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Diagnosis of broken rotor bars in induction motors based on harmonic analysis of fault components using modified adaptive notch filter and discrete wavelet transform

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ABSTRACT

This paper proposes a method for fast and accurate detection of broken rotor bars (BRBs) in a three-phase squirrel cage induction motor. The fundamental component of the stator current signal is extracted using a linear time-invariant filter. The resultant residual signal which contains the harmonic components of the current is then used to detect the BRBs, by means of discrete wavelet transform (DWT). Since in experiment it is not possible to break the rotor bars while the motor is under load, finite element method and MATLAB/Simulink are employed to accurately demonstrate the behavior of the running machine as the BRB happens. To get more accuracy, differential evolution (DE) optimization algorithm is used to obtain the corresponding fault impedance for the rotor external circuit of the MATLAB model. Detail coefficients (DCs) of the wavelet decomposition are employed as the new fault indicators. Simulation results show that using DCs of the harmonic component signal rather than the actual current signal, leads to more distinctive fault signatures in the wavelet decomposition. The obtained results suggest that the proposed fault detection scheme can be employed as a highly reliable technique for diagnosing rotor bar failures in running machines.

1. Introduction

Over the past few decades, squirrel cage induction motors (SCIMs) have attracted much attention in the industry due to their high reliability, low maintenance costs, and ease of use. Hence, condition monitoring of SCIMs has gained more significance as they are the prime movers of most industries. Early detection of potentially catastrophic faults in SCIMs not only can reduce maintenance costs but will also prevent large production losses. If a fault is not diagnosed in its early stages, it could deteriorate leading to more faults, thus resulting in down times and costly machinery repairs [1,2].

It has always been of interest to researchers to improve the accuracy of fault detection schemes. Detection of the fault in the lowest possible time has also been the other subject of interest in this field. Motivated by these two concerns, continuous research has been made over the past few years leading to new fault detection algorithms, new criterions, and new fault indicators [3–8]. The signatures of a broken rotor bar (BRB) can be detected by analyzing the harmonic spectrum of the stator current around the fundamental frequency, i.e. the sidebands. Zoom-MUSIC, a high resolution frequency analysis algorithm,

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is presented in [3] as a new diagnosis scheme that provides better resolution and requires less computation time compared to other traditional algorithms such as Fast Fourier Transform (FFT) and Short Time Fourier Transform (STFT). This approach is highly sensitive to the dimension of the autocorrelation matrix which has no reliable formula, such that if not selected carefully, could lead to results less reliable than FFT. Moreover, amplitude of the fundamental frequency is greater than that of the sideband. A digital/analog cancelling scheme which is based on the recursive discrete-time Fourier transform is employed in [4] to eliminate this fundamental frequency. This technique requires the precise value of the fundamental frequency to perform correctly. To distinguish the fault components, the authors in [5] have used a band pass filter to eliminate the fundamental component of the current. Removal of the fundamental component from the harmonic spectrum significantly improves detection of the sidebands and hence the diagnosis of the faults [5,6]. This is achieved in [6] by using a digital notch filter. By using experimental results it is shown that discrete-time Fourier transform and autoregressive-based spectrum methods with a lower sampling rate can be utilized for motor current signature analysis (MCSA) when a digital notch filter is present. The main drawback of these methods is their inability to track the fundamental component of the current which varies in frequency, phase and amplitude. A novel criterion is proposed in [7] which surpasses the well-known Filippetti criterion [9] in terms of accuracy and universality. Harmonic spectrums of the active and reactive currents are used in [8] to detect BRB faults. Unlike the traditional schemes, this new approach is able to distinguish between the signatures of BRBs from load oscillations. All these methods use the frequency analysis of the stator current in the steady-state operation of the machine to diagnose the fault.

To increase the speed of the diagnosis, many researchers have proposed fault detection schemes based on the start-up process of the machine [10,11]. The fault signatures are more evident in the start-up process due to the high slip situation [11]. Although detection of the BRBs is more accurate and faster using such approaches, the main drawback is the requirement for a minimum start-up time [12]. Furthermore, stopping a production line to perform such a start-up transient analysis on its SCIMs is not a reasonable action. New algorithms have been combined and used in the last few years to detect SCIM faults faster and more accurately. In [13] discrete wavelet transform (DWT) was combined with stationary wavelet packet transform (SWPT) to detect BRBs with a lower sampling rate. Various support vector machine (SVM) schemes were investigated and it was shown that wavelet kernel function can detect the faults with a better accuracy. In [14], power spectral density techniques were combined with DWT and a new fault factor, namely the power detail density (PDD) was introduced. This new technique was then employed in an SCIM under a variable load torque to detect the BRBs. However, careful and correct selection of the sampling frequency and the mother wavelet are essential for this method. The authors in [15] have shown that the BRBs affect the space vector magnitude of the stator current signal in the low frequency bandwidth. Wavelet coefficient energy is utilized to diagnose BRBs under various load levels without the need to estimate the slip. The main drawback is the need for three current sensors which make this method more complex and expensive. In spite of all the existing BRB fault diagnosis schemes, there is a lack for a real-time transient analysis approach that can detect faults in their incipient stages as quick and as accurate as possible.

This paper proposes a new technique for diagnosing BRB faults with an improved accuracy and speed. By passing the stator current signal through an adaptive notch filter, the fundamental and harmonic components of the current are extracted. The extracted harmonic component called the total harmonic signal (THS) is then employed as the new signal for analysis purposes. Detail coefficients (DCs) of the wavelet decomposition of the THS are used as the new fault indicators for detecting fault signatures. To better evaluate the proposed scheme, finite element method (FEM) is utilized and its results are used to refine the MATLAB/Simulink model for validation purposes.

2. Adaptive notch filter

A notch filter is a linear time invariant structure that passes all frequency components of the input signal to the output intact, except for the component with a frequency equal to the notch frequency. Therefore, in the frequency spectrum of the filter's output signal, all frequencies except the notch frequency will exist. An adaptive notch filter (ANF) is capable of changing its notch frequency according to the variations of the fundamental component frequency of the input signal. The dynamic behavior of the ANF employed in this paper is characterized by the following differential equations [16,17]:

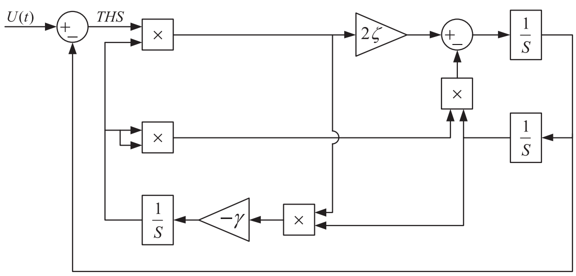

Fig. 1. Block diagram of ANF as a closed loop system.