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Multibody modeling of varying complexity for dynamic analysis of large-scale wind turbines

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ABSTRACT

Guaranteeing a robust and reliable wind turbine design under increasingly demanding conditions requires an expert insight into dynamic loading effects of the complete turbine and its subsystems. Traditionally, aeroelastic codes are used to model the wind turbine, where the gearbox is reduced to a few or only one degree of freedom, as bring limitations to describe the dynamic behavior in detail. In this paper, the gearbox dynamic behavior is assessed by means of three multibody models of varying complexity, which are assessed based on modal and dynamic behaviors. This work shows that the fully flexible multibody dynamic model can better reflect the operating condition of the wind turbine. However, due to high calculation precision, the fully flexible multibody dynamic model consumes much times. Therefore, an artificial neural network method is proposed for the prediction of wind turbine dynamic behaviors. The results show that combination of the multibody method and the artificial neural network can reduce the simulation runtime, guaranteeing the accuracy meantime. Therefore, it is of great significance in engineering practice.

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1. Introduction

Wind energy has been the fastest-growing renewable energy source in the world for some time. At the end of 2014, the global total wind energy capacity had grown to approximately 370 GW [1], which is enough to cover about 4% of the world's total electricity [2]. The total global installed capacity of wind turbines during 1996–2014 is shown in Fig. 1.

However, due to the harsh environment, modern large-scale wind turbines are subjected to different sort of failures, such as main bearings, gearboxes, and generators [3]. Moreover, traffic inconvenience and downtime loss will make huge impacts on the cost of energy [4]. Thus the rapid development of wind power industry requires higher performance and reliability for equipments. If the reliable operation cannot be ensured, the actual utilization of wind turbines will decrease and operation and maintenance (O&M) costs will increase, both of which would greatly reduce the economic benefit of wind power [5].

Guaranteeing a robust and reliable wind turbine design under increasingly demanding conditions requires an expert insight into dynamic loading effects of the complete turbine and its subsystems. Traditionally, aeroelastic codes are used to model relevant external conditions, including aerodynamic loads [6,7], gravitational loads, inertial loads and operational loads. The latter includes generator torque, loads induced by certain control actions such as blade pitching, starting up, braking or yawing. According to Peeters [8,9], outputs of these wind turbine codes include load variations described by means of time series. Experts and research groups in the domains of wind loads, electricity grid, rotor dynamics, generator [10] and control systems [11] greatly contributed to these high-quality modeling techniques. However, as the wind turbine gearbox is reduced to a few or even one degree of freedom in these models, detail in describing the dynamic behavior is limited. Generally, the simulated outputs of the traditional wind turbine codes represent the mechanical loads at the rotor hub, i.e. at the interface between rotor and gearbox. These loads include load variations at the global level, but no dynamic detail of the drive train on component level. These global loads at the rotor hub are processed by the gearbox manufacturer into load spectra and equivalent loads at component

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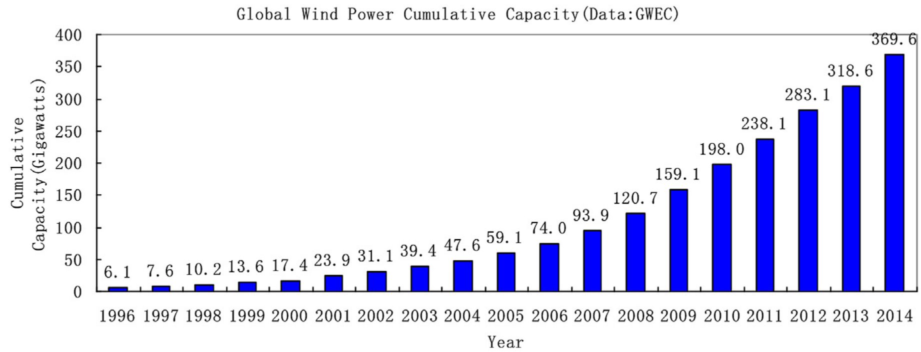

Fig. 1. Global cumulative installed wind capacity 1996–2014 [1].

level in accordance with current industrial standards. In this process, safety and application factors, according to DIN3990 [12] and DIN ISO281 [13], are used to calculate loads on gears and bearings. However, limited knowledge of dynamic loads at component level prevents full assessment under complex loading conditions, so the gearbox dynamic behavior cannot be fully understood. In addition, as wind turbines become increasingly larger in size. The internal flexibility of gearboxes has great influence on the overall dynamic behavior. It makes high quality complete turbine modeling based on the traditional techniques impossible and expresses the need for more advanced numerical simulation techniques.

As the key in modeling the detail of a complete turbine lies in the gearbox, multibody techniques of varying complexity are investigated in this paper to model the gearbox. These techniques can be classified according to the complexity as:

① Torsional rigid multibody model;
② Six degrees of freedom rigid multibody model;
③ Flexible multibody model.

This paper firstly describes and compares the three modeling techniques. Meanwhile, three models are established respectively and compared based on simulations. This work shows that the flexible multibody model can better reflect the operating process of the wind turbine; corresponding simulation and calculation results match better with the actual working conditions of the wind turbine; thus it is of great significance in practical engineering applications. However, due to highly precise calculations, this technique consumes much time. Therefore, based on data from the multibody technique, an artificial neural network technique is proposed for analysis and prediction of wind turbine dynamics. The results show that the trained artificial neural network can accurately predict the dynamic behavior of the wind turbine. Combination of the two technologies may reduce the simulation time, ensuring precise prediction meantime. Therefore, it is of great significance in engineering practice.

2. Introduction of 5 MW wind turbine

The research object of this paper is a 5 MW wind turbine of CSIC (Chongqing) Haizhuang Windpower Equipment Co., Ltd. (as shown in Fig. 2). The turbine features a 154 m rotor diameter and is suitable for both onshore and offshore sites. The company's latest and largest product incorporates a high-speed geared drive system with permanent magnet generator (PMG). 5 MW wind turbine designs feature a single rotor bearing with a short hollow main shaft and a direct flange connection to the gearbox. The combination with a cast main carrier is considered to offer a robust and compact turbine layout, without compromising serviceability, including gearbox exchange. This design has been yield-optimized for Wind Class III + conditions, whereby the '+' stands for additional built-in capability for extreme weather conditions as defined within IEC Wind Class II (50 m/s). CSIC spent three years developing this 5 MW turbine. Now the prototype was installed at the Rudong

Fig. 2. 5 MW wind turbine.

Table 1
Main parameters of 5 MW wind turbine.

Performance	Parameter
Rated power (MW)	5
Control	Variable speed and variable pitch
Drive-train	High speed, multi-level gearbox
Rotor diameter (m)	154
Cut-in, cut-out and rated wind speed (m/s)	3, 25, 11.4
Rated rotating speed of rotor (rpm)	11.3
Number and direction of blades	3 blades, upwind direction

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