International Journal of Advanced Computer Research (ISSN (print): 2249-7277 ISSN (online): 2277-7970)
Volume-3 Number-4 Issue-13 December-2013

Fault Detection of Induction Motor Using Current and Vibration Monitoring

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Abstract

Induction motors are used worldwide as the "workhorse" in industrial applications. Although, these electromechanical devices are highly reliable, susceptible to many types of faults. Condition monitoring and fault diagnosis of induction motors are of great importance in production lines. It can significantly reduce the cost of maintenance and the risk of unexpected failures by allowing the early detection of potentially catastrophic faults. In this paper I have used both vibration and motor current signature analysis to detect the fault. The various fault discussed in this paper are- Mechanical fault such as bearing damage and Electrical Fault such as unbalanced voltage supply, single phasing. Condition monitoring, signal processing and data analysis are the key parts of the Induction Motor fault detection scheme.

Keywords

Induction Motor, Unbalance voltage, bearing damage, condition monitoring, FFT.

1. Introduction

The fault detection and protection are as historic as Induction Motor themselves. Induction motors are critical components in many industrial processes. They are very robust and highly reliable machines however they may be subjected to different types of faults. Failure of such Induction motor may cause plant shutdown, personal injuries and waste of raw material. However, induction motor faults can be detected in an initial stage in order to prevent the complete failure of an induction motor and unexpected production costs.

The main reason for the motor faults is mechanical and electrical stresses. Mechanical stresses are caused by overloads and abrupt load changes, which may cause bearing faults and rotor bar breakage. The electrical stresses may produce stator winding short circuits and result in a complete motor failure.
The different fault may occur in Induction motor can be classified as follows.

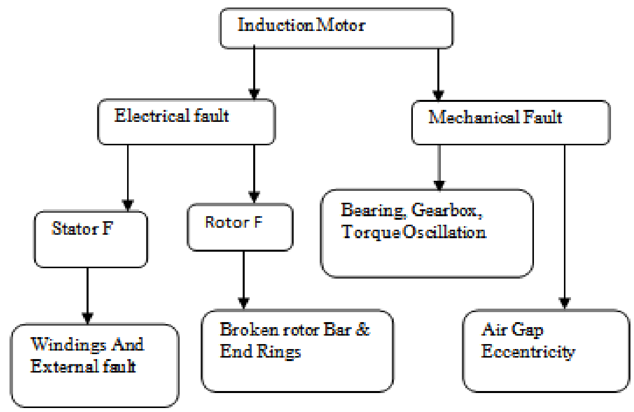

Figure 1: Types of Fault

Bearing faults are the most frequent fault in Electric Motors (41%) according to an IEEE motor reliably study, followed by stator (37%) and rotor fault (10%) [7].

Condition monitoring of Induction motor are of great importance in the production lines. Condition monitoring means continuous evaluation of the health of the motor throughout its service life. There are many condition monitoring methods, including vibration monitoring, thermal monitoring, chemical monitoring, current monitoring techniques are usually applied to detect the various types of induction motor fault. I mainly use Current and Vibration monitoring to detect the fault. In current monitoring, no additional sensors are necessary. This is because the basic electrical quantities associated with electromechanical plants such as current and voltage are readily measured by tapping into the existing voltage and current transformers that are always installed as part of the protection system and for stationary signal this method is beneficial. This method uses the current spectrum of the machine for locating characteristic fault frequencies. But for non stationary signal vibration monitoring is best. In vibration monitoring a vibration spectrum is used to detect the fault in induction motor. Vibration and current are widely used in the industry since both allow detecting several fault conditions from distinct nature [7, 8]. Now days fault diagnosis uses modern techniques data processing and spectral analysis

techniques. In this paper I used the Fourier spectral analysis by FFT to extract the features, which are sensitive to the presence of faults. In this study I used a DAQ card to acquire a sensor signal and a MATLAB programmed to detect the fault frequency.
Mechanical and Electrical faults print frequency features in the spectrum of current and vibration which can be used for fault detection by comparing the amplitude of certain frequency components under fault and normal conditions. Therefore, this paper is organized as follows: first, a qualitative description of the unbalance voltage condition, single phasing, bearing damage, MCSA and vibration are presented. Secondly, experimental are introduced to show the signatures associated to this fault using vibration and stator current signals in an Induction motor. [3, 6].

2. Methodology

A. Bearing Fault in Induction motor

Bearing are common elements of Induction Machines. They are employed to permit the rotary motion of the shaft. The bearing mainly consists of two rings called the inner and outer rings. A set of balls or rolling elements placed in raceways rotate inside these rings. A continued stress on the bearings cause fatigue failures, usually at the inner and outer races of the bearings. Small pieces break loose from the bearing, called flaking or spalling. These failures result in rough running of the bearings that generates detectable vibrations and increased noise levels. And this process is helped by other external sources including contamination. Corrosion, brinelling, improper lubrication, improper installation. In some case shaft voltage and current are also sources for bearing failure. High bearing temperature is also another reason for bearing failure.

The different faults that may occur in bearing as follows

- Outer raceway defect
- Inner raceway defect
- Ball defect

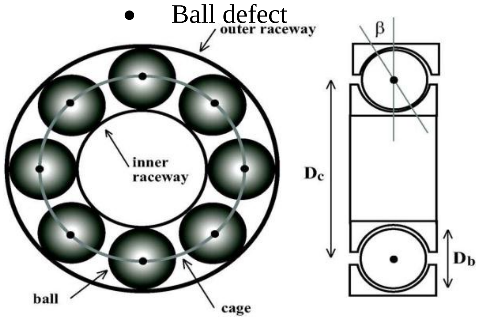

Figure 2: Ball bearing dimensions

Figure 3: Inner Race Fault

Figure 4: Outer Race Fault

B. Unbalance in supply voltage

A very important aspect of condition monitoring of induction motor is to detect the external faults. Unbalance in supply voltage and single phasing are the two types of external faults of induction motor are considered in my work. Unbalance in supply voltage is created by connecting three single phase transformers in three phases of the supply. Here supply voltage in B phase is reduced to 10% less than the rated voltages in the other two phases to create unbalance. Unbalance voltage is nothing but unequal distribution of incoming voltages or when the phase separation is not 120º. When there are unequal incoming voltages between the three legs of a motor, the motor runs hotter. The reason why an unbalance motor runs hotter is because as the voltage is out of balance so is the winding current. A small voltage unbalance causes a larger current unbalance, which in turns causes the motor.

Types of voltage unbalance

- Single phase under voltage
- Two phase under voltage
- Three phase under voltage

Single phase under voltage unbalance condition arises when there is a large single phase load in the system and it doesn't have enough compensation. In this situation the voltage in that particular phase will be lower than the other two phases.

Two phases under unbalance condition arises when two of three phases have heavy load and don't have enough compensation. In this situation those two phases will have a higher voltage drop than third phase. Three phases under unbalance condition arises when the loads of three phases are too heavy and not balanced. Because of voltage unbalance condition resistive load are generally unaffected but it generates excessive heat. Motor torque and speed are affected by the voltage unbalance condition it creates excessive noise and vibration [1].

C. Single Phasing Fault

For proper working of any three phase induction motor, it must be connected three phase alternating current (Ac) power supply of rated voltage and load. Once these three phase motors are started they will continue to run even if one of the three phase supply lines gets disconnected. The loss of current is described as single phasing. Single phasing is the condition in three phase motors and transformers wherein the supply to one of the phases is cut off. Single Phasing causes negative phase sequence components in the voltage. Single Phasing is cause by the use of single phase protection devices such as fuses and circuits breakers. Three phase loads should be protected by devices which cause the interruption of power to all three phases simultaneously hence a fault occurs. Defective contacts in three phase breakers can also cause single phasing. It can be sometimes cause excessive noise and vibration in motors.

D. Condition Monitoring System

Condition monitoring means to access the actual condition of motor using the measurements taken while the motor is operating.

I mainly use two types of condition monitoring technique to detect different fault. Current and vibration monitoring. A block diagram for condition monitoring for fault diagnosis is shown in figure 5.

This is the method for fault diagnosis. In this stage, First of all we create different fault (such as bearing fault, unbalance voltage) due to which symmetry of motor would effect and creates fault characteristics frequency. After that we get that fault frequency by different type of sensors (such as for vibration signal we can use piezoelectric accelerometer, for speed measurement tachometer etc.) shown in block B. In

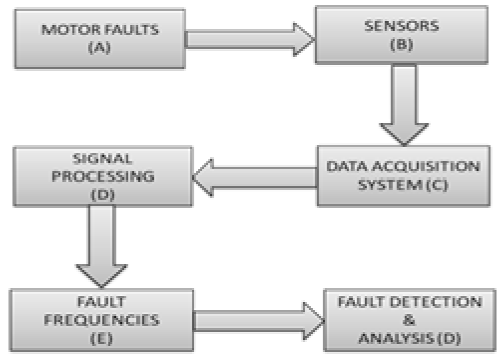

Figure 5: The process for fault diagnosis

the next stage we use a DAQ system means Data acquisition system to record that sensor signal in the digital form. In block C we used different type of signal processing techniques (such as FFT, STFT, Wavelet) to analysed that sensor signal and to extract the feature which are sensitive to presence of fault. In next step we get the fault frequency of different fault by analysing the sensor signal. And finally we get detailed information and degree of severity.

1. Current Monitoring

Current Park's Vector, Zero sequence and negative sequence current monitoring and current signature analysis fall under category of Electrical monitoring. These methods use stator current to detect various kinds of machine and inverter faults. In most applications, the stator current of an induction motor is readily available since it is used to protect the machines from destructive over currents, ground currents etc. Therefore current monitoring is sensor less detection method that can be implemented without any extra hardware. [8]

Motor Current Signature Analysis

This method is used current spectrum to detect the various faults. It is the online analysis of current to detect faults in three phase induction motor. This method analyses the motor signal by using signal processing algorithms such as FFT, STFT, and Wavelet etc. MCSA techniques include parametric, nonparametric, and high-resolution spectrum analysis methods. In the parametric methods, autoregressive (AR) models have been fitted with time series of the signal, and model parameters have been used to compute the frequency spectrum. Furthermore, nonparametric methods are based on Fourier transforms in order to search for periodicities of the signal. And finally a high resolution spectrum

method corresponds to an Eigen value analysis of the autocorrelation matrix of the time series signal [2, 9, and 10]. One of the classical and widely used nonparametric spectrums method as a MCSA technique is the well-known fast Fourier transform (FFT). The FFT is a simple and computationally efficient algorithm to compute the discrete Fourier transform (DFT) of a discrete-time series function.
In my work I used the FFT technique to analyse the signal.

2. Vibration Monitoring

All electric motors generate noise and vibration, and analysis of produced noise and vibration can be used to give information on the condition of motor. Even very small amplitude of vibration of machine frame can produce high noise. Noise and vibrations in electric machines are caused by forces which are of magnetic, mechanical and aerodynamic origin. For stationary signal MCSA best but for non-stationary signal it's not convenient option for non-stationary signal vibration monitoring is generally used.

Four vibration properties are crucial to understanding and resolving the machine problems. These include
Amplitude, which indicate the level of severity of the measured condition. Frequency, which indicates the repetition rate of the contributing source or sources of the measured condition; Phase, which presents the timing relationship between two signals contributing to the measured condition; Modulation, the process by which the response amplitude at some frequency is varied by a lower frequency excitation response.
With the help of this we can get detail information about asymmetry in motor [4].

3. Experiment Set Up 1

Unbalance supply voltage and Single phasing Analysis (MCSA Approach)

In order to diagnose unbalance supply voltage of induction motor, same laboratory test bench is used as shown in Figure 6. It consists of three phase induction motor, current transformer, NI data acquisition card 9203 and Personnel Computer with software Lab VIEW 2011.The rated data of the tested three-phase squirrel cage induction machine were: 1 hp,415 v,1.6Amp. Data under healthy condition of the motor were acquired at first. Then different faults were then created in the motor and data was obtained for the faulty conditions. Unbalance in the supply voltage and single phasing are the two types of external faults of an induction motor that are considered in this work. Unbalance in supply voltage is created by connecting three single phase transformers in three phases of the supply. Here supply voltage in B phase is reduced to 10% less than the rated voltages in the other two phases to create unbalance. In this experiment I have created unbalance supply by setting different voltages for each phase because of that reason I used three single phase auto transformer.

Figure 6: Experiment Set-up for unbalance voltage and single phasing.

Three phases under- voltage unbalance condition
After continuous analysis on that single phase at 140 volt I create a three phase under voltage condition where that all three voltages are too heavy and try to balance the condition. On my next analysis I still increase the voltage of that blue phase till the 160 volt, in this condition that voltages are still too heavy and in this condition motor starts to burn.Fig.12

Single Phasing Fault

In this experiment I have created a single phasing fault by removing the yellow phase. Because of that condition motor starts vibrating and noise was also generates. In this condition because of removing one phase other two phase try to balance the condition. I take FFT to extract the feature which is sensitive to presence of fault. (Fig.13)

In order to diagnose the single phasing of induction motor, same set up I have used to detect the single phasing fault. Single phasing is created by connecting a knife switch in B phase. Here one phase is opened to create single phasing.

Results and Discussion

The experiments have been performed to detect the unbalanced supply voltage faults in three phase induction motor using Lab VIEW software. Different unbalanced condition. The results obtained from these experiments are given below.

Balanced Condition

First of all I create a balanced condition; here I create a balanced condition by setting same voltage of each phase. Means this is nothing but a healthy condition of motor. After that I take FFT of that balanced condition to extract the features which are sensitive to the presence of fault.Fig.7and8.

Unbalanced Condition

Here I create a unbalanced condition by setting different voltage of each phase. Means this is nothing but a faulty condition of motor. After that I take FFT of that unbalanced condition to extract the features which are sensitive to the presence of fault. (Fig.9 FFT) Single phase under- voltage unbalance condition this is my analysis on the unbalance condition, First of all I analysis on the one phase i.e. Blue phase. Here I take lower voltage of blue phase which is 40 volt and from this condition I concluded that this is nothing but a single phase under unbalance condition. In this condition the voltage in that particular phase is lower than the other two phases, in this condition that two voltages try to balance the condition. Fig10.

Two phases under- voltage unbalance condition

In the next step I increase the voltage of that particular phase at 60 volt after that I still increases up to 80 volt, and in this condition I concluded that this is the two phase under voltage unbalance condition where two phases have the higher voltage drop than the third one.(Fig.11)

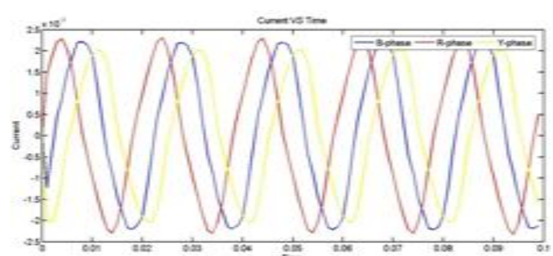

Figure 7: Time Domain Signal (Balanced Supply)

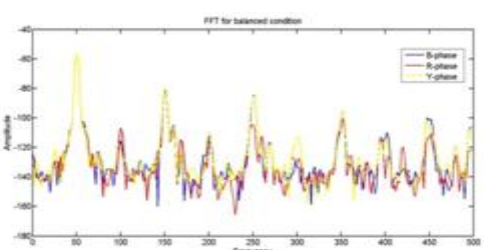

Figure 8: FFT (Balanced Supply)

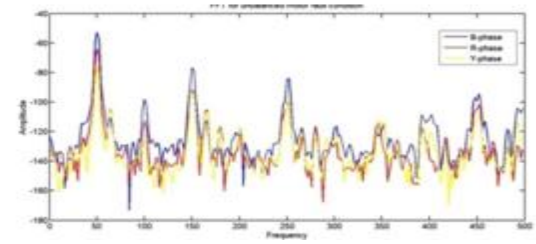

Figure 9: FFT (Unbalanced Supply)

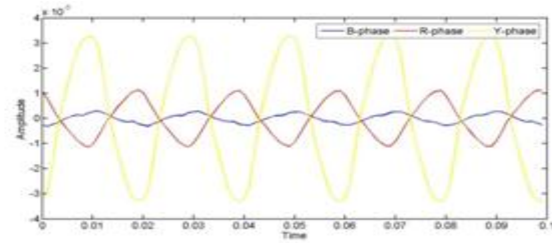

Figure 10: Single Phase under voltage unbalance

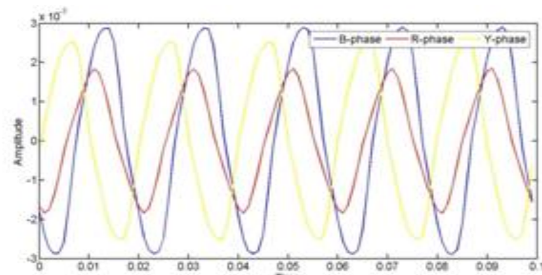

Figure 11: Two Phases under Voltage Unbalance

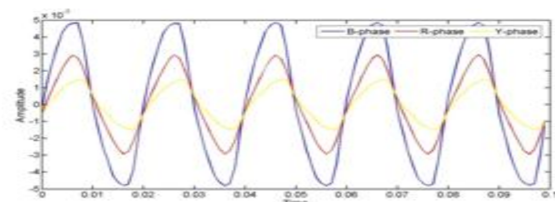

Figure 12: Three Phases under Voltage Unbalance

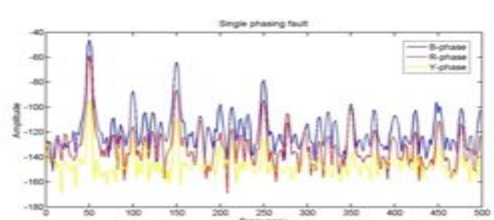

Figure 13: FFT of single phasing The Voltage unbalance percentage

$$VUP = \frac{max.\,deviation\ from\ average\ voltage}{average\ voltage} \times 100$$

Table 1: Voltage unbalances and Temp. Rise percentage

% Voltage Unbalance (V)	% Temperature Rise (°C)
4.9	48.02

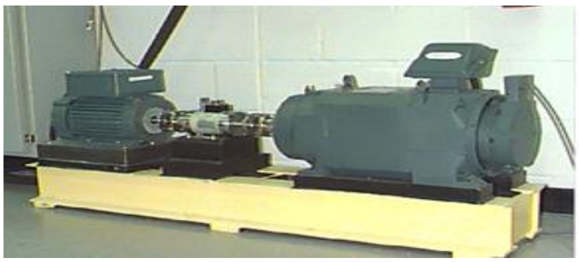

Figure 14: Experiment set up for bearing fault Experiment Set Up 2

Vibration Analysis Approach for bearing fault

In this study of bearing fault I have used the vibration monitoring technique to detect fault frequency. In vibration monitoring we use the vibration signal to detect fault. When carrying out vibration analysis in time domain, some simple quantities can be utilized such as root mean square (RMS), crest factor, kurtosis and other statistical moments. If motor bearing are faulty it affect vibration and motor current signature pattern. First run the motor in normal condition and acquire vibration signal. Acquire vibration signal for faulty motor bearings. Apply advance signal processing techniques (FFT) to extract features from the acquired vibration signal.

Bearing Fault Analysis

In experiment set up I have used 0.5 hp induction motor, a piezoelectric accelerometer, a 16 channel DAT recorder and was post processed in the MATLAB environment. All data files are in Mat lab (*.mat).The bearings of Induction Motor are single row, deep groove ball bearing and type 6203-Z. Each bearing has eight balls. Experiments were conducted on three bearings: one of these is undamaged while two bearing were damaged. One bearing is drilled through outer race with 'hole diameters' of 2 mm while another one bearing drilled through inner race with 'hole diameter' of 2 mm as illustrated in Figures 3 and 4. Bearings of type 6203 -Z were drilled with help of Electric Discharge Machine (EDM) and were installed on motor.

Bearing Specifications: 6203-Z SKF, deep groove ball bearing

- Numbers of balls: 8
- Pitch diameter: 1.537 inches
- Ball diameter: 0.3126 inches

The relationship of bearing vibration to the stator current spectra can be determined by remembering that any air gap eccentricity produces anomalies in the air gap flux density.

Since ball bearings support the rotors, any bearing defect will produce a radial motion between the rotor and stator of the machine. The mechanical displacement resulting from damaged bearing causes the machine air gap to vary in a manner that can be described by a combination of rotating eccentricities moving in both directions. Due to rotating eccentricities, the vibrations generate stator currents at frequencies given by [5, 7].

$$fBPFO = \frac{n}{2}\frac{N}{60}\left(1 - \frac{d}{D}\cos\beta\right)$$

$$fBPFI = \frac{n}{2}\frac{N}{60}\left(1 + \frac{d}{D}\cos\beta\right)$$

Where:

Ball pass frequency outer ring (fBPFO)
Ball pass frequency inner ring (fBPFI)
n = Number of balls
N = rotational speed in RPM
d = Ball diameter
D = Bearing pitch diameter
β = Ball contact angle with the race

Results and Discussion

1. **Normal Condition**

In first stage I have taken the readings of healthy motor because it is necessary to take these readings for comparison point of view.Fig.15 and 18(FFT).

2. **Inner Race Fault Condition**

This is the inner race fault condition. This experiment was performed on the no load condition. The inner race fault in bearing was made by drilling a hole of 2mm diameter in its inner race. It is observed from the power spectrums of motor that fault frequencies are not clearly visible at no-load condition because their magnitude is less. The power spectrum of faulty motor with 2mm hole in inner race of bearing under no load condition is shown in Figures 16 and 19 (FFT).

3. Outer Race Fault Condition

In the next step I have created an outer race fault by drilling a hole of 2mm diameter in its outer race. The power spectrum of faulty motor with 2mm hole in outer race of bearing under no load condition is shown in Fig.17 and 20(FFT).

Table 2: Spectrum Analysis for Outer and Inner Race

Load	0
FBPFO(Hz)	107.32
FBPFI(Hz)	115.40

Time domain signal

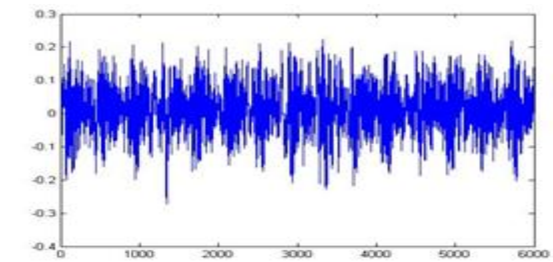

Fig 15: Power Spectrum of Normal Condition

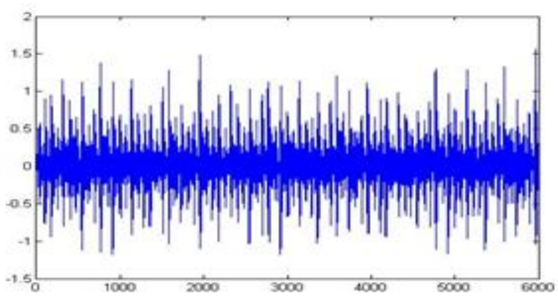

Fig 16: Power Spectrum of Inner Race Fault Condition

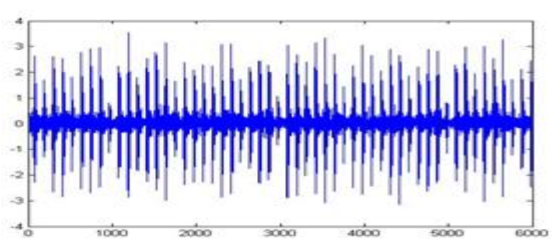

Fig 17: Power Spectrum of Outer Race Fault Condition

Frequency Signal (FFT)

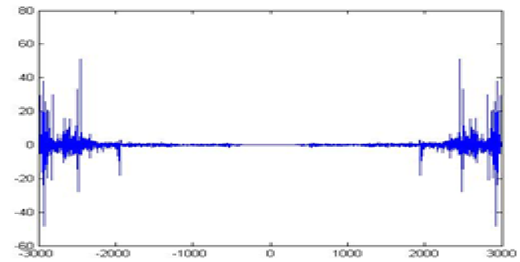

Fig 18: Normal Condition FFT spectrum

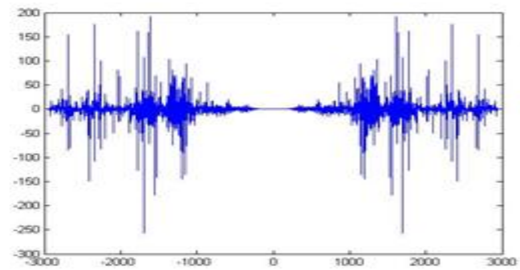

Fig 19: Inner Race Fault Condition FFT spectrum

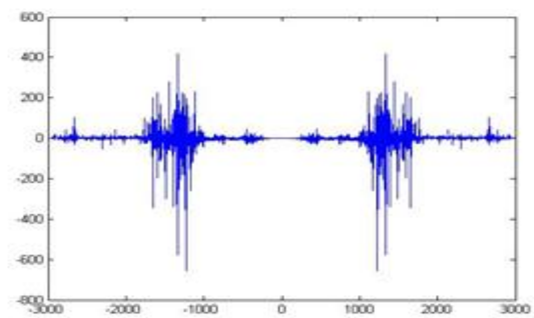

Fig 20: Outer Race Fault Condition FFT spectrum

4. Conclusion and Future Work

The aim of this work is to advance the field of condition monitoring and fault diagnosis in induction motor operating in variety of operating conditions. With the help of condition monitoring we can easily avoid the critical emergency shutdown as well as reduce the maintenance costs of motor other faults

- FBPFO and FBPFI are indirectly depending on the loads so as the load increases the fault frequencies decreases.
- With help of Unbalance condition, I got different situation like Single phase under

voltage, Double phase under voltage and three phases under voltage.

For large size motors, new challenges may exist for current based fault detection. Therefore proposed techniques may be applied for the large size motors. Additional work is needed to investigate the applicability of other signal processing tool in characterizing the fault signature.

Acknowledgment

I express my sincere thanks to my mentor, Dr.C.Y.Patil for his expert guidance, encouragement and motivation during the development of this project, without which this project would not have developed to its present form.
I am thankful to Dr. S. L. Patil, Mr.Ugale for their support and help. I am also very thankful to my friend Ms.Pranali Narwade, Mr.Chaitannya Supe, Ms.Sneha Bramhankar and Mr.Mayuresh Chavan and every person of the department for helping me to complete my project. Last but not the least; I am grateful for the endurance from my family who silently supported me. My project has not been possible without them.

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