Study the Response Of The Wind Turbine System under Realistic Working Conditions Using Simulink

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Abstract: In recent years, there has been a very rapid development in the field of clean energy due to the huge increase in the demand, which prompted the manufacturers and the designers to increase the efficiency and operating life of the energy systems and especially for wind turbine. It can be considered that the control unit is the main key of the wind turbines. Consequently, it’s essential to understanding the working principle of this unit and spotlight on the factors which influence significantly on the performance of wind turbine system. Simulink technique is proposed to find the response of the wind turbine system under different working conditions. In this paper, it was investigated the influence of the rotational speed, type of generator on the response of the wind turbine system.

Keywords: Control system, Wind turbine, Simulink

Introduction

In recent years, it has been observed that wind energy, which provides electricity in many countries, has grown significantly; this led to an increased interest in developing wind turbines and increasing their efficiency. It can be seen the annual additions of wind energy And the global capacity (for years 2007 and 2017) in Figure 1 [1].
The power production of the wind turbines is increased dramatically. Whereas at the mid of 1980s, it was only small turbines with capacity about 30 kw and rotors diameter less than 15 meters, while now there is wind turbine with capacity 7.5 MW and rotor diameter equal to 127 m [2]. Figure 2 exhibits the development in the power capacity (size) of the wind turbine, it can be noticed the future design for power production that take into consideration the increasing of the power production.

Based on the studies that done last years by Iraqi researchers [3-5], it was proved that there is promising wind energy in some sites in Iraq. Where, it can be instilled the wind turbines of small to medium range of power capacity. These promising sites are located in the north, mid and south of Iraq.

It can be considered one of the main motivation to start this research paper is the evidences provided by many organizations (e.g. ALTAI) that emphasized the increase in pollution rates significantly, especially in large cities such as Baghdad, Basra, etc. There are other researchers studied the wind turbines from different point of view, where they investigated in details the stresses, deformations and aerodynamic at the peak of power production [6-8].

In this research paper, it was used the Simulink/Matlab to build a new model for the wind turbine. The study focused on the control system of the wind turbine, and how can to obtain the maximum power under different working conditions.

Figure 1: Global capacity and annual additions of wind power, 2007-2017 [1]
Mathematical Model

This section presents a full description of the modeling of main parts (pitch control, etc.) in the wind energy system. Also, it gives an overview of the design for the pitch controller and the response of this controller according to the variation of wind velocity. Where it can be increase the output power when use the optimal pitch control. Figure 3 shows the main parts of the wind turbine.
The turbine typically consists of the rotor (with blades) which responsible to obtain the mechanical energy from the wind energy (kinetic energy). Where, gearbox has the ability to change the rotor’s speed to the desirable value. The next step is transmitting this power to the generator. Where, the wind turbine has the main control system that including many parts to ensure obtains the maximum output power.

The first step to build the mathematical model for the power of wind that obtained by the rotor is the study deeply and analysis the variation of wind that pass through the blades of wind turbine (swept area). Figure 4 shows the block diagram of wind power system. The power extracted by the rotor can be written as follows,

\[ P_{\text{rotor}} = \frac{1}{2} C_p \rho V_{\text{rated}}^3 A_{\text{rotor}} \]  

(1)

where \( C_p \), \( \rho \), \( V_{\text{rated}} \) and \( A_{\text{rotor}} \) are power coefficient, density of the wind, the rated speed of wind and area of the rotor. In order to find the value of power coefficient, it can be used the experimental method based on of \( \lambda \), pitch angle of the blade \( \beta \) and \( \alpha \) constant. The mechanical power that can be transmitted to electric shaft of wind turbine by the rotor is,

\[ P_{\text{rated}} = \eta P_{\text{rotor}} \]  

(2)

It can be expressed the power train efficiency as following,

\[ \eta = \eta_{\text{GB}} \eta_{\text{G}} \eta_{\text{Conv}} \]  

(3)

Where \( \eta_{\text{GB}} \), \( \eta_{\text{G}} \) and \( \eta_{\text{Conv}} \) are the efficiency of gearbox to transmit the mechanical power to generator, the efficiency of the generator to convert the mechanical power into electric power, and the efficiency to convert electrical power from the generator to electrical grid.

The rotor’s torque and the electromechanical torque that belong to the generator that effect in opposite direction are considered the inputs of the model. While, the rotational speeds are considered the outputs of the model. It can represented these variables as following,

\[ \frac{d\omega_{\text{gen}}}{dt} = \frac{1}{2H_{\text{gen}}} \left[ \frac{P_{\text{elec}}}{\omega_{\text{gen}} + \omega_o} - D_{\text{elec}} \left( \omega_{\text{elec}} - \omega_{\text{rot}} \right) - k_{\text{elec}} \Delta \theta_m \right] \]  

(4)

\[ \frac{d\omega_{\text{rot}}}{dt} = \frac{1}{2H_{\text{rot}}} \left[ \frac{P_{\text{mech}}}{\omega_{\text{gen}} + \omega_o} - D_{\text{elec}} \left( \omega_{\text{elec}} - \omega_{\text{rot}} \right) - k_{\text{elec}} \Delta \theta_m \right] \]  

(5)
\[
\frac{d(\Delta \theta_m)}{dt} = \omega_{base}(\omega_s - \omega_t)
\]  \(6\)

In this model, the inertial constant is a function of the geometrical distribution for mass. Where, the inertia is represents the necessary time for generator to reach the rated power according to the kinetic energy of its mass during the rotation. It can be calculated the inertial moment as,

\[
H_{rotor} = \frac{J_{\text{rotor}} \omega_{\text{rotor}}^2}{2 P_p}
\]  \(7\)

\[
H_{\text{gen}} = \frac{J_{\text{gen}} \omega_{\text{gen}}^2}{2 P_p}
\]  \(8\)

For the rotor of wind turbine, it can be approximated the inertia as follows,

\[
J_{\text{rotor}} = \frac{1}{8} m_r R^2
\]  \(10\)

where \(m_r\) and \(R\) are the rotor mass including the blades and the rotor radius. It can be transformed three phases into an equivalent of two axes in order to model a PMSG. The reason behind this assumption is each phase will act to create the air gap (the geometric space). Along the \(d\) axis (direct axis) in the phase through the field of rotor and the axis of displacement \(q\), it will be 90º forward in a synchronous rotating \((d-q)\) as a reference frame. It will appeared the waves of magnetic flux in two waves (sinusoidal) that distributed with synchronous speed due to the stator winding. Where there are two maximum points, the first one on the axis \(d\) and on the axis \(q\). It can be written the output of the stator \((d-q)\) voltages of the generator as following:

\[
V_d = R_d I_d + L_d \frac{dI_d}{dt} - \omega_{\text{gen}} L_q I_q
\]  \(11\)

\[
V_q = R_q I_q + L_q \frac{dI_q}{dt} - \omega_{\text{gen}} (L_d I_d + \phi_f)
\]  \(12\)

where \(L\), \(R\) and \(I\) are inductances of generator, resistance and currents in \(d\) and \(q\) axes, respectively. \(\phi_f\) is the magnetic flux (permanent). The rotational speed \((\omega_{\text{gen}})\) is for the PMSG is,

\[
\omega_{\text{gen}} = P_p \omega_{\text{ref}}^2
\]  \(13\)

where \(P_p\) is no. of pair for poles. It can be written the electromechanical torque \((T_{\text{gen}})\) as:

\[
T_{\text{gen}} = \frac{3}{2} P_p \omega_{\text{ref}} \left( (L_q - L_d) i_d i_q + \phi_f i_q \right)
\]  \(14\)
Figure 4 shows the block diagram of wind power system

Results of the Wind Turbine Model Based on Simulink

In this section, the developed model of the wind turbine system based on Simulink will present in details and all the results that can be obtained from this model. Figure 5 demonstrates the block diagram of the developed model of the wind power system based on the equations that presented previously using Simulink/Matlab.

Figure 6 shows the active and reactive output power during the specified period. While, Figure 7 illustrates the variation of wind speed with time. It can be seen that when the speed of wind less than the cut-in speed or higher than the value of cut-out speed, there is no power will be generated. Under these working conditions, the machine consumed the reactive power. Therefore, it was occurred the reactive compensation block offsets the reactive power of machine based on the necessary value. The obtained results were consistent with the results obtained by other researchers using different models [9-11].
Figure 6 The active and reactive output power
Figure 7 The variation of wind speed

Conclusions and Remarks
In this research paper, it was developed a new model of the wind turbine using Simulink/ Matlab. It was described the main parts of the wind turbine that responsible of the output power. It has been analyzed the wind velocity using asynchronous generator. The developed mathematical model of the wind turbine has the ability to find the optimal values of each parts of the sub control systems of the wind turbine to enhance the aerodynamic, mechanical and electrical responses. Subsequently, it can be improved the total efficiency of the wind turbine and obtain high power under the same circumstances. Based on the obtained results, which the developed model is reliable and it can be used for further in the research investigations.
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