Multi Sensor Data Fusion Based Expert System in Condition Monitoring and Fault Detection: An Induction Motor Case Study

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Abstract— **Condition monitoring is a predictive maintenance procedure, which is used to provide warning and predict faults of a system at an early stage, so catastrophic breakdown of the system can be avoided. An efficient condition monitoring method can reduce the cost of breakdown maintenance, increase the working life of system, and reduce the spare part inventory. Condition monitoring system acquires raw data of different system parameters using different sensors. Different signal processing techniques are implemented on the raw data to extract vital clues and estimate the probable faults in the machine. This paper gives an overview of condition monitoring system of induction motor and gives an overview of implementation of multi sensor data fusion technique to improve the efficiency of condition monitoring system.**

Keywords- Condition monitoring, multi sensor data fusion, signal processing.

I. Introduction

Electric motors account for 95% of all prime movers in industrialized nations, and among these, three-phase induction motors consume typically 40% to 50% of all generated electrical energy. Induction motors are inherently reliable and require minimum maintenance.

Condition monitoring of any mechanical, electro mechanical or electro static devices is a challenging task. There are different methods of condition monitoring of an induction motor including monitoring of vibration, acoustic emission, and motor current signature analysis etc. These monitoring techniques except motor current signature analysis technique require high precision sensors, DAQ cards and sophisticated signal processing analysis procedures.

An efficient condition-monitoring scheme is one that provides warning and predicts the faults at early stages. Condition monitoring system acquires raw data of different system parameters using different sensors. Different signal processing techniques are implemented on the raw data to extract vital clues and estimate the probable faults in the machine. The problem with this approach is that the results require constant human interpretation. To automate the diagnostic process, recently a number of soft computing techniques have been proposed [5, 6, 7, 8]. The use of soft computing techniques increases the precision and accuracy of the monitoring systems [9].

A single electric motor can have multiple faults, which can't be detected using a single sensor. Multiple sensors are used to acquire multiple signals and multi sensor fusion technique is implemented to detect the faults of a motor.

A Multi Sensor Fusion & Condition Monitoring

Data fusion techniques combine data from multiple sensors to achieve improved accuracies and more specific inferences than could be achieved by the use of a single sensor alone. Multi sensor data fusion is an emerging technology applied to different areas such as automated target recognition, battlefield surveillance, and guidance and control of autonomous vehicles, monitoring of complex machinery, medical diagnosis, and smart buildings. Techniques for multi sensor data fusion are drawn from a wide range of areas including artificial intelligence, pattern recognition, statistical estimation etc.

Data collected from different sensors can be fused in different levels. The data fusion takes place in the following levels.

1. Data level (If the data are commensurate)
2. State vector level
3. Feature level
4. Decision level

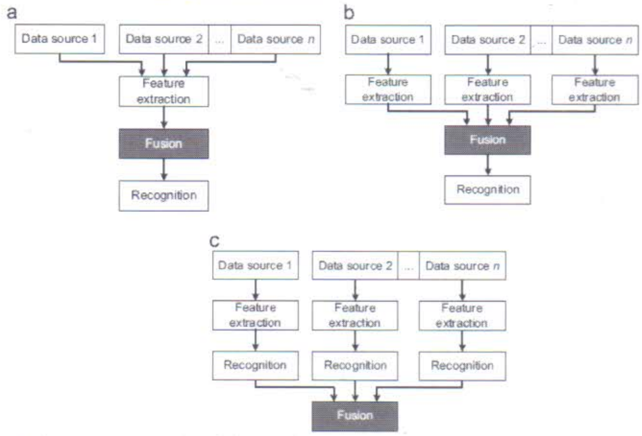

Figure 1: (a) Signal level fusion,
(b) feature level fusion,
(c) decision level fusion

Figure 1 (a), (b) and (c) shows the signal level fusion, feature level fusion and decision level fusion.

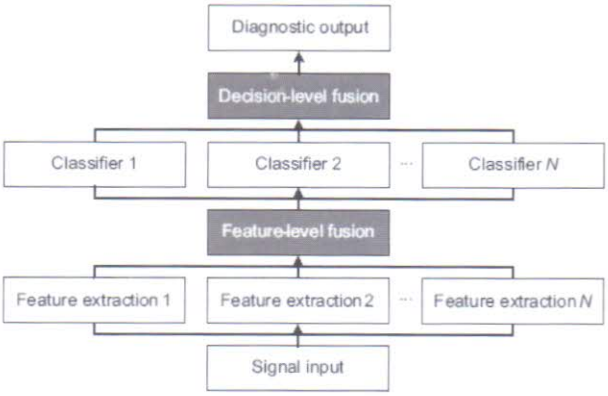

Figure 2: Hybrid architecture

Figure 2 shows the hybrid architecture, where feature level and decision level fusion is implemented to make a diagnosis.

B Condition Monitoring of Induction Motor

Induction motors are most widely used electro-mechanical machines in industry. The wide use of induction motor is because of their low cost, reasonably small size, ruggedness, low maintenance. Although these motors are very reliable, these are subjected to different modes of faults or failures. These faults can be inherent to the machine itself or due to operating conditions. Figure 3 shows the different faults in induction machine [].

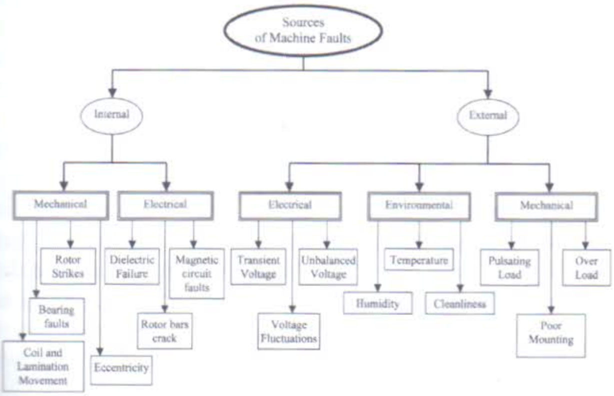

Figure 3: Faults in induction machine

Basically the faults occurring in induction machine are divided in to two parts, i.e faults due to internal factors and faults due to external factors. Some of the internal faults are eccentricity fault, broken rotor bar fault, bearing fault, dielectric failures etc. Faults can occur in induction machines due to some external factors like high temperature, high humidity, overload, unbalanced voltage, transient voltage, voltage fluctuations etc.

According to IEEE and EPRI (Electric Power Research Institute) survey results, the faults and losses of induction motor are summarized below.

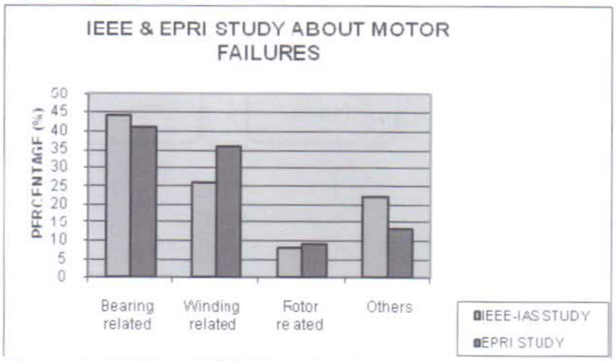

Figure 4: IEEE and EPRI study about motor failures

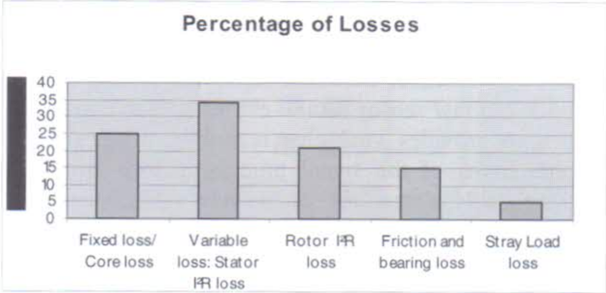

Figure 5: Percentage of losses in induction motor

Traditionally maintenance procedures in industry follow two approaches.

(i) Preventive Maintenance

(ii) Breakdown Maintenance.

In preventive maintenance, maintenance operation is carried out in a regular interval of time. In breakdown maintenance, maintenance is carried out when the breakdown occurs. However, now a day with implementation of different scientific approach, predictive maintenance is possible. In predictive maintenance, different signal processing approaches are used to detect the early signs of defect and suitable actions are taken before any kind of catastrophic failure occurs.

Different fault diagnosis methods are used to detect different faults of induction motor. These techniques are summarized below.

There are basically three techniques for predictive maintenance namely, model based technique, signal processing techniques and soft computing technique.

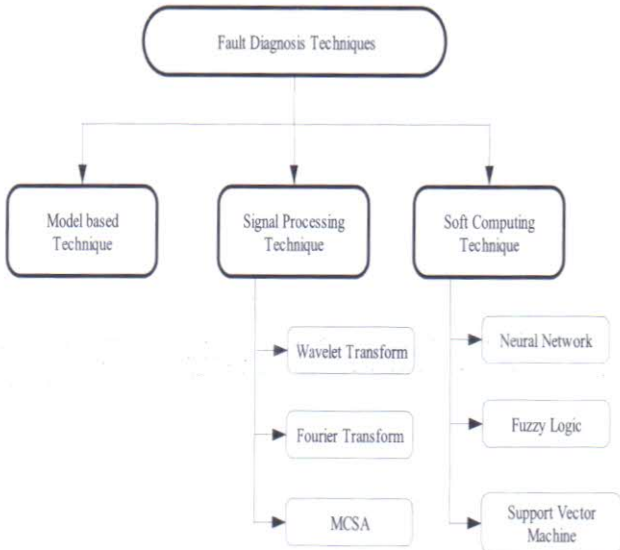

Figure 6: Induction motor fault diagnosis technique

Signal processing technique is widely used to detect faults in induction machine. Different signal processing algorithms are applied in raw sensor data to extract valuable information, which then provides vital clue regarding the health of the machine. Some of the signal processing techniques widely used for fault detections is wavelet transform, Fourier transform, Short Time Fourier Transform, Motor Current Signature Analysis, Power Spectral Density etc. Soft computing techniques like neural network and fuzzy logic can also be used for fault detection in induction motor. Different supervised and unsupervised classification techniques like Support Vector Machines and Self Organizing Maps respectively can be implemented in raw sensor data to ascertain the health of the machine.

II. RELATED WORKS

Lane M D Owsley et.al (1997), uses SOFM to extract feature from vibration signal of induction motor and uses HMM to classify different fault data [5]. Zhongming et al (2001), used WPD to detect both air gap eccentricity and broken rotor bar after giving a brief detail about the wavelet and feature extraction [7]. G K Singh (2002), reviewed the research aspect of multi phase induction machine drives. Multi phase induction machine is a potential alternative of the conventional 3 phase induction machine. This paper reviews the current development and issues and future challenges to design a multi phase induction machine drive [9]. G K Singh et.al (2003) studied the use of signal processing techniques to extract valuable information about machine health condition. The author studied about online and offline condition monitoring techniques [11]. G K Singh et.al (2003), carried out a survey of different techniques used in induction motor condition monitoring and fault diagnosis [12]. B Samanata et.al (2003), compared the working of ANN and SVM for fault detection and condition monitoring of induction motor. In case of SVM, features are optimized with the help of GA [13]. Romero-Troncoso Rene de Jesus et.al (2004) had a study about FPGA based online tool breakage detection system for CNC milling machine. It used DWT and autocorrelation algorithm to detect tool breakage [14]. Hamidi et.al (2004), presented the detection of mixed eccentricity fault using WPD, which was done by a modified winding function [15]. Antonino et al (2005), presented the detection and diagnosis of mixed eccentricities and rotor asymmetries with different sizes and conditions as well as effective oscillations due to the load torque or voltage that were studied individually [19]. Antonino et al (2006), presented many cases for fault diagnosis (mixed eccentricity, broken rotor, inter-turn and inter-coil stator short-circuits) using DWT at start up current of induction machines according to the stator parallel branches [20]. Fulufhelo V Nelwamondo et.al (2006) has reviewed feature extraction techniques to extract both linear and non linear features from vibration signal of a rotating machine. Features are extracted by MFD while considering two parameters like MFCC and Krutosis and bearing fault is classified using GMM and HMM. The result indicates that though computationally expensive HMM is a better classifier than GMM, while classifying bearing faults from time domain vibration signal [23]. Tian Han et.al (2006), has used wavelet transform, ANN and GA to predict the faults in induction machine. These techniques were implemented in stator current and the fault of induction machine is predicted. In pre processing of stator current signal, wavelet transform is used. GA is used to select the most significant feature vector, while ANN is used to predict the fault. The combination of all these techniques improves the diagnosis accuracy [24]. Abhinav Saxena and Ashraf Saad (2007), uses GA to select smaller subset of features that together form a genetically fit family for successful fault identification and classification task [30]. Jafar and Javad (2007) used Meyer wavelet in the WP structure to detect the bearing defect using SCA with energy comparison as the fault index [32]. Bo Suk Yang et.al (2007), surveys the use of support vector machine (SVM) for machine condition monitoring and fault detection. SVM produces higher accuracy in classification tasks for machine condition monitoring and fault diagnosis. Bin and Paghda (2008) used the wavelet to detect the broken rotor bar, eccentricity and bearing due to current, voltage and instantaneous power, while the signals to noise ratio of the spectral components were examined under varying load condition of the single phase in the active cycle [33]. Jawad and Mansour (2009) presented a review for most important indexes in the different types of eccentricities faults in the induction motors as well as the consequences and effects [38]. Yixiang et al (2010), used the lean model to assess the machine performance via DWT for the vibration and bearing induction motor faults [41]. C. Rodriguez-Donate et.al implemented an embedded system with FPGA and SOC (System on Chip) for online monitoring of induction motor failures by measuring the vibration transient signals at the start-up with discrete wavelet transform. Franco-Gasca et.al (2009), presents a hardware signal processing unit implemented in a single field-programmable gate array (FPGA) for acquisition, conditioning, and basic