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POWER FLOW CONTROL OF MULTITERMINAL DC NETWORK FAULT UNDER UNBALENCED GRID CONDITION

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ABSTRACT

The Indian subcontinent is facing a massive challenge with regards to energy security in its member countries; to provide reliable electricity to facilitate development across various sectors of the economy and consequently achieve the developmental targets. The instability of the current precarious situation is observable in the frequent system failures and blackouts. 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 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. 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.

1. INTRODUCTION

Climate change activism as well as a limited access of primary conventional fuels is setting the platform for a subtle shift to a CO_2 neutral, multi-layered energy system. In this transformation renewable energies will play a leading role followed by the formation of energy corridors for transport of the clean energy. A great potential of renewable energy has been estimated in the Indian subcontinent.

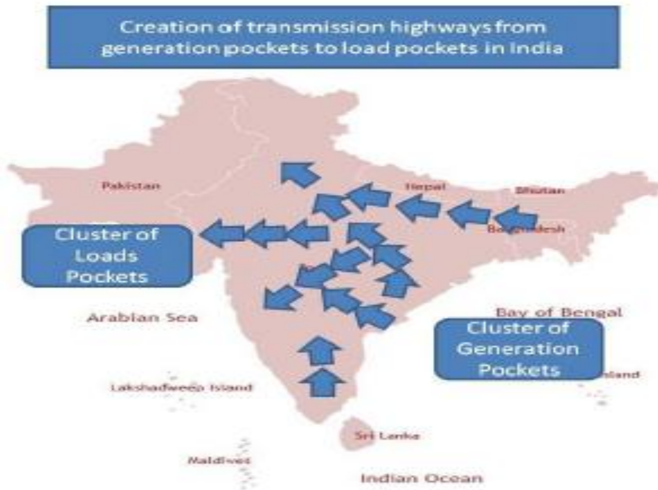


Fig.1. Creation of transmission highways from generation pockets to load pockets in India

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 HVDC projects worldwide, only two are multi-terminal networks, and they have more than three converter terminals connected via a dc network. Different European studies recognize a transnational offshore grid infrastructure as the most efficient way to integrate large amounts of offshore wind power into the national electricity networks. Moreover, these transnational grids could boost the electricity market between countries. Since new offshore projects tend to be erected increasingly further from shore and with growing installed capacity, probably the transnational grid will use DC transmission technology. For large and distant offshore wind farms, the use of HVDC technology is the most efficient and economical way of transmitting the produced energy to shore. The main contribution of this paper is the comparison of different HVDC transmission system topologies under dc fault cases and the analysis of different current limiting reactors and the dc switch breakers' impact on the developing dc fault currents.

2. HVDC TOPOLOGES AND TECHNOLOGIES
3.

Independently from the converter technology, there are two main topologies for HVDC transmission systems: monopolar and bipolar. Table I displays the topologies analyzed in this paper; all of which can be employed to form MTDC net-works.

	Topology			
	A. Monopolar		B. Bipolar	
Return Path	(a)	Symmetric	(d)	Ground Return
	(b)	Assymetric Ground	(e)	Metallic Return
	(c)	Assymetric Metallic		

Table.1. Analyzed HVDC Transmission Topologies

As the name suggests, this configuration has only one pole, mostly of negative polarity to reduce corona effects

. 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. Although the line-commutated current-source converter (LCC-HVDC) remains the most mature HVDC technology, its 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.

4. HVDC METHODOLOGY

The workflow of the proposed methodology is presented in Fig. 4. Each step of the methodology is explained next.

1) **HVDC Topology:** The starting point is the selection of a topology for the MTDC network. In this paper, all topologies are compared through means of a dynamic simulation model.

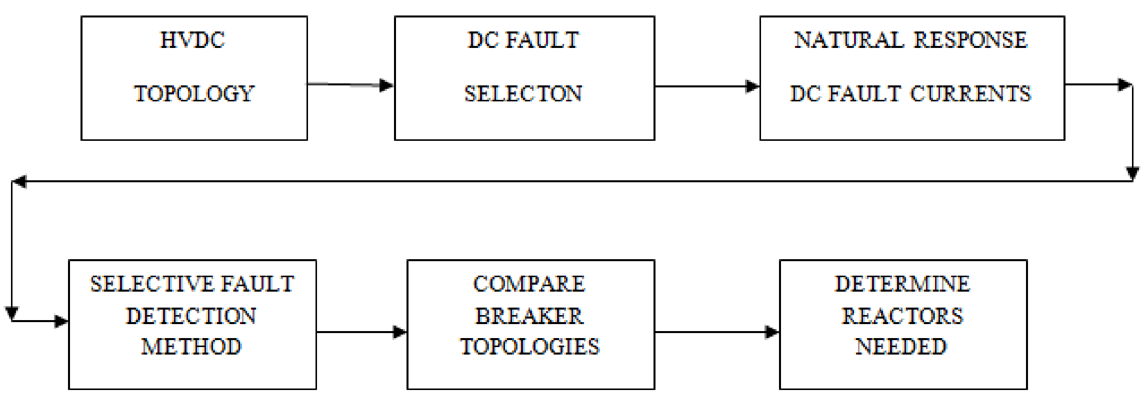


Fig.2. Workflow of the methodology used in the topologies

2) **DC Fault Selection:** Once the dynamic simulation model is built, a dc fault type and location needs to be selected. There are two main types of dc faults, which can occur in an MTDC grid: pole-to-ground fault and line-to-line fault, or short-circuit fault. If underground or submarine cables are used, line-to-line faults are very rare when compared to pole-to-ground faults; hence, the latter was selected. All pole-to-ground faults were simulated with a ground resistance of 7 Ω, corresponding to wet loamy sand ground type .

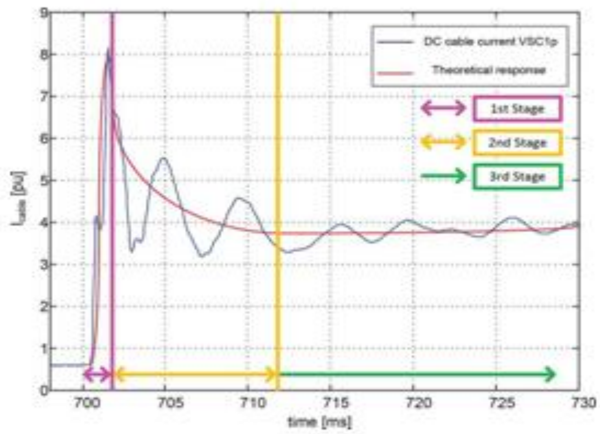
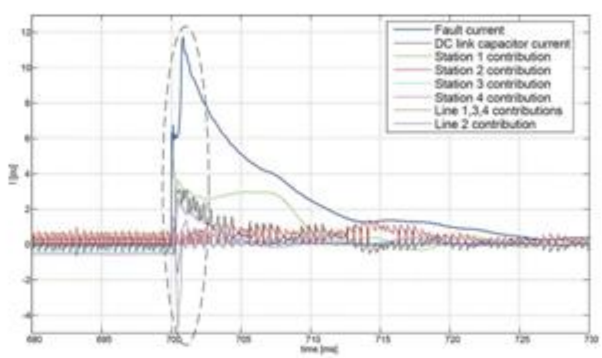


Fig.3. Theoretical and simulated fault current response of a VSC in case of a pole-to-ground fault

In addition to selecting the fault type, the fault location also needs to be determined. Three different fault locations 1, were analyzed. It was found that the closer the fault is to the middle point of the MTDC network, the less time it takes to reach the fault current peak and the higher is the peak value and the current directions in the MTDC network in case of a fault on the dc line leading to VSC2.

5. RESULTS AND DISCUSSIONS

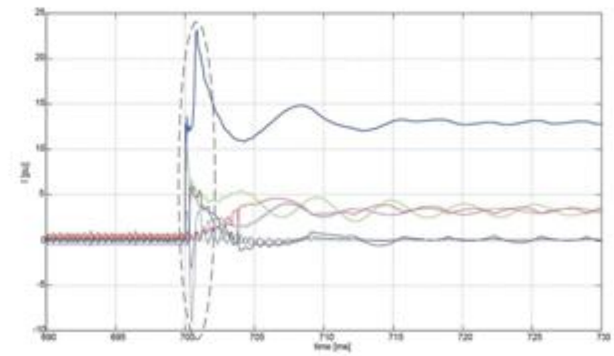
As pole-to-ground faults are investigated, dynamic simulations results have shown that in the bipolar configuration, the dc fault did not influence the negative pole converters. Before, during, and after the fault, the negative pole converters kept operation independently from the positive pole converters.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



(a)

Fig.4. Symmetric monopolar

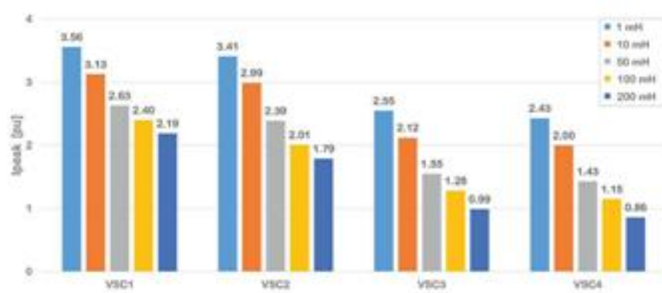
The same reasoning applies to the asymmetric monopolar with metallic return topology, where the fault response is equivalent to that of the bipolar topology with metallic return. The only difference between the bipolar and the asymmetric monopolar topologies, is the inability of the latter to continue normal operation during the pole-to-ground fault.



(b)

Fig.5. Ground return: bipolar and asymmetric monopolar

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 is shown in Table IV. It is worth noting that the VSC stations power references were not changed before and after the fault. In the topologies with metallic return, the peak fault cur-rent reached a value of 18 p.u. during the transient period. The grounding point of the metallic conductor was identified as a crucial issue regarding the dc fault response of these topologies, since it significantly influences the current contributions to the dc fault during steady state. It also affects the time required for each VSC to



(a)

Fig.6. Peak fault dc currents as a function of the limiting reactor size for symmetric monopolar

experience an overcurrent, which is important for designing selective fault detection methods. The graphics in Fig. 6 show that the converters have a limited time to react to the fault currents and that the currents' peaks are excessive.

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.

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