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Research on Local Mean Decomposition Algorithms in Harmonic and Voltage Flicker Detection of Microgrid

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Abstract: In allusion to harmonic and voltage flicker in microgrid, the local mean decomposition algorithm is adopted to analyze harmonic and voltage flicker in power system. Complex original signals can be decomposed into a number of PF (product function) component, each layer of PF is composed of the envelope signal and frequency modulation function, which contains all the instantaneous amplitude and instantaneous frequency information. Further combinations can get the original signal time frequency distribution. Using the LMD to detect the harmonic signal and the multiple frequency voltage flicker signal in microgrid, The simulation results show that this Algorithm can adaptively decompose the signal and highlight the local characteristics of PF data, the method can be accurate analysis of multi frequency harmonic distortion signal, interharmonic signal and multiple frequency voltage flicker signal. Simulation waveform is not only influenced by "end effect" of small effect, and the instantaneous frequency is always positive. According to the actual analysis of a transformer with multi-frequency signal power in a microgrid system, using LMD algorithm and HHT algorithm, The result further prove the correctness of the proposed method, which provides the theoretical fundamental in a new way for the electrical energy detection in power system. *Copyright © 2013 IFSA.*

Keywords: Local mean decomposition, Harmonic, Voltage flicker, Power quality detection, Microgrid.

1. Introduction

The development of new energy and renewable energy is an inevitable choice to solve the contradiction between China's energy shortage, energy utilization and environmental protection. Renewable energy, including wind energy, solar energy, ocean energy, biomass, geothermal-based distributed micro grid technology is one of the development directions of the electric power industry in the 21st century. Microgrid (microgrid, MG): distributed power, energy storage devices, energy conversion device, load and monitoring, protection device pool from generation and distribution system, and this autonomous system is able to achieve self-control, protection and management [1-2].

With the expansion of the depth and range of applications of microgrid work research, micro-grid power quality problems is getting more and more people's attention. Harmonics can be divided into steady-state harmonic and time-varying harmonic, and there are many studies for the steady-state harmonic detection method [3-4]. Microgrid harmonic disturbance signal and inter-harmonic signal is non-linear, non-stationary signals. Fourier transform can not handle non-linear, non-stationary signals, spectral leakage and fence phenomena also exist between treatments harmonic

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shortcomings [5-7]; Analysis of non-linear, non-stationary signals wavelet theory has many limitations, must construct divide strict and energy concentration wavelet basis; 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 [8-9].

Jonathan Smith proposed a new adaptive time-frequency analysis method local mean decomposition (local mean decomposition LMD) in 2005 [10]. LMD time-frequency analysis method is to decompose the original signal into a series of product function group (the Product Function, PF), the layers PF by the envelope signal and pure FM signal is composed of two parts, they contain all of the instantaneous amplitude and instantaneous frequency information, the further combination when you can get the original signal frequency distribution. The LMD method has been successfully applied to the detection of EEG, the instantaneous frequency of the signal extraction and mechanical fault diagnosis [11-12]. This is the first time local mean decomposition (LMD) applied to the power system micro grid harmonic disturbance signal and inter-harmonic signal detection, by simulation experiment verify the effectiveness of the method.

2. Local Mean Decomposition Principle

2.1. Local Mean Decomposition Algorithm

Local mean decomposition can decompose any complicated signal into a number of the PF component which has a certain physical meaning and, each PF component by the plain envelope signal and FM signal integrated. For a signal *x(t)*, the decomposition step is as follows [13-14]:

a) To determine the signal *x(t)* of all local extreme point n_i.

b) Through each extremum point n_i, calculate any two adjacent local extreme point mean m_i and the value of the envelope estimate a_i

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

$$a_i=|n_i-n_{i+1}|/2 \quad (2)$$

Connect the adjacent local mean point mi and m_{i+1} with broken line, and then conduct smooth handling by using the moving average method to get the local mean function $m_{11}(t)$. Connect each adjacent envelope estimate values a_i and a_{i+1} with broken line, and then conduct smooth handling by using the moving average method to get the envelope estimate function $a_{11}(t)$.

c) Separate the local mean function $m_{11}(t)$ from the original signal x(t), and obtain the signal $H_{11}(t)$:

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

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

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

Determine whether the $s_{11}(t)$ is a pure FM signal, the determination condition is to repeat the above steps for $s_{11}(t)$, get the envelope estimation function $a_{12}(t)$ satisfies the $a_{12}(t)=1$, and if not satisfy described and $s_{11}(t)$ is not a pure FM signal and then repeat n times until $s_{1n}(t)$ is a pure FM signal, i.e. $s_{1n}(t)$ the envelope of the estimation functions satisfy $a_{1(n+1)}(t)=1$, so:

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

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

Conditions for iterative terminated:

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

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

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

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

f) Obtain the formula (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:

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

The first PF component contains the highest frequency component of the original signal.

g) Separate PF1(T) from the original signal x(t) to get $u_1(t)$ as a new data to repeat the above steps, the cycle k times until $u_k(t)$ is a monotonic function so far.

$$\begin{cases} u_1(t) = x(t) - PF_1(t) \\ u_2(t) = u_1(t) - PF_2(t) \\ \vdots \\ u_k(t) = u_{k-1}(t) - PF_k(t) \end{cases} \quad (10)$$

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

$$x(t) = \sum_{i=1}^{k} PF_i(t) + u_k(t) \quad (11)$$

2.2. Based on the Instantaneous Frequency of the LMD Strike

By formula (11), the signal is decomposed into a number of PF component and, each PF components represented by the pure envelope signal a(t) and pure FM function $s(t)=\cos\varphi(t)$, its frequency f can be pure FM function s(t) directly solve, namely:

$$\varphi(t)=\arccos(s(t)) \quad (12)$$

Expand the formula (12) and the derivative can be calculated the instantaneous frequency of s(t), the corresponding component of the instantaneous frequency of the PF. s(t) values between ±1, if s(t) value is approximately equal to ±1, ±1 instead because it is derived by the derivative of the cosine function of the instantaneous frequency of the PF. This method of obtaining frequency is intuitive and simple, referred to as "direct method", and compared to the method of the instantaneous frequency of HHT transform strike to strike the instantaneous frequency of the "direct method" is always a positive value, does not appear HHT negative frequencies phenomenon.

3. Detection and Analysis Based on the LMD Microgrid Harmonics and Voltage Flicker Signal

3.1. Causes of Micro-Grid Harmonics and Voltage Flicker

Fig. 1 is a typical micro-grid structure diagram, photovoltaic, fuel cell and micro turbine power electronics connected to the alternating current (AC) busbar through interface micro network, small wind turbine is directly connected to the micro grid. Micro-network system uses a hierarchical control strategy, and allows micro-network as part of the distributed power grid supply to large power grids. Micro grid through the point of common coupling (point of common coupling PCC) connects the main grid.

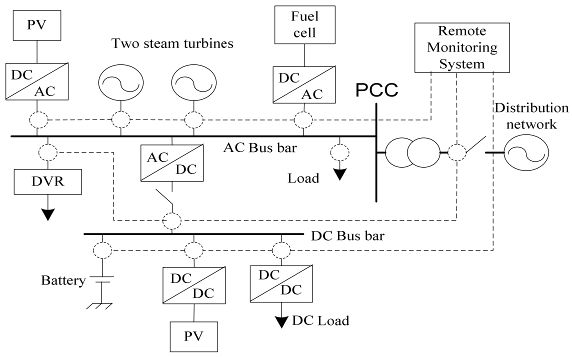


Fig. 1. Structure of typical micro-grid.

Harmonics generated in the micro grid is a harmonic of the generated harmonics and micro-network within the power electronic components by the distributed power generation system includes many distributed power itself. Micro-grids contain nonlinear load and a lot of power electronic equipment, these deflector charged with the important task of load switching and power transfer, but its operation will cause the grid voltage and current waveform distortion, cause harmonics and inter-harmonics pollution. Nonlinear load current of amplitude, phase, and waveform changes, and contains a large number of harmonics and inter-harmonics ingredients. For wind turbines, the volatility of the fans to contribute Fans to contribute due to changes in wind speed and wind turbine tower shadow, the fluctuation precisely in to be able to generate the voltage flicker the frequency range (below 25 Hz). Power transient disturbance and continued volatility are easily caused, resulting in voltage fluctuation and flicker. Motor, rolling mill, electric arc furnace, electric locomotives belong impact load, at run time, such as the load will make the grid voltage is unstable, resulting in a slow or rapid voltage fluctuation. Such impact load characteristics vary, thereby generating the flicker also varies.

3.2. Micro-Grid Harmonic Signal Detection

Analysis the PCC point harmonic current signal x(t) of the micro grid [15]. Harmonic of PCC point and inter-harmonic current signal mathematical expression as follows:

$$\begin{cases} 2\sin(100\pi t) + 1.2\sin(220\pi t), 0 \le t < 0.2 \\ 2\sin(100\pi t) + 0.7\sin(480\pi t), 0.2 \le t < 0.3 \\ 2\sin(100\pi t) + 0.5\sin(800\pi t), 0.3 \le t < 0.4 \end{cases} \quad (13)$$

The current waveform of the signal x(t) is shown in Fig. 2, the sampling frequency is 3200 Hz, disturbance quantity Δ=0.001. To verify the advantages of the LMD, the endpoint is not doing the processing; The LMD correlation waveform analysis is shown in Fig. 3.

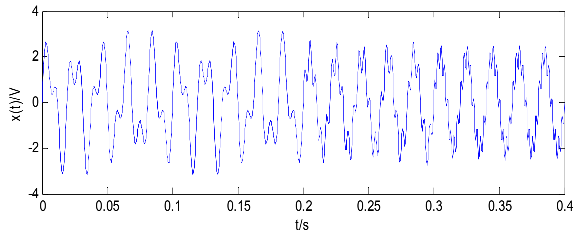
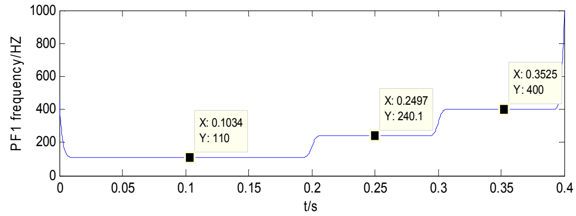
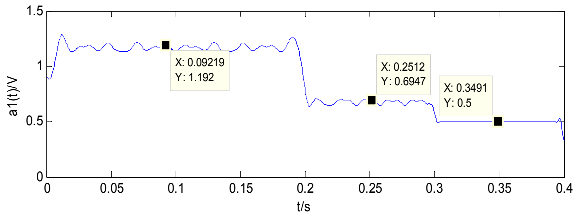


Fig. 2. Micro-grid time-varying inter harmonic signal.



(a) Inter harmonic signal frequency.



(b) Inter harmonic signal amplitude.

Fig. 3. Inter-harmonic time frequency signal analysis in microgrid based on LMD.

Fig. 3(a) shows that the inter-harmonic frequencies in the 0-0.2 s 110 Hz ,0.2-0.3 s as 240 Hz, 0.3-0.4 s for 400 Hz; Fig. 3(b) shows that the harmonic amplitude 0-0.2 s 1.2 V, 0.2-0.3 s to 0.7 V, 0.3-0.4 s for 0.5 V. And compare literature [23] the HHT obtained experimental waveform can find that even if the endpoint LMD analysis inter harmonic is not be processed, the decomposition of the waveform end effect is small, the reason LMD decomposition signal average slip fitting envelope, avoid a HHT cubic interpolation prone to over-the envelope or owe envelope phenomenon; Minus the envelope function "screening" than an intrinsic mode process and HHT, LMD get a PF component divided by the envelope function "screening". The number is significantly larger than the HHT get an intrinsic mode "screening" the number of components is less "Screening" the fewer the number, the less light the endpoint effect inward pollution data.

3.3. Microgrid Voltage Flicker Signal Detection

Microgrid with wind turbines and impact loads such as motors, rolling mill, electric arc furnace, electric locomotive, will cause the micro grid voltage flicker, usually the voltage fluctuations in the frequency range 0.01~35 Hz. Voltage flicker signal can be expressed as:

$$S(t)=\left[A_0+\sum_{m=1}^{k}A_m\cos(\omega_m t)\right]\cos(\omega t), \tag{14}$$

where A_0 is the frequency fundamental voltage amplitude; A_m constitute the amplitude of the harmonics of the flicker signal; ω frequency angular frequency; ω_m to constitute the angular frequency of the flicker signal harmonics, $v(t)=\sum_{m=1}^{k}A_m\cos(\omega_m t)$ is flicker envelope signal.

Fig. 4(a) is a multifrequency voltage flicker waveform of a signal, the corresponding expression is:

$$S(t)=(10+1.2\cos(10\pi t)+\cos(20\pi t)+ \\ 2\cos(40\pi t+\pi/6))\cos(100\pi t) \tag{15}$$

This article through strike a signal maximum point of the envelope of v(t), then its LMD analysis, the sampling frequency of 3200 Hz, the frequency and amplitude of the flicker signal finally obtained.

LMD decomposition of the PF1, PF2 and PF3 are respectively, the PF component LMD decomposition is arranged in descending order of the local frequency, Fig. 4(c) shows that, the microgrid voltage flicker signal frequency is 20 Hz, 10 Hz, 5 Hz, Fig. 4(d) shows that, the amplitude of micro grid voltage flicker signal are 2 V, 1 V, 1.2 V, can be seen that the LMD decomposition can be efficiently extracted out of the multi-frequency voltage in the output voltage of a flicker signal, the successful realization of the disturbance signal component of the frequency and amplitude of the decomposition, exploded waveform can be found from Fig. 4 the instantaneous frequency obtained by the LMD method is very accurate, and strike the frequency is positive, continuous, having a physical meaning of a time varying frequency, no negative frequency unexplained.

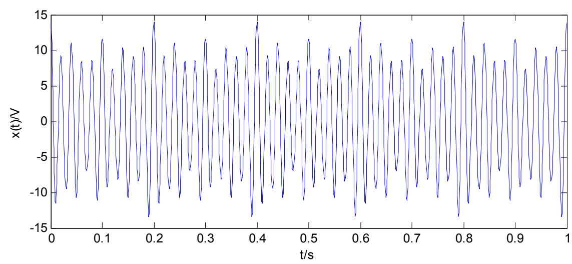


Fig. 4(a). Voltage flicker time-frequency signal analysis in microgrid based on LMD – multifrequency voltage flicker signal.

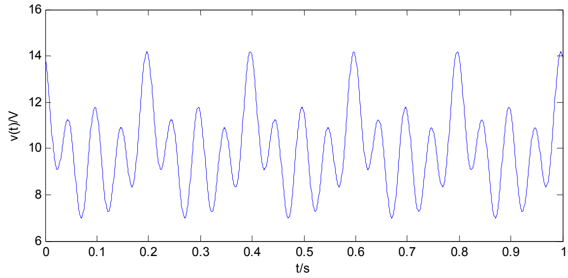


Fig. 4(b). Voltage flicker time-frequency signal analysis in microgrid based on LMD – envelope signal of the voltage flicker signal.

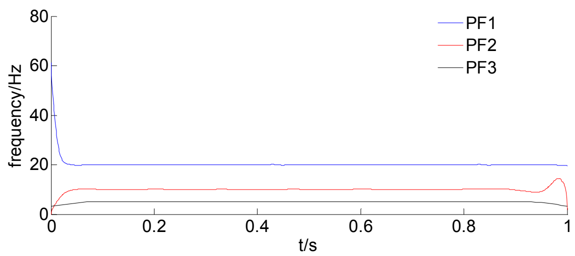


Fig. 4(c). Voltage flicker time-frequency signal analysis in microgrid based on LMD – frequency.

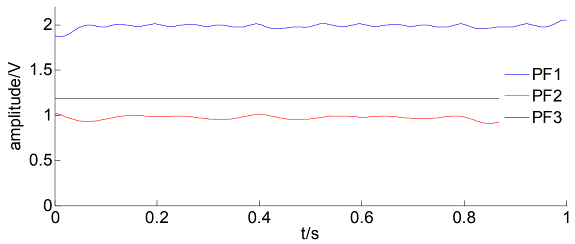
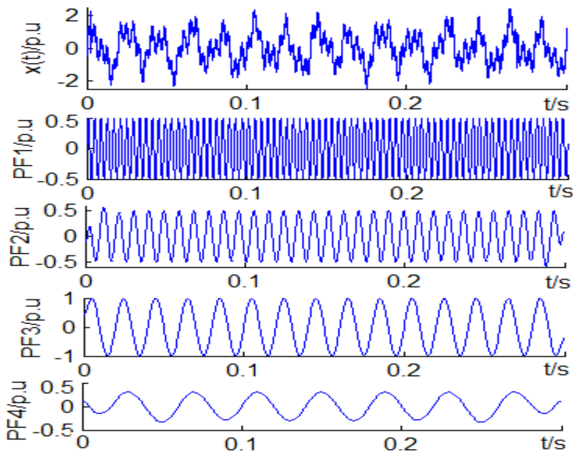


Fig. 4. Voltage flicker time-frequency signal analysis in microgrid based on LMD – amplitude function of PF component.

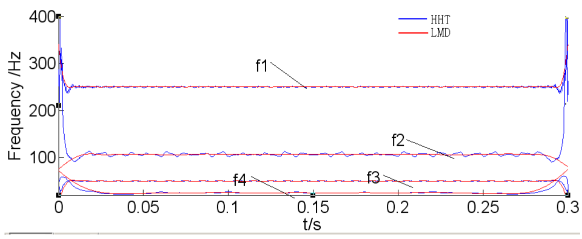
4. Experimental Verification

Fig. 5(a) shows, x(t) is multiple frequency harmonic distortion signal of power transformer in a microgrid system. Sampling frequency is 3200 Hz, Δ=0.001, to filter the high frequency noise signal, the PF component using LMD algorithm separated as shown in Fig. 5(a), the frequency were separated from high to low order using the LMD algorithm; the corresponding instantaneous amplitude function waveform and instantaneous frequency function waveform is shown in Fig. 5(b), 5(c) based on HHT and LMD. Compared with HHT algorithm, simulation results show that LMD algorithm is better than HHT algorithm in the parameter fluctuation of transient characteristic parameter detection, the detection accuracy and the end effect.

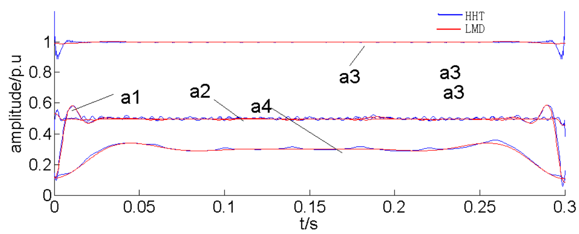
The steady frequency of each PF component by the least squares fitting were 250.06 Hz, 106.50 Hz, 50.04 Hz and 25.01 Hz, the multi frequency harmonic signal in the transformer with 5th harmonic, fundamental harmonic and inter-harmonic. In addition, under the same conditions, the LMD algorithm running 1.143692 s, HHT running 1.962869 s, the running speed of LMD is greatly improved.



(a) PF component



(b) Instantaneous frequency



(c) Instantaneous amplitude

Fig. 5. Analysis results of the multi-frequency harmonic signal in transformer.

5. Conclusions

Micro-grids contain a large number of power electronics components and shock loading harmonics and voltage flicker. This article is the first time to use the LMD method of microgrid mutations, non-smooth inter-harmonic signal and multi-frequency voltage flicker harmonic signal analysis, this method can be seen from the simulation results adaptive signal gradual decomposition, the PF component obtained in the decomposition projecting the local characteristics of the data, and can effectively determine the micro-grid disturbance occurred and the recovery time as well as the amplitude and frequency of the disturbance signal. And the resulting waveform is less affected by "end effect", because the integral calculation is not required, having a small amount of computation, speed, etc., the more important is the instantaneous frequency of the strike with the LMD method are positive. Valid theoretical basis and a new approach for power quality detection are supplied.

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