http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (22): 6859-6864, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.6859.6864
© 2013 Asian Network for Scientific Information

Low Frequency Oscillation Detection in Power System Using LMD Algorithm

Cao Wensi and Chen Jianming
School of Electric Power, North China University of Water Resources and Electric Power,
450045, Zhengzhou, China

Abstract: To realize high-accuracy measurement parameter of low frequency oscillation signal in Power System, the Local Mean Decomposition (LMD) algorithm is applied to the low frequency oscillation signal detection in power system for the first time. This algorithm overcomes the incapability for the Fourier algorithm to deal with non-stationary signals, as well as the difficulty in choosing Wavelet. LMD algorithm can be accurate to abstract the dynamic oscillating performance and abundant transient fault information from the non-stationary signal, The amplitude and frequency curve, not only can accurately locate the disturbance moments butt also can detect the voltage fluctuation amplitude of typical low frequency oscillation signal. The simulation waveform was influenced by "end effect" smaller. Simulation results show that LMD Algorithm is effective and has better locate accuracy and computing speed than the HHT algorithm.

Key words: Local mean decomposition, low frequency oscillation signal, end effect, detection, HHT algorithm

INTRODUCTION

The low frequency oscillation is one of the safe and stable operation of power system problems, how to damp low-frequency oscillation effectively is a hot research topic in recent years. For a long time, people are through small signal stability analysis, linear processing to study the problem of the low frequency oscillation and achieved certain results. However, the power system is a typical nonlinear system, with increasing system size and complexity, linearization method has revealed its deficiencies. For the complex network has strong nonlinear haracteristics, even after installing the amounts of Power System Stabilizer (PSS), low frequency oscillation may still occur. In the northeast and North China power system, low frequency oscillation of some unknown mechanism appeared, many scholars think that is caused by nonlinear interactions. (Yi *et al*., 2010).

At present, the detection methods of power quality transient disturbance have many methods, including FFT algorithm, wavelet transform, S transform, Hilbert-Huang Transform (HHT) and other theoretical combination algorithm. FFT has excellent performance in the analysis of stationary periodic signal butt cannot deal with non-linear, non-stationary signal and detection of inter-harmonics have shortcomings of spectral leakage (Zhao and Yang, 2007) and fence phenomena Wavelet transform can detect nonlinear time-varying high-frequency disturbance signal butt has not very good detecting low-frequency disturbance signal, in addition to selection of basis functions is a difficult problem butt once the decomposition level was determined, its frequency resolution is constant, lack of adaptability butt also limited by the Heisenberg uncertainty principle (Yang *et al*., 2007); S transform is an inheritance and development of wavelet transform, S transform can analyze amplitude of each frequency disturbance signal, butt there are some errors of S transform to detect the amplitude of Composite disturbance signal contains harmonics (Zhan *et al*., 2005); HHT is a new nonlinear, non-stationary signal processing method, HHT decompose the signal according to the inherent characteristics scale, frequency resolution changes along with the signal characteristic scale, HHT has well adaptively (Li and Zhao, 2005) butt HHT using a cubic spline interpolation fitting the envelope signal is easy to appear envelope (Wang *et al*., 2004), owe envelope phenomenon, resulting in the end effects of decomposed signal waveform is serious, in addition to HHT obtain Intrinsic Mode Function (IMF) through continuous minus the mean envelope function, resulting in too many times "screening", HHT in the excessive number of "screening" led to the end effect of pollution throughout the data segment and the instantaneous frequency based HHT time frequency analysis methods often appear to be negative is a physical phenomena which is difficult to explain (Li *et al*., 2005).

In 2005, Smith proposed the Local Mean Decomposition algorithm (Local Mean Decomposition, LMD) (Smith, 2005), LMD can decompose complex signals into Product Function (PF) sum, each product function consists of envelope function and pure frequency

Corresponding Author: Chen Jianming, North China University of Water Resources and Electric Power, 450045, Zhengzhou, China

modulation function, the frequency of Pure frequency modulation function is the instantaneous frequency of PF. LMD and HHT similar butt also according to the inherent characteristics of complex signal decomposed signal butt LMD adopts the sliding average method to fit the envelope function and avoid the envelope, owe envelope phenomenon, in addition, LMD PF by dividing the envelope function (Cao *et al*., 2013), the number of "screening" fewer. LMD has been successfully applied to the extraction of instantaneous frequency, mechanical fault diagnosis and modulation signal analysis field, Aiming at the low frequency oscillation signal is nonlinear, irregular and mutation characteristics, the Local Mean Decomposition (LMD) algorithm is applied to the low frequency oscillation disturbance detection in power system for the first time. Simulation results show that LMD Algorithm is effective and has better locate accuracy and computing speed.

LOCAL MEAN DECOMPOSITION ALGORITHM

Local mean decomposition process: The basic calculation of the local mean decomposition flow chart shown in Fig. 1, the decomposition process of the LMD is a triple

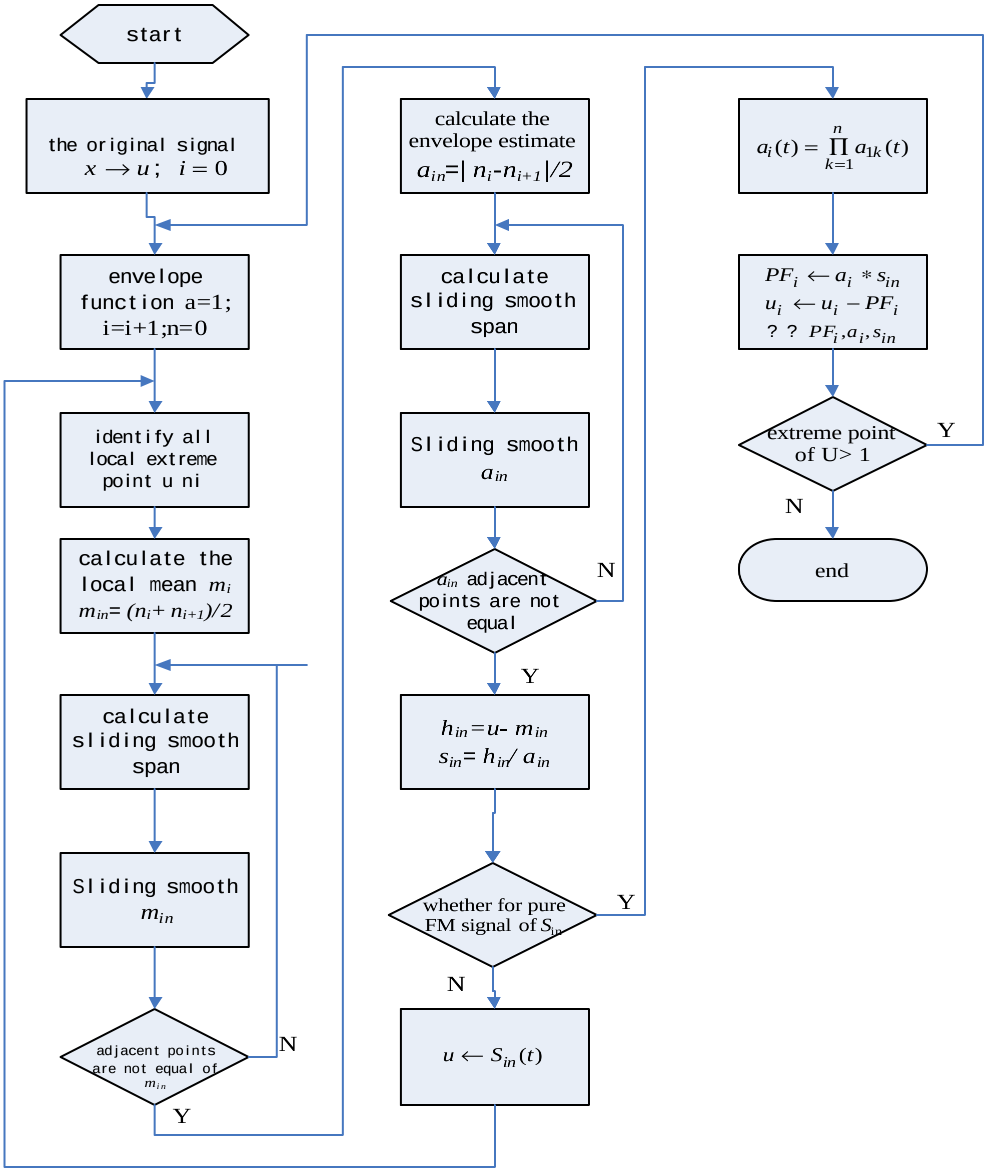

Fig. 1: Flow chart of the local mean decomposition

cyclic process: The first cyclic sliding smoothing strike a local mean function $m_i(t)$ and envelope estimation function $a_i(t)$ and the loop terminates conditions sliding smoothed signal adjacent dots are not equal; The two cyclic strike PF_i (t) the process loop termination condition to strike out the sin (t) is a pure FM signal; The third cyclic process is for the purpose of obtaining all PF_i (t), the loop terminates conditions residual component $u_k(t)$ and only one extreme point. Pure FM signal and the envelope signal is separated from the original signal after three cycles, the pure FM signal and the envelope signal is obtained by multiplying the first PF component and then gradually loop process, the decomposition of the PF component further determine the instantaneous frequency and instantaneous amplitude, we can obtain the complete time-frequency distribution of the original signal.

Local mean decomposition algorithm: For any signal x(t), the local mean decomposition steps are as follows (Cao *et al*., 2013):

Step 1: Find out the signal x(t) the local extreme points of $n_{i,}$ calculate any two adjacent local extrema point mean m_i, there are:

$$m_i = (n_i + n_{i+1})/2 \tag{1}$$

All the adjacent local mean points mi and mi+1 are connected by broken line and then smoothed by sliding average algorithm, get the local mean function m11(t)

Step 2: Calculate the envelope estimate a_i:

$$a_i = n_i - n_{i+1}|/2 \tag{2}$$

Connect each adjacent envelope estimate values a_i and a_{i+1} with broken line and then smoothed by sliding average algorithm to get the envelope estimate function a11(t)

Step 3: Separate the local mean function m11 (t) from the original signal x (t) and obtain the signal $H_{11}(t)$:

$$h_{11}(t) = x(t) - m_{11}(t) \tag{3}$$

Step 4: Divide $h_{11}(t)$ by the envelope estimate function $a_{11}(t)$, get FM signal $s_{11}(t)$:

$$s_{11}(t) = h_{11}(t)/a_{11}(t) \tag{4}$$

repeat the above steps for $S_{11}(t)$, get the envelope estimation function a_{12} (t), If $a_{12}(t)$ is not equal to 1, indicating that $s_{11}(t)$ is not a pure frequency modulation signal and then repeat n times until S_{1n} (t) is a pure FM signal, i.e., namely the envelope estimation function of $s_{1n}(t)$ is $a_{1(n+1)}$ (t) = 1, so:

$$\begin{cases} h_{11}(t) = x(t) - m_{11}(t) \\ h_{12}(t) = s_{11}(t) - m_{12}(t) \\ \vdots \\ h_{1n}(t) = s_{1(n-1)}(t) - m_{1n}(t) \end{cases} \tag{5}$$

$$\begin{cases} s_{11}(t) = h_{11}(t)/a_{11}(t) \\ s_{12}(t) = h_{12}(t)/a_{12}(t) \\ \vdots \\ s_{1n}(t) = h_{1n}(t)/a_{1n}(t) \end{cases} \tag{6}$$

Conditions for iterative terminated:

$$\lim_{n\to\infty} a_{1n}(t) = 1 \tag{7}$$

In practical application, in order to avoid excessive decomposition number, we can set a disturbance Δ, the iteration will end when $1-\Delta \le a_{1n}(t) = 1+\Delta$

Step 5: Multiply the iterative process envelope estimation function, get the envelope signal a_1 (t):

$$a_1(t) = a_{11}(t)a_{12}(t)\cdots a_{1n}(t) = \prod_{k=1}^{n} a_{1k}(t) \tag{8}$$

Step 6: Obtain the Eq. 8 in the envelope signal a_1 (t) and pure FM signal s_{1n} (t) multiplied, to obtain the original signal x (t),as a PF component:

$$PF_1\,(t) = a_1(t)\, s_{1n}(t) \tag{9}$$

It contains the highest frequency component of the original signal, It is a single component amplitude modulation and frequency modulation signal, The instantaneous amplitude is the envelope signal $a_1(t)$, the instantaneous frequency $f_1(t)$can be calculated by pure FM signal $s_{1n}(t)$:

$$f_1(t) = \frac{1}{2\pi} \times \frac{d \arccos(s_{1n}(t))}{dt} \tag{10}$$

Step 7: separate PF_1 (t) components from the original signal x (t) and obtain the signal u_1 (t), u_1 (t) as the new data, repeat the above steps, k cycle, until u_k (t) as monotonic function so far:

$$\begin{cases} u_1(t) = x(t) - PF_1(t) \\ u_2(t) = u_1(t) - PF_2(t) \\ \vdots \\ u_k(t) = u_{k-1}(t) - PF_k(t) \end{cases} \tag{11}$$

As can be seen from the above steps, the original signal can be reconstructed by $u_k(t)$ and all PF components, i.e.:

$$x(t) = \sum_{i=1}^{k} PF_i(t) + u_k(t) \tag{12}$$

DETECTION AND ANALYSIS OF LOW FREQUENCY OSCILLATION SIGNAL IN POWER SYSTEM BASED ON LMD

Low frequency oscillation signal:

$$x(t) = \sin(\omega t) + a \cdot e^{-c(t-t_1)} \cdot [\varepsilon(t_2) - \varepsilon(t_1)] \cdot \sin(\beta\omega t)$$

$\varepsilon(t)$ is unit step function, t_1, t_2 are the beginning and ending time of disturbance signal disturbance, a is amplitude, β is the frequency coefficient, c is the transient oscillation attenuation coefficient.

Example 1: Low frequency oscillation signal:

$$x(t) = \sin(\omega t) + 0.8 \cdot e^{-20(t-6.25T)} \cdot [\varepsilon(7.25T) - \varepsilon(6.25T)] \cdot \sin(10\omega t)$$

This algorithm uses the frequency of 4000 Hz, It meets the requirements of Smart Substation, namely each cycle sampling point 80. Each simulation data were analyzed from 960 sampling points, T = 0.02 sec. low frequency oscillation signal analysis results as shown in Fig. 2. based on LMD.

Remove the endpoint, two extreme points of instantaneous frequency curve are the disturbance start and stop time. All sampling points of the instantaneous amplitude and frequency curve in the all sampling points of the instantaneous amplitude and frequency curve in the disturbance time are fitted by using Least Square Method, obtaining stable interval value is the detection results of disturbance amplitude and frequency. detection results based on LMD algorithm as shown in Table 1.

Example 2: Low frequency oscillation signal:

$$x(t) = \sin(\omega t) + a \cdot e^{-c(t-t_1)} \cdot [\varepsilon(t_2) - \varepsilon(t_1)] \cdot \sin(\beta\omega t)$$

Among them, $\alpha = 0.2$, relative coefficient $\beta = 24$, attenuation coefficient c = 0.05, t1 = 0.12 sec, t2 = 0.1366 sec; $\omega = 2\pi f$, f = 50 Hz, the sampling frequency is 5000Hz, the oscillation signal and time-frequency analysis based on LMD and HHT is shown in Fig. 3.

Figure 3b shows the PF1 waveform obtained by LMD method is better than the imf1 waveform obtained by the HHT method, especially the start and recovery time.

Table 1: Low frequency oscillation detection results based on LMD

Disturbance start time (sec)			Disturbance end time (sec)			Disturbance amplitude (%)			Disturbance frequency (Hz)		
Theoretical value	Measurement value	Error (%)	Theoretical value	Measurement value	Error (%)	Theoretical value	Measurement value	Error (%)	Theoretical value	Measurement value	Error (%)
0.125	0.12575	0.6	0.145	0.14625	0.86	0.8	0.7638	4.5	500	506.55	1.31

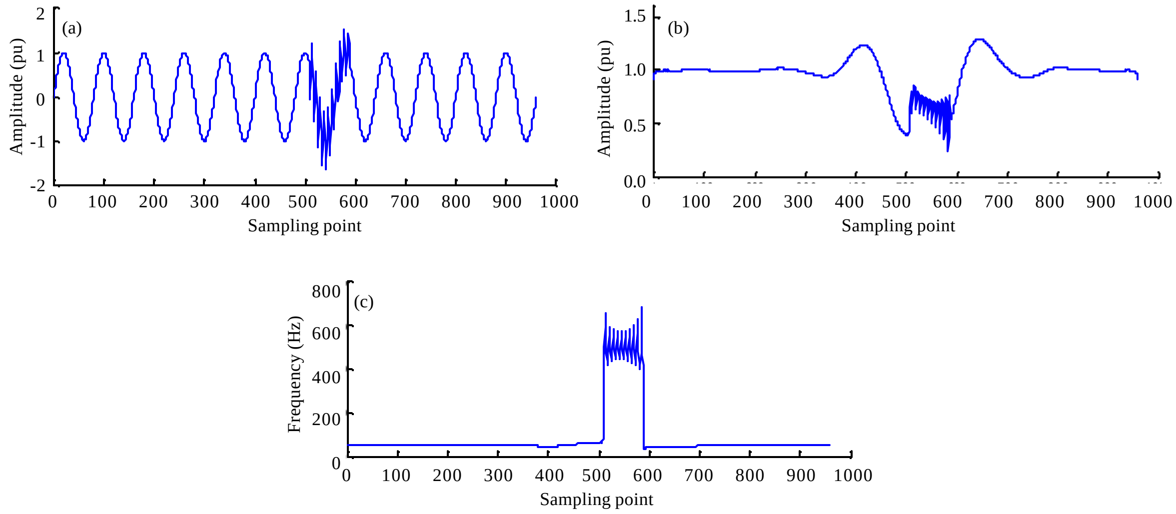

Fig. 2(a-c): Low frequency oscillation signal detection results (a) Original signal, (b) Signal amplitude and (c) Signal frequency

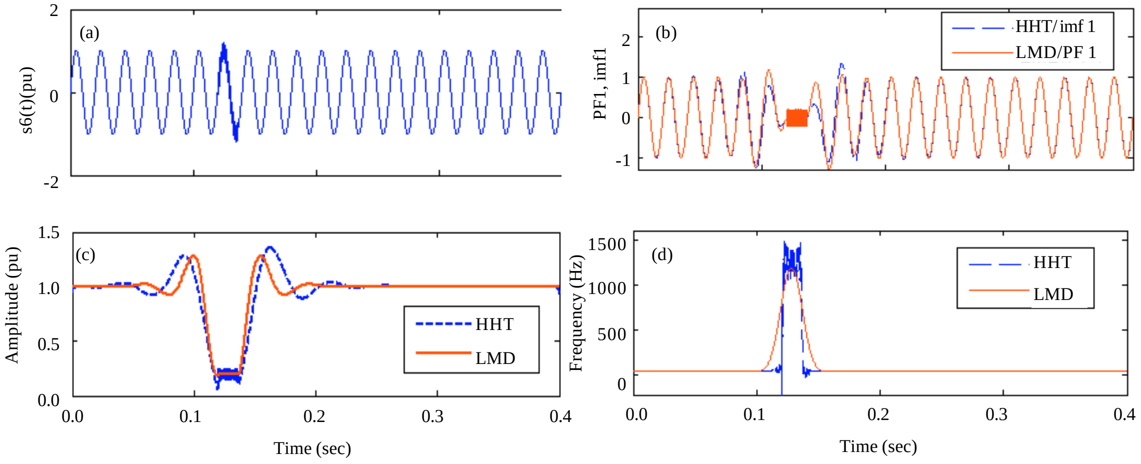

Fig. 3(a-d): Comparative analysis of the low frequency oscillation signal based on LMD and HHT (a) Original signal, (b) PF1 and imf1 component, (c) Instantaneous amplitude and (d) Instantaneous frequency

Figure 3c, the disturbance amplitude changes in 0.1456 and 0.2443 based on HHT method. the disturbance amplitude changes in 0.1965~0.1985 based on LMD method. the disturbance amplitude obtained by LMD method is significantly better than the disturbance amplitude obtained by HHT method. Figure 3d shows that the frequency mutations occur in 0.1209-0.1372 sec based on HHT algorithm, It can determine the voltage disturbance start time and recovery time, the disturbance signal frequency changes in 1065~1485 Hz based on HHT method but the maximum disturbance frequency is 1200 Hz based on LMD method, consistent with the theoretical value, Negative frequency phenomenon occurred in the disturbance moment, it is difficult to explain. In orde to solve the problem of the instantaneous frequency localization by LMD method is not accurate, Figure 3c shows that amplitude reach the minimum value at 0.1195 sec, began to increase at 0.1368 sec, therefore, we can locate disturbance moment by amplitude waveform. Simulation results show that positioning accuracy of LMD algorithm is low than HHT algorithm, Because the HHT algorithm use mutation point of frequency to locate disturbance moment.

CONCLUSION

In order to detect the low frequency oscillation signal, this study uses LMD algorithm to analysis typical low frequency oscillation signal. compared with HHT algorithm, we can get to some conclusions:

- the instantaneous amplitude function can accurately determine the disturbance time, disturbance frequency and the disturbance magnitude based on LMD algorithm, the waveform using LMD algorithm is better than HHT algorithm
- LMD algorithm does not require the integral operation, has a fast computing speeds, the end effect of LMD was better than HHT
- LMD algorithm adopts the sliding average method to fit the envelope function and avoid the envelope, owe envelope phenomenon, in addition, LMD PF by dividing the envelope function, the number of "screening" fewer

ACKNOWLEDGMENT

This study is supported by the Natural Science Foundation of the Education Department of Henan Province (2011 A470005, 12A470005).

REFERENCES

Cao, W., C. Huang and G. Zhang, 2013. Research for power quality disturbing detection based on LMD algorithm. J. Applied Sci., 13 : 5043-5049.

Cao, W., J. Huang and G. Zhang, 2013. New method in voltage flicker parameter identification based on local mean decomposition algorithm. Inform. Technol. J., 12: 3496-3502.

Li, T. and Y. Zhao, 2005. Application of hilbert-huang transform method in detection of harmonic and voltage flicker. Power System Technol., 29: 73-77.

Li, T.Y., Y. Zhao, N. Li, G. Fen and H.H. Gao, 2005. A new method for power quality detection based on HHT. Proc. Csee, 25: 52-56.

Smith, J.S., 2005. The local mean decompositionand its application to EEG perception data. J. Royal Soc. Interface, 2: 443-454.

Wang, Z., S. Zhu and S. Zhou, 2004. Parameter estimation of voltage flicker through Hilbert transform. Automat. Electric Power Syst., 28: 34-37.

Yang, J., G.Y. Li, M. Zhou and X.Y. Duan, 2007. Application of generalized interpolating wavelet in power quality disturbance signal analysis. Electric Power Automation Equipment, 27: 21-25.

Yi, J., J. Peng, A. Luo and H. Tan, 2010. Power quality signal denoising using modified S-transform. Chinese J. Scient. Instrument, 31: 32-37.

Zhan, Y., H.Z. Cheng and Y.F. Ding, 2005. S-transform-based classification of power quality disturbance signals by support vector machines. Proc. Csee, 25: 51-56.

Zhao, F.Z. and R.G. Yang, 2007. Voltage sag disturbance detection based on short time fourier transform. Proc. Chin. Soc. Electrical Eng., 27: 28-34.