The Multi-disturbance Complex Power Quality Signal HHT Detection Technique

Wang Zhan, Zeng Xiangjun, Member, IEEE, Hu Xiaoxi, Hu Jingying

***Abstract*--With the rapid development of new electric load, the power quality of power supply system put forward higher requirements. For the problem of the multi-disturbance complex power quality signal, the paper presents a multi-disturbance complex power quality signal HHT detection method, using Hilbert-Huang transform (HHT) time-frequency analysis on the multi-disturbance complex power quality signal. This paper introduced the basic principle of HHT; put forward to use HHT method to achieve the complex power quality signal detection; analysed of the superiority of HHT in the complex power quality signal detection. The simulation results show that this method can be a real-time accurate detection of disturbance's starting and ending time and disturbance's amplitude, and applicable to the detection and identification system of the multi-disturbance complex power quality signal.**

***Index Terms*-- EMD decomposition; Hilbert transform ; Hilbert-Huang transform; IMF; inter-harmonics ; multi-disturbance signal; power quality; power system harmonics[1]; voltage interruption; voltage sags**

I. INTRODUCTION

With the modern power electronic devices, the non-linear devices and new electric loads are widely used in power system, the power quality transient signal detection and identification has become the hot spot in many areas of research. The analysis of power quality transient signal is the foundation and basis of the power system's fault diagnosis and transient protection. various transient signals involving Power system most belonging to non-stationary signal, and due to the complexity and randomness of the load and external disturbances, this non-stationary transient signals are often intertwined superimposed to form a multi-disturbance signal and affects in the normal electric signal[1], affect the power system's fault diagnosis and transient protection, and affect power quality[2], high power quality is of great significance to ensure the safe and economic operation of power grid and electrical equipment, to guarantee the quality of industrial products and to improve the quality of people's living standards[3], so analysis of this transient multi-disturbance signal has become an important aspect of studying dynamic power quality.

Nowadays, the method of extract disturbances signal characteristic at home and abroad mainly have wavelet transform[4], Fourier transform[5], the S-transform[6]. Wavelet base in the Wavelet transform have a great influence on the result of wavelet transform, and how to choose the wavelet basis there still is no unified approach or principle at home and abroad[7]. Fourier transform is only suitable for the analysis of stationary signal, can not meet the requirement of the non-stationary signal's analysis[8]. This paper adopts HHT (Hilbert-Huang Transform) to accurate detect the complex power quality signal, it is a new signal analysis method developed in recent years. This method has obvious advantages and effectiveness to deal with non-linear, non-stationary signals. It has no fixed priori basement and is fully adaptive; the instantaneous frequency through Hilbert transform obtained has a clear physical meaning, can express the local characteristics of the signal; it is not affected by the Heisenberg uncertainty principle restrict[9], can accurately reveal the internal characteristics of the data, in the time and frequency domain it can get higher resolution, so compared with other methods it can get more accurate results.

II. THE BASIC THEORY OF HHT

HHT transform is widely used in nonlinear and the non-stationary signal analysis, which mainly consists of two parts: the empirical mode decomposition (EMD) and Hilbert transformation.

A. Empirical Mode Decomposition (EMD)

EMD is the extraction of the IMF component in the signal, the method can be as follows: first of all, according to the maximum points and minimum points of $s(t)$, then calculate the average value $m_1(t)$ of the super wrapping lines $v_1(t)$ and the infra wrapping lines $v_2(t)$.

$$m_1(t) = \frac{1}{2}\left[v_1(t) + v_2(t)\right] \tag{1}$$

The original data sequence $s(t)$ minus $m_1(t)$ can be obtained by a new data sequence $h_1(t)$ that removed low-frequency sequence:

$$s(t) - m_1(t) = h_1(t) \tag{2}$$

Repeat the above process k times until the mean $h_1(t)$ tends to zero, so that the first IMF component $c_1(t)$ can be

[1] This work was supported in part by Hunan Provincial & Hengyang City United Natural Science Foundation of China 10JJ8009, Scientific Research Fund of Hunan Provincial Education Department 09K067 and 09CY011.

Wang Zhan is with School of Electrical & Information Engineering, Changsha University of Science and Technology, Hunan Province, 410076, P. R. China (e-mail: 704869953@qq.com).

Zeng Xiangjun is with School of Electrical & Information Engineering, Changsha University of Science and Technology, Hunan Province, 410076, P. R. China (e-mail: eexjzeng@csust.edu.cn).

Hu Xiaoxi is with School of Electrical & Information Engineering, Changsha University of Science and Technology, Hunan Province, 410076, P. R. China (e-mail: addhuxiaoxi@163.com).

Hu Jingying is with School of Electrical & Information Engineering, Changsha University of Science and Technology, Hunan Province, 410076, P. R. China (e-mail: 490824110@qq.com).

obtained, it represents the highest frequency component of the signal $s(t)$.

$$h_{1(k-1)}(t) - m_{1k}(t) = h_{1k}(t)\text{；}\quad c_1(t) = h_{1k}(t) \qquad (3)$$

Separating $c_1(t)$ from $s(t)$ obtains an interpolation signal $r_1(t)$ that removed the high frequency component, and:

$$r_1(t) = s(t) - c_1(t) \qquad (4)$$

Using $R_1(t)$ as the primary data, repeating steps as described above obtains the second IMF component $c_2(t)$, repeating n times until $r_n(t)$ is a monotone function, then the circulation terminates, obtains n IMF components. So it is:

$$s(t) = \sum_{i=1}^{n} c_1(t) + r_n(t) \qquad (5)$$

EMD decomposition is described above, it can isolate different frequency signal from each other.

B. Hilbert transform

Through Hilbert transform on the IMF can get the time-frequency diagram of the signal that can accurately find the time of the signal mutation.

Through Hilbert transform on the $X(t)$ can get $Y(t)$:

$$Y(t) = \frac{1}{\pi} P \int_{-\infty}^{+\infty} \frac{X(\tau)}{t-\tau} d\tau \qquad (6)$$

In the equation, P is the main value of Cauchy, it sets up for all L^P level functions, by this definition, $X(t)$ and $Y(t)$ is the complex conjugate pair:

$$X(t) = \frac{1}{\pi} P \int_{-\infty}^{+\infty} \frac{Y(\tau)}{t-\tau} d\tau \qquad (7)$$

So the analytic signal $Z(t)$ is:

$$Z(t) = X(t) + iY(t) = a(t) e^{i\theta(t)} \qquad (8)$$

Of which

$$\begin{cases} a(t) = \sqrt{\left[X(t)^2 + Y(t)^2 \right]} \\ \theta(t) = \arctan \dfrac{Y(t)}{X(t)} \end{cases} \qquad (9)$$

$a(t)$ is the instantaneous amplitude；$\theta(t)$ is phase.

The definition of Instantaneous frequency is

$$f(t) = \frac{1}{2\pi} \frac{d\theta(t)}{dt} \qquad (10)$$

Empirical mode decomposition (EMD) and Hilbert transform are referred to as HHT, and this program uses the signal instantaneous frequency $f(t)$ to locate the accurate time of the signal.

III. THE SIMULATION AND RESULTS ANALYSIS OF COMPOSITE DISTURBING SIGNAL

HHT has a well detection in a single disturbance case[10]. The frequency of the simulation signal is 50Hz, the effective value of the amplitude is 220V, and with the multi-disturbance transient electricity quality. As an example of the position and the detection of the frequency and amplitude of the harmonics of voltage sags, the harmonics of voltage swell and harmonics of voltage interruption, and do the simulation of the voltage sags and harmonics content.

A. The simulation of the detection of the voltage sags, swell harmonics

When occurred single-phase voltage sags in the short-time, the frequency of the simulation is 50Hz, the effective value of the phase voltage is 220V, the effective value of the 5th harmonic component is 80V which inserted the simulation between 0.25s~0.8s, and from 0.35s~0.60s, the voltage sags occurred, the effective value of the sags amplitude is 120V, after the voltage sags, the amplitude is the 45% of the original value. The voltage disturbances signal is shown in figure 1:

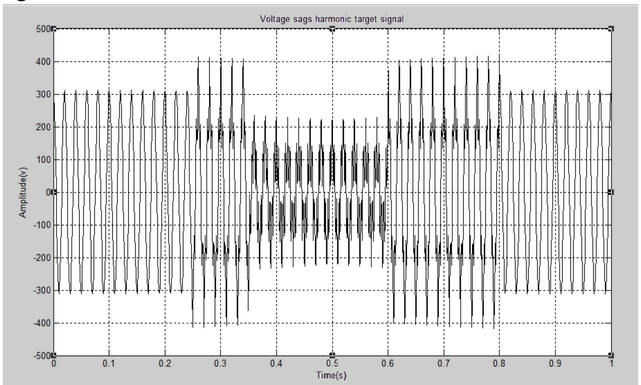

Fig. 1. Voltage disturbances signal.

The EMD decomposition of the signal is shown in figure 2:

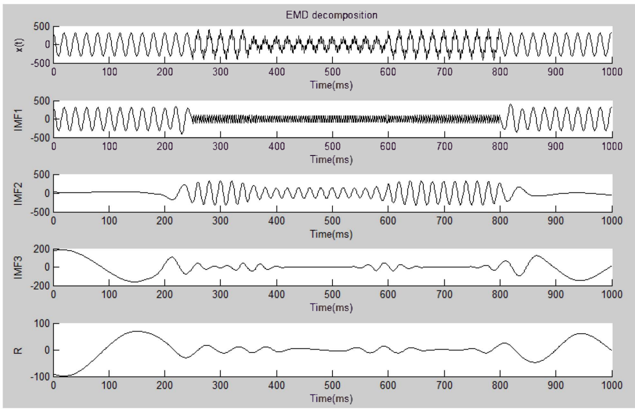

Fig. 2. The EMD decomposition of the target signal.

The instantaneous frequency of the voltage sags is shown in figure 3:

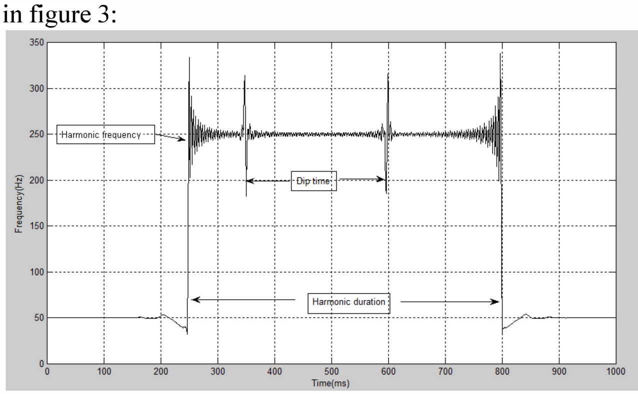

Fig. 3. The instantaneous frequency of the voltage sags.

From figure 3 can clearly find the starting and ending time of the disturbance, the time of the voltage sags and the frequency of the harmonics. The instantaneous frequency is jumped from 0.25s and 0.8s, is the 5th harmonic disturbance, and from 0.35s and 0.6s, the voltage dropped, the international standards claim that when the time intervals over 0.1s, the voltage sags is occurred. It can accurately detect the starting and ending time, the frequency of the harmonics of voltage sags, the simulation of the amplitude of the voltage sags is shown in figure 4:

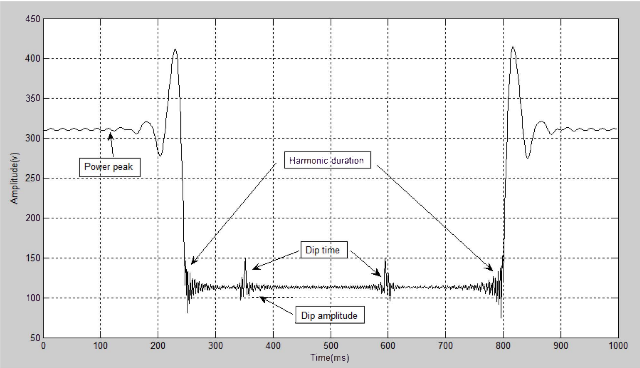

Fig. 4. The instantaneous amplitude of the voltage sags.

From the figure 4 can find the starting and ending time of the disturbance and the amplitude of the voltage sags, the same method can also detect the voltage swell composite disturbance.

B. *The simulation of the detection of the voltage interruption harmonics*

In the simulation, the effective value of the phase voltage is 220V, the frequency is 50Hz, the effective value of the third harmonic is 80V which inserted the simulation between 0.20s~0.80s, and from 0.35s~0.60s, the voltage interruption occurred, the voltage interruption and the signal of harmonics is shown in figure 5:

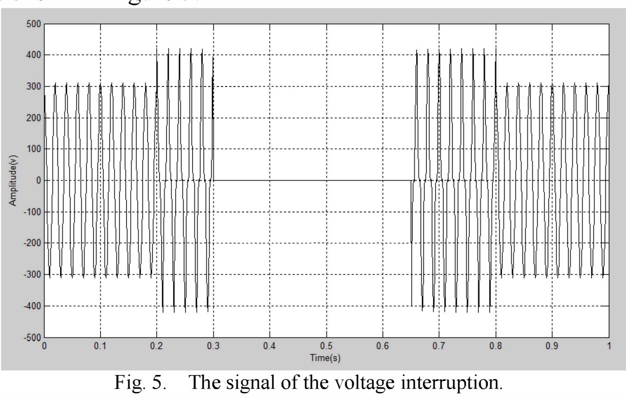

Fig. 5. The signal of the voltage interruption.

Using the HHT transform on the signal can get the time-frequency diagram, as is shown in figure 6:

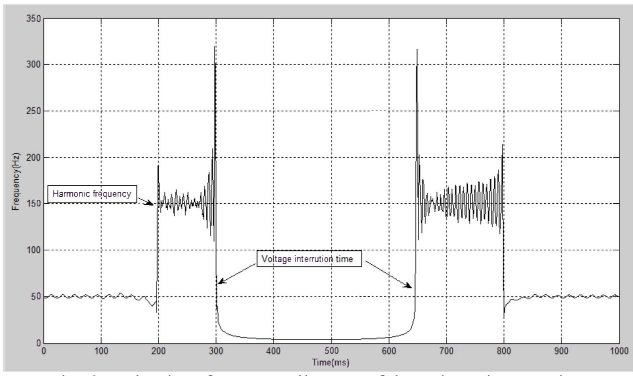

Fig. 6. The time-frequency diagram of the voltage interruption.

From figure 6 knows that among the disturbance of the third harmonic, accompanied with the voltage interruption. From 0.2s to 0.8s, the simulation has the disturbance of the third harmonic, and from 0.3s to 0.65s, the voltage interruption occurred. The error is very small, can precisely get the starting and ending time of the interruption, and able to meet the needs of the engineering application, so the HHT detection algorithm of power quality can accurate detect the voltage transient interruption in the case of the harmonics.

From the above simulation can be drawn that this method can accurately detect the time, frequency and amplitude of the mutation, non-stationary disturbance signal.

IV. MULTI-DISTURBANCE SIGNAL SIMULATION AND ERROR RESULTS ANALYSIS

Select the frequency of the simulation signal is 50Hz, the effective value of the amplitude is 220V, and adding the disturbance at the same time period , and changing the amplitude and the frequency of harmonics many times for simulation, analysis the simulation results and then measuring the error.

A. *voltage amplitude detection*

Select the effective value of the amplitude is 220V, and from 0.10s to 0.70s, joining the 5th harmonic, the amplitude effective value of the harmonic is 80V, changing the amplitude of the voltage sags for simulation, the detect results shown in table 1:

TABLE 1
THE DETECTION OF THE MULTI-DISTURBANCE VOLTAGE AMPLITUDE

Data set	The theoretical value	The value of voltage sags (V)	Error (%)
1	170	175.36	3.15
2	160	163.92	2.45
3	150	153.46	2.31
4	140	141.56	1.09
5	110	113.81	2.73
Average error (%)			2.536

Due to the impact of the end effect, the mode mixing and harmonics, the detection will produce certain error. But can be seen from the table 1, through this detection method, the average error of the repeated detection is less than 3%, basically meet the requirement, it can be said that this detection method of the multi-disturbance voltage amplitude is correct and feasible.

B. The detection of the frequency of harmonics

The set voltage signal in the simulation of harmonics is the standard frequency voltage signal, adding third, 4th, 5th, 6th harmonic for simulation at different times, the signal of voltage harmonics is shown in figure 7:

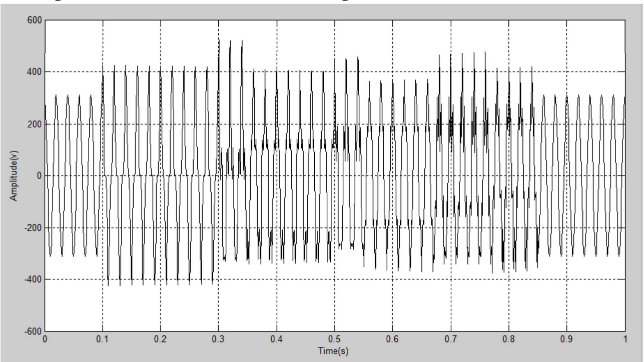

Fig. 7. The signal of voltage harmonics.

Through HHT analysis, the signal of harmonics is shown in figure 8:

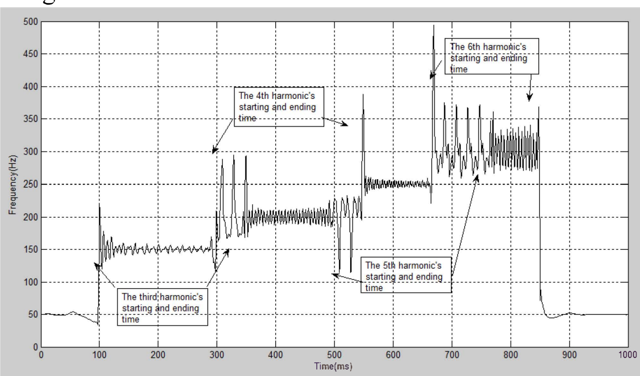

Fig. 8. Multiple times harmonic's time-frequency diagram.

From the figure 8 can clearly find out the signal has forth harmonic, the third harmonic's starting and ending time is 0.100s and 0.350s, the 4th harmonic's starting and ending time is 0.100s and 0.350s, the third harmonic's starting and ending time is 0.310s and 0.570s, the 5th harmonic's starting and ending time is 0.510s and 0.770s, the 6th harmonic's starting and ending time is 0.370s and 0.850s, they are coincided with the theory time, with HHT detection method, can exactly find out the content and starting and ending time of harmonics.

Non-integer multiple times harmonics can also be detected with HHT detection method, from 0.25s to 0.70s, taken in the 5.5-time harmonic whose frequency is 50Hz and amplitude is 80V, the harmonic's equation is:

$$y(t) = 80 \times \sqrt{2} \times \cos(550 \times t) \tag{11}$$

The harmonic's signal is shown in figure 9:

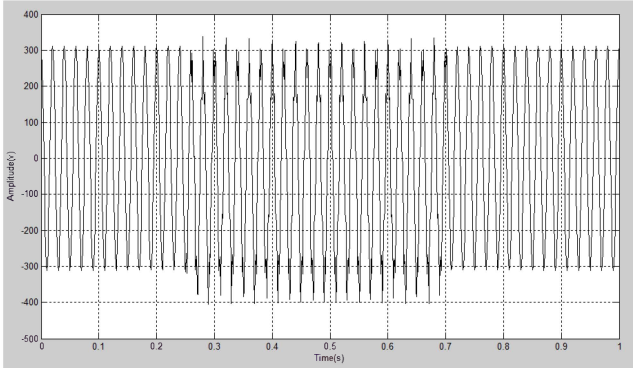

Fig. 9. The signal diagram of inter-harmonic.

Using HHT method analyse inter-harmonic is shown in figure 10:

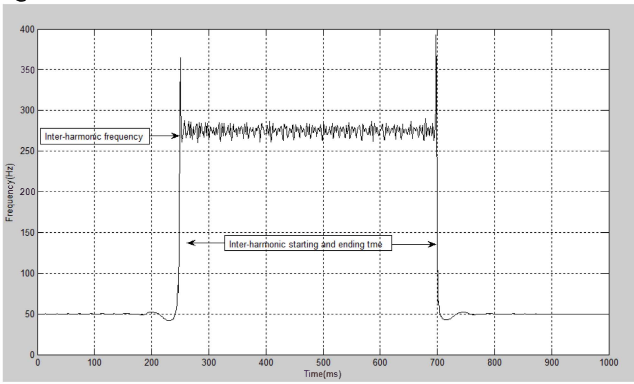

Fig. 10. Inter-harmonic's time-frequency diagram.

From the figure 10 can find out that the detected frequency is almost close to the given 275Hz and the detected starting and ending time is also accurate, so HHT detection method is also suitable for inter-harmonics in the multi-disturbance.

V. CONCLUSION

This paper presents a multi-disturbance complex power quality signal HHT detection method, using HHT algorithm for signal detection. Through theoretical analysis, HHT method is adaptively realized frequency division, breaks through the limitation of defined the signal of harmonics as the basal, so that the signal analysis is more flexible. The simulation results show that the complex power quality signals are decomposed into IMF elements by EMD, and then calculate the instantaneous frequency, can accurately detect the starting and ending time of the disturbances signal; and combining with the solution of instantaneous amplitude, can quickly detect the amplitude of the disturbances signal. This method not only can accurate detect the complex power quality signal, but also simple and quick, easy to implement, can meet the engineering requirements, applicable to the detection and identification system of the multi-disturbance power quality signal, and the application prospect is broad.

VI. REFERENCES

[1] Z. Lu, J. S. Smith, Q. H. Wu, and J. Fitch, "Empirical mode decomposition for power quality monitoring," in *Proc. 2005 IEEE/PES Transmission and Distribution Conference & Exhibition*, pp. 1-5.

[2] H. X. Lin, "Main problems of modern power quality," *Power System Technology*, vol. 25, pp. 5-12, Oct. 2001.

[3] X. N. Xiao, Y. H. Xu, "Power quality analysis and its development," *Power System Technology*, vol. 25, pp. 66-69, Mar. 2001.
[4] Y. H. Xu, and Y. Zhao, "Identification of power quality disturbance based on short-term Fourier transform and disturbance time orientation by singular value decomposition," *Power System Technology*, vol. 35, pp. 174-180, aug. 2011.
[5] M. Shi, J. L. Zhang, X. Xu, and J. P. Yue, "Detection of voltage sags signal parameters," *Control & Automation*, vol. 26, pp. 10-11,122, 2010.
[6] Q. Tang, Y. N. Wang, S. Y. Guo, Z. S. Teng, "Power quality disturbance detection based on S-transform and PNN," *Chinese Journal of Scientific Instrument*, vol. 30, pp. 1668-1673, Aug. 2009.
[7] G. T. Heydt, P. S. Fjeld, C. C. Liu, D. Pierce, L. Tu, and G. Hensley, "Applications of the windowed FFT to electric power quality assessment," *IEEE trans. Power Delivery*, vol. 14, pp. 1411-1416, Oct. 1999.
[8] M. Kezunovic, and Y. Liao, "A novel software implementation concept for power quality study," *IEEE trans. Power Delivery*, vol. 17, pp. 544-549, Apr. 2002.
[9] L. P. He, "Application research of HHT in harmonics analysis of power system," Master dissertation, Dept. circuits & systems, Univ. Central South, 2009.
[10] T. Y. Li, S. Y. Cheng, and M. Yang, "Power system harmonics analysis based on Hilbert-Huang transform," *Proceedings of the CSEE*, vol. 28, pp. 109-113, Feb. 2008.

VII. BIOGRAPHIES

Wang zhan received bachelor's degree from Hunan institute of engineering in 2011. Now he is studying in Changsha University of Science and Technology for his master' degree. His research interest is real-time computer application in power systems control and protection.

Zeng Xiangjun received bachelor's degree from Hunan University in 1993, his M.Sc. degree from Wuhan University in 1996, and Ph.D degree from Huazhong University of Science & Technology in 2001. He then worked as post-doctoral fellow in Xuji Relay Company and the Hongkong Polytechnic University. He is now a Professor and Dean of School of Electrical & Information Engineering, Changsha University of Science and Technology, China. And His research interest is real-time computer application in power systems control and protection.