Establishment and Parameter Allocation of DFIG Wind Turbine Control Model of PSCAD

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Abstract. At present, PSCAD simulation analysis of wind turbine model is not perfect, and with the increasing capacity of wind turbine assembly machine, the simulation model put forward higher requirements. This paper firstly established the wind turbine model, generator and converter model, transmission line and system model of doubly fed wind power generation system using PSCAD simulation software. The wind energy generation system can capture wind energy with the highest efficiency by using the stator flux oriented vector control method. Through the PSCAD model simulation analysis, the wind turbine model established in this paper realizes the MPPT control, voltage control, power factor control and so on. Simulation analysis of fault, depend on the output characteristic of the wind turbine, it is proved that the stable output of active and reactive power depends on the stability of the control system of the turbine side and the network side.

Introduction

With the energy problem becoming more and more serious, the study of renewable energy development and the efficient and safe utilization of clean energy is the only way to cope with the problems of globalization, energy and environment [1]. With the rapid development of wind power, the installed capacity has been expanded, and new large wind turbines have been put into operation gradually, so the installed capacity of the wind farm is comparable to that of the conventional unit. Wind power generator is an important equipment in wind power generation, which determines the power generation efficiency and power quality, and has a great impact on the overall structure of the wind power generation [2].

Therefore, the key to improve the safe, reliable and stable operation of wind turbines is the control technology. The stable operation of power grid system is more and more influenced by wind turbine, so it is an important task and difficult problem to study the control technology of wind power generation [3].

Wind Farm Modeling

Wind Turbine Model

The process of converting wind energy into kinetic energy by a wind turbine is a strongly nonlinear aerodynamic problem, and taking the electrical characteristics of wind turbines as the main object of study [4].

\[ P_e = \frac{1}{2} C_p(\beta, \lambda) \rho \pi R^2 v^3 \]

\[ \lambda = \omega R / v \]

In formula (1): \( P_e \) is the active power outputted by the wind turbine; \( C_p \) is the coefficient of wind energy utilization; \( \rho \) is air density; \( R \) is the blade radius of wind turbine; \( v \) is wind speed. \( C_p(\rho, \lambda) \) is a function of wind turbine blade tip speed ratio \( \lambda \) and propeller pitch angle \( \beta \). According to the Bates theory, the maximum is 0.593.
The control principle of wind turbine in operation is: The \( \omega \) changes with the wind speed to ensure that \( \lambda \) is always the best blade tip speed ratio. The relationship between the wind turbine output power and the angular speed can be obtained:

\[
P_w = \frac{1}{2} \rho \pi R^3 \left( \frac{R}{\lambda} \right)^3 C_p \omega^3 \quad k = \frac{1}{2} \rho \pi R^3 \left( \frac{R}{\lambda} \right)^3 C_p
\]  

(2)

Above the rated wind speed, increasing the pitch angle makes the wind turbine maintain rated power to generate electricity.

**Generator and Converter Model**

Converter and induction generator constitute the main circuit of DFIG generator. PSCAD simulation software has an ordinary induction generator model. The double PWM converter is connected to the rotor winding outlet of the generator and is connected to the power grid through a three-phase transformer, and TL is the prime mover torque input interface of the generator [5]. The induction motor is equivalent to 100 1.5MW wind turbines. For the Crowbar circuit, when the voltage of the network drops, it can trigger the circuit turn-on and the rotor side converter is locked simultaneously, so the rotor side converter can be self-protected [6].

1) Three-phase stator winding voltage and three-phase rotor winding equations

\[
\begin{bmatrix}
u_{a1} \\
u_{b1} \\
u_{c1}
\end{bmatrix} = -R_i \begin{bmatrix} i_{a1} \\
i_{b1} \\
i_{c1}
\end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \psi_{a1} \\
\psi_{b1} \\
\psi_{c1}
\end{bmatrix}
\]

(3)

\[
\begin{bmatrix}
u_{a2} \\
u_{b2} \\
u_{c2}
\end{bmatrix} = R_i \begin{bmatrix} i_{a2} \\
i_{b2} \\
i_{c2}
\end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \psi_{a2} \\
\psi_{b2} \\
\psi_{c2}
\end{bmatrix}
\]

(4)

2) Flux linkage equation

\[
\begin{bmatrix} \psi_1 \\
\psi_2 \\
\end{bmatrix} = \begin{bmatrix}
L_{11} & L_{12} & i_1 \\
L_{21} & L_{22} & i_2
\end{bmatrix} \begin{bmatrix} i_1 \\
i_2
\end{bmatrix} \quad \psi_1 = [\psi_{a1}, \psi_{b1}, \psi_{c1}]^T, \quad \psi_2 = [\psi_{a2}, \psi_{b2}, \psi_{c2}]^T
\]

(5)

And \( \theta_r \) is the rotor position angle.

The wind turbine rises to 66kV through the transformer T1, and then goes up to 110kV through the double return transmission line and then the transformer T2.

![Figure 1. Overall circuit diagram of system and transmission line simulation.](image)

**Network Side Converter Control**

**Control Objective**

When DFIG is operating in sub synchronous state, the rotor absorbs energy from DC, and the two section voltages of DC link have a downward trend because capacitor is discharging. During the operation of DFIG ultra synchronous operation, the rotor releases energy to the DC link, resulting in DC link voltage pumping up. Through AC voltage directional vector control of the network, the network side converter achieves voltage stability control and AC side power factor control [7].
Summary of Control Principle

With the constant network voltage, regulating the d axis current $i_{d1}$ can control the reactive power input, while regulating the $q$ axis current $i_{q1}$ can control the reactive power input by the converter. The decoupling control of active and reactive power is realized [8].

By applying coordinate transformation, the d axis component of the synchronous rotating dq coordinate system is oriented to the vector direction of the grid voltage, and the dq component of the grid voltage is obtained as (6), and the input current meets the following conditions as (7).

\[
\begin{align*}
\begin{cases}
    u_{d1} = u_s \\
    u_{q1} = 0
\end{cases}
\end{align*}
\]  

(6)

\[
\begin{align*}
\begin{cases}
    L \frac{di_{d1}}{dt} = -R_i i_{d1} + \omega_0 Li_{q1} + u_s - u_n \\
    L \frac{di_{q1}}{dt} = -R_i i_{q1} - \omega_0 Li_{d1} - u_q
\end{cases}
\end{align*}
\]  

(7)

In formula (7), $u_{d1}, u_{q1}$ are the d and q components of the AC side voltage of the converter. In accordance with the derivation, the control of the rotor side converter in formula (6) can be rewritten as:

\[
\begin{align*}
\begin{cases}
    u_{d1} = -u_{d1} + \Delta u_{d1} + u_s \\
    u_{q1} = u_{q1} - \Delta u_{q1}
\end{cases}
\end{align*}
\]

\[
\begin{align*}
\begin{cases}
    \Delta u_{d1} = \omega_0 Li_{q1} \\
    \Delta u_{q1} = \omega_0 Li_{d1}
\end{cases}
\end{align*}
\]  

(8)

Sub-module Analysis

Grid Voltage Orientation

Similar to the stator flux orientation, the stator voltage is transformed by $C_{s1}/C_{s2}$. Then according to $\theta_s = \arctan(u_{d1}/u_{q1})$, stator voltage synchronization signal can be obtained.

Calculation of DQ Axis Current

The D and Q components of stator three-phase current is obtained by coordinate transformation of $C_{s2}/C_{s3}$. In addition, a filtering segment is added to filter the DC component, but because it causes the phase shift of the current, the phase compensation segment is added, too.
Acquisition of Reference Voltage Signals for SVPWM Modulation

Figure 4. Reference voltage signal acquisition of module SVPWM modulation

Figure 4. (a) is a double closed loop control system. The voltage outer loop is used to control the DC side voltage of three-phase PWM converters, and then the difference of the DC voltage and the reference value is input to the voltage regulator, to calculate the reference value of the active current $i_{dref}$, which determines the magnitude of the active power, and its symbol represents the direction of the active power [9]. According to the reference current output from the voltage outer loop, current control is carried out in the inner loop. To achieve a power factor of 1, the $i_{iq}$ is set to 0. In figure 4. (b), the output shown is the reference voltage at the AC side of the converter at the DQ axis, and after inverse transformation, the reference voltage in three-phase coordinate is obtained, to carry out the SVPWM modulation.

Simulation Analysis

Wind turbine Parameters Setting

Table 1. Wind power parameters.

<table>
<thead>
<tr>
<th>parameters</th>
<th>value</th>
<th>parameters</th>
<th>value</th>
<th>parameters</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of wind energy utilization</td>
<td>0.28</td>
<td>Rated capacity of motor</td>
<td>200MVA</td>
<td>Inertial time constant</td>
<td>0.73s</td>
</tr>
<tr>
<td>Rated wind speed</td>
<td>12m/s</td>
<td>Rated voltage of motor</td>
<td>13.8kV</td>
<td>DC side capacitive</td>
<td>0.09F</td>
</tr>
</tbody>
</table>

Fault Transient Simulation Results

The fault is set up as a three-phase grounding fault at the stator outlet of wind turbine at 1.2s, with 0.5s duration. As shown in figures 5 and 6. After the fault, the three-phase current at the stator outlet raised gradually, while the voltage dropped. It can see from Figure 7, after the failure, the DC side capacitor voltage has declined, and then fall rapidly after a series of fluctuations. Meanwhile the curve of figure 8 shows that the rotor current rises rapidly after the fault. In fact, when the rotor current exceeds a certain value, the over-current protection will trigger the action of the Crowbar circuit, to block the trigger pulse of generator side circulator. Thereafter, the rotor outlet is connected to the protection circuit, and the rotor current will not continue to rise. (The simulation is carried out under the latching Crowbar circuit, so the rotor current continues to rise during the fault.)

Figure 9. is the three-phase voltage waveform at the wind turbine stator outlet when a three-phase ground fault occurs at the near power system side exit of the transmission line. The results show that the stator side voltage is reduced to lower than 0.5p.u. When the remote fault occurs outside the area, and there will be a low voltage ride through problem at this time.

Figure 5. Three-phase current at stator outlet.

Figure 6. Three-phase voltage at stator outlet.
Conclusion

In this paper, the related modeling technology of wind power generation is studied. Through reference to a large number of relevant literature, combined with existing models, the parameters design method of the control system is explored. And then the pole assignment method is used to design the regulation parameters of wind power model.

Through theoretical research and software simulation, it is proved that the stable output of active and reactive power depends on the stability of the control system of the turbine side and the network side, but the stability of both is closely related to the parameters of the system, transmission line and wind turbine. Any minor changes of any parameter may affect the system's dynamic performance, which is said that "one change makes all change".

The simulation on doubly fed wind power generation system by PSCAD software realizes the voltage stability control through the grid voltage oriented vector control and the AC side power factor control of DC link unit. The results show a perfect control effect. From the fault transient simulation results, it can be concluded that the rotor exit can also be rapidly locked and protected by intervention, in the case of the stator outlet fault, which verifies the correctness of simulation and analysis in this paper.

References


