ANN Approach for Fault Classification in Induction Motors Using Current and Voltage Signal

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Abstract – *In many industries, three-phase Induction motors especially squirrel cage Induction motor plays an very important role as an prime mover. So failure of such motor may leads to increase the production losses and also may leads to shut down the entire industries. Hence to prevent such failure, continuous maintenance schedule is required. Condition monitoring and Fault classification has great importance in the industrial line. In this paper, Fault classification using Artificial Neural Network is proposed. Motor phase currents and voltage recorded under various fault conditions were analyzed by using negative sequence current and Swing angle. The multilayer perceptron feed-forward ANN were used for the classification purpose.*

Key Words: **Broken-bar, inter-turn short circuit, Negative sequence current, swing angle, ANN, Induction Motor**.

1. INTRODUCTION

During 1888, when Nicola tesla was invented of an Induction motor which is simple and rugged for converting electrical energy to mechanical energy. But the use of such types of motor was quite limited due the speed torque control. But when the power controlled switch was come to in phase which has the capabilities to implement the field oriented control system for torque-speed control, the Induction motor was the most popular in every power sector areas, Such as industrial, tractional and also agricultural areas. Now days, accordingly, the induction motor specially squirrel cage Induction motor are the main prime mover at many industrial process. So failure of such motors may leads to increase the production loss due to the shut-down of the plant. Hence maintenance schedules are provided to reduce such types of failure and to prevent from unwanted interruption on motor.

Accordingly, the online fault detection systems become very popular tool to increase the efficiency and reliability of the industrial sectors. Thus online fault classification and diagnosis becoming very importance in electrical machine protection since the greatly improve reliability, availability and maintainability in a wide range of application.

Artificial Neural Network is the most robust technique for the classification purpose. In this, the negative sequence current and swing angle used to classify the healthy condition, rotor broken-bar fault condition and Stator Inter-turn short circuit condition. Symmetrical undaunted motors powered by symmetrical multiphase voltage sources have no negative sequence currents flowing in the motor. The internal failure of motor will break that symmetry and it give rise to a negative sequence current which may be increase as the severity of fault get increase [3]. And also due to these internal failure the air gap magnetic field get disturb. So that these field get oscillate around its original axis due to this the angular phase shift between the current and voltage which is known as swing angle is get change[4]. For the different types of fault condition the values of negative sequence current and swing angles are different which can be used to classify the situation of the motor.

In this paper, Negative sequence current and swing angle is used to classify the healthy, rotor broken-bar, and stator inter-turn short-circuit condition of motor with the help of FFANN. ANN data applied in this work proposed to evaluate the performance of networks and also present the results obtained from experimental data.

2. ARTIFICIAL NEURAL NETWORK

ANN is a system based on the biological neural network such as a brain. The brain has approximately 10^9 neuron, which are communicated through junction called synapses. Each neuron receives thousands of connection approximately 10^{12} with other neuron constantly receiving the incoming signal to reach the cell body. If the resultant sum of the signal surpasses a certain threshold, a response is sent signal through axon.

In a similar way Artificial Neural Network is an efficient computing system whose central theme is borrowed from the analogy of biological neural networks. ANN has large collection of units which are interconnected pattern so that it allows communication between them. These units are known as neurons. Every neuron is interconnected with the other neuron by connection link. Every connection link has weight. Weight has some important information about the input signal for particular solution of the network. To perform specific task, network is adjusted the weight by comparing the output and the target, until the network output is matches with the target.

Neural networks have been trained to perform complex functions in various fields of application including pattern recognition, identification and classification. In this paper multilayer perceptron feed-forward network were used for training purpose, for that pattern recognition neural network toolbox is used for classification purpose.

1.1 Multi-layer Perceptron's

A multi-layer perceptron called feed-forward neural networks with hidden layers contains at least two layers of functional units shown in figure 1.

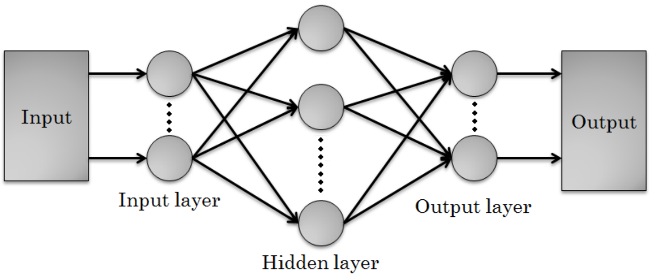

Fig -1: Multilayer Perceptron feed-forward network

In MLP FFN least one layer contains hidden units, which do not communicate with the environment. If the number of hidden units is appropriately chosen multi layer perceptron are universal approximators, i.e. they can solve, at least theoretically, any association problem.

3. NEGATIVE SEQUENCE CURRENT AND SWING ANGLE

When the motor is on healthy condition, it consists of symmetrical condition. If the failure occurred then such motor is categories into unsymmetrical condition. And according to power system, the analysis of unsymmetrical circuit can be achieved by using symmetrical components i.e. positive, negative and zero sequence component and accordingly most of the investigation of fault diagnosis of induction motor were done by using Negative sequence current and negative and zero sequence impedance. In this paper Negative sequence current called are used to classify the machine behaviour. The expression for negative sequence Voltage and current is defined as:

$$V_{ns}(t)=\frac{2}{3}(v_a(t)+\alpha v_b(t)+\alpha^2 v_c(t)) \quad (1)$$

$$I_{ns}(t)=\frac{2}{3}(i_a(t)+\alpha i_b(t)+\alpha^2 i_c(t)) \quad (2)$$

Where, $\alpha = \exp(j2\pi/3)$ is the sequence component transformation operator.

Vns and I_{ns} are the Negative sequence of stator voltage and current respectively. v_a, v_b, v_c and i_a, i_b, ic are the measured quantity of stator voltage and current of phase a, b and c respectively.

For the classification of the different condition, the direct measured signals are not suitable. The signal must have some critical information about the condition of motor, which describe healthy, rotor broken-bar and stator inter-turn short circuit of the motor. Therefore the peak value obtained per cycle of swing angle and absolute value of real part of negative current signal is used, the expression for the absolute value of real part of the negative sequence current and phase shift between current and voltage(δ) is define as:

$$r= \mathrm{abs}(\mathrm{real}(I_{ns}(t))) \quad (3)$$

$$\delta = \angle I_{ns}(t) - \angle V_{ns}(t) \quad (4)$$

Where the swing angle ($\Delta\delta$) is define as

$$\Delta\delta = \delta_{max} - \delta_{min} \quad (5)$$

The quantity r and $\Delta\delta$ is used as an input layer to ANN to train the network.

4. EXPERIMENTAL SETUP

A 2-HP, 4 Pole, 415v, 50Hz, three phase squirrel cage Induction motor was tested under full-Load condition. The Motor used has 36 slots and 24 coils. Each phase comprises with 8 coils which carries 300 turns. As a load a 3HP, 240v, DC shunt generator was used. For capturing the phase current and voltage signals, 16-bit USB 2.0-based DAQ Adlink module is used. To sense current, current probes of input range of 0.01Amps-5 Amps and output range of 400 mV/A, were used and 230/6v, step-down transformers are used to sense the phase voltage. The experimental setup is shown in figure 2.

Fig -2: Experimental Setup

4.1. For Healthy Condition:

A balance three phase power supplies is energized to three phase Induction motor. The motor is operated in healthy condition. The stator phase voltage and current are shown in figure 3.

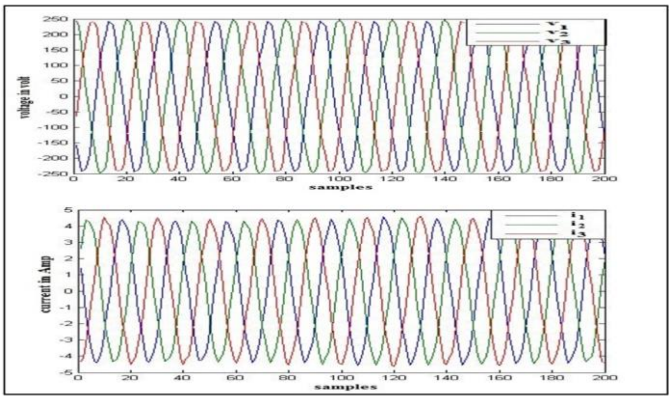

Fig -3: Voltage and current signal at full-load for healthy condition.

4.2. Rotor Broken-Bar Fault Condition:

As the squirrel cage Induction motor is rugged in construction, the bar defect generally occurred in a large machines. This defect comes in machine due to high temperature and large centrifugal force during transient operation of motor, such as continuous start up, this may due to frequent start- stop duty cycle. And also the bar get damage due to poor end ring joints forms during manufacturing. Once the defect occurred, rotor gets overheated in the cage, which produces high centrifugal forces.

In this paper the Rotor Broken bar achieved by cutting 5 bar of the rotor. In this the current and voltage signal are shown in figure 4.

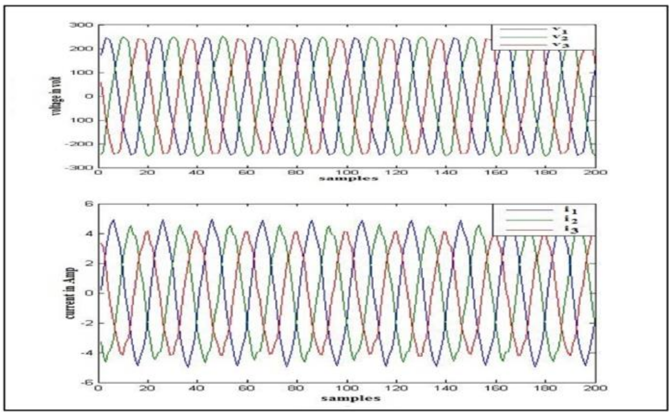

Fig -4: Voltage and current signal at full-load for Rotor Broken-bar

4.3. Stator Inter-turn Short Circuit

Stator faults generally occurred due to the winding insulation failure. This may due to overloading, frequent motor start and stop, coil vibration and due to transient voltage stress. Such faults may leads to generate heat in a defective region of a winding which causes the fault rapidly progress to more severs forms such as phase to ground and phase to phase faults.

In this, A phase has been tapped where each tapping is made after 10 turns, near to the star point (neutral). For Inter-turn fault 20 turn of phase A gets shorted. The current and voltage signal for stator with 20-turn short circuited are shown in figure 5.

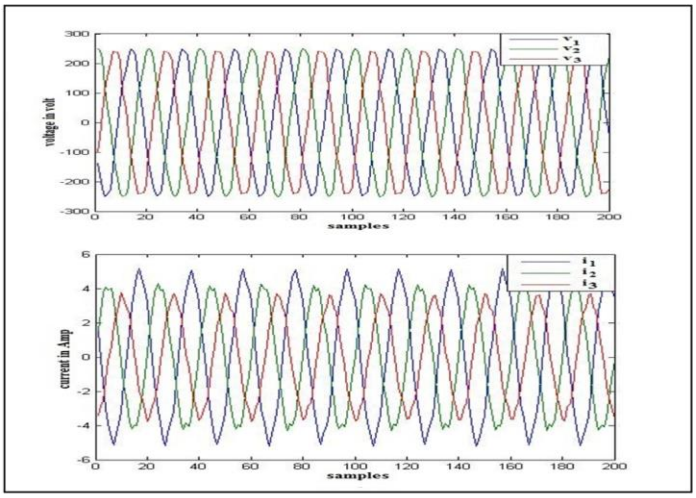

Fig -5: Voltage and current signal at full-load for stator Inter-turn fault.

5. RESULTS:

Stator voltage and currents are captured from motor terminals under healthy and faulty conditions, at full load conditions. From the voltage and current signal, negative sequence current $I_{ns}(t)$ and voltage $V_{ns}(t)$ are obtained by using equation (1) and (2). And to define r and 8 equation (3) and (4) were used. The curve for peak values of r and Δ8 obtained for each cycle for healthy, Rotor broken bar and Stator inter-turn short circuit for seven second are shown in figure 6 and 7 respectively.

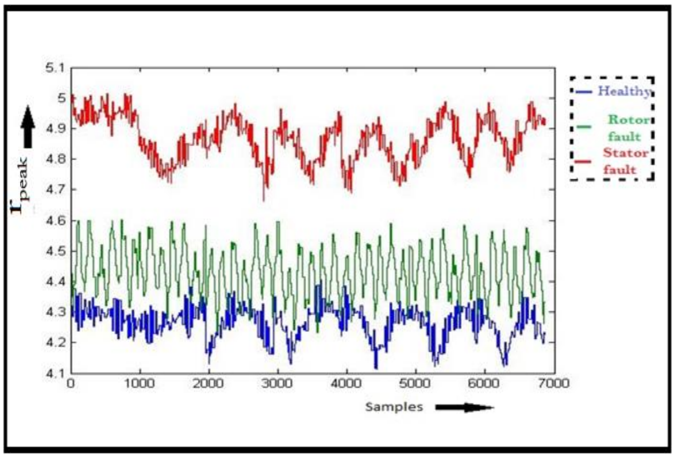

Fig -6: r_{peak} for Healthy, broken rotor-bar and stator inter-turn short circuit

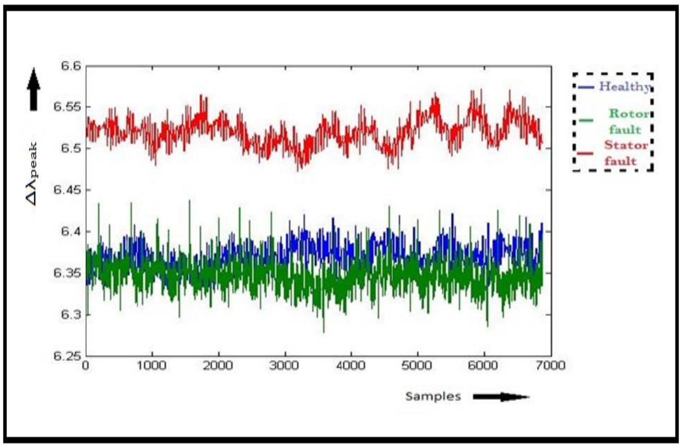

Fig -8: $\Delta 8_{peak}$ for Healthy, broken rotor-bar and stator inter-turn short circuit.

5.1. Fault Classification using ANN

An Artificial neural network with its pattern recognition tool can be effectively employed for the classification of fault of three phase induction motor. In present study two layer feed-forward artificial neural networks is used and trained with supervised learning algorithm. FFANN consists of one hidden layer and one output layer. In Input layer, it consists of 2 neurons; i.e. r_{peak} and $\Delta 8_{peak}$. Output layer consists of three neurons representing healthy, rotor fault and stator fault respectively. For training, Learning rate =0.8, Momentum=0.5,and for constrained output, Tansigmoid Transfer function is used, the samples are divided into three subset which are training subset, testing subset and validation subset. For training subset contains 80% of samples are set, for Testing is 15 % and for validation 05%. With these assumptions variation of percentage accuracy for classification of faults of induction motor with respect to number of processing elements in hidden layer is obtained.

Table 1 and Figure 9 and shows % accuracy with the variation of processing elements.

Table -1: Percentage accuracy of classification

No. of Processing Element	Percentage accuracy		
	Healthy	Rotor Fault	Stator Fault
1	85%	60%	100%
2	100%	80%	100%
3	100%	100%	100%

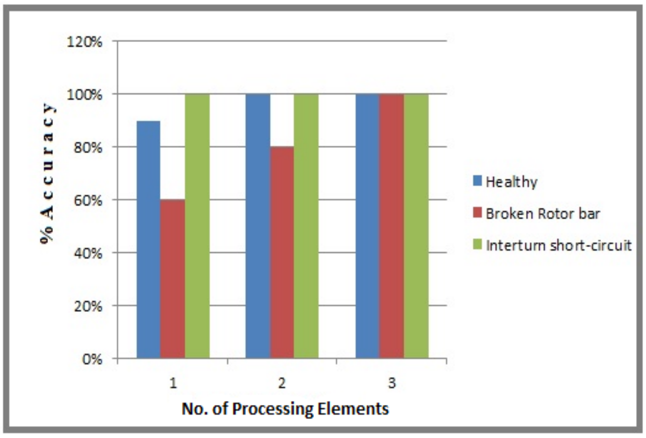

Fig -9: percentage accuracy using ANN

6. CONCLUSIONS

In This paper, an application of neural network for healthy, broken rotor bar and stator inter-turn fault detection of three phase induction motor using stator current data are presented. The major component for analysis is used to extract pattern and data reduction. Stator current and voltage signals are recorded, statistical parameter computed for healthy and faulty conditions. Further analyzed by negative sequence current and swing angle which are fed as an input to ANN. The results shows that the ANN with major principal components was the most efficient regarding the criteria of accuracy in fault detection with three processing elements in hidden layer.

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