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# BIPOLAR TOPOLOGY OF HVDC CIRCUIT BREAKER WITH FAST FAULT CLEARING CAPABALITY

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**Abstract:**

This paper compares how a dc fault affects a multiterminal dc (MTDC) network depending on the HVDC transmission system topology. To this end, a six -step methodology is proposed for the selection of the necessary dc fault protection measures. The network consists of four voltage- source converters radially connected. The converters natural fault response to a dc fault for the different topologies is studied using dynamic simulation models. For clearing of the dc faults, four different dc breaker technologies are compared based on their fault interruption time, together with a current direction fault detection method. If necessary,to isolate the fault without interrupting the MTDC network operation. The study shows that the symmetric monopolar topology is least affected by dc contingencies. Considering bipolar topologies, the bipolar with metallic return exhibits better fault response compared to the one with ground return. Topologies with ground or metallic return require full semiconductor or hybrid breakers with reactors to successfully isolate a dc fault.

**Keywords –** MTDC, Isolate, Monopolar, Hybrid.

## 1. INTRODUCTION

The best sites for the exploitation of renewable resources are usually remotely located from demand centers since these sources have a low power-area ratio. Since space is scarce and costly in densely populated urban regions, long-distance power transmission systems will be vital for higher exploitation of available global energy resources and an increase in energy trade. Especially in cases where electricity needs to be transported via long lines, high-voltage direct current (HVDC) transmission has several advantages over its high-voltage alternate current (HVAC) counterpart, for example, greater power per conductor, fewer problems with resonances, and transmission distance that is not limited by stability. However, out of more than 140 HVDCprojects worldwide, only two are multiterminal networks, and they have more than three converter terminals connected via a dc network [1].Nevertheless, four key aspects need to be thoroughly ana-lyzed before multiterminal dc networks can be successfully developed: system integration, dynamic behavior, power-flow control, and fault behavior.System integration aspects of multi multilevel topologies and multi-terminal dc networks, has been extensively analyzed in the literature. The control of the power flow in MTDC net-works has also been thoroughly analyzed.The response of MTDC networks to contingencies, especially on the dc side of the transmission system, will be vital for its successful development. After a dc fault, the system will most likely have only a few milliseconds to clear the fault before high dc currents pose a threat to the MTDC network. Therefore, several efforts have concentrated on research and development of HVDC switch breakers. Previous re-search on the protection of high-voltage MTDC networks have also focused on how a dc fault develops; dc fault detection methods; and protection systems.

## 2. TOPOLOGIES

Independently from the converter technology, there are two main topologies for HVDC transmission systems: monopolar and bipolar . The topologies analyzed in this paper; all of which can be employed to form MTDC net-works. Fig. 1 depicts a single-phase representation of two HVDC converter stations connected to three-phase ac sys-tems via a transformer. The converter configuration is abstracted as the main HVDC transmission system topologies are distinguished by their dc circuit schemes. As long as the dc side of the transmission system is grounded, the transformers secondary windings need to be designed for high direct voltage stresses, namely, half the direct voltage nominal value. Hence, special attention has to be paid to their insulation. The main advantage of the bipolar configuration is its redundancy, which can be more than half the total transmission capacity if poles can be overloaded whenever one converter suffers a fault. However, there are disadvantages for each of the available bipolar topologies.

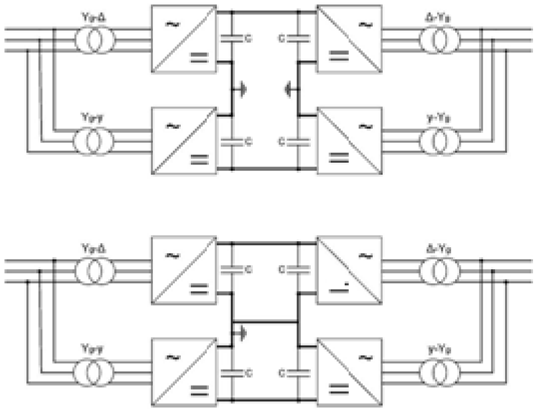

**Fig.1. HVDC transmission system topology**

for example, pole outages or maintenance periods. Even though not necessary, grounding is often provided for the bipolar configuration. If there is no return path for the current, the entire HVDC transmission system will be made unavailable during faults. Although the line-commutated current-source converter inherent low controllability as well as difficulties in forming MTDC networks, have driven researchers and the industry toward the application of VSC for transmission purposes.In a VSC-HVDC system, which uses fully controllable switches, power-flow reversal only involves changing the converter current direction, while the direct voltage remains constant, making it easier to develop MTDC networks. How-ever, the use of insulated-gate bipolar transistor (IGBT) valves is, at the same time, a main drawback. In case of a dc fault, contrary to thyristor valves, IGBT valves cannot block the fault current due to the current path via the anti-parallel diodes which makes converters prone to damage. This issue becomes more challenging in an MTDC network where the costs of power transfer loss are high.

## 3. CONVERTER COMPARISON

HVDC systems use electrical converters in order to switch from DC to AC and vice-versa. There are two main types of energy converters used, the Current Source Converters (CSC) and the Voltage Source Converters (VSC). Both of these converter types will be analyzed and ultimately we will conclude that VSC-HVDC is not only a competitor to CSC-HVDC, but it is the only possible solution for multi- terminal systems. Up until recently multi-terminal systems were not attractive for renewable energy interconnects or for energy distribution, but nowadays their use is being explored.

During the 20th century, HVDC systems used exclusively current source converters, while at that point VSC technology did not exist. Things changed in the 90s when insulated gate bipolar transistors (IGBT) which were a new type of self-commutation high power switches became available. IGBTs are three- terminal power semiconductor devices. They offer both high efficiency and fast switching, two factors which are of great importance for HVDC power systems. In addition,

they allow the system to be much smaller compared to the use of other more conventional devices. CSC systems could not benefit from the new IGBTS and hence became inferior to VSC-HVDC.
Both converter types act differently on the AC and the DC side. More specifically, CSC act as voltage sources and requires major AC filtering in order to eliminate the harmonics which exists in the AC side of the system. VSC acts as a constant current source with no need for large filters and reactive power supply. Their roles are reversed when we move on to the DC side. VSC uses a capacitor to store energy and due to this capacitor no additional DC filtering is required. This is not the case for CSC. Another advantage of VSC-HVDC systems is that the power flow in VSC-HVDC can simply be changed by changing the direction of the current, while in the case of CSC the DC voltage polarity had to be altered which is hard to achieve. Therefore it is clear that multi-terminal systems are only feasible with the use of VSC technology. CSC point to point transmission does not require HVDC circuit breakers, since AC circuit breakers can be used instead. Multi-terminal systems though, which use VSC technology, will require HVDC circuit breakers so that the whole system does not have to shut down. We will next analyze circuit breakers and their use in DC grids.

## 4. RESULTS

As pole-to-ground faults are investigated, dynamic simula-tions results have shown that in the bipolar configuration, the dc fault did not influence the negative pole converters. Before, during, and after the fault, the negative pole converters kept op-eration independently from the positive pole converters.

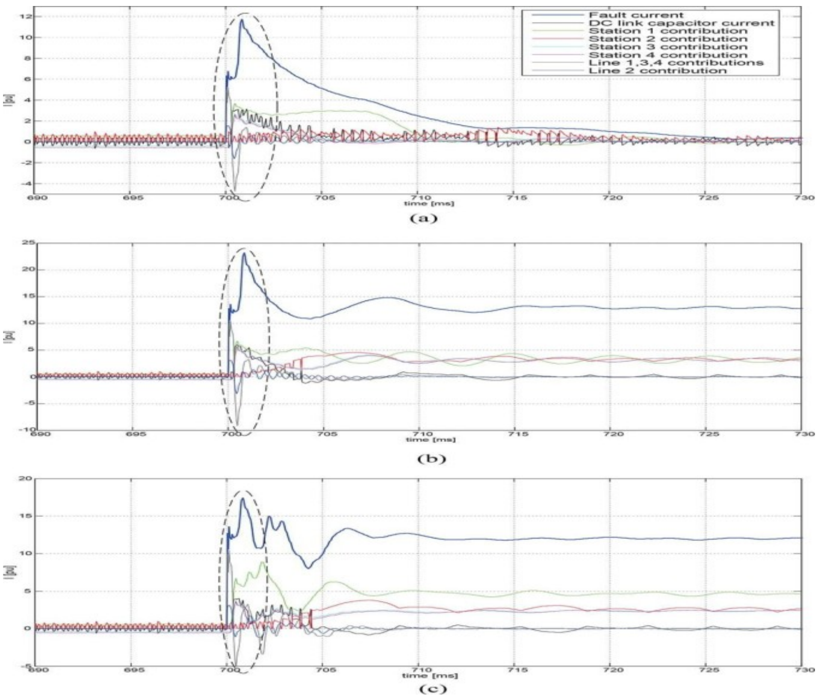


**Fig.2.Waveform analysis**

The same analysis has shown that the fault response of an asymmetric monopolar with ground return can safely be assumed analogous to that of the bipolar topology with ground return. The same reasoning applies to the asymmetric monopolar with metallic return topology, where the fault response is equivalent to that of the bipolar topology with metallic return. The only difference between the bipolar and the asymmetric monopolar topologies, is the inability of the latter to continue normal operation during the pole-to-ground fault.In all simulations, the current was monitored at the converters, dc capacitors, dc lines, and at the fault point. The total simulation time was 1 s and the fault was applied on MTDC line 2, 49 km away from VSC2, at $t=$ 700 ms. The MTDC network voltage is controlled by the VSC1 terminal whereas all other terminals operate in current regulation mode controlling their active power. The order of events in the MTDC network. It is worth noting that the VSC stations power references were not changed before and after the fault. As discussed, the fault currents develop in three phases—two transient and one steady-state phase.The topologies with ground return have the worst perfor-mance compared to other topologies. The total fault current reached a higher peak, since there is no return path impedance, and the fault affected the converters within less than 4 ms, up to 2 ms faster than in the case of metallic return topologies. Except for the VSC1 converter, the converters' currents reached higher peaks in the steady-state phase, namely, 4 p.u., which can pro-duce permanent damage.

## CONCLUSION

A methodology has been proposed to compare different VSC-HVDC topologies with regard to faults on MTDC networks. The proposed methodology consists of six steps which are carried out based on results from a dynamic simulation model of the complete system.Among all analyzed topologies, the symmetric monopolar has the best fault response, especially in combination with at least 50-mH reactors. If the power to be transmitted in the dc net-work requires the use of bipolar topologies, the bipolar topology with metallic return, although it has higher capital installation costs, has superior performance with regard to dc faults than the one with ground return.In conclusion, successful fault isolation in topologies with ground or metallic return requires solid-state breakers or Hybrid I breakers with reactors higher than 50 mH or 100 mH, respec-tively. Since the breakers' interruption time is somewhat uncer-tain, sensitivity analysis can be performed using the proposed methodology. The other two breaker technologies—the Hybrid and the resonant breakers—are not yet fast enough to handle dc contingencies for these grid topologies.

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