Australian Journal of Basic and Applied Sciences, 10(16) November 2016, Pages: 223-240

AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES

ISSN:1991-8178 EISSN: 2309-8414
Journal home page: www.ajbasweb.com

Design and Implementation of an On-line Diagnosis System of IM Electrical FaultsUsing MCSA and ANN Based on Labview

[1]Isam M. Abdulbaqi, [2]AbdulrahimThiabHumod, [2]Omar K. Alazzawi

[1]*Elect. Eng. Dept. / Faculty of Eng. / Al-Mustansiriya Univ. / Baghdad/ Iraq.*
[2]*Elect. Eng. Dept. / University of Technology/ Baghdad/ Iraq.*

Address For Correspondence:
Isam M. Abdulbaqi, Elect. Eng. Dept. / Faculty of Eng. / Al-Mustansiriya Univ. / Baghdad/ Iraq.

ARTICLE INFO

Article history:
Received 11 September 2016
Accepted 10 November 2016
Published 28 November 2016

Keywords:
Fault Diagnosis, ANN, MCSA, Induction Motor, inter turn short circuit, broken bar, end ring.

ABSTRACT

Induction Motor (IM) are wildly used in variety applications because of its known advantages. Because of its necessity in industrial and because the motor prone to breakdowns during the work period and such faults lead to the production stopped abruptly, monitoring system must be designed to avoid a complete stop, which leads to disastrous results. The objective of this work is to build and design on-line practical diagnosis system based on Motor Current Signature Analysis (MCSA) for three phases 380V, 50Hz, 2.2kw, 3000rpm, squirrel cage IM. LabView program is used for classification the type of electrical faults based on Artificial Neural Network ANN, as well as lamps indicators on front screen for fault type and its degree. The results of diagnosis system allowing the user a complete view of the status of the motor for maintenance and repairs valuable timely manner, without impact on workflow and reduce waste of time and cost. Inter turn short circuit with 5%, 10%, 15% and 20% of total stator turns and end ring fault in addition of broken rotor bar fault are studied in this research.

INTRODUCTION

The quality control departments in the manufacturing plant of IM need such a system as well as in the field when it is used in order to reduce efforts, cost and wasted time. So that on-line monitoring system of a 3-phase IM becomes very essential in the industry. An essential step to perform such a monitoring system is presented in this work. Two electrical faults as an example are taken into consideration to show the main steps of this system. This system has the ability to perform total faults in condition that the required data for the expected faults are provided (Filippetti F., *etlal*., 1998).
Rotor bars and end rings are comprised the squirrel-cage. Any partial or complete cracked in bars the motor will have broken bar fault at that point the motor is included broken bar fault. Figure (1) demonstrates rotor furthermore parts of broken rotor bar(Filippetti F., *etlal*., 1998).

The manufacturing defect is the main reason that observed for squirrel- cage induction motor, in the welding process of alloy of cooper and other materials' non- symmetric metallurgical strain may happen in cage collecting which leads to failure in rotation of the rotor(Deleroi W., 1984). The heaviness of end rings of rotor, leads to big centrifugal forces that may cause additional strain on the rotor bar. Rotor bar may get damaged that leads to irregular distribution of rotor currents due to any reasons. In uniformity or asymmetrical case or long time work on the motor and in case of any rotor bar fractured or cracked, overheating will happen in damaged place that may result in the breaking of the bar. In case bar gets damage or crack the sidebar will load excessive currents because of that huge mechanical and thermal strain may occur on side bars. If the rotor keeps revolving

To Cite This Article: Isam M. Abdulbaqi, AbdulrahimThiabHumod, Omar K. Alazzawi., Design and Implementation of an On-line Diagnosis System of IM Electrical FaultsUsing MCSA and ANN Based on Labview. ***Aust. J. Basic & Appl. Sci.,*** *10(16): 223-240, 2016*

or rotate in this state this will leads to cracking of the sidebar. This damage may happen in different places of the rotor like, at the end of the rings, bars and the joints of end rings, damage may increase or spread and cause breaking to all rotor bars(Deleroi W., 1984). The potential risk is more of the joints of the bars and end rings, the possibility of breaking or crack will be doubled if the motor running for a long time or numbers of starts and stops (Alberecht, P.F., *et al*., 1987).

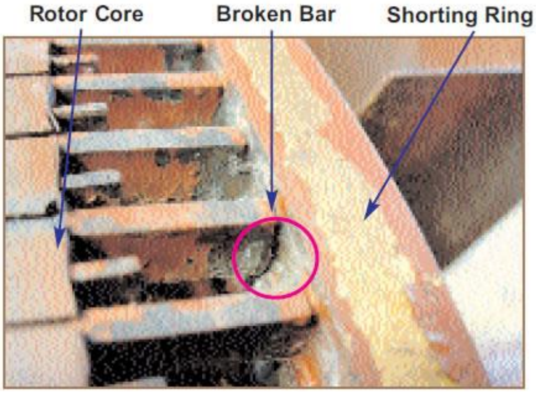

Fig. 1: Photograph of Rotor and Parts of the broken rotor bar (Szabó, L., *et al*., 2008)

As per the study of IEEE and EPRI, given in Table (1), 8–9 % of induction motor faults are due to rotor faults (Alberecht, P.F., *et al*., 1987; Szabó, L., *et al*., 2008).

Table 1: Prospect of Fault Occurrence in IM

Studied by	Bearing fault %	Stator fault %	Rotor fault %	Others%
IEEE	42	28	8	22
EPRI	41	36	9	14

Stator of an induction motor is subjected to various stresses such as mechanical, electrical, thermal, and environmental (Lee, S.B., *et al*., 2003). Accordingly the ferocity of these stresses faults may be occurring in the stator windings. If for a well-designed motor operations and maintenance are done appropriately, then these stresses remain under control. The stator faults can be classified as (i) faults in the laminations and the frame of stator and (ii) faults in stator winding. Out of these the second one is the most common stator fault. As per the study of IEEE and EPRI tab. (1) 28–36 % of induction motor faults are stator winding fault (Su, H., *et al*., 2011). This fault is due to failure of insulation of the stator winding. It is mainly termed as inter-turn short-circuit fault. Different types of stator winding faults shown in fig. (2), the inter turn short circuit (short circuit between two turns of the same phase) is interested in this search.

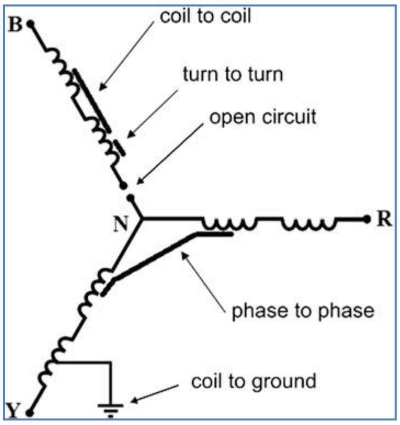

Fig. 2: A Star-connected Stator Showing, Different Types of Stator Winding Faults.

The main causes of stator faults may be explained as:

(i) Mechanical Stresses—these are due to poorly installed of stator coil and rotor hitting the stator. Coil movement which is due to the stator current (as force is proportional to the square of the current (Nandi, S., H.A. Toliyat, 1999) may loosen the top sticks and also may cause damage to the copper conductor and its insulation.

(ii) Electrical Stresses—these are mainly due to the supply voltage transient. This transient arises due to different faults (like line-to-line, line-to-ground, or three-phase fault), due to lightning, opening, or closing of circuit breakers or due to variable frequency drives (Ahmed, I., *et al*., 2004). This transient voltage reduces the life of stator winding and in severe case may cause turn-to-turn or turn-to-ground fault.

(iii) Thermal stresses—these are mainly due to thermal overloading and are the main reason, among the other possible causes, for deterioration of the insulation of the stator winding. Thermal stress happens due to over current flowing due to a sustained overload or fault, higher ambient temperature, obstructed ventilation, unbalanced supply voltage, etc. (Ahmed, I., *et al*., 2004). A thumb rule is there which states that winding temperature will increase by 25 % in the phase having the highest current if there is a voltage unbalance of 3.5 % per phase. Winding temperature will also increase if within a short span of time a number of starts and stops are made in the motor. What may be the reason, if winding temperature increases and the motor is operated over its temperature limit, the best insulation may also fail quickly. The thumb rule, in this regard, states that for every 10°C increase in temperature above the stator winding temperature limit, the insulation life is reduced by 50 %. Table (2) shows the effect of rise of temperature, above ambient on the insulation of winding (Thomson, W.T., *et al*., 1999).

(iv) Environmental stresses—these stresses may arise if the motor operates in a hostile environment with too hot or too cold or too humid. The presence of foreign material can contaminate insulation of stator winding and also may reduce the rate of heat dissipation from the motor (Thomson, W.T., A. Barbour, 1998), resulting reduction in insulation life. Air flow should be free where the motor is situated, otherwise the heat generated in the rotor and stator will increase the winding temperature which will reduce the life of insulation.

Table 2: Effect of rise of temperature

Ambient in °C	Insulation life in hours
30	250000
40	125000
50	60000
60	30000

2. Monitoring System Framework uses (MCSA):

The detection of fault signals and fault diagnosis must be done by sensing the current waveforms of all the three phases feeding the induction motor through current transformers. These current waveforms are sent to a data acquisition unit through a qualified connection board. In this unit the high-frequency components of the waveform that do not contribute to the diagnostic process are excluded. The pure currents signals are sampled and converted to digital signals using analog to digital (A/D) converter.

Digitization processes are followed by calculating the frequency spectrum of the waveforms using Fast Fourier Transform (FFT). The resulting harmonics were fed into an already learned artificial neural network (ANN) in order to detect the faulty signal and compare its harmonics with those stored in its database to diagnose the fault type. Then an algorithm is required to operate certain fault indicators in an interactive board and a post processing system will be needed to generate a diagnostic report. The general framework of the diagnosis system using MCSA is shown in Figure (4).

3. Experimental Setup:

The experimental setup of the monitoring system is shown in figure (5). It's composed of the following main components:

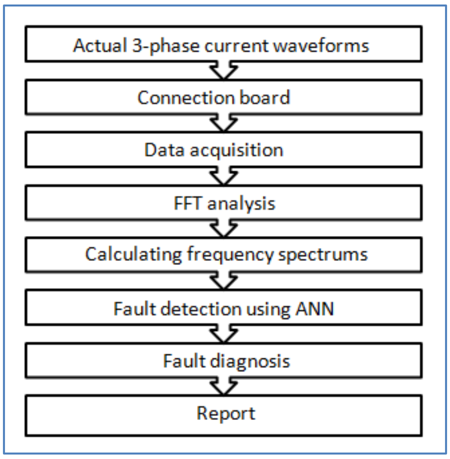

Fig. 4: The Framework of the Monitoring Scheme.

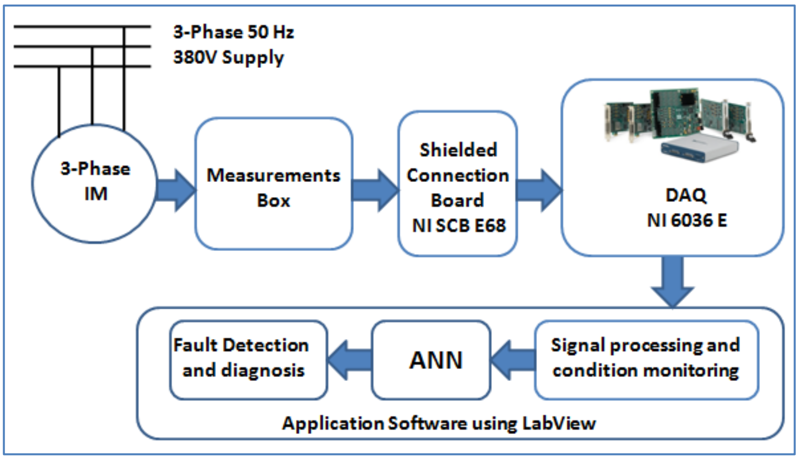

Fig. 5: Experimental Setup of the Monitoring System.

a) The 3-phase induction motor under test equipped with an accelerometer.
b) Measurement Box shown in figure (6) includes the following:
i. Three voltage transformers (VT's).
ii. Three line current transformers (CT's).
iii. One current transformer (summation CT).
c) Shielded Connection Board type (NI SCB 68) (http://www.msm.cam.ac.uk/ mech test/ docs/ scb68%20 manual, 2016, figure (7)
d) Data Acquisition card type (NI DAQ 6036E) (http://academic.amc.edu.au/hnguyen/JEE326IPC/ labappendix, 2016), figure (8).
e) PC (LabView 2015 package).
f) Monitoring screen.

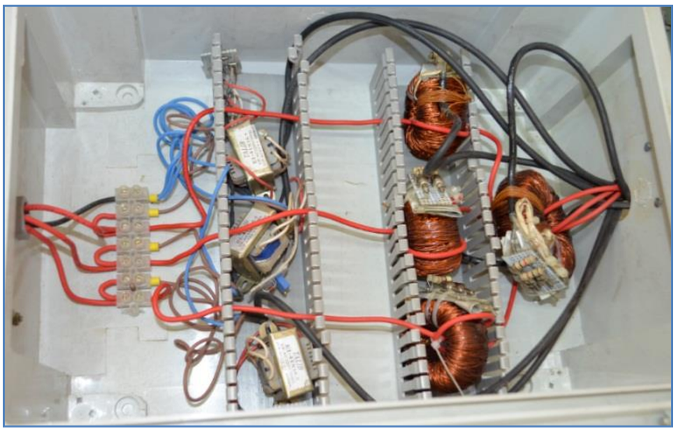

Fig. 6: The Contents of the Measurement Box.

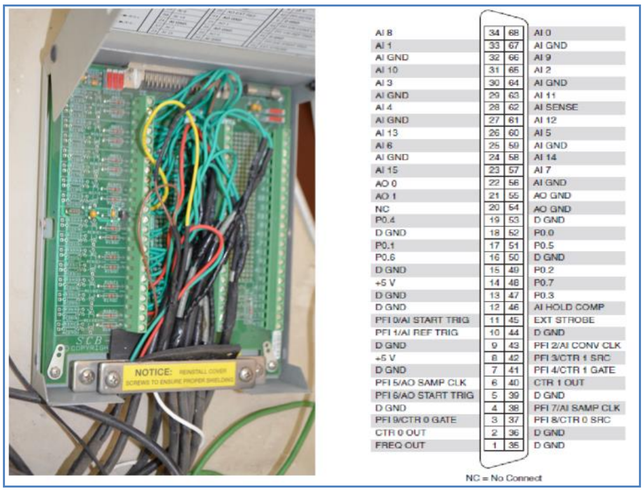

Fig. 7: The Connection Board NI SCB 68

Fig. 8: Data Acquisition Card (DAQ) PCI-6036E

Figure (9) shows the monitoring system components as hardware in the lab. The functionality of these components will be as follows:

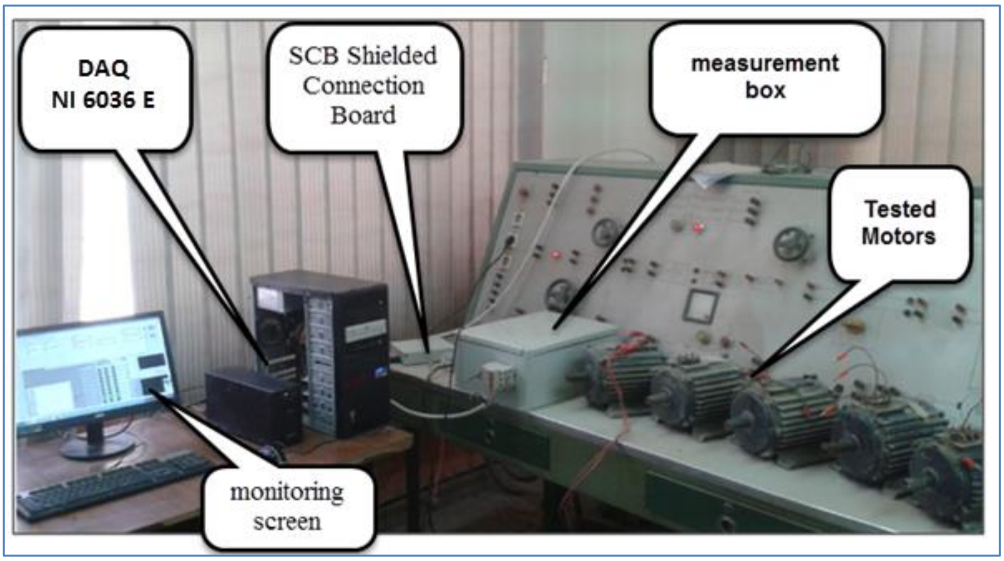

Fig. 9: The Real Experimental Setup in Lab.

3.1 Checking the supply voltage quality:

It is wealthy to mention here that the quality of the 3-phase input voltages to the induction motor have to be checked firstly in order to avoid their effect on the monitoring system performance. Hence, three identical voltage transformers are connected to measure the phase voltages and to display them to the monitoring system before starting the machine under test.

3.2 Checking the healthy case of the machine:

The three VT's of a ratio (220/6) measure the 3-phase supply voltage feeding the motor, while the summation current transformer of a ratio (250/1) , will measure the sum of the three line currents simultaneously. Hence, the "healthy" operation of the machine under test can be assured if and only if the following three conditions are satisfied:

a) The difference between rms values of these VT's approaches zero.
b) The summation CT reading approaches zero.
c) The accelerometer reading range assigns good severity criteria based on ISO2372 (http://www.intech2000.com/downloads/web/41/41.2/Applying%20Examiner,2016).

4. The connection board and data acquisition card:

The transducer signals are fed to the National Instrument (NI) Shielded Connection Block (NI SCB 68) in order to be transferred through a special cable to the Data Acquisition Card (NI DAQ 6036E). The INSCB with I/O connection cable set are adopted to perform shielding and to avoid the interference between transfers signals of each phase and the noise of other electric circuits in the vicinity.

Australian Journal of Basic and Applied Sciences, 10(16) November 2016, Pages: 223-240

Figure (10) shows the DAQ main operation steps. It receives eight signals from the transducers. The first action of DAQ is the separation of the input data according to its required type of analysis.

- The line voltage signals are fed from the voltage transformers through an additional shunt variable resistor (for calibration) and two Zinner diodes for each one to make sure that the output voltage is in the capability range of the DAQ voltages (±10V) (http://academic.amc.edu.au/hnguyen/JEE326IPC/labappendix, 2016).
- The line currents are fed to the amplifier stage, and then the unwanted higher harmonics are discarded by the active filter stage. Since there is more than one analogue signal, the analog multiplexer will control these signals to be fed sequentially to the A/D converter. Since the sampling rate of the DAQ is 200kS/s, then each cycle of the 50Hz signal will be of 4000 samples. These samples fed to the A/D, and then these current data are ready to be processed by the Lab View software on the associated PC.
- The summation CT current signal is directly fed to the Lab View.
- The accelerometer, vibration signal fed to the amplifier and then to the Lab View to be analyzed and displayed on the monitoring screen too.

The voltage signals are directly presented on the main Lab View monitoring screen, as well as they are processed by the summation CT signal and the vibration rate to produce the "healthy" signal due to the above three conditions.

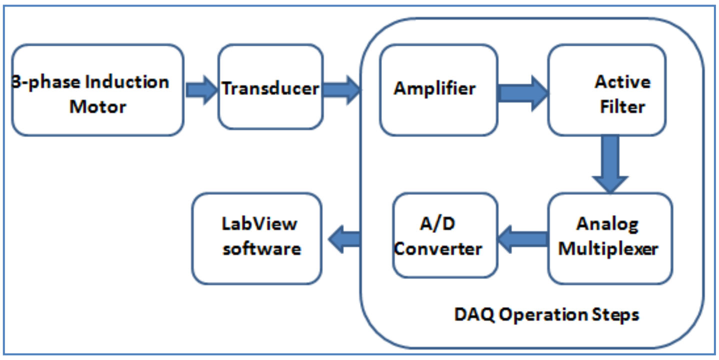

Fig. 10: The Main Steps of (NI DAQ 6036E)

5. The Lab View program processes:

The three line currents and the vibration signal are fed to the LabView program to do the main objectives of the monitoring system:

- The fault detection.
- The fault diagnosis.

To perform these objectives, the need arises to preparation of line current harmonics of the machine under test and compares them with already stored data of the different faults of the machine with the aid of the Artificial Neural Network (ANN). These two processes are done by the PC Lab View program.

5.1 Fast Fourier Transform (FFT):

It is easy to conclude from the literature review of the fault diagnosis subject that the FFT is an effective mean to achieve a frequency spectrum of any periodic distorted signals (Marcelo, C., *et al*., 2012). Since the DAQ send a stream of digital signal representing the sampled line currents, then each sample must be transformed to its analog value in order to be processed by FFT subroutine. The LabView is programmed to repeat the FFT process each 10Cycles, hence the monitoring process repeated each 0.2s.

5.2 Artificial Neural Networks (ANN):

ANN mimics the human brain structure, which consists of simple arithmetic units connected in complex layer architecture. The ANN is one kind of popular artificial intelligence techniques that has been applied to condition monitoring and fault diagnosis for electric motors (Marcelo, C., *et al*., 2012). An ANN is composed of many artificial neurons that are linked together according to specific network architecture. The objective of the neural network is to transform the inputs into meaningful outputs. The architecture of an artificial neuron is shown as Figure (11).

Australian Journal of Basic and Applied Sciences, 10(16) November 2016, Pages: 223-240

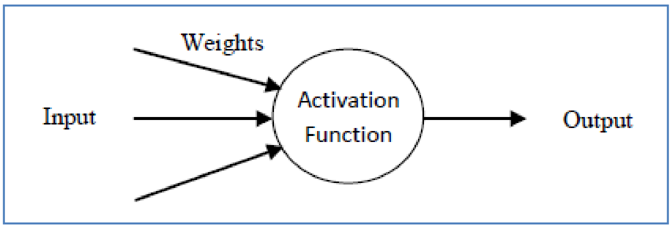

Fig. 11: Architecture of Artificial Neuron

It basically consists of inputs, which are multiplied by weights (strength of the respective signals), and then computed by a mathematical function which determines the activation of the neuron. Another function computes the output of the artificial neuron. The higher the weight of an artificial neuron is, the stronger the input which is multiplied by it. Depending on the weights, the computation of the neuron will be different. By adjusting the weights of an artificial neuron, the output can be obtained for specific inputs. An ANN combines artificial neurons in order to process information. The architecture of an artificial neural network is shown as Figure (12).

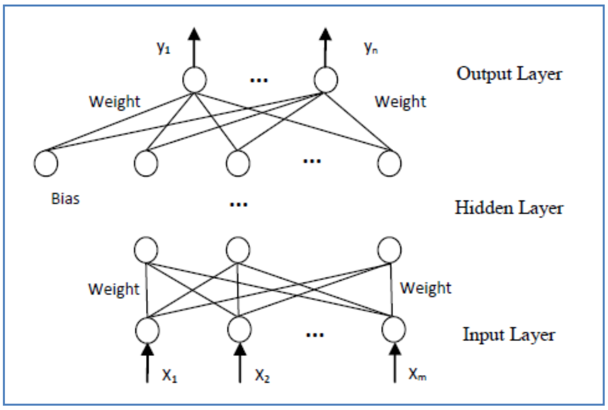

Fig. 12: Architecture of Artificial Neural Network.

A neural network properly trained can be used for both fault and fault severity classification, which is the ultimate objective of fault diagnosis [13]. However to interpret the outputs so formed and to use them for classification, knowledge of the training data set is still required. Nevertheless, unsupervised networks require less iteration in training, since they do not require exact optimization for their decision-making.

6. System Representation Using Lab View Programming:

To detect the induction motor faults, a system for fault detection was designed based on Motor Current Signature Analysis (MCSA) as shown in Figure (4. . The stator current is firstly sampled in the time domain and in the sequence; the frequency spectrum is calculated and analyzed aiming to detect specific frequency components related to incipient faults. The faults are detected comparing the amplitude of specific frequencies with that for the same motor saved in database. In the described system, data acquisition card was used to acquire the current samples from the motor operation. The current signals are then transformed to the frequency domain using a Fast Fourier Transform (FFT) based power spectrum. The block diagram for obtaining the power spectrum using programming in LabVIEW2015 is shown in Figure (6). The first step of Lab View program is receiving signals from DAQ by choosing the input channels for currents, voltages and vibration signals. This step called initializing. The input and initializing steps in Lab View are shown in figure (13).

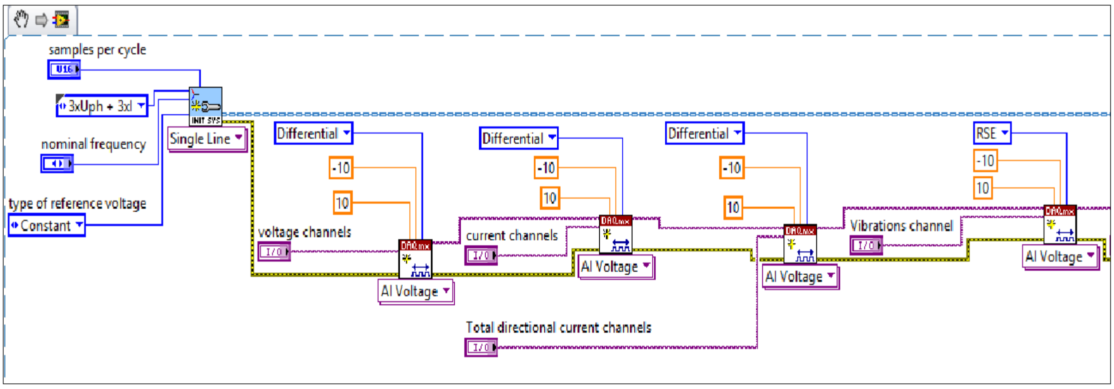

Fig. 13: Initialize Input Channel for Signals

All signals modulated in the second step to transfer it to the processing parts as it needs. This stage called as queue element and it is shown in figure (14).Third step consists a calibration reading of the currents and voltages. Firstly must demodulate signals and possess it severally by using the queue element as shown in figure (15).The fourth stage is to insulate the current waveforms of the three phases and determination of harmonic spectrum and save it as matrix with 1920 elements and send it to the identifier. This stage includes FFT analysis and displays the results as shown in figure (16).

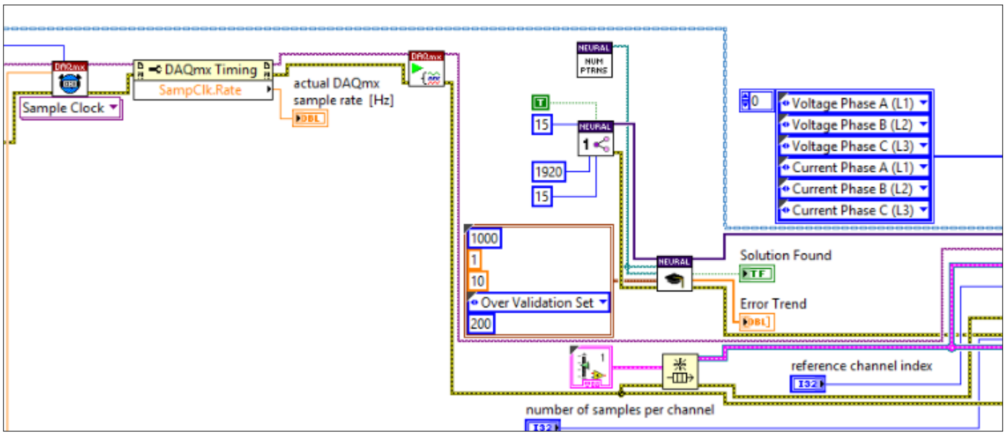

Fig. 14: Queues Generating Element.

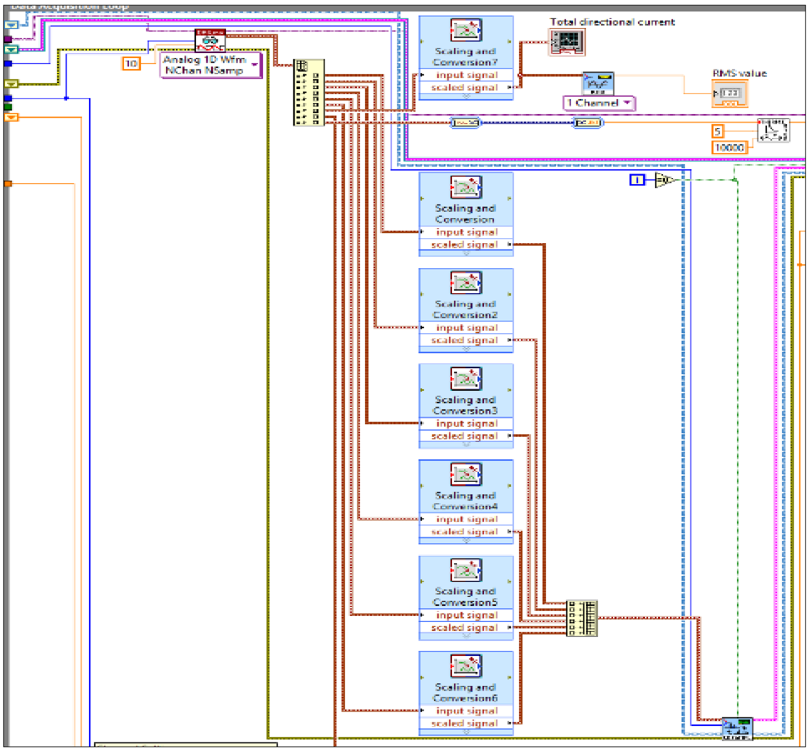

Fig. 15: Calibration of Currents and Voltages.

The final step of the system is comparing the harmonic data matrix with the threshold data which are saved in the ANN database by setting the error ratio, which ranged from 0.5 to 1 as shown in figure (17). The ANN database included all faults experimental harmonics data and it automatically compares it with tested motor current information continuously. This operation will be known as classifying as shown in figure (18).

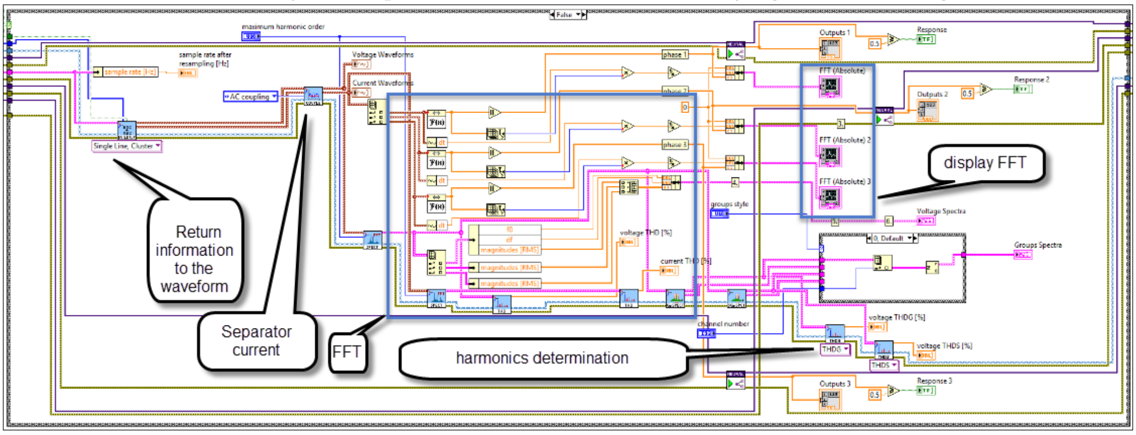

Fig. 16: Current Analysis

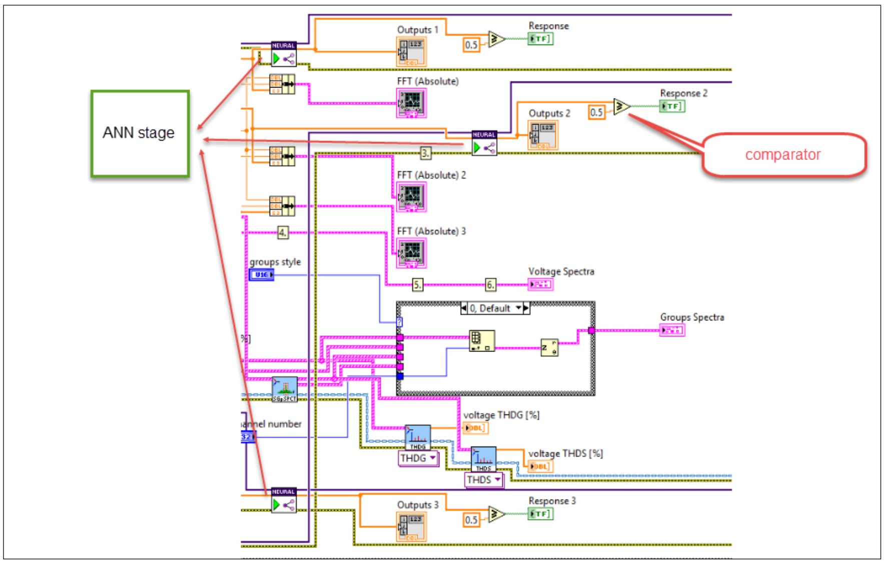

Fig. 17: Comparison and Neural Stage

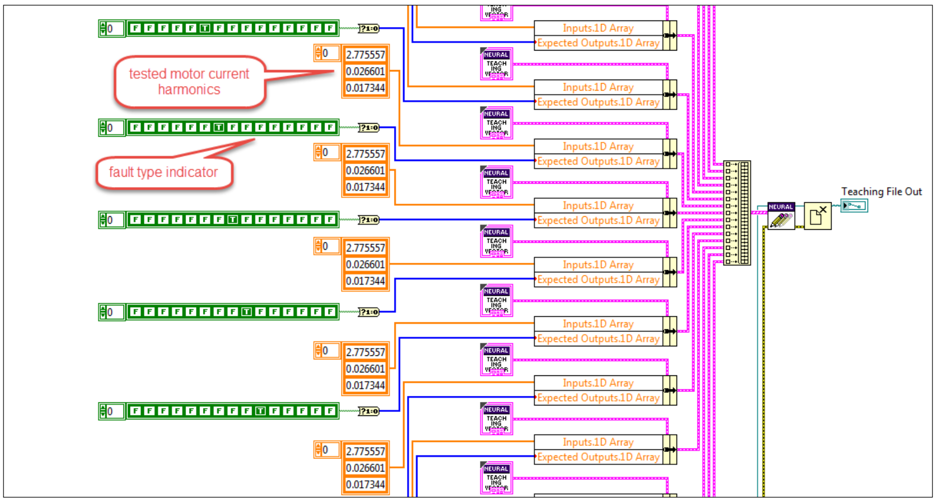

Fig. 18: ANN Stage

7. Experimental results:

To provide a data base for ANN, a real test must be done on a real faulty motor and store the harmonics of their current line during a faulty condition. Three of the most probable electrical faults will be considered as an example.

a. Broken Rotor Bar:

The first test applied to a motor has one broken bar in the rotor. The bar broken by drilling a hole of 5mm diameter and 14mm in depth as shown in figure (19).

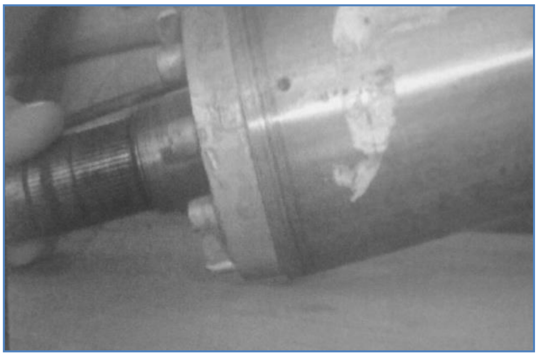

Fig. 19: Broken bar

Australian Journal of Basic and Applied Sciences, 10(16) November 2016, Pages: 223-240

This step must be accurate to insure that this bar will be open circuited and its resistance being infinity and will cause unbalance and non-smooth rotor rotation that causes distortion on MMF and make unbalanced forces causing some vibration and ripple in current waveform and additional harmonics in this waveform as shown in figure (20).

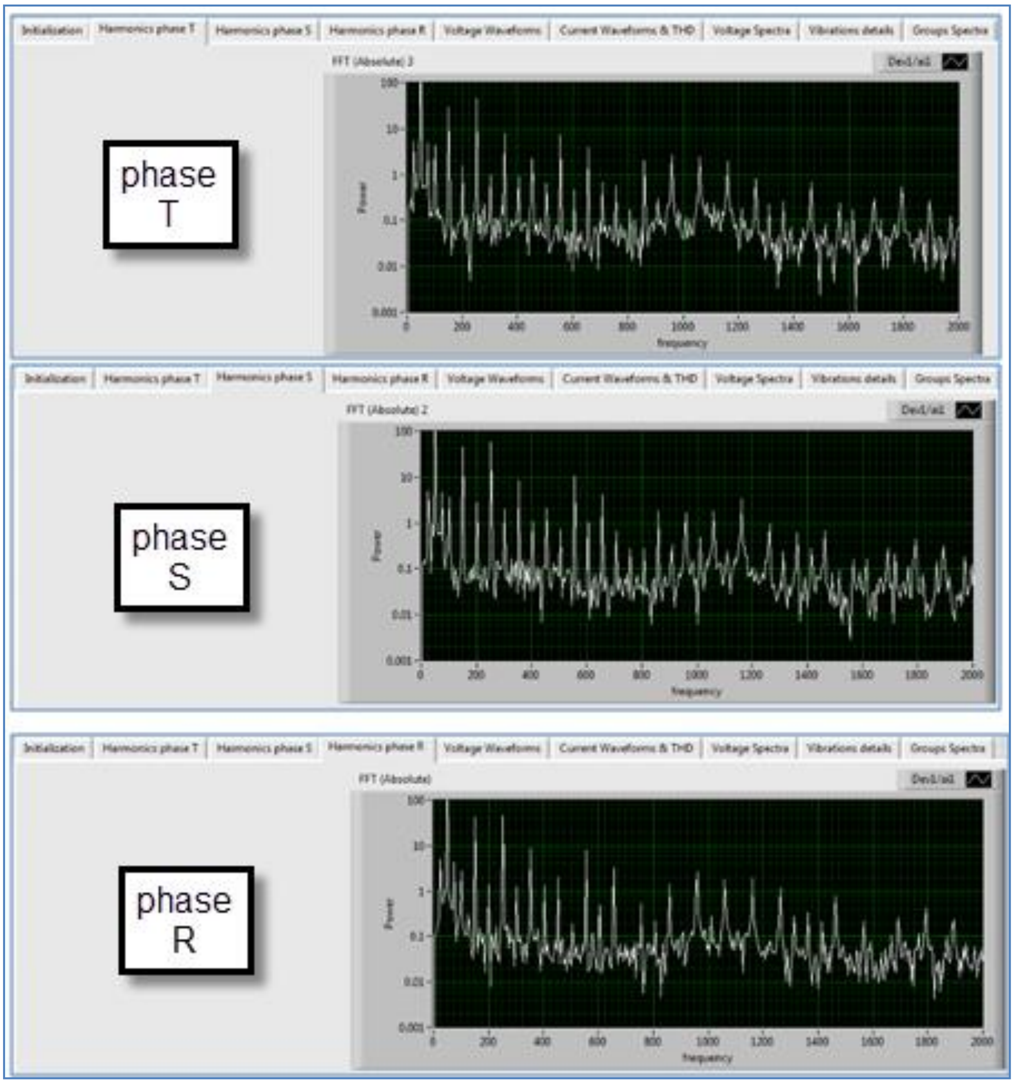

Fig. 20: FFT for Three-phase Current Waveforms for Broken bar Fault.

By these strategies Lab View detected fault type by the ANN classifier. It comparing the FFT data with that saved data in the database and make a fault type decision as bearing no load (BB no load) as shown in figure (21).

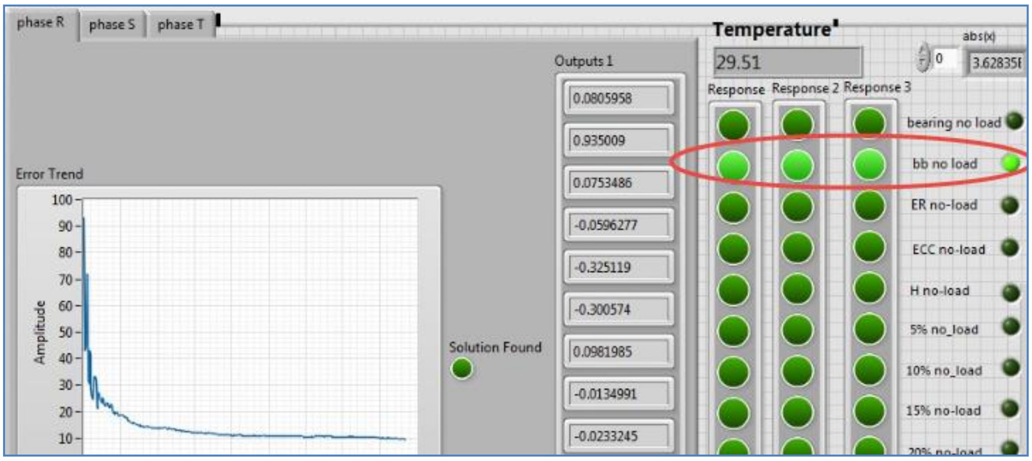

Fig. 21: Broken Rotor Bar Fault Diagnosis

b. End Ring Fault:

In general the end ring fault means a fracture occurs in certain part of the end ring that may cause an open circuit in one or more of the rotor bars. Also, the mass unbalance of rotor due to the fracture will cause unbalance rotation and unbalance EMF and torque pulsations. All these effects will appear as ripples in current waveforms and will generate a new harmonic as shown in figure (22).

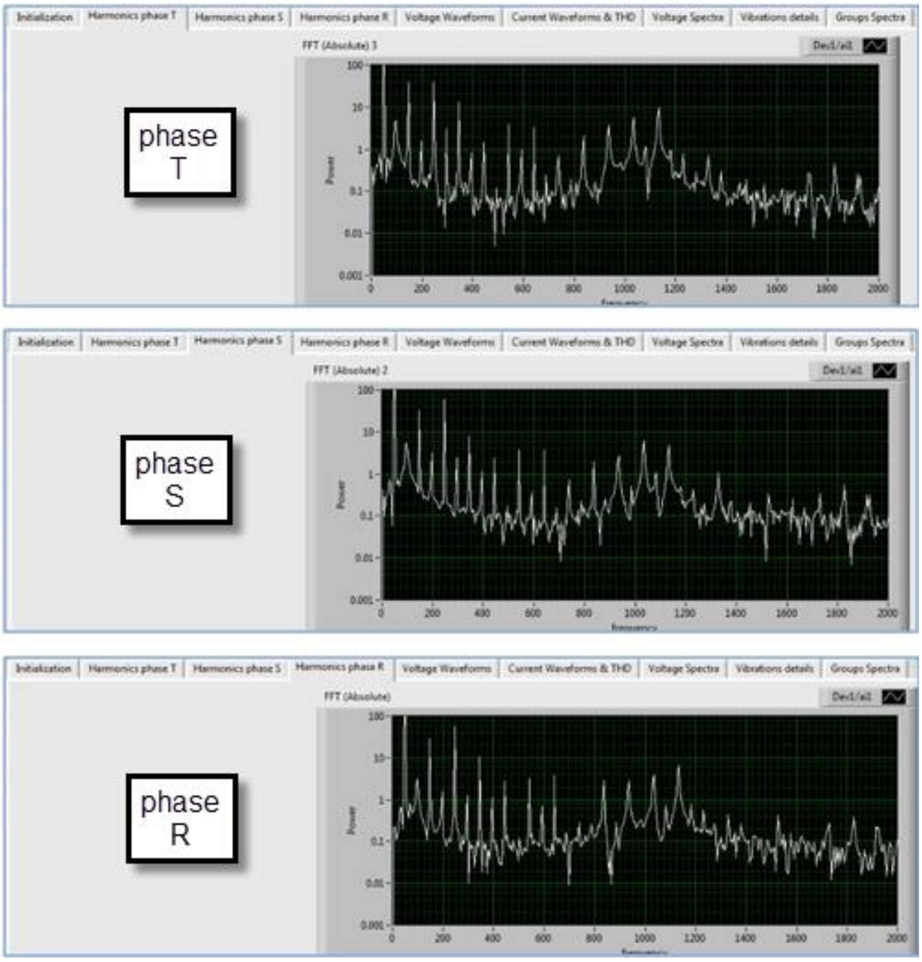

Fig. 22: FFT of Three-phase End Ring Fault Current

The fault diagnosis using ANN classifier is indicated in the monitor screen as ECC. No load as shown in figure (23).

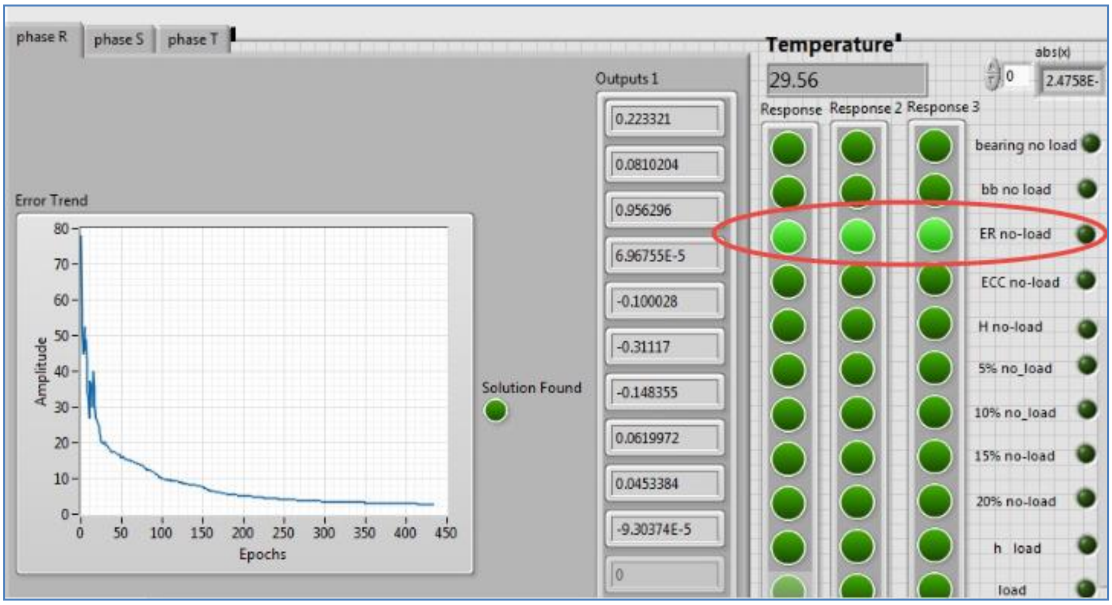

Fig. 23: End Ring Fault Diagnosis

C. Inter Turn Short Circuit Fault:

The electrical faults known as an inter turn short circuit for the stator windings are one of the common faults of the induction motors. This fault could lead to motor stop and isolate the electrical power by circuit breaker. The main reason for the occurrence of this fault is a hole in the winding insulation as a result of high temperature or friction with mechanical parts. The early detection of this fault may help to reduce the damage and prevent the neighboring windings from its effect. This will reduce maintenance costs and downtime of the motor. This kind of faults was conducted by dividing a 20% of the winding of one phase to four sections, starts from 5% up to 20%. The artificial tapping terminals of these5% steps of the winding used to apply these faults practically as shown in figure (24).

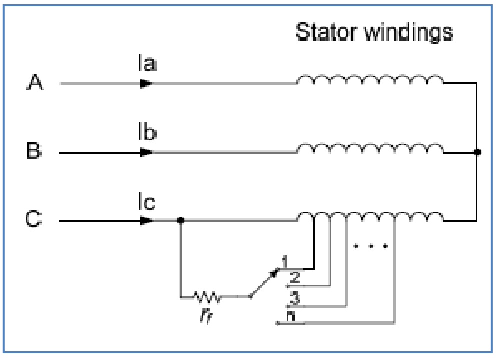

Fig. 24: Schematic of Stator Winding Tapping for Tested Motor

These faults generate a negative MMF, which decrease net MMF of the faulty 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. The frequencies which are appear in the spectrum as shown in figure (25, 27, 19, and31). The fault diagnosis using ANN classifier is indicated in the monitor screen as 5%, 10%, 15% and 20% no load. As shown in figure (26, 28, 30 and32).

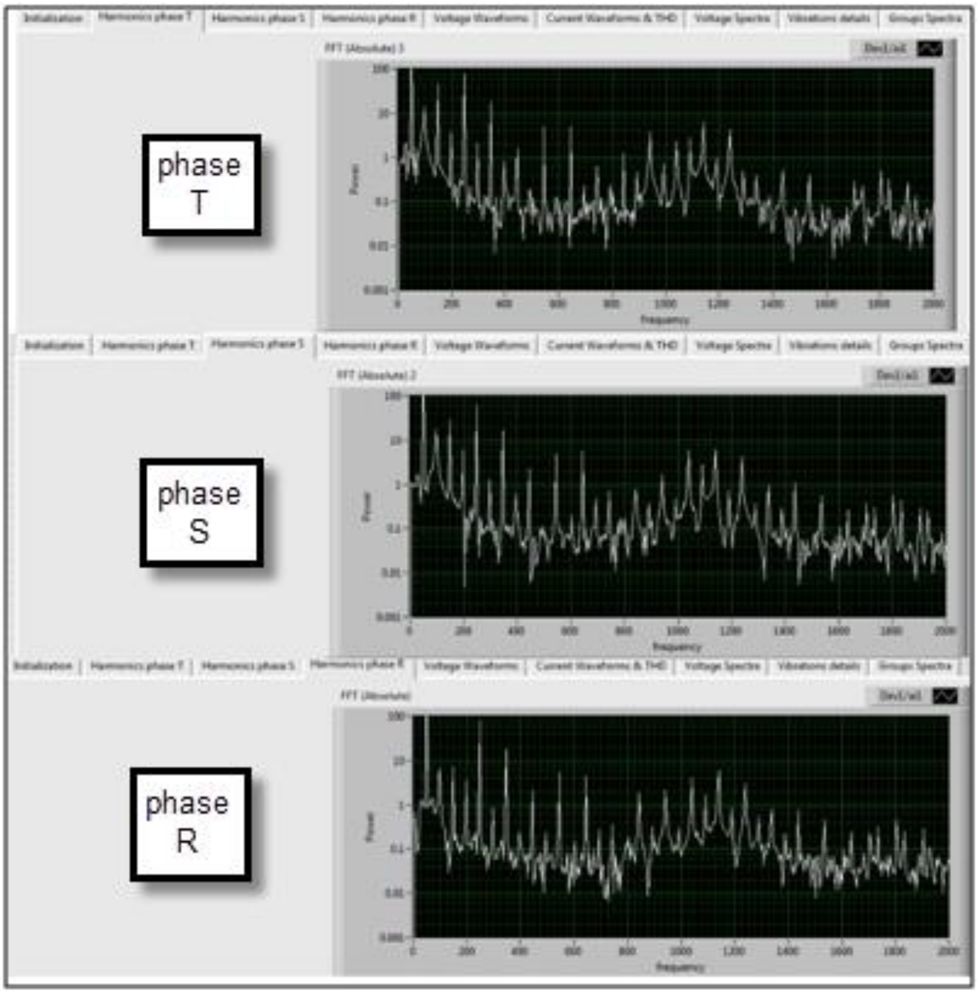

Fig. 25: FFT of 5% Short Circuit Turn 3-phase Current Based in Lab View

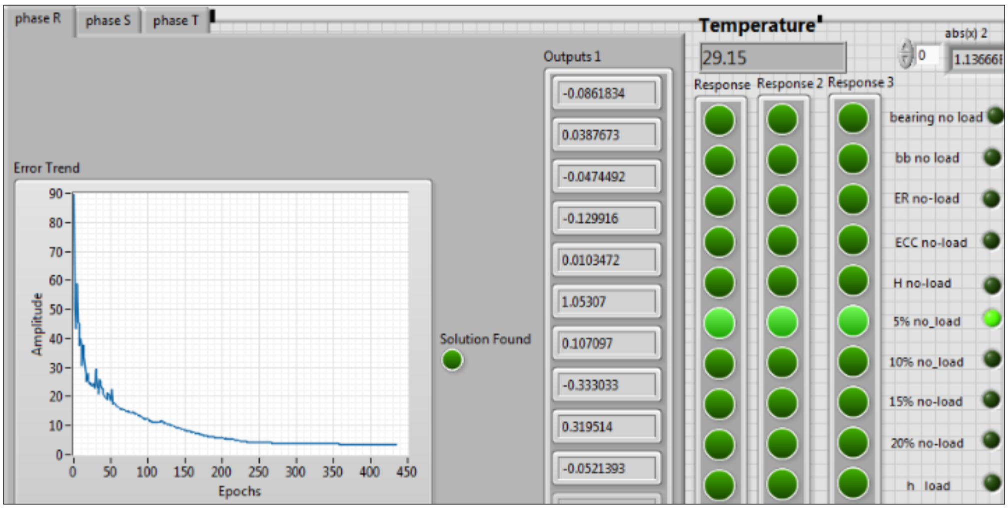

Fig. 26: Fault Diagnosis Of 5% Inter Turn Short Circuit Based In LabView

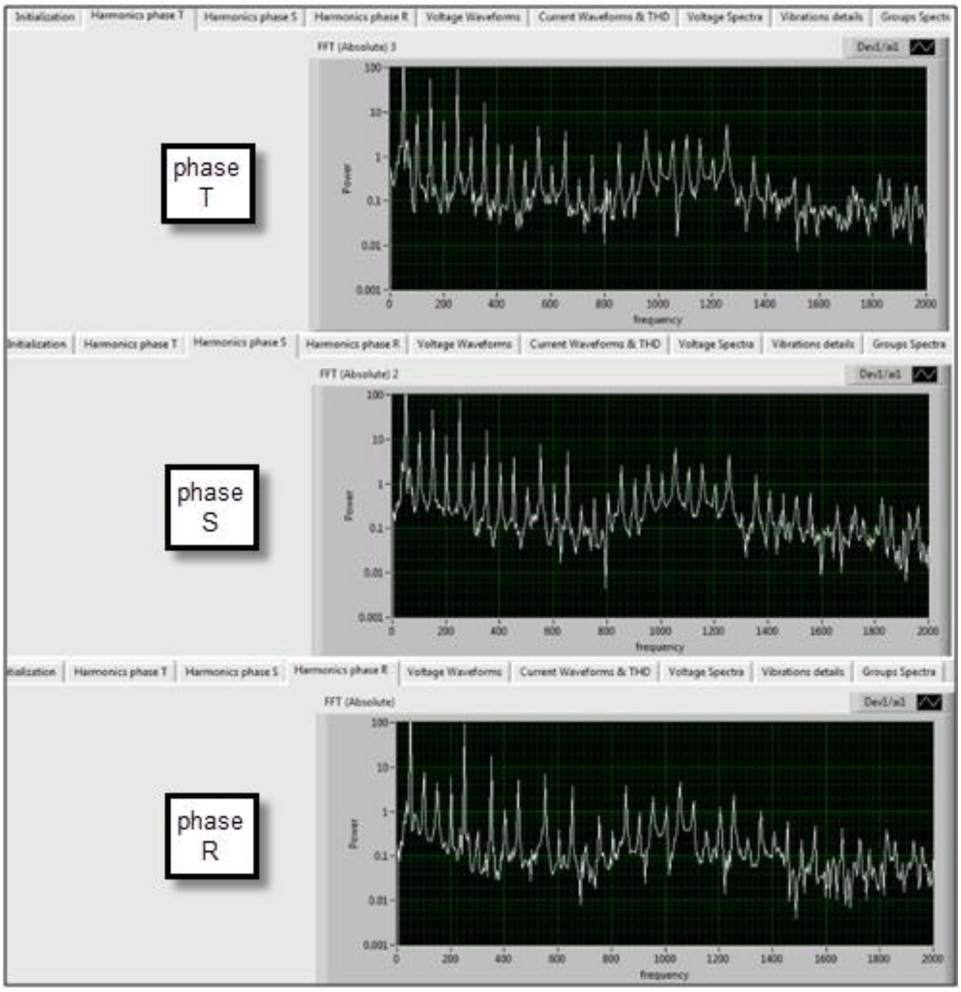

Fig. 27: FFT of 10% short circuit turn 3-phase current based on Lab View

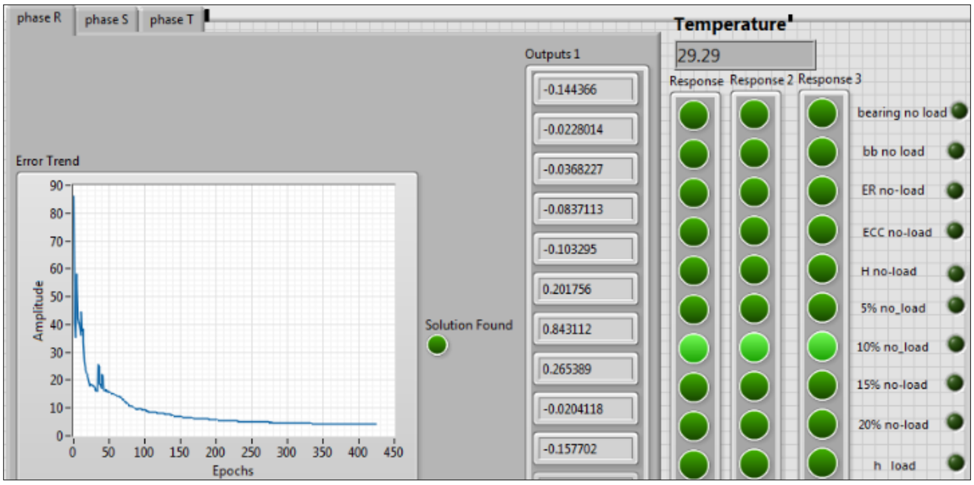

Fig. 28: Fault Diagnosis Of 10% Inter Turn Short Circuit Based In Lab View

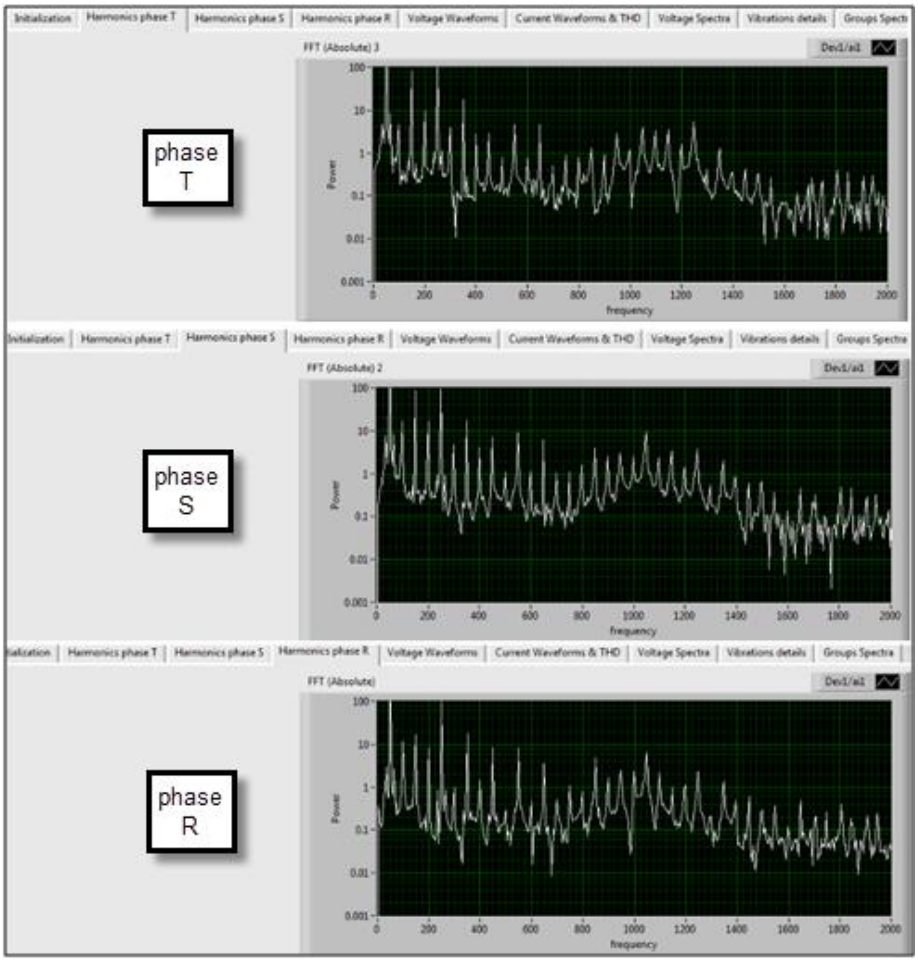

Fig. 29: FFT of 15% Short Circuit Turn 3-phase Current Based in Lab View

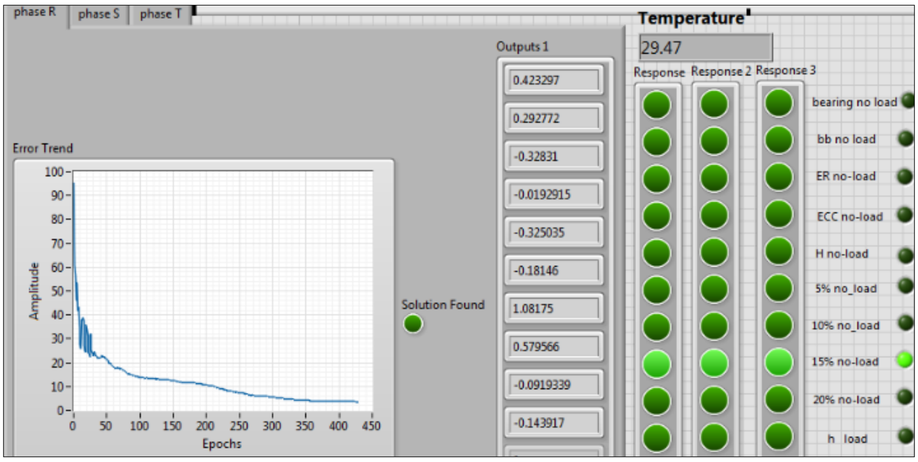

Fig. 30: Fault Diagnosis of 15% Inter Turn Short Circuit Based In LabView

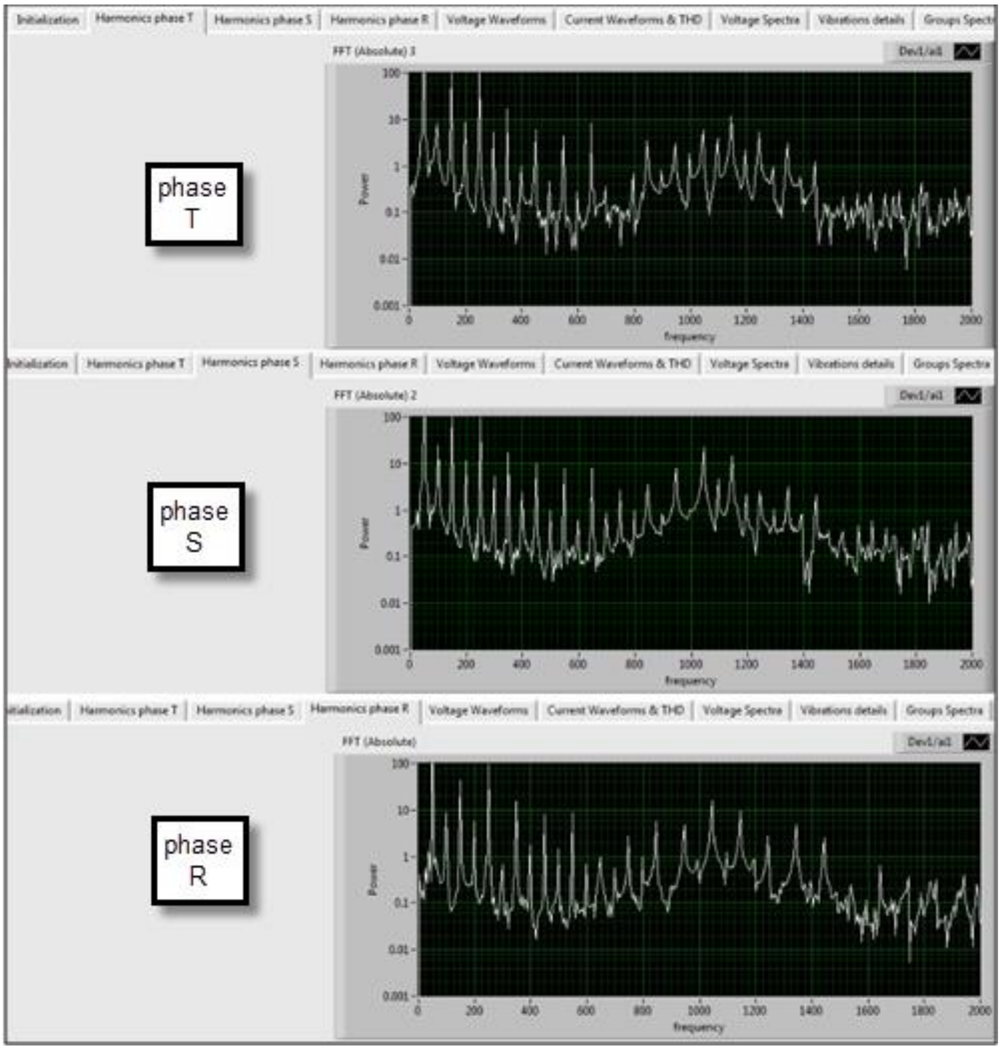

Fig. 31: FFT of 20% short Circuit Turns 3-phase Current Based in Lab View

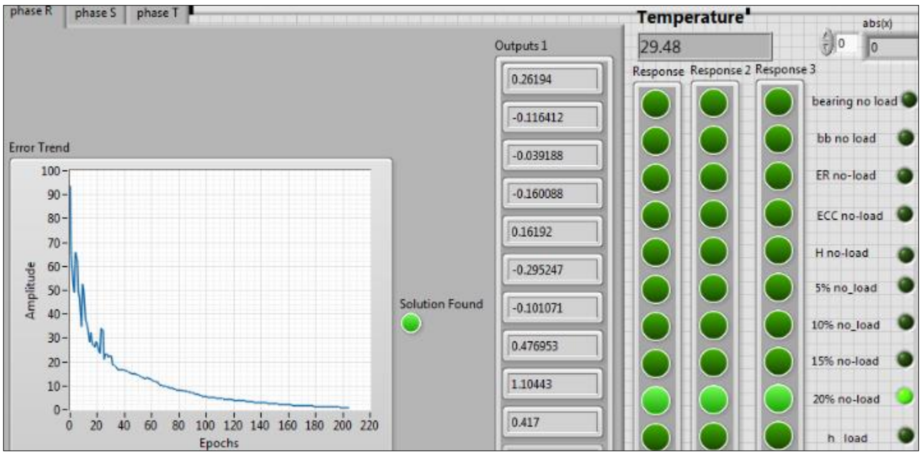

Fig. 32: Fault Diagnosis of 20% Inter Turn Short Circuit Based In LabView

Conclusions:

This work resulted in many important conclusions:

This work show the mainframe of an on-line monitoring system, but it is not sufficient to deal with all fault conditions due to lack of information about all expected faults.

The addition of the vibration sensor to this monitoring system will provide two benefits. It will add another diagnosis parameter and this will increase the ability of fault identification. Also, it will provide an on-line vibration measurement leads to avoid loss fastening of the machine during operation which will lead to a false alarm from the monitoring system.

To achieve an accurate fault diagnosis system able to deal with all expected faults for certain type of induction motor, the data of each fault in all loading conditions must be provided from a real testfor faulty conditions. Since such tests are impossible for certain faults, hence a need arises for a real simulation able to do this job. The 3-D finite element analysis is the best candidate for this task.

To achieve correct decision from such a monitoring system in industrial applications, many points have to be considered:

- The machine installation and alignment with its load must be perfect.
- The source feeding the motor must perform balanced and harmonic free voltages always.

The database must provide the expected mixed fault conditions.

REFERENCES

Filippetti F., Franceschini G., Tassoni C., Vas P. "AI Techniques In Induction Machines Diagnosis Including The Speed Ripple Effect". IEEE Trans Ind Appl 34:98–108. 1998.

Deleroi W. "Broken bars in squirrel cage rotor of an induction motor-part I": description by superimposed fault currents. Arch Elektrotech 67:91–99. 1984.

Alberecht, P.F., J.C. Appiarius, E.P. Cornel, D.K. Sharma, 1987. "Assessment of theReliability of Motors in Utility Applications", IEEE Transactions on Energy Conversion PER-7(3): 396-406.

Szabó, L., F. Tóth, E. Kovács, G. Fekete, 2008. "An Overview on Induction Machine's Diagnosis Methods, Journal of Computer Science and Control Systems, Oradea,. ISSN: 1844-6043, pp: 229-234.

Lee, S.B., R.M. Tallam, T.G. Habetler, 2003. "A Robust On-line Turn-fault Detection Technique for Induction Machines based on Monitoring the Sequence Component Impedance Matrix. IEEE Trans Power Elect., 18(3): 865-872.

Su, H., K.T. Chong, R.R. Kumar, 2011. "Vibration Signal Analysis for Electrical Fault Detection of Induction Machine Using Neural Networks". Neural Compute Appl., 20(2): 183-194.

Nandi, S., H.A. Toliyat, 1999. "Condition Monitoring and Fault Diagnosis of Electrical machines—a Review", Proceedings 34th annual meeting of IEEE industrial applications society, pp: 197-204.

Ahmed, I., R. Supangat, J. Grieger, N. Ertugrul, W.L. Soong, 2004. "A Baseline Study for Online Condition Monitoring of Induction Machines", Australian Universities Power Engineering Conference (AUPEC), Brisbane, Australia.

Thomson, W.T., D. Rankin, D.G. Dorrell, 1999. "On-line Current Monitoring to Diagnose Air Gap Eccentricity in Large Three-phase Induction Motors—Industrial Case Histories to Verify the Predictions", IEEE Trans Energy Conversion, 14(4): 1372-1378.

Thomson, W.T., A. Barbour, 1998. "On-line Current Monitoring and Application of a Finite Element Method to Predict the Level of Air Gap Eccentricity in 3-Phase Induction Motor". IEEE Trans on Energy Conversion, 13(4): 347–357.

Shielded Connector Block User ManualSCB-68, 68-Pin, Retrieved from http://www.msm.cam.ac.uk/mechtest/docs/scb68%20manual, 2016.

Guidelines for National Instrument NI PCI-6036E Card Used with LabVIEW, MATLAB/Simulink/Data Acquisition Toolbox, Retrieved from http://academic.amc.edu.au/hnguyen/JEE326IPC/labappendix, October 2016.

ISO 2372 Standards provide guidance for evaluating vibration severity in machines operating in the 10 to 200 Hz (600 to 12,000 RPM) frequency range,Retrieved from. http://www.intech2000.com/downloads/web/41/41.2/Applying%20Examiner,2016.

Marcelo, C., J.P. Fossatti, J.I. Terra, 2012. "Fault diagnosis of induction motors based on FFT",www.intechopen.com.

Acosta, G.G., C.J. Verucchi and E.R. Gelso, 2006. "A Current Monitoring System for Diagnosing Electrical Failures in Induction Motors",Mechanical Systems and Signal Processing, 20(4): 953-965.