Mechanical Systems and Signal Processing 23 (2009) 2658–2670

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

Induction machine condition monitoring using notch-filtered motor current

Serkan Günal [a], Doğan Gökhan Ece [b,*], Ömer Nezih Gerek [b]

[a] Anadolu University, Department of Computer Engineering, Eskisehir, Turkey
[b] Anadolu University, Department of Electric and Electronics Engineering, Eskisehir, Turkey

ARTICLE INFO

Article history:
Received 28 November 2008
Received in revised form
18 March 2009
Accepted 19 May 2009
Available online 2 June 2009

Keywords:
Induction machine
Condition monitoring
Notch-filter
Skewness
Kurtosis

ABSTRACT

This paper presents a new approach to induction motor condition monitoring using notch-filtered motor current signature analysis (NFMCSA). Unlike most of the previous work utilizing motor current signature analysis (MCSA) using spectral methods to extract required features for detecting motor fault conditions, here NFMCSA is performed in time-domain to extract features of energy, sample extrema, and third and fourth cumulants evaluated from data within sliding time window. Six identical three-phase induction motors were used for the experimental verification of the proposed method. One healthy machine was used as a reference, while other five with different synthetic faults were used for condition detection and classification. Extracted features obtained from NFMCSA of all motors were employed in three different and popular classifiers. The proposed motor current analysis and the performance of the features used for fault detection and classification are examined at various motor load levels and it is shown that a successful induction motor condition monitoring system is developed. Developed system is also able to indicate the load level and the type of a fault in multi-dimensional feature space representation. In order to test the generality and applicability of the developed method to other induction motors, data acquired from another healthy induction motor with different number of poles and rated power is also incorporated into the system. In spite of the above difference, the proposed feature set successfully locates the healthy motor within the classification cluster of "healthy motors" on the feature space.

1. Introduction

The simplicity and ruggedness of the squirrel-cage construction are outstanding advantages of an induction motor and make it by far the most commonly used type of motor in sizes ranging from fractional horsepower to grades of industrial applications. Incipient type of mechanical faults such as cracked or broken rotor bars or end-ring, minor bearing damage, and misalignments which do not completely block the rotor, may cause noise and excessive currents and heat during the steady-state operation of the motor [1]. In addition, magnitude of these currents may be lower than the pick up settings of over current relays and consequently the motor may operate until the complete failure resulting the interruption of an industrial process, causing a down time and even effecting other related machinery. Therefore, mechanical faults must be detected at their inception by means of preventive maintenance in order to avoid undesirable motor failures. Considerable

* Corresponding author.
E-mail address: dgece@anadolu.edu.tr (D. Gökhan Ece).

0888-3270/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ymssp.2009.05.011

amount of research have been conducted on condition monitoring and detection of induction motor faults and the surveys in [2,3] cite most of the work in this area. Both invasive and noninvasive methods are used to measure motor vibration, temperature, speed and torque variations for detection of motor abnormalities. However, the most celebrated and often used method of condition monitoring is the motor current signature analysis (MCSA) since the motor current contains required information for fault detection. Well known signal processing tools of Fourier, Wavelet, and Hilbert–Huang transformations are applied to acquired motor current data to extract necessary features for motor fault detection [4–11]. During steady-state operation, induction motors draw noisy and harmonically rich line current due to their nonlinear characteristics. Spectral methods used for MCSA are employed to extract signature identifiers, namely features to be used for fault classification.

One of the most commonly encountered motor failure is the broken rotor bars. This type of fault is known to cause a rise in magnitude at side band frequency components defined by $f_{BR} = (1 \pm 2ks)f_e$. Here, $k = 1, 2, 3, \ldots, f_e$ is the supply frequency, and s is the slip given by $s = (n_s - n)/n_s$ where n_s is the synchronous speed and n is the rotor speed. For $k = 1$ for example, elevated side bands of the supply frequency above a threshold would indicate broken rotor bars. Similar equations for frequencies corresponding to other types of abnormalities such as misalignment and bearing damage are derived in terms of speed and design parameters of an induction motor in the literature. This way, since the frequencies related to different types of faults are known, detection and classification are performed by comparing the corresponding, for example, wavelet transform decomposition coefficients with a threshold [12]. However, monitoring the increase in magnitude at predicted frequencies alone may yield classification errors due to the fact that, in some cases, different faults may give rise to same frequencies. Consequently, an effective detection and classification method should be able to discriminate motor faults from a healthy motor while distinguishing different fault types.

Frequency of induced voltage and resulting current in the rotor circuitry are proportional to slip s and are slightly less than the stator (supply) frequency. Hence, side band frequency components around the fundamental will appear in the frequency spectrum of the motor current drawn from the supply even in steady-state condition. Magnitude and the frequency of these side bands depend upon the load on the motor and vary with the dynamic change in the load. Therefore, it is very difficult to set a certain threshold level to detect broken or cracked rotor bars at varying load conditions. In addition, extracting the magnitude and frequency information of side band components requires analog/digital conversion with very high sampling rate and signal to noise ratio. When the load on the motor is a light one (half of the rated or less) slip is very small and side bands move towards the strong fundamental component and get overshadowed by it. As a result, side bands may not be visible and their spectral information may not be extracted due to the dominant fundamental component.

Bearing defect is another mostly encountered induction motor mechanical fault faced by the industry due to the contamination, corrosion, and improper lubrication. In the case of a bearing defect, abnormal mechanical noise, excessive heating, and some amount of over current due to the slight blocking effect of the defective bearing to the rotating motor shaft will occur. Measuring the motor current alone as a fault diagnostic parameter naturally excludes the information due to the noise, therefore vibration, and heating. Motor would draw some amount of over current (less current to be picked up by protective circuitry) will occur, and, depending on the type of the bearing fault (inner race, outer race, and defective rolling elements), magnitudes of certain frequency components of the motor current would increase. The effects of different bearing faults to the frequency spectrum of the motor current is investigated in the literature [7]. However, without interrupting the running process of an induction motor and disassembling the motor and the bearing, one could not know what type of a bearing fault has occurred and which frequency component should be inspected and compared with a certain threshold.

This work is motivated from the fact that spectral components of motor current other than the fundamental component carry required information for fault detection therefore removing the 50 (or 60) Hz fundamental by means of notch-filtering would not effect the fault detection process [13]. On the contrary, the confusion of a pronounced fundamental is eliminated this way. Another important development towards fault detection in this paper is the utilization of the energy, maxima, skewness, and kurtosis of notch-filtered current waveform within a sliding time window as signature identifiers. This way, the necessity of proper threshold settings at different frequencies for detecting different fault conditions is rendered obsolete. It can be noted that skewness and kurtosis are higher order statistical parameters related to the higher order spectra, which was previously utilized for machine condition diagnosis [15,16,10]. However, the utilization of higher order spectra in [15,16,10] requires the complete bi- and tri-spectra magnitude, whereas our approach utilizes simple parameters derived from the higher order spectra, and their calculation is significantly simple.

The classification of faulty motors with the proposed parameters is performed using three well known classifiers, namely Bayesian, Gaussian mixture model (GMM), and Fisher's linear discriminant analysis (LDA) to verify the effectiveness and the success of the proposed feature set.

In most of the previous works summarized with great number of bibliographical information in [2,3], considered type of faults were mainly either broken rotor bars or defected bearings and developed fault detection and classification methods have been tested using exactly the same motors with one of them always being the healthy reference. However, in this work for developing and testing the proposed algorithm, in addition to the six exactly the same motor with five of them having different fault conditions, a second healthy induction motor with completely different name plate is incorporated into the test set. The second (and completely different) induction motor verified the fact that the selected feature set is capable of providing a robust fault detection system. When the classification algorithm is performed with two healthy