

# A Review of Wavelet Transformation and its Applications in Electrical Power Systems

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**ABSTRACT:** With the rapid expansion of the electrical transmission and distribution networks, the issues related to power quality (PQ) problems, system monitoring, and detection of fault location are a matter of concern from both the customer and the utility point of view. Digital signal processing (DSP) is essential to analyze all power quality-related problems. Various DSP techniques are used commonly for this purpose. Wavelet Transform (WT) is the most commonly used DSP technique to analyze the problems related to power systems. This paper reviews the applications of WT in power distribution system-related problems along with the review of various wavelet families.

**KEYWORDS:** Wavelet transformation, Continuous wavelet transform, discrete wavelet transforms, power system quality, Artificial Neural Network.

## I. INTRODUCTION

The digital signal processing plays an essential role in analyzing problems related to power systems. There are many signal processing methods developed for this purpose such as discrete wavelet transform (DWT), S-transform (ST), fast Fourier transform (FFT), fast discrete orthonormal ST (FDOST), hyperbolic ST (HST), etc. After the digital signal processing, the extracted features are then given as input to the neural network, or a suitable analysis is done to find the appropriate solution to the problem under consideration [1]. Due to the many flexible features offered by the wavelets, it is one of the most popular digital signal processing methods used in the analysis of power system quality monitoring applications.

A review of these problems related to power systems attempted with wavelets used as a signal processing tool is presented below:

Wavelet transforms and RBF neural networks can be implemented to detect different types of faults that occur in distribution systems. Various features can be extracted using wavelets for better analysis of the problem. The features obtained from wavelet coefficients are used as input to the neural network to identify the disturbances of power quality using the classification of patterns in the input data. The parameters of the power distribution network are obtained through training of the artificial neural network (ANN). By selecting an appropriate number of samples of fault current signals to train the reorganization model of the distribution system and using the concept of a recursive orthogonal least square algorithm of ANN, the nature of fault that has occurred is estimated [2]. To classify the faults and to determine their location in a non-radial power system using the concept of an electromagnetic transient program and ANN. A model of a symmetrical three-phase network with R-L-C load can be designed to simulate different fault conditions on the transmission line in the EMTP toolbox. The samples of fault current signal are analyzed using the wavelet toolbox of MATLAB to evaluate their entropy values which are then given as input to ANN to classify the fault and to identify faulty lines. The model-based methodology has given accurate results in classifying and locating various faults on transmission lines [3]. With the increased use of smart meters and devices in modern power grids, a huge amount of data is transmitted and received through communication systems like Wifi and Zig Bee. The device data is compressed before transmission. The use of wavelet transform is a possible solution for real-time data compression for current and voltage signals [4]. Phasor measurement units (PMU) are commonly used to detect single-line failure conditions in transmission networks. Change in the voltage level at the PMU location detects line failure condition. The change in the value of the voltage signal is processed by wavelets to extract specific features from the voltage signal [5]. Wavelets are used to extract features from voltage and current signals to analyze power quality (PQ) related issues such

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as voltage sag and swell, the presence of harmonics, noise, and power interruptions. ANN are used as classifiers to protect the devices and ensure the availability of continuous supply [6]. Wavelet coefficients are obtained for monitoring PQ-related issues in the power systems to compress a big volume of data by extracting relevant features from data [7]. An approach using wavelets is implemented for detecting high-impedance faults occurring in the distribution systems. The wave transform is suitable for the analysis of transient signals due to the inability of over-current relays to operate at low fault conditions. Specific features like energy coefficients, standard deviation, entropy, etc can be derived. Such features can be used as inputs to ANN and SVM to differentiate high-impedance faults from other types of faults [8]. With the feeder current per phase as the basis for the evaluation of electrical faults in a distribution system, the properties of wavelet transformation can be used to distinguish between wave signatures produced in disturbed conditions and normal conditions. Such a methodology can be used for online monitoring applications and effective diagnosis of faulty conditions including short circuits [9]. Wavelet-based methodology assisted with support vector machine (SVM) as classifier is implemented for exact classification of faults occurring on complex and interconnected transmission and distribution systems using underground cables. The WT is used to extract features from transient information of recorded voltages. The energy coefficients are evaluated and used as input for the classifier [10]. A method based on the concept of traveling waves and impedance measurement for the estimation of fault location is implementing WT as a mathematical tool for signal analysis. The method uses pattern recognition of voltage and current signals during fault conditions [11].

## II. SIGNAL TRANSFORMATION

Certain mathematical processing can be done to obtain detailed information from a signal under consideration. A signal in the time domain is a raw signal obtained from a real-time system. When this signal is processed mathematically using mathematical transformations, it is called a processed signal. Many signal-processing techniques are available for processing a raw signal such as discrete wavelet transform (DWT), S-transform (ST), fast Fourier transform (FFT), fast discrete orthonormal ST (FDOST), hyperbolic ST (HST), etc. Most of the real-time signals are signals in the time domain i.e. they have time on the X-axis and the Y-axis represents the amplitude of the signal under measurement. Even if this type of representation of a signal is common and appropriate in many digital signal-processing applications, suffers from a major drawback in that significant information is hidden as the frequency content of the signal. Therefore, to extract minute details from the signal, its frequency domain representation is also important. In the frequency domain, the various frequencies that are present in the given signal are represented. Frequency is the rate of change of that specific variable under consideration with respect to time. If the rate of change of that specific variable in the concerned time interval is high, it is known as a high-frequency signal. In the same manner, if the rate of change of that variable is slow, it is known as a low-frequency signal and if there is no change with respect to time, it is called a zero-frequency signal [12].

## III. THE WAVELET TRANSFORM

In signal processing applications a particular component of frequency at a specific time interval carries importance and needs to be noted. In wavelet analysis, the basic function of a signal is decomposed and dilated at low frequencies and compressed at high frequencies. Wavelet transformation gives both time and frequency representation of the signal under consideration. In wavelet transformation, the time domain signal is filtered in either high or low frequency components e.g. signal with 100 Hz frequency can be divided into two parts. 0-50 Hz is low frequency and 51-100 is high frequency component. Generally, the low-frequency component is further decomposed like 0-25 Hz, 25-50Hz, 50-100Hz which can be further decomposed. This separation of frequency is carried out till we get a pre-decided component of frequency. These decomposed frequency signals can be put on for 3-D graph like time on the X-axis, frequency on the Y-axis, and amplitude on the z-axis from which it can be understood clearly which frequency components exist at a given time.

Wavelet analysis gives proper and precise information about a signal for analysis in both the low-frequency and high-frequency components. With wavelets, we can analyze specific areas of a larger signal. Thus with wavelets, we can find out minute details of data such as trends of signal, breakdown points, discontinuities, etc which is not possible with other techniques. With wavelets, it is possible to compress or denoise a signal without losing its originality [12].

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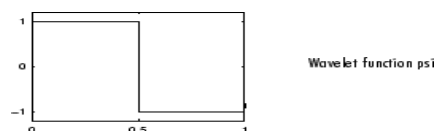
There are two basic types of wavelet transformations: (1) Continuous wavelet transform: It is a summation over the complete time interval of the signal multiplied with scaled, shifted versions of the wavelet, over a complete time interval of signal  $f(t)$  multiplied by a complex exponential.

(2) Discrete wavelet transforms (DWT): In DWT the signal is represented on scales and powers of two. This is called dyadic scales and positions. This type of representation is needed as the calculation of coefficients of wavelets at every scale is not easy work as it produces a large amount of data.

## IV. INTRODUCTION TO WAVELET FAMILIES

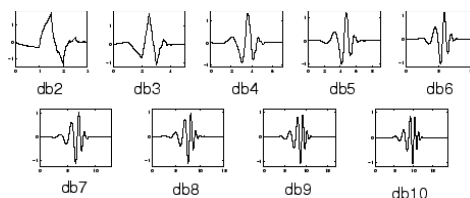
There are eight types of wavelet families namely (1) Haar, (2) Daubechies, (3) Biorthogonal, (4) coieffts, (5) Symlets, (6) Morlets, (7) Mexican Hat, (8) Meyer [13]. A brief description is given about each of the wavelet families as follows:

1. Haar Wavelet: It is the simplest type of wavelet invented by mathematician A. Haar. It is a discrete wavelet and is similar to a step function and the same as Daubechies db1 wavelet. It is represented as shown in the following figure.



(a) Haar Wavelet

2. Daubechies Wavelet: This family of wavelets was invented by mathematician I. Daubechies. These wavelets can be used practically as they are completely supported orthogonal wavelets. The format to represent these wavelets is dbN, where N represents order. db1 is similar to the Haar wavelet. The other members of this wavelet family are db2, db3, db4, db5, db6, db7, db8, db9, and db10. Daubechies wavelets are represented as shown in the following figure.



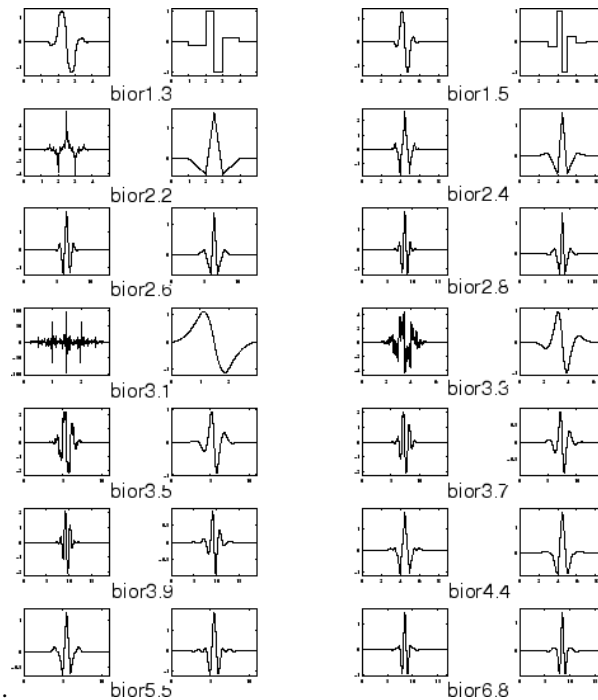
(b) Daubechies Wavelet

3. Biorthogonal Wavelets: Biorthogonal wavelets have properties like linear phase which are required in signal and image reconstruction applications. It gives excellent results in practical applications related to signal decomposition and reconstruction. They are represented as follows.

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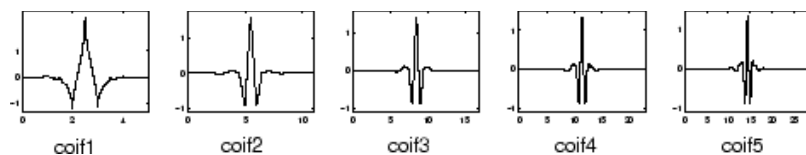
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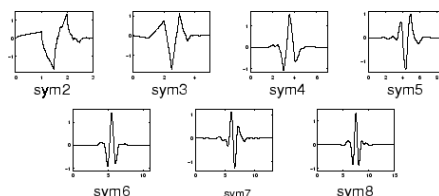
(c) Biorthogonal Wavelets

4. Coiffets Wavelets: I. Daubechies and R. Coifman jointly invented Coiffets having  $2N$  moments equal to 0 and the scaling function has  $2N-1$  moments equal to 0. The Coiffets are represented as shown below.



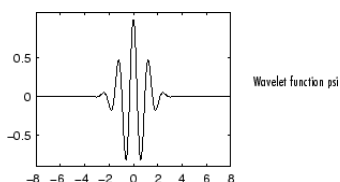
(d) Coiffets Wavelets

5. Symlets Wavelets: Developed by Daubechies as a modification to the DB family as symmetrical wavelets, have similar properties to each other. Symlets are represented as shown below.



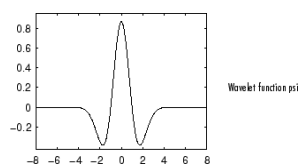
(e) Symlets

6. Morlets Wavelets: These wavelets have no scaling function and are derived from a function that is proportional to the second derivative function of the Gaussian probability density function as shown below.



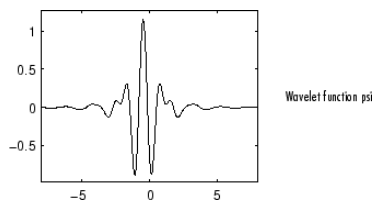
(f) Morlets

7. Mexican Hat Wavelet: This wavelet is also known as the Ricker wavelet. It has no scaling function and is derived from a function that is proportional to the second derivative function of the Gaussian probability density function. This wavelet is also known as the Ricker wavelet.



(g) Mexican Hat

8. Meyer Wavelet: In this wavelet scaling functions are defined in the frequency domain.



(h)Meyer Wavelet

## V. CONCLUSION

Thus it can be concluded that due to the ability of the wavelet transform to represent the signal in both the time and frequency domain simultaneously, it is used as a popular signal analysis tool to analyze various power quality-related problems such as the detection and location of fault conditions, voltage sag and swell, monitoring system condition, estimation of harmonics etc. The use of artificial neural networks or various classifiers is trained using various features derived from wavelet transformation applications to analyze the problems.

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