Analyze the Layered Structure of the DC Transmission System on The Same Tower

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Abstract. HVDC adopts the design concept of a double-circuit erection on the same tower, which can reasonably and efficiently utilize the resources of the ground electrode and the converter station, improve the transmission capacity of the unit corridor, and save valuable transmission corridors, and reduce engineering construction and maintenance costs. Different from the previous single-loop ± 500 kV DC transmission system, DC project needs to implement dual-circuit power control and full-station reactive power control to meet the requirements of the dual-circuit DC power dispatching and the dual-circuit DC transmission to the entire station AC filter.

1. Introduction
This article will analyse the layered structure of the DC transmission system on the same tower, and then adjust power control based on the characteristics of the dual-circuit control unique to the DC transmission system on the same tower [1]. In the independent operation mode, when the DC system is operating, in addition to the unified reactive power control function of the entire station, the two DC systems operate relatively independently according to the conventional operation mode [2]; in the combined operation mode, the two DC systems are controlled by the station control layer equipment according to the operating conditions of the system are uniformly coordinated and controlled. DC control system has specially set up a first-level dual-circuit control layer to implement the coordinated control function of the dual-circuit DC system [3].

2. Dual-Circuit DC Control System on The Same Tower
The structure of the converter station of the same-station dual-circuit DC transmission system is shown in Figure 1. The primary system mainly includes a converter transformer, AC filter, converter valve, smoothing reactor, DC filter, and DC line [4]. There are 4 poles in two times, and each pole uses a 12-pulse converter, which shares the AC field, grounding pole and line pole tower. The 12-pulse converter is the basic operating unit of modern high-voltage DC engineering.
The DC control system is the core of the HVDC transmission system. The performance of the DC control system is crucial to the stability of the DC system operation and the safety of the DC equipment.

3. Methods
Each ±500kV system of DC projects can be operated independently or jointly. The DC control system hardware equipment of the Project is provided with a DC pole control, a DC station control (dual-pole control) and a double-circuit DC system coordinated control system. The double-loop DC system coordinated control system is the highest-level control system in the converter station of the DC project. This control system is a device specially set up in the project to implement double-loop control or control functions related to the entire station, such as power modulation, double circuit power coordination, reactive power control, etc.

4. Hierarchical Control System on Dual-Circuit DC
The control protection system is the "brain" of the HVDC transmission project, which has an important impact on the overall performance and reliability of the project [5]. The DC transmission control system generally adopts a layered structure. All control functions of the DC transmission converter station and the DC transmission line are divided into several layers according to the level, and the following basic principles are followed:

1) Each level is separated in structure. Functions with higher levels can be applied to the lower levels and their directions are unidirectional. Control functions with the same level and their corresponding software and hardware are separated as much as possible in structure. To reduce interactions;

2) The control function directly facing the controlled equipment is set at the lowest level, and the relevant execution links in the control system also belong to this level;

3) The main control functions of the system are distributed to lower levels as much as possible to improve the system availability;

4) When the high-level control fails, each lower-level control can continue to work according to the instructions before the failure and retain as many control functions as possible.
The functional hierarchical structure of the HVDC control system recommended by IEC 60633: 1998 (GB / T 13498-2007) is shown in Figure 2. Its functions are divided into AC / DC system level [6], regional level, high voltage DC bipolar level, High-voltage DC pole stage and converter unit stage, of which the last three layers are functions realized in the converter station.

The steady-state DC can be obtained according to Figure 1:

\[ I_d = \frac{U_{d,0} \cos \alpha - U_{d,0} \cos \beta}{d_r + R + d_s} \]  

(1)

5. DC Transmission System

DC system can be divided into joint operation mode and independent operation mode. In the independent operation mode, when the DC system is operating, in addition to the unified reactive power control function of the entire station, the two DC systems operate relatively independently according to the conventional operation mode; in the combined operation mode, the two DC systems are controlled by the station control layer equipment according to the operating conditions of the system are uniformly coordinated and controlled [7]. The DC project control system has specially set up a first-level dual-circuit control layer to implement the coordinated control function of the dual-circuit DC system.

The joint operation mode is a special operation mode proposed for double-circuit DC on the same tower. When running in this mode, the operator sends the total power setting value of the two DC systems to control the overall DC power [8]. The power setting value is sent to the station control system, and the station control system automatically allocates the power setting value of the two DC systems according to the status of the two systems [9].

In the case of a two-time DC combined operation, if the system fails and needs to be shut down immediately, the shutdown signal will be sent directly to the control system of the corresponding faulty DC system. At this time, the two-time DC coordinated control function will work to improve the soundness of the DC system. Power transmission level until a healthy DC system reaches the power transmission limit.

If two poles of a DC system are operated together, if one pole of the DC system fails, and the system needs to be shut down, the healthy pole of the pole will bear the power lost by the fault pole. If the healthy pole reaches the power transmission limit, the two poles of DC will be coordinated and controlled. The role, a sound DC system can bear part of the lost power.

6. Dual-Circuit Power Control Function

The double-loop control layer includes functions such as double-loop power control, total station reactive power control, power modulation, dual-loop DC operation mode control, ground electrode current monitoring, and balance control. Among them, double-loop power control is the core, and power modulation is realized based on double-loop power, while DC operation mode control, total station reactive power control, and ground current monitoring and control are for bipolar power control. This section only analyzes and studies the dual-loop power control function.

6.1. Coordination Principles of Double-Circuit Power Control

The biggest difference between the control function of the dual-circuit HVDC transmission system on the same tower and the conventional single-circuit HVDC transmission system is the addition of a single-level dual-circuit control layer for the coordinated control function of the two-circuit DC. The coordinated control strategy includes the start-up coordinated control strategy of the two DC transmission systems, the coordinated control strategy of the two DC transmission systems outages, the emergency shutdown coordinated control strategy of the two DC transmission systems, and the stable control power allocation of the two DC transmission systems Coordinate control strategies.

When the DC project runs in the coordinated control mode, the operator will set the total power setting of the entire station. The station system control layer allocates the corresponding power setting value to the bipolar control layer according to the voltage value of each DC system. If the two DC systems operate in a balanced manner, the two DC systems will share the total power setting. If the two
DC systems operate unbalanced, the power reference value allocated to each DC system will be proportional to the total voltage value. The schematic diagram of two-time DC power coordinated control is shown in Figure 3.

![Schematic diagram of two-time DC power coordinated control](image)

Figure 2. The basic principle of power coordination control

Coordinated control allocates the total power setting of two DC systems. Therefore, it is required that at least one pole of a DC system be operated in bipolar power mode before the DC system can be switched to the coordinated operation mode.

6.2. Conversion Principles of Double-Circuit Power Control Mode

Double-circuit power control mode is the most widely used power transmission mode for double-circuit DC projects on the same tower. It can automatically distribute the active power of two DC transmissions according to various working conditions to ensure that the total transmission power remains unchanged. The conversion principle of the double-loop power control mode is as follows:

1) The double-loop power control mode is switched on and off. The two DC cycles can be switched on and off separately.

2) When at least one of the two poles of a DC is in the bipolar power control mode, the circuit is allowed to enter the double circuit power control. The poles in the double circuit power control mode will participate in the power distribution of the double circuit. The poles of the unipolar current control mode remain independently controlled. When both poles of a circuit are in the bipolar power control mode, if the circuit is put into the double circuit power control, both poles will enter the double circuit power control mode and participate in the distribution of the double circuit power.

7. Conclusions

The design and implementation of the dual-loop control layer (including dual-loop power control, total station reactive power control, power modulation, dual-loop DC operation mode control, ground electrode current monitoring and balance control, etc.) of the DC control system are designed and implemented. Among them, dual-loop power control is the core, and power modulation is realized based on dual-loop power. The research results show that the coordinated operation of the double-circuit DC transmission system on the same tower on the same station can maintain the total DC transmission power for a short time after the failure, which can effectively reduce the loss of transmission power.

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