Improved Control Strategy for Doubly-fed wind Turbines in Weak Synchronous Support Systems

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Abstract. When the wind power is sent as the interface by the line commutated converter, the vector-controlled doubly-fed wind turbine will be difficult to operate without power supply support, and it is impossible to send the wind power through the HVDC transmission system on a large scale. Future planned land-based wind power bases are becoming more remote and may not contain synchronous units. Therefore, it is extremely urgent to design a dual-feeder control strategy that can operate independently. In this paper, the control target of the doubly-fed turbine is changed to control the stator voltage and frequency. An improved control strategy of the doubly-fed turbine in the weak synchronous support system is proposed. The doubly-fed turbine will have the ability to send out through the line commutated converter. The simulation analysis of the wind power access weak synchronous support system sent by the HVDC transmission system is carried out. Under the natural wind disturbance, the sending end and the receiving end communication system disturbance, the doubly-fed turbine can quickly resume normal operation. With the effectiveness of this control strategy, the doubly-fed turbine can operate independently even if it loses its synchronous power supply.

1. Introduction

When the wind power is sent as an interface with a line commutated converter (LCC), the vector-controlled doubly-fed wind turbine will be difficult to operate without power supply, and the large-scale wind power cannot be transmitted through the HVDC transmission system [1,2]. Future planned land-based wind power bases are becoming more remote and may not contain synchronous units. Therefore, it is extremely urgent to design a doubly-fed wind turbine control strategy that can operate independently.

Grid-connected doubly-fed wind turbines generally use current vector control to control the active and reactive power of the stator output by controlling the current of the rotor. However, in weak synchronous support systems, this control method is less stable [3]. In this paper, the control target of the doubly-fed wind turbine is changed to the stator voltage and frequency. An improved control strategy of the doubly-fed wind turbine in the weak synchronous support system is proposed. The doubly-fed wind turbine will have the ability to send out through the LCC. The simulation analysis of the wind power access weak synchronous support system sent by the HVDC transmission system is carried out. Under the natural wind disturbance, the sending and the receiving communication system disturbance, the doubly-fed wind turbine can quickly resume normal operation. With the effectiveness of this control strategy, the doubly-fed wind turbine can operate independently even if it loses its synchronous power supply.
2. Improved control strategy of doubly-fed wind turbine in weak synchronous support system

2.1. Rotor-side converter control strategy for doubly-fed induction machine

The stator and rotor adopt the motor convention, \( \psi \) means the flux linkage. The subscript which contains \( s \) means the stator side quantity and the subscript which contains \( r \) means the rotor side quantity. The stator voltage is fixed to the \( d \)-axis. The stator equation ignores the flux linkage change and the resistance voltage drop.

\[
\begin{align*}
\psi_s &= \omega_0 \psi_{sq} = U_s \\
\psi_r &= \omega_0 \psi_{sr} = 0
\end{align*}
\]  

Define the excitation current from equations (1) and (2)

\[
\begin{align*}
i_{sd} &= i_{sd} + \frac{L_s}{L_m} i_{sq} = \frac{u_{sq}}{\omega_0 L_m} \propto u_{sq} \\
i_{mq} &= i_{mq} + \frac{L_s}{L_m} i_{sq} = \frac{u_{sd}}{\omega_0 L_m} \propto u_{sd}
\end{align*}
\]  

By controlling the excitation current in a closed loop, the stator voltage space vector can be controlled and coincided with the \( d \)-axis to obtain the rotor \( dq \)-axis current reference value based on the excitation current.

\[
\begin{align*}
i_{rqref} &= i_{mq} - \frac{L_s}{L_m} i_{sq} \\
i_{rdref} &= i_{sd} - \frac{L_s}{L_m} i_{sq}
\end{align*}
\]  

Similar to the traditional grid-connected doubly-fed wind turbine, according to the rotor current reference value, the inner loop current controller is also required to obtain the voltage reference value of the rotor-side converter.

\[
\begin{align*}
u_r &= R_i + j \omega_0 \psi_r + \frac{d\psi_r}{dt} = (1 - \sigma) L_s \frac{d i_r}{dt} + R_i i_r + sU_s L_m + j \omega_0 L_s (1 - \sigma) i_r \frac{d\psi_r}{du_{pq}} + \frac{d\psi_r}{du_{FF}}
\end{align*}
\]  

Among them, \( \sigma = \frac{L_s}{\omega_0 L_r} \) is the coupling coefficient, \( u_{pq} \) is obtained by the closed-loop PI control of the rotor current, and \( u_{FF} \) is obtained by the feedforward of the rotor current or the stator voltage to achieve the purpose of speeding up the response and decoupling.

For the stator voltage angle, it is necessary to combine the power command value control corresponding to the maximum power point tracking (MPPT) to introduce the "synchronous motor rotor" at the stator output voltage.

\[
\theta_s = \int (\omega_0 + \Delta \omega) dt, \quad \Delta \omega = \frac{P_{ref} - P}{2Hs + D}
\]  

Therefore, the block diagram of the rotor-side converter is shown in Figure 1. At start-up, the exciter of converter needs to be put in first. The task of the stator-side converter is to stabilize the DC voltage after starting, which is the same as the grid-connected doubly-fed wind turbine [4,5].
2.2. Coordinated control strategy of wind turbine and LCC

A doubly-fed asynchronous generator with improved control strategy can control the output of a single wind turbine by adjusting the frequency of its own voltage, thereby realizing MPPT. However, the HVDC system is not sensitive to the frequency of the AC system[6]. It is necessary to control the LCC output power to keep the rotor speed of the wind farm within a reasonable range. The power command of the inverter is matched with the average speed of the wind farm[7]. When the speed is too large in the wind farm, the output power command is increased, and vice versa. The command also needs to cooperate with the voltage dependent current order limitation (VDCOL) to help restore the commutation failure of the inverter station. The overall control structure is shown in Figure 2.

3. Simulation study

The above control method for accessing the wind power of the weak synchronous support system through the HVDC transmission system is constructed, and this section will verify it. The simulation system is shown in Figure 3. The transmitter includes an equivalent wind farm and a small synchronous machine. The small synchronous machine provides the initial excitation of the rotor for the wind turbine to start. If the synchronous machine is cut off, the entire sending end only consists of the doubly-fed wind turbines. The control method of the DC transmission system is the same as that of the Cigre Benchmark except for Figure 2. The rated wind power is 400MW, the wind turbine is operating 12% over the synchronous speed, and the small inertia synchronous machine is 50MVA which can operation as condenser or cut off. The simulation considers three situations: (1) disturbance of natural wind; (2) fault of the AC bus at the sending end; (3) failure of the commutation of the DC system caused by the fault of the receiving end.
3.1. Disturbance of natural wind

The difference between a wind farm and a conventional power plant is not only that the motor is an asynchronous motor, but also because its active output is related to the weather. The dynamic behavior of the whole system caused by the change of the rotor torque caused by the change of the wind speed is simulated below. The rotor torque is shown in Figure 4. The dynamic behavior of the system is shown in Figure 5.
It can be seen from Figure 5(a) that the operation of the condenser is hardly affected by the change of the rotor torque. It can be seen from Figure 5(c) that the DC power transmission system adjusts the power output within a short period of time so that the wind turbine speed changes within a small range. As can be seen in Figure 5(d), the wind farm voltage is also almost unaffected.

3.2. Disturbance of sending communication system

At 6s, the high-voltage bus of the wind farm has a fault and it lasts for 0.1s.

The high-voltage bus voltage of the wind farm is shown in Figure 6(e), and it recovers quickly within 0.1s after the fault is removed. The rotor current of the wind turbine is shown in Figure 6(f), which is subjected to about 3 times overcurrent during the fault. It was also restored after 0.1 s after the failure.

As shown in Figure 6(c)(d), the short-circuit fault of the transmitting terminal bus causes the DC voltage to drop sharply. The power imbalance causes the rotor speed to rise as shown in Figure 6(a). However, after the fault recovery, as shown in Figure 6(d), the delivery power of the DC power transmission system is increased within a short period of time, and the rotor rotation speed is restored to the initial state.

3.3. Disturbance of receiving communication system

A short-circuit fault occurs at 6s in the receiving system and lasts 0.1s. As shown in Figure 7(a)(b), the inverter station fails to commutate, and the turn-off angle and DC voltage drop to zero. During the failure of commutation, the wind farm voltage and rotor current are also affected, but the disturbance is much less than the fault at the transmitter, as shown in Figure 7(b)(c). Unbalanced power due to commutation failure will also cause the rotor speed to rise, as shown in Figure 7(d). After the fault is
recovered, the DC transmission system restores the rotor speed to the original operating state by increasing the transmission power.

Figure 7. Dynamic behavior of three-phase short circuit system of receiving system.

4. Conclusion
When wind power is sent through LCC, the doubly-fed wind turbine that was originally passive cannot operate because there is no power supply support. In this paper, the control target of the doubly-fed wind turbine is changed to the stator voltage and frequency. An improved control strategy of the doubly-fed wind turbine in the weak synchronous support system is proposed. The doubly-fed wind turbine will have the ability to send out through the LCC. The simulation analysis of the wind power access weak synchronous support system sent by the HVDC transmission system is carried out. Under the natural wind disturbance, the sending and the receiving communication system disturbance, the doubly-fed wind turbine can quickly resume normal operation. With the effectiveness of this control strategy, the doubly-fed wind turbine can operate independently even if it loses its synchronous power supply.

References
[1] Zhou X D and Zhao Y 2007 Research on vector control technology of independently operating doubly-fed generator Chinese Society for Electrical Engineering 27 pp 71-76
[2] Liu J and Yao W 2017 Analysis and control of small disturbance stability of doubly-fed wind turbine considering PLL and power grid strength Proceedings of the CSEE 37 pp 3162-3173
[3] He Y K and Hu J B 2012 Grid-connected doubly-fed asynchronous wind turbine operation control China Electric Power Press
[4] Zhang M, Yuan X, Hu J et.al 2015 Wind power transmission through LCC-HVDC with wind turbine inertial and primary frequency supports Power & Energy Society General Meeting pp 1-5
[5] Jain A K and Ranganathan V T 2008 Wound Rotor Induction Generator With Sensorless Control and Integrated Active Filter for Feeding Nonlinear Loads in a Stand-Alone Grid IEEE Transactions on Industrial Electronics 55 pp 218-228
[6] Zhang Y and Ooi B T 2013 Stand-Alone Doubly-Fed Induction Generators (DFIGs) With Autonomous Frequency Control IEEE Transactions on Power Delivery 28 pp 752-760
[7] Phan V T and Lee H H 2011 Control Strategy for Harmonic Elimination in Stand-Alone DFIG Applications With Nonlinear Loads IEEE Transactions on Power Electronics 26 pp 2662-2675