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Motor Current Signature Analysis to Detect Bearing Fault in Three Phase Induction Motor

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ABSTRACT
The aim of this paper is to detect and analyse ball bearing fault in induction motor using Motor Current Signature Analysis and Harmonics FFT analysis. Bearing of Induction Motor are subjected to various forces during operating and loading condition. Therefore Bearing deterioration is the main cause of induction motor failure in the existing system. Many researchers have been developed various tools and techniques for bearing fault detection and diagnosis out of which MCSA is most popular. Experimental analysis is done on three phase 440 V, four pole, 1500 RPM induction motor and three bearing were used for creating bearing fault in Induction Motor that is Dry, Less lubricant and Ball damaged bearing. Results have taken on healthy and faulty conditions at No Load and Rated Load. Results shows that from healthy to faulty condition three phase voltage, three phase current, electrical power, torque, mechanical power and power factor of the motor increases however speed and efficiency of motor decreases. The harmonic content increases up to 21th harmonics.

Keywords- Bearing, Damaged bearing, Dry bearing, Harmonic FFT analysis, Healthy bearing, Motor Current Signature Analysis, Three Phase Induction Motor.

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I. INTRODUCTION

Induction motor is very essential component of various industries and is used in various industrial processes because they are reliable, less expensive, efficient, and easy to operate. Also, the speed control of the induction motor is very simple and convenient to use [1]. Induction motor plays an important role in industries for conversion of the electrical energy into mechanical energy [2].

Ball-Bearing play vital role in the reliability and performance of the induction motor system. Due to the close relationship between motor system development and bearing assembly performance it is very typical to upgrade the rotating machinery without considering the application of ball-bearing into motor system [3]. The result of many studies shows that the bearing fault are the most frequently fault in the induction motor. According to IEEE it accounts for 41% of all total machine failure in induction motor [4].

Recent work shows that, in many conditions ball-bearing fault in induction motor is detected by using a vibration monitoring method as it is a reliable tool for detection of the ball-bearing failure [5]. However placing a sensing device in the motor is not possible in practical situation for many application specially for the application which employs a large number of electrical machines because these sensor are very delicate and expensive if in case any damage occurs to these sensors will cause heavy loss to the consumer and result in huge economic loss [6,7].

Thus, motor current signature analysis and Harmonic FFT can be used for conditioned monitoring of the stator current monitoring system. [8,9]. Many researches have been for the detection of the bearing fault in induction motor by using stator current signature measurement to ensure a higher degree of reliability to the consumer [10,11]. In spite of these techniques, many industries are still facing the problem of the unexpected system failure due to bearing fault which results in heavy economic loss and unscheduled downtime which leads to loss of the production [12, 13].

In this paper, the detection and the analysis of the ball bearing fault in induction motor is carried out by using motor current signature analysis and Harmonic FFT Analysis. Experiment is done on three phase 1 H.P, 440 V, 4 pole, 1500 RPM induction motor that is Dry, Less lubricant and Ball damaged bearing. Results has been taken on healthy and faulty conditions at No Load and Rated Load.

II. FAULTS IN INDUCTION MOTOR

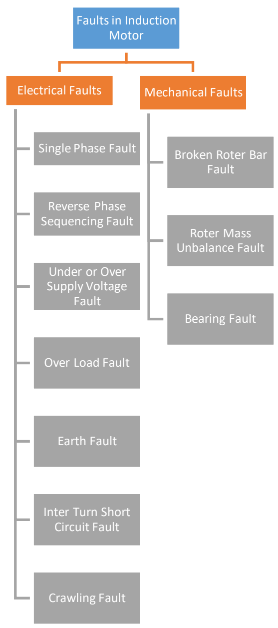

Fig. 1 Faults in Induction Motor

III. METHOD TO DETECT BEARING FAULT

1. Fast Fourier Transform

In this technique, the motor current reading are recorded in time domain. After signal conditioning analog to digital conversion is performed. FFT is used for analyzing signals in frequency domain. It is efficient version of discrete Fourier transform algorithm that reduces the necessary number of computations. FFT is suitable and efficient for characterization of stationary signals.

2. Instantaneous Power FFT.

It is used for additional measurement of supply voltage. Data provided by instantaneous power is greater than available in motor supply current alone. It includes less noise and well bounded dynamic range of remaining harmonics in absence of power grid component.

3. Demodulated Current Spectrum

There is a lot of information is blurred in the noise floor of the spectrum. Demodulation is the process of extraction of the current frequency from the spectrum. In MCSA, demodulation is one of the important steps. By removing carrier frequency, we get the demodulated the current spectrum for further analysis.

4. Wavelet Analysis

Wavelet is a basic function isolated with respect to time or spatial location and frequency or wavenumber. It enables the analysis localized in time frequency or the time-scale domain. It provides a time frequency representation of the signal. Fourier series expansion is unable to do this representation. In real word we need to deal with discrete sample. Hence, we need to localize the sample by wavelet analysis.

5. Parks Vector Approach

The parks Vector approach falls under electric Monitoring. An approach based on parks vector is used for the real time monitoring of motor by using stator current. It is used for diagnosis of bearing failure rotor faults, inter-turn fault, stator faults and unbalanced supply voltage. It is based on the identification of specific current pattern.

6. Motor Current Signature Analysis

Motor Current Signature Analysis is based on the stator current monitoring of induction motor thus it is not very expensive. MCSA uses the stator current spectrum of the machine to detect the ball bearing fault in induction motor [14]. Ideally the current signature should be pure sinusoidal but practically many harmonics are present. It is because when any electrical or mechanical fault takes place in the motor it modulate the motor current signal and lead to the addition of the sides band harmonic in the motor current This added harmonic produces the variation in magnetic field which in turn changes the mutual and self-inductance of the motor which appear in the motor supply current as sidebands around the line supply frequency. Based on these faulty current signatures the motor fault can be identified and severity of the fault can be determined [15].

IV. BEARING FAULTS IN INDUCTION MOTOR

In three phase induction motor generally couple of bearing are used for the supporting the rotary shaft. The main intention of using a couple of bearing are to rotate the motor shaft freely and reduce friction. Bearing consists of an inner ring and outer ring generally called as races and a set of rolling elements they are balls. The balls are placed in between inner and outer sides of race they reduces the friction of shaft. Further reduction of the friction can be done by using lubricating the balls [14]. Sometimes the balls, inner or outer race of bearing is damaged due to several physical problems then the fault occurs. This fault is called as bearing fault. After the occurrence of bearing fault the motor totally jammed. The main factor of bearing failure is foreign material and corrosion. This may often lead contamination of the bearing lubrication [15].

The common bearing failure is as follows:

a) Brinelling
b) Cage Damage
c) Contamination
d) Electric Arcing
e) False Brinelling
f) Lubrication Failure
g) Misalignment

a) **Brinelling:** Brinelling raceway damage usually caused by mounting or dismounting of bearing. It can be identified by minute dents corresponding with the ball location. It can also be caused by shock load exerted on static shaft.
b) **Cage Damage:** Cage damage usually cause due to vibration, excessive speed, wear and blockage.
c) **Contamination:** Contamination caused by the presence of foreign objects into the bearing which causes scratches, pits, and lapping of raceways.
d) **Electric Arcing:** Electric arcing occurs when electric current passing through broken bearing between balls and races. This will produces high temperature at contact points and pits on raceways and balls.
e) **False Brinelling:** False brinelling may occur during transportation of equipment or vibration from running equipment. It appear similar to brinelling.
f) **Lubrication Failure:** Lubrication failure can be identified by the colour of the lubrication if the colour is dark then it indicates lubrication failure. Presence of foreign material causes lubrication failure.
g) **Misalignment:** When one side of bearing is misaligned, the balls will run from one side of race to the other around one half of circumference on the non-rotating race. This will results in high temperature and destroy lubricant [16].

V. MATHEMATICAL MODELLING

Total Harmonic Distortion (THD);

The total harmonic distortion in current is given as

$$\mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} C_{n\,rms}^2}}{C_{fund_{rms}}}$$

or

$$\mathrm{THD} = \frac{\sqrt{c_3^2 + c_5^2 + \cdots \ldots + c_n^2}}{c_1}$$

The addition of current harmonic in the motor leads to the anomalies in the voltage harmonics hence total harmonic distortion in voltage harmonics as

$$\mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} V_{n\,rms}^2}}{V_{fund_{rms}}}$$

or

$$\mathrm{THD} = \frac{\sqrt{v_3^2 + v_5^2 + \cdots \ldots + v_n^2}}{v_1}$$

Crest Factor (K) for current and voltage is given as

$$\mathrm{CF} = \frac{I_{peak}}{I_{rms}} \quad \& \quad \mathrm{CF} = \frac{|V_{Peak}|}{V_{RMS}}$$

VI. EXPERIMENTAL SETUP

The experimental setup for detection of bearing fault is as shown in figure. To illustrate the fault detection scheme, experiments were conducted on a 1 HP, 3-phase, four-pole induction motor. For data acquisition we used Fluke438-II power quality and motor analyser. The rating of motor is given in Table

Table 1: Motor Rating

Power	1 H.P, 3 Phase
Frequency	50 Hz
Voltage	415 V
Current	1.5 A
Speed	1500 RPM
Poles	4

For measurement of the RLC parameter of the motor LCR-Q-Meter Sorter is used.

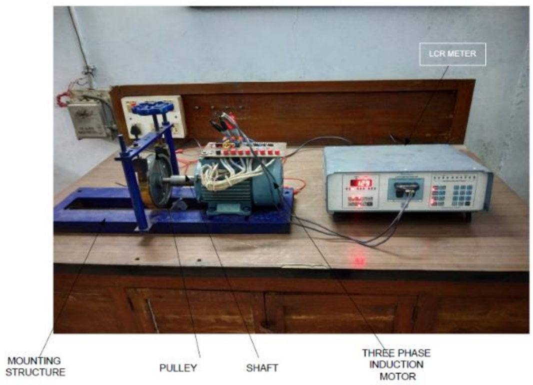

Fig. 2 Measurement of LCR Parameters

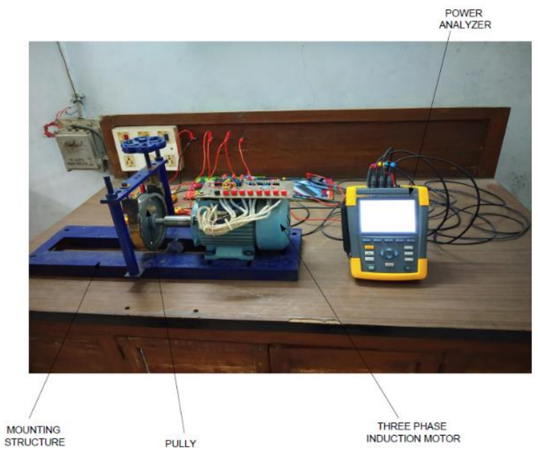

Fig. 3 Measuring Motor Parameter

For analysis we use three bearings of 6205ZR were used. From the bearing data sheet, each bearing had 8 balls the outside diameter of a 6205ZR bearing is 52 mm and inside diameter is 25 mm. Experiments were conducted on three bearings; one of the bearing was healthy, other was dry followed by damage bearing at no load and rated load respectively. Bearing fault was created by drilling holes of various diameters (say 2mm or 3mm) both inner and outer raceways. These faults are not realistic bearing faults but these bearing faults could produce characteristic current harmonic and fault frequencies to illustrate the bearing fault detection.

Table 2: Bearing Specification

No of balls	8 balls
Inner Diameter (d)	25 mm
Outer Diameter (D)	52 mm
Width (B)	15 mm
Weight	0.129 Kg

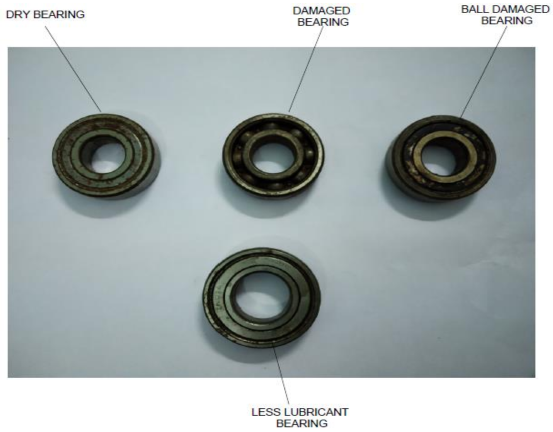

Fig. 4 Types of Bearing

To detect bearing fault motor current signature analysis and harmonic analysis is used. This method is based on stator current monitoring of induction motor. It uses the stator current spectrum of the machine for locating the ball bearing fault in the induction motor. The output stator current of the induction motor is measured by using current transformer which is in the form of probes. These readings are then send to fluke 438-II power quality and motor analyser by means of patch cords. Where we review the 10 second snapshot of mechanical and electrical parameters mainly current, voltage and frequency to view the operation over that time period. After that the data is acquired in fluke SD Card and data is extracted by means of power log fluke 438-II power quality analyser software.

By using this recorded data we calculate no load and rated load voltage, current, mechanical and electrical parameter of the healthy, dry and damage bearing separately and monitors the change in these data during the three condition by plotting the graph.

Then by using harmonic analysis we calculate the total harmonic distortion (THD) with respect to fundamental frequency up to 21st harmonic in voltage and current of healthy, dry and damaged bearing during no load and rated load condition.

VII. RESULT AND CONCLUSIONS

Table 3: Rated Phase Voltage and Rated Phase Current

Rated Load						
Conditions	Phase Voltage (Vrms)			Phase Current (Arms)		
	VRN	VYN	VBN	IR	IY	IB
Healthy Bearing	234.28	232.21	232.1	2.35	2.1	1.8
Dry Bearing	292.85	290.2625	290.125	2.9375	2.625	2.25
Damaged Bearing	366.0625	362.8281	362.6562	3.6718	3.2812	2.8125

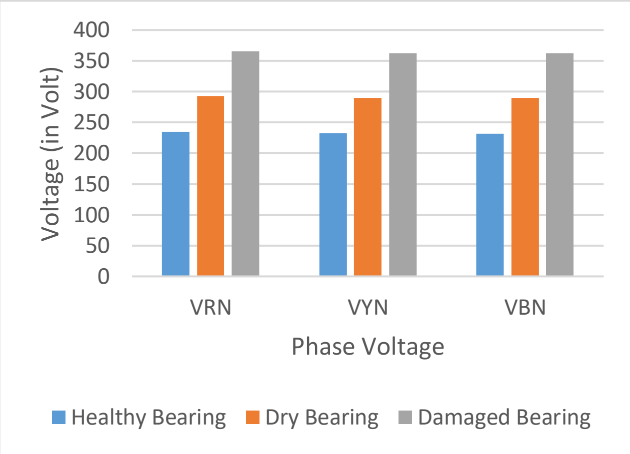

Fig. 5 Rated Load Phase Voltage

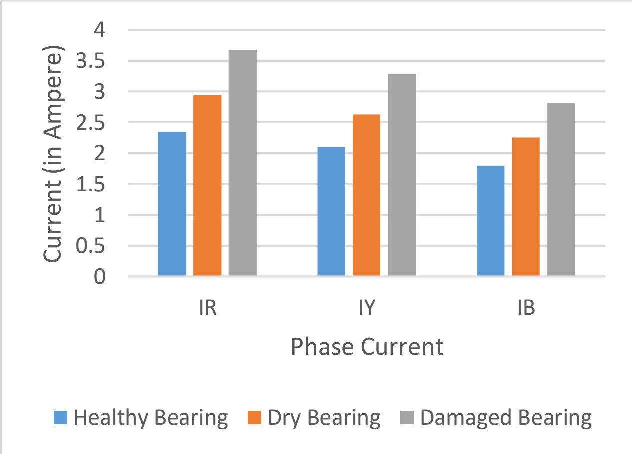

Fig. 6 Rated Load Phase Current

Table 4: Electrical and Mechanical Power

Conditions	Rated Mechanical Power				Rated Electrical Power	
	KW Mech.	Nm Torque	RPM Speed	% Efficiency	KW Elect.	PF Full
Healthy Bearing	0.565	3.76	1437	0.72	0.777	0.22
Dry Bearing	0.689	4.7	1400	0.65	1.29	0.25
Damaged Bearing	0.996	7.05	1350	0.58	2.04	0.29

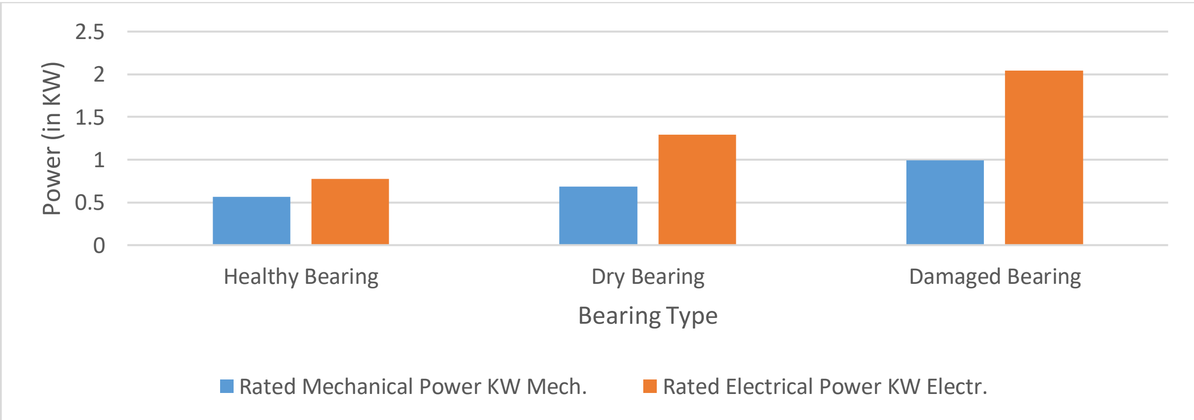

Fig. 5 Electrical Power and Mechanical Power

Table 5: Rated Load Harmonics (Healthy Bearing)

Rated Load Harmonics (Healthy Bearing)												
Conditions	THD	K	1	3	5	7	9	11	13	15	17	21
VRY	2.40%	0	100	0.5	2	1.3	0.5	1	0	0	0	0
VYB	2.40%	0	100	0.7	2	1.2	0.7	1	0	0	0	0
VBR	2.50%	0	100	1	2	1.35	1	1	0	0	0	0
V	2.40%	0	100	0.733	2	1.288	0.733	1	0	0	0	0
IRY	2.60%	1	100	1.3	1.3	1.4	0.2	0.5	0.2	0	0	0
IYB	2.60%	1	100	4.8	1.25	1.3	0.7	0.2	0.3	0	0	0
IBR	2.60%	1	100	4	2	1.4	1	0.3	0.5	0	0	0
I	2.60%	1	100	3.36	1.5166	1.366	0.633	0.333	0.333	0	0	0

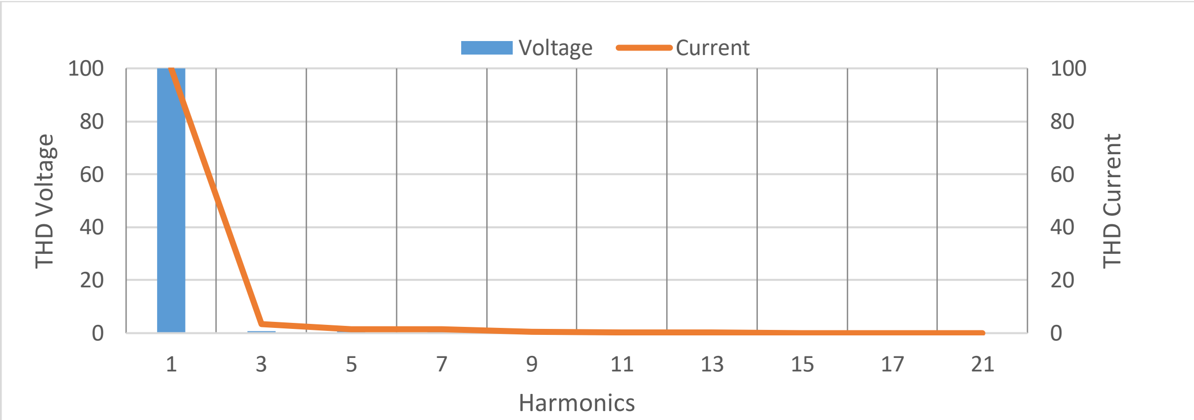

Fig. 6 Rated Load Harmonics (Healthy Bearing)

Table 6: Rated Load Harmonics (Dry Bearing)

Rated Load Harmonics (Dry Bearing)												
Conditions	THD	K	1	3	5	7	9	11	13	15	17	21
VRY	3.20%	1.5	100	1.6	1.9	1.655	1	0.33	0	0	0	0
VYB	3.10%	1.49	100	1.8	1.633	1.33	1	0.484	0	0	0	0
VBR	3.13%	1.48	100	1.72	1.6	1.2	0.8	0.33	0	0	0	0
V	3.15%	1.499	100	1.7067	1.711	1.395	0.9333	0.3813	0	0	0	0
IRY	3.00%	1.504	100	1.78	1.9	1.2	0.63	0.48	0.22	0.15	0	0
IYB	3.60%	1.518	100	2.5	1.9	1.38	0.8	0.5	0.2	0.1	0.01	0
IBR	3.60%	1.519	100	2	2.5	1.48	0.77	0.5	0.4	0.2	0.04	0
I	3.40%	1.514	100	2.0933	2.1	1.3533	0.7333	0.4933	0.2733	0.15	0.0166	0

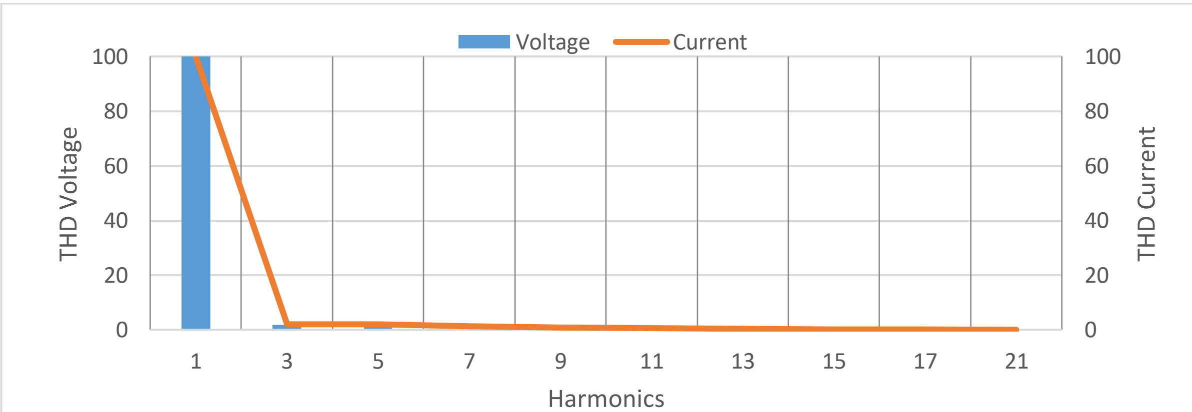

Fig. 7 Rated Load Harmonics (Dry Bearing)

Table 7: Rated Load Harmonics (Ball-Damage Bearing)

Rated Load Harmonics (Ball-Damage Bearing)												
Conditions	THD	K	1	3	5	7	9	11	13	15	17	21
VRY	0.096	1.73	100	4.87	5.5	4.76	2.8	2	1.54	1.09	0.1	0
VYB	0.091	1.7	100	4.76	5.43	4.2	2.36	1.8	1.49	1.09	0	0
VBR	0.091	1.71	100	4.69	5.65	3.9	2.43	1.776	1.398	1.5	0	0
V	0.0927	1.72	100	4.7733	5.5267	4.2867	2.53	1.8587	1.476	1.2267	0.0333	0
IRY	0.094	1.72	100	4.4	5	4.56	3.6	2.83	1.2	0.8	0	0
IYB	0.094	1.72	100	4.2	5.3	4.45	3.5	2.89	1.18	0.85	0	0
IBR	0.093	1.7	100	4	5.36	4.38	3.47	2.7	1.8	0.7	0	0
I	0.0935	1.7133	100	4.2	5.22	4.4633	3.5233	2.8067	1.3933	0.7833	0	0

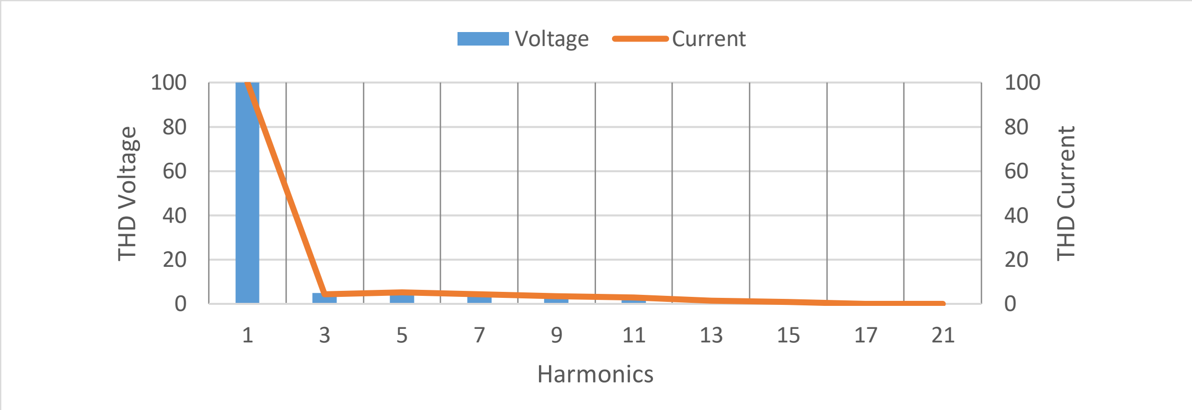

Fig. 8 Rated Load Harmonics (Ball-Damage Bearing)

VIII. RESULT

Induction Motor is one of the most important parts of the industry. It is also called the Horse-force of the industry. If fault placed on motor it leads to shutdown of the industry therefore online condition monitoring and fault detection is essential to prevent industry from huge loss and also helps to prevent valuable human life.

Different types of fault take place on Induction Motor they are classified as electrical fault and mechanical fault. Electrical fault are categorised as Stator related fault such as inter-turn fault, phase to phase, phase to ground, Stator insulation fault. Mechanical fault are categorised as bearing related fault, rotor related fault and eccentricity fault. From the literature it has been observed that 40% of Induction Motor fault are related to bearing failure.

In this project, Analysis of Bearing fault has done through Motor current signature analysis (MCSA) and Harmonics analysis. The Bearing faults has created by using different types of bearing Healthy bearing, Dry bearing, Damaged bearing, Ball damaged bearing. The analysis has been carried out on healthy condition and Faulty condition. The result has been taken on No Load and Rated Load Condition by using MCSA and Harmonic FFT. From Results it can be concluded that three phase voltage has increased from 234.28 V to 366.0625 V, current increased from 2.35 A to 3.6718 A. Mechanical power increase to 0.565 KW to 0.996 KW, torque increased from 3.76 N-m to 7.05 N-m, Electrical power increased from 0.777 KW to 20.4 KW whereas speed decreased from 1437 RPM to 1350 RPM. The efficiency of motor decreased from72% to 58%. Harmonic FFT shows that harmonic contents increases to 21th harmonic.

IX. CONCLUSION

Electrical machinery is the one of the important parts of the industries. Failure of the induction motor can cause production of downtime and result in huge loss of revenue and maintenances. Timely detection of the motor faults results in saving of these losses. Development of fault in the motor lead to addition of harmonic content in motor waveform which can cause mechanical as well as electrical damage to the motor. MCSA and Harmonic analysis helps in continuous real time tracking of ball bearing fault in induction motor operating under continuous and variable load. It can be applied anywhere in the industry where electric motor is used. It serves as the important diagnosis tool for conditioning monitoring of the fault in electric motor.

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