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Comparative investigation of vibration and current monitoring for prediction of mechanical and electrical faults in induction motor based on multiclass-support vector machine algorithms

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ABSTRACT

This paper presents an investigation of vibration and current monitoring for effective fault prediction in induction motor (IM) by using multiclass support vector machine (MSVM) algorithms. Failures of IM may occur due to propagation of a mechanical or electrical fault. Hence, for timely detection of these faults, the vibration as well as current signals was acquired after multiple experiments of varying speeds and external torques from an experimental test rig. Here, total ten different fault conditions that frequently encountered in IM (four mechanical fault, five electrical fault conditions and one no defect condition) have been considered. In the case of stator winding fault, and phase unbalance and single phasing fault, different level of severity were also considered for the prediction. In this study, the identification has been performed of the mechanical and electrical faults, individually and collectively. Fault predictions have been performed using vibration signal alone, current signal alone and vibration-current signal concurrently. The one-versus-one MSVM has been trained at various operating conditions of IM using the radial basis function (RBF) kernel and tested for same conditions, which gives the result in the form of percentage fault prediction. The prediction performance is investigated for the wide range of RBF kernel parameter, i.e. gamma, and selected the best result for one optimal value of gamma for each case. Fault predictions has been performed and investigated for the wide range of operational speeds of the IM as well as external torques on the IM.

1. Introduction and literature review

Induction motors (IM) are most widely used industrial electro-mechanical drives in modern industries owing to their high power capacity, robust performance, low manufacturing cost, and adaptability. Due to various stresses, such as the thermal, mechanical, electrical and environmental acting upon the stator, rotor, bearings and shaft, the performance of IM can drastically diminishes, sometime rapid wear and finally catastrophic failures may occur, if faults are not timely detected. The catastrophic failure leads to disruptive production losses, monetary losses and serious human injuries. Therefore, for timely fault detection to avoid the chances of catastrophic failure, numerous condition monitoring techniques have been developed in last four to five decades based on the vibration, current, voltage, temperature, main air-gap flux and acoustic noise [1].

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Among several condition monitoring methods, the current and vibration based methods are the most widely preferred owing to their reliability, non-intrusiveness and easy measurability. The effectiveness of these methods depends on the loading of machines and signal-to-noise ratio of instruments [2]. The current monitoring can provide a unique fault patterns for the effective prediction of mainly electrical faults, i.e. the stator winding fault, broken rotor bar fault, and phase unbalance and single phasing. The vibration monitoring can be useful for the effective prediction of mechanical faults, i.e. bearing faults, unbalance rotor, bowed and misaligned rotor [3]. But the entire IM can be failed due to the propagation of electrical or mechanical faults. Hence, it would be beneficial to perform the condition monitoring of IM based on the vibration as well as current signals.

In recent years, many artificial intelligent methods such as neural networks, fuzzy logic, neural-fuzzy, immune genetic system and support vector machine algorithms have been employed to improve the effectiveness of prediction and diagnosis of IM faults particularly during the maintenance judgment process [4]. Among several artificial intelligent methods for faults prediction of IMs, nowadays the SVM is extensively gaining popularity owing to their best prediction performance, and less training and testing time [5]. The best property of SVM algorithms is that it can perform well even with the small number of training and testing data hence reduce the computational load [6].

The statistics confirms that half. i.e. 50% of the IM failures occur due to bearing failures, about 40% due to winding failure of stator, and less than 10% due to rotor and shafts failures [7]. Nguyen and Lee [8] and Nguyen et al. [9] investigated mechanical faults diagnosis of IMs based on vibration using SVM, decision tree and GA. Baccarini et al. [10] presented practical industrial application of the SVM for mechanical fault diagnostics of IM based on frequency-domain signals. Chattopadhyay and Konar [11] presented feature extraction using wavelet transform (CWT and DWT) and feature selection using greedy-search technique for the multi-class fault detection of IM using the RBF neural network, multilayer perception (MLP) neural network and SVM classifiers. Widodo and Yang [12] utilized transient current CBM and wavelet SVM for the fault diagnosis of IM. The building of Wavelet kernel function using Haar, Daubechies and Symlet were successfully performed. Bacha et al. [6] and Salem et al. [13] proposed fault condition monitoring of IM based on Hilbert-Park transform using the SVM. Zhou et al. [14] investigated fault diagnosis of IM based on invariant character vectors using a single class-SVM.

Widodo et al. [15] presented the fault diagnosis of IM using combination of independent component analysis (ICA) and SVM based on the vibration and current signatures. The combination of ICA and SVM can serve as an encouraging alternative. Morales et al. [16] introduced the data fusion by using multi-class SVM to detect mechanical faults in IM using the vibration and line current signatures. Tran et al. [17] presented fault detection of IM based on classification and regression tree (CART) decision trees method and adaptive neuro-fuzzy inference based on vibration signatures as well as the MCSA. Garcia et al. [18] presented the high-resolution spectral analysis for diagnosis of multiple faults in IMs using the multiple signal classification (MUSIC) algorithm based on vibration signatures and the MCSA. Tran et al. [19] investigated the transient current CBM based IM fault diagnosis by using Fourier–Bessel expansion and simplified fuzzy ARTMAP, a combination of fuzzy logic and neural network architecture based on Adaptive Resonance Theory (ART). Generalized discrimination analysis (GDA) was used to solve the high dimensionality of feature sets. Ergin et al. [20] proposed fault diagnosis in IM, i.e. the stator, bearing and rotor using common vector approach (CVA). Nakamura et al. [21] presented diagnosis of the electrical and mechanical faults of IM based on the Hidden Markov Model, which is widely used in the field of speech recognition. Park et al. [22] attempted fault diagnosis of IM based on a mixed algorithm of PCA and LDA (linear discriminant analysis). From literature survey, it is evident that faults prediction of IMs using multi-class SVM algorithms is still uncommon and has lot of potential, especially of the mechanical and electrical faults prediction together. Hence, it can be explored further for the perfect multi-class fault prediction in the IM.

In this paper, a comprehensive study on the prediction of faults (mechanical and electrical) in IMs has been attempted using the artificial intelligent method called the MSVM. In Section 2, a brief introduction of the binary and multiclass SVM algorithms is described. In Section 3, the experimental set-up and various faults in the IM are introduced. Procedure of data acquisition and feature extractions are described. In Section 4, the IM fault predictions have been performed for various cases and Section 5 concludes the paper.

2. Brief introduction of SVM algorithms

The SVM, a statistical learning based machine learning/pattern recognition algorithm was first introduced by Vapnik in 1995. The basic SVMs are originally developed to handle the binary classification problems. For illustration, a binary classification problem is considered here as shown in Fig. 1. The circle and square represent two classes. A number of linear classifier (hyperplane) are possible to separate the two classes, however there is one that achieves maximum separation known as optimal separating hyperplane. The goal of SVMs is to construct an optimal hyperplane in the space by using available training samples. The hyperplane can separate the set of vectors without any errors, if the margin is maximal. Overall aim of SVMs is to recognize test samples very well. For a binary classification problem, the process of SVM is described as follows [23].

Now consider a binary classification problem with data points $x_i,\ i = 1, 2, \ldots, n.$, belong to class I or class II, and their associated labels $y_i = \pm 1$, with the following decision function

$$f(x) = sign(w \cdot x + b) \tag{1}$$