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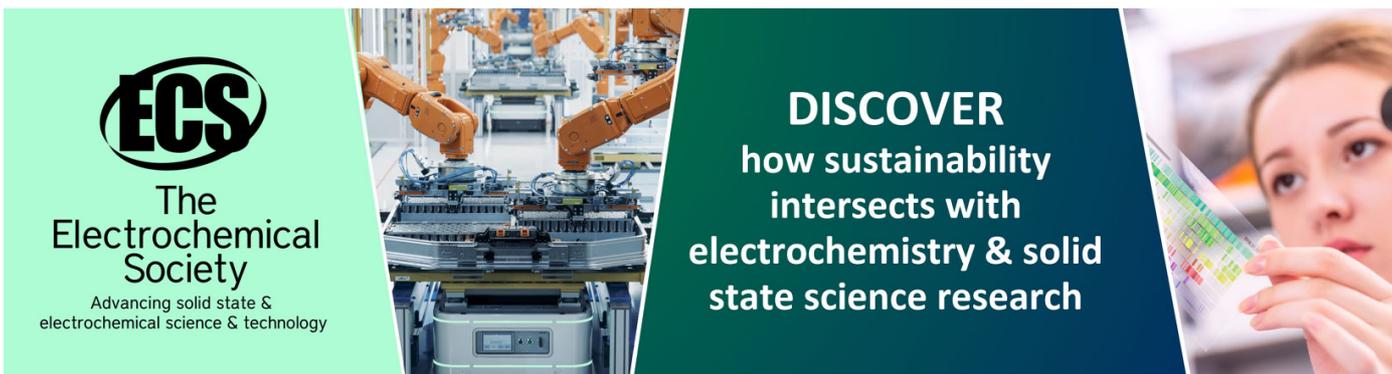
An Alternative Way to Locate Disturbance Source for Low Frequency Oscillation Considering Control Devices of Generator

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An Alternative Way to Locate Disturbance Source for Low Frequency Oscillation Considering Control Devices of Generator

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Abstract. Fast and accurate location of the power oscillation disturbance source is of great significance for the implementation of power system safety and stability control measures. This paper focuses on the applicability study of the oscillation energy flow. Aiming at the evaluation of the oscillation energy flow in disturbance source location of low frequency power oscillation, the effects of different methods are compared. After that, a fast Fourier transform (FFT)-based oscillation energy flow method considering control devices of generator is proposed. Taking a low frequency oscillation case caused by the abnormal governor system as an example, the effectiveness and accuracy of the proposed method is verified.

1. Introduction

In modern large-scale power systems, various types of disturbances often occur. After the disturbance occurs, timely and accurate acquisition of the type and location of the disturbance is essential for the successful implementation of emergency control measures. Synchronous phasor technology can measure the electrical quantity of wide-area distributed power system in real time, providing a new means for safety analysis and stability control of large-scale power systems [1]. At present, phasor measurement unit (PMU) is installed in suitable power plants and substations to form a wide-area measurement system (WAMS), which enables WAMS to have functions such as online disturbance identification, online low frequency oscillation monitoring, and automatic voltage control [2]. Among them, the disturbance source location method based on the oscillation energy flow has been widely used in the dispatching operation, and the dispatcher is instructed to take targeted measures to calm the oscillation quickly [3].

In [4], Yu *et al.* analyzed the energy conversion characteristics of forced power oscillations, and lay the theoretical foundation for the energy function to locate the disturbance sources in the power system. A method to compute oscillation energy flow in the network using WAMS data is proposed in [5], and the location of the disturbance source in the generator can be achieved. In order to improve the accuracy of the disturbance source location, Chu *et al.* proposed to use empirical mode decomposition (EMD) to extract the oscillation dominant component and calculate the oscillation



energy [6]. Furthermore, FFT is used to extract the dominant component of the steady-state power oscillation, and good location accuracy is obtained [7].

In engineering applications, it is of great value to locate the disturbance source to the control systems of the generator. By defining the oscillation energy of the generalized controller, Shu *et al.* propose an integration method for calculating the oscillation energy of the excitation system and the governor system separately [8]. In [9]-[10], Li *et al.* start from the energy distribution characteristics of the generator internal structure, and define the oscillation energy component on the excitation control and speed control channel, and use it as a criterion for location of the control devices. The literature [11] extracted the dominant component by FFT for oscillation energy calculation of control systems, but ignored the premise that the electrical quantities in [9] must be the original value. Different from the previous method, literature [12] ignored the influence of the damper winding during the power oscillation, and gave the formula for oscillation energy flow into the excitation winding, so the oscillation energy flow into the governor system equaled the difference between the total energy and excitation system energy.

In this paper, the focus of research is on the applicability study of the oscillation energy flow. Taking a forced power oscillation due to abnormal excitation system as an example, different methods for the oscillation energy flow are compared and analyzed. On the basis of [12], an alternative way to locate disturbance source considering control devices of generator is proposed. The results show that the proposed method has excellent indication ability for the location of low frequency oscillation in the generator control systems.

2. Oscillation energy theory

2.1 Oscillation energy for generator

Based on the energy function in [5], the oscillation energy transmitted from the bus i through the branch L_{ij} is defined as:

$$W_{ij} = \int (P_{ij} 2\pi \Delta f_i dt + Q_{ij} d(\ln U_i)) \quad (1)$$

Where P_{ij} and Q_{ij} are the active and reactive power of the branch L_{ij} , U_i and θ_i are the voltage amplitude and phase angle of the bus i , f_i is the bus frequency.

Since the energy consumed or generated by the branch has obvious directionality, the deviation of electrical components can be used to calculate the net content of the oscillation energy, that is, the oscillation energy using the deviations:

$$W_{ij}^D = \int (\Delta P_{ij} 2\pi \Delta f_i dt + \Delta Q_{ij} d(\Delta \ln U_i)) \quad (2)$$

With

$$\Delta P_{ij} = P_{ij} - P_{ij,s} \quad (3)$$

$$\Delta Q_{ij} = Q_{ij} - Q_{ij,s} \quad (4)$$

$$\Delta f_i = f_i - f_{i,s} \quad (5)$$

$$\Delta \ln U_i = \ln U_i - \ln U_{i,s} \quad (6)$$

Where $P_{ij,s}$ is steady state value of active power, $Q_{ij,s}$ is steady state value of reactive power, $U_{i,s}$ is steady state value of the voltage amplitude, $f_{i,s}$ is steady state value of bus frequency.

When the change of the node bus voltage and reactive power is ignored, the oscillation energy becomes:

$$W_{ij}^D = \int \Delta P_{ij} 2\pi \Delta f_i dt \quad (7)$$

2.2 Oscillation energy for control system

Similar to the oscillation energy for generator in (2), the amount of deviation can be used to calculate the energy flow into the field winding of the generator, which stands for the oscillation energy for the excitation system:

$$W_i^{exc(D)} = \int (\Delta U_{fd} \Delta I_{fd} - \Delta I_{fd}^2 R_{fd}) dt \quad (8)$$

With

$$\Delta U_{fd} = U_{fd} - U_{fd,s} \quad (9)$$

$$\Delta I_{fd} = I_{fd} - I_{fd,s} \quad (10)$$

Where U_{fd} and I_{fd} are the excitation voltage and excitation current of the i th generator, R_{fd} is the excitation winding resistance.

When ignoring the energy consumption of the mechanical damping and damper windings, the dissipative energy flow into the generator's governor system is approximately:

$$W_i^{gov(D)} \approx W_{ij}^D - W_i^{exc(D)} \quad (11)$$

3. FFT-based oscillation energy for control systems

For the steady state phase of forced power oscillation, the deviation of electrical component can be expressed as a form that superimposes the dominant component and the non-dominant component:

$$\Delta X = \Delta X^1 + \Delta X^{else} \quad (12)$$

The dominant component of ΔX is in the following form:

$$\Delta X^1 = A \cos(\omega t + \phi) \quad (13)$$

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

As a fast algorithm of discrete Fourier transform, the FFT can 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 ΔX in (7) and (8) by ΔX^1 , the FFT-based oscillation energy becomes:

$$W_{ij}^{D1} = \int \Delta P_{ij1} 2\pi \Delta f_{i1} dt \quad (14)$$

$$W_i^{exc(D1)} = \int (\Delta U_{fd1} \Delta I_{fd1} - \Delta I_{fd1}^2 R_{fd}) dt \quad (15)$$

$$W_i^{gov(D1)} \approx W_{ij}^{D1} - W_i^{exc(D1)} \quad (16)$$

4. Case and verification

A low frequency oscillation case occurred in a power plant unit of Hunan power grid during the power-up process. The oscillation recording is shown in figure 1. According to the on-site investigation, when the turbine speed fluctuates around 3002r/min, a frequency adjustment is triggered periodically. The excessive primary frequency modulation function makes the digital electric hydraulic (DEH) control system lose stability. It is a typical forced power oscillation caused by abnormal governor system.

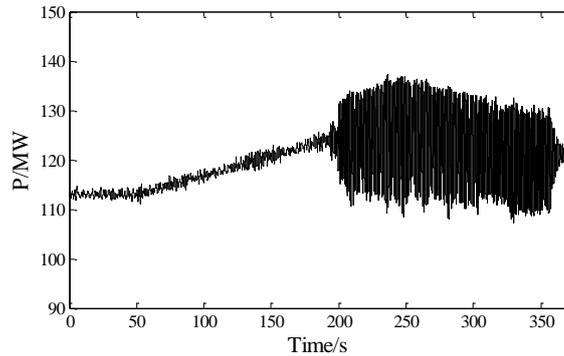


Figure 1. Active power oscillation waveform.

4.1 Comparative analysis

From the steady state low frequency oscillation process, 12.5 s of WAMS data was taken for the oscillation energy calculation. Figure 2 shows the oscillation energy for generator, considering node bus voltage and reactive power and regardless of voltage and reactive power. It can be seen that the trend of the oscillation energy is not monotonically increasing or decreasing, which cannot give clear results for the disturbance source. When the oscillation energy flow is calculated using the deviations, the energy trend in Figure 3 is improved, showing a significant rise. In Figure 2 and Figure 3, the effects of fluctuations in node bus voltage and reactive power on the oscillation energy are negligible.

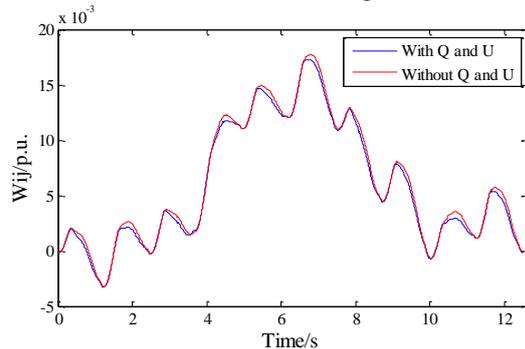


Figure 2. Oscillation energy for generator.

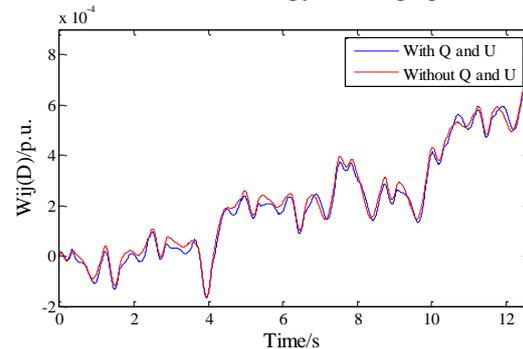


Figure 3. Oscillation energy using the deviations.

4.2 FFT-based oscillation energy

Figure 4 shows the FFT analysis of active power in steady state phase oscillation, where the component with the largest amplitude is the dominant mode.

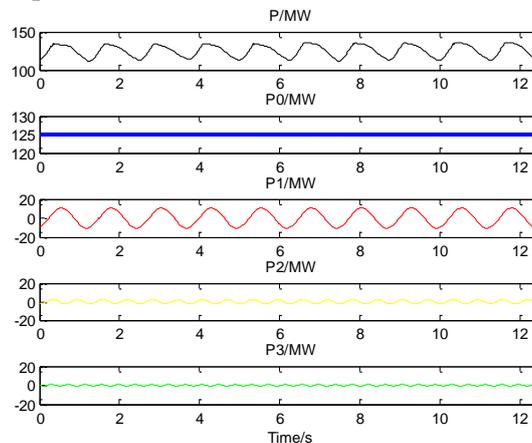


Figure 4. FFT decomposition of active power in steady state oscillation.

Figure 5 gives the comparison results between traditional oscillation energy and FFT-based oscillation energy for generator, showing that the traditional oscillation energy is negative at some moments, while FFT-based oscillation energy has a steady upward trend.

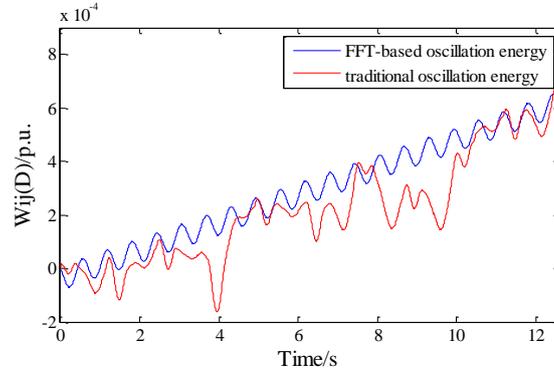


Figure 5. FFT-based oscillation energy.

Using (14)-(16), the FFT-based oscillation energy for excitation system and governor system are shown in figure 6 and figure 7. It can be seen that each trend of both oscillation energy is decreasing or increasing smoothly, and the non-periodic components of both are shown in figure 8 and figure 9 respectively. A slope of the non-periodic component in figure 8 is less than 0, indicating that the excitation system extracts energy from the system continuously, which is conducive to the stability of the grid. On the other side, a positive slope of the non-periodic component in figure 9 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. The oscillation energy indication result is consistent with the on-site analysis, proving the proposed method has excellent ability for the location of low frequency oscillation in the generator control systems.

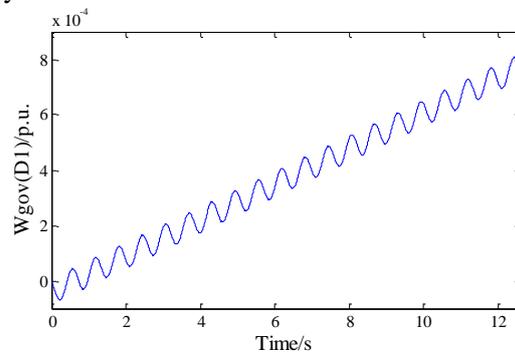
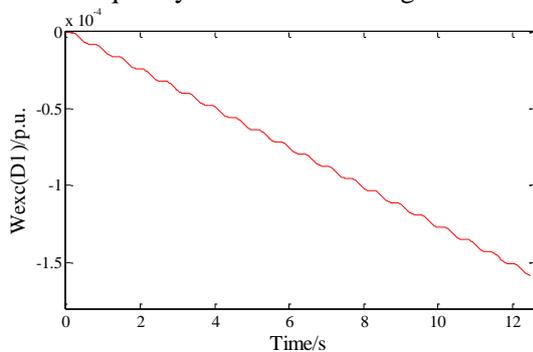


Figure 6. Oscillation energy for excitation system. Figure 7. Oscillation energy for governor system.

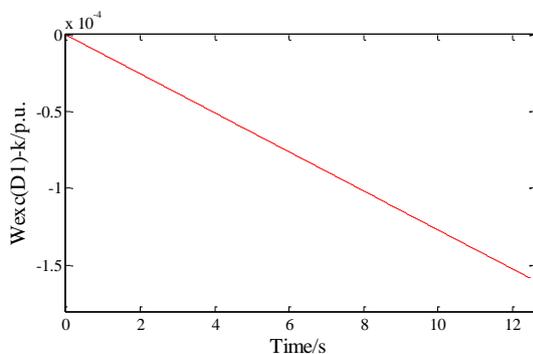


Figure 8. The non-periodic component for excitation system.

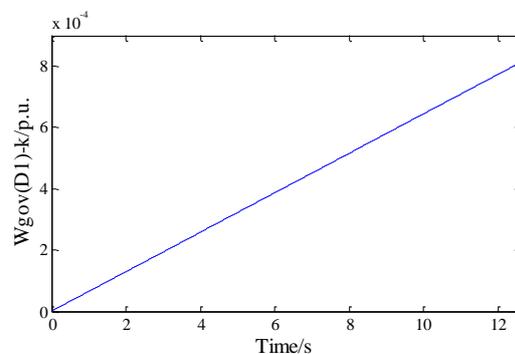


Figure 9. The non-periodic component for governor system.

5. Conclusions

In this paper, an alternative way to locate disturbance source for low frequency power oscillation considering control devices of generator is proposed. The following conclusions could be made:

1) The fluctuation of node voltage and reactive power during power oscillation has little effect on the calculation of oscillation energy, so it can be ignored.

2) For the oscillation energy for generator, FFT-based one has better location accuracy compared to the traditional one. Further, the FFT-based oscillation energy for control systems has excellent indication ability for the location of low frequency oscillation, which is verified by on-site analysis.

Acknowledgments

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