FAULT ANALYSIS OF HVDC TRANSMISSION SYSTEMS

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ABSTRACT

This paper analyzes the behaviour of a Voltage Source Converter Based HVDC system under DC pole to ground fault & AC faults for 2-level VSC-HVDC & 12-pulse VSC-HVDC system in order to better understand the system under such faults. DC line faults on HVDC systems utilising Voltage Source Converters (VSC) are a major issue for HVDC systems in which complete isolation of the faulted system is not a viable option. The occurrence of pole-to-ground faults on DC link is the most common fault in HVDC system. It was observed that with the occurrence of DC pole to ground faults leads to substantial over current in the AC grid system which may lead to damage of the converter valve. Simulation of 2-level VSC-HVDC under AC fault is carried out. The fault current magnitude is attempted with the mathematical analysis & which was found to be the same as the simulated result. This paper also compares the performance of the conventional 12-pulse (CSC) HVDC system with the PWM based 2-level VSC-HVDC & 12-pulse VSC-HVDC system.

Key words: CSC-HVDC, Fault Analysis, IGBT, PWM, THD, VSC


1. INTRODUCTION

In India, with the rapid increase in energy demand, grid integration of renewable energy sources has become very essential [1], [2]. In the different renewable energy sources, wind energy benefits from HVDC technology for power transmission to enhance the system performance [3]. There is two technologies of HVDC transmission
systems: the conventional (CSC) HVDC system which uses the line commutated thyristor valve and VSC based IGBT using PWM technique makes it economically feasible to connect small scale, renewable power generation plants to the main AC grid [4]. Voltage source converter-based HVDC (VSC-HVDC) systems are considered to be the technology of choice for efficient grid integration which provides the fast and independent control of active and reactive power flow in both directions [5]–[8], low harmonic generation which enhances the power quality and stability of the system [9].

The most dominant and frequent faults on the HVDC system are DC Pole-ground fault on DC link & AC faults such as L-G, L-L & LLL. These faults are analyzed in this paper. When DC pole-ground fault occurs, substantial over current generated due to the rapid decrease in the DC voltage. The high AC grid current contribution into DC fault passes through the freewheeling diodes which may damage the converter valve due to high fault current so some protection is needed to overcome the DC side problems in the HVDC Converters [10]. The behaviour of 2-level VSC-HVDC & 12-pulse VSC-HVDC under AC faults on sending end of transformer are analyzed.

This paper is organized in six sections. Following the introduction, Section II presents HVDC system model. Three models have been developed for 2-level VSC, 12-Pulse (CSC) Conventional HVDC & 12-Pulse VSC-HVDC. The simulation result shows the superiority of VSC-HVDC with the CSC-HVDC system. Section III analyses the behaviour of 2-level VSC-HVDC system & 12-pulse VSC-HVDC systems under DC pole-ground fault. Section IV analyzes the behaviour of 2-L VSC HVDC & 12-pulse VSC-HVDC under AC fault. Simulation of 2-level VSC-HVDC is carried out under AC faults e.g. L-G, L-L & LLL faults. The magnitude of fault current is attempted. Section V compares the performance of the conventional 12-pulse (CSC) HVDC system with the PWM based 2-level VSC-HVDC & 12-pulse VSC-HVDC system using FFT analysis. In the last, Section VI consists of conclusion.

2. HVDC SYSTEM MODEL

Figure 1 Basic HVDC transmission system model for Simulation

The block diagram for basic HVDC transmission system model for Simulation is shown in Fig.1. The parameter of the HVDC system are given in Table I [11], [12]. Three simulation models have been developed: 2-level VSC, 12-pulse VSC & 12-pulse conventional HVDC. It consists of the main components such as transformer, AC filter, DC-link capacitor, DC filter & converters. The key parts of HVDC are converters which can realize the conversion from AC to DC bi-directionally.
3. DC POLE-GROUND FAULT ANALYSIS

The behaviour of 2-level VSC-HVDC & 12-pulse HVDC under DC pole-ground faults is analyzed. When DC pole-ground fault occurs, substantial over current generated due to rapid decrease in the DC voltage. The high AC grid current contribution into DC fault passes through the freewheeling diodes which may damage the converter valve due to high fault current [11].

The basic layout of 2-level VSC-HVDC system under the DC pole-ground fault on the DC transmission line shown in fig.2

![Figure 2](image)

**Figure 2** Basic layout of VSC-HVDC under DC pole-ground fault

The simulation of 2-level VSC-HVDC is carried out & corresponding voltage & current waveform during the normal operation is shown in Fig.3 (a) & fig.3 (b) respectively. (a)
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Figure 3 Simulation results for 2-level VSC-HVDC System (a) DC link voltage during normal operation, (b) DC link current during normal condition, (c) DC current during pole-ground fault, (d) DC voltage during pole-ground fault, (e) AC grid current during fault

when a single pole-ground fault occurs at t=0.08s on the sending end of the DC line, the DC voltage of the DC link capacitor voltage rapidly decreases, resulting in a significant rise in DC fault current & after 0.01s isolates the fault so system comes to normal condition as shown fig.3(c) & fig.3(d) respectively. Fig.3 (e) shows the AC grid current contribution during DC Pole-ground fault increases the magnitude of fault current in AC side.

Simulation of 12-pulse VSC –HVDC is carried out the corresponding voltage & current waveform under normal & faulty condition shown in fig.4
Fig. 4 Simulation results for 12-pulse VSC-HVDC System (a) DC link voltage during normal operation, (b) DC link current during normal condition, (c) DC current during fault, (d) DC voltage during fault, (e) AC grid current during fault

Fig. 4 (a) & (b) shows the voltage & current waveform during normal operation for 12-pulse VSC-HVDC respectively. When a single pole-ground fault occurs at t=0.08s on the sending end of the DC line its DC link voltage rapidly decreases & fault current increases in magnitude & at t=0.09s isolates fault so the system comes to normal condition as shown in fig.4(c) & fig.4(d) respectively. Fig.4 (e) shows the AC grid current contribution during the DC Pole-ground fault increases the magnitude of fault current in AC side.

4. AC FAULT ANALYSIS

The behaviour of 2-level VSC-HVDC & 12-pulse VSC-HVDC transmission systems under the AC faults like L-G; L-L & LLL faults are analyzed. Simulation for 2-level VSC–HVDC is carried out for fault on AC side. AC faults like L-G, L-L, and LLL fault are created and variations in current magnitude are observed.
A) Simulation

- Single line to ground (LG) fault: The single line to ground fault occurs on the primary side of the converter transformer at rectifier end. Fault occurs on phase A at 0.08s and lasts for 0.01sec, the current magnitude of phase A increases and voltage across it decreases rapidly to zero. When fault isolates at 0.09sec the waveform comes to normal value as shown in fig 5(a)

- Line- line (LL) fault: The double line fault occurs on the primary side of the converter transformer at rectifier. Fault occurs on phase A & phase B at 0.08s and lasts for 0.01sec, the two phase currents are same in magnitude and system becomes unbalanced as shown in fig.5 (b)

- Three phase to ground (LLL) fault: A three phase is the most severe fault compared to the other two faults. Fault occurs on 3-phases at 0.08sec, the fault current magnitude is found to be more compare to other two faults as shown in the fig.5(c)

Figure 5 Simulation results for 2-level VSC-HVDC System (a) fault current during, (b) Fault current during L-L, (c) fault current during LLL

B) Mathematical Analysis

To validate the result of 2-level VSC–HVDC under the AC fault with the simulated result the mathematical analysis has done, the single line block diagram under such condition is shown in fig.6
The mathematical analysis of same system during L-G, L-L & LLL faults has been attempted; the fault current magnitudes during L-G, L-L & LLL fault are calculated [13]. The magnitude of AC fault current during L-G fault is given by

$$If = \frac{3Ea}{Z1 + Z2 + Z0 + 3Zf}$$

The magnitude of AC fault current during L-L fault is given by

$$If = \frac{j\sqrt{3}Ea}{Z1 + Z2 + Z0 + Zf}$$

The magnitude of AC fault current during L-L-L fault is given by

$$If = \frac{Ea}{Z1 + Zf}$$

It is observed that the magnitude of fault current is calculated mathematically is found to be nearly equal with the simulated result. As the calculation is done neglecting the magnetising components the little variation is observed. The table II shows the fault current magnitude with simulated case result & mathematical calculated results.

**Table II** Fault current magnitude

<table>
<thead>
<tr>
<th>Type of fault</th>
<th>Simulated Result</th>
<th>Mathematical calculated Result</th>
</tr>
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<tbody>
<tr>
<td>L-G</td>
<td>4x10^6 A</td>
<td>3.24x10^6 A</td>
</tr>
<tr>
<td>L-L</td>
<td>4.9x10^6 A</td>
<td>4.54x10^6 A</td>
</tr>
<tr>
<td>LLL</td>
<td>6x10^6 A</td>
<td>5.4x10^6 A</td>
</tr>
</tbody>
</table>

Simulation of 12-pulse VSC-HVDC under AC faults L-G, L-L, LLL faults has been carried out & corresponding fault current magnitude are shown in fig.7

Figure 6 Diagram indicating AC fault location
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**Figure 7** Simulation results for 12-pulse VSC-HVDC System (a) fault current during L-G, (b) Fault current during L-L, (c) fault current during LLL

5. THD COMPARISON

The performance of the 12-pulse conventional (CSC) HVDC system with the PWM based 2-level VSC-HVDC & 12-pulse VSC-HVDC system is done using FFT analysis. The THD comparison for 2-level VSC-HVDC, 12-pulse conventional (CSC) HVDC & 12-pulse VSC-HVDC has been done using FFT analysis as shown in the Fig.8.
Figure 8 FFT analysis (a) 12-pulse VSC-HVDC, (b) 12-pulse conventional (CSC) HVDC, (c) 2-level VSC-HVDC
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Table III Comparison of total harmonic distortion

<table>
<thead>
<tr>
<th>Converter</th>
<th>THD</th>
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<tr>
<td>2-L VSC</td>
<td>15.39%</td>
</tr>
<tr>
<td>12-Pulse CSC</td>
<td>9.21%</td>
</tr>
<tr>
<td>12-Pulse VSC</td>
<td>4.21%</td>
</tr>
</tbody>
</table>

It is observed that the output waveform for 12-Pulse VSC-HVDC nearer to sin wave & its THD is least as compared to the 2-level VSC & conventional HVDC Transmission systems. It also ensures that as the no. of pulses of the converter increases the THD decreases which minimizes the filter requirement & enhances the power quality of the system.

CONCLUSION

This paper analyses the behaviour of HVDC systems under DC pole-ground fault & AC fault for both 2-level VSC-HVDC system & 12-pulse VSC-HVDC technology. It is observed that the occurrence of the DC pole to ground faults leads to substantial over current in the system which may lead to damage of the converter valve. Simulation of 2-level VSC-HVDC is carried out under AC faults like L-G, L-L, LLL faults. The magnitude of fault current is verified by mathematical analysis. This paper also compares the performance of the 12-pulse conventional (CSC) HVDC system with the PWM based 2-level VSC-HVDC system and

12- Pulse VSC-HVDC system using FFT analysis. It is observed that the output waveform for

12-Pulse VSC-HVDC nearer to sin wave & its THD is least as compared to the 2-level VSC-HVDC & conventional HVDC Transmission systems which minimizes the filter requirement & enhances the power quality of the system.

REFERENCES

Mrs. V.A.Kulkarni, Dr. W.Z. Gandhare, R.S. Parulkar, Feasibility of inclusion of active AC Filter in HVDC Transmission Link, Institute of Engineers Conference HARMONICA 09.


