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Nonlinear torsional vibrations of a wind turbine gearbox

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ABSTRACT

This paper studies the torsional vibrations of wind turbine gearbox having two planetary gear stages and one parallel gear stage. The nonlinear dynamic model developed considers the factors such as time-varying mesh stiffness, damping, static transmission error and gear backlash. Both the external excitation due to wind gust and the internal excitation due to static transmission error are included. With the help of time history, FFT spectrum, phase portrait, Poincare map and Lyapunov exponent, the effects of the static transmission error, mean-to-alternating force ratio and time-varying mesh stiffness on the dynamic behaviour of wind turbine gearbox components are investigated by using the numerical integration method. It is found that the external excitation has the most influence on the torsional vibrations of the wind turbine gearbox components. The mesh stiffness, being another significant factor, has more influence than the other internal excitation source, the static transmission error. The static transmission error has the least influence.

1. Introduction

Gearbox is an important component for large modern wind turbines incorporated either by a squirrel cage induction generator or a doubly fed induction generator. Wind turbine gearboxes have distinct features from standard gearboxes. They are used to increase the rotor speed to a speed suitable for the generation of electricity and operate under varying load conditions, while standard gearboxes are designed to step down from high speed to low speed and operate under full load conditions. The modern wind energy industry has been experiencing high gearbox failure rates since its inception. In 2006, The German Allianz received 1000 wind turbine damage claims. One of the common maintenance requirements is to replace the gearbox every five years over the 20 year design lifetime of wind turbines [1].

As shown in Fig. 1, the wind turbine gearbox is located in the middle of the wind turbine drivetrain [2]. The hub is attached to the nacelle frame. The rotor blades attach to a low-speed shaft, and the gearbox connects the low-speed shaft to the high-speed shaft and converts the low rotor speed and high torque to high speed and low torque to meet the electromechanical requirements of the generator. In the context of vibrations, a wind turbine gearbox can be considered as a complex dynamic system that is subjected to highly complex loading. Large torques of gearbox may lead to contact loss of the missing teeth and produce time-varying mesh stiffness. In addition to high torques, the shaft of the gearbox is subjected to the drag force and the bending moments produced by lift forces, weight and imbalance of rotor and blades. The

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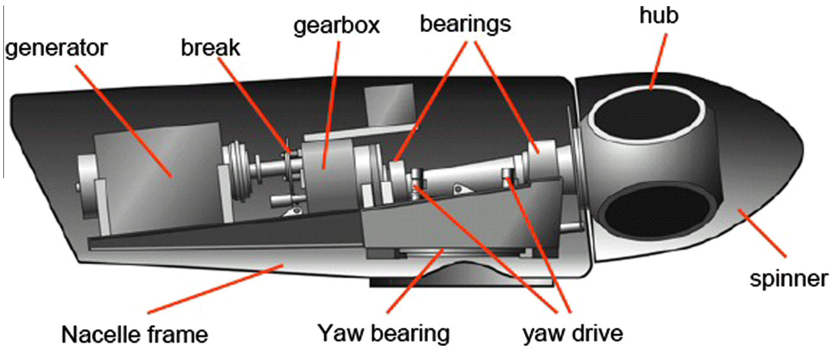

Fig. 1. Wind turbine drivetrain with gearbox [2].

bending moments applied on the input side of shaft can cause variable loads on the teeth to change dramatically. Under such variable loading, vibrations inherently exist within the entire drivetrain.

Gearbox has been the cause of many major reliability problems for the modern wind energy industry. Most vibration problems in wind turbine gearboxes can be considered to be generic in nature, meaning that the problems are not specific to a single gear manufacturer or turbine model [3]. Consequently, vibrations in gearbox has received significant attention from both the industry and researchers as an understanding of failure modes and failure sources could provide useful information to reduce the possibility of gearbox failures at the beginning stage. Due to its complexity and distinct nature, the fundamental failure mechanisms have not been fully understood, to the authors' best knowledge.

The present work focuses on studying the torsional vibration of wind turbine gearboxes by considering several key factors. Both the low-frequency excitation due to external torque fluctuations and the high-frequency internal excitations due to the static transmission error are considered. This paper is organised into seven sections. The published work regarding wind turbine gearboxes and relative theories are listed in Section 2. The nonlinear torsional dynamic model of wind turbine gearbox and equations of motion are discussed in Section 3. Section 4 presents parameter specifications and validation of the simulation program. Results are presented and discussed in Section 5. Conclusions are given in Section 6.

2. Material and methods

A brief review of the existing studies of wind turbine gearbox and drivetrain is given below. Peeters et al. [4–7] developed three types of multi-body models to investigate the dynamics of a wind turbine drivetrain. They found that resonance occurs when the meshing frequencies are close to the natural frequencies of the drivetrain, which leads to large amplitude vibrations and may even to the drivetrain failure. Oyague [8] developed a number of analytical models to investigate the dynamic behaviour of the internal components of a wind turbine drivetrain. The results from these models revealed that the level of complexity does not significantly affect torsional behaviour, but are capable of providing important insight into the loading conditions for the bearings of the gearbox. Coultate et al. [9] studied a new method for the accurate calculation of gear and bearing damage of the wind turbine drivetrain. They found that three-point mounting on shaft is more sensitive to

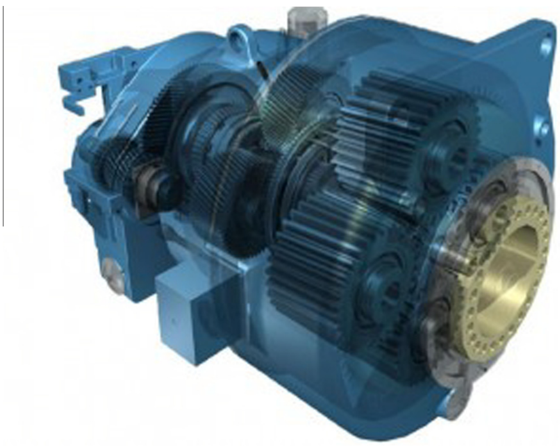

Fig. 2. Wind turbine two-planetary-stage gearbox from GR drivetrains.