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Study on Voltage Sag Detection of Wind Power System Based on HHT

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ABSTRACT

For the output of wind power system has the characteristics of randomness, volatility and intermittence, the voltage of wind power system fluctuates frequently and voltage sag is one of the most common voltage fluctuations in wind power system. For the problem of voltage sag of wind power system, the limitations of the detection methods such as the square detection method, the half-wave RMS detection method and wavelet transform are summed up, and a new detecting method named Hilbert-huang Transform(HHT) is put forward in this paper, which can detect the voltage sag accurately and timely. In order to solve the problem of end effect in the process of empirical mode decompostion (EMD), a self-adaptive method named improved waveform matching is applied in dealing with the end issue. Voltage fluctuations are reflected by two parameters named voltage amplitude and frequency of each intrinsic mode function (IMF) in HHT. The practicality of the method is verified by Matlab simulation.

Keywords: HHT; Wind Power System; Voltage Sag; Detection

1. Introduction

With the development of the society, we are facing a problem of a gradually reduce of primary energy reserves, it is essential for us to develop other forms of energy. In such a background, renewable and clean wind gradually cause concern at home and abroad in the related field, large-scale development and utilization of wind power is considered to be an effective measure to solve the energy crisis and environment pollution problem. Our country has massive land, abundant wind power, so if we make full use of this energy, not only can we create considerable economic benefits, but we can also effectively relieve the pressure caused by the shortage of traditional energy, and we also can provide long-term effective energy supply[1].

The development of new energy resources in China, such as wind power, conforms to the strategic requirements of sustainable development. However, wind power is vulnerable to natural climate influence. The output of wind power system has the characteristics of randomness, volatility and intermittence. Wind power system voltage fluctuations may happen at any time, which is difficult to control. Voltage sag is one of the most common forms of voltage fluctuation. It has serious impact on the power quality of wind power system, causes great harm to the sensitive loads, brings great difficulties to wind power integration, and seriously restricts the large-scale development of wind power.

At the present, there are several common methods for voltage sag detection in wind power system, such as the square detection method, the half-wave RMS detection method and wavelet transform detection method. To some extent, these methods can detect wind power system's voltage sag, but there are also certain deficiencies in these methods. The square detection method ignores the frequency shift component at the moment of voltage's sag[2]. The half-wave RMS detection method needs to take sampling data that is half a cycle in order to get the conclusion, which can't guarantee the real-time. So this method can only be used for occasions that real time requirement is not high[3]. Wavelet transform detection method is appropriate for wave signal which contains one, two or above two frequency. But it requires synchronous signal and carrier signal the same phase, same frequency and to have strict frequency division. It also demands energy concentrated wavelet to improve the detection's precision[4]. By a two-stage decomposition of voltage sag detection, Daubechies wavelet is able to detect the voltage sag's start-stop moment and drop amplitude accurately by making a two-stage decomposition for voltage sag. But the choice of wavelet base is a big problem. At present, how to select the wavelet base is not unified or have a principle[5].

We need to detect real-time wind power system voltage sag's happen time and amplitude effectively, so that we can take certain compensation measures and improve the wind power system's power supply reliability and power quality. This paper presents a improved HHT method to detect voltage sag of the wind power system. This method is based on the waveform matching method for end processing. And the simulation results verify the practicability.

2. Method Introduction

2.1. HHT Introduction

Hilbert-Huang transformation(HHT) is a new developed method for signal analysis. This method consists the empirical mode decomposition(EMD) and Hilbert transformation[6]. Through the EMD decomposition, signal can be decomposed into a series of intrinsic mode function (IMF). The intrinsic mode function is a signal which is approximate to single-frequency components, which means at all times, there is only one signal frequency component. For each intrinsic mode function on Hilbert transform, we can get the instantaneous spectrum of each IMF.

1) EMD process

According to the maximum point and the minimum point of the signal $x(t)$, we can find out the average of the upper envelope $x_1(t)$ and the lower envelope $x_2(t)$.

$$\mu_1 = \frac{1}{2}[x_1(t) + x_2(t)] \tag{1}$$

Then calculate the difference between $x(t)$ and μ_1 as θ_1:

$$\theta_1 = x(t) - \mu_1 \tag{2}$$

If θ_1 satisfies the two conditions of IMF（① The number of the points which past the extreme point and zero point is the same or differ at most one. ②The signal is symmetric about time axis）, θ_1 is the first IMF component of $x(t)$ [7]. If θ_1 doesn't satisfy the two conditions of IMF, Put θ_1 as raw data. Repeat the above process k times, get $\theta_{1k} = \theta_{1(k-1)} - \mu_{1k}$, then judge whether each screening results are IMF components using S_D.

$$S_D = \sum_{t=0}^{n} \left| \frac{\left|\theta_{1(k-1)}(t) - \theta_{1k}(t)\right|^2}{\theta_{1(k-1)}^2(t)} \right| \tag{3}$$

in Formula (3), S_D can be determined according to the actual requirements. If θ_{1k} satisfies the requirement of S_D, then make $\alpha_1 = \theta_{1k}$, and α_1 is the first IMF component of signal $x(t)$. Separate α_1 from $x(t)$ as Formula (4):

$$r_1 = x(t) - \alpha_1 \tag{4}$$

Take r_1 as the new $x(t)$ and repeat the above process, we can get $\alpha_2, \alpha_3, \alpha_4, \cdots$ Stop until r_n is monotonic or $|r_n|$ is very small. The result of the decomposition is as follows:

$$x(t) = \sum_{i=1}^{n} \alpha_i(t) + r_n \tag{5}$$

2) Hilbert transformation

Do Hilbert transformation on $\alpha_i(t)$ which is a IMF component as follows:

$$H_i(t) = \frac{1}{\pi}\int_{-\infty}^{+\infty} \frac{\alpha_i(\tau)}{t-\tau} d\tau \tag{6}$$

Its inverse transform is as follows:

$$\alpha_i(t) = \frac{1}{\pi}\int_{-\infty}^{+\infty} \frac{H_i(\tau)}{t-\tau} d\tau \tag{7}$$

We can get analytic signal $A(t)$:

$$A_i(t) = \alpha_i(t) + jH_i(t) = a_i(t) e^{j\phi_i(t)} \tag{8}$$

The instant amplitude:

$$a_i(t) = \sqrt{\alpha_i^2(t) + H_i^2(t)},$$

The phase:

$$\phi_i(t) = \arctan\left(\frac{H_i(t)}{\alpha_i(t)}\right).$$

The instant frequency:

$$f_i(t) = \frac{1}{2\pi}\frac{d\phi_i(t)}{dt} \tag{9}$$

2.2. Introduction of End Effect

In the decomposition process of empirical mode, we need to calculate the local average of signal according to the envelope in the calculating process of the IMF. What's more, the upper and lower envelope can respectively be obtained by making cubic spline interpolation algorithm on signal's local maximum and local minimum[8]. Due to the signal's two endpoints are not necessarily the extreme point which couldn't satisfy the requirements of interpolation, so it may bring some error, this situation is so-called end effect.

2.3. Introduction of Self-adaptive Method Named Improved Waveform Matching

In the aspect of end effect's inhibition, common methods include mirror continuation method, continuation method based on neural network, continuation method based on polynomial fitting, etc. These methods can inhibit end effect to a certain extent. But they also have some problems[9]. In order to detect voltage sags of wind power system quickly, a self-adaptive method named improved waveform matching is applied in dealing with the end issue. The core idea of the waveform matching method is as follows: According to the law of nature signal, we assume that the development and change of the signal is always according to certain rules. Signal's development trend at boundaries will also be reflected in inner signal, especially for the regularity strong signal, this feature will be more obvious. In order to test the true extent for continuation waveform, we need to introduce the concept of waveform matching degree to test the authenticity of the continuation waveform. Assume $f_1(t), f_2(t)$ are two data sequences whose length both are N. $S_1(t, f_1(t))$, $S_2(t, f_2(t))$ are two points on $f_1(t), f_2(t)$. Then the waveform matching degree of $f_1(t), f_2(t)$ which relative to S_1, S_2 can be obtained according to the following steps.

1) Translating $f_1(t)$ coincides the S_1 and S_2, the new waveform is $f_1^{'}(t)$;

2) Obtain the waveform matching degree of $f_1(t)$, $f_2(t)$ which relative to S_1, S_2 according to formula (10).

$$md(f_1(t),\ f_2(t),\ \mathrm{S}) = \sum_{j=1}^{N} (f_2(j) - f_1^{'}(j))^2 \qquad (10)$$

Concrete steps of waveform matching method are as follows:

1) Obtain all extreme points M_i of original signal $f(t)$, put the maximum points into set{ $M_{i,\max}$ } and the minimum points into set { $M_{i,\min}$ };

2) The first minimum point is M_0 and the first maximum point is M_i. The distance between M_1 and $f(t)$ at the start time is sd_0. The length of sd_0 is l;

3) The waveform matching degree of all $M_{i,\max}$ respect to sd_0 is md_i;

4) The minimum wave band of md_i is sd_i .If $md_i < \alpha \cdot l$ (α is a constant which is determined by the matching accuracy requirements), take md_i as waveform continuation of $f(t)$'s left end. Otherwise, process according to the step (5);

5) Specify the maximum and the minimum of the endpoint directly. Take the average value of two adjacent maximum points at original signal's left-most derivation as the maximum at left end. Take the average value of two adjacent minimum points at original signal's left-most derivation as the minimum at left end.

3. Example Simulation

In fact, due to natural environment's influence on the voltage of wind power system, fluctuations are more complex. This paper does some simulation analysis to voltage sags of wind power system voltage fluctuation. During the non-sag, we assume the wind power system voltage waveform always remain unchanged(amplitude is rated voltage and its frequency is 50 Hz). Voltage sag usually refers to root-mean-square voltage quickly drop to 90% - 10% of the rated voltage, and then quickly restore to the normal voltage. Its typical duration is 0.5-30 period [10]. Accordingly, we assume that a wind power system voltage RMS temporarily reduces to 70% of the rated voltage, and the duration is five period. The voltage function is shown in Equation (11), and the voltage sag waveform is shown in **Figure 1**.

$$u(t)\begin{cases}\cos(100\pi \times t), others \\ 0.7\cos(100\pi \times t), 0.1 < t < 0.2\end{cases} \qquad (11)$$

For the problem of voltage sag, this paper firstly apply waveform matching data continuation subroutine within Matlab to the extension of original signal, which can effectively avoid the end effect in the process of HHT transform. Then call the procedure about Hilbert-huang Transform to do HHT treatment for the continuation signal, and output the amplitude / time, frequency / time curve of IMF1. Finally, according to the amplitude/time, frequency/time curve of IMF1, we got the voltage amplitude and voltage frequency of wind power system when voltage sag happened, which could help to judge the time and the amplitude about voltage sag. HHT simulation results are shown in **Figure 2** and **Figure 3**. And the simulation is after the endpoint processing based on the waveform matching adaptive.

In the simulation, we assume a voltage sag happen after 0.1 - 0.2 s. We can conclude that the voltage is only

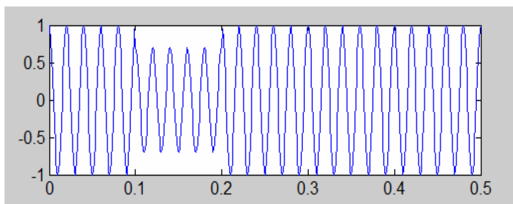

Figure 1. Voltage sag waveform.

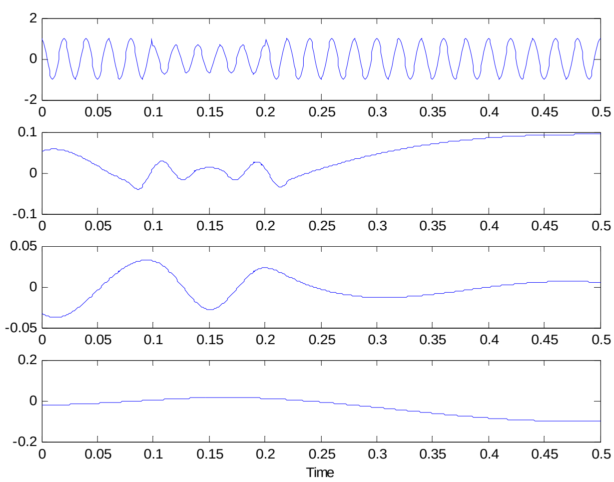

Figure 2. EMD decomposition results.

0.62 times the rated voltage at the moment of 0.1s or 0.2s from the HHT simulation results; At the moment near 0.1 s or 0.2 s, the instantaneous frequency also has great changes. The highest frequency is up to 78.64 Hz, the minimum frequency is only 19.8 Hz. We can judge the situation of voltage sags in wind power system effectively and in real time according to the mutations of the voltage parameter.

If the wind power system voltage RMS temporary decline to 80% of the rated voltage, and the duration is 0.5 a period, then voltage function is shown in formula12, voltage waveform is shown in **Figure 4**.

$$u(t)\begin{cases}\cos(100\pi \times t), others \\ 0.8\cos(100\pi \times t), 0.2 < t < 0.21\end{cases} \quad (12)$$

Voltage sag parameters of a wind power system are as follows: the root-mean-square voltage temporarily reduce to 80% of the rated voltage, the duration is 0.5 periods. HHT simulation results after self-adaptive endpoint treatment based on waveform matching is shown in **Figure 5**, **Figure 6**.

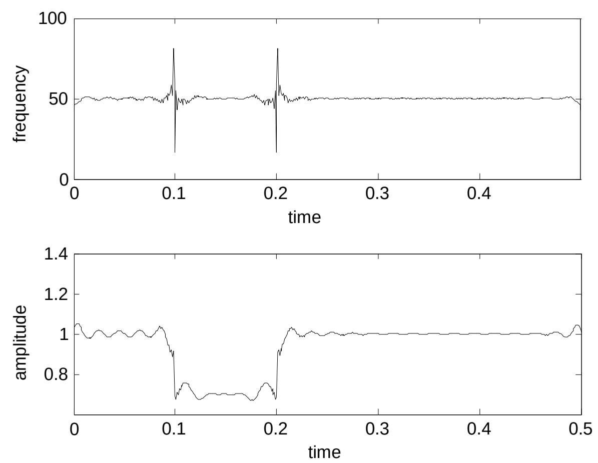

Figure 3. IMF1's amplitude, frequency variation overtime.

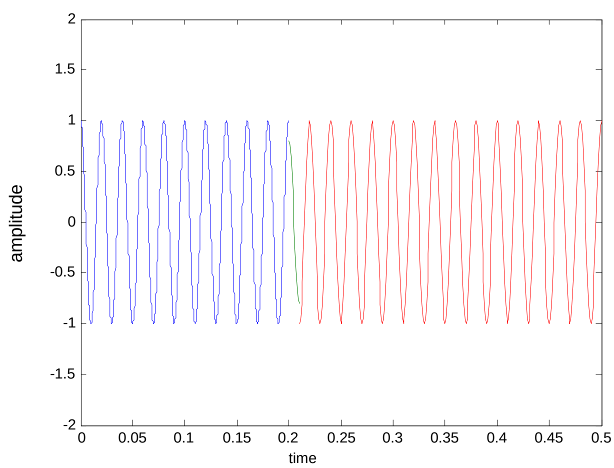

Figure 4. Voltage mutation waveform.

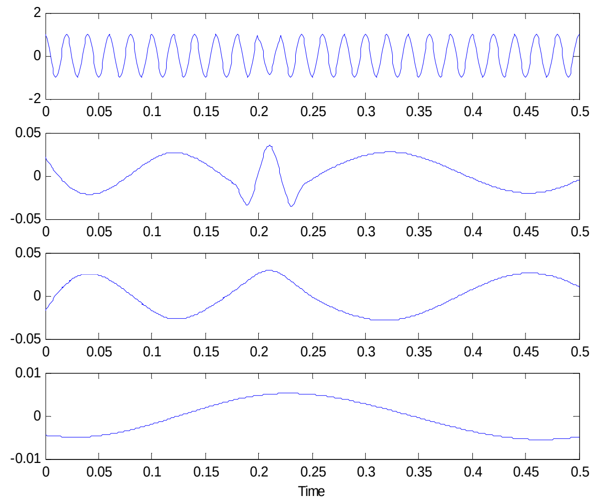

Figure 5. EMD decomposition results.

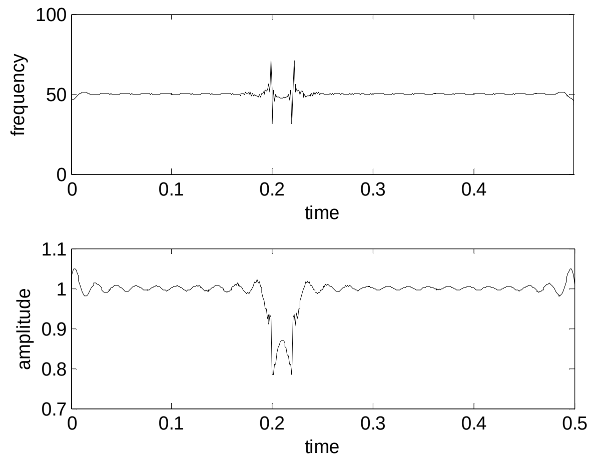

Figure 6. IMF1 amplitude, frequency variation over time.

The HHT simulation results show that in the half cycle start at 0.2 s, the wind power system voltage changes. At the time of 0.2 s, the minimum voltage of wind power system is 0.77 times the rated voltage. At the time of 0.2 s, instantaneous frequency also have great changes, The highest frequency is 68.4 Hz, the minimum frequency is only 32.2 Hz. We can judge the situation of voltage sags in wind power system effectively and in real time according to the mutations of the voltage parameter.

4. Conclusions

This paper applies Hilbert-huang transform method (HHT) to the real-time and accurate detection of the voltage sag for wind power system. In order to solve the endpoint effect when do the EMD decomposition, we use a waveform matching self-adaptive data continuation technology to manage endpoint waveform. Matlab example simulation results show that the HHT can detect the situation of voltage sags in wind power system effectively and in real time, can accurately judge the moment of voltage sag and the voltage amplitude after sag and voltage sag's duration. Export voltage of wind power system is influenced by the natural environment, so the export voltage is fluctuating. Practical problems are more complex than the research of voltage sag in this paper and it is more difficult to detect voltage fluctuation. The detection method used in this paper is especially for voltage sag of wind power system. In order to strengthen the control of the wind power system, we also need to do further research on other voltage fluctuation problems.

REFERENCES

[1] Y. Zhang and G. D. Gao, "Wind power generation," Beijing, China Power Press, 2002.

[2] Y. Y. Hu, S. S. Niu, Z. R. Liang, *etc*. "Of Voltage Flicker Measurement Algorithm," *Journal of Low Voltage Electrical Appliances*, 2012, pp. 32-36.

[3] S. J. Hu, J. L. Li and M. L, "Test Method of Wind Power System's Implementation LVRT Grid Voltage Drop. High Power Communication Technology, Vol. 2, 2008, pp. 17-21.

[4] X. P. Wei, Y. H. Xu and X. G. Xiao, "Voltage Fluctuation and Flicker Detection Methods in Electric Measurement and Instrument., Vol. 46, 2009, pp. 1-6.

[5] Y. C. Liu, "Analysis and Study of Voltage Sag's Detection Method," Changsha: hunan university, 2007.

[6] T. Y. Li, Y. Zhao, N. Li N, *etc*. "New Method for the Detection of Power Quality Based on the HHT," *Chinese Journal of Electrical Engineering*, Vol. 17, 2005, pp. 32-56.

[7] Y. M. Zhong, S. R. Qin and B. P. Shang, "Research of Hilbert - Huang Transform," *Journal of Vibration and Impact*, Vol. 21. 2002, pp. 13-17.

[8] D. J. Yu, J. S. Cheng, Y. Yang and H. Hilbert, "Transform Method for Mechanical Fault Diagnosis," Beijing: Science Press, 2006.

[9] C. X. Shao, J. Wang, J. F. Fan, *etc.*, "An adaptive EMD endpoint continuation method," *Journal of Electronics*, Vol. 35, 2007, pp. 1944-1947.