Two modified method for Harmonic and Flicker measurement based on RWPC considering spectral leakage and edge effects

[1]Marjan Saadati , [2]Seyed Saeedolah Mortazavi
Shahid Chamran University (SCU)
Golestan Boulevard
Ahvaz, Iran

Abstract- **Harmonic is an important issue in electric power systems. A wavelet packet transform (WPT) method is introduced as a powerful tool for detection Harmonics and Flicker. The proposed methods can simultaneously measure the distribution of RMS quantities with respect to individual frequency bands directly from the wavelet transform coefficients. Uniform frequency bands result from the WPT decomposition of power system waveforms can be used for identification of harmonic frequency bands. This paper presents two novel modified methods for harmonic detection and measurement.**

However, use of wavelet packet coefficients has some errors such as the edge effects of wavelet filters and spectral leakage. In first method paper proposes to combine two adjacent frequency bands to reduce error caused by spectral leakage. In the recently methods they place frequency of main harmonics on the edge of the bands. It provides huge errors because of non-ideal characteristics of the filters. In second method paper proposes to change the band width of output to 40 Hz. This causes that the main harmonics be in the band no on the edge. This method has got the chance to measure flicker also.

Use of Wavelet Packet Coefficients for harmonic measurement because of Downsampling reduces number of sampling points and energy content of signal making huge error. This paper also offers the use of a compensation method by use of Reconstructed WPC to prevent energy reduction.

In addition, it introduces a modification method to reduce edge effects and spectral leakage. Methods are simulated and experimented. Parameters are compared with true values that it shows satisfactory results.

I. INTRODUCTION

POWER quality is becoming an issue of increasing concern both to utilities and their customers. One of the major power system problems is steady-state waveform distortion due to harmonics; Harmonics be produced by variable speed drives, arc furnaces, personal computers, and other non-linear devices. Since harmonics can severely degrade the performance of power system equipment, it is necessary to always monitor their parameters such as voltage, current, and power.

The traditional discrete Fourier transform (DFT) is proposed in the and standard as the processing tool for harmonic analysis, using rectangular time windows of ten cycles' width of the fundamental frequency in a 50-Hz system, providing a resolution of 5 Hz. Of course this does not preclude the application of other analysis principles. As is well known, the results obtained using DFT are incorrect in the case of non-stationary signals. A way to overcome this problem is the use of the Short Time Fourier Transform (STFT). The STFT partitions the signal into time segments where the signal is considered stationary, applying the DFT within each segment. Once the size of the time window is selected, the time-frequency resolution obtained is fixed and it is the same for the whole frequency spectrum of the signal. The results obtained show its dependency on the length of the time window selected. An advantage of the STFT method is that it gives information on the magnitude and phase-angle of the fundamental and harmonics [10].

Kalman filters have been used as an alternative method. This method gives information both on the magnitude and phase angle of voltage supply. The detection properties of Kalman filtering and the accuracy in the estimation depend both on the model of the system used and on the magnitude, duration and point-on-wave where the voltage event begins. A possible solution to improve the performance of Kalman filtering is the use of an Extended Kalman filter to better estimate the non-linear process associate with a voltage event.

Wavelet analysis is a powerful signal processing tool specially useful for the analysis of non-stationary signals. The discrete wavelet transform provides a non-uniform division of the time-frequency plane, giving short-time intervals for high-frequency components and long-time intervals for low-frequency components. The use of wavelets for the analysis of harmonics has not been thoroughly investigated until now. Pham and Wong proposed in [2] an approach for identification of harmonics in power systems using a combination of DWT and CWT to quantify harmonic frequency amplitudes and phases. They propose a method to compensate the frequency

---

[1] Post graduated M.S. degree student in power systems from SCU.
Email address : saadati.s@nisoc.ir

[2] Dr. S.S. Mortazavi is Assistant Prof. of Elect Engg of Shahid Chamran University.
Email address : mortazavi_s@scu.ac.ir

response of the filters used in the wavelet transform filter banks. Hamid and Kawasaki [6] proposed the use of the wavelet packet transform, with the Vaidyanathan filter, to improve the results obtained using the discrete wavelet transform for root mean square values of voltage and power measurement. Finally Parameswariah and Cox, Eren and Devaney have studied on the selection of mother wavelet [7].

II. HARMONIC DETECTION USING WPT

Use of Wavelet Transform as a powerful signal processing method is receiving increased attention. Initially they use Multi Resolution Analysis (MRA) for voltage event detection. It produces nonuniform frequency band that is unsuitable for harmonic measurements.

To overcome this limitation of the DWT, the wavelet-packet transform (WPT) can be used to obtain a uniform frequency decomposition of the input signal as in the Fourier analysis. In the WPT, both the detail and the approximation coefficients are decomposed to produce new coefficients, this way enabling a uniform frequency decomposition of the input signal to be obtained. By using the WPT and adequately selecting the sampling frequency and the wavelet decomposition tree, the output frequency bands of the multiresolution analysis can be selected to correspond to the frequency bands of the different harmonic components of the input signal. (The mathematical background is found in [1]).

III. HARMONIC DETECTION USING RWPC

However, use of WPC has some errors such as the edge effects of wavelet filters, the content energy reduction of signal during decomposition caused by Downsampling and spectral leakage.

Use of Wavelet Packet Coefficients for harmonic measurement because of Downsampling reduces number of sampling points (by power of 2) and energy content of signal making huge error. This paper proposes using reconstructed wavelet packet coefficient instead of WPC to prevent energy reduction and decrease the error. For saving energy coefficients are reconstructed in each level. Upsampling is used after downsampling. The other half of the story is how those components can be assembled back into the original signal without loss of information. This process is called *reconstruction*, or *synthesis*. The mathematical manipulation that effects synthesis is called the *inverse discrete wavelet transform* (IDWT). Where wavelet analysis involves filtering and downsampling, the wavelet reconstruction process consists of upsampling and filtering. Upsampling is the process of lengthening a signal component by inserting zeros between samples. The filtering part of the reconstruction process also bears some discussion, because it is the choice of filters that is crucial in achieving perfect reconstruction of the original signal. The low- and highpass decomposition filters (L and H), together with their associated reconstruction filters (L' and H'), form a system of what is called *quadrature mirror filters(QMF)*. Its theory is presented in [9]. Fig. 4 and 5 show the Reconstruction mechanism and Quadratore Mirror Filters (QMF) respectively [11].

IV. MODIFICATION

A signal can be fully decomposed into levels, given by, where is the total number of data points. Each of these wavelet levels correspond to a frequency band given by $f = 2^v(f_s / N)$ Where f is higher frequency limit of the frequency band represented by the level v; f_s is sampling frequency; N is the number of data points in the original input signal [7].The maximum frequency that can be measured is given by the Nyquist theory as $f_{max} = f_s/2$, Where f_s is the sampling frequency.

V. METHOD I

The sampling frequency selected is 1.6 kHz and the sampling window width is 10 cycles of the fundamental frequency (200 ms in a 50-Hz system). The output of the filter bank is divided into thirty two uniform bands of 25-Hz width (coefficients $d1(n)$to $d32(n)$in Fig. 6). Decomposition is performed in 5 level and 32 output band. Higher sampling frequencies can be selected to extend the range of harmonic groups computed in the input signals. The extension of the sampling frequency implies the use of a different wavelet decomposition tree to obtain the same output frequency bands. Thus, doubling the sampling frequency is needed.

By set frequency band in 25 Hz band width main harmonics set on the edge of filters. Because of nonideal characteristic of the filters edge effect error occurs and generates spectral leakage. This makes measurement so inaccurate specially in frequencies near $f_{max}/2$. An example of frequency response of LP and HP filters is presented in Fig.7 that shows nonideal characteristics and edge effect. More investigation of spectral leakage caused by edge effect is there in [3-5]. Paper has focus on two important points to generate better accuracy:

1. *Choose of mother wavelet*. It is important to choose a wavelet function that has a frequency response near the ideal and has fast responding. Wavelet mother daubechies with 40 coefficients has good frequency response as shown in Fig.8 [8]. The algorithm uses the DB40 as the wavelet function.

2. *Combination of two adjacent frequency bands.* The method proposes to combine two adjacent frequency bands to reduce error caused by spectral leakage. The outputs of the filter bank are grouped to produce 15 output bands, with each harmonic frequency component (both odd and even harmonics) in the center of each band and with a uniform 50-Hz interval as depicted in Fig. 9.

VI. METHOD II

In the recently methods they place frequency of main harmonics on the edge of the bands [3-5]. It provides some errors because of nonideal characteristics of the filters. This makes measurement so inaccurate specially in frequencies near $f_{max}/2$.This method proposes to change the band width of output to 40 Hz. This causes that the main harmonics be in the band, not on the edge. This method has got the chance to measure flicker also. Then Sampling frequency selected is 2.56 kHz.

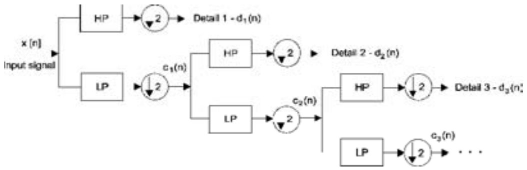


Figure 1.Multi Resolution Analysis (MRA)

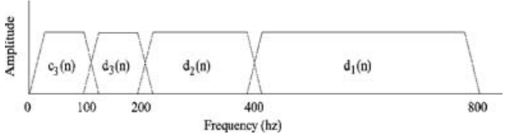
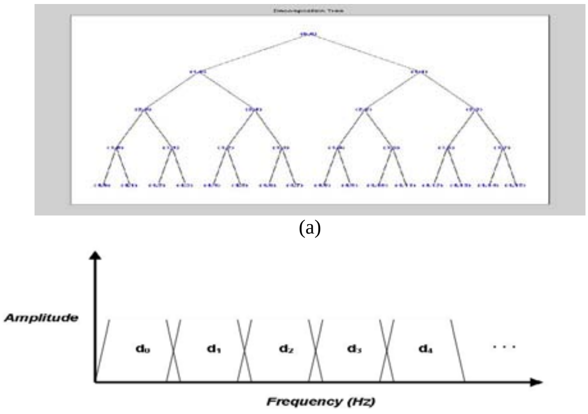


Figure 2.Nonuniform freq. bands of MRA



(a)

(b)

Figure 3.(a) Decomposition tree,(b) Uniform decomposition of WPT

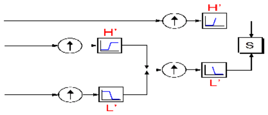


Figure 4.Reconstruction mechanism

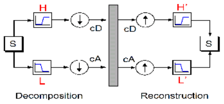


Figure 5.quadratore mirror filters (QMF)

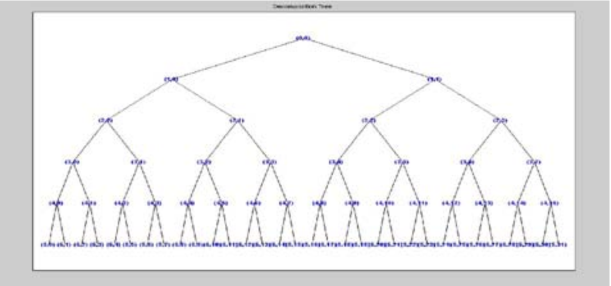


Figure 6. Decomposition tree in five levels

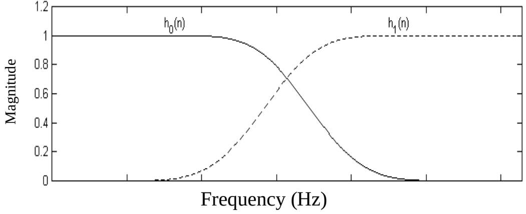


Figure 7.Nonideal characteristics of HP& LP filters

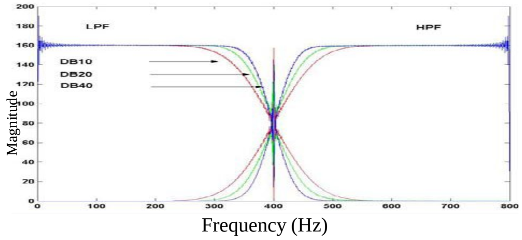


Figure 8. Characteristics of HP& LP filters of DB

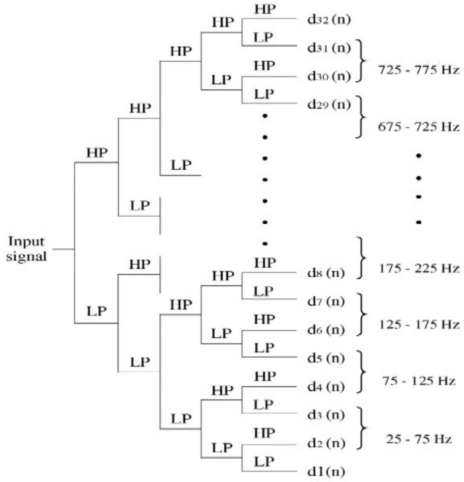


Figure 9. Combination of two adjacent frequency bands that each harmonic frequency component is in the center of each band and with a uniform 50-Hz interval.

VII. PRESENTATION

The derivation of the rms using discrete wavelet-based algorithm was proved in [2]. In practice, the analogue waveforms are digitized. In the WPT algorithm, only the wavelet coefficients at a certain level j are used for the rms and power calculations. More information can find in [2].

VIII. SIMULATION

Consider *V(t)* as a periodic steady state signal. It has some harmonics that are mentioned in Table I. This signal is simulated and by MATLAB and WPT is applied to it. Table I and II represents the harmonics produced using method I and II respectively. Figs. 11-14 show the 4 first coefficients that are obtained. Results show that using RWPC has less error and better response. In practice signal is produced in 16 cycles and applied to WPT. The three cycle of beginning and three cycle of end of the obtained responses are deleted. This is for elimination edge effect of wavelet filter when applied to signal. (10 cycles is used.).

IX. CONCLUSION

A wavelet packet transform (WPT) method is introduced as a powerful tool for detection, classification and quantification of power quality events. The paper proposed two methods can simultaneously measure the distribution of RMS quantities with respect to individual frequency bands directly from the wavelet transform coefficients. In first method paper proposes

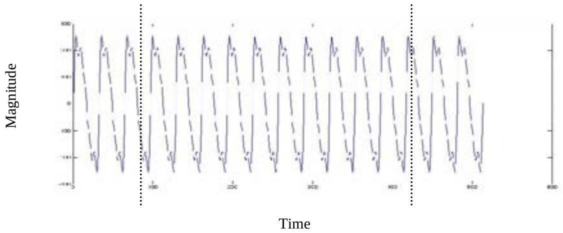


Figure 10. In practice signal is produced in 16 cycles the three cycle of beginning and end of the obtained responses are deleted for elimination edge effect of wavelet filter.

TABLE I
Simulation results of method I

Bands↓	True value	Method using WPC	Method using RWPC
1st	230	225.74	229.91
2nd	53	51.72	52.68
3rd	50	48.29	50.07
4th	44	42.31	43.26
5th	30	26.09	28.79
6th	0	0.26	0.07
7th	6	5.71	6.02
8th	0	0.29	0.31
9th	3	2.82	2.98
10th	0	0.04	0.02
11th	1	1.01	0.99
12th	0	0.09	0
13th	0	0.05	0
14th	0	0.06	0.05
15th	0	0.08	0.02

to combine two adjacent frequency bands to reduce error caused by spectral leakage. In second proposes to change the band width of output to 40 Hz. This causes that the main harmonics be in the band, not on the edge. This method has got the chance to measure flicker also. Use of a compensation method by use of Reconstructed WPC is effective in prevention in energy reduction. In addition, modification method to reduce edge effects and spectral leakage is applicable. Method is simulated and experimented. Parameters are compared with true values that it shows satisfactory results.

TABLE II
Simulation results of method II

Bands↓	Frequency (Hz)	True value	Method using WPC	Modified method using RWPC(40)
1st(flicker)	0-40	0	0	0.01
2nd	40-80	230	225.74	227.931
3rd	80-120	53	51.72	54.68
4th	120-160	50	48.29	49.02
5th	160-200	44	42.31	41.72
6th	240-280	30	26.09	29.11
7th	280-320	0	0.26	0.03
8th	320-360	6	5.71	5.75
9th	360-400	0	0.29	0.31
10th	440-480	3	2.82	2.88
11th	480-520	0	0.04	0.01
12th	520-560	1	1.01	0.99
13th	560-600	0	0.09	0
14th	600-640	0	0.05	0
15th	640-680	0	0.06	0.04
16	680-720	0	0.08	0.01

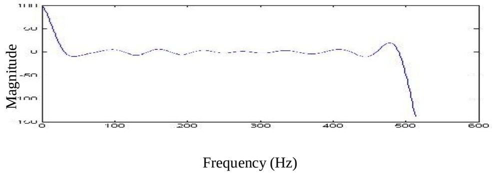


Figure 11.coefficient 1

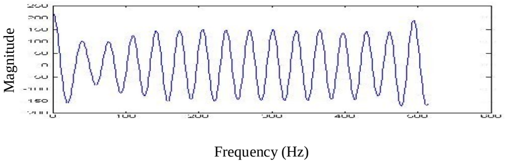


Figure 12 .coefficient 2

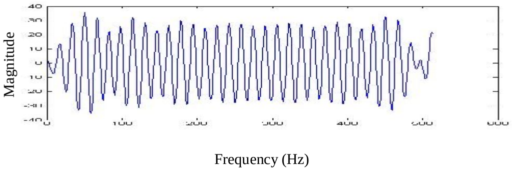


Figure 13 .coefficient 3

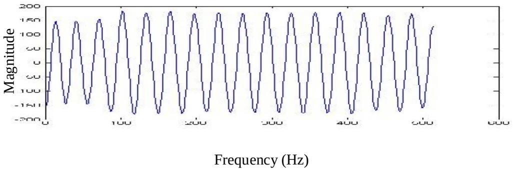


Figure 14 .coefficient 4

REFERENCES

[1] S.Sangeethapriya, M. Prabhakar, "Harmonic detection using Wavelet Transform", IEEE Proceedings of International joint conference on Neural Networks, Volume 4, 31 July-4 Aug. 2005 Page(s):2228-2231

[2] V.L. Pham and K.P. Wong, "Wavelet-transform-based algorithm for harmonic analysis of power system waveforms," IEE Proc. On Generation, Transmission and Distribution, 146 (1999) 249-254.

[3] J. Barros and R.I. Diego, "Application of the wavelet-packet transform to the estimation of harmonic groups in current and voltage waveforms," IEEE Trans. Power Delivery, Vol. 21, No.1, January 2006, pp. 533-535.

[4] Julio Barros , Ramon I. Diego ,"A new method for measurement of harmonic grups in power systems using wavelet analysis in the IEC standard framework" Elsevier power system research. Vol. 76 PP. 200-208, 2006

[5] Julio Barros, Ramon I. Diego," Analysis of Harmonics in Power Systems Using the Wavelet- Packet Transform" IEEE Trans. Instrumentation and Measurement, Vol. 57, No. 1 , Jan 2008

[6] E. Y. Hamid and Z. Kawasaki, "Wavelet packet transform for rms walues and power measurements," IEEE Power Eng. Rev., vol. 21, no. 9, pp. 49–51, Sep. 2001.

[7] C. Parameswariah and M. Cox, "Frequency characteristics of wavelets," IEEE Trans. Power Del., vol. 17, no. 3, pp. 800–804, Jul. 2002.

[8] A. Mazloomzadeh , M. Mirsalim , H. Fathi and H. Sadeghi, "Optimized method measurement using discrete wavelet packet transform" 23th PSC ,Iran ,1-3 December 2008

[9] Stephane Mallat, "A Wavelet Tour of Signal Processing", Academic Press, London, 2nd Edition, 2001.

[10] Francisco Jurado, Jose R. Saenz , "Comparison between discrete STFT and wavelets for the analysis of power quality events" electric power System Research

[11] MATLAB help on Wavelet.