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Power system low frequency oscillation detection using local mean decomposition algorithm

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ABSTRACT

In allusion to 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. Complex original signals can be decomposed into a number of product function component, Each layer of product function component is composed of the envelope signal and frequency modulation function, which contain all the instantaneous amplitude and instantaneous frequency information, Further combinations can get the original signal time frequency distribution. The typical power quality low frequency oscillation signal is selected and analyzed by LMD algorithm. 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, but also can detect the voltage fluctuation amplitude. 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.

KEYWORDS

Low frequency oscillation signal; Local mean decomposition; Power quality detection; End effect; Detection; HHT algorithm.

INTRODUCTION

The low frequency oscillation has always been one of the problems on the safe and stable operation of power system. How to effectively damping low frequency oscillation is a research hotspot in recent years, and the low frequency oscillation modal parameters accurately and effectively extract is a difficulty. For a long time, people are through small signal stability analysis, linearized processing to study low frequency oscillation problem, and has obtained the certain effect. But the electric power system is a typical nonlinear system, along with the scale and the increasing complexity of system, linearization method is increasingly exposed its shortcomings. For strong nonlinear characteristics of complicated power grid, even installed a lot of power system stabilizer (PSS), low frequency oscillation is still possible. Such as northeast China, north China power grid is seen in some unknown mechanism of low-frequency oscillation, many scholars believe is caused by nonlinear interaction[1-11].

At present, the detection method of the power system low frequency oscillation of power quality with Fourier transform, wavelet transform and S transform, the HHT transform, and the method of combining theories. Traditional Fourier transform because of global transformation properties, can't deal with nonlinear and non-stationary signal, when dealing with harmonics exist shortcomings and so on phenomenon of frequency spectrum leakage and fence[12-15]. Research in recent years, more is the theory of wavelet transform, wavelet transform is not really a adaptive transform, USES the theory of wavelet analysis of nonlinear and non-stationary signal has significant limitations, strictly have to construct the frequency division and energy concentration of wavelet basis function, decomposition effect depends on the choice of basis functions and decomposition scale, there is no guarantee that the optimal decomposition effect. S transform is to add a window Fourier transform and continuous wavelet transform extension or promotion, in S transform, the window function is a can follow the change of frequency and scale of Gaussian function, the S transform is strongly influenced by noise. HHT based power quality detection method, though a good results have been achieved, but experience in modal decomposition using the cubic spline interpolation is appeared when the envelope signal envelope, owe envelope phenomenon, the number of "screening" too much in the HHT cause pollution of the endpoint effect degree of the whole data segment is larger, and based on the HHT time-frequency analysis method of instantaneous frequency is often appear negative physical phenomena is difficult to explain[16-18]. Therefore, to find a more effective and easier to realize detection method is very necessary.

In 2005, Jonathan Smith proposes a new adaptive time-frequency analysis theory of local mean decomposition method (local mean decomposition, LMD)[18]. Local mean decomposition method is according to the different main frequency content in the original signal will signal is decomposed into a set or more sets of Product Function, the Product Function, PF) component, Product Function component of each group were by a amplitude envelope signal and multiply by a pure frequency modulation signal, the amplitude envelope signal can show all the instantaneous amplitude information in the original signal, pure modulation signal to display all instantaneous frequency information in the original signal. The product function together to get the original signal is a complete time-frequency distribution.

LMD method has been successfully applied to EEG signals detection, instantaneous frequency signal and the extraction of mechanical fault diagnosis[19]. In this paper, the local mean decomposition (LMD) is first used in electric power system low-frequency oscillation signal disturbance time, frequency and amplitude detection, through simulation experiment, proves the effectiveness of the method.

COMPOUND MORPHOLOGY FILTER AND CENTER EXTREMUM DIFFERENCE ALGORITHM

Local mean decomposition signal process is as follows:

(1) For an original signal $x(t)$, to determine the signal local extremum points n_i of all.

(2) According to the extreme value point n_i, calculation of arbitrary two adjacent local extreme value point $m_i = \frac{(n_i + n_{i+1})}{2}$ and average amplitude envelope estimates $a_i = \frac{|n_i - n_{i+1}|}{2}$. Connect the local average of all adjacent points m_i and m_{i+1}, then use moving average method for smoothing processing, get the local mean value function $m_{11}(t)$. Each adjacent amplitude envelope estimate a_i and a_{i+1} connected, and then use moving average method for smoothing processing, get the amplitude envelope estimation function $a_{11}(t)$. Moving average processing computation formula is as follows:

$$y_s(i) = \frac{1}{2n+1}\left[y(i+n) + y(i+n-1) + \cdots + y(i-n)\right]$$

Among them, $y(i)$ is the original sequence data, $2n+1$ is the width of sliding, at that time $i < n$, should be reduced accordingly span, is limited to no more than sequence endpoint.

(3) The local mean value function $m_{11}(t)$ is separated from the original signal $x(t)$, get signal $h_{11}(t)$:

$$h_{11}(t) = x(t) - m_{11}(t) \tag{1}$$

(4) $h_{11}(t)$ divided by the amplitude envelope estimation function $a_{11}(t)$, frequency modulation signal $s_{11}(t)$:

$$s_{11}(t) = \frac{h_{11}(t)}{a_{11}(t)} \tag{2}$$

Determine $s_{11}(t)$ whether it is a pure frequency modulation signal, judge condition is to $s_{11}(t)$ repeat the above steps, $a_{12}(t)$ get $s_{11}(t)$ amplitude envelope estimation function, if, then is a pure frequency modulation signal, if $a_{12}(t) = 1$, $s_{11}(t)$ is a pure frequency modulation signal, otherwise, $s_{11}(t)$ is not pure frequency modulation signal, the iterative process should be repeated, until $s_{1n}(t)$ for a pure frequency modulation signal, as shown in the following type.

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

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

The terminating condition is $\lim_{n\to\infty} a_{1n}(t) = 1$. Amounts of practice, in order to avoid decomposition, set Δ terminated an iterative threshold, when $1 - \Delta \le a_{1n}(t) \le 1 + \Delta$, iteration terminates.

(5) The iterative process of all amplitude envelope estimation function to do product, get 1 is the instantaneous amplitude envelope signal amplitude function $a_1(t)$:

$$a_1(t) = a_{11}(t)a_{12}(t)\cdots a_{1n}(t) = \prod_{k=1}^{n} a_{1k}(t) \tag{3}$$

(6) Type (3) to be pure frequency modulation signal amplitude envelope signal $a_1(t)$ and $s_{1n}(t)$ do product, get the original signal x (t) of the first component of the product function:

$$PF_1(t) = a_1(t)s_{1n}(t) \tag{4}$$

The product function component contains the entire highest frequency signal in the original signal instantaneous amplitude and instantaneous frequency information, is a single component of am-fm signals, the instantaneous frequency function $f_1(t)$ can be determined by pure frequency modulation signal $s_{1n}(t)$, namely: $f_1(t) = \frac{1}{2\pi} \cdot \frac{d[\arccos(s_{1n}(t))]}{dt}$

(7) $x(t)$ isolated from original signal after the first component of the product function to get the residual signal $u_1(t)$, $u_1(t)$ as a new original signal repeat the above steps, circle k times, until the $u_k(t)$ is a monotonic function, calculation process is shown below.

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

Can be seen from the above steps, the product of original signal can be made by $u_k(t)$ and all function component refactoring, namely:

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

POWER SYSTEM LOW FREQUENCY OSCILLATION EXAMPLE ANALYSIS

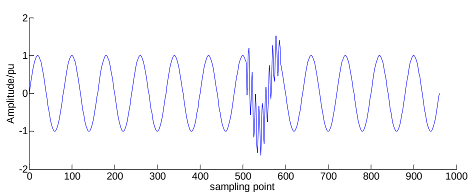
Example 1

Power system low-frequency oscillation signals:

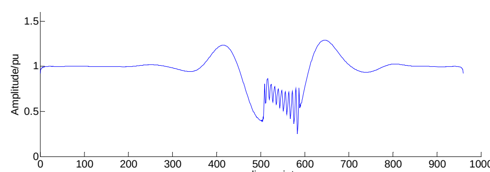
$$x(t) = \sin(\omega t) + 0.8 \cdot e^{-20(t-6.25T)} \cdot \left[\varepsilon(7.25T) - \varepsilon(6.25T)\right] \cdot \sin(10\omega t)$$

$\varepsilon(t)$ as the unit step function, t_1, t_2 as the time of beginning and ending of disturbance signals respectively, a for the disturbance amplitude, β for the frequency coefficient, c for transient oscillation damping coefficient

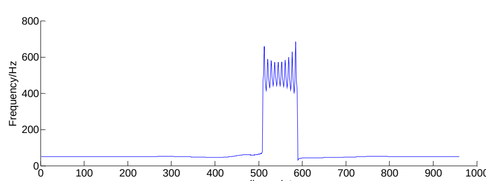
This algorithm USES to meet the requirements of intelligent substation frequency 4000 Hz, or weekly wave sampling 80 points. The simulation data of each group were intercepted 960 sampling points were analyzed. To test the disturbance signal, the mathematical model generated by the disturbance signal as shown in TABLE 1, $T = 0.02s$.



(a) The original signal



(b) Amplitude function



(c) Frequency

Figure 1 : Low frequency oscillation signal detection results

In addition to the endpoint in the instantaneous frequency curve two starting and ending times for maximum points for the disturbance. Curve of instantaneous amplitude and instantaneous frequency disturbance time all sampling points corresponding value curve after the least-square fitting processing, get the steady state interval value is the value perturbation amplitude and frequency in test results. Transient disturbance detection results Based on local mean decomposition method of summary as shown in TABLE 1.

TABLE 1 : Low frequency oscillation detection results based on LMD

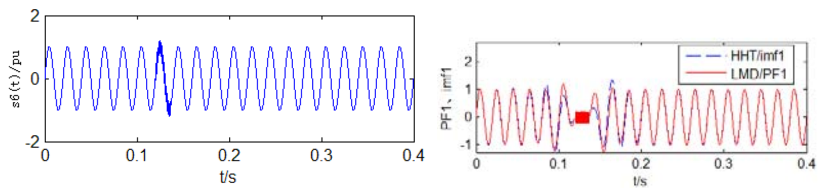
Disturbance start time/s	Disturbance end time /s	Disturbance amplitude /%	Disturbance frequency /Hz

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

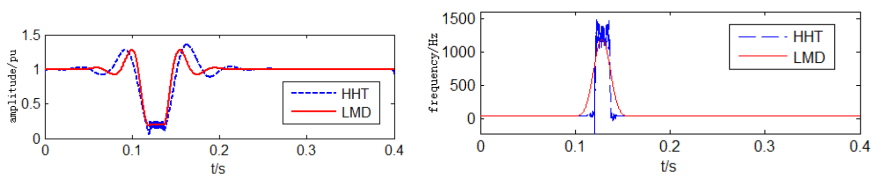
Example 2

The transient low frequency oscillation:

$x(t) = \sin(\omega t) + a \cdot e^{-c(t-t_1)} \cdot [\varepsilon(t_2) - \varepsilon(t_1)] \cdot \sin(\beta\omega t)$, The alpha = 0.2, the relative coefficient beta = 24, attenuation coefficient c = 0.05, t_1 = 0.12 s, t_2 = 0.1366 s. Omega = 2 PI f, f = 50 Hz, the sampling frequency is 5000 Hz, oscillation signal and LMD and HHT time-frequency analysis is shown in Figure 2.



(a) The transient low frequency oscillation signals **(b) PF1 and imf1 components**



(c) The instantaneous amplitude **(d) Instantaneous frequency**

Figure 2 : Comparative analysis of the low frequency oscillation signal based on LMD and HHT

From Figure 2 (b), the effect is better the LMD method for PF1 than HHT method to obtain the imf1, especially at the disturbances and recovery moment. Figure 2 (c), with HHT to calculate the instantaneous amplitude disturbance changes between 0.1456 ~ 0.2443, disturbance of LMD calculating instantaneous amplitude changes between 0.1965 ~ 0.1985, known LMD method for transient disturbance amplitude obviously better than the HHT; From Figure 2 (d) is obtained by HHT instantaneous frequency of the frequency of mutation happened in 0.1209 s and 0.1372 s, which can determine the voltage disturbance and recovery time, but the HHT method to calculate the disturbance signal frequency changes between 1065 Hz ~ 1485 Hz, and the LMD method to calculate the maximum perturbation frequency is 1200 Hz, consistent with the theoretical value, in addition, the HHT method for instantaneous frequency in disturbance moment appeared difficult to explain the negative frequency. For LMD method for the instantaneous frequency of positioning inaccurate problem, from Figure 2 (c) in 0.1195 s amplitude to the minimum, in 0.1368 s began to rise, so it can be LMD disturbance signal to obtain the instantaneous amplitude function positioning, but the positioning precision than HHT method using frequency mutation point positioning.

CONCLUSIONS

To the power system low-frequency oscillation signal detection, in this paper, the electric power system low-frequency oscillation signal is a typical disturbances, and the comparison study is made from LMD algorithm and HHT method, get the following conclusion:

(1) According to the instantaneous amplitude of LMD gain function disturbance moment can accurate positioning; the disturbance during the disturbance amplitude and frequency, the analysis of the effect is better than that of HHT method.

(2) The LMD endpoint effect significantly better than the HHT.

(3) The LMD method without integral operation has a faster speed.

(4) The endpoint of LMD method effect is small, "screening" fewer, inward pollution data to a lesser degree, the desires of parameters in steady state basic don't change, no need for data fitting, and the precision of the request parameter is very high, especially the frequency of the calculating value is always positive, almost equal to the theoretical value completely in steady state.

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