Research on starting control strategy of hybrid-DC transmission system based on line polarity switching

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Abstract. The paper presented two kinds of typical topology structures of hybrid-DC transmission system along with the principle of the voltage source converter for the flexible DC transmission system. After that, the paper found that the flexibility of DC voltage in the start-up process should be restricted to an extent due to the unidirectional mobility of the HVDC transmission system. Therefore, the traditional start-up control method cannot be directly applied in the starting process of the hybrid-DC transmission system. To solve this problem, the paper proposed a starting control strategy based on DC line polarity switching, which is reliable for hybrid HVDC transmission. Finally, the effect of the control strategy is verified by simulation.

1. Introduction

Hybrid-DC transmission system, which includes the traditional dc transmission and flexible direct current transmission technology, featured as flexible control and efficient performance by independent controlling of active and reactive power along with low loss and engineering cost, faces a grand application field. In Germany, France, Sweden and other western developed countries, the adoption of hybrid-DC transmission has become the best solution for power supply to isolated islands, weak power grid, offshore oil platforms and distributed new energy grid connection. In China, The Wudongde hybrid HVDC under construction project is the world's highest voltage and largest transmission capacity hybrid HVDC project. The project will optimize the allocation of resources, and play an important role in maintaining security and stability of power grid.

2. Principle of hybrid DC transmission system

2.1. Typical topology of hybrid DC transmission system

Hybrid-DC transmission system combines the traditional DC transmission system (Line Commutated Conversion, LCC) half controlled inverter with the flexible transmission system (Voltage Source Conversion, VSC) full control type inverter. The collocation of two kinds of inverter can make up to different kinds of topological structure. The typical hybrid-DC transmission system mainly includes two types: the two-terminal hybrid-DC transmission system and the multi-terminal hybrid-DC transmission system [1].

Double-end hybrid-DC system included single input and output port. Each end consists of single type of inverter, which mainly provides power supply to passive network, weak systems and distributed new energy grid. The multi-terminal hybrid-DC transmission system is a structure in which multiple traditional DC systems and flexible DC systems are inducted by more than two AC systems.
to supply power to the other AC system side by side [2], as shown in figure 1. The system not only transfers the power supply through the DC power line to the weak AC systems, big cities or a remote isolated power load center, but also can be used as other small new energy exchange center, access networks to implement the interconnected AC/DC system. The hybrid-HVDC system is the cut-edge technology of HVDC transmission field.

![Figure 1. Topology Structure of Hybrid Multi-terminal HVDC](image)

2.2. Principle of VSC converter station
At present, the world's flexible DC transmission systems all adopt a voltage-source converter composed of full control devices, which does not need to rely on the AC system to provide commutation voltage [3]. The bridge arm of the converter consists of an insulated gate bipolar transistor (IGBT), a reverse parallel diode, and a DC container. Pulse width modulated (PWM) is often used to control the converter [4,5]. As shown in figure 2, the three-phase modulated wave Uc (ABC) and the triangular carrier Ur control the upper and lower bridge arm on and off by output rectangular trigger pulses after the modulation circuit. Phase A modulated wave Uca is compared with triangular carrier wave Ur. When the value of modulated wave is greater than triangular carrier wave, the guide of upper bridge arm of phase A is triggered to shut off the lower bridge arm at the same time. When the value of the modulated wave is lower than that of the triangular wave, the guide of the bridge arm under phase A is triggered to simultaneously close the upper bridge arm, as shown in figure 3. By controlling the bridge arm on-off, the AC outlet voltage of the converter will generate a series of voltage pulses with amplitude of plus or minus Ud/2 (Ud is DC side voltage). Because the reference wave amplitude and phase modulation can be adjusted through the PWM pulse width modulation ratio M (export fundamental frequency phase inverter AC voltage amplitude and the ratio of the DC voltage) and phase-shifting angle δ, the voltage source inverter AC output voltage amplitude and phase of fundamental frequency component can be adjusted through the two variables.

![Figure 2. VSC converter structure based on PWM technology](image)

3. Hybrid-DC transmission system starting control strategy

3.1. Introduction of hybrid-DC transmission system starting control strategy
Starting control is an important part of DC transmission system control system, and an appropriate starting control strategy is important to reduce over current and overvoltage in the process of starting. Unique topology structure hybrid HVDC system makes the trend of the transmission irreversibility.
Compared with the traditional DC transmission system and flexible HVDC system, the advantages of hybrid HVDC system lies in the trend of the one-way liquidity [6], leading to that DC voltage in the process of start to build flexibility will be restricted to a certain degree. So the traditional way can't be directly applied to hybrid startup process of DC transmission system. Nowadays the main strategy for the startup control are based on polarity DC circuit switching and auxiliary power supply [7].

3.2. Starting control strategy of hybrid-DC transmission system based on DC line polarity switching

The main point of this starting control strategy is to make the LCC converter charge the DC capacitance first by controlling the polarity switching mode of the DC circuit, so as to start the system [8]. Topology structure of hybrid-DC transmission system with DC line polarity switching is shown in figure 4. Specific implementation steps are as follows:

- Close the DC circuit switch breaker SB and SC and LCC AC breaker, start the LCC inverter and its control procedure, charge capacitance by constant DC voltage from the LCC inverter as a rectifier.
- When the DC voltage reaches 0.95 pu, disconnect circuit breaker SB and SC, block LCC inverter and its control procedure, close circuit breaker SA, SD and VSC AC circuit breaker and start the VSC converter for active power control (active instruction value of 0.2 pu).
- When the DC voltage continues to rise to 1.05 pu, restart LCC inverter and its control procedure. Meanwhile the control circuit switch to inverter mode operation, power form AC system of rectifying side begin to transfer to the AC system of the inverter side, and gradually increase the VSC converter active power instruction value to 1.0pu. Transmission power will also rise gradually to the rated power, the entire startup process is complete.

4. Verification by simulation

PSCAD software was used for simulation to verify the above startup strategy. Established model for hybrid-DC system structure was shown in figure 4. The rectifier side AC system rated voltage is 220 kV, frequency is 50 Hz. The converter transformer is 220 kV/240 kV, 480 MVA. DC capacity is 2 x 1000 μF. DC line π equivalent parameter C=11.55 μF, L=0.0318 H, R=2.78 Ω. Flat wave reactance is 0.32 H. The rated voltage of the AC system of the inverter side is 220 kV, the capacity of the converter transformer is 240 MW, and the variable ratio is 220 kV/169 kV. In addition, the rated transmission power of the system is 400 MW, and the rated DC voltage is ±200 kV.

When the system is starting directly without the start control mode, some current simulation waveforms are shown in figures 5 and 6. In the absence of any starting control strategy, the direct use of steady-state control mode will generate over current, causing harm to the system.
Figure 5. AC current of rectifying side.  

Figure 6. DC current.  

The startup control strategy based on polarity DC line switch, at the beginning of the simulation, start the LCC inverter and switching circuit breaker BRK2, SB and SC for DC charging, at the time of 0.58s DC voltage reaches 380 kV (0.95 pu). Step by step, disconnect the AC breaker and DC breaker, block LCC inverter, closed circuit breaker BRK1, SA, SD and start the VSC converter. Due to VSC converter has started and the power of a given value of 0.2 pu, rectifier sides appears tiny over current, voltage rising is relatively slow. As a result of direct current voltage has been basically reach the rating value, the over current flow hardly affects the system. When the voltage when 0.74s rises to 408 kV (1.02 pu), restart LCC inverter for constant DC voltage control operation. Then the DC current and power rises gradually until finishing the boot process. Some simulation waveforms are shown in figures 7-9.  

Figure 7. DC current of rectifying side.  

Figure 8. Active power of rectifying side.  

Figure 9. AC current of rectifying side.  

As shown in figures 7-9, starting procedure of rectifier DC current appears to be a short period of reverse side rise abruptly and then smooth trend later, which is the initial capacitor charging current trends. Because of the saturated capacitor voltage, during the period from 0.58s (starting VSC converter) to 0.74s (starting LCC converter again), the VSC converter is charged with a micro current, and the voltage grows slowly. After starting the LCC converter at 0.74s, as the power instruction value of the rectifier side increasing, the DC current starts to rise to a stable value after a short period of
fluctuation. The active power curve of the power supply also conforms to the control requirements and power flow direction during start-up process. It can be seen from the AC current waveform on the rectifier side that the over current shock is basically eliminated through the starting strategy.

5. Conclusion

Unique topology structure of hybrid HVDC system makes the trend of the transmission of irreversibility. Compared with the traditional DC transmission system with the flexible HVDC system, the one-way liquidity of hybrid HVDC system takes advantages to make that the flexibility of the DC voltage in the process of startup are restricted to a certain extend [9]. And hybrid-DC transmission system based on DC circuit polarity switch startup control can solve the problem when startup process produces over current in the system. It is approved to be a kind reliable starting strategy of hybrid HVDC system.

References

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