Acta Technica *62* (2017), No. 7A, 35–42

A mixed mode empirical mode decomposition (EMD) method based on cosine window mask signal

Lina Zhang[1], Nan Wang[1], Hao Wu[2]

Abstract. To improve the effect of harmonic detection algorithm of wind power generation, a kind of harmonic detection method of wind power generation based on aliasing empirical mode decomposition (EMD) of mask signal of cosine window is proposed in the Thesis. Firstly, conduct research on the EMD algorithm to improve the end effect of EMD algorithm based on mirror extension and cosine window function and achieve aliasing improvement of EMD mode through mask signal; secondly, conduct experimental contrast verification on the effect of EMD algorithm on harmonic detection of wind power generation. The experimental results show that the harmonic detection algorithm referred to can provide a more precise parameter distribution scope, reflecting the advantage of the algorithm.

Key words. Cosine window, Mask signal, Empirical mode decomposition, Wind power generation, Harmonic detection.

1. Introduction

Various power electronic inverters, non-linear and impact load in modern micro-grid gradually connect to the micro-grid, bringing severe power quality problems to the micro-grid and even the power distribution network after grid connection, such as harmonic, inter-harmonics, voltage drop, voltage swell, voltage interruption and etc. To ensure the safe and reliable operation of equipment in the power grid, it is especially necessary to conduct real-time detection and analysis on the power quality of micro-grid (especially harmonics) through microcomputer and automatic monitoring equipment and then carry out the harmonic suppression.

During the practical engineering application, the pollution of power grid by har-

---

[1] Economic & Technology Research Institute, State Grid Shandong Electric Power Company, Jinan, Shandong, China

[2] Shandong Qilu Electrical Machinery Co., Ltd., Jinan, Shandong, China

monic directly influences the safety of power grid. For the detection and analysis of power grid harmonic problems, domestic and foreign scholars put forward many methods. Literature [] proposes the parallel detection algorithm of harmonic current based on instantaneous reactive power theory. The dynamic response speed of this kind of method is fast and the detection is relatively accurate. However, for the instantaneous reactive power theory, the signal is only converted at time domain which is adverse to spectral analysis of signal. Literature [] adopts a kind of fast Fourier transform of window function to analyze the harmonic signal in power quality. The simulation indicates that the algorithm can better detect the frequency and phase position of steady-state harmonic. However, the short-time Fourier transform has the following disadvantages: the window is changeless and it is hard to analyze the non-steady harmonic signal; Literature [] proposes the harmonic detection technology based on wavelet transform algorithm. The wavelet transform has such advantages as high calculation accuracy and good adaptivity. However, calculation amount is large and it relies on the selection of wavelet basis function; Literature [] proposes a kind of adaptive harmonic detection method based on least square method. It has good real-time performance and can effectively extract the information of fundamental wave and harmonic. However, its accuracy for the fundamental wave with large frequency fluctuation range will be affected; in addition, there are such analysis methods for harmonic detection in power grid as space vector analysis method, BP neural network method, d-q rotating coordination transformation method and etc.

To improve the known effect of harmonic, a kind of harmonic detection of aliasing EMD wind power generation based on the mask signal of cosine window is proposed in the Thesis to achieve the improvement of harmonic detection level of wind power generation.

2. EMD and relevant processing methods.

2.1. General of EMD method

EMD method can be regarded as a high-pass filter of wind power generation harmonic which decomposes IMF one by one in accordance with the size of characteristic time scale in the signal. In this method, all local extremums of signal $u(t)$ are firstly determined and then the local maximum and minimum values of the signal are fitted with cubic spline function to form the upper and lower envelope lines and obtain the average value of the upper and lower envelope lines denoted by $m_1(t)$ and calculate: $h_1(t) = u(t) - m_1(t)$. If h_1 meets the condition of IMF, the first IMF component will be got and denoted by $c_1(t)$; if the condition is not, take $h_{11}(t) = h_1(t)$ as a new signal and repeat the above steps till the $h_{1k}(t)$ meeting the condition is decomposed and it will be the first IMF component $c_1(t)$ of the signal. Then, separate $c_1(t)$ from the original signal and obtain $r_1(t)$ and repeat the above steps to get the second IMF component meeting the condition. After n times of circulation, $u(t) = \sum\limits_{i=1}^{n} c_i(t) + r_n(t)$ is got.

During the above decomposition progress, the fitting error will occur during the cubic spline interpolation due to the uncertainty of extremum at both ends of signal at each time the envelope line being fitted with cubic spline curve and fitted envelope line near the end deviates from the real envelope line and the errors are constantly accumulated and diffuse inward with each decomposition calculation, thus causing the end effect. However, the mode aliasing phenomenon is as follows: after the EMD, an IMF component includes frequency component with large scale difference or frequency component with a similar scale occurs in different components and the occurrence of mode aliasing causes the original IMF component decomposed by EMD losing the physical significance it shall contain. The research indicates that the following situations may cause mode aliasing: (1) When the decomposed signal contains discontinuous signal with small amplitude and high frequency, the mode aliasing will occur in the decomposition result and this kind of discontinuous signals are collectively referred to as “abnormal event”. (2) When the processed signal contains components of a certain frequency or amplitude relation, the mode aliasing phenomenon may also occur in the EMD result.

2.2. Improvement of cosine window function of EMD end effect

EMD based on mirror extension and cosine window function can effectively resolve the adverse effect of end effect on signal decomposition. This method assume to place a mirror respectively at both end of signal data; the image of data as part of extension will be processed with the addition cosine window to form a new data series with the processed extension data and original data; after the decomposition processing of the new data series, only the original data processing result will be output and displayed.

For the cosine window function, the definition is as follows: the amplitudes on both sides gradually reduce from 1 to 0 and amplitude of the middle window function is 1. The cosine window function is as shown in Fig.1. The process of windowing is to multiply the extension part by attenuation part on both sides of the signal and multiply the original signal by the middle part of window function. Accordingly, it can be ensured that the sudden change on both ends of signal will not occur after the windowing of the newly extended data to prevent the decomposition result from excessively deviating from the actual curve and the value of the signal will not change. Control the end effect of EMD on both ends of signal to slow down the development towards the inside of data and ensure the correct decomposition of data at the middle of signal.

2.3. Improvement of mask signal method of EMD aliasing mode

During the research on EMD algorithm, Literature [] concludes that when the frequency ratio of two adjacent components occurring in the signal containing more than two frequency components is $0.5 < f_1/f_2 < 2$, the mode aliasing will occur if EMD is used. Literature [] proposes the mask signal method which can suppress the

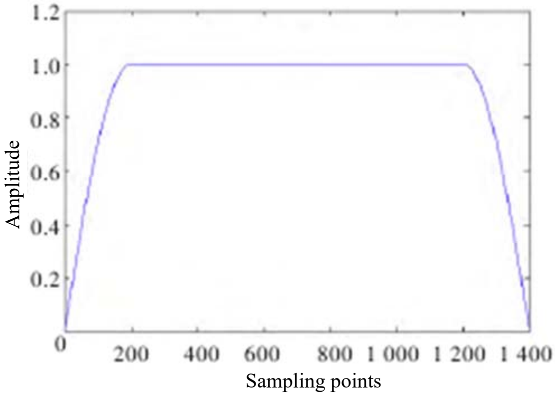

Fig. 1. Cosine Window Function

mode aliasing occurring during the EMD signal decomposition. For signal $u(t)$, the basic process of mask signal method is as follows:

(1) Create mask signals$s(t)$, $s(t) = a_0 \sin(2\pi f t)$.

(2) Carry out EMD decomposition on $u_+(t) = u(t) + s(t)$ and $u_-(t) = u(t) + s(t)$ and take their first IMF component respectively and denote them by $z_+(t)$ and $z_-(t)$.

(3) Calculate the average value of $z_+(t)$ and $z_-(t)$: $z(t) = (z_+(t) + z_-(t))/2$. Take $z(t)$ as the first IMF component decomposed of $u(t)$.

Whether the mask signal method can effectively suppress the mode aliasing phenomenon relies on whether the amplitude a_0 and frequency f of mask signal $s(t)$ can be accurately found out. For signal $u(t)$, assume its highest frequencies as f_1 and f_2 and the corresponding amplitudes are M_1 and M_2. If t he frequency and frequency of the signal meet the following conditions:

$$f_1 \leq 1\&\&M_1 < R_{21}M_2\,. \tag{1}$$

$$f_1 > 1\&\&f_1 \leq R_1 f_2\,. \tag{2}$$

$$f_1 > 1, R_1 f_2 < f_1 < R_2 f_2\&\&M_1 \leq R_{22}M_2\,. \tag{3}$$

$$f_1 > 1, f_1 \geq R_2 f_2\&\&M_1 \leq R_{23}M_2\,. \tag{4}$$

Where, $R_{21} = 1.1, R_1 = 1.5$, $R_2 = 2, R_{22} = 2, R_{23} = 0.5$.

The mask signal added at that time is $s_1(t) = M_1 \sin(2\pi(f_1 + f_2)t)$. That is to say the signal frequency id the sum of the above two highest frequencies and the amplitude is the amplitude of the highest frequency. $N - 1$ mask signals shall be added to the signal containing N frequency components during the decomposition process. Repeat the above three steps till each IMF contains only single frequency component.

2.4. Steps for harmonic detection of wind power generation

The Thesis emphasizes on the research on the end effect and mode aliasing problems existing in the traditional EMD method and a kind of improved EMD method is proposed combining the advantages of the existing processing methods, i.e.: solve end effect problems through mirror extension and cosine window function method; then suppress the mode aliasing phenomenon caused by abnormal event and similar frequencies through high-frequency harmonic and mask signal method. Therefore, the harmonic processing process of wind power generation based on the improved EMD algorithm is as follows:

Step 1: Extend a section of time data on both ends of the original signal $u(t)$ of harmonic of wind power generation through the mirror extension and multiply the whole section data by the cosine window function.

Step 2: Analyze the frequency range and characteristic of the above signal and add high-frequency signal with a frequency higher than that of the abnormal event and carry out EMD decomposition on it and to make the abnormal event submerge in the high-frequency signal.

Step 3: Remove the high-frequency signal and abnormal components. If the remaining IMF components do not contain mode aliasing, end the decomposition. Otherwise, sum the remaining IMF components and margin error to get signal $u'(t)$.

Step 4: Carry out fast Fourier transform for $u'(t)$ and obtain all frequency components contained $f_1, f_2, \cdots, f_n$ and the corresponding amplitudes $A_1, A_2, \cdots, A_n$.

Step 5: Create the first mask signal $s(t) = A_n \sin(2\pi(f_n + f_{n-l})t)$ and carry out EMD calculation for $u'_+(t) = u'(t) + s(t)$ and $u'_-(t) = u'(t) - s(t)$ and take the first IMF as $z'_+(t)$ and $z'_-(t)$. Therefore, the first frequency component of signal $u'(t) \quad IMF1 = (z'_+(t) + z'_-(t))/2$.

Step 6: $N - 1$ mask signals shall be added to the signal containing N frequency components. Continuously add mask signals in accordance with the mask signals creation method in step 5 to decompose the original signal of harmonic of wind power generation till only the last single frequency component of harmonic of wind power generation is left.

3. Example of verification and result analysis.

3.1. Simulation signal experiment

Assume the expression of simulation signal as: $u(t) = \sin(2\pi 5t) + \sin(2\pi 20t)$, sampling frequency as 1000Hz and sampling time is 0∼1 s. Add mask signals to signal $u(t)$. It can be seen from the spectrogram of $u(t)$ that the frequency composition is 10Hz and 15Hz and only one mask signal is required to be added. The theoretical value of the mask signal is 25Hz. It is found from the experiment that the actual mask signal frequency is smaller than the theoretical frequency. When the mask signal frequency is 18.9Hz, the decomposition result is the best. Remove the extension part during t he display of decomposition result as shown in Fig.2.

It can be seen clearly from Fig.2 that the mode aliasing phenomenon in the result

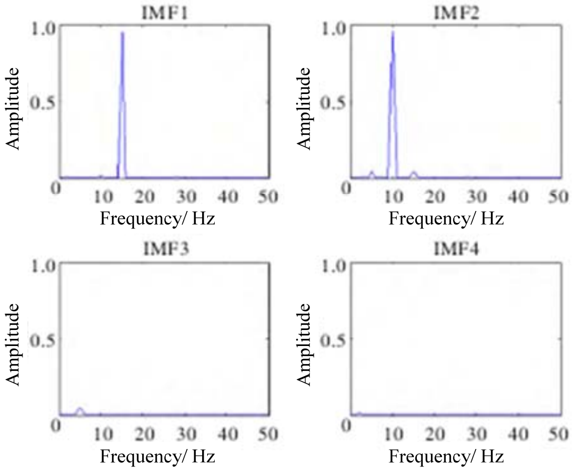

Fig. 2. Amplitude and Frequency Decomposition of Mask Signal

is suppressed and deviation does not exist at the ends.

3.2. Experimental comparison of harmonic detection

The Thesis takes the combination of actual power grid data and simulation data of a certain area as an example and takes harmonic current injected into the power grid during the access of two wind power plants to power grid as the input random variable. Analyze the power grid based on the harmonic analysis method proposed in the Thesis after de-correlation. Concretely, assume two wind power plants (A and B) as the harmonic injection source which will serve as the known random variable; take harmonic current of two certain lines (X and Y) in the power grid as the random variable (observation branch line) to be obtained; calculate the harmonic signal of the random variable to be obtained with three methods respectively based on the simulation data of harmonic current of two wind power plants. Calculation method 1: Monte Carlo method (1000 times); calculation method 2: interval analysis method; calculation method 3: harmonic detection method in the Thesis.

For simplicity, take the fifth harmonic current as an example. The harmonic current injection in Area A conforms to the normal distribution with a mean value of 0.5881 and standard deviation of 0.1028; The harmonic current injection in Area B conforms to the normal distribution with a mean value of 0.4794 and standard deviation of 0.1318. Take the phase position in Area A as the reference point and then the harmonic current in Area B relative to the harmonic current in Area A is $I\angle\theta$. Assume that the phase position of harmonic current in Area B relative to that of Area B shows uniform distribution within in the scope $0 \sim 180°$; take $15°$ as step length and adopt the uniform sampling method, and then the probability distribution of the phase position of harmonic current in Area B can be obtained.

Since the phase position information of the harmonic current of harmonic source is considered, the harmonic signal calculation result of calculation method 1$\sim$ calculation method 3 is as shown in Table 1. Monte Carlo method serves as the pseudo-true value.

Table 1. Comparison of harmonic current distribution range of the observation branch line

Name of line	Method in the Thesis		Interval analysis method		Monte Carlo method	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Line X	0.372	1.053	0.213	1.196	0.373	1.049
Line Y	0.429	1.215	0.264	1.423	0.443	1.247

It can be seen from the experimental comparison data in Table 1 that the upper and lower limits given by the method in the Thesis are closer to the distribution range obtained through Monte Carlo method and its accuracy is obviously higher than that of the interval analysis method, reflecting the effectiveness of the harmonic detection method proposed in the Thesis.

4. Conclusions

In the Thesis, a kind of harmonic detection method of wind power generation based on the aliasing empirical mode decomposition (EMD) of cosine window mask signal is proposed. It improves the end effect of EMD algorithm based on mirror extension and cosine window function and achieves the aliasing improvement of EMD mode through the mask signal method and then achieves the harmonic detection of wind power generation of the improved EMD algorithm. The experimental result indicates that the method proposed has higher detection accuracy.

Acknowledgment

Open Project Program of Xinjiang Uygur Autonomous Region Key Laboratory (2015KL020); Program for Innovative Research Team in University(IRT1285); The Research Fund for the Doctoral Program of Higher Education(Priority)(20126501130001); The Xinjiang Uygur Autonomous Region Science and Technology Key Project(201230115).

References

[1] S. J. Sun, R. Wang, N. G. Corporation: *Harmonic Suppression Method of Doubly-fed Wind Power Generation System Based on Resonant Controller*[J]. Power Electronics, (2015).

[2] Y. Xiyun, C. Chao, L. Xiangjun, et al.: *Control method of smoothing wind power output using battery energy storage system based on empirical mode decomposition*[C]// Control Conference. IEEE, (2015).

[3] L. Chen: *Harmonic Detection and Control of Power System Based on Improved EEMD Algorithm*[J]. (2015).

[4] W. Wei, X. Peng: *Study on Harmonic Detection and Suppression Methods of*

EAF[J]. International Journal of Multimedia & Ubiquitous Engineering, *10* 2015, No. 1, 239–246.

[5] Y. Zhang, Y. Gong, J. Chen, et al.: *Harmonic Suppression Method Based on Immune Particle Swarm Optimization Algorithm in Micro-Grid*[J]. Journal of Power & Energy Engineering, *02* (2014), No. 4, 271–279.

[6] L. Wu, Y. Z. A. Gao: *Novel Harmonic Detection Method Based on Wavelet Analysis*[J]. Advanced Materials Research, (2014), No. 945-949, 2057-2061.

[7] A. H. M. Niaki, S. Afsharnia: *A new passive islanding detection method and its performance evaluation for multi-DG systems*[J]. Electric Power Systems Research, *110* (2014), No. 5, 180–187.

[8] J. Wang: *Robust Pitch Detection Based on Recurrence Analysis and Empirical Mode Decomposition*[J]. Telkomnika Indonesian Journal of Electrical Engineering, (2015).

[9] G. Bao, Z. Song, G. Wu, et al.: *EMD and morphology based voltage disturbance detection method for power system connected with wind turbine generation*[J]. Transactions of the Chinese Society of Agricultural Engineering, (2016).

[10] J. Y. Hu and Z. W. Gao.: *Distinction immune genes of hepatitis-induced heptatocellular carcinoma*[J]. Bioinformatics, *28* (2012), No. 24, 3191–3194.

[11] D. Jiang, X. Ying, Y. Han, & Z. Lv: (2016). *Collaborative multi-hop routing in cognitive wireless networks. Wireless personal communications*, *86*, No. 2, 901–923.

[12] Z. Lv, A. Tek, F. Da Silva, C. Empereur-Mot, M. Chavent, & M. Baaden: *Game on, science-how video game technology may help biologists tackle visualization challenges.* PloS one, *8* (2013), No. 3, e57990.

[13] D. Jiang, Z. Xu, & Z. Lv:*A multicast delivery approach with minimum energy consumption for wireless multi-hop networks.* Telecommunication systems, (2015), 1–12.

[14] Z. Lv, J. Chirivella, & P. Gagliardo: (2016). *Bigdata Oriented Multimedia Mobile Health Applications.* Journal of medical systems, *40*, No. 5, 1–10.

[15] L. I. Zheng-Ming, X. U. Min, T. H. Pan, et al.: *A harmonic detection method for distributed connected grid system by using wavelet transform and HHT*[J]. Dianli Xitong Baohu Yu Kongzhi/power System Protection & Control, *42* (2014), No. 4, 34–39.

Received May 7, 2017