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A Review of Fault Analysis of the HVDC Transmission System

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ABSTRACT

The classification and identification of transmission line and system failures are covered in this paper. A difficulty affects how well the converter station and converter perform, thus it is investigated how MMC-HVDC responds in AC and DC situations. AC and DC precision and efficiency aid in performance tests and quick and precise issue diagnosis. Following the examination of fault Transient Characteristics, appropriate protective systems are implemented. A successful technique is the use of Flexible Direct Current Transmission Technology to link considerable volumes of clean energy to the power grid.

Faults, on the other hand, are widespread in HVDC systems and cannot be isolated due to the occurrence of DC pole-to-ground faults, which increase the overcurrent in the AC grid system and destroy the Voltage Source Converter valve. The scheme's rapid action time, excellent dependability, and capacity to handle transition resistance have all been validated.

Keywords: *HVDC, AC, DC, Fault classification, Fault Detection, Fault Analysis, Protection Schemes, External fault, Internal fault.*

INTRODUCTION:

Renewable energy grid integration has become essential in India due to the nation's quickly expanding energy consumption. Through the use of HVDC transmission systems, renewable energy sources in remote areas can now be connected to AC grids. HVDC transmission systems have two categories: traditional (CSC) HVDC systems that employ line-commutated thyristor valves and VSC-based IGBTs that make use of PWM technology.

As the preferred technology for efficient grid integration, (VSC-HVDC) systems provide quick and independent control of active and reactive power flow in both directions, minimal harmonic generation that enhances power quality, and system stability.AC faults like L-G, L-L, and LLL as well as DC Pole- ground faults on DC links are the most frequent and pervasive flaws in the HVDC system.

A DC pole-ground failure causes the DC voltage to drop rapidly, which results in large overcurrents. Protection is necessary to handle the DC side problems in the HVDC Converters because the converter valve may be harmed by the excessive AC grid current contribution that contributes to the DC fault through freewheeling diodes. In order to secure these systems, it is crucial to concentrate on operational procedures, redundancy, and operational plans for failure scenarios. It has been demonstrated that the scheme can endure transition resistance and has a short action time and good dependability.

1. INTRODUCTION TO HVDC TRANSMISSION LINE

It is advantageous to use an HVDC system when huge amounts of power are necessary to transfer over long distances, as well as for interconnections between different frequency systems. HVDC lines are less expensive and have lower losses than AC lines for long-distance power transmission. It joins networks with varying frequencies and characteristics.

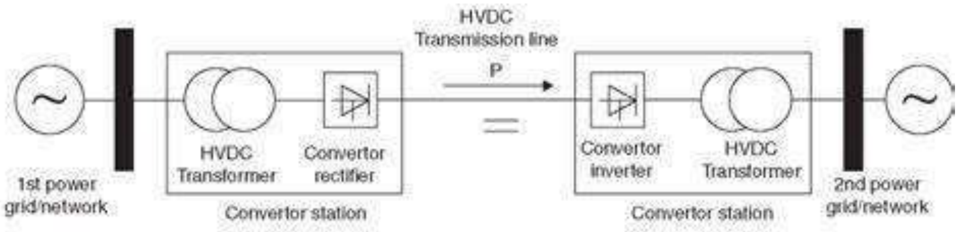

Fig.1 HVDC system model

2. INTRODUCTION TO FAULT IN HVDC

A short circuit is a phenomenon in a transmission line in which current pass through an undesired, shorter channel

2.1 Classification of Faults

The faulty transmission system component should be separated from the healthy component. Furthermore, if the fault current is allowed to continue for an extended period of time, the entire power system will collapse.

2.1.1 Types of Faults:

Nowadays, protection against transmission defects and system failure is critical. [2]This paper provides information on many sorts of errors and associated protection solutions. To protect those gadgets, various strategies that have already been deployed are introduced. The methods of protection are described below. Line protection, Back-up protection, Morphological Gradient protection, and Differential protection are the four types.

The following various types of faults may occur in an HVDC system:

- Between ground fault and Positive pole
- Between ground fault and Negative pole
- Between negative line fault and Positive pole
- Among negative line, Positive pole and ground fault
- Overcurrent faults
- Overvoltage faults

1. **Line to Ground Faults:** An L-G fault occurs when the negative or positive line comes into contact with the ground. Lightning strikes on electricity lines have the potential to cause them to fail.
2. **Line-to-Line Faults:** An L-L fault is the most severe DC fault that can occur on a VSC-HVDC system.[2] The L-L fault has three ranges. the DC capacitor discharges, causing the DC voltage to decrease to zero.
3. **L-L-G Fault:** Following the fault event, three steps occur: capacitor discharge (1st Stage), diode freewheeling (2nd Stage 2), and grid cutting-edge feeding (3rd Stage) (3rd stage).[2] In the second stage, the DC fault cutting-edge is accelerated to an exceptional height and then to a constant value, resulting in diode freewheeling motion.
4. **Overcurrent Faults:** Overcurrent protection in converters is based on the same principles as in AC systems. It may contain features such as selectivity, sensitivity, dependability, and backup.
5. **Overvoltage Faults:** Overvoltage is a serious problem in the event of a converter failure. When an inverter fails and the DC link capacitors are rapidly charged, voltage spikes occur as a result of too much power

3. FAULT DETECTION IN HVDC

This section examines the fundamentals of many DC fault detection technologies used on HVDC grids.

3.1 Fault Detection methods can be classified into unit protection and non-unit protection

3.1.1 Unit Protection

1) **Current Differential**: - Current differential is a unit protection mechanism in which the protected unit can be a busbar, a converter station, [3]or a DC line. For DC lines, this strategy can be implemented by using relays at both ends of the protected unit.

2) **Directional Protection**: Another way of communication is directional protection. [3]When a defect is discovered, each relay communicates only the current direction to the other.

3.1.2 Non-unit Protection

1) **Overcurrent and Undervoltage:** Overcurrent is the most basic approach for detecting faults, in which current measurements are taken at a single terminal and are usually based on a time-graded characteristic.

2) **Travelling-wave-based Techniques**: When a failure develops, voltage and current waves are formed and swiftly spread along the HVDC network's DC connections, according to travelling wave theory.

3) **Voltage and Current Derivative**: Voltage derivative, or simply DV/it, has been frequently employed in HVDC point-to-point transmission using Line- commutated Converters (LCCs

4) **Wavelet Transform**: [3]Signal processing has helped to enhance and improve travelling wave-based approaches.

3.1 Fault Detection methods can be classified into unit protection and non-unit protection

The defence consists of a starting unit, a unit for identifying line faults, and an identification unit for damaged poles.[4] The guiding principles and standards for each unit are as follows.

1) Use a 1 MHz sampling frequency to sample and store the positive- and negative-pole voltages and currents.
2) Start-up elements can be produced utilising voltage signals with frequencies ranging from 3 to 10 kHz.[4] The starting threshold is set to allow for a single-pole to ground fault with a fault resistance of no more than 300. This value can be calculated using (6) and the band-pass filter's feature. Backup protection is activated when the fault resistance measurement exceeds 300.
3) Following initialization, the pole-to-mode transform shown in (5) will be performed. Then Eq. (9) will be used to determine if the strike was caused by indirect lightning. [4]Given that the ratio of zero-mode to pole-mode surge impedance is 1.4 and that zero-mode voltage is much higher than pole-mode voltage during indirect lightning, this value can be multiplied by a large number to serve as the setting value in (9).
4) If the issue is not a noise disturbance, the basic and supplemental criteria in Section 3.2 will be used to establish whether a shielding failure without a flashover is present.
5) If there is no shielding failure and no flashover, a real defect is determined. Finally, steps (6) through (8) will perform fault pole selection, and DC CBs will be issued the trip command.

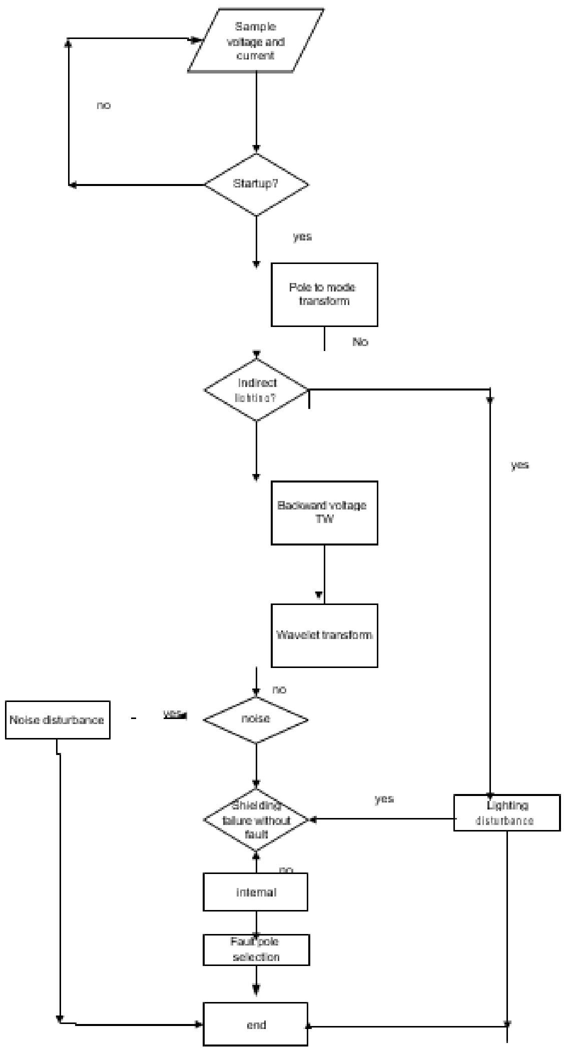

Figure 3. Flow chart for Protection Scheme

4. DC POLE-GROUND FAULT ANALYSIS

Under DC pole-ground faults, the behaviour of 2-level VSC-HVDC and 12-pulse HVDC is investigated. When a DC pole-ground fault occurs, a significant overcurrent is generated due to the quick reduction in DC voltage. [1] The high alternating current grid current Contribution to DC fault passes through freewheeling diodes, which may cause converter valve failure due to excessive fault current.

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

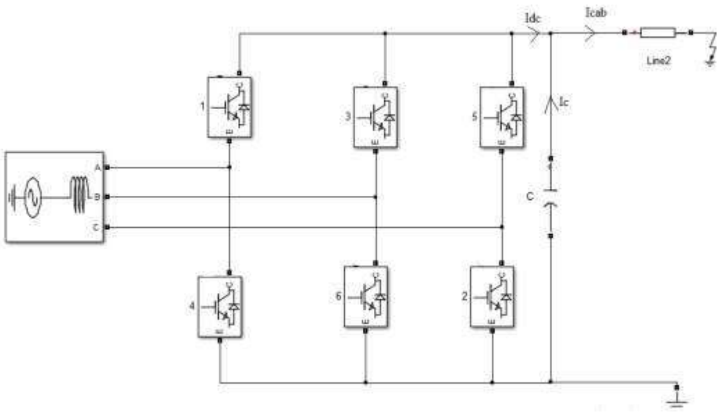

Fig. 2 Basic layout of VSC-HVDC under DC pole-ground fault

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 respectively. (a)

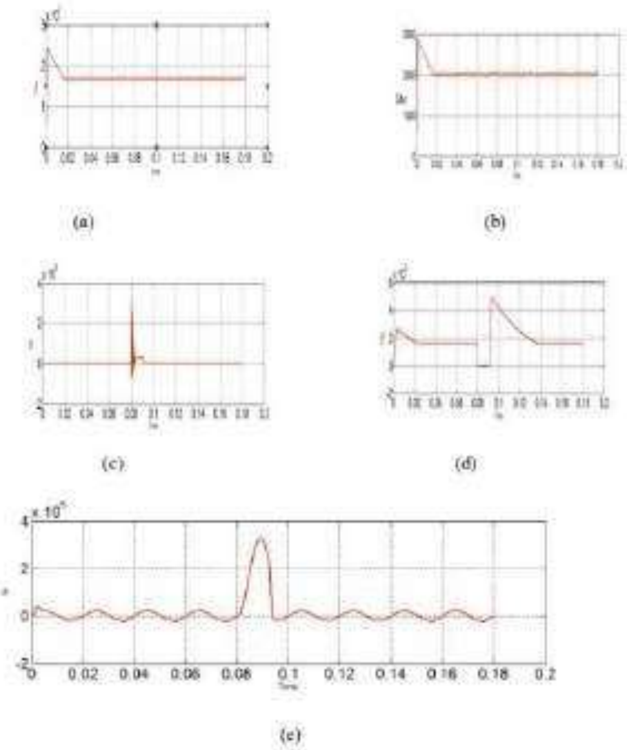

Figure 3 Simulation results for 2-level VSC-HVDC System (a) DC link voltage during normal operation, (b) DC link current during normal condition, (c) DC current during pole ground fault,(d) DC voltage during pole-ground fault, (e) AC grid current during fault

[1]. When a single pole-ground fault develops on the transmitting end of the DC line at t=0.08s, the DC voltage of the DC link capacitor voltage rapidly declines, resulting in a considerable rise in DC fault current and, after 0.01s, the fault is isolated, and the system comes to a halt.

Figures 3(c) and 3(d) demonstrate the normal condition. Figure 3 (e) depicts the contribution of AC grid current during DC. A pole-ground fault increases the size of the fault current on the alternating current side.

The related voltage and current waveforms under normal and defective conditions are illustrated in fig.4 for a 12-pulse VSC-HVDC simulation.

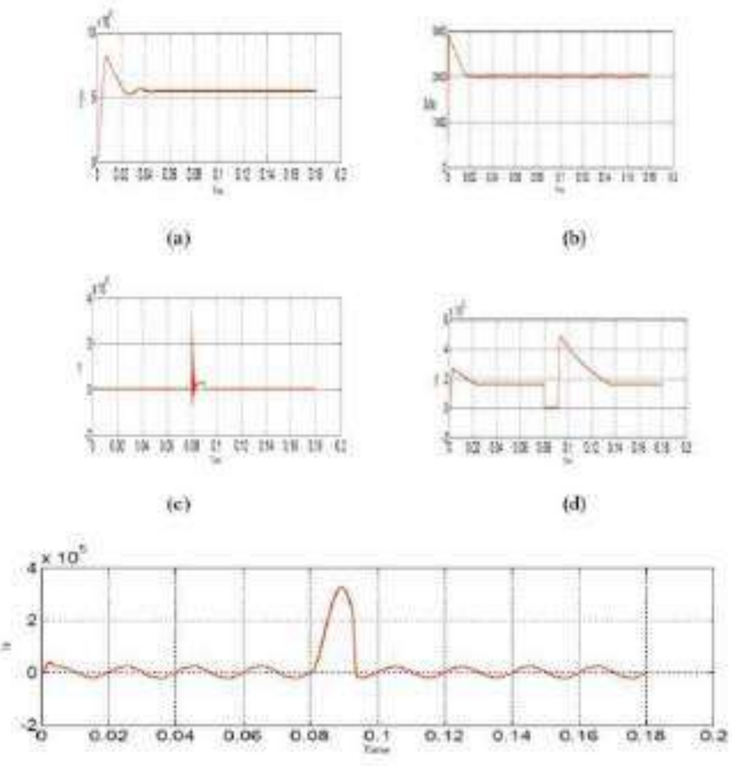

Fig 4: Simulation results for 12-pulse VSC-HVDC System (a) DC link voltage during normal operation, (b) DC link current during normal condition, (c) DC current during fault, (d) DC voltage during fault, (e) AC grid current during fault

Figures 4 (a) and (b) show the voltage and current waveforms for a 12-pulse VSC-HVDC during normal operation. When a single pole-ground fault occurs on the transmitting end of the DC line at t=0.08s, the DC link voltage rapidly drops and the fault occurs.

As shown in fig.4(c) and fig.4(d), current increases in magnitude and, at t=0.09s, the fault is isolated, and the system returns to normal operation. The AC grid current contribution during the DC Pole-ground fault increases the magnitude of the fault current in the AC side, as shown in Fig.4 (e).

Conclusions

This paper reviews the techniques for fault localization, classification, and detection in transmission lines and distribution systems. A variety of strategies are described, and thorough examples are presented. It has been observed that the occurrence of DC pole-to-ground failures results in a sizable quantity of system overcurrent, which could harm the converter valve. In this review work, various DC fault detection systems are applied to HVDC grids using various principles, and various protection mechanisms are compared. The methodologies for defect detection are divided into two groups: unit protection methods and non-unit protection methods. The DC pole-ground faults analysis is done and simulation result are analysed.

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