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Research Paper

ADAPTIVE NEURO FUZZY CONTROLLED MACHINE HEALTH DIAGNOSIS USING LABVIEW

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Induction motors are used worldwide as the "workhorse" in industrial applications. Although, these electromechanical devices are highly reliable, susceptible to many types of faults. Condition monitoring and fault diagnosis of induction motors are of great importance in production lines. It can significantly reduce the cost of maintenance and the risk of unexpected failures by allowing the early detection of potentially catastrophic faults. In this paper I have used both neural network and fuzzy logic to detect the fault and failure priorly by ANFIS Technique. The various fault discussed in this paper are- electrical fault and mechanical fault.Condition monitoring, signal processing and data analysis are the key parts of the Induction Motor fault detection scheme.

Keywords: Single phase induction motor, Condition monitoring, Fault diagonosis, ANFIS technique

INTRODUCTION

The fault detection and protection are as historic as Induction Motor themselves. Single phase Induction motors are critical components in many industrial processes. They are very robust and highly reliable machines however they may be subjected to different types of faults. Failure of such Induction motor may cause plant shutdown, personal injuries and waste of raw material. However, induction motor faults can be detected in an initial stage in order to prevent the complete failure of an induction motor and unexpected production costs.

The main reason for the motor faults is mechanical and electrical stresses. Mechanical stresses are caused by overloads and abrupt load changes, which may cause bearing faults and rotor bar breakage. The electrical stresses may produce stator winding short circuits and result in a complete motor failure.

The different fault may occur in Induction motor can be classified as follows.

Bearing faults are the most frequent fault in Electric Motors (41%) according to an IEEE motor reliably study, followed by stator (37%) and rotor fault (10%).

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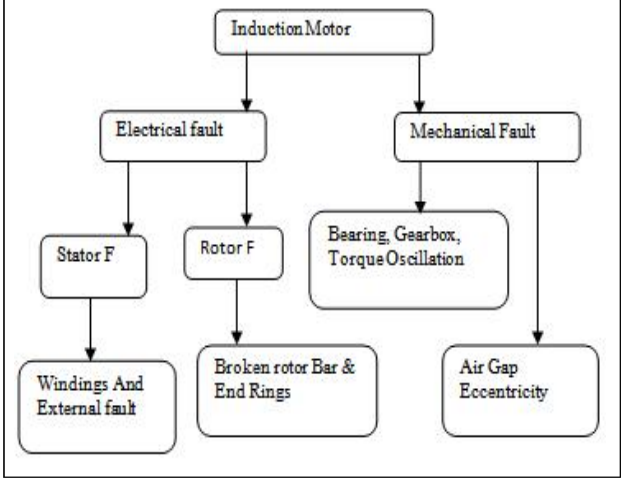
Figure 1: Types of Fault



Condition monitoring of Induction motor are of great importance in the production lines. Condition monitoring means continuous evaluation of the health of the motor throughout its service life. There are many condition monitoring methods, including vibration monitoring, thermal monitoring, chemical monitoring, current monitoring techniques are usually applied to detect the various types of induction motor fault. I mainly use the ANFIS Technique to detect the fault. For current, voltage, temperature and vibration monitoring, we use sensors are necessary. This is because the basic electrical quantities associated with electromechanical plants such as current and voltage are readily measured. But for non stationary signal vibration monitoring is best. In vibration monitoring a vibration spectrum is used to detect the fault in induction motor. Vibration and current are widely used in the industry since both allow detecting several fault conditions from distinct nature. Now days fault diagnosis uses modern techniques that is ANFIS technique.

In this paper I used the three key components of ANFIS are data acquisition, data processing and decisionmaking. In this study I used aDAQ card to acquire a sensor signal and a LABVIEW programmed to detect the fault frequency.

Mechanical and Electrical faults print frequency features in the spectrum of current and vibration which can be used for fault detection by comparing the amplitude of certain frequency components under fault and normal conditions. A method of using fuzzy logic to interpret current sensors signal of induction motor for its stator condition monitoring was presented. Correctly processing theses current signals and inputting them to a fuzzy decision system achieved high diagnosis accuracy. There is most likely still room for improvement by using an intelligent means of optimization. Fault Detection Scheme using Neuro-Fuzzy Approach ANFIS had gained popularity over other techniques due to its knowledge extraction feasibility, domain partitioning, rule structuring and modifications.

The artificial neural network (ANN) has the capability of solving the motor monitoring and fault detection problem using an inexpensive, reliable procedure. However, it does not provide heuristic reasoning about the fault detection process. On the other hand, fuzzy logic can easily provide heuristic reasoning, while being difficult to provide exact solutions. By merging the positive features of ANN and fuzzy logic, a simple noninvasive fault detection technique is developed. By using a hybrid, supervised learning algorithm, ANFIS can construct an input-output mapping. The supervised learning (gradient descent) algorithm is used here to train the weights to minimize the errors. Therefore, this paper is organized as follows: first, a qualitative description of the unbalance voltage condition, single phasing, bearing damage, are presented. Secondly, experimental are:

METHODOLOGY

Bearing Fault in Induction Motor

Bearing are common elements of Induction Machines. They are employed to permit the rotary motion of the shaft. The bearing mainly consists of two rings called the inner and outer rings. A set of balls or rolling elements placed in raceways rotate inside these rings. A continued stress on the bearings cause fatigue failures, usually at the inner and outer races of the bearings. Small pieces break loose from the bearing, called flaking or spalling. These failures result in rough running of the bearings that generates detectable vibrations and increased noise levels. And this process is helped by other external sources including contamination. Corrosion, brinelling, improper lubrication, improper installation. In some case shaft voltage and current are also sources for bearing failure. High bearing temperature is also another reason for bearing failure.

The different faults that may occur in bearing as follows

- Outer raceway defect
- Inner raceway defect
- Ball defect

Figure 2: Ball Bearing Dimensions

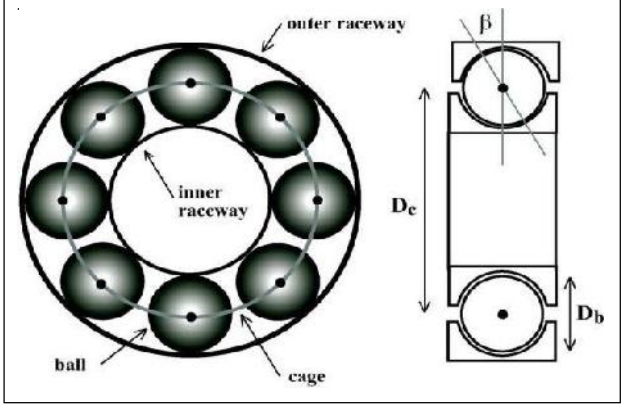


Figure 3: Inner Race Fault

Figure 4: Outer Race Fault

Unbalance in Supply Voltage

A very important aspect of condition monitoring of induction motor is to detect the external faults. Unbalance in supply voltage and single phasing are the two types of external faults of induction motor are considered in my work. Unbalance in supply voltage is created by connecting three single phase transformers in three phases of the supply. Here supply voltage in B phase is reduced to 10% less than the rated voltages in the other two phases to create unbalance. Unbalance voltage is nothing but unequal distribution of incoming voltages or when the phase separation is not 120º. When there are unequal incoming voltages between the three legs of a motor, the

motor runs hotter. The reason why an unbalance motor runs hotter is because as the voltage is out of balance so is the winding current. A small voltage unbalance causes a larger current unbalance, which in turns causes the motor.

Types of voltage unbalance

- Single phase under voltage
- Two phase under voltage
- Three phase under voltage

Single phase under voltage unbalance condition arises when there is a large single phase load in the system and it doesnt have enough compensation. In this situation the voltage in that particular phase will be lower than the other two phases.

Single Phasing Fault

For proper working of any three phase induction motor, it must be connected three phase alternating current (Ac) power supply of rated voltage and load. Once these three phase motors are started they will continue to run even if one of the three phase supply lines gets disconnected. The loss of current is described as single phasing. Single phasing is the condition in three phase motors and transformers wherein the supply to one of the phases is cut off. Single Phasing causes negative phase sequence components in the voltage. Single Phasing is cause by the use of single phase protection devices such as fuses and circuits breakers. Three phase loads should be protected by devices which cause the interruption of power to all three phases simultaneously hence a fault occurs. Defective contacts in three phase breakers can also cause single phasing. It can be sometimes cause excessive noise and vibration in motors.

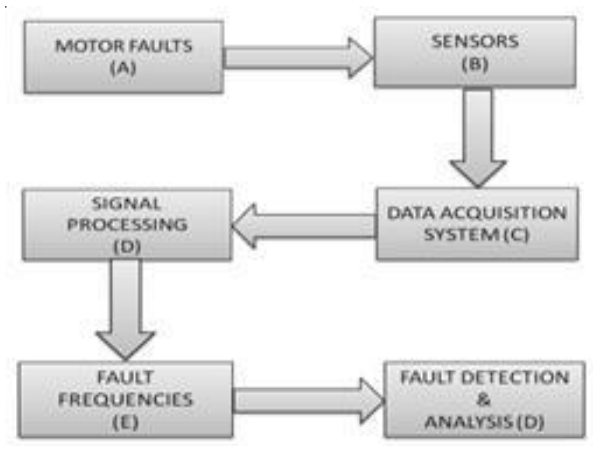
Condition Monitoring System

Condition monitoring means to access the actual condition of motor using the measurements taken while the motor is operating.

I mainly use two types of condition monitoring technique to detect different fault. Current and vibration monitoring. A block diagram for condition monitoring for fault diagnosis is shown in Figure 5.

This is the method for fault diagnosis. In this stage, First of all we create different fault (such as bearing fault, unbalance voltage) due to which symmetry of motor would effect and creates fault characteristics frequency. After that we get that fault frequency by different type of sensors (such as for vibration signal we can use piezoelectric accelerometer, for speed measurement tachometer, etc.) shown in block B. In the next stage we use a DAQ system means Data acquisition system to record that sensor signal in the digital form. In block C we used different type of signal processing techniques (such as FFT, STFT, Wavelet) to analysed that sensor signal and to extract the feature which are sensitive to presence of fault. In next step we get the fault frequency of different fault by analysing

Figure 5: The Process for Fault Diagonisis



the sensor signal. And finally we get detailed information and degree of severity.

Current Monitoring

Current Parks Vector, Zero sequence and negative sequence current monitoring and current signature analysis fall under category of Electrical monitoring. These methods use stator current to detect various kinds of machine and inverter faults. In most applications, the stator current of an induction motor is readily available since it is used to protect the machines from destructive over currents, ground currents, etc. Therefore current monitoring is sensor less detection method that can be implemented without any extra hardware (Mehala Neelam, 2010).

Motor Current Signature Analysis

This method is used current spectrum to detect the various faults. It is the online analysis of current to detect faults in three phase induction motor. This method analyses the motor signal by using signal processing algorithms such as FFT, STFT, and Wavelet, etc. MCSA techniques include parametric, nonparametric, and high-resolution spectrum analysis methods. In the parametric methods, autoregressive (AR) models have been fitted with time series of the signal, and model parameters have been used to compute the frequency spectrum. Furthermore, nonparametric methods are based on Fourier transforms in order to search for periodicities method corresponds to an Eigen value analysis of the autocorrelation matrix of the time series signal (Benbouzid, 2010; Norman Mariun and Mohammad Rezazadeh Mehrjou, 2011; and Benbouzidi *et al.*, 2011). One of the classical and widely used nonparametric spectrums method as a MCSA technique is the well-known Fast Fourier Transform (FFT). The FFT is a simple and computationally efficient algorithm to compute the Discrete Fourier Transform (DFT) of a discrete-time series function.

Vibration Monitoring

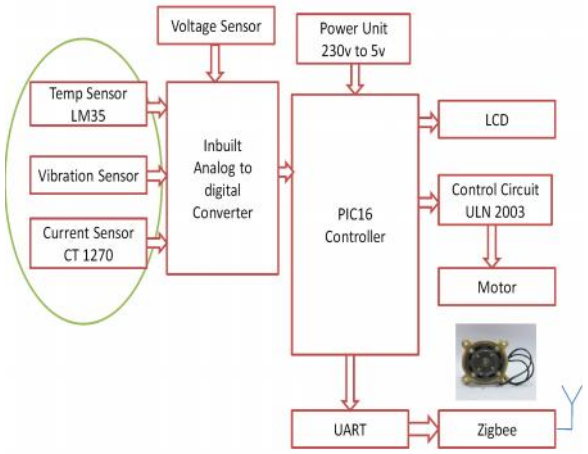
All electric motors generate noise and vibration, and analysis of produced noise and vibration can be used to give information on the condition of motor. Even very small amplitude of vibration of machine frame can produce high noise. Noise and vibrations in electric machines are caused by forces which are of magnetic, mechanical and aerodynamic origin. For stationary signal MCSA best but for non-stationary signal its not convenient option for non-stationary signal vibration monitoring is generally used.

Four vibration properties are crucial to understanding and resolving the machine problems. These include Amplitude, which indicate the level of severity of the measured condition. Frequency, which indicates the repetition rate of the contributing source or sources of the measured condition; Phase, which presents the timing relationship between two signals contributing to the measured condition; Modulation, the process by which the response amplitude at some frequency is varied by a lower frequency excitation response. With the help of this we can get detail information about asymmetry in motor.

EXISTING WORK

Unexpected machine breakdowns can cause significant economical losses due to the material damage and lost production time. this high power consumes process, has the in capabilities of electrical equipment structural health monitoring one third of all maintenance cost is wasted as the result of unnecessary or improper maintenance activities. Malfunction is difficult to

Figure 6: Block Diagram



locate and repair in a reasonable time, which causes an productiondrop.

PROPOSED WORK

In our proposed work we use two important aspects in a neuro-fuzzy system.

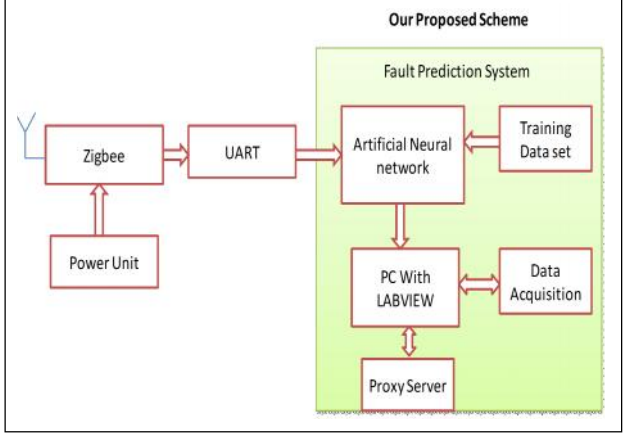
Diagonosis is the ability to detect fault prediction, isolate and identify which component is going to failure and decide on the potential impact of failed component on the health of the system.

Prognosis is the capability to use available observations to predict upcoming states of machine or forecast the fault before it occurs.

The last step is one of the most step is decision making.

There are different techniques for fault identification and protection of Induction motor. Some of fault detection using Artificial Neutral Network, Stator fault checking strategies, Microcontrollers based protection system . In this task, the technique utilized is Microcontroller based protection system. The circuit will take the full control of the motor and it will protect the motor from several faults, for example, over voltage and

Figure 7: Block Diagram



under voltage and the circuit will switch on the motor under safety conditions. This additionally protects induction motor from single phasing which is also a major fault. The circuit is completely controlled by the microcontroller and the microcontroller will consistently monitors the voltages of the three phases and if the voltage goes abnormal then it will switch off the motor until they are typical. With the help of current transformer which senses the current and if it exceeds some particular level then comparator sends this signal to microcontroller to stop the motor. All the conditions are shown by it over the LCD display. In this paper we are utilizing PIC Microcontroller PIC16F877A. It is a 40 pin microcontroller and high performance RISC CPU. It is of In-Circuit Serial Programming (ICSP). The protection of induction motor with microcontroller has adaptability to switch off at required time, monitors phase of motor at each time furthermore every motoring activity is known through LCD display. It also protects the motor from single phasing as its maintenance cost and power consumption is low.

Fault Detection Identification

The new in this paper is the online detection of the motor fault conditions using neuralnetwork

and ANFIS techniques. The induction motormonitoring diagnosis techniquessuch that magnetic flux, vibration, stator currents, induced voltage, power and surgetesting are used for detection of the motor faults . The stator current signal are containspotential fault information and is the most suitable measurements for diagnosing the faults under consideration, in term of easy accessibility, reliability, and sensitivity. A simple construction using stator current for motor fault detection is indicated in Figure 8, the linguistic variables of the induction motor stator conditions are shown in Figure 9.

Figure 8: Artificial Intelligent Techniques

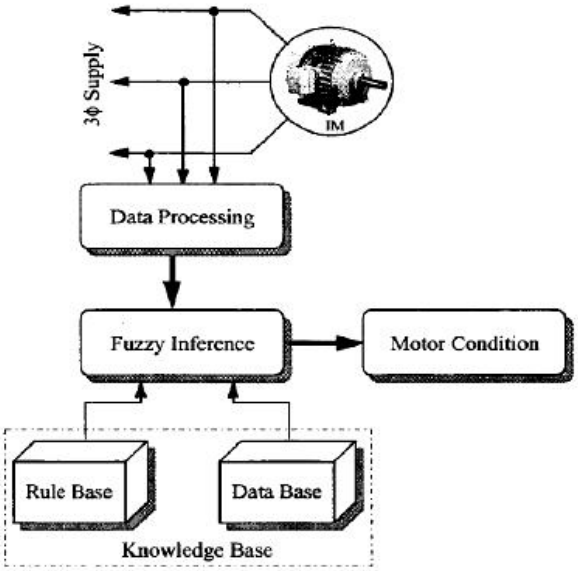
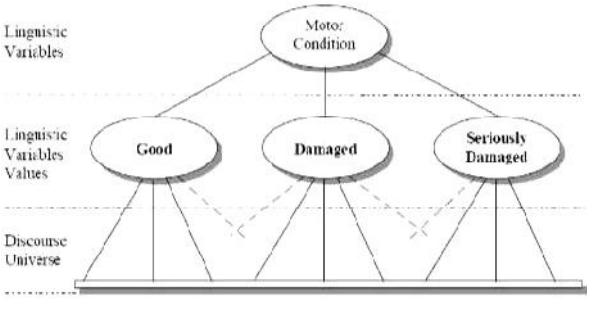


Figure 9: Linguistic Variables of the Induction Motor Stator Condition



Neuro Fuzzy Controller

A list of industrial applications and home appliances based on this neuro fuzzy controller. An Adaptive Neuro-Fuzzy Inference System (ANFIS) is a cross between an Artificial Neural Network (ANN) and a Fuzzy Inference System (FIS). An artificial neural network is designed to simulate the characteristics of the human brain and consists of a collection of artificial neurons. An adaptive network is a multi-layer feed-forward network in which each node (neuron) performs a particular function on incoming signals. The form of the node functions may vary from node to node. In an adaptive network, there are two types of nodes, adaptive and fixed. The function and the grouping of the neurons are dependent on the overall function of the network. Based on the ability of an ANFIS to learn from training data, it is possible to create an ANFIS structure from an extremely limited mathematical representation of the system.

In sequel, the ANFIS architecture can identify the near-optimal membership functions of FLC for achieving desired input-output mappings. The network applies a combination of the least squares method and the back propagation gradient descent method for training FIS membership function parameters to emulate a given training data set. The system converges when the training and checking errors are within an acceptable bound. The ANFIS system generated by the fuzzy toolbox available in LABVIEW allows for the generation of a standard Sugeno style fuzzy inference system or a fuzzy inference system based on sub-clustering of the data.

The Sugeno FIS is similar to Mamadani format except the output memberships are singleton spikes rather than a distributed fuzzy set. Using

singleton output simplifies the defuzzification step.

The ANFIS network shown in Figure 11 is composed of five layers. Each node in the first layer is a square (adaptive) node with a node function. The basic diagram computation in ANFIS is sown in Figure 10. This structure contains the same components as the FIS, expect for the NNblock. The structure of the network is composed of a set of units (and connections) arranged into five connected network layers.

Figure 10: Basic Diagram of ANFIS Computation

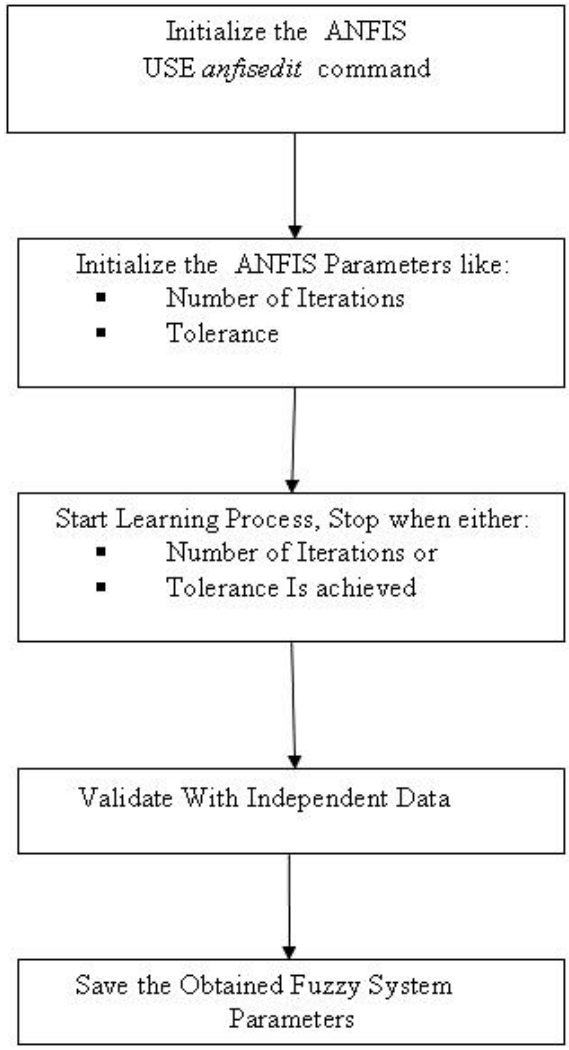
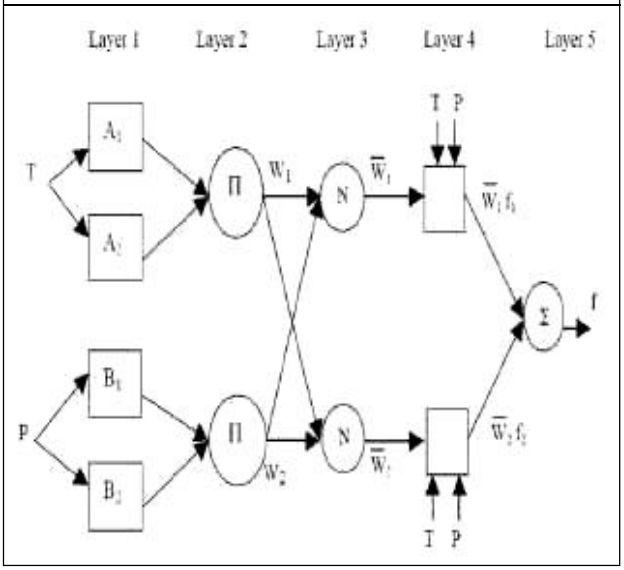


Figure 11: ANFIS Architecture for a Two Input System



Layer 1: This layer consists of input variables (membership functions), via., input 1 and input 2. Here, triangular or bell shaped MF can be used. This layer just supplies the input values x to the next layer, where i = 1 to n.

Layer 2: This layer (membership layer) checks for the weights of each MFs. It receives the input values x from the 1st layer and act as MFs to represent the fuzzy sets of the respective input variables. Further, it computes the membership values which specify the degree to which the input value x belongs to the fuzzy set, which acts as the inputs to the next layer.

Layer 3: This layer is called as the rule layer. Each node (each neuron) in this layer performs the pre-condition matching of the fuzzy rules, i.e., they compute the activation level of each rule, the number of layers being equal to the number of fuzzy rules. Each node of these layers calculates the weights which are normalized.

Layer 4: This layer is called as the defuzzification layer and provides the output values y resulting from the inference of rules. Connections between

the layers l3 and l4 are weighted by the fuzzy singletons that represent another set of parameters for the neuro fuzzy network.

Layer 5: This layer is called as the output layer which sums up all the inputs coming from the layer 4 and transforms the fuzzy classification results into a crisp (binary). The ANFIS structure is tuned automatically by least-square estimation as well as the back propagation algorithm. The algorithm shown above is used in the next section to develop the ANFIS technique to control the various parameters of the induction motor. Because of its flexibility, the ANFIS strategy can be used for a wide range of control applications.

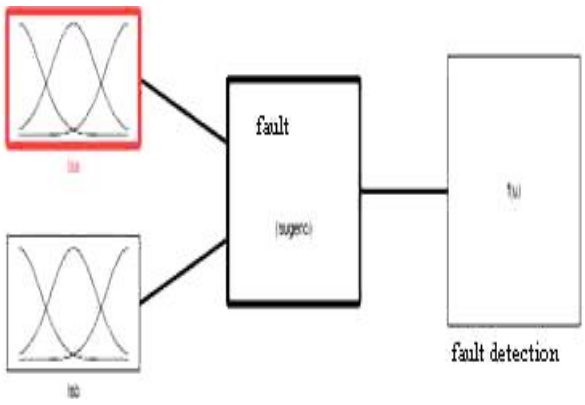
ANFIS Design for Motor Fault Detection Conditions

The main purpose of using ANFIS controller in this paper is for identification of the fault occurrence in the saturated model of induction motor. The ANFIS controller structure is shown in Figure 8. The fuzzy logic membership functions for the input and output are turned using neural network method which is well known in MATLAB program as ANFIS structure. The parameters are selected such that, optimization method is hybrid, the membership function output is linear, error

Table 1: Motor Parameters

Parameters	® - Model	Unit
R_s	8	
R_r	6	
$L\sigma s$	NA	H
$L\sigma r$	NA	H
Lm	NA	H
Ll	0.062	H
J	0.06	Kgm^2
B	0.04	No / Rad

Figure 12: Fault Detection Controller Using ANFIS

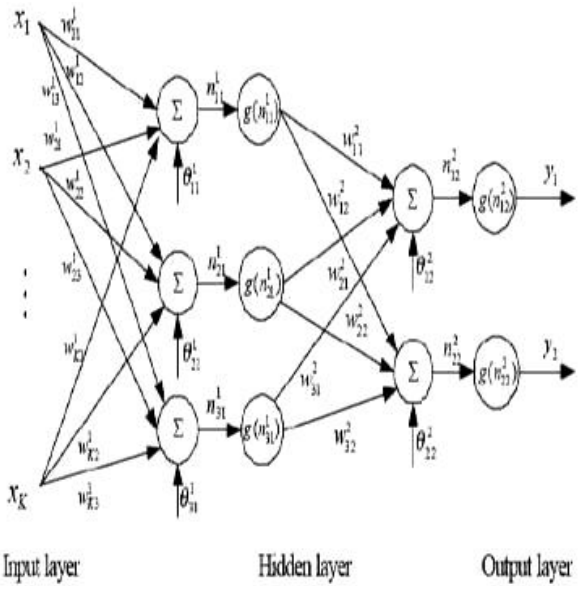


tolerance was chosen to be 0. 01, the no of epochs are 1000, grid partitions, the inputs of the grid partitions are the number MFS are 3, MF type is gbellmf, the outputs is MF type defined to be constant. The motor parameters that used in simulation are shown in Table 1.

Neural Network

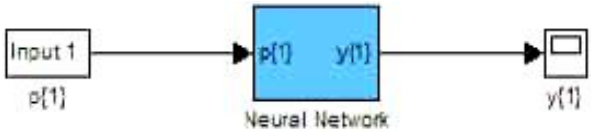
A Neural Network (NN) is a machine like human brain with properties of learning capability and generalization. It requires a lot of training to

Figure 13: Structure of Neural Network



understand the model of plant. The basic property of this network is capability to learn the characteristic of nonlinear dynamic system mappings. The neural network consists as shown in Figure 13 of three layers, an input layer, one or more hidden layers and an output layer. Neurons of hidden and output layers have an activation functions. The knowledge of NN can be achieved through a learning algorithm process. In this paper, the inputs to the ANN block is the stator currents Isa and Isb while the output is the fault detection signals.

Figure 14: ANN Block



SIMULATIONS

Using LABVIEW SOFTWARE program we have the stimulation outputs.

Using the saturated model of the three phase induction motor with the parameters in Table 1, the applied supply voltage are:

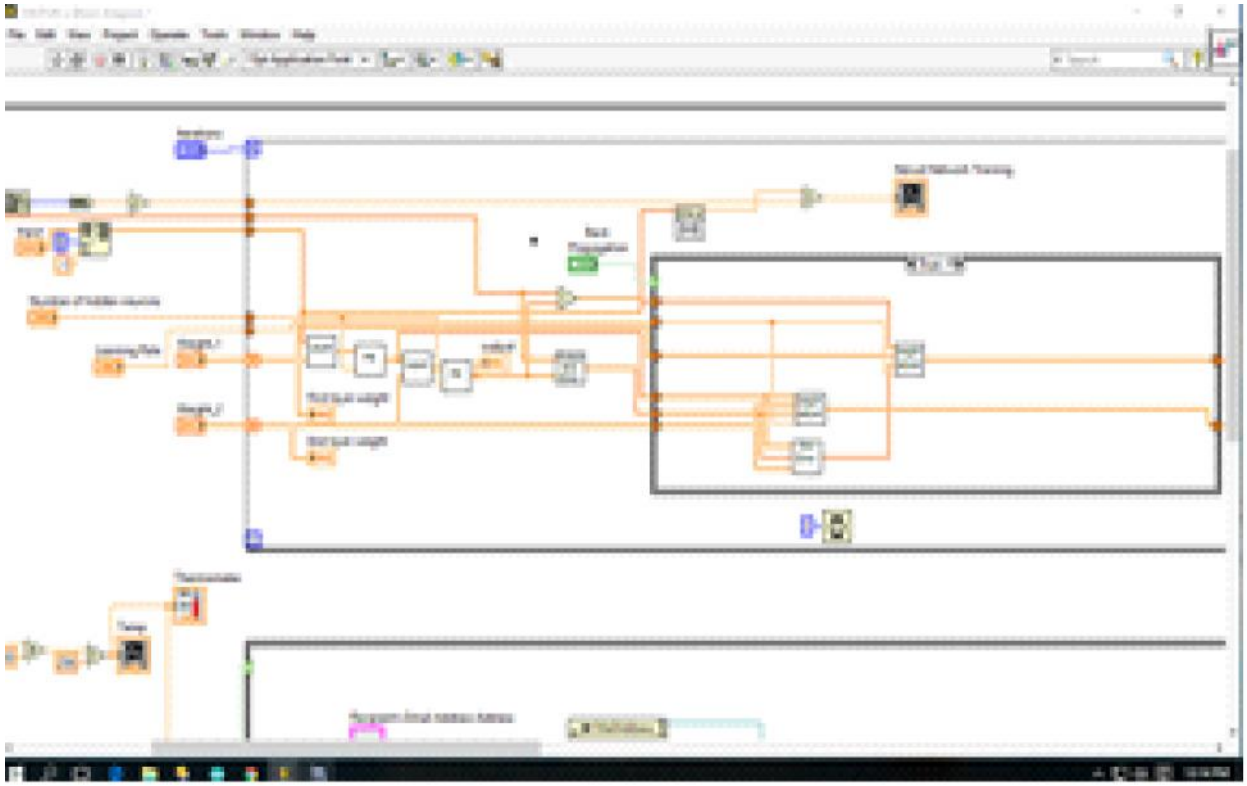
Ua = 380 sin(2Π 50tΨ, Ub = 380 sin(2π 50t – 2Π/3Ψ, Uc = 380 sin(2Π 50t + 2Π/3Ψ the simulation duration is 20 second.

Start the simulation on the three phase induction motor by performing the different fault conditions stated before and plotting the effect of the faults on the measured signals of the stator currents. The result of the simulation is indicated.

From the simulation results, the speed and load torque are the same using three and five and six phase saturated motor model for the same supply voltage and load torque and same motor parameters. But the stator currents and stator and rotor fluxes are decreases in the six phases more than five and three phases respectively. That indicate by using the multiphase induction machine give the same output of the three phase

Figure 15: Simulation 1 - Neural Network Training

Figure 16: Simulation 2 - Block Diagram of ANFIS Computation



motor (speed and load torque) but we decrease the currents and fluxes in the motor winding which is more better for the motor life time and operating conditions.

Based on the ability of an ANFIS to learn from training data, it is possible to create an ANFIS structure from an extremely limited mathematical representation of the system. In sequel, the ANFIS architecture can identify the near-optimal membership functions of FLC for achieving desired input-output mappings. The network applies a combination of the least squares method and the back propagation gradient descent method for training FIS membership function parameters to emulate a given training data set. The system converges when the training and checking errors are within an acceptable bound.

CONCLUSION

The new in this paper is by using Neural Network (NN) as well as ANFIS techniques for detection of the induction motor at different fault conditions taking the saturation effect in consideration. The simulations present that these methods are effective for the three and multi phase induction machines. This paper is different from the previous work that we are using NN and ANFIS controllers for detection of the supply voltage faults as well as any short circuit appears in the motor windings. The percentage of the error is accepted in both cases, while ANFIS technique gives better accuracy than NN technique. From the simulations, we find that both methods can be used for early detection of any failure start in the motor winding for predictive maintenance. Predictive maintenance is very important factor

in the industrial operation to reduce the running cost.

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