Network Fault Tolerant using Multilevel Voltage Source Converter for HVDC Transmission Systems

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Abstract: A VSC-HVDC transmission system is the network to meet all these challenges due to its operational flexibility, such as voltage support to ac networks, its ability to operate independent of ac network such as offshore wind farms, suitability for multi terminal HVDC network realization as active power reversal is achieved without dc link voltage polarity change. Present VSC-HVDC transmission systems rely on their converter station control systems and effective impedance between the point-of-common-coupling (PCC) and the converter terminals to ride through dc side faults. With present converter technology, the dc fault current comprises the ac networks contribution through converter free-wheeling diodes and discharge currents of the dc side capacitors. The magnitude of the dc-side capacitors discharge current decays with time is larger than the ac networks contribution. This project proposes a new breed of high-voltage dc (HVDC) transmission systems based on a hybrid multilevel voltage source converter (VSC) with ac-side cascaded H-bridge cells. The proposed HVDC system offers the operational flexibility of VSC based systems in terms of active and reactive power control, in addition to improved ac fault ride-through capability and the unique feature of current-limiting capability during dc side faults. The proposed HVDC system, in this project assesses its dynamic performance during steady-state and network alternations, including its response to AC and DC side faults. In this proposed topology is implemented in MATLAB/SIMULINK environment and the simulation results are observed.

Keywords: DC Fault Reverse Blocking Capability, Hybrid Multilevel Converter with Ac Side Cascaded H-Bridge Cells, Modular Multilevel Converter, And Voltage-Source-Converter High-Voltage DC (VSHVDC) Transmission System.

I. INTRODUCTION

The main limitation using the conventional HVAC solution is the required compensation of the reactive power generated by the long underground and submarine cables. Recent studies indicate that the HVDC solution is more economically feasible than the HVAC for distances above approximately 70 km to the grid connection point. Detailed knowledge and understanding of the characteristics and behavior of all relevant power system components are required in order to develop reliable OWFs employing HVDC. There exist fundamentally two HVDC technologies: (i) the conventional thyristor-based line commutated converter (LCC) HVDC, which is a well proven technology, with the first application in 1954 in Gotland. (ii) VSC-HVDC, which is a relatively new technology, which is under rapid development. The VSC technology was initially developed for drive technologies. Due to significant increase in voltage and power ratings of semiconductors such as the insulated gate bipolar transistor (IGBT), the VSHVDC scheme started to find applications in the late 1990s, especially where the interconnected AC networks had low short circuit level or where space was limited. A VSC-HVDC transmission system is a candidate to meet these challenges due to its operational flexibility, such as provision of voltage support to ac networks; its ability to operate independent of ac network strength therefore makes it suitable for connection of weak ac networks such as offshore wind farms, suitability for multi terminal HVDC network realization as active power reversal is achieved without dc link voltage polarity change, and resiliency to ac side faults (no risk of commutation failure as with line-commutating HVDC systems).

However, vulnerability to dc side faults and absence of reliable dc circuit breakers capable of operating at high-voltage restrict their application to point-to-point connection. Commensurate with the second approach, this paper presents a new HVDC transmission systems based on a hybrid-voltage-source multilevel converter with ac-side cascaded H-bridge cells. The adopted converter has inherent dc fault reverse-blocking capability, which can be exploited to improve VSC-HVDC resiliency to dc side faults. The VSC offers several advantages over the LCC-HVDC scheme, as the IGBT’s can be turned on/off using an electronic gate signal. This offers a number of advantages including insensitivity to the strength of the AC network, black start capability, and fast and decoupled control of bidirectional active and reactive power flow. Furthermore, the VSC-HVDC DC link voltage is not
required to invert polarity in case of power flow reversal as in the LCC scheme, which makes it possible to use extruded polymer cables, which offers the advantages of lower weight and cost compared to the mass-impregnated cables used in the LCCHVDC scheme. For high power VSC-HVDC transmission system applications, the three main topologies utilized so far are the two-level, three-level and the multi-level (ML) converters.

II. VSC HVDC APPLICATION

The two- and three-level technologies enable switching between two or three different voltage levels to the AC terminals, respectively. The main drawbacks of these technologies include high switching losses, high at relative high switching frequency, which necessitate high insulation requirements of the interfacing transformer, as well as extensive filter installations (although lower requirements than for the LCC scheme). Although the switching frequency has decreased from approximately 2 kHz to 1 kHz within the last decade, the efficiency of each converter station is in the range of 2 %, which is inferior to 0.7 % losses per LCC-HVDC station. Typically, multiple series-connected IGBTs with a blocking capability of a few kV are used in each valve in order to provide a higher blocking voltage capability of the converter and thereby increase the DC voltage. The series connected IGBTs have to switch simultaneously (within a few) in order to ensure uniform voltage distribution between the IGBTs statically as well as dynamically, which is not a straightforward task.

Fig. 1 shows one phase of a hybrid multilevel VSC with H-bridge cells per phase. It can generate voltage levels at converter terminal “a” relative to supply midpoint “0.” Therefore, with a large number of cells per phase, the converter presents near pure sinusoidal voltage to the converter switches, therefore no direct path exists between the ac and dc side through freewheel diodes, and cell capacitor voltages will oppose any current flow from one side to another. Consequently, with no current flows, there is no active and reactive power exchange between ac and dc side during dc-side faults.

Fig. 2. (a) Representation of VSC station and (b) schematic diagram summarizing the control layer of the hybrid multilevel converter with ac side cascaded H-bridge cells.

This dc fault aspect means transformer coupled H-bridges cannot be used. The ac grid contribution to dc-side fault current is eliminated, reducing the risk of converter failure due to increased current stresses in the switching devices during dc-side faults. From the grid standpoint, the dc fault reverse-blocking capability of the proposed HVDC system may improve ac network voltage stability, as the reactive power demand at converter stations during dc-side faults is
significantly reduced. A HVDC transmission system based on a hybrid multilevel VSC with ac-side cascaded H-bridge cells requires three control system layers. The inner control layer represents the modulator and capacitor voltage-balancing mechanism that generates the gating signals for the converter switches and maintains voltage balance of the H-bridge cell capacitors. The intermediate control layer represents the current controller that regulates the active and reactive current components over the full operating range and restraints converter station current injection into ac network during network disturbances such as ac and dc side faults. The outer control layer is the dc voltage (or active power) and ac voltage (or reactive power) controller that provide setpoints to the current controllers. The inner controller has only been discussed to a level appropriate to power systems engineers. The current, power, and dc link voltage controller gains are selected using root locus analysis, based on the applicable transfer functions. Some of the controller gains obtained using root locus analysis give good performance in steady state but failed to provide acceptable network disturbance performance. Therefore, the simulation final gains used are adjusted in the time domain to provide satisfactory performance over a wide operating range, including ac and dc side faults. Fig. 2 summarizes the control layers of the hybrid multilevel VSC.

III. SIMULATION RESULTS

The ability of the VSC-HVDC system that uses a hybrid multilevel VSC with ac-side cascaded H-bridge cells is investigated here, with emphasis on its dynamic performance during network alterations. The converters are configured to regulate active power exchange and dc link voltage, and ac voltage magnitudes at respectively. The test system in Fig.3 is simulated in the MATLAB Simulink environment.

Fig.3: Test network and waveforms demonstrating the steady-state operation of HVDC system based on hybrid voltage source multilevel converter with ac side cascaded H-bridge cells.

During the fault period the power command to converter 1 is reduced in proportion to the reduction in the ac voltage magnitude (this is achieved by sensing PCC2 voltage). This is to minimize the two-level converter dc link voltage rise because of the trapped energy in the dc side, since power cannot be transferred as the voltage at PCC2, collapses.

Fig.4. Active and Reactive Power Converter Station 1 Exchanges With PCC1.

Fig.5. Active and Reactive Power Converter Station 1 Exchanges With PCC2.

Fig.6. Voltage Magnitude at PCC1.
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**Fig. 13.** Voltage Magnitude at PCC₁.

**Fig. 14.** Voltage Magnitude at PCC₂.

**Fig. 15.** Current Waveforms Converter 2 Injects Into PCC₂.

**Fig. 16.** Converter 2 DC Link Voltage.

**Fig. 17.** Line-To-Line Voltage Waveform at the Terminal of Converter 1.

**Fig. 18.** Voltage across 21 H-Bridge Cells of the Converter 2.
This system will demonstrate the case when the converter stations operate close to their maximum active power capabilities (power command at converter 1 is set to 0.75pu, which is 515 MW and system is subjected to a three-phase fault with a 300-ms duration.

Fig. 19. Active and Reactive Power Converter 1 Exchanges with PCC₁.

Fig. 20. Active and Reactive Power Converter 2 Exchanges with PCC₂.

Fig. 21. Voltage Magnitude at PCC₁.

Fig. 22. Voltage Magnitude at PCC₂.

Fig. 23. Current waveforms converter 2 Injects into PCC₂.

Fig. 24. Converter 2 DC Link Voltage.
The inherent current-limiting capability of the hybrid multilevel VSC with ac-side cascaded H-bridge cells that permits the VSC-HVDC system to ride-through dc-side faults will be demonstrated here. The test network is subjected to a 140 ms solid pole-to-pole dc-side fault when the test network is subjected to a temporary solid pole-to-pole dc fault at the middle of the dc link.

Fig. 25. Voltage across the 21 H-bridge Cell Capacitors of Converter 2.

Fig. 26. Active and Reactive Power Converter 1 Exchanges with PCC1.

Fig. 27. Active and Reactive Power Converter 2 Exchanges with PCC2.

Fig. 28. Voltage Magnitude at PCC1.

Fig. 29. Voltage Magnitude at PCC2.

Fig. 30. Current Waveforms Converter 1 Exchange with Grid G1 at PCC1.
IV. CONCLUSION

The viability of the VSC-HVDC system that uses a hybrid multilevel VSC with ac-side cascaded H-bridge cells is investigated here, with emphasis on its dynamic performance during network alterations. There are few vendors of the VSC-HVDC technology and there exist no standardization of the technology, which further has little operation experience for offshore applications. Further studies and benchmarking of the operation performance of the VSC-HVDC is required in order to further develop the technology. It is furthermore important to understand the similarities and differences between the commercial available VSC-HVDC schemes in order to improve the standardization process of the technology. Based on the developed control strategy for the VSC-based HVDC power transmission i.e. the design of the current controller, the DC voltage controller, the active and reactive power controllers and the AC voltage controllers, the VSC-HVDC transmission system based on a hybrid multilevel converter with ac-side cascaded H-bridge cells is
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implemented. The behavior of the four-quadrant operation, voltage support capability and the ac fault ride-through capability of the HVDC system are simulated in the MATLAB Simulink and results are obtained.

V. REFERENCES


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