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DETECTION OF BALL BEARING FAULT IN INDUCTION MOTOR USING MCSA AND HARMONIC ANALYSIS

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ABSTRACT

Induction motor is one of the important part of industry. Therefore, induction motor is called the "horse-force" of the industry. Failure of induction motor leads to industry shut down and huge economic loss to the industry. The faults in induction motor are classified as electrical and mechanical faults. Bearing fault account for 40% fault in the induction motor. Bearing fault deterioration is the main cause of induction motor failure in the existing system. This paper presents the analysis and the detection of bearing fault using motor current signature analysis and harmonic FFT analysis. The experimentation is carried on 1 hp, 3 phase, 4 pole and 1500 rpm induction motor with healthy, dry and damaged bearing on No load and Rated load conditions. From experimentation it can be concluded that during faulty conditions three phase voltages, three phase current, mechanical power, torque, electrical power and power factor increases whereas speed and efficiency of electric motor decreases. Harmonic FFT analysis shows that from healthy to faulty conditions the harmonic contents increases up to 21th harmonics.

KEYWORDS: Faulty Bearing, Harmonic FFT Analysis, Healthy Bearing, Motor Current Signature Analysis (MCSA), Three Phase Induction Motor.

I. INTRODUCTION

Induction motor are widely used in industrial drives because they are cheaper, efficient, reliable and have a high starting torque, also speed control and operation of induction motor is very convenient.[1] Induction motor became an industry workhorse and play a vital role in industry for conversion of electrical energy into mechanical energy.[2]

Bearing play an important 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 the consideration of the application of bearing into motor system. The result of many studies shows that the bearing fault are the most frequently fault in the induction motor. It accounts for 41% of all machine failure.[3]

Previous work show that, in many situation an incipient bearing fault can be detected by the using a vibration monitoring method as it is a reliable tool for detection bearing failure.[4] However placing a sensing device on the motor might not be possible for in practical for many application specially for the application that employs a large number of electrical machines because these sensor are too delicate and expensive if in case any damage to these sensors can cause heavy loss to the consumer.[5,6]

Hence motor current signature analysis can be used for conditioned monitoring of the various parameter of the motor.[7,8] Many research have been done in presenting the methods for the detection of the bearing fault by using stator current signature measurement to ensure a higher degree of reliability to the consumer.[9,10] In spite of these tools, many companies are still facing the problem of the unexpected system failure which results in large maintenance cost and unscheduled downtime which leads to loss of the production.[11]

In this paper, the experiment are presented using motor current signature analysis (MCSA) and harmonic analysis to the stator current that give the indication of the ball bearings faults. Also, it demonstrates the feasibility and significant implementation of the detection method as it helps in continuous real time detection of bearing fault in induction motor operating under no load and rated load during faulty condition.

Test results showing that the MCSA and harmonic analysis is the best method to detect real time ball bearing fault in induction motor. Also, it is non-intrusive and uses the stator winding current. It is not affected by the type of load and other asymmetries.

II. BEARING FAILURE

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 rotate in raceways. 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. 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.[12] Bearing faults are major cause of motor failure. Appropriately 40-50% faults are related to bearing. Factors that profound effect on real life of bearing are as follows:

Contamination	= 45% to 55%
Lubrication	= 11% to 17%
Improper assembly	= 11% to 13%
Misalignment	= 10% to 13%
Overloading	= 8% to 10%
Other	= 1% to 6%

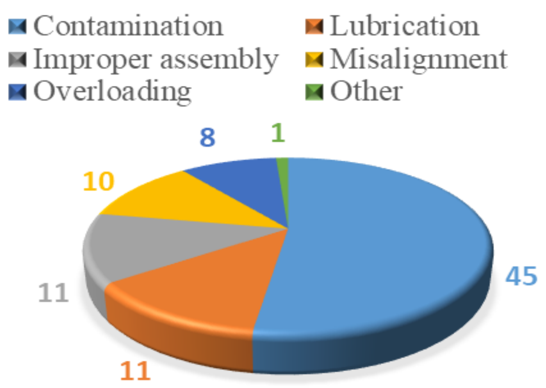

Figure 1: Bearing Fault Distribution.

Normal operating conditions of proper load and alignment, fatigue failure begins with small affected area between raceway and rolling element (balls) leads vibrations and noise. If continuous further causes flaking. The affected area will expands rapidly contaminating lubricant and cause overloading the entire circumference of raceway. Finally, this failure results in rough running of bearing. External sources which affects bearing failure are contamination, corrosion, improper lubrication, improper installation or brine-ling.[13]

III. Motor Current Signature Analysis (MCSA) and Harmonic Analysis

Motor Current Signature Analysis and Harmonic Analysis is based on the conditioned current monitoring of induction motor thus it is not very expensive. MCSA and Harmonic Analysis uses the stator current spectrum of the machine to detect the ball bearing fault in induction motor.[14] When any electrical or mechanical fault takes place in the motor it vary the motor current signal and lead to the addition of the side band harmonic in the motor current. This added harmonic produces the variation in magnetic field and changes the mutual and self-inductance of the motor which appear in the motor supply current signature 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. METHODOLOGY

As the MCSA and Harmonic Analysis uses conditional stator current monitoring system to detect the bearing fault, we use three phase stator current monitoring system i.e. monitoring stator current of all the three phase of the supply current.

Motor current is sensed by the current transformer which is in the form of i430 thin flexible current probes and voltage signal is sensed by clamping probes in time domain. This recorded current and voltage signal is then send to the fluke 438-II power quality and motor analyzer for monitoring of various electrical and mechanical parameter mainly current, voltage, and frequency to view operation of the motor over that period. Where we take data by reviewing 10 second snapshot of various electrical and mechanical parameter of the motor. After that the data is acquiesced in fluke SD Card and the data is extracted by means of power log fluke 438-II power quality analyzer software.

The software developed will extract the data acquiesced in fluke SD Card by converting the time domain signal into frequency domain. Then the harmonic analysis of the current and voltage signal is done up to 21th harmonic which gives magnitude of Total Harmonic Distortion (THD) with respect to the fundamental component of the frequency during the fault at no load and rated load.

Thus, this purposed method involves the continuous real time tracking of ball bearing fault in induction motor operating under continuous and variable load during faulty condition.

V. 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 Fluke 438-II power quality and motor analyzer. The rating of motor is given in Table 1.

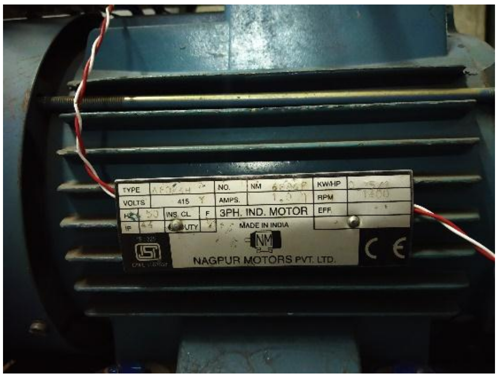

Figure 2: Motor Rating.

Table 1: Motor Rating

Power	1 H.P, 3 Ø
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.

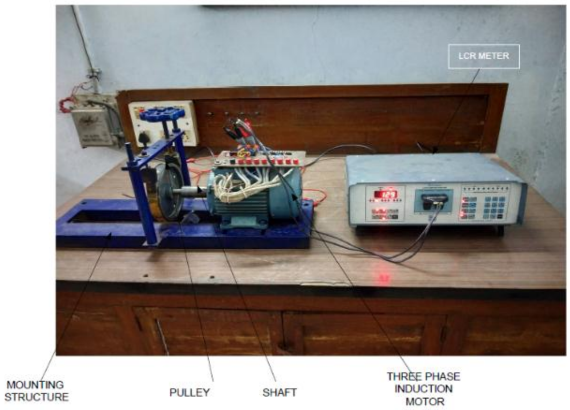

Figure 3: Measuring RLC Parameter

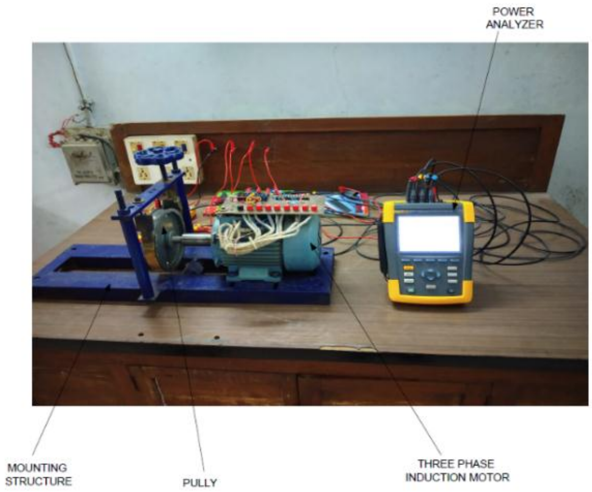

Figure 4: Measuring Motor Parameters

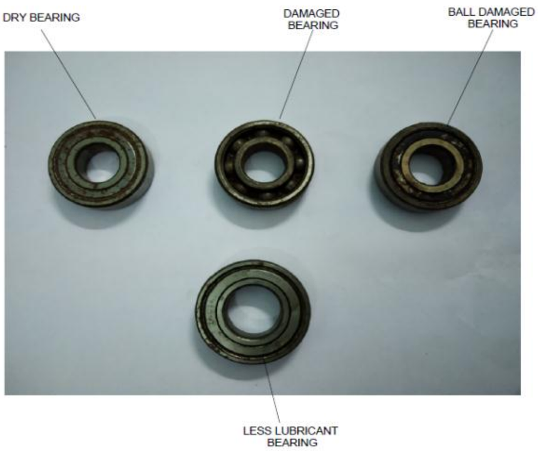

Figure 5: Types of Bearing

Table 2: Bearing Specification

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

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.
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 analyzer 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 acquiesced in fluke SD Card and data is extracted by means of power log fluke 438-II power quality analyzer 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 21^{th} harmonic in voltage and current of healthy, dry and damaged bearing during no load and rated load condition.

VI. MATHEMATICAL MODELLING

When ball bearing fault takes place in the motor it varies 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 and changes the mutual and self-inductance of the motor which appear in the motor supply current signature as current harmonics around the supply frequency which is given as total harmonic distortion in current harmonics as

$$\mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} C_{n\,rms}^{2}}}{C_{\mathrm{fund}_{\mathrm{rms}}}} \quad \text{or} \quad \mathrm{THD} = \frac{\sqrt{c_3^2+c_5^2+\cdots....+c_n^2}}{C_1}$$

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

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} V_{n\,rms}^2}}{V_{fund_{rms}}} \quad \text{or} \quad THD = \frac{\sqrt{v_3^2 + v_5^2 + \cdots + v_n^2}}{V_1}$$

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

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

VII. ANALYSIS

Phase Voltage and Phase Current

Table 3: Phase Voltage and Phase Current.

Conditions		Phase Voltage (V_{rms})			Phase Current (A_{rms})		
		V_{RN}	V_{YN}	V_{BN}	I_R	I_Y	I_B
Healthy Bearing	No Load	232.85	229.89	233.08	1.2	1	0.9
	Rated Load	234.28	232.21	232.1	2.35	2.1	1.8
Dry Bearing	No Load	291.06	287.36	291.35	1.5	1.25	1.125
	Rated Load	292.85	290.26	290.13	2.937	2.625	2.25
Damaged Bearing	No Load	363.83	359.2	364.19	1.875	1.563	1.406
	Rated Load	366.06	362.83	362.66	3.671	3.281	2.812

It has been seen From Table 3. That phase voltage and phase current are increasing from no load to rated load during bearing faults conditions.

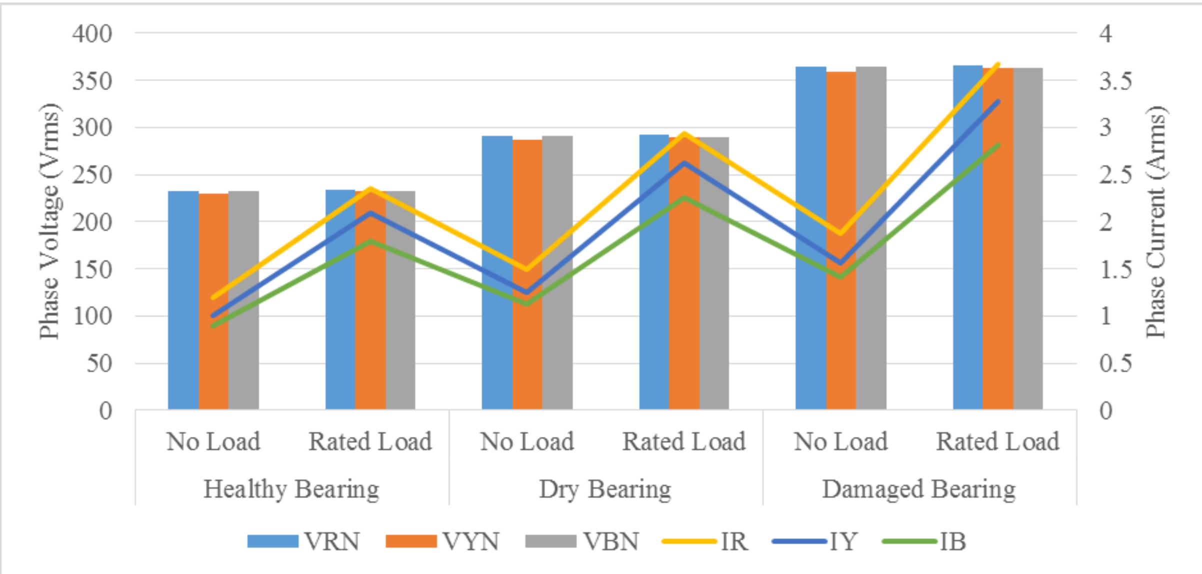

Figure 6: Phase Voltage and Phase Current.

Rated Mechanical and Electrical Power

Table 4: Rated Mechanical and Electrical 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

It can be concluded that mechanical power and torque increases whereas speed and efficiency decreases. Similarly, electrical power and power factor increases from healthy condition to faulty conditions as shown in table 4.

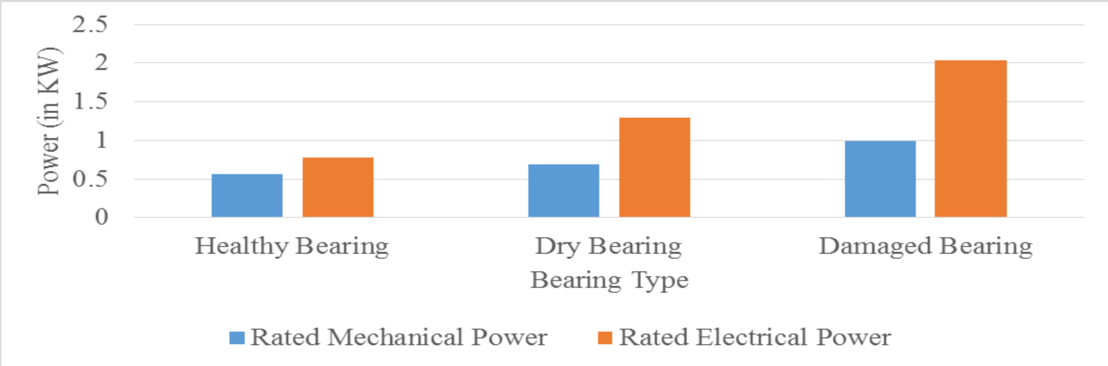

Figure 7: Rated Mechanical and Electrical Power.

VIII. Harmonics Analysis:

1. Healthy Bearing Condition

Table 5: Healthy Bearing Harmonics.

Harmonics (Healthy Bearing)													
Conditions		% THD	K	1	3	5	7	9	11	13	15	17	21
No Load	VRY	2.80	0	100	1	2	1	0	0	0	0	0	0
	VYB	2.90	0	100	0	2	1	0	0	0	0	0	0
	VBR	2.70	0	100	0	2	1	0	0	0	0	0	0
	V	2.80	0	100	0.333	2	1	0	0	0	0	0	0
	IRY	6.90	1.1	100	3	2	1	0	0	0	0	0	0
	IYB	6.90	1.1	100	1	1	1	0	0	0	0	0	0
	IBR	6.90	1.1	100	4	2.5	1	0	0	0	0	0	0
	I	6.10	1.1	100	2.666	1.833	1	0	0	0	0	0	0
Rated Load	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	1.516	1.366	0.633	0.333	0.333	0	0	0

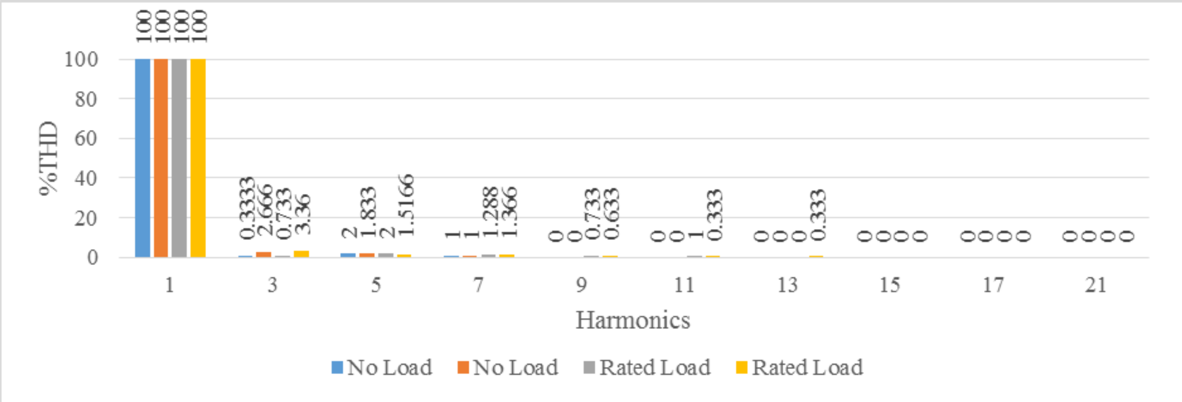

Figure 8: Healthy Bearing Harmonics.

2. Dry Bearing conditions

Table 6: Dry Bearing Harmonics.

Harmonics (Dry Bearing)													
Conditions		% THD	K	1	3	5	7	9	11	13	15	17	21
No Load	VRY	3.30	1.49	100	2.8	1.5	1.3	0.88	0.33	0.1	0	0	0
	VYB	3.70	1.51	100	2.9	1.7	1.11	0.75	0.32	0.15	0	0	0
	VBR	3.40	1.51	100	2.65	1.75	1.01	0.68	0.29	0.12	0.01	0	0
	V	3.47	1.5	100	2.783	1.651	1.14	0.77	0.313	0.123	0.003	0	0
	IRY	3.20	1.51	100	2.1	1.63	1.24	0.75	0.33	0.1	0	0	0
	IYB	3.20	1.52	100	2.21	1.7	1.18	0.68	0.299	0.11	0.05	0	0
	IBR	3.30	1.5	100	2.08	1.53	1.07	0.54	0.3	0.05	0	0	0
	I	3.27	1.5	100	2.13	1.62	1.163	0.65	0.30	0.086	0.016	0	0
Rated Load	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	0.48	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	1.70	1.71	1.39	0.93	0.38	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	1.513	100	2.09	2.1	1.35	0.73	0.49	0.27	0.15	0.0	0

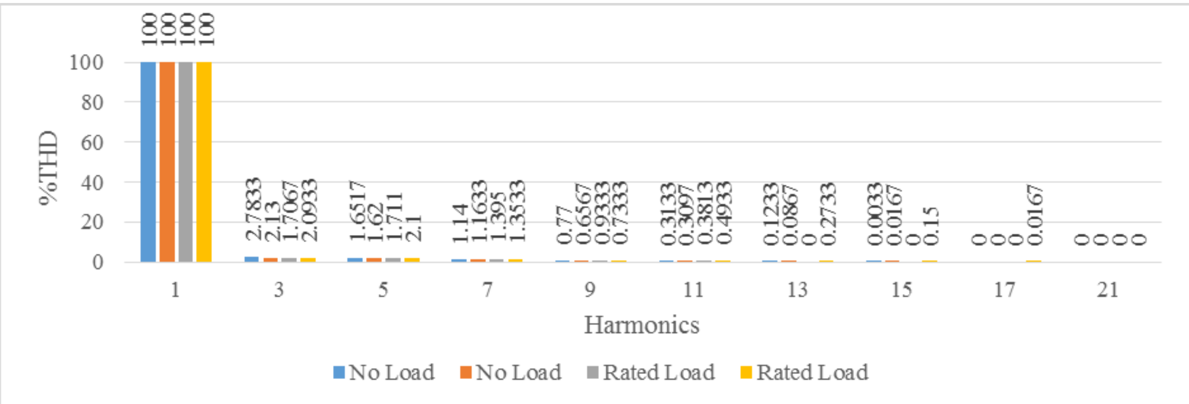

Figure 9: Dry Bearing Harmonics.

3. Damage Bearing Condition

Table 7: Damage Bearing Harmonics.

Harmonics (Damage Bearing)													
Conditions		% THD	K	1	3	5	7	9	11	13	15	17	21
No Load	VRY	9.60	1.74	100	4.1	5.44	4.45	3.7	2.99	2.05	1.14	0	0
	VYB	9.50	1.73	100	4.2	5.3	4.3	3.8	2.88	2.01	0.99	0.29	0
	VBR	9.56	1.72	100	4.15	5.25	4.35	3.65	2.84	1.98	1.01	0	0
	V	9.50	1.73	100	4.15	5.33	4.36	3.71	2.90	2.01	1.04	0.09	0
	IRY	9.60	1.74	100	4.33	5.64	4.11	3.5	2.74	2	1.1	0.33	0
	IYB	9.55	1.7	100	4.46	5.2	4	3.33	2.4	1.8	0.9	0	0
	IBR	9.60	1.72	100	4.1	5.44	4.19	3.34	2.7	2.01	0.87	0.33	0
	I	9.60	1.73	100	4.29	5.42	4.1	3.39	2.61	1.93	0.95	0.22	0
Rated Load	VRY	9.60	1.73	100	4.87	5.5	4.76	2.8	2	1.54	1.09	0.1	0
	VYB	9.10	1.7	100	4.76	5.43	4.2	2.36	1.8	1.49	1.09	0	0
	VBR	9.10	1.71	100	4.69	5.65	3.9	2.43	1.77	1.39	1.5	0	0
	V	9.27	1.72	100	4.77	5.52	4.28	2.53	1.85	1.47	1.22	0.03	0
	IRY	9.40	1.72	100	4.4	5	4.56	3.6	2.83	1.2	0.8	0	0
	IYB	9.40	1.72	100	4.2	5.3	4.45	3.5	2.89	1.18	0.85	0	0
	IBR	9.30	1.7	100	4	5.36	4.38	3.47	2.7	1.8	0.7	0	0
	I	9.35	1.713	100	4.2	5.22	4.46	3.52	2.80	1.39	0.78	0	0

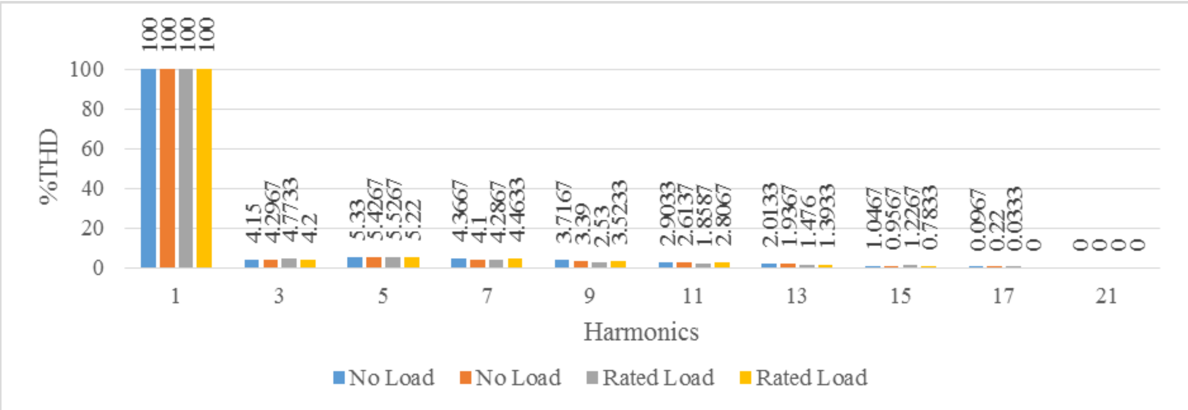

Figure 10: Damage Bearing Harmonics.

IX. RESULT

Induction Motor is one of the vital part 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 categorized as Stator related fault such as inter-turn fault, phase to phase, phase to ground, Stator insulation fault. Mechanical fault are categorized 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.

Many researchers have been developing various tools and techniques for bearing fault detection such as Motor current signature analysis, Fast Fourier transform, Instantaneous power FFT, Parks vector approach, Wavelet transform.

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 and 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. The result has taken on Healthy bearing condition on No-load and Rated-load and faulty bearing condition on No-load and Rated-load from the result it has concluded that during faulty conditions three phase voltages, three phase current, mechanical power, torque, increases to 76.28% whereas electrical power and power factor increases to 162.54% speed decreases to 6.05% and efficiency of electric motor decreases to 19.44%. Harmonic FFT analysis shows that from healthy to faulty conditions the harmonic contents increases up to 21^{th} harmonics.

X. CONCLUSION

Electrical machinery is the horse force 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. From the analysis it can be conclude that mechanical and electrical power has increased at the same time the speed of motor is decreased and huge energy loss is taken on the motor.

XI. ACKNOWLEDGMENT

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XII. REFERENCES

1. Bednarczyk J R 2012, “Induction Motor Theory”, PDH Center.
2. Thornton E J and Armintor J K 2003, “The Fundamentals of AC Electric Induction Motor Design and Application”, in proceedings of twentieth international pump users symposium, Houston, Texas.
3. Schoen R R et al., (1995), “Motor bearing damage detection using stator current monitoring”, in IEEE Transactions on Industry Applications, Volume 31, Issue 6, pp. 1274-1279.
4. Anon (1992), “Methods of motor current signature analysis”, Electric Machine Power System, Volume 20, pp. 463–474.
5. Kliman G B and Stein J (1990), “Induction motor fault detection via passive current monitoring”, in proceeding International Conference of Electrical Machinery, Cambridge, Volume 1, pp. 13-17.
6. Kliman G B and Stein J (1992), “Methods of motor current signature analysis”, Electric Machine Power System, Volume 20, Issue 5, pp. 463-474.

7. M E H Benbouzid et al., (1999), “Induction motors faults detection and localization using stator current advanced signal processing techniques”, in IEEE Transactions on Power Electronics, Volume 14, No. 1, pp. 14-22.
8. Riley C M et al., (1999), “Stator current harmonics and their causal vibrations: a preliminary investigation of sensorless vibration monitoring applications”, in IEEE Transactions on Industry Applications, Volume 35, No.1, pp. 94-99.
9. Önel I et al., (2005), “Detection of outer raceway bearing defects in small induction motors using stator current analysis”, Sadhana 30, Volume 6, pp. 713-722.
10. Singh S et al., (2014), “Motor current signature analysis for bearing fault detection in mechanical systems”, 3rd International Conference on Materials Processing and Characterisation, Volume 6, pp. 171-177.
11. Thomson W T and Gilmore R J 2003, “Motor Current Signature Analysis To Detect Faults in Induction Motor Drives-Fundamentals, Data Interpretation, and Industrial Case Histories”, Texas A&M University, Turbomachinery Laboratories.
12. https://microcontrollerslab.com/different-types-of-fault-in-three-phase-induction-motor/
13. An Investigation into “Fault Diagnosis of Induction Motor by Artificial Intelligent Technique”, Ph. D. (Tech) Thesis, Department of Applied Physics, C.U., 2010.
14. Miljković D (2015), “Brief Review of Motor Current Signature Analysis”, CrSNDT Journal, Vol. 5, No. 1, pp. 14-26.
15. Singhal A and Khandekar M A (2013), “Bearing fault detection in induction motor using motor current signature analysis”, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Volume 2, Issue 7, pp. 3258-3264.
16. Blodt M et al., (2008), “Models for Bearing Damage Detection in Induction Motors Using Stator Current Monitoring”, IEEE Transactions on Industrial Electronics, Volume 55, Issue 4, pp. 1813-1822.
17. Mehla N and Dahiya R (2007), “An Approach of Condition Monitoring of Induction Motor Using MCSA”, International Journal of Systems Applications, Engineering & Development, Volume 1, Issue 1, pp. 13-17.
18. Mehala N and Dahiya R (2007), “Motor current signature analysis and its application in induction motor fault diagnosis”, International journal of systems applications, engineer and development, Volume 2, Issue 1, pp. 29-35.
19. https://www.allaboutcircuits.com/technical-articles/the-importance-of-total-harmonic-distortion/

20. http://nepsi.com/resources/calculators/total-harmonic-voltage-distortion.htm
21. https://www.engineeringtoolbox.com/electrical-motors-hp-torque-rpm-d_1503.html
22. https://myelectrical.com/notes/entryid/8/three-phase-power-simple-calculations