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A novel approach for fault diagnosis of induction motor with invariant character vectors

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ABSTRACT

This paper proposes a novel approach for the fault diagnosis of induction motors. The invariant character vectors of fault signals are first extracted from the training samples. A single-class support vector machine (SC-SVM) is then used to detect the occurrence of faults, and the obtained invariant character vectors are employed as the desired references to classify the faults associated with the nearest neighbor classifier. The new diagnosis algorithm is validated for an induction motor (Y132S-4), which has shown excellent performance.

1. Introduction

Induction motors have been widely used in manufacturing, transportation and many other industrial systems due to their low cost and ability to operate in different working environments [5,7]. However, most induction motors experience faults after long operation times, such as short-circuits in the stator windings, bearing cracks, air–gap eccentricity, and breakage of rotor bars, which may cause the system operations to fail. Therefore, the development of efficient fault diagnosis techniques is crucial for preventing fault occurrence, unexpected interruption, and the failure of industrial system operations.

In general, the major faults of induction motors may be roughly classified as follows: (i) stator faults, e.g., winding inter-turn shorts faults; (ii) rotor faults, such as broken bars; (iii) eccentricity faults; and (iv) bearing faults. Approximately 40% of motor faults are reportedly related to stators, and 5–10% of faults are relevant to rotors [26,27].

The selection of a set of proper motor signals is well known to be essential to capturing the characteristics of faults, such as the vibration signals of motors, stator current, air–gap or external magnetic flux density. Among all of the above measured information, the stator current is particularly useful for gaining insight into the faulty state of motors [38]. In practice, the stator current in a healthy induction motor has a single frequency component. However, in the case of any fault occurrence, the extra frequency components induced by the faults will appear in the stator current spectrum.

In this paper, the stator current is used to acquire information on the faulty state of induction motors. The harmonic components in the stator current spectrum are known to remarkably change when a fault occurs. Thus, using these harmonic frequency components to describe the characteristics of the faulty state of induction motors is reasonable. In this work, a

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state variable vector, consisting of the harmonic amplitudes of a stator current at a specified frequency band that is induced by faults is defined to depict the status of induction motors.

In recent years, many techniques have been used to detect mechanical and electrical faults in induction motors. For example, the Fourier transform of the transient stator current is used to create a unique stamp of harmonics induced by a fault [19]; the rotor magnetic field space vector is utilized to diagnose broken-bar faults in induction motor operation at steady state [26]. Neural networks are trained with the stator current and mechanical vibration spectra to detect faults [18,22,24,27]. Recently, support vector machines (SVM) have been adopted to recognize motor faults [3,4,23,36]. Notably, most of these techniques are employed to diagnose one or two faults only in induction motors, and none have been adopted to simultaneously handle multiple-fault diagnosis. Because multiple-fault diagnosis can be regarded as a multi-classification issue [18,24], the neural classifiers trained with back-propagation (BP) [22,31] and SVM [4,20,21,25,37] are often employed to diagnose faults. However, these classifiers usually need a large number of samples for training in order to ensure good classification performance. In practice, obtaining a large amount of faulty samples is difficult. Moreover, the sampled data are often disturbed by noises and degenerated by the measurement devices. Methods to extract and accurately classify faults using neural classifiers trained with the BP and the SVM remain a challenging topic.

In this paper, we propose a novel fault diagnosis algorithm for induction motors. In the training phase, the invariant character vectors that are capable of describing the main features of faults are extracted from the training samples. The subsequent diagnostic process is twofold: first, a single-class support vector machine (SC-SVM) [32] is employed to detect the occurrence of faults from the measured system signal. As the faults occur, the invariant character vector is then extracted from the data and compared with the desired invariant character vectors derived in the training phase to determine the fault class. The key points to develop this fault diagnosis algorithm are the extraction of the invariant character vectors, which ensures that the faults can be accurately classified under different noisy environments.

The rest of the paper is organized as follows. In Section 2, the selection of characteristic frequencies of the stator current spectrum is introduced for four classes of faults. In Section 3, the extraction of the invariant character vectors of faults is addressed. The diagnosis of fault occurrences with the SC-SVM classifier and the final fault classification with invariant character vectors are discussed in detail in Section 4. In Section 5, an experiment to diagnose the fault of an induction motor (Y132S-4) is conducted to demonstrate the good diagnosis performance. Section 6 gives the conclusion.

2. Problem formulation

Fig. 1 shows a three-phase asynchronous induction motor (Y132S-4). Its corresponding parameters are detailed in Table 1. In this section, we will briefly describe the four classes of faults that may occur in Y132S-4 induction motors: the bearing fault (Fault 1), rotor broken bars fault (Fault 2), stator winding inter-turn shorts fault (Fault 3), and rotor eccentricity fault (Fault 4). The detection and diagnosis of these faults will be discussed in the latter sections.

2.1. Character of bearing fault

Bearing faults such as inner race, outer race, and ball defect, cause machine vibration [21]. The mechanical vibration induced by the bearing defect results in air gap eccentricity. Oscillations in air gap length, in turn, cause variations in the flux density. The variations in the flux density affect the machine inductances, which produce harmonics of the stator current. For the convenience of analysis, suppose that the number of balls, diameter, and the corresponding cage diameter are denoted by N_b, D_b, and D_c, respectively. The point of contact between the ball and the raceway is described by the contact angle, α. Current harmonics have been noted to result in certain frequency bands when the rolling elements roll over the defect place. Furthermore, the characteristic frequencies are the functions of the bearing geometry and the mechanical rotor frequency, f_r. According to [15], the outer race characteristic frequency, f_o, i.e., the ball passing frequency on the outer race, is given by the following:

Fig. 1. Motor (Y132S-4).