TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol. 12, No. 12, December 2014, pp. 7996 ~ 8000
DOI: 10.11591/telkomnika.v12i12.6474

A High-accuracy Detection Method Research for Electric Power Harmonic

Jingfang Wang
School of Information Science and Engineering, Hunan International Economics University, Changsha, China, postcode:410205
email: matlab_bysj@126.com

Abstract

In this paper, a time-frequency filter is designed, which can detect the frequency, amplitude and phase of any order harmonics and interharmonics in signal by means of time domain convolution. The theory analysis are carried to this method and the calculate formula are concluded, the spectral leakage and the barrier domino offect are shun, the non-integer order wave are eluded, which are engendered in Fourier domain. Experiment simulation results show that time-frequency filtering convolution flunction can be designed and realized neatly and conveniently ; the influences of fundamental frequency fluctuation on harmonic analysis are restrained by using the approach presented in this paper; the relative errors of calculating fundamental frequencies with many order harmonics and interharmonics are no more than 0.00008％, the relative erors of calculating amplitudes are no more than 0.00013％, and those of calculating initial phases are no more than 0.078％.

***Keywords**: harmonic analysis, time-frequency filtering, convolution, frequency fluctuation*

Copyright © 2014 Institute of Advanced Engineering and Science. All rights reserved.

1. Introduction

High-precision analysis of harmonic power measurement, harmonic power flow calculation, network testing equipment, power system harmonics compensation and suppression is of great significance [1]. Because non-synchronous sampling and data truncation, the use of fast Fourier transform (FFT) algorithm to generate harmonic analysis and fence effect of spectrum leakage, the accuracy of harmonic analysis [2-3].

To reduce such errors, scholars at home and abroad based on rectangular window [4], Hanning window [5], Hamming window [6], Blackman window [7], Blackman-Harris window [8], Kaiser window [9] and other windowed interpolation FFT signal analysis algorithms, FFT can reduce the encounter alone and fence effect of spectrum leakage problems and improve the detection accuracy of harmonic parameters, but can not detect integer harmonics harmonics near the asking; use combination of high-end window-based double-cosine spectrum [5,7,10] or line [11-12] interpolation FFT algorithm to estimate fundamental and the harmonic parameters, need to solve high-order equation [13-15], computing complex; continuous wavelet transform [16-17] can be realized between/harmonic detection, but the wavelet functions of different scales exist in the frequency domain interference, when the test signal contains harmonic frequencies close to, the detection method failure; Prony method [18-19] is harmonic, harmonic analysis and modeling of inter-effective way to accurately estimate the sinusoidal component of frequency, amplitude and phase angle, but the need to solve equations and two sets of odd a polynomial, computational complexity and high sensitivity to noise; there are other methods [20-22], or limited frequency resolution, or computing capacity, both in the specific application limitations.

This paper presents a time-frequency filters, time domain convolution with high accuracy by detecting the signal among all the harmonics and the harmonic frequency, amplitude and phase. In this paper, a theoretical analysis and calculation formula is derived, the method to avoid the Fourier (FFT) domain spectral leakage, the entire sub-barrier effect and non-wave phenomenon. The simulation results show that: time-frequency convolution filter design flexible, easy to use, this algorithm can eliminate the harmonic interference and improve signal analysis precision, high accuracy for harmonic analysis.

Received June 27, 2014; Revised September 21, 2014; Accepted October 16, 2014

2. The Time-Frequency Filter Design

Time-frequency filter:

$$g(t,\omega_0) = (\frac{(at)^4}{12} - \frac{(at)^5}{30} + \frac{(at)^6}{90})e^{-at+j\omega_0 t} \quad (1)$$

Where $a = \frac{2\pi}{\sqrt{3}B}$ Center for the filter parameters, the coefficient B to adjust the filter bandwidth (such as taking B = 0.04), ω0 center frequency. The frequency domain expression is:

$$G(\omega,\omega_0) = H(\omega-\omega_0) = \frac{2a^4}{(a+j(\omega-\omega_0))^5} - \frac{4a^5}{(a+j(\omega-\omega_0))^6} + \frac{8a^6}{(a+j(\omega-\omega_0))^7} \quad (2)$$

Figure 1 shows the trend of time-frequency filter characteristics, (a) trends in the time domain graph, (b) trends in the frequency domain; they change with the center frequency ω0. By (2) and Figure 1 (b) shows G (ω, ω0) only in a narrow band centered ω0 significant amplitude, the other is almost zero. Farther away from the ω0, | G (ω, ω0) | is smaller.

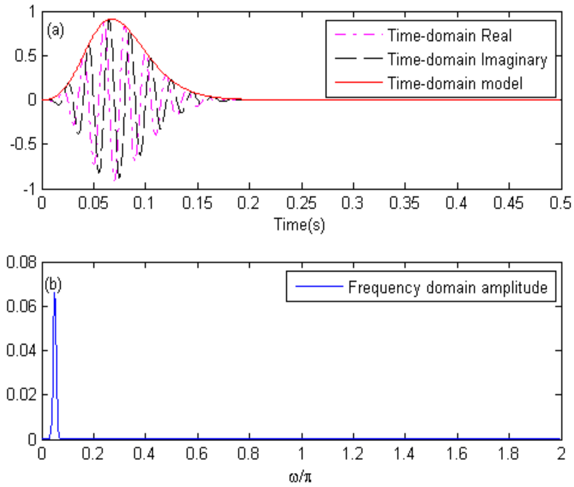

Figure 1. Time-frequency filter of time/frequency

3, Theoretical Analysis and Calculation Formulas by

3.1. Analysis of Continuous

If ω0 centered within the range of narrow-band frequency ω1 of the harmonic signal:

$$f(t) = A\cos(\omega_1 t + \phi) \quad (3)$$

Its frequency domain expression:

$$F(\omega) = A\pi[\delta(\omega-\omega_1)e^{j\phi} + \delta(\omega+\omega_1)e^{-j\phi}] \quad (4)$$

$$\begin{aligned} Y(\omega) &= G(\omega,\omega_0)F(\omega) = H(\omega-\omega_0)F(\omega) \\ &= A\pi[H(\omega_1-\omega_0)e^{j\phi}\delta(\omega-\omega_1) + H(-\omega_1-\omega_0)e^{-j\phi}\delta(\omega+\omega_1)] \end{aligned} \quad (5)$$

$$y(t) = f(t) \otimes g(t, \omega_0) = \frac{A}{2}[H(\omega_1 - \omega_0)e^{j\phi}e^{j\omega_1 t} + H(-\omega_1 - \omega_0)e^{-j\phi}e^{-j\omega_1 t}] \quad (6)$$

Where $\otimes$ for the convolution operation, $|H(-\omega_1 - \omega_0)| \approx 0$:

$$\omega_1 = \frac{d(Arg(y(t)))}{dt} \qquad Arg \text{ is Angular} \quad (7)$$

$$A = \frac{2|y(t)|}{|H(\omega_1 - \omega_0)|} \quad (8)$$

$$\phi = Arg(y(t)) - \text{mod}[\omega_1 t, 2\pi] - Arg(H(\omega_1 - \omega_0) \quad \text{mod}[] \text{ The remainder is divisible} \quad (9)$$

3.2. Calculation of Discrete

Set of discrete sampling frequency fs, the sampling period DT= $\frac{1}{fs}$, Number of samples is N; take N_1=[0.5N], N_2=[0.94N], Computing discrete convolution:

$$y(k) = DT \sum_{i=\max\{1,k-N\}}^{\min\{k-1,N\}} g(i) f(k-i) \qquad k = 1,2,\cdots,N \quad (10)$$

$$\theta(k) = Arg(y(k)) - Arg(y(k-1)) + 2\pi \max\{0, Sign(-Arg(y(k)) + Arg(y(k-1))\}$$
$$k = N_1, \cdots, N_2; \qquad \text{Sign function} \qquad (11) \quad (11)$$

The harmonic frequency f (Hz), amplitude A, the initial phase φ (˚C) as, respectively:

$$f = \frac{fs}{2\pi(N_2 - N_1 + 1)} \sum_{k=N_1}^{N_2} \theta(k) \quad (12)$$

$$\omega_1 = \frac{2\pi f}{fs} \quad (13)$$

$$A = \frac{2}{|H(\omega_1 - \omega_0)|(N_2 - N_1 + 1)} \sum_{k=N_1}^{N_2} |y(k)| \quad (14)$$

$$\psi = \frac{1}{(N_2 - N_1 + 1)} (\sum_{k=N_1}^{N_2} \{Arg(y(k)) + 2\pi \max\{0, Sign(-Arg(y(k))\} - \text{mod}[\frac{2\pi(k-1)f}{fs}, 2\pi]\})$$
$$- Arg(H(\omega_1 - \omega_0)) \qquad (15) \quad (15)$$

$$\phi = \frac{180(\psi + 2\pi \max\{0, Sign(-\psi)\})}{\pi} \quad (16)$$

4. Experimental Evaluation

Signal contains fundamental, DC, between 2 and 3 harmonic harmonic, and their parameters in Table 1, the expression:

$$f(t) = \sum_{i=0}^{6} A_i \cos(\omega_i t + \phi_i) \quad (16)$$

Its sampling frequency fs = 2000Hz, number of samples N = 5000. This method results are in Table 1 the right department. To the harmonic frequency, amplitude, initial phase of testing the value of the real value and are plotted in the same plot, the result is very accurate.

Table 1 Truth Component of the signal & their testing result

	Actual value			Detection value		
Waveform	Freq./Hz	Amplitude/V	Phase/℃	Freq./Hz	Amplitude/V	Phase/℃
DC	0.00	1.5000	0	0.0000	1.5000	0.0000
Fundament	50.10	35.3553	10	50.1000	35.3553	9.9922
Interharm	25.05	5.0000	165	25.0489	4.9999	165.8787
Harmonic	150.30	2.4819	40	150.3002	2.4820	39.8771
Interharm	175.35	2.0000	55	175.3495	2.0000	55.3907
Harmonic	250.50	1.2516	70	250.5002	1.2516	69.8432
Harmonic	350.70	1.1250	110	350.7000	1.1250	109.9976

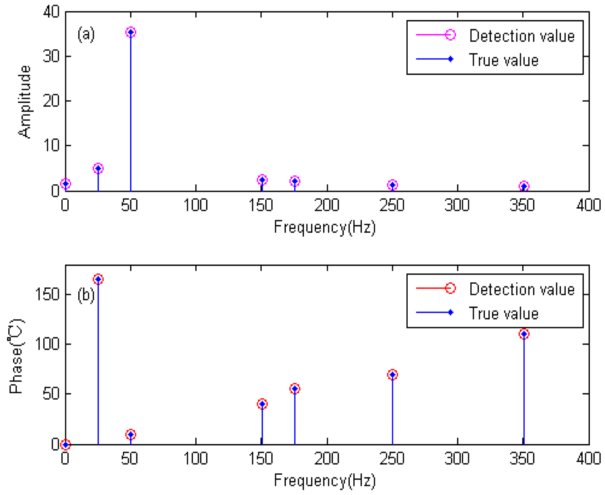

Figure 2. The harmonic characteristics of the true value of parameters compared with the measured values

Table 1 harmonic of the frequency f = 350.7Hz specific icon near the detection algorithms 3, Figure (a), (b), (c) of the abscissa as the sample points. Figure (a) the type (10) the magnitude, Figure (c) signal after filtering in frequency domain inverse Fourier transform (IFFT) of the amplitude, both in the same 500 points; Figure (b) the type (11) transient frequency.

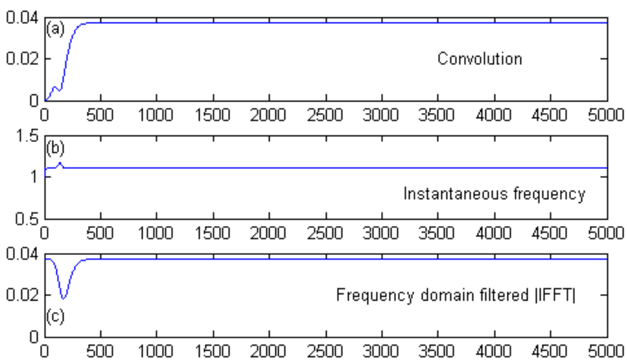

Figure 3. The results of harmonic frequency f = 350.7Hz

5. Conclusion

This paper presents a time-frequency filter, through the time-domain convolution can accurately detect the signal between all the harmonics and the harmonic frequency, amplitude and phase. In this paper, a theoretical analysis and calculation formula is derived, the method to avoid the Fourier (FFT) domain spectral leakage, the entire sub-barrier effect and non-wave phenomenon. The simulation results show that: time-frequency convolution filter design flexible, project implementation and the algorithm is simple convenient, quick response. This algorithm can eliminate the harmonic interference and improve signal analysis precision, high accuracy for harmonic analysis.

References

[1] Ortmeyer TH, Chakravarthi KR, Mahmoud A A. The effects of power system harmonics on power system equipment and loads. *IEEE Trans. on Power Apparatus and Systems*. 1985; 104(9): 2555-2563.
[2] Gregorio A, Mario S, Amerigo T. Windows and interpolation algorithms to improve electrical measurement accuracy. *IEEE Trans. on Instrumentation and Measurement.* 1989; 38(4): 856-863.
[3] XUE H, YANG RG. *Precise algorithms for harmonics analysis based on FFT algorithm.* Proceedings of the CSEE. 2002; 22(12): 106-110.
[4] Jain VK, Collins WL, Davis DC. High-accuracy analog measurements via interpolated FFT. *IEEE Trans. Instrum. Meas.* 1979; 28(2): 113-122.
[5] PAN W, QIAN YSH, ZHOU E. Power harmonics measurement based on windows and interpolated FFF (Ⅱ) dual interpolated FFT algorithms. *Transactions of China Electrotechnical Society*. 1994; 2(1): 50-54.
[6] XIL XU WS, YU YL. *A fast harmonic detection method based on reeursive DFT[C]. Electronic Measurement and Instruments*. ICEM107. 8th International Conference on. 2007: 972-976.
[7] QIAN H, ZHAO RX, CHEN T. Interharmonics analysis based on interpolating windowed FFT algorithm. *IEEE Trans. Power De1.* 2007; 22(2): 1064-1069.
[8] HARRIS FJ. *On the use of windows for harmonic analysis with the discrete Fourier transform*. Proceedings of the IEEE. 1978; 66(1): 51-83.
[9] Gao YP, Teng ZSH, Wen H, et al. Harmonic analysis based on Kaiser window phase difference correction and its application. *Scientific Instrum*. 2009; 30(4): 767-773
[10] PANG H, LI DX, ZU YX, et al. *An improved algorithm for harmonic analysis of power system using FFT technique.* Proceedings of the CSEE. 2003; 23(6): 50-54.
[11] AGREZ D. Weighted muhipoint interpolated DFT to improve amplitude estimation of multifrequency signal. *IEEE Trans. Instrum. Meas.* 2002; 51(2): 287-292.
[12] AGREZ D. Dynamics of equeney estimation in the frequency domain. *IEEE Trans. Instrum. Meas.* 2007; 56(6): 2111-2118.
[13] LIN HC. Inter-harmonic identification using group-harmonic weighting approach based on the FFT. *IEEE Trans. Power Eleetr.* 2008; 23(3): 1309-1319.
[14] Lobos T, Leonowicz Z, Rezmer J, et al. High-resolution spectrum-estimation methods for signal analysis in power systems. *IEEE Trans. Instrum. Meas.* 2006; 55(1): 219-225.
[15] Liguori C, Paolillo A, Pignotil A. Estimation of signal parameters in the frequency domain in the presence of harmonic interference: A comparative analysis. *IEEE Trans. Instrum. Meas.* 2006; 55(2): 562-569.
[16] Xue H, Yang RG. Morlet wavelet based detection of noninteger harmonics. Power *System Technology*. 2002; 26(12): 41-44.
[17] Pham VL, W ong KP. *Wavelet-transform-based algorithm for harmonic analysis of power system waveforms.* IEE Proceeding of Generation, Transmission and Distribution. 1999; 146(3): 249-254.
[18] Leonowicz Z, Lobos T, Rezmer J. Advanced spectrum estimation methods for signal analysis in power electronics. *IEEE Transactions on Industrial Electronics*. 2003; 50(3): 514-519.
[19] Ding YF, Cheng HZH, Lu GY, etal. Spectrum estim ation of harmonics and interharmonics based on prony algorithm. *Transactions of China Electrotechnical Society*. 2005. 20(10): 94-97.
[20] Cai T, Duan SHX, Liu F Ri. Power Harmonic Analysis Based on Real-Valued Spectral MUSIC Algorithm. *Transactions of China Electrotechnical Society*. 2009; 24(12): 149-155.
[21] Wen H, Teng Z SH, Zeng B, et al. High accuracy phase estimation algorithm based on spectral leakage cancellation for electrical harmonic. *Scientific Instrum*. 2009; 30(11): 2354-2360.
[22] Su YX, Liu ZH G, Li K, et al. Electric Railway Harmonic Detection Based on HHT Method. *Railway Society*. 2009; 31(6): 33-38