Research on doubly-fed wind power system based on MATLAB/Simulink software

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Abstract. With wind randomness and burstiness, output power of wind turbine will be fluctuated, and fluctuating power affected the operation of power grid in the grid-connected. Therefore, it is necessary to research wind power system. The structure and principle of Doubly-fed wind power system are introduced in the paper, by analysing the principle, we build simulation model of Doubly-fed wind power system using MATLAB/Simulink software. In order to test the performance of the model, the phase-voltage, phase-current and active power of the system are tested under three status, which are steady-state operation, different wind speed and three-phase short circuit. The experimental results show that Doubly-fed wind power system has strong anti-interference and good safety.

1. Introduction
On July 28, 2017, the National Energy Administration issued “Guidance on the 13th five year plan for renewable energy development”, the guidance proposes that total capacity of new building wind power system reaches to 126GW in 2017-2020 year[1]. According to industry statistics, wind turbine power generation is 366 billion KW.H in 2018, for 79% of total installed capacity, and 0.4% higher than 2017 year[2]. With the rapid development of wind power industry, a series of problems are brought. With wind speed randomness and burstiness, output power of wind turbine will be fluctuated, and fluctuating power affected the operation of power grid in the grid-connected[3-4]. Therefore, it is necessary to research wind power system.

Doubly-fed wind turbine are used widely in wind power equipment, frequency converter is connected between generator rotor and power grid in Doubly-fed wind power system[5], by changing the frequency of rotor excitation current, make the stator generate the same voltage and frequency as the power grid, but this makes wind turbine generator easy to trip[6]. In the paper, doubly-fed wind power system is used as the research object, and analyse its operation characteristics using MATLAB simulation method.

2. Mathematical model

2.1. Doubly-fed wind power system structure
Doubly-fed wind power system concludes wind turbine, gearbox, doubly-fed generator, frequency converter, transformer and power grid[7], the structure diagram is shown in Figure 1. In the Doubly-fed wind power system, stator winding is connected to power grid, bidirectional special frequency
converter are used to rotor winding, adjust wind turbine speed, and make wind turbine operate in the optimal working status[8]. The device can improve wind energy utilization and system stability.

2.2. Doubly-fed generator theoretical analysis

Doubly-fed generator is the core of Doubly-fed wind power system, the equivalent circuit of Doubly-fed generator is shown in Figure 2[9]. Through the analysis the circuit, mathematic formula of Doubly-fed generator is shown in Formula (1).

![Figure 1. Doubly-fed wind power system structure diagram.](image1)

![Figure 2. The equivalent circuit of Doubly-fed generator.](image2)

\[
\begin{align*}
\dot{U}_1 &= -\dot{E}_1 - \dot{I}_1 (R_1 + jX_1) \\
\frac{\dot{U}_2}{s} &= -\dot{E}_2 + \frac{\dot{I}_2}{s} \left( \frac{R'_2}{s} + jX'_2 \right) \\
\dot{E}_1 &= \dot{E}_2 = -\dot{I}_m (jX_m) \\
\dot{I}_1 &= \dot{I}_2 - \dot{I}_m
\end{align*}
\]

In the formula(1), $R_1$ and $X_1$ are resistance and capacitive reactance of stator side, $R'_2$ and $X'_2$ are resistance and capacitive reactance of rotor converted to stator side, $X_m$ is excitation reactance, $\dot{U}_1$ is
stator side voltage, $\dot{E}_1$ and $\dot{I}_1$ are electromotive force and current, $\dot{U}_2'$ is rotor excitation voltage after winding conversion, $\dot{U}_2'/s$ is the value of frequency conversion.

### 2.3. Wind speed model analysis

With wind randomness and burstiness, the wind is divided into four categories, there are basic wind, gust wind, gradient wind and disturbance wind\[10\].

The basic wind reflects average wind speed, which is persistent. The power rating of the generator is determined by the size of the basic wind. The basic model is shown in formula (2).

$$V_{\text{basic}} = \text{const}$$  \hspace{1cm} (2)

The gust wind model is shown in formula (3).

$$V_{\text{gust}} = \begin{cases} 0 & t < T_{ga} \\ \frac{V_{\text{gmax}}}{2} \left[ 1 - \cos 2\pi \left( \frac{t - T_{ga}}{T_{ga}} \right) \right] & T_{ga} \leq t < T_{ga} + T_g \\ 0 & t \geq T_{ga} + T_g \end{cases}$$  \hspace{1cm} (3)

The gradient wind model is shown in formula (4).

$$V_{\text{ramp}} = \begin{cases} 0 & t < T_{ra} \\ \frac{V_{\text{rmax}}}{T_{rb} - T_{ra}} \left( T_{rb} - T_{ra} \right) & T_{ra} \leq t < T_{rb} \\ V_{\text{rmax}} & T_{rb} \leq t < T_{rb} + T_r \\ 0 & t \geq T_{rb} + T_r \end{cases}$$  \hspace{1cm} (4)

In the formula(4), $V_{\text{ramp}}$(m/s) is the gradient wind speed, $V_{\text{max}}$(m/s) is the maximal gradient wind speed, $V_{\text{ra}}$(s) is start time, $V_{\text{rb}}$(s) is the end time, $V_r$(s) is duration.

The disturbance wind model is shown in formula (5).

$$V_{\text{noise}} = 2 \sum_{i=1}^{n} \sqrt{S_{v}(\omega_i)\Delta\omega} \cdot \cos(\omega_i t + \varphi_i)$$

$$S_{v}(\omega_i) = \frac{2K_{c}F^2 |\omega_i|}{\pi^2 [1 + \left( \frac{F\omega_i}{\mu \pi} \right)^2]^{\frac{3}{2}}} \quad \omega_i = (i - 0.5) \cdot \Delta\omega$$  \hspace{1cm} (5)

### 2.4. Mathematical model

According to Doubly-fed generator theoretical analysis, Doubly-fed wind power system simulation model is shown in Figure 3. The wind form is 9MW. The grid data acquisition and wind turbine data acquisition are modules. The grid data acquisition module is shown in Figure 4. The wind turbine data acquisition module is shown in Figure 5.

### 3. Model analysis

In order to test the performance of the model, the phase-voltage, phase-current and active power of the system are tested under three status, which are steady-state operation, different wind speed and three-phase short circuit. 2MW load is used in the simulation model.
Figure 3. Doubly-fed wind power system simulation model.

Figure 4. The grid data acquisition module.

Figure 5. The wind turbine data acquisition module.
### 3.1. Steady state simulation experiment

The steady-state circuit simulation model is shown in Figure 6. From Figure 6, we can see phase voltage waveform, phase current waveform and active power waveform. When the wind speed is 10 m/s, the system output is stable within 50 seconds. The active output of the generator is the same as 2 MW load, the reactive output is negative. The pitch angle is always 0 degree, and the wind turbine speed gradually tends to 1.

### 3.2. Different wind Simulation experiment

The different wind simulation model is shown in Figure 7. The wind speed change from 8 m/s to 14 m/s within 10 seconds, the pitch angle increase from 0 degree to 0.6 degree. Phase voltage remain constant, phase current is increasing and tends to be stable. While wind speed increases, the mechanical torque became large, the active output of the generator increases and the reactive output decreases to negative value. When wind speed is stable, the system output maintain stability.

![Figure 6. The steady-state circuit simulation model.](image)

![Figure 7. Protection circuit simulation model](image)

### 3.3. Short-circuit fault Simulation experiment

Experiment of three-phase short-circuit fault with protection circuit is tested. The results show that the different phase-voltage and different phase-current have the same simulation results. A-phase short-circuit fault simulation model is shown in Figure 8. Protection circuit simulation model is shown in Figure 9. While three-phase short-circuit fault occur, the system will cut off the circuit within 0.01 seconds, the phase voltage is 1, the phase current is 0, and power is 0, the wind turbine speed and pitch angle fluctuate. In the end, all waveform tends to stable.

### 4. Conclusions

In the paper, we take Doubly-fed wind power system as a case, analyze the system structure and principle. With wind randomness and burstiness, output power of wind turbine will be fluctuated, and fluctuating power affected the operation of power grid in the grid-connected. The phase-voltage,
phase-current and active power of the system are tested under three status, which are steady-state
operation, different wind speed and three-phase short circuit. Experimental results demonstrate that
Doubly-fed wind turbine can adjust the speed under different wind speed, and make the wind turbine
run in the best condition. Doubly-fed wind turbine has strong anti-interference and good safety
performance. The conclusion provide reference value for fan maintenance people.

Figure 8. A-phase short-circuit fault simulation model.  

Figure 9. The different wind simulation model.

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