Current-Based Diagnosis for Gear Tooth Breaks in Wind Turbine Gearboxes

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CONCLUSIONS

1. A mathematical model has been developed to derive the characteristic frequencies in generator stator current measurements for a WT gearbox with gear tooth breaks.

2. A fault detector based on statistical analysis on the stator current signatures has been developed for diagnosis of the gear tooth defects.

3. Experiments have been carried out for a two-stage gearbox under constant-speed conditions to validate the mathematical analysis and the proposed fault detector.

4. Results have shown that the characteristic frequencies can be clearly observed in the frequency spectra of the generator stator current signal and gear tooth breaks can be effectively identified by using the proposed fault detector.

RELIABILITY ANALYSES

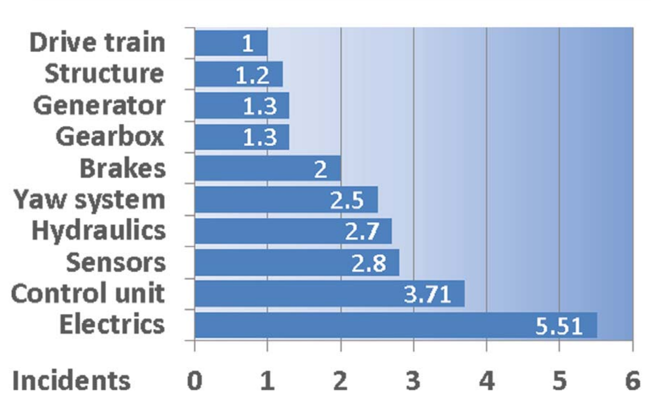


Fig. 1: Incidents per ten machine years.

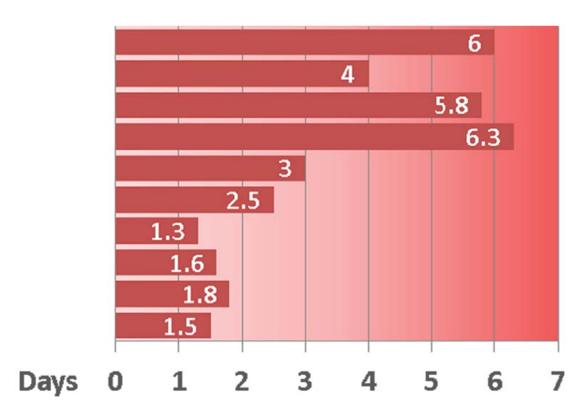


Fig. 2: Days per failure.

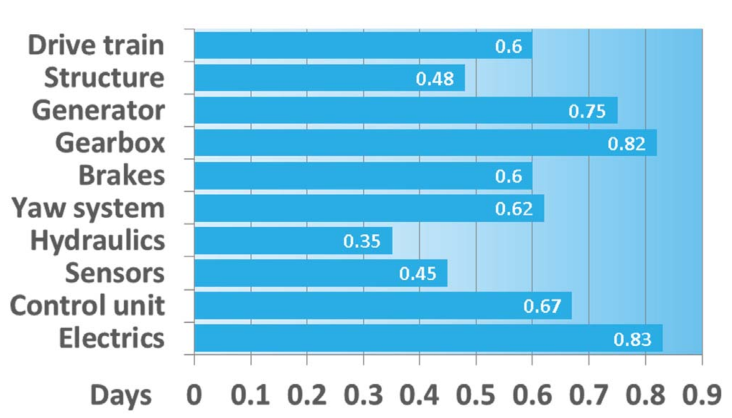


Fig. 3: Total days out per year.

CHARACTERISTIC FREQUENCIES

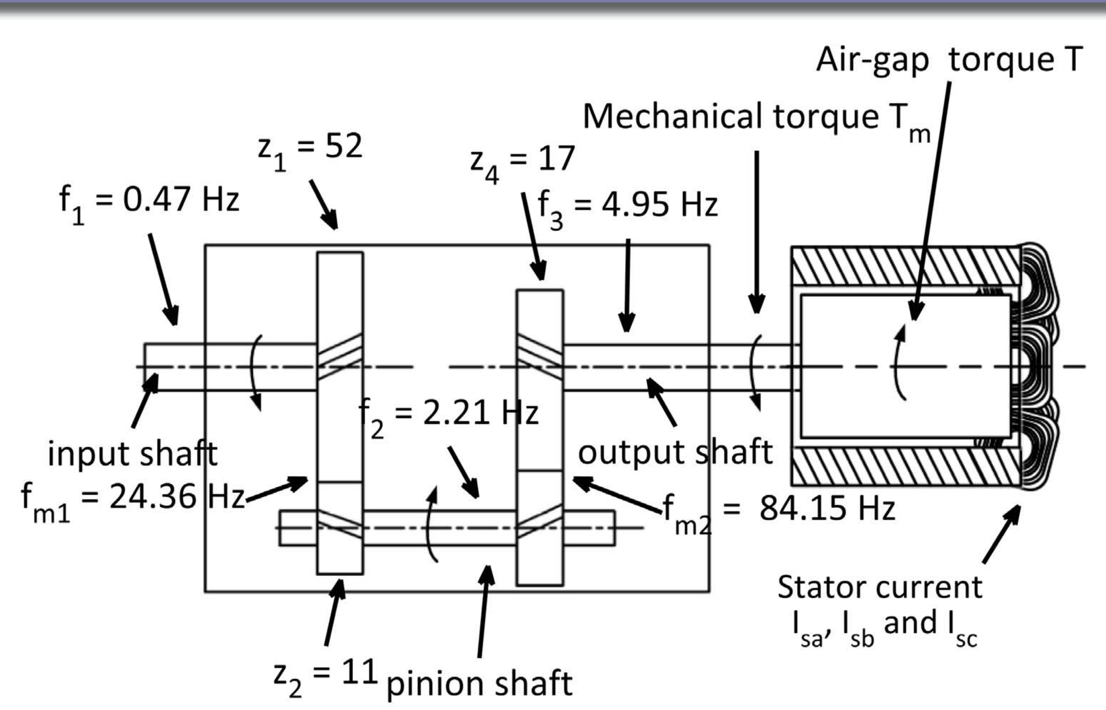


Fig. 4: Schematic of a two-stage gearbox connected to a PM machine with characteristic vibration frequencies.
f_1: input shaft frequency f_2: pinion shaft frequency f_3: output shaft frequency
f_{m1} & f_{m2}: mesh frequencies $z_1 \sim z_4$: tooth number

$$T = T_0 + T_1 cos(2\pi f_1 t + \Phi_1) + T_2 cos(2\pi f_2 t + \Phi_2) + T_3 cos(2\pi f_3 t + \Phi_3) \quad (1)$$

$$I_{sT} = I_{sT0} + A_{sT1} cos(2\pi f_1 t + \Phi_{T1}) + A_{sT2} cos(2\pi f_2 t + \Phi_{T2}) + A_{sT3} cos(2\pi f_3 t + \Phi_{T3}) \quad (2)$$

With the existence of torsional vibrations, the stator current will be modulated by these vibrations. For example, the A-phase current can then be written as:

$$\begin{aligned} I_{sa} &= I_{sM} sin 2\pi f_s t + I_{sT} \cos 2\pi f_s t \\ &= I_{sM0} sin 2\pi f_s t + [I_{sT0} + A_{sT1} cos(2\pi f_1 t + \Phi_{T1}) \\ &\quad + A_{sT2} cos(2\pi f_2 t + \Phi_{T2}) + A_{sT3} cos(2\pi f_3 t + \Phi_{T3})] cos 2\pi f_s t \end{aligned} \quad (3)$$

where A_{sTi} $(i = 1, 2, 3)$ represent magnitude of each current component.

$$\begin{aligned} I_{sa} &= I_0 cos 2\pi f_s t + ½A_{st1}[cos(2\pi (f_s - f_1) t - \Phi_{T1}) + cos(2\pi (f_s + f_1) t + \Phi_{T1})] \\ &\quad + ½A_{st2}[cos(2\pi (f_s - f_2) t - \Phi_{T2}) + cos(2\pi (f_s + f_2) t + \Phi_{T2})] \\ &\quad + ½A_{st3}[cos(2\pi (f_s - f_3) t - \Phi_{T3}) + cos(2\pi (f_s + f_3) t + \Phi_{T3})] \end{aligned} \quad (4)$$

FAULT DETECTOR

$$M'_i = M_i \Big/ \textstyle\sum M_i / 6 \quad (5)$$

$$M = ½(M'_{fs-ft} + M'_{fs+ft}) \quad (6)$$

$$NPD_j = M_{fault} - M_{health} \quad (7)$$

M_i $(i = 1 \ldots 6)$ is the magnitude of each frequency component. The resulting normalized power difference NPD_j, $(j = 1,2,3)$, between the healthy case and tooth break case can be utilized to identify the gearbox fault.

EXPERIMENTAL STUDIES

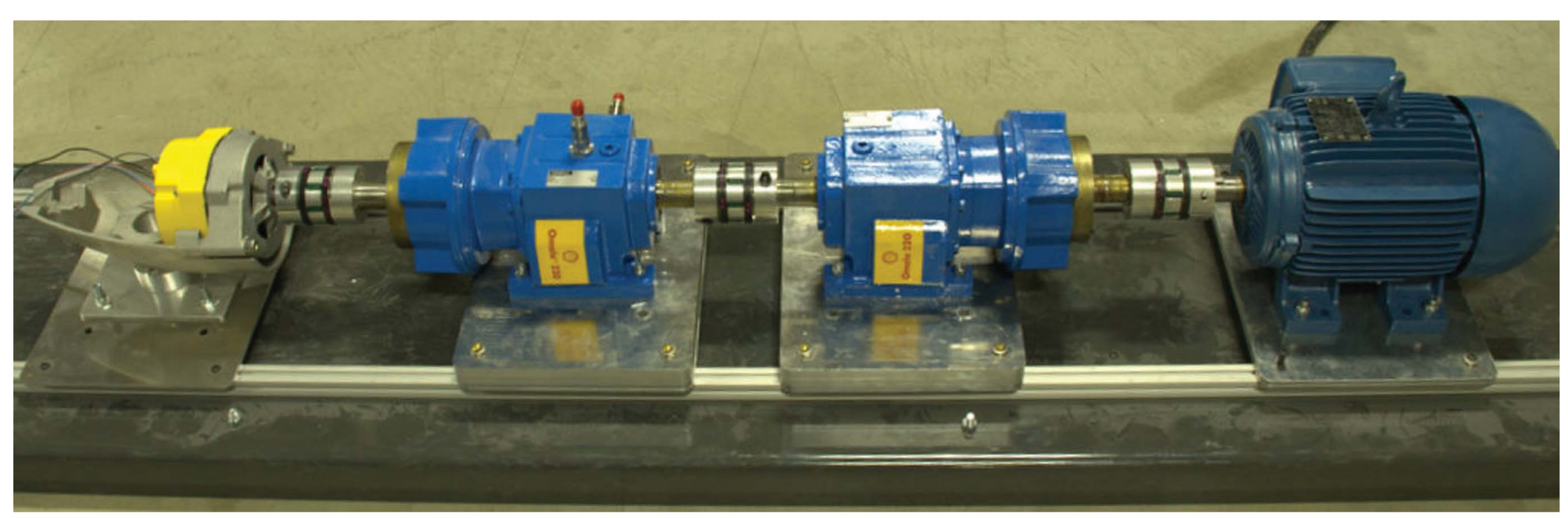
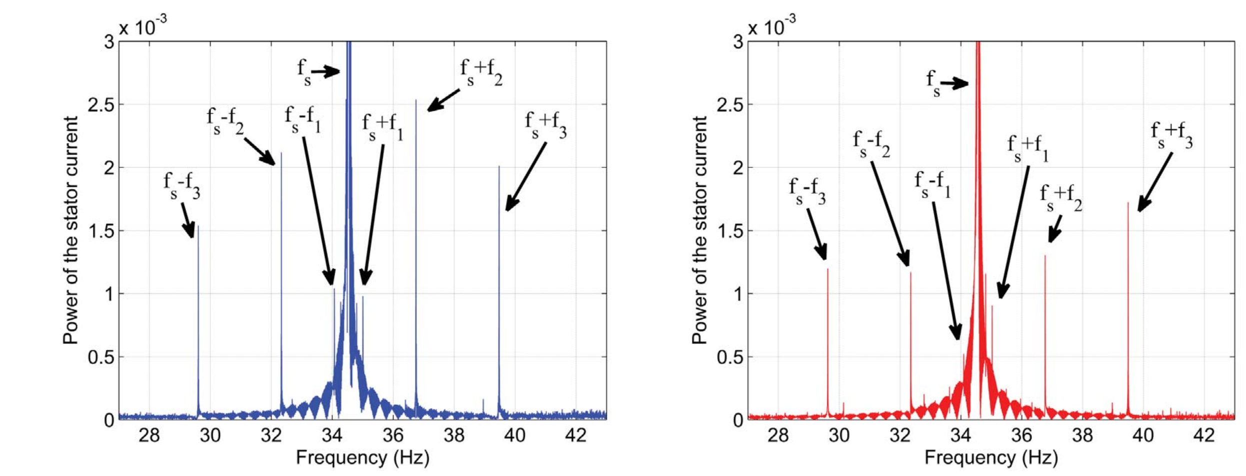


Fig. 5: The experimental system. From left to right: EXTRACTOR wind turbine, testing gearbox, speed reducer and induction machine.

Fig. 6: The testing gear with one tooth removed.

The testing gear is mounted at the input shaft of the testing gearbox and pretreated by removing one gear tooth, as shown in Fig. 6. By mounting the WT on the foundation through a single pole, the test bed (Fig. 5) is specially designed to simulate a real WT running under harsh conditions in nature environment. The system is tested for constant-speed conditions. One phase stator current of the PM generator is recorded via a Fluke current clamp and NI DAQ system with a sampling rate of 10 kHz. The current samples are acquired by the NI LabView installed in a laboratory computer. The length of the data record is 210 seconds.

RESULTS & ANLYSES



(a) healthy gear case (b) tooth break case
Fig. 7: Fundamental component of the stator current and its sidebands.

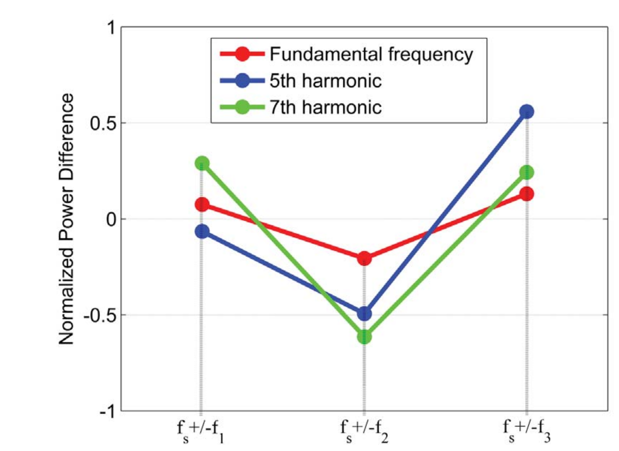
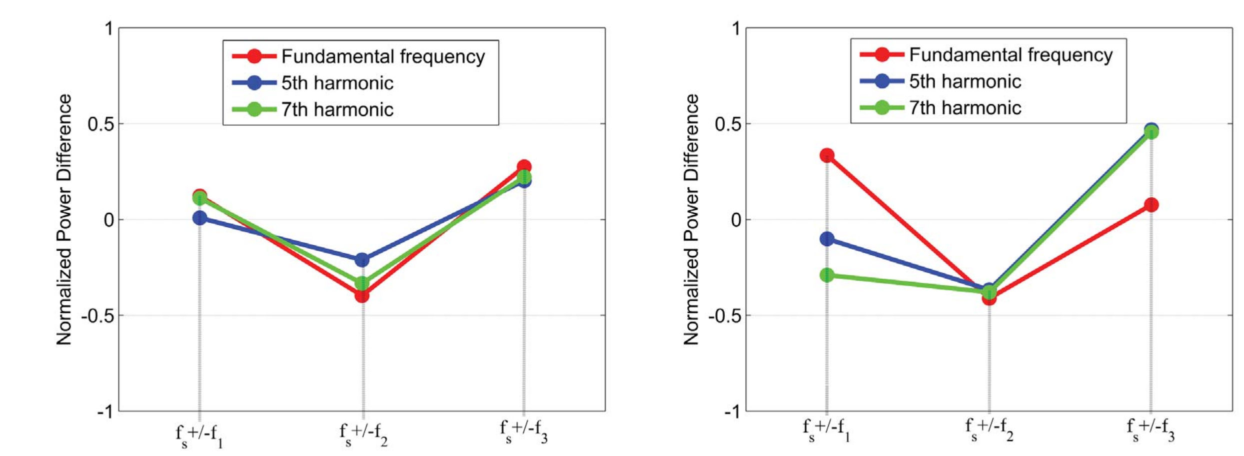


Fig. 8: Comparison of NPDs at 10% load and 297 RPM of the PM machine.



(a) 2% load and 297 RPM (b) 10% load and 891 RPM
Fig. 9: Comparison of NPDs at various speed and loads.

1. Fundamental component of the stator current and its sidebands are observed in both healthy gear case and tooth break case. The observation verifies the theoretical derivation of the characteristic frequencies.

2. Gear tooth break fault has altered the sideband distribution.

3. Changes in the NPDs of the sidebands can be used as an operative index for effective detection of the tooth break fault, which is called a "V-shape" fault detector.

ACKNOWLEDGMENT

This work is supported by the University of Nebraska-Lincoln, the U.S. Department of Energy under Grant DE-EE0001366, the Nebraska Center for Energy Sciences Research, and the Nebraska Public Power District.

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