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Detecting Faults Based on Motor Current Signature Analysis for Electric Motor

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ABSTRACT
Motor electrical current signature analysis (MCSA) is sensing an electrical signal containing current components that are direct by-product of unique rotating flux components. Anomalies in operation of the motor modify harmonic content of motor supply current. Inductions motor drives are the most widely used electrical drive system and typically consume 40 to 50 percent of an industrialized nation's total generating capacity. Induction motors have applications in the field of transportation, manufacturing, mining, and petrochemical and in almost every other fields dealing with electrical power. So, condition monitoring and fault diagnosis become necessary to monitor the health of the machine. The present paper discusses the fundamentals of Motor Current Signature Analysis and fault detection of the induction motor using MCSA.
Keywords: *Induction motor; MCSA; Signature Analysis; FFT; Fault Detection*

I. INTRODUCTION

Induction motors are mainly used in industrial drives as they are rugged, reliable and economical. Motor Current Signature Analysis (MCSA) is a condition monitoring technique which helps to find and diagnose problems in induction motors. MCSA is a method from wider field of Electrical Signature Analysis (ESA), useful for analyzing not only electrical induction motors, but also generators, power transformers as well as other electric equipment. Most popular techniques of signature analysis are: Voltage Signature Analysis (VSA), Current Signature Analysis (CSA), Instantaneous Power Signature Analysis (IPSA) and Extended Park's Vector Approach (EPVA) also includes Motor Circuit Analysis, involving analysis of resistance, impedance, inductance, phase angle, current/frequency response and insulation to ground faults [2].

Critical applications of induction motor are found in all industries and include all motor horsepower. For typical low- to medium-horsepower induction motors many of the commercial products to monitor induction motors are not cost effective. Advances in sensors, architectures and algorithms are the necessary technologies for effective incipient failure detection. For the purpose of failure monitoring, a variety of sensors could be used to collect measurements from an induction motor. These sensors can measure stator voltages and currents, case vibrations, internal and external temperature air-gap, output torque, external magnetic flux densities, rotor position and speed etc. [2].

A. Various types of faults in induction motor

There are different types of faults which occur within the three phase induction motor during the course of normal operation. These faults may lead to a potentially catastrophic failure if remain undetected [9]. The common internal faults can be mainly categorized into two groups:

1. Electrical type of faults:

The following two major types of electrical faults are very common in three phase induction motor while operating in industries.

- Stator fault

This type of fault in a symmetrical three phase ac machine cause a large circulating current to flow and leads to generation in the shorted turns. These can be line-to-line fault, Coil-to-coil fault, Open circuit fault, Turn-to-turn fault, and Line-to-ground fault.

- Rotor Fault
  The rotor faults occurs due to several reasons such as,
- While manufacturing during breezing process, non-uniform metallurgical stresses may be built into cage assembly and these may also lead to failure during operation.
- At start of machine, a rotor bar may be unable to move longitudinally in the slot which it occupies, when the thermal spaces are imposed.
- Heavy end ring can result in large centrifugal forces,
  this can cause dangerous stresses on the bars.

2. Mechanical type of faults:

In three phase induction motor, common mechanical faults found are Air gap eccentricity, this can be static eccentricity, Dynamic eccentricity and mixed eccentricity, Bearing faults and Load faults [9].In proposed approach, we concentrates on two faults such as broken rotor fault and vibration problems in induction motor.

1. Broken Rotor Bar

If there exists a broken rotor bar or open braze joint then no current will flow in the rotor bar. As a result, no field exists around that particular bar in the rotor. Therefore, the force applied to that side of the rotor would be different from that on the other side of the rotor which will create an unbalanced magnetic force which rotates at one times rotational speed and it modulates at a frequency equal to slip frequency times the number of poles.

In addition, broken rotor bars or a variation in resistivity of bar may cause a variation in heating around the rotor. This in turn can bow the rotor, creating an eccentric rotor, causing basic rotor unbalance and a greater unbalanced magnetic pull, thereby creating a high one times and some minimal twice line frequency vibration.

2. Vibration Problem

Vibration problems can occur at anytime during the installation or operation of a motor. There are many electrical and mechanical forces present in induction motors that can cause vibrations. Motor is a mechanical machine having all the forcing functions as any rotating mechanical machine. There are some conditions that shaft must be straight, the rotor must be balanced, bearings must be adequate, etc. Electrically, various inherent electromagnetic forces exist which we cannot eliminate. Problems occurs when either the mechanical, electromagnetic, or electromechanical forces become excessive, which can occur due to a number of reasons.

II. PROPOSED WORK

A. Block Diagram of Proposed Scheme

The proposed system shown in figure 1 consists of microcontroller along with other peripherals. We used microcontroller Arduino Uno as shown in figure 2. Other peripherals include Induction motor, signal conditioning circuit, current transformer, a serial communication circuit, USB to serial converter, PC and power supply. We used using induction motor with 3Kg-cm torque.Two faults are monitored first is broken rotor shaft and other is the vibration of motor. For broken rotor detection, we measured the current. The current of the motor is monitored through the current transformer. The current should effectively monitor to achieve improved condition monitoring and protection system for induction motor. A Signal conditioning circuit is used to measure current at microcontroller end. Signal conditioning is needed to make the current signal compatible to the microcontroller to read. The current is measured through internal ADC of the microcontroller. The current data in the form of digital signal is transmitted to PC end through serial communication circuit and USB to serial converter. At the PC end, current data is processed through various blocks. FFT is performed on the data. Also, healthy waveforms are stored in the database. Also, 2nd fault, the vibration of the motor is measured using vibration sensor ADXL335. The output of this sensor is analog.ADC needed to acquire the digital signal of the vibration sensor. Similar to a 1st fault, the signal of vibration sensor is also sent to MATLAB and is processed. FFT of the signals is calculated and compared with the previously stored healthy waveform.

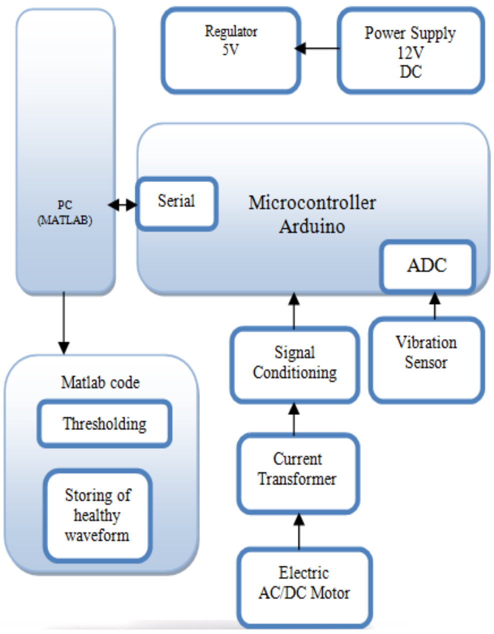


Fig. 1 Block diagram of proposed induction motor fault detection system

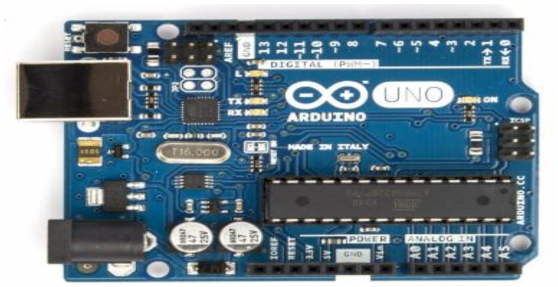


Fig.2 Arduino Uno Board

III. FAULT DETECTION AND ANALYSIS

B. Fast Fourier Transform

Motor current readings are recorded in the time domain. After that signal conditioning is performed and also signal is converted from analog-to-digital. For spectrum analysis of the motor current, spectral analysis techniques are used [4]. If signal is represented by x(t) as N discrete samples it can be expressed as a sum of N sinusoidal components of frequencies ωi, and phase shifts θi, as described in (1) and (2):

$$x(t) = A_0 + \sum_{i=1}^{N} A_i \sin(\omega_i t + \theta_i) \quad \text{……………(1)}$$

$$\omega_i = \frac{2\pi f_s i}{N} \qquad i=1, \ldots, N \quad \text{……………………(2)}$$

Where ωi, is circular frequency and fs signal sampling rate. Same signal can be expressed using sinus and a cosine term is given in (3):

$$x(t) = A_0 + \sum_{i=1}^{N} (a_i \cos(\omega t) + b_i \sin(\omega t)) \quad \text{……….(3)}$$

Values of coefficients can be determined by Discrete Fourier Transform, (4), (5), (6):

$$a_{i_i} = \frac{2}{N} \sum_{i=1}^{i=N} x(t) \cos(\omega_i t) \quad \text{…………………………(4)}$$

$$b_{i_i} = \frac{2}{N} \sum_{i=1}^{i=N} x(t) \sin(\omega_i t) \quad \text{……………………………(5)}$$

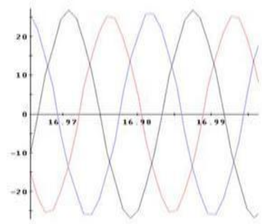
$$A_i = \sqrt{a_i^2 + b_i^2} \quad \text{………………………………………(6)}$$

Where,
a_i is cosine term,
b_i is sine term,
A_i amplitude for frequency component i.

For analyzing signals in the frequency domain, most common technique used is Fast Fourier Transform (FFT). It is a computational efficient version of Discrete Fourier Transform algorithm which reduces the necessary number of computations (from O(N^2) to O(Nlog$N$)). After applying FFT to stator supply current, amplitudes of frequency components are normalized by the value of the amplitude of first harmonic. The normalization of frequency components reduces influences of motor's load conditions.

C. Motor Current Signature Analysis technique

The motor current signature is recorded in a time domain format. The current is represented in a graphical format with the amplitude shown on the "Y" axis and the time on the "X" axis. It results in a typical current sine wave shown in Figure 3. In order to analyze the data, a Fast Fourier Transform (FFT) is performed. An example of an FFT spectrum is shown in Figure 4. FFT spectrum is a great source for identification of rotor bar problems in motors.



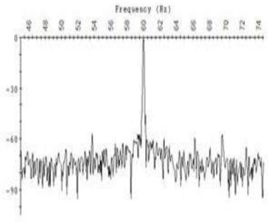


Fig.3 Current Time Domain Format
Fig.4 CurrentFrequency Domain

D. Vibration Problem Detection and Analysis

To measure frequencies we use an accelerometer. The accelerometer measures the acceleration that it being is subjected to the model used in the proposed system is mounted on a breakout board from SparkFun and use the ADXL335 3-axis accelerometer from Analog Devices [10]. It measures ±3 g in three orthogonal axes labeled the X, Y and Z direction. It can read frequencies in the range of 0.5 Hz to 1600 Hz for the X and Y axis while the Z axis has a range of 0.5 Hz to 550 Hz.

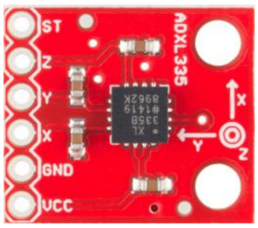


Fig.5 The accelerometer breakout board with the ADXL335

SparkFun model comes mounted with 0.1 μF capacitors that acts as a low-pass filter and limits the lower band-width of each axis to 50Hz.

Fig 6. Images of Healthy Rotor & Damaged Rotor bars

Figure 6. shows the pictures of healthy and damaged rotor bars. These healthy rotor bars shows that the condition of motor is good and its working efficiently. Damaged rotor bars degrade the performance of motor as the amount of current it was carring previously has changed. Such change in current passing through motor is analysed by its current spectrum in MATLAB.

IV. SIMULATION RESULTS

E. Output of opamp as level shifter on DSO:

The AC sine wave of current signal is shifted by some voltage as shown in fig. 7 so that the analog readings of current can be read by Arduino for further computations.

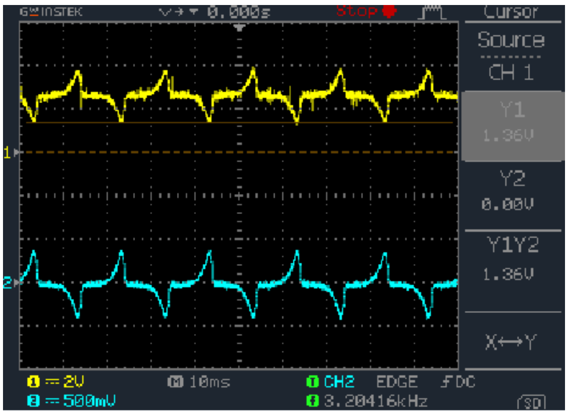


Fig.7 Level Shifted Output of Op-amp on DSO

The blue color sine wave indicates the output of current transformer on DSO. Whereas the yellow color is the shifted output of op-amp obtained at the output of LM358 which is an level shifting IC.

F. Fault Detection of Broken Rotor:

Figure 8 shows the comparision between FFT's of current waveforms. Amplitude of FFT of the signal is plotted against frequency of signal.

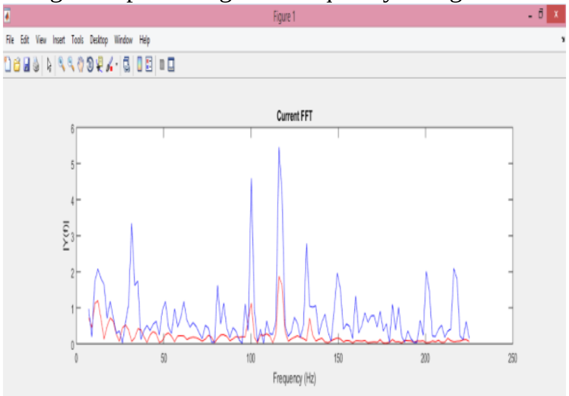


Fig.8 Comparision between FFT of healthy rotor current waveform and FFT of the broken rotor bar's current waveform

Serial data received by MATLAB is analysed and current spectrum is plotted to find out the faults in the motor. Blue color spectrum waveform indicates the FFT of healthy motor whereas red color spectrum waveform indicates the FFT of unhealthy motor.

G. Fault Detection of Vibration of motor

Figure 9 shows the difference in vibration spectrums due to the fault induced in motor.

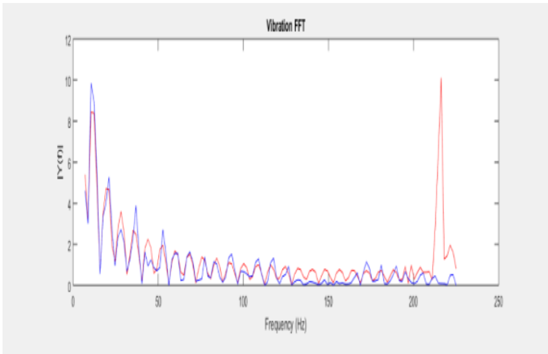


Fig.9 Comparision of vibration FFT spectrums

These spectrums are plotted against amplitude verses frequency of signal. Vibration is one of the fault used to monitor the health of the electric motor.

V. CONCLUSION

This paper discusses the fundamentals of Motor Current Signature Analysis technique which can be used for the fault detection and condition monitoring of induction motor. Two types of faults are detected and monitored. Fault analysis is done by performing FFT of the input signal by using MATLAB. Failures of electric motors cause production downtime and may generate large losses in terms of maintenance and lost revenue. Timely detection of incipient motor faults is hence of great importance. Depending on the system available for data collection and evaluation, this technique can be fairly used in conjunction with other technologies like motor circuit analysis, in order to analyze a complete motor circuit.

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