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A novel multi-agent approach to identify faults in line connected three-phase induction motors

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ABSTRACT

Three-phase induction motors (TIMs) are the key elements of electromechanical energy conversion in a variety of productive sectors. Identifying a defect in a running motor, before a failure occurs, can provide greater security in the decision-making processes for machine maintenance, reduced costs and increased machine operation availability. This paper proposes a new approach for identifying faults and improving performance in three-phase induction motors by means of a multi-agent system (MAS) with distinct behavior classifiers. The faults observed are related to faulty bearings, breakages in squirrel-cage rotor bars, and short-circuits between the coils of the stator winding. By analyzing the amplitudes of the current signals in the time domain, experimental results are obtained through the different methods of pattern classification under various sinusoidal power and mechanical load conditions for TIMs. The use of an MAS to classify induction motor faults allows the agents to work in conjunction in order to perform a specific set of tasks and achieve the goals. This technique proved its effectiveness in the evaluated situations with 1 and 2 hp motors, providing an alternative tool to traditional methods to identify bearing faults, broken rotor bars and stator short-circuit faults in TIMs.

1. Introduction

Three-phase induction motors (TIMs) consume over 60% of the electrical energy in the industrial sector [1] and are the primary means of energy transformation in mechanical drives [2–4]. Like any other electrical machine, these motors require proper maintenance, as breakdowns can impact on productivity and cause substantial losses in industrial processes. While profitability depends on various factors, equipment maintenance is one of the most important. According to [5], all these factors justify increased efforts to develop new techniques to detect possible motor faults with enough time for proper and planned maintenance procedures.

Malfunctioning is divided into two major groups: electrical faults and mechanical faults. The most common failures are related to electrical problems in the stator winding, rotor winding, broken rotor bars, broken rotor rings, and connections, among others [6]. Mechanical failures are derived from problems such as wear and tear on the bearings and couplings, eccentricity, and misalignment. According to the research conducted by [7], over 80% of unwanted downtime in electrical motors is related to rotor, stator, and bearing problems.

To contribute to the study and development of electric machine fault identification, this paper proposes the implementation of a multi-agent computer system, based on computational intelligence, which identifies faults in the stator, rotor, and bearings of TIMs, where the input parameters are the amplitudes of three-phase currents of power supply to the machine, considering the occasional asymmetrical unbalancing of the voltages and covering a wide range of mechanical loads applied to the machine shaft. The early identification of faults is designed to bring greater security to the decision-making process, with the possibility of reducing maintenance costs and increasing the operating availability of the motor. The use of the proposed architecture for MAS provides the opportunity to explore its parallelism, extensibility, redundancy and robustness, also combining the usage of different pattern identification methods. In the case of the need to monitor a network

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with many motors which requires a higher computational power. It is possible to distribute the processing of the motor fault recognition system on different hardware and even the construction of a system with different classifier types that could better adapt to a specific fault type, although the system may require more information processing power compared to traditional systems found in the literature.

This paper is divided into six sections. Section 1 presents the introduction and a review of related research in the field. Section 2 briefly discusses previous works. Section 3 presents the methodology of the study. Experimental results appear in Section 4, while Section 5 presents findings in comparison with previous works. Section 6 presents the conclusion and final discussions.

2. A brief discussion of previous works

Induction motors play an important role in industry, a fact which underscores the importance of accurate diagnosis and classification of faults in these motors in the early stages of their evolution. Accordingly, in this work, motor faults are diagnosed by MAS with intelligent pattern classification methods, considering a pre-processing method based on the time domain, by the discretization of the stator current signals for rotor, bearing and stator fault classification.

When assessing incipient problems in TIMs, bearing-related issues have been the subject of considerable research, due to the high percentage these components occupy in the classification of motor faults. Bearing faults, according to [7], can account for over 40% of the problems that typically occur in electric motors. Several methods are used to detect these types of faults, such as analyzing mechanical vibration, spectral frequency of the stator current and axial flux. Several techniques are used to identify these faults, as demonstrated in the research presented by [8], where a methodology for monitoring bearing defect conditions by using voltage and stator current signals was developed. This system diagnoses various types of bearing defects in a 0.5 hp motor, considering different loading conditions. The strategy presented by [9], considers a model based on the entropy permutation of the vibration signal that is calculated to detect problems in the bearing during motor operation. In case of bearing failures, the vibration signal is decomposed into a set of intrinsic mode functions by means of the decomposition set in an empirical way. The authors used a variation of the support vector machine (SVM) method to classify and determine the severity of the studied defect.

Rotor faults in TIMs account for approximately 10% of the problems presented [7]. Such faults can generate thermal stress, electromagnetic forces, electromagnetic noise and vibrations and are caused by centrifugal forces, environmental stresses (abrasion) and mechanical stress [10]. Several related research projects are ongoing, such as observed in the work presented by [11], where the authors proposed a new approach to identify broken rotor bars in induction motors under different load conditions based on wavelet coefficients of the stator current in a specific frequency range. In case of faults, by increasing the number of broken bars and load levels, the amplitude of some particular components of the stator current sideband will also increase. The quantities – stator current, rotor speed and torque – are used to show the relationship between these parameters and the broken rotor bar severity. An induction motor with 1, 2 or 3 broken rotor bars is used under adversities of load variation on the motor shaft. Finally, this work also evaluates the severity of rotor faults based on data originated from stator current and rotor speed. In the work of [12] an experimental analysis of an induction motor driven at different speeds and load levels was performed. The main objective was to study experimentally the ability of the method by using the motor current signature analysis to diagnose the occurrence of broken rotor bars. In [13], a method for identifying broken rotor bar defects was also presented, based on the transformed stator current Wavelet in a specific frequency range. The method allows diagnosis of the occurrence and determination of the number of broken bars at different loads. Also, due to the properties of Wavelet transform during transient conditions, it is possible to detect the defect during motor start-up. Experimental results show data concerning motors with 1, 2, 3 and 4 broken bars with the motor operating at rated load. The motor operating with four broken bars was also tested with no load, 33%, 66%, 100% and 133% of load torque. In addition, the authors considered the finite element method to model broken bar defects.

Stator coils are subject to various anomalies which can cause different responses in the equipment. Changes in the stator winding can manifest themselves in several ways, including overheating of the motor, electrical overload, and faults in the coil insulation. The stator is subjected to critical situations in the operation of a TIM, such as thermal, electrical, mechanical and environmental, all of which can severely affect the stator condition and lead to breakdowns. As faults in the stator can cause problems with the operation of the motor, several studies to identify these faults are proposed in the literature, such as the work of [14] where the authors presented the analysis of the signature instantaneous active and reactive power in the frequency domain for diagnosing stator faults in motors driven direct on line and also considering an inverter-fed situation. The experimental and simulation results demonstrate the effectiveness of the proposed approach. The severity of the conditions is tested and the behaviors of frequency ranges are observed for the detection of stator faults. In the work presented by [15] the authors carried out a comparative study considering the evaluation of SVM/SMO, multilayer perceptron (MLP) and fuzzy ARTMAP network classifiers to diagnose the severity of stator short-circuit faults. Recently, the work of [16] presented a method considering FFT at the pre-processing stage and an MLP network to classify the severity of stator short-circuit faults in a permanent magnet synchronous motor. Breakdowns related to the stator are responsible for approximately 37% of undesired stoppages in TIMs [7].

The most common methods used in the detection and diagnosis of incipient faults in TIMs are those based on models, specialized systems and intelligent systems that simulate biological models. The diagnosis of such faults can be accomplished through spectral analysis, analysis in the time domain, finite elements, and by means of intelligent systems, as mentioned in the work of [10]. Intelligent systems in this context are presented in various topologies and procedures such as artificial neural network (ANN), fuzzy logic, and hybrid systems. On the other hand, there are few works on distributed artificial intelligence related to recognition of faults in TIMs. According to [17], distributed artificial intelligence is classified by distributed problem solving (DPS), multi-agent systems (MAS) and parallel artificial intelligence (PAI).

For over a decade, the proposed use of MAS to address engineering challenges has been reported in several instances in the literature. The use of MAS appears in works on the diagnosis of energy systems related to protection [18], systems monitoring [19], restoration of the power system [20], control [21,22] and automation [23]. For example, the work of [24] employed an intelligent agent methodology for the reconfiguration of power systems. The research conducted by [25] discussed reconfiguration for the restoration of power systems using an MAS. The authors also mentioned that the majority of approaches for restoration found in the literature are centralized solutions which lead to the single point of failure. Additionally, the research conducted by [26] proposed an MAS for fault detection and system reconfiguration for power distribution. Another related study was performed by [27], who designed a MAS integrated with fuzzy systems in order to control reactive power in a distribution system. In the area of protecting power systems, the work developed by [28] proposed an MAS to