Simulating the Speed control System of Wind Turbines Using MATLAB Software

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\textbf{Abstract}

In this paper, a mathematical method is proposed to control the output frequency of a self-excited induction generator using wind turbines and static loads. A dynamic model of the wind turbine is implemented to model the Connections and fittings of the wind turbine to convert the wing energy to electrical energy. Also a PID controller system is proposed to control the rotor speed of the wind turbine. The proposed mathematical model is developed in MATLAB-Simulink software. The simulation results showed that the developed controller can be used to control the wind turbine velocity.

1. Introduction

Demand for energy is increasing all over the world. Therefore, the need for renewable energy resources which don’t harm the environment is increasing too [1]. Some predictions show that energy demand will be tripled until 2050. Currently, the renewable energy resources constitute 15 to 20% of all energy produced in the world. Transforming the wind energy in various scientific fields is developing [2]. According the USA wind energy association, the installed capacity average of the wind energy is increasing 29 percent a year [3]. At the end of 2009, the installed capacity of wind energy was 159 megawatts and it’s predicted to reach 580 megawatts by the end of 2014 [4] the wind energy marked has grown due to the environmental benefits and its renewability and accessibility and financial encouragements of the governments [5, 6] which can be used in many infrastructure projects like factories, construction, transportation to optimize energy consumption [7]. However, there are many unsolved challenges in expanding the wind energy. The standard control methods are presented to develop advanced controls to change the speed of the wind [8]. Most wind turbines are equipped with self-initiating generator. They have an integrated and simple performance in structure and use in different conditions. Induction machineries are cheaper and need less maintenance. These generators are suitable for wind turbines because of their high speed [9]. Recent advances in power electronics to adjust the Self Excited Induction Generator have provided this opportunity in small scales. In recent years, MATLAB software was the mostly used software for modelling and simulating dynamic systems [10] especially in wind turbines, the blades play the fundamental role which has been studied many. In Blades the part of high significant aspect is the thin walls of blade, which is calculated by thin-walled theories and it can be found in many research like Khezri et al. and so forth [11-13]. Wind turbine systems are an example of such dynamic systems which include sub-systems with different ranges of time constants: turbine, wind, generator, power electronics and transformer [14].There are two main principals in transforming the wind energy: 1- connecting the wind generator to the network is under the name frequency of the network. Once the generator is connected to the network, the network begins to produce reactive power for the induction machines and most of the times a DC-Link in needed to control while connecting the wind powerhouse to the network and with a special technique. 2- The wind generator connection system is for isolating the wind to far areas. The output frequency of the SEIG connected to an isolated load is directly dependent to the main speed of the rotor. Therefore, the fixed speed of the rotor will lead to a fixed terminal frequency. The SEIG rotor speed is adjusted using a regulator which

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adjusts the speed of the wind turbine [15]. In this article, PID controller is used to control the speed of the turbine rotor, therefore, frequency adjustment is suggested using the MATLAB software. It should be noticed that PID controller parameter is chosen such that the speed so rotor stays in a certain and defined value.

2. Dynamic modeling of the wind turbines

Wind turbine has a property without dimension and the coefficient power \( (C_p) \) curves are a function of both blade speed \( (\lambda) \) and blade step angle \( (B) \) [16]. For optimized and full use of the wind energy, \( \lambda \) must be kept at an optimized positive value. Therefore, the corresponding coefficient power must be maximum [17]. The blade speed ratio could be as the angle speed of the wind turbine rotor to the linearity of the wind speed at the top of the blades and could be stated as (1):

\[
\gamma = \frac{\omega_t}{\omega_w} \tag{1}
\]

\( R \) is the radius of the wind turbine; \( \omega_w \) is the wind speed and \( \omega_t \) is the angle speed of the wind turbine rotor. The output power of the wind turbine could be calculated using (2):

\[
P_m = \frac{1}{2} P A C_p \omega_w^2 \tag{2}
\]

In which \( P \) is the air density and \( A \) being the area swiped by the camera and \( C_p \) is calculated using this relation:

\[
C_p = (0.044 - 0.0167\beta) \sin \left( \frac{\pi (\gamma - 3)}{15 - 0.03\beta} - 0.00184(\gamma - 3)\beta \right) \tag{3}
\]

And also, the torque of the wind turbine can be defined as (4):

\[
T_t = \frac{1}{2} P A R C_p \omega_m^2 \tag{4}
\]

In which \( C_T \) is the torque coefficient and its value are set by \( C_T = C_p/\lambda \). Therefore, the aerodynamic torque \( T_m \) can be defined as (5):

\[
T_m = 0.5 P A \left[ \left( 0.44 - 0.0167\beta \right) \sin \left( \frac{\pi (\lambda R)}{V_m^2 - 3} - 0.00184\frac{\lambda R}{V_m^2 - 3}\beta \right) \right] \left( \frac{V_m^3}{\omega_t} \right) \tag{5}
\]

Table 1 shows the wind turbine parameters for simulation.

| Parameter        | Range          |
|------------------|----------------|
| Power            | 1 KW           |
| Speed            | 450 RPM        |
| \( \omega_t \)   | 12.5 m/s       |
| Height           | 4 m            |
| Radius           | 1 equator      |
| Sweep area (A)   | 4M²            |
| Air density      | 1205 kg/m²     |

This article uses a traditional approach to linearize the dynamic model of the turbine. PIDs must linearize the non-linear dynamics of the turbine at the work point. The linear equation of the turbine is \( f_j \Delta \omega_1 = \gamma \Delta \omega_1 + \varepsilon \Delta V_w + \delta \Delta \beta \). Therefore, the linear coefficients are as (6-18):
\[
\gamma = \frac{\delta T_m}{\delta W_t} = \frac{\delta}{\delta W_t} (j_t \Delta w_t^p) = \frac{1}{2} PAV_{wp}^2 \delta \left[ C_p(\gamma, \beta) \right] = \frac{\delta T_m}{\delta W_t} = k_1 + k_2 + k_3 \tag{6}
\]
\[
\delta = \frac{\delta T_m}{\delta V_w} = \frac{\delta}{\delta V_w} (j_t w_t^p) = \frac{1}{2} PAV_m^2 \delta \left[ C_p(\gamma, \beta) \right] = \frac{\delta T_m}{\delta V_w} = k_{21} + k_{22} + k_{23} \tag{7}
\]
\[
\delta = \frac{\delta T_m}{\delta \beta} = \frac{\delta}{\delta \beta} (j_t w_t^p) = \frac{1}{2} PAV_m^2 \delta \left[ C_p(\gamma, \beta) \right] = \frac{\delta T_m}{\delta \beta} = k_{31} + k_{32} + k_{33} \tag{8}
\]
\[
k = \frac{1}{2} \rho AR \tag{9}
\]
\[
\gamma_p = \frac{R w_{wp}}{V_{wp}} \tag{10}
\]
\[
k_{11} = \left\{ k \frac{\nu_{wp}^3}{R w_{wp}} (0.44 - 0.0167 \beta_{op}) \frac{\pi R}{V_{wp}^2 (15 - 0.3 \beta_{op})} \cos \left( \frac{\pi \gamma_{op} - 3}{15 - 0.3 \beta_{op}} \right) \right\} \tag{11}
\]
\[
k_{13} = -0.00184 \left[ \beta_{op} \nu_{wp}^2 + \frac{3 \beta_{wp}^3}{R w_{wp}^2 \gamma_{op}} \right] k \tag{12}
\]
\[
k_{21} = (0.44 - 0.0167 \beta_{op}) \left( \frac{3 \nu_{wp}^3}{R w_{wp} \gamma_{op}} \right) \sin \left( \frac{\pi \gamma_{op} - 3}{15 - 0.3 \beta_{op}} \right) \tag{13}
\]
\[
k_{23} = -0.00184 k \left( 2 \nu_{wp} \beta_{op} \gamma_{op} \right) \tag{14}
\]
\[
k_{22} = \left( \frac{4.4 - 0.0167 \beta_{op}}{\nu_{wp}^2} \right) \left( \frac{k \nu_{wp}^3}{R w_{wp} \gamma_{wp} (15 - 0.3 \beta_{op})} \right) \cos \left( \frac{\pi \gamma_{op} - 3}{15 - 0.3 \beta_{op}} \right) \tag{15}
\]
\[
k_{31} = -0.0167 k \frac{\nu_{wp}^2}{\gamma_{op}} \sin \left( \frac{\gamma_{op} - 3}{15 - 0.3 \beta_{op}} \right) \tag{16}
\]
\[
k_{33} = -0.0184 k \left( \gamma_{op} - 3 \right) \nu_{wp}^2 \tag{17}
\]
\[
k_{32} = 0.0167 k \frac{\nu_{wp}^2}{\gamma_{wp} (0.44 - 0.0167 \beta_{op})} \left( \frac{3 \mu}{\gamma_{wp} (15 - 0.3 \beta_{op})} \right) \cos \left( \frac{\gamma_{op} - 3}{15 - 0.3 \beta_{op}} \right) \tag{18}
\]

And the linearization of the wind turbine equation is as below:

Here, \( \Delta \omega \), \( \Delta V \), and \( \Delta \beta \) show the performance deviation of the chosen points \( \omega_{top}, V_{top} \), and \( B_{top} \). Choosing the work point is important to conserve the aerodynamic stability. The rotational speed of the work point for arbitrary speed of the turbine is 450 rounds per minute which equals 47.1 radian per second and the blade step distance and wind speed at the work point are \( B_{top}=90 \) and \( V_{wp}=6.4 \text{m/s} \). therefore, by replacing them in the linearized equation of the turbine, we achieve:

\[
j_t \Delta w_t = \delta \Delta 3 w(s) + \gamma \Delta w_t(s) + \delta \Delta u(s) \tag{19}
\]

And by replacing \( D = \gamma / j_t \) the rotation speed of the turbine shaft equals:

\[
\Delta w_t = \left[ \frac{\delta}{j_t} \Delta v_o(s) + \frac{\delta}{j_t} \Delta u(s) \right] \frac{1}{s - D} \tag{20}
\]

Which describes the linearized model of the wind turbine. Such model is shown in figure 1:
3. Operator model

DC motor with constant magnet is used to adjust the turbine blade and its function is shown as (21):

\[
\frac{\mu_a(s)}{\mu_o(s)} = \frac{kw}{\tau_m s + 1}
\]  

(21)

In this function \( u_a(s) \) and \( u_o(s) \) are the Laplace transformation of the step angle and \( K_w \) is the constant and \( \tau_m \) is the constant time of the DC motor. PID controller is used to control the speed of the rotor. If \( \Delta \phi(s) \) is the rotor input speed (error signal) and \( \Delta U_o(s) \) is the changes of the output step angle, the transition function between the rotor speed and the input and output step angles is as followed:

\[
C(S) = \frac{\Delta U_o(s)}{\Delta \phi(s)} = \frac{k_p s + k_i + k_d s^2}{s}
\]  

(22)

The suggested speed control diagram of the wind turbine is shown in figure 2. Simulations were done using MATLAB software and in Simulink environment. PID controller design provides a method to get the error speed mean root using visual observations.

The simulation was repeated over and over. The observation of the input answers in choosing the obtained values was done directly. PID controller parameters must be adjustable to get the maximum performance. \( K_p = 15 \) and \( K_i = 20 \) and \( K_d = 0.1 \) are assumed. The wind speed varies from 4.7 m/s to 8.1 m/s. the control changes of the blade distances are between 10 to 15 degrees to keep the rotor speed at 47.1 rad/s.
4. Conclusions

In this article, the output voltage frequency of a Self-Excited Induction Generator is controlled using a wind turbine and static equipment. Adjusting the output voltage frequency was done via controlling the speed of the rotor and to achieve this, a PID controller was used. Speed control of the wind turbine is suggested and simulated in the Simulink part of the MATLAB software. PID controller parameter to optimize the speed are: Kp=15 and ki=20 and kd=0.1. The wind speed varies from 4.7 m/s to 8.1 m/s. in this control system, the blade distance changes are between 10 to 15 degrees to keep the rotor speed at 47.1 rad/s.

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