Mechanical Systems and Signal Processing 85 (2017) 296–311

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Review

Trends in non-stationary signal processing techniques applied to vibration analysis of wind turbine drive train – A contemporary survey

R. Uma Maheswari [a,*], R. Umamaheswari [b]

[a] Anna University, Chennai, India
[b] Velammal Engineering College, Chennai, India

ARTICLE INFO

Article history:
Received 3 June 2016
Received in revised form
26 July 2016
Accepted 30 July 2016

Keywords:
Vibration analysis
Condition monitoring
Fault diagnosis
Drive trains
Non-stationary signal processing
Time frequency analysis

ABSTRACT

Condition Monitoring System (CMS) substantiates potential economic benefits and enables prognostic maintenance in wind turbine-generator failure prevention. Vibration Monitoring and Analysis is a powerful tool in drive train CMS, which enables the early detection of impending failure/damage. In variable speed drives such as wind turbine-generator drive trains, the vibration signal acquired is of non-stationary and non-linear. The traditional stationary signal processing techniques are inefficient to diagnose the machine faults in time varying conditions. The current research trend in CMS for drive-train focuses on developing/improving non-linear, non-stationary feature extraction and fault classification algorithms to improve fault detection/prediction sensitivity and selectivity and thereby reducing the misdetection and false alarm rates. In literature, review of stationary signal processing algorithms employed in vibration analysis is done at great extent. In this paper, an attempt is made to review the recent research advances in non-linear non-stationary signal processing algorithms particularly suited for variable speed wind turbines.

Contents

1. Introduction . . . 297
1.1. Vibration analysis–condition monitoring technique . . . 298
1.2. Characteristic faults in bearings . . . 299
1.3. Characteristic faults in gears . . . 299
1.3.1. Gear fault indicators . . . 299
2. Drive train vibrations and degradation process . . . 300
2.1. Gear vibrations . . . 300
2.2. Shaft vibrations . . . 301
2.3. Bearing defect vibrations. . . . 301
2.3.1. Inner race defect vibration . . . 301
2.3.2. Outer race defect vibration . . . 301
2.3.3. The factors influences the degradation process . . . 301

* Corresponding author.
E-mail addresses: uma.bhuvan@gmail.com (R. Uma Maheswari), umavijay.iitm@gmail.com (R. Umamaheswari).

http://dx.doi.org/10.1016/j.ymssp.2016.07.046
0888-3270/

3. Non linear dynamic data driven signal based feature extraction techniques . . . 301
3.1. Mathematical morphological filtering . . . 301
3.2. Chaotic vibration feature extraction techniques. . . . 302
3.3. Adaptive filtering techniques . . . 302
3.4. Bi-coherence bi-spectra techniques . . . 302
3.5. Spectral Kurtosis techniques . . . 303
3.6. Order tracking algorithms . . . 303
3.6.1. Tacho-less order tracking . . . 304
3.7. Adaptive resonance stochastic (ASR) technique . . . 304
4. Linear time-frequency algorithms. . . . 304
4.1. Empirical Mode Decomposition (EMD) . . . 304
4.1.1. Empirical Mode Decomposition in Fault Diagnostics . . . 304
4.2. Intrinsic Time Scale Decomposition (ITD) technique . . . 305
4.2.1. ITD in fault diagnostics . . . 305
4.3. Synchrosqueezing transform. . . . 306
5. Quadratic time-frequency (QTFR) algorithms. . . . 306
5.1. General parameterized time-frequency analysis . . . 306
5.2. Zhao-Atlas-Marks (ZAM) distribution in fault diagnostics. . . . 307
6. Model based condition monitoring. . . . 307
6.1. Knowledge based observer models. . . . 307
6.2. Parameter estimator models . . . 307
6.3. Support vector regression techniques. . . . 308
7. Conclusion . . . 308
References . . . 309

1. Introduction

Rapid developments in industries and automobile sectors makes thrust for energy. As conventional sustainable energy sources alone could not meet the growing demand for power, renewable energy sources play important role in energy sector. Wind energy conversion is the fastest growing in sustainable energy resources with full day output. From field experience, it is observed that the wind energy industry often suffers from premature turbine components failures as they are exposed to highly variable harsh weather conditions. Since these wind turbines are located at remote and un manned locations, comparatively it demand a high degree of maintenance to provide a safe, cost effective and reliable power output with acceptable equipment life. Changes in loading conditions of wind turbine due to time varying phenomenon increase the complexity of operation and maintenance. The cost of energy (COE) of wind power is calculated as in [1]

$$COE = \frac{ICC*FCR + LRC}{AEP_{NET}} + O\&M \tag{1}$$

$$AEP_{NET} = AEP_{GROSS}*Availability*(1 - Loss) \tag{2}$$

COE is cost of energy \$/kWh, ICC is the initial capital cost \$, FCR is the fixed charge rate (%/Yr), LRC is the level replacement cost \$/Yr, O&M is the operations and maintenance costs (\$/kWh), AEP_{NET} is the annual energy production (kWh/Yr). From Eq. (1) COE for wind power increases with the rise in operation and maintenance (O&M) cost. Predictive maintenance is the condition based maintenance that monitors the condition of the system and if any unusual trends identified then the turbine maintenance may be scheduled accordingly. The main objective of CMS is to reduce the turbine down time and thereby O&M cost. Condition monitoring is the process of monitoring parameters that describe the operating conditions of the machines. The mechanical drive train contains all the rotating components in between the rotor to generator. Condition monitoring of drive train is very useful to reduce the O&M cost.

Based on rotor support and bearing configurations the wind turbine geared drive trains are categorized as (i) three point suspension, (ii) two main bearing suspension, (iii) integrated suspension, and (iv) torque only suspension. Three point suspension is commonly used configuration which is more susceptible to non-torque loads. In two main bearing suspension, rotor shaft supported by two main bearings that pass on non-torque load into tower. In integrated suspension, the main bearings are integrated with gearbox. Torque only suspension configuration has a set of flexible coupling that connects rotor with main shaft [2].

The Gearbox Reliability Collaborative (GRC) stall controlled three bladed upwind turbine drive train three point suspension configuration is shown in Fig. 1 [3,4]. In this configuration the main bearing, main shaft and gears are the main components. The gears are mounted on three shafts namely high speed shaft, intermediate speed shaft and low speed shaft. Bearings are employed to support main shaft, gearbox shafts and generator input shaft. Deterioration in performance of these components eventually leads to turbine downtime.