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Detection of Broken Rotor Bar Fault of Three Phase Induction Motor by Fast Fourier Transform Using ARM Microcontroller

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Abstract: Induction machines are the backbones of many industrial processes due to its robustness and reliability. Condition monitoring of induction motors is the process of monitoring the behavior of motor before significant change which leads to developing fault. Online fault diagnostics of induction motor is important, and its real function is to attempt to recognize the development of faults at an early stage, which are highly useful preventive rescue especially in high power applications. Researches reveal that motor currents and/or voltages signals are always modulated by fault condition inside the motor. Using different signal processing and mathematics techniques, these signals can be analyzed, interpreted and faults inside the motor can be identified. It is observed that the fault frequencies for different faults of induction motor are unique. MCSA (Motor Current Signature Analysis) technique using FFT (Fast Fourier Transform) approach is utilized in this research work to identify broken rotor bar fault of induction motor under different loading conditions. Hence in this paper RISC (Reduced Instruction Set Computing) based ARM (Advanced RISC Machine) architecture controller (LPC2148 from NXP) for current signature analysis is developed to analyze the broken rotor bar fault. An experimental setup, using the ARM based data acquisition board and PC based analysis software is also developed and results are given for multiple broken rotor bars fault.

Keywords: Induction motor, MCSA, FFT, Rotor fault, ARM controller

1. INTRODUCTION

Three phase induction motors play very important role in the safe and efficient running in industry and are the most widely used electrical machine. In a developing nation the induction motors can consume power nearly 50% of total generated capacity of that country [1]. They are considered inherently reliable due to its robust construction and simple design. However due to electrical, thermal and mechanical failures are unpredictable and unavoidable in induction motors, so early detection of abnormalities in the motors will help to avoid expensive failures and reduces the cost of maintenance. From the study of faults in the induction motor [2] reports clearly that percentage of rotor related fault is nearly 10% including broken rotor bar fault. It is important to notify that broken rotor bars are the common rotor fault in three phase squirrel cage induction motors. Generally rotor bar fault are happened due to thermal stresses on the rotor or frequent starting and stopping operation or imperfections in the manufacturing of rotor or pulsating in mechanical load. Once a rotor bar start to break which affect the adjacent bars also due to the increased stresses, broken rotor bar causes unbalanced current and torque pulsation resulting decreases the average torque [3]. Initially broken rotor bar do not cause stop or failure of an induction motor, but it can lead to serious secondary problem like broken rotor bar hitting the end winding at high velocity, causes weakening winding insulation resulting failure of an induction motor, it is believed that these faults starts as undetected broken rotor bar fault, which grow rapidly and causes major fault [4]. There are number of techniques available to detect the rotor faults. In last two decades several researches have been developed to identify

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the faults in the three phase induction motor. Many of these fault detection techniques based on stator current analysis and some other techniques include vibration analysis, acoustic noise measurement, temperature measurement, magnetic field analysis and torque monitoring [5][6][7], these techniques need additional equipment and transducers for measuring signals, provision of these additional equipment and sensors are very costly. Apart from the cost, sensitivity of the sensor affects due to environmental condition which makes error in the measurement. Detection of broken rotor bar fault in three phase cage induction motors is possible by based on stator current fluctuation of zero crossing times without using additional sensor [8],modeling and analysis of induction motors with rotor asymmetries [9][10][11] and the artificial intelligence based techniques [12][13]. At present current monitoring technique is popular one. Due to the advancement in the digital signal processing techniques (DSP), fault diagnosis in the induction machine is being easy for the researchers. They used motor stator current with DSP techniques such as Fast Fourier Transform (FFT). On line fault detection uses measurements taken while a machine operating to determine if a fault exists. Fig. 1 shows a block diagram of the general approach of fault detection of induction motor.

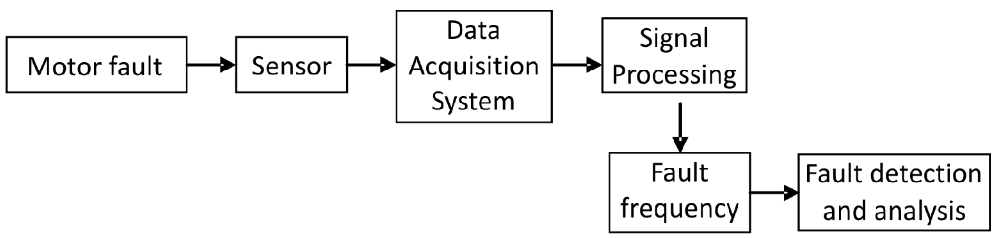


Figure 1: Block diagram of the general approach of fault detection of induction motor

The common on line detection of motor faults is known as motor current signature analysis (MCSA) [14][15]. This method based on the motor line current monitoring and consequent inspection of its deviations in the frequency domain. The objective of this technique is to find specific components in the stator current spectrum that are related to specific faults. Under this context, this paper propose a dedicated cost effective ARM data acquisition platform as well as the analysis software for the detection of rotor broken bar fault in the three phase cage induction motors using FFT approach. MCSA is a condition monitoring technique that will be used to diagnose problems in electrical motors. It has many advantages because non-intrusive, need stator winding only, not affected by loads or asymmetric. The online diagnosis using MCSA gives the spectral analysis of the stator current and detects several faults such as stator fault, rotor fault, bearing damage and eccentricity fault in induction motors. This method based on that when three phase balanced voltage applied to unbalanced machine and this voltage produces specific components in the stator current, whose magnitude and frequency depends on the asymmetry level and nature of the fault. This method is based on the current spectrum and this spectrum analyzed through Fast Fourier Transform (FFT). The fault produces harmonic components in the stator current at a characteristic frequency in the current spectrum [16]. In this paper a novel approach has been adopted by utilizing fully RISC (Reduced Instruction Set Computing) based ARM (Advanced RISC Machine) architecture controller (LPC2148 from NXP) for current signature analysis. The advantage of ARM controller is that, the hardware is highly efficient, cost effective and portable, and it can perform a very high speed analog to digital data conversion and serial transmission of the data in required resolution to universal serial bus (USB) port. The prototype hardware using ARM controller is highly suitable for performing required mathematical transformations such as FFT by using real time mathematical kernel libraries. Appropriate PC based analysis software has been developed to fetch the data from the ARM based data acquisition hardware and plots the motor current signatures in PC screen. The developed hardware using ARM and the PC based software for signature analysis is very cost effective for industries which need such types of condition monitoring systems. The extreme cost cutting in this condition monitoring system using MCSA is due to the design of a dedicated ARM data acquisition platform as well as the analysis software.

2. MCSA BASED CURRENT MONITORING TECHNIQUES

Motor Current Signature Analysis technique using Fast Fourier Transform is used to detect the broken rotor bar fault.

2.1. Detection of Broken bar rotor fault using Fast Fourier Transform

We know that a three phase balanced voltage with frequency f_1 is supplied to a three phase balanced stator winding will produce a resultant forward rotating magnetic field which rotates at synchronous speed ($120f_1/p$, p= no. of poles), there will be no resultant backward rotating magnetic field. If the supply is unbalanced or three phase stator windings impedance is unequal which cause the resultant backward rotating magnetic field produce by the stator windings. When applying the same rotating magnetic field with frequency (f_1) to the rotor which induces voltage in the bars, the bars are short circuited either end by end rings, so the current will be flowing in the rotor bars is at slip frequency f_2 (i.e.) $f_2=sf_1$, s= rotor slip. This symmetrical rotor bar current produces three phase forward rotating magnetic field with same no. of poles as the stator magnetic field but rotating at slip frequency. If there is any asymmetry (broken bar) occurs in the rotor, there will be resultant backward rotating magnetic field at slip frequency which induces voltage and current in the stator winding at

$$f_{sb} = f_1(1 \pm 2s) \text{ Hz} \quad (1)$$

This is referred to as the lower sideband twice slip frequency due to broken rotor bars. There is a variation of current in the rotor causes a torque pulsation at twice slip frequency ($2sf_1$) resulting oscillation in the speed. This speed oscillation can reduce the amplitude (amperes) of the lower sideband $f_1(1 \pm 2s)$ but it induces upper sideband current component at $f_1(1+2s)$ in the stator winding. From that the current components being induced in the stator windings due to broken rotor bars is[16][17]

$$f_{sb} = f_1(1 \pm 2s) \text{ Hz} \quad (2)$$

These sidebands are found in the stator current spectrum around the supply frequency, the frequency of sideband can be expressed in equation (2)

Stator phase current is measured directly with the help of current transformer and then noise components and unwanted high frequencies are filtered. A window of sampled points is recorded for a certain time depending on frequency resolution selected. Signal processing technique such as FFT is applied to detect the fault. A FFT is an algorithm designed to extract the frequency information from the time domain and transform into the frequency domain. FFT reduces the amount of calculation required. Fourier transforms are good to analyze standing signals, it means non transitory.

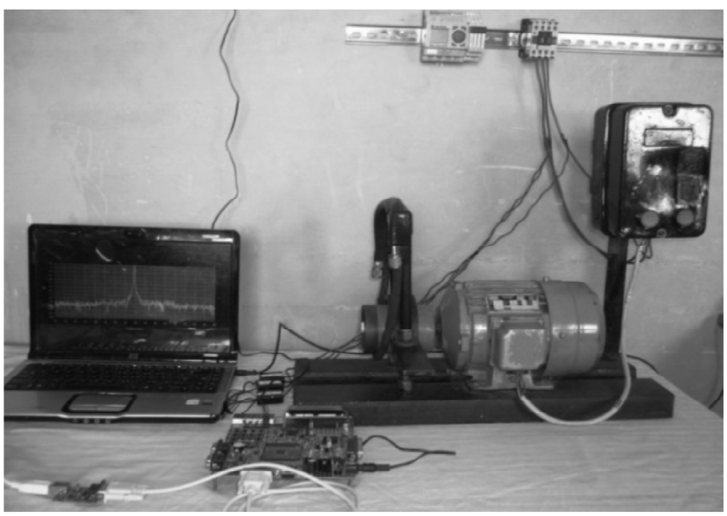
Broken rotor bars fault have produced certain frequency components in the current spectrum. The incipient fault can be identified by sampling the stator current and analyzing its current spectrum. In induction motor, the frequency produced by broken rotor bar failure in the stator current around fundamental frequency is given in equation (2). From this equation, the abnormal fault frequency of stator winding due to broken rotor bar fault can be calculated and these values are shown in table(1),

Table 1
Expected fault frequencies at various load conditions

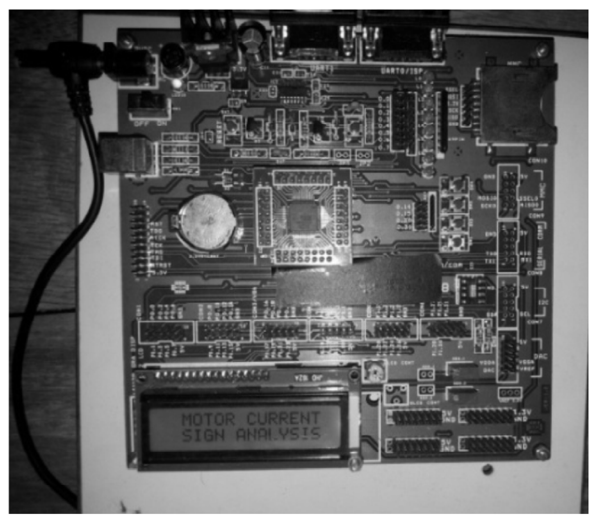
Speed (rpm)	*Slip*	*Loading conditions*	*Fault frequencies (Hz)*	
			LSB	*USB*
1450	0.033	Quarter load	46.7	53.3
1438	0.041	Half load	45.9	54.1
1379	0.081	Full load	41.9	58.1

2.2. Experimental Setup

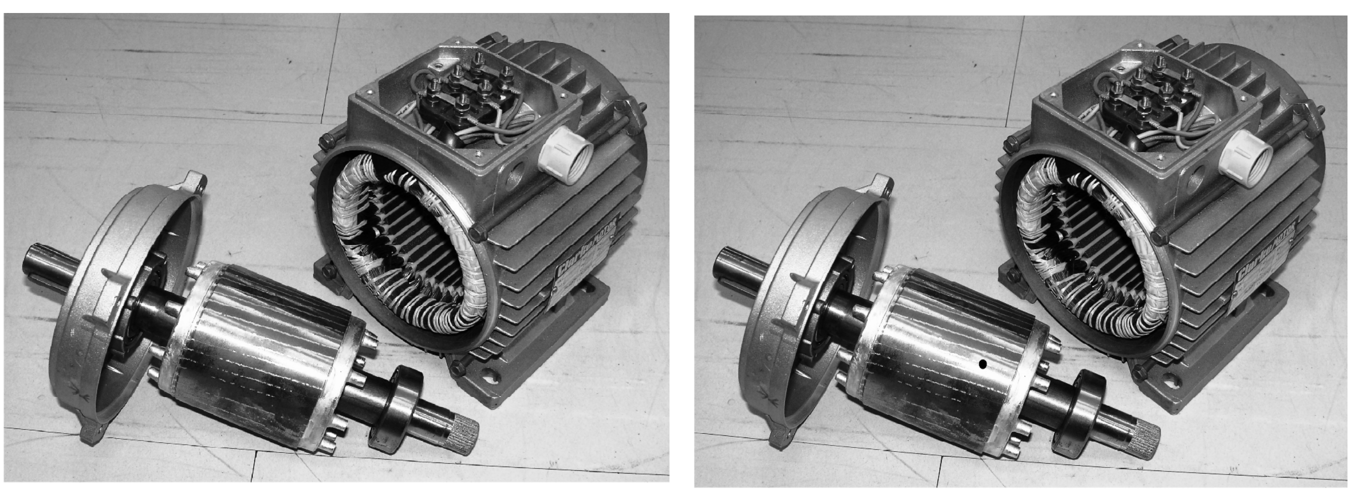
The experimental setup for MCSA is shown in Fig. 3. It comprise of a three phase induction motor of 0.75HP, 1460RPM, 50Hz, DOL starter, current transformer, data acquisition hardware using ARMLPC2148 microcontroller, a LCD display, PC with i-core3 processor with windows7 operating system and signature analysis software through mathematical transforms. The specification of three phase motor and data acquisition hardware is presented in the table (2) and (3) respectively. In order to identify current signature of healthy as well as faulty motor with load and without load, suitable laboratory arrangement are made to perform the experimental analysis. As the motor runs, the current is sampled and given to the data acquisition hardware which is build around ARMLPC2148 microcontroller. ARMLPC2148 microcontroller has RISC architecture and suitable user peripherals such as 10 bit ADC with 8 analog input channels and also built-in USB port. The controller is driven by 20MHz crystal oscillator. The ADC as well as USB port of ARMLPC2148 microcontroller forms the heart of the data acquisition hardware. The current signals are sampled and converted into digital values and communication to PC via USB port at 10Mbps speed. The analysis software acquires the current as equivalent digital data and performs FFT by means of mathematical libraries suitable for .NET frame work in VB.NET programming language. This software is developed exclusively for FFT analysis of the current acquired through the DAQ board. In this experimental setup, broken rotor bar fault is studied using the DAQ board as well as the plotting software.



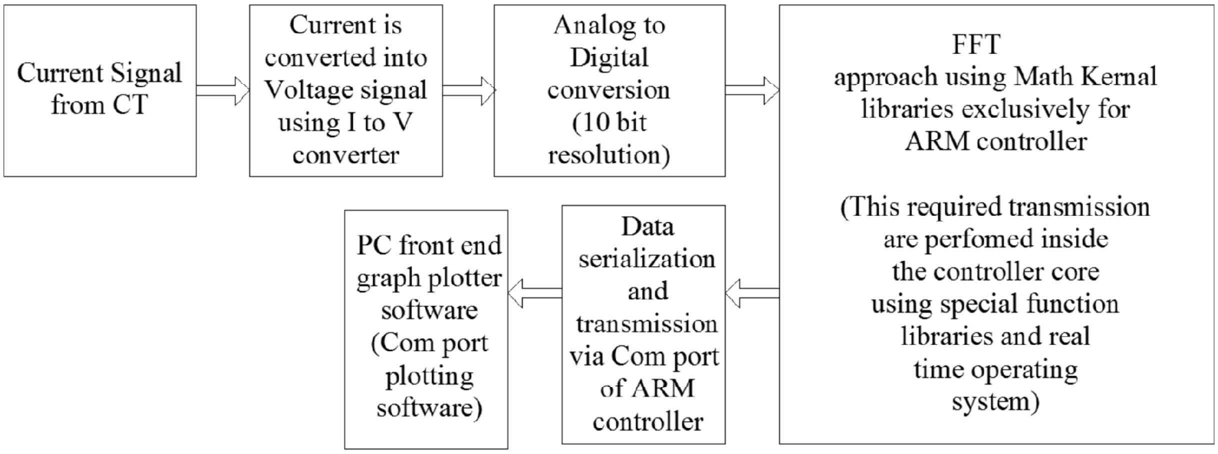
(a) Experimental Setup



(b) Data Acquisition Board



(c) Healthy and Broken rotor bar



(d) Block diagram of rotor broken bar fault detection

Figure 3: Experimental setup and Block diagram

Table 2
Electrical Name plate characteristics of Induction Motor

S. No	*Parameter*	*Details*
1	Frame	B 80L
2	Volts	415 volts
3	Horse Power	0.75
4	KW rating	0.55 KW
5	RPM	1460
6	Phase	Three
7	Frequency	50 Hz
8	Current	1.5 amps
9	No. of poles per pair	2
10	No. of rotor slots	36
11	Efficiency	85%
12	Make	Batliboi

Table 3
Specifications of Data acquisition Hardware (DAC LPC2148 Board)

S. No.	*Specifications*	
1	Analog inputs	8
2	Resolution	10 bits
3	Analog input span	0 – 3.3 volt
4	Sampling rate	0.1 micro second
5	Clock speed of data acquisition. HW	20 MHz
6	Supported Transforms	FFT
7	PC interface	USB

3. RESULTS AND DISCUSSION

In this section, Motor current signature analysis is carried out with the help Fast Fourier Transform and laboratory test results are presented for various broken rotor bar fault.

3.1. Motor current signature analysis using FFT

The broken rotor bar tests were carried out by boring in the bars with drill (Fig.3(c)). Initially, the test was carried out with the healthy motor and then the rotor was bored in order to test the broken rotor bar fault under various loading conditions.

The different faults are performed in the 36 rotor bars three phase squirrel cage induction motor. The following cases have been tested.

(i) Healthy rotor at no load

(ii) One bar broken at quarter load, half load and full load

(iii)Two broken bars at quarter load, half load and full load

(iv)Three broken bars at quarter load, half load and full load

3.1.1. Case (i): Healthy rotor at no load

The current spectrum of a healthy three phase induction motor at no load is shown in figure (4), where slip(s) = 0.027.

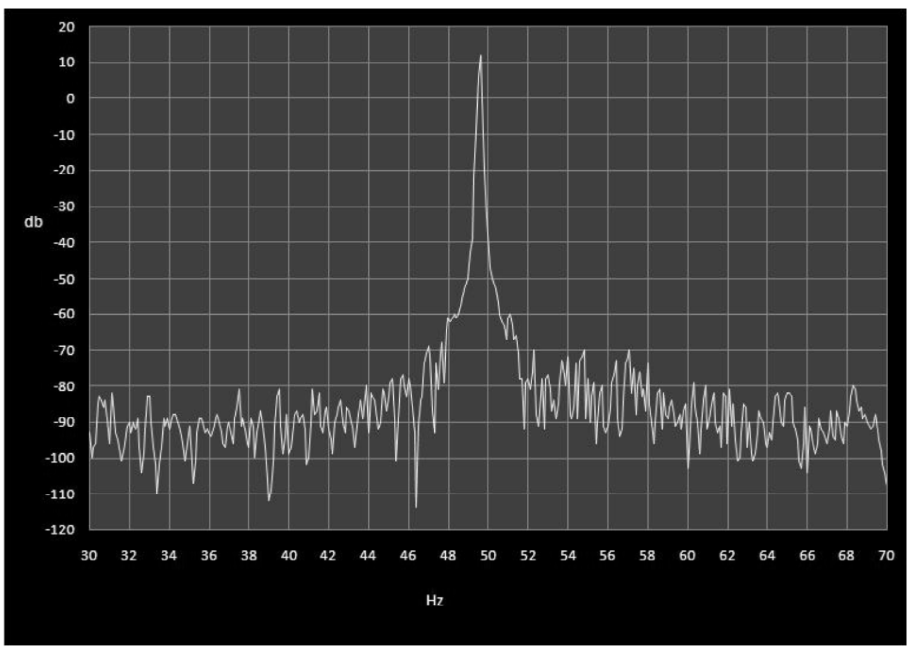


Figure 4: Current spectrum of healthy rotor

3.1.2. Case (ii): One broken bar failure

The current spectrum of one broken bar failure of three phase squirrel cage induction motor at quarter load, half load and full load has shown in figures (5.1), (5.2) and (5.3) respectively. At quarter load the side band frequency is very nearer to the supply frequency and the amplitude of side band frequencies are very lesser value because of the current in the rotor bars is smaller value. The lower side band (LSB) fault frequency is at 46.7Hz with amplitude of -81db and upper side band (USB) fault frequency is at 53.3Hz with amplitude of -81db. At half load the side band fault frequencies are clearly visible, the lower side band fault frequency is at 45.9Hz with amplitude of -72db and upper side band fault frequency is at 54.1Hz with amplitude of -79db. The side band frequencies for also visible at full load, it can be seen that the lower side band fault frequency is at 41.9Hz with amplitude of -68db and upper side band fault frequency is at 58.1Hz with amplitude of -68db. It can be observed that the amplitude of side band frequencies is increases with increase in the load on the motor. From the observations it can be realized that fault frequency component coincide with predicted values (table 1)

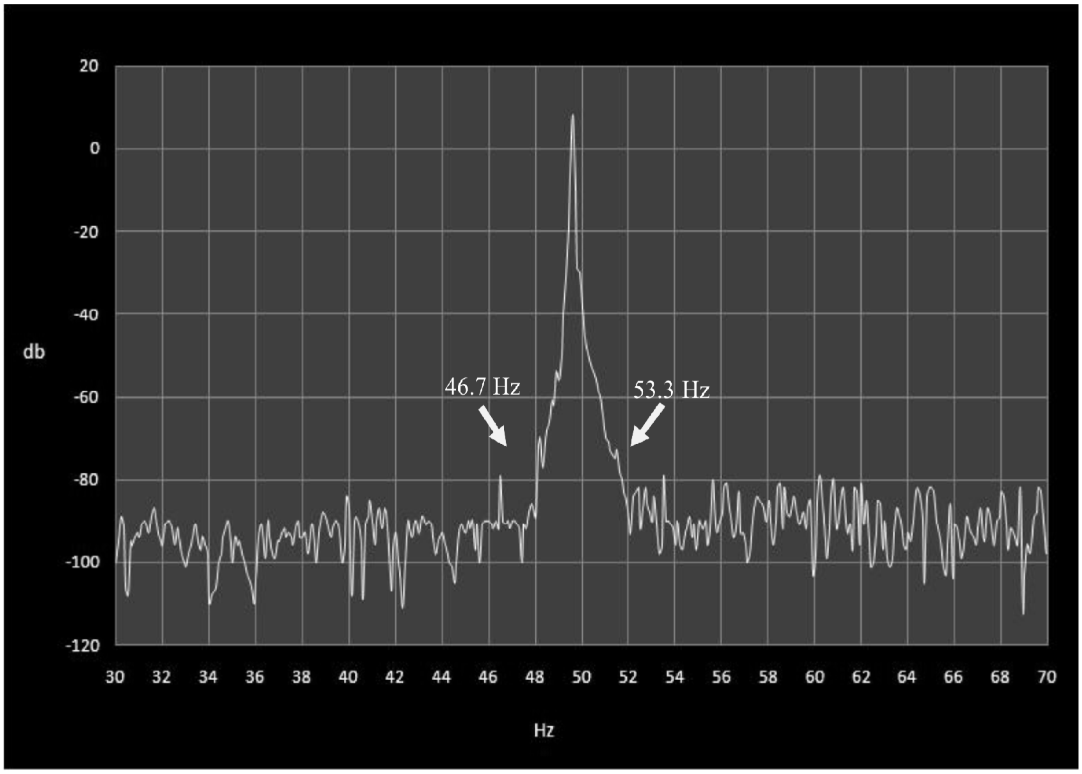


Figure 5.1: Current spectrum of faulty motor with one broken bar under quarter load condition

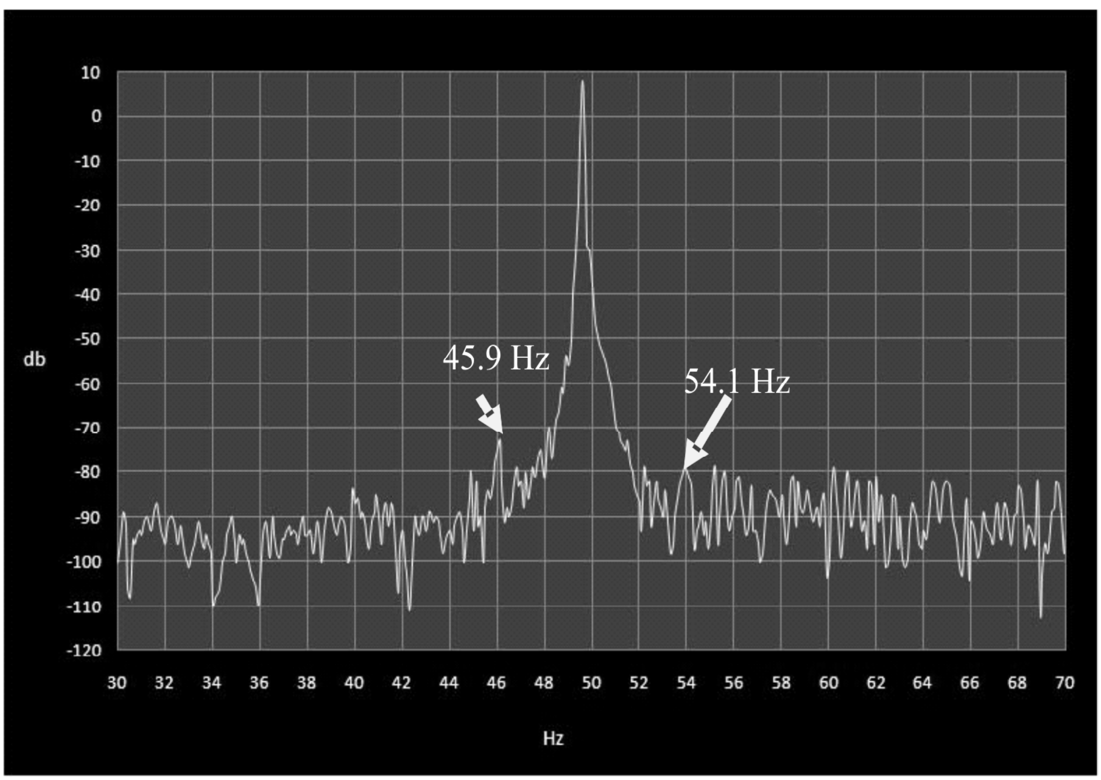


Figure 5.2: Current spectrum of faulty motor with one broken bar under half load condition

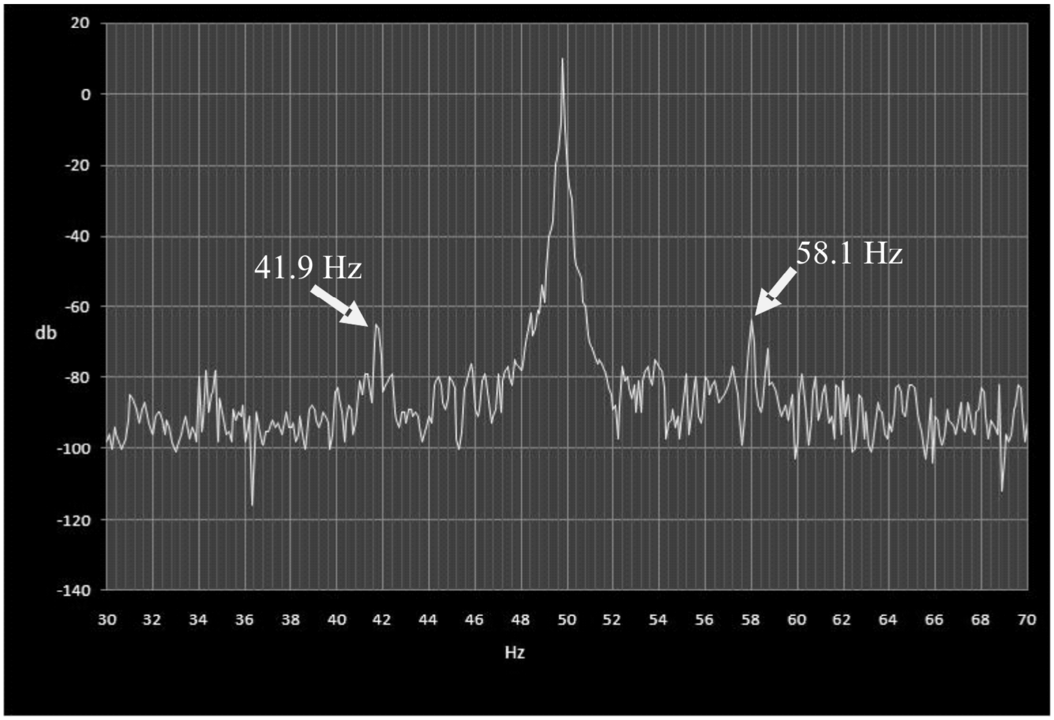


Figure 5.3: Current spectrum of faulty motor with one broken bar under full load condition

Table 4
Current spectrum analysis of one broken rotor bar failure at different loading conditions

Slip	*Loading conditions*	*Fault frequencies(Hz)*		*Amplitude(db)*	
		LSB	*USB*	*LSB*	*USB*
0.033	Quarter load	46.7	53.3	-81	-81
0.041	Half load	45.9	54.1	-72	-79
0.081	Full load	41.9	58.1	-68	-68

3.1.3. Case (iii): Two broken bar failure

The current spectrum of two broken bar failure of three phase squirrel cage induction motor at quarter load, half load and full load has shown in figures (6.1), (6.2) and (6.3) respectively. At quarter load the lower side band (LSB) fault frequency is at 46.7Hz with amplitude of -76db and upper side band (USB) fault frequency is at 53.3Hz with amplitude of -76db. At half load the LSB fault frequency is at 45.9Hz with amplitude of -62db and upper side band fault frequency is at 54.1Hz with amplitude of -62db, The side band frequencies for two broken bar at full load is LSB fault frequency is at 41.9Hz with amplitude of -61db and USB fault frequency is at 58.1Hz with amplitude of -62db. From the figures it can be seen that fault frequency component coincide with predicted values (table 1).

Table 5
Current spectrum analysis of two broken rotor bars failure at different loading conditions

Slip	*Loading conditions*	*Fault frequencies(Hz)*		*Amplitude(db)*	
		LSB	*USB*	*LSB*	*USB*
0.033	Quarter load	46.7	53.3	-76	-76
0.041	Half load	45.9	54.1	-62	-62
0.081	Full load	41.9	58.1	-61	-62

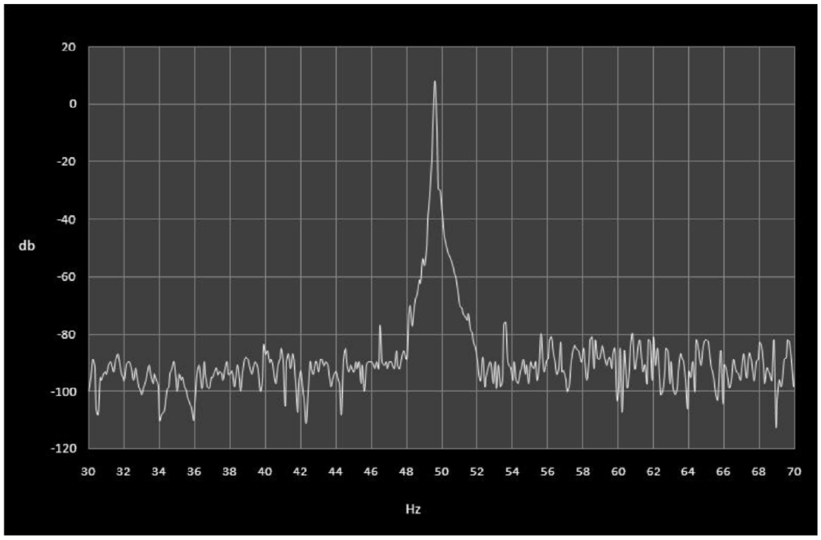


Figure 6.1: Current spectrum of faulty motor with two broken bar under quarter load condition

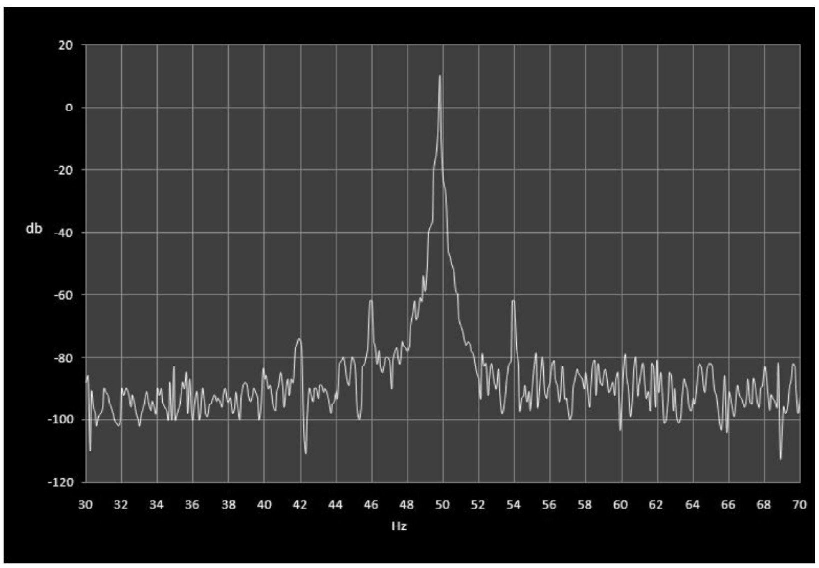


Figure 6.2: Current spectrum of faulty motor with two broken bar under half load condition

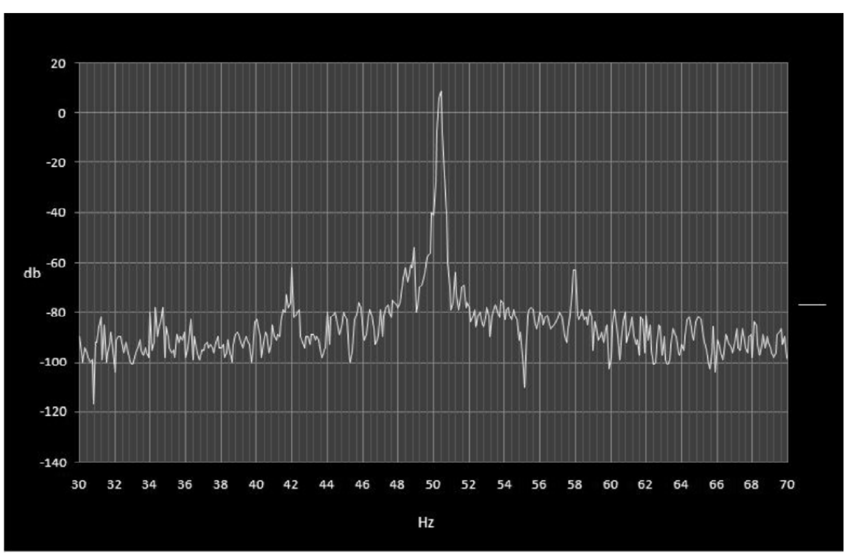


Figure 6.3: Current spectrum of faulty motor with two broken bar under full load condition

3.1.4. Case (iv): Three broken bar failure

The current spectrum of three broken bar failure of three phase squirrel cage induction motor at quarter load, half load and full load has shown in figures (7.1), (7.2) and (7.3) respectively. At quarter load the lower side band (LSB) fault frequency is at 46.7Hz with amplitude of -74db and upper side band (USB) fault frequency is at 53.3Hz with amplitude of -74db. At half load the lower side band fault frequency is at 45.9Hz with amplitude of -60db and upper side band fault frequency is at 54.1Hz with amplitude of -60db.The side band frequencies for three broken bar at full load, the LSB fault frequency is at 41.9Hz with amplitude of -58db and USB fault frequency is at 58.1Hz with amplitude of -58db. From the observations it can be understand that fault frequency component coincide with predicted values (table.1)

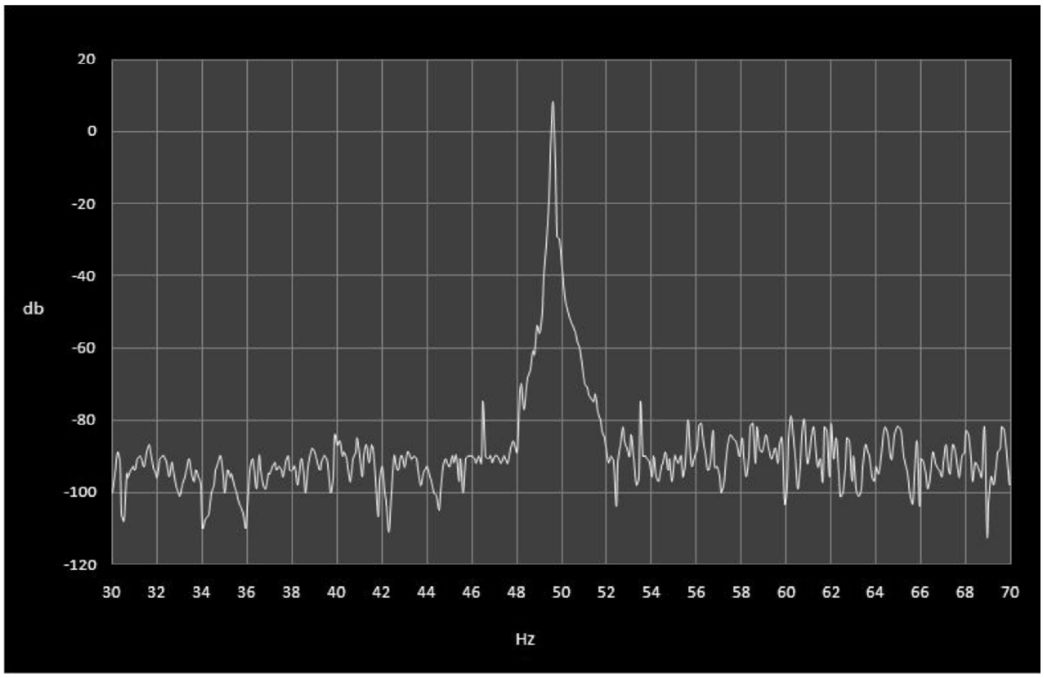


Figure 7.1: Current spectrum of faulty motor with three broken bar under quarter load condition

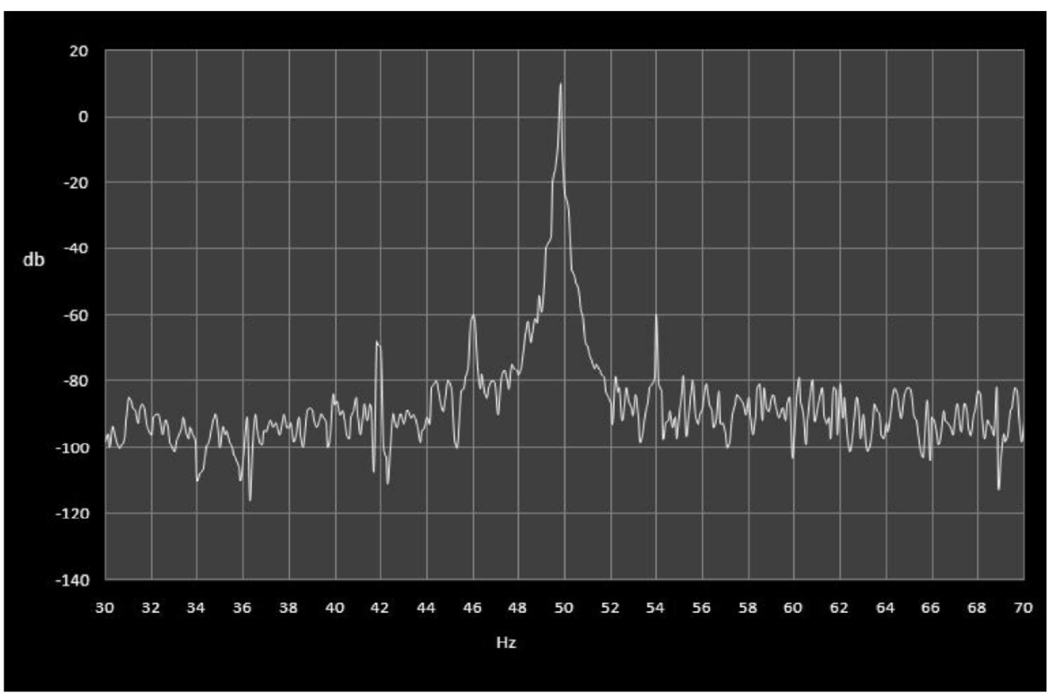


Figure 7.2: Current spectrum of faulty motor with three broken bar under half load condition

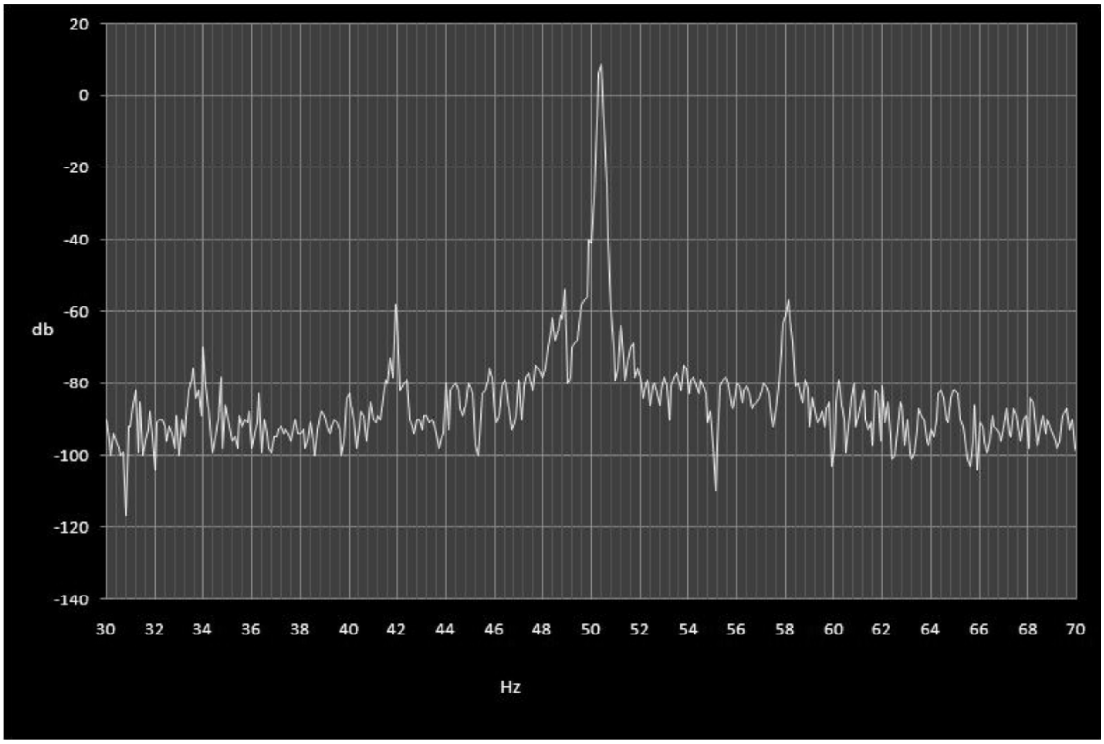


Figure 7.3: Current spectrum of faulty motor with three broken bar under full load condition

Table 6
Current spectrum analysis of three broken rotor bars failure at different loading conditions

Slip	*Loading conditions*	*Fault frequencies(Hz)*		*Amplitude(db)*	
		LSB	*USB*	*LSB*	*USB*
0.033	Quarter load	46.7	53.3	-74	-74
0.041	Half load	45.9	54.1	-60	-60
0.081	Full load	41.9	58.1	-58	-58

From the equation (2) and from the results given in tables 4-6, the fault frequencies quarter load, half load and full load can be predicted, which are same irrespective of the severity of the fault. Only the amplitude will raise depends on the severity of the fault, which are clearly reflected in the experimental results.

CONCLUSION

This paper dealt with the method of broken rotor bar fault detection in three phase squirrel cage induction motors based on MCSA using FFT. The detection of broken rotor bar failure in induction motor is found by analyzing the current spectrum of stator current. It is experimentally observed that when the load on the induction motor increases, the amplitude of fault frequencies of the induction motor also increases. In this paper, RISC (Reduced Instruction Set Computing) based ARM (Advanced RISC Machine) architecture controller (LPC2148 from NXP) for current signature analysis is developed. The ARM based data acquisition board and PC based analysis software are cost effective and the experimental results are well focused for various loading conditions of broken rotor bar fault using FFT approach. The fault frequency and corresponding amplitude values are listed in table, which gives an idea about the severity of the fault. The result of experiment shows that FFT approach can be successfully used for on line diagnosis of rotor broken bar fault using the developed experimental setup.

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