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Analysis and Estimation of Harmonics Using Wavelet Technique

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Abstract

The paper develops an approach based on wavelet technique for the evaluation and estimation of harmonic contents of power system waveform. The proposed algorithm decomposes the signal waveforms into the uniform frequency sub-bands corresponding to the odd harmonic components of the signal. The proposed implementation of algorithm determines the frequency bands of harmonics which retain both the time and frequency relationship of the original waveforms and uses a method to suppress those harmonics.Thewaveletalgorithm is selected to obtain compatible output bands with the harmonic groups defined in the standards for power-supply systems. A comparative analysis will be done with the input and the results obtained from the wavelet transform (WT) for different measuring conditions and Simulation results are given.

Keywords: *harmonic distortion, electric power quality, multi resolution analysis, wavelets, signal and noise*

1. Introduction

The growing use of power electronics systems in power supply networks nowadays presents an increasing importance of harmonic studies. A power quality problem can be described as any variation in the electrical power service, such as voltage dips and fluctuations, momentary interruptions, harmonics and transients, resulting in misoperation or failure of end-use equipment. The presence of harmonic distorts the shape of the voltage and current which in turn creates many problems. Traditionally, the discrete Fourier transform (DFT) is proposed for harmonic analysis and it gives the frequency information of the signal, which means that it tells us how much of each frequency exists in the signal, but it does not tell us when in time these frequency components exist [1]. Therefore, DFT is not a suitable technique for non-stationary signal.

A new approach called Wavelet technique is applied here for harmonic studies to overcome the limitations in the conventional methods and gives an improved power quality. Wavelets are a set of functions that can be used effectively ina number of situations, to represent natural, highly transient phenomena that result from a dilation and shift of the original waveform. Wavelet Transform represents a powerful signal processing with a wide variety of applications that is particularly useful for the analysis of non- stationary signals [2].

In wavelet analysis, the wavelet function is compared to a section of the signal under study, obtaining a set of coefficients that represent how closely the wavelet function correlates with the signal. Wavelet Transform (WT) is designed to give good time resolution and poor frequency resolution at high frequencies and good frequency resolution and poor time resolution at low frequencies. This approach makes sense especially when the signal has high frequency components for short durations and low frequency components for long durations. Finally, this paper compares the performance of the results obtained using proposed wavelet transform (WT) for different conditions such as stationary, non-stationary signals and Noise signals.

2. Wavelets

Wavelets are oscillating waveforms of short duration with amplitude decaying quickly to zero at both ends. In WT, the wavelet is dilated and shifted to vary the frequency of oscillation and time location, and are superimposed onto the signal under analysis. These dilating and

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shifting mechanisms are more desirable for analyzing waveforms containing non-stationary events than that of traditional methods such as discrete Fourier transform (DFT) and short time Fourier transform (STFT). Wavelet technique analyses the signal at different frequencies with different resolutions. Wavelets have important properties suitable for analysis of non-stationary waveforms.

The filtering process shown in Figure 1 is the design method of most of the practically relevant discrete wavelet transforms (DWT) and the first component to multiresolution analysis is vector spaces [3]. For each vector space, there is another vector space of higher resolution until you get to the final signal. Also, each vector space contains all vector spaces that are of lower resolution. The basis of each of these vector spaces is the scale function for the wavelet and represents the detailed version of the high-frequency components of the signal and the approximation version of the low-frequency components and the reconstruction process of wavelet transform shown in Figure 2.

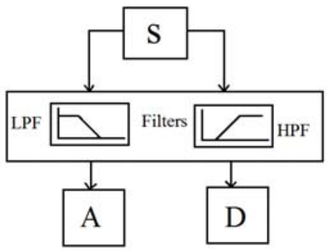


Figure 1. Filtering Process

The lowpass filtering, A and high pass filtering, D removes the high frequency information and low frequency information respectively, but leaves the scale unchanged. Only the subsampling process changes the scale. Resolution, on the other hand, is related to the amount of information in the signal, and therefore, it is affected by the filtering operations.

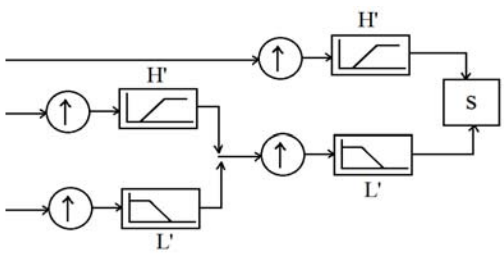


Figure 2. Wavelet Reconstruction

Half band lowpass filtering removes half of the frequencies, which can be interpreted as losing half of the information. Therefore, the resolution is halved after the filtering operation [4]. However, the subsampling operation after filtering does not affect the resolution, since removing half of the spectral components from the signal makes half the number of samples redundant anyway. Half the samples can be discarded without any loss of information. The authors (in [5]) propose a method to compensate the imperfect response of the filters used in the wavelet-transform filter banks.

The new improved approach Wavelet Transform (WT) was implemented to overcome the disadvantages of conventional methods. In the WT, the details are further decomposed to produce new coefficients, this way enabling a frequency decomposition of the input signal to be obtained.

3. Proposed Algorithm

The algorithm proposed in this paper is wavelet transform (WT) which is compatible with the frequency bands of the different harmonic groups and uses the Daubechies 20 as the wavelet function and the filter bank with three levels of decomposition shown in Figure 3. The sampling frequency selected is 1.6 kHz with fundamental frequency of 50 Hz.The decomposition process can be iterated, so that one signal is broken down into many lower-resolution components and higher-resolution components respectively as shown in Figure 3 and the output frequency bands of wavelet transform shown in Figure 4. The output of the filter bank is divided into frequency bands (coefficients of d1 to d4) which offers information about harmonic groups presents in the input signal [6-7]. The flowchart for the process of wavelet transforms which is shown in Figure5.

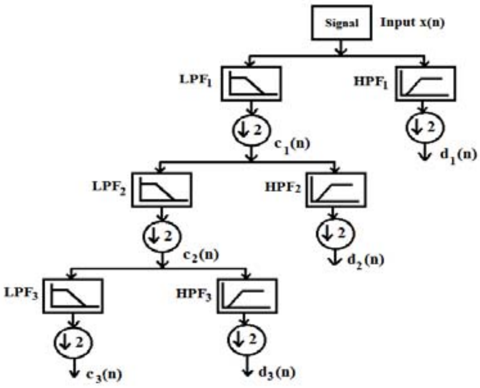


Figure 3. Three level Wavelet Decomposition Tree

Each transform coefficient represents a measure of the correlation between the signal and the basis function. Large coefficients represent good correlation; conversely small coefficients represent poor correlation. By analyzing the components of harmonics in the terminal output bands, the suitable method of threshold will be applied to those output bands by retaining the coefficients which preserves original signal. The wavelet algorithm keeps only the significant coefficients, representing the signal based on non-linear thresholding. It discards the coefficients that fall below a given magnitude. After adjusting the coefficients, the decomposed components could be assembled back into the original signal with no loss of information.

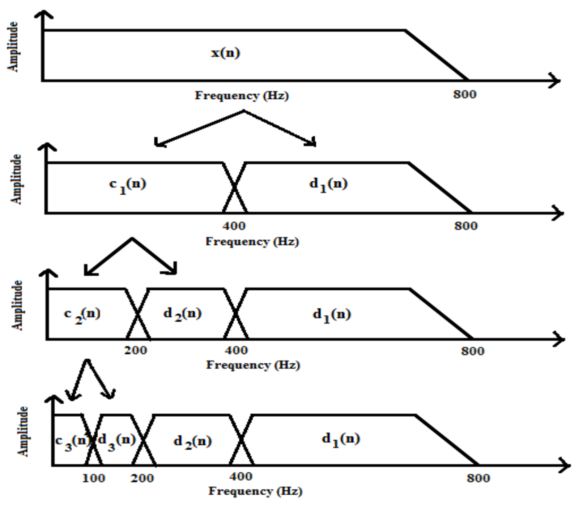


Figure 4. Output Frequency bands of Wavelet Decomposition

The filtering part of the reconstruction process is the choice of filters that is crucial in achieving perfect reconstruction of the original signal [6]. The reconstructed details and approximations are true constituents of the original signal. The RMS magnitude of input and output signals are obtained by using the square root of the mean square of the wavelet coefficients. It is important to note that the downsampling of the signal components performed during the decomposition phase introduces a distortion called aliasing. It turns out that by carefully choosing filters for the decomposition and reconstruction phases that are closely related (but not identical); we can cancel out the effects of aliasing.

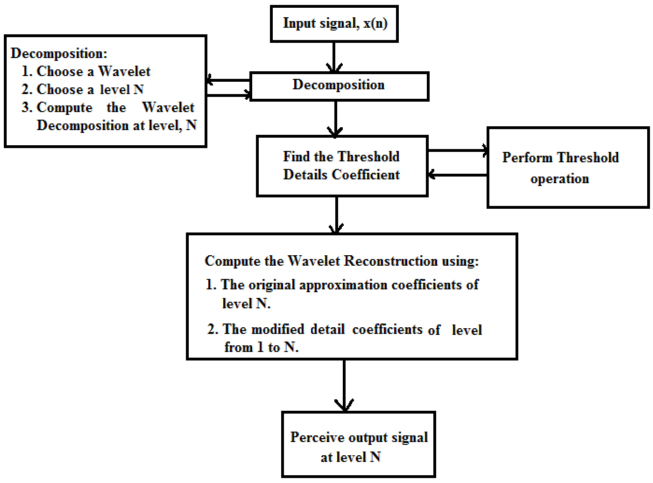


Figure 5. Flowchart for Wavelet Transform

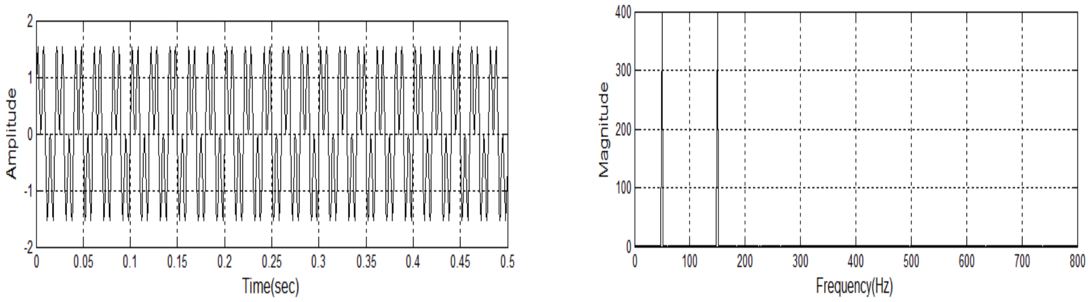
Generally, it is necessary to ensure maximum flat pass band characteristics and good frequency separation. This way, wavelet functions with a large number of coefficients have less distortion than wavelets with fewer coefficients and according to [8], the frequency characteristics of Daubechies wavelet function is an appropriate wavelet filter bank for power-quality monitoring. In order to measure higher range of harmonic orders (greater than 15^{th} order), the sampling frequency and level of the decomposition will be increased in Figure 1 according to the harmonic conditions [7].

4. Simulation Results

The Wavelet Transform (WT) technique for analyzing the harmonics was implemented by using the software package of MATLAB. In this section, a comparative analysis will be done with the input and the results obtained from the wavelet transform (WT) for different measuring conditions, stationary signal with harmonic components, non-stationary signals and noise signal.

4.1. Stationary conditions

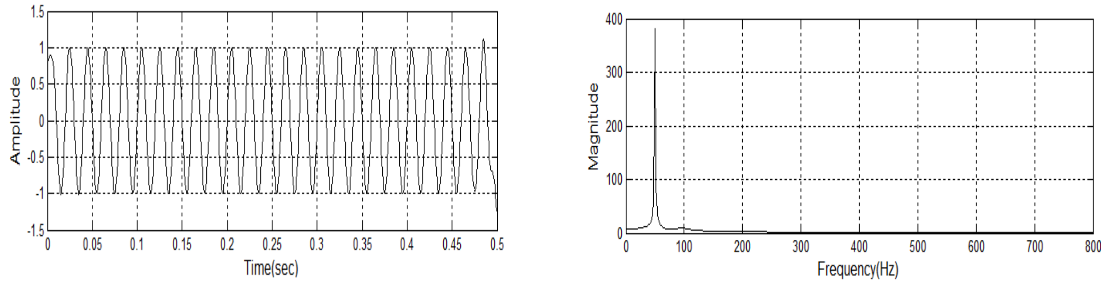
Consider the stationary signal shown in Figure 6(a) which contains third harmonic component in fundamental component signal of 50 Hz and its corresponding FFT analysis is shown in Figure 6(b).



(a) (b)

Figure 6. (a) Input Third harmonic signal, (b) FFT analysis

In this case, one does not need to know at what times frequency components exist, since all frequency components exist at all times.By analyzing the components of harmonics in the input signal (Figure 6(a)) and suppressed using Wavelet Transform (WT) technique, then the output signal was obtained as shown in Figure 7(a). Then, the RMS value of the input signal and the results of proposed technique and its corresponding spectrum, which is obtained by applying the FFT analysis on a rectangular window, is shown in Figure 7(b) were compared.



(a) (b)

Figure 7. (a) Output signal, (b) FFT analysis

Table 1. RMS Values of The Input and Output for the Harmonic signal using the db20 Wavelet Functions

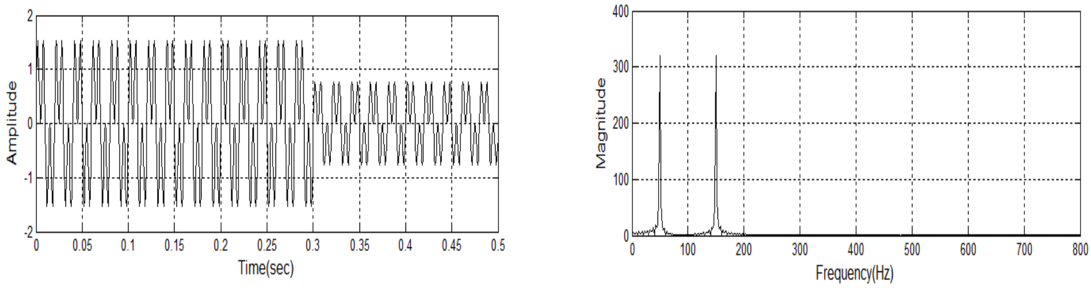
Harmonic order	RMS of input	Output RMS of WT	Error of WT (%)
1	0.7071	0.7071	0
1+3	1.0000	0.7169	1.38
1+3+5	1.2247	0.7278	2.92
1+3+5+7	1.4142	0.7302	3.26
1+3+5+7+9	1.5811	0.7344	3.86
1+3+5+7+9+11	1.7321	0.7376	4.31
1+3+5+7+9+11+13	1.8708	0.7395	4.58
1+3+5+7+9+11+13+15	2.0000	0.7401	4.66

In the same way, the Wavelet Transform (WT) technique was applied to up to 15thorder harmonic with fundamental signal and the results of output signal were comparedby calculating

RMS value of the signal, which is shown in Table 1. In this case, the error with third harmonic component of proposed technique has only 1.38% using db20 wavelet function.\

4.2. Non-Stationary signals

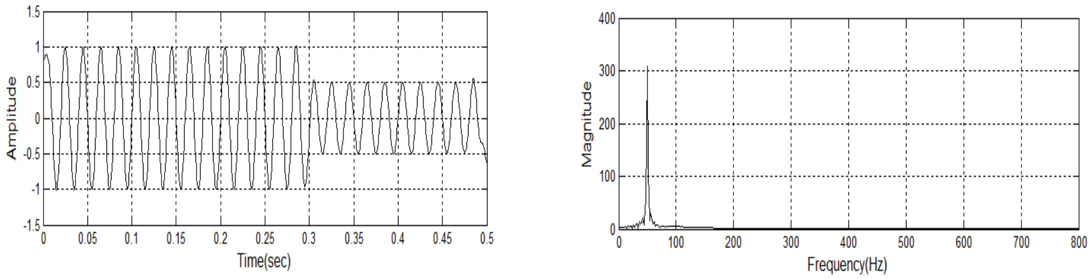
Signals whose frequency content varies with time are called Non-Stationary signals. A Fluctuating signal is not a complete interruption of power and voltage sags are probably the most significant power quality (PQ) problem facing industrial customers today, and they can be a significant problem for large commercial customers as well.



(a) (b)

Figure 8. (a) Input Fluctuating harmonic signal, (b) FFT analysis

Figure 8(a) shows the case of the fundamental signal with third harmonic that is fluctuating from magnitude of 1 to 0.5 and Figure 8(b) shows the corresponding spectrum obtained by applying the FFT analysis on a rectangular window. The change in the magnitude of the signal occurs after 0.3 periods of the third harmonic signal. The input harmonic signal (Figure 8(a)) was analyzed and the harmonics which presents in the input signal was suppressed using Wavelet Transform (WT) technique, then the output signal was obtained as shown in Figure 9(a). Then, the RMS value of the input signal and the results of proposed technique and its corresponding spectrum, which is obtained by applying the FFT analysis on a rectangular window, is shown in Figure 9(b) were compared.



(a) (b)

Figure 9. (a) Output signal, (b) FFT analysis

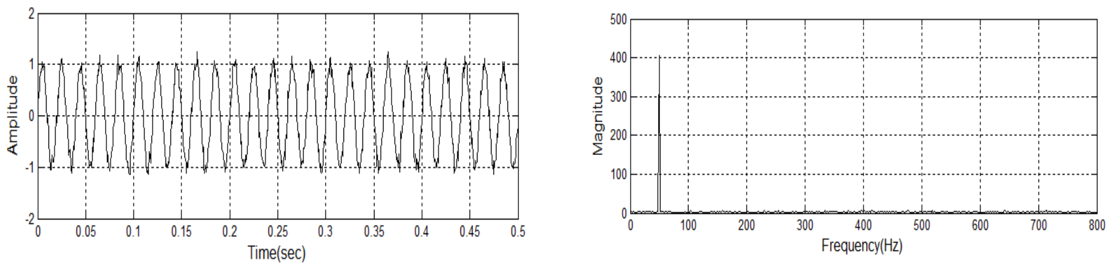
Table 2 shows the comparative analysis of the input signal and the results obtained from the wavelet transform (WT) for different measuring conditions. In this case, the error with third harmonic component of proposed technique has only 0.45% using db20 wavelet function.

Table 2. RMS Values of The Input and Output for the Harmonic signal using the db20 Wavelet Functions

Harmonic order	RMS of Input	Output RMS of WT	Error of WT (%)
1	0.5916	0.5916	0
1+3	0.8367	0.5943	0.45
1+3+5	1.0247	0.5993	1.30
1+3+5+7	1.1832	0.6014	1.65
1+3+5+7+9	1.3229	0.6037	2.04
1+3+5+7+9+11	1.4491	0.6055	2.34
1+3+5+7+9+11+13	1.5652	0.6064	2.50
1+3+5+7+9+11+13+15	1.6733	0.6068	2.56

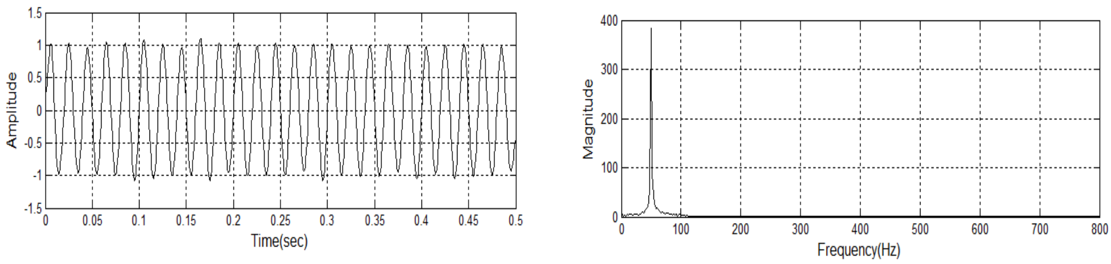
5. Noise Signal for Analysis

Noise generated by electronic devices varies greatly, as it can be produced by several different effects. Signal-to-noise ratio (often abbreviated SNR or S/N) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power.



(a) (b)

Figure 10. (a) Input Noise signal, (b) FFT analysis



(a) (b)

Figure 11. (a) Output signal. (b) FFT analysis

In Input signal (Figure 10(a)), the signal to noise ratio amount of 20 (Gaussian noise) was added to the signal for analyzing purpose and the corresponding FFT analysis which is shown in Figure 10(b). Then, the Figure 11(a) shows the output signal obtained by using WT technique and Figure 11(b) shows the corresponding spectrum obtained by applying the FFT analysis on a rectangular window.

By the same token, the Wavelet Transform (WT) technique was applied to upto 15th order harmonic with fundamental signal and the results of output signal were compared by calculating RMS value of the signal, which is shown in Table III. In this case, the error with noise signal component of proposed technique has only 0.19% using db20 wavelet function.

Table 3. RMS Values of The Input and Output for the Harmonic signal using the db20 Wavelet Functions

N = Gaussian Noise

Harmonic order	RMS of input	Output RMS of WT	Error of WT (%)
1	0.7071	0.7071	0
1+N	0.7122	0.7085	0.19
1+N+3	1.0019	0.7141	0.98
1+N+3+5	1.2282	0.7257	2.63
1+N+3+5+7	1.4191	0.7268	2.78
1+N+3+5+7+9	1.5843	0.7291	3.11
1+N+3+5+7+9+11	1.7283	0.7358	4.05
1+N+3+5+7+9+11+13	1.8678	0.7386	4.45
1+N+3+5+7+9+11+13+15	2.0105	0.7411	4.80

6. Conclusion

This paper has presented a new method of wavelet technique based algorithm for the analysis of harmonics using db20 wavelet function. Several case-studies, related to the most common disturbances in electrical power quality analysis, have shown the suitability of the method. The performance of the proposed method has been compared with the input signal by calculating RMS value of the signal for different measurement conditions and showing the wavelet technique analysis as an alternative processing tool for the harmonic estimation.

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