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Fault Detection In Induction Machine By Analysis Of Stator Current In Transient Condition By Continuous Wavelet Transform

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Abstract

Using of wavelet transform for monitoring and diagnosis of fault in induction motors is increasing because analyzing of the stator is possible in transient conditions by these methods.This method can be used for local analysis in the domain time - frequency or dimension time scale. In this paper, the detection of hanging load fault in a stator current signal is presented using the Morse wavelet in the structure of the continuous wavelet transform. In the proposed algorithm, firstly, the stator current signal is measured by the sensors, then by analogue-to-digital converter of the relevant signal is sampled , using the MATLAB software by wavelet transform,The sampling signal is processed. Experimental and practical results indicate that the method selects the fault with high accuracy and reliability without the need of complex calculation in a short time, which makes it possible to use it in operation. In this paper, the ability to select a wavelet compared to the Bump wavelet is investigated and ultimately the accuracy and ability of the selected wavelet are discussed.

Keywords: Fault detection,Continuous wavelet transform, Induction motor, Wavelet transform, Transient state , Hanging load fault, Signal processing.

1. Introduction

Three-phase induction motors have the most applications among electric machines in the industry, and consumes between 40% and 50% of their production in industrial societies [1]. Most of the equipment comes with the motor plays a key role in the industry [2,3].Due to the importance of continuous engine operation in the industry and its wear and tear due to continuous operation and various stresses, and the need for permanent maintenance and care in this device, timely detection of them is the great technical and economic importance for the industry. Troubleshooting is direction to increase efficiency, raising the quality and quantity of production, preventing accidents caused by the failure of large motors in industrial environments, preventing additional costs and lowering maintenance costs. At first all faults in the motor are not clearly identified, and long-term perceptions can cause many losses and, on the other hand, some motor faults, even when opening the engine, are not visible. For example, the break of rotor bars, if not timely diagnosed and resolved, will damage rotor and stator eventuates to motor failure. Over the past two decades, extensive research has been carried out to create new monitoring techniques for induction motors based on vibration signal oscillation analysis, current , etc . In this regard, in this article we have tried to provide a suitable method for identifying these faults. faults generated in the motor are detected in the specified frequencies for each fault in the stator current signal [4]. To determine the amplitude and frequency of the generated components (which have relatively high bandwidth), each fault requires the strong signal processing can determine their domain and frequency with proper accuracy [5]. The frequencies

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in the signal, according to the diagnostic motor, are given to the frequency , each fault produces [4]. Due to the wide range of frequencies created for processing various faults, signal wavelet transform is used in this paper. By using a wavelet, the ability to calculate low frequencies in the motor is up to the mechanical vibration frequencies of the motor. The superiority of this method compared to the previous methods is the high accuracy in the characteristics of the computed frequency components of the signal and the identification and better diagnosis of fault. This method can also be used to investigate the transient state behavior of the motor. Research and research on fault diagnosis is based on two basic logics: 1. fault detection (fault occurrence) 2 - fault diagnosis (fault type) The most well-known method for detecting faults is the current signal analysis method, which is based on the monitoring and processing of the stator current to identify the bundles around the base phase of the phase current . However, the problem of identifying the fault is a difficult task because the behavior of the motor system is a nonlinear behavior.

Usually, in the signal analysis method, the effect of the motor current from FFT is used to obtain current frequency content. Over the past decades, pattern recognition methods such as neural network methods have been widely used in fault detection [6]. In this paper, due to the nature of the stator current signal, which is a non-stationary signal, and a method such as FFT is limited in its analysis [8].Wavelet transform techniques, especially continuous wavelet transform, have been used for real-time processing and analysis. In order to eliminate this problem, advanced signal processing techniques have recently been used. Wavelet transform is one of the most applicable and most powerful mathematical transformations in the processing field, especially signal processing and image processing. In fact, this technique is a window technique with variable windows. This technique allows us to use long-length windows where we require high-frequency information with high accuracy and short window lengths , we want to use high frequency information with high precision [9].

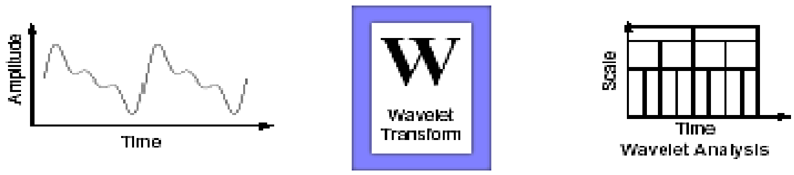

Figure 1: Effect of wavelet transform on signal in time domain

Due to the nature of the multi-resolution analysis of this transform, the selective approach is a promising and reliable approach for detecting and detecting faults in electric motors. It opens up a broading new horizon in the field of identifying and detecting faults. Our experimental and practical results on actual measured data indicate the effectiveness of the proposed method. For this purpose, for the purpose of testing and measuring the practical data, a series of two cranes, each of them are used by the power of 22 kW, single-pole, 47 Hz, 300/2400 V, three-phase squirrel cage Has been. In this section, the structure of this paper continues. In the second part, the wavelet transform technique, especially the continuous wavelet transform, is introduced and presented.

In the third section, the method of measuring the practical data is described, and in the fourth section, the method for detecting the error with the selected wavelet Morse is presented and described in theCWT structure, in the fifth part, its results are compared and compared. In sixth part, the experimental and practical results are presented.

2. Wavelet transform

Wavelet transform is one of the most widely used mathematical transforms in the field of processing , especially signal and image processing. Depending on the nature of the multi resolution analysis, this transform has opened up many processing applications, sometimes seen as the most powerful tool. Fourier transform is a very suitable method for static measurements and is not suitable for analyzing transient transient signals such as drift, suddenly change, and frequency deviations. In order to overcome this problem, it is suggested in some references at any one moment a portion of the measured signal is used in the time domain for analysis. This technique is known as the Fourier Transform of Short Time or Window. This shows the signal transform to a two-dimensional frequency function.. Fourier Transform The short time STFT provides a comparison between two frequency and time displays of a signal and gives information about each of them. Of course, we can only have information with limited accuracy, this precision limitation determines the size of the selected window. The fixed size of the window in this method is the main problem of the method [10].The wavelet transformation has come up with the idea to solve this problem.

In this method, a variable-size window is used to improve the signal analysis.The wavelet transform allow us to use widescreen windows where we need low frequency data, and use narrower windows where high-frequency information is needed. The ability to improve local analysis is one of the coolest characteristics of wavelet transforms [11].

2.1 Continuous Wavelet Transform

Continuous wavelet Transform was developed as an alternative to STFT to solve the resolution problem. Wavelet analysis is done in a similar way to STFT. The signal is multiplied in a function (wavelet function), which is similar to the window function in STFT, and the transform is calculated separately for different parts of the signal in the time dimension.

The continuous wavelet transform is defined as follows:

$$C_{a,b} = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t)\, \bar{\varphi}\left(\frac{t-b}{a}\right) dt \qquad (1)$$

As seen in above, the transformed signal is a function of two variables, b and a, which are translation and scale parameters, respectively. Wavelet's term is a small wave. A small attribute means that the function (window) has a limited length (compressed backup). The wave also means that the function has an oscillatory shape. The term mother implies that functions with the different locations and backups are used in the conversion process are derived from a parent or mother-wavelet function. In other words, the mother wavelet is a prototype for building other window functions. The transformation term here is as same as in the STFT, it refers to the process that the window changes throughout the signal. Obviously, this term refers to time information in the transformation space.

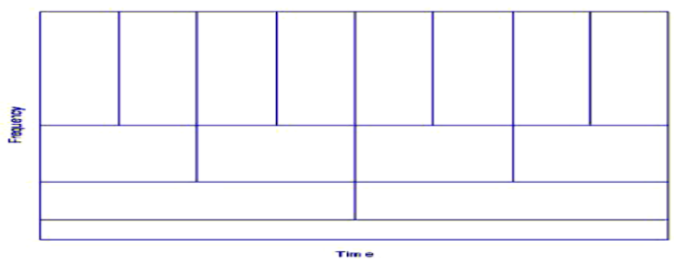

Figure 2: Time-frequency Classification in wavelet transform

2.2 Mother Wavelet

Several algorithms are proposed for selecting the optimal wavelet. Obviously, selecting an optimal wavelet, the wavelet must be selected to have the most similar shape with the wavelet of the source. In this case, the coefficients obtained from wavelet transform of the signal under investigation at the time of the occurrence of the wavelet of the source are amplified that why its possible tracking in the signal. Some researchers have suggested that the optimal mother-wavelet be selected according to its function in identifying the characteristics of the search [12]. The most important step in wavelet transform analysis is to select mother wavelet . The higher derivation of the wavelet function of the mother, in other words, the maximum initial value of the wavelet function is zero, the similarity coefficient between the signal and the wavelet function is more accurate. Function $\Phi(t) \in L^2(R)$ And its Fourier transform $\hat{\psi}(W)$ Consider, if $\Phi(t)$ In (2), then they call the mother's wavelet. $\hat{\psi}(t)$ و

$$\begin{cases} C_\varphi = \int_{-\infty}^{+\omega} \frac{\left|\hat{\varphi}(t)\right|^2}{|\omega|} d\omega \langle \infty \\ \int_{-\infty}^{+\infty} \varphi(t)dt = 0 \quad \|\varphi(t)\| = 1 \end{cases} \tag{2}$$

The wavelet transform is defined as follow.

$$C(a,b) = \int_{-\omega}^{+\infty} f(t)\overline{\varphi_{a,b}(t)}dt =< f(t), \overline{\varphi_{a,b}(t)} > \tag{3}$$

$\overline{\varphi_{a,b}(t)}$: Mixed conjugate $\varphi_{a,b}(t)$ wavelet.

$$\varphi_{a,b}(t) = \frac{1}{\sqrt{a}} \varphi(\frac{t-b}{a}) \tag{4}$$

The variable causes the expansion or density of the function in the time domain and the variable b changes the time position. The variable a, b provides the possibility of having a wavelet at the desired frequency. In (3), C is in fact a coefficient that shows the similarity of the signal to the mother's wavelet. The larger wavelet's similarity with the signal is greater than the magnitude, and vice versa, the smaller the similarity, the coefficient C is smaller and, if there is no similarity between them, the coefficient C is zero. In Equation (4), the coefficient is used to have the same energy in each analysis wavelet.

2.3 Morse wavelet

Generalized Morse wavelets are the family of exactly analytic wavelets. Analytic wavelets are complex-valued wavelets whose Fourier transforms are supported only on the positive real axis. They are useful for analyzing modulated signals, which are signals with time-varying amplitude and frequency. They are also useful for analyzing localized discontinuities. The seminal paper for generalized Morse wavelets is Olhede and Walden [14]. The theory of Morse wavelets and their applications to the analysis of modulated signals is further developed in a series of papers by Lilly and Olhede [15], [16], and [17]. Efficient algorithms for the computation of Morse wavelets and their properties were developed by Lilly [18].

3. Measurement data

The practical and experimental testing conditions consist of a series of two cranes, each of them have three phases induction motor with a power of 22 kW, a single pole, 47 Hz, and a squirrel cage (Fig. 3)

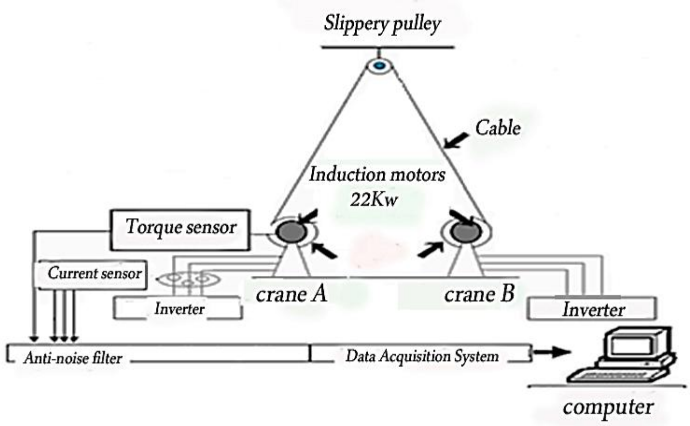

Figure 3: Configuration for testing the proposed crane system

Crane A for lifting and crane B for simulating performance conditions. The A crane is connected by a motor to a Solar gearbox with a 1: 77 reduction ratio to reduce the speed and increase the torque output . The test performed by the inverter , in open circuit mode with the frequency of 45 Hz at the charge level of 300 decaniton and in two up and down movement modes. In this paper, the signal related to the stator current was measured at the constant time interval of T = 32s and the sampling frequency Fs = 25 kHz for all experiments to have a high resolution frequency (0.02 Hz) for spectral analysis.

3.1 The proposed method for detecting the fault in the stator current signal

In (Fig. 4), the levels of the proposed method for detecting the fault in the stator current signal is shown. In the first step, by the sensor current is measured the stator current signal in the time domain. Then, an analog to digital converter, a stator current signal is sampled. Then, through using the wavelet transform technique, the sampled signal is examined and processed. At the end , the fault is visible and recognizable.

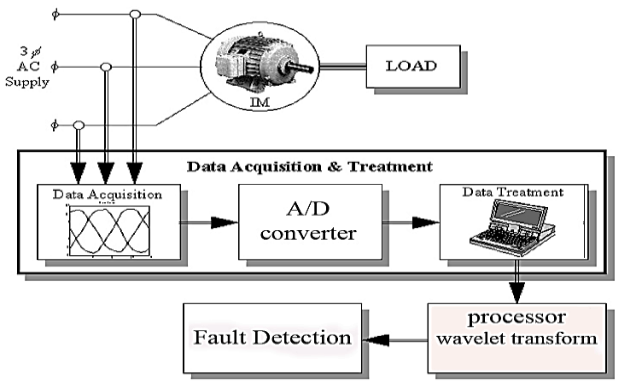

Figure 4: Schematic diagram of the fault detection system

4. Experimental analysis and simulation results

4.1 Stator current signal analysis in time domain

Fig. 5 shows the stator current signal in a state of health in the time domain.

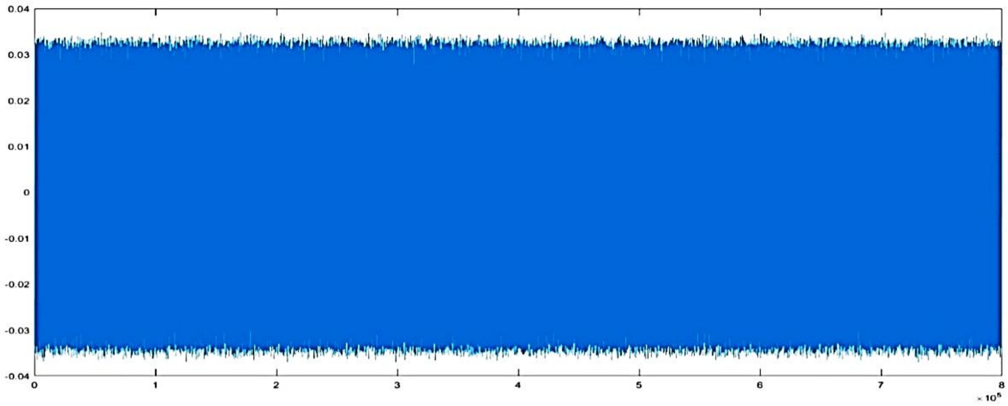

Figure 5: The stator current signal in a state of health in the time domain

Fig. 6 shows the stator current signal in the fault state in the time domain for the fault of 10%. In this case, the load connected to the system at a given time increased suddenly by 10% compared to the nominal load, after a while this overload was reduced to the same amount of load as the crane.

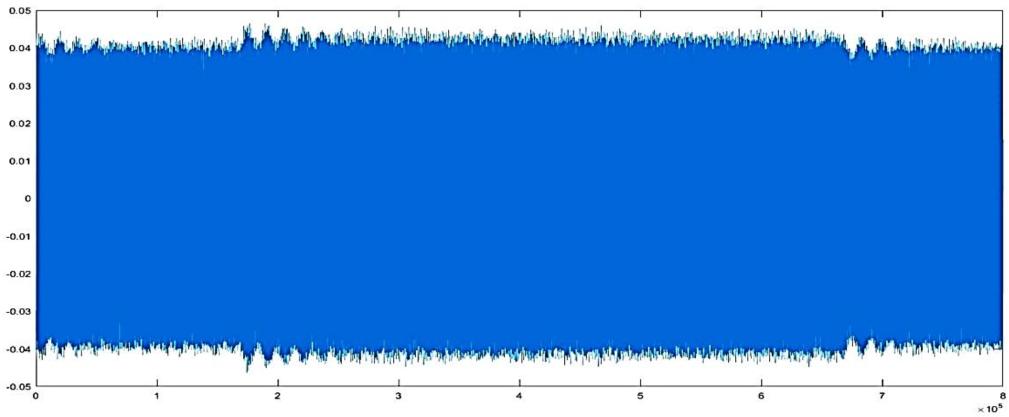

Figure 6: The stator current signal in an fault state in the time domain for an fault of 10%

Fig. 7 shows the stator current signal in the fault state in the time domain for the fault of 20%. In this case, the load connected to the system at a given time increased suddenly by 20% compared to the nominal load., and after a while this overload was reduced to the same amount of load as the crane.

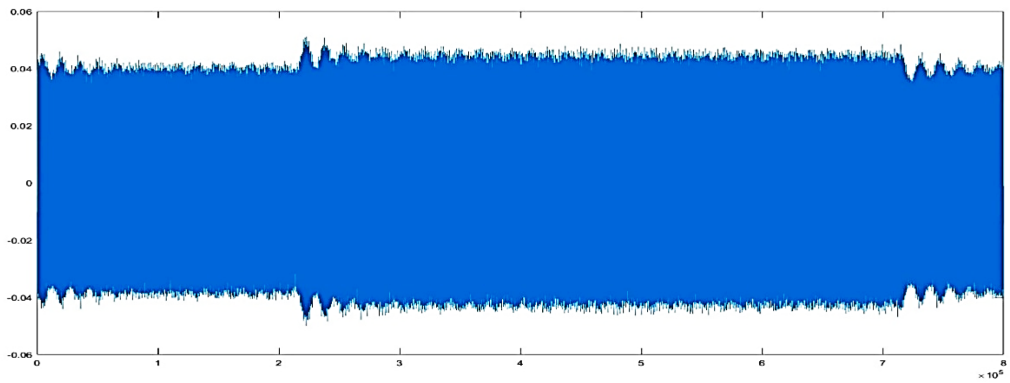

Figure 7: The stator current signal in an fault state in the time domain for an fault of 20%

4.2 Continuous Wavelet Transform Analysis of stator current signal

The CWT signal transform propose the x (t) from the domain time - scale to domain time frequency. The decomposition coefficients are the result of the main signal reflection in some particular aspects, can be used to extract useful information to detect the fault in the induction motor.Using the continuous wavelet transform, the frequency spectrum of the stator current signal was shown in health and fault mode. An analysis was made using Morse wavelet.In the form of the color spectrum below (8 and 9), it shows the more changes, represent the greater effect on the brown color spectrum. Which locates the coordinates of one of the peaks at the start of the induction motor. This point is at t = 0.8285 with a frequency of 44.66 Hz and a range of 0.03. As shown in the figure below, the amplitude of the amplitudes and the frequency is the same throughout the load time and is in the form of a brown color.

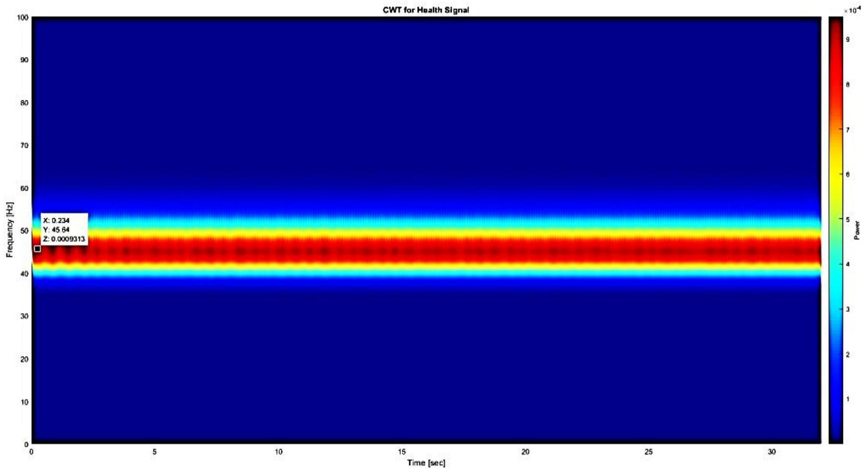

Figure 8: Continuous wavelet transform of Stator current signal in health mode in time domain – Frequency

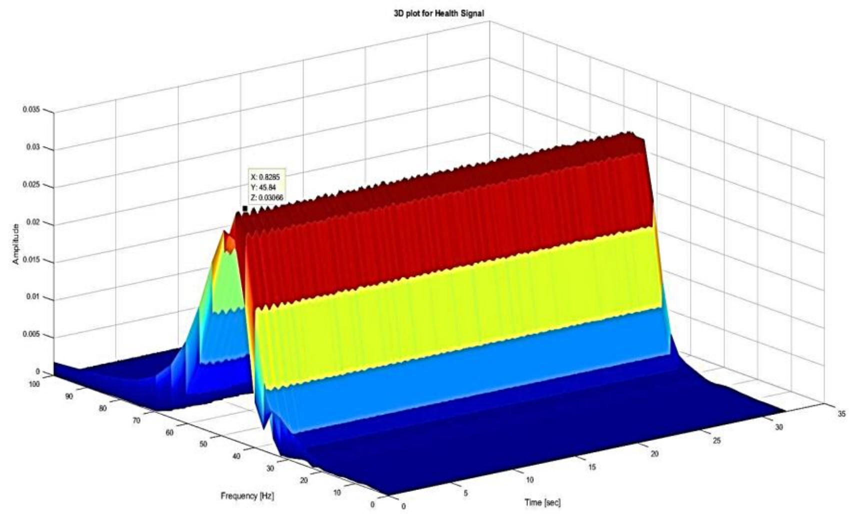

Figure 9: Continuous wavelet transform of Stator current signal in health mode in time domain – Frequency(3D)

In the following figures, you can see the continuous wavelet transform of a stator current in a 10% fault state. The place of brown color which is shown to the higher peaks relative to the other peaks (red), where the load has been applied suddenly to the system by 10% more than the load rating (sec

6.7 t)**.** After a period of time (20 seconds), the load on the system is reduced to an initial value. This sudden overload has caused the strong oscillation or a significant change in the signal. The coordinates of the fault points are shown in Fig(10,11).

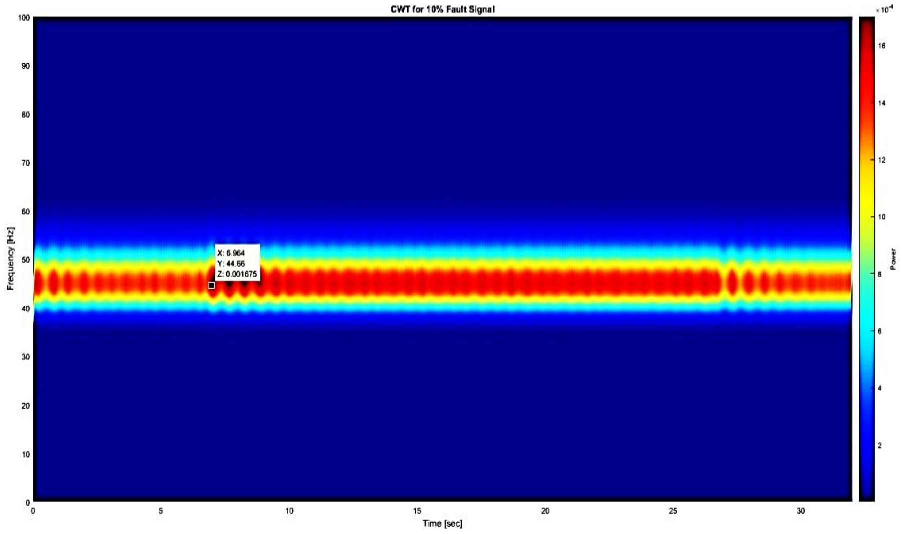

Figure 10: Continuous wavelet transform of Stator current signal in fault(10%) mode in time domain – Frequency

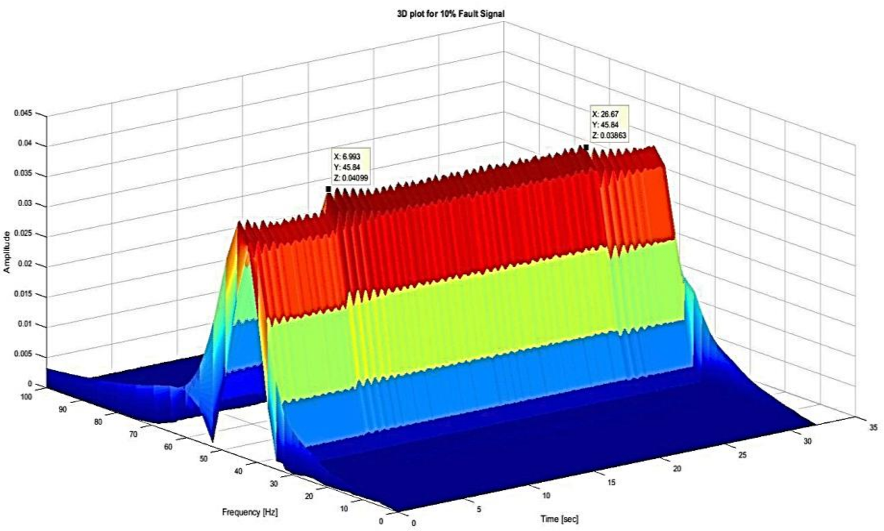

Figure 11: Continuous wavelet transform of Stator current signal in fault(10%) mode in time domain – Frequency(3D)

In the following figures, you can see the continuous wavelet transform of a stator current in a 20% fault state. The place of brown color which is shown to the higher peaks relative to the other peaks (red). It is a place where the load has been applied suddenly to the system by as much as 20% more than the nominal load (sec. 8.596 t), and after a period of time (20 seconds) the system load has been reduced to its initial value. But this sudden load fault has caused a lot of oscillation or a significant change in the signal**.** The coordinates of the fault points are shown in Fig(12,13). Compared to a sudden load fault of 10%, the fault amplitude measure has increased.

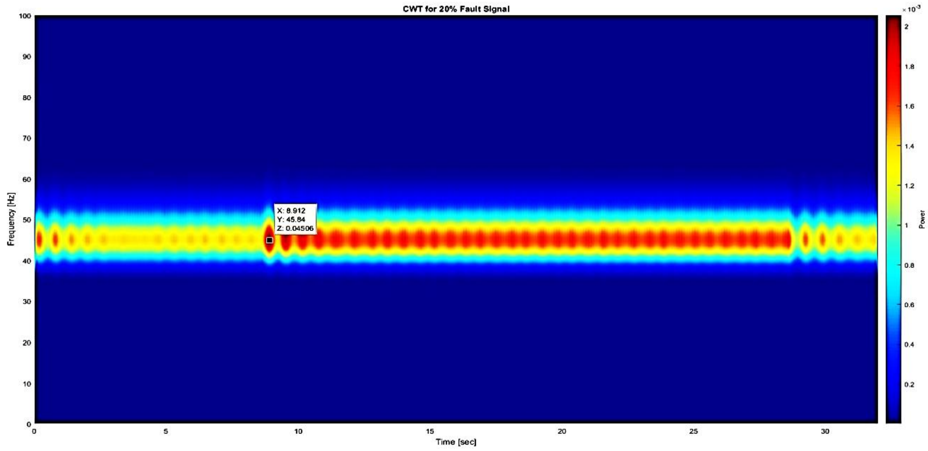

Figure 12: Continuous wavelet transform of Stator current signal in fault(20%) mode in time domain – Frequency

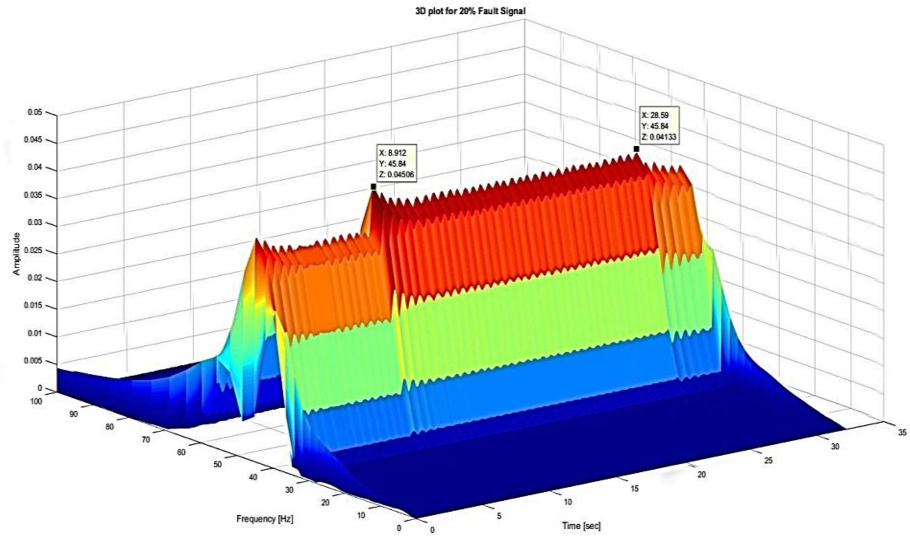

Figure 13: Continuous wavelet transform of Stator current signal in fault(20%) mode in time domain – Frequency(3D)

5. Morse waveform comparison with Bump wavelet

As shown in Figs. (8) to (13), the Morse wavelet, by generating the resolution suitable frequency and time, was able to detect the time and place of the created fault. But in the Bump wavelet, it does not have a good ability to detect the frequency effects of the Morse wavelet. Because in the case where the amplitude of the component of the error frequency is not very large, as shown in the figure below, the color spectrum (color coefficients), which indicates the intensity of the oscillations, is weaker than the morse wavelet.

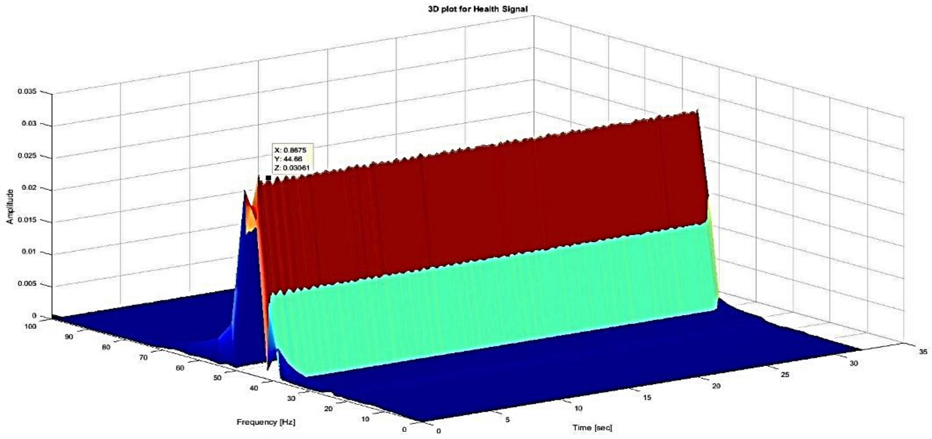

Figure 14: Continuous wavelet transform of Stator current signal in health mode in time domain – Frequency(Bump wavelet)

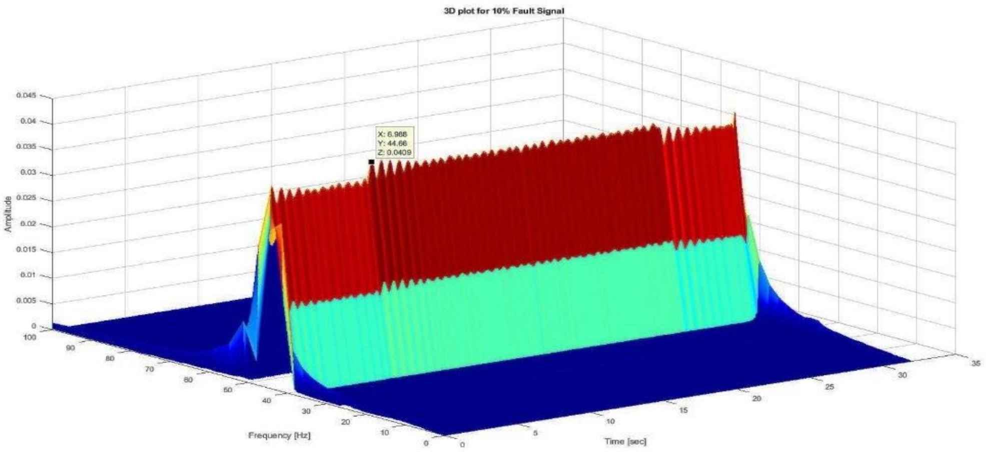

Figure 15: Continuous wavelet transform of Stator current signal in fault(10%) mode in time domain - Frequency(Bump wavelet)

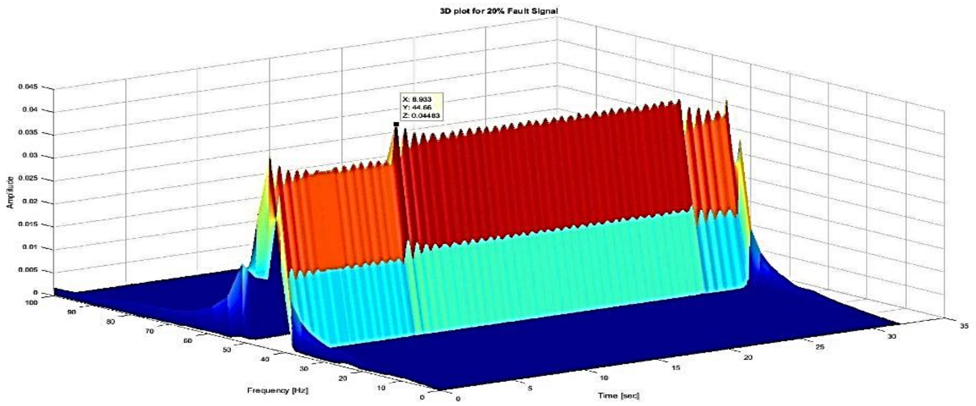

Figure 16: Continuous wavelet transform of Stator current signal in fault(20%) mode in time domain - Frequency(Bump wavelet)

CONCLUSION

In this paper, the method for detecting the sudden load fault in three-phases induction motors is presented**.** In the proposed method, the detection of the sudden load fault by the analysis of the Stator current signal using a continuous wavelet transform technique, which is one of the techniques of signal processing is presented , an analysis of its experimental results is enunciated with real data. In this article, the CWT method is used to calculate the frequency spectrum of time using the wavelets as an adaptive window. The common method, such as STFT, is the intrinsic defect in choosing the length of the window that makes the processing and interpretation inherent**.** The CWT method solves this problem and provides, more powerful technique for analyzing the time frequency features.The expansion and compression of the wavelet provides the length of the desired window depending on the frequency of the signal effectively. since, the CWT provides optimal time resolution.The experimental results presented in this paper suggest that the Morse wavelet in the continuous wavelet structure with an exact and reliable precision is able to detect stator current signal fault in induction motors. In fact, this method demonstrates the efficiency of this method in relation to the Bump wavelet, because in these cases where the component domain of the fault frequency is not very large (at the time of the occurrence of the fault), the proposed method can be considered faster.

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