International Journal of Engineering Research and Development
***e**-ISSN: 2278-067X, **p**-ISSN: 2278-800X, www.ijerd.com*
Volume 3, Issue 9 (September 2012), PP. 73-83

Motor Health Detection using Fuzzy Logic

Millind S. Patil, Amir M. Shaikh, Ravindra R. Mudholkar
Department of Electronics, Shivaji University, Kolhapur (MS), INDIA-416 004

Abstract—The lack of an accurate model that describes a fault motor is major difficult. Many researches dealt to interpret measurement data that are frequently inconclusive. The main objectives of this paper are to perform fault analysis on an induction motor using both Simulation and Real-time study, devise a failure identification technique to be applied for condition monitoring of the motor and help design an On-line condition monitoring system with fuzzy logic controller using Matlab. The motor condition is described using linguistic variables.

Keywords—Induction motor, fault-diagnosis, fuzzy logic, stator current amplitudes, Condition monitoring.

I. INTRODUCTION

The induction motor has been widely used motor for industry it continues with increasing applications. This is chiefly due to its low cost, reasonably small size, ruggedness, low maintenance, and operation on easily available power supply. On the other hand, the spreading of Power Electronics and the development of Modern Control Techniques has made the induction machine a good solution for very newer kind of applications [1]. Textile industry is not the exception to use induction motors. Fault in motor could be either mechanical or electrical in nature.

It is well known that Induction Motor monitoring has been studied by many researchers and reviewed in a number of works [3]–[5]. Reviews about various stator faults and their causes, and detection techniques, latest trends, and diagnosis methods supported by the artificial intelligence, the microprocessor, the computer, and other techniques in monitoring and protection technologies have been proposed. The major intricacy is the lack of an accurate model that describes a fault in the motor. Moreover, experienced Engineers are often called upon to interpret measured and/or observed data that are frequently inconclusive or unconvincing. A Fuzzy Logic approach help diagnose induction motor faults under such jittery situations. In fact, Fuzzy Logic is reminiscent of human thinking process and natural language enabling decisions to be made based on vague information. Therefore, fuzzy logic technique can adequately be extended to the Induction Motor Fault Detection and Diagnosis. The motor condition is described using linguistic terms like ‘good’, ‘bad’, ‘overload’, ‘performance declined’ etc. Thus health interpretation of induction motor turns out to be a Fuzzy Concepts [2].

II. MOTOR CONDITION MONITORING USING STATOR CURRENT

Fuzzy subsets can be assigned to describe the stator current amplitudes by means of corresponding membership functions. A knowledge base pertaining to situations liable for faults in the motor comprising rule base and data base can be built to activate the fuzzy inference. The induction motor condition can thus be diagnosed using an apparatus of fuzzy inference. Induction motor under consideration is of *2-KW, 220/380 V, 15/8.6 A, 50-Hz, 4 pole, Δ connected squirrel cage* type.

The judgment of induction motor condition made based on fuzzy inference is capable of better diagnosis as it shares the human’s knowledge expressed in vague terms like "*somewhat secure*", "*little overloaded*" with computing abilities of computer etc. Such linguistic input prepositions can be directly expressed by Fuzzy System. The structure of Fuzzy Monitoring and Diagnosis is shown in Fig. 1 and Fig. 2. The stator current signal reciprocates the promising information relating to motor fault. The Fuzzy systems rely on a set of rules. These rules allow the input to be fuzzy permitting the words to describe the fault conditions bringing a sort of robustness in information processing. Motor being an electro-mechanical system, the applied voltage, current drawn by the motor and internal temperature play a major role in reciprocating the faults. In the present study the motor phase currents have been monitored and based on the subsequent trend in the current values diagnosis of motor status has been judged. For Fault Detection and Diagnosis of Induction Motor stator current amplitudes viz. I_a, I_b, and I_c have been considered as the *input variables* to the fuzzy system. The motor condition, M_c, has been chosen as the *output variable*. We have defined the fuzzy subsets $\widetilde{I_a}$, $\widetilde{I_b}$ and $\widetilde{I_c}$ for input variables given to the Fuzzy Systems and $\widetilde{M_c}$ for output variable as follows-

$$\widetilde{I_a} = \mu_a(i_a)/i_a, \forall i_a \in I_a$$

$$\widetilde{I_b} = \mu_b(i_b)/i_b, \forall i_b \in I_b$$

$$\widetilde{I_c} = \mu_c(i_c)/i_c, \forall i_c \in I_c$$

$$\widetilde{M_c} = \mu_{M_c}(m_c)/m_c, \forall m_c \in M_c$$

Where i_a, i_b, i_c and m_c are elements of the discrete Universe of Discourse (UoD) viz.I_a, I_b, I_c and M_c.

Fuzzy logic works with linguistic variables whose values are words or sentences in a natural or artificial language. This

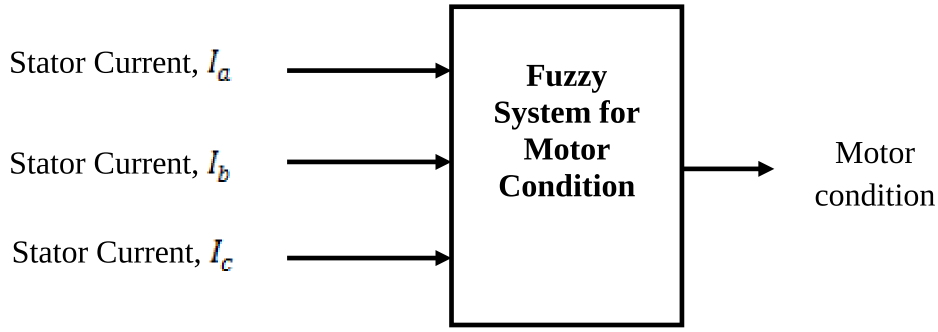

Fig. 1: Motor Condition Status

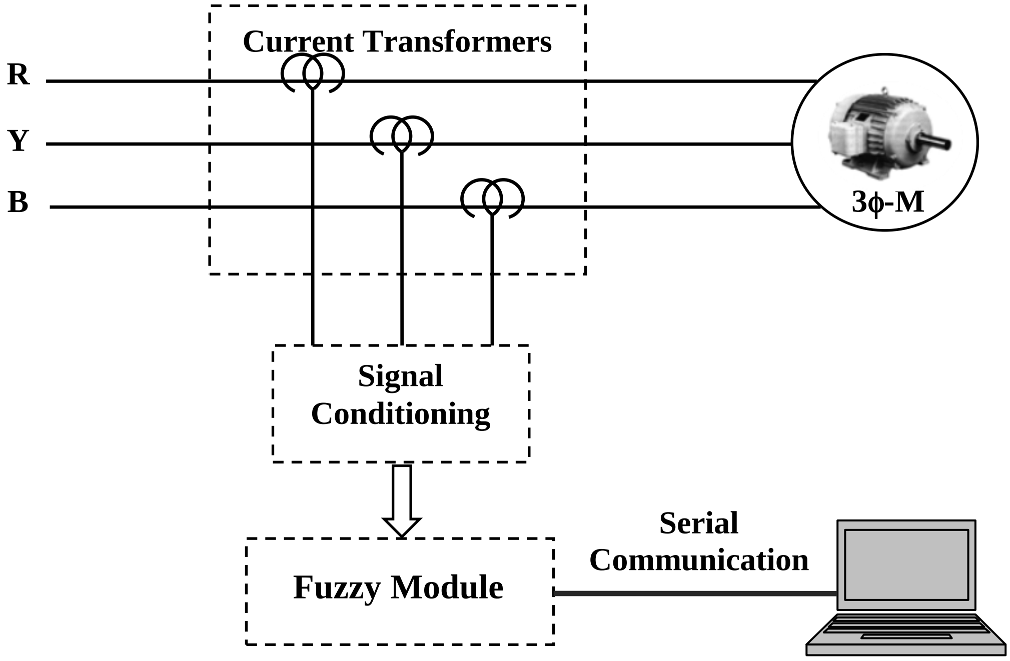

Fig. 2: Motor Condition determination Setup Layout

provides a means of systematic manipulation of vague and imprecise information. The term set (T) is a collection of linguistic values assigned to linguistic variable. The term sets used for stator current and motor condition are as follows-

T (I_a, I_b, I_c) = {Zero (Z), Small(S), Medium (M), Big (B), Very Big (VB)}

T(M_c) = {Open_phase, Damage, Critically_overloaded, Overloaded, Good }

The optimized rule base has been developed so as to encompass all possible healthy and faulty conditions of the motor.

III. FIS DESIGN FOR MOTOR STATUS DETECTION

Fuzzy Inference System (FIS) for Motor Status Detection has been created using Fuzzy Tool Box of MATLAB. The input stator motor currents are portioned in to five fuzzy subsets labeled with linguistic values as *Zero* (Z), *Small*(S), *Medium* (M), *Big* (B), *Very Big* (VB). In a same way the output variable- the Motor_condition (Stator condition) is interpreted as linguistic variable with linguistic values as *Open_phase, Damage, Critically_overloaded, Overloaded and Good.* Membership functions are constructed by observing the data set and the trends in the stator currents that are likely to cause the faults in the motor. For the sake of initial design success we did relied on the triangular membership functions. The membership functions for output and input variables are shown in Fig.3 and Fig.4 respectively.

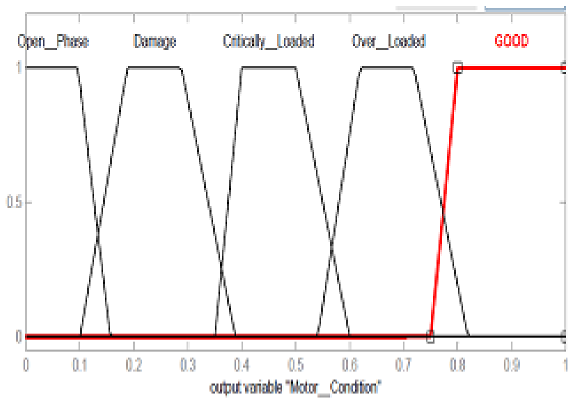

Fig. 3: Membership functions of Motor Condition

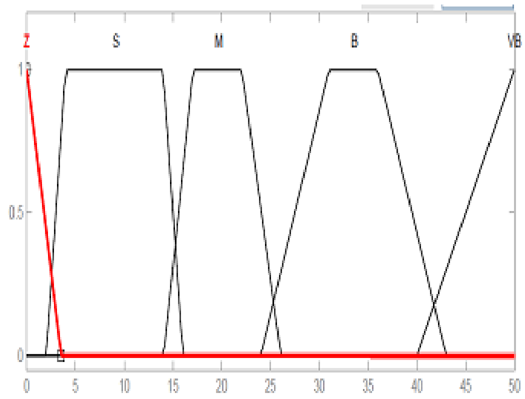

Fig. 4: Membership functions of Stator Current : I_a, I_b, and I_c

IV. RULE BASED INFERENCE

This is the critical part of any Fuzzy System. After keen study of motor and fault prone situation we could identify 23 situations where motor condition is unhealthy. The inference rules can be classified into six distinct categories based on consequent parts. After vigorous analysis of all rules we could develop a rule base comprising only 5 rules covering whole health condition of motor. These rules along with their firing weights are enlisted in table-I.

Rule	If I_a is	or I_b is	or I_c i s		Motor Condition	Rule Weight
1	Z	Z	Z	THEN	*Open_phase*	(1)
2	B	B	B		*Critically_Overload*	(0.9)
3	M	M	M		*Over_Load*	(0.8)
4	S	S	S		*Good*	(0.7)
5	VB	VB	VB		*Damage*	(1)

***Table-I:* Rule base for Motor Health**

By *Inference* input conditions of stator currents are mapped with consequential output motor health conditions and output on the health of the motor at any instant of time is derived. It is followed by the process of *Defuzzification* for computing crisp indication of motor health condition based on the fuzzy output generated by rule firing process of Fuzzy Inference. There are many types of defuzzification methods available. But we have employed the Center of Area (COA) method for defuzzification.[5,6] Despite its complexity it is more popularly used because, if the areas of two or more contributing rules overlap, the overlapping area is counted only once.

If any incipient faults or slight voltage unbalance occurs, then the output of the FIS generates the output corresponding to Damage. Immediately the fault data and the current are stored in a file for analysis purpose with time as long as fault persists. For the severe faults such as open phase, open coil, single line to ground short and line to line short, the Fuzzy Inference output will be seriously damaged. In this state the machine should not be allowed to operate any further. Whenever the FIS output indicates condition '*Damaged*', the machine gets isolated from the supply and stores the instantaneous fault data. For illustration, Fuzzy Inference of different stator currents is shown, for which the induction motor stator condition is good, Over_Load, Critically_Overload, Damaged, or Open_phase. As it could be noticed, fuzzy rules are solicited, according to stator current amplitudes, leading to the determination of the motor condition.

V. DEVELOPMENT OF SIMULATION SET UP

About 70 % of mechanism are directly or indirectly depends on the proper function of Motors used in the Textile Industry. In other words Motors play significantly a vital role in the Textile Industry and therefore prime attentions are being focused on the health conditions of Motors. We have developed a fuzzy based simulation model using *Simulink Blockset* of MATLAB for determining the health of motor under supervision. The complete set up of Fuzzy based Fault Detection and Diagnosis for Induction Motor has been built around the Fuzzy Inference System designed in Simulink for detection of motor health condition and it is shown in Fig. 5. The built-in blockset of Induction motor has been employed for the purpose of study. Simulink model is categorized into different categories like *Induction Motor Drive with Power Supply, FIS, RMS to DC conversion* and *Fault creation*. Three phase voltage supply is applied to induction motor. The induction Motor parameters are specified in the specific block like speed, torque as indicated in figure. *Induction Motor Drive* block includes the three phase induction motor in same block.

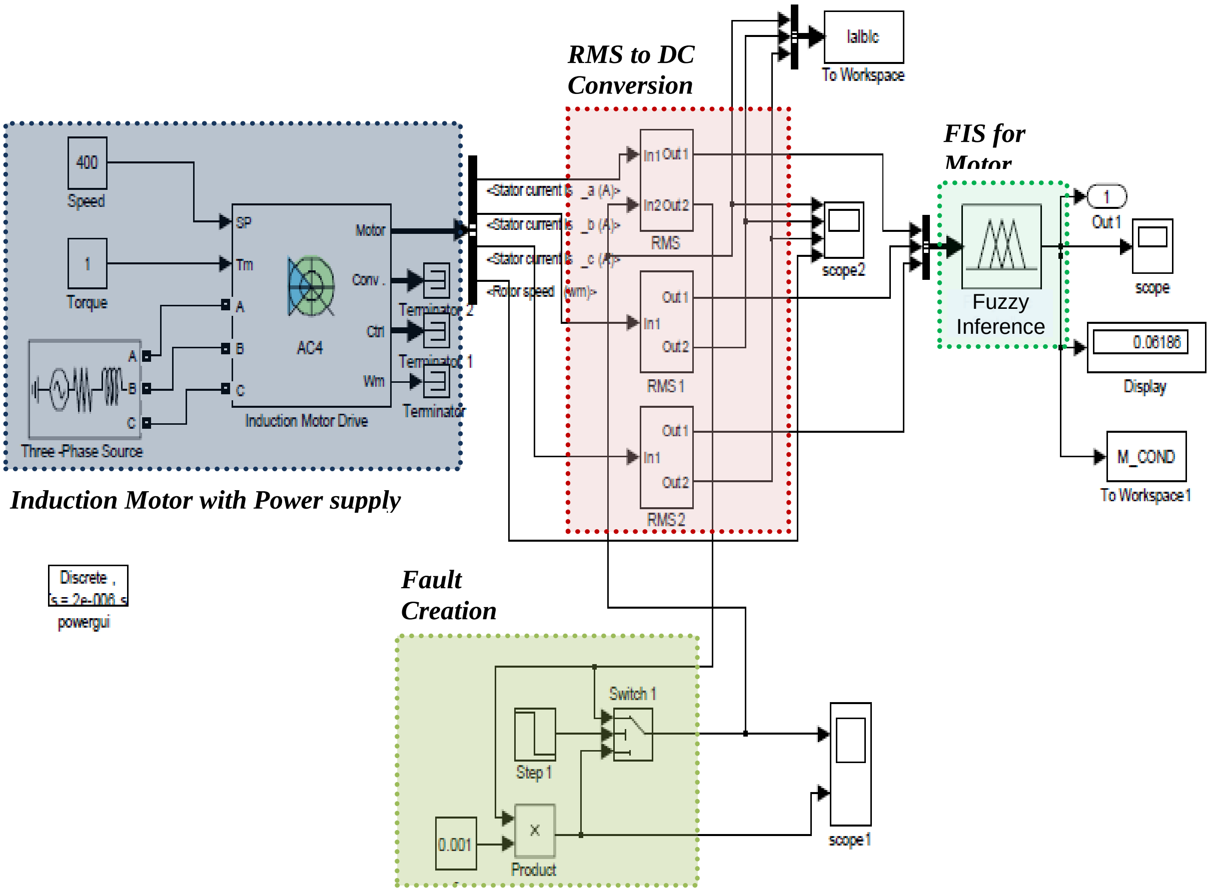

Fig. 5: Simulink Model for Motor Condition determination

The stator current of the induction motor is in AC form, it is necessary to convert it into DC. Therefore next block is RMS to DC conversion, which converts the RMS value into DC form. This block measures the root means square value of instantaneous current signal connected to the input of the block. The RMS value is calculated over a running window of one cycle of the specified fundamental frequency Fault creation block is for simulating of faults. Different faults like open phase, unbalance of input voltage are artificially generated in this block. Different blocks like Sum, Product, Step input and Constant are used in fault creation.

The block FIS for Motor implements a fuzzy inference system (FIS) in Simulink. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The in our case is Stator current from each phase and output is condition of motor in linguistic form using fuzzy logic.[7-9] The output is having range from 0 to 1 which is stored as variable M_COND in workspace and display on scope as well as its value on Display block. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves all of the pieces that are Membership Functions, Logical Operations, and If-Then Rules.

The motor condition may be good, damaged, overloaded, critically overloaded or open phase. The standard test input signals to the input of Stator current *Ia, Ib, Ic* are applied to fuzzy logic controller for observing the motor condition output.

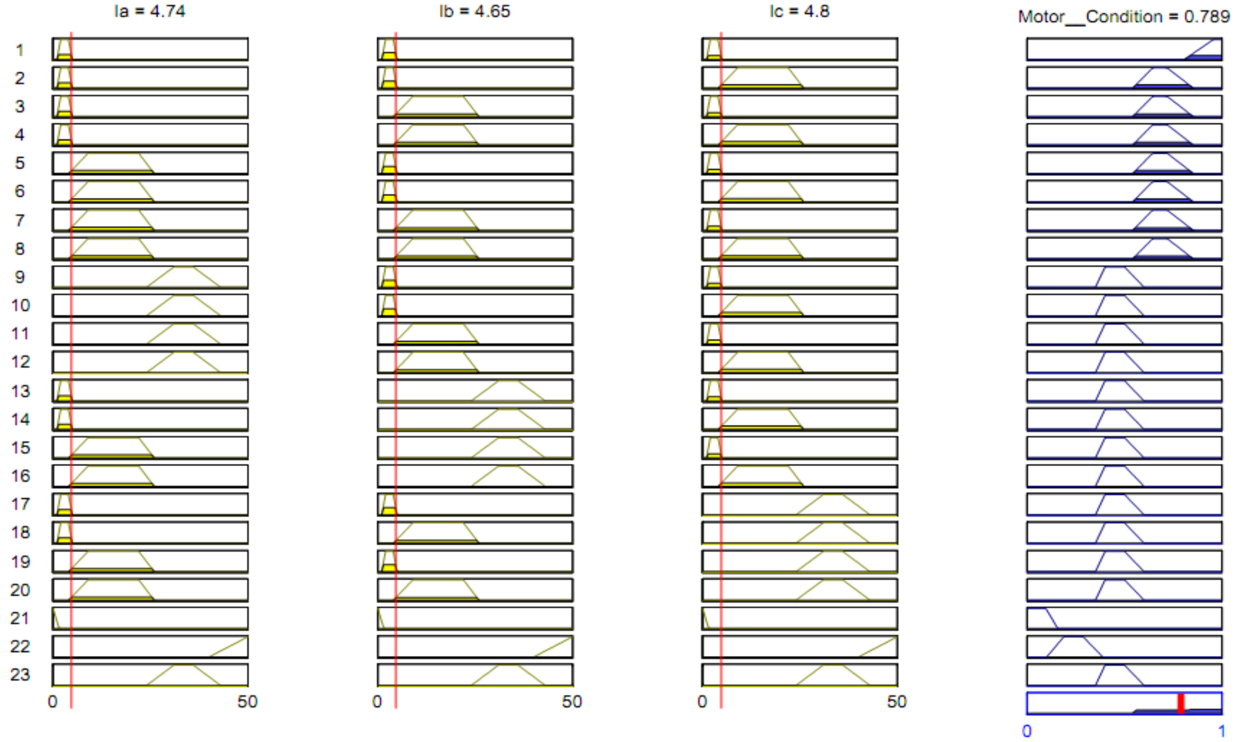

Fig. 6: Rule viewer for Good condition

MATLAB *Fuzzy Tool* facilitates the insight to Fuzzy Inference process vide the *Rule Viewer* option on FIS Edit Menu. This greatly helps the FIS development phase for proper designing of Fuzzy Sets, Fuzzy Rules and overall performance of FIS in terms of output targeted for all possible range of inputs. Fig. 6 depicts the whole process of Fuzzy Inference for the rule (1) to (8) under activation. The present stator currents are I_a = *4.74A*,I_b = *4.65A*, I_c = *4.80A*which are falling in fuzzy set "S". The fuzzy inferred Motor_condition value comes to be 0.789. This indicates the motor is in 'Good' Condition there by matching the anticipated on time by common sense.

VI. EXPERIMENTAL SET UP

The experimental setup for Motor parameter measurement is shown in Fig. 7. The experimental setup includes the embedded circuit board which is made from PIC18F2480 having inbuilt CAN controller, power supply section, signal conditioning for Current transformer (CT) and three phase motor of 440 V, 1 Amp. The CT used is of 30/30mA specification. CT is specially used for measuring the current of motor because it gives total isolation. Each phase R, Y and B are attached with individual CT for current measurement. The voltage transformers are used to monitor the present voltages of the respective phases. The line frequency of the supply is monitored using the zero crossing detector circuit. With this experimental setup we generated some faulty conditions those can occur in the real time environment. The faults such as single phasing, overload and low and high voltage were tested with the FIS.

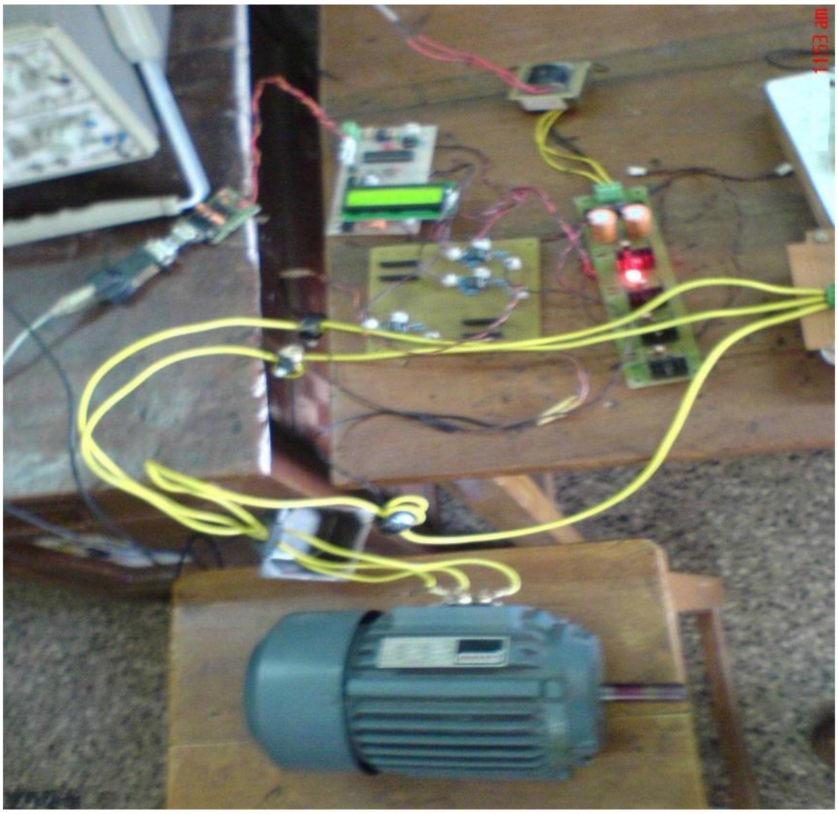

Fig. 7: Experimental System Test setup

VII. RESULT AND DISCUSSION

The result of motor condition determination is shown in the following section. The different mode of operations like *Normal operation mode, Unbalanced input voltage, Open phase output* has been tested.

1. Normal Operation Mode:

Fig. 8 shows the Motor Stator currents and the health of induction motor. While simulating the induction motor, the rated voltage was applied and initially no mechanical load was applied. From above waveform, it is observed that the motor draws high starting current. From these results it can be concluded that after the transient period is over, the health of the motor appeared to be '*Good*' as highlighted in Fig. 8.

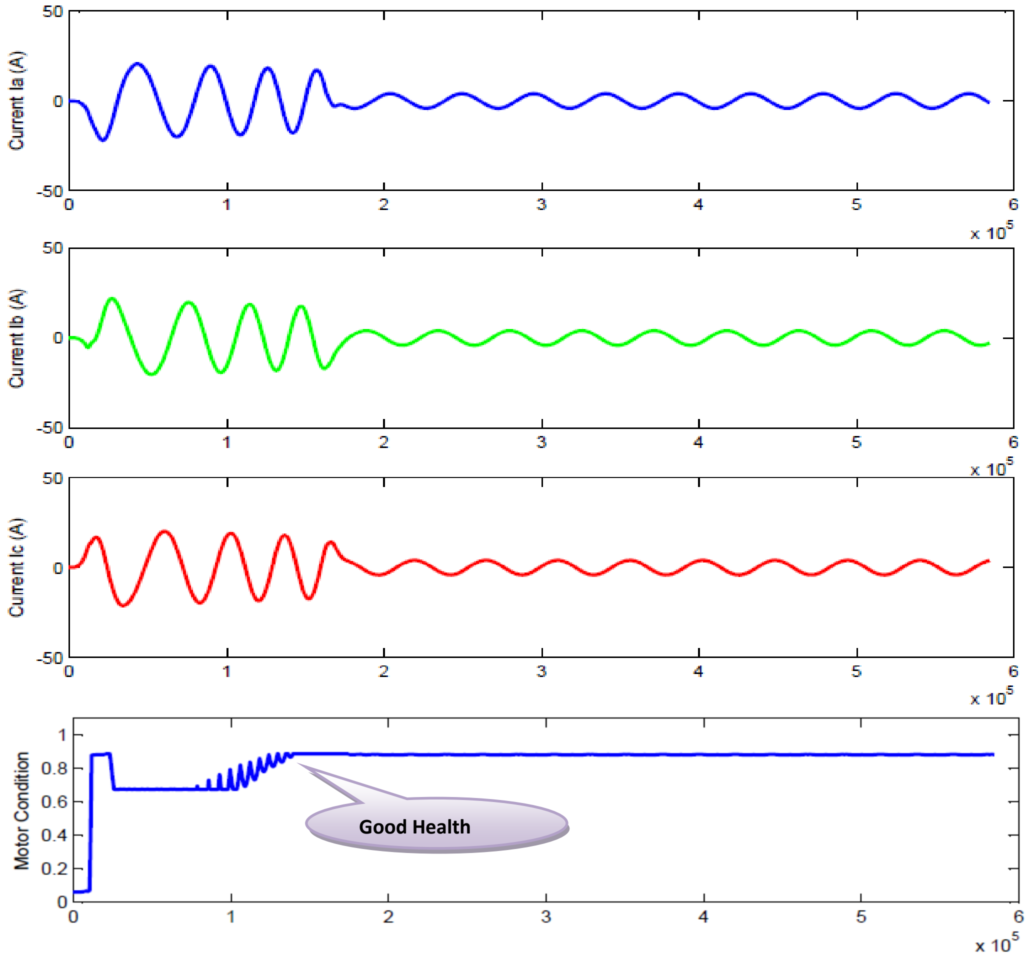

Fig. 8: Waveforms Normal Mode Operation of Motor

2. Unbalanced Input Voltage

The simulation of induction motor energized with any kind of unbalance in voltage can be created by simply varying the voltage magnitude in any one of the phase and no other parameter needs to be changed. The machine is made to start up with normal status parameters. After time lapse of about 1.5 second the current takes its steady state value. After that a fault has been created by changing the voltage of R-phase. In this case the rated voltage in R-phase was reduced to create unbalance in the inputs.

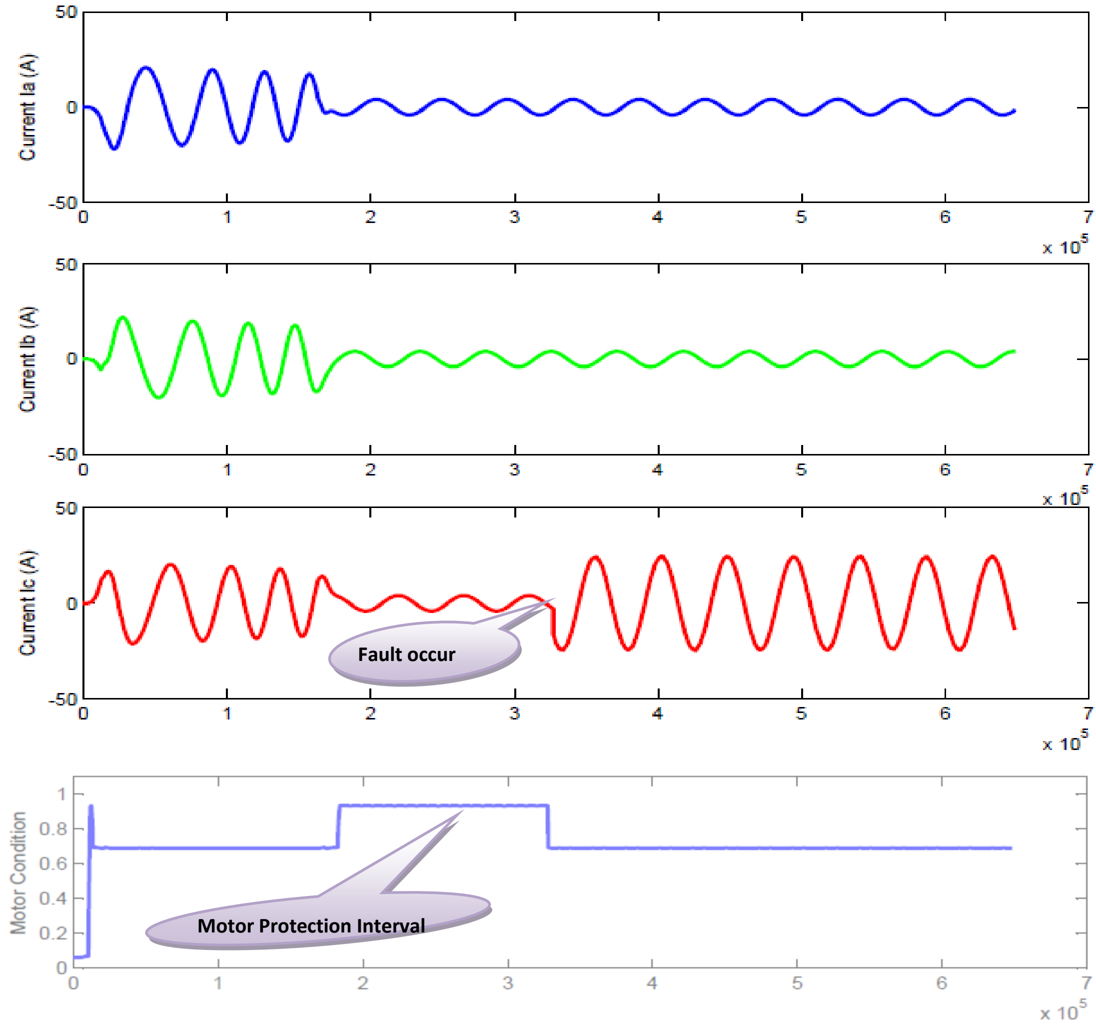

Fig. 9: Waveforms for Unbalanced input voltage

Fig. 9 shows the Stator current and health of induction motor for unbalanced input voltage. From these results it can be concluded that during normal operation (before fault) the health of the motor is implied as '*Good*'. As soon as the fault is created the stator current becomes unbalanced, and the health of the induction motor goes transitorily *Seriously Damaged*' state, and finally settles down to '*Damaged*' state. It is perceptible distinctly form waveforms corresponding to the motor condition.

3. Open Phase Output

In this case after normal startup with time lapse of about 1.5 second, R phase was open circuited and the corresponding results obtained are shown in Fig. 10 along with the condition monitoring of motor. The motor used in the experimental testing was a three phase motor. Thus if any one phase amongst three fails, the motor may go to state of 'Damage' within diminutive to time. It turns out to be important criteria to predict the motor going toward a state of 'Damage'. This is of immense practical use as motor can be protected from the total damage and hence the complete breakdown of machine. From these results it can be concluded that after the transient period of 1.5 second the health of the motor goes to state of 'Open Phase'.

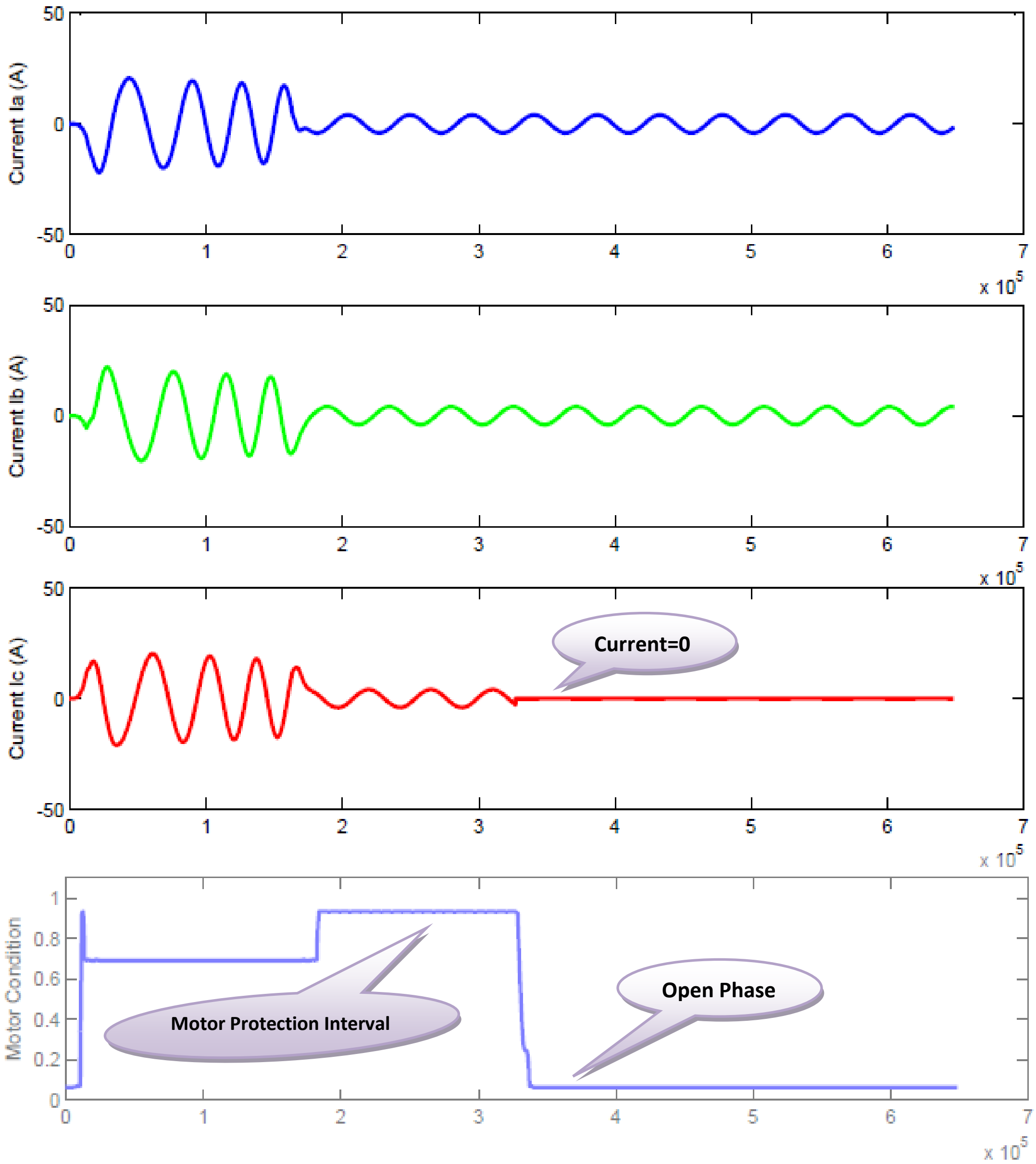

Fig. 10: Waveforms for Open Phase Motor Condition

4. Experimental Results of Motor Condition

The experimental results of motor condition monitoring are shown in Fig. 11 to Fig. 13. In all waveforms the initial startup current of motor is comparatively high as depicted in the waveforms. The Fig. 11 shows the waveforms of current of motor under no load condition. At the beginning the current increases and then motor begins to draw almost steady current.

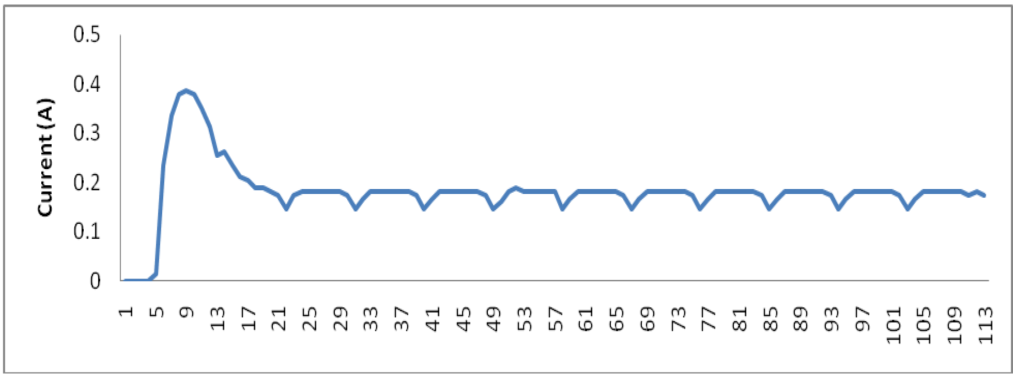

Fig. 11: Waveforms of Current of Motor with no load

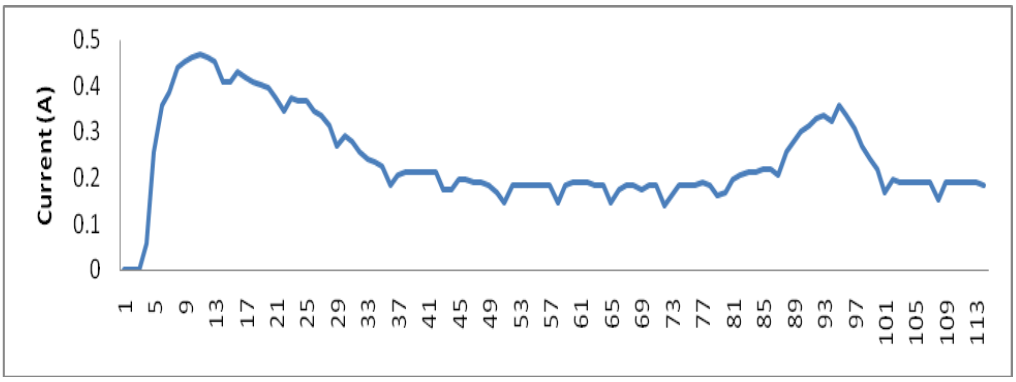

Fig. 12: Waveforms of Current of Motor with load

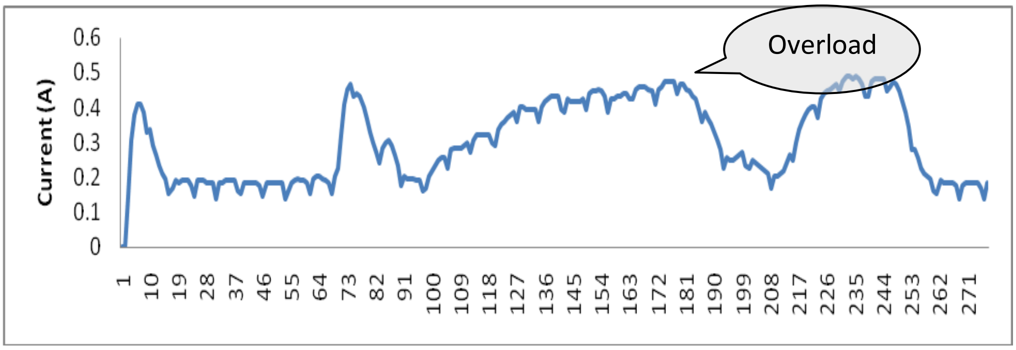

Fig. 13: Waveforms of Current of Motor with Overload

Fig. 12 indicates the waveform of motor current under normal load. Moment the load is applied to motor, the current increases depending upon the load. From the value of rated motor current and the actual motor current it is possible to determine the condition of motor as '*Good*', '*Medium*' or '*Bad*'. Fig. 13 shows the current waveform of the '*Overloaded*' motor as the motor current builds up high enough and '*Good*' health condition of motor health turns out to be '*Medium*'. Further increase in the load drops the health level to '*Bad*' as motor goes to '*Critically Overloaded*' state consuming excessive current to drive the load. This causes the heating of motor and it ends up with severe damage to the motor.

REFERENCES

[1]. YE Zhongming and WU Bin, Ryerson, *A Review on Induction Motor Online Fault Diagnosis*, Proceedings of third international conference on Power Electronics and Motion Control, 2000.

[2]. M.E.H. Benbouzid, H. Nejjari, University of Picardie, France, *A Simple Fuzzy Logic Approach for Induction Motors Stator Condition Monitoring*, IEEE International Electric Machines and Drives Conference, pp. 634 – 639, 2001.

[3]. A. Siddique, G. S. Yadava, and B. Singh, *A review of stator fault monitoring techniques of induction motors,* IEEE Trans. Energy Convers., vol. 20, no. 1, pp. 106–114, Mar. 2005.
[4]. Y. Zhongming and W. Bin, *A review on induction motor online fault diagnosis*, in 3rd Int. Power Electron. Motion Control Conf. (PIEMC 2000),vol. 3, pp. 1353–1358.
[5]. M. E. H. Benbouzid, *Bibliography on induction motors faults detection and diagnosis*, IEEE Trans. Energy Convers.,vol. 14, no. 4, pp. 1065–1074, Dec. 1999.
[6]. E. Cox, *The Fuzzy Systems Handbook - A Practitioner's Guide to Building, using, and Maintaining Fuzzy Systems,* New York: Academic Press, 1994.
[7]. L Zeng and Z. Wang, *Machine fault classification: a fuzzy approach,* The International Journal of Advanced Manufacturing Technology, 83-94. 1991.
[8]. M.Y. Chow et al., *Intelligent Motor Fault Detection, in Intelligent Techniques in Industry*. L.C. Jain, Ed.: CRC Press, 1998.
[9]. D. Dzonlagic, *Basics of the design of fuzzy control systems*, Faculty of Electrical Engineering and Computer Science, Maribor, 1995.
[10]. Dunn S., *Condition Monitoring in 21st Century*, The plant maintenance resource center. pp. 8, 2002.