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Assessment of Gearbox Operational Loads and Reliability under High Mean Wind Speeds

Dariusz Dąbrowski[a]*, Anand Natarajan[a]

[a]*Dept. of Wind Energy, Technical University of Denmark, Risø campus, Roskilde 4000, Denmark*

Abstract

This paper investigates the dynamic loads occurring in the drivetrain of wind turbines with a focus on offshore applications. Herein a model of the gearbox of the 5 MW wind turbine is presented. The model is developed in a multi-body framework using commercial software MSC ADAMS. Validation of the model was based on the experimental data provided by NREL for 750 kW prototype gearbox. Failures of gearboxes caused by high dynamic loads have a significant influence on the cost of operation of wind farms. For these reasons in the study, the probability of failure of the gearbox working in an offshore wind turbine that operates in storm conditions with mean wind speeds less than 30 m/s is presented. In the study, normal shut-downs of a wind turbine in storm conditions were investigated. The analysis were conducted for two storm control strategies and different wind conditions from an extreme operating gust, normal turbulence model and extreme turbulence model. In the paper, loads in the planetary gear are quantified as well as the torsional moments in the main shaft. On the basis of simulation results the annual probability of failure of the gearbox in a wind turbine with soft storm controller is calculated, and compared with the one had the gearbox working in a wind turbine operating with hard storm controller. In the study, it was found that normal shut-downs do not have a significant influence on the ultimate loads in the gearbox, since they are related mostly to the gusts occurring during turbulence. Application of the storm controller with reduction of the wind turbine power allowed the decrease of the probability of failure for ultimate stresses.

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Keywords: gearbox model; extreme gearbox loads; offshore wind energy; relaibility assassment; multibody; planetary gear

* Corresponding author. Tel.: +45-935-111-55.
E-mail address: dard@dtu.dk

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1. Introduction

Offshore wind turbines are exposed to the extreme events such as emergency stops, wind gusts and grid losses, that often occur at mean wind speeds near 25 m/s. These events can have significant influence on the reliability of wind turbine drivetrains, especially of gearboxes. Despite the well-defined international standards, gearboxes require repairs before the expected lifetime is reached. In the lifetime of a wind turbine gearbox repairs and replacements have to be done even few times, what have significant influence on the overall energy costs [1]. In spite of the great efforts of the manufacturers to improve gearboxes design, their failures are still a main reason for downtimes of wind turbines. Nowadays, gearbox related failures are responsible for over 20% of downtimes of wind turbines [2], and they need replacement after 6–8 years which is much less than expected 20-years of failure free operation [2, 3]. Several basic problems that influence wind turbine gearboxes reliability can be listed [4]: the majority of wind turbine gearbox failures initiate in the bearings, mostly failures are not directly related to the quality issues and most of the problems are not specific to a single gear manufacturer or turbine model. To cover the risk due to the possibility of gearbox failures, wind turbine manufacturers increase significantly the sales price what increased cost of the electrical energy produced by wind farms. To reduce these prices one solution is to increase reliability of gearboxes components [5, 6]. Gearboxes mounted in offshore wind turbines are exposed to extreme loads due to emergency stops, wind gusts and grid losses that occur at high mean wind speeds. In order to reduce these loads proper storm control strategy can be applied.

The traditional controller strategy applied in wind turbines will shut-down the turbine when the mean wind speed reaches the cut-out value, which is usually 25 m/s. When the mean wind speed drops below the shut-down value, the wind turbine starts again. However, many offshore wind turbines are equipped with a storm control system so that the wind turbine does not shut-down at 25 m/s mean wind speed, instead has reduced power and operation till mean wind speeds of 30 m/s, an example of which can be the Enercon Storm Control System [7, 8].

At high mean wind speeds, significant dynamic loads occur in the gearbox components. These loads may be reduced by application of a proper storm control strategy. In this study, particular attention is paid to the loads in the planetary gear. Simulations of the wind turbine drivetrain are performed using appropriate generator control and blade pitch control algorithms. Normal shut-downs are simulated at mean wind speeds from 24 m/s to 28 m/s at different blade pitch angles and with normal turbulence, extreme turbulence and gust inputs. In the study, loads in the planetary gear are quantified and compared for other operation scenarios. On the basis of maximum loads the probability of failure of the gearbox is calculated and compared for other investigated storm control strategies.

2. Multibody Model of 5 MW Drivetrain

2.1. Reference Gearbox

In the study, the preliminary design of a 5 MW gearbox was developed by application of upscaling rules to the 750 kW prototype, of which the technical documentation, tests and field data were provided by NREL [1, 9]. The upscaling rules applicable to wind turbines were defined by Sieros et al. [10]. The authors stated that if geometrical similarity is enforced, the weight and power in a wind turbine scale according to $m \sim s^3$ and $P \sim s^2$ where s is the scaling factor. Scaling in such a way, moments corresponding to the aerodynamic forces follow the s^3 rule, so the gearbox input torque will increase cubically. Sieros et al. presented general upscaling rules applicable to wind turbines but for upscaling of a gearbox, detailed information related to the geometry and inertia of gears, torsional stiffness of shafts, bearing stiffness and contact parameters are required. Basic upscaling rules applicable to gearboxes parameters are presented hereunder.

The radial stiffness of a roller bearing without clearance working under pure radial loads and line contact on each raceway can be defined as follows [11]