REVIEW ON FAULT DETECTION AND ANALYSIS TECHNIQUES FOR THREE PHASE INDUCTION MOTOR

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ABSTRACT

Induction motors, also named as asynchronous motor, are generally using equipment in manufacturing industry, petrochemical, transportation, and power systems, due to simple structure, high overload capability, reliability, and better efficiency. Different sizes of induction motors are available in industry from small to over 100K Horsepower (Hp). Compared with direct current motors, the induction motors are more rugged, cheap, and require less overall maintenance. Therefore, these are preferred choice as industrial motors by engineers.

Different methods of induction motor fault diagnosis were under investigated by few researchers and different techniques have been proposed [4] for fault diagnosis. But, the most common used approach is motor Current Signature Analysis (MCSA). Several induction motor faults diagnosis techniques are based on Fast Fourier Transform (FFT) using electrical signal signature analysis. Other diagnosis methods including vibration analysis, temperature measurements, harmonic analysis of speed fluctuations, vibration monitoring, state and parameters estimation, either axial flux, acoustic noise measurement, and magnetic field analysis may diagnose through other techniques. Currently, Artificial Intelligence (AI) techniques have been combined with traditional diagnosis methods for detection of the right faults, such as Fuzzy Logic (FL), Genetic Algorithms (GA), Neural Network (NN), Bayesian classifiers, and envelope technique.

In this paper, different techniques for three phase induction motor fault analysis and detection. This paper, useful for different future researcher and students in the field of three phase induction motor fault analysis and detection applications.

Keyword: - *Induction motor, fault detection, fault analysis*.

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1. INTRODUCTION

Induction motors, also named as asynchronous motor, are generally using equipment in manufacturing industry, petrochemical, transportation, and power systems, due to simple structure, high overload capability, reliability, and better efficiency. Different sizes of induction motors are available in industry from small to over 100K Horsepower (Hp) [1].

Compared with direct current motors, the induction motors are more rugged, cheap, and require less overall maintenance. Therefore, these are preferred choice as industrial motors by engineers. The rotating parts do not require connecting electricity because electromagnetic induction provides the transfer of energy from stationary parts to the rotating components. The stator produces a rotating magnetic field, which convert into alternating electromotive force and current in the motor rotor. This rotor current and the rotating components of the stationary winding interact with each other and produce a motor torque. The characteristic of torque-speed is related to the components resistance and reactance of the rotor. Therefore, with different percentage values of rotor resistance to reactance in rotor circuits, it is possible to achieve different torque-speed characteristics [2].

Minor symptoms of motor faults may cause lower efficiency, high energy utilization, improper performance, and long-time equipment operating shutdown. Even minor faults can increase the loss chances such as reducing efficiency and increasing motor temperature, which will reduce the winding insulation life span and increasing motor vibration [3].They are caused by the operating environment circumstances and the equipment internal mechanical factors. Therefore, the diagnosis of motor faults is important task for engineers at early stage and avoids maintenance cost.

Different methods of induction motor fault diagnosis were under investigated by few researchers and different techniques have been proposed [4] for fault diagnosis. But, the most common used approach is Motor Current Signature Analysis (MCSA) [5]. Several induction motor faults diagnosis techniques are based on Fast Fourier Transform (FFT) using electrical signal signature analysis. Other diagnosis methods including vibration analysis, temperature measurements, harmonic analysis of speed fluctuations, vibration monitoring, state and parameters estimation, either axial flux, acoustic noise measurement, and magnetic field analysis [6] may diagnose through other techniques, for example, Short-

Time Fourier Transform (STFT) and Wavelet. Currently, Artificial Intelligence (AI) techniques have been combined with traditional diagnosis methods for detection of the right faults, such as Fuzzy Logic (FL), Genetic Algorithms (GA), Neural Network (NN), Bayesian classifiers, and envelope technique [7].

The methods used to diagnose BRB fault can be generally categorized into two types, invasive and noninvasive fault diagnosis techniques [8].The invasive methods diagnose the broken bars by monitoring the deviation of the magnetic potential vector and asymmetrical magnetic flux distribution, gyration radius, asymmetrical magnetic flux distribution, torque, and speed fluctuation. In this method, sensors and costly measurement equipment are needed, which will make the process of the diagnostic method more complex and expensive.

Induction motor faults often generate particular frequency components in the electric current spectrum. The abnormal harmonics contain potential information of motor faults. Therefore, the frequency analysis approach is the most commonly used method to diagnose induction motor faults. MCSA is commonly used method for diagnosing the motor faults due to its simple implementation and low cost

[8]. This technique is based on the detection of sidebands around the fundamental frequency in the stator electric current signal [9]. Firstly, the motor faults are simulated to observe the spectrum of stator currents for each fault condition. From the simulation, abnormal harmonics of stator currents are obtained as reference signals. Secondly, the recorded stator current signal is transferred from time domain to frequency domain by using Fourier Transform.

Finally, the motor faults could be diagnosed through the comparison of recorded stator current signals and the reference signals in the frequency domain.

Some latest research has investigated fault diagnosis process that focused on broken rotor fault detection at various load level. In [10], Naha et al.'s MCSA technique is used to detect the BRB fault under low-level load condition using the combination of FFT and Hilbert Transform (HT) on small induction motors. But only half part of the fault signal around the supply frequency was considered without any knowledge-level approach for decision-making. The Kalman filter is applied to identify and estimate the fundamental frequency components of the stator current spectrum and removal of noisy signal. But, through this method, some significant features are also removed from the signal that plays an important role in decision-making if knowledge level technique is used in parallel. The injection method of high frequency noisy signal into healthy signal to create the fault abnormal components at standstill operating condition. But, this method is not suitable when the induction motor is operating with a variable frequency drive at low-load level. And it also requires additional experimental setup arrangement and cost as well.

On the other hand, one can observe a potential growing interest in fault diagnosis process using different knowledge level techniques. Many research studies have investigated the field of fault detection using isolated induction motors based on diffident AI technique [12–15]. The Artificial Neural Network (ANN) has been perhaps the most commonly used artificial intelligence technique in motor condition monitoring and fault diagnosis due to its excellent pattern recognition ability and ability to recognize fuzzy and indefinite signals. Diagnosis system based on ANN on machines isolated from system, which applies the RMS measurements of current, voltage, and speed to train the ANN in diagnosis of motor rotor faults. Voltage faults are only identified in a steady-state condition, not in a dynamic load condition. Based on the influence of the rotor fault on current in the frequency domain, using ANN in a steady motor operating condition. This study demonstrated the possible symptoms of significant frequency components on the frequency spectrum related to a broken rotor bar fault.

These symptoms are used as an input matrix using the supervised ANN architecture. But the selection criteria of hidden layer were not addressed in that condition when the signal characteristics are in steady state. The proposed technique concluded that the process of rotor fault diagnosis and discrimination between each fault occurred with reasonable accuracy.

2. DIFFERENT TECHNIQUES FOR THREE PHASE INDUCTION MOTOR FAULT DETECTION AND ANALYSIS

Computer simulation of electric motor operation is particularly useful for gaining an insight into their dynamic behavior and electro-mechanical interaction [1]. A suitable model enables motor faults to be simulated and the change in corresponding parameters to be predicted without physical experimentation. This paper presents both a theoretical and experimental analysis of asymmetric stator and rotor faults in induction machines. A three-phase induction motor was simulated and operated under normal healthy operation, with one broken rotor bar and with voltage imbalances between phases of supply. The results illustrate good agreement between both simulated and experimental results.

The simulated results showed that a clear typical fault symptom of 100 Hz ripple for asymmetrical stator voltage supply can be found in both electro-magnetic torque and rotor speed. The ripple amplitude increases with increasing asymmetric stator supply. Experimental results verified the simulations but showed higher rotor speed ripple amplitudes when compared with the simulated results (with a 30–50 rpm error).

Another modified model for asymmetric rotor faults (such as broken rotor bars) was also constructed and examined. The simulated results illustrated noticeable $2s\omega$ modulations in stator phase current, electromagnetic torque and rotor speed. The experimental results also showed the symptoms but with much less phase current modulation and higher fluctuations in rotor speed than the simulated results. The reason for the phase current discrepancy may be related to the assumptions and approximations of the modified model for broken rotor bar.

The simulated and experimental results indicate that model-based fault detection and diagnosis is useful.

The simulation showed that the dynamic characteristics of induction motors under different conditions can be obtained purely by computer simulation. With a suitable model, motor faults may be simulated and predicted without any experimental analysis.

A new concept is introduced based on an analysis of transient machine currents [2]. The technique centers around the extraction and removal of the fundamental component of the current and analyzing the residual current using wavelets. Test results of induction machines operating both as a motor and a generator shows the ability of the algorithm to detect broken rotor bars. It has been shown that broken rotor bars can be detected by the decomposition of the startup current transient in motors as well as the transient current in wind generators. Constant speed is a not valid wind generator. Consequently, the steady-state algorithms previously developed are inadequate and the new algorithm should be used. This method has advantages over the traditional steady-state condition monitoring methods. It is not load dependent and can be effective on small lightly loaded machines.

The machine does not have to be heavily loaded to make an accurate assessment of the machine's condition. There is no need for speed, torque, or vibration measurement. The contribution here is the ability to detect a broken rotor bar while the machine is operating in the transient. It is not aimed at the detection of a specific bar at this stage. Currently, previous knowledge of a healthy machine is needed to make a diagnosis. Different starting methods such as Y or Delta starting should not affect the detection of broken rotor bars. These starting transients will only differ in the time duration of the starting envelope. It has been shown in the results that this method is not load dependent and, therefore, should be immune to different starting methods.

Presently, many condition monitoring techniques that are based on steady-state analysis are being applied to wind generators. However, the operation of wind generators is predominantly transient, therefore prompting the development of non-stationary techniques for fault detection. This method presents steady-state techniques e.g. Motor Current Signatures Analysis (MCSA) and the Extended Park's Vector Approach (EPVA), as well as a new transient technique that is a combination of the EPVA, the Discrete Wavelet Transform and statistics [3], to the detection of turn faults in a doubly-fed induction generators (DFIG). It will be shown that steady-state techniques are not effective when applied to DFIG's operating under transient conditions. The new technique shows that stator turn faults can be unambiguously detected under transient conditions.

Wavelet analysis has been successfully applied to the detection of stator turn faults in doubly-fed induction generators found in wind turbines. The detection algorithm is a combination of the Extended Park's Vector, wavelet analysis and statistics. This technique is not affected by changes in the speed of the machine which is crucial when applied to wind generators.

One of the study describes broken bar detection in induction motors without using additional sensor [4]. It is based on observation of the fluctuations of stator current zero crossing times (ZCT). Instead of sampling motor current with a high resolution A/D converter, zero crossing instants are recorded as waveforms cross zero. Fluctuations in the intervals between successive zero crossings of the three phase current waveforms are analysed using Fast Fourier Transforms (FFT). Diagnostic information is found in the spectrum of the ZCT signal through the presence of specific fault related frequencies. A rotor bar fault is manifested as an increase in the amplitude of the $2sf$ and other spectral components. This paper analyses the effect of an electrically unbalanced rotor on the ZCT spectrum of stator current, and discusses the various frequency components associated with rotor bar faults seen in the ZCT spectrum. It is important to eliminate the dependence of the index on the parameters of the induction motor. Particularly, the effect of motor inertia, supply harmonics, and variable load are discussed to increase the reliability of the rotor fault index, and simulation results are presented. It is found that the $2sf$ frequency component is independent of inertia, load, and harmonics, and thus it is suitable as an index for broken rotor bar.

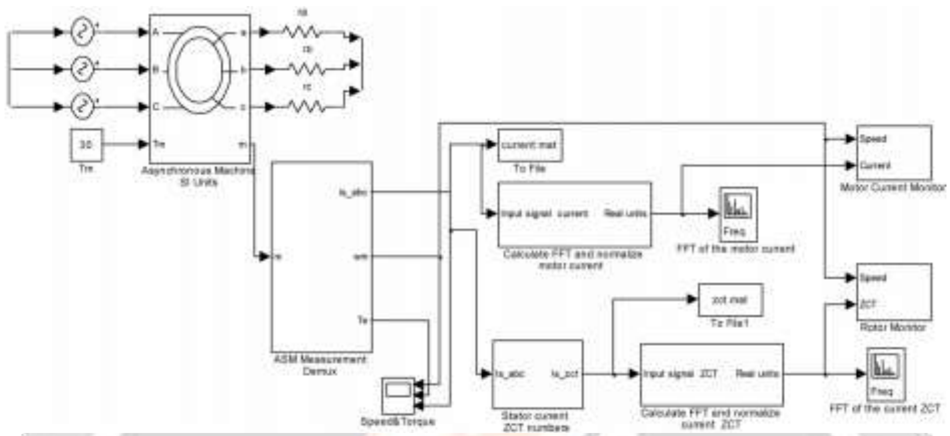

Fig 1:- Simulink model of sensorless broken bar detection for induction motor [4]

Having only one diagnostic index enables the use of a diagnostic system with minimum requirements. Also, pre-history of the motor is not demanded by such diagnostic system. Diagnostic system as simple as look-up table could be implemented. Similar approach, based on one diagnostic index, has been proposed before as based on a sum of three spectral components extracted from stator phase current. The ZCT rotor fault detection has the advantage that it requires single diagnostic index present in the spectrum, and also can be extracted from current signals sampled at only $6f$ sampling rate. However, exact specifications of a rotor fault diagnostic system can be obtained from experiments in real practical high power additional number of induction motors having more rotor bars.

One of the paper presents the results of an investigation regarding the thermal behavior of a three-phase induction motor when supplied by a reconfigured three-phase voltage source inverter with fault-tolerant capabilities [5]. For this purpose, a fault tolerant operating strategy based on the connection of the faulty inverter leg to the dc link middle point was considered. The experimentally obtained results show that, as far as the motor thermal characteristics are concerned, it is not necessary to reinforce the motor insulation properties since it is already prepared for such an operation.

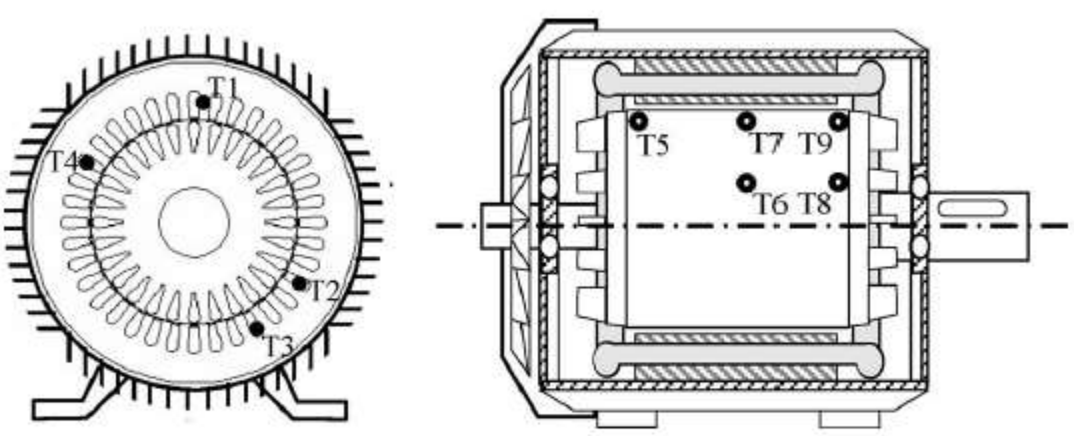

Fig 2:- Induction motor scheme with thermocouples location [5].

Despite the peculiar supply conditions offered by the reconfigured three-phase voltage source inverter, as far as the motor temperature is concerned, the performed thermal tests demonstrate that the obtained stator temperatures under the SPC drive reconfiguration strategy are similar to the ones obtained under normal operating conditions. Taking into account that a significant cause of a three phase induction motor failure is related to the stator insulation breakdown as a consequence of a temperature rise inside the motor, this result is of paramount importance since it reveals that it is not necessary to reinforce the induction motor stator insulation when supplied by such a fault-tolerant inverter.

In one of the paper, a fault diagnostic system in a multilevel- inverter using a neural network is developed [6]. It is difficult to diagnose a multilevel-inverter drive (MLID) system using a mathematical model because MLID systems consist of many switching devices and their system complexity has a nonlinear factor. Therefore, a neural network classification is applied to the fault diagnosis a MLID system. Five multilayer perceptron (MLP) networks are used to identify the type and location of occurring faults from inverter output voltage measurement. The neural network design process is clearly described. The classification performance of the proposed network between normal and abnormal condition is about 90%, and the classification performance among fault features is about 85%. Thus, by utilizing the proposed neural network fault diagnostic system, a better understanding about fault behaviors, diagnostics, and detections of a multilevel inverter drive system can be accomplished. The results of this analysis are ide.

The proposed networks perform well with the selected testing data set. The classification performance is high, more than 98%. Obviously, the classification performance between normal and abnormal condition is quite satisfactory in both testing categories; whereas, the classification performance among fault features is acceptable even when tested at modulation indices other than the training data set. The classification performance decreases when the operating point of the MLID is different from the training set. The results indicate that a new training set, or more training data, may be needed to accomplish a wide range of operation.

In one of the paper presents a neural approach to detect and locate automatically an interterm short-circuit fault in the stator windings of the induction machine [7]. The fault detection and location are achieved by a feedforward multilayer-perceptron neural network (NN) trained by back propagation. The location process is based on monitoring the three-phase shifts between the line current and the phase voltage of the machine. The required data for training and testing the NN are experimentally generated from a three-phase induction motor with different interturn short-circuit faults.

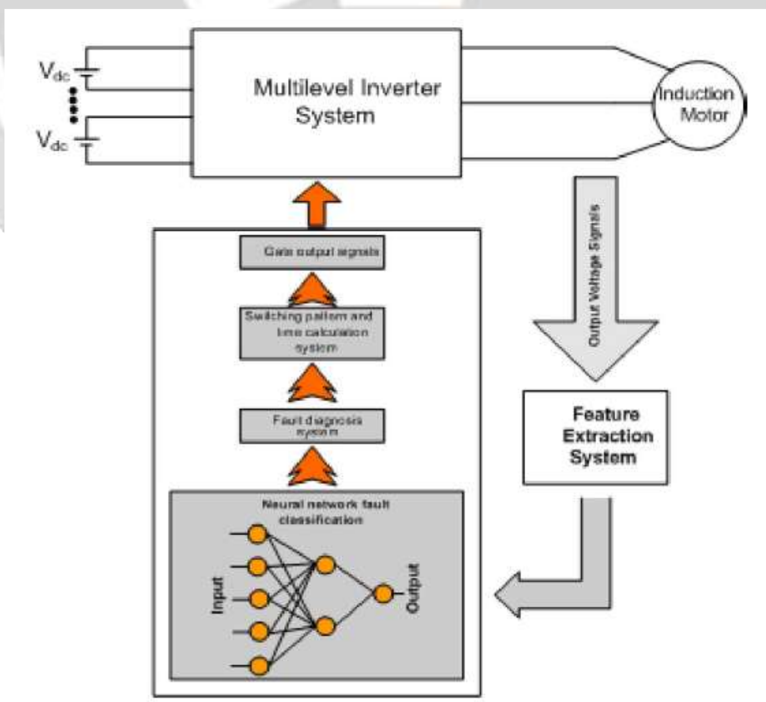

Fig 3:- Structure of fault diagnostic system [6].

The diagnostic process is automated through monitoring simultaneously the values of the three-phase shifts between the line current and the phase voltage by a simple MLP NN. The novel features of phase shifts including information about the detection and the location of fault let them to be reliable indicators of interturn short-circuit fault in the stator windings of the IM. The simulation results are verified and experimentally validate on two IMs. The successful obtained results prove that this approach is effective to ensure a reliable and precise fault diagnosis process. Furthermore, in this paper, it is important to mention an interesting benefit of this diagnosis method, which is resumed in the fact that, once the NN is trained by data from a machine and performed correctly, it can find its application with other machine having the same power without training it again.

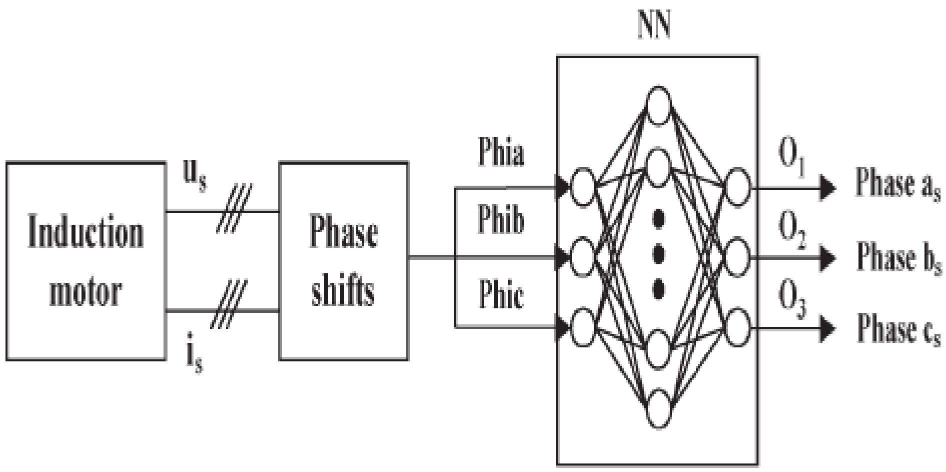

Fig 4:- Block diagram of the fault location procedure [7]

The online monitoring of induction motors is becoming increasingly important. The main difficulty in this task is the lack of an accurate analytical model to describe a faulty motor. A fuzzy logic approach may help to diagnose induction motor faults [8]. One methodology presents a reliable method for the detection of stator winding faults (which make up 38% of induction motor failures) based on monitoring the line/terminal current amplitudes. In this method, fuzzy logic is used to make decisions about the stator motor condition. The fuzzy system is based on knowledge expressed in rules and membership functions, which describe the behavior of the stator winding. The Finite Element Method (FEM) is utilized to generate virtual data that support the construction of the membership functions and give the possibility to online test the proposed system. The layout has been implemented in MATLAB/SIMULINK, with both data from a FEM motor simulation program and real measurements. The proposed method is simple and has the ability to work with variable speed drives. The fuzzy system is able to identify the motor stator condition with high accuracy.

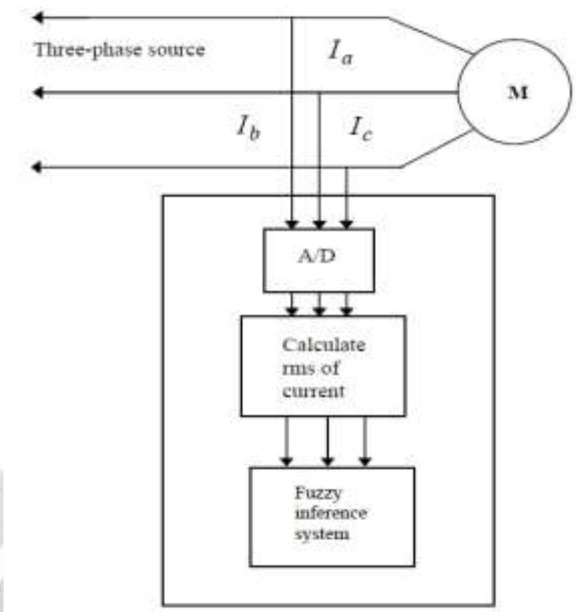

Fig 5:- Block diagram of the stator protection system using fuzzy logic controller [8]

This work shows the feasibility of spotting stator failures in an induction motor by monitoring the motor current amplitudes using fuzzy logic. Its forward application is in variable speed drives. This system could be implemented in the software of the inverter to monitor the stator condition online. It is able to work with motors connected in star and delta. In addition, it has two important abilities: to work in variable speed drives and a short delay time between fault and response. This work is also an example of fusion between soft computing (fuzzy logic) and hard computing techniques (FEM) in order to design a reliable system. A possible drawback of the method is associated with the fact that a current unbalance originating from the supply source may be identified as a fault condition of the motor. But even this shortcoming can be overcome by monitoring the voltage and introducing new rules in the inference system.

A negative sequence analysis coupled with a fuzzy logic based approach is applied to fault detection of permanent magnet synchronous motors (PMSM) [9]. First, the fundamental components of the motor terminal currents and voltages are separated effectively, based on which the negative sequence components are calculated. A fuzzy logic based approach is implemented to generate a robust detection using the adjusted negative sequence current and negative sequence impedance. The adjusted negative sequence current is obtained by separating the high frequency components caused by the load fluctuation from the total negative sequence current. The adjusted negative sequence current provides a qualitative evaluation on severity of the stator fault. Validation of the method is performed online using a PMSM experimental setup with dSPACE® and Matlab®/Simulink® environment. The use of fuzzy logic improves the sensitivity of fault detection while reducing false alarm rate under load fluctuations.

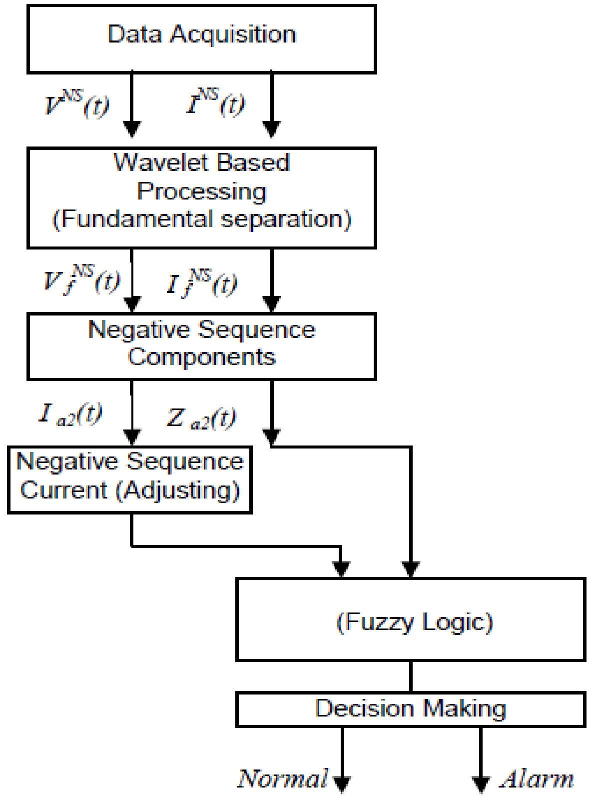

Fig 6:- Schematic diagram of the detection process [9].

Application of fuzzy logic during the fault detection stage enhances the FDD robustness against external disturbances, such as load fluctuations. Experimental study shows that the proposed detection approach is not only immune to load fluctuation, and other inherent asymmetries of the motor, but also capable of providing a measurement of the severity level of the stator interturn short fault. For all the tests carried out, the fault is identified promptly and properly. In the future, this work will be extended to consider the asymmetries caused by unbalance voltage supplies.

One of the techniques introduces a new fault-tolerant operation method for a symmetrical six-phase induction machine (6PIM) [10] when one or several phases are lost. A general decoupled model of the induction machine with up to three open phases is given. This model illustrates the existence of a pulsating torque when phases are opened. Then, a new control method reducing the pulsating torque and the motor losses is proposed in order to improve the drive performances.

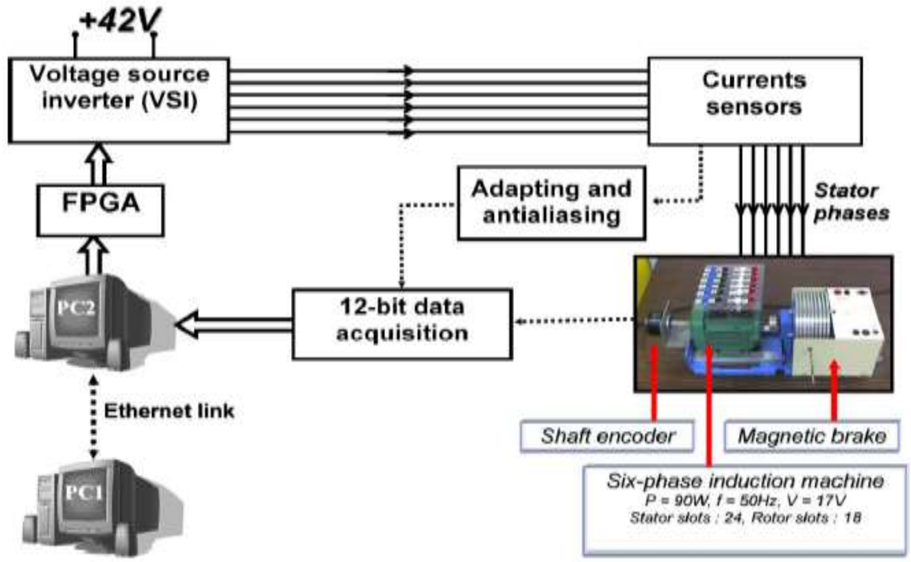

Fig 7:- Experimental test-rig [10].

This model [10] is very general and it can be used for up to three open stator phases by applying a convenient rotating reference frame with *αβz* components. The model allowed to compute the instantaneous electromagnetic torque and to evaluate its oscillations during steady state. It has been shown that the loss of at least one stator phase produces electromagnetic torque oscillations at twice the frequency of the stator current with a magnitude depending on the difference between the *αβ*-subspace current components. A proper choice of these components ratio minimizes the torque oscillation magnitude.
The aim of one of the paper is to present a diagnosis methodology for the detection of electrical faults in three-phase wound-rotor induction machines (WRIMs) [11]. In the considered application, the rotor windings are supplied by a static converter for the control of active and reactive power flows exchanged between the machine and the electrical grid. The proposed diagnosis approach is based on the use of wavelet analysis improved by a preprocessing of the rotor-voltage commands under time-varying conditions. Thus, the time evolution of fault components can be effectively analyzed. This method proves also the importance of the fault components computed from rotor voltages in comparison to those coming from rotor currents under closed-loop operation. A periodical quantification of the fault, issued from the wavelet analysis, has been introduced for accurate stator- or rotor-fault detection. Simulation and experimental results show the validity of the proposed method, leading to an effective diagnosis procedure for both stator and rotor electrical faults in WRIMs.
This technique [11] can be particularly useful for modern wind turbine generators. The proposed approach is based on the use of the discrete WT improved by a preprocessing of the variables that have to be analyzed. Both simulation and experimental results prove that, under closed-loop operation, rotor voltages are more sensitive than rotor currents to both stator or rotor imbalances. The proposed method is a viable solution to overcome the limit of the classical MCSA under time-varying conditions. Furthermore, a time–frequency fault indicator has been introduced to quantify the fault severity. Once again, simulation and experimental results have shown the effectiveness of this approach, which can be applied also in speed-varying operating conditions.

3. CONCLUSION

Induction motors, also named as asynchronous motor, are generally using equipment in manufacturing industry, petrochemical, transportation, and power systems, due to simple structure, high overload capability, reliability, and better efficiency. Different sizes of induction motors are available in industry from small to over 100K Horsepower (Hp). Compared with direct current motors, the induction motors are more rugged, cheap, and require less overall maintenance. Therefore, these are preferred choice as industrial motors by engineers.
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