A New Method for Measurement of Harmonic Groups Using Wavelet-Packet-Transform

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Abstract: This paper presents a new method based on the wavelet-packet transform for analysis of harmonics in power systems. The proposed method decomposes the voltage/current waveforms into the uniform frequency bands corresponding to the odd and even harmonic components of the signal. It also uses a filter to reduce the spectral leakage being due to the imperfect frequency response of the used wavelet filter banks so that the spectral leakage becomes almost zero. In addition to measure odd-harmonic components, even-harmonic components are also measured which are not clearly considered by previous methods. The accuracy of the method is considerable and it can be adjusted through utilizing an iterative algorithm. To compare the performance of the proposed method with previous methods especially the IEC method, two examples are served.

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Key words: Harmonics; Measurement of harmonics; International Electro technical Commission (IEC) standards; Wavelet-Packet Transform (WPT).

1. Introduction

Nowadays use of nonlinear power electronics coupled with more prevalent use of more sensitive computer-controlled and microprocessor-based equipment has brought power quality issues on power system networks to forefront and one of the most important steady-state concerns in power quality issues is harmonic distortion. Variable speed drives, arc furnaces, personal computers, and other nonlinear devices produce harmonics. Since harmonics can severely degrade performance of power supplies and their connected equipment, it is necessary to always monitor harmonic parameters such as voltage, current, and power [2-4].

Before using wavelet transform and computer modeling, techniques such as the Fourier spectral analysis are often applied to analyze harmonic distortions. The Fourier transform (FT) and the short time Fourier transform (STFT) provide good information on the frequency domain but the time at which a particular disturbance in the signal occurred is lost [5-7].

Application of FT and STFT to analyze non-stationary signals is not efficient, although STFT is better than FT. Analysis and processing of different classes of non-stationary (in time) or inhomogeneous (in space) signals is the main field of applications of wavelet analysis. Wavelets are used when the simulated results of a particular signal must contain not only its typical frequencies (scales) but also the knowledge of the definite local coordinates where these properties are important.

In addition to the upper mentioned reasons, the IEC Standard 61000-4-7 defines standards which must be used in the harmonic-measuring instruments [1]. Discrete FT (DFT) has been suggested to analyze harmonics in this standard. The standard itself states that the specification of a DFT reference instrument for harmonic and inter-harmonic measurement does not preclude the application of other analysis principles, such as the wavelet analysis [9]. Furthermore, the application of wavelet for measuring non-integer and harmonics caused by sudden changes is better than DFT.

The discrete wavelet transform (DWT) decomposes a power system waveform into a non-uniform frequency bands (a logarithmic decomposition) in such a way that frequency bands at higher levels include more harmonic components than those at lower levels. Hence, the use of Wavelet Packet Transform (WPT) that provides uniform frequency bands is purposed in this study. Furthermore, the WPT decomposition algorithm is compatible with the harmonic groups defined in the harmonic measurement standards for power-supply systems [10].

Many works in the literature have been found that use wavelet to detect power quality problems but a few works has been done to investigating the performance of wavelet only for the analysis of harmonic distortion such as [3, 8, 11-14]. These works only describe performance of wavelet in harmonic analysis and measurement of harmonic components is not considered in these papers. Only Julio Barros and Ramon I. Diego in [9-10, 15] use wavelets for analysis of harmonic components in voltage and current waveforms. But their methods cannot separately compute the even harmonics and the accuracy of their methods is low. Therefore, in this paper, a new method is presented which increases the accuracy of measurement and, moreover, in addition to odd harmonics, it measures even harmonics.

2. New method development

In [9], by selecting a sampling frequency of 1.6 kHz and using a three-level decomposition tree, the frequency range of the output is divided into eight bands with a uniform 100-Hz interval. As mentioned in [9], the odd-harmonic frequencies are presented in the center of the bands and the even harmonics cannot separately be computed using the mentioned method. In order to measure even harmonics, each of those coefficients (d1 to d8) must be converted to coefficients corresponding to even and odd harmonics.

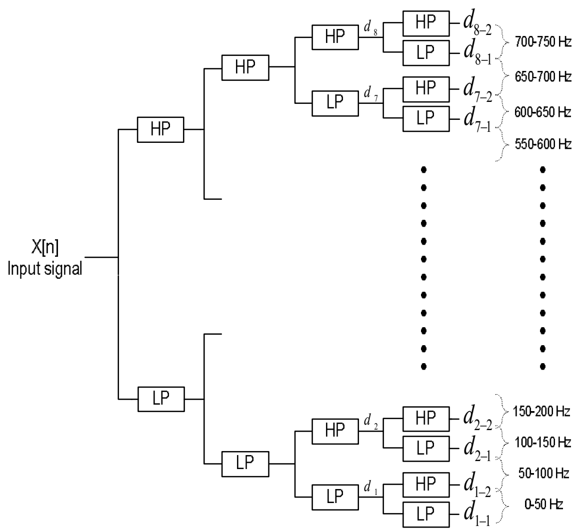

Figure 1: Obtained coefficients corresponding to even and odd harmonics

Therefore, the obtained coefficients *d*1 through *d*8 for another time goes from the same wavelet filter bank to separate even harmonic coefficients from odd-harmonics coefficients. Obtained coefficients are named as d_{1-1}, d_{1-2} through d_{8-1} and d_{8-2} as shown in Fig 1. Fig. 2 shows frequency bands of the four-level decomposition tree in Fig. 1 for a sampling frequency of 1.6 kHz.

It can be seen from Fig. 1 that energy of even harmonics is usually detected in detail coefficients while energy of odd harmonics is detected in approximated coefficients if the filter performances close to the ideal. However as shown in Fig. 2 due to shows that adjacent coefficients have overlap and energy Therefore, the *rms* magnitude of odd harmonics can be calculated using the root of the total of the mean square of detail and approximated coefficients of each level, as the *rms* of *(2i-1)*-th odd harmonic is calculated as:

$$H_{2i-1}^{odd} = \sqrt{D_{i-1}^{\ 2} + D_{i-2}^{\ 2}} \quad (1)$$

Where D_{i-1} is the *rms* of approximated coefficients in the *i*-th level and D_{i-2} is the *rms* of detail coefficients in the same level.

The *rms* magnitude of even harmonics is calculated using the root of the total of the mean square of detail coefficients in the *i*-th level and approximated coefficients in the $(i+1)$-th level as the *rms* of 2*i*-th even harmonic is calculated as:

$$H_{2i}^{even} = \sqrt{D_{i-2}^{\ 2} + D_{(i+1)-1}^{\ 2}} \quad (2)$$

The calculated magnitudes are not accurate and interference of even and odd harmonics in each level is high. To reduce the spectral leakage, a filter which only passes harmonics with considerable magnitudes and almost nulls others is used. The output magnitudes of harmonics in this filter are calculated as:

$$HF_{2i-1}^{odd} = H_{2i-1}^{odd\,(D_{i-1}\times D_{i-2})^{-m}} \quad (3)$$

$$HF_{2i}^{even} = H_{2i}^{even\,(D_{i-2}\times D_{(i+1)-1})^{-m}} \quad (4)$$

where *m* is an exponent. The greater *m*, the higher accuracy of detection. However, the magnitude of greater harmonic may be decreased. In this study, the value of the exponent has been taken as 1.

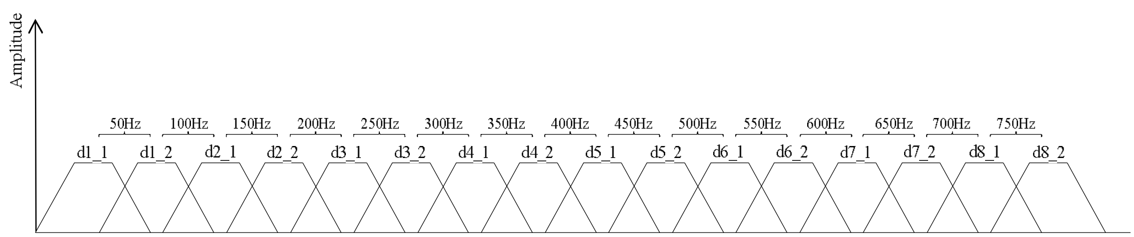

Figure 2: Output frequency bands of the four-level decomposition tree in Fig. 1 for a sampling frequency of 1.6 kHz

Fig. 3 shows a signal including different harmonics. The difference between the magnitudes of two main harmonics of this signal is not considerably clear. However, when this signal is passed through the filters defined by Eq. (3) and (4) Fig. 4 is obtained. As can be seen in this figure, harmonics with low magnitudes is damped completely. Difference of two other harmonics is also cleared in this figure.

3. Iterative Algorithm Development

To measure each harmonic, the spectral leakage due to greater harmonics must be removed from the signal. Therefore, the harmonics must be measured respectively based on their magnitudes and then they must be removed from the signal. This action must be repeated until all harmonics in the signal are measured. Therefore, an iterative algorithm is used. In the proposed algorithm, in the each iteration the an iterative algorithm is used. In the proposed algorithm, in the each iteration the greatest harmonic.

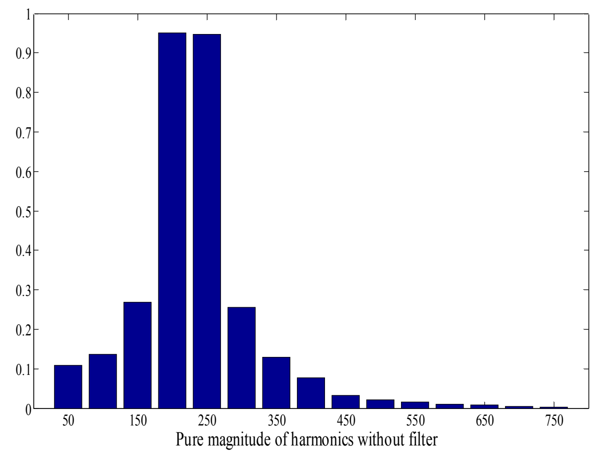

Figure 3: A signal including different harmonics

The magnitudes of other harmonics in the next iterations are calculated based on this standard energy. The first calculated harmonic is 50(60) Hz due to the main frequency of the power systems is 50(60) Hz. The iterations are continued until the energy of the remaining signal (ERS) is less than an amount which can adjust the accuracy of the proposed method. The magnitude of a harmonic may be calculated in several various iterations.

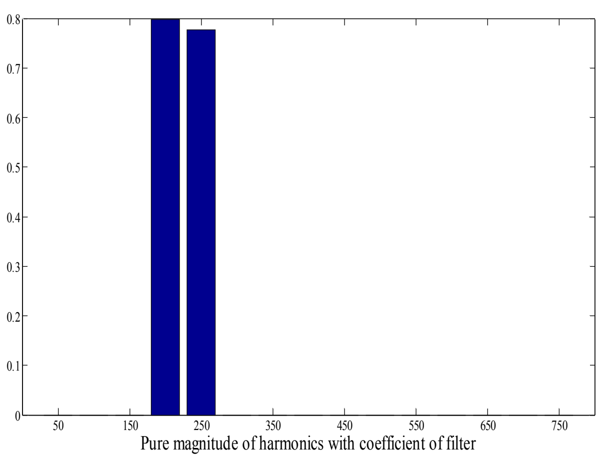

Figure 4: The signal of Fig. 3 after passing through filters of Eq. (3) & (4)

Therefore, the accuracy of measurement is increased considerably and can be adjusted.This method is following the structure that mentioned in [9-15]. Hence, this method is compatible with the new IEC standard 61000 and the result that followed in next section show that additional to high accuracy, the proposed method can measure inter-harmonics better than the IEC method. Fig. 5 shows flowchart of the proposed method.

4. Simulation Results

Simulation results have been presented in two parts. First the accuracy of the proposed method for odd harmonics is investigated and it is compared with previous methods and IEC method. Then, with regarding to measure both kinds of harmonics highlighting even harmonics, the performance of the proposed method is assessed.

a. Test I

In [9], a sample signal including odd harmonics until 15-th order is studied. The same signal is studied in this section. The used wavelet mothers in [9] are *v24* and *db20* but in this paper discrete approximation of Meyer wavelet (dmey) is used. This wavelet mother unlike *v24* is available in Wavelet Toolbox of MATLAB and has the same performance.

Table I shows the results when the mentioned signal is simulated using different methods. The table shows that the accuracy of the proposed method is better than the method suggested by [9] and comparable with the IEC method.

Table 1: Results of the three methods for the sample signal in test I

Input signal		IEC method	Method suggested in [9]		The proposed method
Harmonic order	Magnitude (%)		Db20	Dmey	
1	100.00	100.00	99.43	99.56	100.00
3	1.00	1.00	0.95	0.94	1.00
5	2.50	2.50	2.00	2.12	2.50
7	1.10	1.10	0.83	0.95	1.10
9	0.20	0.20	0.46	0.37	0.20
11	0.30	0.30	0.27	0.28	0.30
13	0.10	0.10	0.13	0.11	0.10
15	0.10	0.10	0.10	0.095	0.10

The accuracy of the proposed method is obtained after 28 iterations.

Test II

Detection and measurement of neighboring harmonics due to spectral leakage is difficult. If these harmonics are related to even and odd harmonics of a level, it is hard to separate and measure them. Therefore, a sample signal having these characteristics is studied in this section. The sample signal includes all even and odd harmonics from 50Hz to 750Hz. The magnitudes of this harmonics and the measured values are shown in Table II.

Table II shows that, after 15 iterations (minimum iterations to clear all harmonics), all harmonics except the 12-th and 14-th are measured with good accuracy.

During 21-th iteration, the 14-th order is also detected and in the next iterations only the accuracy of measurement is increased. At this table, the accuracy of the proposed method in terms of ERS is also presented. 19 and 31 iterations are required to that ERS becomes smaller than 1e-5 and 1e-7, respectively.

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These test results show that the proposed method has two main advantages compared with the method suggested by [9] which are:

1. Measure even harmonics
2. Better accuracy

Table 2: Results of the proposed methods for the sample signal in test II

Input signal		After 15 iterations	After 45 iterations	ERS<1e-5 (19iterations)	ERS<1e-7 (31iterations)
Harmonic order	Magnitude (%)				
1	100.00	100.00	100.00	100.00	100.00
2	0.2000	0.1946	0.1998	0.1946	0.1998
3	3.0000	2.9836	3.0000	2.9994	2.9994
4	0.1000	0.0964	0.1001	0.0964	0.1001
5	2.5000	2.4831	2.5001	2.5001	2.5001
6	0.1000	0.0996	0.0996	0.0996	0.0996
7	2.0000	2.0120	1.9997	2.0120	2.0004
8	0.0500	0.0517	0.0504	0.0517	0.0504
9	1.0000	1.0200	1.0003	1.0063	1.0003
10	0.0400	0.0429	0.0401	0.0429	0.0406
11	0.7000	0.6903	0.7002	0.6903	0.7002
12	0.0200	0.0000	0.0203	0.0212	0.0212
13	0.5000	0.5028	0.5002	0.5028	0.5007
14	0.0100	0.0000	0.0099	0.0000	0.0099
15	0.3000	0.3012	0.3004	0.3012	0.3012

5. Conclusion

In this paper, a new method based on the wavelet-packet transform for the analysis of harmonics in the power systems was presented. The proposed method decomposed the voltage/current waveforms into the uniform frequency bands corresponding to the odd and even harmonic components of the signal. It used a filter to reduce the spectral leakage being due to the imperfect frequency response of the used wavelet filter banks. Additional to measure odd-harmonic components, even-harmonic components was also measured which are not clearly considered by the previous methods. The accuracy of the method was good and it can be adjusted through utilizing an iterative algorithm.

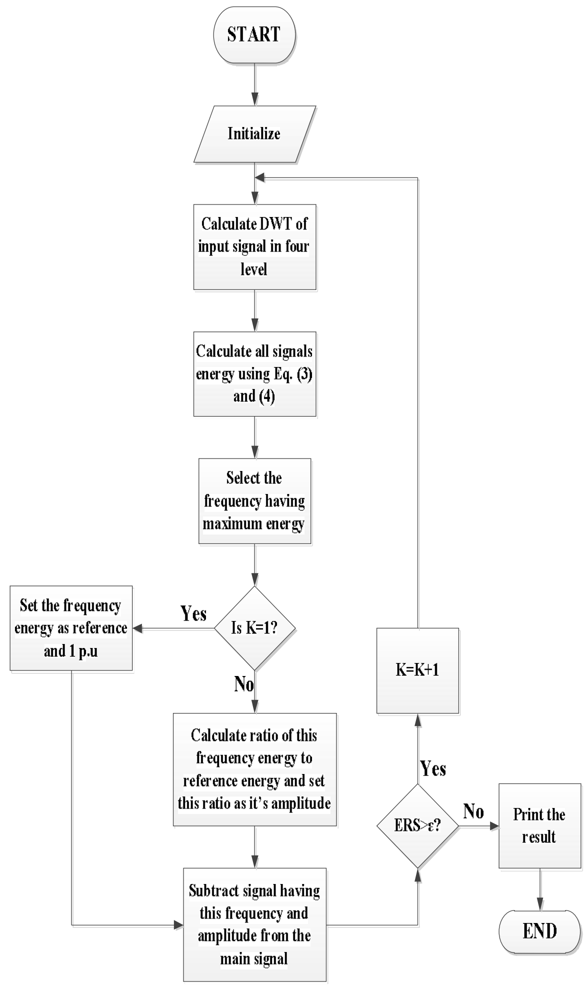

Figure 5: Flowchart of the proposed method

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