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Assessment of sideband energy ratio technique in detection of wind turbine gear defects

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ABSTRACT

Gearbox failure is one of the highest risk events in wind turbines. In most of the wind turbines, planetary gearboxes are preferred over conventional gearboxes due to their significant advantages. But condition monitoring of planetary gearboxes present a huge challenge to the vibration analysts due to complex design and construction of its unit, vibration transducer type and locations, wide frequency range of the vibrations, resolution required to separate frequencies and dynamic range required to observe both low frequency and high frequency components in the spectrum.

Due to strong Gear Mesh Frequency (GMF) signals, gear defect vibration characteristics can often be suppressed in the overall vibration signal. So there is a need to develop or utilize various special signal processing techniques in order to identify and monitor the progression of defects in gears more effectively.

This paper focuses on one such technique namely Sideband Energy Ratio (*SER*) for monitoring of gear defect progression in wind turbine gearboxes. Theory behind *SER* is and its significance in gear defect monitoring is presented in this paper through three case studies. In all the three case studies, *SER* of 2XGMF were found to be more sensitive than 1XGMF towards gear defect progression.

1. Introduction

Gearbox failure is one of the highest risk events in wind turbines [1]. In most of the wind turbines, planetary gearboxes are preferred over conventional gearboxes due to their advantages [2]. Gear defects in a planetary gearbox have been extremely difficult to detect and track at an early stage. The present study showcases the application of *SER* in gear defect monitoring for wind turbine gearboxes.

2. Literature survey on various condition monitoring techniques for wind turbine gearboxes

Hanna et al. [3] investigated the significance of *SER* in detection of gear tooth defects. For gear damage detection, the sideband distributions were used to estimate the gear meshing condition and *SER* was used to qualitatively evaluate the

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gear damage. A comprehensive review of the state-of-art of condition monitoring and fault diagnosis techniques for wind turbine gearboxes has been carried out by Mengyan Nie et al. [4] and stressed the importance of advanced signal processing techniques and data mining strategies. Hameed Z et al. [5] made an attempt to review maximum approaches related to Condition Monitoring of wind turbines. Pierre Tchakoua et al. [6] provided a general review and classification of wind turbine condition monitoring (WTCM) methods and techniques with a focus on trends and future challenges. C.Hatch [7] stressed the importance of Acceleration enveloping technique in wind turbine condition monitoring. Wei Teng et al. [8] found out that Empirical Mode Decomposition is a more powerful technique than conventional demodulation techniques using Hilbert transform for identification of gear pitting failures in a wind turbine gearbox. James C. Robinson [9] found that analysis of stress waves proved to be an effective diagnostic tool for fault detection and severity assessment in gearboxes. Shawki Abouel-seoud et al. [10] through experimental studies found that Root Mean Square (RMS) value analysis could be a good indicator for early detection and characterization of faults.

3. Sideband energy ratio (SER) technique

The vibration of the machine is a physical motion. Vibration Transducers convert this motion into an electrical signal. The electrical signal is then passed on to analyzers. The analyzers then process this signal to give the Fast Fourier Transform [FFT]. The most widely used conventional analysis in the frequency domain is the spectrum analysis using FFT. The most commonly used tool in spectrum analysis is power spectrum which is a positive real function of a frequency variable associated with a stationary stochastic process, or a deterministic function of time, which has dimensions of power per hertz (Hz), or energy per hertz, which is often called simply the spectrum of the signal. Intuitively, the spectral density measures the frequency content of a stochastic process and helps identify periodicities. In this paper, frequency-domain analysis is utilized for calculation of *SER*. Theory behind calculation of *SER* is explained in this section.

3.1. Calculation of SER

3.1.1. Modulations

Modulations, frequently seen in vibration measurements on gearboxes are caused by eccentricities, varying gear-tooth spacing, pitch errors, varying load, etc. [11]. Sidebands appear in a spectrum around a center frequency and generally occur as a result of modulation of that center frequency. A damaged gear within the gearbox can cause this phenomenon because the damaged tooth will produce modulations (Combination of Amplitude and Frequency modulations) of its associated GMF each time it passes through the mesh. That modulation occurs once per revolution of the shaft that the damaged gear is mounted on. When viewed in a spectrum, this modulation shows up as a series of spectrum lines at evenly spaced frequencies on either side of the Center Mesh Frequency (CMF). These sidebands occur at frequencies of $\omega_{GM} \pm n\,(\omega_S)$, where ω_{GM} is the associated gear mesh frequency, 'n' is an integer of 1 or higher (although we only use $n = 1$–6 in the *SER* calculations [3]) and is the rotational frequency of the shaft with the damaged gear.

SER are calculated by summing up the amplitudes of the first six sideband amplitude peaks on either side of CMF and dividing by the amplitude of CMF [3].

$$\mathrm{SER} = \frac{\left(\sum_{n=1}^{6} \text{Sideband Amplitude}_{\mathrm{n}}\right)}{\text{CMF amplitude}} \tag{1}$$

The assessment of SER as gear health monitoring parameter is evaluated from three case studies,

- Case study #1 Broken HS Pinion tooth in a 3MW gearbox,
- Case study #2HS Gear wheel pitting in a 2MW gearbox and
- Case study #3 IS Pinion Tooth Crack in a 1.8MW gearbox.

Gearbox test set up, Condition Monitoring System (CMS) setup, Data collection, GMF Calculations, Analysis & Results are covered in the following sections.

4. Test setup

The Reliability test is performed to verify the reliability of the gearbox. The testing methodology is based on transferring the stressors (load, speed, gradients of Torque and speed, etc.) from the WTG operation to the test rig modes. The reliability test period is about nine months, which is equivalent to twenty years life of Gearbox at field operating conditions.

Fig. 1 shows the general arrangement of gearbox test stand. The test rig can be controlled at either constant or variable speed, depending on the user's requirements. The test bench contains a drive arrangement comprising motor and a slave gearbox (step down), which drives the "gearbox (step up) under test or master gearbox". This master gearbox is then coupled