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A combined image processing and Nearest Neighbor Algorithm tool for classification of incipient faults in induction motor drives☆

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ABSTRACT

Switching Devices such as IGBT used in Pulse Width Modulation (PWM) Inverter feeding an induction motor often suffer from different types of incipient faults like improper contact points, poor connections and problematic solder joints. These are due to ageing or prolonged operation in unfriendly environments. These faults need to be detected at their initial stages to prevent subsequent spreading of faults. In the present work, different variations of the above mentioned faulty cases in a PWM-Inverter have been studied by recording three phase inverter output current profiles and converting them to Concordia patterns. It has been observed that the Concordia patterns are quite different in shapes for different types of faults. A suitable image based shape descriptor has been applied to extract relevant information from these Concordia patterns. Finally, Nearest Neighbor Algorithm is employed on this information to identify the nature and location of faults. Performance of the algorithm is found to be quite satisfactory when its results are compared with two more related algorithms.

1. Introduction

Induction motors those are being extensively used in various industries have to often operate under harsh conditions, and thus can develop faults in different internal parts which include stator, rotor and bearings. These faults greatly hamper the performance of the machine and operation of the whole process. Early detection of these faults is of great concern to industries and they are thus abundantly investigated in different literatures [1–3]. In addition to such studies over internal motor faults, studies over the years have shown that in voltage-fed PWM inverter induction motor drives, the probability of fault in the drive itself is around 63% over the first 12 months of operation. It has been further observed that 70% of such drive faults are related to power electronics component failures such as IGBTs [4]. Three faults, namely open circuit faults [4,5], short circuit faults [6] and intermittent misfiring faults [7,8] are the most common types of faulty phenomenon in IGBTs. Monitoring any inverter fault involves measurement of electrical parameters at certain key points such as inverter pole voltage [9], collector-emitter voltage in lower switch [5], Gate voltage [10] and stator current trajectories [11]. Among all of them, however, analysis of stator current trajectory is found to be accurate, effective yet economically prudent

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technique. These stator current data are processed by different fault detection and diagnostic methods such as, current vector instantaneous frequency [12], Concordia stator mean current vector [7], Switching Function model [5], Modified normalized DC component method [13], Observer Based schemes [4], waveform and harmonic analysis [14] and Wavelet Transform [15]. In both Wavelet Transform with multi-resolution analysis [6] and Discrete Wavelet Transform [15], the fault information in the transformations are found and correlated with time of fault, thus discriminating faulty states. Among all these monitoring processes, it has been cited that analysis of Concordia pattern is quite successful in providing fault indicators for all the three most common motor drive related faults mentioned above. Further processing of the drive fault indicators have been done in the past with different artificial intelligent methods such as Model based schemes [4], Fuzzy logic [7] and Artificial Neural Network (ANN) [16].

Another type of inverter failure can be caused by partial break down of leads, improper soldering joints or connection problems which result in development of spurious resistance in series with the terminals of IGBTs. These parasitic developments can be attributed to various reasons that include:

- High frequency operation of switches creates temperature cycling in the soldering joints. This along with environmental stress and chemical pollution in industrial sites cause the joints to become resistive [17].
- Differences in coefficients of expansion between the soldering materials, the connecting leads of IGBTs and the copper wires generate thermal stresses at different levels of loading, finally leading to deformation and deterioration of the joints.
- Differences between di/dt in all switches of an inverter lead to different switching energies for different switches; causing thermal dissymmetry and ultimately affecting soldering joints of the power switches [18].

Unfortunately, such incipient faults have either been overlooked by previous researchers, or not given due importance because they were always considered to be of ‘minor’ in nature. However, early detection of such minor faults is of equal importance as they do not normally trip the protective devices. If remain undetected, they will cause overstressing of other IGBTs terminals causing catastrophic failure of the inverter. Again, severe torque ripples [19] also appear in motor operation leading to possible mechanical damage. Whereas, previous researchers have presented methods to identify major faults such as open circuit (OC), short circuit (SC), and misfiring of drive elements, main aim of the present contribution is to address the fourth type of fault in inverter, i.e. the one due to spurious resistance arising at IGBT terminals. Key features of the current research work are:

- Detection and classification of incipient faults in induction motor PWM drives.
- Detection and classification of such faults when they occur simultaneously in more than one switch and at varying load levels.
- Use of suitable data and image processing techniques for effective data reduction without sacrificing relevant fault information.

In the present work, three-phase line current profiles are recorded for a PWM inverter driving an induction motor under different faulty situations due to appearance of spurious resistances at IGBT drain terminals. The three-phase line currents are first converted to Concordia patterns as the first stage of data reduction. These Concordia patterns are then converted to binary images, discretized and relevant shape descriptors are derived there from. These shape descriptors are further processed by an artificial intelligent algorithm to identify and classify different faults. In the present diagnosis, Nearest Neighbor Algorithm is used as the classifier since it has been found to be very well suited for image classification [20,21] problems. The performance of the algorithm is also compared with two other related algorithms in the present work. It is pertinent to highlight here that objective of this work is however, not to emphasize performance of the classifier algorithm. Theoretically speaking any proven classifier including Artificial Neural Network (ANN), Fuzzy, Support Vector Machine (SVM), Nearest Neighbor Algorithm (NNA) could be used to perform the fault classification with comparable performance. The major challenge faced in this work has been to identify suitable features that could characterize a variety of minor incipient faults in drives and making those features immune to load variations. Encouraging results are obtained that demonstrate efficacy of the proposed scheme.

The remainder of this paper is organized as follows: Different faults in inverter are simulated in Section 2. Section 3 describes how data processing is done with the faulty inverter output current profiles. Sections 4 and 5 describe the fault classification algorithm used and the corresponding results. Finally, Section 6 summarizes contributions of the present study.

2. Simulation model under study

The simulation model used for this study has been developed in PSIM software that includes an open loop sinusoidal–PWM Voltage fed Induction motor drive as shown in Fig. 1. Faults in the inverter have been simulated by adding spurious resistances to different IGBT terminals, as shown by R1 and R3 with T1 and T3 respectively in Fig. 1.

The main aim of this work is to study incipient fault conditions of power switches rather than studying the drive performance. So the open loop configuration has been chosen over a closed loop one to avoid unnecessary circuit complications. Comparing with a practical induction motor of 1.5 kW, 440 V rating, parameters are set in the simulated scheme as detailed in Table 1.

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