TEST Engineering & Management

January - February 2020
ISSN: 0193 - 4120 Page No. 11340 - 11348

Induction Motor Fault Diagnosis Using Wavelets and FFT

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Article Info
Volume 82
Page Number: 11340 - 11348
Publication Issue:
January-February 2020

Article History
***Article Received**: 18 May 2019*
***Revised**: 14 July 2019*
***Accepted**: 22 December 2019*
***Publication**: 21 February 2020*

Abstract
This paper introducea a protection scheme based on Fast Fourier transform along with Wavelet Multi Resolution Analysis for detection and classification of various faults like Stator turn fault, Locked rotor and rotor broken bars faults of a 3-Ø Asynchronous induction motor and the motor is represented with distributed high-frequency universal model which is validated over a wide range of operating frequencies. The simulation model has been to be simulated using MATLAB/Simulink software and tested for various types of Induction motor faults. The 3-Ø stator currents signals are decomposed by using debauchies5 (db5) mother wavelet. Fault index is defined by using maximum value of the absolute peak value of the highest level (d1) coefficients. In order to detect the faults the fault index is compared with a predefined threshold

Keywords: *Fast Fourier transform, Wavelet Multi Resolution Analysis, Fault index, Threshold*

I. INTRODUCTION

AC rotating machines especially induction motors are used in electrical drives because of their low cost, rugged construction, small in size and can be operated flexible power supply. During their operation they are subjected to varieties of stresses like environmental, electrical, thermal and mechanical. Hence in order to avoid the failures in induction motors the condition monitoring is an essential factor. [1]. Recent study reports shows that 35% of failures in induction motor are due to electrical faults like inter-turn ,L-G,L-L and single phasing faults and rotor faults around caused by stator winding related faults and rotor faults along with external motor faults around 10% of the total failures [2]. When the motor is not operates within its rating it causes excessive heating occurs this leads the de-rated of the motor performance [3]-[4]. The internal developed unavoidable inter-turn stator faults are gradually leads to major damage to motor. [5].For monitoring the faults of the motor, motor current signature analysis (MCSA) is employed as a definitive technique. It is a non-invasive method. For the detection of the turn-level faults of 3-ϕ currents using frequency spectrum, many signal processing techniques have been reported in [6].A Fast-Fourier transform cannot analyze a signal which has the characteristics like abrupt changes, frequency trends and drifts. When wavelets are employed for detection of faults, it involves high computational burden [7]. The multi resolution analysis (MRA) techniques of wavelets can be used for the analysis of a signal locally. For detection of cracked rotor bars, Discrete Wavelet Transform (DWT) can be used employed[8].In reference faults in the 3- ϕ induction machines are distribute by considering modulus maxima of detail coeffients of 3-phase

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currents. In the recent past intelligent techniques like soft computing, neural networks and fuzzy

Systems have been employed developments the detection of faults in a 3-phase induction motor .In this research work blocked rotor fault, broken rotor bar fault and stator inter-turn faults are considered. By using the absolute peak first level detail coefficient of stator currents the fault detection is carried out.

II. WAVELET ANALYSIS

Fourier transform gives only the information related to frequency of the signal but it does not gives the information related at what time the frequency component exist. This transform useful only when analyzing the signal under stationary condition is not required when the signal is so called stationary but most of the practical signals are available in non-stationary form. Hence this disadvantages can be overcome by using wavelet techniques.

The transient behavior of voltage and current signals can be analyzed by using Wavelet transform (WT).This feature employs a non-uniform decomposition in the frequency-domain. A WT extracts data during in the long period of the to a low frequency component and vice-versa. The most important feature of WT is to analyze a two-dimensional signal in time and frequency domains. The decomposition can be carried out by using low and high pass filters. Different frequency bands can be obtained by the decomposition of the signal. In this section a little introduction regarding WT and MRA is presented. The solution of wavelets is done using two basic equations, the wavelet function ψ(t) and the scaling function φ(t)

$$\varphi(t) = \sqrt{2}\sum h(n)\varphi(2t-n) \qquad (1)$$

$$\Psi(t) = \sqrt{2}\sum g(n)\varphi(2t-n) \qquad (2)$$

Here $g(n)=(-1)^n h(1-n)$

The above mentioned functions (1) and (2) depends on a scaling function called the mother wavelet which follow the conditions mentioned below:

$$\sum_{n=1}^{N} h(n) = \sqrt{2} \qquad (3)$$

$$\sum_{n=i}^{N} h(n)h(n+2l) = \begin{cases} 1 & if\ \ i=0 \\ 0 & if\ \ i\neq 0 \end{cases} \qquad (4)$$

The sequences g(n) & h(n) present the digital discrete filters that solved for every equation, here $g(n)=(-1)^n h(N-n+1)$. The wavelet functions & scaling are the earlier type of an orthonormal basis functions in the form

$$\varphi_{m,n}(t) = 2^{m/2}\,\varphi(2^m t-n); \quad m,n \in Z \qquad (5)$$

$$\Psi_{m,n}(t) = 2^{n/2}\,\varphi(2^m t-n); \quad m,n \in Z \qquad (6)$$

Here the compression and dilation is controlled by

Parameter m and translation controlled by parameter n.

$$f(t) = \sum_{l=\in} c(l)\,\varphi_l(t) \sum_{m=1}^{N-1}\sum_{n=z}^{\infty} d(m,n)\,\Psi_{m,n}(t) \qquad (7)$$

here the coefficients d(m,n) & c(l) are calculated as

$$c(l) = (\varphi_l|f) = \int f(t)\,\varphi_l(t)dt \qquad (8)$$

$$d(m,n) = (\Psi_{m,n}|f) = \int f(t)\,\Psi_{m,n}(t)dt \qquad (9)$$

The original signal can be approximated as f(t) is given by c(l) with resolution of one point out of 2^N of the actual signal. The details of the expansion signal are given as d(m,n).

III. INDUCTION MOTOR FAULT DIAGNOSIS

The following induction motor mathematical model is considered for simulation study is shown in the

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following Fig. A 5HP, 3-ϕ, 460V, 36slot with 4pole, per phase 6coils and per coil 30 turns Asynchronous Induction Motor is considered.

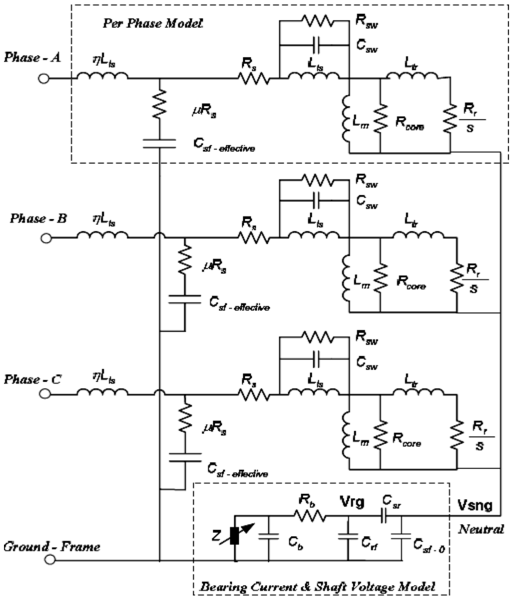

Figure 1. Universal Model representation of 3-ϕ Induction Motor

The per phase stator winding represented as with a coil of high frequency π configuration distributed model shown in figure.(2)

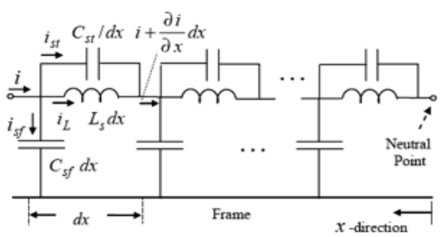

Figure 2. stator winding distributed high frequency model

In this proposed algorithm for fault identification wavelet multiresolution analysis with Bior 5.5 mother wavelet used for analyzing captured current signals in the simulation with a sampling frequency of 6KHz for getting detailed coeffients for defining a fault indices.

Simulation Diagram of Universal Induction Motor Model

Induction motor mathematical model is considered for simulation study is shown in Figure.3 A three-phase, 5HP, 3-phase, 460V, 36slot with 4pole, per phase 6coils and per coil 30 turns Asynchronous Induction Motor is considered.

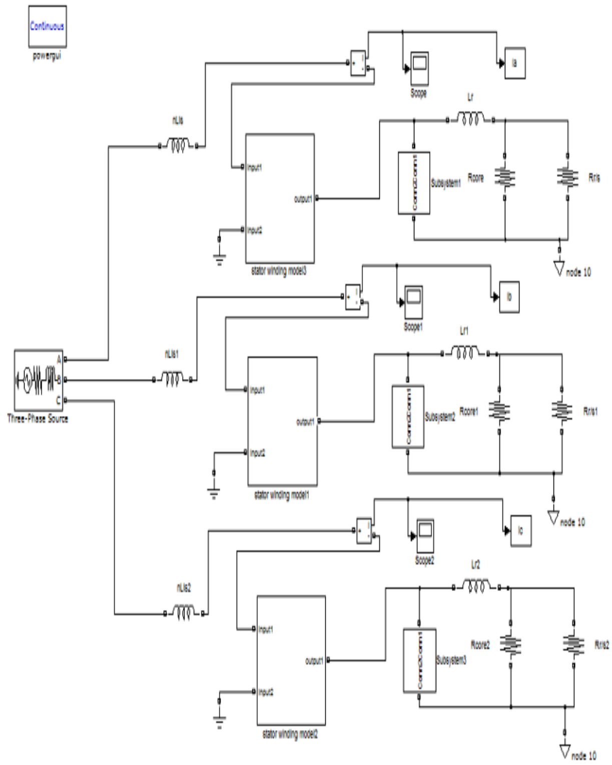

Figure 3. 3 phase induction motor Simulation model

A. Inter-turn Faults

The breakdown of the winding insulation leads to stator faults. As insulation of the winding becomes weak, ultimately it leads to line short-circuit .By short circuiting the appropriate number of turns an inter-turn fault is simulated in the induction motor model considering 3 and 5 turns. 3 and 5 turns shorting in each phase by placing a circuit breaker across the turns. The fault is initiated at fourth-cycle. At every switching instant the simulation is done and the fault detection is carried out with energy of d1 coeffients of decomposed current signals from FFT.

B. Induction motor Rotor Broken bar Faults

Whenever the motor is subjected to a

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mechanical rotor fault, the current in the nearby rotor bars is increased leading then causes to break. It can be modelled by introducing very high value of resistance than bar resistance.

The increment in resistance is given by

$$\Delta R = \frac{3R_2 n}{N}$$

N=Total no of rotor bars=45

n=number of rotor bars broken i.e., 3, 5, 7.

Where R_2 is rotor resistance.

In this proposed work 3, 5, and 7 broken bars are considered and

the detection is carried out with d1 coefficients of the wavelets and

classification is done by with the energy content of the current signals

from FFT.

C. Blocked Rotor Faults

The rotor is obstructed from rotation in the locked rotor condition. Under this condition it draws 5 to 8 times the full load current. As the rotating Induction motor is not design to draw such a higher magnitude of current, a protective system is to be employed against blocked rotor condition. This is modelled by equating the slip to unity.

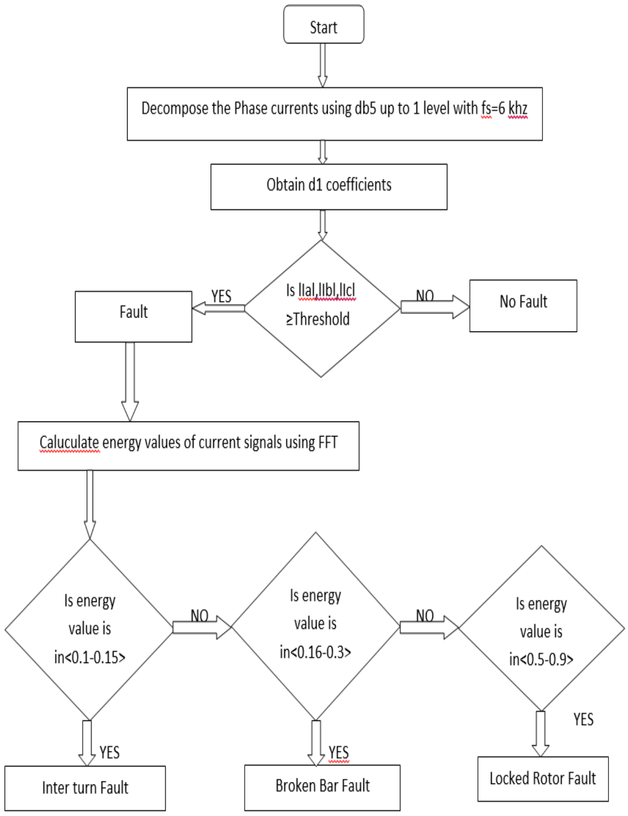

Figure 4. Fault detection and classification flow chart

IV. DETECTION AND CLASSIFICATION FAULTS

The algorithm developed based on the transients of 3-ϕ line currents sampled at a frequency of 6KHz. This level contains

the high frequencies that are encountered with faults.The calculated

peak absolute value of all 3-phases exceeds a certain threshold, when the motor is faulty condition for detection and classify the type of fault, can be calculated current signal energy values by using FFT.

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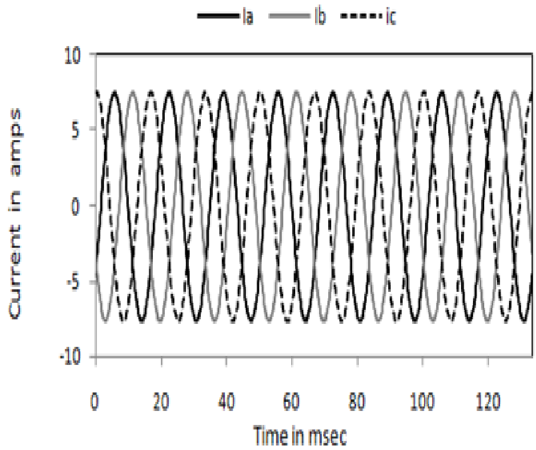

Figure 5. Current Signals for healthy Case.

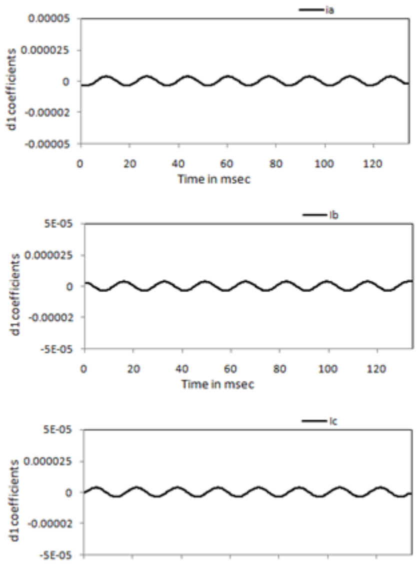

Figure 6.d1 coefficients for healthy case

A.INTERTURN FAULTS

An Inter-turn fault is mainly occurred due to the breakdown of winding insulation, the fault is introduced in the given circuit by shortening the appropriate turns across each phase individually. Here 3, 5 turns short in each phase is considered individually. The Fig 7 shows current signals with short-circuit inter turn fault 5 turns short shown in Phase A, and Fig 8 shows first level detail coefficients in Phase A 5 turn inter turn fault short. Similarly fault detection and classification can be carried out to the remaing phases B and C.

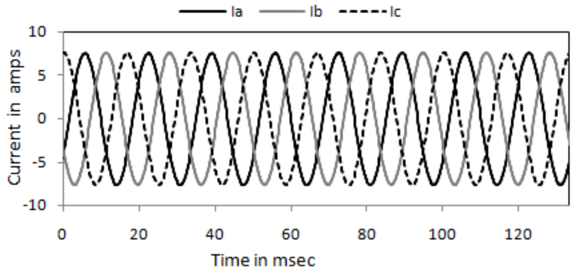

Figure 7. Phase A 5 turn inter turn fault Current signals for in

at FIA (Fault Inception Angle) of 0^0

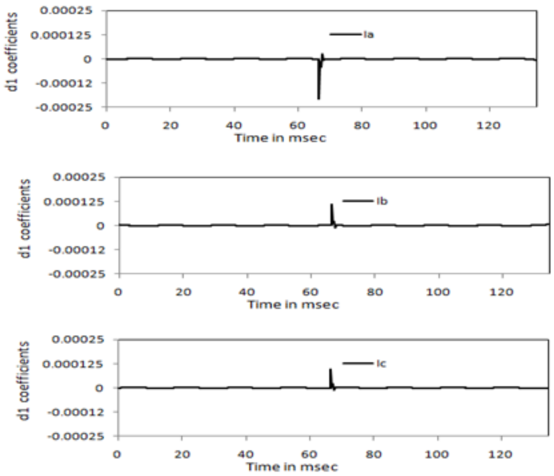

Figure 8. d1 coefficients for an interturn fault (5 turns) in phase A at

of FIA (Fault Inception Angle) of 0^0

B.ROTOR BROKEN BAR FAULTS

Whenever a broken bar rotor fault causes excessive current on adjacent bar increases and cause them to break. The Fig.9 shows current signals for 7 broken bars respectively and Fig 10 shows variation d1 coefficients for 7 broken bars. Similarly fault analysis can be carried out to the 3,5 broken bars.

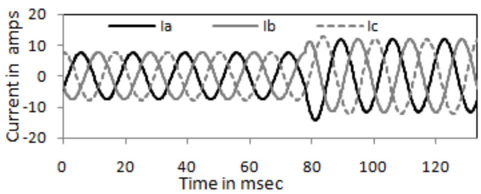

Figure 9. Current signals for 7 broken bars at FIA of 240^0

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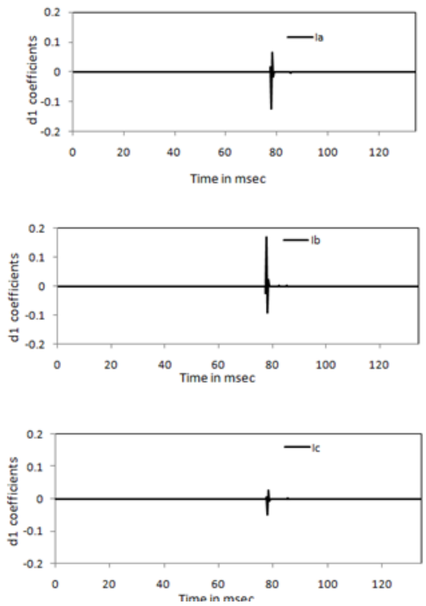

Figure 10. d1 coefficients for 7 broken bars at FIA of 240^0

C.BLOCKED ROTOR FAULT

Rotor locked is meant as the rotor of induction machine stopping for rotation due to subjectected some mechanical obstacles. During this condition, the the motor draws nearly 5 to 8 times the rated current. It is simulated with s=1.The Fig 11 shows current transient signals for locked rotor fault and Fig 6.22 Shows first level detail coefficients for blocked rotor at FIA of 270^0.

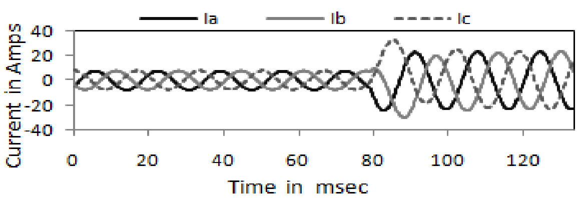

Figure 11. Blocked rotor fault Current signals at FIA of 270^0

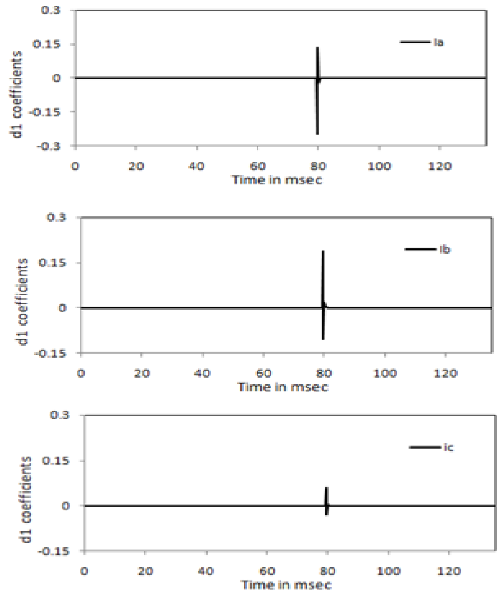

Figure 12. d1 coefficients for Locked rotor fault at FIA of 270^0

DETECTION OF FAULTS

The current signals are decomposed into 1 st level detail coefficients using db5 mother wavelet for the extraction of fault feature of current signals with a sampling frequency of 6 kHz. These coefficients are used for fault detection .The fault detection can be performed with 1/8 of cycle. The following figures shows fault indices variation with respect to Fault inception angle. Fig 13 shows fault indices variation of for 5 turns short in phase C, Fig 14 shows fault indices variation for 3,5and 7 broken bars respectively and Fig 15 shows fault indices variation for Locked rotor fault. Similarly remaing cases also the fault analysis can be carried out.

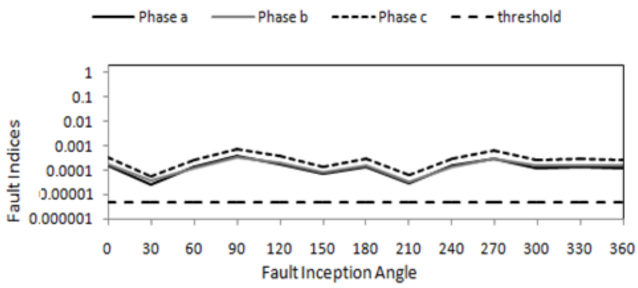

Figure 13. Fault indices variation of with 5 turns short in Phase C

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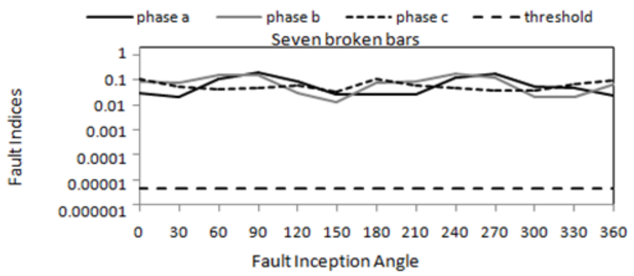

Figure 14. Fault indices Variation of w.r.t FIA for 7 broken bars.

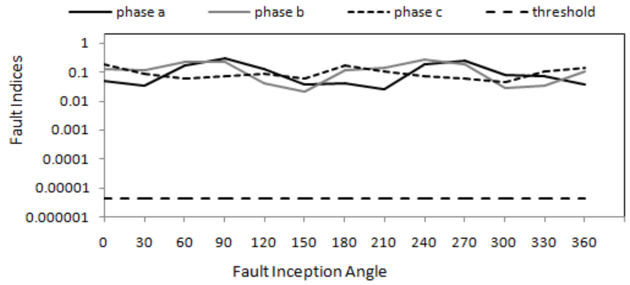

Figure 15. Variation of Fault indices w r. t FIA for locked rotor.

CLASSIFICATION OF FAULTS

The classification of Faults is done by determining the current signal energy values during fault by using FFT and observed the variation in energy values for different faults. For classifying an inter turn faults the energy value lies in between 0.1-0.15, for broken bar fault the energy value lies in between 0.16-0.3 and similarly if the energy value lies in between 0.5-0.9, so the fault is locked rotor fault.

$$\text{Energy value}= \sum_{n=-\infty}^{\infty}|x(n)|^2 = \frac{1}{N} \sum_{k=0}^{N-1}|X(k)|^2$$

Where X(k) is FFT signal, x(n) is sample signal and N=number of samples in FFT.

Fig 16 shows FFT energy signal for 5 turns short in Phase A., Fig 17, shows FFT energy signal for 5 broken bars and Fig 18 shows FFT energy signal for locked rotor. From the above figures it is evident that the peak value is obtained at fundamental frequency.

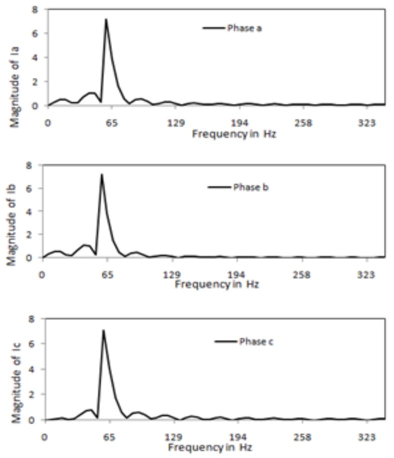

Figure 16. FFT energy signal for 5 turns short in Phase A

Table. 1 Energy values for 5 turns short in Phase A.

Energy Values for 5 turns short in Phase A			
Fault Inception Angle	Phase A	Phase B	Phase C
0	0.143744	0.14305	0.14388
30	0.143741	0.143047	0.143881
60	0.143726	0.143047	0.143874
90	0.143714	0.143058	0.143857
120	0.143722	0.14308	0.143839
150	0.143746	0.143103	0.143828
180	0.143765	0.143113	0.143828
210	0.143756	0.143106	0.14383
240	0.143715	0.143092	0.143824
270	0.143665	0.143082	0.143809
300	0.143631	0.143081	0.143792
330	0.143623	0.143086	0.143784
360	0.143627	0.143087	0.143784

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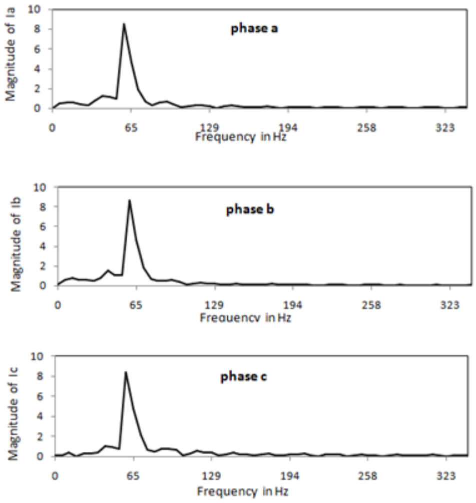

Figure 17. FFT energy signal for 5 broken bars.

Table 2. Energy values for 5 broken bars.

Energy Values for 5 Broken Bars			
Fault Inception Angle	Phase A	Phase B	Phase C
0	0.203524	0.211638	0.203314
30	0.21441	0.207705	0.201145
60	0.211195	0.20011	0.199863
90	0.207246	0.197857	0.210636
120	0.199671	0.196562	0.20744
150	0.197453	0.20724	0.203483
180	0.196171	0.204056	0.195972
210	0.206866	0.200091	0.193886
240	0.20366	0.192641	0.192647
270	0.199682	0.190662	0.203452
300	0.192229	0.189463	0.200194
330	0.190243	0.20036	0.196205
360	0.189048	0.197055	0.188684

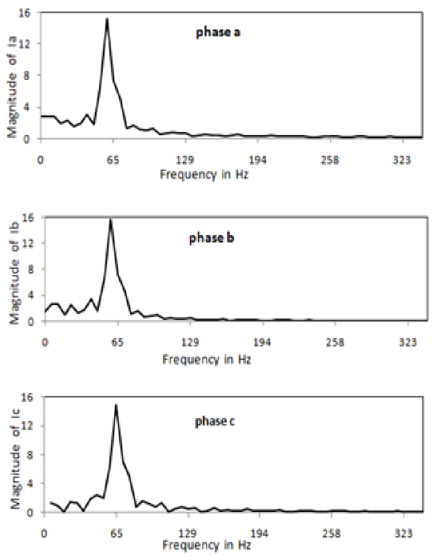

Figure 18. FFT energy signal for Locked rotor.

Table 3. Energy values for locked rotor.

Similar the energy value calculation using FFT for the remaing cases also verified.

Energy Values for Locked Rotor Fault			
Fault Inception Angle	Phase A	Phase B	Phase C
0	0.808386	0.794227	0.715865
30	0.810936	0.737617	0.735464
60	0.7676	0.711851	0.768489
90	0.710047	0.731383	0.770891
120	0.701062	0.764239	0.736063
150	0.702023	0.766483	0.668647
180	0.734289	0.722491	0.64117
210	0.736273	0.66439	0.659175
240	0.692709	0.637321	0.690906
270	0.635699	0.655685	0.692678
300	0.610128	0.687514	0.649483
330	0.629846	0.689109	0.593467
360	0.662376	0.645661	0.569293

CONCLUSION

This research paper introduces a Wavelet and FFT based algorithm for diagnosis the faults on induction motor is simulated in the MATLAB simulation model and analyzed with different faults. The identification of various faults on 3-phase Induction motor has been done using the FFT and wavelet transform which captures the features of current signals generated during occurrence of faults. To discriminate the various faults fist level detailed coefficients (d1) of db5 extracted from original current signals are used for fault detection. The absolute peak d1 coefficients are set as a fault indices which are compared with a pre-defined threshold to detect the fault. The original current signals energy values are calculated by using FFT for various fault classification the fault detection can be performed with 1/8 of cycle. So, the simulated results explains the developed algorithm is very faster and accuracy for diagnosis of various faults with different fault inception angles **(FIA).**

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