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Content list available at: www.benthamopen.com/TOEEJ/

DOI: 10.2174/1874129001711010038

RESEARCH ARTICLE

# Voltage Flicker Detecting Based on Improved HHT

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Received: May 25, 2016 Revised: November 08, 2016 Accepted: December 08, 2016

**Abstract:** This paper puts forward a new method based on Hilbert-Huang Transform (HHT) and Wavelet denoising for extracting feature information of voltage flicker signal. Firstly, envelope signal could be extracted by using HHT from original signal containing noises. Then the noises and higher harmonic components of envelope signal could be removed by using Wavelet denoising. Finally, the noise-removing envelope signal could be decomposed by using Empirical Mode Decomposition (EMD) for getting accurate amplitude modulation wave. The new method was applied to virtual instrument by using the MATLAB script node in LabVIEW. Experimental results show that this new method is applicable for analyzing voltage flicker signal both in time domain and frequency domain. The accurate time, amplitude and frequency of voltage flicker signal which is mutational and non-stationary can be obtained by using this new method.

**Keywords:** HHT, EMD, Envelope, Flicker, Wavelet denoising.

## 1. INTRODUCTION

With the development of industrial technology, a large number of high-power and variable loads have been incorporated into the power grid,such as rolling mill, electric locomotive, electric arc furnace, *etc.* [1, 2]. When the reactive power and active power of these equipment change sharply, a lot of voltage fluctuation and flicker will appear in the distribution system, which brings great harm to normal production [3, 4]. Therefore, voltage fluctuation and flicker should be properly detected and evaluated [5]. Flicker is caused by voltage fluctuations. Voltage fluctuation detection can be defined as a single frequency amplitude modulation wave modulating the power frequency carrier [6], so, it is very important to extract amplitude modulated wave accurately. The extraction of amplitude modulation wave recommended by International Electrotechnical Commission (IEC) is square detection method [7], but the method includes the frequency multiplication components of amplitude modulation wave. Fast Fourier Transformation (FFT) algorithm is used to analyze the voltage flicker signal directly [8, 9], but the method is suitable for analyzing the relatively stable signal [10]. Today, the envelope signal and mutation time of voltage flicker could be obtained by using wavelet decomposition and synchronous detection method [11], however, this method requires a signal with the same frequency and phase of the carrier wave, otherwise the error of the amplitude modulation wave is relatively large. To solve the above problems, this paper proposes a new method based on Hilbert-Huang Transform (HHT) and Wavelet denoising for detecting voltage fluctuation and flicker. The key technologies and hardware of the system are stated below.

## 2. THE HARDWARE OF THE SYSTEM

The voltage flicker detecting system was developed by using the virtual instrument technology. The hardware of system consists of sensors, signal conditioning circuits, transfer boards, data acquisition (DAQ) and computer. The sensors are HYH-SB-13/16 voltage sensor and C2N current sensor. The signal conditioning circuit revises error of sensor caused by individual difference, it is inverse proportion operation circuit composed of integrated operational

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amplifier OP07. The data acquisition is USB-6211, which provides the following standard features: 16 channel analogy single, 8 channel difference analogy input, 16 bit precision, 250KS/s sampling frequency, ±0.05V to ±10V input range, 24 digital I/O lines.

## 3. ARITHMETIC MODEL OF EXTRACTING AMPLITUDE MODULATION WAVE BASED ON HHT AND WAVELET DENOISING

HHT is an adaptive signals processing method and could be applied to non-linear and non-stationary signal processing [12]. In HHT, the Empirical Mode Decomposition (EMD) is the key component for decomposing natural signals into intrinsic mode functions (IMFs) [13].

### 3.1. Arithmetic Model of Extracting Amplitude Modulation Wave

New arithmetic model of extracting amplitude modulation wave is shown in Fig. (**1**). Firstly, envelope signal could be extracted from original signal by using HHT method. The noises and higher harmonic components of envelope signal could be removed by using Wavelet denoising. Then, the noise-removing envelope signal could be decomposed by using EMD for getting accurate amplitude modulation wave. Finally, time-frequency diagrams could be obtained by analyzing time-frequency information of amplitude modulation wave.

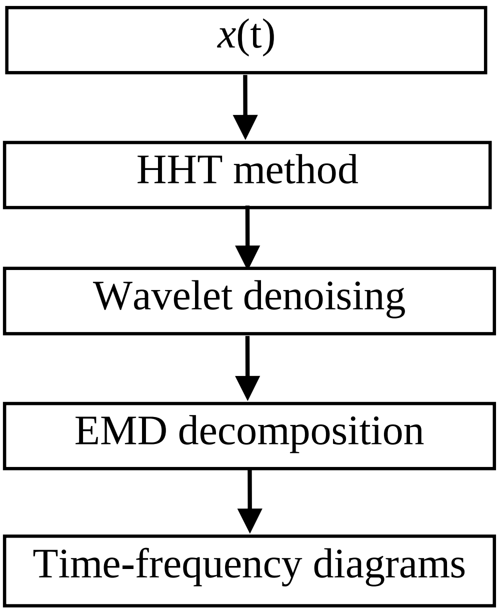


**Fig. (1).** The arithmetic model of extracting amplitude modulation wave.

### 3.2. Hilbert Transform

For any continuous time signal $x(t)$, its Hilbert transform can be described as [14, 15]:

$$H \; x \; t = \frac{1}{\pi}\int_{-\infty}^{(\infty)} \frac{x \; \tau}{t-\tau} d\tau \tag{1}$$

The analytic signal of $x(t)$ can be described as:

$$X(t) = x(t) + jH\{x(t)\} \tag{2}$$

The equation also can be described as:

$$X(t) = A(t)e^{-j\theta(t)} \tag{3}$$

Where $A(t)$ is instantaneous amplitude. $\theta$(t) is instantaneous phase.

Instantaneous frequency can be described as:

$$f\ t = \frac{1}{2\pi}\frac{d\theta(t)}{dt} \tag{4}$$

### 3.3. Empirical Mode Decomposition

For any given signal $x(t)$, all the extreme points of $x(t)$ should be searched. Then, cubic spline interpolation algorithm is used to connect all the maximum values to form the upper envelope, connect all the minimal values to form lower envelope. The mean value of the upper and lower envelopes is $m(t)$. The difference between $x(t)$ and $m(t)$ can be expressed as [16]:

$$h(t) = x(t) - m(t) \tag{5}$$

If $h(t)$ is IMF, $h(t)$ will meet:

(1) The extreme point number of the signal curve is equal to that of the signal curve passing through the zero point, or the maximum difference of the two is 1.

(2) On any signal point, the mean value between envelope of maximum value and envelope of minimum value is 0.

If $h(t)$ is not the IMF, $h(t)$ can be seen as a new $x(t)$ and step(1) should be repeated until $h(t)$ meets the IMF conditions. The first IMF1 extracted from original signal is denoted as $C_1(t)$, symbolizing high frequency component of the original signal.

The difference between $x(t)$ and $C_1(t)$ can be expressed as:

$$r_1(t) = x(t) - C_1(t) \tag{6}$$

Longer cycle components are still contained in $r_1(t)$. So $r_1(t)$ can be seen as new data sequence. Then above steps should be repeated and other IMFs can be obtained.

$$r_2(t) = r_1(t) - C_2(t) \tag{7}$$

…

$$r_n(t) = r_{n-1}(t) - C_n(t) \tag{8}$$

The decomposition process is over until $r_n(t)$ is monotonic or $r_n(t)$ has only one extreme point. The original data can be finally decomposed as:

$$x(t) = \sum_{i=1}^{n} c_i(t) + r_n \tag{9}$$

Each IMF is symbolized as $C_1(t)$, $C_2(t)$,........,$C_n(t)$, representing frequency components of the signal from high to low.

The original signal is decomposed by using EMD for getting each IMF signal. Then the parameters of each IMF could be obtained by using Hilbert transform. This method is called Hilbert-Huang transform. HHT can be used for accurately detecting the disturbance time, frequency and amplitude of mutation signal and non-stationary disturbance signal.

### 3.4. The Simulation of Signal Which Has Higher Harmonics and Noises by Using HHT

Flicker is caused by voltage fluctuations, instantaneous voltage fluctuation can be described as [7]:

$$u = U[1 + m\cos(\Omega t)]\cos(\omega t) \tag{10}$$

Where $U$ is amplitude of power frequency carrier wave and $\omega$ is angle frequency, $m$ is amplitude of amplitude modulation wave and $\Omega$ is angle frequency.

Because, amplitude modulation wave can be seen as synthesis of various frequency components, and considering higher harmonic components, the above equation, can be expanded as [17]:

$$u = U\left[1+\sum_{i=1}^{N} m_i \cos\left(2\pi f_i t+\varphi_i\right)\right]\left[\cos\left(2\pi f_0 t+\varphi_0\right)+\sum_{j=2}^{K} m_j \cos\left(2\pi f_j t+\varphi_j\right)\right] \quad \mathbf{(11)}$$

Where $m_i$ is relative amplitude of the ith amplitude modulated wave. is amplitude of fundamental voltage. $f_i$ and $\varphi_i$ are frequency and phase of the ith amplitude modulated wave. $f$ and $\varphi$ are frequency and phase of fundamental wave. $m_j$ is relative amplitude of the $j^{th}$ harmonic wave. $f_j$ and $\varphi_j$ are frequency and phase of the jth harmonic wave.

Envelope signal could be extracted from original voltage flicker signal by using HHT.

A original signal can be described as

$$u = \begin{cases} \cos 100\pi t & t < 0.3\text{s} \\ (1+0.1\cos 20\pi t)(\cos 100\pi t + 0.1\cos 300\pi t) & 0.3\text{s} \le t \le 0.7\text{s} \\ \cos 100\pi t & t > 0.7\text{s} \end{cases} \quad \mathbf{(12)}$$

Where signal noise ratio (SNR) of $u$ is 23, sampling frequency is 3200Hz, The simulation results by using HHT are shown in Fig. (**2a**) is original signal containing noise, Fig. (**2b**) is the voltage flicker envelope signal extracted by using HHT.

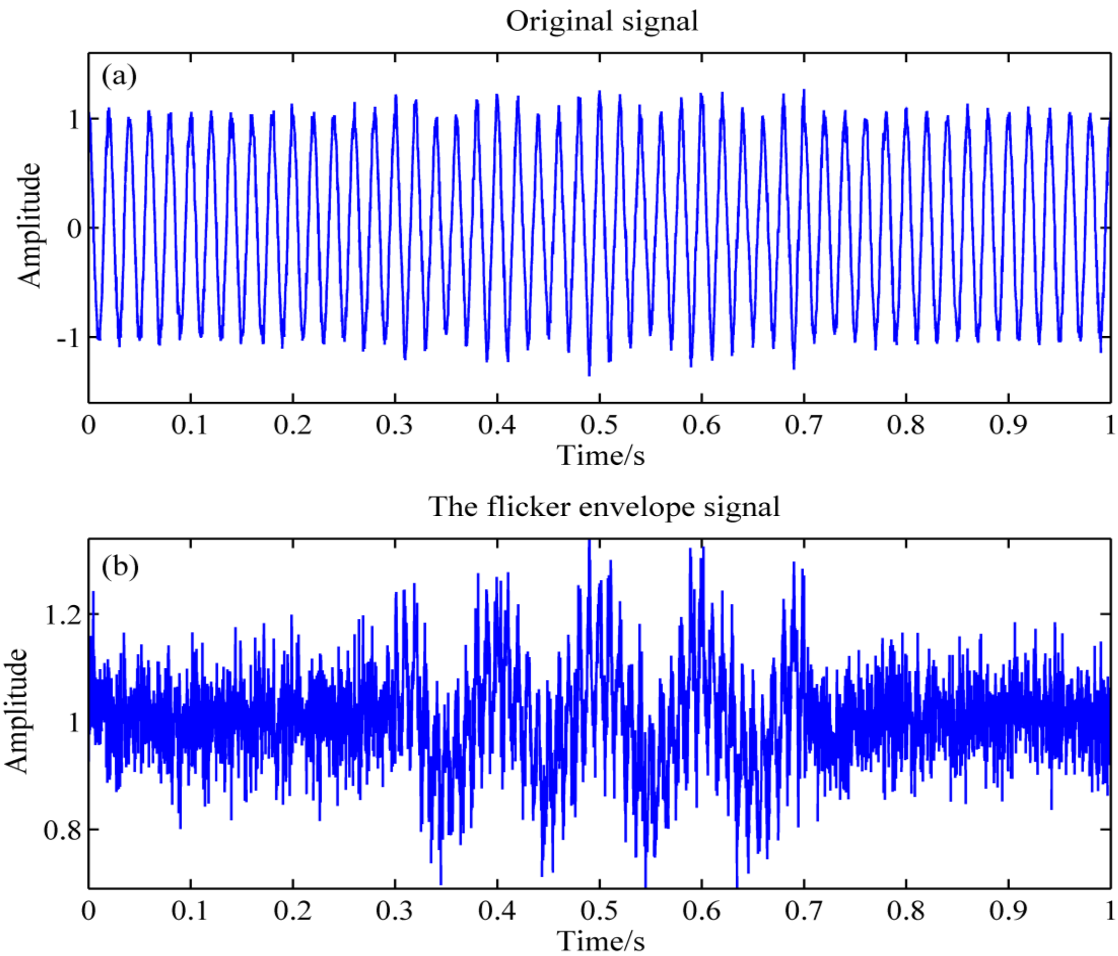


**Fig. (2).** Envelope signal extracted from voltage flicker signal by using HHT (**a**) Original signal, (**b**) The flicker envelope extracted by HHT.

The simulation results show that the voltage flicker envelope signal extracted only by using HHT contains noise and harmonics components, the amplitude and frequency of the calculated flicker signal have large errors, so denoising is necessary. Wavelet denoising can be used for non-stationary signals, which has good denoising effects. So, we use Wavelet denoising.

### 3.5. Wavelet Denoising

The process of Wavelet denoising:

1. By using wavelet decomposition, the signal which contains noise could be decomposed. There are two parts in decomposition results. They are detail signal and approximate signal.
2. Approximate signal was reserved. Depending on the nature of noise, detail signal was processed by using the method of threshold.
3. After the above processing, noise of the signal was basically eliminated, different scales of signal which had been processed could be restructured.

The key of threshold processing is how to determine an appropriate threshold value of $\delta_j$, The system selects the universal threshold method by Donoho [18].

$$\delta_j = \sigma_j\sqrt{2\ln(N_j)} \quad \textbf{(13)}$$

Here, $\sigma_j$ is the noise variance and $N_j$ is the signal length.

At present, widely used in practice is hard threshold function and soft threshold function, hard threshold function is [19].

$$\widehat{\omega}_{j,k} = \begin{cases} \omega_{j,k} & |\omega_{j,k}| \geq \delta_j \\ 0 & |\omega_{j,k}| < \delta_j \end{cases} \quad \textbf{(14)}$$

Where $\omega_{j,k}$ are the coefficients of the wavelet without noise removal.

Soft threshold function is [20].

$$\widehat{\omega}_{j,k} = \begin{cases} (|\omega_{j,k}| - \delta_j)sign(\omega_{j,k}) & |\omega_{j,k}| \geq \delta_j \\ 0 & |\omega_{j,k}| < \delta_j \end{cases} \quad \textbf{(15)}$$

Because the hard threshold method is not continuous and soft threshold method biased. In his paper, an improved threshold function is used based on soft and hard threshold function.

$$\widehat{\omega}_{j,k} = \begin{cases} \alpha\omega_{j,k} + (1-\alpha)(|\omega_{j,k}| - \delta)sign(\omega_{j,k}) & |\omega_{j,k}| \geq \delta \\ 0 & |\omega_{j,k}| < \delta \end{cases} \quad \textbf{(16)}$$

Where α is compromise coefficient, and 0 ≤ a ≤ 1. If $a = 0$, formula 16 and formula 15 are equal, and are soft threshold estimation methods. If a=1, formula 16 and formula 14 are equal, and are hard threshold estimation methods. So, a is added to the threshold algorithm, we can get a better denoising effect by adjusting the value of a between 0 and 1. The improved threshold function overcomes the shortcoming of the hard threshold method and soft threshold method.

In the simulation, wavelet function DB5 was selected and decompose level was five. Using the soft threshold, the hard threshold and the improved threshold, the signal in Fig. (**2b**) eliminated noise and harmonics components. Simulation results are shown in Fig. (**3**), The simulation results show that the improved threshold method has better denoising effect than the other methods.

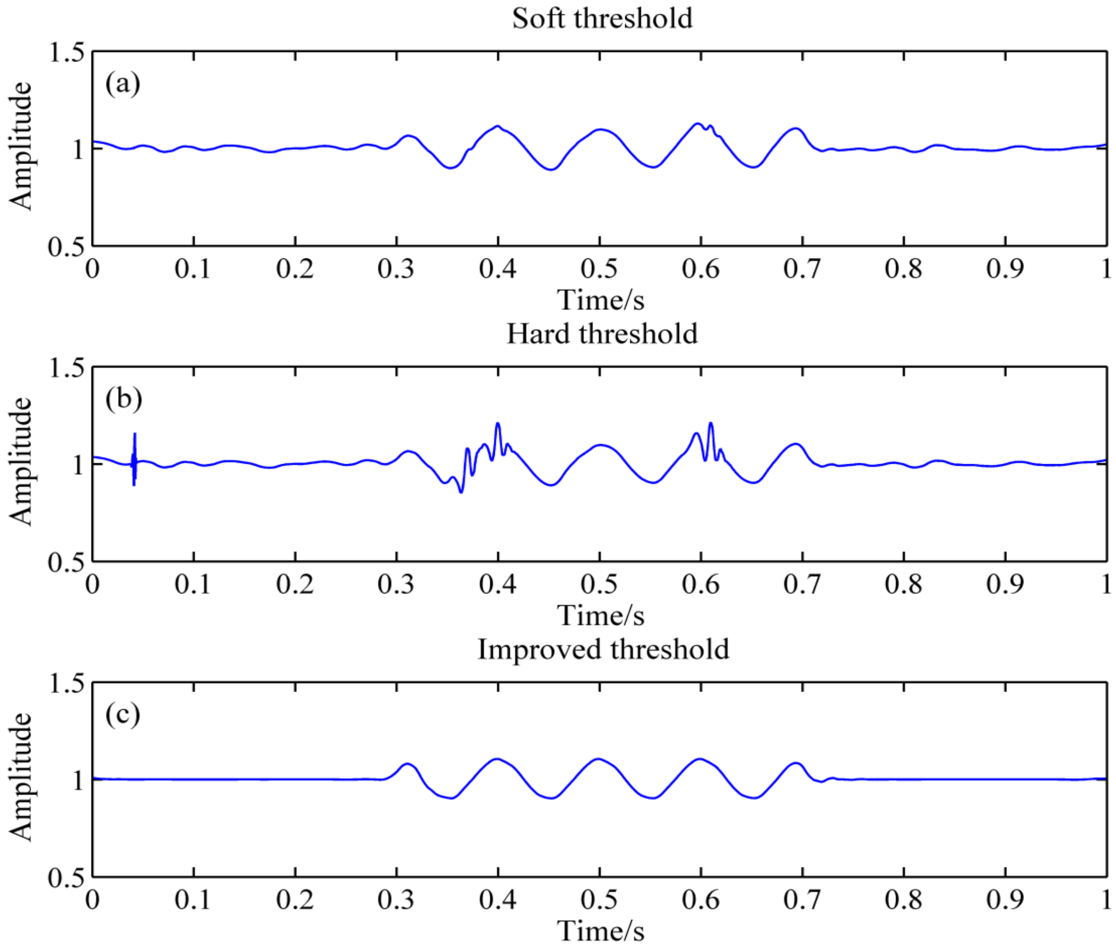


**Fig. (3).** Wavelet denoising results, (**a**) Soft threshold, (**b**) Hard threshold, (**c**) Improved threshold.

### 3.6. The Program Designing

The software development platform of monitoring voltage fluctuation and flicker is LabVIEW. The program designing based on HHT and Wavelet denoising can be realized by mixed programming of MATLAB and LabVIEW. Firstly, set up MATLAB scripts nodes, then, add input and output terminals, select types of input and output variable, and input program to MATLAB script frame. Fig. (**4**) shows the flow chart in LabVIEW. Where *fs* is sampling frequency, z represents a sampling signal, *a* is compromise coefficient, aabs expresses the voltage flicker envelope signal extracted by using HHT, my() expreses Wavelet denoising subprogram, *bb* expreses denoised signal, *ff* expreses Hilbert-Huang spectrum, oscilloscopes display aabs, bb and other waveforms.

## 4. SIMULATION AND ANALYSIS

### 4.1. A Single Frequency Voltage Flicker Signal

Voltage flicker signal could be simulated by using wavelet decomposition and synchronous detection method (also called wavelet method), HHT and wavelet denoising method (also called improved HHT), IEC square detection method, respectively.

A single frequency voltage flicker signal can be described as:

$$u = [1 + 0.1\cos(20\pi t)]\cos 100\pi t \qquad \textbf{(17)}$$

Where signal noise ratio (SNR) of *u* is 25, sampling frequency is 3200Hz, Wavelet basis function is DB5 and the decomposition level is 5.The simulation results are shown in Fig. (**5a**) is original signal containing noise, Fig. (**5b**-**d**) are the voltage flicker envelope signals extracted by using different ways. The simulation results show that IEC square detection method is worse than the other two methods. Because of the boundary effect of improved HHT, sampling time is 4s, when the amplitude and frequency of the signal are calculated, both sides of the signal waveform should be removed two cycles to ensure the accuracy of the measurement. The calculation results are shown in Table **1**. The simulation results show that improved HHT method is better than wavelet decomposition and synchronous detection.

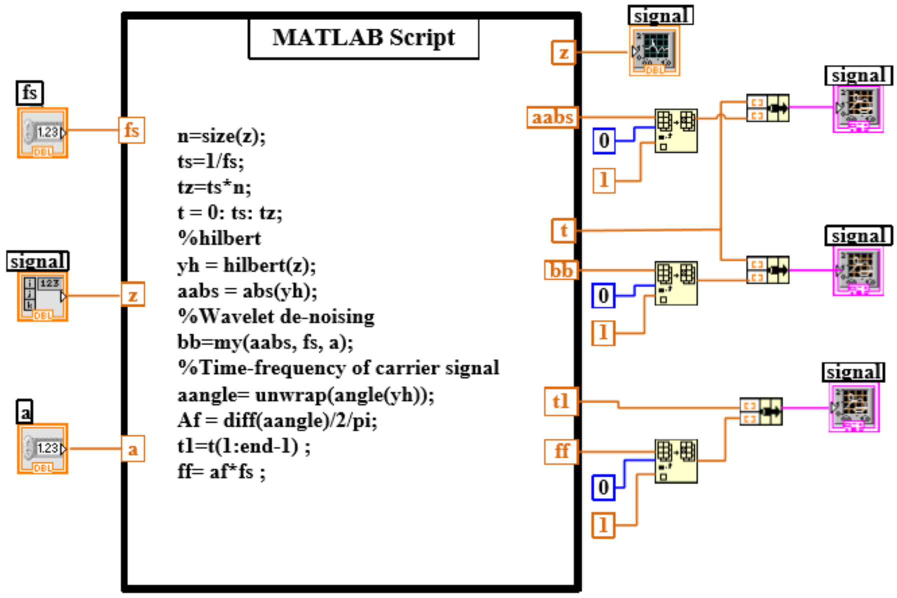


**Fig. (4).** The flow chart of monitoring voltage flicker.

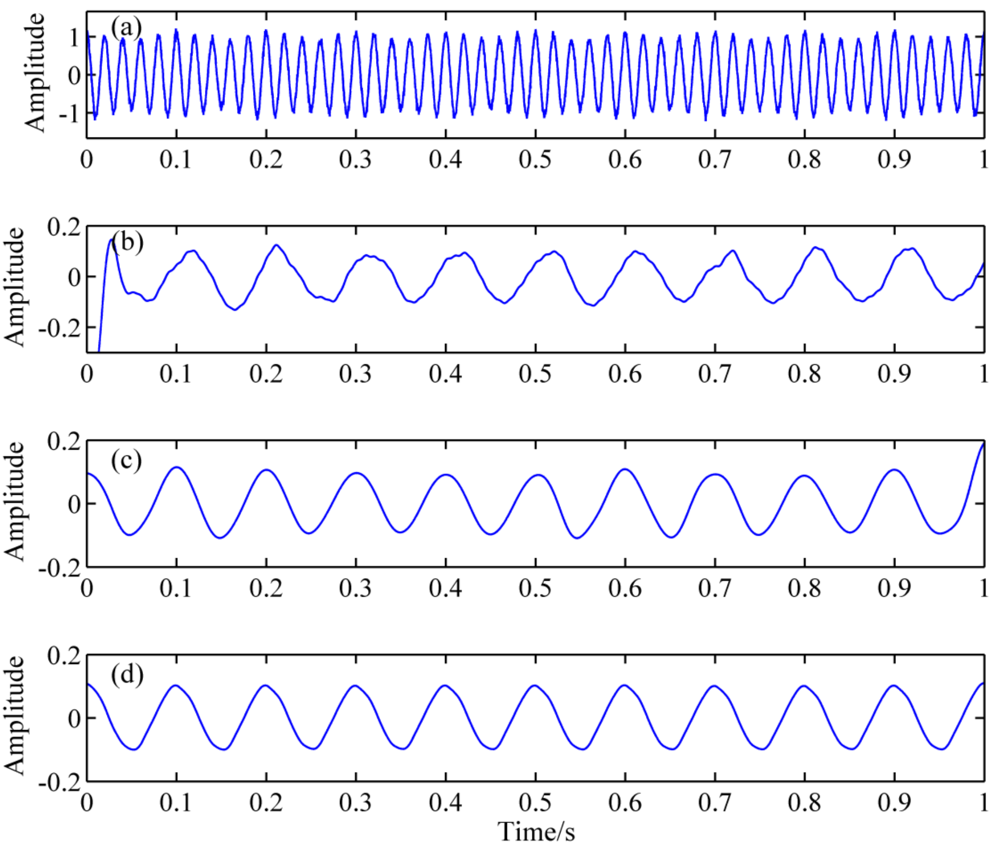


**Fig. (5).** The simulation of a single frequency flicker signal (**a**) Original signal, (**b**) IEC square detection, (**c**) wavelet decomposition and synchronous detection, (**d**) HHT and Wavelet de-noising.

**Table 1. The simulation results of a single frequency voltage flicker signal by using two methods.**

**Table 1. The simulation results of a single frequency voltage flicker signal by using two methods.**

| | Amplitude measurement | | Frequency measurement | |
|---|---|---|---|---|
| | Relative amplitude | Error (%) | Frequency (Hz) | Error (%) |
| Wavelet method | 0.100692 | 0.692 | 8.995 | 0.0556 |
| improved HHT | 0.099985 | 0.015 | 8.9951 | 0.054 |

### 4.2. Voltage Flicker Signal During a Certain Time Period

Voltage flicker during a certain time period can be expressed as:

$$u = \begin{cases} \cos 100\pi t & t < 0.3\text{s} \\ (1 + 0.1\cos 20\pi t)\cos 100\pi t & 0.3\text{s} \le t \le 0.7\text{s} \\ \cos 100\pi t & t > 0.7\text{s} \end{cases} \tag{18}$$

Sampling frequency is 3200Hz, Wavelet basis function is DB5 and the decomposition level is 5. The simulation results are shown in Fig. (**6**).

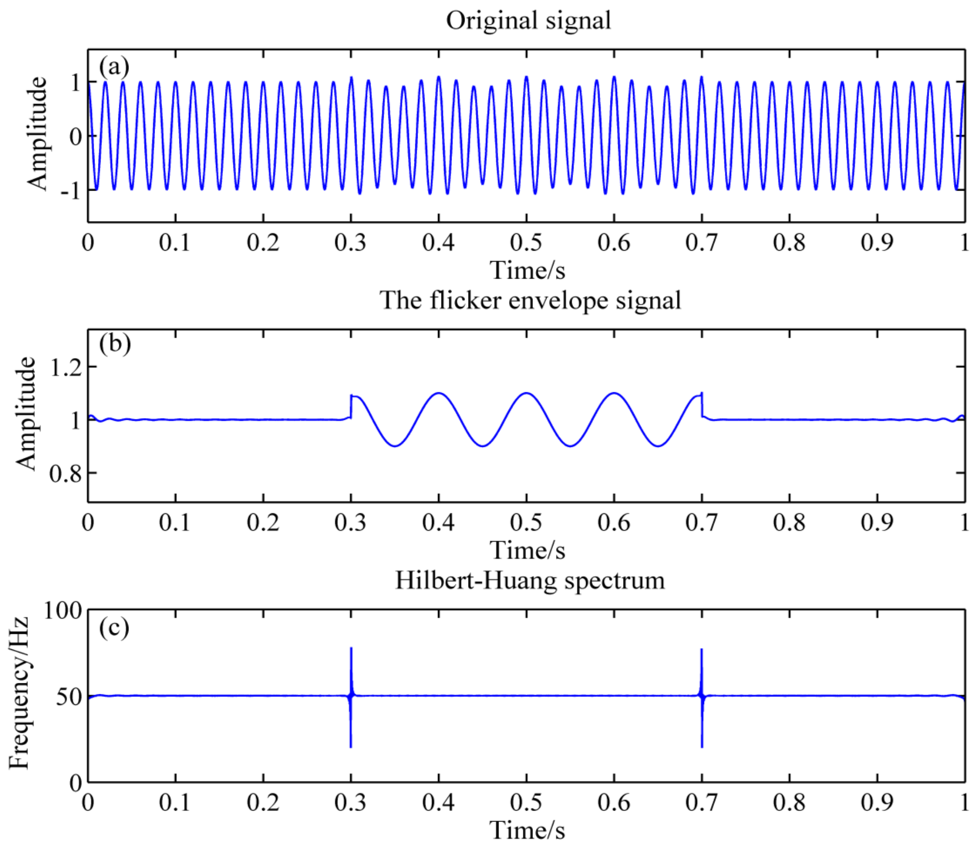


**Fig. (6).** The simulation waveform of adding flicker signal during a certain time period **(a)** Original signal, **(b)** Envelope signal, **(c)** Hilbert-Huang specture.

By using improved HHT, the parameters of voltage flicker signal can be calculated. The relative amplitude of this voltage flicker signal is 0.09984 and the error is 0.00016. The frequency is 10.0313 Hz and the error is 0.0313Hz, the start time of voltage flicker is 0.3s and the end time of voltage flicker is 0.7s.

### 4.3. Multiple Frequency Voltage Flicker

Multiple frequency voltage flicker can be describe as:

$$a = [1 + 0.1\cos(12\pi t) + 0.04\cos(40\pi t)]\cos 100\pi t \tag{19}$$

Where signal noise ratio (SNR) of *u* is 25, sampling frequency is 3200Hz, Wavelet basis function is DB5 and the decomposition level is 5. The simulation results are shown in Fig. (**7**). Where the noise-removing envelope signal could be decomposed into IMFs by using EMD, IMF3 is 20Hz amplitude modulated wave as shown in Fig. (**7c**), IMF4 is 6Hz amplitude modulated wave as shown in Fig. (**7d**). By using the improved HHT, the parameters of voltage flicker signal can be calculated.

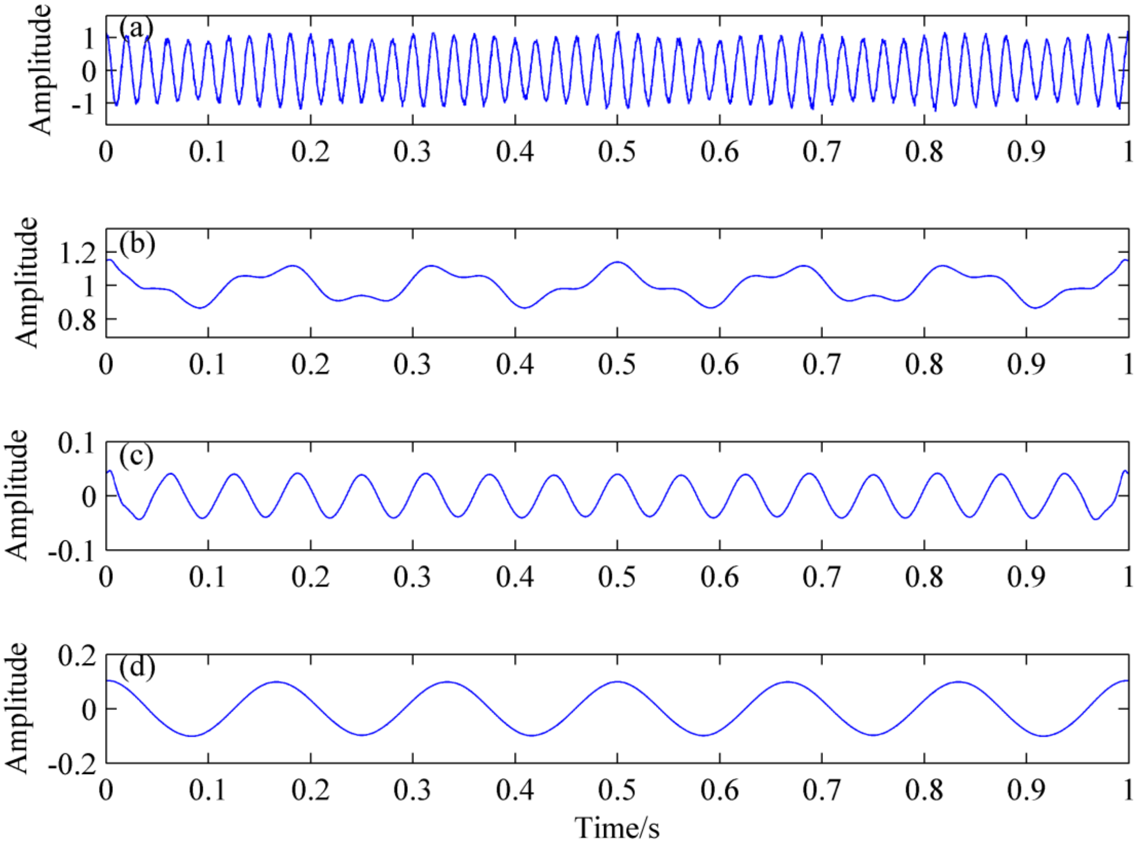


**Fig. (7).** The simulation waveform of multiple frequency voltage flicker signal. **(a)** Original signal, **(b)** Envelope signal, **(c)** A little higher frequency amplitude modulated wave, **(d)** low frequency amplitude modulated wave.

The relative amplitude of 20Hz amplitude modulation wave is 0.03941, and the error is 0.00059. The frequency of 20Hz amplitude modulation wave is 20.0121Hz, and the error is 0.0121. The relative amplitude calculation result of 6Hz amplitude modulation wave is 0.09821 and the error is 0.00179. The frequency calculation result of 6Hz amplitude modulation wave is 5.9682Hz and the error is 0.0318Hz.

## CONCLUSION

A new method based on HHT and Wavelet de-noising was proposed in this paper for extracting feature information of voltage flicker signal. Firstly, envelope signal could be extracted by using HHT. Secondly, the noise and harmonic components of envelope signal could be eliminated by using wavelet denoising. Finally, accurate amplitude wave could be obtained by decomposing the denoising envelope signal. HHT algorithm and Wavelet denoising algorithm were applied to virtual instrument by using the MATLAB script node in LabVIEW. This paper compares the commonly used voltage flicker detection method, such as wavelet method, the square detection method and improved HHT method. The simulations show that results of improved HHT method are the most accurate. This improved HHT method can not only analyze the single frequency flicker signal, but also analyze the multi frequency single containing noise and harmonic component, and can get the accurate time, amplitude and frequency of voltage flicker.

## CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

## ACKNOWLEDGEMENTS

This work was financially supported by the National Nature Science Foundation of China under Grant (51407112).

## REFERENCES

[1] S. Bhattacharyya, S. Cobben, J. Myrzik, and W. Kling, "Flicker propagation and emission coordination study in a simulated low voltage network", *Eur. Trans. Electr. Power,* vol. 20, pp. 52-67, 2010.
[http://dx.doi.org/10.1002/etep.402]

[2] M. Maksic, and I. Papic, "Analysis of flicker propagation with representative samples of network voltage", *IEEE Trans. Power Deliv.,* vol. 26, pp. 2066-2067, 2011.
[http://dx.doi.org/10.1109/TPWRD.2011.2123474]

[3] G.C. Montanari, M. Loggini, I.A. Cavallin, L. Pitti, and D. Zaninelli, "Arc furnace model for the study of flicker compensation in electrical networks", *IEEE Trans. Power Deliv.,* vol. 9, pp. 2026-2036, 1994.
[http://dx.doi.org/10.1109/61.329535]

[4] Z.M. Li, J. Shen, W. Liu, and Y.J. Wang, "Voltage flicker monitoring based on virtual instrument and wavelet packet transform", *Int. J. Adv. Comput. Technol.,* vol. 23, pp. 466-474, 2012.

[5] Y. Liu, and H.G. Yang, "Voltage flicker detection based on independent component analysis", *Electr. Power Autom Equip.,* vol. 27, pp. 34-37, 2007.

[6] S.H. Guo, C. Huang, L. Wang, and G.J. Cao, "Detection and suppression methods for voltage fluctuation and flicker", *Relay,* vol. 32, pp. 45-48, 2004.

[7] S.M. Halpin, R. Bergeron, T.M. Blooming, R.F. Burch, L.E. Conrad, and T.S. Key, "Voltage and lamp flicker issues: Should the IEEE adopt the IEC approach?", *IEEE Trans. Power Deliv.,* vol. 18, pp. 1088-1097, 2003.
[http://dx.doi.org/10.1109/TPWRD.2003.814261]

[8] Z.J. Zhou, W.H. Zhou, and Q. Li, "A new method for the detection of voltage flicker using wavelet transform and synchronous detection", *Proceedings of the EPSA,* pp. 23-25, 2001.

[9] K. Srinivasan, "Digital measurement of voltage flicker", *IEEE Trans. Power Deliv.,* vol. 6, pp. 1593-1598, 1991.
[http://dx.doi.org/10.1109/61.97697]

[10] M.T. Chen, "Digital algorithms for measurement of voltage flicker", *IEE Proc., Gener. Transm. Distrib.,* vol. 144, pp. 175-180, 1997.
[http://dx.doi.org/10.1049/ip-gtd:19970683]

[11] J. Chen, "Wavelet transform and synchronous detection method applied in detection of voltage flicker", *Electric Power Science and Engineering,* vol. 32, pp. 20-23, 2007.

[12] R.T. Rato, M.D. Ortigueira, and A.G. Batista, "On the HHT, its problems, and some solutions", *Mech. Syst. Signal Process.,* vol. 22, pp. 1374-1394, 2008.
[http://dx.doi.org/10.1016/j.ymssp.2007.11.028]

[13] W.C. Shen, Y.H. Chen, and A.Y. Wu, "Low-complexity sinusoidal-assisted EMD (SAEMD) algorithms for solving mode-mixing problems in HHT", *Digital Signal Process Rev. J.,* vol. 24, pp. 170-186, 2013.
[http://dx.doi.org/10.1016/j.dsp.2013.08.004]

[14] Y. Önal, D.G. Ece, and Ö.N. Gerek, "Hilbert-Huang transform based approach for measurement of voltage flicker magnitude and frequency", *Electr. Power Comp. Syst.,* vol. 43, pp. 167-176, 2015.
[http://dx.doi.org/10.1080/15325008.2014.978054]

[15] H. Shu, and Y. Wang, "Voltage flicker detection method based on mathematical morphology filter and hilbert transform", *Proc. Chin. Soc. Electr. Eng.,* vol. 28, pp. 111-114, 2008.

[16] H. Jiang, X.Q. Wang, and J.C. Peng, "Method to measure voltage flicker based on Hilbert-Huang transform", *Dianwang Jishu,* vol. 36, pp. 250-256, 2012.

[17] S.J. Huang, and C.W. Lu, "Enhancement of digital equivalent voltage flicker measurement via continuous wavelet transform", *IEEE Trans. Power Deliv.,* vol. 19, pp. 663-670, 2004.
[http://dx.doi.org/10.1109/TPWRD.2003.820174]

[18] D.L. Donoho, and I.M. Johnstone, "Ideal spatial adaptation by wavelet shrinkage", *Biometrika,* vol. 81, pp. 425-455, 1994.
[http://dx.doi.org/10.1093/biomet/81.3.425]

[19] F.F. Cunha Caio, T. Carvalho André, R. Petraglia Mariane, and C.S. Lima Antonio, "A new wavelet selection method for partial discharge denoising", *Electr. Power Syst. Res.,* vol. 125, pp. 184-195, 2015.
[http://dx.doi.org/10.1016/j.epsr.2015.04.005]

[20] D.L. Donoho, "De-noise by Soft-thresholding", In: *IEEE Trans on Information Theory,* vol. 41. 1995, pp. 613-627.

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