A METHODOLOGY FOR TRANSIENT BEHAVIOUR ANALYSIS OF HORIZONTAL AXIS WIND TURBINE

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Abstract. *This work aims to present a simplified mathematical model for analyzing of wind turbine performance operating at variable speed, considering the coupling between rotor and electrical generator, taking into account the inertial characteristics of the wind turbine components. Therefore, in this work, is presented a methodology applied to the horizontal axis wind turbine design in a non-stationary regime, using the Blade Element Momentum (BEM). The results are compared with other model in the literature, showing good agreement.*

Keyword*: Variable Speed Wind Turbine, Horizontal Axis Wind Turbine, Blade Element Momentum.*

1. INTRODUCTION.

This paper presents a mathematical model that considers a complete wind system operating at variable speed. In general, the models employed to wind turbine analysis, consider a fixed speed results in variation on the rotor speed, and to take into a account such variation is necessary to model the complete system, providing the coupling between the wind rotor and electric generator (Bao and Ye, 2001; Camblong et al, 2004; Muljadi et al, 2000). Thus, this work shows a methodology that considers the effects of inertia, friction and electromagnetic losses caused along of the system in operation, in order to optimize the wind turbines design capable of efficiently meet the conditions and characteristics wind from a given locality. The proposed methodology is generalized to consider turbines designed from the BEM method.

2. THE MATHEMATICAL MODEL.

A wind turbine system consists of a wind rotor with mass-moment of inertia J_r connected to a generator with mass-moment of inertia J_g, through a multiplication system with transmission ratio *vi,* see Fig. (1).

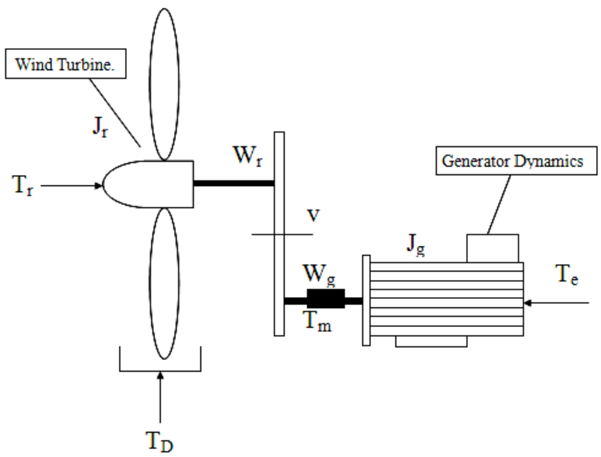

Figure 1. Illustration of the complete system (Bao e Ye, 2001).

The transient moment balance equation considering the transmission system is given by (Camblong et al, 2004):

$$J_r \frac{dw_r}{dt} = T_r - T_D - v_i T_m \tag{1}$$

Where w_r is the rotor speed, T_r is the rotor torque, T_D is the total torque relating to the friction of the system and T_m is the reaction torque of the second axis of the system, if any. Rotor torque T_r is given by:

$$T_r = \frac{P_r}{w_r} = \frac{1}{2}\frac{rpR^2V^3}{w_r}C_p\left(l\,,b\right) \tag{2}$$

Where $l = w_r R/V$ is the Tip-Speed-Ratio, b is the pitch angle and C_p is the power coefficient. In this case, T_D is given by (Bao e Ye, 2001; Chen e Jiang, 2009):

$$T_D = C_1 + \frac{C_2}{w_r} + C_3 w_r \tag{3}$$

Where C_1, C_2 and C_3 are appropriate constants due to friction of the mechanical parts imposed on the rotor. For the electric generator equation governing the coupling is given by (Slootweg et al, 2003; Camblong et al, 2004):

$$J_g \frac{dw_g}{dt} = T_m - T_e \tag{4}$$

Where $w_g = v_i w_r$ the generator speed and T_e is is the electromagnetic torque. Electromagnetic torque T_e, for an asynchronous generator, in this case, can be given by (Bao et al, 1996):

$$T_e = K_e w_g + K_0 \tag{5}$$

Where K_e = 378.9 Nms and K_0 = -59548 Nm. Therefore, relating Eq. (1), (2), (3) and (4) has the transient model for the coupling rotor generator.

$$J_{eq}\omega_r \frac{d\omega_r}{dt} + C_3\omega_r^2 + \left[C_1 + v_i T_e\left(\omega_r\right)\right]\omega_r - \left[\frac{1}{2}\rho\pi R^2 V^3 C_p\left(\lambda,\beta\right) - C_2\right] = 0 \tag{6}$$

Where $J_{eq} = J_r + v_i^2 J_g$ is the equivalent mass-moment of inertia. Equation (6) is a first order nonlinear ordinary differential equation, where the rotation depends on the time variable for any wind speed at which the turbine is subjected. This equation can be solved using the Runge-Kutta method (Burden, R. L. and Faires, J. D. 2010)

3. VALIDATION OF MODEL.

To validate the model, uses Eq. (7). The input parameters for the simulation are shown in Tab. (1).

$$C_p\left(\lambda,\beta\right) = 0.2\left(\frac{151}{\lambda_i} - 0.65\beta - 10\right)e^{-\frac{12}{\lambda_i}} \tag{7}$$

Where

$$l_i = \frac{1}{\dfrac{1}{l - 0.001b} - \dfrac{0.0001}{b^3 + 1}} \tag{8}$$

Table 1. Parameters considered in the simulation (Bao e Ye, 2001).

J_r = 350000 kg m^2	R = 15 m	J_g = 32 kg m^2
C_1 = 1000 Nm	C_2 = 1000 rad/s	C_3 = 100 s/rad
v_i = 28.32	r = 1.25 kg/m^3	$h_{generator} = 0.90$
V_0 = 20 m/s	$w_0 = 54$ rev/min	$h_{transmission} = 0.97$

It is observed in Fig (2) that the mathematical model described in this work converges to the approach described by (Bao and Ye, 2001) when the pitch angle is 3^0. In the work of (Bao and Ye, 2001) the pitch angle was omitted for this result.

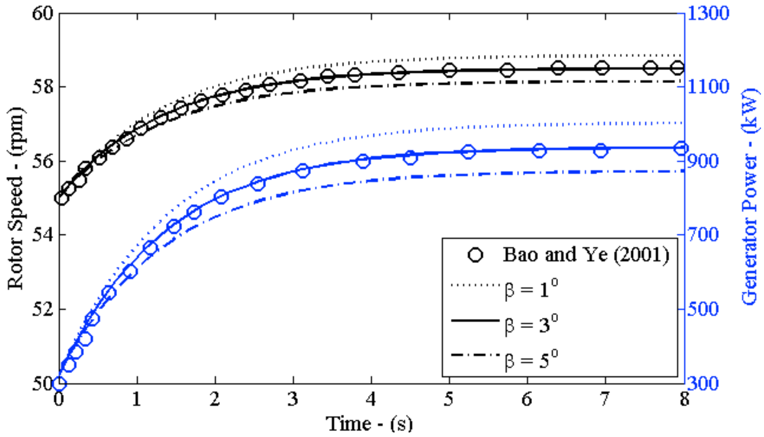

Figure 2: Rotation and generator power for some values of pitch angle.

4. RESULTS AND DISCUTIONS.

Here are shown the results for a turbine designed from classical BEM method. Therefore, consider the following data for the design of the turbine: 30 m rotor diameter, hub diameter 3 m, number of blades 3, NACA 0012 airfoil, constant speed of 59 rpm and angle picth 0^0. The projected blade is shown in Fig. (3).

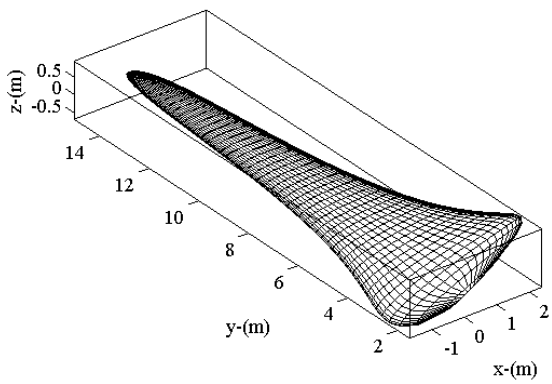

Figure 3: Wind blade designed.

The power coefficient obtained with the BEM model is shown in Fig. (4). Figure (5) shows the results obtained using the transient model described in this work for a constant wind velocity of 20 m/s. The parameters considered in the simulation are the same as described by (Bao and Ye, 2001) and are in Tab. (1). It is observed that the rotation of the turbine stabilizes at 60.3 rpm from 9s, and the generator power stabilizes at 1282 kW.

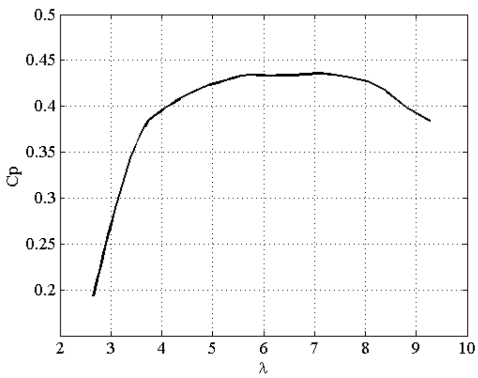

Figure 4. Power coefficient obtained with BEM model.

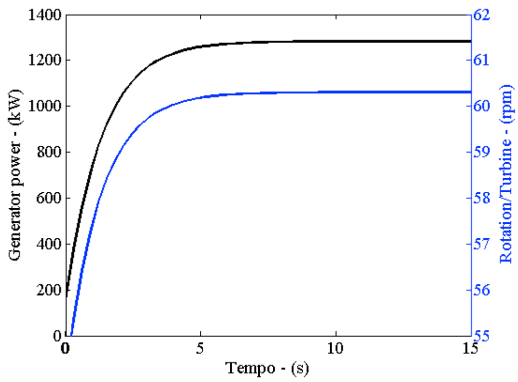

Figure 5. Generator power and rotation for a wind speed of 20 m/s.

5. CONCLUSIONS.

The proposed methodology represents and efficient approach for the design of wind turbines, considering the inertial effects and loss of power on the complete generation system. An important aspect of the proposed approach is that the model can be applied to wind turbine designed with the BEM method, since, in general, the existing model describes the power efficient in a simplified form as Eq. (7). Therefore, the methodology described here extends the dynamics equation given in (7) where the power coefficient is determined with the classical BEM model, because the model needs only the turbine aerodynamics information, in this case, the power coefficient in relation to the tip speed ratio. The model is validated with the results obtained by (Bao and Ye, 2001), showing good agreement.

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