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# Diagnostic monitoring of drivetrain in a 5 MW spar-type floating wind turbine using Hilbert spectral analysis

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## Abstract

The objective of this paper is to investigate the frequency-based fault detection of a 5MW spar-type floating wind turbine (WT) gearbox using measurements of the global responses. It is extremely costly to seed managed defects in a real WT gearbox to investigate different fault detection and condition monitoring approaches; using analytical tools, therefore, is one of the promising approaches in this regard. In this study, forces and moments on the main shaft are obtained from the global response analysis using an aero-hydro-servo-elastic code, SIMO-RIFLEX-AeroDyn. Then, they are utilized as inputs to a high-fidelity gearbox model developed using a multi-body simulation software (SIMPACK). The main shaft bearing is one of the critical components since it protects gearbox from axial and radial loads. Six different fault cases with different severity in this bearing are investigated using power spectral density (PSD) of relative axial acceleration of the bearing and nacelle. It is shown that in severe degradation of this bearing the first stage dynamic of the gearbox is dominant in the main shaft vibration signal. Inside the gearbox, the bearings on the high speed side are those often with high probability of failure, thus, one fault case in IMS-B bearing was also considered. Based on the earlier studies, the angular velocity error function is considered as residual for this fault. The Hilbert transform is used to determine the envelope of this residual. Information on the amplitude of this residual properly indicates damage in this bearing.

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*Keywords:* Floating Wind Turbine; Wind Turbine Gearbox; Fault Detection; Envelope Analysis; Hilbert Transform; Condition Monitoring

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## 1. Introduction

One of the main objectives in wind turbines (WT), like any power generation approach, is to lower the cost of energy (COE), which is the ratio between the total lifetime cost and the total generated energy during a WT lifetime. Unlike conventional power plants, wind turbines (WTs) are exposed to severe and highly variable environmental disturbances and, for floating turbines, also the fluctuating mechanical loads due to waves. These external factors

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contribute to large amount of downtime and high operation and maintenance (OM) costs during WTs typical operational lifetime of 20 years [1]. OM costs are estimated to be 10-15% of a total turbine cost for onshore WTs. Increase in WTs size and more WTs deployed offshore raises OM costs up to 20-25% of a total turbine cost for offshore WTs [2]. OM costs, therefore, represent a significant share of the total cost for offshore wind energy [2]. In this respect, condition monitoring (CM) can play a significant role.

Using condition-based maintenance (predictive maintenance) instead of periodic maintenance (preventive maintenance) maximize the reliability and minimize the maintenance cost of WTs [3]. Despite of the general development in WT industry, its condition monitoring is still premature. The use of other industries condition monitoring techniques needs adaption in order to be used in WT industry [3]. A failure mode, effects and criticality analysis (FMECA) is required to consider all the major assemblies and the effects of their failure on the overall turbine performance [4]. Many researchers have investigated the WT dynamic global responses due to different dominant failures [5, 6]. WTs undergo the highest downtime due to failure in gearboxes [7]; accordingly, effective signal processing for gearbox defect detection and diagnosis is becoming an active research area.

A review of wind turbine gearbox monitoring techniques using data acquisition and CM techniques was presented in [8]. CM techniques are classified into model-based and signal-based approaches with the common feature that residuals are generated to monitor changes in the system. Residuals are signals that are sensitive to faults but robust to noise and unknown disturbances [9, 10]. Model-based techniques may have high complexity and the modelling part may be a significant engineering effort [11, 12]. Reduced order model techniques are new approaches in the area to derive a wind turbine model for this purpose [13, 14]. On the other hand, signal-based approaches avoid dynamic modelling and look instead at changes in the properties of residual signal. Signal-based approaches include vibration-based, oil and debris analysis [15, 16] and non-destructive test, such as thermography and ultrasound analysis [17, 18]. Most of the WT gearbox failures initiate from bearing degradation [19, 20], as bearings protect gears from non-torque loads in axial and radial directions. Likelihood ratio test (a time-domain approach) was investigated in [21] to detect the fault in the main shaft bearing of a floating WT. Probabilistic neural network (PNN) and a simplified fuzzy adaptive resonance theory map (SFAM) were used in [22] to distinguish between seven bearing status. In many industrial applications, it is hard to access bearings inside a gearbox due to the location of the equipment and the choice of the implemented sensors; C.P. Mbo'o and K. Hameyer offered a bearing fault detection using the frequency analysis of stator current using linear discriminant analysis and the Bayes classifier [23].

In this study, the possibility of fault detection of damage in two different bearings in 5MW gearbox is investigated exploiting relative axial acceleration and angular velocity error function. The damage in this context is the worn condition - primarily due to fatigue - and initiation of fatigue cracks. Fatigue for rolling bearings is defined by ISO 15243 as “the change in the structure, which is caused by the repeated stress developed in the contacts between the rolling elements and the raceways” [24]. Such damage and degradation mechanism can be modelled by local stiffness reduction [25-27] which is employed in this paper.

The remainder of the paper is organized as follows. Section 2 gives a detailed explanation of the WT and the drivetrain model. Section 3 explains the seeded faults in SIMPACK and the detection methodology. Section 4 presents the fault detection results. Finally, Section 5 concludes the paper.

## 2. Wind turbine and drivetrain model

A 5 MW reference gearbox [28] mounted on the floating OC3 Hywind spar structure [29, 30] is used in this study. This WT is a 3-bladed upwind WT with characteristic features shown in Table 1. The spar-floating structure is a column-shaped structure connected by mooring lines to the seabed. The spar structures have a large draft and a small waterline area. The details of the spar structure analyzed in this paper were described by Nejad et al. [31]. The 5 MW reference gearbox used in this study was developed by Nejad et al. [28] for offshore WTs. The gearbox consists of three stages: two planetary and one parallel stage gears. Table 2 shows the general specifications of this gearbox. Fig.1