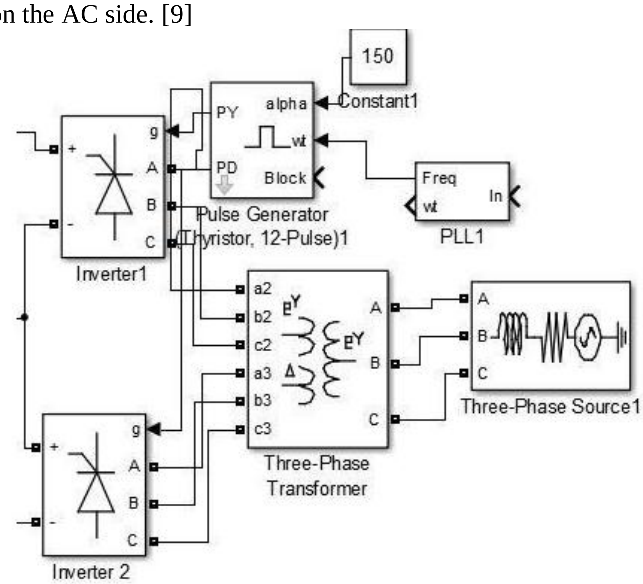

Figure 4: Block Diagram of DC/AC Conversion

The simulation of Inverter is also revealed in the following figure:

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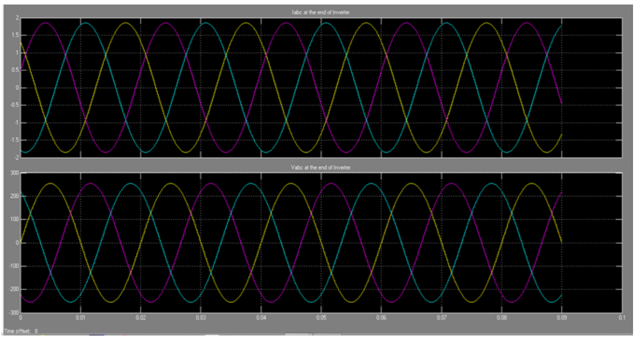

Figure 5: Current and voltage output of Inverter, respectively

As we have noticed from the above figure 5, we have observed that the inverter voltage and current output signals have almost striking resemblance with that of the original AC signals. This signifies by reducing noise and distortion with the help of AC and DC filters we can construct almost a pure AC signals after a long journey of transmission line by using power electronic converters.

5.3 The overall Simulation diagram

the overall simulation diagram is drawn in the Simulink model as shown below

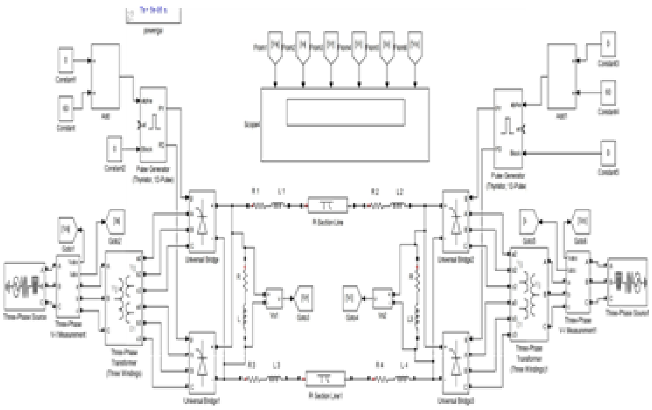

Figure 6: Overall Simulink circuit diagram of HVDC Power Transmission

The result of the above overall simulink circuit diagram model in figure 6 is depicted in a complete wave forms as follows:

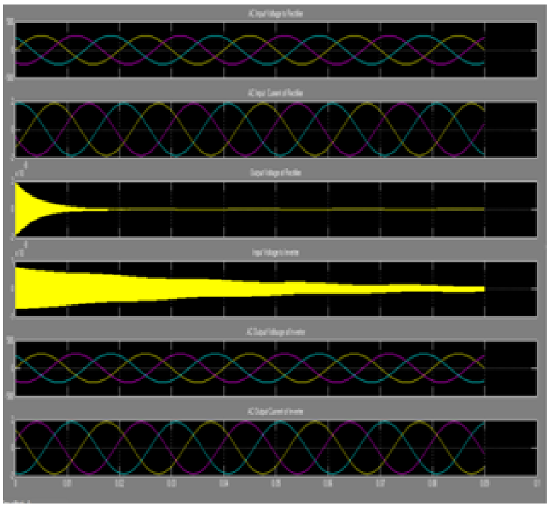

Figure 7: Complete simulated wave forms

6. Conclusion

As we have seen from the above figure 7 completed simulated wave forms, simply the simulations pertain AC source input signals and output signals of converters. Generally, the simulation result shows when the AC source fed to the rectifier converter through a step down transformer and then passes through AC filter to the rectifier. The rectifier then converts the AC signals in to the corresponding pulsating DC signals. Then these pulsating DC signals treated with DC filter and smoothing reactor resulting in reduced harmonic signals and then reaches to the inverter. Then, the inverter converts these signals in to the original reconstructed AC signals.

Generally, HVDC has less power loss compared to HVAC power transmission. The overall transmission efficiency for HVDC is around 87 % but for HVAC found to be 76%. For the net length of transmission line, the net loss of the bipolar line is 16.27MW, but for HVAC line the total power loss for corona 72. 65MW. This signifies that HVDC is more advantageous than HVAC. From the harmonic simulation the characteristic harmonics (5th,7th,17th,19th,29th ,31th) are cancelled out due to phase shift transformer and the rest harmonics eliminated by harmonic filters. THD before filters 51.44% and THD after shunt filters 9.48%. when we use AC harmonic filter THD after shunt filter becomes 0.97%.

Acronyms

HVDC	High Volt Direct Current
HVAC	High Volt Alternative Current
DC	Direct Current
VSC	Voltage Source Converter
CSC	Current Source Converter
PWM	Pulse Width Modulation
KM	Kilo Meter
IGBT	Insulated Gate Bipolar Transistor
XLPE	Cross Linked Polyethylene
RLC	Resistor Inductor Capacitor
ACSR	Aluminum Conductor Steel Reinforced
OH	Over Head
V	Volt
A	Ampere.

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Author Profile

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