Fatigue Analysis of Wind Turbine Gearbox Bearings using SCADA Data and Miner’s Rule

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Objectives

The gearbox is one of the important subassemblies within a wind turbine (WT), in respect of downtime. High bearing failures have been observed in modern WT gearboxes. The premature failure of gearbox bearings causes unplanned WT shutdowns and early bearing replacements, reducing WT availability and increasing the cost of energy.

Due to the stochastic nature of wind, a WT gearbox experiences a wide loading variation during its service life, which is difficult to predict. Operational control of the WT is intended to maximise wind energy extraction and minimize turbine damage under extreme wind conditions however it complicates the loading condition.

This study aims to use recorded SCADA field data to analyse loading characteristics of a wind turbine to derive the loading histograms applied to the WT gearbox. By investigating wind speed, rotor speed and power output time histories, the relationship between these three parameters can be established. Therefore, cyclic loading conditions, caused by wind speed variation and WT operational control, can be considered for analyzing gearbox bearing performance and predicting fatigue life.

Methods

This work has developed a weighted average method to derive the relationship between rotor and wind speeds from SCADA data. Rain-flow counting has been applied to determine the number of loading occurrences at different load values. A typical WT gearbox design with one planetary and two parallel stages has been used in this work [1]. Damage ratios of high speed shaft (HSS) bearings have been predicted using this data by the application of Miner’s rule [2]:

\[ \frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \ldots + \frac{n_i}{N_i} = 1 \]

where \( n_i \) = No. of cycles at \( i^\text{th} \) load value; \( N_i \) = No. of cycles to failure at \( i^\text{th} \) load value; \( n_i/N_i \) = Damage ratio at the \( i^\text{th} \) load value.

The number of cycles at \( i^\text{th} \) load value can be determined by:

\[ n_i = \alpha \cdot N \]

where \( \alpha \) = Cycle Ratio (fraction of cycles) at the \( i^\text{th} \) load value; \( N \) = Resultant fatigue life (total cycles).

Results

The SCADA data used in this study were recorded over a period of 29 months on one WT without gearbox problems. Figure 1 shows the WT load distribution recorded at 10 minute intervals. By calculating the weighted average of the rotor speed at different wind speed values, the relationship between rotor and wind speeds can be generated, as shown in Figure 2.

Only results obtained for the high-speed shaft (HSS) of the gearbox are given here. Figure 3 shows the load histogram of the HSS right-hand side roller bearing. For both left- and right-hand side (LHS & RHS) bearings the majority loading is below the rated loading, however, approximately 20% of the Cycle Ratio range is above the rated value, as can be seen in Fig. 3.

Figure 1: Wind speed distribution

Figure 2: Rotor speed vs. wind speed

Figure 3: Load histogram of RHS bearing

Figure 4: Damage ratios of LHS and RHS bearings

Conclusions

- SCADA data can be used to analyze the load variation and its effects on gearbox fatigue damage.
- For the WT analyzed, the majority of HSS bearing loading values are below the rated load; however, there is a noticeable overload Cycle Ratio of more than 20%.
- Peak loads cause significantly higher bearing damage even though they are present for short periods of time.
- The damage distributions show that peak loads are more damaging to the HSS RHS bearing than to the LHS bearing.

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References