An Application of Wavelet Analysis to Detect Disturbances in Power Quality

Shangfu Hao[1], Baili Sun[2] , Yuanqiang Wang[3] and Xiao Zhang[*1]

[1.] *School of Information Science and Engineering*, University of Hebei North, Zhangjiakou, Hebei,075000, China

Abstract **— In this paper, an online monitoring method based on wavelet decomposition is proposed for the efficient localization of power disturbance source. First, the principles of wavelet analysis are considered, including wavelet transform modulus maxima and MALLT method. Second, the application of wavelet de-noising and modulus maxima theory is further considered for disturbance detection. Third, the proposed method is outlined and it is based on the fact that the detailed structure of wavelet is very sensitive to abrupt signal change. When the disturbance appears in the power net, the voltage signal changes abnormally, and causes modulus maxima in wavelet signal. Finally, the simulation studies are carried out on several disturbance sources, including de-noising and wavelet decomposition. The experimental results show that the wavelet based method can detect and localize the common disturbance sources reliably and efficiently.**

Keywords - Power quality; Disturbance detection; Wavelet decomposition; Wavelet coefficient

I. INTRODUCTION

The requirements on power quality has increased significantly since the nineties of last century. There are two reasons for that: first, the network voltage and current quality is dropped due to the wide use of High-frequency switching devices; second, the requirement is increased due to the wide use of micro processes, who are very sensitive to power quality. Therefore, the detection of power quality disturbance becomes a very important problem. The disturbance sources may be categorized into following types: sudden voltage drop, sudden voltage increase, temporal interrupt, pulse, and oscillation.

In reference [2], the wavelet transform is introduced to the detection of power quality disturbance. However the localization of time is not accurate. In reference [3], the temporal voltage drop is discussed, and other disturbance sources are not studied. In reference [4], the detection algorithm cannot handle environment noise, and the resolution drops significantly due to the noise in voltage signal.

In this paper, we apply wavelet transform to analyze the disturbance. First, we perform multi-layer wavelet decomposition and extract the high frequency structure. Second, when the signal changes abruptly, we perform localization in time domain according to the maxima in the detailed structure of wavelet signal.

II. WAVELET DECOMPOSITION

Wavelet transform was invented in last century, in data processing. It has a obvious advantage against the Fourier transform who is only suitable for stationary signal. Compared with the traditional method, the wavelet transform can be used to analyze the temporal structure of signals. Therefore it is considered as a microscope to observe specific frequency and time period.

A. Basic Theory of Wavelet Transform

Definition: given function $\psi(t)$ satisfies $\psi(t) \in L^2(R)$, denote the Fourier transform is $\widehat{\psi}(t)$.

When $\widehat{\psi}(\omega)$ Satisfies:

$$C_\psi = \int_R \frac{\left|\widehat{\psi}(\omega)\right|^2}{|\omega|} d\omega \prec \infty \tag{1}$$

$\psi(t)$ is the mother wavelet, after scaling or translation $\psi(t)$ we can get a serial of wavelets:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi(\frac{t-b}{a}) \tag{2}$$

where $a,b \in R; a \neq 0$

The continuous wavelet transform of function $f(t) \in L^2(R)$ can be represented as:

$$(W_\psi f)(t) = \int_{-\infty}^{\infty} f(t) \overline{\psi_{a,b}}(t) dt \tag{3}$$

Wavelet refers to the small region, limited length and zero mean waveform. It has the character of waveform and it may decrease along time. In above equation, a is the scale factor, related to frequency. And b is the translation factor, related to time t.

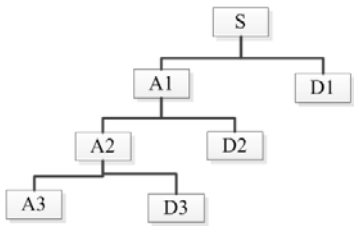

Figure 1. A depiction of wavelet decomposition

B. Multi-Resolution Analysis and MALLT Method

Suppose the approximate value of energy bounded signal f under resolution 2^j is $H_j f$. $H_j f$ can be further decomposed as $H_{j-1} f$ under resolution 2^{j-1} and $D_{j-1} f$ who is the sum of detailed signal between resolution 2^{j-1} and 2^j . Decomposition may last like this so on and so forth.

We can get the coefficient $\{h_k\}$ and $\{g_k\}$ in the double scaling equation based on inner product:

$$h_{m-2n} = \sqrt{2}\left\langle \varphi_{j-1}\varphi_{j,m} \right\rangle g_{m-2n} \\ = \sqrt{2}\left\langle \varphi_{j-1,n}\varphi_{j,m} \right\rangle \tag{4}$$

For the following component,

$$H_{j-1} f(x) = \sum_{-\infty}^{\infty} a_k^{j-1} \varphi(2^{j-1}x - k)$$
$$D_{j-1} f(s) = \sum_{-\infty}^{\infty} d_k^{j-1} \varphi(2^{j-1}x - k) \tag{5}$$
$$H_j f(x) = \sum_{-\infty}^{\infty} a_k^j \varphi_{j,k}(x)$$

The signal de-composition and re-composition are equal to searching for the relation among a_k^j , a_k^{j-1} and d_k^{j-1} . The coefficients may be represented as:

$$a_l^{j-1} = \sum_{k\in Z} \overline{h_{k-2l} a_k^j} \\ d_l^{j-1} = \sum_{k\in Z} (-1)^k h_{1-k+2l} a_k^j \tag{6}$$

The coefficient of re-composition may be represented as:

$$a_k^j = \sum_{l\in Z} h_{k-2l} a_l^{j-1} + \sum_{l\in Z} (-1)^k h_{1-k+2l} d_l^{j-1} \tag{7}$$

C. Wavelet Modulus Maxima and Signal Singularity

Under certain scale, if there exist a point (a_0, b_0) , for any point b within certain neighborhood, we have:

$$\left|WT_X(a_0, b)\right| \le \left|WT_X(a_0, b_0)\right| \tag{8}$$

$\left|WT_X(a_0, b_0)\right|$ is the modulus maxima of wavelet coefficients.

Generally, the singularity of signal is an important character and the singularity point is depends on the modulus maxima. We use Lipschitz index to verify this theory.

Suppose $x(t) \in L^2(R)$, x(t)∈L. Function $x(t)$ has Lipschitz index α at t_0 . For any $t \in Bt_0$ exist constant K that satisfies $\left|x(t) - x_0(t)\right| \le k\left|t - t_0\right|^{\alpha}$. We can see that when α increase, the function becomes more smooth.

The singularity of the original signal may be reflected by the modulus maxima of wavelet transform coefficients. Therefore, we may use this character to detect the power quality disturbance and localize the disturbance in time domain.

III. DETECTION AND LOCALIZATION OF POWER DISTURBANCE

A. Signal Denoising Based on Wavelet Transform

The signals collected from real world application contain noise, and we need to preprocess the signals using denoising algorithm. The threshold method based on wavelet is a good denoising algorithm. It may preserve many important characters of the signal. It can be implemented in the following steps:

(1) choose the correct wavelet base, and perform multi-resolution decomposition of the noisy power signal.

(2) Perform threshold quantification on high frequency coefficients of wavelet decomposition according to certain rules.

(3) Perform one-dimension wavelet re-composition on low level coefficients from Step2)

B. Power Disturbance with Modulus Maxima

In this paper we mainly focus on the study of disturbance detection based on the high frequency coefficient of wavelet transform. The basic wave is the 50Hz frequency, and the coefficients of discrete wavelet transform is related to the smoothing contour of voltage change. The signal volume can be achieved. When the coefficients of high frequency change abruptly, we can calculate the signal changing time based on the modulus maxima.

Suitable decomposition layer and wavelet transform may improve the accuracy of detection and localization. The sudden changes and singularity in signals need to be captured in disturbance detection. After a few comparison, we choose db4 wavelet to implement the detection of power disturbance and the specific scale signal can be captured. When determining the decomposition layers, we consider the location of fundamental frequency. We locate the fundamental frequency at the center of each sub-band in order to reduce the influences on other sub-bands. We may adopt the following calculation:

$$p = \log 2\left(\frac{f_s}{\sqrt{8} f_b}\right) + 0.5 \tag{9}$$

We use frequency $fs = 3200Hz$, for all the rest simulations. The decomposition layer is 5, and d1 and d2 are sensitive to disturbance according to our observations.

IV. SIMULATION AND EXPERIMENTAL RESULTS

Based on the characters of different disturbance, we simulate the voltage signal in MATLAB and verify the proposed method. Finally, we analyzed the actual signals in experiment.

A. Simulation Results and Analysis

We simulate several types of power disturbance, including: sudden voltage increase, sudden voltage decrease, interrupt of power, pulse signal and transient voltage oscillation. The results are shown as follows, the frequency of voltage signal is 50Hz, and sampling rate is 3200Hz.

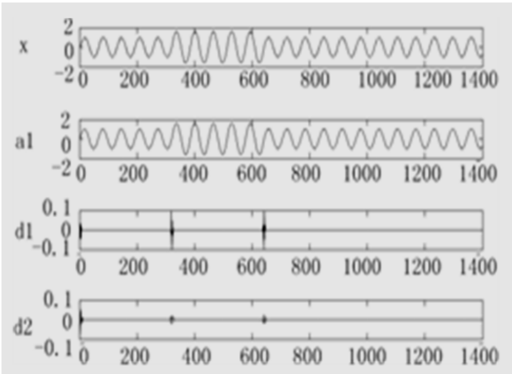

Figure 2. Wavelet decomposition of sudden voltage increase

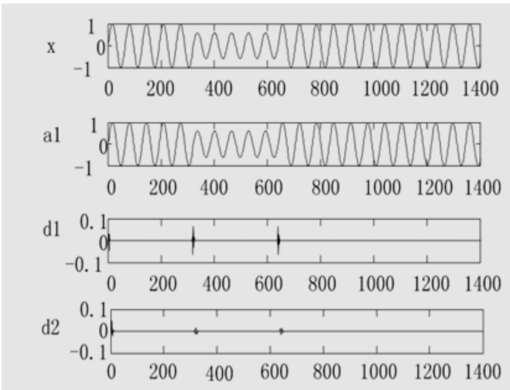

Figure 3. Wavelet decomposition of sudden voltage decrease

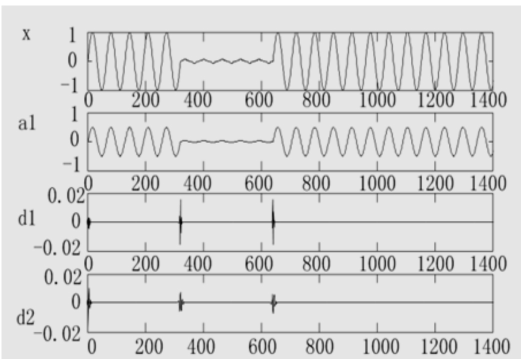

Figure 4. Wavelet decomposition of sudden voltage interrupt

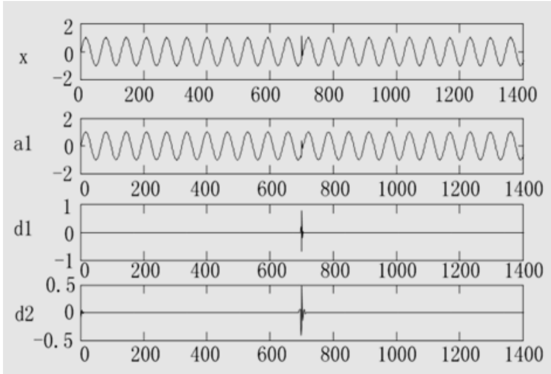

Figure **5.**Wavelet decomposition of voltage pulse

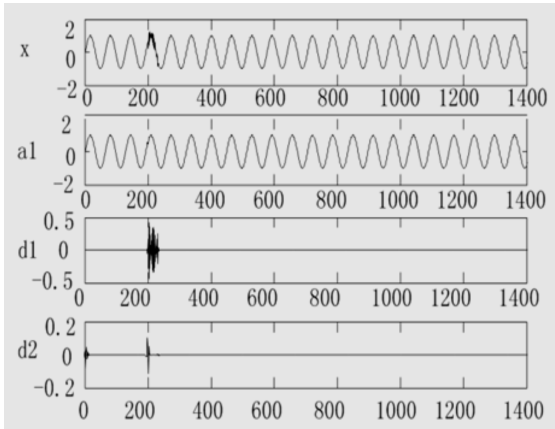

Figure **6.** Wavelet decomposition of transient voltage oscillation

Through Fig.2 to Fig.6, we show the wavelet decomposition results of sudden voltage increase, sudden voltage decrease, interrupt of power, pulse signal and transient voltage oscillation. x is the original signal, a1 is the low frequency signal of the first layer decomposition, d1 is the high frequency signal o the second layer decomposition. We can see that, the start time and the end time are well detected according to the first and the second layer wavelet decomposition, except for transient voltage oscillation. The end time of transient voltage oscillation is not well localized by the second layer decomposed signal. Take the sudden voltage increase as an example, we add disturbance to signals at 0.1s, and the duration is 0.1s. We can see that, in the first layer of the signal, the modulus maxima happens twice, once between point 320 and point 330 (between 0.1s and 0.103s), and the other between point 640 and point 650 (between 0.2s and 0.203s). This result is the same as calculation. Therefore the modulus maxima based on wavelet transform can detect and locate disturbance accurately.

B. Experimental Analysis

To verify the proposed method, we use the city power supply for experiment. The sampling frequency is 5000Hz, and the disturbance source is added at specific time duration.

We add sudden voltage increase, sudden voltage decrease, and voltage interrupt at 0.1s, 0.2s, and 0.4s. The duration is 0.05s, 0.1s, and 0.05s respectively.

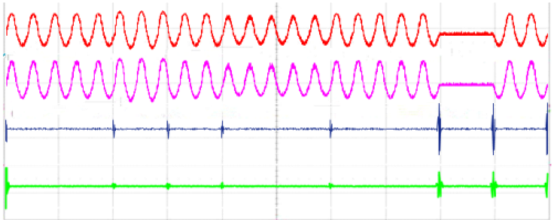

Figure **7.**Analysis result of voltage increase, decrease and interrupt.

In Fig.7, we demonstrate the original voltage signal, the voltage signal after denoising, the first layer decomposition signal, and the second layer decomposition signal. The maxima in the first two layers match the start point and the end point of disturbance. The proposed method is effective on the detection of three types of disturbance sources.

The pulse voltage and oscillation is added at 0.2s and 0.3s in experiment. As shown in Fig. 8, The detection result is the same as the disturbance source. The proposed disturbance source detection method is verified.

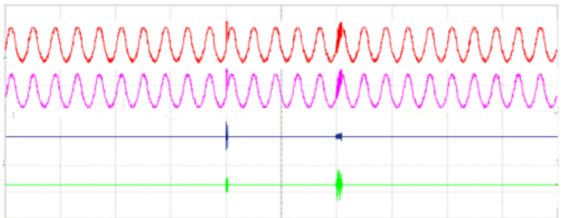

Figure **8.** Result of voltage pulse and oscillation analysis

V. CONCLUSION

In this paper we analyzed the wavelet high frequency coefficient for the power disturbance detection. Based on the theoretical study, we simulated the power disturbance including: sudden voltage drop, sudden voltage increase, temporal interrupt, pulse, and oscillation. The experimental results show that the proposed method can provide an accurate detection and localization. Voltage signal is analyzed in this method and it may innovate future online application of power quality monitoring.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest

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REFERENCES

[1] Guozhi Fang, Chao Yang, Hong Zhao. Detection of harmonic in power system based on FFT and wavelet packet [J]. Power System Protection and Control,2012,40(5):75-80.

[2] Jidong Wang. Detection and localization of power quality disturbance based on binary wavelet transform [J]. Proceedings of the CSU-EPSA, 2007, 19(1):100-103.

[3] Rongjing Wei, Yaqun Jiang, Chun Huang, etc Voltage sag real-time detecting method based on wavelet transform [J] Computer Engineering and Applications, 2013, 49(11)：252-257

[4] Baczynski, D.Parol, M. Influence of artificial neural network structure on quality of short-term electric energy consumption forecast[J].Generation, Transmission and Distribution, IEE Proceedings.2004,151(2):241-245.

[5] Xuefeng Wang and Junyu Zhou. Research on Fault Location Based on Wavelet Technology in Transmission Lines [J]. High Voltage Engineering. 2006.32(1):84-87.

[6] Huafeng Chen, Lei Qiao, Shuangling Liu. Power Quality Disturbances Identification Using Decision Tree and Support Vector Machine [J]. Electrical Engineering.2013. 2:14-19

[7] Shilei Song. Quality Transient Analysis of Wavelet Transform.[J]. Electronics Quality, 2013,10:9-14.

[8] Li Xiaoling ; Yuan Jimin. On the study of the quality of electric energy of switch power supply[J]. Mechatronic Science, Electric Engineering and Computer (MEC), 2011 International Conference on .2011,8:76-80