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Voltage Sags Detection Based on Hilbert-Huang Transform

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Abstract

Voltage sag is a prominent problem in power quality. It is key to identify voltage sag exactly for choosing scheme of managing power quality. Hilbert-Huang transform (HHT) is applied for the voltage sag recognize. Using the empirical mode decomposition (EMD) for voltage sag, the intrinsic mode function (IMF) can be obtained, then perform the Hilbert transform in each IMF, after that the instantaneous frequency spectrum can be obtained. And then determine start and end. Simulation results show the method has better effect on detecting voltage sag.

Keywords: *Voltage Sags, Hilbert-Huang transform, EMD*

1. Introduction

With the development of science technology and industry, power consumption of the national economic are increased gradually, the level of electrification is more and more high, the new technologies are applied in industrial production and people's life, more and more users adopt high-tech equipment which has a good performance, high efficiency, but sensitive to changes of the power supply, so the users' requirement for power quality is increasing [1]. Many of the new electrical equipment in operation bring kinds of electromagnetic interference, causing the influence on the safe operation of the power system and the normal operation of electrical equipment. Voltage sags, as a key problem of power quality, have been gotten more and more attention by a majority of electricity consumers.

Voltage sags is the root mean square values of the power supply voltage falls sharply in a short time, and it is the main reason that sensitive equipment work abnormally, and nearly 70% of the power quality problems are caused by voltage sags. Voltage sags can lead to relay protection equipments malfunction, data loss of precision computing devices, stop of production process, *etc.*, the detection and recognition of voltage sags have become an important link in power quality monitoring system. The conventional analysis method is the one based on Fourier transform, to analyze the signal in time domain and fail to finish the analysis of frequency content at any time, not suitable for analysis of non-stationary signal. Although the wavelet transform could be used in time-frequency local analysis, the wavelet decomposition has a large amount of calculation, and number of decomposition layer and the selection of wavelet basis have a great influence on analysis results [2].

Hilbert-Huang transform is a better method to analyze the nonlinear, non-stationary signal, and the method has good local ability of analysis in time-frequency field [3]. Hilbert-Huang transform is used for voltage sag detection in this paper. Considering the choice of the sampling frequency in practice, IMF with only one frequency is obtained by empirical mode

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decomposition. Using Hilbert-Huang transform for IMF, you will get instantaneous frequency and the value of amplitude. Simulation results show that the proposed method is effective.

2. Basic Principle of Hilbert-Huang Transform

Hilbert-Huang transform has a certain adaptive ability of time-frequency analysis. The signal is decomposed into several IMF components, making Hilbert transform for each IMF component, and then getting the instantaneous frequency and instantaneous amplitude of each component. The method in detail is shown in Figure 1.

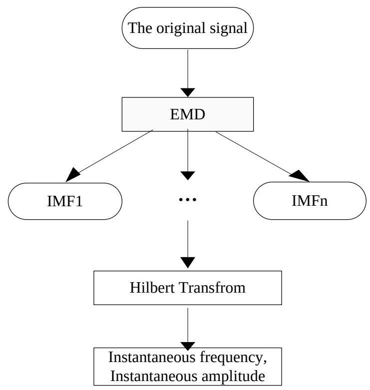


Figure 1. The Hilbert-Huang Transform Principle of Signal Detection

2.1. Hilbert Transform

Hilbert transform of continuous signal is defined as follows [4]

$$\hat{x}(t) = \frac{1}{\pi}\int_{-\infty}^{+\infty}\frac{x(\tau)}{t-\tau}d\tau = \frac{1}{\pi}\int_{-\infty}^{+\infty}\frac{x(t-\tau)}{\tau}d\tau = x(t) * \frac{1}{\pi t} \tag{1}$$

Where $\hat{x}(t)$ is Hilbert transform, it can be regard as output of $x(t)$ through a filter, " $*$ "stands for convolution. t Is time; τ refers to integral variable.

By the Fourier transform theory, $jh(t) = j(1/(\pi t))$'s Fourier transform is a symbolic function $\mathrm{sgn}(\omega)$, ω is continuous angular frequency variable of continuous signal $x(t)$ .Frequency response of Hilbert Transform is as follows:

$$H(j\omega) = -j\,\mathrm{sgn}(\omega) = \begin{cases} -j & \omega > 0 \\ j & \omega < 0 \end{cases} \tag{2}$$

Assume $H(j\omega) = |H(j\omega)|e^{j\varphi\omega}$, then $H(\omega) = 1$

$$\varphi(\omega) = \begin{cases} -\frac{\pi}{2} & \omega > 0 \\ \frac{\pi}{2} & \omega < 0 \end{cases} \tag{3}$$

You can get instantaneous frequency f and the value of amplitude of $x(t)$, $a(t)$, in terms of the following formulas:

$$a(t) = \sqrt{x^2(t) + \hat{x}^2(t)} \tag{4}$$

$$f = \frac{1}{2\pi}\frac{d\varphi(t)}{dt} \tag{5}$$

2.2. Intrinsic Mode Function

Because most of the signal at any time may contain multiple oscillation manners, simple Hilbert transform cannot make a complete description of the signal frequency, so the signal is decomposed into intrinsic mode function. An intrinsic mode function should meet the following two conditions [5].

(1) In the whole data sequence, the number of its extreme-value point and the number of passing zero must be equal or the maximum difference is one.

(2) At any time, the mean value of upper and lower envelope formed by the local maximum points and minimum points is zero. The signal is local symmetry about the timeline.

2.3. Classical Modal Method

For a time series signal $x(t)$, the empirical mode decomposition process as follows [6]

(1) To determine the local maximum value point and local minimum value point of original signal.

(2) Using cubic spline interpolation method to connect all the maximum points and minimum points, forming the upper and lower the envelope, and the envelope must contain all data points, and calculate the mean value $m_1(t)$.

(3) Difference, assume $h_1(t) = x(t) - m_1(t)$.

(4) If $h_1(t)$ accords with the termination condition of IMF, $h_1(t)$ is the first IMF component signal $x(t)$.

(5) If $h_1(t)$ does not meet the conditions for the termination of IMF, $h_1(t)$ will be as the input signal to repeat step (1) and (2), getting $m_{11}(t)$, calculating $h_1(t) - m_{11}(t) = h_{11}(t)$,then we should judge whether it conform to a termination condition; Repeat with the above method until it can meet the termination condition of IMF, when the conditions of $h_{1k}(t)$ are right, take it down $c_1(t) = h_{1k}(t)$, now $c_1(t)$ becomes the first intrinsic mode function signal.

(6) Assume $r_1(t) = x_1(t) - c_1(t)$;Taking $r_1(t)$ what you get as a new signal data and repeat the above (1) to (3) steps, and then obtain the second intrinsic mode functions $c_2(t)$ and repeat m times. Then we can get m intrinsic mode functions, the following two conditions can be meet for $r_m(t) = r_{m-1}(t) - c_m(t)$

① r_m is less than a predetermined error;

② r_m become a monotone function.

3. Simulation Experiment

The mathematical expression for voltage sag signal is as follows:

$$u(t) = (1 - \alpha \cdot (u(t_2) - u(t_1))) \cdot \sin(\omega_0 t) \quad (6)$$

where $\alpha = 0.1 \sim 0.9$ stands for sags amplitude, $T < t_1 - t_2 < 6T$ is the duration of voltage sags, t_1 is the moment voltage sag beginning, t_2 is the moment voltage sag ending. T Is a cycle time.

Voltage sag is a typical transient power quality disturbance signal, voltage sag caused by single-phase earth fault is considered in this paper, the power frequency of 50 HZ, voltage sag happening from 0.08 s to 0.18 s, sag amplitude becoming 3% of the original's, as shown in Figure 2. The intrinsic mode functions by empirical mode decomposition are shown in Figure 3. The intrinsic mode function's frequency-time characteristic curves are shown in Figure 4. The intrinsic mode function's amplitude-time curves of voltage sag signal are shown in Figure 5.

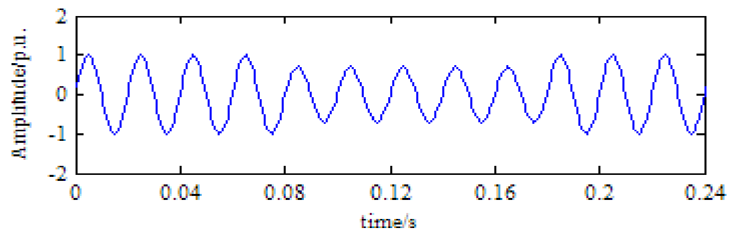
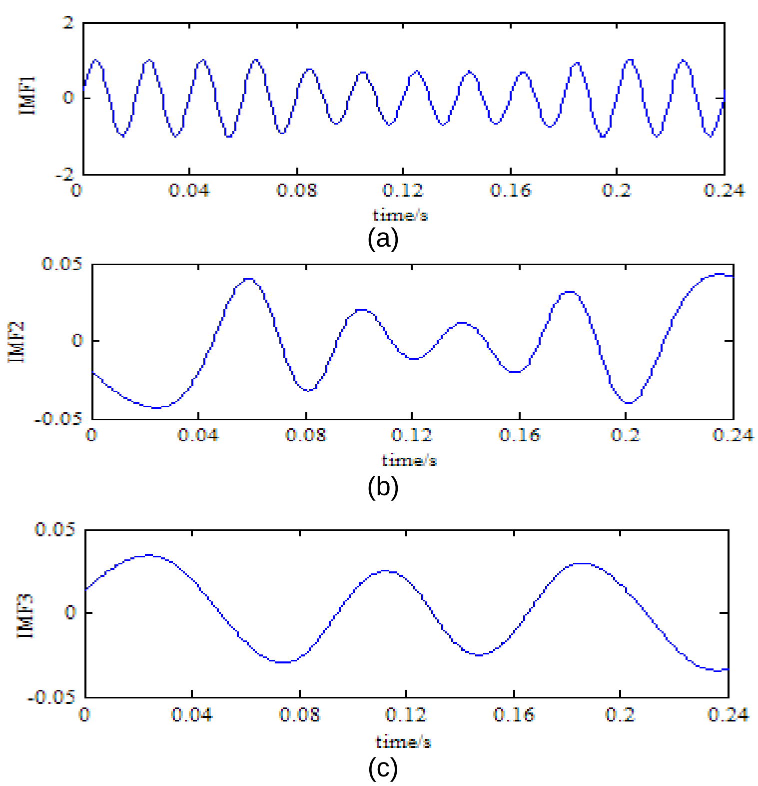
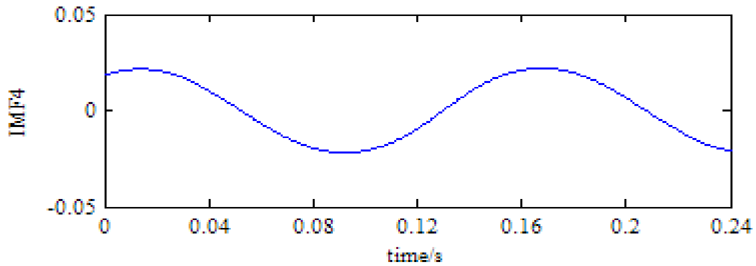


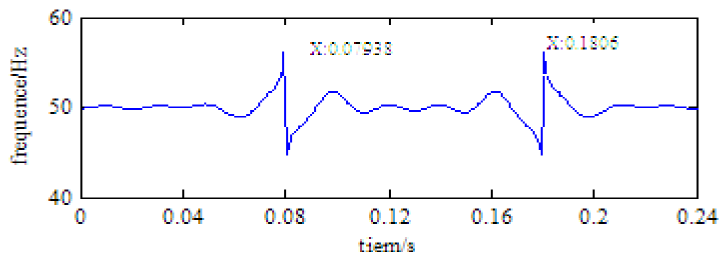
Figure 2. Voltage Sag



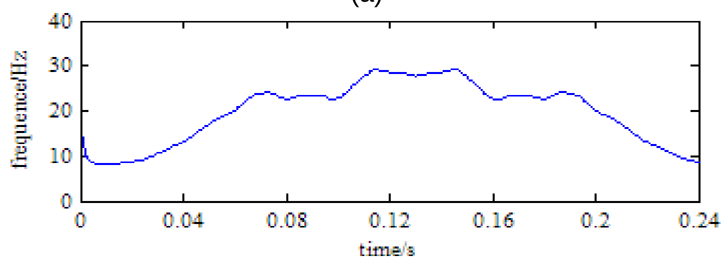


(d)

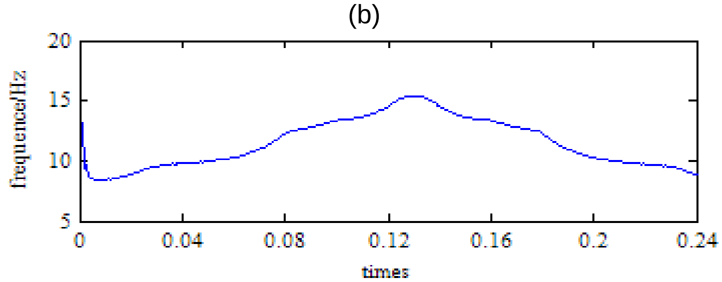
Figure 3. IMF



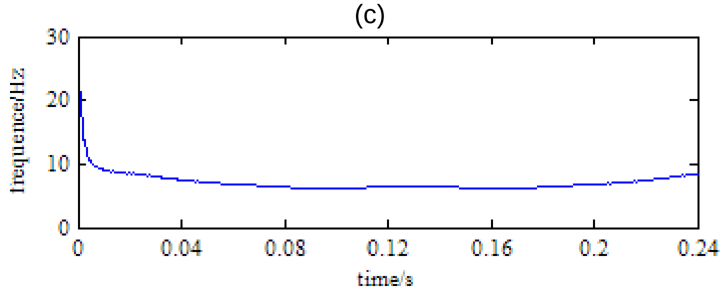
(a)



(b)



(c)



(d)

Figure 4. The Characteristic Curves of IMF in Frequency – Time for Soltage Sag

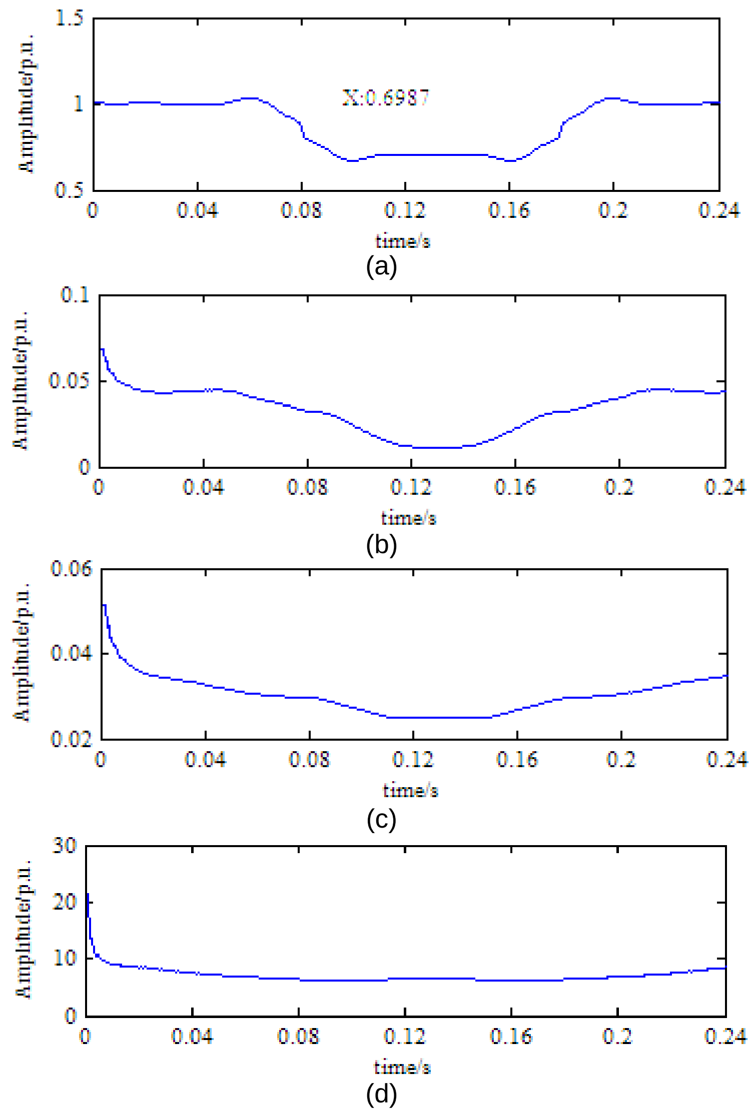


Figure 5. The Amplitude-time Characteristic Curves of IMF

From the above Figures, we can get intrinsic mode function from the EMD for the signal, then the Hilbert transform was carried out on the intrinsic mode function to get the signal instantaneous frequency and instantaneous amplitude, there was a high frequency change for measured signal at 0.07938 s and 0.1806 s in the instantaneous spectrum , which indicate the moment of start and end of voltage sag, and the relative error is 0.775% and 0.333% respectively, determining the duration of the signal on voltage sag, and the relative error is 0.122%. From the instantaneous amplitude diagram, we can see that falling range of the signal is 0.6987 and the relative error reaches 0.1857%.

4. Conclusions

The Hilbert-Huang transform based on empirical mode decomposition and Hilbert spectrum is applied in analysis and detection of voltage sag, and some problems in application are discussed in this paper. The simulation experiment shows that EMD is used for voltage sags and the moment of beginning and end of voltage sags can be obtained by getting instantaneous frequency of each IMF component, so can duration of voltage sags. Using the Hilbert-Huang transform analysis of voltage sag signals is not only feasible but also effective.

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