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An Improved Low Frequency Oscillation Disturbance Source Localization Method in Control Devices of Generator

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Abstract. In this paper, an improved oscillation disturbance source localization method in control devices of generator is investigated. Using the dominant component of the electrical signals by the fast Fourier transform (FFT), the oscillation energy for governor system and excitation system is obtained separately. Then, based on the direction of the non-periodic component of the oscillation energy for the two systems, the control device level locating of the oscillation disturbance source is realized. Taking the forced power oscillation accident caused by too strong primary frequency modulation as an example, the oscillation energy based on FFT for the two systems show that the proposed method can locate the disturbance source accurately.

1. Introduction

With the large-scale grid connection of new energy units and the commissioning of ultra-high voltage direct current (UHVDC) transmission projects, the complexity of the grid structure and operation mode has been greatly improved, and the problem of low frequency oscillation of power systems has become more prominent [1]. In recent years, in addition to the low frequency oscillations caused by the traditional weak damping mechanism, the power grid has repeatedly suffered forced power oscillations caused by the abnormality of the control systems [2].

The oscillations caused by the weak damping mechanism mainly adopt reducing the active power of the relevant generators and putting into the power system stabilizer. For forced power oscillation, it is the core problem to quickly locate the oscillation source and guide the dispatcher to take control measures after the occurrence of the oscillation. Currently, there are mainly three kinds of methods for low frequency oscillation disturbance source localization: judgment of oscillation property based on time domain waveform characteristics [3]-[4], judgment of oscillation property based on the frequency domain phase relation [5] and disturbance source location method using oscillation energy exchange relationship [6]-[7]. Aiming at the causes and characteristics of the weak damping power oscillations and forced power oscillations, the oscillation properties are identified by comparing the first difference and the second difference symbols of the maximum power in each period of the waveform in the initial oscillation period [3]. The literature [4] starts from the time domain, extracts the dominant mode oscillation curve by empirical mode decomposition (EMD) method, and judges the oscillation type by curve fitting according to the expressions of envelope lines of different oscillation types. Because of the problem of mode aliasing in EMD, the extraction of dominant mode has a great influence on the result. The literature [5] analyzes the phase relationship between the unit's mechanical power, electrical power and terminal frequency in the oscillation process, and points out that the criterion for forced power oscillation source is that the oscillation phase of the mechanical power is ahead of the oscillation phase of the electrical power. However, when the oscillation amplitude is small, the solution is greatly affected by the accuracy of unit inertia. The literature [6]-[7] analyzes the change relations and characteristics of internal and external energy during the oscillating process, and points out that the disturbance source can be located by using the energy conversion characteristics in the steady-state period of oscillations.

Based on the Hamilton realization, Li Y *et al*. divide the oscillation energy injected into the power grid by the generator into two components corresponding to the excitation system and the governor system respectively [8], and use these two energies to judge the control device where the disturbance source is. In [9], according to the contribution of generator control device to system damping and the phase shift characteristics of forced power oscillation disturbance source, Jiang *et al.* propose a method for locating and identifying the disturbance source of generator control devices. Li W *et al*. define the oscillation energy of the generalized controller as the integral of torque deviation and rotational speed deviation. When the integral result is positive, the damping provided by the controller is positive. When the integral result is negative, the damping provided by the controller is negative [10].

Since the oscillation energy in [8] contains clutter signals determined by non-disturbance source, the accuracy of disturbance source localization is affected. The criterion index of disturbance source locating in [9] depends on the accuracy of EMD extraction, while the applicability of [10] for governor system still needs to be improved. In view of the shortcomings of current research methods, an improved disturbance source localization method in control devices of generator is proposed. Using the dominant component of the electrical signals by the fast Fourier transform (FFT) [11], the oscillation energy for governor system and excitation system is obtained separately. By decomposing the oscillation energy of control systems into periodic and non-periodic components, the direction of non-periodic component is used to realize the localization of disturbance source. Taking the low-frequency oscillation accident occurring in Hunan power grid as an example, the effectiveness and accuracy of the proposed method is verified.

2. Oscillation disturbance source location method in control devices of generator

2.1. Oscillation energy for governor system and excitation system

According to the oscillation energy decomposition in [8], the oscillation energy for governor system and excitation system are defined as:

$$W_i^{gov} = \int (P_{ei} 2\pi\Delta f_i + E_{\text{inter}})dt \tag{1}$$

$$W_i^{exc} = \int (Q_{ei} \frac{\dot{U}_{ti}}{U_{ti}} + E_{ex} - E_{\text{inter}})dt \tag{2}$$

with

$$E_{ex} = \frac{(Q_{ei} + \frac{U_{ti}^2}{x_q})P_{ei}U_{ti}^2}{x_q\left[P_{ei}^2 + (Q_{ei} + \frac{U_{ti}^2}{x_q})^2\right]^2} \cdot \left[(Q_{ei} + \frac{U_{ti}^2}{x_q})\dot{P}_{ei} - (\dot{Q}_{ei} + \frac{2U_{ti}\dot{U}_{ti}}{2})\right] \tag{3}$$

and

$$E_{\mathrm{inter}} = \frac{(Q_{ei} + \frac{U_{ti}^2}{x_q})\dot{P}_{ei}P_{ei} - P_{ei}^2\dot{Q}_{ei} - \frac{2P_{ei}^2 U_{ti}\dot{U}_{ti}}{x_q}}{P_{ei}^2 + (Q_{ei} + \frac{U_{ti}^2}{x_q})^2} \tag{4}$$

where P_{ei} and Q_{ei} are the active and reactive power of the ith generator, $U_{t\mathrm{i}}$ is the terminal voltage amplitude of the ith generator, f_{i} is the terminal frequency, and x_{q} is q-axis synchronous reactance.

2.2. FFT-based oscillation energy

In the steady state phase of power oscillation, the change of electrical signals are not ideal cosine functions that periodically alternate with the oscillation frequency, including the clutter signal determined by the undisturbed source. The amount of change in signal X ($X = P_{\mathrm{ei}}$, Q_{ei}, $U_{t\mathrm{i}}$ and f_{i}) can be expressed as:

$$\Delta X = X - X_s \tag{5}$$

where X_{s} is steady state value of signal X.

The signal ΔX can be expressed as a form that superimposes the dominant component and the non-dominant component:

$$\Delta X = \Delta X^1 + \Delta X^{else} \tag{6}$$

The dominant component of ΔX is in the following form:

$$\Delta X^1 = A\cos(\omega t + \phi) \tag{7}$$

where A is the magnitude of the dominant component ΔX^1, and ϕ is the initial phase angle.

The Fourier algorithm establishes a one-to-one correspondence between time domain and the frequency domain, and has good frequency characterization in the frequency domain. As a fast algorithm of discrete Fourier transform, the fast Fourier Transform (FFT) can easily extract harmonic signals of different frequencies from stationary signals. Perform FFT on X in the steady state phase of power oscillation, the dominant component ΔX^1 can be obtained.

Replace X ($X = P_{\mathrm{ei}}$, Q_{ei}, $U_{t\mathrm{i}}$ and f_{i}) in (1) and (2) by ΔX^1, the FFT-based oscillation energy becomes:

$$W_i^{gov(D)} = \int (\Delta P_{ei}^1 2\pi\Delta f_i + E_{\mathrm{inter}}(\Delta X^1))dt \tag{8}$$

$$W_i^{exc(D)} = \int (\Delta Q_{ei}^1 \frac{\Delta \dot{U}_{ti}^1}{\Delta U_{ti}^1} + E_{ex}(\Delta X^1) - E_{\mathrm{inter}}(\Delta X^1))dt \tag{9}$$

3. Example and verification

In March 2018, the 3# unit of a power plant in Hunan Province experienced multiple low-frequency oscillations during the power-up process. The phasor measurement unit (PMU) recorded wave is shown in figure 1. After the on-site investigation, the main reason for the active power oscillation of the unit was that the improper setting of the local speed unequal rate, the large feed forward gain of the primary frequency modulation and the large proportional gain of the power control loop, which caused the frequency modulation loop to be too strong. When the unit speed fluctuates around 3002r/min, it triggers a frequency adjustment action periodically. The excessive frequency regulation makes the power control system lose stability during the adjustment process. This is a typical forced power oscillation caused by abnormality of governor system.

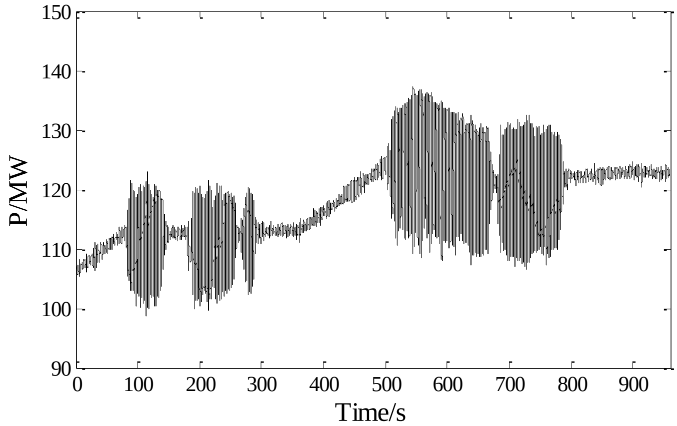
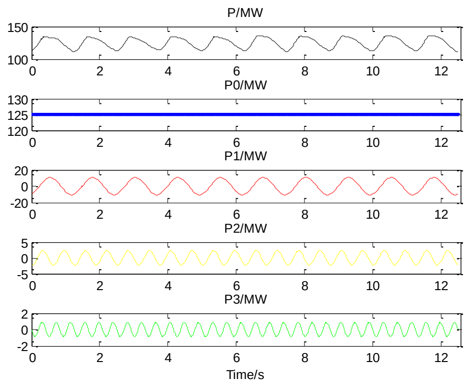
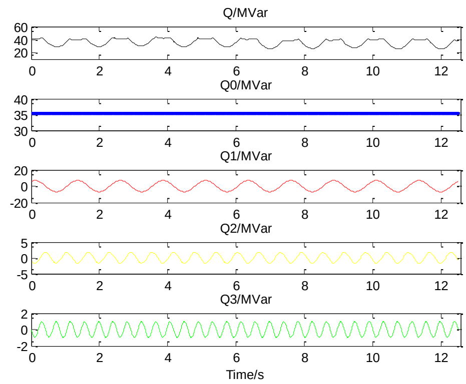


Figure 1. The active power oscillation waveform.

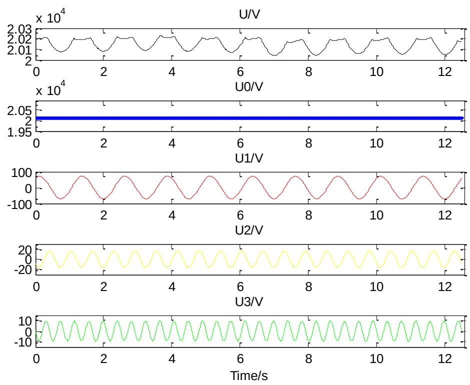
The PMU data for a period of 12.5s in the steady-state oscillation of figure 1 is used for analysis. Perform FFT on the electrical signals P_{ei}, Q_{ei}, U_{ti} and f_i, respectively, and the main harmonic and DC components are shown in figure 2. It can be seen that oscillation frequency of the dominant component is 0.8 Hz.



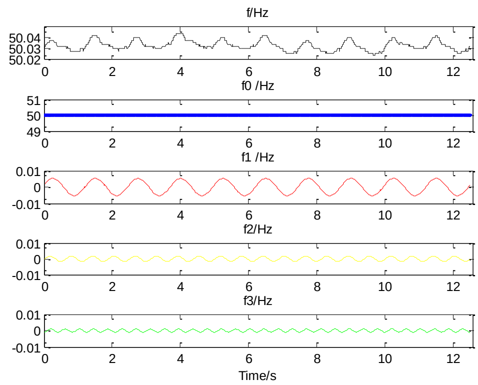
(a) The active power



(b) The reactive power



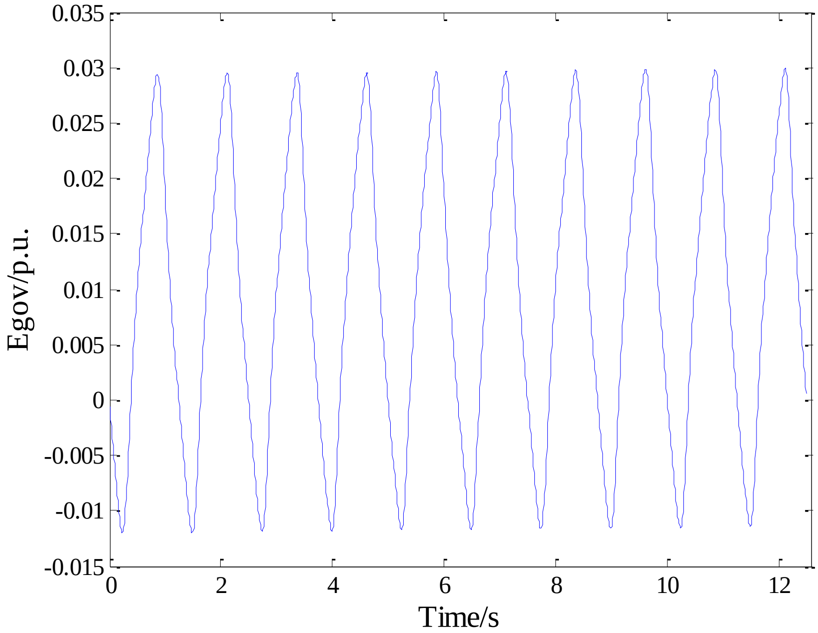
(c) The terminal voltage



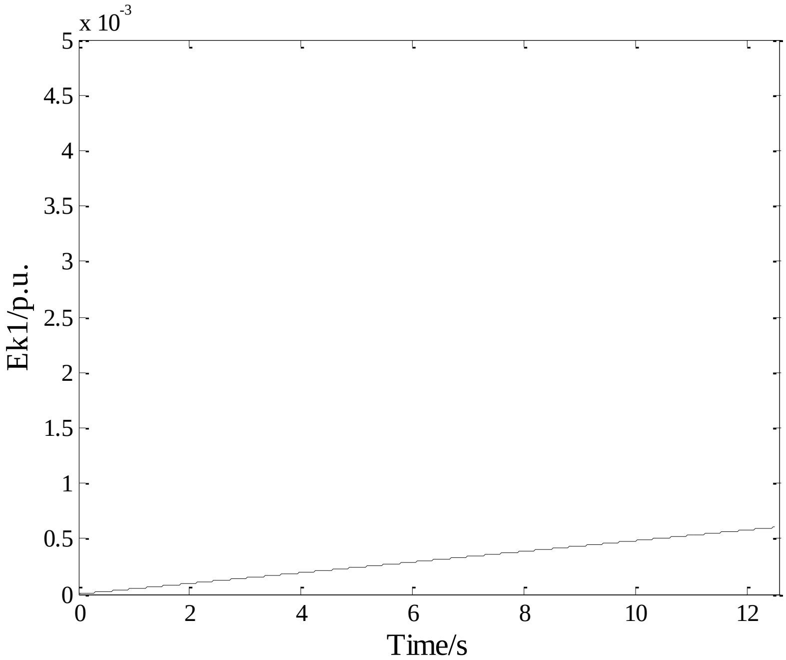
(d) The terminal frequency

Figure 2. FFT decomposition of electrical signals in steady-state oscillation.

According to (8) and (9), the FFT-based oscillation energy for governor system and excitation system are shown in figure 3 and figure 4. It can be seen that the straight line in figure 3 has a positive slope, while the straight line in figure 4 has a negative slope. A positive slope of the non-periodic component in figure 3 indicates that the governor system continues to inject energy into the system, which is not conducive to system stability, so the disturbance source exists on the governor system. For the negative slope of the non-periodic component in figure 4, it means that the excitation system extracts the oscillation energy from the system and there is no disturbance source.

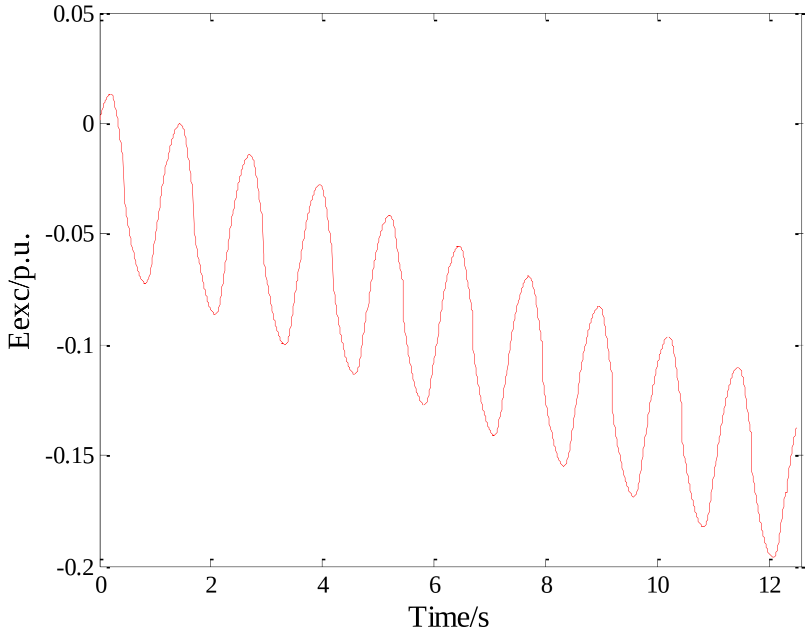


(a) The total oscillation energy

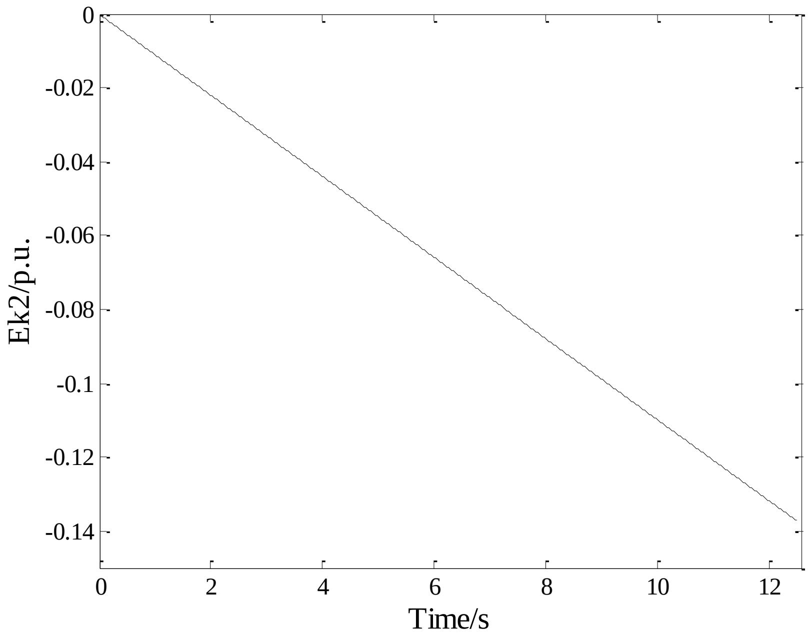


(b) The non-periodic component

Figure 3. Oscillation energy for governor system



(a) The total oscillation energy



(b) The non-periodic component

Figure 4. Oscillation energy for excitation system

4. Conclusions

In this paper, an improved disturbance source localization method in control devices of generator is proposed. By FFT decomposition of electrical signals in steady-state oscillation, the improved oscillation energy for governor system and excitation system is obtained. Using the direction of the non-periodic component of the oscillation energy, the disturbance source localization in control devices of generator can be achieved. Taking the low-frequency oscillation accident occurring in Hunan power grid as an example, the effectiveness of the proposed method is verified.

Acknowledgments
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