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Methodology for fault detection in induction motors via sound and vibration signals

Paulo Antonio Delgado-Arredondo [a], Daniel Morinigo-Sotelo [b], Roque Alfredo Osornio-Rios [c], Juan Gabriel Avina-Cervantes [a], Horacio Rostro-Gonzalez [a], Rene de Jesus Romero-Troncoso [a,*]

[a] *HSPdigital – CA Telematica, Procesamiento Digital de señales, DICIS, Universidad de Guanajuato, Carr. Salamanca-Valle km 3.5+1.8, Palo Blanco, 36700 Salamanca, Gto., Mexico*

[b] *HSPdigital – Department of Electrical Engineering, University of Valladolid, UVa., 47011 Valladolid, Spain*

[c] *HSPdigital – CA Mecatronica, Facultad de Ingenieria, Universidad Autonoma de Queretaro, Campus San Juan del Rio, Rio Moctezuma 249, 76807 San Juan del Río, Qro., Mexico*

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ABSTRACT

Nowadays, timely maintenance of electric motors is vital to keep up the complex processes of industrial production. There are currently a variety of methodologies for fault diagnosis. Usually, the diagnosis is performed by analyzing current signals at a steady-state motor operation or during a start-up transient. This method is known as motor current signature analysis, which identifies frequencies associated with faults in the frequency domain or by the time–frequency decomposition of the current signals. Fault identification may also be possible by analyzing acoustic sound and vibration signals, which is useful because sometimes this information is the only available. The contribution of this work is a methodology for detecting faults in induction motors in steady-state operation based on the analysis of acoustic sound and vibration signals. This proposed approach uses the Complete Ensemble Empirical Mode Decomposition for decomposing the signal into several intrinsic mode functions. Subsequently, the frequency marginal of the Gabor representation is calculated to obtain the spectral content of the IMF in the frequency domain. This proposal provides good fault detectability results compared to other published works in addition to the identification of more frequencies associated with the faults. The faults diagnosed in this work are two broken rotor bars, mechanical unbalance and bearing defects.

1. Introduction

Nowadays, the applications of monitoring sound signals are diverse and present daily in modern life. In medicine, it is a key element for the diagnosis and analysis in the form of ultrasound echoing [1]. In the industrial field, it is used in a wide variety of applications in the form of acoustics, acoustic emission and ultrasound [2]. In the construction industry, it is used

* Corresponding author.
E-mail addresses: pa.delgadoarredondo@ugto.mx (P.A. Delgado-Arredondo), daniel.morinigo@eii.uva.es (D. Morinigo-Sotelo), raosornio@hspdigital.org (R.A. Osornio-Rios), avina@ugto.mx (J.G. Avina-Cervantes), hrostrog@ugto.mx (H. Rostro-Gonzalez), troncoso@hspdigital.org (R.d.J. Romero-Troncoso).

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for structural analysis [3], whereas military applications include the sonar [4]. In addition, the sound is a physical phenomenon that provides information about the behavior of a system and can be used as a parameter for determining the condition thereof. By considering the sound as the propagation of acoustic sound waves produced by mechanical vibrations, it can be expected that the acoustic sound waves produced by a machine contain information about the machine behavior and operating condition [5]. The electric motor is not an exception, and the vibrations generated by defects in bearings, mechanical unbalances and broken rotor bars produce sounds with characteristic frequencies associated with each fault [6]. This correlation between faults and characteristic frequencies makes possible to determine the operating condition of the electric motor through the spectral analysis of the acoustic sound signal. Besides, the diagnosis through the analysis of acoustic sound signals is a non-invasive method that may be easily implemented.

The most popular techniques for the detection of faults in induction motors are the MCSA (motor current signature analysis) and the analysis of vibration signals. On the other hand, the analysis of acoustic sound or acoustic emission signals for detecting faults in induction motors has been used less. All these techniques for fault diagnosis have advantages and disadvantages. The MCSA technique has the advantages of being noninvasive and easy to implement, providing good results in fault diagnosis [7]; however, under certain conditions its application is not sensitive enough because it has a low signal-to-noise ratio, which is more evident in inverter-fed motors. Other known disadvantages are related to the spectral leakage and its low-frequency resolution. Vibration analysis has the advantage that its results are independent of the type of motor power supply and yields good results [8], but its implementation requires using accelerometers as the basic sensors that must be placed near or on the motor, which sometimes is difficult to achieve. The analysis of acoustic sound signals for fault diagnosis on induction motors also has the advantage that the results are independent of the type of power supply; besides, the primary sensor is a standard acoustic microphone that can be placed anywhere near the machine under analysis, not necessarily in direct contact, which simplifies its installation. Nevertheless, the downside of acoustic sound signal analysis is its sensitivity to external noise, which should be avoided whenever possible [6]. This drawback is overcome by the technique of acoustic emission, which measures the acoustic signals in the ultrasonic range providing a high signal-to-noise ratio, but it has the disadvantage of requiring a more complex implementation [9].

The MCSA technique involves the analysis of stator current signals collected with a current clamp. The signal acquisition can be carried out during either a startup transient or a steady-state regime of the induction motor. For signals acquired during a steady state, it is expected that the frequency content remains time invariant, and the analysis is performed with methods that provide efficient frequency decomposition with good tolerance to low signal-to-noise ratio. The Fourier Transform is the most common technique in the analysis of stationary signals. But, it has the disadvantage of a limited frequency resolution, the spectral leakage, and a low noise tolerance. Another method used for the stationary signal analysis is MUSIC. This technique is based on a harmonic decomposition of the signal, in which the noise can be discriminated. It provides a high-resolution spectrum estimation that is exempt of noise. Nevertheless, it also has some drawbacks. This algorithm is based on the previous knowledge of the number of spectral components of the signal. If this number is unknown, it can generate spurious frequencies if the spectrum estimation is done with a high order, which may lead to incorrect interpretations, as these are frequencies that are not really contained in the signal. The MUSIC algorithm provides a pseudospectrum, and this makes up its other drawback. In a pseudospectrum, the amplitudes of the frequency components are not directly related to the real ones [10,11]. So, these amplitudes cannot be used directly as evidence of change in the real frequency components from one signal compared to another. In comparison, the Gabor representation, although it is based on the Fourier Transform, has a higher noise tolerance, has a better resolution than the Fourier transform, does not generate spurious frequencies and also yields a smoothed spectrum through the use of the Gaussian window [12]. However, it is a time–frequency distribution and to take advantage of these characteristics when applied to a stationary signal, its frequency representation is calculated as the frequency marginal. The signal spectrum is obtained with better quality than the Fourier transform and without spurious frequencies like in MUSIC.

If the motor operates in non-steady regimes, several processing methods have been proposed. The signal is analyzed by time–frequency decomposition techniques such as the short-time Fourier transform [13–15], the discrete wavelet transform (DWT) [16–19], the continuous wavelet transform (CWT) [20–23], the Hilbert transform [24,25], the Hilbert-Huang transform [24,25], the Wigner-Ville distribution [23–32], the Choi-Williams distribution [24–26], and the multiple signal classification (MUSIC) [33]. Some of these techniques work together with artificial intelligence (AI) classifiers for decision-making about the components or signatures that are present in the signals for identifying faults and their severity. These AI classifiers include artificial neural networks (ANN), fuzzy logic, fuzzy neural networks, and genetic algorithms [14,18,20,21,28,34,35].

Vibration analysis requires the use of an accelerometer installed on the motor. Several methods have been utilized for the frequency and time–frequency decomposition of the measured signals. In [36], the time–frequency distribution of Gabor (TFDG) and MUSIC were applied to the vibration signals during a startup transient. In other works, the fast Fourier transform (FFT) [37], the Zhao-Atlas-Marks (ZAM) distribution [38], MUSIC [6], and the DWT [39] were used for the signal processing.

Regarding the analysis of acoustic sound signals, Yumi et al. [40] proposed a method for detecting abnormal sounds of the motor for condition monitoring and fault diagnosis. The system accuracy for anomaly detection was evaluated with an F-value. Another work was done by Salazar-Villanueva and Ibarra-Manzano [41], where they proposed an approach based on the EMD (Empirical Mode Decomposition) and the FFT for detecting mechanical unbalance and defects in the bearings of induction motors. Ackay and Germen [42] proposed a methodology to identify broken rotor bars and bearing faults on induction motors tested under different load conditions. The acoustic sound signals were acquired with five microphones placed hemispherically around the motor. They used a hybrid algorithm for calculating the PSD (power spectral density) and

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