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Induction machine fault detection using stray flux EMF measurement and neural network-based decision

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Abstract

The aim of this paper is to present the performances of voltage unbalance and rotor fault detections using an external stray flux sensor in a working three-phase induction machine. The automatic classification and fault severity degree evaluation are realized by using a neural network approach based on a multi-layer perceptron (MLP) structure. In this paper, it is proved that a simple external stray flux sensor is more efficient than the classical stator current sensor to detect rotor broken bar and voltage unbalance, using data processing at low-frequency resolution.

Keywords: Induction machine; Fault detection; Rotor broken bar; Voltage unbalance; Stray flux; Neural network

1. Introduction

Electrical machines are the workhorses of the present industry. Safety, reliability, efficiency and performance are some of the major concerns for any electrical machine applications. With issues such as aging systems, high reliability demands and cost competitiveness, preventive and condition-based maintenance, online monitoring, fault detection, diagnosis and prognosis are of increasing importance. Different internal electrical machine faults (e.g., inter-turn short-circuits, ground faults, worn-out broken bearings, broken rotor bars) along with the external ones (e.g., phase failure, supply asymmetry, mechanical overload) are expected to happen sooner or later. Early fault detection allows preventive and condition-based maintenance to be planed for any electrical machine during scheduled downtimes. It prevents an extended period of maintenance caused by system failures, improving the overall availability and performance while reducing expenses [1].

The monitoring and fault detection of electrical machines have moved in recent years from traditional decision techniques based on human analysis to computational intelligence (CI). Such techniques require "minimum configuration intelligence", since no detailed analysis of the fault mechanism is necessary as well as no modelling of the system is required. When a CI-based technique is used, any fault detection can be accomplished without an expert [2].

In the CI-based electrical machine monitoring systems, several variables are used as stator currents and voltages, magnetic fields, frame vibrations. In general, stator currents and voltages are preferred because they are qualified as non-invasive sensor-based method.

The main steps of a diagnostic procedure can be classified as follows:

(1) Use of sensors to obtain information.
(2) Signature extraction.
(3) Fault identification and fault severity evaluation.

Condition monitoring systems depend on sensors for obtaining the necessary information. However, the probability of sensor failure is often of the same order of magnitude as the probability of electrical machine failure. Since the diagnosis determined by a condition monitoring system can only be accurate if the measured information is correct, the sensors play an important role. Particularly, the reliability of the sensors can be increased by the choice of a minimum number

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of them with a simple technology and an easy implementation.

Various variables used for fault detection have been reported in the literature. Intensive research efforts have been focused on the machine current signature analysis (MCSA) in order to detect electrical and mechanical faults in three-phase induction machines [3,4]. In Ref. [5], the authors present a selection of industrial case histories that verify MCSA and that can diagnose broken rotor bars, shorted turns in low voltage stator windings and air gap eccentricity. In Ref. [6], the authors describe the use of the extended Park vector approach (EPVA) to diagnose the occurrence of stator winding faults in operating three-phase induction machines. However, this method requires three current sensors. In Ref. [7], the results of a comparative experimental investigation of various media for non-invasive diagnosis of rotor faults are presented. In this case, stator voltages and currents are used for the computation of the partial and total input powers and to estimate the electromagnetic torque. Then, this method requires the use of three current sensors and three voltage sensors.

In Ref. [8], the authors present the advantage of stator fault detection using an external stray flux sensor in a working induction machine. It is shown that a simple external stray flux sensor can be a good candidate to detect inter-turn short-circuits as well as rotor broken bars. Following the criteria of the minimum number and the simplicity of the used sensors, this paper proposes to detect rotor broken bars and voltage unbalances using a stray flux sensor.

Concerning the CI-based approach, the neural network input number is very important for successful fault detection. As the analyzed spectra include many frequency components, they can be reduced into fewer useful features. Generally, the components are selected according to the type of analyzed faults [2]. Other methods propose the spectrum compression maintaining nearly the shape of the real one. The first method requires knowledge of the characteristic frequencies in the type of machine faults involved, but in practical situations, many unexpected conditions can degrade the results. The second method attempts to use the shape of the signal spectrum, but the compression of the spectrum is too complicated and time consuming.

In Ref. [9], the authors use four features extracted from the vibration signal power spectra. When the induction machine is under fault condition, the shape of the energy frequency distribution differs from the normal condition. The dispersion of the power spectrum about its standard frequency is used to obtain information about the fault condition. In Ref. [10], a wavelet-based approach is proposed to detect and to classify various types of power system disturbances. Using a reduced number of coefficients, a neural network structure is developed to classify the typical disturbances. In Ref. [11], the authors propose a procedure for monitoring and classification of induction machine loads using an unsupervised neural network. In order to detect disturbances and faults, a current signature extraction is performed by the time–frequency spectrum approach.

It is obvious that there are many types of CI-based techniques. Some of these techniques use expert systems, artificial neural networks (ANN), fuzzy logic, genetic algorithms (GA). All these techniques have been summarized recently in Ref. [2]. One of the aims of this paper is to present a new technique for detection and classification of three-phase induction machine faults by using a stray flux sensor for measurement and an artificial neural network for decision. This method is applied to the broken rotor bars and the unbalanced voltage supply using components independent of the load and extracted from the stray flux EMF spectrum.

2. Stray flux analysis and signature extraction

The stray flux of an induction machine is a residual and undesirable effect which does not participate in the process of generating electromagnetic torque. What is meant by "stray flux" in this paper is the magnetic flux that radiates out of the machine, outside of its frame. In a first approximation, the stray flux can be related to the *0* component of the main path flux using the classical *dqo* model of the induction machine either in a static reference frame or a rotating reference frame and related to the axial leakage flux of the machine too. The axial leakage flux is essentially the result of the stator and rotor currents on the machine extremities in the stator coil ends or the rotor end-rings and it causes eddy heating of the iron elements and negatively influences machine bearings. In fact, it will be difficult to quantify the magnitude of the stray flux since it is related to the place where it is sensed around the machine body. In an ideal three-phase induction machine during its normal operation, the stray flux practically does not exist. Because of the inherent machine dissymmetry due to its manufacturing, the stray flux can always be detected even with a symmetrical voltage in the power supply [8]. The analysis of the stray flux frequency spectrum gives information about the phenomena occurring in the squirrel-cage induction machine. The occurrence of a fault on the stator windings or the squirrel cage results in a change in the air-gap space harmonic distribution. This fact is reflected in both stator and rotor currents depending on the fault origin and modifies the spectrum of the initial healthy conditions. For a healthy induction machine, the stator and rotor circuit structural characteristics can be evaluated from the point of view of the stator and rotor current spectra. The characteristic spectrum of the electromotive force (EMF) induced in both stator and rotor sides are evidently influenced by the discrete distribution of stator windings and rotor meshes. When the initial stator and rotor circuit topologies are modified because of a short circuit or an open circuit in the stator windings or because of a broken bar in the rotor squirrel cage, the current spectra are also modified. The most interesting feature in the stray flux is its dependence on stator and rotor currents. These phenomena can be used to find modifications in both stator and rotor circuits. The effect of a broken rotor bar can be analyzed by studying the corresponding induced MMF effect in the air gap. Considering that the stator structure is not modified, the frequencies induced by the stator winding in the rotor currents are not modified. On the other hand, a broken bar modifies the rotor cage structure and consequently the distribution of the rotor MMF. Other types of faults such as static or dynamic eccentricity or bearing failure, which can modify the MMF air-gap space harmonic distribution, can be analyzed in