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DC LINE-TO-LINE FAULT ANALYSIS FOR VSC BASED HVDC TRANSMISSION SYSTEM

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ABSTRACT

The DC transmission lines have become one of the components with high fault probability as DC transmission technology based on VSC is often used for long distance transmission in which system most of faults are line to line fault. Therefore, with line to line fault of DC lines being a severe fault of DC transmission system, a detailed analysis of the fault characteristics is of great practical significance for fault detecting and protection design. According to the characteristics of the fault current circuit when the line to line fault occurs, the three stages of fault process were presented in detail. This paper also proposes a protection principle for transmission line in VSC- HVDC system.

Keyword : VSC-HVDC, Line to Line fault, Fault characteristics, Fault Analysis, DC fault clearing methods, PSCAD.

I. INTRODUCTION

In recent years, DC power supply technology has been retarded again. High Voltage Direct Current technology has proved to be an efficient, cost effective and reliable way of transmitting electrical power over long distances as compared to the classic and traditional AC transmission [1]. Except for the advantages of traditional HVDC, VSC-HVDC also has the characteristic of fast independent control of active and reactive power, unaltered voltage polarity when flow is turned, power energy quality improving ability and dynamic reactive power compensation ability. Therefore, it has attracted a lot of researchers, and many projects have been built in the world. So far, most of the research in VSC-HVDC has focused on operating principle and control strategy. Research in DC fault analysis and line protection is still in the beginning stage. The VSC-HVDC cable line has become one of the components with the highest failure rate in VSC-HVDC transmission systems. However, the correct action ratio of protection for VSC-HVDC transmission lines was low. Improvement of the theoretical level of protection for VSC-HVDC transmission lines is imperative. Depth fault transient analysis of VSC-HVDC transmission system can lay the foundation for research on protection principles for VSC-HVDC transmission lines [2]. With the development of power electronic technology and the relatively high switching frequency of Pulse Width Modulation (PWM), HVDC transmission system based on Voltage Source Converters has taken on some excellent advantages. The differences in structure between the two types of converters such as Conventional HVDC and VSC-HVDC contribute to the differences in their performance. Generally, the new

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transmission technology has the following advantages compared with conventional, thyristor based HVDC [3-5]:

- Possibility to control the reactive power (consumed or generated by the converter) independently of the active power (to or from the converter).
- No risk of commutation faults in the converter.
- Ability to connect to weak AC networks, or even dead networks.
- Faster response due to increased switching frequency (PWM).
- Minimal environmental impact.

There are two approaches to assist VSC-HVDC transmission systems to ride-through dc side faults. The first approach is to use a fast acting dc circuit breaker, with considerably high let-through current to tolerate the high dc fault discharge current that may flow in the dc side. This breaker must be capable of operating at high voltage and isolates temporary or permanent dc faults, plus have a relatively high current breaking capacity. The second approach is to use converter stations with dc fault reverse-blocking capability. Each converter station must be able to block current flow between the ac and dc sides during a dc fault. However, the drawback is that the active power exchange between the ac networks reduces to zero during the dc fault period [3].

This paper is organized as follows. In Section II, the DC line-to-line fault and the fault process is divided into three stages such as capacitor discharge, grid-side current feeding and voltage recovery stages. In Section III, the simulation of circuit by using PSCAD / MATLAB and analysis show out the characteristics of DC line-to-line HVDC system, and then proposes the recovery demand of faults at overhead line scheme. In Section IV, recovery methods are proposed. Finally, concluding remarks are given in Section V.

The characteristic of voltage and current in a VSC-HVDC system after the occurrence of a DC fault is different from that in traditional HVDC system. It is because there are big dc-link capacitors in the both terminals of DC cables. In this paper, a model of a two terminal VSC-HVDC is shown in Fig.1.

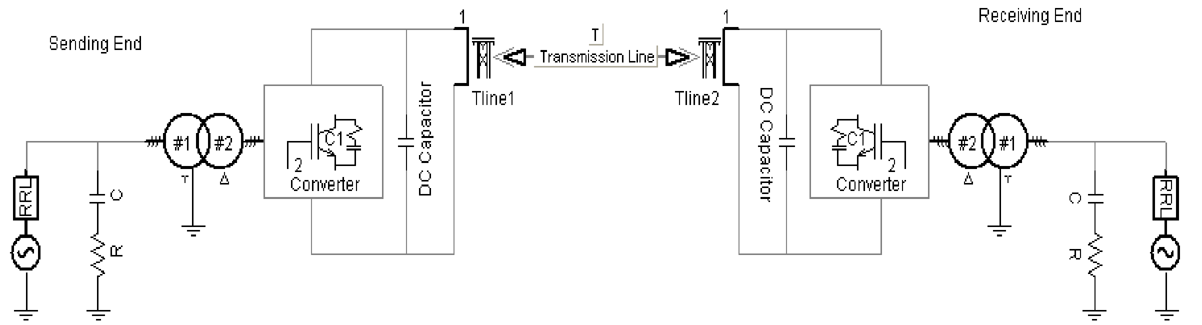

Fig.1: Two Terminal VSC-HVDC Model

It includes three main parts of VSC-HVDC, i.e. model of VSC ac side, dynamic model of inner DC system and model of control system. The transient stability simulation for system is realized with the help of PSCAD. Then transient characteristic analysis of electrical quantities on VSC-HVDC transmission line is carried out. This work can provide direct and effective reference for subsequent studies on fault transient analysis of VSC-HVDC transmission systems, and lays a foundation for the research on protection and fault location principles for VSC-HVDC transmission lines [2].

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Fault vulnerability and protection are significant issues that constrain the development of voltage-source converter based DC networks, especially in high-power scenarios. This is primarily due to the lack of mature commercial DC switchgear products. However, VSC-based high-voltage direct current power transmission is attracting more research interest as it provides greater operational flexibility which suits renewable energy sources a prerequisite [4].

II. DC LINE FAULTS

The common fault types for DC transmission line are line- to-ground fault and line-to-line fault. Because faults of cables are usually caused by external mechanical stress, therefore the faults are generally permanent, for which a lengthy repair is needed. The converters should be stopped immediately while a cable fault is detected. But for overhead line, the faults are always caused by lightning strikes and pollution; faults along the line are likely to be temporary, which demands a fault restoration after the fault clearance. This paper will focus on the fault analysis of DC line, and demonstrates the demand and solution of VSC-HVDC system restoration after DC temporary faults for overhead line [5].

The line-to-line fault means insulation failure between the two DC conductors. The fault demands that both converters should be blocked. But we should note that, the ac system is still short- circuited through the VSC freewheeling diodes. Which means the ac system will continue to feed current into the fault even if the converter is blocked, to avoid this besides blocking the converters. The DC line is also needed to be isolated from the ac system by tripping ac breakers to enable the air insulation to de-ionize. Another method is to introduce DC breakers and open these breakers when a fault is detected [6]. Such faults occur as a result of direct contact or insulation breakdown between positive and negative conductors of a DC transmission line. Line-to-Line faults are not common but can be severe to the system. A line-to-line fault fed from a two-level VSC can be divided into the following three stages.

2.1 Line-to-Line Fault

In this section, DC transmission line, line-to-line fault is analyzed. A DC line-to-line fault is a rare accident. However, it is the most catastrophic fault for VSCs.

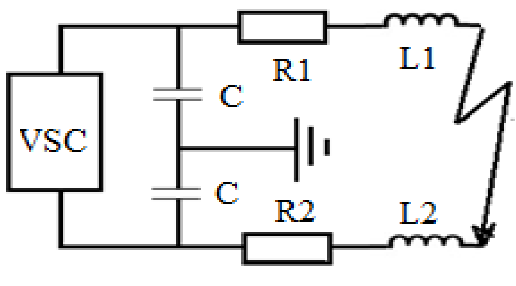

Fig.2: Equivalent Circuit of DC Line-to-Line Fault

The IGBTs will be blocked to avoid exposing to over-current caused by the fault. A DC line-to-line fault can be expressed by an equivalent circuit shown in Fig 2. R1, R2, L1, L2 are the equivalent resistances and inductances of the positive and negative lines from the VSC to the location of the line-to-line fault respectively and C is the capacitance of the dc-link capacitor in parallel with the VSC.

The DC line-to-line fault can be divided to three stages.

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2.2.1 Capacitor Discharge Stage

The equivalent circuit of the capacitor discharge stage is represented in Fig.3. When a DC line-to-line fault occurs, a loop circuit without source is formed, and the DC-link capacitor starts discharging rapidly; consequently the DC voltage collapse occurs. The natural fault current response is characterized by a high peak and fast rate of change. This stage ends as the capacitor voltage drops to zero.

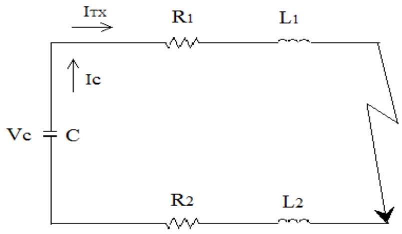

Fig.3: Equivalent Circuit of Capacitor Discharge Stage

When the dc-link capacitor begin to discharge through the DC transmission line, the DC voltage in both the positive and negative line will decrease rapidly, while the DC current will increase. It will lead to a huge over-current in the AC side.

2.2.2 Diode Freewheel Stage

The equivalent circuit of the diode freewheel stage is represented in Fig.4. This stage is initiated when the DC fault commutates to the converter free- wheeling. This is the most hazardous period as the circulating fault current can destroy the anti-parallel diodes.

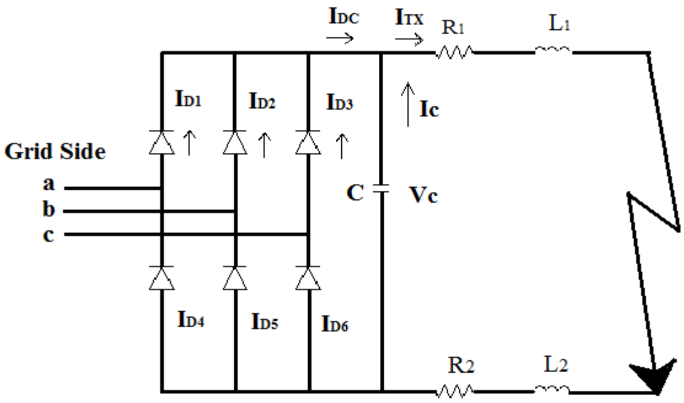

Fig.4: Equivalent Circuit of Diode Freewheel Stage

When the dc-link voltage drops to zero, the freewheel diodes and cable inductance will form a loop circuit. Initially, the IGBT is blocked for self-protection, and there is a high initial over-current though the diodes, which may make huge damage to the diodes. Then the DC current and diodes current will decrease rapidly.

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2.2.3 Capacitor Recharging Stage

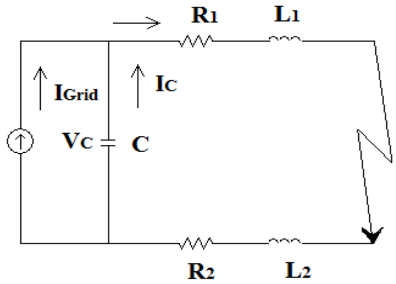

Fig.5: Equivalent Circuit of Capacitor Recharging Stage

The equivalent circuit of the capacitor recharging stage is represented in Fig.5. During this stage the IGBTs are blocked and the converter behaves as an uncontrolled rectifier, injecting current into the DC side fault. During this stage, the dc-link capacitor, cable inductance and AC side form a forced response, and the capacitor will be charged. This results in an increase in DC voltage.

III. METHOD USED FOR REQUIREMENT ANALYSIS

This paper focus on the faults analysis of DC line to line fault solution of VSC-HVDC system restoration after DC faults for overhead HVDC transmission line. PSCAD simulation software is used to simulate the VSC based HVDC system. EMTDC and MATLAB are almost suitable for simulating the time domain instantaneous responses, also popular for analyzing electromagnetic transients of electrical systems. PSCAD / MATLAB allow assembling the circuit, running the simulation, analyzing the results, and managing the data in a completely integrated graphical environment.

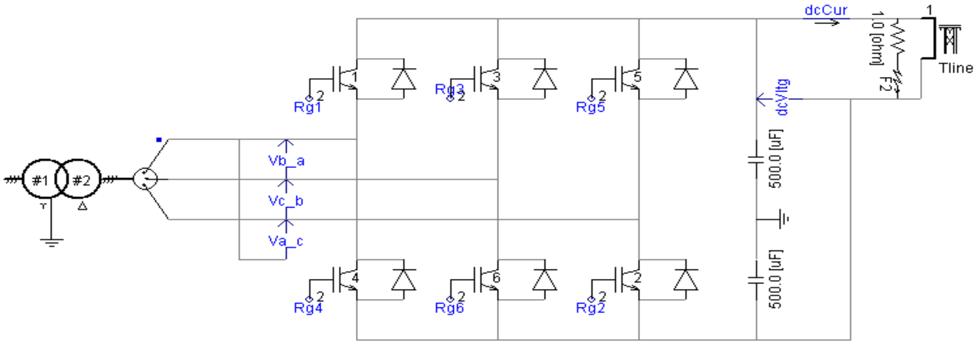

Fig.6: DC Line-to-Line Fault model in PSCAD

The performance under DC transmission line transients investigated under power system software tool PSCAD. The simulation of circuit by using PSCAD / MATLAB and analysis show out the characteristics of DC line-to-line HVDC system, and then proposes the recovery demand of faults at overhead line scheme. Fig.6 shows DC Line-to-Line Fault model in PSCAD. The simulation test is done at the sending end of VSC-HVDC transmission system. Line-to-line fault is the severe fault in the DC transmission system. In this system, a line-to- line fault is demonstrated and the response of the system is analyzed.

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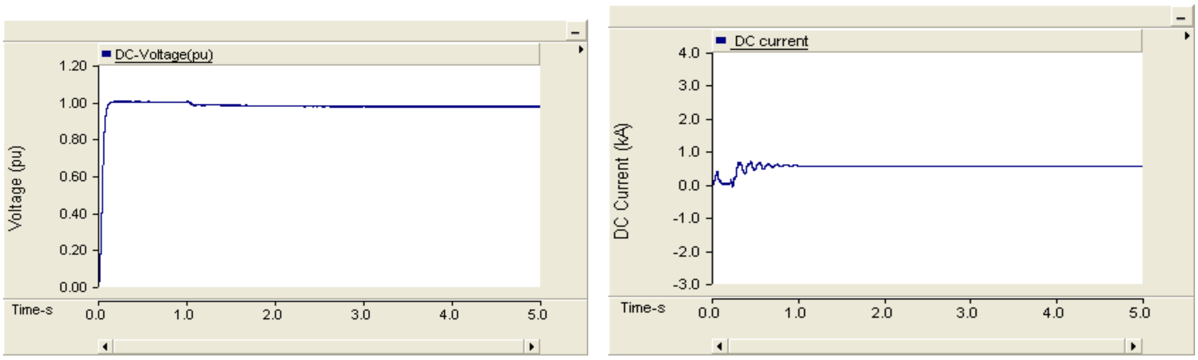
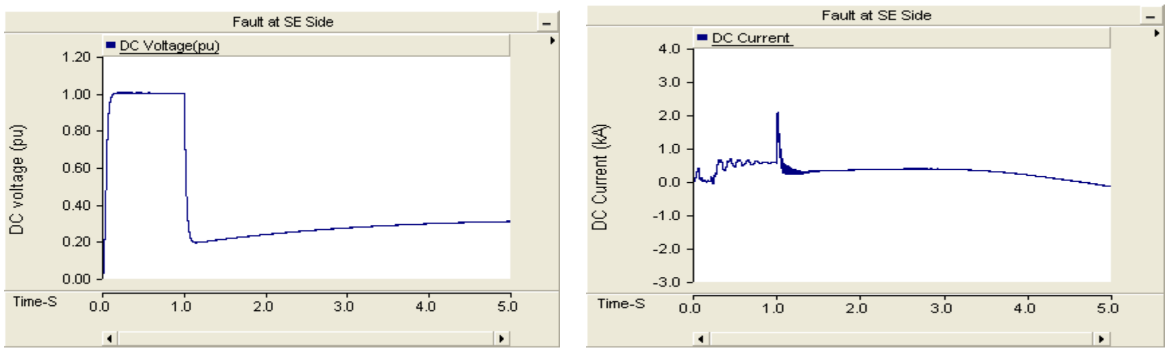


(a) DC Link Voltage during Normal Operation **(b) DC Link Current during Normal Condition**



(c) DC Link Voltage during Line-to-Line Fault (d) DC Link Current during Line-to-Line Fault

Fig.7: Simulation results for VSC-HVDC System

when line-to-line fault occurs at t=1.0s on the sending end of the DC transmission line, the DC voltage of the DC capacitor voltage rapidly decreases, resulting in a significant rise in DC fault current as shown Fig.7(c) & Fig.7(d) respectively.

VI. RECOVERY METHOD

The demand for transmission line faults is also to correctly detect the faults and then block and trip the converter for repairing. To avoid the overcurrent stress of freewheeling diodes after blocking, DC breakers can be introduced. For overhead line, temporary line-to-ground faults. The rebalance of capacitors can be realized by:

- Grounding by high impedance branch
- Reconnecting transformer secondary winding to Yn type
- Monopolar scheme operation
- The design philosophy of fast DC breakers

4.1 Grounding by High Impedance Branch

In direct grounding system, the unbalance of capacitor is caused by the discharging of the faulty pole and the DC voltage controller. In high impedance grounding system, the discharging current is very small so that the voltage of the capacitor can maintain without any over current stress. The line-to-line voltage can be recover after fault as shown in Fig.8 and output waveforms of recovery method is shown in Fig. 9.

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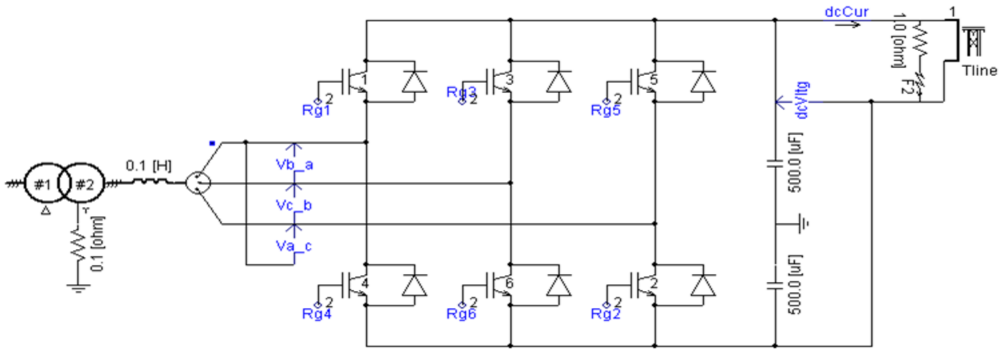

Fig. 8: Grounding By High Impedance Branch Recovery Method For Line-To-Line Fault

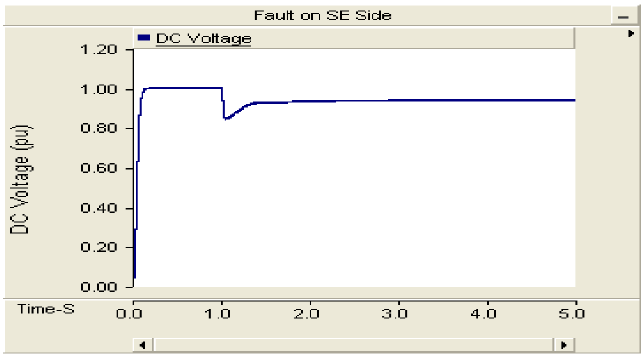

Fig.9: Simulation results of DC link voltage for VSC-HVDC System using Grounding by High Impedance Branch

4.2 The Design Philosophy of Fast DC Breakers

The basic demand of fast DC breakers is to isolate the DC pole and converter punctually so as to avoid the ac system. By using IGBT with anti-paralleled diode, the normal operating current can pass through IGBT of the sending end and diode of the receiving end. While the DC line is under fault condition, the discharging current will force the IGBT to turn off immediately to realize the pole isolation. This can avoid the ac breaker tripping, and then the converter can restart faster.

V. CONCLUSION

VSC-HVDC technology is continually developing and more and more applied in renewable power integration, so it has a broad prospect. DC transmission line faults have a detrimental effect on VSC-HVDC system operation and may make damage to the system components. This paper analyses the transient characteristics of electrical quantities in a two terminal VSC-HVDC system after the occurrence of line-to-line fault. The results are analyzed in PSCAD detailed.

The analysis and simulation show out the characteristics of DC line-to-line fault of VSC-HVDC system. The line-to-line fault leads to the unbalance of DC voltage which is difficult to rebalance. For overhead line temporary line-to-line faults, the rebalance of capacitors can be realized by using high impedance grounding system. In this recovery method the discharging current is very small so that the voltage of the capacitor can maintain without any overcurrent stress.

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