Research on Wavelet Energy Entropy and Its Application to Harmonic Detection in Power System

Na Wu and Yong-Qin Wei

***Abstract*—Aiming at the problem that FFT can't detect the transient signal, and wavelet analysis is easy to produce energy leakage and frequency aliasing in power harmonic detection, the paper gives a new algorithm which combined wavelet with information entropy in order to design a new function that is wavelet energy entropy, it is used to extract informations of transient signal effectively in power system. According to the harmonic characters in power system, a mathematic model is done based on it. The simulation results in Matlab indicate that the new algorithm is validated in transient signal detection.**

***Index Terms*—Wavelet energy entropy, transient signal, power harmonic, matlab simulation.**

I. Introduction

The traditional algorithm in power harmonic detection is based on FFT or improved FFT, and it can detect the amplitude and phase of steady signal, but it can't detect the transient signal. Wavelet analysis has high distinguish ability whether in time domain or in frequency domain, it can extract mutational signal effectively in power system, and wavelet analysis is very suitable to detect transient signal in power system. But wavelet analysis has some shortcomings: such as power transient signal has so many datas and calculated amounts after wavelet analysis, and it has energy leakage and frequency aliasing,the extraction result of transient characters is unexpected[1]. The paper gives a new algorithm which combines wavelet with information entropy to produce wavelet energy entropy(WEE) ,it can overcome the disadvantages of wavelet analysis.And it has both the characteristics of multi-resolution in wavelet analysis and entropy being good at indicating the chaos degree of system.So the new algorithm can detect either steady or transient signal comprehensively.

II. Wavelet Energy Entropy

A. Multi-Resolution Wavelet Analysis

In 1989 S. Mallat applied the theory of multi-resolution to wavelet analysis, and he put forward a new fast algorithm of wavelet analysis, that is Mallat Fast Wavelet Algorithm[2].The fast wavelet algorithm based on the multi-resolution is to divide the signal into multiple components of different scales by orthogonal wavelet, its implementation is equivalent to the repeated use of a group of high and low pass filter, the time sequence signals were decomposed step by step, the high pass filter generates signals of high frequency components, the low pass filter generates signals of low frequency approximation component. The two components of pass filter are equal in the width of the frequency band, and each accounts for1/2 spectral band. After each decomposition, the sampling frequency of signals reduces the times. And aiming at the low frequency component, it repeats the above decomposition process fatherly, thus gets the two components of the next level. After a signal is converted by fast wavelet analysis, we define high frequency coefficients which are at K moment of J decomposition scale as cDj(K) ,and define low frequency coefficients as cAj(K). The signal component of Dj(k) and Aj(k) are reconstructed of single branch, and the frequency range of the information contained in them is as follows.

$$\begin{cases} D_j(k):[2^{-(j+1)} f_s, 2^{-j} f_s] \\ A_j(k):[0, 2^{-(j+1)} f_s],\ j=1,2,...m \end{cases} \quad (1)$$

In the above formula f_s is the sampling frequency of signal, and the original signal sequence x(n) can be expressed as the sum of the m's components, that is:

$$x(n) = D_1(n) + A_1(n) = D_1(n) + D_2(n) + A_1(n) = \sum_{j=1}^{m} D_j(n) + A_m(n) \quad (2)$$

For convenience, $A_{m(n)}$ is expressed as $D_{m+1}(n)$, then

$$x(n) = \sum_{j=1}^{m+1} D_j(n) \quad (3)$$

Mallat algorithm improves the speed of discrete wavelet greatly,but almost all of the wavelet functions have frequency aliasing,and that is easy to lead to the adjacent scale energy leakage and produce frequency aliasing phenomenon[3].So if all wavelet coefficients of high frequency or single branch signal which is reconstructed are directly used as criteria of extraction in transient harmonic signal, that is easy to lead to inaccurate results inevitably.

B. Information Entropy

In 1948, C. E. Shannon put forward the concept of information entropy firstly; he put the entropy as the uncertainty of a random event or the amount of information. For a system with uncertainty, if we use a random variable X with values of limited numbers, it represents the state of the

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system. Let its probability space as:

$$\begin{bmatrix} X \\ P(j) \end{bmatrix} = \begin{bmatrix} x_1, x_1, \ldots x_l \\ p(x_1), p(x_2) \ldots p(x_l) \end{bmatrix} \tag{4}$$

Then the average uncertainty of the whole probability space, also as information entropy, is defined as:

$$H(X) = -\sum_{j=1}^{l} P_j \log(P_j) \tag{5}$$

Information entropy H is an information measurement which is used to locate a system under certain conditions, it is a measurement to unknown degree of a sequence, and it can be used to estimate the complexity of random signal.

C. Wavelet Energy Entropy (WEE)

Wavelet analysis has good ability of time-frequency localization. Multi-resolution analysis make construction and implement of wavelet into a unified framework, and it has a corresponding practical and fast algorithm. So with combining multi-resolution wavelet and information entropy, we can get the wavelet entropy definition of a signal and its calculating method [4].

Let $E = E_{1,} E_{2,} \ldots E_m$ be equal to the wavelet energy entropy spectrum of m's decomposition scale of signal $x(t)$, and then it can be formed into a division of the signal's energy in the scale of E. From the properties of orthogonal wavelet, it's known that the total power E is equal to the sum of the components' power E_j within a time window (the width of the window is ω, $\omega \in N$). Let $p_j = E_j / E$, then $\sum_j p_j = 1$, so the corresponding WEE is defined as follows.

$$W_{EE} = -\sum_j p_j \log p_j \tag{6}$$

In the above formula, $E_j = \sum_k |D_j(k)|^2$

Along with the sliding of time window, we can get the rule of wavelet energy changing with time.

III. Detection Method and Simulation of Power System Harmonic Signal

A. The Construction of a Power System Signal

A complex continuous power signal of time x(t) is constructed that *x(t)* contains fundamental wave,3 、5、7 odd steady harmonic,17 odd steady harmonic, and the process is accompanied with random disturbance signal.

The mathematical expressions of *x(t)* is as follows.

$$x(t) = \begin{cases} \sin(2\pi f_0 t) \quad 0 \le t \le 0.1s \\ \sin(2\pi f_0 t) + 0.2\sin(3*2\pi f_0 t) \quad 0.1s \le t \le 0.15s \\ \sin(2\pi f_0 t) + 0.2\sin(3*2\pi f_0 t) + 0.1\sin(5*2\pi f_0 t) \\ \quad 0.15s \le t \le 0.2s \\ \sin(2\pi f_0 t) + 0.2\sin(3*2\pi f_0 t) + 0.1\sin(5*2\pi f_0 t) + 0.1 rand(t) \\ +0.3\sin(7*2\pi f_0 t) + 0.4e^{-100(t-0.2)}\sin(17*2\pi f_0 t) \quad 0.2s \le t \le 0.5s \end{cases} \tag{7}$$

In the above formula, $f_0 = 50Hz$, rand(t) is the random noise signal of normal distribution function.

The waveform of original signal is shown in Fig. 1.

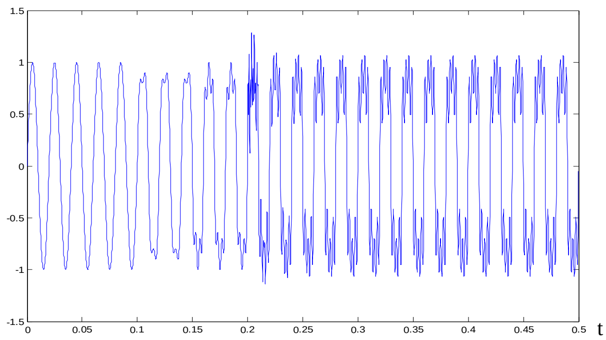

Fig. 1. The waveform of original signal.

B. Wavelet Analysis

Selecting the sampling frequency as 12800Hz, discrete time series as analysis object,Mallat DB4 wavelet is selected, and is decomposed of 3 layer wavelet.

Steps are as follows in Fig. 2.

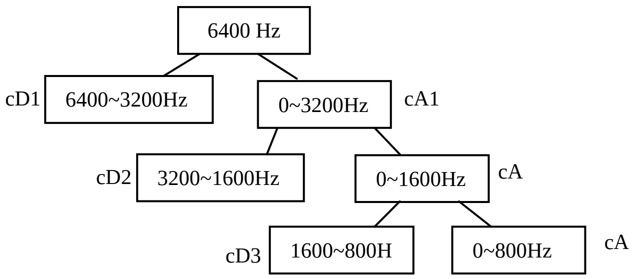

Fig. 2. Th steps of wavelet analysis

The occupied frequency of cA3 is 0~800 Hz. According to the characteristic of harmonic in power system, less than 17 times of harmonic is considered as steady-state harmonic, more than 17 times of harmonic is considered as transient harmonic.Then cA3 contains all of the informations of steady-state harmonic,and traditional FFT can be used to analyse the informations of its frequency entropy.

$cD1$, $cD2$ and $cD3$ contain all of informations of transient harmonic,it can be reconstructed by wavelet analysis. Letting the reconstructed signal be $cD_1^{'}, cD_2^{'}, cD_3^{'}$,the sum of $cD_1^{'}, cD_2^{'}, cD_3^{'}$ is transient harmonic signal.The waveform of $cD_1^{'} + cD_2^{'} + cD_3^{'}$ is shown in Fig. 3.

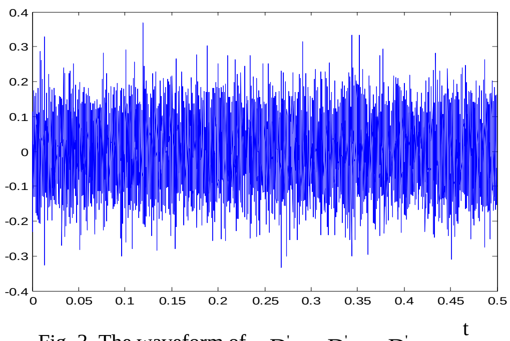

Fig. 3. The waveform of $cD_1^{'} + cD_2^{'} + cD_3^{'}$

From the above Fig.3, we can see that wavelet analysis can't distinguish the transient harmonic signal from noise signal,but Wavelet energy entropy can be used to distinguish it.

C. Wavelet Energy Entropy Analysis

The formula (6) is used to solve the W_{EE} of transient harmonic signal. Because the signal is divided into 3 layers by wavelet analysis, j is equal to 3. Selecting the moving window ω be equal to 100, step length δ be equal to 1, the calculated waveform of W_{EE} is shown in Fig. 4.

From the analysis of Fig. 4, the value of W_{EE} increased suddenly, that is the time that 17 times transient harmonic occurring. After several periods, the value of W_{EE} returned to the state before 0.2s, it shows that the attenuation of transient harmonic is in end. Thus the time of W_{EE} mutation is the time of appearing or disappearing of a harmonic. Compared to the time characteristics of wavelet analysis, it is more convenient for analysis.

In addition, W_{EE} can reflect variations of the signal energy in different times, and also express the degree of harmonic complexity in some time.

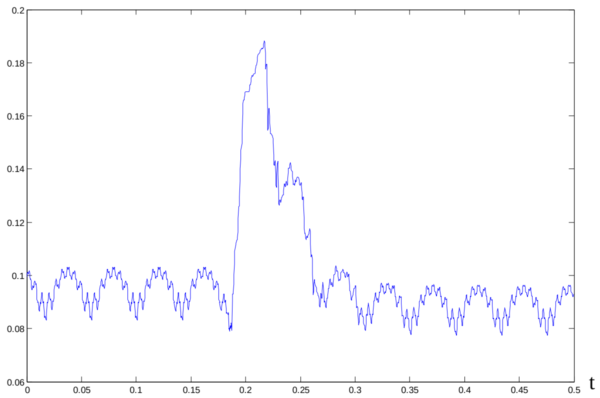

Fig. 4. The waveform of W_{EE}

IV. Conclusion

This paper studies the mechanism of applying W_{EE} into harmonic dictions of power system. By wavelet, signal can be separated into two parts of high frequency and low frequency. About low frequency, its amplitude-frequency characteristic can be extracted by traditional FFT; About high frequency, we can make full use of the advantages of W_{EE}, and extract the characteristics of transient signal effectively. Simulation experiments indicate that wavelet can't extract transient signal from the high frequency signal including noise, but W_{EE} can extract characteristic informations of transient signal successfully.

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References

[1] G. M. Luo, Z. Y. He, and S. Lin, "Discussion on Using Discrepancy Among Wavelet Relative Entropy Values to Recognize Transient Signals in Power Transmission Line," *Power System Technology*, vol. 32, vol. 15, pp. 47-51, 2008.

[2] J. W. Sweldens and P. Schroder, "Building Your Own Wavelets at Home," *Wavelets in Computer Graphics*, ACM SIGGRAPH Course Notes, 1996.

[3] R. Q, Quiroga, O. ARosso, and E. Basar, "Wavelet entropy in event-ralated potential: a new method shows ordering of EEG oscillations," *Biological Cybernetics*, vol. 84, no. 4, pp 291-299, 2001.

[4] Z. Y. He, Y. M. Cai, and Q. Q. Qian, "A study of wavelet entropy theory and its application in electric power system fault detection," in *Proc. of the CSEE*, 2005, vol. 25, no. 5, pp. 23-43.

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