Research on Hierarchical Coordination and Coordinated Realization of DC System

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Abstract. DC converter station needs to consume a large amount of reactive power when transmitting active power. Insufficient or excessive reactive power will cause fluctuations in the AC voltage, which will affect the safety and stability of the entire system in severe cases. Simulation results verify the correctness, robustness, and superiority of the proposed active power allocation principle. This paper proposes a reactive power control strategy by fixing the position of the converter transformer tap and increasing the trigger angle/cut-off angle during the low-load operation of the DC transmission system.

1. Introduction
Based on the current dual-loop power control function of the DC, it can reduce the ground electrode current and maintain the reactive power balance of the converter to optimize the distribution coefficient of the two DC power and effectively increase the reactive power in the switching process [1]. Compared with the conventional DC transmission system, the double-circuit DC transmission system on the same tower has two operation modes: joint operation mode and independent operation mode [2]. The system operation mode is more flexible. In the joint operation mode, the two DC systems are uniformly coordinated and controlled by the station control layer equipment according to the operating conditions of the system [3]. In the independent operation mode, when the DC system is running, in addition to the unified reactive power control function of the entire station, the two DC system operates relatively independently by the conventional operating mode [4].

2. 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 first-level dual-circuit control layer, which is used to implement the coordinated control function of the two DC circuits. 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 system runs in the coordinated control mode, the operator will set the total power setting of the entire station[5]. 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 \([6]\). If the two DC systems operate unbalanced, the power reference value assigned to each DC system will be proportional to the total voltage\([7]\). The schematic diagram of the two-time DC power coordinated control is shown in Figure 1.

**Figure 1. Basic principle diagram of power coordinated control**

### 3. Methods
To make the power distribution between the two DCs take the minimum change in the reactive power of the converter station as the objective function, we use the GSO optimization algorithm to optimize the power distribution coefficient of the two circuits to maintain the reactive power balance of the converter station as much as possible; The internal power distribution between the DC bipolar poles is distributed in proportion to the absolute value of the DC voltage of the two poles, to ensure the internal ground electrode current balance every time.

### 4. DC transmissions
When the system needs to switch to the coordinated operation mode, if the power values of the two DC transmissions are different at this time, the operator needs to set the total power setting and the rate of power rise and fall. The coordination control logic will allocate the corresponding power to the two DC transmissions.

#### 4.1. Two-Pole DC System
The fixed value and the same power rise and fall rate are sent to the two-pole DC control system through the network. After receiving the set value, the two-time power set processing unit will automatically refresh its own power set value and power rise and fall. Rate, if the allocated power is greater than the operating power of this DC, the power of this DC will be increased to the assigned value at a predetermined rate. Similarly, if the allocated power is less than the current operating power value, the power of this DC will be reduced at this rate. The coordinated control detects the running status of the two poles in real-time. If one DC is in a restricted state, the coordinated control function automatically increases the power transmission level of the other DC to ensure that the two DC powers transmitted are constant.

The operating personnel can directly switch the system’s operating mode from the coordinated operation mode to the independent operation mode; when switching from the independent operation mode to the coordinated operation mode, first ensure that the two DC circuits have the same power rise and fall rate, to ensure that after the switch, the system's power disturbance is minimal.
4.2. **Double-Circuit Power Control Mode**

1) When the two poles of one round are only in the bipolar power control mode and the double-loop power control is not put into operation, the power of this round remains independent of the control and does not participate in the distribution of the double-loop power.

2) When both poles of a circuit are in the double circuit power control mode, one pole of the circuit can be directly switched from the double circuit power control to the unipolar current control, and the other pole remains in the double circuit power control mode.

5. **HVDC System**

In the conventional HVDC system, the 5-layer control function in the converter station is composed of two layers of pole control and station control in the physical structure, that is, bipolar, stage and converter unit-level control functions are concentrated in the pole control equipment. Other functions related to the whole station are realized in station control equipment. Among them, Gz and DC station control equipment include DC station control and AC station control [8]. Reactive power control, DC field control, and main control station control functions are implemented in DC station control; In the station control, there is only the AC station control function, and the reactive power control and DC field control are implemented in the pole control system. In conventional DC transmission projects, DC protection is configured independently [9].

Each pole of the UHVDC transmission project is composed of two 12-pulse converters connected in series. Its functional layering still meets the definition of IEC 60633, but it is physically different from conventional DC. ± 800kV UHV DC adopts the Win-TDC UHV DC control and protection system. The equipment is configured according to the DC station control layer (including bipolar layer), pole layer and inverter layer. The bipolar function is controlled at the station. Layer (including bipolar layer). The ± 800kV UHV DC transmission project uses the DCC800 control and protection system, and the equipment is arranged according to the bipolar layer, the polar layer, and the converter layer. The control and protection system of the Hami-Zhengzhou ± 800kV UHV DC transmission project under construction uses the PCS9550 system. The control and protection equipment is configured according to the pole layer and the inverter layer. Independent bipolar control is not set. The bipolar layer functions are configured in It is implemented in a polar pole host.

5.1. **HV / UHVDC Transmission Systems**

As can be seen from the analysis above, modern HV / UHVDC transmission systems use a 12-pulse converter as the basic unit to configure control and protection functions. The control and protection functions of a single 12-pulse converter are independent of each other. When the pulsation converter fails, only the operation unit is withdrawn to avoid causing other operation units to quiet operation, ensuring the independence of operation and maintenance of the 12-pulsation converter.

For DC, a common-station double-circuit HVDC transmission system on the same tower, the control, and protection system function layering and equipment configuration should also follow the independence of operation and maintenance of a single 12-pulse converter. With the characteristics of the station, the two-circuit DC system can either operate independently as two independent bipolar DC systems or jointly operate as a whole, giving full play to its comprehensive benefits. Different from the conventional single-circuit HVDC transmission system, the DC project control system adds a first-level double-circuit control layer above the bipolar layer to coordinately control the double-circuit DC as a whole. Its hierarchical structure is shown in Figure 2.
Figure 2. The hierarchical structure of the same-station double-circuit DC transmission system on the same tower

On the physical equipment, DC is equipped with an independent double circuit control system, a DC station control system (bipolar control system) and a DC pole control system. The double-loop 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 whole station, including double-loop power control (such as power setting and power allocation), total station reactive power control (such as total station reactive power calculation, AC filter bank switching), power modulation (power boost, power fallback, frequency control, power limit, power Swing damping control, etc.), dual-circuit DC system operation mode control, ground current monitoring, and balance control.

5.2 DC Control System

The double circuit control system is used to realize the coordinated control function between the double circuit DC transmission systems. This function coordinates the operation mode and power level of the two-circuit DC system according to the current operating conditions of the system to meet the requirements of the stable, reliable and optimized operation of the entire converter station. Its main control functions include:

1) During joint operation, power fixed value distribution is performed in two DC transmission systems;
2) During joint operation, the power is distributed between the two DCs during the DC startup/exit of one DC;
3) The additional modulation signal generated by the stability control function coordinates the control function between the two DC systems.
4) The coordinated control function of reactive power control in two-time DC system;
5) Coordination of four-pole fault restart function of two-time DC system;
6) Two DC operation modes are coordinated.

The bipolar control system is used to perform control functions related to bipolar control, such as processing of the DC power set value set by the operator, bipolar stable control function, bipolar power limit, bipolar power transmission capacity calculation, calculation of power adjustment amount generated by extremely stable control function, current setting value calculation (P/U function), current setting value calculation in current mode, power / current mode selection, PPT (inter-pole current transfer) function, CBC (current balance control) Functions, etc.; DC field sequence control such as
ground electrode connection/isolation sequence, pole connection/isolation sequence, metal loop/ground loop sequence control, etc.

6. Conclusions
Our test and field commissioning of DC control protection system show that the dual-loop control layer function proposed in this research is reasonable and effective. The research content includes the study of the hierarchical structure of dual-circuit control and protection on the same tower and two-time DC power distribution. A simulation study, an optimization study of a two-time DC power distribution coefficient, and an explanation of its physical equipment host. Through experimental research, many considerable achievements have been made.

Acknowledgments
This research was financially supported by Guangdong Province's Colleges and Universities Innovation Project (Natural Science) " Research on Key Technologies of E-commerce Analysis Platform" (Project No. 2018KTSCX262). And Guangdong Province Project, Construction of Teaching Team in Guangdong Province's Colleges and Universities Project "E-commerce Teaching Team", (Project No. 2019SJJXTD01).

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