Diagnosis of Faults in Three Phase Induction Motor using Neuro Fuzzy Logic

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Abstract
Three Phase Induction motor is the major running part in the Industries and is the most used electrical machines. Hence detection of faults in the motor is very important in order to improve the performance of the induction motor, avoid the production lost and also to reduce the operational costs. The methods used for this process is mainly based on measuring and analyzing the vibration and current. Here, a novel technique based on the stray flux measurement different positions around the electrical machines is proposed. The main objective of the proposal is to detect the faults in induction motor due to electrical and mechanical origin by vibration analysis. The paper gives justification for the change in machine vibration due to the change in voltage harmonics; this will help to find the fault in induction motor. The main aim is to present a new approach to find the rotor bar failures. The method focuses on the study of an approximation signal resulting from the wavelet decomposition of the start-up stator current using Neuro Fuzzy Logic.

Keyword: Electric Machines, fault detection, diagnosis, location identification, Induction motors, Statistical analysis, wavelet transform, and Neuro Fuzzy Logic.

INTRODUCTION
Induction motors are widely used in the industry and are essential to industrial processes. The breakdown of the motors causes financial losses due to unexpected downtime. The survey of the existing condition monitoring and protection methods are provided in the paper [1]. The protection methods are concentrating on the following five areas they are: thermal protection and temperature estimation, stator insulation monitoring and fault detection like, bearing fault, broken rotor bar/ end-ring, and air gap eccentricity detection.

Induction motor presents numerous advantages due to their robustness and power-weight ratio. Thus, they are widely used in the industries. There is a considerable demand to reduce the operational costs and improve the production downtimes for industrial machines particularly AC Induction Machines. Different Techniques have been proposed for the diagnosis of rotating machinery [2]. The contribution of this paper is the development of a condition-monitoring strategy that can make accurate and reliable assessments for the presence of specific faults in induction motors with single or multiple combined faults present.

In modern industrial facilities, thousands of electric motors work together in the manufacturing process. A great percentage of the applied motors are essential to process. An unscheduled shutdown occurs if one of these motors were to fail. If it were possible to detect a developing fault, it would be possible to schedule an orderly shutdown of the entire process with efficient utilization of material and labour. Because of the great expenses associated with sudden downtime, it may be cost effective to monitor the critical motors continuously for certain incipient faults before one of these motors become inoperable.

Automatic condition monitoring and diagnosis are needed to recognize system faults. There are various approaches to determine motor faults and diagnose them. These algorithms can be classified into various domains like time, frequency, time-frequency, higher order spectral analysis, neural Network, and model based techniques. Many condition monitoring methods [8], such as analysis of current spectrum, vibration and thermal have been proposed for various types of faults in motors.

In this paper the types of faults detected by means of statistical processing of the stray flux measurements [3] is presented. The fault detection in the rotor bar using wavelet analysis is proposed.

LITERATURE SURVEY ON FAULT DETECTION
In this literature survey focused on the use of the stray flux for diagnostic purposes is reported.

In [4] the flux measurements have been carried out on a three-phase IM (35kw, 4poles, skewed rotor), with many types of faults: shorted stator winding turns, broken or damaged rotor bars, static and dynamic rotor eccentricity, bearing faults. One of the external search coils described has 200 turns. Its length is equal to the active axial length of the machine; while its width is equal to two pole pitches. Such a coil can be suitable only for one size of the machine. The other external search coil has 200 turns of 0.2mm diameter wire and can be
The harmonic components of interest are the sidebands (1+/-2s) \( f_s \) under 1KHz, whereas to diagnose broken rotor bars the different rotor faults of various IMs have been investigated are.

In [7] another type of external flux sensor is proposed which measurement after supply disconnection [33].

diagnosis has been investigated by means of the stray flux around the supply frequency \( f_s \). Finally, the broken bar positioned to the frontal section of the machine. In [13] detect stator faults by means of motor current signature mains and a flux analysis has been proven more effective to an 11kw, 4 poles, squirrel cage IM supplied from both the order to set the bandwidth frequency to an accurate range for sensor. Moreover; a low-pass anti-aliasing filter is used in machine, to perform the measurement of flux in an area the dimension of the coil is never independent from the machine size. The voltage at the coil terminals is proportional to the derivative of the stray flux, so it has a low magnitude and a large frequency bandwidth since the derivation tends to maximize the magnitude of high-frequency devices. A variable gain (from 10 to 100) amplifier is connected at the terminals of this flux sensor. Moreover; a low-pass anti-aliasing filter is used in order to set the bandwidth frequency to an accurate range for the spectrum analysis. In [6] the tests have been carried out on an 11kw, 4 poles, squirrel cage IM supplied from both the mains and a flux analysis has been proven more effective to detect stator faults by means of motor current signature analysis (MCSA) technique. In [11] the same motor is tested in normal operation along with the stray flux sensor is parallel positioned to the frontal section of the machine. In [13] different rotor faults of various IMs have been investigated are under 1KHz, whereas to diagnose broken rotor bars the harmonic components of interest are the sidebands (1+/-2s) \( f_s \) around the supply frequency \( f_s \). Finally, the broken bar diagnosis has been investigated by means of the stray flux measurement after supply disconnection [33].

In [7] another type of external flux sensor is proposed which is made of 300turns on a “C” magnetic core and it is located on the machine frame. The authors used it to identify broken or damaged rotor bars. They observed that the amplitude increases in right sideband component with the slip more than the left one because flux derivative is used as measured variable. The conclusion of this paper is to identify or detect the faults in the rotor, by using the line current and stray signals with the same effectiveness. The optimal choice depends on the specific application and on the easiness of deploying and operating flux or current sensors in the specific industrial environment. This is because stray flux is induced by rotor and stator currents, but the effect of stator currents prevails, since the stator acts as a magnetic shield with respect to the rotor. So, stray flux analysis is expected to convey the same information that were similar to the one provided by conventional stator current analysis [8].

In [9] the authors consider the axial-radial decomposition of the external magnetic field. The axial field is in a plane which includes the axis of the machine and is generated by currents in the stator end windings or rotor cage end ring. The radial field is located in a plane that is perpendicular, to the machine axis and it is an image of the air-gap flux density which is reduced by the stator magnetic circuit and by the stator magnetic circuit and by the external frame of the machine. These fields can be measured separately by a convenient placement of a wound flux sensor. When the sensor is positioned on the machine body and parallel to its longitudinal plane, the flux linked to the sensor is radial. On the contrary, when the sensor is perpendicularly positioned, it measures the radial field, but it also embraces one part of the axial field. On analysis of the magnetic field spectrum emitted by an IM, there has been observed that asfs component is appeared, only in the axial field. Its magnitude can be relatively low for a machine in healthy condition. Moreover, the appearance of the sfs harmonic can be observed in the spectrum of the axial field, generated by broken or damaged rotor bars. The fault diagnosis becomes more difficult for weak loads, because these harmonics do not appear for a very low slip.

A type of meter named, Bell 7030 Tesla-meter, has been fixed in the center of the stator frame length to measure the tangential component of the stray flux is presented in [10]. The authors affirm that this equipment is very expensive for practical industrial applications, especially for small IMs. With this sensor dynamic rotor eccentricity and a bearing fault in the inner race was investigated. It was concluded that the stray flux is advantageous for the detection of dynamic eccentricity, due to a significant relationship between the amplitude of characteristic spectral components and the eccentricity level. But, the practical utilization of the magnetic stray flux for observing bearing defect is still controversial, as the amplitudes of the characteristic spectral components are very low in both stator current and stray flux.

In another approach giant magneto resistance (GMR) sensors are used to measure the stray flux around electrical actuators. GMR sensors produce a resistance change when the devices are undergone to a magnetic field. They are particularly suitable for purposes of range measurement and their linearity [15].

In [18] this study the features for bearing fault diagnosis is investigated based on the analysis of vibration, current measurements and temperature of a 3 phase, 4 poles, 5HP Induction motors, which worn out after very long usage. The worn out might be due to heat, power fluctuation etc. Then three neuro-inference systems which take the inputs like...
current, vibration measurements and the conditions of the motors are determined, and the performances of these networks are compared.

**THE PROPOSED FAULT DETECTION METHOD**

Since it was already presented previously the most interesting feature of stray flux round an IM is its dependence on the stator and rotor currents [6]. Therefore, studying the significant frequency components of the stray flux, stator or rotor asymmetries can be detected [16]. The stray flux in the vicinity of an electrical machine is inherent to its running. It is interconnected to the magnetic state of the motor and therefore can be affected when there is a fault in the machine. A simple model of the external magnetic field is presented and a study in healthy and faulty conditions is developed. The main intention of the work is to detect and analyze induction motor faults, caused due to electrical or mechanical origin by vibration analysis. Here, a novel technique based on the stray flux measurement in different positions around the electrical machine is proposed. This paper gives a justification for the change in machine vibration due to the excitation of voltage harmonics; which in turn helps in electrical fault detection in induction motor. The proposed method based on statistical analysis of data is actually applicable in industrial environment as a truly accurate, yet simple and robust fault indicator [17].

**SIMULATIONS AND ANALYSIS**

The above process is just to simulate the diagnostics of faults in three phase induction motor using wavelet Analysis. In the simulation wav audio files are used which produces the noise and sound similar to a running motor. This audio data has been loaded to simulate a running motor. Time series data slicing has been done by introducing time delays in the loaded audio file and the same data has been used in further analysis. The Time series data has been used in further analysis and simulation. The time series data has been used in the following Fuzzy Inference System generation methods they are as follows Grid Partitioning (genfis1), Subtractive Clustering (genfis2) and FCM (genfis3).

Grid Partitioning generates an initial Sugeno-type FIS for ANFIS training using a grid partition. FIS=GENFIS1 (DATA) generates a single-output Sugeno-type Fuzzy inference system (FIS) using a grid partitioning on the data (no clustering). FIS is used to deliver initial conditions for ANFIS training. DATA is a matrix with N+1 column where the first N columns contain data for each FIA input, and the last column contains the output data. By default, for each input GENFIS1 uses two ‘gbellmf’ type membership functions. Each rule generated by GENFIS1 has one output membership function, which is of type ‘linear’ by default.

Subtractive Clustering generates a Sugeno-type FIS using subtractive clustering. Given separate sets of data for input and output, GENFIS2 generates a fuzzy inference system (FIS) using fuzzy subtractive clustering. GENFIS2 can be used to provide an initial FIS for ANFIS training by applying subtractive clustering on the data. GENFIS2 accomplishes this by extracting set of rules that models the data behavior. The rule extraction method first uses the SUBCLUST function to determine the number of rules and membership functions and then uses linear least squares estimation to determine each rule’s consequent equations.

FCM clustering given separate sets of input and output data, GENFIS3 generates a fuzzy inference system(FIS) using FCM clustering. GENFIS3 accomplishes this by extracting a set of rules that models the data behavior. The FCM clustering function uses the rule extraction method to determine the number of rules and membership functions for the antecedents and consequences. The output data from each of the above specified generation methods will be processed using ANFIS algorithm. ANFIS Adaptive Neuro-Fuzzy training of Sugeno-type FIS. ANFIS uses a hybrid learning algorithm to detect the single-output membership function parameters, Sugeno type fuzzy inference systems (FIS). A combination of back propagation and least-squares gradient decent methods are used for training FIS membership function parameters to model a given set of input/output data. Finally, the processed output from ANFIS algorithm has been used to plot the graphical output. This research is targeting in identifying the faults in an induction motor. A flux sensor, which is used to record the electro-magnetic field, has been placed on the running motor body and the electro-magnetic field has been recorded using sig view in waveform. The wave output file has been used as input to analyse, identify and detect the faulty part in the targeted induction motor, using various types of Fuzzy Logic Mechanism using Matlab. The output is devised in the model of graphs having time series in x-axis and the high and low values of the Flux Variation Range in Hertz as y-axis.

Train data is a data which is modelled to have a predefined input/output. This ensures the fuzzy logic is working as expected. Fig 1 shows train data usage in Grid Partitioning Fuzzy Logic Mechanism. Fig 5 shows train data usage in Subtractive Clustering Fuzzy Logic Mechanism. Fig 9 shows train data usage in FCM Clustering Fuzzy Logic. Test data is a data which is used to validate the logic without any predefined output. Using the output, the behaviour of the respective Fuzzy Logic have been validated. This ensures the fuzzy logic is working as expected. Fig 2 shows test data usage in Grid Partitioning Fuzzy Logic Mechanism. Fig 6 shows test data usage in Subtractive Clustering Fuzzy Logic Mechanism. Fig 10 shows test data usage in FCM Clustering Fuzzy Logic.

All data represents the actual data, that is retrieved based on the device on which the fuzzy logic experimentation has been applied. Fig 3 shows the results plotted using all data in Grid Partitioning Fuzzy Logic Mechanism. Fig 7 shows the results plotted in Subtractive Clustering Fuzzy Logic Mechanism. Fig 11 shows the results plotted usage in FCM Clustering Fuzzy Logic. Regression is a validation mechanism to validate each and every unit behaviour of the Fuzzy Logic using possible data. Fig 4 shows Regression Validation in Grid Partitioning Fuzzy Logic Mechanism. Fig 8 shows Regression Validation in Subtractive Clustering Fuzzy Logic Mechanism. Fig 12 shows Regression Validation usage in FCM Clustering Fuzzy Logic.
Figure 1: Train Data (Grid Partitioning)

Figure 2: Test Data (Grid Partitioning)

Figure 3: All Data (Grid Partitioning)

Figure 4: Regression (Grid Partitioning)

Figure 5: Train Data (Subtractive Clustering)

Figure 6: Test Data (Subtractive Clustering)

Figure 7: All Data (Subtractive Clustering)

Figure 8: Regression (Subtractive Clustering)
CONCLUSION

The proposed method, which can be defined as non-invasive and quasi-online, needs an initial data set as “healthy reference” for successive measurements comparisons during the lifetime of the motor. This data set should be collected during the commissioning of the motor or, otherwise, in the initial period of its lifetime (when it can be reasonably considered healthy), and also can be compared with the initial data sets of similar machines and/or requiring the manufacturer a particular quality control on the bearings. The main advantages granted by the sensor are related to its simplicity, small size, low cost and flexibility, since it is easily positioned anywhere around the machine and adapted to a large range of powers. These sensors was made more suitable due to these characteristics, than the commercial examination in industrial environments, where the machines have to be tested during their normal operation and it is necessary to measure the magnetic field in various positions around a motor, in order to identify the best location where the flux measurement is less influenced by other nearby electrical devices.

This study provides an excellent health monitoring for Industrial Motor systems to detect the severity level of mechanical fault conditions. The major contributions of this work are to identify the exact location of the fault occurrences in the rotor.

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