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A prognostic method for fault detection in wind turbine drivetrains

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ABSTRACT

In this paper, a prognostic method is presented for fault detection in gears and bearings in wind turbine drivetrains. This method is based on angular velocity measurements from the gearbox input shaft and the output to the generator, using two additional angular velocity sensors on the intermediate shafts inside the gearbox. An angular velocity error function is defined and compared in the faulty and fault-free conditions in frequency domain. Faults can be detected from the change in the energy level of the frequency spectrum of an error function. The method is demonstrated by detecting bearing faults in three locations: the high-speed shaft stage, the planetary stage and the intermediate-speed shaft stage. Simulations of the faulty and fault-free cases are performed on a gearbox model implemented in multibody dynamic simulation software. The global loads on the gearbox are obtained from a dynamometer test bench and applied to the numerical gearbox model. The method is exemplified using a 750 kW wind turbine gearbox. The case study results show that defects in the high- and intermediate-speed bearings can be detected using this method. It is shown that this procedure is relatively simple, yet accurate enough for early fault detection in wind turbine gearboxes.

1. Introduction

The trend in wind turbine development is toward applications farther offshore, in deeper waters, using larger, multi-megawatt turbines. Difficult and costly offshore access, maintenance limitations and environmental restrictions demand new design considerations compared to land-based turbines. Moreover, the loadings on drivetrains, in particular on floating wind turbines, are very different than those on onshore turbines [1]. Gearbox solutions for offshore development demand higher reliability, availability, maintainability and serviceability (RAMS) than land-based designs.

Maintenance, in general terms, is classified into corrective and preventive actions [2]. Among preventive actions, condition monitoring (CM) is one approach to improving wind turbine availability. Condition monitoring is based on the fact that an incipient defect can be detected from changes in the system conditions. A condition monitoring system comprises sensors and data acquisition systems that collect vibration, noise, temperature and strain measurements or oil particle data during a predefined period, either online with an integrated measuring system or offline with portable instruments, on a regular basis [3].

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Nomenclature

Abbreviations

INP-A	main shaft bearing
PLC-A, B	planet carrier bearings
PL-A, B	planet bearings
LS-SH-A, B, C	low speed shaft bearings
IMS-SH-A, B, C	intermediate speed shaft bearings
HS-SH-A, B, C	high speed shaft bearings
Main SH	main shaft
IMS SH	intermediate speed shaft
LS SH	low speed shaft
NREL	National Renewable Energy Laboratory
GRC	Gearbox Reliability Collaborative
TE	transmission error
LC	load case
FFT	fast Fourier transform
LMD	local mean decomposition
CM	condition monitoring
RAMS	reliability, availability, maintainability and serviceability

Variables

$\mathbf{M}$	mass/inertia matrix of gearbox components
$\mathbf{C}$	damping matrix of gearbox components
$\mathbf{K}$	stiffness matrix of gearbox components
$\mathbf{x}$	displacement matrix of gearbox components
$\mathbf{F}$	force/moment matrix applied on gearbox components
ω_{MS}	angular velocity, main shaft
ω_{LS}	angular velocity, low speed shaft
ω_{IMS}	angular velocity, intermediate speed shaft
ω_{HS}	angular velocity, high speed shaft
e	angular velocity error
e_{LS}	angular velocity error, low speed shaft
e_{IMS}	angular velocity error, intermediate speed shaft
e_{HS}	angular velocity error, high speed shaft
e_t	total angular velocity error
α	inverse gear ratio
Z	number of gear teeth
ϕ	angular position
f_m	gear mesh frequency
f	frequency range
f_x	frequency range for fault x
$E^*()$	normalised energy function
$\phi()$	frequency spectrum

Today, there are many condition monitoring systems available in the industry. In gearboxes and drivetrains, noise and vibration signal processing are used for fault detection [4–7]. For example, Elforjani and Mba [8] as well as Ghazali et al. [9] demonstrated the application of acoustic emission technology to detect damage in a single bearing in a test rig. Randall used acoustic measurements and proposed a signal decomposition method to distinguish the signals from gears and bearings in a gearbox [10]. Liu et al. [11] proposed a local mean decomposition (LMD) method that was applied to the gear mesh frequency signal. Wind turbine gearbox fault detection through vibration analysis was also investigated by Feng et al. [12]. Vibration measurement is claimed to have a high hardware cost and to produce false alarms [13]. Gearbox vibration is normally measured through sensors installed on the gearbox housing and supports. Although the overall health of a gearbox can be monitored by measuring the vibration of the housing, it is not possible to find the root cause or to detect the faulty gear or bearing component. One solution is to instrument all the gears and bearings, but this is neither practical nor cost effective in the wind energy sector. Another option is to use a vulnerability map of the gearbox, as introduced by Nejad et al. [14], which can be developed based on analysis during the design phase and used in conjunction with vibration data obtained during an inspection.