Coordinated Control Strategy Based on MMC and DFIG

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Abstract. The AC-DC hybrid distribution network based on modular multilevel converters (MMC) is beneficial for receiving distributed generation (DG), energy storage devices and DC loads. Therefore, the coordinated control of MMC and DG is very important for its safe operation. In this paper, doubly-fed induction generator (DFIG) are used as DG, and the control strategies of DFIG and MMC systems are analyzed. The system modeling research is carried out on a real time digital simulator (RTDS) platform. Then based on MMC control, an improved adaptive Crowbar circuit is proposed to improve inverter AC system low-voltage ride-through (LVRT) capability. The results show that the coordinated control strategy can better compensate the reactive power of the system to achieve LVRT, and verify the effectiveness of the control strategy adopted by the converter station.

1. Introduction
Facing the increasingly serious energy crisis and environmental pollution, countries around the world are vigorously developing clean energy based on wind and solar energy. The DC distribution network is conducive to the widespread acceptance of distributed generation (DG). Studies show that AC-DC hybrid distribution networks are more suitable for the development of modern urban distribution networks [1]. Therefore, the coordinated control of MMC and DG is very important for the safe operation of AC-DC hybrid distribution networks.

 Reactive power power control of wind turbines plays many important roles in maintaining grid voltage stability and achieving low voltage ride through (LVRT). Therefore, it is of great significance to deeply study the reactive power control technology of grid-connected Doubly-Fed Induction Generator (DFIG) [2,3]. DFIG can achieve independent decoupling control of active and reactive power, but the reactive power it sends is limited by the maximum rotor current and the capacity of the "back-to-back" converter, which cannot meet the system's reactive power requirements [4]. Here, the DC system based on voltage source converter (VSC) can realize the compensation of the reactive power of the system [5,6,7]. At present, the simulation research of flexible DC systems mostly focuses on offline simulation software such as Matlab, PSCAD. Using these platforms for modeling research has certain limitations on the simulation of high-frequency power electronic devices [8,9]. The real-time digital simulator RTDS developed by the Canadian Manitoba company has strong real-time performance. It provides an effective simulation analysis platform for flexible DC simulation research based on high frequency power electronic switching devices.

In this paper, the AC-DC hybrid distribution network converter station uses MMC topology. Fully controlled Insulated Gate Bipolar Transistor (IGBT) can flexibly implement independent decoupling control of active and reactive power [10]. Modeling and simulation of DFIG system and MMC system...
using small step components of RTDS. Analysis of the support effect of the coordinated control of MMC and DFIG on the reactive power of the AC bus when the inverter AC system fails [11,12]. Among them, the "back-to-back" converter inside DFIG adopts vector control strategy. The MMC sending-end converter station adopts a constant DC voltage and constant reactive power control strategy, and the receiving-end converter station adopts a constant AC voltage and constant frequency control strategy. Then based on coordinated control, an improved adaptive Crowbar circuit is proposed to improve LVRT of the inverter AC system. Simulation results verify that the coordinated control method of DFIG and MMC can support the reactive power of the system to achieve LVRT.

2. Coordinated control based on MMC and DFIG

The MMC converter station adopts a double closed loop vector control strategy. The control system includes a current inner loop controller, a voltage power outer loop controller, a phase locked loop (PLL), and a trigger pulse generation. The outer loop controller provides reference values $i_{dref}$ and $i_{qref}$ for the inner loop controller through reference values such as voltage and power. The inner loop controls the amplitude and phase of the AC side voltage of the converter station according to $i_{dref}$ and $i_{qref}$ provided by the outer loop, so that its active current $i_d$ and reactive current $i_q$ quickly track its reference value, as shown in equation (1).

$$I = \frac{U_S - V}{(R_e + jX_e)} = I_{\text{ref}}$$ (1)

Among them, $I$ is the AC side current of the converter station. $I_{\text{ref}}$ is a reference value provided by the outer loop controller. $U_S$ is the PCC point voltage on the AC side of the converter station. $V$ is the AC voltage output from the converter station outlet. $R_e + jX_e$ is the equivalent impedance from the converter station to the PCC point.

Normally, the functions of the outer loop controller vary depending on the control target. Active current reference $i_{dref}$ includes constant active power and constant DC voltage control; reactive current reference $i_{qref}$ includes constant reactive power and constant AC voltage control [10]. When the MMC converter station is connected to a passive network containing DG, the most important factor is to control the stability of the AC side voltage and frequency. At the same time, DFIG connected to the passive network need a stable synchronous AC excitation power supply. Based on this, constant AC voltage and frequency control are generally used. It has two control objectives. The first is to ensure that the frequency of the AC side of the MMC is a power frequency, which is equivalent to a given grid frequency. Second, the voltage amplitude $U_{sm}$ of the MMC AC system is kept constant, and it is given as the outer loop of the reactive current reference value $i_{qref}$. In the case of voltage drop, it has a certain reactive power support role. In the case of multiple converter stations, there must be a converter station using constant DC voltage control to maintain the stable operation of the DC system. Generally works in constant DC voltage and constant reactive power control mode. The control strategy is shown in Figure 1.
3. **Low voltage ride-through analysis based on MMC and DFIG**

When the AC system fails, both the converter station and the fan will provide certain reactive power support for the AC bus to reduce the voltage sag. When the grid-side voltage drops, MMC will reduce the active power delivered to the AC system. After receiving the AC fault voltage signal, it adjusts the voltage amplitude of the MMC output through feedback control, and provides reactive power to the access point to reduce the voltage drop of the bus.

For the reactive current $i_q$ of the MMC converter station, the reference value after the fault is:

$$i_{qref} = K_P(A_{ref} - A) + K_i \int (A_{ref} - A) dt$$  

If the outer loop adopts constant AC voltage control, $A_{ref}$ represents the set value of AC voltage, $A$ represents the actual value of AC voltage, and $K_P$ and $K_i$ represent the proportional and integral coefficients of the controller. When a three-phase short circuit occurs, the AC voltage will drop, but the
set value of the voltage will not change, so $A_{\text{ref}} - A$ will increase. As a result, the absolute value of $i_{\text{qref}}$ output by the outer loop controller will increase to reduce the degree of AC voltage drop at the PCC point, and eventually increase to the limiting value $i_{\text{qmax}}$. The output reference current of the outer loop controller is the input of the inner loop controller, so the AC-side voltage reference value of the output of the inner loop controller will change.

DFIG reactive power compensation includes two parts: grid-side reactive power and stator reactive power output [4]. When the voltage drops 20%, the grid-side converter provides a maximum reactive power compensation of 0.12pu, and the stator side can provide a maximum reactive power of 0.7pu. The reactive power output on the grid side is much smaller than the stator side. Generally, the stator side adjustment is given priority. The stator output reactive power limit $Q_{\text{smax}}$ is as follows:

$$Q_{\text{smax}} = 3u_s \sqrt{\left(\frac{L_m}{L_s}I_{r\text{max}}\right)^2 - \left(\frac{P_G}{u_s(1-s)}\right)^2} - \frac{3u_s^2L_m}{\omega_1L_s^2}$$

Among them, $u_s$ is the stator voltage, $I_{r\text{max}}$ is the rotor side converter current limit value, $P_G$ is the active power injected into the system by DFIG, $L_s$ is the stator self-inductance, and $L_m$ is the stator and rotor mutual inductance.

Improved adaptive Crowbar circuit control: When the rotor current reaches the threshold value (usually 1.5 ~ 2 pu), it will be put into the crowbar circuit after a delay of 3 ~ 5ms. The attenuation of the crowbar circuit is determined adaptively by calculating the AC component of the attenuated rotor speed frequency in the DFIG stator fault current. After the crowbar circuit is removed, the rotor-side converter resumes excitation. Then, the stator side is controlled to emit reactive power to the maximum extent, and the reactive power adjustment capability of DFIG itself is brought into full play. Crowbar adaptive optimization control flow chart shown in Figure 2.

![Figure 2. Crowbar adaptive optimization control flowchart](image)

4. Simulation analysis
Figure 3 shows the topology structure of a radial AC-DC hybrid distribution network with DG. DG is DFIG, which is installed at nodes 5, 6, 7, and 8. capacities are 0.2MVA, 0.3MVA, 0.1MVA, 0.2MVA. The DC network voltage level is selected to $\pm 10$kv, which matches the existing AC network 10kv And
connected through MMC. In this AC-DC hybrid distribution network model, bus 8 is the balanced node of the system. The outer loop of converter station MMC1 uses constant DC voltage and constant reactive power control to stabilize the voltage of the DC system. For the passive network containing DG connected to bus 5, in order to stabilize the AC voltage and frequency of the grid connection point, Converter station MMC2 adopts constant AC voltage and constant frequency control.

The simulation analysis above shows that the three-phase short-circuit fault occurs on the inverter-side AC system line 5, and the fault occurs at \( t = 0.16 \)s. The voltage drop of bus 5 \( \text{Upu}_5 \) is shown in Figure 4. MMC2 inverse converter station reactive current reference value IQREF2, actual reactive current measurement value Iq2 changes shown in Figure 5. And reactive power \( \text{QMMC2}_5 \) changes shown in Figure 6. DFIG2 reactive power \( \text{QDFIG2}_5 \) injection on bus 5 is shown in Figure 7.

![AC-DC hybrid distribution network topology](image1)

**Figure 3.** AC-DC hybrid distribution network topology

![Voltage drop of bus 5](image2)

**Figure 4.** Voltage drop of bus 5
As can be seen from the above figure, because the MMC2 converter station uses a constant AC voltage control method, during the fault, the absolute value of the outer loop controller output IQREF2 will increase and eventually increase to the limit value 1.1. \(i_q\) tracks IQREF2 to provide reactive support for the exit voltage, which will improve the transient characteristics of the bus 5 voltage to a certain extent. At the same time, DFIG crowbar circuit is cut off after 30 ms of failure. Therefore, the
stator side can send out reactive power during the remaining fault time, which gives full play to the reactive power adjustment capability of DFIG itself. The voltage sag level during the fault is improved.

5. Conclusion
Build AC-DC hybrid distribution network model on real-time digital simulation platform RTDS. Based on the coordinated control strategy between MMC and DFIG, an improved adaptive Crowbar circuit is proposed to improve the LVRT of the AC system. The simulation experiment results show that, when the AC bus has a three-phase short circuit, the coordinated control between the internal converter of the wind power system and the DC system converter station will compensate the reactive power of the access point to reduce the voltage sag. At the same time, LVRT verified the effectiveness and correctness of the coordinated control strategy of MMC and DFIG.

Acknowledgments
This work was financially supported by Natural Science Foundation of Inner Mongolia Autonomous Region (2018LH05032).

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