On-line identification method for low-frequency oscillation of power system based on fuzzy filtering

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Abstract: Considering that Prony algorithm is very sensitive to input signal and sensitive to the noise of analysis data, a new identification method of online low frequency oscillation mode of power system based on fuzzy filter and Prony algorithm is proposed. The method uses wide area measurement signal as input, and it can filter the input signal quickly through very simple fuzzy logic reasoning. After analyzing the filtered digital signal by Prony algorithm, the mode of power system low frequency oscillation can be obtained. A 1648-bus system is offered from PSS/E software for the analysis. By comparing the input signals before and after the fuzzy filter, this method can be more accurately identified by the mode of oscillation.

Keywords: Fuzzy filter; On-line identification; power system; Low frequency oscillation

1. INTRODUCTION

With the increasing scale of interconnected power system, the low frequency oscillation caused by system interconnection has become one of the most important factors endangering the safe operation of power grid and restricting the transmission capacity of power grid. The traditional analysis methods of low frequency oscillation are mostly numerical and off-line analysis, so it is difficult to meet the requirements of on-line analysis. Literature [1] points out that how to use the field measured data to find oscillating characteristic parameters on line and real-time analysis of the oscillation mechanism is a problem worthy of study. Wide-area measurement system (WAMS) based on synchronous measurement technology provides a new idea for dynamic analysis of large-scale interconnected power system. Literature [2] uses the Calman filter method to calculate the electromechanical oscillation mode of the system using the measured values of the discrete time points provided by WAMS. Document [3] uses fast Fourier transformation and wavelet analysis to analyze the voltage phase difference oscillation time curve between nodes provided by WAMS and extract the oscillation mode. However, whether it is Calman filter or Fu Liye change or wavelet analysis, these algorithms are difficult to extract the attenuation characteristics and other limitations.

Prony algorithm uses a linear combination of exponential functions to analyze equidistant sampling data, which can conveniently estimate the frequency, attenuation, amplitude and initial phase of a given signal. Therefore, the field measured data provided by WAMS can be used to analyze the low frequency oscillation mode by the Prony algorithm. The [4] presents an analysis method for low frequency oscillation in power system WAMS measurement and improvement of Prony algorithm based on singular value two moments of the sample matrix actual order estimation system of low frequency decomposition and then Prony analysis can achieve the online analysis of electromechanical mode using the method. However, due to the influence of noise, the dominant mode of order estimation more often than signals, and the noise effect will lead to inconsistent estimates of the order, so as to further reduce noise, to estimate the actual leading mode of order and system is more close to more accurately find the electromechanical oscillation analysis[5]-[8]. The traditional method of filtering noise Calman filtering, Wiener filtering, the adaptive filtering and filtering method based on wavelet transform has been widely used, but these methods require complex mathematical calculations, with the method of discrete data measured of the pretreatment, relevant parameters of predefined filter or system model needs [9]-[10]. And the noise filtering effect of these methods on the different forms of different, it may be difficult to meet the requirements of mixed noise filtering.

With the above research, this chapter proposes a fuzzy filtering and Prony algorithm based on the combination of low frequency oscillation in power system online identification method, the first method of discrete measured signal is filtered by simple fuzzy rules, and then the signal and filtered by the improved Prony algorithm for pattern recognition. The process of fuzzy filtering is very simple, and the precision of pattern discrimination can be greatly improved on the premise that the burden of calculation can not be increased.

2. FILTERING METHOD BASED ON FUZZY LOGIC

Let $s(n)$ be the digital input signal of any noise in the area between [0, L-1]. W={s_j} is a collection of adjacent M samples for s_0: W = {s_1,s_2,…,s_M} = {$s(n-M/2)$,…, $s(n-2)$, $s(n-1)$, $s(n+1)$, $s(n+2)$,…, $s(n+M/2)$}. The input variable of the fuzzy filter is the difference of the input signal amplitude, as shown in formula (1)

$$x_j = s_j - s_0 \quad (1 \le j \le M)\,(1)$$

The output variable y of the fuzzy filter can obtain the new sample value as the correction item and the original sample s_0.

$$s_0^{'} = s_0 + y\,(2)$$

For the general purpose, this paper adopts the triangle membership function shown in figure 1. The membership function mainly has two parameters: triangle center coordinate c and half of the side length of the triangle w. Due to the input and output variables are defined as the signal amplitude difference between the three results can use xj or y, which are positive (PO), zero (ZE), negative (NE), to represent the relationship between the s_j and $s0$.

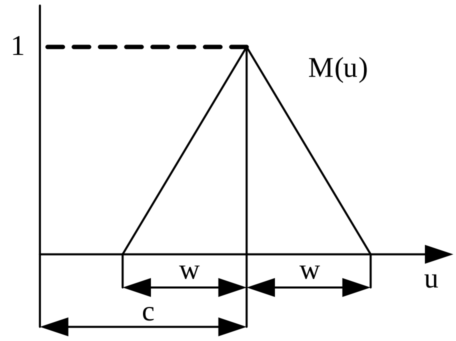


Figure 1. The definition of triangular-shaped membership function

The process of deblurring the modification of item y can be represented by the following formula.

$$y = \frac{c_{PO} w_{PO} \lambda_1 + c_{ZE} w_{ZE} \lambda_0 + c_{NE} w_{NE} \lambda_2}{w_{PO} \lambda_1 + w_{ZE} \lambda_0 + w_{NE} \lambda_2} \quad (3)$$

$$c_{PO} = -c_{NE} = L-1$$
$$c_{ZE} = 0 \qquad (4)$$
$$w_{PO} = w_{ZE} = w_{NE} = L-1$$

The resulting simplified y value is represented by the following formula

$$y = (L-1)(\lambda_1 - \lambda_2)\,(5)$$

3.ANALYSIS OF POWER SYSTEM OSCILLATION MODE BASED ON FUZZY FILTERING

The analysis method of low-frequency oscillation mode based on fuzzy filter is shown in figure2. The content of the fuzzy filter element is described in the previous section. Input signal ($s(0)$,…,$s(N-1)$) obtained from the wide-area measurement system. In Prony analysis, the estimate of the measurement signal can be expressed as:

$$\hat{s}(n) = \sum_{i=1}^{p} A_i e^{j\theta_i} e^{(a_i + j2\pi f_i)\Delta t} \quad (5)$$

A_i is the amplitude. θ_i is the phase. f_i is frequency. a_i is the attenuation factor. $\triangle t$ is the sampling interval. The sample function is calculated by the sampling point and the extended matrix R_e is shown as follows:

$$r(i,j) = \sum_{n=p_e}^{N-1} s(n-j) s^*(n-i) \qquad (6)$$
$$(i, j = 0,1,\ldots,p_e)$$

$$R_e = \begin{bmatrix} r(1,0) & r(1,1) & \ldots & r(1,p_e) \\ r(2,0) & r(2,1) & \ldots & r(2,p_e) \\ \ldots & \ldots & \ldots & \ldots \\ r(p_e,0) & r(p_e,1) & \ldots & r(p_e,p_e) \end{bmatrix} (7)$$

According to formula (7), the a_1,a_2,…,a_p can be obtained.

$$\begin{bmatrix} r(0,0) & r(0,1) & \ldots & r(0,p) \\ r(1,0) & r(1,1) & \ldots & r(1,p) \\ \ldots & \ldots & \ldots & \ldots \\ r(p,0) & r(p,1) & \ldots & r(p,p) \end{bmatrix} \begin{bmatrix} 1 \\ a_1 \\ \ldots \\ a_p \end{bmatrix} = \begin{bmatrix} \varepsilon_p \\ 0 \\ \ldots \\ 0 \end{bmatrix} (8)$$

According to the obtained a_1,a_2,…, the polynomial root for formula (7) can be obtained (Prony pole) :

$$1 + a_1 z^{-1} + \ldots + a_p z^{-p} = 0\,(9)$$

According to the recursion (9) and equation (8), the parametersb_1,b_2,…,b_p can be obtained.

$$\hat{s}(n) = -\sum_{i=1}^{p} a_i \hat{s}(n-i), \quad n = 0,1,\ldots,N-1\,(9)$$

$$\begin{bmatrix} 1 & 1 & \ldots & 1 \\ z_1 & z_2 & \ldots & z_p \\ \ldots & \ldots & \ldots & \ldots \\ z_1^{N-1} & z_2^{N-1} & \ldots & z_p^{N-1} \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ \ldots \\ b_p \end{bmatrix} = \begin{bmatrix} \hat{s}(0) \\ \hat{s}(1) \\ \ldots \\ \hat{s}(N-1) \end{bmatrix} (10)$$

The final amplitudeA_i, phase θ_i , frequency f_i and attenuation factor a_i can be obtained by (11) :

$$\begin{cases} A_i = |b_i| \\ \theta_i = \arctan|\mathrm{Im}(b_i)/\mathrm{Re}(b_i)| \\ a_i = In|z_i|/\Delta t \\ f_i = \arctan|\mathrm{Im}(z_i)/\mathrm{Re}(z_i)|/2\pi\Delta t \end{cases} \qquad (11)$$

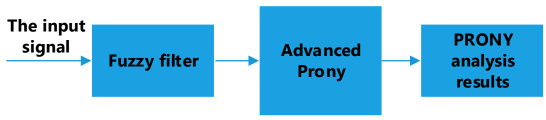


Figure 2. Flow chart of mode analysis combining with fuzzy filter and improved Prony analysis

4. CASE STUDY

In this paper, the PSS/E simulation software is used to verify the proposed method. With the main transmission line 1089-485 as the research object, the power oscillation curve of this branch is obtained by simulation calculation as shown in Figure 3. The sampling interval is 0.01s. From Figure 3, we can see that the amplitude of oscillation does not increase significantly in the first 20 seconds, and takes the first 2 seconds (200 sampling points) as the wide area measurement signal collected. In consideration of the measurement error, the white noise signal of 10% is superimposed on the whole process. The measurement signal is filtered by fuzzy filter (as shown in figure 4), where (a) is the original measurement signal, (b) and (c) are the results of the first and the second filtering respectively, which indicates that the noise is suppressed well after two times of filtering, and the result is satisfactory.

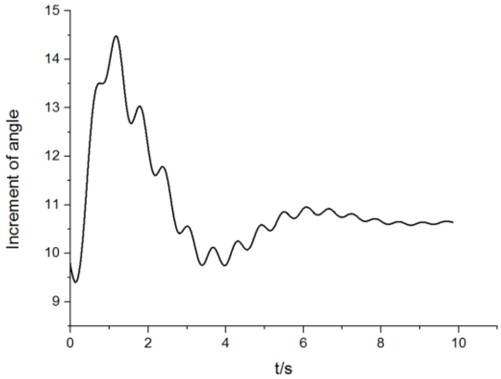


Figure3. Active power curve of branch 1089-485

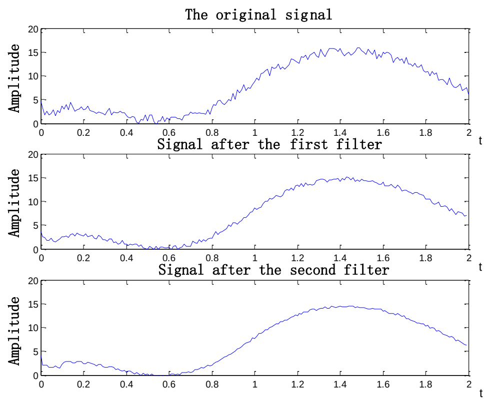
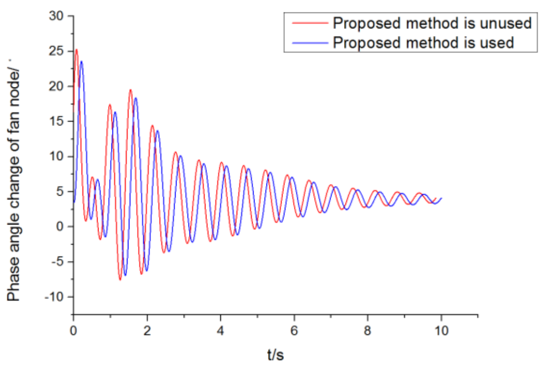


Figure4. Performances yielded by the fuzzy filter



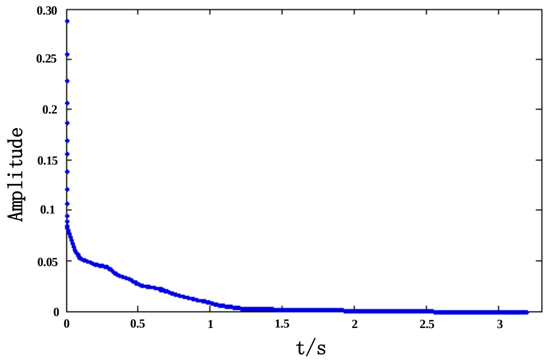


Figure 5. The Prony analysis approximate results of original sample signals

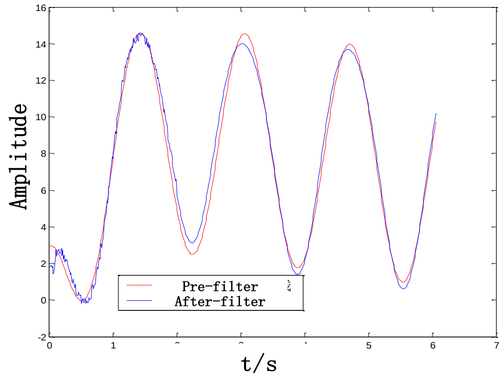


Figure 6. The Prony analysis approximate results of signals performed twice by fuzzy filter

Respectively in Figure 4 (a) and (c) signal in 2 seconds as the sampling signal analysis model using the improved Prony algorithm, figure 5, Figure 6 (a) (a) approximation results of the input signal Prony analysis to the original signal by sampling the signal fuzzy filter filtering two times after the are, of which 2 seconds after the dotted line represents the actual oscillation curve. Figure 5 (b) and Figure 6 (b) are the above two approximation error squared correlation curves, respectively. 2 seconds before it is the error squared of approaching signal and sampling signal, 2 seconds is the error square of real signal and sampling signal. Through the comparison between figure 5 (a), Figure 6 (a), and graph 5 (b) and Figure 6 (b), Prony analysis after two fuzzy filtering can more accurately approximate the actual oscillation curve.

5. CONCLUSION

Because the Prony algorithm is very sensitive to noise, it is difficult to completely or effectively eliminate the influence of noise only by the least square estimation that is contained in the Prony algorithm itself. Therefore, it is necessary to filter the input data first. In this paper, the fuzzy filter is used to preprocess the input data, and then the improved Prony algorithm is used to analyze the pattern. The example shows that the filtered Prony analysis can be more accurate approximating the actual oscillation curve with less computation order, which is an effective method.

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