Advanced Algorithms for Wind Turbine Condition Monitoring and Fault Diagnosis

Raed Kh. Ibrahim, Simon J. Watson

Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, UK.

SUPERGEN WIND Wind Energy Technology

Loughborough University

Abstract

Reliable and efficient condition monitoring (CM) techniques play a crucial role in reducing wind turbine (WT) operations and maintenance (O&M) costs for a competitive development of wind energy. Two algorithms are proposed to track the useful and valuable features related to the fault in the WT current signals which are corrupted by strong noise due to the constantly varying shaft rotating speeds and varying loads of the turbines. The performance of the proposed algorithms is validated using experimental data, that had sustained a rotor unbalance fault, from a WT drive train test rig at Durham university. The results demonstrate that the proposed approaches can successfully extract the fault features under two different fault levels at variable speed conditions.

Objectives

- Develop a low cost, non-intrusive, WT condition monitoring, diagnostic and prognostic methods.
- Detect early abnormalities and forecast the expected degree of deterioration over a particular time frame.
- Identify fault trends with time for minor repairs, major repairs and major replacements.
- Present a better remaining useful life prediction to create long-term forecasts of future asset conditions.

Methods

(1) WT CM by Current Signal Analysis:

- A rotor unbalance fault was implemented on the test rig and the generator current spectra for the test rig under healthy and two different fault levels shown in Fig.1.
- The fault introduces sideband harmonics called fault signature components (FSCs) around the main frequency components in the current spectra.

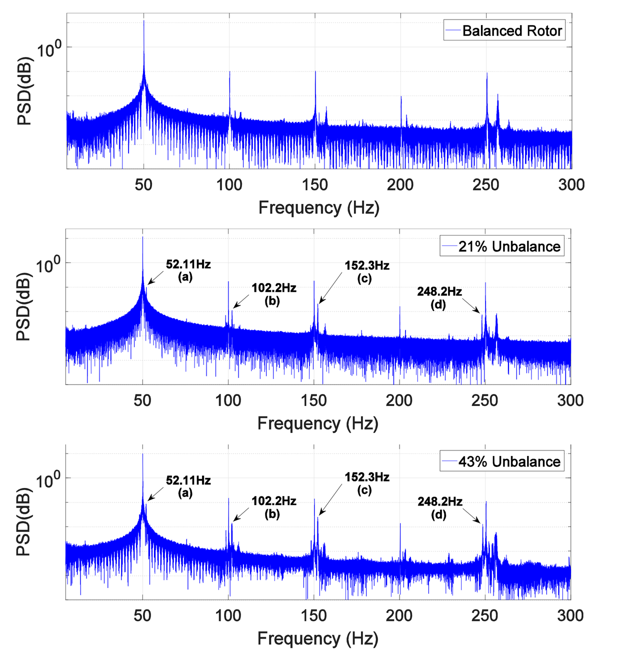

Fig. 1. The current spectra for the test rig at fixed speed.

(2) CM and Fault Detection Techniques: A continuous wavelet transform (CWT) and Kalman Filter (KF) techniques are used to extract the four FSCs which labelled in Fig.1.

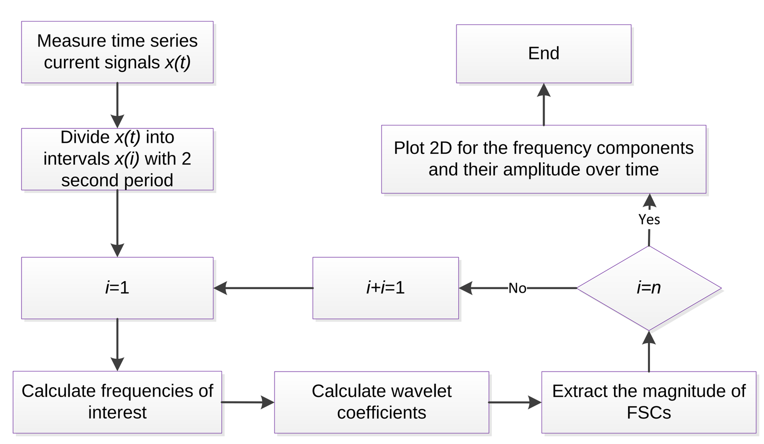

Fig. 2. Workflow for CWT based CM and fault detection.

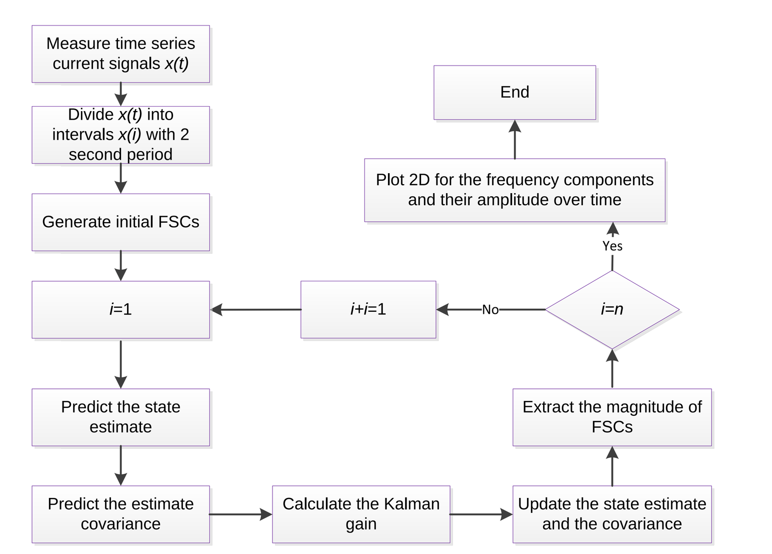

Fig. 3. Workflow for KF based CM and fault detection.

Results

The effectiveness of the proposed algorithms has been examined under variable speed conditions based on the 7.5m/s, 6% turbulence and 15m/s and 20% turbulence conditions. In all the cases analysed, the CWT is only capable of quantifying the presence of the fault component 'a' which has the highest amplitude and the lowest frequency. In contrast, the KF algorithm has successfully picked up the four fault signature components that are changing proportionally to the rotational speed.

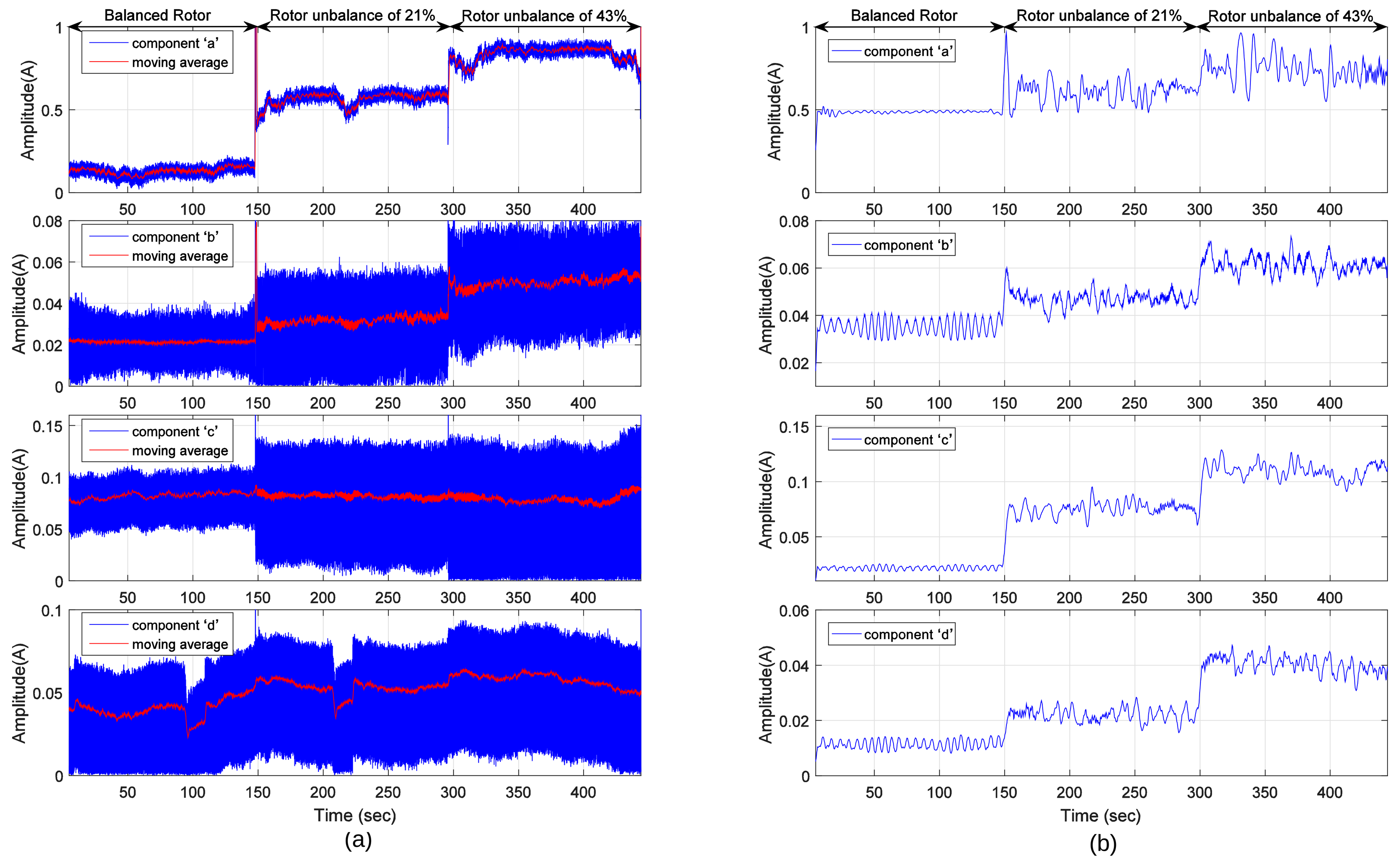

Fig. 4. Tracking the magnitude of fault signature frequencies of interest for the detection of rotor unbalance using (a) CWT and (b) KF with the test rig driven by 7.5m/s, 6% turbulence conditions..

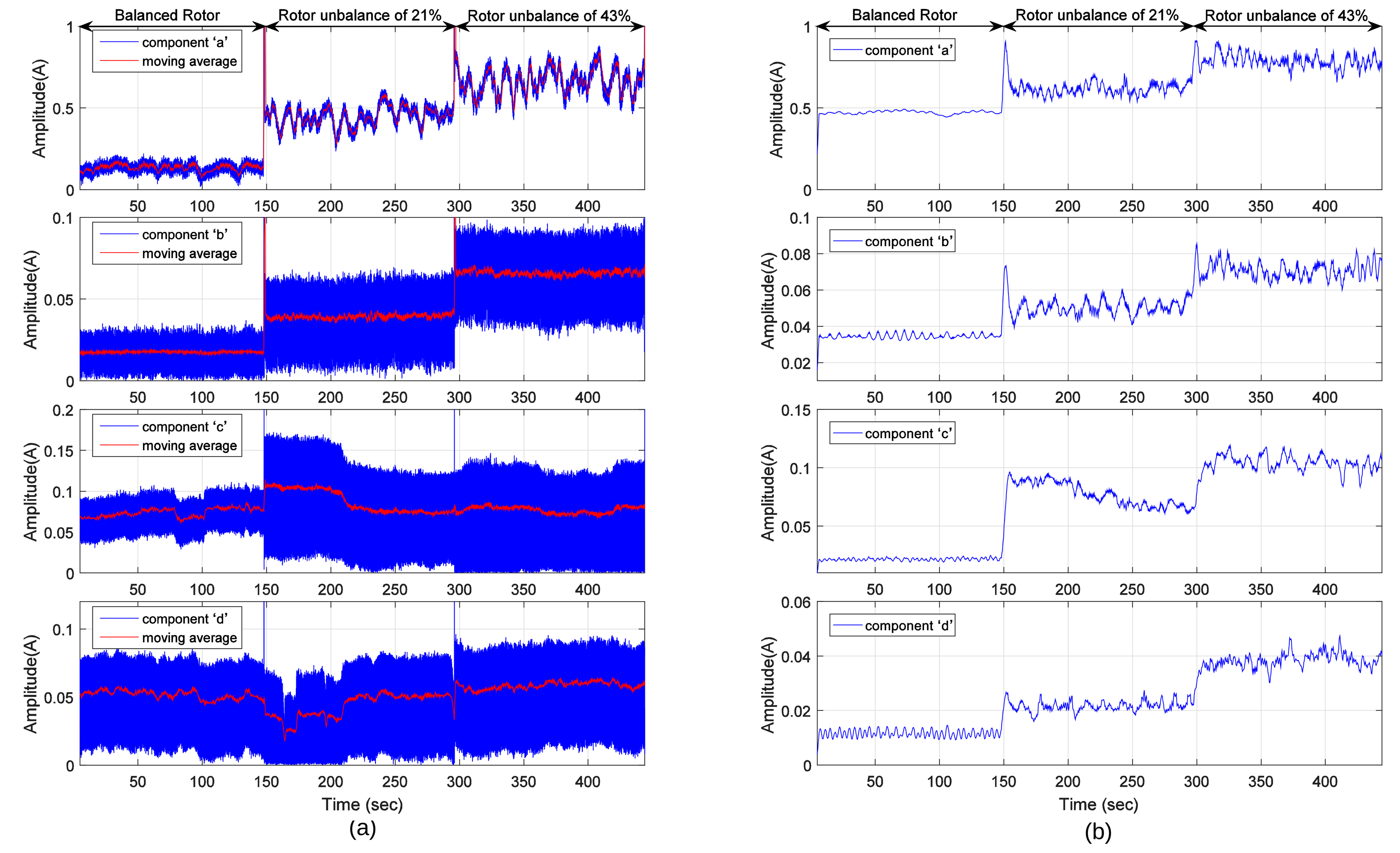

Fig. 5. Tracking the magnitude of fault signature frequencies of interest for the detection of rotor unbalance using (a) CWT and (b) KF with the test rig driven by 15m/s, 20% turbulence conditions..

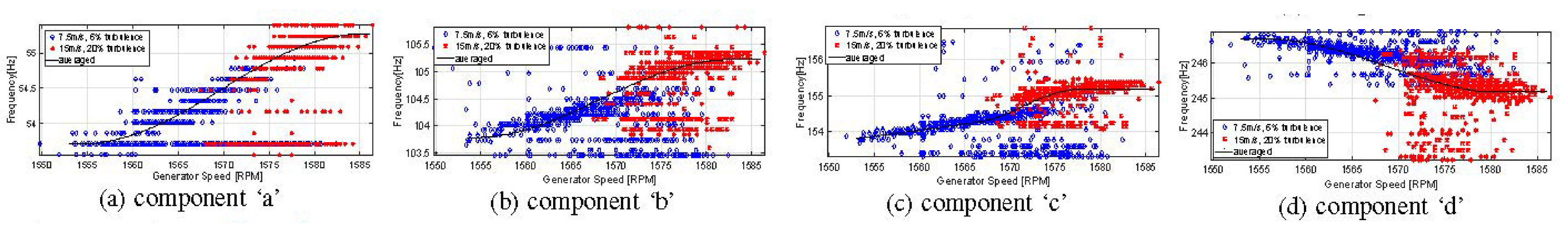

Fig. 6. The impact of the rotational speed variation on the fault signature frequencies.

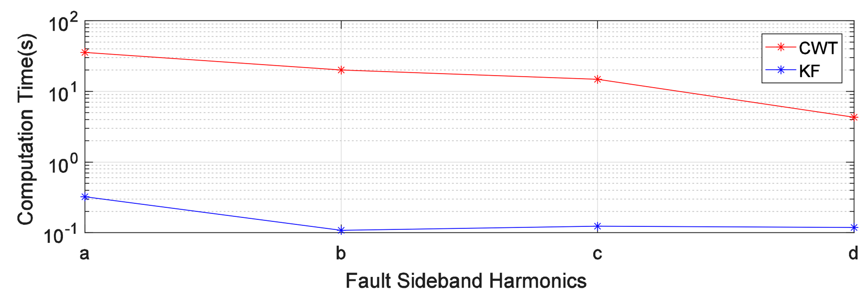

TABLE I: Comparison of calculated fault degree and experimental degree conditions under variable speed.

Driving Conditions	Degree of rotor unbalance				
	Experiment	'a'	'b'	'c'	'd'
7.5m/s, 6% turbulence	23%	24.12%	22.19 %	79.97%	21.75 %
	46%	48.3 %	44.91 %	130 %	51.55 %
15m/s, 20% turbulence	23%	26.96 %	29.3 %	89.99 %	33.62 %
	46%	63.25 %	61.86 %	126.68 %	62.78 %

Computational time: The KF method consistently maintains the computation time of less than 1 sec for all the side band harmonics considered. This is due to the fact that in the KF method no windowing technique like the CWT is required as the method only extracts energy at particular fault frequencies, while irrelevant frequencies to the fault are left unprocessed.

Quantification: Table I compares the calculated fault degree from the SFCs extracted by the KF method and experimental degree conditions under variable speed. The results show that the proposed technique has the potential to detect two levels of fault severity and forecast the fault progression over time even under variable speed conditions. Hence, today, the operators can observe the need for the maintenance is coming which enable them avoiding unexpected and unnecessary maintenance and outages particularly offshore.

Conclusions

- To improve the WT availability and reduce the operational and maintenance costs, two algorithms based on a CWT and KF WT CMS to provide accurate interpretation of the generator current signal have been proposed.
- Rotor unbalance fault was clearly detected in both algorithms. The algorithm also proved capable of dealing with different variable speed driving conditions.
- The KF compared favourably with the CWT and produced results of better quality for the fault progression.
- The advantage of using the KF algorithm is that it is only the sideband components related to the fault that need to be tracked in time and this substantially reduces the required computational resources as a matter of fact it can be applied in real-time operation.