Intelligent Condition Monitoring & Fault Diagnosis of Induction Motor

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ABSTRACT

Electrical motors are the majority of the industry prime movers. Induction motors are the most popular ones for their reliability and simplicity of construction. Although induction motors are reliable, they are subjected to some modes of failure. Condition monitoring is used for increasing machinery availability and machinery performance, reducing consequential damage, increasing machine life, reducing spare parts inventories, and reducing breakdown maintenance, An efficient condition-monitoring scheme is capable of providing warning and predicting the faults at early stages when the fault is about to take place or has just occurred. Recently artificial intelligent techniques such as expert system, neural network, fuzzy logic and genetic algorithm have been employed to assist the diagnostic task to correctly interpret the fault data.

***Index Terms** : condition monitoring, fault diagnosis, artificial intelligence, induction motor*

I. INTRODUCTION

THE induction motor is considered as a robust and fault tolerant machine and is a popular choice in industrial drives. It is important that measures are taken to diagnose the state of the machine as and when it enters into fault mode. It is further necessary to do so on-line by continuously monitoring the machine variables. There are a wide variety of monitoring systems starting from a very simple to a very complex one with advanced and intelligent instrumentations. An example of simple monitoring system is an over-current relay connected with alarm, when the current exceeds a certain limit; the system gives a warning alarm. However, complex systems are used in very important and critical position such as nuclear reactors, space rockets, submarines, airplanes, and continuous process plants etc. where accurate information about the parameters being monitored is needed. The reasons behind failures in induction motors have their origin in design, manufacturing tolerance, assembly, installation, working environment, nature of load and schedule of maintenance. It is important that measures are taken to diagnose the state of the machine as and when it enters into the fault mode. There are many monitoring systems available commercially developed by multinational companies such as B&K, ABB, PDMA, PRUFTECHNIK, CIS, etc. These systems are developed for certain specific applications. The cost of such systems is very high and there is less flexibility in changing system parameters. In general, economical and safety considerations play an important role in the selection of the monitoring system.

II. NATURE OF ELECTRICAL MACHINE FAULTS

Induction motor like other rotating electrical machines is subjected to both electromagnetic and mechanical forces. The design of motor is such that the interaction between these forces under normal condition leads to a stable operation with minimum noise and vibrations. When the fault takes place, the equilibrium between these forces is lost leading to further enhancement of fault and increased level of vibrations. All types of rotating electrical machines, even new ones, generate some level of vibrations.

Machine vibrations are mostly due to three origins, mechanical, electrical (electromagnetic) and environmental.The vibrations due to the environment can be defined as the vibrations transmitted to the machine from the surrounding. Vibrations due to mechanical origin are produced by the rotor movement then transmitted to the stator, while the vibrations due to, magnetic origin are produced by the machine winding and the magnetic circuits and act directly on the stator structure.

The following failure modes were identified during a 1985 study by the Electric Power Research Institute (EPRI): bearings 41%; stators 37%; rotors 10%; others

12%.

A. Stator Faults

The stator of the motor is subjected to electrical and mechanical stresses. The electrical stress may cause winding faults due to insulation failure, short circuit, winding cut, bad connections and displacement of conductor. The core of the stator may become defective due to high value of local eddy current, frame vibration etc. The detail of each type of faults can be presented as follows.

Winding insulation failure often causes turn to earth fault, turn to turn fault and phase to phase fault that occur due to manufacturing weakness or to working environment and operating conditions. The quality and age of insulation depends upon its electrical isolations, chemical reactions, and ability to face the mechanical forces and vibration. Working environment such as high ambient temperature, high humidity and dirtiness may cause rapid deterioration leading to the damage of insulation. Electrical stresses such as over current and over voltage are the other causes of winding failure.

Slacking of the core and excessive vibration may occur due to high mechanical forces acting on the slot ending and the core body. In addition the presence of foreign materials between the core laminations and rotor rubbing can lead to local circulating currents. If the level of these currents is high, hot spots will be presented in the deformation. Eccentricity of the stator can lead to unbalance magnetic pull and so vibration. The core condition may be obtained by continuous monitoring of the flux and temperature.

B. Rotor Faults

The induction motor rotor is either slip ring or squirrel cage type. The slip ring rotor is subjected to wear of winding due to insulation failure, excessive mechanical vibrations and stator or foreign material strike. In addition, slip rings and brushes are subjected to wear and fretting as well as looseness. On the other hand, squirrel cage rotor suffers from crack and broken rotor bars. Moreover, a turn to turn fault hi the rotor winding or cracks in the rotor bars cause unequal heating distribution that may lead to bending of the rotor and eventually cause unbalanced magnetic pull.

C. Bearing Faults

Bearing is an essential part in electrical motor. Roll element bearings (ball bearings) commonly used in the medium size machines. Roll element bearing consists of two rings with a set of rolling elements running hi their tracks. Bearings are subjected to different types of faults such as bearing misalignment, loss of lubrication and bearing failure. The bearing failure may be due to the unbalanced magnetic pull, excessive bearing clearance, incorrect loading, defective installation, contamination of oil and overheating.

III. DEVELOPMENT OF MONITORING SYSTEM AT IIT, ROORKEE

For the purpose of online monitoring and diagnosis of the machine condition, a computerized monitoring system is indigenously developed. The monitoring system has high accuracy, fast response, simple design with reliability and rugged construction. The basic elements of monitoring systems are sensors, signal conditioning, data acquisition and signal processing. The rudimentary step in design is specifying the size and the type of the machine to be monitored. Machine variables such as three phase terminal voltages, three phase stator current, speed, temperature, and frame vibration (radial and axial) that cover all the

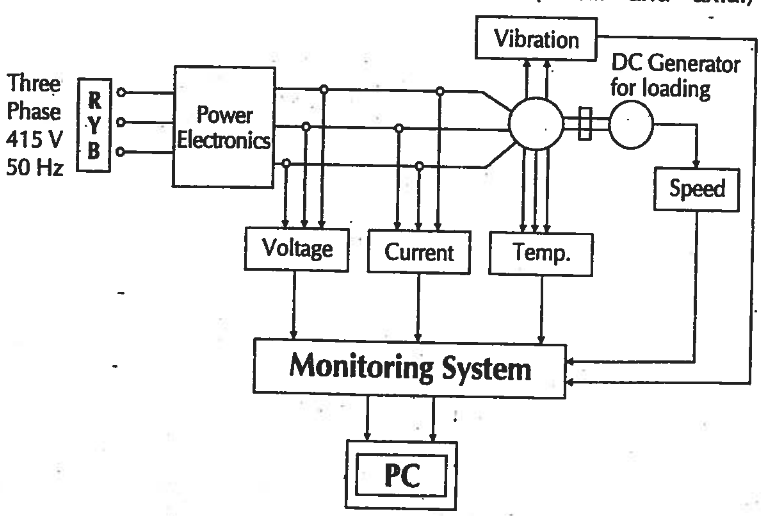

Figure I (a) : Schematic diagram of the monitoring systemDSA-10Health Monitoring

requirement to recognize the expected types of faults, are selected for monitoring.

Potential transformers, Hall-effect current probes, pulse tacho-generator, thermocouples and piezoelectric accelerometers are the transducers used to measure the mentioned machine variables. A schematic diagram and experimental setup of the developed monitoring system is shown in Figure I(a) and I(b).

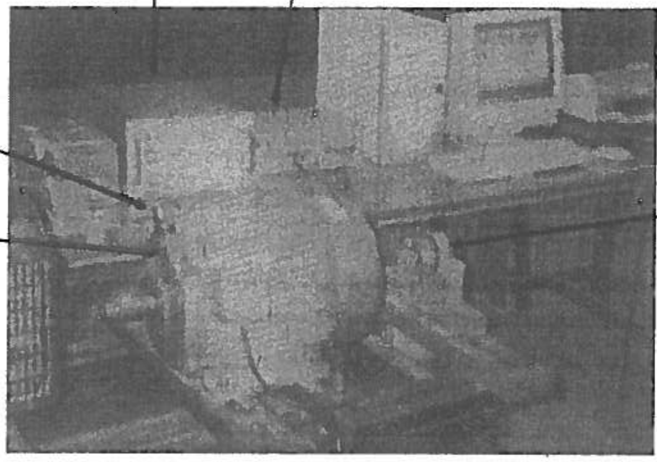

Figure I (b) : Experimental Set-up of PC Based Monitoring of the Test Motor

To transfer the collected machine data to the computer, multipurpose DAQ card has been used. The DAQ card has the facility for analogue inputs, digital inputs, and digital outputs. The speed of data acquisition system and the number of inputs to be scanned are controlled by the software. The hardware along with the software allows the user to effectively monitor, store and analyze machine variables. The system provides on-line display of voltages, currents, temperatures, and speed with simple graphic user interface environment or directly storing the acquired data for off-line data analysis and processing. The system is portable and modular in design and flexible to allow for expansion for different size of machines, yet easy to use, so that it can be used in an industrial environment.

IV. SIGNAL PROCESSING TECHNIQUES FOR MONITORING SYSTEM

Electrical signals obtained from physical systems by different type of transducers contain information about their conditions, the suitability of a technique to be used depends upon the nature of the signal and the required accuracy of the obtained information. Signal obtained from the transducers are in the form of continuous voltage or current signals. It is necessary to define their values at certain instants of time to be suitable for digital signal processing applications. The obtained digital signal is an adequate substitute for the underlying continuous signal if the interval between the successive samples is sufficiently small. The sampling frequency must be twice the highest frequency components of the signal to avoid aliasing of high frequencies components in the low frequency region of the spectrum.

There are two approaches used for processing the signal; time domain and frequency domain. In time domain approach, the discrete time signal is directly analyzed by one of the digital signal processing techniques such as, filtering, averaging, convolution correlation, etc. In frequency domain approach, the signal is first transformed to the frequency domain using Fourier transform. Different methods of analysis such as averaging, convolution, power spectrum etc., can then be applied. Different signal processing approaches have been used here to extract the salient feature of the signals obtained from the machine.

V. DEVELOPMENT AND IMPLEMENTATION OF AN INTELLIGENT DIAGNOSTIC SYSTEM

Perfect fault diagnostic system is difficult to achieve because it is not always possible to exactly describe the relationship between the fault phenomena and its reasons. However, a human expert can give accurate decision about the machine condition through his accumulative experience. Artificial intelligence is a field that investigates how the computers can be made to exhibit intelligence in different aspects of thinking, reasoning, perception or action. Different artificial intelligence methods such as expert system, genetic algorithm, fuzzy logic, neural network etc have been used to solve non-conventional real life problems.

ANN with a reasoning algorithm has been used here to build an intelligent monitoring and diagnostic system. Various topologies of feed-forward supervised ANN with back propagation learning algorithm are implemented. The output of the neural network is then fed to a reasoning algorithm to obtain the final conclusion about the machine health. The results of implementing the ANN as fault classifier shows an improvement in diagnosis task over the traditional methods. The ANN schemes and reasoning algorithm are implemented using programs developed in C^{++}. Eventually the system is tested with on-line data obtained from the machine under test and the results show a good correlation with the machine conditions.

VI. IMPLEMENTATION OF AN ANN MODULE

In the present work, a multilayer feed-forward neural network with back-propagation algorithm is designed for the classification and diagnosis of faults in induction motors. As mentioned earlier, many machine variables are affected by the fault and the supply conditions. However, if a simple neural structure is used to include all the above effects, the structure of the network becomes very complex and eventually the number of iterations needed to converge to the target error may become too high or it may not converge at all. Therefore, different cascaded neural network modules are used for different fault conditions. The main function of the neural network modules is to determine supply conditions, supply harmonics, incipient faults, classification of fault and degree of severity of these faults. The connections between these modules are performed using if-then rules based reasoning algorithm. The back-propagation algorithm is used for the training of these modules. The neural network program is designed to occupy two hidden layers, one input layer and one output layer with variable number of nodes in each layer.

The optimum size of the neural network for all modules is obtain by different trials, using different initial weights and varying the number of the hidden layers and nodes in the hidden layers. Seventeen neural network modules are used to build an efficient diagnostic system. The algorithm has been tested with many data sets and the results are quite satisfactory. The efficiency of diagnosis of the proposed algorithm for different machine conditions are given in Table 1. It can be noticed that the system has the ability to detect the presence of machine fault with 100% accuracy, and 95% accuracy for classifying the fault.

VII. CONCLUSIONS

A high precision monitoring and diagnostic system of electrical machine has been the aim of researchers working in this area. The accuracy and the precision of the monitoring system are somehow related to the system complexity. The relation between the machine faults and machine variables is complex and non-linear in nature. Many attempts have been made to deal with this complex and non-linear in nature. Many

	Conditions detectio			Fault classification					Fault level estimation			
Phenomena	Supply condition	Supply harmonics	Bearing faults	Bearing faults	Machanical unbalanced and coupling fault	Supply unbalanced	Over/under voltage	Supply distortion	Supply condition	Supply harmonics	Defects in bearing parts	Dry Bearing faults
Diagnostic efficiency	100%	100%	100%	95%	95%	100%	95%	100%	87.5%	92.3%	87.5%	81.8%

Table 1. Diagnostic efficiency for different machine conditions

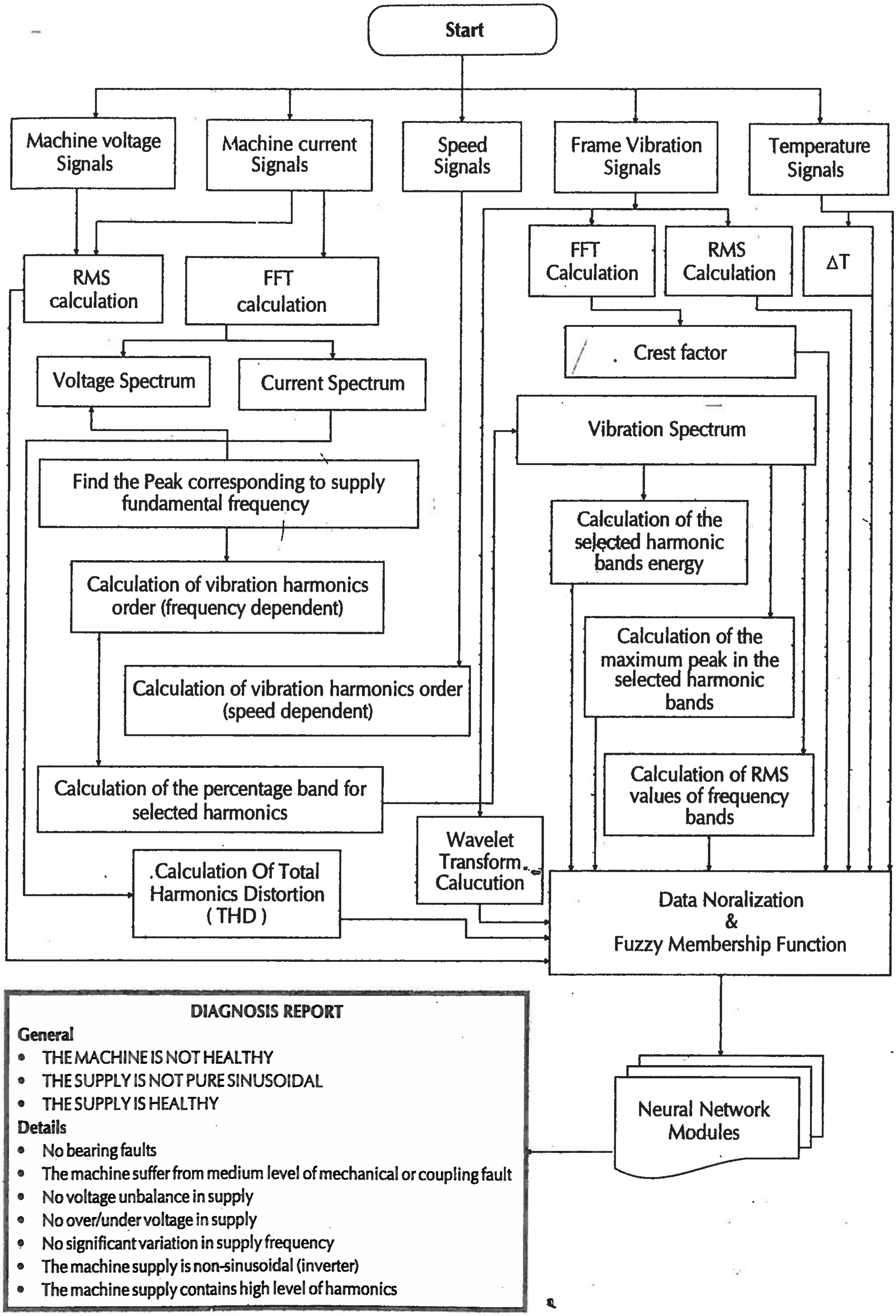

Figure 2. Flowchart of machine health diagnostic using ANN modules

attempts have been made to deal with this complex relation through the use of advanced signal processing and diagnosing methods.

When the machine under monitoring is working in industry, the supply, load and environment conditions are mostly non-ideal. The supply in industry usually suffers from unbalance between phases and voltage waveform is not pure sinusoidal due to transient in voltage. This may increase the complexity of the relation between machine parameters and faults. In this situation, the diagnostic system has to include reasoning processing or intelligent treatments of data. However, human intelligence and expertise have superiority over all modern intelligent equipment. Due to the lack of availability of human experts hi the area of electrical machine monitoring and fault diagnostics, there is a growing demand for automation of monitoring system. The artificial neural network deals with this complex relation. The supervised neural network has excellent characteristics for fault mapping. The above algorithm is tested with many data obtained directly from the machine and obtained results are highly corrected with machine condition.

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