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Investigation of Induction Motor Stator Faults Using Motor Current Signature Analysis and Multisim

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Abstract: The unremitting examine of the fitness of the industrial appliances is obligatory to verdict the fault of the machines at premature stages and prevents the machine from brutal damage. Induction motors are widely used in hauling, mining, petrochemical, manufacturing and in almost every other fields dealing with electrical power. For industry, a faulty induction motor signifies reduction in production and cost increases. Motor Current Signature Analysis (MCSA) is the most popular method used for fault detection in the induction motor. MCSA is a diagnosis method for induction motors fed by supplies with high harmonic content and also helps in the detection of faults due to remarkable noise on the line current and transient operating conditions. This harmonic content, which is normally known as a major side effect, gives rise to extra signatures which is utilized by the MCSA in distinctive imperfect current spectrum patterns from healthy ones. From the detailed analysis of the current spectrum, the system will describe the typical fault state. The proposed system is a verdict simulation method for the discovery of stator faults occurring in three phase squirrel cage induction motors and correction of extra signatures in the current spectrum using the combination of MULTISIM and LabVIEW.

Key words: Induction Motor · MCSA · Stator faults · Current Spectrum · Harmonics

INTRODUCTION

Induction motors are the bastion for every industry. However these machines, will eventually fail because of heavy duty cycles, installation, poor working environment and manufacturing factors, etc. With increasing demands for efficiency and reliability, the field of fault diagnosis in induction motors is gaining importance [1]. There are numerous methods available in existing like based on chemical monitoring, machine vibration monitoring, temperature monitoring, acoustic/sound emission monitoring but all have need of expensive sensors or specialized apparatus to acquire the specific gesture to process, where as in this proposed current monitoring practice there is no additional sensors required [2]. This is because of the basic electrical quantities associated with electromechanical plants such as voltage and currents are readily measured by tapping into existing voltage and current transformers at the protection system. Before entitle the practice the idea must be validate with the help of simulation is highly appreciated in the engineering environment. Likewise the proposed technique is simulated with the help of combination of two software tools named as LabVIEW and MULTISIM. There is no method deal with the simulation environment of MCSA in the LabVIEW platform and this is performed first time in this paper. With the hope of utilizing the rewards of current monitoring the MCSA based fault diagnosis system [3] is proposed here. A mixture of faults occurs within the three phase induction motor during the course of typical operation. These faults can direct to a potentially catastrophic failure if undetected [4]. Accordingly, a variety of condition monitoring techniques has been developed for an analysis of uncharacteristic conditions. The common internal faults can be primarily categorized into two groups named as electrical faults and mechanical faults.

The stator faults and rotor faults are very common electrical faults in three phase induction motor while operating in industries. These can be typically classified as Open circuit fault, Line-to-line fault, Turn-to-turn fault, Coil-to-coil fault and Line-to-ground fault as shown in the Figure 1. A stator turn fault in a balanced three phase ac machine cause a large circulating current to flow and

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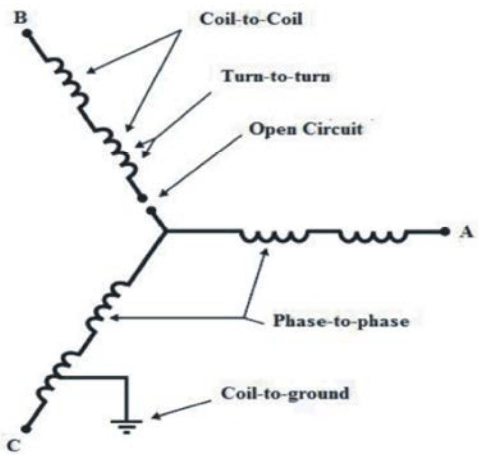

Fig 1: Types of stator winding faults of induction motor

subsequently generates excessive heat in the shorted turns is considered as a first type of fault in the given induction motor [5, 6].

Inter-turn short circuit is the second type of motor fault investigated in this paper. The inter-turn short circuit of the stator winding is the starting point of winding faults such as turn loss of phase windings. The short-circuit current flows in the inter-turn short circuit windings. This initiates a negative MMF, which reduces the net MMF of the motor phase. Therefore, the waveform of air-gap flux, which is changed by the distortion of the net MMF, induces harmonic frequencies in a stator-winding current as:

$$f_{stator} = \left\{ \frac{n}{p}(1-s) \pm k \right\} f_1 \quad (1)$$

Where p is the number of pole pairs, n = 1, 2, 3 and k = 1, 3, 5, respectively.

With sinusoidal mmf the frequency of the slot harmonic component for the stator current can be expressed as:

$$f_{stator} = \left\{ z_2((1-s)\frac{f_1}{p} \pm f_1 \right\} \quad (2)$$

Z being the rotor slot number.

To take stator mmf time harmonic into account, f_1 must be multiplied by h, the harmonic number of the stator mmf time harmonics (h = 1, 3, 5, 7….).

The slot harmonic frequency for the stator current will come out as

$$f_h = \left\{ z_2((1-s)\frac{f_1}{p} \pm hf_1 \right\} \quad (3)$$

The rotor faults occurs due to several reasons such as,

- During the breezing process in manufacture, non-uniform metallurgical stresses may be built into cage assembly and these can also lead to failure during operation.
- A rotor bar may be unable to move longitudinally in the slot it occupies, when the thermal stresses are imposed upon it during starting of machine.
- Heavy end ring can result in large centrifugal forces, which can cause dangerous stresses on the bars.

Common mechanical faults found in three phase induction motor are Air gap eccentricity, bearing faults and load faults. The air gap eccentricity can be further classified as static eccentricity, dynamic eccentricity and mixed eccentricity.

Fault diagnostic techniques are gaining importance in industry because of the need to increase reliability and to decrease the possibility of production loss due to machine breakdown. By comparing the signals of a machine running in normal and faulty conditions, detection of faults such as mass unbalance, shaft misalignment, gear failures and incipient failures of the components, through the online monitoring system, decreasing the possibility of catastrophic damage and the downtime. Although often the visual inspection of the frequency domain features of the measured signals is adequate to detect the faults, there is a requirement for a reliable, fast and automated procedure of diagnostics [7].

This paper proposed to detect the stator electrical faults like open circuit, short circuit of turn-turn, coil – coil and leakage faults. Significant efforts have been devoted to induction machine stator electrical fault diagnosis and many techniques have been proposed based on the following [8, 9].

- Stator current spectral analysis, which uses the power spectrum of the stator current to detect short circuit faults [10].
- Magnitude of certain frequency components of the stator currents.
- Analysis of the negative sequence components of the stator current (mainly used to detect inter-turn short circuits).

Other techniques include vibration analysis [11], acoustic noise measurement, temperature analysis, torque profile analysis and magnetic field analysis [12].

These techniques require sophisticated and expensive sensors, additional electrical and mechanical installations and frequent maintenance and are not preferred [13, 14].

The most popular methods of induction machine condition monitoring utilize the steady-state spectral components of the stator quantities. These stator spectral components includes voltage, power and current and are used to detect turn faults, broken rotor bars, air gap eccentricities, bearing failures. Presently, many techniques that are based on steady-state analysis are Motor Current Signatures Analysis (MCSA) and the Extended Park's Vector Approach (EPVA) [6], as well as a new transient technique that is a combination of the EPVA, the Discrete Wavelet Transform [13, 15].

The MCSA technique exploiting the current spectrum through the MULTISIM and LabVIEW is discussed in brief. In this paper two software's are used to design the proposed technique in the simulation platform. There is no simulation is proposed yet in this category. Machine model is developed in the Multisim software and the data acquisition; signal processing & conditioning parameters are developed in the Labview software. Both are interfaced and obtain the simulation result. In this simulation the stator side faults are only considered.

Motor Current Signature Analysis (MCSA): Motor-current-signature analysis (MCSA) is a condition monitoring technique that will be widely used to diagnose problems in electrical motors. MCSA focuses its efforts on the spectral analysis of the stator current and has been successfully applied to detect abnormal levels of status of stator windings like open circuit fault, short circuit faults of turn-turn, coil-coil, leakage faults, air-gap eccentricity and broken rotor bars among other mechanical problems. The main purpose of MCSA is to analyze the stator current in search of current harmonics directly related to new rotating flux components, which are caused by faults in the motor-flux distribution [16, 17].

Motor Current Signature Analysis is a system used for analyzing or trending dynamic energized systems [18]. The results of MCSA assist in the identification of the following:

- Incoming winding health
- Stator winding health
- Rotor Health
- Air gap eccentricity
- Coupling health, together with direct, belted and geared systems
- Load issues
- Bearing health

Process Involved in Mcsa Based Fault Diagnosis: The block schematic for the analysis of the current spectrum of the three phase induction motor using MCSA is shown in Figure 2. The MCSA fault detection system consists the current transformer, Data Acquisition system, Signal Processing and Analyzing, MULTISIM and LabVIEW.

Current transformer (CT) senses the signal from the induction motor. Depending on the installation, the CT can be of two types, namely a clip-on CT around one of the phases of the supply or around the secondary side of an existing instrumentation. Only one CT is required for MCSA based systems and can be in any one of the three phases. The fundamental reason is that the rotating flux waves produced by the different faults cut all three stator phase windings and corresponding currents are induced in each of the three phases [19]. The data acquisition card is used to acquire the signal from the current transformer.

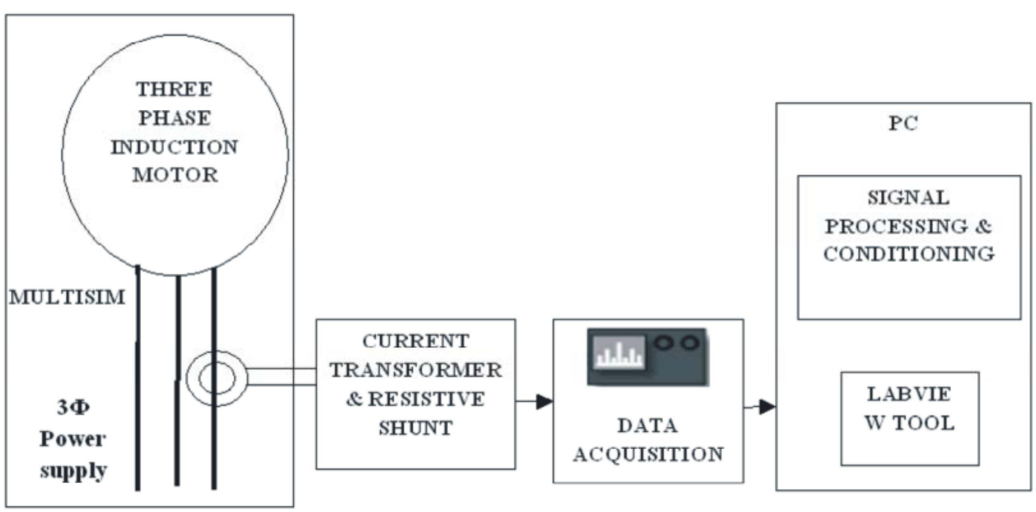

Fig 2: Block Schematic of the proposed system

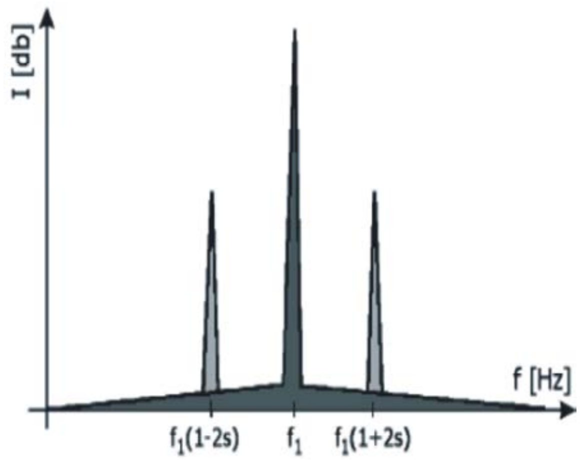

Fig 3: Idealized current spectrum

An idealized current spectrum is shown in Figure 3. It represents the twice slip frequency sidebands along decibel (dB) versus frequency spectrum (referred as linear root mean square (rms)) giving a wide dynamic range to detect the unique current signature patterns that are characteristic of different faults. In the occurrence of any fault, results in a backward rotating field in the air gap and the spectrum of stator current will change.

Motor current signature analysis is the procedure of capturing a motor's current & voltage signals and analyzing them to detect various faults.

The MCSA uses the current spectrum of the machine for locating characteristic fault frequencies. When a fault is present, the frequency spectrum of the line current becomes different from healthy motor. Such a fault modulates the air-gap and produces rotating frequency harmonics in the self and mutual inductances of the machine. It depends upon locating specific harmonic component in the line current [20].

The spectrum of supply current of an induction motor can be analyzed for the diagnosis of faults appearing in it. This is done by verifying and comparing certain parts of the analyzed signal's harmonic content with those of the signal measured for a healthy machine. For a healthy motor, there will be no existence of backward rotating field and only the forward rotating magnetic field rotates at synchronous speed [21].

In an induction machine, depending on the type of fault, the detected sideband harmonic components of the line current may differ. By comparing the faulty spectrum with the healthy spectrum the detection of various faults can be identified [22].

There are a number of simple steps that can be used for analysis using MCSA. The steps are as follows:

- Map out an overview of the system being analyzed.
- Determine the complaints related to the system are question. For instance, is there reason for analysis due to improper operation of the equipment and other data that can be used in an analysis.
- Acquire data.
- Review data and analyze:

- Review the snapshot of current for 10 second to view the operation over that time period.
- Review low frequency demodulated current spectrum to view the condition of the rotor and identify any load-related issues.
- Review high frequency demodulated voltage and current in order to determine other faults including electrical and mechanical health.

Data Acquisition system is a method based on the spectral decomposition of the steady state stator current which can be acquired with simple measurement equipment and under normal operation of the machine. In the MCSA method, the current frequency spectrum is obtained with the use of data acquisition module and specific frequency components are analyzed by the software tools such as LABVIEW and MULTISIM installed in the PC. These frequencies are related to well-known machine faults. Therefore, after processing the stator current, it is possible to infer about the machine's condition.

The MULTISIM is an electronic workbench simulation program for the designing the proposed MCSA based fault detection system as illustrated in Figure 4. With the advanced analysis and design capabilities it simulates the system to provide optimized performance, reduce design errors and shorten time to prototype.

The protection devices such as MCB, MCCB, OLR and RCCB are used in the industrial factory field. These protection devices are not shown in the simulation design in order to avoid complexity and time consumption factors. By using LABVIEW virtual instruments all the performance parameters of the induction motor in the real world is converted into digital data and be processed by computer.

The performance parameter here is the current spectrum or signature will appear at monitor. The simulation model for the proposed system is shown in the Figure 4.

A PC based DAQ system is plugged in for the combination of the computer with the signal from induction motor. It shows the real time characteristic of the experimental induction motor during its operation.

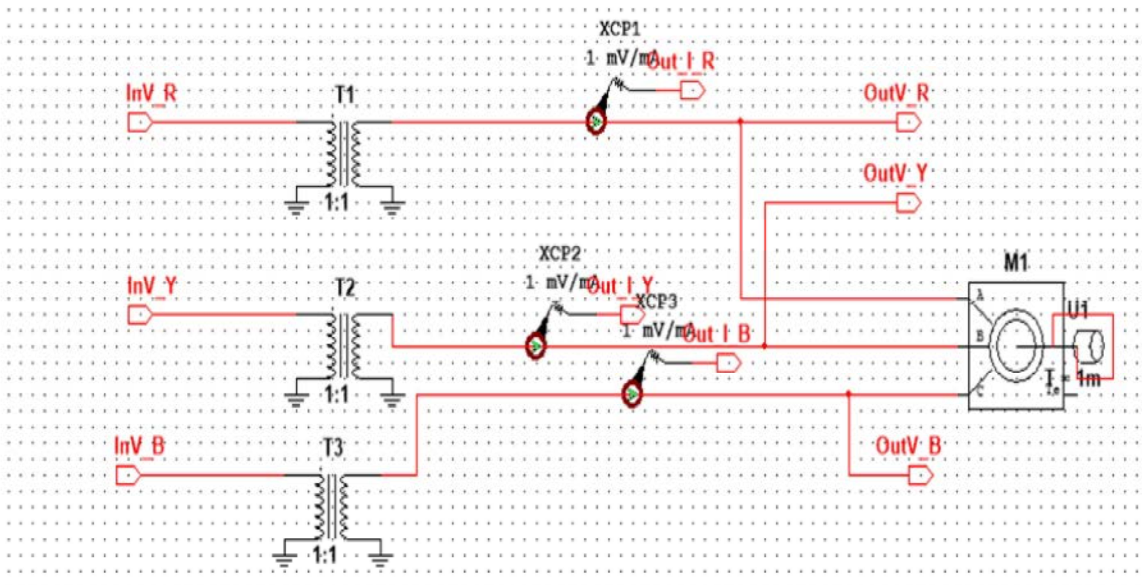

Fig 4: Multisim model for signature acquisition

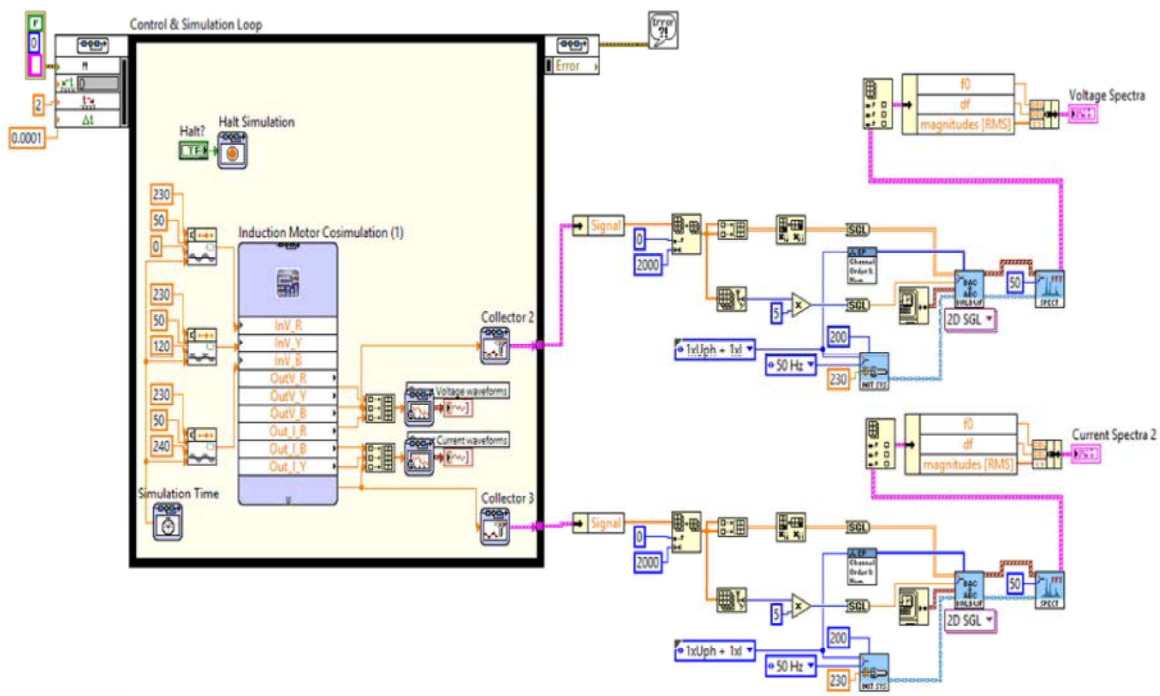

Fig 5: Simulation model of the proposed system

Beside give the graphical views to the user, LABVIEW also give a good analysis capabilities about the measurements on the induction motor in the proposed system. The simulation model of the induction motor is designed with Multisim software depicted in Figure 5.

The current signature of the induction motor is acquired from each phase of the power supplied to the IM. Analysis of the current signature is carried out as a co-simulation in LabVIEW. Simulation of healthy and faulty motors and comparison of their respective signatures is accomplished with the help of labVIEW tool [23]. In order to create faults in motor the Multisim software has been utilized [24].

Simulation Results: The faulty motor designed with different fault types are simulated by clicking on the Simulation button. The output current spectrum or signature of the motor with each of open circuit, short circuit and leakage faults are presented here.

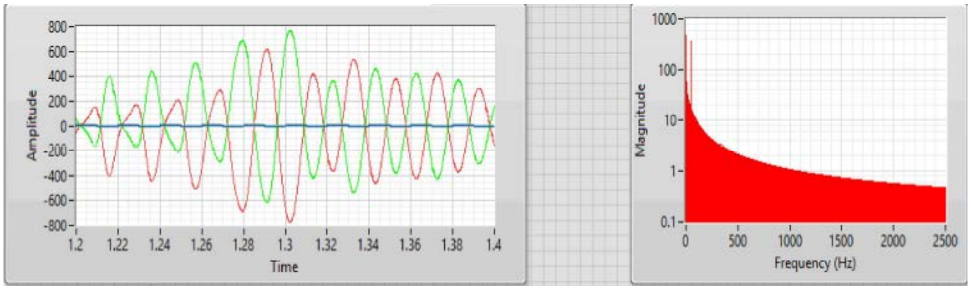

Fig 6: Signature of the faulty IM with Open Circuit fault (Phase A opened)

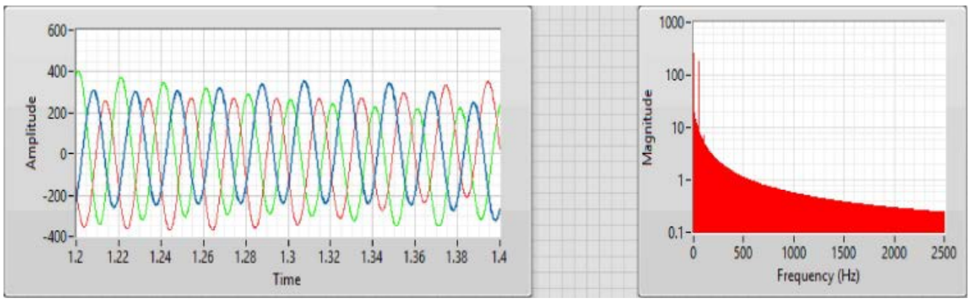

Fig 7: Signature of the faulty IM with Leakage fault

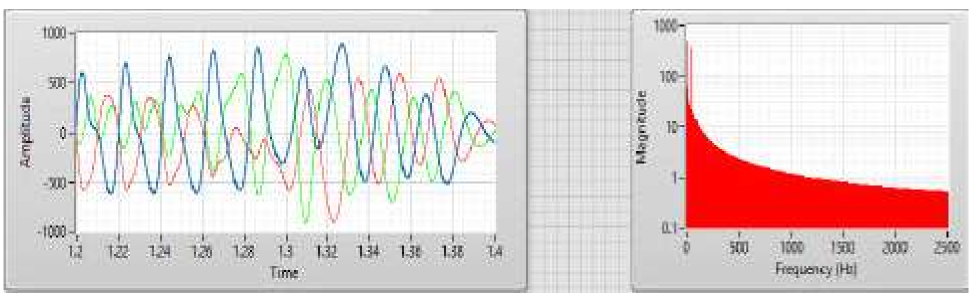

Fig 8: Faulty current Spectrum by shorting A & B phases

Open Circuit Fault: Due to aging, high speed applications and mechanical stress cut off of any of the winding presented in the stator side the open circuit fault occurs. The opened phase directly goes to zero and other phases are affected by noise shown as fluctuations.

With each phase opened the following waveform shown in Figure 6 depicts the faulty current spectrum.

Leakage Fault: Winding turn-to-turn or turn-to-earth occurrences causes the leakage faults. This is the early fault of open circuit and short circuit of the windings. This result causes the uneven voltage and currents among the three phases and creates noise, heat and variations in the speed. Leakage occurring at any of the stator winding phase causes similar faulty spectrum.

Due to such leakages winding may suffer short circuit whose affected signature is shown in the Figure 7.

Short Circuit Fault: The shorting between the two different phases in stator windings of the induction motor causes short circuit fault producing enormous flow of current and zero voltage resulting in a faulty current spectrum. By shorting three different combinations of the phases of the induction motor stator winding,the faulty output current spectrums are acquired as in Figure 8.

Thus the current spectrum of the healthy motor for the comparison with that of the faulty motor is obtained from the simulation results. In order to acquire the current spectrum of faulty motor, the internal fault is created with the use of the fault options provided by the LabVIEW simulation tool.

CONCLUSION

Thus the efficiency of the MCSA method to detect different stator faults in the IM and to discriminate between them has been proved along with its important advantages such as the simplicity of the data acquisition systems and the required software, along with the robustness of the tools used, which has provided quite satisfactory results. Also, from the stator current spectrum analysis it is possible to detect rotor as well as stator faults. Hence, the simulation presented in this paper establishes the efficiency and effectiveness of this method via the area of computer aided condition monitoring of induction machines.

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