Research on Applicability of Directional Element Mutation in UHVDC Hierarchical Connection Mode

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Abstract. In order to solve the problem of voltage-supporting capability and evacuation difficulties caused by UHVDC from the structure of power grid, Chinese scholars first proposed a UHVDC hierarchical connection to AC grid. In this way, the electrical coupling by the AC-DC hybrid system is more complicated, while the traditional relay protection elements have been misoperated many times. Therefore, the research on the adaptability of the protection directional elements mutation has become an urgent problem to be solved. Respectively, a variety of sudden changes in the amount of directional components and direction of a comprehensive analysis of components, according to the principle of phase direction components and the sequence of the elements of the conditions. In AC / DC hybrid power system, due to the positive and negative sequence impedance of the inverting side equivalent AC system are not equal and the impedance angle and the line impedance angle are quite different, the positive and negative sequence directional components will be misjudged, Performance cannot be guaranteed; As for the zero-sequence principle of the directional element, as the inverter side of the zero sequence network is more stable, reliable performance, to correct operation. PSCAD simulation data verify the correctness of the analysis.

Introduction

For a long time, there exists between China's energy consumption and resource endowment Serious spatial heterogeneity, the requirements of large-scale and long-distance transmission have promoted the continuous construction and development of ultra-high voltage DC projects, At present, multi-infeed DC systems have been formed in East China and South China, and the supporting capacity of the end-grid is facing a severe challenge. In order to solve this problem from the grid structure, domestic scholars first proposed a UHVDC hierarchical connection AC grid [1] approach, That is, the DC inverter station is high and the low-end converter is respectively connected to the 500 kV / 1000 kV receiving grid through the converter transformer.

For this new model, the current research is still relatively less, mainly introduced in the way of hierarchical connection system [2-4], the applicability of multi-infeed layered short-circuit ratio [2], the overall design of DC control system [3-4] and the coordination of power control [5] etc. Compared with multi-infeed direct current, the topological structure of the receiving end stratified hybrid system is more complicated, and the coupling between the AC and DC systems is more serious. It is particularly noteworthy that the interaction between the recipient hybrid systems may lead to the occurrence of cascading failures, which is also the crux of the current status quo of "strong HVDC and weak AC system" in some of China's power grids. Therefore, the accurate judgment of the fault location of the AC system and the quick disconnection of the AC system protection are the keys to ensure the stable operation of the "strong HVDC and weak AC system" power grid.

In order to study the influence of the interaction of layered access method on the direction of the sudden changes in the amount of directional elements, this paper uses the research steps from the
mechanism analysis and dynamic simulation. First of all, taking a ± 800 kV UHVDC hierarchical connection project as the research object, the impedance characteristics of positive, negative and zero sequence of dorsal side in DC system commutation failure are simulated. Then from the principle of directional element variation, the conditions for the application of directional elements and directional elements are analyzed. Finally, we analyze the performance change of the directional component in the DC layered access mode. The electromagnetic model of layered access was established by PSCAD, which verified the correctness of the theoretical analysis.

**UHVDC Hierarchical Connection Models**

A UHVDC hierarchical connection project by the end of the power grid structure is shown in Figure 1. Under the access mode, the DC inverter side double low-side converter (TZ-C1) is connected to the 1000 kV AC power grid by high-voltage converter, and the high-side converter (TZ-C2) into the 500 kV AC power grid and evacuate large-scale electric power through multiple return ultra-high voltage AC lines. UHVDC hierarchical connection under the monopolar model of the grid-connected grid shown in Fig.2.

![Diagram](image)

For the UHVDC hierarchical connection system, commutation failure of the DC system occurs when the AC system fails. Due to the nonlinearity of power electronics and the function of control system, the magnitude and phase angle of positive and negative sequence impedance of DC system in the past are greatly different from the AC system[6].

As for the zero-sequence current, although the commutation failure will lead to a thyristor is always on, three-phase current is no longer symmetrical, but due to the conduction characteristics of the commutation valve and the commutation converter wiring, the DC side will not affect the zero sequence current distribution of the AC system, that is to say it will not affect the zero sequence impedance of the AC system.
Directional Element Mutation Applicable Conditions

There have been extensive studies on the application of the direction element mutation to the AC line. As the core element of longitudinal direction protection, the performance of the directional element mutation will directly determine the action performance of longitudinal direction protection. In order to ensure the correct operation of longitudinal protection in AC/DC hybrid system, it is necessary to analyze the applicability of the directional components mutation in the DC hierarchical connection mode according to the principle of sudden directional elements. The existing direction of direction elements mutation can be respectively based on the principle of sudden changes in the phase of directional elements and direction of the sudden changes in the sequence. The direction of the sudden change in the direction of the element is divided into phase and phase difference of the direction of the element, expressions are as shown in equations (1) and (2). Sequential directional elements are divided into positive, negative and zero sequence directional elements, the expressions are (3), (4) and (5) respectively.

\[
\theta_{\phi} = \arg \left( U_{\phi} - U_0 \right) / \left( I_{\phi} - I_0 \right) \, , \quad \phi = A, B, C
\]  

(1)

\[
\theta_{\phi\phi} = \arg U_{\phi\phi} / I_{\phi\phi} \, , \quad \phi = AB, BC, CA
\]  

(2)

\[
\theta_1 = \arg U_{1g} / I_{1g}
\]  

(3)

\[
\theta_2 = \arg U_{2g} / I_{2g}
\]  

(4)

\[
\theta_0 = \arg U_{0g} / I_{0g}
\]  

(5)

Where: subscript g said the amount of mutation, the subscript 1, 2, 0, respectively, said the positive sequence, negative sequence, zero sequence components, \( \theta \) said the impedance phase angle.

The directional elements (1) and (2) are the same as the directional elements (3) and (4) Phase performance, can clearly distinguish between positive and negative direction of failure. If in the real system, the negative sequence impedance is not equal, the directional elements (1), (2) will have a phase error, the performance will be severely affected. In addition, the actual system assumes that the sequence impedance angles of the components are equal to the sequence impedance angles of the lines. Based on this, the impedance angles in the positive and negative directions will be different by 180° and the directivity is very clear. If there is a large difference in sequence impedance between the components in the system, the direction of the positive fault and the negative direction of the fault will not be clear at this moment, which may lead to the problem of misjudgment of protection. In summary, the strict sense, the conditions for the application of the direction of the amount of mutation as follows:

1. For the direction phase element mutation and the phase-difference directional element mutation, it is required to protect the system on the back side of the installation that the positive and negative sequence impedances are equal, so that the positive sequence impedance of the backside system can be accurately detected.
2. For the direction sequence element mutation, the positive, negative and zero sequence impedances of the system on the back of the protection installation can be accurately detected, but the phase angle of the positive, negative and zero sequence impedances of the back system and the impedance of the line order Phase angle equal, so as to accurately determine the fault direction.

Simulation Verification and Analysis

In the PSCAD simulation platform, a unipolar equivalent system model of ± 800 kV UHVDC hierarchical connection 500/1000 kV AC system is built. The DC system adopts double 12-pulse 400 kV + 400 kV converter, rated DC power is 5000 MW, rated DC current is 6.25 kA, converter's
The arc-extinguishing angle is 22°. The steady-state operating voltages of the two ends of the system are 520 kV and 1050 kV respectively. The equivalent model is used for the equivalent impedance of the terminal AC system. The corresponding parameters are $Z_1 = 10.67 + j42.7 \, \Omega$ and $Z_2 = 5.335 + j21.35 \, \Omega$, $Z_{12} = 50 + j973.9 \, \Omega$. A-phase ground fault occurs on line L1. DC system commutation fails. Fault occurred at 0s, fault duration 50ms, sampling frequency of 4000Hz, due to the use of full-cycle Fourier algorithm to calculate the amount of change in impedance, 20ms after the data.

Figure 3 shows the impedance of the first and second floors of the backside system impedance calculated by the fault component at the exit of the inverter side circuit in Figure 2, that is, the positive and negative sequence impedance of the DC system. The sequence impedance is calculated as:

$$
\dot{Z}_m(k) = -\Delta U_m(k)/\Delta I_m(k)
$$

Where: $m = 1, 2, 0$ denote the positive sequence, negative sequence and zero sequence respectively; $\Delta U_m(k)$ and $\Delta I_m(k)$ are respectively the kth harmonic voltage and current fault component of the AC side of the converter; Say, only concerned with the frequency of workers, that $k = 1$.

Figure 3 shows the positive sequence and negative sequence impedance on the DC system side of lines L1 and L2. Where: in Fig 4, the two graphs on the left are 500kV layer impedance, the two graphs on the right are 1000kV layer impedance. The blue line is the positive sequence impedance and the green line is the negative sequence impedance.

It can be seen from the figure that the positive sequence of the outlet on the inverter side and the negative sequence element have not correctly judged. This is due to the positive sequence and negative sequence network of the inverter side should take into account the DC system, while the DC system on the inverter side of the outlet voltage and current are transient regulation control, inverter side equivalent AC system positive sequence, Negative sequence impedance is also transient, and its nature and pure AC system positive and negative sequence impedance will be different.

Figure 4 shows the positive sequence and negative sequence impedance of the line-to-line AC system on lines L1 and L2. Where: in Fig 4, the two graphs on the left are 500kV layer impedance, the two graphs on the right are 1000kV layer impedance. The blue line is the positive sequence impedance and the green line is the negative sequence impedance. It can be seen from the figure that the negative sequence direction component of the opposite AC system has been misjudged and the positive sequence direction component can judge correctly.

Figure 5 and Figure 6 show the zero-sequence impedance corresponding to the DC system side and the AC system side of lines L1 and L2, respectively. Where: in Fig 5 and Fig 6, the two graphs on the left are 500kV layer impedance, the two graphs on the right are 1000kV layer impedance. It can be seen from the figure that the direction of the zero-sequence directional component at the outlet on the inverter side is correctly determined, which is determined by the DC system feeding into the zero-sequence current that will not affect the AC system.
Summary

In this paper, based on the established UHVDC hierarchical connection AC-DC hybrid system, theoretical and simulation analysis of the adaptability of the direction elements mutation, draw the

![Graph showing zero sequence impedance on DC system side](image1)

![Graph showing zero sequence impedance on AC system side](image2)

Figure 5. Zero sequence impedance of lines L1 and L2 on DC system side.  
Figure 6. Zero Sequence Impedance of line L1 and L2 on AC Systems Side.

Following conclusions:

1) The conditions for obtaining the direction elements mutation are as follows: The sequence impedance angles of the various elements in the faulty network are equal to the sequence impedance angles corresponding to the line. The positive and negative sequence impedances of the system on the backside of the protection installation are equal for phase and phase difference of the direction of the element.

2) Due to the non-linearity of the power electronics, the positive and negative sequence impedance of the DC system experienced by the inverter side are different, so the positive and negative sequence impedance direction protection of the AC system will be wrongly judged. Due to the characteristics of the commutation valve itself and the wiring of the commutation transformer, the feed-in of the dc system will not affect the zero-sequence network of the ac system. Therefore, the performance of the directional element based on zero-sequence will be guaranteed.

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References


