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Characteristics Analysis of Interphase Short Fault in AC-DC Hybrid Distribution System Containing Flexible DC Device

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Abstract: Fault mechanism of AC-DC hybrid distribution system is more complicated compared with that of traditional AC distribution network. Characteristic analysis of interphase short fault in hybrid system is conducted taking into account flexible DC device in this paper. Fault simulation of hybrid distribution network is carried out in PSCAD/EMTDC, which verifies effectiveness of the analysis method.

Keywords: AC-DC hybrid distribution system; Interphase short fault; Characteristic analysis

1. Introduction

Compared with traditional AC distribution network, flexible AC-DC distribution network with the advantages of low loss, high power supply capacity and high reliability gradually becomes the development trend of future distribution system [1]. The introduction of flexible AC-DC hybrid technology has improved distribution network architecture while brought many new problems. For example, the effective analysis of fault mechanism faces certain challenges [2]. Nonlinear control strategies adopted by converters in flexible DC equipment leads to traditional failure analysis methods are no longer applicable to a hybrid system [3]. Therefore, it is necessary to study fault mechanism that takes into account control strategies.

This paper launches a specific study based on the master-slave control method, that is, one converter uses the DC voltage and reactive power control (referred to as VQ control), and the others use the active and reactive power control (referred to as PQ control) [4]. When an asymmetric fault occurs, AC voltage symmetry is broken and a large number of negative sequence currents are produced, which will cause double-frequency harmonic component of the DC bus voltage [5]. Therefore, in order to suppress the negative sequence currents under asymmetric conditions, it is necessary to consider the use of positive and negative sequence separation control.

This paper studies mechanism of phase-to-phase short fault in flexible AC-DC hybrid distribution system. Firstly, taking a two-port flexible device as an example, according to the sequence separation control strategy adopted by internal converters, output characteristics are analyzed to establish equivalent models. Secondly, for a distribution network containing the flexible device, theoretical fault analysis is carried out. Lastly, simulation is conducted in PSCAD/EMTDC to verify rationality of the theoretical analysis method proposed in this paper.

2. Modeling for Flexible DC Equipment

Fig. 1 shows a typical structure of a distribution system with a dual-port flexible DC device. HV1 and HV2 are 110kV high-voltage AC buses, MV1 and MV2 are 10kV medium-voltage AC buses, T_1 and T_2 are 110kV/10kV main transformers, while T_3 and T_4 are converter transformers that select the connection method of Δ/Yg for blocking the flow of zero-sequence components between AC and DC systems [6]. C is the DC voltage stabilizing capacitor, f_1 and f_2 are the fault points on the AC grid side, f_3 and f_4 are the fault points on the AC valve side.

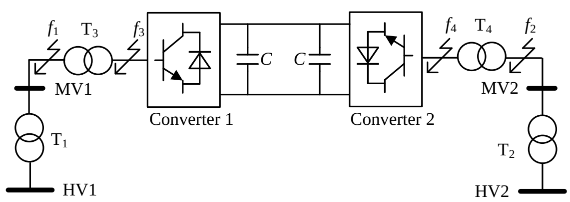

Figure 1. Typical structure of a distribution system with a dual-port flexible DC device

In order to achieve fast dynamic response of the system, a current inner loop is introduced. PI regulators control actual currents under the d-q synchronous rotation coordinate axis to track reference values, which are PQ or VQ outer loop output signals.

When the sequence separation control method is adopted, in order to suppress negative sequence currents, negative sequence reference values are set equal to 0, while positive ones are still determined by outputs of outer loop controllers.

When an interphase short fault occurs at the constant power end, the drop of $U_{d(1)\_1}$ that is the d-axis component of local side positive sequence voltage, will cause active power P_1 of the local converter to fall instantaneously. In order to ensure that P_1 tracks the given value, the active power outer loop controller responds quickly resulting in an increase of its output $I_{dref(1)\_1}$. Affected by the adjustment of the current inner loop controller, the d-axis component of the positive sequence current $I_{d(1)\_1}$ will rise accordingly. Due to the limited overcurrent capability of power switches in the converter, a current limit module is introduced. Even if $U_{d(1)\_1}$ falls too much and the corresponding target current exceeds the limit range, $I_{dref(1)\_1}$ will remain at the limit setting value. In addition, in order to make full use of energy transmission capability of the flexible device, Q_{ref_1} is usually set to 0. The drop of $U_{d(1)\_1}$ will not cause the change of Q_1. Therefore, the control effect of the q-axis component of positive sequence current $I_{q(1)\_1}$ remains the same regardless of the fault.

When an interphase short fault occurs at the constant voltage terminal, the drop of local voltage $U_{d(1)\_2}$ will also cause the active power P_2 received by the local converter to drop instantaneously. However, supported by power regulation of the contra-side converter, P_1 remains the same as before the fault. Hence, partial active power is left on the DC side to charge the DC capacitor, which causes the DC voltage E_{dc} to rise. In order for E_{dc} to track the given value, the voltage outer loop controller responds quickly resulting in a decrease of its output $I_{dref(1)\_2}$. $I_{d(1)\_2}$ will decline due to regulation of the current inner loop controller and is also limited by the current limit module. Response of the reactive power control loop will not be affected by the fault, and will not be repeated here.

Therefore, whether it is a converter at the constant power terminal or constant voltage terminal, the converter can be equivalent to a positive sequence current source whose value is controlled by the positive sequence voltage of AC valve side, and within the limiting range.

3. Analysis of Interphase Short Fault in Flexible AC-DC System

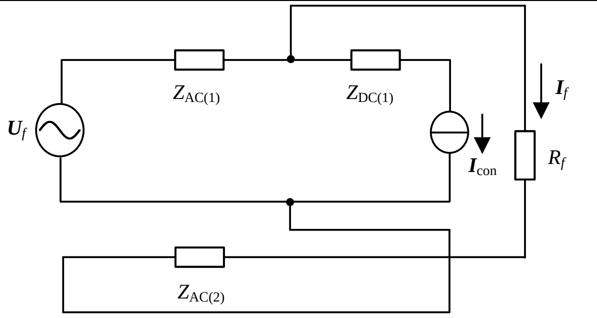

Figure 2. Compound sequence network of a phase-to-phase short fault

The compound sequence network of a two-phase short fault is shown in Fig. 2, where U_f is the fault virtual voltage source, R_f is the transition resistance, I_{con} is the equivalent positive sequence current source of the converter, $Z_{DC(1)}$ is the positive sequence impedance of DC side from the fault point, $Z_{AC(1)}$ and $Z_{AC(2)}$ are the positive and negative sequence impedances of AC side from the fault point, respectively. It can be seen from the figure that if $Z_{AC(1)}$ and $Z_{AC(2)}$ are considered equal, I_f can be expressed as:

$$\boldsymbol{I}_f = \frac{\boldsymbol{U}_f - Z_{AC1}\boldsymbol{I}_{con}}{2Z_{AC1} + R_f} \quad (1)$$

Compared with the condition of the same fault occurring in a traditional AC distribution network, the change degree of I_f is closely related to the R_f. The smaller R_f is, the greater the drop of AC positive sequence voltage is, the larger the coefficient that can be obtained from dividing $Z_{AC(1)}$ by ($2Z_{AC(1)}$+ R_f) and the amplitude of I_{con} are, and the more obvious the change of I_f will be.

4. Simulation and Result Analysis

Table 1. Setting of simulation parameters

Simulation parameters	Setting values
DC rated voltage /kV	±10
DC capacitance/μF	500
Rated active power /MW	5
Current limit /kA	±0.75

In order to verify rationality of the above theoretical analysis, the system model as shown in Fig. 1 is built in PSCAD/EMTDC. Converter 1 adopts the PQ control, Converter 2 adopts the VQ control, neutral points of the main transformers adopt the non-grounding mode, and setting of simulation parameters is shown in Table 1.

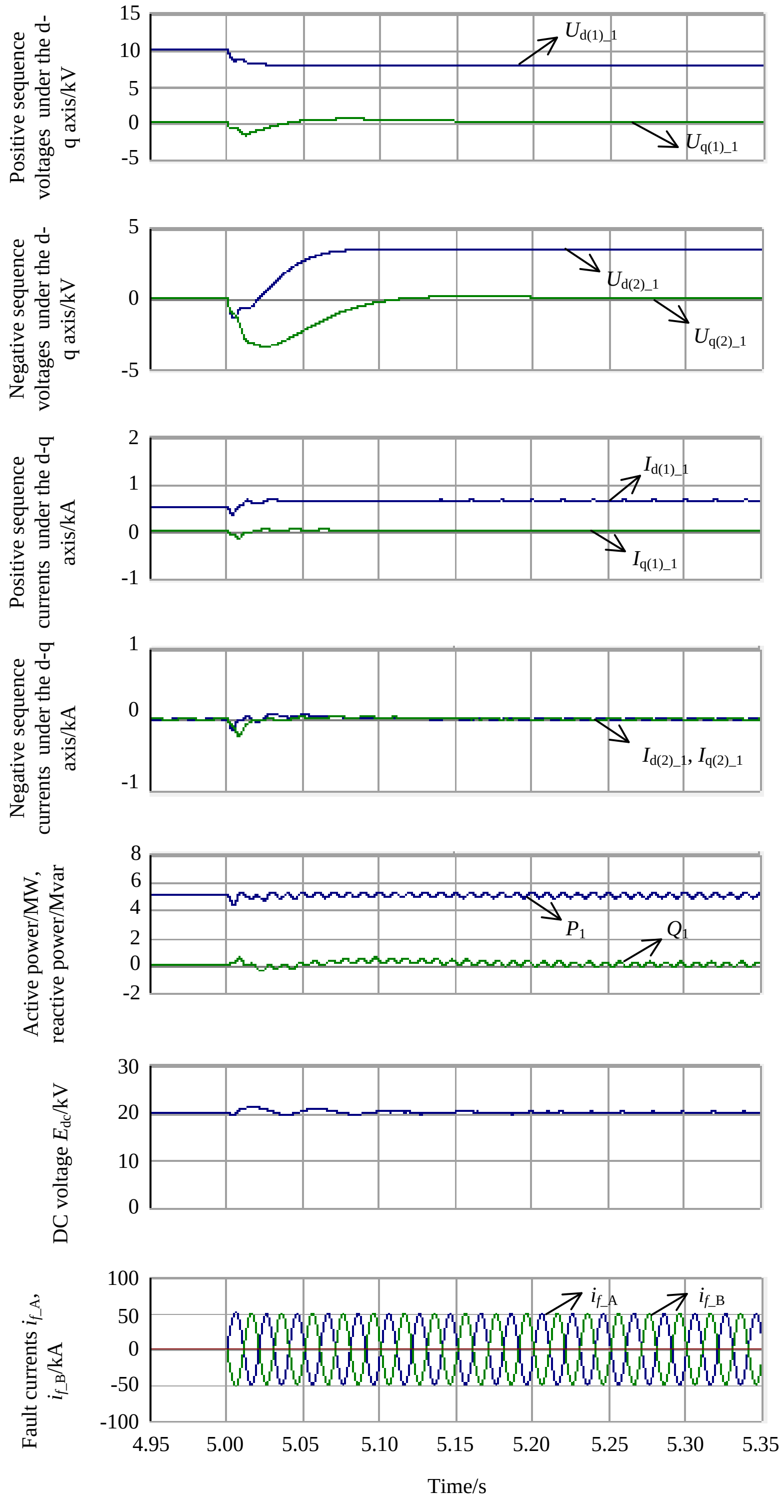

Figure 3. Simulation waveforms of a two-phase short fault at the constant power terminal

At 5s, an A-to-B phase short fault occurs on the AC grid side at the constant power end and R_f is 0.2Ω. Simulation related waveforms are shown in Fig. 3. As the fault happens, a negative sequence voltage appears on the valve side, while the negative sequence current is well suppressed. The drop of $U_{d(1)\_1}$ during the failure causes

$I_{d(1)\_1}$ to rise from 0.5kA to 0.63kA, which is less than the current upper limit. Hence, Converter 1 can maintain the same active power transmission capacity as before the fault. Q_1 and E_{dc} are maintained basically unchanged by respective controllers. Affected by the negative sequence current suppression, double frequency fluctuation of E_{dc} is significantly weakened. The fault phase current shows a decrease of 0.54% compared with the same fault in a traditional network.

If R_f is further reduced so that $I_{d(1)\_1}$ reaches the current limit, the ability to transmit active power decreases, while the other control objects remain unaffected by the fault. Specific waveforms are no longer drawn here. The fault phase current shows a decrease of 0.73% compared with the same fault in a traditional network. The degree of decline is greater compared with the former simulation, which verifies the theoretical analysis result that the smaller R_f is, the more obviously the fault current changes.

When the fault is located at the constant voltage end and $U_{d(1)\_2}$ has a small decrease, $I_{d(1)\_2}$ is within the limit range and each control object can remain stable. When $U_{d(1)\_2}$ has a large decrease, $I_{d(1)\_2}$ is limited to the limit value. The active power exchange capacity decreases and the remaining active power on the DC side causes E_{dc} to continue to rise. Q_2 is maintained at about 0MVar and specific waveforms are no longer drawn here.

If the fault is located on the AC valve side, the effect of positive sequence current source equivalent to the converter on fault characteristics is similar to the above situations and will not be repeated here.

5. Conclusions

In this paper, specific research is conducted on characteristics of interphase short fault in AC-DC hybrid power distribution system. When the drop of positive sequence voltage on the valve side is small, the positive sequence current is within the limiting range and the power and DC voltage remain controllable. When the voltage drop is too large to cause the positive sequence current to reach the limit value, if the fault is located at the constant power end, the active power transmission capability of local converter decreases and the DC voltage remains stable; if the fault is located at the constant voltage end, the active power exchange capability of local converter reduces and the remaining active power on the DC side causes the DC voltage to rise continuously. Under the condition of effective suppression of negative sequence components, double frequency fluctuation of the DC voltage is well suppressed.

6. Acknowledgment

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