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EEMD-based wind turbine bearing failure detection using the generator stator current homopolar component

Yassine Amirat [a,b], Vincent Choqueuse [b], Mohamed Benbouzid [b,*]

[a] ISEN, EA 4325 LBMS, 20, Rue Cuirassé Bretagne, 29200 Brest, France
[b] University of Brest, EA 4325 LBMS, Rue de Kergoat, CS 93837, 29238 Brest, France

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ABSTRACT

Failure detection has always been a demanding task in the electrical machines community; it has become more challenging in wind energy conversion systems because sustainability and viability of wind farms are highly dependent on the reduction of the operational and maintenance costs. Indeed the most efficient way of reducing these costs would be to continuously monitor the condition of these systems. This allows for early detection of the generator health degeneration, facilitating a proactive response, minimizing downtime, and maximizing productivity. This paper provides then an assessment of a failure detection techniques based on the homopolar component of the generator stator current and attempts to highlight the use of the ensemble empirical mode decomposition as a tool for failure detection in wind turbine generators for stationary and non-stationary cases.

1. Introduction

Wind energy conversion systems are the fastest-growing sources of new electric generation in the world and it is expected to remain so for some time, and those sources are becoming a reliable competitor of classical power generation systems, which are facing to constantly changing operating parameters, such as fuel cost, multiple fuel tradeoffs and maintaining older systems becomes more costly. WECS offer an alternative and emerging solution by deploying wind farms offshore or onshore, where there are substantial wind resources, leading to a best electricity generating opportunities. However, the offshore or onshore environments impose a high demand for reliability on the installed equipment because they are hardly accessible or even inaccessible [1].

1.1. *Wind turbine failure detection context*

Many techniques and tools have been developed for wind turbine electric generator condition monitoring in order to prolong their life span as reviewed in [2]. Some of these techniques used the existing and pre-installed sensors, which may measure speed, output torque, vibrations, temperature, flux densities, etc. These sensors are managed together in different architectures and coupled with algorithms to allow an efficient monitoring of the system condition [3]. Those methods have shown their effectiveness in electric motor condition monitoring. From the theoretical and experimental point of view, the

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[*] Corresponding author. Tel.: +33 2 98 01 80 07; fax: +33 2 98 01 66 43.
E-mail addresses: Mohamed.Benbouzid@univ-brest.fr, meh.benbouzid@gmail.com (M. Benbouzid).

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Nomenclature

WECS	wind energy conversion systems;
FFT	fast Fourier transform;
PSD	power spectral density;
TFR	time frequency representation;
TKEO	Teager–Kaiser energy operator;
HT	Hilbert transform;
CT	Concordia transform;
PCA	principal component analysis;
EMD	empirical mode decomposition;
EEMD	ensemble empirical mode decomposition; and
IMF	intrinsic mode function.

well-established methods are: electrical quantities signature analysis (current, power, etc.), vibration monitoring, temperature monitoring and oil monitoring.

In the case of wind turbines, it has been shown that failures in the drive train could be diagnosed from the generator electrical quantities [1]. The advantage of signature analysis of the generator electrical quantities is that those quantities are easily accessible during operation (i.e. the current can be acquired by current transformer or Hall effect device, the voltage via a voltage transformer, and the power by computation). For steady-state operations, the FFT, the PSD, and other techniques based upon them, are widely used in the literature [4]. However, in the case of variable speed wind turbines, FFT is difficult to interpret and it is difficult to extract the variation features in time-domain, since the operation is predominately non-stationary due the stochastic behavior of the wind speed. To overcome this problem, failure detection procedures based on time–frequency representation (Spectrogram, Quadratic TFR, etc.) or time-scale analysis (wavelet) have been proposed [5–9]. Nevertheless, these techniques have drawbacks such as high complexity, poor resolution or may suffer from artifacts (cross-terms, etc.). Moreover, failure frequencies tracking is not an easy task [10].

1.2. Bearing failures importance

Since induction machine rotors are under high stresses, including thermal stresses, mechanical stresses, and electrical stresses, they are statistically more vulnerable compared to the stator. Particularly, bearings are the most frequently failed component [11]. Moreover, in the wind power industry context, bearing failures have been a persistent problem which account for a significant proportion of all failures in wind turbines [1]. Bearing failure of WECS generators is the most common failure mode associated with a long downtime.

Bearing failure is typically caused by some misalignment in the drive train, which gives rise to abnormal loading and accelerates bearing wear. Because of their construction, rolling element bearings generate precisely identifiable signature on vibration with characteristic frequencies. Those frequencies present an effective route for monitoring progressive bearing degradation. It is therefore possible to detect on the stator side the frequencies associated with the bearings using accelerometers mounted directly on the bearing housing, which is not often easily accessible [12]. Nonintrusive condition monitoring techniques, which monitor the bearing condition using only the generator currents or voltages, are preferred due to their nonintrusiveness and also low cost. To tackle this problem, numerous failure detection techniques have proposed by analyzing the stator side electrical quantities; such as the current [13] or the instantaneous power factor [14].

In this important and particular context, this paper will focus on bearing failure detection. As this failure leads to stator current modulation [15], it is therefore proposed to assess the efficiency of the EEMD using the homopolar current as a failure detection tool.

2. Failure detection using advanced signal processing techniques

2.1. Why monitoring the homopolar current?

In theory the homopolar current occurs only for unbalanced three-phase machines. However, in real world industry applications, this component is present regardless the machine condition (healthy or faulty). This study suggests then the use of this current as the variable to be monitored for failure detection. Indeed, majority of failures lead to an obvious unbalance behavior of a three-phase machine. This will give rise to a homopolar component of the current. This component could be very useful if the neutral point is connected allowing the use of one current sensors. In a wind turbine application, no homopolar current is produced by the generator (i.e. doubly-fed induction generator) since the neutral point is disconnected. However, the component could be computed and therefore monitored.

The homopolar current, I_0, is computed through the Clarke transform and is given by

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{1}$$

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