Method for Suppressing AC Side Fault Feed Current of Flexible DC Distribution Network Based on Improved Bidirectional Thyristor

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Abstract. In the flexible DC power distribution system, once the DC side fails, the converter's interior will be quickly affected by the AC side fault feed. In view of the shortcomings of the current fault feed suppression methods, an improved AC side fault feed suppression method based on the improved bidirectional thyristor is proposed. The simulation results show that the above method can suppress the impact of the feed current inside the AC side converter and limit the short-circuit current flowing into the bidirectional thyristor on the AC side.

Keywords: The DC side fails, the current fault feed, bidirectional thyristor.

1. Introduction
In the flexible DC distribution network system, the freewheeling diode inside the converter is the most sensitive component in the system, and it is very important to suppress the fault current flowing through the freewheeling diode [1]. Since the VSC has no defense against fault current on the AC side, once the voltage between the electrodes on the DC side is lower than any phase voltage on the AC side, the AC side will cause irreversible overcurrent impact on the freewheeling diode. In the actual project at this stage, the DC circuit breaker is mainly used to isolate the faulty line, and it will act immediately when the voltage between the poles is not lower than any phase voltage of the AC side, thereby suppressing the AC side fault feed [2]. However, for a bipolar short-circuit fault that is close to the fault point and the transition resistance is close to 0, the voltage between the poles will be lower than any phase voltage on the AC side instantly, and the DC circuit breaker will not be able to effectively suppress the fault feed. If the AC circuit breaker responds to the AC circuit breaker after a fault occurs, the AC circuit breaker also needs an opening time of 20ms to 60ms [3], and the freewheeling diode inside the converter will be subject to an overcurrent impact of at least 20ms.

2. Method for suppressing fault feed current of parallel bidirectional thyristor
In the flexible DC distribution network system, when a bipolar short-circuit fault occurs, the boundary capacitance between the electrodes on the DC side discharges, and the voltage udc between the electrodes decays rapidly. Once udc is lower than any phase voltage on the AC side, the AC side fault
current will be fed into the freewheeling diode. The fault feed path is shown in Figure 1. In order to quickly suppress the AC side fault current from feeding into the freewheeling diode, consider adding an auxiliary circuit of parallel bidirectional thyristors between the AC side and the inverter. Figure 2 shows a schematic diagram of the auxiliary circuit of parallel bidirectional thyristors. When the system is operating normally, the bidirectional thyristor is opened, which will not increase the loss of the system. When a bipolar short circuit fault occurs in the system, the internal IGBT tube of the converter is blocked [5]. At this time, in order to prevent the AC side fault current from being fed into the freewheeling diode and the DC side, the bidirectional thyristor in the auxiliary circuit is turned on immediately. The three-phase current on the AC side forms a short circuit between the AC system and the auxiliary circuit, thereby isolating the AC side and the inverter circuit. However, after the bidirectional thyristor is turned on, a three-phase short circuit occurs between the AC side and the auxiliary circuit, and the bidirectional thyristor needs to continue to withstand a large three-phase short-circuit current, as shown in Figure 3. At this time, the AC side fault current will not flow into the converter and the DC side, and the current-limiting reactor in the AC side line will serve as the load of the AC side short circuit circuit.

![Figure 1. Equivalent circuit diagram of AC side fault current feeding stage](image1)

![Figure 2. Schematic diagram of auxiliary circuit of parallel bidirectional thyristor](image2)
Figure 3. Equivalent circuit diagram of three-phase short circuit loop

From Figure 3, three-phase short circuit current $i_{fa}$, $i_{fb}$, $i_{fc}$ can be expressed as:

$$
\begin{bmatrix}
  i_{fa} \\
  i_{fb} \\
  i_{fc}
\end{bmatrix} = I_f \begin{bmatrix}
  \sin(\omega t - \varphi_f) \\
  \sin(\omega t - 2\pi/3 - \varphi_f) \\
  \sin(\omega t + 2\pi/3 - \varphi_f)
\end{bmatrix} + \begin{bmatrix}
  C_{fa} \\
  C_{fb} \\
  C_{fc}
\end{bmatrix} e^{-\frac{t}{\tau_f}}
$$

(1)

Among them, $I_f$ is the amplitude of the periodic component of the three-phase short-circuit current on the AC side, $\varphi_f$ and $\tau_f$ are the impedance angle and time constant of the AC side short-circuit circuit. Due to the presence of inductance in the AC side short-circuit circuit, the short-circuit current cannot be changed suddenly, and the moment of short-circuit is recorded as $t=0$, then the integral constants $C_{fa}$, $C_{fb}$, $C_{fc}$ can be given by:

$$
\begin{bmatrix}
  C_{fa} \\
  C_{fb} \\
  C_{fc}
\end{bmatrix} = I_s \begin{bmatrix}
  \sin(\omega t - \varphi_0) \\
  \sin(\omega t - 2\pi/3 - \varphi_0) \\
  \sin(\omega t + 2\pi/3 - \varphi_0)
\end{bmatrix} - I_f \begin{bmatrix}
  \sin(\omega t - \varphi_f) \\
  \sin(\omega t - 2\pi/3 - \varphi_f) \\
  \sin(\omega t + 2\pi/3 - \varphi_f)
\end{bmatrix}
$$

(2)

$$
I_f = \frac{U_s}{\sqrt{R_{ac}^2 + X_{ac}^2}}
$$

(3)

Therefore, the three-phase short-circuit current on the AC side can be expressed as:

$$
\begin{bmatrix}
  i_{fa} \\
  i_{fb} \\
  i_{fc}
\end{bmatrix} = I_s \begin{bmatrix}
  \sin(\omega t - \varphi_0) \\
  \sin(\omega t - 2\pi/3 - \varphi_0) \\
  \sin(\omega t + 2\pi/3 - \varphi_0)
\end{bmatrix} e^{-\frac{t}{\tau_f}} + \frac{U_s}{\sqrt{R_{ac}^2 + X_{ac}^2}} \begin{bmatrix}
  \sin(\omega t - \varphi_f) \\
  \sin(\omega t - 2\pi/3 - \varphi_f) \\
  \sin(\omega t + 2\pi/3 - \varphi_f)
\end{bmatrix}
$$

(4)

From equation (4), the short-circuit current that the AC system and the auxiliary circuit bidirectional thyristor need to bear is determined by the inductance and resistance in the line reactor. The bidirectional thyristor will withstand a large three-phase short-circuit current after it is turned on, and the great feed impact also puts forward extremely high requirements on the short-circuit capacity of the bidirectional thyristor. The following article will add current limiting measures between the AC side and the auxiliary circuit under the premise of suppressing the AC
side feed current to limit the three-phase short-circuit current that the bidirectional thyristor will endure to ensure that the bidirectional thyristor can still work stably after it is turned on.

3. Improved method for suppressing fault feed current of bidirectional thyristor

3.1. Fault feed suppression method

In order to limit the overcurrent impact of parallel bidirectional thyristor on the basis of suppressing the internal feed of freewheeling diodes, an improved method for suppressing the fault feed of parallel bidirectional thyristor is proposed, as shown in Figure 4, adding between the AC system and bidirectional thyristor auxiliary circuit Switch type current limiter.

![Figure 4. DC distribution network test model with improved bidirectional thyristor](image)

To improve the method of suppressing the fault feed current of the bidirectional thyristor, the effective cooperation of the bidirectional thyristor and the switching current limiter is required to complete the timely suppression of the AC side converter or the DC side feed. The specific cooperation measures are as follows: When the system is operating normally, the switch K of the switch type current limiter vacuum circuit breaker is in the normally closed state, the current-limiting resistor is short-circuited, and the bidirectional thyristor G is in the open state. Therefore, neither the switching current limiter nor the bidirectional thyristor adds redundant losses during normal operation. When a bipolar short-circuit fault is detected, the bidirectional thyristor and the switching current limiter immediately respond to the triggering signal and the triggering opening signal, thereby completing the AC side current feed suppression and the internal short-circuit current limiting of the bidirectional thyristor.

3.2. Selection of current-limiting resistance of switch-type current limiter

For the selection of the internal current-limiting resistance of the switch-type current limiter, the larger the current-limiting resistance, the better the current-limiting effect of the internal short-circuit current flowing into the bidirectional thyristor. However, too large current-limiting resistance will affect the balance and stability of the system and increase the energy consumption at the time of system failure. Considering that the short-circuit current flowing into the bidirectional thyristor will be limited to the current level during normal operation of the system. When G is turned on, after K is opened, the fault current amplitude $I_f'$ can be expressed as:
\[ I_{fs}' = \frac{U_s}{\sqrt{(R_{ac} + R_p)^2 + X_{ac}^2}} \] (5)

Therefore, the short-circuit current index \( \mu \) can be expressed as:

\[ \mu = \frac{I_s'}{I_{fs}'} = \frac{I_s\sqrt{(R_{ac} + R_p)^2 + X_{ac}^2}}{U_s} \] (6)

In order to limit the short-circuit current flowing into the bidirectional thyristor to the current level during normal operation of the system, set \( \mu = 1 \) to calculate the value of the current-limiting resistance \( R_p \).

3.3. Simulation

In order to verify the effectiveness of the improved bidirectional thyristor fault feed suppression method in suppressing the AC side fault feed, the test model shown in Figure 4 was simulated and verified in PSCAD/EMDTC. Refer to the data of the flexible DC power distribution demonstration project in Shenzhen Baolong Industrial Zone [4]. Table 1 shows some parameter values on the AC side.

| AC side parameters                                | values |
|--------------------------------------------------|--------|
| AC side stable operating voltage amplitude \( U_s \)/kV | 10     |
| AC side stable operating current amplitude \( I_s \)/kA | 0.75   |
| AC side current limiting inductor \( L_{ac} \)/H   | 0.002  |
| AC side current limiting resistor \( R_{ac} \)/Ω   | 0.18   |

According to the data in Table 1, setting the short-circuit current index \( \mu = 1 \), the current-limiting resistance \( R_p \) can be set to 13Ω by equation (6). Now suppose that a bipolar short-circuit fault occurs at a distance of 1km from the converter at 2s, and the transition resistance is 0.01Ω. Three methods of fault feed suppression are examined: (1) The DC circuit breaker fault feed suppression method is used, as shown in the figure 5; (2) Add the fault feed current suppression method of the bidirectional thyristor auxiliary circuit, as shown in Figure 6; (3) Improve the fault feed current suppression method of the bidirectional thyristor auxiliary circuit, as shown in Figure 7. The AC side current \( i_a \) (single-phase) in the above three fault feed suppression methods and the internal freewheeling diode current \( i_d \) of the inverter are simulated and verified.

![Figure 5](image-url)  
*Figure 5. Simulation of using DC circuit breaker to suppress fault feeder*
After the fault occurs, the DC circuit breaker responds to open 2ms after the fault. According to Figure 5, the current diode will continue to withstand 5 to 6 times the AC side feed current during normal operation. According to Figure 6, the bidirectional thyristor is turned on, and there is basically no current flowing inside the freewheeling diode; but from Figure 6(a), it can be seen that the bidirectional thyristor will continue to withstand a large three-phase short-circuit current instead of the freewheeling diode. According to Figure 7, after a fault occurs, the bidirectional thyristor is turned on and the current-limiting switch is turned off, so that basically no AC side feed current passes through the freewheeling diode, and the three-phase short-circuit current flowing through the bidirectional thyristor on the AC side is restricted.

Conclusions
When a fault occurs, the voltage between the poles of the DC side is quickly lower than any phase voltage on the AC side, and the AC side will feed fault current to the DC side, causing an impact on the freewheeling diode. Therefore, a method for suppressing AC side fault feed current based on improved bidirectional thyristor is proposed. First of all, the current fault feed suppression method of bidirectional thyristor is used to replace the internal freewheeling diode of the bidirectional thyristor to withstand the impact of the fault current, so it is necessary to add a switch-type current limiting device on the AC side; then the current limiting resistor is discussed selection; Finally, by comparing DC circuit breakers, bidirectional thyristors and improved bidirectional thyristor fault feeder suppression methods, the effectiveness of the method based on improved bidirectional thyristor fault feeder suppression is verified.
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