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Condition Based monitoring system using IoT

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Abstract

With the advent of Internet of Things (IoT), a new industrial revolution is around the corner. Industries are tapping this unprecedented technology to improve their manufacturing processes. In this paper we demonstrate the integration IoT technology with Industrial Induction Motors. A network of sensors continuously monitors the "health" (viz. Current, Voltage, Vibration, Temperature, shaft alignment & rpm) of the Motor. This data is sent to a dedicated microprocessor unit(DHU) for remote online condition monitoring. The DHU is connected with a laptop (wirelessly) to analyse the data collected in MATLAB to gain insights regarding the health of the motor. Condition based maintenance(CBM) can be used to conduct predictive maintenance when the motor requires rather than conduct scheduled maintenance. A DHU is also integrated with a Global System for Communication (GSM) modem to convey the operator of the health of the motor in emergencies when immediate attention is required.

Keywords: Internet of Things (IoT), Condition based monitoring(CBM), induction motor faults

INTRODUCTION

Internet of Things(IoT) is an upcoming technology whose application are becoming more pervasive as we progress. It is basically a network of physical devices talking to each other via the help of electronics such as sensors, microprocessors etc. One of its greatest advantage is its ease of integration with the existing technology and machinery. The use of sensors with the reduction in cost and size has augmented the way machines communicate with each other and has led to a manufacturing revolution. Manufacturing industries are tapping into this unprecedented technology to improve its process productivity and efficiency [1]. Connectivity and data acquisition are key parameter that act as a foundation for smarter, more sophisticated and intelligent machines. With the advent of data, gaining insights regarding the machine has become more feasible [2]-[5]. Predictive maintenance has emerged as one of the most popular trends in the industry and is quickly gaining popularity to improve efficacy and reduce erratic machine downtime, improving the labor productivity while efficiently utilizing time dedicated to maintenance of machines. Condition based monitoring is a primary step to gain insights about a machinery while in service. The key to successful implementation of Condition based maintenance relies upon the accurate means of condition assessment and fault diagnosis.

Electrical motors have been in use since the dawn of the industrial revolution, acting as the backbone of the manufacturing process. Three phase induction motors are widely used in industries due to their high reliability, feasibility and wide range of torque output available with simple build and maintenance. As their failures could have catastrophic consequences financially and productivity wise, safe and reliable working of these motors should be ensured. CBM using IoT uses measurements taken while a machine is operating, to determine if a fault exists [6]. Different types of sensors can be used to measure signals to detect various faults. Various signal processing techniques can then be applied to these sensor signals to extract particular features which are sensitive to the presence of faults. Finally, in the fault detection stage, a decision needs to be made as to whether a fault exists or not with previous knowledge [7]-[8].

INDUCTION MOTOR FAULTS

Induction motor faults are broadly classified into internal and external faults. Internal faults are comparatively difficult to discern and require sophisticated tools to detect. They are further categorized as mechanical and electrical faults.

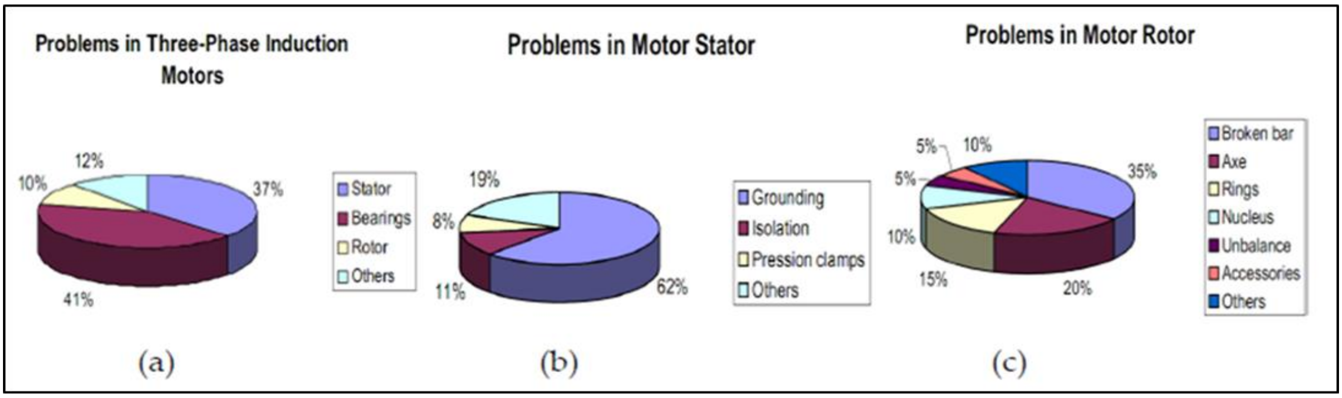

Figure 1. Problems in a) Three Phase Induction Motor b) Motor Stator and c) Motor Rotor

A. Bearing fault

These are one of the most common types of faults which account for almost 40% of all induction machine failures. Bearing defects are generally observed to be distributed or localized. These defects create a series of impact vibrations at an instant when a running roller passes over the surface of a defect whose period and amplitude are calculated by the anomaly's position, speed and bearing dimension as per the formulas derived. These frequencies are unique for every bearing dimension and rotating speed.

$$f_{cbf} = | f_s \pm n f_{rc} | \qquad (1)$$

$$f_{rc} = \frac{N_b f_s}{2}\left[1 \pm \frac{D_b}{D_P}\cos\theta\right] \qquad (2)$$

B. Stator Fault

It accounts for almost 37% of the total induction faults. General stator faults are turn – to – turn, coil – to – coil and coil – to – ground faults. As a three-phase motor consists of stator slots filled with winded copper wires; they occur mainly due to interturn winding faults caused by insulation breakdown.

$$f_{cbrf} = f_s\left[n\frac{(1-s)}{P} \pm s\right] \qquad (3)$$

C. Rotor Fault

These faults generally occur due to rotor windings and account for almost 10% of the total induction faults. The common type of rotor fault is broken rotor bar which usually occurs due to pulsating loads. These faults lead to fluctuations in speed, vibrations and pulsated torque outputs.

CONDITION MONITORING AND TECHNIQUES

Condition monitoring is the continuous evaluation of the various crucial parameter that act as the governing parameters to determine the "health" of the induction motor. These parameters herald the inception of faults that would eventually lead to its failure. Thus, it is crucial to monitor and look for these faults as the reduction in downtime of these faults leads to higher plant efficiency and better utilization of available funds. Various condition monitoring techniques are as follows.

1) *Vibration Monitoring:* It is widely used to detect mechanical faults. A 3-axis accelerometer is used to determine the vibrations in each direction. This data is then used to plot the FFT diagram to detect bearing faults, rotor faults and air gap eccentricity.

2) *Motor Current Signature Analysis (MCSA):* It is a more recent method used to detect stator faults by capturing the motor's current and voltage signals and analysing them to detect various faults.

With the increase in demand of condition monitoring, various other methods have also been formed such as extended park's vector approach(EPVA) and instantaneous power signature analysis (IPSA) which are developed to detect particular problems. All the techniques discussed above are generally applied to detect the following defects in an induction motor.

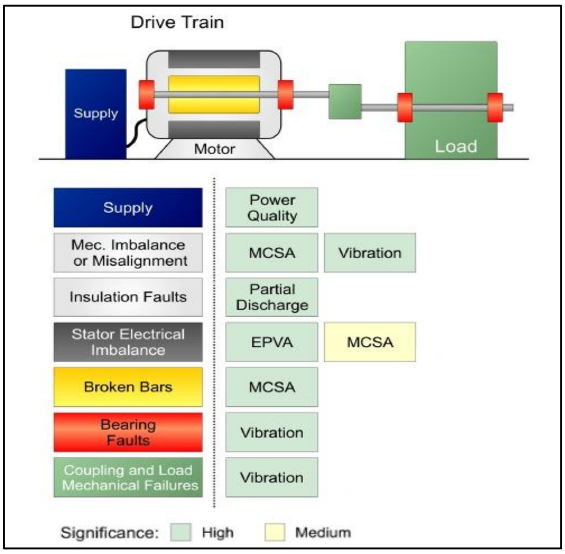

Figure 2. Comparison of Condition Monitoring techniques

SYSTEM DESCRIPTION

Data Acquisition is a key step in predictive maintenance. As with most technologies, sensors are swiftly becoming economically feasible, miniscule and more advanced. Sensordriven computing or Continuous remote monitoring of critical elements of a motor displays the current "health" of the motor and helps us gain critical insights related to the motor. Various sensors such as hall sensor, proximity sensor, accelerometer, temperature sensor and CT coil were used to monitor the various parameters of the motor.

In this experiment we developed an independently function monitoring system using raspberry pi 3B integrated with the above-mentioned sensors. Each sensor has its own sensor response time and all the sensors are integrated with the Raspberry Pi GPIOs with respective pull-up resistances, capacitors and potentiometers. This micro-processor based hardware unit is termed as a dedicated hardware unit(HDU). The data transmitted by the sensors is collected and then stored to a pc which is wireless communicating with the Raspberry Pi module. This data is analyzed using MATLAB using methods such Motor Current Signature Analysis(MCSA) and Vibration analysis.

Table I. Sensor list with their respective fault detection

Sr. No.	Sensor Name	Test	Fault Detection
1	ADXL 345 Accelerometer	Motor and bearing vibration	Shaft or bearing housing vibration
2	PR30-15DN2 Inductive proximity Sensor	Shaft Misalignment	Air-gap eccentricity
3	Hall Sensor	Motor RPM	Digression in shaft RPM
4	LM 35DZ thermocouple	Stator Temperature	Indirect measure of winding temperature
5	CT Coil	Supply voltage	Rotor faults

A GSM Sim900A module is used to inform the operator about the critical parameters that cross a pre-defined threshold value which is set by the operator on the basis of previous experiences [10]. The message is intended to draw the attention in case the operator is not active at the display monitor. The circuit diagram of the connection is as shown in Fig. 3.

The GSM supports extended AT commands and has an inbuilt COM port with RS232 protocol-based interfacing facility. The micro-processor initially sends an "AT" command as sequence initiation to which an "OK" response is sent by the GSM modem [11]. The following steps are performed to retrieve the PIN (personal identification number) and checks if the SIM card is ready and if the link is established. Further using the AT commands, the required messages are conveyed to the concerned authority.

METHODOLOGY

In this proposed study, we develop a novel process of feasible condition monitoring system. It consists of four major sub-systems or blocks viz. DHU, GSM module, Remote PC and phone that function independently. DHU acts as a partially autonomous block and collects data from the array of sensors for further processing. This data is then wirelessly sent to a remote PC with an assigned operator. The operator with his past experience and the visual tools monitors the parameters and detect anomalies if any. He then further investigates the anomalies detected in the FFT spectrum to decipher the root cause of the anomaly [13].

The GSM module is used to send emergency signals to the operator. This is done autonomously as the threshold values are predefined and eliminates the need of continuous attention of the operator giving DHU-GSM module partial autonomy.

Since, a motor's health deteriorates over a long range of time, we ran the experiments with various motor conditions. A brand-new motor was initially used to detect the values which would be further used as a benchmark. A faulty motor with broken rotor bar was then used. A significant change was noticed in the FFT frequency spectrum as shown in the figure below.

Further a slotted disc with variable weights were introduced with a speed regulator to measure the change in the amplitude of vibrations induced in the bearing and the motor mounting. Mainly two major non-invasive techniques i.e MCSA and Vibration analysis were used to detect major rotor faults.

MCSA is mainly used to detect broken rotor bars, shorted turns and air gap eccentricity while vibration analysis was used to detect major mechanical faults such as bearing fault, gear faults, unbalanced rotors and rotor eccentricities. With advancement in sensor technology leading to feasible and inexpensive accelerometers, this method is swiftly gaining popularity. After collection of the data it is processed using the MATLAB software to obtain a frequency spectrum using FFT. As the frequency spectrum often contains a lot of noise produced due to the presence of multiple elements, a lot of professional experience with pre-established frequency values of each anomaly should be known beforehand. Also, the load condition and speed are perpetually varied thus altering the fault signature characteristics as well. A lot of test samples were initially conducted to detect a fault's frequency associated with it [14] – [15].

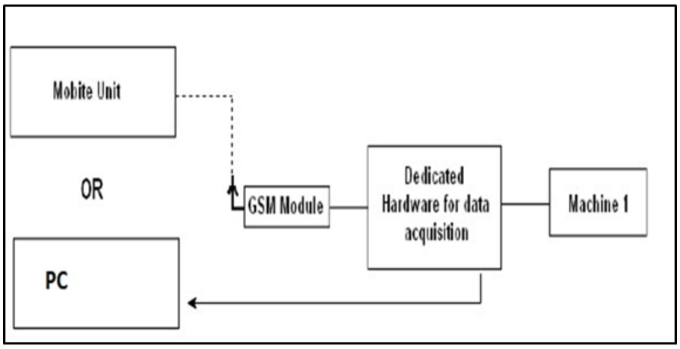

Figure 3. Block Diagram of the experimental setup

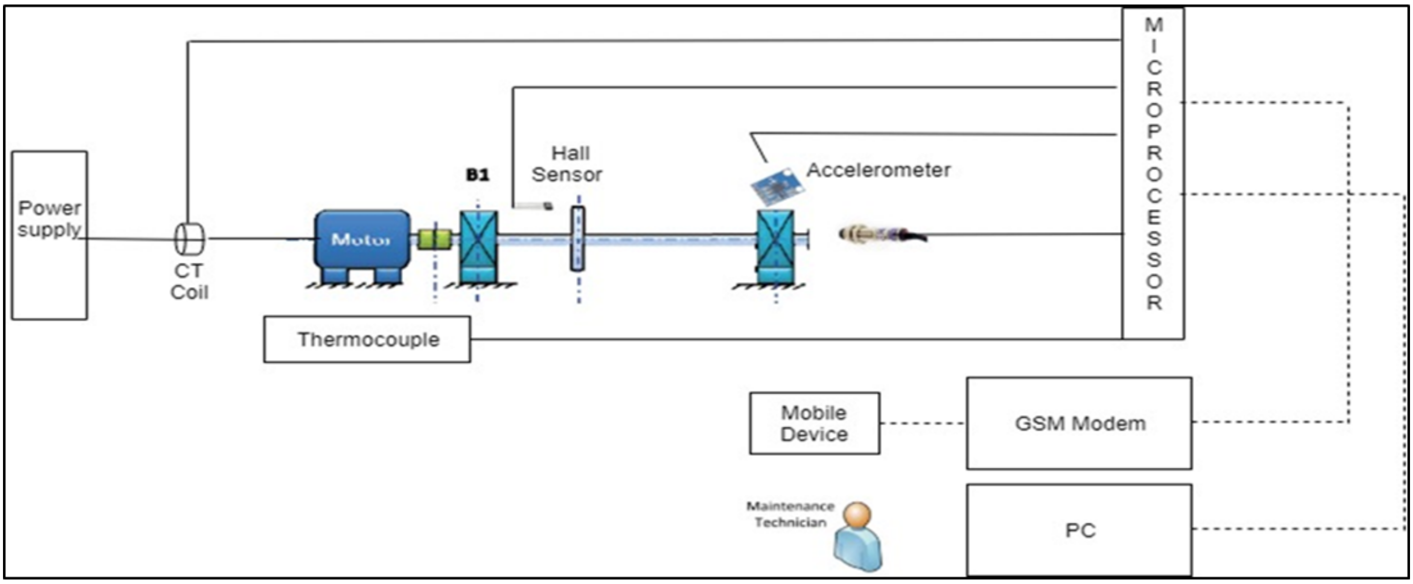

Figure 4. Schematic Diagram of the experimental setup

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RESULT AND DISCUSSIONS

In this experimental setup, an off the shelf 3-axis ADXL 345 accelerometer is used due to its cheap, portable and accurate measurements and can measure vibration in three different orientation X, Y and Z. The readings are updated every 0.5 seconds. Its mounting position is of paramount importance as it would affect the amplitude of vibrations being recorded. These reading are then saved in an excel sheet. The data is read using 'xlsread' and used to plot a graph with X vector being the frequency of the amplitude and Y vector being the amplitude value for each signal or frequency. But the generated spectrum includes only the magnitude information about each frequency component. The signature analysis of a bro rotor bar in Fig 5 and Fig 6.

With an increase in broken rotor bars, the frequency of the fault also increased. For 1 ,2,3 and 4 broken rotor bars the fault frequencies were 57 Hz, 94 Hz, 141 Hz and 208 Hz respectively. This trend has been graphically displayed in Fig. 7

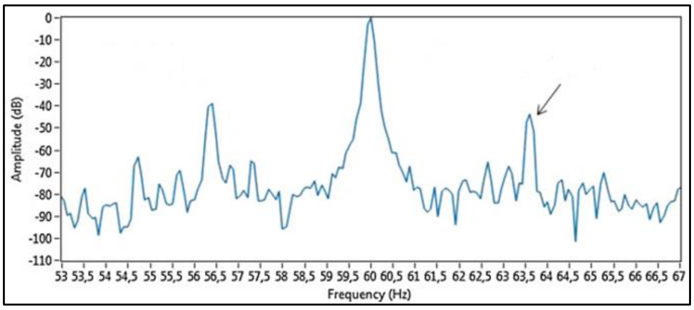

Figure 5. FFT spectrum of Loaded heavy motor with defects

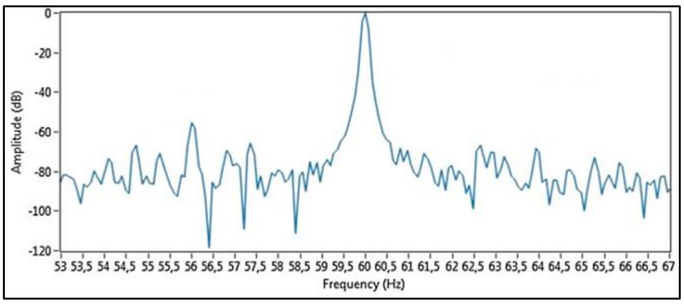

Figure 6. FFT spectrum of loaded healthy motor

A similar trend is observed when the load on the motor is increased with the increase in its RPM. Since the fault is not a spurious event and continues to degrade the mechanical stability of motor over time it is of primary concern to check the intermitted hikes in amplitude of frequency. Using other widely available sensors with the integration of IoT acts a catalyst to improve the maintenance techniques of the critical components and eliminated the use of scheduled and preventive maintenances.

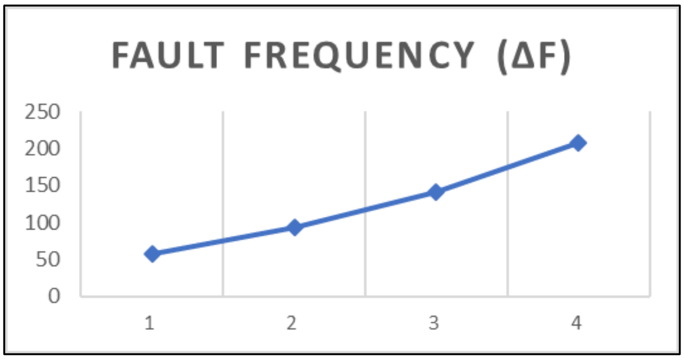

Figure 7. Variation of fault frequency with increase in broken rotor bars

CONCLUSION AND FUTURE SCOPE

The objective of this paper was to develop a novel and feasible technique of condition monitoring of critical machines used in daily life. Electrical Induction motor being the backbone of the industries and other service sectors form an integral link of the whole system and thus its reliable functioning is a must. This paper successfully achieved the target of integrating the monitoring process with IoT technology. Here motor monitored from remote places will result in better manpower utilization and labor efficiency. It offers major benefits to both, the individual users as well in industry in terms of reliability, efficiency and cost saving. This technique could be further implemented in industries for major cost savings and avoiding major downtime of critical equipment.

Data acquisition is an important step that that helps use this data to further gain more insights about the machine. Condition monitoring techniques can further be integrated with neural networks to predict the remaining life of the components. It can used to classify the faults in case of unsupervised data sets which is common in the induction motor faults. Data acquisition is a key step for predictive maintenance and as well as to detect faults. Thus, developing an independent and economical condition monitoring system with IoT technology has unprecedented potential which the industries could use to improve the productivity of their system.

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