Failure and remaining useful life of wind turbine generators

Alan Turnbull, James Carrol, Alasdair McDonald

Wind & Marine Energy Systems CDT, Rm 3.36, Royal College Building
University of Strathclyde, 204 George Street, Glasgow, G1 1XW

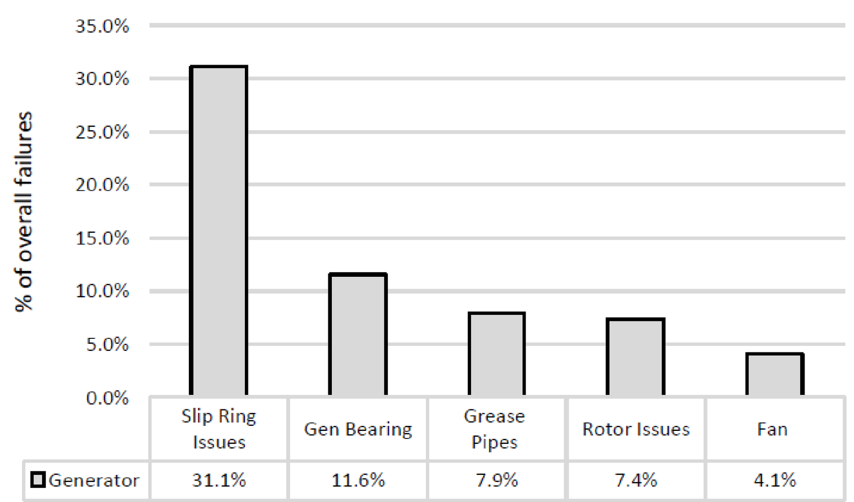
a.turnbull@strath.ac.uk

Context

With the current trend of larger wind farms being designed for sites further offshore, the use of intelligent condition monitoring systems to correctly predict the remaining useful life of turbine components is becoming increasingly important. The levelised cost of energy can be reduced by improving availability of the turbine as well as costs associated with repair and replacement.

Reliability of wind turbine generators

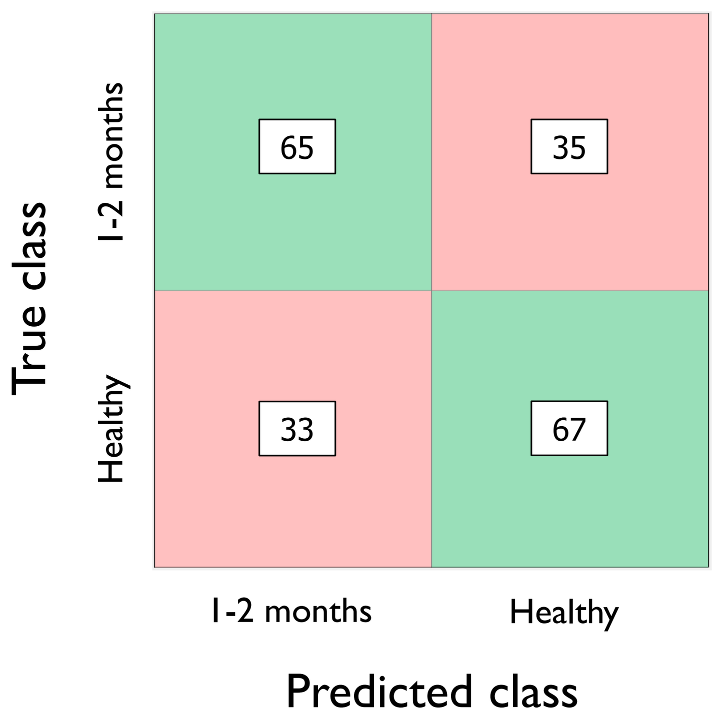
Generator faults can contribute significantly to the overall downtime experienced by a wind farm due to component failure, with around 1 failure per year in state of the art offshore wind turbines. Faults in the generator can be both mechanical or electrical, with the most common types of mechanical failure being due to mechanical looseness, misalignment and rotor imbalances within the system. The figure below shows the largest contributors to failure modes related to generators and associated failure rate [1].



[1] J Carroll, A McDonald, D McMillan, Failure Rate, *Repair Time and Unscheduled O&M Cost Analysis of Offshore Wind Turbines*

Application of machine learning algorithms for fault prognosis

Once features were successfully identified and verified, machine learning algorithms were then trained. Both decision trees and support vector machine algorithms were tested and the best chosen and applied to the set of features specific to the failure mode, classifying the condition according to whether it is healthy or not, and the time before failure. The algorithm was then tested against unseen vibration data from wind turbines omitted from the training process. The prognostic process was evaluated, using a confusion matrix giving correct/incorrect classification and the likelihood of false positives/ negatives. The example below shows results for a 2-class systems trained and cross-validated using 100 samples of each classification.

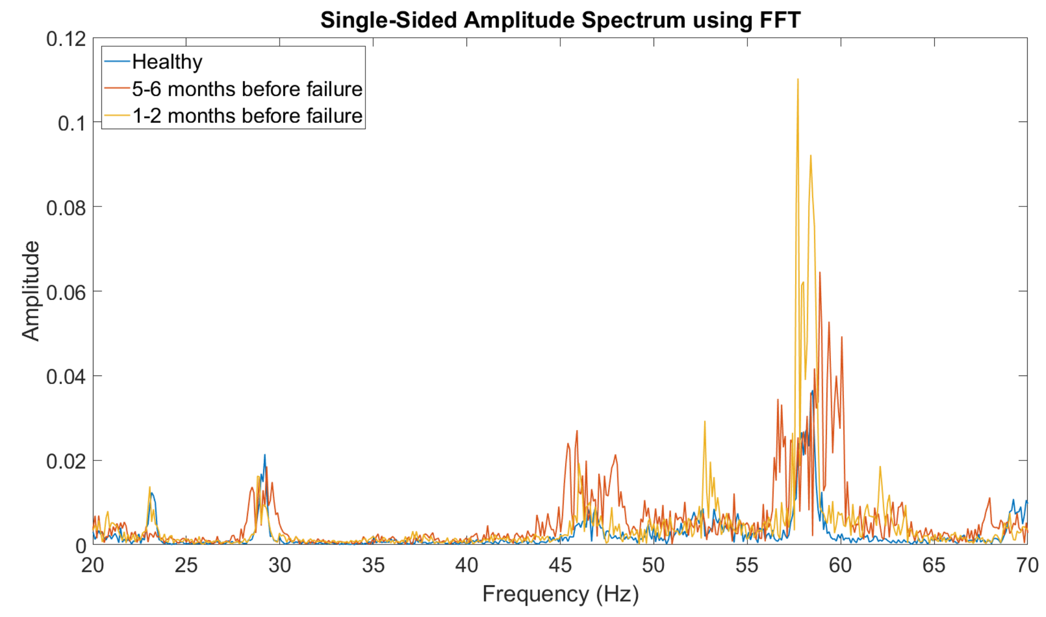


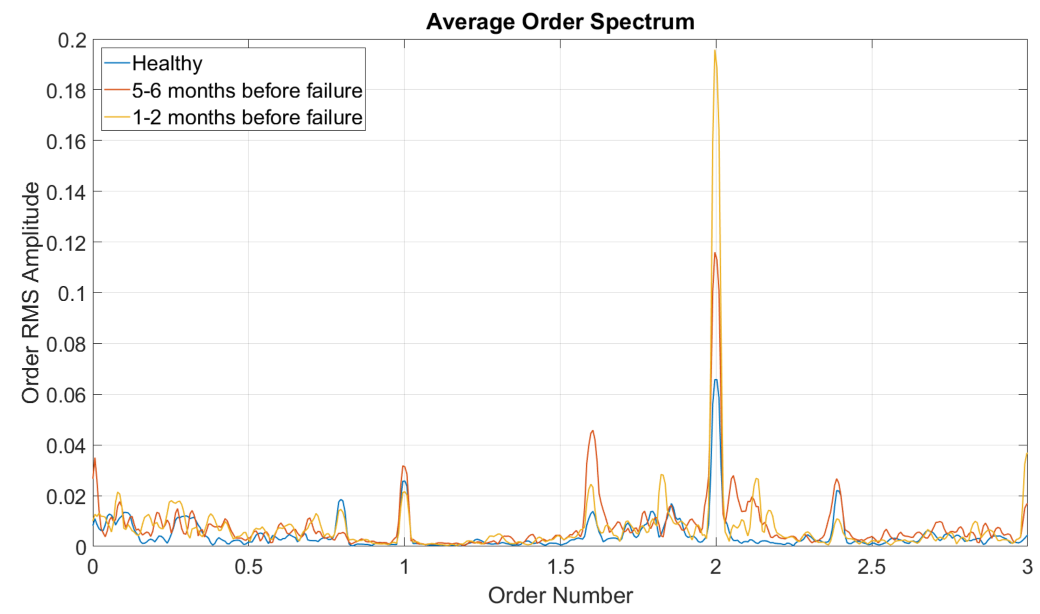
Vibration analysis

This investigation utilises data from eight different wind farms, with at least one wind turbine from every site, each with a doubly fed induction generator (DFIG) of identical power rating. The same generator bearing failure was identified in each machine and vibration data was gathered leading up to its failure. The vibration data gathered consists of at least seven samples 1 year, 5-6 months and 1-2 months before failure. A sample was taken from both the drive-end and non-drive end generator bearing and lasts approximately 10s with a sampling frequency of approximately 25kHz.

A variety of techniques have been used to analyse the data generated from the vibration signal including statistical analysis, order analysis and frequency domain analysis. This allows for key frequencies associated with the fault to be identified and features extracted. By looking at the Fast Fourier Transform (FFT) spectra at these frequencies at different times prior to failure, the amplitude and shape of the spectral peaks can be observed, tracked and compared over time.

It can be observed that at 1-2 months before failure, the order RMS amplitude visibly increases at 2× the rotational speed of the generator shaft, which is consistent with literature surrounding generator faults associated with mechanical looseness. This feature is apparent in both the order and frequency domain, and was primarily extracted to train the machine leaning algorithm for fault prognosis.





Future work

Future work related to this failure mode will involve refining and improving the model with the following steps;

1. Try different techniques to both extract features from the vibration signal and train the machine learning algorithms
2. Analyse SCADA data over the same period leading up to failure to identify more indicators of failure
3. Combine SCADA analysis and vibration analysis techniques

Other areas of interest are;

- Other failure modes associated with generators
- Cost benefit analysis of component replacement considering likelihood of premature replacement vs major failure of generator
- Failure identification using generator current signatures

EPSRC Pioneering research and skills
CATAPULT Offshore Renewable Energy
DNV·GL
SKF
futureWind & Marine 2018