Detection and Discrimination of Bearing Faults of A Three Phase Induction Motor from Single Phasing Faults using Wavelet Transform

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***Abstract*— This paper describes a protection scheme for a 3phase induction motor to detect and discriminate the bearing faults from single phasing faults. The loyalty of an Asynchronous induction motor is of predominant importance in various applications like industrial, commercial, aerospace and military. Rotating mechanical part bearings played an important role in the reliability and performance of all motor systems. In this paper the 3phase stator current signals are captured in P.C using DIP8000 that is having a sample frequency of 5.3KHZ. These signals are analyzed with Bior5.5 wavelet and decomposed up to 5th level. The values of d1 coefficient is above the predefined value of Threshold1 (th1) then the motor is under fault. In case of bearing faults all these values are above the predefined threshold otherwise it is healthy. The phase which is above Th1 represents the single phasing fault on that phase.**

Index Terms:- Bearing fault, sampling frequency, Threshold and Wavelet Transform.

I. INTRODUCTION

AC rotating Electrical motors especially induction motors are used for various industrial utilities because it plays a non-interchangeable role in many of the industrial processes [1]. Those asynchronous induction motors possess a variety of features those are not compatible with other motors like low cost, reliability and ruggedness but still those motors are devoted to some failures due to malfunctioning and manufacturing defects. Hence condition monitoring is necessary in order to reduce the cost of production [2].In rotating machinery bearing is one of the significant mechanical rolling part and it has expansive industrial and domestic applications proper function depends on the smooth operation performed by the bearings [3-4].Hence early fault detection is not done those faults are gradually degrade the performance of machine and also leads to motor interruption.

II. FAULTS CLASSIFICATION

Induction motor during running condition subjectected to various faults like electrical as well as mechanical faults.The fig.1 shows the percentage of various faults distribution shows in the pie diagram. Bearing faults are mechanical faults accounting for most motor failures.

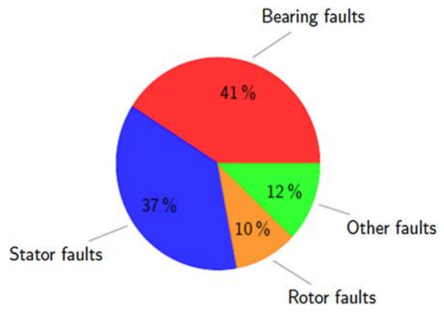


Fig.1 Pie diagram for various faults distribution

Similarly in the recent past several research studies shows that major category of faiulers in induction motor are bearing faults.The following below table I confer various research surveys performed by Electric Power Research Institute (EPRI), surveyed 6312 motors[5] and the reliability Working Group of motor of the IEEE-IAS, surveyed 1141 working machines [6].

Table 1 – Percentage of failure by component

Failed Component	Percentage Failures (%)	
	IEE-IAS	EPRI
Bearings Related	44	41
Windings Related	26	36
Rotor Related	8	9
Others	22	14

It is clear from the above table shows that the prevailing causes of the machines failures are mechanical rotating part bearing faults are major contribution. For significant fault detection various research studies gives out the least expensive bearing faults to fix the problem and at the same time it is most challenging to detect the fault under different operating conditions.

SINGLE PHASING FAULTS

Single-phasing means nothing but opening of one of the any three-phases. It leads to unbalance in the voltage. If a single phasing occurs in 3-phase motor full horse power will be delivered that is enough for driving the load. The motor continues to drive the load till it may burns out or until properly sized dual element and over load elements. The motor will be off from the line with the help of time delaying fuses. In the case of lightly loaded motors the phase currents increased by square root of three (√3) that secondary single-phasing conditions. This leads to draw an over current of 20% more than the full-load value. The motor may be damaged by the circulating currents if the overloads are sized at 125% of the rotating condition. Hence it is more appropriate to protect the motor against over loads rather than against the rated current.

In order to detect and classify the various faults several signal processing techniques involves the electrical machines data collection and the available data is processed by using several fault detection techniques. The rotating electrical machine condition monitoring is tested with the raw signal, those data collected by through various supportive equipment and sensors. The fault feature extraction done by comparing healthy case to faulty case by choosing a suitable signal processing technique. Earlier a several number of data acquisition approaches have been established for collection of certain parameters of electrical machines.

In most of the condition monitoring techniques the motors operating under different loaded conditions, for analyzing the fault feature the captured raw current with signal contaminated with noise, non-stationary condition. Hence it is very difficult to analyze the signal in the time-domain[7].For recent years advanced powerful signal processing techniques available analyze the signal in time-frequency domain for identification of faults[8] and also other non-invasive vibration and motor current signature analysis are used for condition monitoring of bearings[9],especially the following four methods frequency, time domain[10-11],enhanced frequency[12-13] and time-scale[14-15] signal processing methods are used to extract the fault feature of the bearing.

WAVELET TRANSFORM

For the analyzation of a signal in both frequency and time domains, the wavelet is found to be a powerful mathematical tool. A given signal is split into a number of signals corresponds to different frequency bands. These splitted signals store information more efficiently than of Fourier transform.Varites of wavelets are used for condition monitoring of electrical machines out of them Discrete wavelet transform (DWT) with multi-resolution analysis is used frequently. It provides a signal information in time-scale domain. This transform is an ideal tool analyzing the signal in non-stationary and transient nature. The continuous wavelet transform (CWT) of a given function *f*(t) gives the approach in time-scale domain used for identified as overall sum of the signal is the product of shifted and scaled version of the mother wavelet function *Ψ(t)*.Those function was given by Smith and McFadden as follows below

$$WT\,(a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} f(t)\Psi^{*}\left(\frac{t-b}{a}\right)\,dt \qquad (1)$$

Here the parameters *a* represented as scale index, it is a reciprocal of frequency and the parameter *b* shows the translation or tme-shifting. The transform is derived from the discretization of CWT (*a*,*b*) and those function was proposed by Smith and McFadden as follows below

$$DWT\,(j,k) = \frac{1}{\sqrt{2j}} \int_{-\infty}^{\infty} f(t)\Psi^{*}\left(t - \frac{2^{j}k}{2j}\right) \qquad (2)$$

here *a* and *b* replaced with by *2j* and *2jk*. In 1989 Mallat developed an efficient method using filters. The signal *f*(t) is passed through by two complementary filters and appears as low and high frequency signals. The signals are further broken into lower and higher resolution with successive approximations. The following fig.2 explains the Dyadic wavelet decomposition algorithm

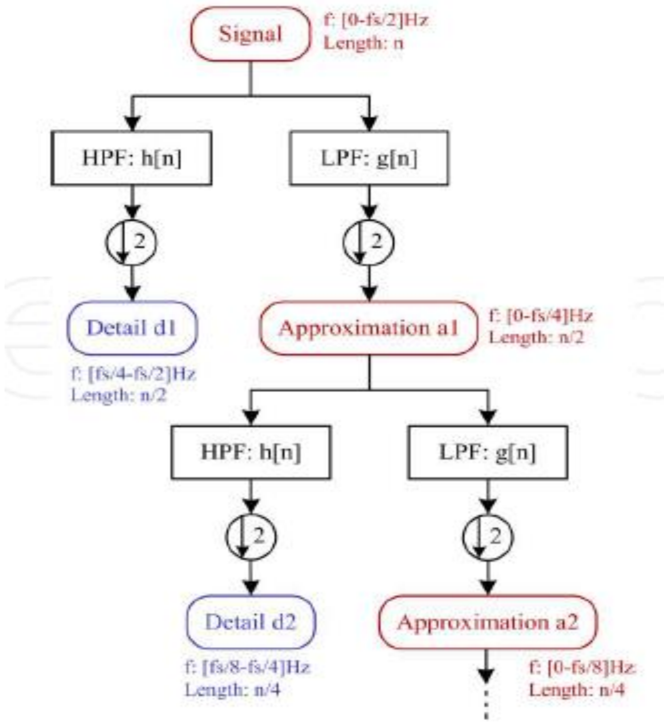


Fig.2. Dyadic wavelet decomposition algorithm

III. EXPERIMENTAL SETUP AND DATA ACQUISITION

A 3HP, 3 phase, 4 pole, 415 volts, 4.8A, 50Hz Induction motor is used for various bearing faults detection. The stator currents under various bearings faults condition are captured with UNIPOWER DIP8000 power network analyser with a measuring capacity of 5300 samples per second. After that export and import of those signals with a PC inter faced RS 232 port and complete the analysis with MATLAB software. The fig.3 and fig.4 shows the pictorial representation of Induction motor with UNIPOWER DIP8000 respectively.

Fig.3. Experimental test bench

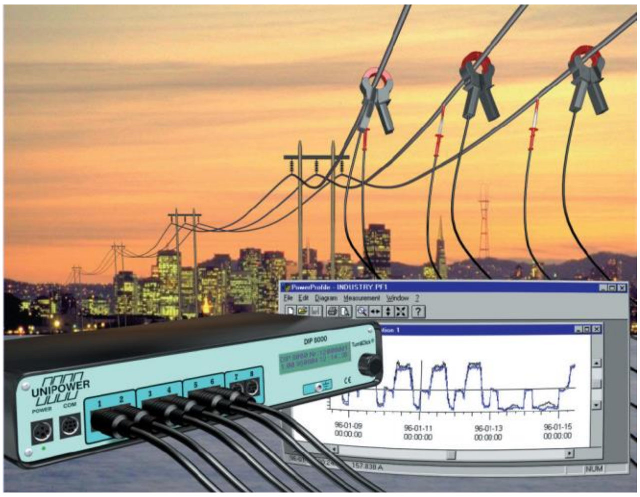


Fig.4 Power network analyzer

The following fig.5,fig.6,and fig.7shows the pair of healthy bearings, pair of outer race defect bearings and pair ball defect bearings respectively used for done the bearing faults.

Fig.5. Pair of healthy bearings.

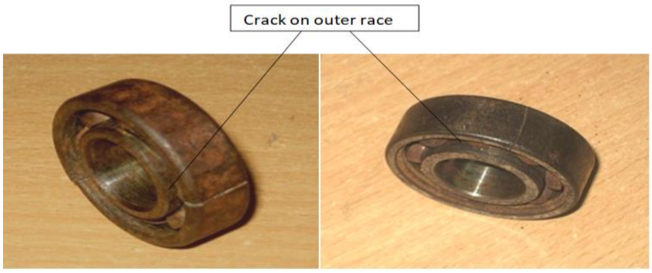


Fig.6. Pair of faulty bearings (Inner and outer race defect)

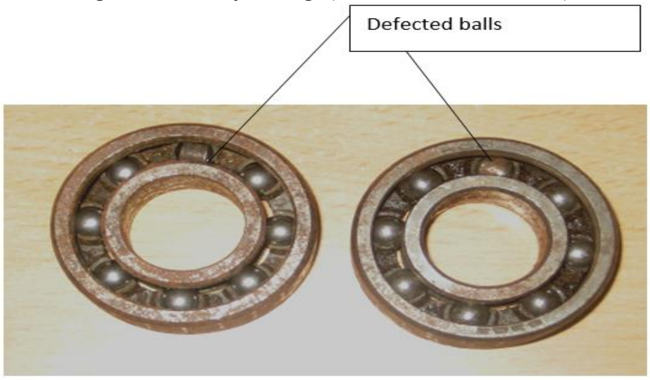
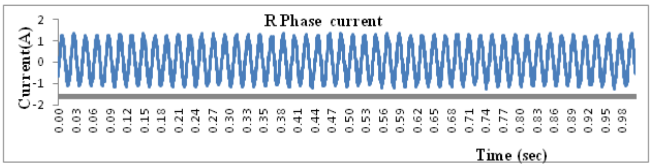


Fig.7. pair of faulty bearings (ball defect)

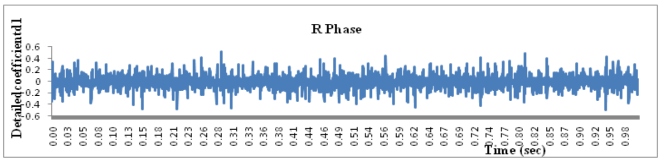
IV. EXPERIMENTAL RESULTS

The Fig.8 shows the 3-phase currents of the induction motor, which are captured from the Dip 8000(power network analyzer). These currents are analyzed with bior5.5 to obtain the d1 coefficients.Fig.8 represents the variation of d1 coefficients with respect to time for healthy bearings. The sum of absolute value of d1 coefficients are compared for all the phase currents with predefined Threshold1(1.16) All these values are below the threshold1 hence the motor is in healthy condition.

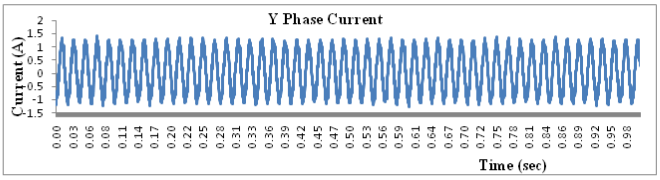
A.HEALTHY BEARING:



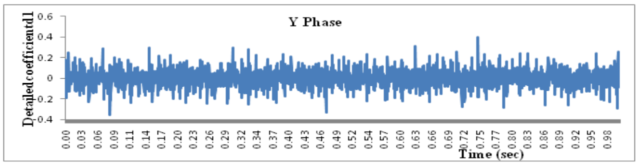
(a)



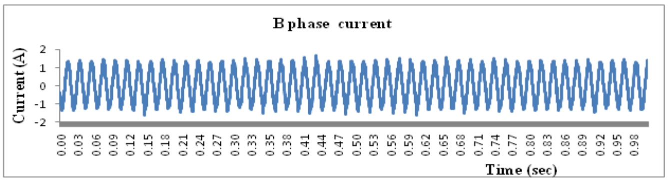
(b)



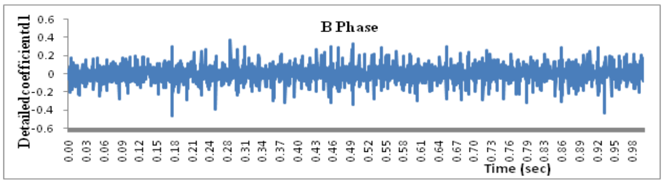
(c)



(d)



(e)

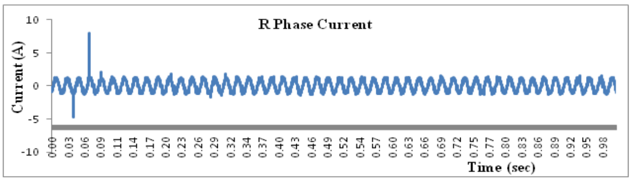


(f)

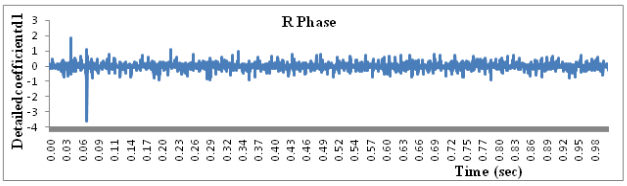
Fig,8(a),(b),(c),(d),(e) and (f) shows the variation of 3-phase Currents R,Y and B and ther d1 coeffient varion respectively.

B. BALL DEFECT:

The following Fig 9. represents the R-phase current in the 3-phase induction motor with Ball defect for which are captured from the Dip 8000(power network analyzer). These currents are analyzed with bior5.5 to obtain the d1 coefficients. The sum of absolute value of d1 coefficients are compared for all the phase currents of Ball defect with predefined Threshold1 as illustrated in fig.9 All these values are above the threshold1 (1.16) hence the motor bearings are faulty. Similarly Ball defect in Y-phase and B-Phase also verified .



(a)

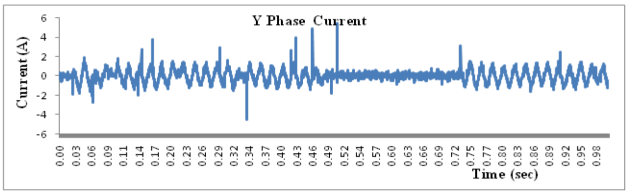


(b)

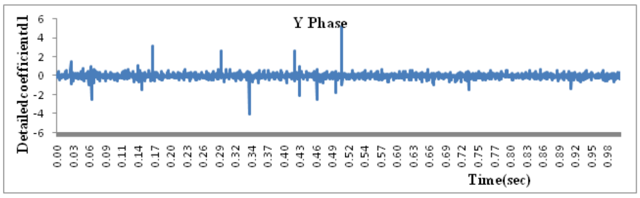
Fig,9(a) and (b) shows the variation of R-Phase current and ther d1 coeffient varion respectively.

C.INNER RACE DEFECT:

The Fig.10 (a) shows the Y-phase stator current variation for inner race defect bearing which are captured from the Dip 8000(power network analyzer). These currents are analyzed with bior5.5 to obtain the d1 coefficients. Fig.10 (a) represents the variation of d1 coefficients with respect to time. The sum of absolute values of d1 coefficients are compared for all the phase currents of Inner race defect with predefined Threshold1 as illustrated in fig 10 (b). Similarly Inner race defect in R-phase and B-Phase cases also the values are above the threshold1 (1.16), hence the motor bearings are faulty.



(a)



(b)

Fig,10 (a) and (b) shows the variation of Y-Phase current and ther d1 coeffient varion respectively.

CLASSIFICATION OF BEARING FAULTS:

R-phase Currents:

The captured current signals are analyzed by Wavelet analysis. The energy value of 5th level detail coefficients of three phase currents are tabulated as follows. Energy value of 5th level detail coefficients of three phase normal & faulty currents in R phase shown in Fig.11, fig.12 and Fig.13 respectively. The detection of faulty phase can be analyzed by comparing the energy value of 5th level detail coefficients of three phase currents are compared with a predefined threshold to identify the faulty phase. The energy values of d1 coefficients are high compared to d2, d3, d4, d5. All the values are shown in table1,2&3.

Table-1: Energy values of 5th level detail coefficients of 3-ph induction motor under healthy &faulty conditions in R- phase

Level	Healthy Bearing Current I_1	Ball defect Bearing Current I_1	Inner race defect Bearing Current I_1	Single Phasing Current I_1	Threshold
1	1.16	3.5314	1.2653	7.0777	1.16
2	0.6652	0.7563	0.4638	2.0649	1.16
3	0.338	0.2945	0.2439	0.5675	1.16
4	0.3219	0.2379	0.1351	0.3144	1.16
5	0.2244	0.771	0.7111	0.9201	1.16

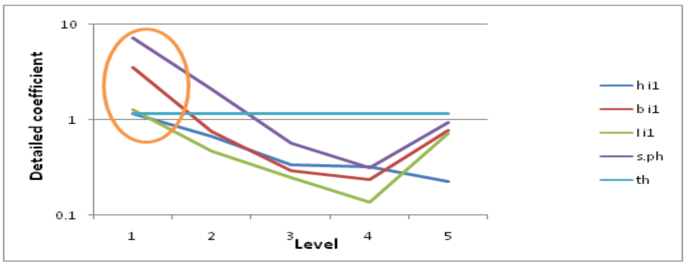


Fig.11 Energy value of 5th level detail coefficients of 3-ph induction motor under healthy & faulty conditions in R phase

Table-2: Energy values of 5th level detail coefficients of 3-ph induction motor under healthy &faulty conditions in R- phase

Level	Healthy Bearing Current I_2	Ball defect Bearing Current I_2	Inner race defect Bearing Current I_2	Single Phasing Current I_2	Threshold
1	0.4663	2.9738	6.2699	10.9285	1.16
2	0.2525	0.8928	2.6059	3.2018	1.16
3	0.1315	0.3121	1.1876	1.0901	1.16
4	0.2413	0.1716	0.7112	0.5352	1.16
5	0.3398	0.554	0.9168	0.7907	1.16

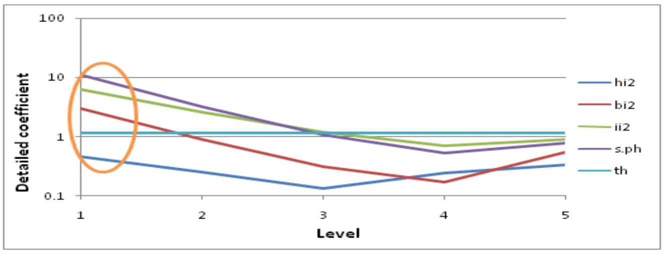


Fig.12 Energy value of 5th level detail coefficients of 3-ph induction motor under healthy & faulty conditions in R phase

Table-3: Energy values of 5th level detail coefficients of 3-ph induction motor under healthy &faulty conditions in R- phase

Level	Healthy Bearing Current I3	Ball defect Bearing Current I3	Inner race Bearing defect Current I3	Single phasing Current I3	Threshold
1	0.4704	2.1582	2.4054	9.8616	1.16
2	0.2933	0.7412	0.6093	2.9722	1.16
3	0.1483	0.2364	0.3455	0.8916	1.16
4	0.1887	0.1329	0.3532	0.3836	1.16
5	0.237	0.6501	0.8227	1.045	1.16

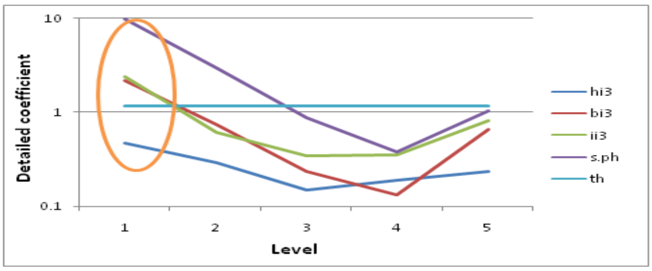


Fig.13. Energy value of 5th level detail coefficients of 3-ph induction motor under healthy & faulty conditions in R phase

Y-phase Currents:

The captured current signals are analyzed by Wavelet analysis. The energy value of 5th level detail coefficients of three phase currents are tabulated as follows. Energy value of 5th level detail coefficients of three phase normal & faulty currents in Y-phase shown in Fig.14, fig.15 and Fig.16 respectively. The detection of faulty phase can be analyzed by comparing the energy value of 5th level detail coefficients of three phase currents are compared with a predefined threshold to identify the faulty phase. The energy values of d1 coefficients are high compared to d2, d3, d4, d5. All the values are shown in table4, 5 & 6.

Table-4: Energy values of 5th level detail coefficients of 3-ph induction motor under healthy &faulty conditions in Y-phase

Level	Healthy Bearing Current I1	Ball defect Bearing Current I1	Inner race Bearing defect Current I1	Single phasing Current I1	Threshold
1	1.16	3.5314	1.2653	4.4779	1.16
2	0.6652	0.7563	0.4638	1.3638	1.16
3	0.338	0.2945	0.2439	0.4316	1.16
4	0.3219	0.2379	0.1351	0.1938	1.16
5	0.2244	0.771	0.7111	0.1638	1.16

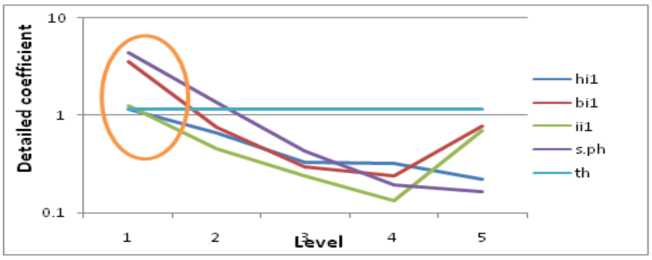


Fig.14 Energy value of 5th level detail coefficients of 3-ph induction motor under healthy & faulty conditions in Y- phase

Table-5: Energy values of 5th level detail coefficients of 3-ph induction motor under healthy &faulty conditions in Y-phase

Level	Healthy Bearing Current I2	Ball defect Bearing Current I2	Inner race Bearing defect Current I2	Single phasing Current I2	Threshold
1	0.4663	2.9738	6.2699	17.7159	1.16
2	0.2525	0.8928	2.6059	4.6711	1.16
3	0.1315	0.3121	1.1876	1.4521	1.16
4	0.2413	0.1716	0.7112	0.4636	1.16
5	0.3398	0.554	0.9168	0.4392	1.16

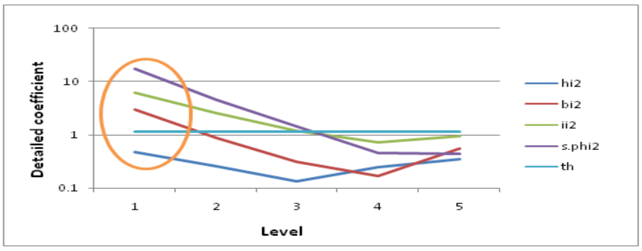


Fig.15. Energy value of 5th level detail coefficients of 3-ph induction motor under healthy & faulty conditions in Y- phase

Table-6: Energy values of 5th level detail coefficients of 3-ph induction motor under healthy &faulty conditions in Y-phase

Level	Healthy Bearing Current I3	Ball defect Bearing Current I3	Inner race Bearing defect Current I3	Single phasing Current I3	Threshold
1	0.4704	2.1582	2.4054	9.0567	1.16
2	0.2933	0.7412	0.6093	1.9296	1.16
3	0.1483	0.2364	0.3455	0.7196	1.16
4	0.1887	0.1329	0.3532	0.2799	1.16
5	0.237	0.6501	0.8227	1.0775	1.16

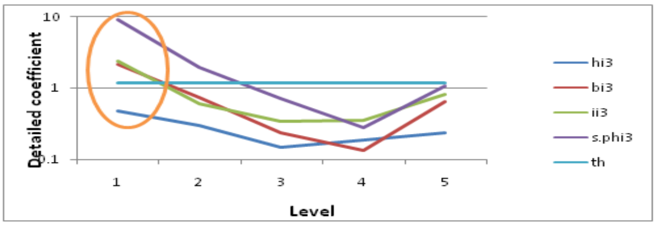


Fig.16. Energy value of 5th level detail coefficients of 3-ph induction motor under healthy & faulty conditions in Y- phase

B-phase Currents:

The captured current signals are analyzed by Wavelet analysis. The energy value of 5th level detail coefficients of three phase currents are tabulated as follows. Energy value of 5th level detail coefficients of three phase normal & faulty currents in B-phase shown in Fig.17,fig.18 and Fig.19 respectively. The detection of faulty phase can be analyzed by comparing the energy value of 5th level detail coefficients of three phase currents are compared with a predefined threshold to identify the faulty phase. The energy values of d1 coefficients are high compared to d2, d3, d4, d5. All the values are shown in table7,8 and 9.

Table-7: Energy values of 5th level detail coefficients of 3-ph induction motor under healthy &faulty conditions in B-phase

Level	Healthy Bearing Current I1	Ball defect Bearing Current I1	Inner race Bearing defect Current I1	Single phasing Current I1	Threshold
1	1.16	3.5314	1.2653	6.392	1.16
2	0.6652	0.7563	0.4638	1.6718	1.16
3	0.338	0.2945	0.2439	0.5564	1.16
4	0.3219	0.2379	0.1351	0.2315	1.16
5	0.2244	0.771	0.7111	1.0396	1.16

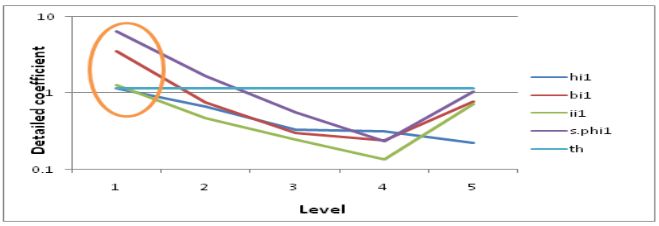


Fig.17. Energy value of 5th level detail coefficients of 3-ph induction motor under healthy & faulty conditions in B- phase

Table-8: Energy values of 5th level detail coefficients of 3-ph induction motor under healthy &faulty conditions in B-phase

Level	Healthy Bearing Current I2	Ball defect Bearing Current I2	Inner race Bearing defect Current I2	Single phasing Current I2	Threshold
1	0.4663	2.9738	6.2699	14.7018	1.16
2	0.2525	0.8928	2.6059	4.0878	1.16
3	0.1315	0.3121	1.1876	1.3547	1.16
4	0.2413	0.1716	0.7112	0.4661	1.16
5	0.3398	0.554	0.9168	1.009	1.16

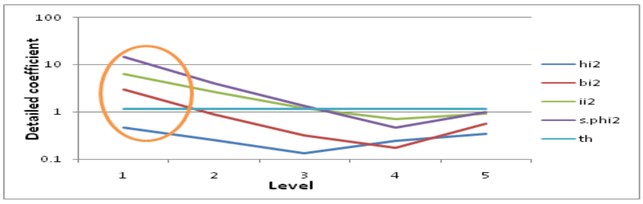


Fig.18. Energy value of 5th level detail coefficients of 3-ph induction motor under healthy & faulty conditions in B- phase

Table-9: Energy values of 5th level detail coefficients of 3-ph induction motor under healthy &faulty conditions in B-phase

Level	Healthy Bearing Current I3	Ball defect Bearing Current I3	Inner race Bearing defect Current I3	Single phasing Current I3	Threshold
1	0.4704	2.1582	2.4054	22.7754	1.16
2	0.2933	0.7412	0.6093	6.2595	1.16
3	0.1483	0.2364	0.3455	1.7263	1.16
4	0.1887	0.1329	0.3532	0.6073	1.16
5	0.237	0.6501	0.8227	0.314	1.16

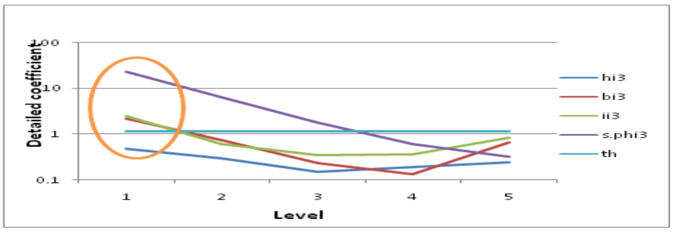


Fig.19. Energy value of 5th level detail coefficients of 3-ph induction motor under healthy & faulty conditions in B- phase

From the above analysis the energy value of 5th level detailed coefficients of three phase currents are used to identify the faulty phase. The values of d1 coefficients of normal and fault conditions compared with predefined threshold. At d1 coefficient identify the fault compared to remaining coefficient values. All these values are above the threshold hence the motor bearings are faulty.

SINGLE PHASING FAULT:

The Fig. 20,22,and fig.24 shows the 3-phase currents of the induction motor of R,Y and B-phases of single phasing phase-R, which are captured from the Dip 8000(power network analyzer). These currents are analyzed with bior5.5 to obtain the d1 coefficients. The Fig. 21,23,and fig.25 shows variation of d1coefficients with respect to time for single phasing fault for R,Y and B Phases respectively. Similarly in the remaing two phases Y and B-phases validated results are verified.

Single phasing Phase -R:

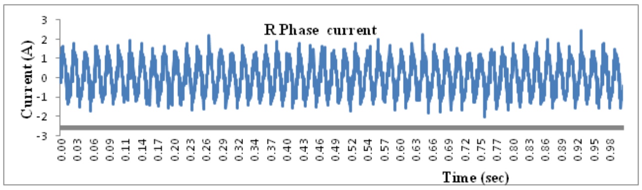


Fig.20 Variation of R-Phase Current in single–phasing –R

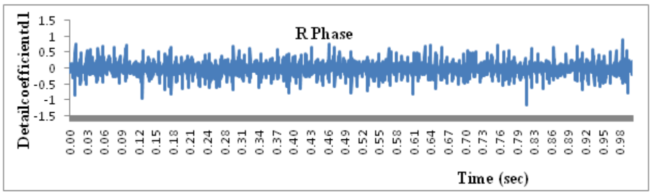


Fig.21 Variation of d1 coefficients of R-phase in Single–phasing –R

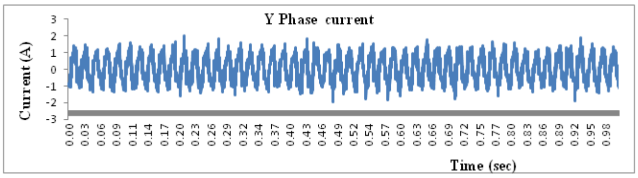


Fig.22 Variation of Y-Phase Current in single–phasing –R

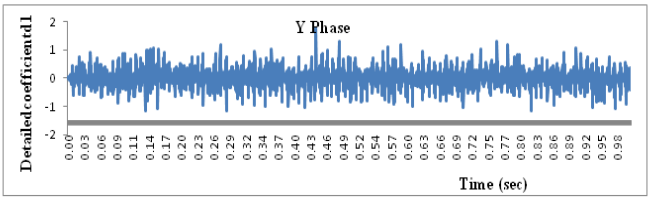


Fig.23 Variation of d1 coefficients of Y-phase in Single–phasing –R

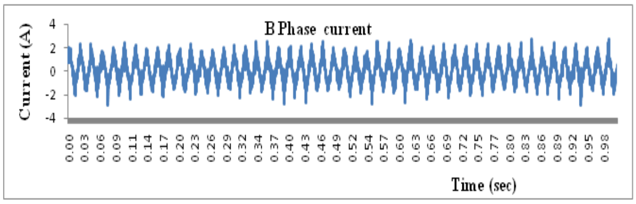


Fig.24 Variation of B-Phase Current in single–phasing –R

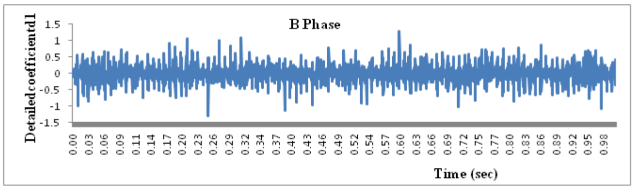


Fig.25 Variation of d1 coefficients of B-phase in Single–phasing –R

CONCLUSION

This paper introduces wavelet decomposition method for analyzing the transients of three-phase induction motor line currents. This scheme effectively detects and discriminate the type of fault(i.e. bearing fault or single phasing fault) by comparing the d1 coefficients with a predefined threshold . This scheme also classifies the bearing faults effectively by comparing the values of d5-coefficients with predefined threshold .The energy value of 5th level detailed coefficients of three phase currents are used to identify the faulty phase. This proposed scheme is fast and reliable to detect and classify most common bearing fault from single phasing fault.

REFERENCES

[1] Didier G, Ternisien E, Caspar O, Razik H. A new approach to detect broken rotor bars in induction machines by current spectrum analysis. Mechanical Systems and Signal Processing. 2007; 21: 1127–1142.

[2] Chow MY. Guest editorial special section on motor fault detection and diagnosis. IEEE Transactions on Industrial Electronics. 2000; 47.5: 982–983.

[3] Yan R. and Gao R X 2009 Base Wavelet Selection for Bearing Vibration Signal Analysis Int. J. Wavelets Multiresoluton & Inf. Process 7(4) 411-26

[4] Tandon N and A Choudhury 1999 A Review of Vibration and Acoustic Measurement Methods for The Detection of Defects in Rolling Element Bearings Tribolgy International 469-80.

[5] P. D. McFadden and J. D. Smith, "Model for the vibration produced by a single point defect in a rolling element bearing," Journal of Sound and Vibration, vol. 96, no. 1, pp. 69-82, 1984.

[6] Y.-T. Su and S.-J. Lin, "On initial fault detection of a tapered roller bearing: Frequency domain analysis," Journal of Sound and Vibration, vol. 155, no. 1, pp. 75-84, 1992.

[7] Bin GF, Gao JJ, Li XJ, Dhillon BS. Early fault diagnosis of rotating machinery based on wavelet packets – Empirical mode decomposition feature extraction and neural network. Mechanical Systems and Signal Processing. 2012; 27: 696–711.

[8] Burnett R, Watson J, Elder S. The application of modern signal processing techniques to rotor fault detection and location within three phase induction motors. Signal processing. 1996; 49.1: 57–70.

[9] R. B. Randall, Vibration-Based ConditionMonitoring: Industrial,Aerospace and Automotive Applications, John Wiley & Sons,Chichester, UK, 2011.

[10] J. Pons-Llinares, J. A. Antonino-Daviu, M. Riera-Guasp, S. B. Lee, T.-J. Kang, and C. Yang, "Advanced induction motor rotor fault diagnosis via continuous and discrete time-frequency tools," IEEE Transactions on Industrial Electronics, vol. 62, no. 3, pp. 1791-1802, 2015.

[11] M. E. H. Benbouzid, M. Vieira, and C. Theys, "Induction motors' faults detection and localization using stator current advanced signal processing techniques," IEEE Transactions on Power Electronics, vol. 14, no. 1, pp. 14-22, 1999.

[12] L. Eren and M. J. Devaney, "Bearing damage detection via wavelet packet decomposition of the stator current," IEEE Transactions on Instrumentation and Measurement, vol. 53, no. 2, pp. 431-436, 2004.

[13] Z. Ye, B. Wu, and A. Sadeghian, "Current signature analysis of induction motor mechanical faults by wavelet packet decomposition," IEEE Transactions on Industrial Electronics, vol. 50, no. 6, pp. 1217-1228, 2003.

[14] S. Prabhakar, A. R. Mohanty, and A. S. Sekhar, "Application of discrete wavelet transform for detection of ball bearing race faults," Tribology International, vol. 35, no. 12, pp. 793-800, 2002.

[15] H. R. Cao, F. Fan, and K. Zhou, Z. J. He, "Wheel-bearing fault diagnosis of trains using empirical wavelet transform," Measurement, vol. 82, pp. 439-449, 2016.

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