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Wind turbine model simulation: A bond graph approach

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ABSTRACT

A wind turbine is composed by three principal parts (blades, gearbox and generator). In this paper each of them is represented by using the bond-graph methodology. Then, they are combined together in order to simulate the complete system. The complete aerodynamic model is simulated and validated using real data provided in the open literature (blade profile and gearbox parameters for a 750 kW wind turbine). Different simulations are carried-out in order to validate the proposed wind turbine model.

1. Introduction

Wind turbine is a complex system in which different technical areas are involved (mechanics, aeronautics, electrical, among others). Some recent publications deal with this topic, e.g. [1–3]. In [1] a parametric and nonparametric model is proposed using advantage algorithms, only the power curve is considered. Other contribution [2] reviews recent research of numerical simulation applied to wind energy and in [3] the modeling of a small-scale distributed power system containing the power demand, a wind turbine, the photovoltaic arrays and the electrical connection is presented. These contributions highlight the importance of having a reliable model of the wind turbine, in order to conduct dynamic studies of such a system. Nevertheless, the use of different techniques previously developed, and the complexity of a wind turbine make possible to visualize even different approaches for their study and analysis. Under this context, in order to analyze the system in the same reference frame, the bond-graph methodology [4–6] can represent the whole structure. This methodology presents some proprieties that can be applied directly to the model [7].

A bond graph consists of subsystems linked together by half arrows, representing power bonds. They exchange instantaneous power at places called ports. The variables that are forced to be identical, when two ports are connected are the power variables, considered as functions of time. The different power variables are classified in a universal scheme, and are called either effort $e(t)$ or flow $f(t)$. Their product $P(t) = e(t)\cdot f(t)$ is the instantaneous power flowing between the ports.

The main advantages of the bond graph tool for modeling purposes is summarized through few keywords, which makes this approach quite specific and justifies its use in the paper are the following:

- It provides the analyst with a unified graphical language to represent with physical insight power exchanges, energy dissipation and storage phenomena in dynamic systems of any physical domain.
- It allows the visualization of causality properties before writing equations, according to selected modeling hypotheses.

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- Some software exists with bond graph graphical editor, thus exempting the analyst from writing global equations.

The bond graph wind turbine model has been addressed in several works, e.g. [8–10]. In the first publication, a detailed model of a blade is proposed. The aerodynamic structural forces are considered, and also real data of a wind turbine are used, in order to calculate the output torque. Besides, it is a general model that can be applied to any wind turbine blade.

In [9] a six-mass drive train model is presented. This complete model is formulated and then simplified. The authors did not use real parameters of a wind turbine and the aerodynamics forces are not considered. In [10], a complete wind turbine based on parameters taken from a real turbine is proposed. The model presents all components of the wind turbine, but the aerodynamics are not considered in detail. The publication is centered on drive train effects.

In this contribution a complete bond graph model is presented, which accounts real data and parameters of a real wind turbine of 750 kW [11]. Also, this model will enlighten the connection (electricity production) to the power network. Besides, it will be used in a future work as a base, in order to formulate the control laws. These control laws will consider the dynamic behavior involved in each stage, e.g. blades or gearbox, with the purpose to compensate any perturbation due to a turbulent wind or a default in the gearbox.

Gearbox is the most important part of a wind turbine, because is at this stage where most of faults occur. It is estimated that a wind turbine has around 20 years of life span, but normally the gearbox needs to be replaced every 5 years [12]. It is for this reason that at present, big manufacturer companies of wind turbines have the intention to use a direct drive wind turbine without a gearbox.

Nowadays, most of the installed wind turbines have kept this configuration (using a gearbox). Actually, most of the 270 GW of wind turbine power is installed around the world with this configuration [13]. Based on this context, a model of the gearbox is presented in this paper. In terms of a bond graph methodology, gears have been modeled for transmission applications [14,15]. The model used here is based on the one reported in [16], in which a planetary gears is adopted. Also, in [17] a complete review of graphical tools for modeling gears is given. The authors conclude that bond-graph methodology has major properties, when compared to others.

The induction machine is normally operated as generator, but in some wind turbines a synchronous machine can be found (if used a direct drive wind turbine). For an induction machine, different arrangements have been used. In this paper a squirrel cage induction machine model is presented, in order to allow an easy connection to the external power network. This allows to handle the wind turbine without the power electronics converters required in other configurations i.e. doubly-fed, and also, because no control laws are presented in the paper.

The outline of this paper is as follows: in the first part, the wind turbine model is developed, and then main components are individuality shown. The complete model is also recalled and then simulated, reporting the verification of results. Conclusions of the conducted research investigation are drawn.

2. Presentation of the system

The wind turbine connected to the power network can be represented by Fig. 1. Every single part (blades, hub, bearing, etc.) of the wind turbine scheme in Fig. 1, is joined by a bond. In most of the elements there is an associated mechanical power, but the last part (generator) transforms this mechanical power into a three phase electrical power, represented by three bonds.

Different considerations can be made for the study of this system. Here, an analysis of the complete model is presented, by considering all the components as shown in Fig. 1. It is important to mention that a complex system, such as the wind turbine, needs different stages of control, which are not considered in this paper. The objective is only to show the complete wind turbine in a unified framework. This model will be used in a future work to formulate the control stages involved in it.

The main components identified in a turbine are: the blades, the gearbox and the generator. The function of blades is to convert the wind velocity into a torque, transforming the wind into a force and then into a torque. In Fig. 1 the causality of the first bond shows that torque is provided by the blades.

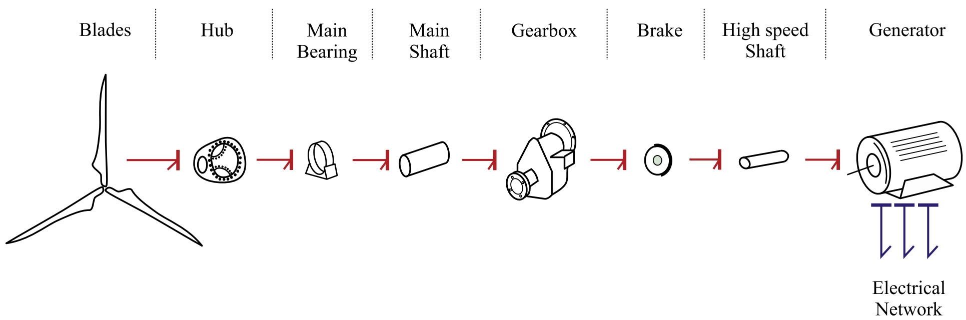

Fig. 1. Wind turbine presented in terms of word bond graph.