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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet

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

Information Technology Journal 12 (16): 3496-3502, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.3496.3502

New Method in Voltage Flicker Parameter Identification Based on Local Mean Decomposition Algorithm

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Abstract: To realize high-accuracy measurement parameter of voltage flicker, Focusing on the amplitude modulation wave and inter-harmonics fluctuation problem in voltage flicker based on conventional algorithm, the Local Mean Decomposition (LMD) algorithm is adopted to analyze voltage flicker parameter identification in power system for the first time. LMD algorithm principles were briefly introduced, signal adaptively is decomposed into a number of single-component FM-AM function (Product Function, PF) by LMD. For mixed voltage flicker signal, the fundamental component that modulated by the low frequency modulated waves and inter-harmonic components are separated based on LMD after the first decomposition. Amplitude modulation function of fundamental component contains time-varying amplitude modulated wave, Amplitude and frequency information can be obtained by its LMD. Amplitude modulation function of inter-harmonic components corresponding to the amplitude, frequency can be obtained by pure frequency modulation function. The paper selects typical voltage flicker signal, Comparison of the simulation results by LMD algorithm and HHT algorithm, simulation results show that Because the LMD algorithms get a PF by dividing by the envelope function and the number of "Screening" is relatively less. the end effect is small. The flicker parameter in the steady state basically does not change based on LMD. Simulation results prove LMD superiority. the method is simple, rapid and high accuracy. The results show the feasibility and accuracy of LMD algorithm.

Key words: Voltage flicker, amplitude modulation wave,inter-harmonic, adaptive decomposition, local mean decomposition

INTRODUCTION

With the development of the social economy, in the power system, the impact load and fluctuating load increasing, which lead to voltage fluctuation and flicker in power distribution network is more and more serious.

In order to improve power quality, voltage flicker analysis has become a research hotspot. The cause of voltage flicker is mainly modulated wave and inter harmonics in power system (Yi *et al.*, 2010).

Method of amplitude modulation wave induced voltage flicker, traditional methods including square adjustment method, half wave effective value method and full wave, rectification voltage method, but the three method is not suitable for time-varying flicker signal analysis; Document (Chen and Yang, 2006) proposed using recursive least square method to track the voltage flicker and with FFT transform on the envelope analysis, Independent component analysis method to isolate the envelope of voltage flicker of reference (Liu and Yang, 2007) and then analyze the envelope signal with high precision FFT transform, but Fourier transform can not handle non-linear, non-stationary signals; Wavelet transform can detect nonlinear time-varying high-frequency disturbance signal, Document (Chen, 2004)to analysis of voltage flicker using wavelet theory, but the method is limited by the Heisenberg uncertainty principle, lack of adaptability; S transform is used to analyze the voltage flicker (He and Lei, 2010), Stransform essentially belongs to the wavelet transform;Hilbert transform can detect the non stationary voltage flicker signal (Wang *et al.*, 2004); the experimental results show that the detection results by using Hilbert transform is superior to the Teager energy operator method andsquare detection method; Hilbert-Huang Transform (HHT), has been widely used in electric power engineering signal analysis and its application in the detection of voltage flicker, achieved good results (Li and Zhao, 2005).

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HHT power quality detection methods achieved good results, but the decomposition of the modal experience using a cubic spline interpolation fitting the envelope signal is easy to appear envelope, owe envelope phenomenon; 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.

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 modulation function, the frequency of Pure frequency modulation function is the instantaneous frequency of PF. LMD and HHT similar, but also according to the inherent characteristics of complex signal decomposed signal, but 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, the number of "screening" fewer (Cao *et al*., 2013). LMD has been successfully applied to the extraction of instantaneous frequency, mechanical fault diagnosis and modulation signal analysis field, Aiming at the voltage flicker is nonlinear, irregular and mutation characteristics, the local mean decomposition (LMD) algorithm is applied to the voltage flicker detection in power system for the first time.

LOCAL MEAN DECOMPOSITION PRINCIPLE

For any signal x(t),the local mean decomposition steps are as follows:

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 $1-\Delta \le a_{1n}(t) \le 1+\Delta$

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 $s_{1n}(t)$:

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

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.

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

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

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

DETECTION OF VOLTAGE FLICKER SIGNAL BASED ON LMD

LMD can decompose complex signals into Product Function (PF) sum and PF component is ordered from highest frequency to lowest. each product function consists of envelope function and pure frequency modulation function, the frequency of Pure frequency modulation function is the instantaneous frequency of PF.

Detection of amplitude modulation signal: Due to the low frequency of the amplitude modulation signal, fundamental component is first isolated, its envelope signal is modulated signal. envelope signal of the voltage flicker caused by amplitude modulation wave can obtain the frequency and amplitude of the voltage flicker, because the LMD can be directly isolated from the envelope signal, so LMD is especially suitable for voltage flicker detection of amplitude modulated wave. Its detection steps:

- The voltage flicker signal was decomposed by LMD and we can obtain some PF components.
- To continue using LMD decomposition signal of envelope signal a1(t) of PF1 component, according to (8) and (10) the amplitude and frequency information of the voltage flicker can be derived

Detection of harmonics and inter-harmonics signal: Flicker signal consisting of fundamental component, harmonic and inter-harmonic signal, the detection steps are as follows:

- Using LMD decomposition method, we can obtain the fundamental, harmonics and inter harmonics
- According to Eq. 8 can obtain the amplitude of the fundamental harmonic and inter harmonic, According to Eq. 10 to obtain the corresponding frequency

Mixed signal detection: For the low frequency amplitude modulation mixed signal is composed of fundamental and harmonics,inter-harmonics, the detection steps are as follows:

- Using LMD decomposition method, we can obtain the fundamental, harmonics and inter harmonics of the low frequency amplitude modulation mixed signal
- According to equation (8) can obtain the envelope signal, According to equation (10) to obtain the corresponding frequency
- To continue using LMD decomposition signal of envelope signal of 50Hz PF component, we can obtain amplitude modulation wave, Repeat steps 2

SIMULATION AND ANALYSIS OF VOLTAGE FLICKER SIGNAL

Voltage flicker analysis of Single modulation rate: Voltage flicker is most obvious caused by 8.8 Hz amplitude modulation wave, therefore first take the frequency is 8.8Hz, voltage fluctuation for sine wave voltage 0.25%, expression is as follows:

$$x(t) = A_0(1 + 0.0025/2\sqrt{2} * \cos(17.6\pi t))\sin 100\pi t \quad (12)$$

A_0 = 1 pu ,voltage flicker signal analysis results as shown in Fig. 1. based on LMD.

Figure 1b is PF1 component of the flicker signal, Fig. 1c is the residual signal, Fig. 1d can be seen, the LMD method to get the flicker envelope signal and the theory of the flicker envelope signal almost completely.

Figure 1e is a pure FM signal of PF1, the frequency as shown in Fig. 1f shows, 50 Hz, To continue using LMD decomposition signal of envelope signal a1(t) of PF1 component, the amplitude and frequency are shown in Fig. 1g and 1h, the amplitude is 0.000625 pu, frequency is 8.8 Hz and the theoretical value is completely consistent, so The LMD algorithm can be used to obtain single flicker signal parameters.

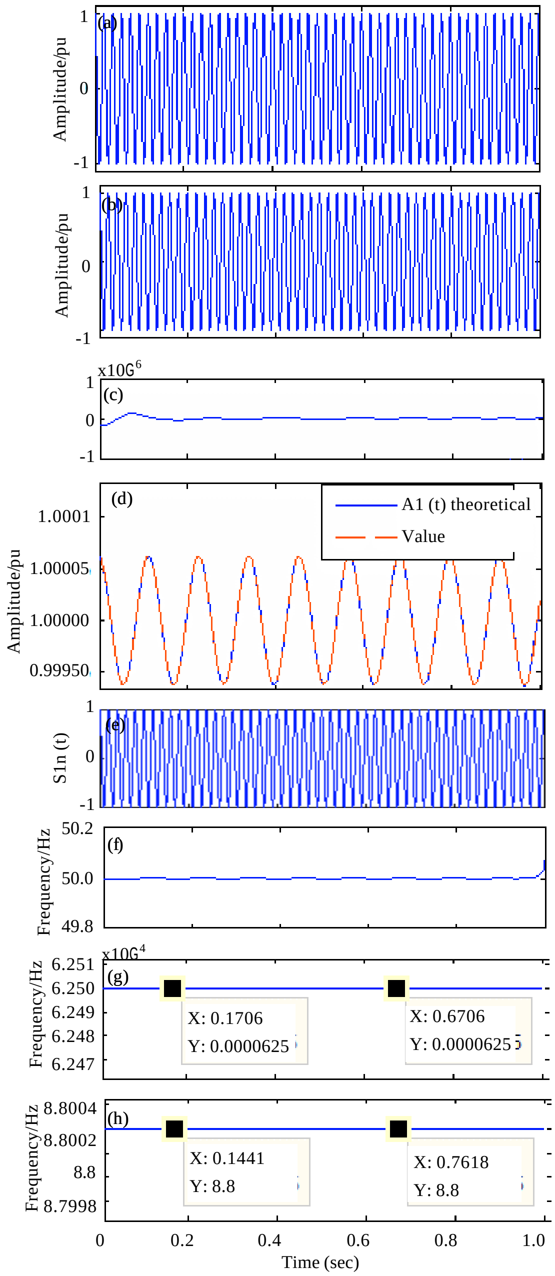

Fig. 1(a-h): Results of Single flicker frequency (a) Voltage flicker signal, (b) PF1 component, (c) Residuals uk, (d) Envelope signal of PF1, (e) $s_{1n}(t)$, (f) frequency of PF1, (g) Using a1(t) to obtain flicker frequency and (h) Flicker signal frequency based on LMD Algorithm

In addition, the LMD algorithm in the process of solving the amplitude and frequency, no integral calculation and inversion, has high operation speed, In the 4G memory for the win7 system, using Matlab2011a running a single flicker analysis program, based on the HHT algorithm 1.858464s and the LMD algorithm only 1.490855s, Therefore, according to the method of LMD algorithm time reduced by 19.78%, greatly improves the operation speed.

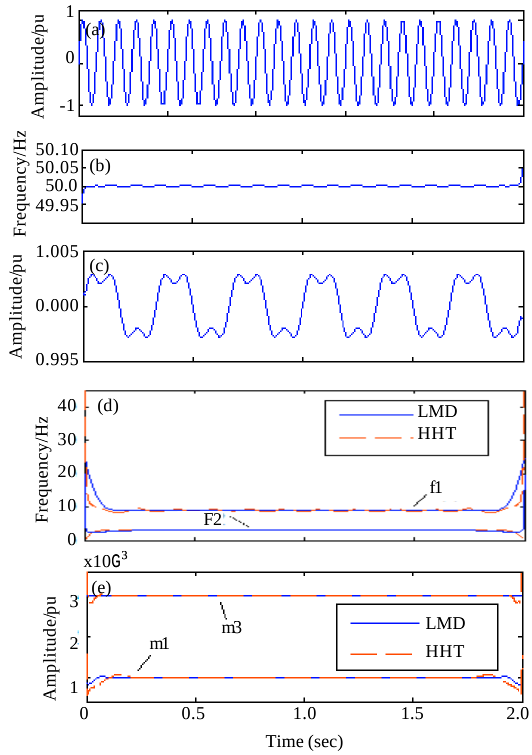

Fig. 2(a-e): (a) Voltage flicker signal, (b) Frequency of PF1, (c) Envelope signal a1 of PF1, (d) Flicker signal frequency and (e) Flicker signal amplitude

voltage flicker analysis of multiple modulation rate:

$$x(t) = (1 + m_1 \sin 2f_1\pi t + m_2 \sin 2f_2\pi t)\sin 100\pi t \qquad (13)$$

We use the LMD algorithm and HHT algorithm to detect the voltage flicker signal, The results as shown in Fig. 2.

From Fig. 2b, c the application of LMD algorithm to separate PF1component is the power requency current AM-FM components, frequency of 50Hz, it contains the envelope signal amplitude and frequency information of voltage flicker. Figure 2d, e is the flicker frequency and amplitude information using the LMD method and HHT method, it can be found that, by using the LMD method, the end effect of waveform significantly improved.

In addition, from Fig. 1d show that the HHT to obtain the frequency has obvious fluctuation, but also by data fitting to find the frequency, while the LMD method to obtain the waveform curve more smooth, LMD adopts the sliding average method to fit the envelope function and avoid the envelope, owe envelope phenomenon flicker amplitude and frequency parameters as shown in Table 1, we know from the table, Flicker parameters based on LMD more accurately.

voltage flicker analysis of Contains the harmonic and inter-harmonic signal:

$$x(t) = A_0 \sin 2\pi f_0 t + A_1 \sin 2\pi f_1 t + A_2 \sin 2\pi f_2 t \qquad (14)$$

A_0 = 1V, f_0 = 50 Hz; m_1 = 0.3, f_1 = 150 Hz; m_2 = 0.005, f_2 = 25 Hz We use the LMD algorithm and HHT algorithm to detect the voltage flicker signal, The results as shown in Fig. 2 and Table 2.

Table 1: Flicker parameters based on LMD and HHT

	m1(mV)	m2(V)	f1(Hz)	f2(Hz)
LMD	0.999	2.997	8.994	2.997
HHT	0.9988	2.995	8.936	2.985

We can see from Fig. 3, the end effect of LMD was better than HHT, LMD PF by dividing the envelope function, the number of "screening" fewer. the measured results are more accurate. We can see from Table 2, parameter extraction using LMD method than the HHT method to extract the values of higher accuracy, especially LMD to obtain the frequency values and theoretical values agree. While the end effects of HHT method is stronger and the "screening" times more serious pollution, these parameters fluctuate in a certain extent, also needs to make the curve fitting.

Mixed signal analysis:

$$x(t) = (1 + m_1 \sin 2\pi f_1 t)\sin 2\pi f_0 t + m_2 \sin 2\pi f_2 t \qquad (15)$$

Table 2: Parameter of harmonic and inter-harmonic

	A0 (V)	m1 (V)	m^2 (mV)	f0 (Hz)	f1 (Hz)	f2 (Hz)
LMD	0.9996	0.2992	0.4968	50	150	25
HHT	0.9935	0.2986	0.4952	49.91	149.6	24.95

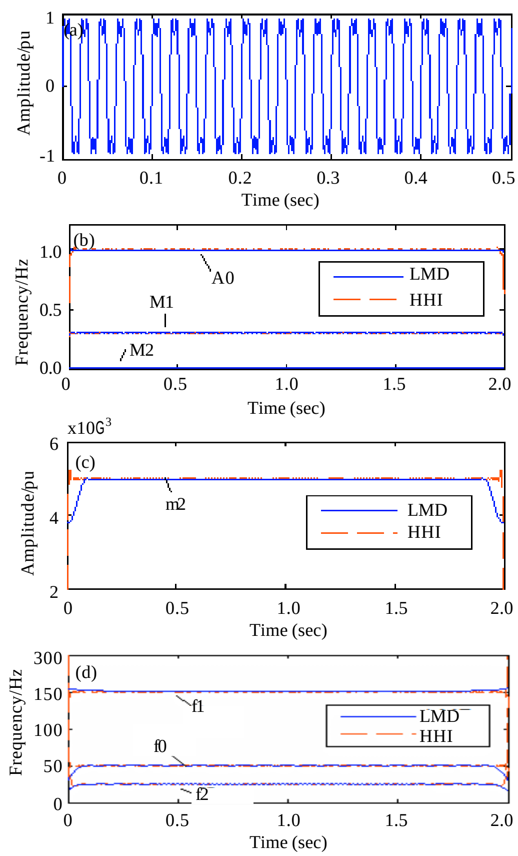

Fig. 3(a-d): Results of harmonic and interharmonic (a) Voltage flicker signal, (b) Flicker signal amplitude, (c) m2 and (d) Flicker signal frequency

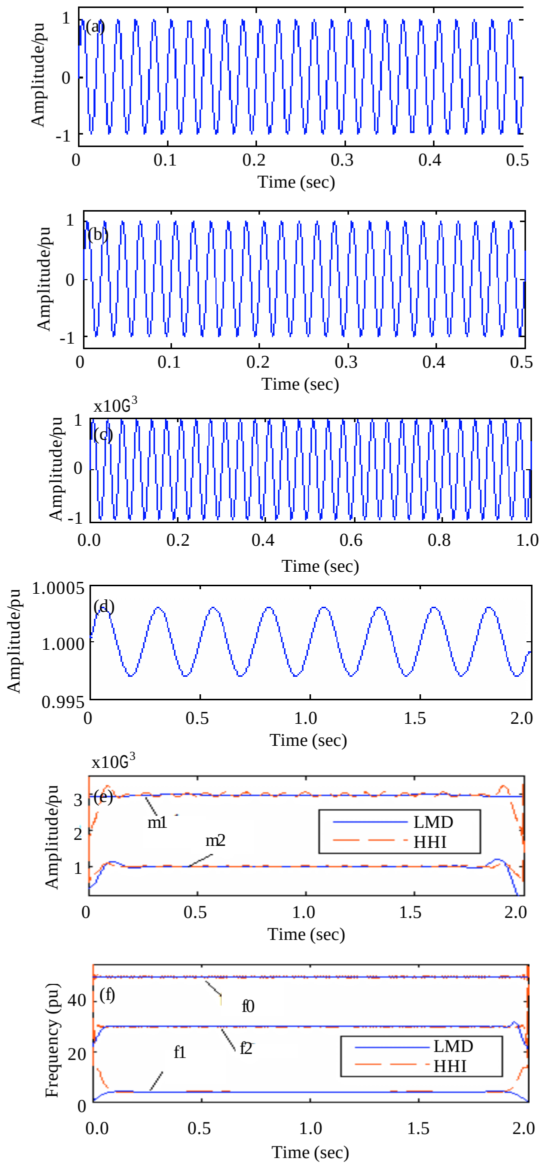

Fig. 4(a-f): Results of composite signal (a) Voltage flicker signal, (b) PF1, (c) PF2, (d) a1, (e) Flicker signal amplitude and (f) Flicker signal frequency

f_0 = 50 Hz, m_1 = 0.003, f_1 = 4 Hz; m_2 = 0.0.1, f_2 = 30 Hz. We use the LMD algorithm and HHT algorithm to detect thevoltage flicker signal, The results as shown in Fig. 4.

From Fig. 4b, d and f, LMD method can isolate the Fundamental component, from Fig. 4c harmonic component that also can be separated effectively, but 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

Table 3: Parameter of composite signal

	m1 (mV)	m2 (mV)	f0 (Hz)	f1 (Hz)	f2 (Hz)
LMD	2.991	0.9954	50	4.002	29.99
HHT	2.957	0.9836	49.64	3.993	29.83

analysis methods often appear to be negative is a physical phenomena which is difficult to explain. Simulation results show that LMD algorithm is better than HHT algorithm in the parameter fluctuation of characteristic parameter detection, the detection accuracy from Table 3, the end effect and running time.

CONCLUSION

- LMD can decompose complex signals into Product Function (PF) sum, each product function consists of envelope function and pure frequency modulation function, the frequency of Pure frequency modulation function is the instantaneous frequency of PF. Voltage flicker analysis method based on LMD algorithm has simple steps, without the need for filtering decaying DC component
- LMD algorithm does not require the integral operation,has a fast computing speeds
- 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, 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).

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