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An Analysis on Fault Detection of VSC Based HVDC Transmission Lines

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ABSTRACT

The detection and operation of transmission lines and systems are discussed in this paper. As a fault affects the performance of the station of converter, an analysis of response of HVDC under DC conditions is performed. The correctness and effectiveness of the DC assist in checking performance and detecting faults quickly and accurately.The following analysis of Characteristics of fault Transient, suitable protection schemes are introduced. The voltage source converter (VSC) is used in majority of HVDC transmission lines, which fail DC links. MMC (Modular Multilevel Converter) is widely used.Never the less, flaws are prevalent in HVDC systems and are challenging to isolate, given the occurrence of DC pole-to-ground faults. These faults contribute to heightened overcurrent in the AC grid system, leading to damage to the Voltage Source Converter valve. The system has been confirmed to exhibit rapid response times, exceptional reliability, and the capacity to endure transition resistance.

Keywords: Protection Schemes, DC, Fault Detection, Fault Analysis ,External Fault ,HVDC, Internal Fault.

1. Introduction

India's rapidly growing energy consumption has made grid integration of renewable energy necessary. Remote locations can now be connected to AC grids by HVDC transmission systems for renewable energy sources. There are two types of HVDC transmission systems: VSC-based IGBTs that use PWM technology and classic (CSC) HVDC systems that use line-commutated thyristor valves. These techniques allow small-scale, renewable power generators to be affordably connected to the main AC grid. System stability, minimal harmonic generation that improves power quality, and fast and independent control of both reactive and active power flow are all provided by (VSC-HVDC) systems, the chosen technology for effective grid integration. Most common and widespread defects in the HVDC system include AC faults such as L-G, L-L, and LLL, and DC Pole-ground faults on DC lines. Strong over currents are produced when there is a DC pole-ground failure because the DC voltage drops quickly. Because the excessive AC grid current contribution that causes the DC fault through freewheeling diodes may damage the converter valve, protection is required to tackle the DC side issues in HVDC converters. Operational protocols, redundancy, and operational planning for failure situations must be the primary focus in order to secure these systems. Using the extracted features method, the defect is identified. It has been shown the scheme is a little action time, dependability is good, and can withstand resistance to transitions.

2. HVDC Transmission System

The advantage of employing an HVDC system is that it may be used for interconnections between various frequency systems, even at huge transmission power requirements over long distances. It links networks cmbinely disparate frequencies,features together.

2.1. Operation of the HVDC transmission system

Rectifiers are used to transform AC power produced in producing substations into DC power. A line's inverters and rectifiers are located at both ends in an HVDC substation or converter substation. AC is converted to DC of the rectifier terminal, and DC is converted into AC , the terminal of inverter.Along with the overhead lines, DC is shifted into AC at the user's ends through the use of inverters, which are housed in the substation of converter. In both of the transmitting and receiving edges of the line, power is not changing. Because DC reduces losses and boosts efficiency, it is transmitted over long distances.

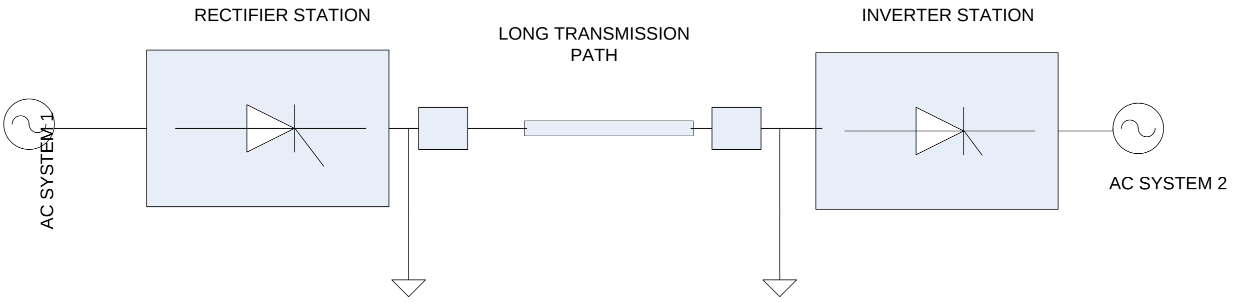

Fig 1 HVDC System model

“Two-terminal DC system" or "point-to-point system" refers to a system that consists of more than two converter stations and one transmission line. Similarly, a substation is referred to as multiterminal DC substation if it contains more than two converter stations and linked DC terminal line.

3. Fault in HVDC

A transmission line occurrence known as a short circuit occurs when electricity flows through an unwanted, shorter channel.

3.1. Types of faults

These days, safeguarding against system failure and communication errors is crucial. This work provides information on various fault types and related mitigation methods. Many strategies that have previously been put into practice are presented to safeguard those gadgets. The following is a list of the protective methods. These four types of protection are Differential, Morphological Gradient, Line, and Backup.

3.1.1. Line to Ground Faults

Either the positive or negative line coming into contact with the ground results in an L-G fault. Failures could result from lightning strikes on overhead electrical wires. This could lead to a malfunctioning circumstance where the line breaks and falls to the ground. Since the fault in this instance is irreversible, the line needs to be split in order to fix it. In certain situations, an object that generates a ground fault may separate from the line and the system can resume regular functioning.

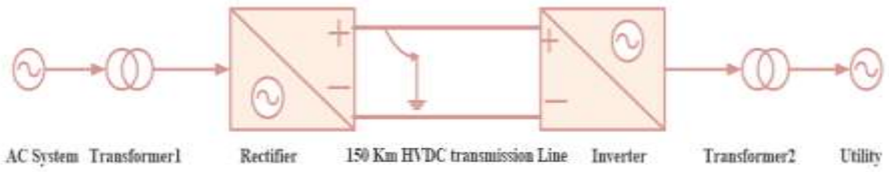

Fig 2 PG fault on HVDC system

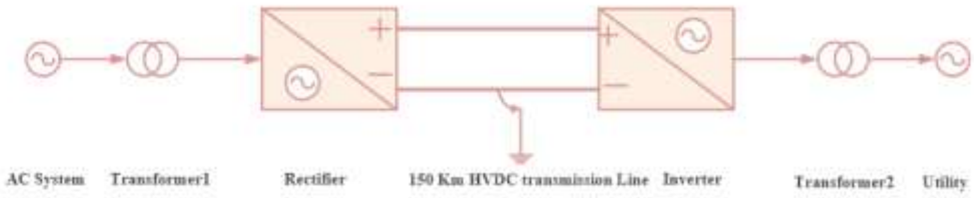

Fig 3 NG fault on HVDC system

3.1.2. Line-to-Line Faults

An Line-to-Line fault is the worst kind of DC failure that can happen to a VSC-HVDC system. Whatever the configuration of converter stations, a switching failure happens when the positive bus inside the converter is shorted to the negative bus.Any line-to-line fault, whether temporary or permanent, could happen.

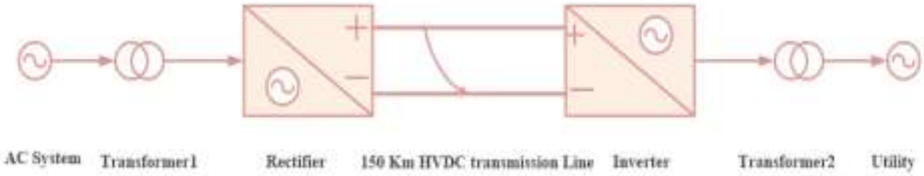

Fig 4 PN fault on HVDC system

3.1.3. Line-to-Line-to-Ground Fault

The fault occurrence is followed by three stages: grid cutting-edge feeding (stage 3), diode freewheeling (stage 2), and capacitor discharge (stage 1) before the next step. The diode freewheeling motion is caused in the stage by rapidly increasing the DC fault cutting-edge to an uncommon height and bringing it down to a accurate solution.

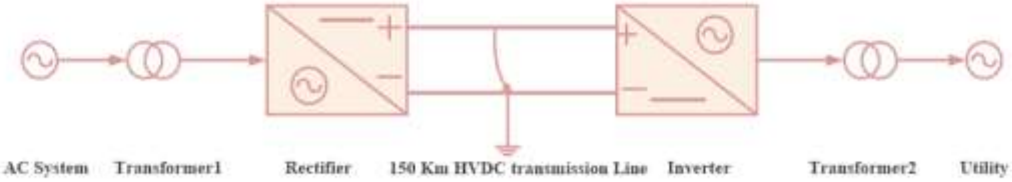

Fig 5 Positive to Negative to Ground (PNG) fault on HVDC system

4. FAULT DETECTION IN HVDC

This section provides an overview of the essential principles behind different techniques for detecting DC faults in HVDC grids. Broadly, there are two categories of DC fault detection methods: single-ended and double-ended. Single-ended methods rely solely on local measurements, whereas double-ended methods utilize both local measurements and remote measurements from the opposite end of the line. The objective of both types of methods is to analyze these measurements to identify the fault's location and assess whether corrective action is necessary.

4.1 Fault detection methods can be classified into unit protection and non-unit protection

When using non-unit protection methods, the protection borders are often defined by placing inductors at each end of each line. Additionally, the series inductor inhibits the pace at which the fault current (di/dt) rises by acting as a current limiter.Series inductors are not necessary for unit-protection techniques like current differential or directional protection, on the other hand. As long as the protection zones are well-defined, two-ended fault detection techniques are essentially unit protection techniques. DC protection techniques that are selective are those mentioned above.

4.1.1 UNIT PROTECTION

Current Differential: A busbar and a converter station or else a DC line are examples of units that can be safeguarded using current differential technology. Relays at both splits of the protected unit can be used to accomplish this technique for DC lines. Every relay calculates the value in local currency and transmits it to the other end of the line.

Directional Protection: Another communication-based technique is directional protection. When a defect is identified in this scenario, each relay just transmits the current direction to the other end. The protected line is isolated and a trip command is output if relays detect a problem in either of their forward directions. This makes the method is more reliable than the idiff method since the conveyed information is simpler (i.e., the current sign). When a defect is identified in this scenario, each relay just transmits the current direction to the other end. The protected line is isolated and a trip command is generated if the relays detect a problem in either of their forward direction.

4.1.2 Non-unit Protection

Travelling-wave-based Techniques: As per the travelling wave theory, the entire HVDC network's DC cables generate and quickly spread waves of voltage and current when a breakdown occurs. The initial voltage , current travel from fault location to line's carry a great deal of information.

Voltage and Current Derivative: The voltage derivative is utilized instead of the under-voltage approach, the basic idea is the same. Measured at predetermined intervals of time is the rate of voltage change.

Wavelet Transform: Through the use of signal processing, traveling based on wave approaches have been further enhanced.These techniques use mathematical techniques like Fourier analysis, but they are still dependent on voltage and current data.

4.2 PROTECTION SCHEME

Based on the polarity properties of current fault components, a pilot protection system for a hybrid HVDC transmission line is recommended. The following list outlines the criteria and guiding principles for each unit.

4.2.1 stating unit

The existing gradient serves as the initial prerequisite for protection. The criterion and computation expression are as follows:

$$\nabla x(k) = \sum_{j=0}^{2} x(k-j) - \sum_{j=3}^{5} x(k-j) \qquad (1)$$

$$\nabla x(k) > \Delta 1 \qquad (2)$$

In which x(k-j) represents the voltage value measured at time j before the current one. x(k) is an estimate of the voltage.In order to guarantee prompt and reliable beginnings for mistakes, the recommended threshold value is bigger than the maximum voltage gradient under typical operating conditions.

4.2.2 Line fault identification unit

The examination presented earlier suggests that, even when there is a considerable disparity in the magnitudes of the current fault components at the two ends of the line, it is possible to distinguish between internal and external faults in various fault scenarios. During the initial transient phase following an internal fault, the current fault components at both ends of the line exhibit the same positive polarity, whereas in the case of an external fault, they display opposite polarities.

$$\mathrm{Nix} = \sum_{k=kst}^{k5+kst-1} \mathrm{Pix}(k) \qquad (3)$$

$$\mathrm{Pix}(k) = \mathrm{sign}\,(\Delta \mathrm{ix}\,(k)) = \begin{cases} 1 & \Delta \mathrm{ix}\,(k) > 0 \\ -1 & \Delta \mathrm{ix}\,(k) < 0 \end{cases} \qquad (4)$$

The parameters on the inverter side and rectifier side are denoted by the subscripts M and N, respectively. For both the positive and negative current fault components, Nix is the difference in sampling values within the data window. Sample number k5, or the sample number in 5 milliseconds, is obtained by satisfying the starting unit condition at sampling point kst.

$$\text{Ni-sum} = \text{Nim} + \text{Nin} \qquad (5)$$

$$\text{Ni-sum} > \text{Ni-set} \qquad (6)$$

where the cutoff number is Ni set. It is defined as 50% of the all number of samples that have been digitally captured in the data windows at both ends of the line , as a positive integer. In present case, the Ni set is 50%.

4.2.3 Pole of fault detection unit

The interaction of electromagnetic forces between parallel transmission lines within the bipolar HVDC system suggests that issues on one line have the potential to impact the current on the adjacent line, potentially leading to a malfunction in the transmission. The distinctive polarity of the voltage fault component can be employed to pinpoint the problematic pole. Once the protection procedure begins, the polarities of the voltage fault components are evaluated at each sampling point, and the distinction between positive and negative components is established.

$$\mathrm{Nvx} = \sum_{k=kst}^{k5+kst-1} \mathrm{Pvx}(k) \qquad (7)$$

$$\mathrm{Pvx}(k) = \mathrm{sign}\,(\Delta \mathrm{vx}\,(k)) = \begin{cases} 1 & \Delta \mathrm{vx}\,(k) > 0 \\ -1 & \Delta \mathrm{vx}\,(k) < 0 \end{cases} \qquad (8)$$

Similar to the explanation of (3) and (4), but with regard to voltage, are (7) and (8). Both of the inverter side,rectifier side communicate a computed results to one another and add the results following the data window:

$$Nv\text{-}sum = Nvm + Nvn \quad (9)$$

In case the summing is a positive or has a low accurate value, the pole is considered as non-faulty. The criteria for identifying a malfunctioning pole identification unit are described below:

$Nv\text{-}sum > Nv\text{-}set$

in which case the Nv specified threshold value is employed. It has an absolute value that is negative, and 30% of the complete number of digitally recorded researches is what it is worth in data of windows each end of the line. The Nv set in this case is 30.

5. INTERNAL FAULT ANALYSIS

5.1. Positive-pole-to-ground fault occurs near terminal R

The calculated differential current for the positive-pole-to-ground fault, located 0.1 I away from terminal R at the compensation point CM. As the differential current in the common mode rises and crosses the fault identification threshold (Top fd), the differential mode's current also increases and reaches the threshold for positive fault pole selection (Top ps).

In the case of a negative-pole-to-ground fault occurring at the midpoint, the computed differential current at the compensation point CM is displayed in 0.5 I from terminal R. In the differential mode, the differential current decreases and falls below the threshold for negative fault pole selection (Iop ps), while in the common mode, the differential current increases and surpasses the fault identification threshold (Iop fd).

5.2. EXTERNAL FAULT ANALYSIS

5.2.1.External fault occurs out of the transmission line

The solid positive-pole-to-ground fault that originated at the rectifier and inverter terminals along the transmission line is represented by the modeling findings.

5.2.2.External fault occurs at terminal R

The fault identification threshold Iop fd is not reached by the common mode differential current.Both stability and inactivity are present in the security.

5.2.3.External fault occurs at the terminal I

The protection either keeps working or doesn't work under the external fault at terminal I. As seen in Fig. 6, the differential current of the common mode is smaller than the fault detection threshold, and for external faults the protection is either stable or inactive.

The simulation findings indicated above show that the proposed protection method functions correctly under an internal fault in the transmission line during the duration of the fault, including both the transient and steady-state processes.

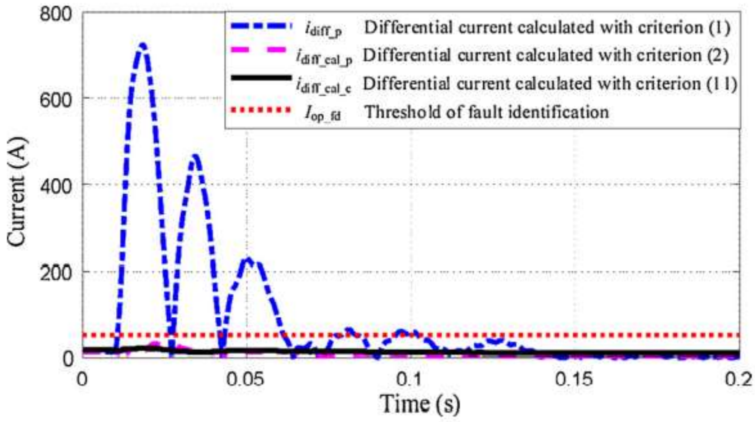

Fig 6.Results of the simulative comparison (external fault).

6. Conclusions:

This article provides an overview of the methods used in distribution and transmission lines for fault location, classification, and detection. Detailed examples are provided along with descriptions of various tactics. One finding is that a significant amount of system overcurrent is produced when DC pole-to-ground failures occur, which may cause damage to the valve.

Flaws in HVDC transmission system, both internal and external, are tested. The effectiveness of these strategies and the impact of additional grid attributes including converter technology, grid complexity, and DC grid and converter control systems should be the subject of future research. As a result, it becomes simple to comprehend and has engineering application terminology. Regarding HVDC systems with many terminals and different converter structures, the protective principle is applicable since it is not impacted by the types of converters.

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