Development and application of AC section power loss protection device

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Abstract—The so-called AC section power loss refers to the loss of all AC power supplies of the system on this side. After the AC section at the receiving end of the converter station loses power, it will lead to serious AC overvoltage, and the energy of the arrester will increase sharply at the same time, which will seriously affect the safety of the equipment. In view of this situation, this paper studies the action mechanism of AC section power loss protection, and gives the design scheme of AC section power loss protection device. The developed protection device has been verified by RTDS simulation test, passed the third-party detection test of a detection and Research Institute, and is running on site. The field operation is good. The device is not only suitable for conventional DC system and flexible DC system, but also for some occasions where regional stability needs to be considered.

1. Introduction
The so-called AC section power loss refers to the loss of all AC power supplies of the system on this side. Loss of power at the section of the converter station refers to the abnormal disconnection with the AC outgoing line of the converter station, resulting in the loss of power exchange channel of the converter station. This working condition may occur in level I section, level II section and further sections [1-6]. For the primary section, whether the conventional DC converter or flexible DC converter, the final circuit breaker protection is usually configured, so that the converter can be locked quickly. For the secondary and further sections, corresponding AC section power loss protection devices need to be configured to lock the converter station. In the conventional DC project, when the section of the receiving terminal station loses power, the receiving terminal loses the energy output channel, and the surplus power flows into the AC filter capacitor, resulting in serious AC overvoltage [7-9]. In order to ensure the safety of converter and other equipment, the final circuit breaker protection logic is set in the project. Among them, reference [10] introduces the final circuit breaker protection logic based on the switching signal of AC circuit breaker to quickly lock the converter after section power loss to reduce the overvoltage level at the converter grid side. Reference [11-12] introduces the implementation method of lightning arrester type final circuit breaker protection. The energy of the lightning arrester is calculated by measuring the voltage and current of the lightning arrester at the converter grid side. When the energy approaches the limit that the lightning arrester can withstand, the converter is locked to protect the safety of the equipment. At present, there are few research results on AC section power loss...
at home and abroad. This paper presents the development and application of AC section power loss protection device for the first time, which proves the practical value of the device in practical engineering.

2. Mechanism of AC section power loss protection

The device is mainly used to detect whether the AC part is powered off. There are generally two outgoing lines at the substation side connected to the converter station side. The typical main wiring form is shown in Figure 1.

The protection configuration scheme that can be adopted is to install two line detection nodes and a comprehensive discrimination node at the converter station side and the substation side respectively, and automatically judge whether the AC surface loses power by integrating the operation and fault status of the lines on both sides; When it is judged that the AC section loses power, the AC section loses power information is sent to the DC control system.

![Figure 1. applicable typical main connection type.](image)

2.1. Communication connection mode

Communication connection mode Figure 2 is the detection block diagram of AC section power loss protection device. Regardless of communication links, AC section power loss refers to the situation that the circuit breakers at both ends of two lines are disconnected.

![Figure 2. communication connection of AC section power loss protection device.](image)

2.2 Detection principle of AC section power loss protection device

Figure 3 is the detection block diagram of AC section power loss protection device. Regardless of the communication link, AC section power loss refers to the situation that the circuit breakers at both ends of the two lines are disconnected.

The device starts the AC section power loss discrimination logic after receiving the corresponding breaker opening command. The specific detection logic is as follows: the detection node collects the instantaneous value of three-phase current of side circuit breaker and middle circuit breaker CT of lines 1 and 2 on this side, collects the instantaneous value of three-phase voltage at the installation of PT on this side, and calculates the effective values of three-phase voltage $U_a$, $U_b$, $U_c$, three-phase current $I_{sa1}$, $I_{sb1}$ and $I_{sc1}$ of side switch of line 1, and the effective values of three-phase current $I_{ma1}$ and $I_{mb1}$ of switch in line 1, $I_{mc1}$ and active power $P_1$ and $P_2$ of lines 1 and 2 on this side. The discrimination steps of line trip on this side are as follows:
Figure 3. Detection block diagram of AC section power loss protection device.

1) Discrimination of line tripping at substation side
Trip discrimination is carried out for line 1 and line 2 respectively. The line is considered to have tripped when the side of the line and the interrupter are in the split position, the three-phase current of the line is less than the current threshold, and the three-phase power of the line is less than the active threshold. When the substation side integrated logic discrimination node knows that both substation line 1 and substation line 2 have tripped, it sends the substation side tripped information to the converter station side integrated logic discrimination node.

2) Discrimination of line tripping at converter station side
If both converter station line 1 and converter station line 2 have tripped, the converter station side comprehensive logic discrimination node sets the converter station side tripping state. According to the tripping results of the lines on both sides, the AC section is determined as power loss only when the tripping state at the substation side and the tripping state at the converter station side are set. The comprehensive logic discrimination node at the converter station side sends the section power loss signal to the DC pole control.

2.3 Others
The AC section power loss detection does not consider the single-phase tripping and single-phase reclosing of the line, but only considers the three-phase tripping and non-reclosing of the line. The line trips in single phase. After single-phase reclosing, if the reclosing is unsuccessful, the line will still trip in three phases. The AC section power loss protection device avoids the damage to the thyristor or IGBT components of the DC system in the case of AC section power loss, and provides a strong guarantee for the safe and stable operation of the DC system.

3. Realization of AC section power loss protection device
Fig. 4 shows the block diagram of the line detection node. The line detection node collects the three-phase voltage of lines 1 and 2 and the three-phase current of the switch in the side, calculates and determines whether lines 1 and 2 trip; At the same time, these information are sent to the comprehensive logic discrimination node.
Fig. 5 shows the block diagram of the comprehensive logic discrimination node. The comprehensive logic discrimination node on the substation side performs logic discrimination according to the operation and fault status of lines 1 and 2 on this side, and sends the line trip signal to the comprehensive logic discrimination node on the converter station side. The converter station side integrated logic discrimination node forms the line trip signal on this side, and the AC section power loss signal is formed according to the line trip signal sent by the substation side integrated logic discrimination node and the line trip signal on this side; Finally, the section power loss signal is sent to the DC pole control.

The AC section power loss protection device adopts the general hardware platform of the new generation zynq chip. The overall large panel and fully enclosed chassis, the hardware circuit adopts the plug-in structure of rear plug-in, the CPU circuit board adopts 6-layer board, and the surface mount technology is adopted to improve the reliability of the device hardware.

3.1 Plug-in introduction
(1) The regulated power supply plug-in is a DC inverter plug-in. After the DC 220 V or 110 V voltage is input through the anti-interference filter circuit, the inverter principle is used to output the 5 V DC voltage required by the device. The power plug-in has the function of power loss alarm.

(2) The AC input plug-in converts the secondary side signals of the system voltage transformer and current transformer into weak current signals required by the protection device, and plays the role of isolation and anti-interference at the same time.

(3) The expansion plug-in provides 30 input channels, which are used to input the hard pressing plate or external switching value signal to the device.

(4) The signal plug-in supports 9 channels, two groups of instantaneous signal contacts and one group of magnetic holding signal contacts.

(5) The interface communication function is realized by the communication management plug-in, which can be used as the communication and man-machine interface management unit of AC section power loss protection device.

(6) The main CPU plug-in mainly completes the functions of AD sampling, policy control, communication transceiver, export logic and switching value input, and communicates with the communication management CPU and communication extension plug-in.
(7) The communication expansion plug-in can expand 8 internal optical fiber interfaces to communicate with the station device and DC pole control respectively.

3.2 Software design
The logic function design of AC section power loss protection device is based on the visual logic development environment, and adopts the design idea of layering and sub module. The strategy control function is divided into modules such as data processing, component calculation, communication processing, control strategy analysis and retrieval, control measure implementation, export logic, device self inspection, etc.

(1) The device samples the input AC voltage and current. 24 points are sampled in a power frequency cycle. After digital filtering, the effective values of voltage and current, active power, reactive power, etc. are calculated according to the following algorithm. The general algorithm of three-phase active power and reactive power is as follows:

\[
P = \frac{1}{24} \sum_{k=1}^{24} [u_a(k)i_a(k) + u_b(k)i_b(k) + u_c(k)i_c(k)] \text{MW}
\]

\[
Q = \frac{1}{24} \sum_{k=1}^{24} [u_a(k-6)i_a(k) + u_b(k-6)i_b(k) + u_c(k-6)i_c(k)] \text{MVar}
\]

Where: \(u_a(k), u_b(k)\) and \(u_c(k)\) are the instantaneous values of current phase A, B and C voltages; \(i_a(k), i_b(k)\) and \(i_c(k)\) are instantaneous values of current phase A, B and C currents.

(2) The starting criterion of current sudden change is: ABC three-phase current is divided into phases. The current of each phase is compared with the current before one cycle. If any phase meets the following formula for three consecutive times, the device enters the starting state.

\[
\Delta I_{pmax} > 1.25 \Delta I_r + \Delta I_{dc}
\]

among \(\Delta I_{pmax}\) is the current starting setting.

(3) Tripping criterion of electrical quantity + circuit breaker position: when the sudden variable is started, any phase of this side and interrupt circuit breaker changes from closing to opening. When this side and interrupt circuit breaker are in opening, the power is less than the active threshold, at least two-phase current is less than the current threshold, and the delay is greater than the delay setting. If the above conditions are met, it is judged as line tripping.

4. Test verification
During the test verification of AC section loss of power, DC model shall be provided at the converter station side, and the actual control and protection system shall be connected to RTDS. The test wiring diagram is shown in Figure 6.

Figure 6. main wiring of a back-to-back flexible DC transmission system.
AC power grid B transmits electric energy to AC power grid a, with active power of 1250MW and reactive power of -515mvar on both sides. AC section power loss occurs on side A. The relevant waveforms are shown in the figure below.

![Figure 7. Energy of line end arrester.](image1)

![Figure 8. Line terminal voltage.](image2)

![Figure 9. Arrester energy.](image3)

![Figure 10. DC voltage.](image4)

For the logic functions of AC section power loss pro As can be seen from the above figure, when the AC section at the receiving end of the converter station loses power, the receiving end loses the energy output channel, and the surplus power flows into the AC filter capacitor, resulting in serious AC overvoltage. The surge arrester energy calculated by measuring the voltage and current of the surge arrester on the converter grid side increases sharply at the same time. Therefore, it is urgent to develop AC section power loss protection devices to avoid the adverse effects of AC section.

Under the RTDS simulation environment, the AC section power loss protection device has carried out the following experimental items:

1. The Metallic transient fault.
2. Permanent metal failure.
3. Developmental and transformational faults.
4. Test of simulating another fault after one fault.
5. The converter station side cannot receive the AC station side signal or the AC station side data is invalid.
6. Bus or line maintenance test.
7. Maintenance test of middle (side) circuit breaker.
8. Abnormal position test of circuit breaker.
9. CT Disconnection Test.

After testing, the device has good performance and meets the actual demand.
5. Conclusion
After the AC section at the receiving end of the converter station loses power, it will lead to serious AC overvoltage, and the energy of the arrester will increase sharply at the same time, which will seriously affect the safety of the equipment. In view of this situation, this paper studies the action mechanism of AC section power loss protection, and gives the design scheme of AC section power loss protection device. The developed protection device has been verified by RTDS simulation test, passed the third-party detection test of a detection and Research Institute, and is running on site. The field operation is good. The device is not only suitable for conventional DC system and flexible DC system, but also for other occasions where regional stability needs to be considered, so as to provide reliable technical guarantee for the safe and stable operation of power system.

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