Fault Transient Analysis of Flexible Medium Voltage DC Distribution

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Abstract. The analysis of fault transient characteristics of flexible dc distribution is the basis of dc distribution protection technology. Based on the construction of the two-terminal power supply code flexible dc distribution system, the problems of different system grounding methods are analyzed in detail, and the connection of the converter transformer using Yn/△ and the dc capacitance using split midpoint high-resistance grounding method are proposed. Under this grounding method, transient models of transient grounding faults of ac and dc lines are established and their transient characteristics are studied. Using PSCAD/EMTDC software to build the simulation model, through the analysis and simulation proved that the system grounding method can effectively limit the instantaneity ground fault transient fault current during the period of over current levels, to maintain the dc voltage stability, improve power supply reliability of the system, has the strong ability of fault crossing ability and fault recovery.

Introduction

With the gradual change of China's industrial structure, load types are diversified. Meanwhile, the development and application of distributed power supply, energy storage and other equipment have posed an impact on the existing ac distribution network. In recent years, the flexible dc transmission technology based on voltage source converters has been extended to the distribution network, which makes the flexible dc distribution network become a hot research topic.

The research of flexible dc distribution mainly focuses on control strategy, network topology, fault analysis and protection technology. The paper [1] discusses in detail the fault characteristics under the double-pole short circuit of the dc line, and divides the fault into the dc capacitance discharge stage, the diode natural commutation conduction stage, and the diode simultaneous conduction stage, and establishes the fault transient model. In reference [2], the fault model of dc micro grid is established, and the transient characteristics of different feeders under different location faults are analyzed, but the grounding mode of the system is not considered. Literature [3] established a simulation model for single-pole grounding fault of converter dc line and asymmetric fault of ac outlet, and the study showed that the fault characteristics of voltage between dc poles were affected by the grounding mode of converter transformer. The fault characteristics of the flexible dc system are affected by the system grounding mode.

DC power distribution system is proposed in this paper a kind of flexible topology structure, the failure characteristics of different grounding modes are analyzed in theory, puts forward the converter transformer adopts Yn/delta connection, dc side with the method of dividing capacitance midpoint high resistance grounding, effectively limiting the fault current flow level, improve the power supply reliability of the system.

Modeling of Flexible Medium Voltage DC Distribution

The topology structure of the flexible dc power distribution system proposed in this paper is shown in figure 1. Double-ended ac power supply is adopted for power supply. The 110kV ac system at both ends is reduced through 110kV/10kV converter transformer respectively.

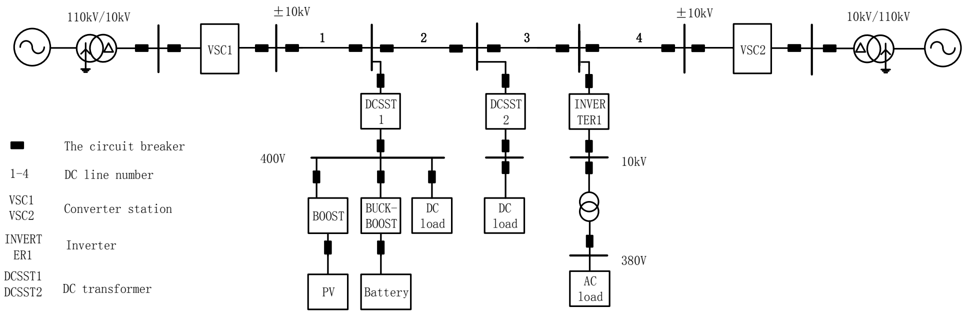


Figure 1. Flexible dc distribution system topology

Selection of System Grounding Mode

At present, it is the only economic and feasible means for almost all flexible dc projects to deal with dc side short-circuit fault by using ac circuit breaker to cut the fault current through the blocking converter station.

When the converter transformer △/Yn wiring, converter dc side using split capacitor midpoint grounding, converter VSC1 equivalent circuit is shown. When single-phase grounding fault occurs on the ac side of the converter. The zero-sequence component of the ac system will cause the base-frequency common mode fluctuation of the positive and negative voltages. When the dc line has a grounding fault, the ac system feeds the fault current to the fault point through the converter, and if the fault current is too large, it will trigger the IGBT self-protection to shut it off.

When the converter transformer Yn/△wiring, converter dc side using split capacitor midpoint grounding, converter VSC1 equivalent circuit is shown. When the single-phase grounding fault occurs, the capacitor provides the discharge current to the fault point through IGBT, so that the fault current flowing through IGBT is too large and the converter is turned off. For the positive pole grounding, since the capacitor discharge current will not flow through IGBT during the fault, the converter can be continuously powered for a period of time.

Modeling and Analysis of System Fault Transient

Modeling and Analysis of Single-phase Grounding Fault on Ac Side

The equivalent circuit when single-phase grounding fault occurs on the ac side of converter VSC1 is shown in figure 2.

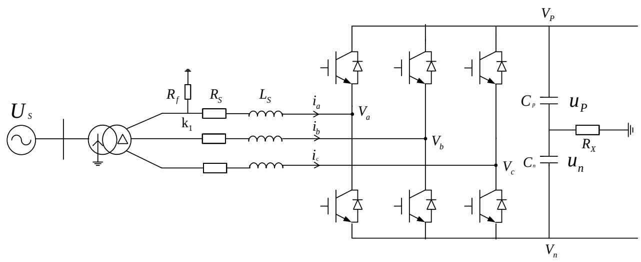


Figure 2. Single-phase grounding fault equivalent circuit

Derived from the switching function of the VSC.

$$V_a = u_p + (s_a - 1)U_{dc} + U_{R_X} \tag{1}$$

$$u_f - R_s i_a - L_s \frac{di_a}{dt} - V_a = 0 \tag{2}$$

When the transition resistance is small, the fault phase voltage $u_a \approx 0$.

$$\frac{1}{3}u_f + u_0 - R_s i_0 - L_s \frac{di_0}{dt} = u_p + (s_0 - 1)U_{dc} + U_{R_X} \tag{3}$$

$$\frac{2}{3}L_s C_P \frac{d^2 u_p}{dt^2} + \frac{2}{3}R_W C_P \frac{du_p}{dt} + u_p = u_0 \tag{4}$$

Formula (5) is obtained.

$$\begin{aligned} u_p &= B_1 \cos(\omega \cdot t) + B_2 \sin(\omega \cdot t) \\ &= \sqrt{B_1^2 + B_2^2}\sin(\omega \cdot t + \varphi_1) \end{aligned} \tag{5}$$

Modeling and Analysis of Dc Line Grounding Fault

See fig.3 for the equivalent circuit of dc line in case of positive pole grounding fault.

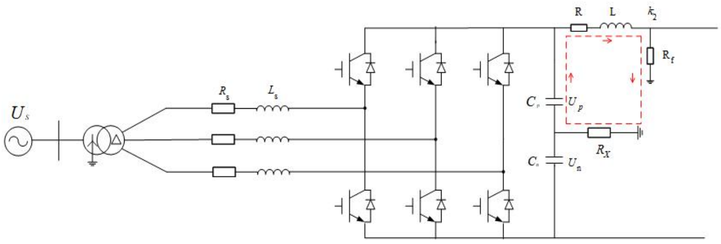


Figure 3. Positive ground fault equivalent circuit

$$LC_p \frac{d^2 u_p}{dt^2} + R_Z C_p \frac{du_p}{dt} + u_p = 0 \tag{6}$$

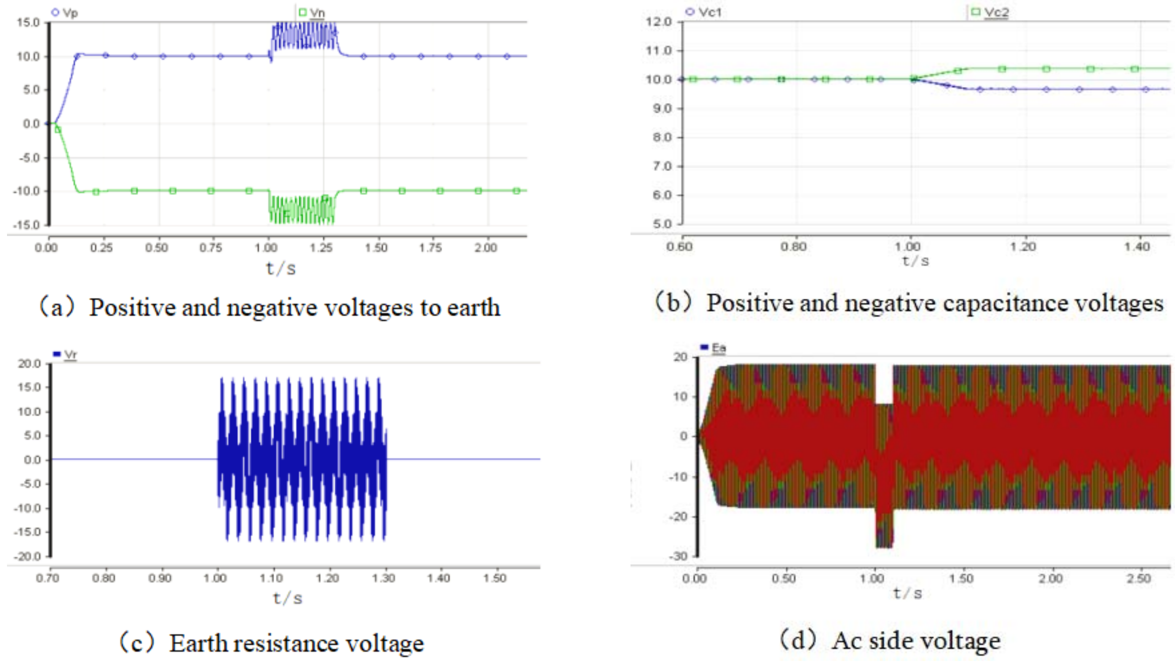
$$\lambda_{1,2} = -\frac{R_Z}{2L} \pm \sqrt{\left(\frac{R_Z}{2L}\right)^2 - \frac{1}{LC_p}} \tag{7}$$

Since the high resistance at the midpoint of the capacitor is large enough, and (9) is two unequal real roots, the transient process of the discharge is in an overdamped state, and the discharge voltage of the capacitor is of non-oscillation type.

The Simulation Analysis

Single-phase Grounding Fault of Ac Line

Suppose that at 1s, an A ground fault occurs on the ac side of VSC1. The fault duration is 0.3s, and the simulation results are shown in FIG.4.



(a) Positive and negative voltages to earth (b) Positive and negative capacitance voltages

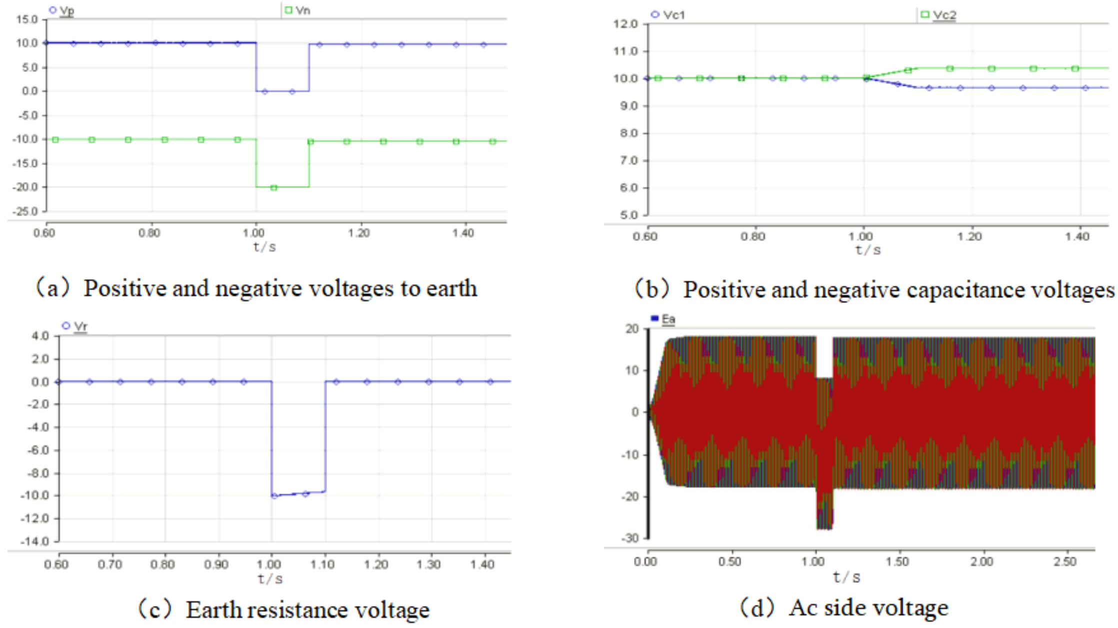
(c) Earth resistance voltage (d) Ac side voltage

Figure 4. Voltage and current characteristics of the system in the case of single-phase grounding fault

It can be seen from figure 4 (a) that in the transient process of fault, the ground voltage of the positive and negative poles is added with the baseband common mode voltage. As shown in figure 4 (b), the capacitance voltage of positive and negative electrodes is not affected by the zero sequence component and remains stable. As shown in figure 4 (d), the three-phase voltage on the ac side of the VSC maintains the rating regardless of faults. In conclusion, the fault crossing ability of the system is improved, and the fault recovery ability of the system is enhanced.

Dc Line Grounding Fault

Suppose for 1s, a positive pole grounding fault occurs at the dc side of VSC1, and the fault duration is 0.1s. The simulation results are shown in figure 5.



(a) Positive and negative voltages to earth (b) Positive and negative capacitance voltages

(c) Earth resistance voltage (d) Ac side voltage

Figure 5. Voltage and current characteristics of the system in the case of a positive ground fault

According to figure 5 (a), the positive pole-to-ground voltage drops to 0 at the moment of failure, and the negative pole-to-ground voltage rises to twice the rated value to maintain the interpole voltage under the action of constant dc voltage control. The discharge current of the positive capacitor is very small, so that the voltage of the positive capacitor decreases only slightly, as shown in figure 5 (b) (c). Figure 5 (d) shows that the ac voltage is offset during the fault and recovered after the fault is removed. The conclusion shows that the fault crossing ability and fault recovery ability of dc distribution system are improved obviously.

Conclusion

Firstly, the topological structure of the system is presented, and the connection of the converter transformer (Yn/ △) and dc capacitance (split midpoint high resistance grounding) are proposed. Under this grounding method, the transient models of single-phase grounding fault on the ac side of VSC and single-pole grounding fault on the dc line are established and their fault characteristics are analyzed. Simulation results show that the grounding method proposed in this paper limits the fault current, improves the power supply reliability of the system, and has strong fault crossing ability. The basic frequency common mode component of capacitor voltage is eliminated and the unbalanced dc voltage is recovered quickly, which improves the fault recovery ability of the system. The conclusion of this paper provides a theoretical basis for the research of dc protection.

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