A Master-Slave Collaborative Control Strategy of High Voltage DC Circuit Breakers

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Abstract: High voltage DC circuit breaker is the key equipment in DC grid since its rapid and reliable breaking is a critical precondition for safe and reliable operation of system. In the paper, breaking of hybrid high voltage DC circuit breaker is analyzed first. Then to solve the problem about response time and system reliability, a master-slave collaborative control strategy of high voltage DC circuit breaker is proposed, it regards the grid-level protection as master control, and the inner protection is slave control. Making full use of the advantages of both two controls, the breaking is rapid and reliable. What’s more, DC circuit breaker could still cut off the fault current in case of malfunction of one of these two protection. Finally, the simulation results in PSCAD/EMTDC show that the proposed control strategy is correct and effective, it shortens the fault response time and improves system reliability.

1. Introduction

High-voltage DC circuit breaker (HVDCCB) is one of the key equipment in the DC power grid. [1-3]. In order to break the DC fault current rapidly, various DC breaker topologies have been proposed [1-4]. The topology of hybrid high-voltage DC breaker with arcless breaking method is shown in Figure 1. This DC breaker mainly includes parallel mechanical branch, main branch and energy absorption branch. In this paper, a four-phase high-voltage DC circuit breaker is taken as an example. The mechanical branch includes series mechanical switch K and IGBT switch groups Tm; the main branch includes the IGBT switch groups T1, T2, T3, and T4, which are connected in series. Each group of switches is formed of multiple IGBTs connected in series; the energy absorption branch is formed of a plurality of groups of arresters connected in series, and each arrester is formed of a plurality of arresters in parallel with IGBT switch groups.

![Figure 1. Hybrid DC circuit breaker](image-url)
2. Master-slave collaborative optimization control strategy

With the development of power electronics and its voltage-balancing technology, the breaking performance and reliability of HVDCCB have been greatly improved [4-6]. And research on the strategy of the breaking methods and controls for high-voltage DC breakers have been deepened.

Aiming at the high fault response speed and system reliability of breakers, a master-slave collaborative control strategy for HVDCCB is designed in this paper. The system protection signal is the master, and the breaker internal protection signal is the slave. Detection includes fast overcurrent detection and current-limiting detection. The control process is shown in Fig. 2, and the control strategy consists of three parts: master-slave collaborative breaking, main breaking control, and slave breaking control.

![Diagram: A master-slave collaborative control strategy](image)

2.1 Master-Slave collaborative Breaking

If a short-circuit fault occurs in the system, the breaker receives both master and slave control signals, and the breaking process is as follows:

First, after current in mechanical branch reaches the overcurrent reference value, the fast overcurrent detection immediately sends a signal to shut off the mechanical branch, that is, the IGBT switch $T_m$ and the mechanical switch $K$ are turned off in sequence; Second, after the mechanical switch $K$ breaks and voltage endurance capability meets requirement, if the system fault signal is received, the main branch is immediately shut off, that is, $T_1$, $T_2$, $T_3$, and $T_4$ are simultaneously turned off to complete the breaking; Third, if the system protection doesn’t issue a fault signal and the DC current drops below the overcurrent reference value, the mechanical branch is reconnected and normal operation resumes.

2.2 Master Breaking Control

When operating in normal, and the system needs coordinated control over a wide range of power grids such as circuit overhaul or equipment installation, or a fault occurs on the slave control during the system fault, the breaker can only receive the signal from the system fault signal. In this case, the breaker will break in the normal sequence described in section II.

2.3 Slave Breaking Control

If the master control fails while the system fault occurs, the DC breaker can still be disconnected from the slave control. Since the instantaneous overcurrent capability of the IGBT is limited, and excessive current will also cause impact on other devices, it is necessary to set the current limit reference value for the magnitude of the fault current. The process of breaking from slave control is as follows:

First, after the DC current reaches the overcurrent reference value, the fast overcurrent detection
sends a signal to shut off the mechanical branch immediately; Second, after the voltage endurance capability of mechanical switch K meets requirement, if the current-limiting detection sends a breaking signal, the main branch is immediately shut off and the breaking is completed.

3. Simulation and example analysis

The simplified model of the short-circuit fault on the DC side is shown in Fig. 2, and the parameters are shown in Table 1. Then the master-slave collaborative control strategy of breaker is simulated and analyzed.

| Parameters                      | Value  | Parameters                      | Value  |
|---------------------------------|--------|---------------------------------|--------|
| rated voltage/kV                | 200    | equivalent resistance/Ω         | 133.3  |
| equivalent inductance/H         | 0.1    | rated DC current/kA              | 1.5    |
| conduction resistance of Tm /Ω  | 0.01   | current-limiting reference/kA    | 9      |
| conduction resistance of T1, T2, T3, T4 /Ω | 0.3 |                         |        |

3.1 Master-Slave Collaborative Breaking

As shown in Figure 3, the DC-side current reaches the overcurrent reference value when $t=1.0002s$. Then the overcurrent breaking signal is transferred from the slave control, and the mechanical branch is rapidly shut down with current transferred to the main branch. Since the all-solid-state switch is turned off quickly, the process time is within milliseconds. After the mechanical branch current drops to 0, the mechanical switch begins to be turned off, thereby achieving the arcless breaking. About 2ms later, the voltage endurance capability of mechanical switch meets the requirement, and then main branch turns off as soon as it receives the master control signal with current transferred to the energy absorption branch and decreasing to zero.

3.2 Master Breaking Control

Assuming that short circuit fault occurs when $t=1s$, and the slave control fails, the current of each branch and the value of each signal is shown in Figure 5 (a), (b). About 2ms later, the DC circuit
breaker receives the main control signal and starts to break: IGBT in mechanical branch turned off quickly, and then current is transferred to the main branch. When the current of mechanical branch becomes 0, the mechanical switch begins to be turned off. About 2ms later, voltage endurance capability of mechanical switch meets the requirement, and then main branch shut off rapidly with current transferred to the energy absorption branch, and dropping to zero.

According to the simulation, the fault response time is about 4.2ms, the peak current is about 8.6kA, and the sum of the energy absorbed by arresters of each group is about 7.15MJ.

3.3 Slave Breaking Control
Assuming that the short circuit fault occurs when \( t = 1s \), and master control fails. The current and signals are shown in Figure 6 (a), (b). After mechanical branch is turned off, the main control doesn’t send the fault signal. Current reaches current-limiting reference value when \( t = 1.052s \), which is 9kA, and then current-limiting breaking signal is sent from the slave control. Since voltage endurance capability of fast mechanical switch K has met requirement, the main branch is rapidly shut off with the current transferred to the energy absorption branch and decreasing to zero.

According to the simulation, the fault response time in this process is about 5.2ms, the breaking current is about 9.0kA, and the sum of the energy absorbed by the arresters of each group is about 8.00MJ.

According to Fig. 4, Fig. 5 and Fig. 6, under the DC-side fault, the performances of three breaking under master-slave collaborative control strategy are shown in Table 2:

|                     | Response time /ms | Breaking current /kA | Absorbed energy /MJ |
|---------------------|-------------------|----------------------|---------------------|
| collaborative breaking| 2.2               | 5.2                  | 2.73                |
| master breaking control | 4.2               | 8.6                  | 7.15                |
| slave breaking control    | 5.2               | 9.0                  | 8.00                |

Since the breaking method of main breaking control is same to conventional breaking method, after comparing, it can be known that when the master control and the slave control do not fail, the fault response time of the master-slave collaborative control strategy is less than that of the conventional breaking, with smaller breaking current and less energy absorbed by arresters. If one of the two control fails, the DC breaker can still be broken, and the system reliability is still ensured. So master-slave collaborative control strategy could greatly improve the breaking performance of the DC circuit breaker.

4. Conclusion
Aiming at the high fault response speed and system reliability of breakers, this paper proposes a master-slave collaborative control strategy for DC circuit breakers, which is mainly based on the
system protection signals, and supplied by internal protection signal control. The effect of this control strategy is as follows:

--First, the control strategy could bring to fast fault response, low breaking current, and low energy absorption by arresters. It could still complete the DC circuit breaker breaking after one protection system fails, and then system fault is removed and the system reliability is enhanced.

--Second, when system failure occurs, taking advantage of the rapidity of the slave control and the reliability of the master control, the breaking is fast and reliable. The fault response time is shortened, and breaker is prevented from misoperation.

--Third, when the DC circuit breaker receives breaking signal only from master control, the DC circuit breaker will be normally broken, and fault clearing can be realized.

--Fourth, when the master control fails, the current-limiting detection could still make it possible for DC circuit breaker to break, which could enhance the system reliability.

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