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Pre-dimensioning of the Dynamic Properties of the Wind Turbine System Using Analytical Approach

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Abstract. The higher complexity of the mechatronic wind turbine system requires taking a great effort from the early stage of the design process. Wind turbine power trains are subjected to a very diverse spectrum of dynamic loads. In order to obtain preliminary information about the dynamic behavior of the wind turbine system and its operating environment, the drive system model is developed in this paper. This model contains flexible and rigid structural components in order to predict the dynamic characteristics of the torsional vibration. All these structural components are systematically coupled in one analysis model, through a simple modeling process in Modelica/Dymola environment. Making the right technology and architectural choices early in the development program, will substantially decrease rework and related costs.

Keywords: Wind turbine, Flexible, Preliminary design, Torsional vibration, Modelica/ Dymola.

1 Introduction

Mechatronic is the synergistic integration of mechanical system, electronics components, actuators and sensors. The mechanical system can be seen as a multi physic system coupling the mechanical structure with other multi-physic subsystems such as electrical, thermal and electromagnetic (Hammadi et al. 2014). Integrated mechatronic design aims to analyze the behavior of the mechatronic system, taking into consideration the tight coupling between control and multi-physic system (Hammadi 2012).

The wind turbine can be considered as a typical mechatronic system which is consisting of mechanical, electrical and control subsystems interacting among

each other. It became an important choice for renewable electrical energy production throughout the world. Because of this, Investigation of wind turbines using numerical simulation becomes more and more significant.

Similar to all projects, the one of wind turbines is divided, with well-defined target, into successive phases. In every phase, operations have to be carried out and decisions must to be taken by various actors, taking into consideration the technical, environmental, economical and political issues.

In the past few decades, wind turbine technology has been substantially developed. Latest technology enables wind turbines to generate large electrical power in order to meet the energy demand. In fact, the aim of the modern wind turbine research is to maximise the output electrical power and to have stable power output with the minimum possible cost and with the instability of wind speed. To achieve this, specific information on the environmental loading and structure response is needed from the early phase of the design cycle of the wind turbine.

For instance, (Arbaoui and Aski 2010) developed a support tool for the preliminary design of a wind turbine. This approach is based on the development of a set of constraints derived from engineering knowledge, in order to support the different actors in making decisions about choices inherent to their activities in the field of wind energy. It targets to maximize the performance and to reduce the cost of the produced energy.

In the preliminary design phase, a quick overview on the environmental load of the wind turbine on its structure may be very useful. Moreover, in this phase a very few detail about the environmental parameters and the wind turbine structure is known. Therefore, to simulate the wind turbine requires just the most principal input data. In the last few years a lot of attention has been given to model the mechanical structure of wind turbine. For example, (Zhao et al. 2007) developed a new multi-rigid-body model for a wind turbine structure. In this approach, the flexible bodies like shafts, rotors blades and tower are modelled by a set of rigid bodies connected by cardanic joints geometrically and constrained by spring forces elastically. This methodology is adapted for the analysis of global vibration. (Chantharasenawong et al. 2011) proposed a preliminary design of the modular tower of 1.5-MW onshore wind turbine. This method is based on studying the increased tower base diameter effects on its tower mass and wall thickness.

(Lee et al. 2002) presented a new methodology to study the dynamic behavior of the wind turbine. This method is based on representing the wind turbine as a multi-flexible-body system. In fact, it is based on separating the complete system into rigid body (nacelle, hub) and flexible subsystems (blades, tower). The rigid bodies are modeled using Kane's method. This method allows reducing the complexity of the equations of motions for the multi-rigid body part. The tower and the blades are considered to be flexible in bending and torsion in two directions.

Extreme fatigue and structural loads are important issues in turbine design; the reduction of these loads might create a significant diminution in turbine cost by reducing required materials, decreasing maintenance, and improving global turbine reliability. Thus, applying new and innovative load control techniques can decrease excessive loads, which affect the mechanical structure of the system.

This engineering challenge pushes researchers to ameliorate the techniques of controlling rotors power and loads. Many published literature is available regarding wind turbine control. For examples, PID (proportional integral derivative controller) was used to control the rotor speed in order to regulate the output frequency of induction generator (Paret 2014). PID controller can also eliminate system error, adjust overshoot of the system and regulate rotor speed in order to capture the maximum rotor power (Hou 2014).

The objective of this paper is to propose a pre-dimensioning approach to study the influence of various parameters on the dynamic response of the wind turbine system driven in order to produce a suitable compromise between the viability, the cost as well as the quality of the energy produced. A proportional derivative integral Controller (PID) is used to control the aerodynamic power of the wind turbine. The organization of this paper is as following: the first section deals with this introduction. In Section 2, the wind turbine description is presented. In section 3, we introduce the modelling of the system using the modelling language Modelica. The results of simulation are shown in section 4. The conclusion of our paper is given in section 5.

2 Wind Turbine Description

The current wind power generation system is adapted to transform the slow rotation speed of the rotor side to a fast rotational speed of the generator side. It consists of a rotor, a low speed of the rotor shaft, a gearbox and a high-speed shaft of the generator rotor. The slow shaft is considered as flexible while the fast shaft is infinitely rigid. The flexible modes of blades are supposed high enough to be neglected and all the flexible modes are located in the flexible element of the slow shaft. We consider that the mechanical system is characterized by the sum of all the mechanical characteristics. We used then, the mechanical model of the drive system having two-mass which is very used in the literature as shown in Fig. 1.

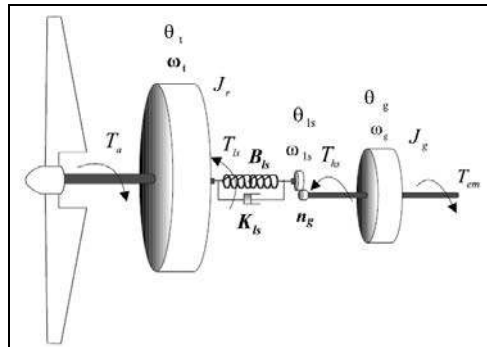


Fig. 1 Schema of the drive system with two masses

The masse inertia of the rotor side is represented by J_r , the slow shaft is characterized by a torsion coefficient B_{ls} and an elasticity K_{ls} , the fast shaft is rigid; the inertia of the fast shaft associated with the generator is represented by J_g .

The power available from the wind through a surface s is defined by:

$$P_v = \rho \cdot s \cdot v^3 \quad (1)$$

where, ρ is the air density and v is the wind speed.

The mechanical power of the wind turbine is then:

$$P_{tur} = C_p \frac{\rho \cdot s \cdot v^3}{2} \quad (2)$$

The power coefficient is defined by the ratio of the power received by the turbine on the wind power:

$$C_p = \frac{P_{tur}}{P_v} \quad (3)$$

The aerodynamic torque is given by this relation:

$$T_a = \frac{P_{tur}}{\omega_t} = \frac{1}{\omega_t} C_p \frac{\rho \cdot s \cdot v^3}{2} \quad (4)$$

Where, ω_t is the rotor speed.

The multiplier is the connection between the turbine and the generator in order to adjust the speed of the turbine with that of the generator. Friction, elasticity and wasted energy in the multiplier are neglected. For an ideal multiplier:

$$T_{ic} = n_g \cdot T_{hc} \quad (5)$$

where, n_g is the transmission ratio of the multiplier, T_{ic} is the torque of the slow shaft, T_{hc} is the torque of the fast shaft.

The rotor dynamic is characterized by a differential equation of the first order:

$$J_t \dot{\omega}_t = T_a - T_{ls} \quad (6)$$

$$T_{ls} = B_{ls} (\theta_t - \theta_{ls}) + K_{ls} (\omega_t - \omega_{ls}) \quad (7)$$

where, ω_{ls} is the speed of the slow shaft, θ_t is the angular position of the rotor and θ_{ls} is the angular position of the slow shaft.

The speed and the angular position of the generator

$$\begin{aligned} \theta_g &= n_g \theta_{ls} \\ \omega_g &= n_g \omega_{ls} \end{aligned} \quad (8)$$

3 Modelica Implementation

Exploiting the object-oriented features of the Modelica language, we implement the studied model in Modelica. The system may be composed of a connected set of objects using the standard Modelica library.

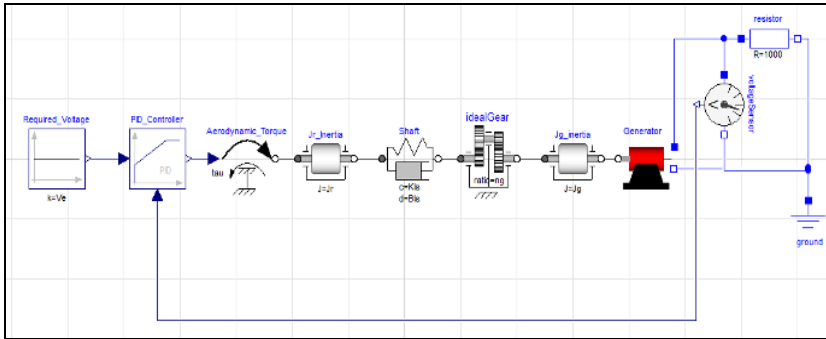


Fig. 2 Model of the system in Dymola/Modelica

The considered elements in the wind turbine modeling are: Control part (PID), torque, generator, inertias, spring, damper, ideal gear, voltage sensors, ground and resistor.

In order to control the output power, we used a control system. The PID controller checks the power output of the turbine. In fact, we used a voltage sensor to measure the voltage at the terminals of the generator. When the power output cross a threshold limit, it sends an actuating signal in order to adjust the input torque. We assume that the PID controller allows generating a maximum torque of 7000 N. m, and the desired generated voltage is about 700 V.

4 Parametric Study

After modelling the entire system, an analysis was carried out for different parameters. Figs.3 and 4 show the input torque and the measured voltage according to time.

Figs.3 and 4 show that when the measured voltage is very low, a maximum torque is needed (the rotor will rotate with a very quick speed) until the voltage reaches the value of 700V (the nominal value). After that, the rotor will run freely and the amplitude of torque tends to zero. Therefore, the PID controller tries to maintain the output voltage.

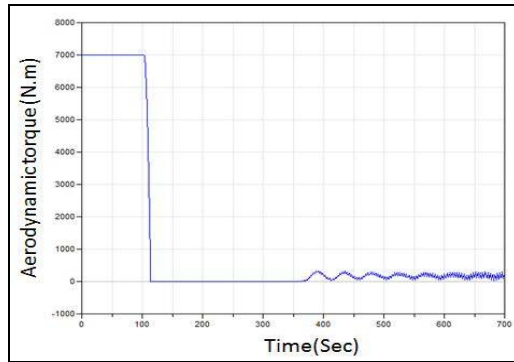


Fig. 3 Input torque (N.m)

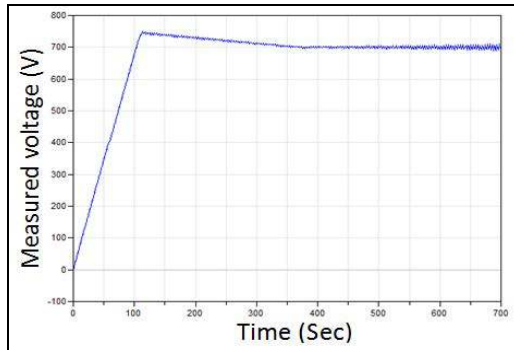


Fig. 4 Measured voltages (V)

To bring up the effect of the mechanical characteristic of the wind turbine on the output power, we observed the response of the system (the variation of the input torque and the measured voltage) for three values of the multiplier ratio ($n_g = 0.01$, $n_g = 0.02$ and $n_g = 0.03$) as shown in Figs. 5 and 6.

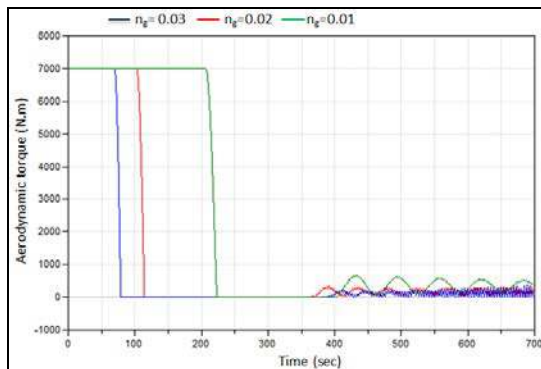


Fig. 5 Aerodynamic torque according to the multiplier ratio

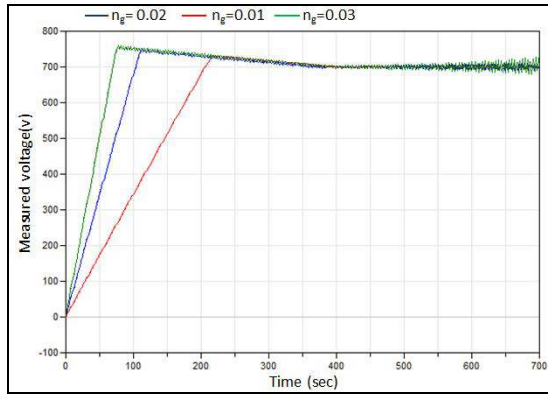


Fig. 6 Measured voltages according to the multiplier ratio

Figs. 5 and 6 illustrate that when $n_g = 0.03$, the measured voltage reached quickly the nominal value (700V) and the input torque lasts less time at the nominal value (7000 N.m). But we can notice also, that the fluctuation frequency on the two curves (torque and voltage) when $n_g = 0.01$ is the lower. We can deduce that the multiplier ratio has a great effect on the response time to generate electricity and that the right choice of the multiplier can reduce vibration and minimizing mechanical stresses in the wind turbine structure.

The mechanical properties have a great influence on the dynamic response of the wind turbine system. Fig. 7 shows the variation of the angular position of the generator according to the friction and the twist coefficients on the slow shaft. It can be seen that the angular position of the generator increases with the increasing of the two parameters (the twist and the friction coefficient) and then, the torsion vibration increases with the flexibility of the slow shaft. Therefore, we can deduce that the shaft characteristics have an important impact on reducing the torsional vibration of wind turbine components.

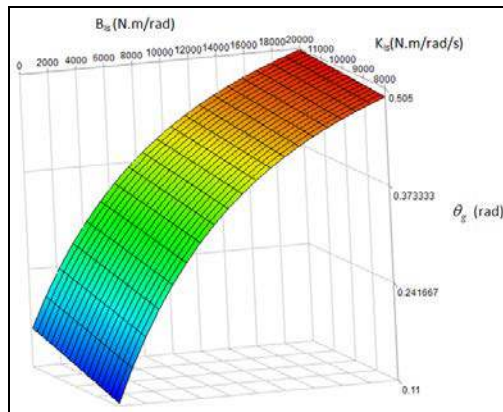


Fig. 7 Angular position of the slow shaft according to the twist and friction coefficient

Fig. 8 illustrates the variation of the angular position of the generator according to the multiplier ratio. As it can be seen, the angular position increases with the increasing of the multiplier ratio. So, despite the increase value of the multiplier ration has the advantage of quickly reach the value of the desired voltage, the increasing of this ratio has an important impact on the torsional vibration of the shafts.

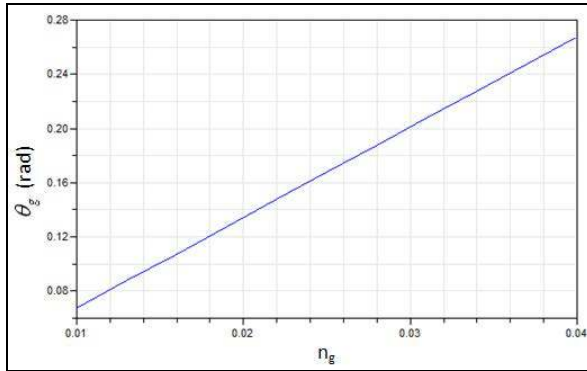


Fig. 8 Angular position of the generator according to multiplier ratio

Figs. 9 and 10 show the variation of the measured voltage according to diverse inertia values of inertia (mass inertia of the rotor side J_r and mass inertia of the generator side J_g)

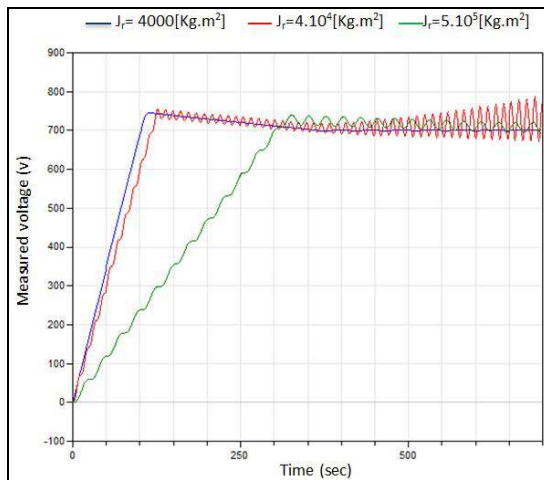


Fig. 9 Measured voltages according to different values of J_r

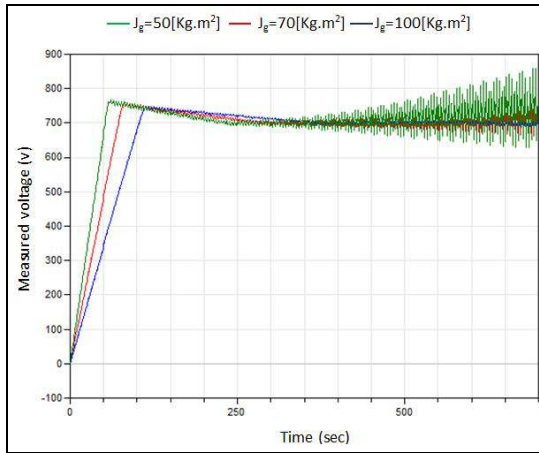


Fig. 10 Measured voltages according to different values of J_g

These figures show clearly that the output generated power depends enormously on the mass inertia of the rotor side as well as the mass inertia of the generator side. So, the more the inertia value decreases the more the desired tension value reached very quickly. Inertias of the rotating components have an influence on the output voltage value.

5 Conclusion

In this paper, we proposed a method of the preliminary design. This method allows studying the dynamic behaviour of the wind turbine drive system. In order to capture the pertinent characteristics, a two mass model has been used. A Proportional Integral Derivative (PID) controller is used to control the voltage produced in order to adjust the input torque and therefore to maximize the generated electric power. The system was simulating using Modelica/Dymola. This method can be useful to study the influence of various parameters on the mechatronical system response in order to regulate the output power and to minimize the mechanical vibration on various parts of the wind turbine.

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