# Wind Turbine Simulator Including Pitch Angle Control, Shaft Torsional Vibration and Tower Effect

Ahmed G. Abo-Khalil, Dong-Choon Lee
Department of Electrical Engineering, Yeungnam University

ABSTRACT

This paper proposes a modeling of wind turbine simulator which includes the dynamic characteristics such as pitch angle control, torsional vibration, and tower effect. Simulation results using PSCAD are provided to show the wind turbine simulator performance.

## 1. Introduction

The control of a system, that generates power from an unsteady input as the wind, presents a formidable problem. The wind speed varies from time to time due to gusts, and is further disturbed by the effect of supporting tower shadow and torsional vibrations. While analyzing the wind turbine generation system and its influence on the power system, it is necessary to take into consideration the effects that go through the shaft and generator onto the electric parts of the wind generation system, which appear as harmonics in the electric power supplied to the grid. Approaches to simplify aerodynamic modeling of wind turbines have been presented in [1] and [2].

The main idea of those papers is to represent the interaction of turbine blades with the wind speed distribution over the rotor swept area in different wind speeds. The resulting wind data are then applied to the static power curve $C_p(\lambda)$ in order to determine the driving torque without considering the pitch angle control. The effect of turbulence and dynamic disturbance are shown in [3], where the wind turbine was modeled as a two-mass system. Turbine model with pitch angle control was introduced in [4], where the main idea is modelling a wind turbine simulator without considering the dynamic performance of the turbine and the coupled generator.

In this work, the static characteristics of a three blades wind turbine are modeled through the power equation containing the power coefficients $C_p$ as a function of the tip speed ratio λ and the pitch angle β as parameters. These coefficients are calculated for a 3.6 MW wind turbine. The effect of the blades asymmetry and vortex tower interaction are modeled as a set of harmonic signals added to the power extracted from the wind. The torsional torque of the drive train for variable speed wind turbines are also investigated in this paper. A detailed description of the modelling as well as simulation results are shown.

## 2. System Modeling

### *2.1 Wind turbine model*

The wind turbine is characterized by nondimentional curves of the power coefficient $C_p$ as a function of both tip speed ratio λ, and the blade pitch angle β. The tip speed ratio is the ratio λ of linear speed at the tip of blades to the speed of the wind. It can be expressed as [5]

$$\lambda=\frac{\omega R}{\upsilon} \tag{1}$$

where R is the blade radius[m], ω is the mechanical angular velocity of the blade[rad/s] and υ is the wind velocity[m/s]. For the wind turbine used in the study, $C_p$ is approximated as a function of λ and β as [5]

$$C_p(\lambda,\beta)=0.22\left(\frac{116}{\Lambda}-0.4\beta-5\right)e^{\frac{-12.5}{\Lambda}} \tag{2}$$

where

$$\frac{1}{\Lambda}=\frac{1}{\lambda+0.08\beta}-\frac{0.035}{1+\beta^3}$$

The output mechanical power of the wind

turbine $P_{turbine}$ can be calculated from the following equation

$$P_{turbine}=0.5C_p\rho\pi R^2 v^3 \quad (3)$$

where ρ is the air density.

*2.2 Mechanical oscillations*

The wind turbine construction causes excitation of various forces and torques acting on blades and tower. Blades asymmetrical and vortex tower interaction (shadow) are the main source of turbine mechanical oscillations, which can be expressed as a set of harmonics added to the extracted power. Therefore the oscillations can be defined by [5]

$$P_{oscillations}=\sum_{k=1}^{3}A_k\left(\sum_{m=1}^{2}a_{km}g_{km}(t)\right)h_k(t) \quad (4)$$

where

$$g_{km}(t)=\sin\left(\int_0^t m\omega_k(t)dt+\phi_{km}\right)$$

and Ak is the magnitude of the kth kind of eigenswing, ωk is the eigenfrequency of kth kind of eigenswing, hk(t) is the modulation of kth kind of eigenswing, m is the harmonics, gkm is the distribution of kth kind of eigenswing for the mth harmonic, akm is the normalized magnitude of akm, ϕkm is the phase of kth kind of eigenswing for mth harmonic and t is the time.

*2.3 Drive train model*

In order to model the drive train, the simple two-mass model in Fig. 1 is chosen [5]. The mechanical equations of turbine and generator inertia are

$$T_t-T_k=(J_t s+D_t+K/s)\omega_t \quad (5)$$

$$T_k-T_g=(J_g s+D_g+k/s)\omega_g \quad (6)$$

$$T_k=(\frac{k}{s}+D_{tg})(\omega_t-\omega_g) \quad (7)$$

where Tt is the aerodynamic torque referred shaft, Jt and Dt are the inertia and friction

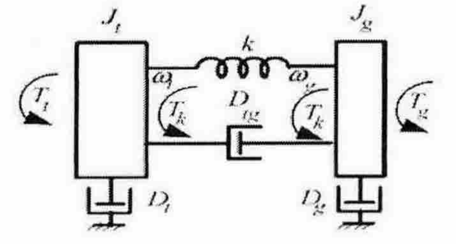

Fig. 1 Modeling of drive train

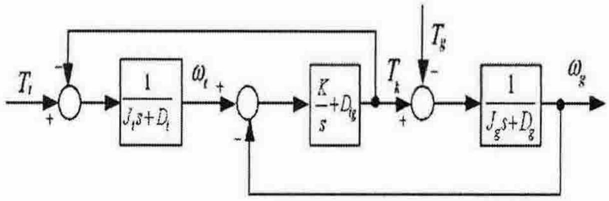

Fig. 2 Block diagram of a two-mass system

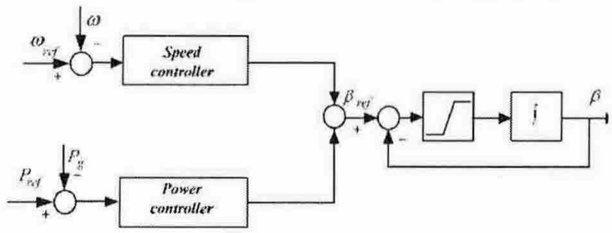


Fig. 3 Block diagram of wind turbine controller

to the high shaft respectively, Tk and Tg are the torque in the flexible coupling and in the electric generator respectively, Jg and Dg are the inertia and friction of generator side, respectively.

Fig. 1 gives the model of the two-mass system and Fig. 2 shows its block diagram.

*2.3 Pitch angle control*

The blade pitch angle is controlled over the wind speed range between the nominal value and shut-down value. In this region, the power output is limited to the nominal value.

Figure 3 shows the pitch angle control block diagram. The speed controller operates as a main controller in case of starting or shut-down. Then the reference speed value changes as required. When the generator power is less than the rated value, the pitch angle reaches the minimum value βref. At full load, the power controller operates as a main controller.

*2.4 Overall system*

The model of the wind turbine is composed of a wind speed profile, blade power calculations, asymmetry of blades, tower shadow effect, and a two-mass torsional drive train.

## 3. Simulation Results

The described wind turbine model has been designed and tested using the PSCAD. The turbine output torque is shown in Fig. 4(a).

The generated active and reactive power

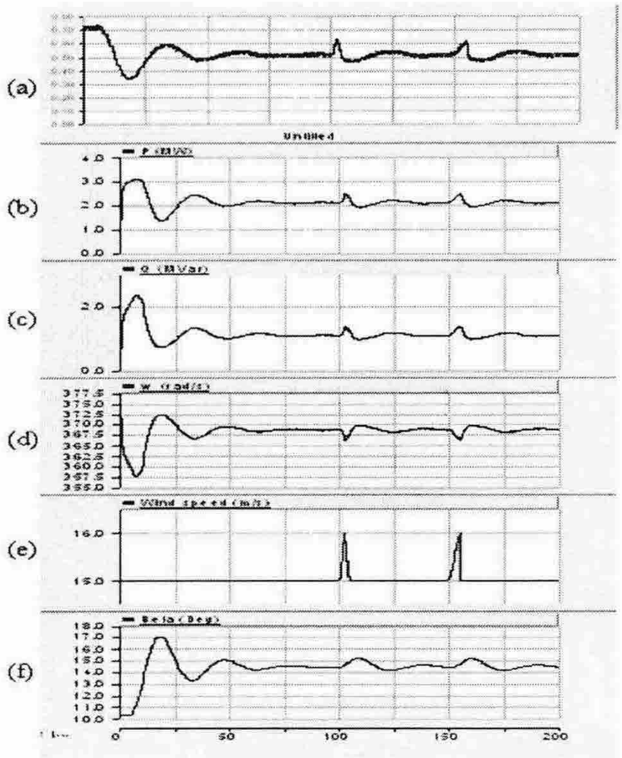

Fig. 4 Wind turbine characteristics

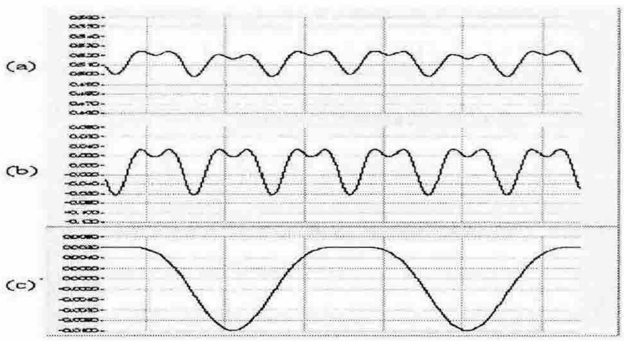

Fig. 5 Effect of tower

waveform are shown in case of constant speed and in case of smooth gusts in Fig. 4(b) and (c). In such cases, the power oscillation amplitude in case of disturbance is small and source of this oscillations is the blade torsional vibration. Fig. 4(d) shows the generator speed for wind speed variation. Fig. 4(e) represents wind speed and (f) shows the pitch angle control in order to keep the generated power constant.

Fig. 5(a) shows the effect of the blades passing in front of the wind turbine tower. The asymmetry of the blades and the individual effects are shown in (b) and (c).

Fig. 6 shows the mechanical torque response

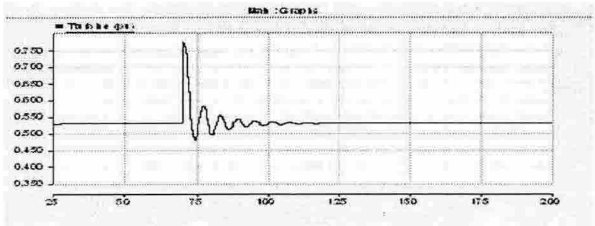

Fig. 6 Torque pulsation at abrupt wind speed change

in case of abrupt wind speed variation. The torque oscillation due to the torsional vibration is more pronounced in this case more than the smooth change in the wind speed. The torsional vibration source is the big difference between the inertia of the turbine and the generator.

## 4. Conclusions

A two-mass model for wind turbine generation system has been presented. The effects of the wind vortex interaction, blade asymmetry and torsional vibration have been investigated. Power limitation by controlling the pitch angle was also discussed. Simulation results show the wind turbine performance at smooth and sharp wind speed variation.

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