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A new diagnosis of broken rotor bar fault extent in three phase squirrel cage induction motor

Pu Shi *, Zheng Chen, Yuriy Vagapov, Zoubir Zouaoui

Glyndwr University, Wrexham, UK

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ABSTRACT

This paper proposes a new induction motor broken bar fault extent diagnostic approach under varying load conditions based on wavelet coefficients of stator current in a specific frequency band. In this paper, winding function approach (WFA) is used to develop a mathematical model to provide indication references for parameters under different load levels and different fault cases. It is shown that rise of number of broken bars and load levels increases amplitude of the particular side band components of the stator currents in faulty case. Stator current, rotor speed and torque are used to demonstrate the relationship between these parameters and broken rotor bar severity. An induction motor with 1, 2 and 3 broken bars and the motor with 3 broken bars in experiment at no-load, 50% and 100% load are investigated. A novel criterion is then developed to assess rotor fault severity based on the stator current and the rotor speed. Simulations and experimental results confirm the validity of the proposed approach.

1. Introduction

Induction machines have been widely used in many industrial processes and have been playing a non-substitutable role in a variety of diverse industries [1,2]. In spite of their low cost, reliability, and robustness, induction machines are still prone to failures due to exposed to the wide variety of harsh environments and conditions, misoperations or even manufacturing defects, etc. [3]. These faults, failures and gradual deterioration can lead to motor interruption if left undetected and their resulting unplanned downtime are very costly. It is well known that fault detection in induction machine at an early stage may not only minimize breakdowns and reduce maintenance time but also stop propagation of the fault or limit its escalation to severe degrees. Therefore, a diagnostic system or condition monitoring program which can predict such a failure of electrical machines has received considerable attention for many years [2,4,5].

From the investigations on different failure modes in induction motors that the rotor related faults is around 20% including broken rotor bar fault which is the subject of this paper [6]. Although this percentage is not noticeable of all the different motor faults, rotor faults consisting of bars and end-rings breakage or cracks are hard to diagnose due to the inaccessibility of the rotor [7]. Moreover, this type of fault may not show any symptoms during early stage until propagating to the next bars and leading to the sudden collapse [7–9]. However, by detecting the number of broken bars it is possible to evaluate the operation condition of induction motor and avoid this situation happens. Furthermore, precise detection of the broken bars is also help accurately predict motor future performance. Therefore, the best decision for broken bars motor can be made based on the work conditions, motor conditions and fault conditions such as number of broken bars [7].

* Corresponding author. Tel.: +44 1978293132.
E-mail addresses: shi-paul@hotmail.com, S07001957@mail.glyndwr.ac.uk (P. Shi), z.chen@glyndwr.ac.uk (Z. Chen).

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In the past, computer based mathematical models enable the simulation of different types of malfunctions and the study of the changes of the operational characteristics without purposely destroying expensive laboratory machines. In this paper, winding function approach is used for modeling broken rotor bars faults in induction motors. In this modeling, effects of the stator winding distribution, stator and rotor slots, geometrical and physical characteristics of different parts of the motor and non-linearity of the core materials are taken into account. In [10], the performance of multiphase machines designed for operation with static power converters is investigated. The winding distributions are intentionally rectangular to better accommodate the rectangular waveforms of solid-state inverters. An analysis method is developed for the modeling of multiphase cage induction motors with inter-turn fault asymmetry in the stator. This approach based on the winding functions includes all the space harmonics in the machine [11]. A new multiple coupled circuit model is presented for the simulation of induction machines with both arbitrary winding layout and/or unbalanced operating conditions in [12]. The model is derived by means of winding functions and no symmetry is assumed. In [13], a new detailed mathematical d–q model is introduced. This model is based on the coupled magnetic circuit theory and complex space vector notation and takes into account the actual nonsinusoidal rotor bar distribution. It is shown that both stator and rotor circuits can be modeled by the simple set of only four coupled differential equations, i.e., the d–q model. In [14], a model based technique is presented, which relies on comparing the actual torque of the machine with a value predicted by a model.

Signal processing is one of the most important steps used for condition monitoring and fault diagnostics, whose aim is to find the important information contained in the signals and then, the dominant features of signals can be extracted for fault diagnostics. Hitherto, many signal processing methods have been proposed in the literature [15]. The most important step in the fault diagnosis in electrical machines is paying attention to choosing proper signal processor. Analytical processors [16], time-series data mining (TSDM) [17], fast Fourier transform (FFT) [18–25], multiple signal classification (MUSIC), zoom multiple signal classification (ZMUSIC) [21] and wavelet transform (WT) [26–33] are the most important processors for fault diagnosis of induction motors.

The TSDM is applicable only to signals with rapid variations. Since the torque signal has such a feature, in [17] the TSDM is used for processing the torque signal; it can diagnose the static and dynamic eccentricity as well as broken rotor bars and end rings. However, using torque for processing and fault diagnosing is considered invasive. The processors used in [34] are only useful in particular conditions, and broken rotor bars cannot be diagnosed by those methods. Another motor processor that was used for analysis of a faulty induction motor was the FFT. The precision of the FFT for steady state analysis of the stator current at rated load and speed is desirable. Since the transient stator current signal is not periodic, it is not amenable to analyze the signal by FFT. Also it is impossible to estimate the time of the fault occurrence using the FFT.

Using wavelets can solve the above mentioned problems and a more precise behavior of the stator current signal can be described. The WT is a powerful signal processing tool used in power systems and other areas. The WT, like the STFT, allows time localization of different frequency components of a given signal, however, with one important difference: the STFT uses a fixed width windowing function. As a result, both frequency and time resolution of the resulting transform will be fixed but in the case of the WT, the analyzing functions, which are called wavelets, will adjust their time widths to their frequency in such a way that, higher frequency wavelets will be very narrow and lower frequency ones will be broader. Therefore, in contrast to the STFT, the WT can isolate the transient components in the upper frequency isolated in a shorter part of power frequency cycle. The ability of the WT to focus on short time intervals for high frequency components and long intervals for low-frequency components improves the analysis of the signals with localized impulses and oscillations. In [30], it has been shown that use of high-order wavelets can improve the accuracy of diagnosis of the broken rotor bars. In [31], wavelet packet decomposition of the stator current is used for online noninvasive detection of broken rotor bars. In [32], the evolution of certain frequency components associated with broken rotor bars, during the start-up transient mode has been extracted.

Although many researchers have been devoted on the diagnosis of the rotor broken bars for many years, there are still some difficulties with regarding to the broken bars number diagnosis and determination. Bashir et al. introduced novel indices for broken rotor bars diagnosis in three-phase induction motors. This report is based on wavelet coefficients of stator current in a specific frequency band. However, this report did not study the influence of broken rotor bars severity to stator current, speed and torque. They also did not explain the reason to the chosen indices to diagnose broken rotor bar numbers [7]. Mario et al. proposed a new diagnostic technique for broken rotor bars in induction motors using Beirut diagnostic procedure (BDP). In this paper, a severity factor was defined in order to evaluate the extension of the fault. This paper was more concentrated on constant load and steady state conditions which were not applicable in realistic industrial environment [35]. Didier et al. also presented a method to detect broken rotor bars in induction machines. This technique was based on the Fourier and Hilbert transform of the stator current and rotor fault severity was not considered [1]. Antonino-Daviu et al. investigated the application of a transient based methodology to diagnose broken damper bars in synchronous motors. This approach relied on the analysis of the stator start-up current by discrete wavelet transform which was not always available and cannot be treated as a general broken bar fault detection method [36]. Most of the above mentioned approaches are concentrated on induction motor works in steady state and ignore the transient situations. In this paper, a fault diagnosis method based on wavelet transform is proposed for fault diagnosis and determination of the broken bars numbers both in the transient and steady conditions.

One of the difficulties existing in the fault diagnosis approaches is the precise diagnosis of the fault in induction motor with varying load. For instance, the FFT based MCSA method which uses side band components around fundamental harmonic to detect the fault, suffers from this difficulty. The reason is the amplitude of the side band components is load