Detection and Diagnosis of Broken Rotor Bars in Induction Motors Using the Fuzzy Min-Max Neural Network

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ABSTRACT

In this paper, a fault detection and diagnosis system for induction motors using motor current signature analysis and the Fuzzy Min-Max (FMM) neural network is described. The finite element method is first employed to generate experimental data for predicting the changes in stator current signatures of an induction motor due to broken rotor bars. Then, a series real laboratory experiments is for broken rotor bars detection and diagnosis. The induction motor with broken rotor bars is operated under different load conditions. In all the experiments, the FMM network is used to learn and distinguish between normal and faulty states of the induction motor based on the input features extracted from the power spectral density. The experimental results positively demonstrate that the FMM network is useful for fault detection and diagnosis of broken rotor bars in induction motors.

Keywords: Condition Monitoring, Fault Diagnosis, Fuzzy Min-Max (FMM) Neural Network, Induction Motor, Pattern Classification

1. INTRODUCTION

A motor is a widely used device for converting electrical energy to mechanical energy. Owing to the use of variable-speed drives in improving motor efficiency, issues related to over-heating and harmonic problems occur; which in turn result in a shorter operational life of motors. In terms of applications, induction motors are widely used in industries, which include manufacturing machines, belt conveyors, cranes, lifts, compressors, trolleys, electric vehicles, pumps, and fans (Montanari et al., 2007).

The Motor Current Signature Analysis (MCSA) technique can be used to examine the supply currents for detecting a particular
motor failure in the drive system. One way to use MCSA is to sample the harmonics components in the stator-current spectrum using the Fast Fourier Transform (FFT) (Benbouzid & Kliman, 2003). Current monitoring can then be implemented by using current transformers on small to large motors. Indeed, a lot of research work has been conducted to detect machine faults using MCSA (Thomson et al., 1999). Methods for detecting mechanical faults in induction motors using MCSA generally ignore the load effects (Benbouzid et al., 1999; Thomson & Fenger, 2001), or assume that the load is known (Kim et al., 2003).

Comparing different types of soft computing techniques, neural networks have been shown to be useful for undertaking fault detection and diagnosis tasks (Ho & Lau, 1995; Tallam et al., 2003). Some of the popular neural network models include the Radial Basis Function (RBF) networks (Ghate & Dudul, 2010a) and the Multi-Layer Perceptron (MLP) networks (Ghate & Dudul, 2010b). One of the main advantages of these networks is the flexibility to learn from data samples, whereby the learning procedure does not require an exact mathematical model of the problem under scrutiny. However, the conventional RBF and MLP networks operate in an offline batch learning mode, and re-training is necessary when more data samples are available after the training phase. As such, in this study, the supervised Fuzzy Min-Max (FMM) (Simpson, 1992) neural network is selected mainly because of its capabilities of online, one-pass learning without the need for re-training. In other words, FMM has the capability of learning new data samples and adapting to new classes incrementally while refining the existing classes quickly and autonomously (Simpson, 1992).

The organization of this paper is as follows. In Section 2, the theory and related work of fault detection and diagnosis of broken rotor bars are given. The proposed method using the supervised FMM network is detailed in Section 3. This is followed by an experimental study, results, and discussion in Section 4. Finally, concluding remarks are presented in Section 5.

2. BROKEN ROTOR BARS

In this section, the theory of broken rotor bars is first given. This is followed by a review of related work pertaining to fault detection and diagnosis of broken rotor bars.

2.1. Theory

Cast cage and fabricated cage are two different types of cage rotors in induction motors. Cast cage rotors are normally used in induction motors up to 3000-kW rating while fabricated cages are used in induction motors of higher ratings and in special application machines (Awadallah & Morcos, 2003). Cast rotors are difficult to fix once breakage or cracks develop in them, although they are more durable and rugged than fabricated cages. According to Montanari et al. (2007), broken rotor bars constitute about 10% of the total induction machine faults. During broken rotor bars events, the sideband currents are given by (Awadallah & Morcos, 2003):

\[ f_k = (1 \pm 2ks)f, \]

Where \( k = 1, 2, 3 \). Considering the speed ripple effects, other frequency spectrums, which can be observed in the stator-current spectrum, are given by (Awadallah & Morcos, 2003):

\[ f_k = \left[ \frac{k}{p} \right] (1 - s) \pm s f, \]

Where \( p \) is the number of pole pairs, and \( k/p = 1, 2, 3 \).

2.2. Related Work

Back Propagation (BP) is a commonly used supervised learning method for feedforward neural networks (Arabacı & Bilgin, 2010). In Arabacı and Bilgin (2010), current signals were transformed to magnitudes using FFT, and side-band frequency magnitudes were fed into a feedforward neural network trained with
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