

Modeling and Simulation of Doubly Fed Induction Wind Generator Based on Matlab / Simulink

Yun Sha

North China Electric Power University, Changping District, Beijing

1124756041@qq.com

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Abstract. Targeting the doubly-fed wind power system, this paper establishes the overall mathematical model composed of wind turbine, drive system, double-fed induction generator, stator flux orientation vector control tactics, maximum power point tracking tactics. By applying the simulink in the matlab software, and based on the mathematical model mentioned above, the paper also sets up a double -fed wind power system simulation model, and taking two step-up wind speeds as examples, simulation studies are made on the dynamic characteristics of the model with the grid connected. The simulation studies show that the model realizes the maximum power point tracking and decoupling control of power, and the double-fed wind power system has satisfactory dynamic characteristics, thus proving that the model established is correct and valid.

Introduction

During the past two decades, there has been tremendous growth in many aspects of wind power generation and related technologies. The capabilities of wind turbine generators (WTGs) have improved significantly in conjunction with the process made in power electronic industries, both in terms of the costs and capabilities; thus, it is possible to build modern wind turbines to meet modern grid requirement at affordable costs.

Wind turbine installations have continued to multiply, and the penetration level of wind generation on the grid has steadily increased. Similarly, challenges in operating a power system with high penetration levels of wind power within the next few years. In anticipation of these challenges, the wind industry and utility industry have been moving forward developing dynamic models for WTG and wind power plant (WPP). Each group of WTGs constitutes a significant portion of the output power of the WPP[1-5].

The development of a dynamic model of a WTG is the first major step toward representing a WPP, wherein the WTG is represented correctly in the power system instead of a negative load. The next step is to validate the WTG dynamic model to ensure it can be represented as accurately as possible to the actual turbine.

Mathematical Model

Mathematical Model of Wind Turbine. The mechanical energy acquired from wind by turbines is a complex function, whose variables include wind speed, pitch angle of blade and mechanical rotating speed. The function can be described by algebraic equations as follows,

$$P_m = \frac{1}{2} \rho v_w^3 r C_p(\lambda, \theta) \quad (1)$$

In the formula, P_m is mechanical energy acquired from wind (W); ρ is air density (kg/m³); r is radius of turbine blade(m); v_w is wind speed(m/s); C_p is wind power factor; λ (blade speed ratio) is the ratio of blade tip speed and wind speed, which is,

$$\lambda = \frac{\omega_t r}{v_w} \quad (2)$$

In the formula, w_t is mechanical rotating speed (rad/s).

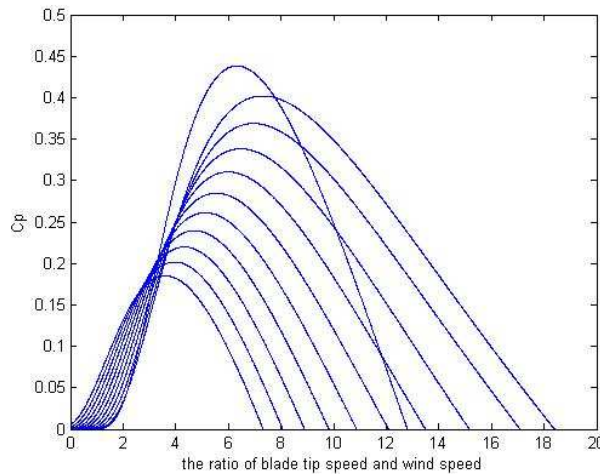


Figure 1. The variation curve of power factor with blade speed ratio

The relationship between wind power factor and ratio of blade tip speed and wind speed is shown in Fig. 1. For a given blade pitch angle, the difference of wind power energy factor to the different blade tip ratio is large, and only one optimum tip speed ratio can maximize the wind power factor. In the case of constant wind speed, to maintain the best tip speed ratio, the wind turbine mechanical speed changes referring to the wind speed. Only maintaining the best tip speed ratio can turbine captures the maximum wind energy.

Mathematical Model of Mechanical Transmission. The mechanical transmission between the hub and the rotor of the generator is described by the practical model of a mass when the hardness and damping coefficients are ignored. The formula is as follows[6]:

$$T_{gen} - T_{wind} = J_d \frac{d\Omega_e}{dt} \quad (3)$$

In the formula, T_{wind} is equivalent torque of hub, T_{gen} is rotor torque, J_d is equivalent moment of inertia, Ω_e is mechanical rotating speed of rotor.

Mathematical Model of Doubly Fed Induction Generator. In the establishment of mathematical model, the stator current to flow out is the positive and the rotor current to flow in is the positive.

The stator winding voltage equation is:

$$u_{d1} = P\psi_{d1} - \omega_l \psi_{q1} - R_1 i_{d1} \quad (4)$$

$$u_{q1} = P\psi_{q1} - \omega_l \psi_{d1} - R_1 i_{q1} \quad (5)$$

The rotor winding voltage equation is:

$$u_{d2} = P\psi_{d2} - \omega_s \psi_{q2} + R_2 i_{d2} \quad (6)$$

$$u_{q2} = P\psi_{q2} - \omega_s \psi_{d2} + R_2 i_{q2} \quad (7)$$

In the formula, u_{d1} , u_{q1} , u_{d2} and u_{q2} are respectively the d 、 q components of the stator and rotor's voltage. i_{d1} , i_{q1} , i_{d2} and i_{q2} are respectively the d , q components of the stator and rotor's current. $\omega_s = \omega_l - \omega_r$ is the angular velocity of d q coordinate system relative to the rotor's one.

The flux linkage equation is:

$$\begin{cases} \psi_{d1} = -L_1 i_{d1} + L_m i_{d2} \\ \psi_{q1} = -L_1 i_{q1} + L_m i_{q2} \\ \psi_{d2} = -L_m i_{d1} + L_s i_{d2} \\ \psi_{q2} = -L_m i_{q1} + L_2 i_{q2} \end{cases} \quad (8)$$

In the formula, ψ_{d1} ψ_{q1} ψ_{d2} ψ_{q2} are respectively the d q component of the stator and rotor's flux; L_1 is the equivalent inductance between two - phase stator windings in the d q coordinate system; L_m is the equivalent inductance between stator and rotor windings coaxially in the d q coordinate system; L_2 is the equivalent inductance between two - phase stator windings in the d q coordinate system;

Therefore, The relationship between current and voltage is: P is differential symbol.

$$\begin{bmatrix} u_{d1} \\ u_{q1} \\ u_{d2} \\ u_{q2} \end{bmatrix} = \begin{bmatrix} -R_1 - L_1 P & \omega_1 L_1 & L_m P & -\omega_1 L_m \\ -\omega_1 L_1 & -R_1 - L_1 P & \omega_1 L_m & L_m P \\ -L_m P & \omega_s L_m & -R_2 - L_2 P & -\omega_s L_2 \\ -\omega_s L_m & -L_m P & \omega_s L_2 & R_2 + L_2 P \end{bmatrix} \begin{bmatrix} i_{d1} \\ i_{q1} \\ i_{d2} \\ i_{q2} \end{bmatrix} \quad (9)$$

The electromagnetic torque equation is:

$$T_{em} = \frac{3}{2} N_p L_m (i_{q1} i_{d2} - i_{d1} i_{q2}) \quad (10)$$

The power equation is:

$$\begin{cases} P_1 = \frac{3}{2} (u_{d1} i_{d1} + u_{q1} i_{q1}) \\ Q_1 = \frac{3}{2} (u_{q1} i_{d1} - u_{d1} i_{q1}) \\ P_2 = \frac{3}{2} (u_{d2} i_{d2} + u_{q2} i_{q2}) \\ Q_2 = \frac{3}{2} (u_{q2} i_{d2} - u_{d2} i_{q2}) \end{cases} \quad (11)$$

Where, P_1 and Q_1 are respectively active power and reactive power from stator to power grid; P_2 and Q_2 respectively active power and reactive power from power grid to rotor.

Vector Control Strategy. Vector control theory is proposed by the German F.B laschke in 1971, the application of vector control technology makes the AC speed control really get the same excellent performance as the DC speed control. After more than 20 years of industrial practice test and improvement, it has now reached the mature stage. In this theory, the AC motor stator's current is decomposed into excitation and torque variable according to the theory of motor unity and coordinate transformation, After the decomposition of the stator current excitation components and torque components, they no longer have a coupling relationship and they can be controlled respectively. You can achieve the AC motor flux and torque decoupling control, so that the AC motor can be comparable to the control performance of DC The motor[7-8].

DFIG stator windings are directly connected to the infinite power grid, the stator voltage amplitude and frequency are constant approximately. In this paper, the vector control of stator flux orientation (SFO) is adopted. When the stator flux is oriented, it is assumed that the stator flux d vector coincides with the axial direction.

$$\begin{cases} \psi_{d1} = \psi_1 \\ \psi_{q1} = 0 \end{cases} \quad (12)$$

When the stator resistance is ignored:

$$\begin{cases} u_{d2} = p i_{d2} (L_2 - \frac{L_m^2}{L_1}) - \omega_s i_{q2} (L_2 - \frac{L_m^2}{L_1}) + R_2 i_{d2} \\ u_{q2} = p i_{q2} (L_2 - \frac{L_m^2}{L_1}) + \omega_s [\frac{L_m}{L_1} u_1 + i_{d2} (L_2 - \frac{L_m^2}{L_1})] + R_2 i_{q2} \end{cases} \quad (13)$$

Considering that the rotor voltage and current are not fully decoupled, we assume:

$$\begin{cases} u_{d2}' = p i_{d2} (L_2 - \frac{L_m^2}{L_1}) + R_2 i_{d2} \\ u_{q2}' = p i_{q2} (L_2 - \frac{L_m^2}{L_1}) + R_2 i_{q2} \\ \Delta u_{d2} = -\omega_s i_{q2} (L_2 - \frac{L_m^2}{L_1}) \\ \Delta u_{q2} = \omega_s [\frac{L_m}{L_1} u_1 + i_{d2} (L_2 - \frac{L_m^2}{L_1})] \end{cases} \quad (14)$$

Where, u_{d2}' and u_{q2}' are the decoupling section; Δu_{d2} and Δu_{q2} are the compensation section.

The stator side power equation is:

$$\begin{cases} P_1 = \frac{3}{2} \frac{L_m u_1}{L_1} i_{q2} \\ Q_1 = \frac{3}{2} (\frac{L_m u_1}{L_1} i_{q2} - \frac{u_1^2}{L_1 \omega_1}) \end{cases} \quad (15)$$

It can be seen from the above formula, controlling the rotor current axis component can control the stator winding active output and controlling the rotor current axis component can control the stator winding reactive output. Through the vector control technology, we can achieve active and negative decoupling control.

Active and Reactive Power Control. The reference value for torque or active power for doubly-fed asynchronous generator control is obtained primarily by wind turbine control. The control objective of the wind turbine is to obtain the maximum power from the wind energy as far as possible within the allowable range of wind turbine speed, the current and voltage limitation of the doubly-fed asynchronous generator and the power electronic converter. When the available power in the wind energy exceeds the rated power of the generator, the variable pitch control mechanism will be activated to limit the power and wind turbine speed below the rated speed. The system will use the following means to control the electrical power or torque to achieve maximum Power tracking.

The way in this paper is to obtain the reference value of the rotor speed from the maximum power tracking characteristic, and then adjust the wind turbine speed to the parameter value by closed-loop control. The rotor speed control loop is as follows:

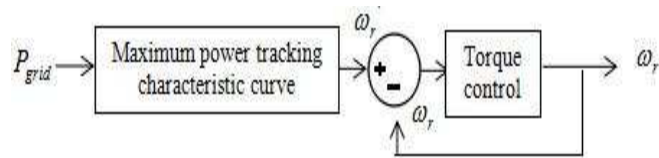


Figure 2. Active power control

The reactive power reference acquisition method includes voltage regulation at the network connection, power factor command and directive reactive power support. It is shown below:

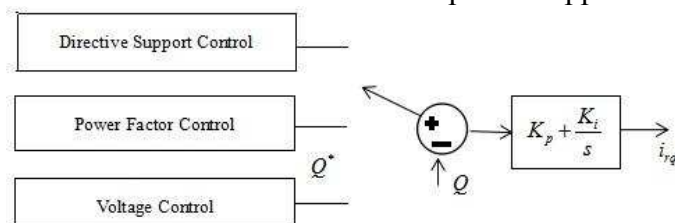


Figure 3. Reactive power control

Simulation

A wind farm usually includes a few wind turbines, and it is not necessary to separately describe each wind turbine in a wind farm if the main effect of the wind farm on the system's dynamic performance is investigated. Usually, wind farms are described as a suitable equivalent wind turbine and are interconnected with the grid at the appropriate point of interconnection. In this paper, the numerical simulation of the doubly fed generator system is carried out by using the control method described above, and the corresponding results are given. The simulation results verify the correctness of the model[9-10].

The simulation set is that the wind speed increases from 10m / s to 12m / s in 5s. The maximum power tracking method is used to control the active power. The reactive power control method includes voltage control and setpoint control.

Fig. 4a,4b gives the wind speed, rotor speed curve. It can be seen from the figure, the rotor speed changes with the wind speed, to ensure that the blade speed ratio for the optimal value.

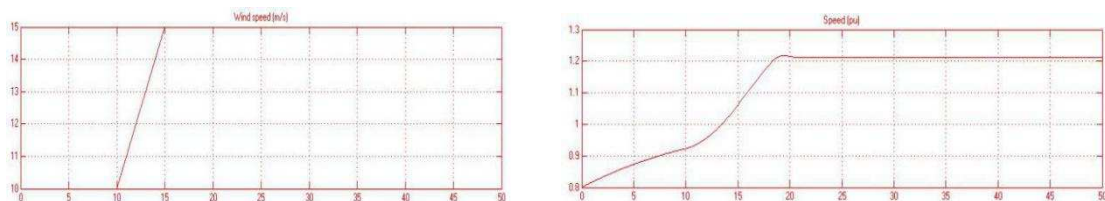


Figure 4a. Wind Speed 4b. Rotor Speed

Fig.5a,5b shows the system's active power and current.

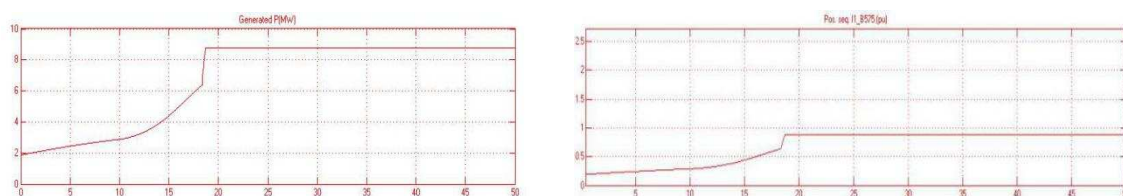


Figure 5a. Generated Active Power 5b. Generated Current

Fig. 6a,6b shows the reactive power generated by the system under voltage control and setpoint control.

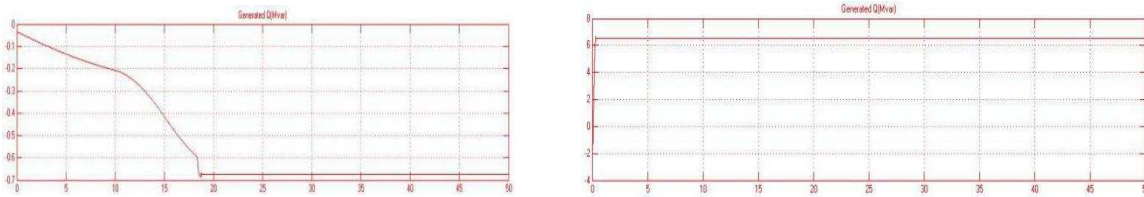


Figure 6a. Generated Positive Power under voltage control 6b. Generated Positive Power under setpoint control

Conclusion

Based on the Matlab/Simulink software, the dynamic simulation of the double-fed wind turbine is carried out. The wind speed model is used to simulate the double-fed wind turbine. The maximum wind energy capture and decoupling control is realized. The simulation results show that the double The wind turbine generator set has good running characteristics, and validates the correctness and validity of the model. Firstly, the model established by Matlab / Simulink has laid a good foundation for the further study of doubly-fed wind turbine.

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