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Research for Power Quality Disturbing Detection Based on Lmd Algorithm

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Abstract: For the problems of power quality disturbances, the local mean decomposition algorithm is adopted to analyze harmonic, voltage fluctuation and transient disturbance signal in power system for the first time. Complex signal is decomposed into a number of Product Function (PF for short) by the method and the PF components are made of FM function and amplitude modulation function. The frequency and amplitude of PF components obtained respectively by the FM function and amplitude function such as HHT or LMD uses the signal inherent characteristic scale to decompose signal but LMD fits the signal envelope by sliding average algorithm to avoid over the envelope and owe envelope phenomenon with the result of small end effect. In addition, LMD algorithm obtaining the instantaneous frequency is positive and the time varying frequency has a physical meaning. The paper selects typical disturbance signals prescribed by IEEE, respectively its LMD and HHT time-frequency analysis and simulation results show that the LMD algorithm in the analysis of short-time voltage sag and swell signal, harmonic disturbance and long-term voltage fluctuations has good performance, which provides the theoretical fundamental in a new way for the electrical energy detection in power system.

Key words: Local mean decomposition, hilbert-huang transform, power quality, short-time voltage disturbances, harmonic, end effect

INTRODUCTION

With the development of the industrial society, the power quality requirement is more and more high, solve the power quality problems have become the key problem in the development of power, the power quality disturbance signal detection has become a focus (Hu and Chen, 2001; Liu *et al*., 2005; Huang and Wu, 2010).

The research method of the power quality disturbance signal detection has many methods, including FFT algorithm (Zhao and Yang, 2007), wavelet transform, S transform (Chen, 2002; Zhan *et al*., 2005). Hilbert-Huang Transform (HHT) (Li *et al*., 2005). FFT has excellent performance in the analysis of stationary periodic signal but cannot deal with non-linear, non-stationary signal and detection of inter-harmonics have shortcomings of spectral leakage and fence phenomena (Li *et al*., 2004); Wavelet transform can detect nonlinear time-varying high-frequency disturbance signal but has not very good detecting low-frequency disturbance signal (Gu and Bollen, 2000), in addition to selection of basis functions is a difficult problem but once the decomposition level was determined, its frequency resolution is constant, lack of adaptability but also limited by the Heisenberg uncertainty principle; S transform is an inheritance and development of wavelet transform, S transform can analyze amplitude of each frequency disturbance signal, but there are some errors of S transform to detect the amplitude of Composite disturbance signal contains harmonics (Zhou *et al*., 2008); 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 but HHT using a cubic spline interpolation fitting the envelope signal is easy to appear envelope, 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 (Ren *et al*., 2009).

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In 2005, Smith proposed the Local Mean Decomposition algorithm (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. LMD has been successfully applied to the extraction of instantaneous frequency, mechanical fault diagnosis and modulation signal analysis field (Cheng *et al.*, 2009), this paper presents a new method for power quality disturbances detection based on LMD. This is the first time Local Mean Decomposition (LMD) applied to the power system the short-time voltage fluctuation signal, harmonic signal and Long-term voltage fluctuation signal detection, by simulation experiment verify the effectiveness of the method.

LOCAL MEAN DECOMPOSITION PRINCIPLE

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

- 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).

- 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 a_{11} (t).

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

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

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

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

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

- 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) :

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

- 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:

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

POWER QUALITY DISTURBANCE SIGNAL DETECTION AND ANALYSIS

IEEE according to the frequency spectrum characteristics, voltage disturbance duration, amplitude, the power quality disturbance signal consists of short-time voltage fluctuation, Long-term voltage fluctuation, waveform distortion and electromagnetic transient and other typical disturbance and the electromagnetic interference of typical feature has been classified, according to the provisions of IEEE, the typical voltage disturbance signal is simulated based Matlab2011, Time-frequency characteristics of signal are analyzed using LMD and HHT and using mirror extension to improve the end effect in the analysis, the disturbance of $\Delta = 0.001$.

Short-time voltage fluctuation: Short-time voltage sag:

$$S1\ (t) = (a-\alpha\ (u\ (t_2)\ -u\ (t_1)))\ \sin\ (100\ \pi t)$$

The amplitude of voltage sag is $\alpha = 0.35$, u (t) is unit step function, $t_2 = 4.5s$, $t_1 = 0.5s$. Sampling frequency is 3200 Hz, corresponding time-frequency analysis is shown in Fig. 1.

Figure 1a shows, LMD algorithm can effectively decompose short-time voltage sag signal by comparing the PF1 waveform and HHT imf1 waveform; from Fig.1b shows that, compared with HHT algorithm, instantaneous amplitude waveform at the endpoint using LMD algorithm is better, waveform is also more smooth from the the initial stage of disturbance signal to the disturbance recovery time. in addition, also known amplitudes of 0.503 sec is 0.65, 4.506 sec moment magnitude is 1, Therefore, the amplitude waveform can accurately judge the disturbance occurred time and recovery time; Fig. 1c is a pure frequency modulation function of PF1 component; the instantaneous frequency waveform based on LMD and HHT shown in Fig. 1d, we can see HHT algorithm to obtain the instantaneous frequency variation at the endpoints is larger, frequency have a mutation at the initial stage of disturbance signal and the disturbance

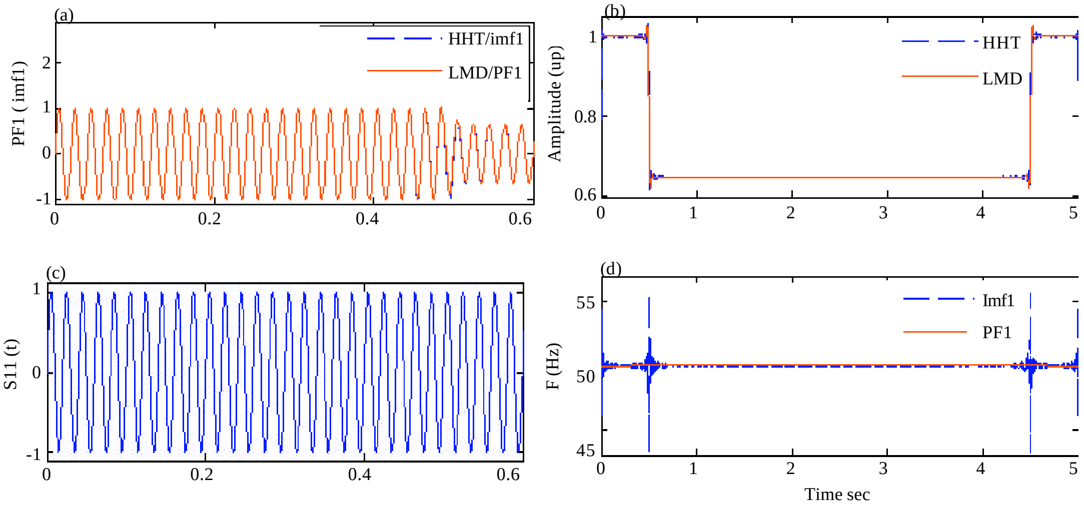

Fig. 1(a-d): Comparative analysis of the short-time voltage sag signal based on HHT and LMD, (a) PF1 and imf1, (b) instantaneous amplitude by HHT algorithm and LMD algorithm , (c) Pure frequency modulation function of PF1 and (d) instantaneous frequency waveform of imf1 and PF1

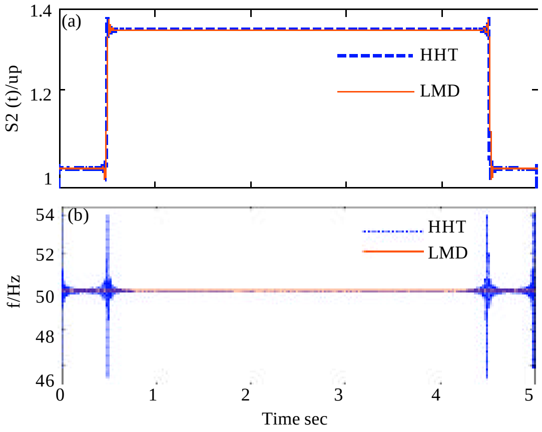

Fig. 2(a-b): Comparison Based on short-time voltage swell signals HHT and LMD analysis (a) Instantaneous amplitude and (b) Instantaneous frequency

recovery time, During this period, the instantaneous frequency is changing (49.35-50.51 Hz) but the LMD method to get the frequency is a smooth straight line (50 Hz), In accordance with the disturbance signal is amplitude change, the fixed frequency characteristics. In addition, the LMD method does not need the integral operation in calculating the instantaneous frequency, has a fast speed.

Short-time voltage swell:

$$S2\ (t) = (1\text{-}\alpha\ (u\ (t_2)\ \text{-}u\ (t_2)\ \text{-}u\ (t_1)))\ \sin\ (100\ \pi t)$$

The amplitude of voltage swell is $\alpha = 0.35$ in expression, u (t) is unit step function, t2 = 4.5, t1 = 0.5 sec. Sampling frequency is 1000 Hz, the corresponding instantaneous amplitude function waveform and instantaneous frequency function waveform is shown in Fig. 2 based on HHT and LMD.

From Fig. 2a shows the instantaneous amplitude waveform can accurately determine the disturbance time, recovery time and the disturbance amplitude magnitude of short-time voltage swell signal but amplitude using LMD algorithm more smooth, the end effect is smaller; from Fig. 2b shows, the instantaneous frequency waveform using LMD algorithm is better, no mutation point, in accordance with the actual disturbance signal. HHT algorithm to obtain the instantaneous frequency has a mutation at the initial stage of disturbance signal, the disturbance recovery time and the endpoints.

From the simulation results, we know the HHT algorithm should consider the end effect waveform

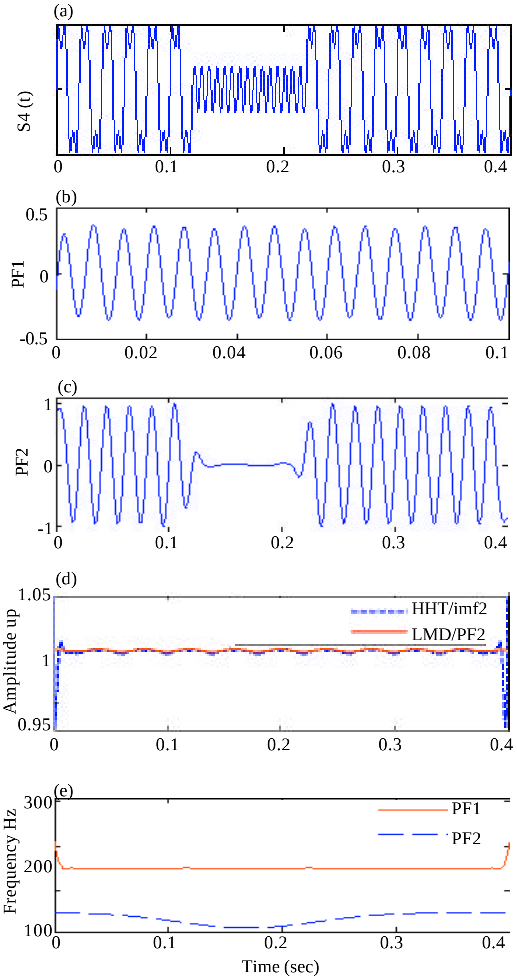

Fig. 3(a-e): Analysis of the voltage interruption plus harmonic signal based on LMD, (a) voltage interruption with harmonics, (b) PF1 component, (c) PF2 component, (d) Instantaneous amplitude of PF1 and PF2 and (e) Instantaneous frequency of PF1 and PF2

$$s4\ (t) = (1\text{-}\ (u\ (t_2)\ \text{-}u\ (t_1)))\ \sin\ (100\ \pi t)\ t)\ +0.35\ \sin\ (300\pi t)$$

distortion signal: Voltage interruption and harmonic signal expression: Where, u (t) is unit step function, $t_2 = 0.22$, $t_1 = 0.12$ sec. sampling frequency is 3200Hz, time-frequency analysis results as shown in Fig. 6 based on LMD algorithm.

Figure 3b and c indicates that the LMD method can effectively extract harmonic signal and voltage interruption signal; Fig. 3d shows that harmonic signal amplitude using the LMD algorithm is 0.35, the fundamental amplitude has obvious mutation, according to the mutation points of fundamental amplitude can determine the start and recovery time of voltage interruption disturbance signal. Figure 3e shows that the waveform is harmonic and fundamental frequency waveform, Frequency waveforms obtained by LMD algorithm without the mutation point.

Long-term voltage fluctuation: Long term voltage fluctuation signal:

$$s5\ (t) = (1+\alpha \sin(\beta\omega_0 t) \sin(\omega_0 t))$$

Among them, $\omega_0 = 2\pi f$, f = 50 Hz, $\alpha = 0.2$ is amplitude of fluctuation, $\beta = 0.2$ is fluctuation frequency coefficient, sampling frequency is 3200Hz, time-frequency analysis of voltage fluctuation signal results as shown in Fig. 4 based on LMD algorithm and HHT algorithm.

From Fig. 4b, LMD algorithm and HHT algorithm, can also effectively extract long-term voltage waveform signal, Fig. 4c shows that the frequency of PF1 and imf1 is 50 Hz, it is the fundamental frequency component, further we can find that LMD algorithm for frequency effect is good. Figure 4d shows Instantaneous amplitude of PF1 and imf1 is in the change, So it can be identified fundamental voltage fluctuates. in addition, instantaneous amplitude function waveform also shows that the endpoint values using LMD algorithm is larger than HHT algorithm. In order to calculate the fluctuation amplitude and frequency, instantaneous amplitude of PF1 and imf1 are analyzed based on LMD and HHT algorithm, fluctuant frequency and amplitude as shown in Fig. 5.

Figure 5a shows that the long-term fluctuant frequency voltage is about 10Hz, LMD method is more accurate. Figure 5b shows, fluctuant amplitude is 0.2, consistent with the theoretical value, the waveform for LMD method is more smooth.

Electromagnetic transient disturbance: Transient signal of low frequency oscillation:

$$s6\ (t) = \sin(\omega_0 t) + \alpha e^{-c\,(t2-t1)} \sin(\omega_0 t)\ [s\ (t_2) - s\ (t_1)\ ]$$

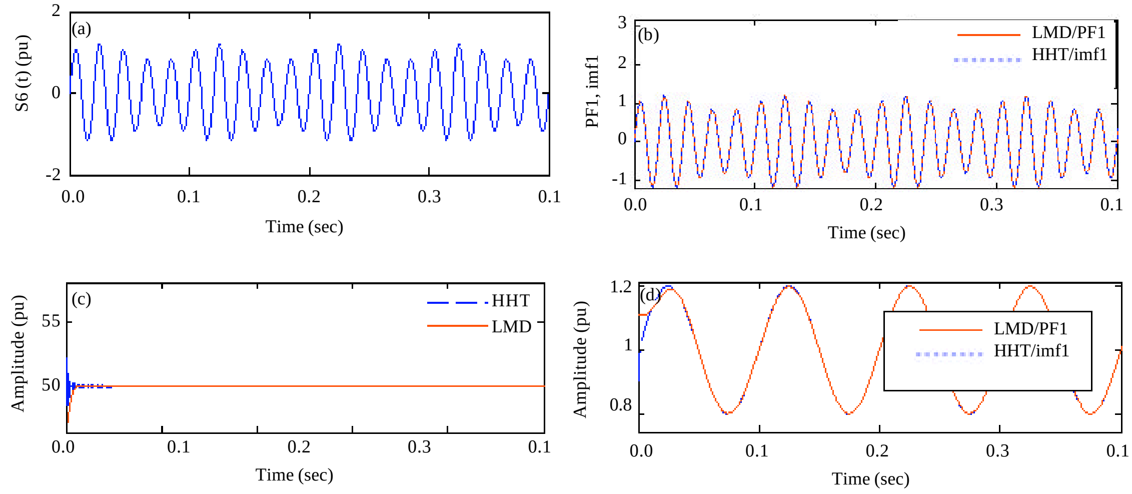

Fig. 4(a-d): Time-frequency analysis of long term voltage fluctuation signal, (a) Long term voltage fluctuation signal, (b) PF1 and imf1, (c) Instantaneous frequency of PF1 and imf1 and (d) PF1 and imf1 instantaneous amplitude

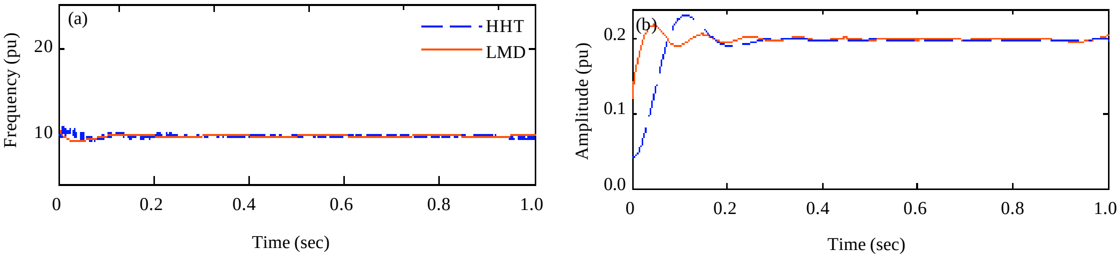

Fig. 5(a-b): Fluctuant frequency and amplitude of long term voltage fluctuation signal, (a) Fluctuant frequency and (b) Fluctuant amplitude

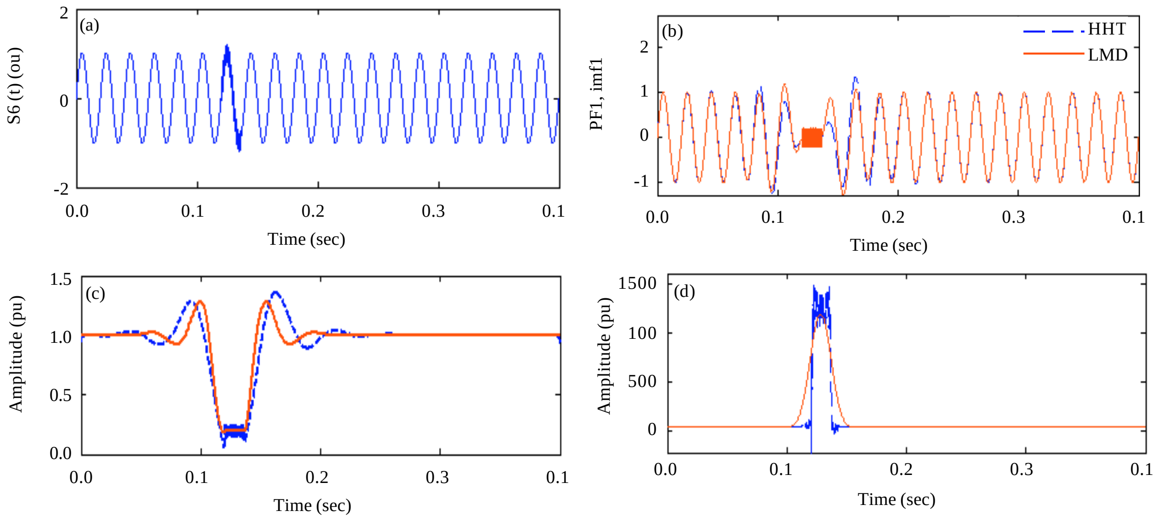

Fig. 6(a-d): Comparative analysis of the transient low-frequency oscillation signal based on LMD and HHT, (a) Signal of low frequency oscillation transient, (b) PF1 and imf1 component, (c) Instantaneous amplitude and (d) Instantaneous frequency

Among them, $\alpha = 0.2$, relative coefficient $\beta = 24$, attenuation coefficient c = 0.05, t1 = 0.12 sec, t2 = 0.1366 sec; $\omega_0 = 2\ \pi f$, f = 50 Hz, the sampling frequency is 5000 Hz, the oscillation signal and time-frequency analysis based on LMD and HHT is shown in Fig. 6.

Figure 6b 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. Figure 6c, the disturbance amplitude changes in 0.1456 and 0.2443 based on HHT method. the disturbance samplitude 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 6d 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, Fig. 6c 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.

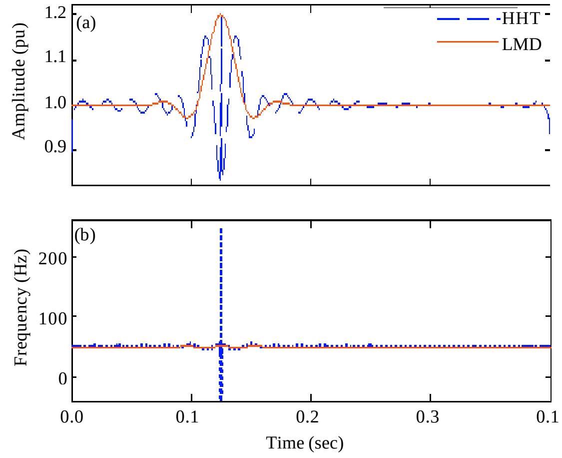

Fig. 7(a-b): Comparative analysis of the impact signal based on LMD and HHT, (a) Impact signal amplitude and (b) Impulse signal frequency

Impact signal:

$$s7\ (t) = \sin\ (\omega_0 t) + \alpha[s\ (t_2)\ - s\ (t_1)\ ]$$

The pulse amplitude $\alpha = 0.2$, $t_1 = 0.1248$, $t_2 = 0.1256$ sec, the sampling frequency is 6400 Hz, time-frequency analysis based on LMD and HHT is shown in Fig. 7.

Figure7a shows the disturbance amplitude obtained by LMD method has smaller fluctuations than the disturbance amplitude obtained by HHT method. the maximum value is 1.2 in 0.1248~0.1256 sce, therefore, we can locate disturbance moment by amplitude waveform. Figure 7b shows that instantaneous frequency appears mutation point, the HHT algorithm use mutation point of frequency to locate disturbance moment. But negative frequency phenomenon occurred in the disturbance moment, it is difficult to explain.

CONCLUSION

The study analyzes the typical short-time voltage fluctuation signal, waveform distortion signal, long-term voltage fluctuation signal and electromagnetic transient disturbance etc with the LMD algorithm. Results are compared to the HHT algorithm and the following conclusions are obtained:

The end effect of LMD is better than HHT:

- The instantaneous amplitude function can accurately determine the disturbance time, disturbance frequency and the disturbance magnitude of short-time voltage swell signal and the short-time voltage sag signal based on LMD algorithm and the waveform using LMD algorithm is better than HHT algorithm
- With regard to analyze harmonics signal and long term voltage fluctuation signal, the instantaneous amplitude and instantaneous frequency, the LMD algorithm is significantly higher than HHT algorithm that of HHT
- Through the analysis of electromagnetic transient disturbance signal and pulse signal, positioning accuracy of LMD algorithm is low than HHT algorithm, because the HHT algorithm uses mutation point of frequency to locate disturbance moment. positioning accuracy is higher but the instantaneous amplitude and instantaneous frequency waveform using LMD algorithm is better than HHT algorithm and negative frequency phenomenon is difficult to explain based on HHT algorithm

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