Discrete Wavelet Transform Applied to 3-Phase Induction Motor for Air Gap Eccentricity Fault Diagnosis

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ABSTRACT

Keywords
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Air-gap Eccentricity
Discrete Wavelet

Induction motors consume about 60% of the energy in industry, indicating that they are an important part of the industry. Despite their sturdy construction, these induction motors are often susceptible to damage from prolonged use without maintenance. Bearing failure accounts for up to 40% of all failures and can result in serious engine damage if not treated promptly. For effective operation, this failure must be continuously monitored, otherwise it may cause serious damage to the induction motor. Normal vibration monitoring is difficult as it requires the use of expensive sensors. To detect and localize these faults, a new method of performing leakage flux analysis is widely used. In this paper, failure due to gap eccentricity is predicted by decomposing the waveform of the leakage flux spectrum using a discrete wavelet transform. The proposed method was evaluated based on the leakage flux obtained from a 1.5 kW induction motor. Experimental results have confirmed the effectiveness of the method used to detect eccentricity failures.

1. Introduction

Induction motors have always been popular in industry due to their ease of use. This machine's operating conditions or prolonged operation may result in a malfunction. Mechanical or electrical sources are commonly responsible for disruptions [1]. Seat and coil misalignment, bearing failure, dynamic and static eccentricity are all examples of mechanical failures. Insulation faults, rotor faults, and magnetic circuit faults are the three major types of electrical faults. Bearing, stator, rotor, and eccentricity disturbances are common in induction motor [2][3]. Bearing failure, stator failure, rotor failure, and other failures are the most common failures, according to the literature . The early detection of these failure is critical to the industry's effectiveness. Otherwise, this error will reduce productivity [4]–[6]. Diagnostic approaches and methods for predictive maintenance of rotating electric machines have been developed for decades. They allow for early detection and severity assessment, saving time and money [7]–[9]. A good diagnostic approach for induction motor should also include failure coverage to help with life optimization and maintenance schedule development. The diagnosis of rotor eccentricity is a interesting topic in this field due to the potentially disastrous consequences. Due to limited manufacturing and assembly accuracy, there is an acceptable level of built-in eccentricity. Errors such as misalignment and bearing wear can affect the allowable eccentricity. Shaft tilt and rotor eccentricity can be caused by lateral damage to ball bearings. The increase in eccentricity causes unbalanced magnetic attraction, excessive vibration, and an increase in rotor temperature [10]. This feedback eventually causes friction between the rotor and stator, causing damage to the laminations and sparks.

Air gap eccentricity in a three-phase induction motor is a condition in which the motor rotor (rotating part) is not properly centered on the stator magnet (the stationary part). In a three-phase induction motor, the eccentric rotor means that the distance between the rotor surface and the stator surface (air gap) is uneven around the circumference of the rotor [11]. Several cases of air gap eccentricity in 3 phase induction motors in large scale industries often occur but are difficult to

detect, the cause of the air gap eccentricity in 3 phase induction motors is caused when the rotor is not properly attached to the motor shaft, if the rotor is not installed properly or if there is a wrong installation of other components, such as bearings, it can cause air gap eccentricity. In addition, if the bearings in the motor shaft are worn or damaged, the rotor can become eccentric with respect to the stator, causing changes in the air gap. Sometimes due to accidents or other factors, motor parts may experience structural deformation, which may cause air gap eccentricity [12].

The wavelet transform, like the Fourier transform, is a tool for signal processing. Instead of using different frequencies in the Fourier transform, the first decomposes the signal into a set of scaled and transformed versions of the mother wavelet. Flexibility in describing transient signals is the main advantage of this method. The wavelet transform is considered as an important component of variable speed or load. It is very similar to Fourier analysis in this context. In contrast to the sinusoidal function from Fourier analysis, most wavelets quickly decay the oscillation function [13][14]. Wavelets are classified as mathematical tools in two categories: continuous and discrete. The signal is multiplied by the wavelet using a function in Continuous Wavelet Transform (CWT), and the transform is calculated separately for each segment of the time domain signal. The Discrete Wavelet Transform (DWT) is based on the same basic idea as the Continous Wavelet Transform (CWT), but it was designed to process sampled signals. Furthermore, DWT calculations resembling the concept of a filter are quick and simple to implement for diagnostics. This, however, does not preclude the use of continuous wavelets to analyze the signal [15] [16].

In this article, we will discuss the process of detecting damage to a 3-phase induction motor due to airgap eccentricity through the analysis of the Discrete Wavelet Transform (DWT) method on the leakage flux around the stator so that it can prevent more severe damage. This research was conducted to help detect early damage to the air gap eccentricity in induction motors caused by several conditions that have been described. The model of the proposed method was proved using experiment of operating conditions has described in section 2. The results of the proposed method are expected to be able to detect the fault of the air gap eccentricity in a 3-phase induction motor without having to disassemble the body. In section 3 describes the performance of detecting air gap eccentricity failure with the help of a flux sensor which is analyzed using the Discrete Wavelet Transform (DWT) method. Finally, the conclusions are present in section 4.

2.   The Proposed Method

In this section, several experiments are carried out to identify the effect of air gap eccentricity on the performance of a three-phase induction motor on three different axes of magnetization. Next, we analyze the flux leakage by processing discrete wavelet transforms. The system configuration consists of several steps, namely by installing a flux sensor, changing the eccentricity of the air gap by changing the bearing components, designing the load module used, designing the measurement system, and processing the data for the deflection flow signal. Figure 1 describes the experimental steps that have been carried out, where a 3-phase induction motor was reconstructed to experience an air gap eccentricity failure. Loading with a synchronous generator is also carried out so that the detection results can be seen clearly for the difference between healthy conditions and conditions when experiencing an air gap eccentricity failure [17].
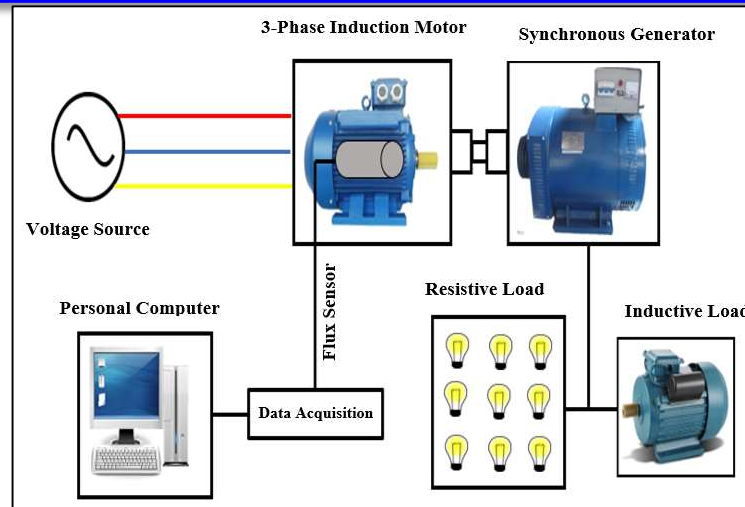
Fig. 1.   Experimental Procedure

The flux sensor is used by bringing it closer to the side of the stator, the flux data obtained is then recorded using data acquisition and processed using the Matlab software installed on the computer. The load used for this experiment consists of a single phase induction motor and lamp.

2.1.   Reconstruction of Eccentricity Fault

To make the rotor asymmetrical with respect to the air gap, replace the existing bearing with a smaller size, i.e. 47 mm outside diameter, and keep the inside diameter the same, i.e. 25 mm. For a more precise and asymmetrical bearing in the bearing housing, ring bearings are manufactured with an outer diameter of 52 mm and an inner diameter of 47 mm. The function of this bearing ring is to coat small bearings of the same size as existing bearings. The rings have different wall thicknesses to make the rotor shaft asymmetrical. The top ring is 2.6 mm thick and the bottom ring is 2.4 mm thick so that the rotor shaft is 0.1 mm apart. These rings are installed parallel to each side of the bearing housing. The rotor shaft is moved downwards by 0.1 mm, increasing the upper air gap from 0.2 mm to 0.3 mm and the lower air gap from 0.2 mm to 0.1 mm.
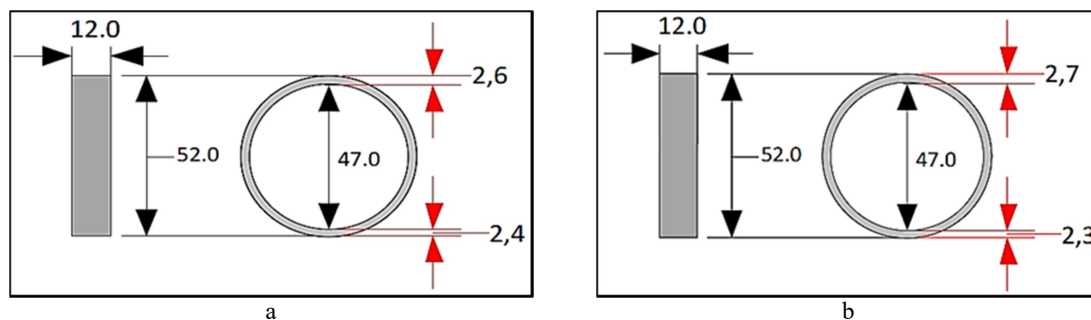

Fig. 2.   Bearing reconstruction (a) Eccentricity 0,1 mm (b) Eccentricity 0.2 mm

Figure 2 is the result of a reconstruction of the bearing which is modeled by an imbalance in its diameter, so that a 3-phase induction motor will later experience an air gap eccentricity failure. The top ring is 2.7 mm thick and the bottom ring is 2.3 mm thick, resulting in an asymmetrical air gap. In this research, we will use a static air gap eccentricity that is experiencing an air gap unbalanced but the rotor and stator remain aligned. Then the installation of ring bearings of different thicknesses will be installed in consistent.

2.1.   Decomposition Process of DWT

This type of decomposition samples expansion parameters instead of signals to achieve high resolution. As with other wavelet transforms, the main advantage of the Discrete Wavelet

Transform (DWT) compared to the Fast Fourier Transform (FFT) is its temporal resolution, which provides time and frequency information. There are many types of wavelets including Haar, Daubechies and Orthogonal, but the Daubechies type is the most commonly used [18][19]. In the Discrete Wavelet Transform, the estimated coefficients and sample details are decomposed using order 2. This wavelet decomposition process is illustrated in Figure 3.
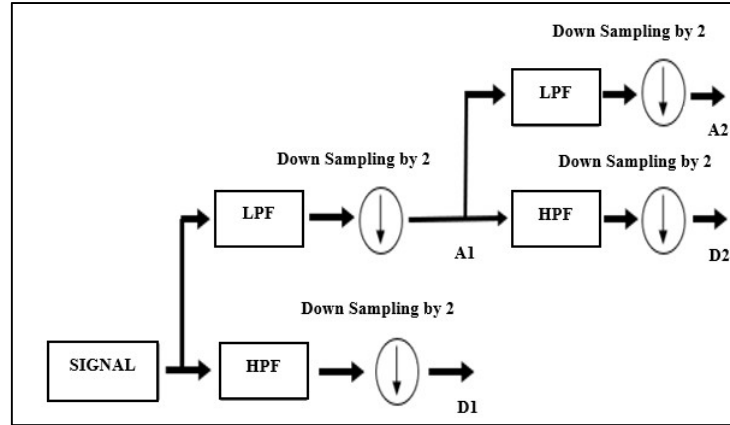

Fig. 3. Decomposition of Discrete Wavelet Transform

Figure 3 shows the signal decomposition process using the Discrete Wavelet Transform (DWT) method, where S is the input signal then LPF and HPF are the low pass and high pass filters. It should be note that, in the wavelet signal transformation is broken into two parts, which are the input from the LPF and HPF. The output of the first level low pass filter (LPF) is then divided into two in the frequency bandwidth. The complete error analysis process, from data collection to fault identification, is illustrated by a flowchart in Figure 5.
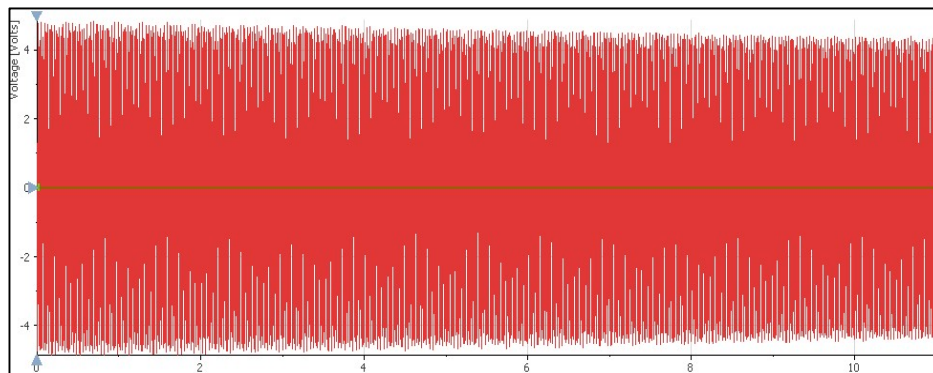

Fig 4. The Results of Recording the Flux Leakage Signal using NI-DAQ 9775

3.   Method

In the first stage, namely in the process of taking leakage flux data obtained from a flux sensor that is installed close to the stator section. The flux data is then recorded by data acquisition equipment using NI-DAQ 9775. The results of recording the flux signal using an acquisition device can be seen in Figure 4. In the recording of the leaking flux signal in Figure 4, it is still not possible to detect the failure of the air gap eccentricity in the 3-phase induction motor that occurs. So go to stage two, namely using the Discrete Wavelet Transform (DWT) for a more in-depth detection process. With the help of matlab software, data processing using the Discrete Wavelet

Transform (DWT) can be carried out. The type of wavelet used is the Daubechies type with an extraction process of 12 levels. Then, by calculating the energy in the resulting wavelet spectrum, predictions of air gap eccentricity failures can be detected. To characterize the signal, the signal obtained from data acquisition must have energy and power values or signal strength.

Table I. Test Data Schema

Percentage Loading	Fault Condition
0%	Normal
50%	Eccentricity 0.1 mm
100%	Eccentricity 0.2 mm

After connecting all of the devices, start the induction motor until a steady state condition is reached. The data acquisition tools record the signal which is then passed to Matlab software to measure the leakage flux, using the data scheme with the cases in Table I. In Table 1 there are two experimental scenarios that will be carried out, namely with an eccentricity of 0.1 mm and 0.2 mm with a load percentage used of 0%, 50% and 100% of the total load power of 1500 watts.
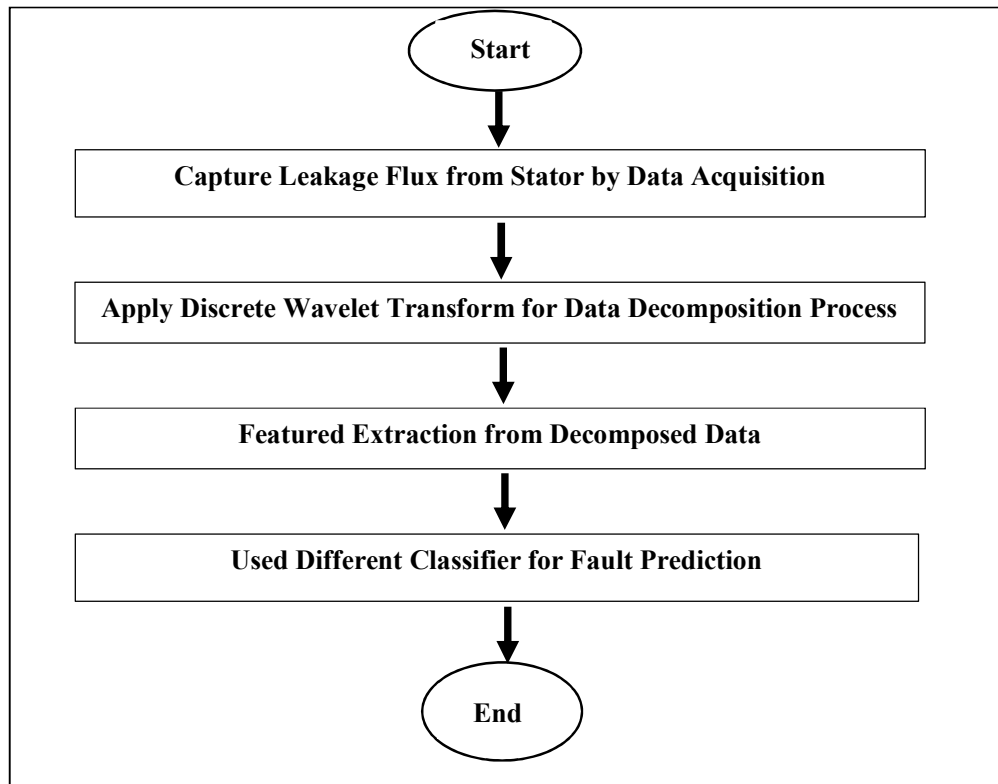

Fig. 5. Flowchart of Data Processing System using Matlab

Table II. Equipment Used

| Equipment	Specification Tools
Data Acquisition	NI-DAQ 9775
Flux Sensor	Extremly Low Frequency (ELF) Gaussmeter IDR-210
Synchronous Generator	Shantou Electric Machinery 5 kW
3-Phase Induction Motor	ADK Motor 1,5 kW

In Table II are some of the equipment needed to carry out the experiment. For data acquisition equipment using the NI-DAQ 9775, the Flux Sensor uses the IDR-210 Gaussmeter model, the induction motor used as the research object has a rating of 1.500 Watts which is coupled to a 5.000 Watt synchronous generator.

4. Result and Discussion

This section describes the results of an air-gap eccentricity test performed on a 3-phase induction motor using the wavelet decomposition method to process signals. The data used is real-time and steady-state. The data collection process was then completed, revealing that the induction motor was still in healthy, with an eccentricity of 0.1 mm and an eccentricity of 0.2 mm. The fault condition created is an asymmetrical air gap condition. The level that will be used is level 12.

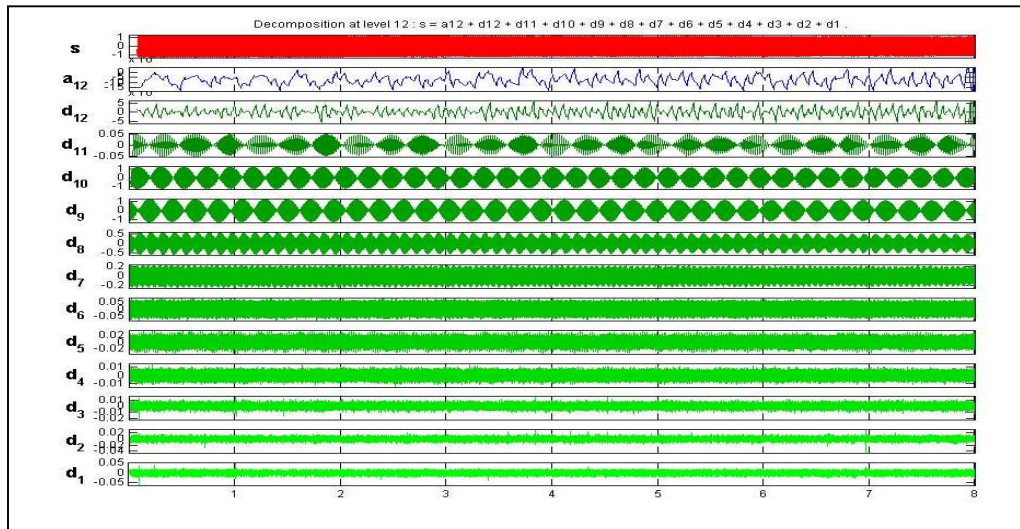### 4.1. Result of Daubechies Wavelet Method

Define Spectral reduction is a widely used tool for speech enhancement as well as noise removal in audio data processing. This technique is used in this article to reduce the effect of acoustic components on output as well as the impact of noise generated by induction motors.
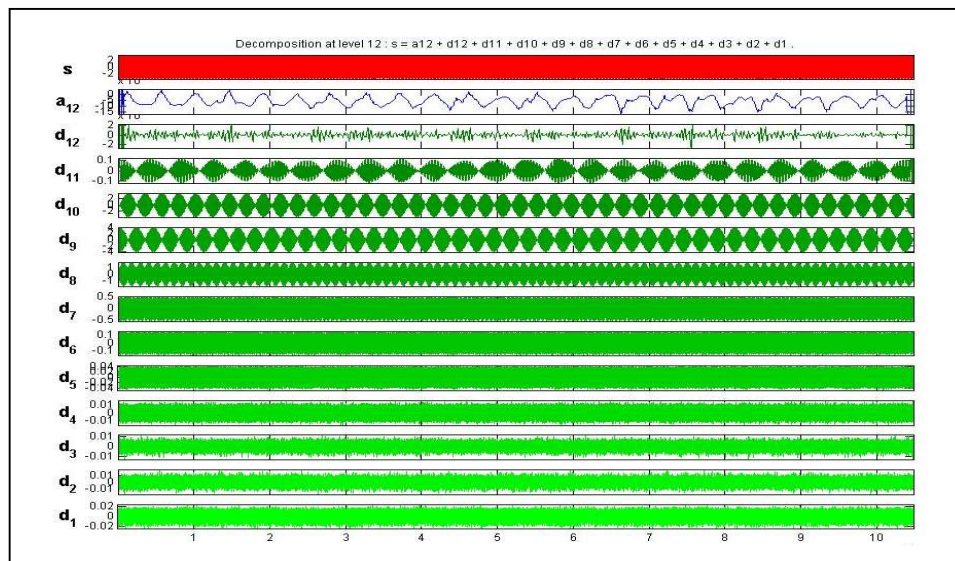

(a)
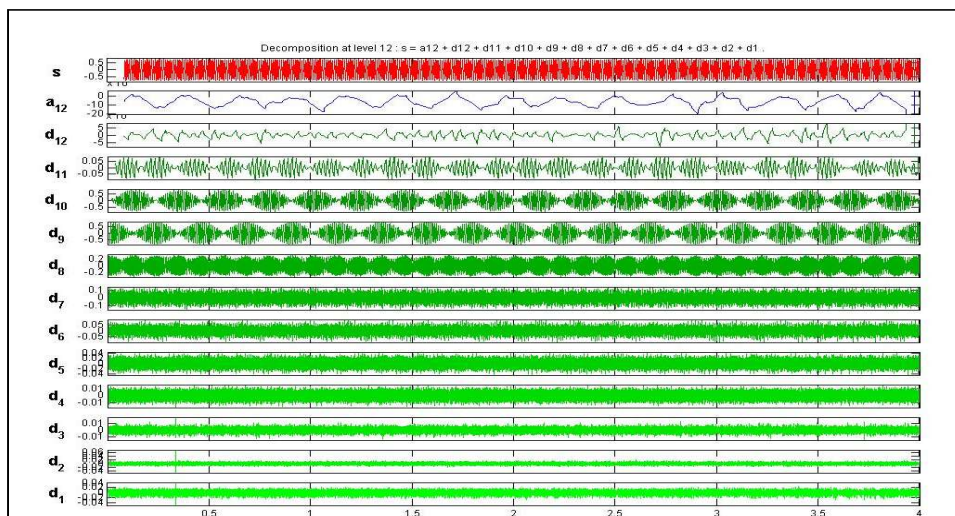
(b)

(c)

Fig. 6. Wavelet Signal Decomposition: (a) Healthy (b) Ecc. 0.1 mm (c) Ecc. 0.2 mm

The wavelet decomposition transform is used by the Daubechies wavelet analysis during enumeration. The main signal in the form of leakage flux that appears around the stator will be described into the desired signal form according to the level that will be used for wavelet db. An example of DWT signal processing can be seen in the Figure 6. In Figure 6 is the result of extraction of 12 levels with Daubechies wavelet type with eccentricity conditions of 0.1 mm and 0.2 mm with 50% load percentage. There are differences in the wavelet spectrum at level 11 and above, but for more details we need to calculate the difference in energy values at level 11 to see in more detail the detection of the eccentricity of the air gap.

In Figure 7 is the result of the wavelet transformation of the leakage flux wave with full load. Visually the results of the transformation can be compared roughly, from the waveform, wave period, and the value of the amplitude of each level. The wave difference has been seen from the decomposition level 1 to level 12. However, the selection of this level needs to be further validated because this selection needs to be compared directly in one graph. The results of the wavelet decomposition from normal conditions with an eccentricity of 0.2 mm have no defects in the waveform and have a shape that is almost the same as the normal condition. This causes the wavelet transformation results to be not too different between 0.2 mm eccentricity and normal condition. Then normalization is carried out, this normalization is carried out to reduce errors in detecting that has been reconstructed by the air gap.
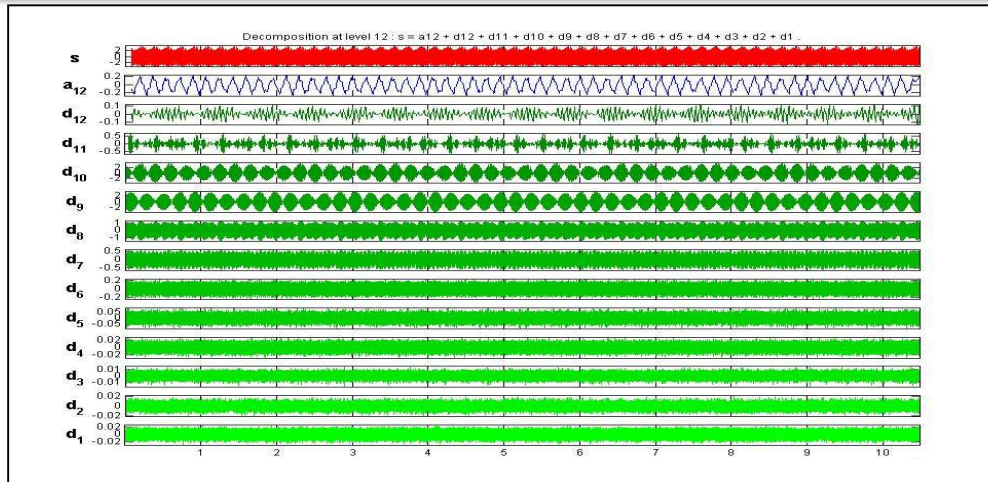
(a)
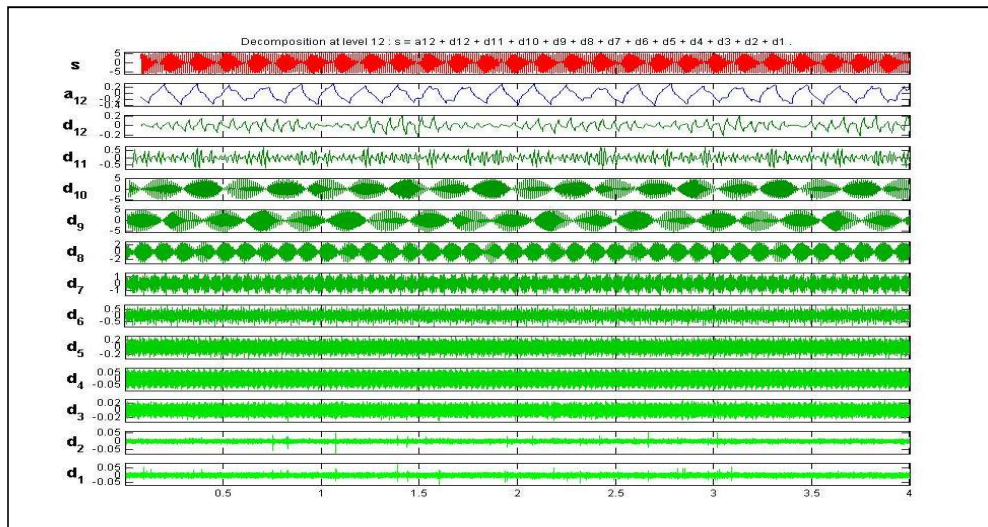
(b)
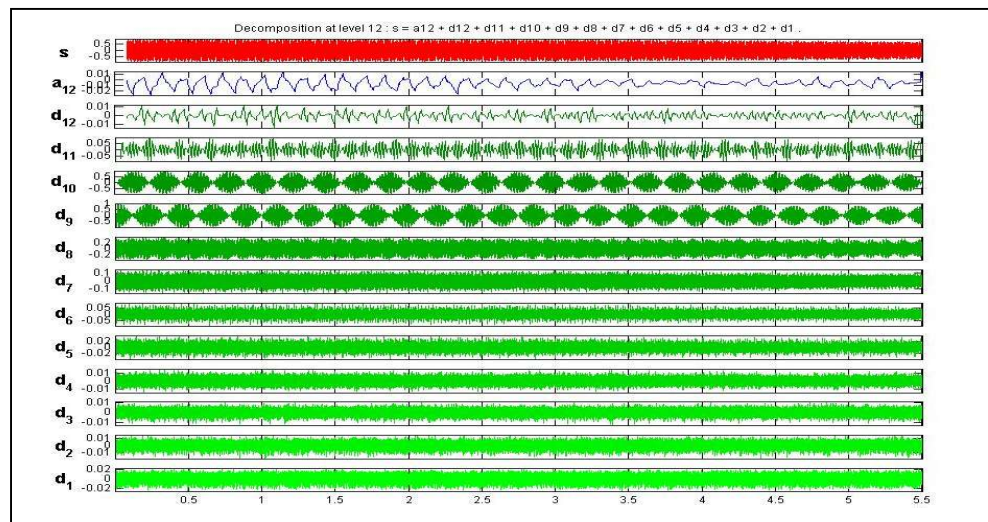
(c)

Fig. 7. Wavelet Signal Decomposition on full load: (a) Healthy (b) Ecc. 0.1 mm (c) Ecc. 0.2 mm

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If an error occurs during the reading process, some signal information may be lost because sampling drops at each stage of the discrete wavelet transform and gives an incorrect indication. Half of the frequency spectrum is covered by each level of signal separation the filter produces. This increases the frequency resolution, which lowers the frequency uncertainty. At low frequencies, frequency resolution produces good results. However, at high frequencies, the temporal resolution increases. When determining the number of decomposition steps, the characteristics of the signal must be taken into account accordingly.

4.2. Characteristics DWT on Eccentricity

In Discrete Wavelet Transforms (DWT), of the order of 32 db, Daubechies wavelets are used to break the decomposition signal into 12 levels for high-resolution signal analysis. To determine whether it can be used in fault diagnosis, the energy connected to each decomposition level is assessed. Equation (1) can be used to determine the energy of each frequency band [20].

$$E_j = \sum_{n=1}^{N}|dj(n)|^2 \tag{1}$$

Where, N is the number of samples, dj is the detail signal at the level j. It is discovered that there are clear differences between levels d6 to d12. Different motor failure circumstances can be efficiently determined at level d11.

Table III. Energy Of the Decomposition Level d_{11}

Loading	Energy (J)		
	Healthy	*Ecc. 0.1 mm*	*Ecc. 0.2 mm*
0%	2120	2315	2410
50%	2208	2435	2520
100%	2415	2620	2700

Table III contains the summarized energy values at d11. Using both data windows, the tendency of the changes is consistent for energy on healthy and faulty motor conditions. The changes are more pronounced between d6 to d12, with the maximum energy at d11. In level 12 decomposition, the signal is sampled at each decomposition level to achieve higher resolution. Table 2 also clearly shows the difference in energy values in healthy conditions with those experiencing air gap eccentricity, seen in healthy conditions with a load percentage of 50% the total energy value produced at level 11 decomposition is 2208 joules and for a 100% load percentage the total energy value generated by 2415 joules. On the other hand, when the motor is experiencing eccentricity, there is an increase in the energy value at level 11 decomposition, which is 2435 joules and 2520 joules for the 0.1 mm and 0.2 mm eccentricity cases with 50% of the total load. Meanwhile, under 100% installed load conditions, the two excitation conditions increased by 2620 joules and 2700 joules. From the difference in the total energy value in joules units, it can be used to predict the failure of the air gap eccentricity that occurs in a 3-phase induction motor without having to remove the main parts of the motor. It is important to regularly inspect and perform maintenance on induction motors. By early detection, air gap eccentricity problems can be resolved before they impact motor performance and reliability, thereby extending motor life and reducing the risk of more serious damage.

5. Conclusion

The results obtained compete according to the Discrete Wavelet Transform decomposition theory. As a result, it can be concluded that Discrete Wavelet Transform decomposition enhanced by the Wavelets Toolbox procedure is an effective tool for error detection at medium speeds. Discrete Wavelet Transform is very important for the diagnosis of electrical machines, as a method of time and frequency in the case of varying loads. We have shown that level 12 decomposition can provide fault signal information. Although the Discrete Wavelet Transform (DWT)

decomposition has proven to be effective in terms of fault detection accuracy, future research will focus on intelligent techniques as a promising method in fault detection and monitoring.

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