Applicability Analysis of Directional Components in AC/DC Hybrid System

Chenyun He*, Binyuan Yang
School of Electric Power, Inner Mongolia University of Technology, Hohhot, China

*Corresponding author e-mail: 1401181264@qq.com

Abstract. AC/DC hybrid power grids are more and more widely used in China, and the traditional relay protection directional components have experienced multiple misoperations. The adaptability of traditional directional components in AC / DC hybrid power grids is studied. Traditional direction components are based on fault sequence component network analysis. During the fault, the positive and negative sequence impedance of the AC-DC hybrid power grid is quite different, and the impedance angle of the line impedance and the equivalent impedance of the grid is no longer close to 90°. Misjudgment will occur in the direction component with sudden change, and performance cannot be guaranteed. As a result, directional elements based on the positive and negative sequence current branching coefficients being approximately equal are not suitable for AC/DC hybrid power grids. As for the directional element of the zero sequence principle, since the zero sequence network on the inverter side is relatively stable, its performance is reliable and it can operate correctly.

1. Introduction
The particularity of China's energy distribution makes the AC/DC hybrid power grid have good development prospects. In recent years, China has gradually formed the world's highest voltage level and the largest AC/DC hybrid transmission system. However, in the AC/DC power grid, the interaction of the AC/DC system changes the operating environment of traditional AC protection, which in turn affects its operating characteristics. This poses severe challenges to the safety, stability, and economic operation of the power system.

Literature [1] pointed out that during the transient process of AC system failure in the background of AC/DC hybrid power grids, the transient power reverse phenomenon will occur in the AC transmission system under certain conditions. Transient power reversal will cause the misdirection of the fast direction pilot protection of the AC transmission line. Literature [2-4] pointed out that the directional longitudinal protection with directional components of power frequency mutation is likely to cause the malfunction of the relay protection device in the AC/DC hybrid system. Reference [5] analyzed the mechanism of the influence of DC feed-in on the distance protection of transmission lines combing the principle of distance protection, and pointed out that the impact is mainly due to the fluctuation of the measured reactance caused by the DC system equivalent current. Literature [6] pointed out that in the AC/DC hybrid system, the equivalent positive and negative sequence impedances of the DC system are not approximately equal, they have an impact on the directional

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Published under licence by IOP Publishing Ltd
component of the sudden change, but the applicability of the directional component of the sudden change has not been theoretically analyzed.

Therefore, this article will analyze the applicability of positive sequence fault component directional elements, negative sequence directional elements, and zero sequence directional elements in AC / DC hybrid systems from theoretical perspective. Firstly, the principle of the directional element is analyzed. Secondly, based on the simulation results of equivalent positive and negative sequence impedance of DC system, the applicability of traditional directional components in AC / DC hybrid system is analyzed.

2. Principle of directional components
The fault component directional elements include positive sequence fault component directional elements, negative sequence directional elements, zero sequence directional elements and phase fault component directional elements. For the line with both ends connected to the traditional synchronous power supply, the systems on both sides are composed of synchronous generators, lines, and transformers. The equivalent positive and negative sequence impedances are almost equal. When ignoring the resistance, the three-sequence impedance angle is $90^\circ$. If the positive direction of the current is specified as the bus flowing to the line, the fault additional network shows that the ratio of $\Delta U$ and $\Delta I$ is the negative value of the equivalent impedance of the back side system. When the fault is in the positive direction, and the phase angle is $-90^\circ$. In the reverse direction fault, the ratio of $\Delta U$ and $\Delta I$ is the sum of the impedance of the contralateral system and the protected line, and the phase angle is $90^\circ$. Therefore, the criteria for all kinds of fault component direction components to judge the fault as a positive direction fault can be uniformly expressed as:

$$0 \leq \arg \left( \frac{\Delta U}{\Delta I} \right) \leq 180^\circ$$

(1)

2.1. Principle of directional element based on sequential fault component
The directional element based on the sequence fault component is realized by comparing the phase relationship between the voltage and current of each sequence fault component.

Directional element of positive sequence fault component

$$\theta_1 = \arg \left( \frac{\Delta U}{\Delta I} \right)$$

(2)

Negative sequence direction element

$$\theta_2 = \arg \left( \frac{U_2}{I_2} \right)$$

(3)

Zero sequence direction element
\[
\theta_0 = \arg\left\{ \frac{-U_0}{I_0} \right\}
\] (4)

Where subscripts 1, 2, and 0 represent positive sequence, negative sequence, and zero sequence, \( \Delta U \) and \( \Delta I \) represent positive sequence mutation voltage and current.

3. Analysis of action performance of directional components in AC / DC hybrid system

Figures 3 (a) and 3(b) are the system model of conventional direct current transmission and the additional network diagram of the positive direction fault. In the figure, \( Z_{NS} \) is the equivalent impedance of the system, \( Z_M \) and \( Z_N \) are the impedance from the fault point to the M and N sides, and \( Z_{hvdc} \) is the impedance of the DC transmission line. Assuming that a phase A ground fault occurs at point k in the positive direction of protection 1, the action performance of the three fault component directional components will be analyzed in detail based on Figure 1 (a) and 3 (b).

![Diagram](image)

Figure 1. HVDC system model and additional network for forward faults

(1) Positive sequence fault component directional element

The positive sequence impedance of the line with a relatively small count value is not counted. Protection 1 uses the positive sequence fault voltage and fault current to calculate the impedance, it is approximately equal to the positive sequence impedance of the HVDC transmission system. The corresponding impedance angle is:

\[
\arg\left\{ \frac{\Delta U_{M1}}{\Delta I_{M1}} \right\} \approx \arg(Z_{hvdc})
\] (5)

(2) Negative sequence direction element

Similarly, the negative sequence impedance of the line with a relatively small value is not counted. Protection 1 uses the negative sequence fault voltage and fault current to calculate the impedance. It is approximately equal to the negative sequence impedance of the high-voltage DC transmission system, the corresponding impedance angle is:
\[
\arg \left( \frac{\Delta U_{M2}}{\Delta I_{M2}} \right) \approx \arg (Z_{hvdc})
\]

(3) Zero sequence direction element
For the zero-sequence network, due to the presence of the commutation transformer, the zero-sequence network is terminated by the commutation transformer, so the zero-sequence network on the inverter side of the converter station is stable and not affected by the failure of the DC system commutation. Therefore, the performance of the zero sequence direction component will be guaranteed.

4. Simulation analysis
This article builds an AC/DC hybrid system model in RTDS / RSCAD, as shown in Figure 2. The rectification side converter transformer ratio is 230/24KV, the inverter side converter transformer ratio is 24/345KV, the transformer rated power is 122MVA, the DC line transmits 168MW active power, and the DC transmission line rated voltage is 56KV, and the system sampling frequency is 4KHz. The length of the DC transmission line is 50km, the AC transmission line MN is 50km, and the NL is 60Km. Line unit positive sequence line resistance, reactance and capacitance are \( r_1 = 0.018 \Omega/km, x_1 = 0.277 \Omega/km, c_1 = 0.013 \mu F/km \), line unit zero sequence line resistance, reactance and capacitance are \( r_0 = 0.231 \Omega/km, x_0 = 0.973 \Omega/km, c_0 = 0.008 \mu F/km \). The power grid of the rectifier and inverter is replaced with an infinite power supply. The rated voltage on the rectifier side is 230KV, and the rated voltage on the inverter side is 345KV. Constant current control is adopted on the rectifier side, and constant angle extinction angle control is adopted on the inverter side.

\[\begin{array}{c}
\text{Figure 2. AC/DC hybrid system}
\end{array}\]

4.1. Simulation Analysis of Equivalent Positive and Negative Sequence Impedance of DC System
Taking the single-phase grounding short circuit at the midpoint K of the inverter-side AC line MN as shown in Figure 2 as an example, by setting different transition resistances, the equivalent positive and negative sequence impedance values of the DC system when the AC system fails are explored. The fault occurrence time is 0.05s and the fault duration is 0.1s. When the fault occurs, the relay protection device operates within 30ms, and the positive and negative sequence impedances in the transient process are constantly changing, so this experiment uses the average value of the amplitude and phase angle within 30ms after the fault occurs. The equivalent power frequency positive and negative sequence impedance characteristics are shown in Table 1. And all the faults in Table 1 lead to commutation failure.
Table 1. DC system equivalent power frequency positive and negative sequence impedance characteristics

| Transition resistance (Ω) | Positive sequence impedance phase angle(°) | Negative sequence impedance phase angle(°) | Positive sequence impedance amplitude(Ω) | Positive sequence impedance amplitude(Ω) |
|---------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|-------------------------------------------|
| 0                         | -48.8                                     | -167.2                                    | 31.1                                      | 130.2                                     |
| 5                         | -63.3                                     | -165.4                                    | 35.3                                      | 89.4                                      |
| 10                        | -56.9                                     | -176.7                                    | 27.6                                      | 122.4                                     |
| 15                        | -63.7                                     | -177.1                                    | 26.1                                      | 121.6                                     |
| 20                        | -59.3                                     | -178.1                                    | 39.3                                      | 51.6                                      |
| 25                        | -97.4                                     | -178.7                                    | 39.3                                      | 50.4                                      |
| 30                        | -99.7                                     | -178.9                                    | 38.4                                      | 52.2                                      |
| 35                        | -100.8                                    | -182.6                                    | 38.5                                      | 52.1                                      |
| 40                        | -101.8                                    | -184.2                                    | 38.2                                      | 51.4                                      |
| 45                        | -103.0                                    | -183.6                                    | 37.3                                      | 52.7                                      |
| 50                        | -103.6                                    | -185.8                                    | 37.7                                      | 48.7                                      |
| 55                        | -107.0                                    | -180.0                                    | 36.4                                      | 55.5                                      |
| 60                        | -109.0                                    | -179.0                                    | 36.9                                      | 48.4                                      |
| 65                        | -103.0                                    | -193.1                                    | 38.7                                      | 42.4                                      |
| 70                        | -104.2                                    | -192.4                                    | 39.2                                      | 49.1                                      |
| 75                        | -104.3                                    | -197.6                                    | 39.9                                      | 44.0                                      |
| 80                        | -104.9                                    | -198.8                                    | 39.3                                      | 42.9                                      |

From Table 1, it can be seen that when a single-phase grounding short circuit occurs through different transition resistances, the phase angle of the equivalent positive and negative sequence impedance of the DC system is less than 0.

From equation (2-1), when the ratio of voltage and current is greater than 0, the directional element is judged as a positive direction fault. From the simulation results in Table 1, the phase angle of the equivalent positive and negative sequence impedance of the DC system during the fault is less than 0, so the values of equations (3-1) and (3-1) are less than 0, which does not satisfy the positive criterion. The positive and negative sequence direction components cannot accurately determine the fault.

5. Conclusion
When the AC line directly connected to the inverter station of the AC-DC hybrid system fails, the commutation will fail, and the equivalent positive and negative sequence impedance of the DC system will be different. This will make the sequence component directional element based on pure AC system unable to accurately determine the fault in the positive direction, resulting in misjudgment.

References
[1] Liu Qiang, Cai Zexiang, Liu Weixiong, Zeng Genghui. Transient power reversal of AC-DC interconnected power grids and its impact on relay protection [J]. Automation of Electric Power System, 2007, 31 (7): 34-38.
[2] Zhao Qiang, Impact of HVDC transmission on AC grid relay protection and solutions [D]. Baoding: North China Electric Power University, 2009.
[3] H. C. SHU, S. Y. SUN, Q. L. Song, Y. T. Dai, M. Zhang and Y. N. Wang. Full Process Dynamic Voltage Stability of 2015 Yunnan- Guangdong Ultra-high Voltage AC/DC Hybrid Transmission System[C]. International Conference on Sustainable Power Generation and Supply.2009,1-5.
[4] Eajal, Student Member, IEEE, E. F. El-Saadany, Senior Member, IEEE, and K. Ponnambalam. Inexact Power Sharing in AC/DC Hybrid Microgrids[J]. Canadian Conference
on Electrical and Computer Engineering (CCECE).2006.

[5] Zhang Pu, Wang Gang, Li Haifeng, et al. Analysis of the operation characteristics of distance protection for transmission lines under DC feed-in [J]. Automation of Electric Power Systems, 2012, 36 (6): 56-62.

[6] Qiu Yutao, Chen Shuiyao, Yang Huihong, Lei Zhenfeng, He Fangming, Song Guobing, Suonan Jiale. Applicability of directional components in catastrophe of AC-DC hybrid system [J]. Power System Protection and Control. 2012, 40 (13); 116-120.