Fault analysis caused by short circuit current DC component Related to circuit breaker

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Abstract-Concerning a 750kV power plant circuit breaker refused to move accident,combined with the action process of accident circuit breaker and the waveform of fault current,analyze the cause of the breakout of the circuit breaker. This paper described the process of the accident from four stages and analyzed the fault waveform in detail. The result shows that the circuit breaker in the DC converter station recloses when the current of circuit breaker in power plant reaches the maximum reverse. The recloses of the circuit breaker in the converter station causing the power plant of the circuit breaker to produce a larger DC component and the DC component caused the short-circuit current-zero offset of the circuit breaker in power plant and the breaker on the power plant side failed to open due to no zero crossing. The simulation result shows that the circuit breaker of power plant does not appear DC component while the reclosing time of the circuit breaker in the DC converter station ahead of 5ms. It verifies that the analysis results are correct.

1. Introduction
In case of short-circuit fault in power system, the short-circuit current to be cut off by the circuit breaker is the superposition of AC component and DC component. Due to the lack of due attention to the DC component and attenuation of short-circuit current in early practical engineering applications, the domestic attention to short-circuit current mainly focuses on the calculation of AC component[1-2]. With the rapid development of 750kV power grid and the access of high voltage direct current transmission (HVDC), the influence of DC component on the breaking fault current of circuit breaker is becoming more and more prominent[3-5]. The influence of DC component on circuit breaker is mainly reflected in the following two aspects:1) The time constant of DC component affects the large half wave peak of short-circuit current, which affects the energy released by arc in the process of arc extinguishing, resulting in the abnormal breaking of circuit breaker[6-7]. 2) The DC component may cause the zero crossing drift of short-circuit current, prolong the arcing time of the circuit breaker, and lead to the arc extinguishing failure of the circuit breaker[8].

Aiming at a 750kV circuit breaker breaking accident, combined with the fault time nodes and fault current waveform, the author analyzes the breaking process and accident causes of the circuit breaker in detail, and verifies the analysis results by using the simulation software, which can be used as a reference for subsequent fault analysis.

2. Accident overview
A 750kV power plant trip accident caused load loss, unit trip and damage to 7522 switch on side B of the power plant. The power plant and converter station adopt 3/2 wiring and three semi complete
strings. The operation mode in case of accident is shown in Fig. 1. The field inspection found that the basin insulator at the lower end of CT near the I bus side of the circuit breaker of converter station a discharged to the ground, and the specific discharge points are shown in Fig 1. At the same time, at the time of failure, phase B of 7522 circuit breaker in the second series of circuit breakers of power plant B failed, resulting in the failure protection action of bus II of power plant B and tripping all connecting switches of bus II in order to isolate the fault.

![Fig.1 Operation mode of the system](image)

3. Accident analysis

3.1 Analysis of circuit breaker action process

In case of single-phase grounding fault in the converter station, 7532, 7530 and 7531 circuit breakers at the converter station side trip, and 7522 and 7520 circuit breakers at the power plant side trip, so as to cut off relevant fault lines. The protection action sequence diagram of each side is shown in Fig. 2.

![Fig.2 Protection action sequence diagram](image)

According to the action of circuit breaker and line protection, combined with the protection action sequence diagram, the whole accident process is divided into four stages:

Phase I: From fault time to fault removal time of protection action. At the time of failure, each circuit breaker is closed, so the fault current on the bus side of power plant B, power plant C and converter station a flows to the fault point, and the fault current flows to the fault point through the circuit breakers numbered 7530, 7531 and 7532 on the converter station side. The fault point is located within
the line protection range of connecting line II between converter station A and power plant B and power plant C. Therefore, the protection of both lines will trip at the outlet and jump out of B-phase of the corresponding circuit breaker on both sides of the line. As the 7530 circuit breaker of the converter station received the line protection action command on both sides at the same time, resulting in its protection failure, the instantaneous three-phase exit jumped out of the three-phase.

Phase II: From the reclosing time of 7522 switch on side B of the power plant to the reclosing time of 7531 circuit breaker on side of the converter station. After the fault of circuit breakers on both sides of the line is removed, the 7522 circuit breaker on the B side of the power plant is reclosed. Since the 7531 circuit breaker at the converter station side has not been reclosed, the fault current flows from the converter station to the fault point through power plant B through the I and II connecting lines between the converter station and power plant B at this stage.

Phase III: The switch reclosing time of 7531 B-phase circuit breaker at the converter station side to the accelerating tripping time after the reclosing of 7531 B-phase and 7532 B-phase circuit breakers at the converter station side. According to the protection action record, when the fault occurs for 692ms and 693ms, the 7531 and 7532 circuit breakers at the converter station side shall be reclosed. Since the reclosing operation of 7522 circuit breaker on side B of the power plant has been completed in the second stage, the fault current flowing through the fault point in this stage consists of two parts: Part of the current flows through the fault point of I and II connecting lines between the converter station and power plant B, and the direction is from the converter station to power plant B. The other part flows from Bus I at the converter station side to the fault point through 7531 circuit breaker. In the whole process, the fault current flows through the connecting line II between the converter station and the side B and C of the power plant, and the fault current promotes the accelerated action of line protection. From the protection action record results, the protection action outlets of 7531 and 7532 circuit breakers at the converter station side tripped, but the 7522 circuit breaker at the B side of the power plant did not perform protection tripping.

Phase IV: After the 7531 B-phase circuit breaker and 7532 B-phase circuit breaker on the converter station side coincide, accelerate the tripping time until the 7522 B-phase circuit breaker on the B side of the power plant fails, and the fault is removed by tripping 7512 circuit breaker at the II bus failure protection action outlet. Since the 7522 circuit breaker on the side B of the power plant in the third stage did not trip, the fault current always flows to the fault point through the connecting line II between the converter station and power plant B, and the current direction flows from power plant B to the converter station. The fault current channel is disconnected when the failure protection action outlet of 750kV II bus at side B of the power plant trips 7512 circuit breaker, and the fault point is completely removed.

3.2 Waveform analysis of fault current
From the analysis of the four stages, the tripping accident is mainly because the 7522 circuit breaker on the B side of the power plant did not perform protection tripping in the third stage. In order to further find out the reason why the 7522 circuit breaker on side B of the power plant did not trip, the fault waveform in the third stage was retrieved and analyzed. The fault waveform on each side is shown in Fig.3.
From the analysis of fault process and waveform, the reasons for the opening failure of 7522 circuit breaker on side B of the power plant mainly include the following two aspects:

1) The initial angle of supply voltage and the current value in the circuit before short circuit affect the initial value of DC component can be seen from Fig.3 that when the 7532 and 7531 circuit breakers of the converter station are reclosed, the voltage of line I between the converter station and power plant B is at the zero crossing point, and the power frequency fault current of line II on the side of power plant B is just at the negative half wave peak at the same time. Moreover, the impedance angle of high-voltage transmission line is near 85° in the case of short circuit, and it's load is close to inductive. Based on the above three conditions, the starting value of DC component flowing through line II of power plant B and converter station during fault is large, and the starting value is almost equal to the amplitude of steady-state short-circuit current.

2) The increase of arc combustion time increases the arc energy flowing through the circuit breaker, the energy reduces the zero crossing rate of current and TRV parameters of the circuit breaker. These conditions lead to harsh breaking conditions of the circuit breaker. Transmission line is a resistance inductance element. The attenuation time constant of aperiodic component current is \( t = \frac{L}{R} \). The R value of EHV line is very small, so the attenuation is very slow. The system side power supply basically provides power frequency current (about 11.24A) to the fault point through 7531 circuit breaker, so the power frequency current provided through line II of power plant B and converter station is very small. Therefore, the percentage of DC component of short-circuit current flowing through 7522 circuit breaker on side B of power plant increases, which increasing the breaking burden of circuit breaker.

4. Simulation analysis

Combined with the equipment parameters and primary wiring diagram of power plant and converter station, the equivalent modeling of generator, transformer and shunt reactor is carried out, and the accident is simulated and calculated by electromagnetic transient simulation software. In the whole simulation calculation process, the action timing of each side is carried out according to the timing shown in Fig.2. The simulation waveform is shown in Fig.4.
In the simulation waveform shown in Fig.4, the upper part is the B-phase voltage waveform on the B-side of the power plant, and the lower part is the B-phase current waveform on the B-side of the power plant. The waveform is basically consistent with the fault waveform, which shows that the simulation model is reliable. In order to verify the analysis results, the closing time of the circuit breaker is advanced by 5ms during the simulation, which is to coincide when the fault current on side B of the power plant crosses zero. The simulation waveform of phase B current of line II at side B of power plant and converter station is shown in Fig.5.

Through the comparative analysis with the phase B simulation current on the side B of the power plant shown in Fig.4, it can be seen that there is no DC component when the 7531 circuit breaker on the side of the converter station is closed at the zero crossing of the fault current of the 7522 circuit breaker on the side B of the power plant.

5. Conclusion
The accident was due to the inconsistent closing time of 7522 circuit breaker on the B side of the power plant and 7531 circuit breaker on the converter station side, inconsistency of time resulting in the continuous flow of large DC component of 7522 circuit breaker. The DC component causes the opening failure of the circuit breaker. Considering the influence of DC component, the influence of short-circuit DC component on the breaking capacity of circuit breaker and system operation shall be studied. Corresponding preventive measures shall be formulated to avoid the switch opening failure caused by inconsistent reclosing time. Because of the randomness of switch reclosing on both sides (including switch reclosing action sequence and reclosing time of rear reclosing switch) in the process of fault removal, the time difference caused by circuit breaker reclosing should be considered in the process of formulating protection scheme.

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