Fault Detection and Diagnosis of Induction Motors Using Motor Current Signature Analysis and a Hybrid FMM–CART Model

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Abstract—In this paper, a novel approach to detect and classify comprehensive fuzzy min-max (FMM) neural network and classification and regression tree (CART) is proposed. The hybrid model, known as FMM–CART, exploits the advantages of both FMM and CART for undertaking data classification and rule extraction problems. A series of real experiments is conducted, whereby the presented signature analysis method is applied to a current database comprising stator current signatures under different motor conditions. The signal harmonics from the power spectral density are extracted as discriminative input features for fault detection and classification with FMM–CART. A comprehensive list of induction motor fault conditions, viz., broken rotor bars, unbalanced voltages, stator winding faults, and eccentricity problems, has been successfully classified using FMM–CART with good accuracy rates. The results are comparable, if not better, than those reported in the literature. Useful explanatory rules in the form of a decision tree are also elicited from FMM–CART to analyze and understand different fault conditions of induction motors.

Index Terms—Classification and regression tree, fault detection and diagnosis, fuzzy min–max neural network, induction motor, motor current signature analysis.

I. INTRODUCTION

MOTORS are commonly used devices to convert electrical energy to mechanical energy. In order to improve motor efficiency, variable speed drives are commonly used, and this has led to increased motor overheating problems, harmonic problems, and shorter operational life of motors [1], [2]. As a result, effective fault detection and diagnosis techniques are needed in order to reduce the maintenance and downtime costs of motors. From the literature review, useful techniques for online detection and diagnosis of induction motor faults emerge rapidly, which are able to avoid unexpected failures of induction motors [1]. Examples include online condition monitoring techniques to observe motor parameters such as stator resistance and inductance [2], [3].

In general, fault detection and diagnosis techniques for electric motors are provided by some combination of mechanical and electrical condition monitoring methods. Whenever mechanical sensors are used to assess the health conditions of a machine, they normally are installed on some expensive or load-critical machines where the high cost of a continuous monitoring system can be justified [4]. Nevertheless, current monitoring can be implemented inexpensively on machines with arbitrary sizes by using current transformers. In this regard, effective and low-cost fault detection techniques can be implemented, hence saving the maintenance and downtime costs of motors. This is the reason why this paper focuses on motor current signature analysis (MCSA) for fault detection and diagnosis of induction motors.

Among different types of electric motors, induction motors contribute more than 60% of the electrical energy produced [5]. Induction motors are widely used in different areas, which include manufacturing machines, belt conveyors, cranes, lifts, compressors, trolleys, electric vehicles, pumps, and fans [6]. It has been reported [7]–[9] that shipment of AC motors and three-phase induction motors in Europe are at 96.2% and 87%, respectively. Failure surveys by electric power research institute [10], [11] show that the typical failure percentages of induction motors are as follows: stator-related faults 38%, rotor-related faults 10%, bearing-related faults 40%, and other faults 12%.

This paper aims to design and develop a low-cost and yet effective method to detect and classify comprehensive fault conditions of induction motors, as indicated in [10] and [11]. We select MCSA, which is a low-cost and convenient method, for fault detection and diagnosis in this paper. MCSA deploys the results of spectral analysis of the supply current to detect a particular motor failure in the drive system. There are also reports [12], [13] that focus on detecting mechanical faults of machines using MCSA, but most of the methods used ignore the load effects, or assume that the load is known [14]. An effective use of MCSA in fault detection of induction motors is to sample the harmonics components in the stator-current spectrum using the fast fourier transform (FFT) [11], [15]–[22]. FFT is a popular and useful technique for signal analysis, and is applied in this paper to process signals derived from stator currents for detecting and diagnosing induction motor faults under different load conditions.

Rule extraction plays an important role in fault detection and diagnosis systems. Rules provide explanation of the system