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A new noise-controlled second-order enhanced stochastic resonance method with its application in wind turbine drivetrain fault diagnosis

Jimeng Li, Xuefeng Chen*, Zhaohui Du, Zuowei Fang, Zhengjia He

State Key Laboratory for Manufacturing Systems Engineering, Xi'an Jiaotong University, 710049 Xi'an, China

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ABSTRACT

Condition monitoring of a wind turbine is important to extend the wind turbine system's reliability and useful life. However, in many cases, to extract feature components becomes challenging and the applicability of information drops down due to the large amount of noise. Stochastic resonance (SR), used as a method of utilising noise to amplify weak signals in nonlinear systems, can detect weak signals overwhelmed in the noise. Therefore, a new noise-controlled second-order enhanced SR method based on the Morlet wavelet transform is proposed to extract fault feature for wind turbine vibration signals in the present study. The second-order SR method can obtain better denoising effect and higher signal-to-noise ratio (SNR) of resonance output by means of twice integral transform compared with the traditional SR method. Morlet wavelet transform can obtain finer frequency partitions and overcome the frequency aliasing compared with the classical wavelet transform. Therefore, through Morlet wavelet transform, the noise intensity of different scales can be adjusted to realize the resonance detection of weak periodic signal whatever it is a low-frequency signal or high-frequency signal. Thus the method is well-suited for enhancement of weak fault identification, whose effectiveness has been verified by the practical vibration signals carrying fault information. Finally, the proposed method has been applied to extract feature of the looseness fault of shaft coupling of wind turbine successfully.

1. Introduction

With the shortage of fossil fuels and serious environment problems, wind energy sources have drawn intense attention from various countries around the world. At the end of 2011, the global total wind energy capacity had grown to approximately 238 GW, which is enough to cover about 3% of the world's electricity demand [1]. And China installed about 17.6 GW in 2011, which captured almost 44% of the world's new additions in wind capacity. The total installed capacity of wind turbine reached nearly 62.4 GW, which was more than one-quarter of the world's total installed capacity. China has surpassed USA as the world's top producer of energy from wind. The wind turbine total installed capacity 2001–2011 of global and China is shown in Fig. 1. However, due to the harsh operation environment of wind turbines, the rapid development of wind power and the increase of unit capacity put forward higher demands for performance and reliability of wind turbines. If the long time safe and reliable operation of wind turbines cannot be ensured, the actual utilization of wind turbines can be decreased and operation and maintenance (O&M) costs can be increased, both of which would greatly reduce the economic benefit of wind power. Fig. 2 presents the statistics of wind turbines accidents from 1990 to 2011 obtained from some wind power farms [2]. It can be found from the numbers of recorded accidents that the tendency is as expected as more wind turbines are built, more accidents occur. In order to keep wind turbines on-line, the O&M costs of offshore turbines are almost €100,000 – €300,000 per year, which is 2–6 times higher than that of onshore turbines €45,000 per year [3]. Moreover, 66% of offshore O&M costs are caused by unscheduled corrective maintenance [3]. In Fig. 3, the contributions of offshore wind turbine components to the total O&M costs and downtime are given. As can be seen, the failures of the blade, generator and gearbox contribute together for over 75% to the costs and the downtime, although they are not the components with the highest failure rate [4]. Consequently, in order to reduce the O&M costs, some approaches have been studied [5], one of which is the application of condition monitoring for early failure detection. If failure can be detected at an early stage, the consequence damage can be less and the repair will be less expensive. As core components converting wind energy into electrical energy, wind turbine drivetrain is often subjected to various loads like wind gust impaction and irregular alternating loads, and ensure its long

* Corresponding author.
E-mail address: chenxf@mail.xjtu.edu.cn (X. Chen).

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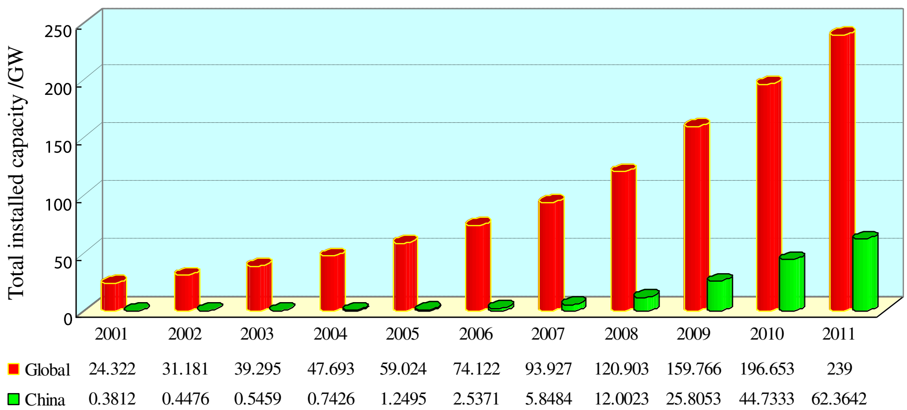

Fig. 1. Wind turbine total installed capacity 2001–2011.

term safe reliable operation has important significance in greatly reducing the O&M costs of wind turbines. Therefore, many researchers have conducted various researches to condition monitoring and fault diagnosis technology of wind turbines drivetrain.

The gearbox of wind turbine often endures the harsh conditions due to the temperature varying and the dynamic loads caused by the random wind speed. Therefore, the study of condition monitoring and fault diagnosis technology of wind turbine gearbox is very necessary to ensure the reliable operation of wind turbine. The research conducted by McNiff et al. found that the majority of wind turbine gearbox failures appeared to initiate in the bearings [6]. In particular, it was pointed out that among all bearings in a wind turbine gearbox, the planetary bearings, the intermediate shaft-locating bearings and high-speed locating bearings exhibited a higher percentage of application failures than other locating bearings. According to the non-stationary and time-varying characteristics of vibration signal acquired from wind turbine gearbox, Tang et al. studied a new time-frequency analysis method combined Morlet wavelet transformation with Wigner–Ville distribution (WVD) to extract the wind turbine gearbox vibration transient feature for fault diagnosis [7]. Spectral kurtosis (SK) is an effective tool which is capable of detection of non-Gaussian components in a signal [8]. Therefore, based on the characteristics that the structural responses to an excitation by a cracked tooth are non-Gaussian components, Tomasz et al. presented the application of the spectral kurtosis technique for detection of a tooth crack in the planetary gear of a wind turbine [9]. In the planetary gearboxes, complicated structure and multiple axes gear transmission make the spectral of vibration signals quite complex. The complex spectrum makes it difficult to diagnose planetary gearbox faults by traditional spectral analysis. Therefore, through modelling the vibration signals of planetary gearboxes as amplitude modulation and frequency modulation (AMFM) processes, Feng et al. proposed a simple yet effective demodulation analysis method based on ensemble empirical mode decomposition (EEMD) and energy separation to diagnose planetary gearbox faults [10]. Additionally, Huang et al. [11] and Yao et al. [12] studied the method of wind turbine gearbox fault classification based on wavelet neural network and the method of the crack tooth of wind turbine gearbox detection based on adaptive Morlet wavelet filter, respectively.

Apart from the gearbox, the generator that runs in electromagnetism environment is also prone to failure. Failure surveys have reported that percentage failure by components in induction machines is typically: about 40% failures are related to bearings, 38% to the stator, 10% to the rotor and 12% to others [13,14]. Therefore, in view of the fault characteristics of generator, various generator fault diagnosis methods have been studied. Watson et al. presented the analysis of the power output of a doubly fed induction generator (DFIG) by the use of wavelets to detect generator failure [15]. Kusiak et al. studied a data-mining approach that using neural network algorithms to capture the relationship between input parameters and generator bearing temperature during normal behavior, and then the trained neural network models were applied for the detection of generator bearing anomalies [16]. When a local fault exists in a ball bearing, the surface is locally affected and the vibration signals exhibit modulation. Therefore,

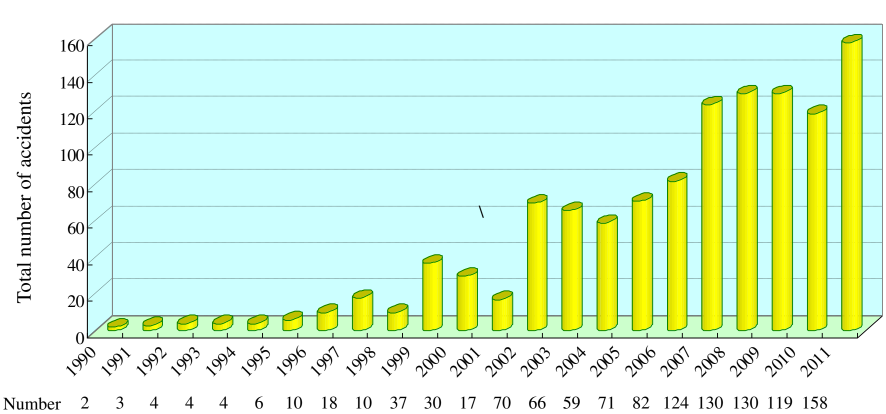

Fig. 2. The summary of wind turbine accidents 1990–2011.