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Induction motor broken rotor bar fault location detection through envelope analysis of start-up current using Hilbert transform

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ABSTRACT

Robustness, low running cost and reduced maintenance lead Induction Motors (IMs) to pioneerly penetrate the industrial drive system fields. Broken rotor bars (BRBs) can be considered as an important fault that needs to be early assessed to minimize the maintenance cost and labor time. The majority of recent BRBs' fault diagnostic techniques focus on differentiating between healthy and faulty rotor cage. In this paper, a new technique is proposed for detecting the location of the broken bar in the rotor. The proposed technique relies on monitoring certain statistical parameters estimated from the analysis of the start-up stator current envelope. The envelope of the signal is obtained using Hilbert Transformation (HT). The proposed technique offers non-invasive, fast computational and accurate location diagnostic process. Various simulation scenarios are presented that validate the effectiveness of the proposed technique.

1. Introduction

Induction Motor (IM) can be considered as the most popular type motor in energy conversion and industrial drive fields, because of its robustness, low cost and easy maintenance. Squirrel-cage IMs contribute around 85% of the installed motors in industry [1,2]. Electrical, mechanical, thermal, magnetic and environmental stresses cause faults in the IM during the operation process [3,4].

One of the challenging topics for several researchers is the development of robust IM fault diagnostic techniques. Recently, several improvements in the design and manufacturing of IM stator windings lead to mitigate common stator electrical faults. On the other hand, squirrel cage rotor design did not see noticeable improvements which consequently makes the rotor faults account for a high percentage of total IM failure [5]. Serious consequences of IM rotor faults mandate its early detection. The broken rotor bar (BRB) fault is one of the important faults that need to be early detected due to its sudden sever damages. This fault represents around 5–10% of motor faults as stated in literature [6–8]. BRB fault can hiddenly occur without any symptoms. It may propagate to the next bars and leads to sudden shut down unless continuous monitoring of fault exists [9].

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Detection of BRB fault of IM can be developed using several fault signatures like motor current, vibration, acoustic noise and magnetic flux [10,11]. The most common fault signature is the Motor Current Signature Analysis (MCSA). Conventionally, BRB fault detection relies on traditional analysis technique as Fast Fourier transform (FFT). Despite of its efficient detection performance, this technique suffers from several limitations such as spectral leakage due to the finite time window, need for high frequency resolution [12] and in applicability to varying load conditions [13,14]. FFT technique cannot offer exact distinguish between healthy and faulty rotors in case of light loads because the characteristic BRB fault frequencies in the stator current are very close to the fundamental-frequency component and their amplitudes are small in comparison. The load sensitivity issue can be mitigated by considering the detection of the BRB in case of transient time using the start-up motor current.

The transient start-up current gives better results in fault diagnosis due to its high value, hence many researches depend on analysis of stator current transient interval instead of steady state [15]. FFT is more suitable for steady-state analysis. Therefore, in order to diagnose the start-up motor current and to overcome FFT previously mentioned drawbacks, more sophisticated signal processing techniques are needed to investigate the detection process; such as Short Time Fourier Transform (STFT), Wavelet Transform (WT) and Hilbert Transform (HT). In some researches a combination of more than one signal processing technique is used and also the assist of artificial intelligence techniques is recalled for more efficient and accurate detection process.

This paper presents a time-frequency signal processing tool, as Hilbert Transform (HT), that can be considered as a promising BRB fault diagnostic technique with high frequency resolution especially at very low slip. It allows an easy filtering of the transient IM stator current component corresponding to the mains. As the transient current is a non-stationary signal, another advantage evolves since it can generate the Hilbert Spectrum (HS) which is a replacement of the Fourier Spectrum for the analysis of non-stationary signals. The HT can be used for BRB fault detection process by the analysis of the IM start-up current. HT offers low sensitivity to the level of motor loading in comparison to steady state current. In addition reliable conclusions obtained from the data analysis even at light or no mechanical load [16]. The faulty case of the motor can be investigated through the analysis of the motor current envelope [17,18]. The envelope of the signal is the modulus of an analytic signal. This signal is represented in a complex form where its real part is the original signal and the imaginary part is the Hilbert transform of the signal [19–21]. The fault signature presented in the modulated current signal and the envelope analysis are used to detect the fault as amplitude modulation [22]. The envelope works on narrow band frequencies, mono-component signal, below the supply frequency. A statistical measurement of the envelope is considered to represent the BRB fault location. Many researches investigated the fault diagnosis under various operating conditions as line start and inverter fed [23,24]. The main difference between those operating modes is the ability of the inverter fed to control the speed or the reference frequency. In addition, several fault detection techniques that rely on IM voltage measurement can be affected by the pulsating voltage in case of inverter fed.

Most researches were based on detecting the BRB faulty case only. In this paper, the authors consider defining the exact location of the broken bar in the squirrel cage rotor of IM not only detects the fault case. The detection of the location depends on the analysis of the startup current envelope as the effect of the broken bar is included in the envelope of the current which represents the low frequency oscillation (fault frequency band). The effect of the fault presented in the low frequency component of the current is due to the distortion of the air gap flux density which leads to distorted induced voltage in the stator winding. The proposed detection technique is validated under two operation modes: (1) line start and (2) inverter fed supply for different loading level and fault severity. For more emphasis of the effectiveness of the proposed technique and its tolerance to IM parameter change, a parameter sensitivity analysis is considered. Stator and rotor resistance are the motor parameters investigated in the sensitivity analysis presented in the paper and they are tested for varying range of values around ±25%.

The contributions of this paper can be summarized as follow:

1. A novel approach is presented concerning developing a mathematical formula that specify the exact location of the broken bar in the IM rotor.
2. The fault severity level is taken into consideration in the analysis process as well as the developed BRB location detection formula.
3. Various loading levels are considered to attest the enhanced performance proposed technique.
4. Sinusoidal supply in addition to constant v/f operation are attested.
5. IM parameters' sensitivity analysis is carried out.

The presented paper is organized into seven sections. Following the introduction, the second section demonstrates the IM model as a group of linear non-homogeneous differential equations. The detailed theoretical background of HT is considered in the third section. After that the envelope detection of the stator current is considered in section four. The proposed technique used to detect the fault location is explained in section five through statistical analysis of the motor stator current envelope. The proposed technique is investigated for several operating modes, loading levels and fault severity. Parameter sensitivity analysis is considered in section six to validate the proposed technique tolerance to IM parameter variation. Finally, results discussion and conclusion are presented in section seven.