FAULT DIAGNOSIS OF INDUCTION MOTOR USING ENVELOPE SIGNALS & POWER SPECTRAL DENSITY

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Abstract: This paper proposes a novel and easy method for diagnosing the broken bar fault in induction motor. Discrete wavelet transform (DWT) along with Power Spectral Density (PSD) is used on the envelope of the stator current signal, a new dimension on fault diagnosis. The severity of the faults is also investigated. DWT is used for decomposing the signals into wavelet coefficients and PSD is used for calculating the energy of the wavelet coefficients. The energy of the higher level detail coefficients provides better fault diagnosis. The proposed method shows reliability in fault diagnosis and effectiveness in fault severity identification.

Key words: Broken bar fault, Discrete Wavelet Transform (DWT), Fault Identification, Power Spectral Density (PSD).

1. Introduction

The induction motors are popularly used machines and they have to be monitored regularly to reduce the unknown shutdown time and to schedule the maintenance [1]. Some of the conventional monitoring techniques and fault diagnosing methods are vibration monitoring [2], acoustic pressure measurement [3], electromagnetic field monitoring [4] and motor current signature analysis (MCSA) [5]. In vibration analysis, the sensors must be of non-invasive and reliable ones; this method is sensitive to the installation position; also it has the problems like signal background noise [2]. Even though the acoustic pressure measurement is a good alternative to the vibration analysis, it has received less attention due to the noise in acoustic signal [3]. The search coil can also be used to enhance the detection and location accuracy of the fault. But this method implies less possibility as the installed motors don't include the search coil in its design [4]. Motor Current Signature Analysis (MCSA) is the one used popularly to detect faults at early stages. Fast Fourier Transform (FFT) has the draw backs like frequency resolution, inaccuracy at steady state which are generally due to data processing [6]. Zoom FFT (ZFFT) was introduced to improve the frequency accuracy in a specified frequency range without increasing the computational complexity. Short Time Fourier Transform (STFT) is able to provide the clear idea of the band; also it gives the information of the time and frequency [7]. But it requires high processing power to obtain good resolution.

Parametric methods have high frequency resolution and they are classified into linear prediction methods and subspace techniques. These methods use small number of data in fault diagnosis, but the analysis of fault identification is through the frequency components [9], which may increase the complexity of the diagnostic process. But, they provide is no information on for fault severity. There are plenty of literatures available on fault diagnosis [1]-[10] in parametric and non-parametric methods which lack in accuracy and resolution. Most of these methods do not provide information regarding severity of the fault. This paper aims to provide a new simple reliable algorithm for fault diagnosis and identification of severity. The novelty lies in the application of PSD and DWT on the envelope of the motor current, obtained for broken bar faults. The envelope of the motor current signature is a new dimension in fault diagnosis. The proposed algorithm provides a clear distinction of the healthy and faulty conditions.

2. Background

2.1 Broken bar Fault frequency (f_b)

The fault frequency appearing on the stator current spectrum of the induction motor due to broken bar fault is given by the formula,

$$f_b = (1 \pm 2ks)f_s \tag{1}$$

f_s is supply frequency, s is slip and k is harmonics frequency index; k=1,2,3….

2.2 Discrete Wavelet Transform with Power Spectral Density

Wavelet analysis is breaking up of signal into shifted and scaled versions of the mother wavelet. The discrete wavelet transform (DWT) consists of sampling the scaling and shifted parameters, which leads in high frequency resolution at low frequencies and high time resolutions at higher frequencies. Discrete Wavelet Transform (DWT) can be used in fault identification. The mother wavelet chosen is Daubechies-10 (db-10) with 8 decomposition levels. The filter coefficients of DWT are used to calculate the wavelet coefficients. These coefficients are passed through low pass and high pass filters and down sampled by2. The detail and approximate coefficients are obtained from the high pass filter and low pass filters respectively. Fig.1 shows the filter bank structure for three decomposition levels.

The squared summation of detail and approximate

coefficients give the energy of the signal. It is calculated using Parseval's theorem as given in equation 2.

$$\sum_{n=1}^{N}|x(n)|^2 = \sum_{n=1}^{N}|a_j(n)|^2 + \sum_{j=1}^{m}\sum_{n=1}^{N}|d_j(n)|^2 \qquad (2)$$
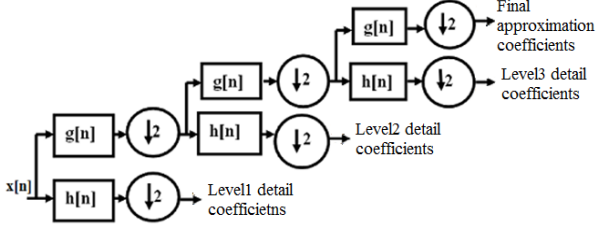

Fig.1. Filter bank structure for three decomposition levels

2.3 Envelope analysis

Envelope analysis is based on the extraction of the envelope of the signal to be analyzed. Envelope is used for investigation of faults where faults have amplitude modulation effect on the characteristics frequencies. Envelope detection or amplitude demodulation is a technique of extracting the modulating signal from amplitude modulated signal. Envelope analysis is the FFT spectrum of modulating signal.

The spectrum of the current signal obtained on a machine with rotor fault will contain one or more fault frequencies. Most often, the frequency caused by the fault may be obscured by the other frequencies from the rotating parts like shaft, gear, bearing etc. And the fault frequencies cannot be seen in either the time history or in the current spectrum. The fault frequencies are present throughout the spectrum but obscured by other frequency components.

Envelope is the modulus of the Complex Analytic signal generated by using the original signal as the real part and its Hilbert Transform as the imaginary part. Hilbert transform changes the phase of the spectral components depending on the sign of their frequency. It has the effect on phase of the signal, not on the amplitude. Let the real time signal is x(t). Hilbert transform,

$$y(t) = H[x(t)]$$
(3)

Where

$$y(t) = \int_{-\infty}^{\infty} \frac{x(\tau)}{\tau - t} d\tau$$
(4)

The analytical signal z(t)is represented by equation(4).

$$z(t) = x(t) + jy(t)$$
(5)

All the negative frequencies of x(t) are filtered.
Envelope E(t), is absolute value of z(t).
i.e. $E(t) = |z(t)| = |x(t) + jy(t)|$ (6)

3. Experimental setup

Every change in the operating condition of the induction motor appears as transient phenomena at the supply side [10] and the stator current is taken as the source parameter to analyze. The test motor has the following specification: 1 hp, 415V, 3ϕ, 50Hz, 4 pole with dynamometer loading arrangement. The analysis was performed on the stator current signal acquired

from the healthy and faulty induction motor. After acquiring the healthy current, the fault is created manually on the rotor to acquire the stator current for broken bar faults. Fig. 2 shows the experimental setup.
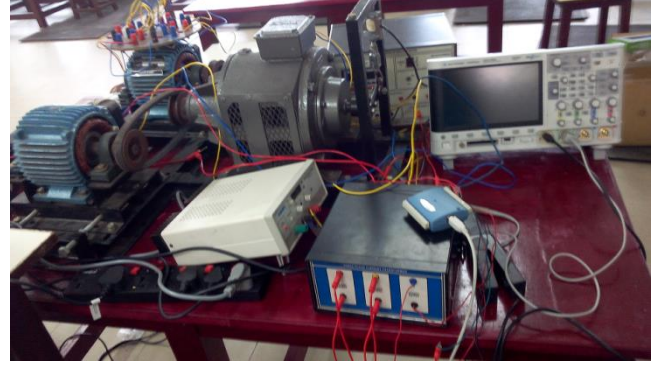

Fig. 2. Experimental setup

3.1 Broken bar fault:

Fig. 3 shows the broken bar created on the rotor bar. The rotor is removed from the motor and a punch is created on the rotor bar for 1.6mm diameter and 5mm depth. It is fixed properly and the stator current is acquired. The second punch is created with the same diameter and depth but 180 deg opposite to the first bar and the stator current is acquired for analysis. The third punch is created in the next bar of the broken bar 1. Every time the fault created, the current is acquired for analysis.

The stator current signals are acquired using DSO-X 3024A MY54020518 – Channel1, at healthy and faulty conditions, with the sampling frequency of f_s = 20000 samples/s. Fig.4 and Fig.5 shows the current spectrum for healthy and single bar broken case respectively. Stator current cannot be directly used for fault diagnosis.

Fig3. Broken bar in the rotor

4. Result and Discussion

The envelope of the original current spectrum for healthy and various faulty conditions are obtained using matlab. Fig. 4 shows the stator current and its envelope under healthy condition and Fig. 5 shows the stator current and its envelope under single broken bar condition. Envelope signal is the modulating signal obtained from the original current spectrum which contains the repetitive fault frequency components.
The envelope of the original stator contains frequency

components related to the fault.

Discrete wavelet transform (DWT) & Power spectral density (PSD):

The frequency components appearing on the stator current of the induction motor, for the broken bar are 47.33, 48, 48.67, 49.33, 50.67, 51.33, 52, 52.67 Hz……. With k values varying from, 1,2,3…. The sampling frequency of acquired data is 20000 samples/s. When the data acquired is decomposed with Daubechies-10, the decomposition level 8 covers all the frequency related to the faults. Therefore db-10 with level 8 is chosen. Table1 shows the decomposition levels and corresponding frequency ranges.
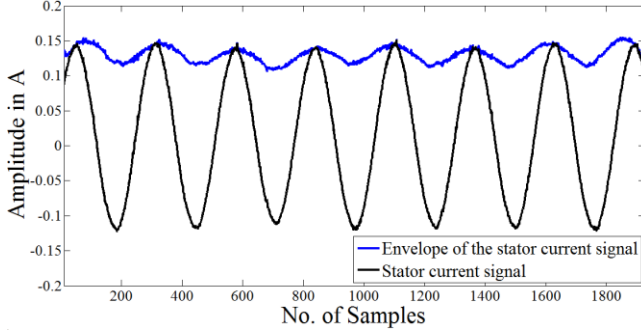

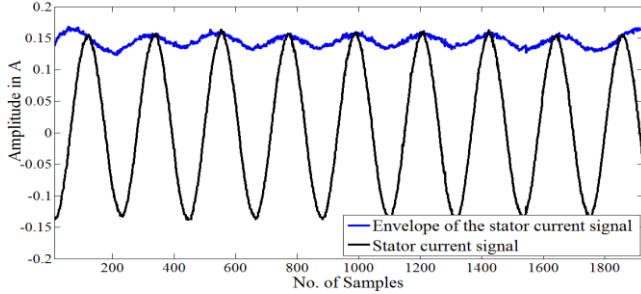*Fig4. Stator current and its envelope under healthy condition.*

Fig5. Stator current and its envelope under broken bar condition.

Table 1
Decomposition levels and its frequency ranges

level	Frequency range in Hz	
	From	*To*
1	10000.00	5000.00
2	5000.00	2500.00
3	2500.00	1250.5
4	1250.0	625.00
5	625.00	312.5
6	312.5	156.25
7	156.25	78.13
8	78.13	39.07

DWT is applied on the envelope of signal to estimate the wavelet coefficients. Fig. 6 and Fig. 7 show the wavelet decomposition of the envelope of the healthy and faulty stator current signal respectively.
It is clear from the fig 6&7 that it is not so easy to diagnose the fault with the wavelet coefficients. The

approximate and detail coefficients from DWT are used in calculating the energy of the signal using equation (2). The energy of the envelopes acts as the fault index in diagnosing the broken bar fault and in identifying the fault severity.

DWT and PSD on envelope of the stator current:

DWT and PSD are applied on the envelope of the healthy current and the faulty current. It is shown in Fig 8&9 under various loads.
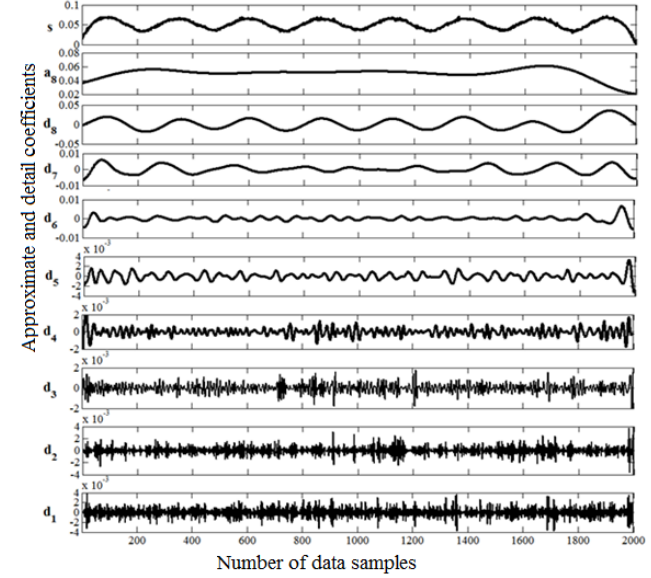

Fig6. Wavelet decomposition of envelope of the stator current signal under healthy condition
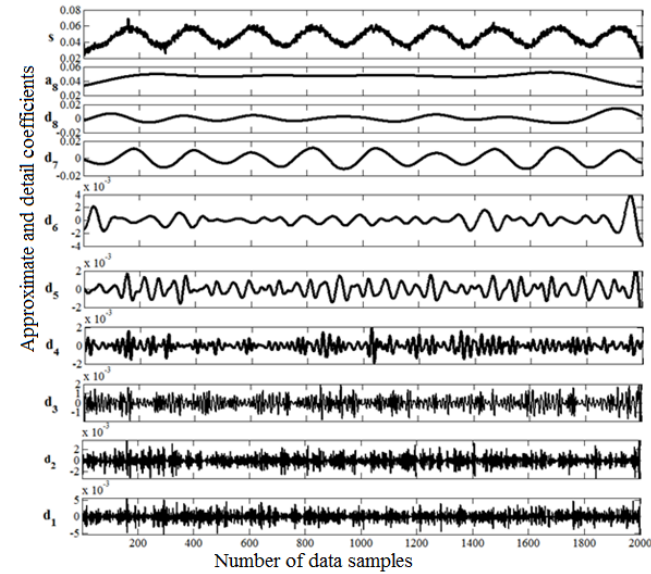

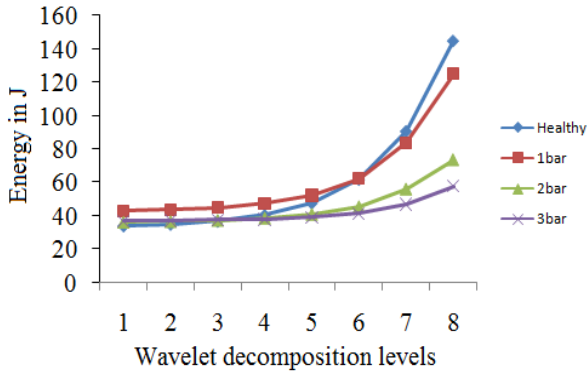Fig7. Wavelet decomposition of envelope of the stator current signal under faulty condition

Fig8. Energy of healthy & faulty signal calculated using envelope of the stator current with 1A load

From fig8&9, it is seen that the diagnosis is clear with higher decomposition levels. i.e. the decomposition levels 6 and above provides clear fault identification. Particularly, it gives better result with decomposition level8, as the frequency band of this level covers the frequencies related to the broken bar faults. i.e. the energy of the higher decomposition levels results in better fault identification.

Also it can be noticed that, the energy of the wavelet coefficients of healthy stator current is high compared to the other faulty conditions. The energy of the wavelet coefficients of the stator current with one bar broken is lesser compared to the healthy conditions.

As the number of broken bar increases the energy of the wavelet coefficients, calculated from the envelope of the stator currents also reduces and deviates from the healthy condition. i.e. the energy of the wavelet coefficients reduces with the increase in fault severity. This helps in diagnosing the faulty condition and its severity. It has to be mentioned here that when energy calculation are done using DWT of original spectrum, identification of fault severity may not be always possible.
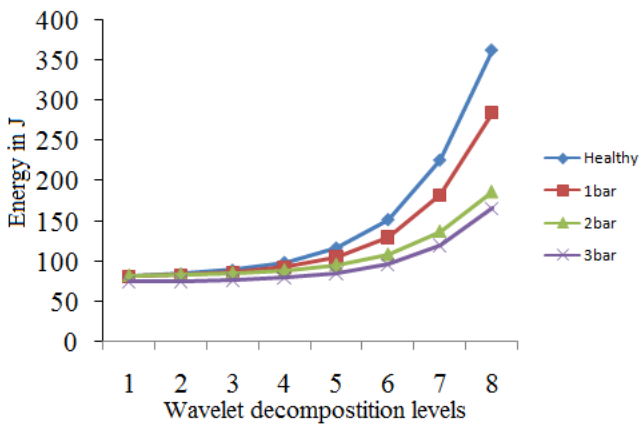

Fig9. Energy of healthy & faulty signal calculated using envelope of the stator current with 1.4A load

Comparison of the results with the original signal:

The reason for selecting the envelope of the signal can be proved by the comparison of the results of envelope with the results of the original signal. Fig. 10

shows the wavelet decomposition of the original signal under 1 bar broken condition.

The wavelet coefficients from the wavelet decomposition of the original signal, is used in calculating the energy and is shown in the following figure. Fig. 11 shows the energy calculated for healthy and faulty conditions using original stator current.

It is seen from figure 11 that the energy of the 1 bar broken is lesser compared with the healthy condition. Even though the energy calculated using 2 bar and 3 bar broken condition helps in diagnosing the fault, it doesn't give information about the severity of the fault. In other words, the analysis with original stator current helps in fault identification but not to identify the fault severity.

Comparing the graph of the energy calculated from the envelope of the signal which is shown in figure 8 and 9, with the energy calculated using the original stator current which is shown in figure 11, it is clear that the envelope gives better diagnosis results and information about the fault severity.
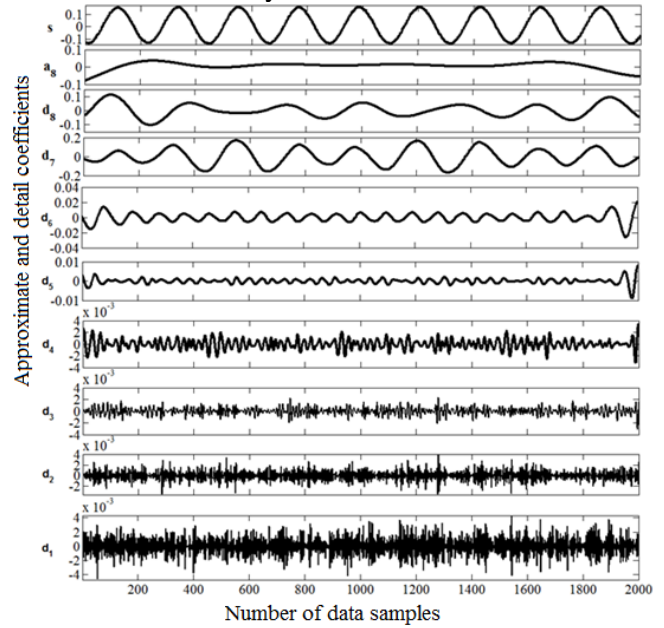

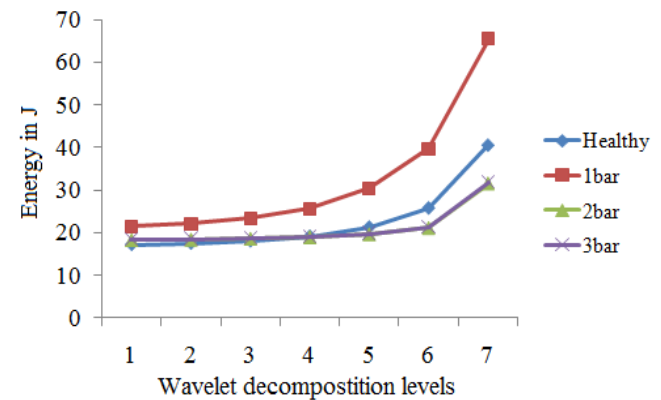Fig10. Wavelet decomposition of the original signal

Fig11. Energy of healthy & faulty signal calculated using original stator current

5. Conclusion

The broken bar fault is identified using Discrete wavelet transform and power spectral density. The envelope of the stator current is selected for better fault diagnosis as it contains dominant repetitive fault frequency components. The analysis of the envelope is able to yield better detectability of fault. When DWT along with PSD is applied on the envelope of the stator current, good results are achieved when compared to the conventional MCSA method. Also the proposed method is able to identify the fault and its severity. The energy of the higher level decomposition results in easy identification of fault severity.

The mother wavelet Daubechies-10 with 8 decomposition levels are selected for diagnosis, as higher level decompositions covers the frequency related to the broken bar fault. The proposed methodology is able to identify the fault & its severity with this decomposition level.

Therefore the envelope analysis using DWT along with PSD is a better tool for diagnosing the faults. It is an offline method which can also be used for continuous monitoring of induction motor. It gives very simple and clear clarification about the fault severity which can be obtained by unskilled persons also. This work can be extended to diagnose the other types of faults. Online implementation of this kind of fault diagnosis is very simple.

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