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# Research on the transient power quality disturbance detection based on HHT

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***Abstract**：Real time detection of transient power quality disturbance signal is an effective way to analyze and eliminate the fault of power grid and improve power quality. The traditional time frequency analysis method has some limitations and large errors in the detection of transient power quality disturbances. In order to improve the accuracy of real-time detection and analysis of power system signal which is interfered by complex disturbance signal, the power quality multi-disturbance signal is detected by the Hilbert-Huang transform method. And the simulation results are verified by MATLAB, and the simulation results show that the method is effective and accurate.*
***Keywords:** Transient power quality; Disturbance detection; Signal analysis; Hilbert-Huang transform;*

## I. Introduction

The application of a large number of nonlinear power electronic devices in power system and the input of impact load will seriously affect the stability of the power quality. It is embodied in the voltage sag, voltage collapse, voltage oscillation, voltage pulse and instantaneous interruption of voltage. Therefore, the detection of transient power quality disturbance signal has the value of practical application and field research. The traditional power quality disturbance signal detection is based on Fourier transform, wavelet transform, time and frequency domain analysis methods[1]. Wavelet transform is used to approximate the non-stationary signal with wavelet transform, which overcomes the shortcomings of the Fourier transform. However, the theory of wavelet transform is still based on Fourier transform, there are limitations of false signal and false frequency[2]. The HHT (Hilbert-Huang Transform) algorithm absorbs the advantage of wavelet transform and overcomes the difficulty of choosing wavelet bases[3].The characteristics which obtain basis functions directly from the signal itself, have a good adaptive ability[4]. For this purpose, the HHT algorithm is introduced to realize the real-time detection of the transient power quality disturbances.

### 1 HHT analysis of power quality disturbance signal

The detection principle of the power disturbance signal is shown in Figure 1 by using the HHT algorithm.

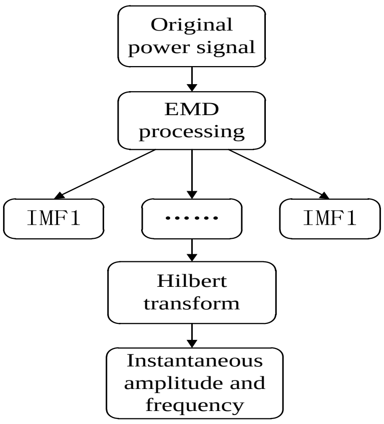


**Fig. 1** principle of power disturbance signal detection

The collected original power signal firstly is processed by the Empirical Mode Decomposition called EMD, it is decomposed into a number of Intrinsic Mode Functions called IMF. The characteristic of IMF is that it has a reasonable definition of instantaneous frequency. Then the instantaneous amplitude and instantaneous frequency of each IMF are obtained by Hilbert transform, and the Hilbert spectrum is constructed[5]. By studying the characteristics and distribution of HHT, the parameters and characteristics of the input time series are identified.

## II. The basic principle of HHT

### 2.1 Empirical mode decomposition method (EMD)

Empirical mode decomposition (EMD) is proposed for the analysis of signal structure which cannot be directly carried out by Hilbert transform and does not satisfy the condition of the intrinsic mode function. The idea of empirical mode decomposition is based on this assumption: Any signal is composed of a series of intrinsic mode functions, that is the superposition of these modal functions which forms the original complex signal[6].Based on the above assumptions, it is possible using empirical mode decomposition method to decompose complex signals. The decomposition steps are:

Step1: Determine the maximum and minimum points of the signal $x(t)$. By using the three spline function interpolation the upper enveloping line $v_1(t)$ and the lower enveloping line $v_2(t)$ of the data series are constructed. And according to the formula (1) obtain the average sequence $m_1(t)$ of $v_1(t)$ and $v_2(t)$.

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

Step2: The difference value between the original signal function $x(t)$ and the mean sequence of the upper and lower envelope function is $h_1(t)$. Its essence is the new data sequence generated by the original signal which removes the low frequency data.

Step3: Judge whether the sequence $h_1(t)$ is the IMF function or not, if not, make the $h_1(t)$ as a new $x(t)$ and repeat the above steps, until the conditions are met. Note $c_1(t)$ as the first intrinsic mode function component $imf(1)$, and make $h_1(t) = c_1(t)$.

Step4: Then make:

$$r(t) = x(t) - c_1(t) \qquad (2)$$

And regard it as a new $x(t)$, repeat above step1 and step 2. The IMF components of each order can be obtained successively until the screen ends when the given termination conditions are met.

(5) The original signal can be expressed by the formula (3).

$$x(t) = \sum_{i=1}^{n} c_i(t) + r(t) \qquad (3)$$

In the formula, $c_i(t)$ the inherent modal components which are obtained from the decomposition of the original signal $x(t)$, $r(t)$ is trend term. In formula (3), the $imf$ components of the large-to-small frequency which constitute the original signal represent the data sequence with different characteristic scales. It can be seen that the essence of the reconstruction of the original signal is the superposition of all the intrinsic mode functions.

Although the EMD decomposition results have the advantages of finite IMF components, the three spline fitting is easy to be disturbed by human[7]. At the same time, the average value of the envelope of the IMF component which is decomposed from the actual signal is very difficult to meet the requirements that the average value of the upper and lower envelope is zero. In order to meet the requirement, it is needed to increase the number of screening. However, if the screening times are too many, the frequency modulated wave with constant amplitude can only be obtained so that the original signal can lose its true physical meaning[8].In this, the standard deviation of the results obtained from the two screening results before and after the standard deviation SD is used as an iterative threshold to constrain the number of iterations[9].The expression of the standard deviation is shown in the formula (4). A large number of tests show that, the SD value is usually taken as 0.2~0.3.

$$SD = \sum_{t=0}^{T} \frac{[h_{k-1} - h_k(t)]^2}{h_{k-1}^2(t)} \qquad (4)$$

### 2.2 Hilbert spectrum and Hilbert marginal spectrum

HHT is based on the local characteristics of the signal after the EMD decomposition, each IMF component is transformed by the Hilbert transform, so as to get the time domain properties of signals. The modal functions $c_1(t)$ of the formula (3) are obtained by the Hilbert transform.

$$\hat{c}_i(t) = \frac{1}{\pi}\int_{-\infty}^{\infty}\frac{c_i(\tau)}{t-\tau}d\tau \qquad (5)$$

An analytic signal expression is constructed as shown in the formula (6).

$$z_i(t) = c_i(t) + j\hat{c}_i(t) = a_i(t)e^{j\phi_i(t)} \quad (6)$$

Then get the amplitude function.

$$a_i(t) = \sqrt{c_i^2(t) + \hat{c}_i^2(t)} \qquad (7)$$

And phase function:

$$\varphi_i(t) = \arctan\frac{\hat{c}_i(t)}{c_i(t)} \qquad (8)$$

The instantaneous frequency can be obtained:

$$f_i(t) = \frac{1}{2\pi}w_i(t) = \frac{1}{2\pi}\frac{d\phi(t)}{dt} \qquad (9)$$

In this way, we can get:

$$x(t) = RP\sum_{i=1}^{n} a(t)e^{j\phi(t)} = RP\sum_{i=1}^{n} a(t)e^{j\int w(t)dt} \quad (10)$$

Then get the amplitude function:

$$a_i(t) = \sqrt{c_i^2(t) + \hat{c}_i^2(t)} \qquad (11)$$

In the formula (11) the relationship between the signal amplitude and the time and frequency is revealed, the distribution of the signal amplitude in the time-frequency domain is the Hilbert time spectrum, namely the Hilbert spectrum, its expression is shown in the formula (12).

$$H(w,t) = RE\sum_{i=1}^{n} a_i(t)e^{j\int w_i(t)dt} \qquad (12)$$

In formula (14), $w_i(t) = w$, $RE$ is showed to calculate the real part. Formula (13) is the expression $H(w)$ of Hilbert marginal spectrum.

$$H(w) = \int_0^T H(w,t)dt \qquad (13)$$

In the formula, T is the signal length.

## III. System Simulation Analysis

### 3.1 Analysis of voltage sag with short time harmonics

The waveform of voltage sag with short harmonics is shown in Figure 2. The simulation parameters are set to: The effective value of the standard voltage is 220V, the frequency is 50Hz, add the 5 harmonic component of which the effective value is 80V during the time period 0.15~0.80s, in the time period 0.40~0.65s the voltage sag fault is simulated, the temporary drop voltage amplitude value is 120V. Figure 2~5 in turn are the instantaneous frequency waveform and amplitude waveform of the voltage sag signal, the three component of EMD decomposition, the residual component signal waveform and temporary drop signal.

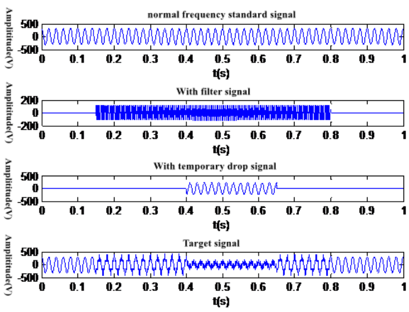


**Fig. 2** voltage sag signal with short time harmonics

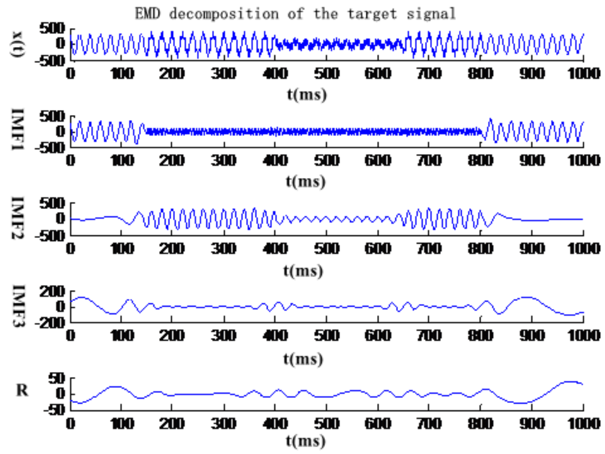


**Fig. 3** EMD decomposition of voltage sag signal in Figure

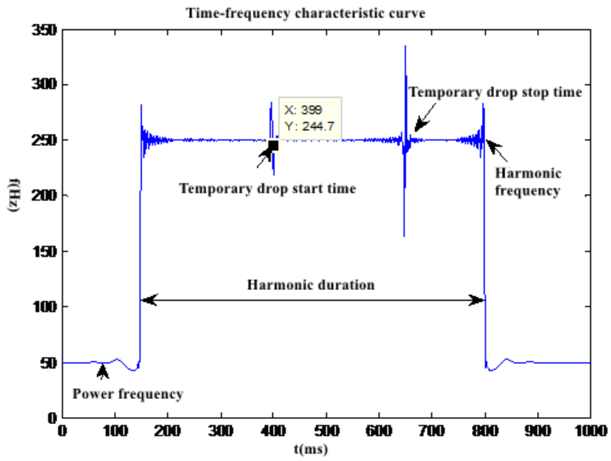


**Fig. 4** frequency characteristic curve

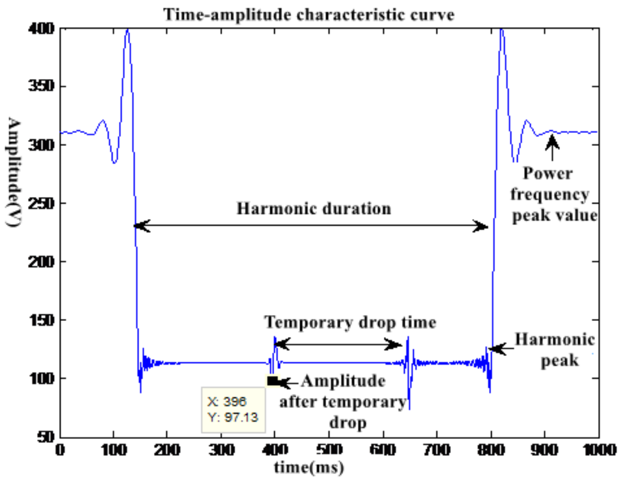


**Fig. 5** amplitude characteristic curve

As can be seen from Figure 3, the instantaneous frequency jumps during 0.399s and 0.649s, the error is less than 1%, the starting and ending time of the voltage sag are accurately detected. It is not difficult to see from Figure 4, the temporary drop amplitude peak value is detected as 97.13V, the temporary drop effective value is 117.4V, and the error of amplitude is 2.17%. From the simulation results, it can be seen that HHT is correct and effective for the detection of the power sag with harmonics.

### 3.2 voltage interruption analysis with short time complexity

In MATLAB simulation, the voltage interruption waveform with short harmonics is shown in 6.

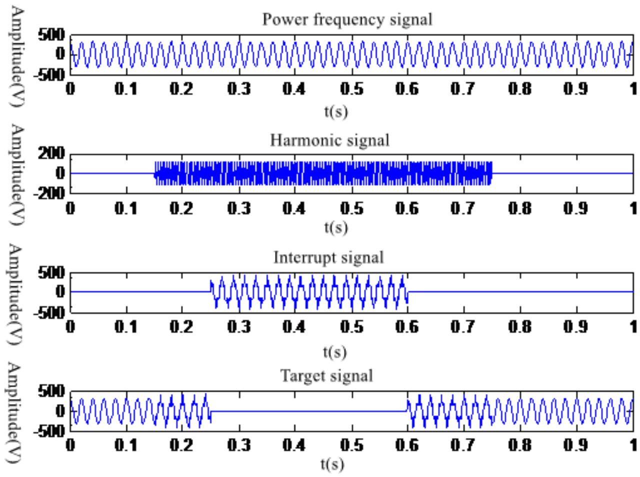


**Fig. 6** voltage interruption signal with harmonic

Simulation parameters are set as: the standard voltage effective value is 220V, frequency is 50Hz, the 5 harmonic components that the effective value for 80V are added in the time 0.15~0.75s . the voltage interruption fault is simulated in the time period 0.25~0.60s, HHT analysis as shown in Figure 7-9 shows：

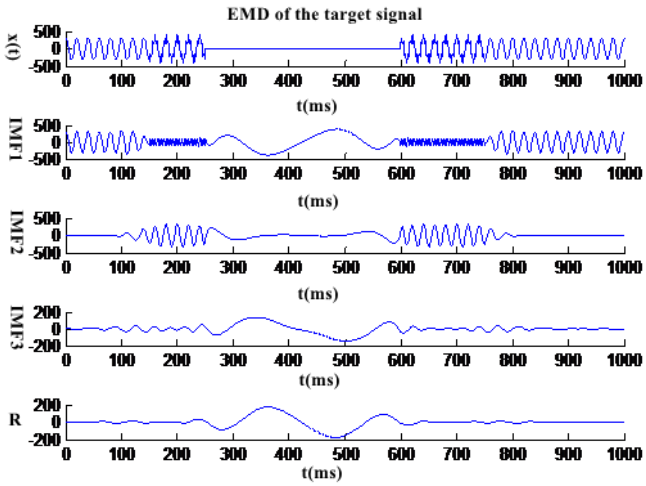


**Fig. 7** EMD decomposition of voltage interrupt signal

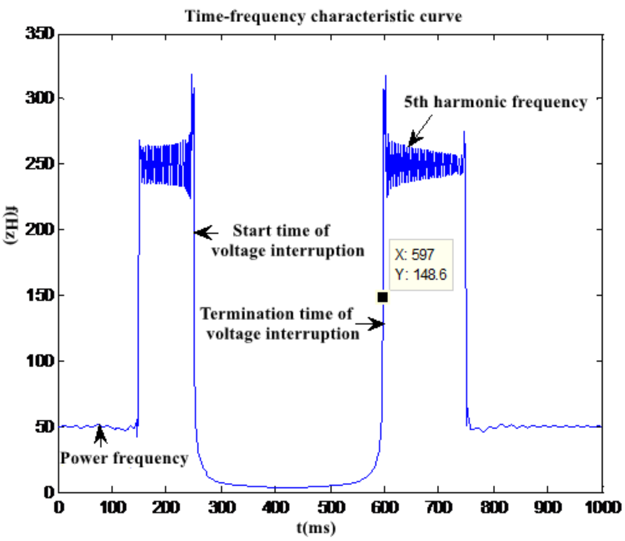


**Fig. 8** frequency characteristic curve

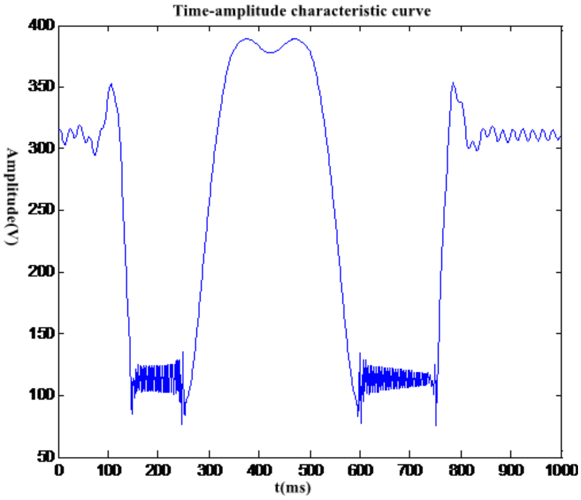


**Fig. 9** amplitude characteristic curve

Hilbert-Huang transform can be obtained from table 1.It can be applied to the instantaneous voltage interruption and its error is less than 2%. So the interrupt start and stop time can be obtained accurately, and the engineering needs can be met. Therefore the Hilbert-Huang transform is accurate and effective for the detection of harmonic interference in the instantaneous voltage interruption.

**Table 1** Analysis of HHT detection results with harmonic voltage interruption

| | Start time (unit: s) | Termination time (unit: s) | Duration time (unit: s) |
|---|---|---|---|
| Theoretical value | 0.250 | 0.600 | 0.350 |
| Detection value | 0.251 | 0.597 | 0.346 |
| Error (%) | 0.4 | 1.167 | 1.143 |

## IV. Conclusions

Based on the EMD and Hilbert spectrum analysis, the HHT transform is applied to analyze and detect the voltage multi-disturbance signal, the voltage disturbance signal is decomposed by EMD, and the instantaneous frequency of each IMF component is obtained. The simulation results provide a sufficient basis for accurate and fast detection of the occurrence and termination time of the voltage disturbance signal, which indicates that it is feasible and effective to analyze the multi-disturbance signal of power quality based on Hilbert-Huang transform.

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