International Journal of Signal Processing, Image Processing and Pattern Recognition
Vol.7, No.2 (2014), pp.317-326
http://dx.doi.org/10.14257/ijsip.2014.7.2.29

The Detection of Transient Power Disturbances Based on Complex Wavelet Transform

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Abstract

A detection method for transient power disturbances by complex wavelet transform is proposed in this paper. The core of it is that, the compactly supported dyadic orthogonal linear- phase complex wavelet (CSDOLCW, compactly supported dyadic orthogonal linear-phase complex wavelet) is constructed in terms of lifting scheme. Amplitude feature, phase feature and frequence feature can be obtained by complex wavelet coefficient, which also indicate characteristic of time domain, such as start-end time of disturbances occur, the amplitude of disturbance, and then realizing the correct detection and classification. Simulation results show that complex wavelet transform can distinguish various voltage transient disturbances and reflect disturbance's each characteristic, in the condition of lower SNR, classification results are also acceptable.

Keywords: *complex wavelet; transient power disturbances; lifting scheme*

1. Introduction

Transient power quality problems include short duration voltage changes and various transient, various types of transient disturbances have a large irregularity. These different disturbances having inherent characteristics cause great harm on security and economy for the power system [1, 2].

Due to some time-domain analysis method which is represented by wavelet go into power quality field many achievements have been obtained in the transient disturbance analysis. However, the lack of phase information for non-stationary signals in wavelet analysis is restricted [3]. Complex wavelet transform not only provides amplitude information and phase information also can provide complex information and overcome real wavelet translation sensitive problem [4, 5]. Because signal phase is an important feature for the power system, Complex wavelet has the ability of extracting phase in signal processing for power system.

This paper uses compactly supported dyadic orthogonal linear-phase complex wavelet for power quality detection and classification. CSDOLCW is constructed employing compactly supported dyadic orthogonal real-valued wavelet according to lifting method, and extract the amplitude and phase information of transient voltage disturbances. Obtaining characteristics of disturbance frequency through the phase change, thereby determine the starting and ending time of disturbance occurrence and duration accurately. The distinct amplitude feature of different types disturbance can be obtained by complex wavelet coefficients, which is combined with the frequency change can achieve fast and accurate classification of power quality disturbances.

The rest of this paper is organized as follows, Section 2 formulates complex wavelet construction and Section 3 describes implement of compactly supported dyadic orthogonal

ISSN: 2005-4254 IJSIP

linear-phase complex wavelet in voltage disturbance detection. Numerical results for the proposed method are also shown in Section 3. Conclusions are given in Section 4.

2. Complex Wavelet Construction

According to Vetterli-Herley lemma, a new compactly supported dyadic wavelet can be constructed by lifting scheme. The first lifting is expressed as follows [6]:

$$\begin{aligned} G_0^{new}(\omega) &= G_0(\omega) + G_1(\omega)\overline{S}(2\omega) \\ H_1^{new}(\omega) &= H_1(\omega) - H_0(\omega)S(2\omega) \end{aligned} \tag{1}$$

$$\begin{aligned} H_0^{new}(\omega) &= H_0(\omega) + H_1^{new}(\omega)\overline{S}(2\omega) \\ G_1^{new}(\omega) &= G_1(\omega) - G_0^{new}(\omega)S(2\omega) \end{aligned} \tag{2}$$

where $H_0(\omega)$, $H_1(\omega)$, $G_0(\omega)$ and $G_1(\omega)$ are a filter banks of compactly supported dyadic orthogonal real-valued wavelet, where $S(2\omega)$ is trigonometric polynomial with 2π as period which can be determined by the requirements of the new wavelet. Assume that the trigonometric polynomial $S(2\omega)$ is the form below. A_0 , a_n and b_n are undetermined coefficients.

$$S(2\omega) = A_0 + \sum_{n=1}^{N} a_n \cos(2n\omega) + b_n \sin(2n\omega) \tag{3}$$

Suppose the new wavelet has vanishing moments of 0-M order, what need to be calculated is:

$$H_1^{new(m)}(0) = H_1^{(m)}(0) - \sum_{k=0}^{m} \frac{m!}{k!(m-k)!} H_0^{(k)}(0) S^{(m-k)}(0) = 0 \tag{4}$$

where $m = 0,1,2,\cdots,M$, add undetermined complex coefficients in $S(2\omega)$ to which makes real filter banks into complex filter banks. Using the compactly supported dyadic orthogonal wavelet, bior1.3 wavelet in this method, and the first lift function can be expressed as:

$$\begin{aligned} S_1(2\omega) &= A - A\cos(2\omega) - (i/4)\sin(2\omega) \\ &= -(A/2 + 1/8)z^{-2} + A - (A/2 - 1/8)z^{-2} \end{aligned} \tag{5}$$

where $A = i$,the filter banks of the complex wavelet by the second lifting can be expressed as

$$H_0^{new}(z) = \sum_{n=-7}^{6} h_0^{new} z^n \qquad H_1^{new}(z) = \sum_{n=-5}^{4} h_1^{new} z^n \tag{6}$$

$$G_0^{new}(z) = \sum_{n=-5}^{4} g_0^{new} z^n \qquad G_1^{new}(z) = \sum_{n=-7}^{6} g_1^{new} z^n \tag{7}$$

The complex wavelets have characteristic of the odd symmetry real part and the even symmetry imaginary part. It is shown as Figure 1. Fluctuations signal will be mapped two orthogonal spaces by the complex wavelet transform to realize demodulation.

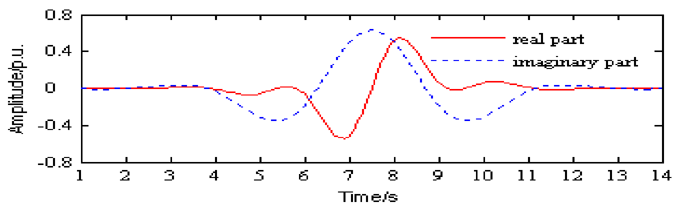


Figure 1. Wavelet Function Constructed by bior1.3

Table 1 is filter coefficients of the complex wavelets corresponding to the filter banks by the second lifting. The Line-phase complex wavelets constructed in Table 1,

Table 1. Filter Confficients of the Complex Wavelets by the Second Lifting

n	h_0^{new}	h_1^{new}	g_0^{new}	g_1^{new}
-6	0.0146+0.0078i	0	0	-0.0146-0.0078i
-5	-0.0146-0.0078i	0	0	-0.0146-0.0078i
-4	-0.1797-0.0781i	-0.0078+0.0313i	0.0078-0.0313i	0.1797+0.0781i
-3	-0.0547-0.0469i	0.0078-0.0313i	0.0078-0.0313i	-0.0547-0.0469i
-2	0.4561+0.3672i	0.0625-0.3125i	-0.0625+0.3125i	-0.4561-0.3672i
-1	0.5439-0.1171i	0.0625-0.1875i	0.0625-0.1875i	0.5439-0.1171i
0	-0.2656-0.5i	-0.5156+0.5i	0.5156-0.5i	0.2656-0.5i
1	-0.2656+0.5i	0.5156+0.5i	0.5156+0.5i	-0.2656+0.5i
2	0.5439+0.1171i	-0.0625-0.1875i	0.0625+0.1875	-0.5439-0.1171i
3	0.4561-0.3672i	-0.0625-0.3125i	-0.0625-0.3125i	0.4561-0.3672i
4	-0.0547+0.0469i	-0.0078-0.0313i	0.0078+0.0313i	0.0547-0.0469i
5	-0.1797+0.0781i	0.0078+0.0313i	0.0078+0.0313i	-0.1797+0.0781i
6	-0.0146+0.0078i	0	0	0.0146-0.0078i
7	0.0146-0.0078i	0	0	0.0146-0.0078i

3. Implement of CSDOLCW in Voltage Disturbances Detection

Complex coefficients which are can be obtained by complex wavelet transform, we know amplitude information and phase information from it [7].

$$w_c = w_{Re} + j w_{Im} \tag{8}$$

$$w_M = \sqrt{w_{Re}^2 + w_{Im}^2} \tag{9}$$

$$w_{Ph} = \arctan(w_{Im} / w_{Re}) \tag{10}$$

$$w_f = \frac{1}{2\pi} \frac{d w_{Ph}}{dt} \tag{11}$$

where w_{Re} is real part of complex coefficient, w_{Im} is imaginary part, w_M is amplitude, w_{Ph} is phase. Complex wavelet transform is actually real wavelet transform in two orthogonal space at the same time, complex wavelet coefficients also provide two orthogonal spatial information. Thus, the complex wavelet transform not only provides real wavelet transform amplitude information, but also provides phase information which have the unique relationship information in two Orthogonal Space. Using of phase information by complex wavelet transform can sensitively reflect the signal mutation information, more comprehensive and clearer demonstration of signal distortion.

3.1. Voltage Disturbances Models

This paper considers five kinds of power quality distrubances, which are voltage swell, voltage sag, voltage interruption, harmonic, transient oscillation. Sampling frequence is 1600Hz, time window is 0.32s. The start time of disturbance is 0.12s, the end time is 0.22s. The mathematical models are as follows [8].

Voltage swell:

$$F_1 = \left\{1 + A\left[u(t-t_1) - u(t-t_2)\right]\right\}\sin \omega t$$

$$0.1 \le A \le 0.9 \quad T \le t_2 - t_1 \le 6T$$

Voltage sag:

$$F_2 = \left\{1 - A\left[u(t-t_1) - u(t-t_2)\right]\right\}\sin \omega t$$

$$0.1 \le A \le 0.9 \quad T \le t_2 - t_1 \le 6T$$

Voltage interruption:

$$F_3 = A\left[u(t-t_1) - u(t-t_2)\right]\sin \omega t$$

$$0 \le A \le 0.1$$

Harmonic:

$$F_4 = \sin \omega t + A_3 \sin 3\omega t + A_5 \sin 5\omega t$$

$$0 < \alpha \le A_3, A_5 \le 0.1$$

Transient oscillation:

$$x(t) = \sin \omega t + Ae^{-\alpha(t-t_1)} \sin \beta\omega t \cdot \left[u(t-t_1) - u(t-t_2)\right]$$

$$0.1 \le A \le 0.8 \quad 0.5T \le t_2 - t_1 \le 3T$$

3.2. Simulation

Calculate difference between test disturbances and standard disturbances of complex coefficients of power network signal in consider of average amplitude and average phase of test disturbances, respectively. The differences are regard as criterion of classification. Different types of disturbances's differences are shown as Table 2.

Table 2. The Criterion of Disturbance

Difference	Swell	Sag	Interruption	Harmonic	Transient oscillation
Amplitude	0.1060	-0.1055	-0.2632	0.0074	0.0174
Phase	0.0471	0.0496	0.0547	-0.0514	0.0229

The feature of different types of disturbances is shown as from Figure 2 to Figure 6. The start-end time of disturbances can be indicated from frequency information obviously. Relative errors of voltage swell and harmonic reach 0.1083%. Relative errors of voltage sag and interruption reach 0.5454%. Relative errors of transient oscillation are 0.1083% and 0.5909%. The results of classification for five types are shown in Table 3. From Table 3 we can distinguish voltage swell, interruption and voltage sag according to amplitude of complex coefficients. The phase of harmonic has more change than that of transient oscillation. Recognition between harmonic and transient oscillation is realized by phase information. This results are acceptable in 20dB, 25dB, 30dB, 35dB, 40dB.

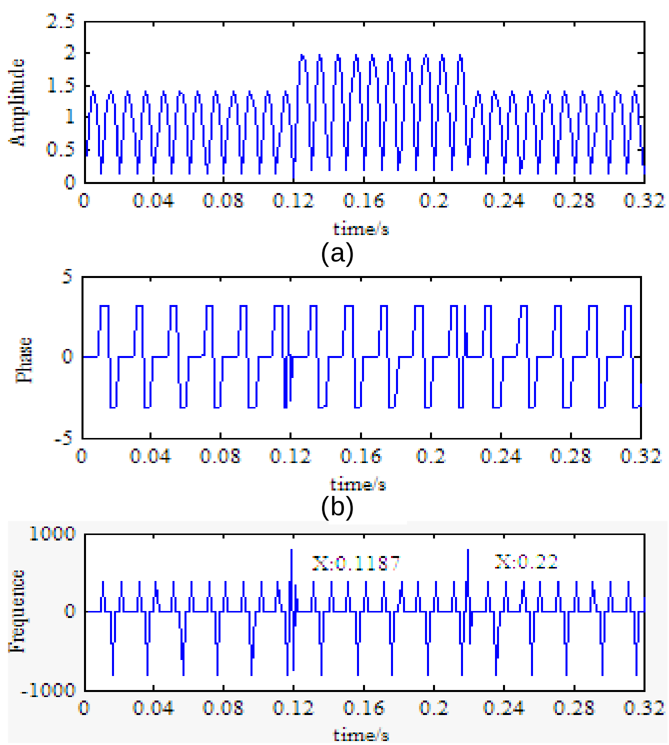
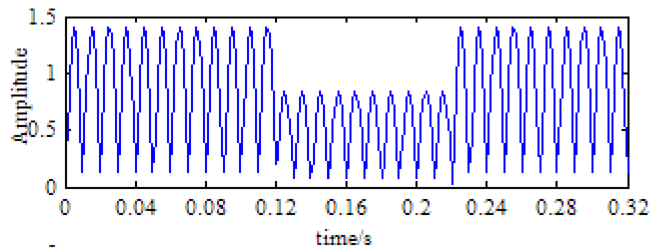


Figure 2. Complex Wavelet Transform for Voltage Swell



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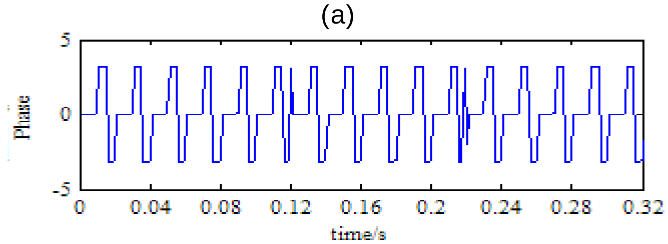

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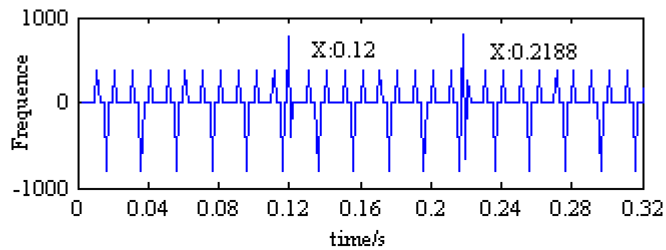
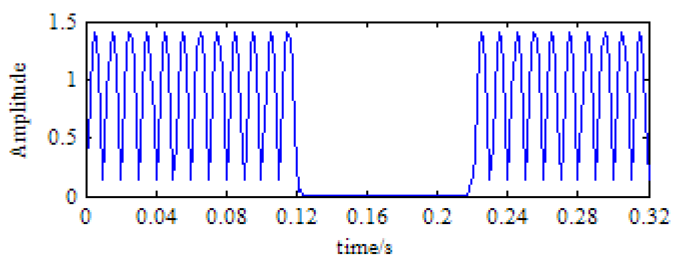


(c)

Figure 3. Complex Wavelet Transform for Voltage Sag



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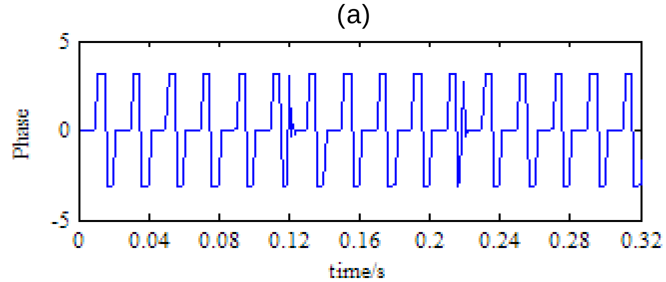

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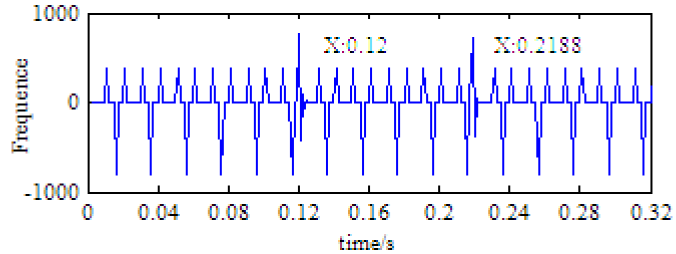

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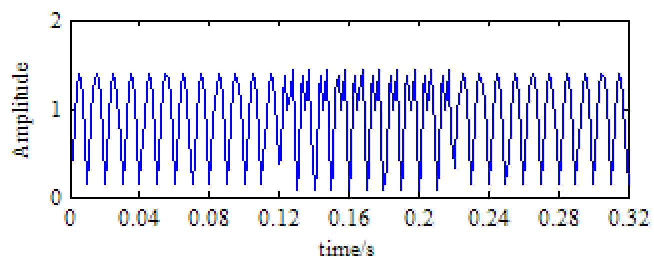
Figure 4. Complex Wavelet Transform for Voltage Interruption



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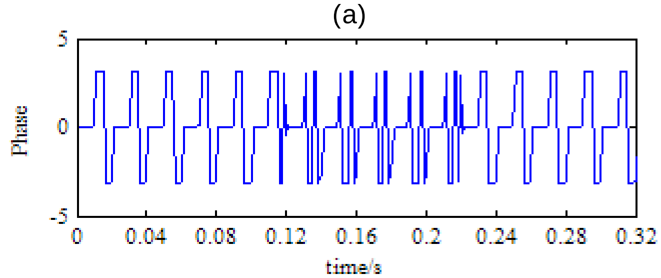

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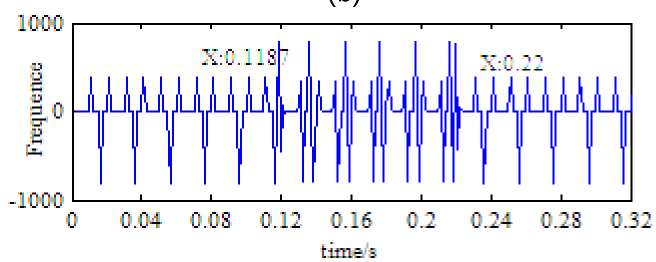

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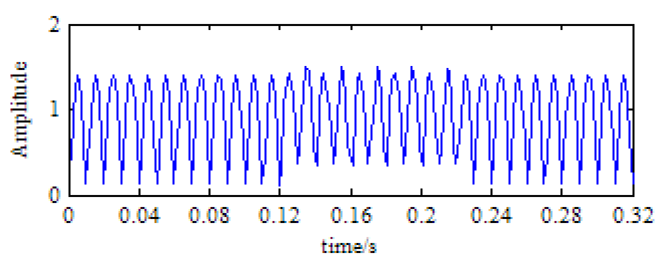
Figure 5. Complex Wavelet Transform for Harmonic



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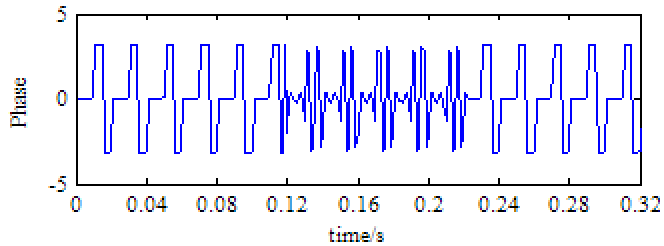

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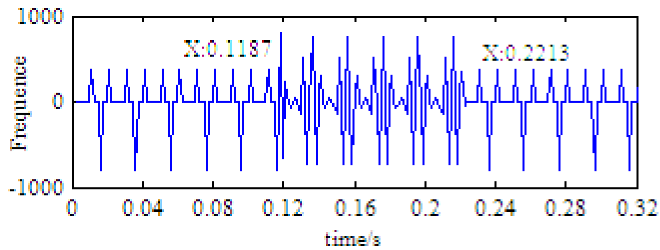

(c)

Figure 6. Complex Wavelet Transform for Transient Oscillation

Table 3. Different Signal-to-noise Ratio Disturbance Classification

SNR	Classification Accuracy (%)				
	Swell	Sag	Interruption	Harmonic	Transient oscillation
20dB	100	100	98.5	98.5	98
25dB	100	100	99	99	98.5
30dB	100	100	99	99	99
35dB	100	100	100	100	100
40dB	100	100	100	100	100

4. Conclusions

In this paper, the detection method of power quality disturbances based on complex wavelet is presented, using the lifting method to construct compactly supported dyadic orthogonal linear-phase complex wavelet, establishing the standard characteristic value of various disturbances in terms of complex wavelet coefficient. The types of disturbances can be determined through difference between test disturbance and standard characteristic value of disturbances. Simulation results show that the method proposed can realize accurate detection and classification.

Acknowledgements

This work was supported by The Science Technology Research General Project of Department of Education in Heilongjiang Province, 2011 (12511077).

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