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A Novel High Voltage Direct Current Transmission and Protection System

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***Abstract*- From the start of time, electricity has been transmitted using the traditional method of AC transmission over large distances. But using this transmission technique, there are many issues and disadvantages, including transmission losses and having an extremely small power factor due to transmission line material. To remedy these losses, researchers plan to devise another transmission system named a high voltage direct current (HVDC). Using the HVDC system, bulk power can be transmitted over a large distance without losses and with greater efficiency. Using this method, the cost is also improved, and the security is overwhelmed. The purpose is to devise such a system and simulate the HVDC system under various parameters of system protection and fault conditions. To simulate the research, MATLAB/SIMULINK tool is exploited and verified, which shows better performance than AC transmission.**

***Index Terms*— DC circuit breaker, HVDC, Hybrid transmission system, LCC-HVDC system, VSC-HVDC system**

I. INTRODUCTION

The electrical power system generates, transfers, and distributes cost-effective, stable, and dependable electrical energy to consumers. Large-scale power plants generate electricity and then transmitted over the large distance. In today's fast-paced world, humans rely on a reliable and unaffected electricity supply to maintain a pleasant lifestyle and a higher standard of living. Electricity's utilization demonstrates its significance in society's progress. Electricity has become the most important asset in human society, with applications ranging from home to industrial and commercial. Because of its importance, we require a power system that is dependable, consistent, and cost-effective. To be more effective, the power system must be a viable power system that efficiently and cost-effectively transmits electrical energy from generating stations to load centers. The flow chart graphic in Fig. 1 depicts the significance of electrical energy.

Initially, electricity was created using direct current (DC). Still, with the advent of transformers and induction motors around the turn of the century, alternating current (AC) gained the upper hand. It became a more popular source of electrical energy transmission and distribution. Another essential issue was that in the case of AC, the magnitude of the voltage could be increased or decreased with the use of transformers. As the population grows, the demand for electric power stations is typically positioned near sources of energy like coal, natural gas, water, and so on; these stations are typically a long distance from customers. Power must be transmitted efficiently and affordably as the distance increases. High voltage alternating current (HVAC) and high voltage direct current (HVDC) are the two systems now employed to carry high voltage from powerhouses to end-users (HVDC). Both topologies have their benefits and drawbacks. There are common high voltage ranges for both systems, and the distance and cost of the transmission infrastructure determine the way to choose for transmission. Figure 1 depicts the many options for electrical power transmission systems.

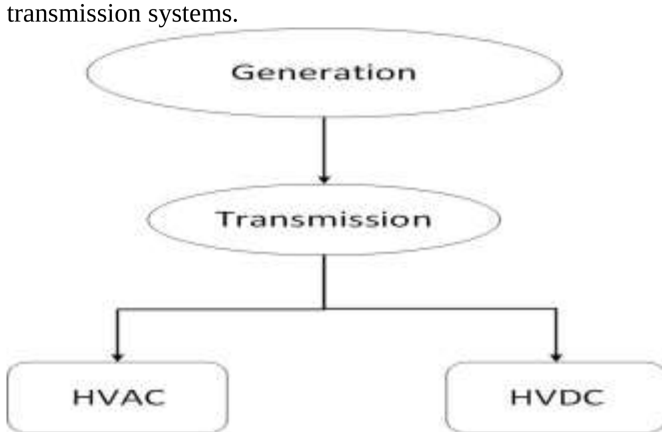

Figure **Error! No text of specified style in document.** possible choices for electrical power transmission

Both systems have advantages and disadvantages, similar to air conditioning, which is favoured because most consumer appliances are air-conditioned. Furthermore, the magnitude could be increased or decreased in response to client demand using transformers. Because of the additional power lost due to the corona, induction, skin effect, and radiation losses, the HVAC transmission system's temperature rises, and the lines become heated, making it impossible to utilize the AC system's full thermal capacity and resulting in a reduction in the amount of voltage that could be transmitted. As a result of these losses, the AC infrastructure grows in size and cost. Reactive power

adjustment is provided by increasing the capacitance and inductance of the transmission line in this model.
Because the conductor has no skin effect and can operate at its full capacity, transmission using HVDC results in lower losses due to the absence of inductance and capacitance, Corona losses are also reduced because there is no radiation and no frequency, while induction losses are reduced because of the uniform DC magnetic field and the current.
HVDC is also used to connect offshore wind power installations to existing AC networks and transport power between asynchronous networks. Since of the preceding advantages of HVDC over HVAC, it is a good choice for transmission because it allows for greater control over power flow due to the presence of semiconductor devices. This research looks at different HVDC transmission line configurations and HVDC converter control systems. A bipolar HVDC transmission and protection system is constructed in MATLAB/SIMULINK for this purpose, with various faults created and a protective method implemented.

II. LITERATURE REVIEW

Different types of HVDC links, DC circuit breaker designs, converter types, and control methods are addressed in this section. Monopolar, bipolar, and back-to-back transmission topologies are the three types of HVDC transmission topologies. Details on their construction and application can be found in [1-3]. The invention and modification of various converters, such as multilevel diode converters, are discussed. This converter comprises many diodes grouped in a three-level converter, capacitors, and a single DC source, and its construction and operation are described in [4]. A different topology is employed in capacitor converters to clamp capacitors between switches for voltage sharing. As the number of converter layers rises, so do the converter's weight, cost, and complexity. The converter is described and illustrated in [5]. Cascades on an H-Bridge To control an array of converters connected in series, you'll need a unique DC source for each one, which complicates things. In [6,] you'll find all the details. Two more advanced topologies for HVDC transmission are voltage source converters and line-commutated converters. Detailed information can be found in [7-9].
Controllers form the basis of LCC's control system. Controls for protecting valves are employed via the voltage-dependent current limit (VDCOL). In [10], several controllers are discussed. Q-Compensation and inductive filters are the other control mechanisms for LCC topologies listed in [11]. Point-to-point LCC-based HVDC systems are studied in [12, 13, 14] in terms of the current control margin technique and current coordinated control margin, which includes droop characteristics for the control mechanism. Extended and multistage current margin control is given for parallel-linked LCC-based LCCs. Please see [15] for more information. As a result of its simplicity and ability to control both active and reactive power, voltage controllers are commonly employed to regulate voltage source converters. According to [16], the advanced vector current controller, built on the d-q method and uses a current vector controller, has a stronger capacity to interact with weak AC grids. As mentioned in [13,14], the voltage droop control approach includes two control loops: an inner and an outer control loop that both regulates DC voltage and choose droop factors using SteadyState analysis. Power synchronization using phase-locked loop criteria and an ABC frame controller method is discussed in [15-17]. If you want your system's performance to be more dynamic, you could utilize PI compensators in two different control loops to find the best values. In [18-20], there is a detailed illustration [21-23] provide additional details on this system of control. In VSC converter topology, a stable voltage could be achieved by using the flexible power management approach while also independently adjusting the power supply, as described in detail in [24, 25].
To protect the grid and conduct transient tests, a hybrid DCCB with a residual mechanical switch, quick mechanical disconnects, and an IGBT has been created. It is tested in various ways, including opening the circuit breaker during fault current, shutting it down with an insufficiently powerful circuit breaker, and closing it again with current-limiting control. [26,27] One more hybrid DC circuit breaker uses fast thyristors. It achieves a circuit breaker running time of 2.3ms, and good responsiveness—a prolonged circuit breaker opening time [28]. A new interlink hybrid DC circuit breaker could be employed for the unidirectional and bidirectional interruption.
For both line and DC bus fault current interruption, the main circuit breaker in a unidirectional system is connected to two low-loss branches; in a bidirectional system, however, the main circuit breaker is connected in a star-connected network, yielding the same results as a hybrid circuit breaker with fewer components and lower costs. [29] It is possible to achieve zero crossing of, such as eliminating the need for surge arrestors for the de-magnetization of network inductance, by using couple inductor-based two-hybrid DC circuit breakers.
Pre-charged capacitors suppress the fault current when turning off the problematic line in a hybrid HVDC circuit breaker. Instead of IGBTs, the developed device uses thyristors to reduce power loss and circuit breaker failure. Prototype solid-state DC circuit breakers are constructed instead of using capacitors to store energy, detecting and opening the fault in less than three seconds. [30] When a PEM (power electronic module) is employed on both sides of the DC lines, a sequential auto-reclosing technique is employed to perform its operation step by step [43]. As part of the Zhangbei Project's requirements, it built a prototype half-bridge multilevel converter and 500kv VSC valve for the project's bipolar DC transmission system [31-34].

III. METHODOLOGY

The basic structure of the hybrid HVDC transmission system is shown in Fig. 2. On both the transmitting and receiving ends, AC sources, converter transformers, AC filters, and two three-phase bridge converters are employed. The two bridges are connected in series to give twelve pulse converters. These twelve pulses are based on thyristors and are known as line-commutated converters. The voltage generated by the three-phase, and a DC transmission line, is employed for DC transmission. Because it's a hybrid system, an inverter station follows the DC transmission line, converting the DC supply to AC.

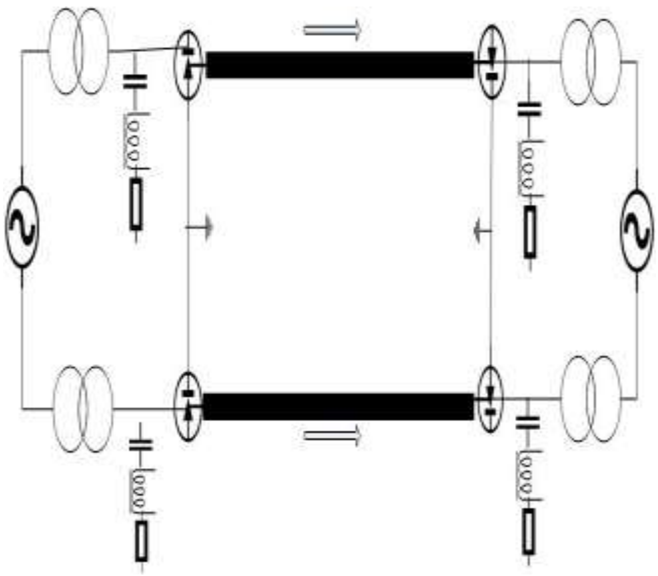

Figure 2. Basic model of hybrid bipolar HVDC system

The three-phase source delivers 500x103V at 50Hz. Source inductance and resistance are also part of the source. The source impedance can be evaluated as,

$$Z_{SSC} = \frac{V^2}{S_{SC}} \quad (1)$$

$$0.998xZ \quad (2)$$

$$R = \sqrt{Z^2 + X^2} \quad (3)$$

Because the hybrid system uses twelve pulse converters, 300 phase shift is necessary to run these converters, provided by the converter transformer and given by (4).

$$\text{Phase shift} = \frac{2\pi}{pulse\ number} \quad (4)$$

IV. PROPOSED SCHEME FOR REQUIRED SYSTEM

In this part, the HVDC system's proposed scheme is discussed. For simulation and theoretical research, the bipolar HVDC model is chosen and then built in MATLAB/ Simulink. After the model has been created, it is tested to examine how it operates in the presence of defects, and for this purpose, all possible faults are generated in the model. The designed model for MATLAB simulations is shown in Fig. 3. Even though there are various HVDC transmission systems, only the bipolar model is examined in depth in this research.

At the sending and receiving ends, AC systems are installed, but the transmission between them is entirely DC. In this system, there are also rectifiers and inverters installed for this reason. The suggested system's usual operation is depicted in Fig. 3. Figure 4 shows that all AC voltage and current signals run smoothly and without errors.

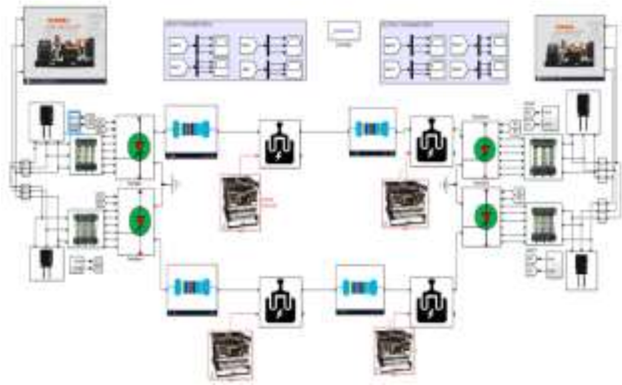

Figure 3 MATLAB model for HVDC system

IV. RESULTS & DISCUSSION

Figure 2 depicts the proposed plan for the bipolar HVDC system, which was created in MATLAB/Simulink. Figure 3 depicts the blocks that were employed in the creation of this scheme. At the sending point, an AC power generation unit generates AC power, converted to DC power for long-distance transmission. For domestic users, DC electricity is inverted into AC power at the receiving end. Table I lists the parameters for the bipolar HVDC model that was chosen.

Table I

Parameters description for the proposed system

Sr. No	Parameters	Sending End	Receiving End
1	Power Capacity	5000 MVA	10000 MVA
2	Line Voltage	500kV	500kV
3	Frequency	50 Hz	50 Hz

Figure 5 depicts the voltages of both DC lines, fault on DC transmission line

CASE STUDY 1

A defect on the positive DC line is triggered at t=0.1s after the HVDC system has normally been operating. The impact on the system is examined using scopes in the Simulink model. Figure 4 depicts a DC line fault, with the amount of current flowing during the responsibility abruptly increasing to 3000A at t=0.1s, as seen in Fig. 6.

Because a relay is utilized in this hybrid HVDC model and is activated when a fault occurs, Fig. 7 depicts DC when the relay is activated and the initiation of the relay when the fault occurs, resulting in the system returning to a stable and normal functioning condition at t=0.15s.

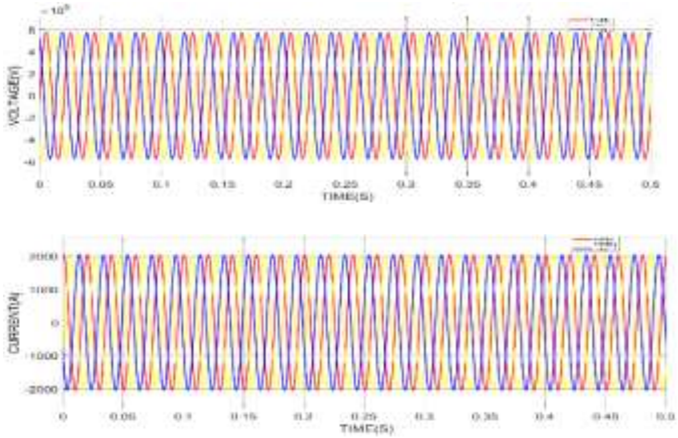

Figure 4. AC voltages and currents

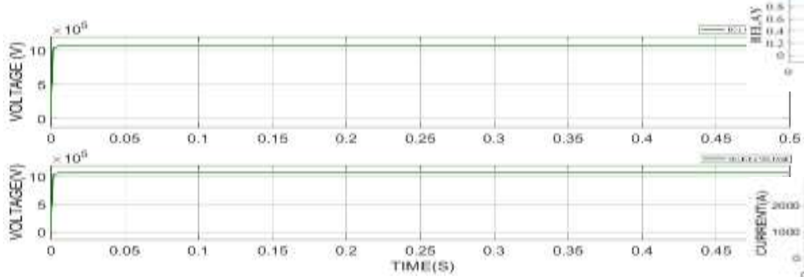

Figure 5. DC voltages

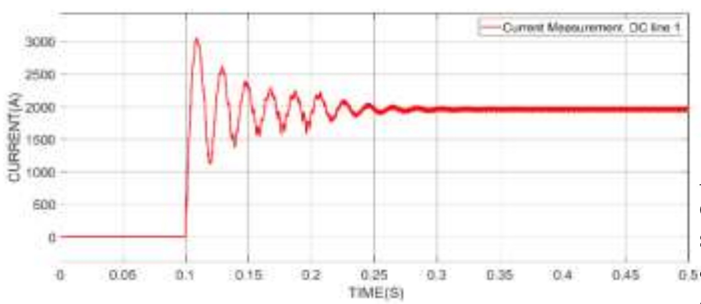

Figure 6. Faulty DC line current

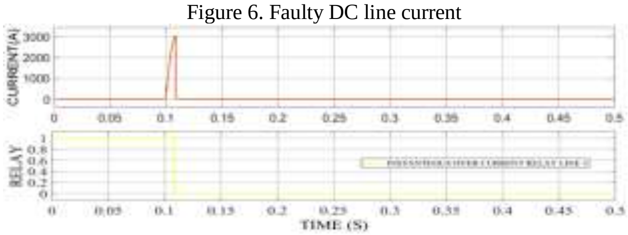

Figure 7. DC when the relay is operated and relay initiation when the fault occurs

CASE STUDY 2

Similarly, the fault is now triggered at t=0.1s on the positive line and t=0.3s on the negative line, with the impact on the system being monitored. Figure 8 depicts the fault on both the positive and negative lines, with the current jumping to 3000A in both the positive and negative directions in 0.1s and 0.3s, respectively. Figure 9 depicts the relay operation and the behaviours of both DC lines when the relay is turned on. Figure 10 shows the behaviour of both DC lines when the relay is turned on.

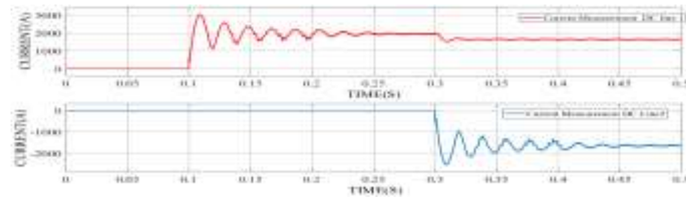

Figure 8. Fault on both DC lines

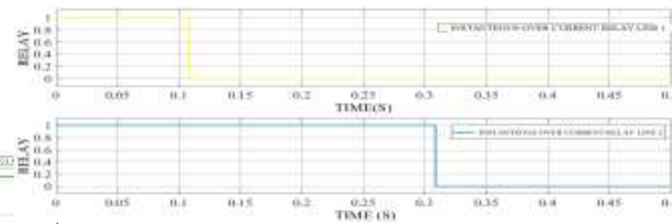

Figure 9. Relay operation for fault clearance

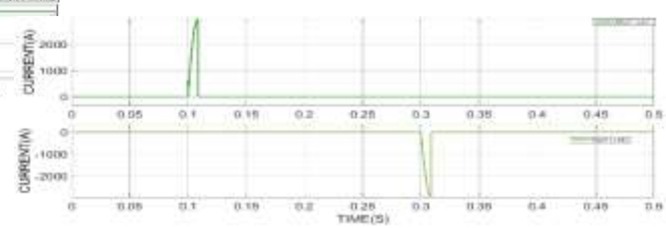

Figure 10. DC behaviour after the operation of the relay

V. CONCLUSION

A High Voltage Direct Current (HVDC) network is available to carry high power over great distances. Compared to the HVAC system, HVDC operation improves the power system's stability and ensures electricity is delivered even during grid outages. As a result, the HVDC network is preferred over the HVAC network for high power transmission across long distances for secure and stable power system operation. Furthermore, when two places must be connected with the same or different frequencies, as well as when high power must be carried from faraway areas, such as offshore wind farms, utilizing underground cables, the HVDC network is preferred. When compared to an AC system, however, the HVDC network requires more attention in terms of protection.

This research involved the development of a bipolar high-voltage direct current transmission, as well as the modelling of the protective system in MATLAB/Simulink. The simulation model is a two-terminal system that includes a rectifier and inverter, a converter transformer, alternating current filters, and relays. Both in normal system operation and when faults were introduced on a single DC line and both lines, the model was tested and found to be accurate. The instantaneous overcurrent relay modelled in this work has the potential to isolate the malfunctioning component of the system while leaving the rest of the system intact, hence ensuring the safe operation of the power grid.

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The authors declare they have no conflicts of interest to report regarding the present study.

CONFLICT OF INTEREST

The Authors declare that they have no conflicts of interest to report regarding the present study.

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