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Power Quality Identification and Classification Using Wavelet Method in Smart Power Grids

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Abstract

In this paper, different methods of wavelet coefficients have been used to detect power quality in smart power grids and have investigated the advantages and disadvantages of continuous and discrete wavelet transforms in detection and performance of different mother wavelets in detecting different types. The perturbations are investigated by discrete wavelet transform. Also, in analyzing the power quality of smart grids, the type of disturbance in voltage or current signals is discussed.

Keywords: systems Wavelet, Smart Grid, Power Quality
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1. Introduction

High power quality (PQ) level represents one of the main objectives towards smart grid. The currently used PQIs that are a measure of the PQ level are defined under the umbrella of the Fourier foundation that produces unrealistic results in case of non-stationary PQ disturbances. In order to accurately measure those indices, wavelet packet transform (WPT) is used in this paper to reformulate the recommended PQIs and hence benefiting from the WPT capabilities in accurately analyzing non-stationary waveforms and providing a uniform time–frequency sub-bands leading to reduced size of the data to be processed which is a necessity to facilitate the implementation of smart grid. Numerical examples' results considering non-stationary waveforms prove the suitability of the WPT for PQIs measurement; also the results indicate that Daubechies 10 could be the best candidate wavelet basis function that could provide acceptable accuracy while requiring less number of wavelet coefficients and hence reducing the data size. Moreover, a new time–frequency overall and node crest factors are introduced in this paper. The new node crest factor is able to determine the node or the sub-band that is responsible for the largest impact which could not be achieved using traditional approaches [1]. The concept of power quality has become increasingly important due to the increasing load on the quality of power supply, especially in smart grids. This concept encompasses both the aspects of maintaining the ideal nutrition at the power grid and the consumers [2]. One of the important fields of study in the field of power quality is the analysis of current and voltage waveforms to detect power quality problems, identify the type of disturbance existing, and calculate important power quality indices. Since the waveforms of the current and voltage are twice as non-static and non-periodic in most cases, the use of Fourier transform is not suitable for their analysis. For this reason, wavelet transform is used to analyze power quality disturbances. Wavelet transform is a powerful tool for detecting and classifying power quality phenomena. Conventional and discrete wavelets transforms are used to detect perturbations [3]. Existing power quality indices are based on the Fourier foundation [4–7]. Fourier series and Fourier transform can provide accurate results only for stationary waveforms along with satisfied Nyquist criterion and with sampling frequency being an exact integer multiple of the waveform fundamental period with no time varying harmonics [8]. If one of those conditions is not met, Fourier transform produces large errors for the measured quantities and therefore fails to accurately quantify the electric power quality [9-11].

2. Wavelet Transform

Signal analysts already have at their disposal an impressive arsenal of tools. Perhaps the most well known of these is Fourier analysis, which breaks down a signal into constituent sinusoids of different frequencies. Another way to think of Fourier analysis is as a mathematical technique for transforming our view of the signal from time-based to frequency-based. Wavelet analysis represents the next logical step: a windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information. Figure 1 shows Wavelet Transform function.

Fig. 1. Wavelet Transform function [3]

The description of wavelet analysis uses the time zone - the scale rather than the time zone - the frequency. wavelet analysis of a single signal and obtaining coefficients of detail and approximation in two ways, single-stage analysis, multi-molecular analysis possible.

3. Single-Step Decomposition

The basic algorithm of this method is illustrated in Figure 2. According to the shape of the original signals, the two filters pass through each other and become two signals. Unfortunately, if this operation is performed on a real digital signal, twice the input data will be delivered at the output. There is another trick to parsing. Only one point from each of the 2 samples of total information is retained. This is called a drop sampling operation. So there are two categories of data called A and D (shown in figure 3).

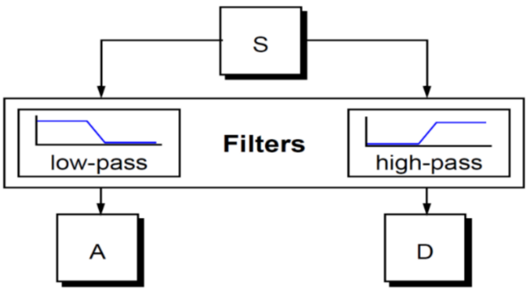

Fig. 2. The filtering process, at its most basic level [3]

Unfortunately, if we actually perform this operation on a real digital signal, we wind up with twice as much data as we started with. Suppose, for instance, that the original signal S consists of 1000 samples of data. Then the resulting signals will each have 1000 samples, for a total of 2000. These signals A and D are interesting, but we get 2000 values instead of the 1000 we had. There exists a more subtle way to perform the decomposition using wavelets. By looking carefully at the computation, we may keep only one point out of two in each of the two 2000-length samples to get the complete information. This is the notion of down sampling. We produce two sequences called cA and cD. The process on the right, which includes down sampling, produces DWT coefficients. To gain a better appreciation of this process, let's perform a one-stage discrete wavelet transform of a signal. Our signal will be a pure sinusoid with high-frequency noise added to it .Here is our schematic diagram with real signals inserted into figure 4.

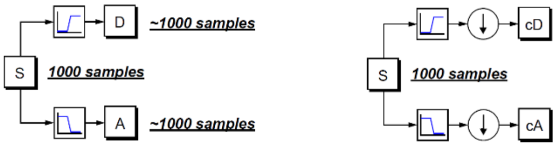

Fig. 3. Single-Stage Wavelet Transform with down sampling process [3]

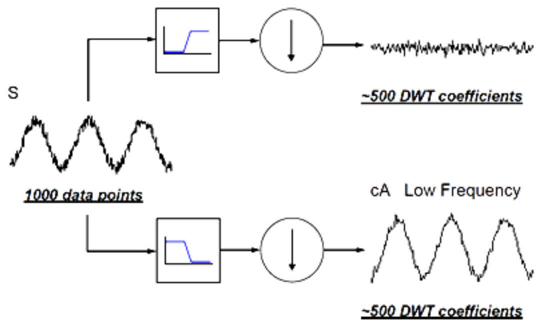

Fig. 4. Decay of sinusoidal waveforms corrupted by noise [4]

The CD coefficients are small and consist mainly of high-frequency noise, while the approximate CA coefficients are lower than the original signal. The actual length of the vector coefficients of detail and approximation are slightly more than half the signal length due to the filtering process carried out by filtering the signal. The cannulation process adds additional samples to the result.

4. Multi- Level Decomposition

The decomposition process can be iterated, with successive approximations being decomposed in turn, so that one signal is broken down into many lower resolution components. This is called the wavelet decomposition tree. Looking at a signal's wavelet decomposition tree at figure 6 can yield valuable information.

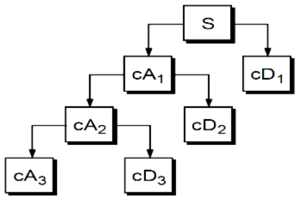

Fig. 5. Multi- Level Decomposition [5]

Since the analysis process is iterative, in theory it can be continued indefinitely. In reality, the decomposition can proceed only until the individual details consist of a single sample or pixel. In practice, you'll select a suitable number of levels based on the nature of the signal, or on a suitable criterion such as entropy.

5. Voltage Oscillation Software Analysis

At this stage, using the Voltage Software Simulator, one of the phases of the three-phase smart grid line 25 kv is measured and then the relevant parameters are extracted as shown in Figure 7 and the voltage flicker is observed.

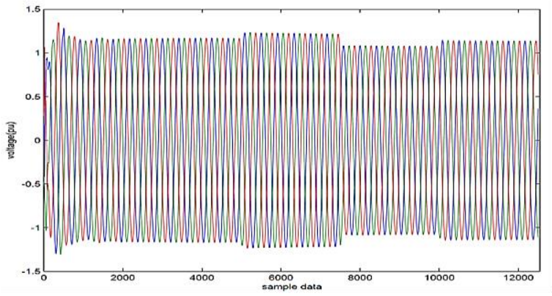

Fig. 6. Wavelet input waveform

In this step, the two functions Daubechies and Dmey of the Wavelet functions are examined. Using the Daubechies function, which is one of the most widely used wavelets in the field of power quality; the results are more acceptable than other types of wavelets. By testing all Daubechies wavelets from number 1 to 20, the most appropriate db6 wavelet is the one that reconstructs the chart with the best approximation, and the number of steps to perform the db6 to the fifth stage is the most appropriate.

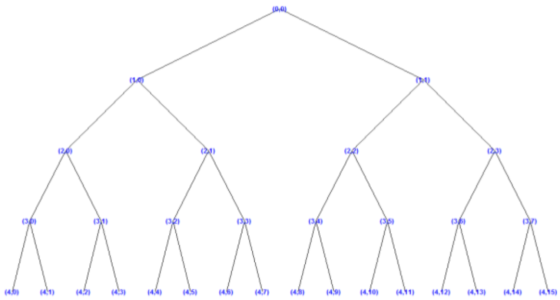

Fig. 7. The voltage flicker tree

As Figure 8 shows, the resulting tree is of 5 stages, and in the fifth stage we have the problem of multiplying the trees, so we choose the best tree as shown in figure 9.

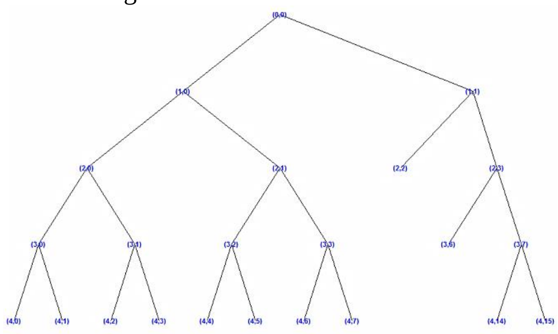

Fig. 8. The best voltage flicker tree

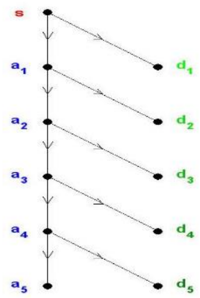

Fig. 9. Tree used for voltage flicker software

The standard form of the wavelet tree that the software also uses is the simple tree shown in Figure 10. Figure 11 shows the results of the db6 wavelet analysis up to 5 steps, which is the best stage for this waveform. Figures d1 through d5 indicate details and a5 represents approximations. The approximations are the high-scale components (low frequency) and the details of the low-scale components (high frequency). As shown in Figure 10. Unlike the Fourier transform, which only separated the harmonics and did not reveal the exact location of the perturbation and only indicated the existence of the perturbation, the precision turbulence time was precisely determined in the wavelet Transform, and this product produced windows of arbitrary length and width. That is, this shortcoming of Fourier transform was eliminated by the small-time Fourier transform by creating square-frequency time windows, but it also operated at equal frequency bands if the perturbation was an unimaginable and non-periodic phenomenon and alternately It may not be created so converting the wavelet by creating c The arbitrary sounds form the frequency band of the arbitrary band, which makes it always possible to interfere within these frequency bands. In Figure 11, the top diagram shows the signal in the fifth step and the middle diagram shows all the details up to the fifth step in a single figure and the bottom diagram shows the color spectrum of the wavelet Transform whose scaling is evident.

Figure 12 shows the color spectrum diagram of all high-frequency components and their time of occurrence referred to as noise or unwanted signal. However, Fourier transform was only capable of harmonic separation and failed to show the exact timing of the phenomenon.

6. Flickr analysis with demy function

In this step, another wavelet that yields good results, known as demy wavelet, performs the wavelet analysis, which in step 5 has the best response. Figure 13 shows the results of the demy wavelet analysis. Figure 13 shows the main waveform of the signal along with the color spectrum chart (CFS) to the corresponding approximations and the details of the wavelet analysis. Figure 14 also shows the color spectrum details. It should be noted that the amount of skylights varies from dark (min) to light (max).

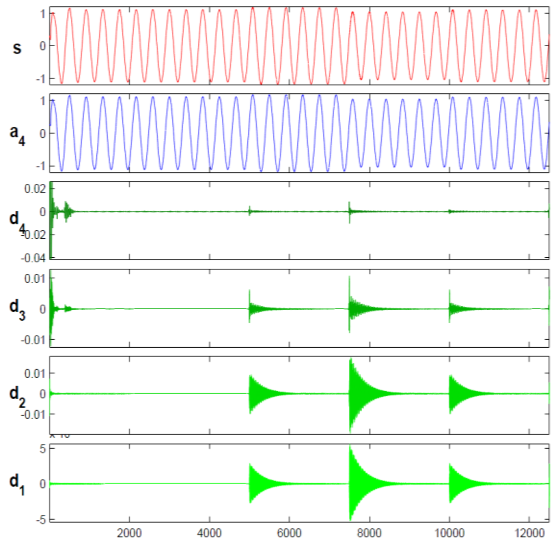

Fig. 10. The results of the Flickr Voltage Wavelet Analysis

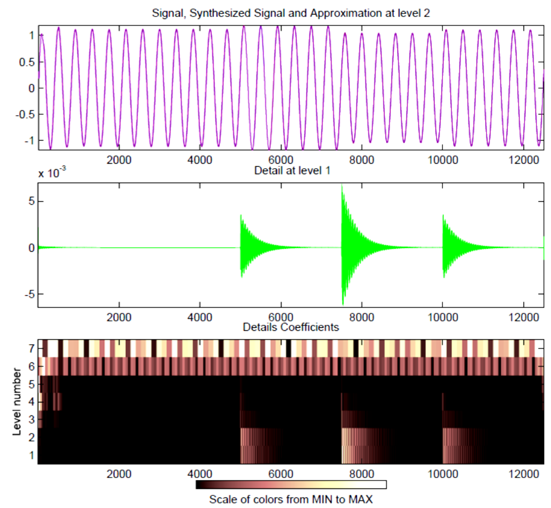

Fig. 11. The results of comparing the details with the original shape and the corresponding color

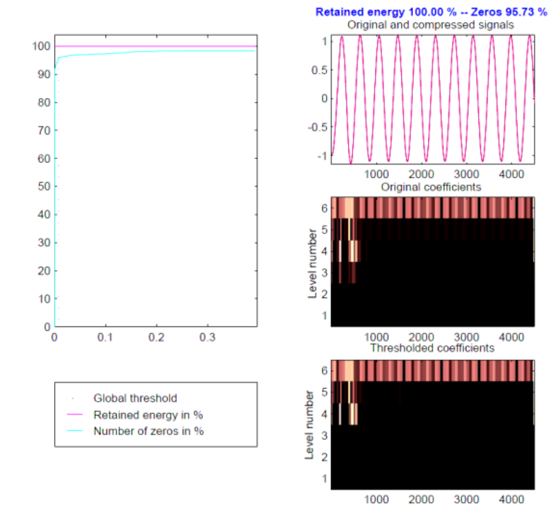

Fig. 12. Original shape and detail with the corresponding color spectrum using the demy wavelet

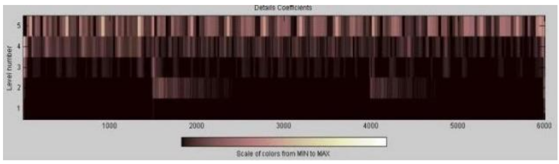

Fig. 13. Details of the corresponding color spectrum using the demy wavelet

7. Conclusion

Wavelet transforms can identify and classify all types of disturbances in smart power networks more precisely. Since wavelet transforms act as a filter, it divides the signal energy into different levels and if frequencies other than frequencies are used. Power is present in the signal. The energy is expressed at that level. And according to the user's preferred scaling, it is possible to match all high-frequency components with a small scale and all low-frequency components with a large scale and thus accurately. At the time of occurrence, the phenomenon can be significantly enhanced. This paper presents a wavelet analysis to identify, locate, and classify transient and sometimes persistent disturbances in the power system that are crucial in terms of power quality and prove their effectiveness. The proposed parameter plotted against different WPT decomposition levels show its usefulness in PQ analysis applications like identification and classification. The parameter at some specific decomposition level, also show its possible usage for PQ identification and classification. This work can be further extended with more such distinguishing parameters for the automatic identification and classification of the power quality disturbances using intelligent classifiers such as; artificial neural networks, fuzzy logic controllers etc.

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