Modeling and Simulation of an Induction Generator based Wind Turbine Systems

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ABSTRACT

This paper describes the modeling and simulation of a wind energy conversion system in Matlab/Simulink environment. The wind energy conversion system consists of a wind turbine, gear box, and induction generator. The dynamic model of a 30 kW induction generator is used for performance testing of the proposed system. Simulink models of the individual components of wind energy conversion are formed with the help of their equivalent mathematical equations. Intermediate output of different models and the overall electrical power output of the proposed wind energy conversion are presented in this paper. The scope of the present work is limited for operation of the wind energy conversion system below rated wind speed provided that pitch angle is maintained at a constant value.

1. INTRODUCTION

Renewable energy sources have a great potential to generate electricity due to abundant in nature, cost-effective and provides contribution to the climate change goals. Of all the most, wind energy has been developed rapidly as one of the best sources for electricity generation over the last few decades. Large wind turbines deploy multitude of control methods and operate mainly in grid-connected mode.

It can be found in the previous research that reduced aerodynamic power can be achieved by stall, passive stall and pitch control [1]. In this report, a pitch control method is adapted for the aerodynamic power control. The standard control of wind turbine are based on the fact that below rated wind speed, the wind turbine will trace the maximum power/torque curve and above rated wind speed, the output power is limited to its rated power. To trace the maximum power/torque curve, speed/current control mode is typical, while pitch regulation ensures the rated power for above rated wind speed.

The considered wind energy conversion system is shown in Fig.1. Intermediate output of different models and the overall electrical power output of the proposed wind energy conversion are presented in this paper. The scope of the present work is limited for operation of the wind energy conversion system below rated wind speed provided that pitch angle is maintained at a constant value.

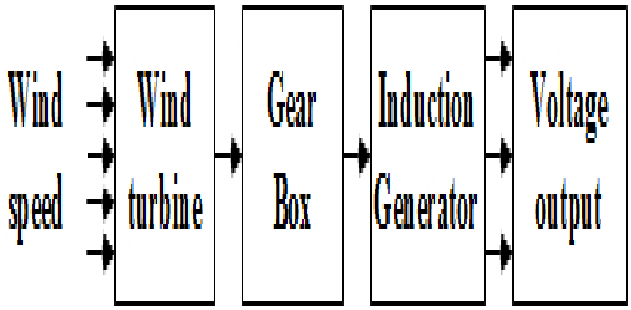

Fig. 1: Block diagram of the 30kW wind energy conversion System

This paper is organized as follows. The first section is a short overview of the work presented in this research. In the second section, modeling of the components of the wind energy conversion system is presented. And the third section contains simulation results. Finally, the findings of the investigations are highlighted in the conclusions.

2. MODELING OF THE COMPONENTS

2.1 Wind Turbine

A wind turbine can be characterized by the non-dimensional curve of power coefficient C_p as a function of Tip Speed Ratio (TSR) λ, where λ is given in terms of rotor speed ω (rad/s), wind speed V (m/s), and rotor radius R (m) as shown in given below:

$$\lambda = \frac{R\omega}{V} \qquad (1)$$

Wind turbine power coefficient, *Cp* is dependent upon λ, Tip Speed Ratio (TSR). If pitch angle, β is incorporated, *Cp* befalls a function of λ and β, i.e. $Cp = f(\lambda, \beta)$. The power coefficient as a function of λ and β can be expressed as [2, 3]

$$C_p(\lambda,\beta) = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right)e^{-\frac{21}{\lambda}} + 0.0068\lambda \qquad (2)$$

Where, $\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$

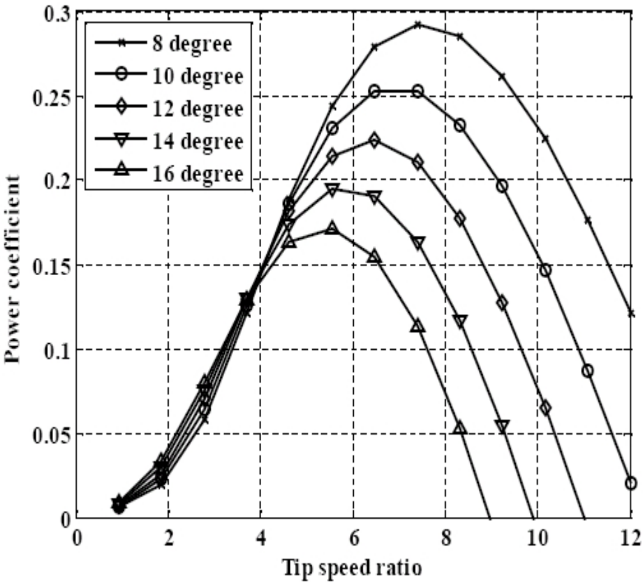

Fig. 2: Power coefficient as a function of TSR and pitch angle.

Variation of β with *Cp* are shown in Fig. 2, which ensures that as β increases, *Cp* decreases, thus reducing the power produced by the wind turbine. In order to obtain the optimal power for below rated wind speed, the pitch angle (β) is usually held to an optimum value and a rate limiter is often used to limit the rate of change of the pitch angle. For this preliminary investigation, the pitch angle is set to 8^0 and the TSR assumes the optimum value which assures maximum power production.

The mechanical output power of the wind turbine can be expressed as

$$P_m = 0.5\rho A C_p(\lambda,\beta)V^3 \qquad (3)$$

Where, ρ is the air density (kg.m-3) and A is the rotor rotational area, i.e., πR^2. Assuming the pitch angle as 8^0, the power production and the maximum power locus of the wind turbine with the variation in wind speed is presented in Fig. 3.

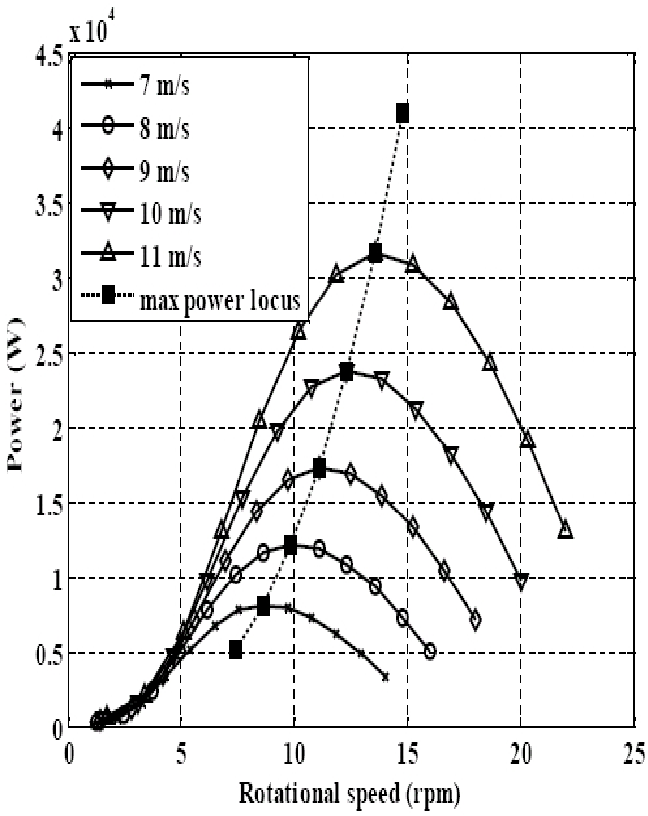

Fig. 3: Rotational speed versus power curve of the wind turbine

The torque term can be expressed as

$$T_m = \frac{0.5\rho A C_p(\lambda,\beta)V^3}{\omega_m}. \qquad (4)$$

2.2 Gear Box

Input to the gear box is the aerodynamic torque. This torque is low-speed shaft torque T_L, which is converted to high-speed shaft torque T_H through gearbox. It is assumed that the losses in the gearbox are zero, thus gear transmits ideally from low speed to high speed. The relation between high-speed shaft torque and low-speed shaft torque is

$$T_H = \frac{T_L}{\eta_{gear}} \qquad (5)$$

2.3 Induction Generator

There are numerous ways of formulating the equations of ab induction machine for the purposes of the computer simulation [4, 5]. The main variables of the machine in rotating frame are flux linkages φ_{qs}, φ_{ds} φ'_{qr}, φ'_{dr} in state space form are derived. Substituting the conditions $\omega = \omega_r$ and $V_{qr}=V_{dr}=0$ in the flux linkage equation, we get:

$$\varphi_{qs} = \omega_b \int \left(V_{qs} - \frac{\omega_r}{\omega_b}\varphi_{ds} + \frac{r_s}{x_{ls}}\left(\varphi_{mq} - \varphi_{qs}\right) \right) \quad (6)$$

$$\varphi_{ds} = \omega_b \int \left(V_{ds} - \frac{\omega_r}{\omega_b}\varphi_{qs} + \frac{r_s}{x_{ls}}\left(\varphi_{md} - \varphi_{ds}\right) \right) \quad (7)$$

$$\varphi'_{qr} = \omega_b \int \left(\frac{r'r}{xl_r}\left(\varphi_{mq} - \varphi'_{qr}\right) \right) \quad (8)$$

$$\varphi'_{dr} = \omega_b \int \left(\frac{r'r}{xl_r}\left(\varphi_{md} - \varphi'_{dr}\right) \right) \quad (9)$$

The currents can now be calculated as

$$i_{qs} = \frac{\left(\varphi_{qs} - \varphi_{mq}\right)}{x_{ls}} \quad (10)$$

$$i_{ds} = \frac{\left(\varphi_{ds} - \varphi_{md}\right)}{x_{ls}} \quad (11)$$

$$i'_{qr} = \frac{\left(\varphi'_{qr} - \varphi_{mq}\right)}{x'_{lr}} \quad \text{and} \quad (12)$$

$$i'_{dr} = \frac{\left(\varphi'_{dr} - \varphi_{md}\right)}{x'_{lr}} \;. \quad (13)$$

Solving equations (10-13), the φ_{mq} φ_{md} are obtained as

$$\varphi_{mq} = x_m \left(\frac{\varphi_{qs}}{x_{ls}} + \frac{\varphi'_{qr}}{x'_{lr}} \right) \quad (14)$$

$$\varphi_{md} = x_m \left(\frac{\varphi_{ds}}{x_{ls}} + \frac{\varphi'_{dr}}{x'_{lr}} \right) \quad (15)$$

Where, $x_m = \dfrac{1}{\left(\dfrac{1}{x_m} + \dfrac{1}{x_{ls}} + \dfrac{1}{x_{lr}} \right)}$ (16)

Electromagnetic torque of the induction generator, expressed in terms of d-q axis flux linkages and currents is given by:

$$T_{em} = \left(\frac{3p}{4\omega_b} \right)\left(\varphi_{ds} i_{ds} - \varphi_{qs} i_{qs} \right) \quad (17)$$

The equation that governs the motion of rotor is obtained by equating the inertia torque to the accelerating torque

$$J\left(\frac{d\omega_m}{dt} \right) = T_{em} + T_m - T_{damp} \quad (18)$$

Expressed in per unit values, equation (18) becomes:

$$2Hd\frac{\left(\dfrac{\omega_r}{\omega_b} \right)}{dt} = T_{em} + T_m - T_{damp} \quad (19)$$

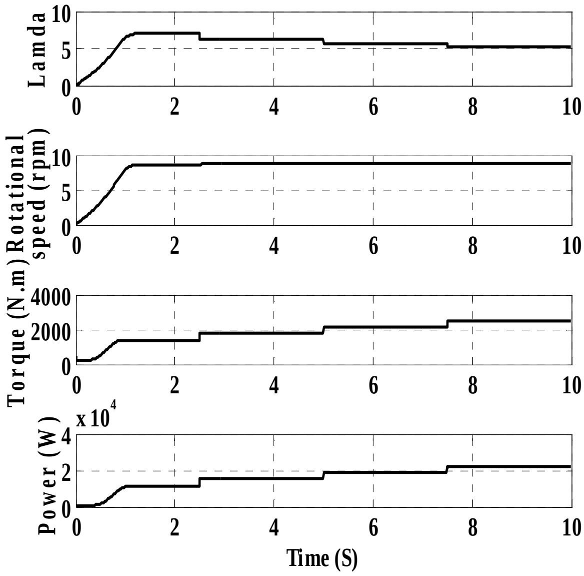

Fig. 4: Time variation of the wind turbine quantities (step wind speed)

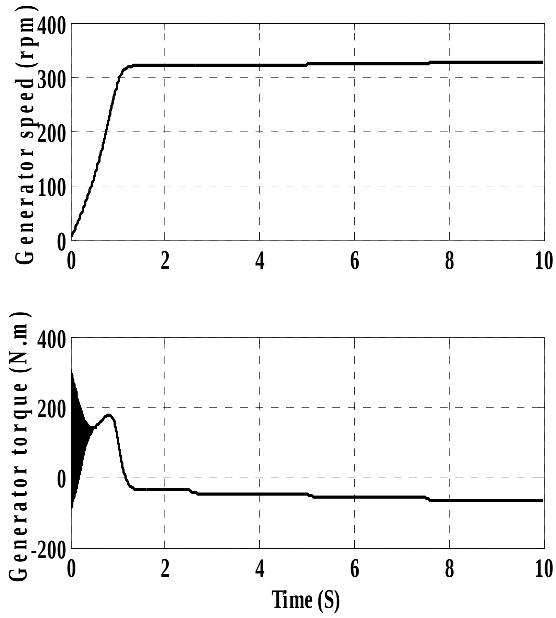

Fig. 5: Time variation of the wind turbine quantities (step wind speed)

3. SIMULATION RESULTS

The system that has been described above was simulated using Matlab-Simulink™ blocks. The rated power of the wind turbine is considered as 30 kW. A step wind speed of 8 m/s to 11 m/s are considered for the simulation. Figure 4

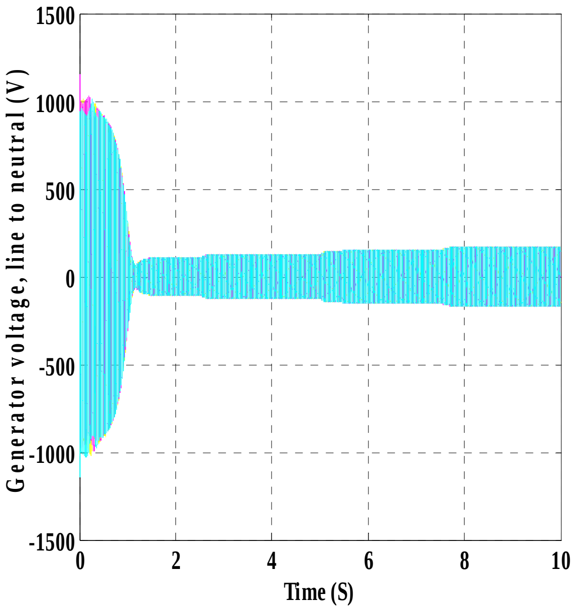

Fig. 6: Time variation of the generator voltages (step wind speed)

presents the variation of tip-speed-ratio, speed, torque and power of the wind turbine with step wind speed variation. It is easily notable that all the quantities settles to a steady state value after 1.2 second. Fig. 5 presents the induction generator speed and torque for a step variation in wind speed and noted that after some initial transients, the quantities settle to a new higher value and remain stable. The 3-phase line-to-neutral voltage output of the generator is presented in Fig. 6, and Fig. 7 presents a closer look of the induction generator voltages. It is expected that the output of the generator will be sinusoidal and found by the simulation.

4. CONCLUSIONS

The paper has presented dynamic modeling and simulation of a wind energy conversion system. The wind turbine has been modeled based on an induction generator. A step wind speed variation is shown and proven that the developed model is able to reflect the characteristic of the individual components, thus validates the modeling approach.

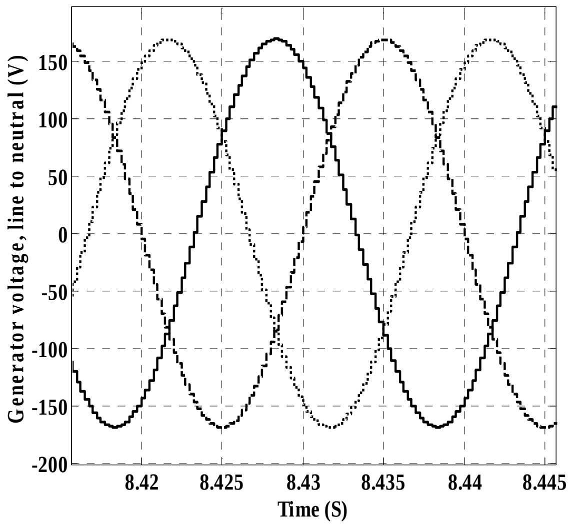

Fig. 7: Time variation (closer look) of the generator voltages (step wind speed)

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