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A Case Study of Low Frequency Oscillation Caused by PSS Field Test

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A Case Study of Low Frequency Oscillation Caused by PSS Field Test

Siyuan Guo[1], Shoushou Zhang[2], Jian Zuo[1], Li Li[1]and Ting Cui[1]

[1] State Grid Hunan Electric Power Company Limited Research Institute, Changsha 410007, China
[2] Bangor College, Central South University of Forestry and Technology, Changsha 410018, China

Email: sszhang@whu.edu.cn

Abstract. In this paper, the event of low-frequency power oscillation caused by power system stabilizer (PSS) field test in a power plant is introduced, and the mechanism of oscillation is analyzed. In view of the existence of several dominant components in this low frequency oscillation accident, an improved measure is proposed to achieve the disturbance source localization. Based on fast Fourier transform (FFT) decomposition of active power and frequency in steady-state oscillation, several dominant components of the oscillation are obtained. By superimposing the non-periodic components of the oscillation energy for several dominant modes, the disturbance source of the low frequency oscillation accident is determined.

1. Introduction

With the expansion of power grid, the problem of low frequency oscillation becomes more and more serious. Severe oscillation will destroy the parallel operation of interconnected systems, lead to over-current tripping of tie lines, and cause a large area of power failure. Serious accidents caused by low frequency oscillation occur in many countries.

Excitation system is an important part of synchronous generator. By adjusting the excitation current of the rotor winding, the terminal voltage of generator is controlled to meet the needs of normal operation. Meanwhile, the rational distribution of reactive power among generator units is controlled to improve the stability of power grid. The literature [1] summarizes the main causes and suppression measures of low frequency oscillation caused by generators, and points out that improper excitation control system will lead to the damping ratio changing from positive to negative. In view of abnormal power fluctuation of the Three Gorges hydropower station, Zhang J *et al*. successfully located the accident cause through real-time digital simulation technology, namely wrong setting of internal reactance parameter x_q of PSS [2]. For the low frequency oscillation event in [3], the excitation regulator contains the logic of PSS locking when the active power is suddenly changed, which affects operation stability of the generator. For "12.2" low frequency oscillation in Pingban Power Plant [4]-[5], the angular velocity input signal of PSS was shielded by mistake during the software upgrade process of excitation regulator. The literature [6] 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 phase of forced oscillations. In order to overcome the shortcomings of the traditional energy function method, Guo S
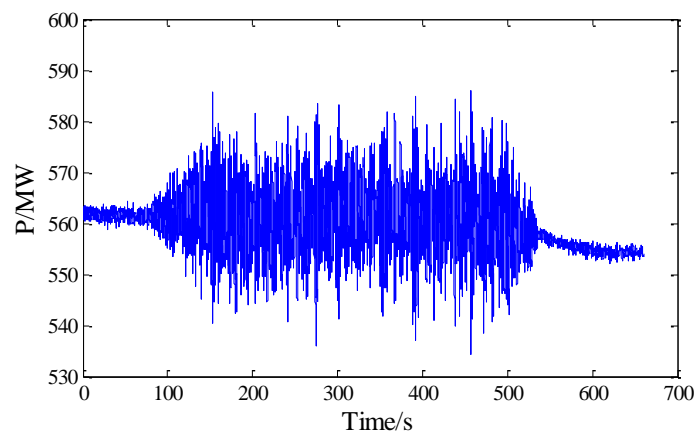
et al. extract dominant component of the electrical signals by FFT, and calculate the oscillation energy to locate the power oscillation disturbance source [7].

   This paper studies the low frequency oscillation caused by PSS field test [8] in a power plant of Hunan power grid, and explains the oscillation mechanism. Using FFT decomposition of active power and frequency in steady-state oscillation, several dominant components of the oscillation are obtained. By superimposing the non-periodic components of the oscillation energy for several dominant modes, the disturbance source of the accident is determined.
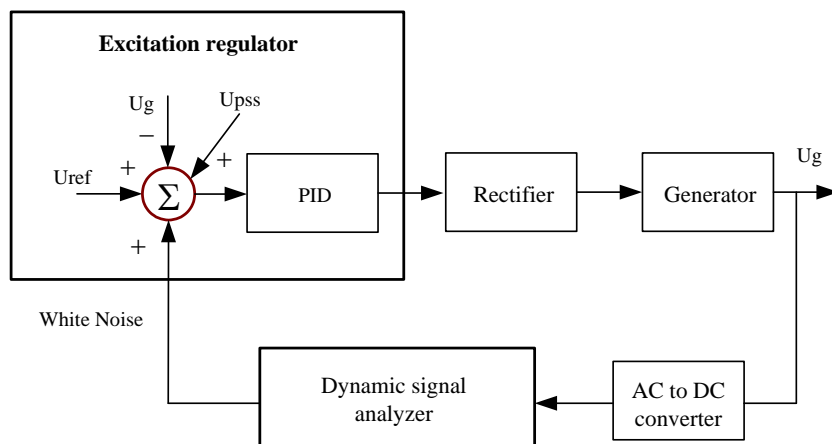
2. Low frequency oscillation event process

A power plant in Hunan power grid has two 660 MW turbine generators, in which unit 2 is connected to the 500kV system via a 140km tie line. The wide area measurement system (WAMS) of Hunan dispatching control center records the power oscillation waveform, which is shown in figure 1.

Figure 1. Power oscillation waveform.

   After field investigation, the PSS test for unit 2 is being carried out when the oscillation occurs. The measurement method of the uncompensated phase frequency characteristic for the excitation system is shown in figure 2, where U_g and U_{ref} are the terminal voltage and terminal voltage reference value of the generator, U_{pss} is PSS output value. When the measurement starts, exit the PSS and add a white noise signal to the voltage reference point. The random signal is gradually increased from the minimum amount until the terminal voltage appears slightly oscillating. Since the start and end time of the power fluctuation during this period coincide with the time points of adding and exiting the white noise, it is initially suspected that the addition of white noise induces the low frequency oscillation event.

Figure 2. Measurement of excitation system phase frequency characteristics without compensation.

3. Disturbance source location based on oscillation energy method

3.1. Energy Function Construction Using Deviations

According to the theory of oscillation energy, the contribution of the branch consuming the oscillation energy to the oscillation attenuation is positive, and the contribution of the branch generating the oscillation energy to the oscillation attenuation is negative. If the oscillation energy of the connected branch is solved at the corresponding bus in the system, the forced power oscillation disturbance source can be located by the energy flow direction.

Since the energy consumed or generated by the branch has obvious directionality, the variation of P and f can be used to calculate the net content of the oscillation energy, that is, the oscillation energy using the variation:

$$W_{ij} = \int \Delta P_{ij} 2\pi \Delta f_i dt \tag{1}$$

$$\Delta P_{ij} = P_{ij} - P_{ij,s} \tag{2}$$

$$\Delta f_i = f_i - f_{i,s} \tag{3}$$

where P_{ij} is the active power of the branch L_{ij}, f_i is the bus frequency, $P_{ij,s}$ is steady state value of active power, $f_{i,s}$ is steady state value of bus frequency.

In the steady state phase of oscillation, each electrical quantity changes with the dominant frequency periodically:

$$\Delta P_{ij}^1 = A_1 \cos(\omega_1 t + \phi_1) \tag{4}$$

$$\Delta f_i^1 = A_2 \cos(\omega_1 t + \phi_2) \tag{5}$$

where A_1 and A_2 are the magnitudes of power variation and frequency variation, respectively. ϕ_1 and ϕ_2 are the initial phase angles of power variation and frequency variation.

Bringing (4) and (5) into (1), the oscillation energy for the dominant oscillation mode becomes:

$$W_{ij}^{D(1)} = a_1 \sin(2\omega_1 t + \phi_1 + \phi_2) + b_1 t + c_1 \tag{6}$$

$$a_1 = \frac{\pi}{2\omega_1} A_1 A_2 \tag{7}$$
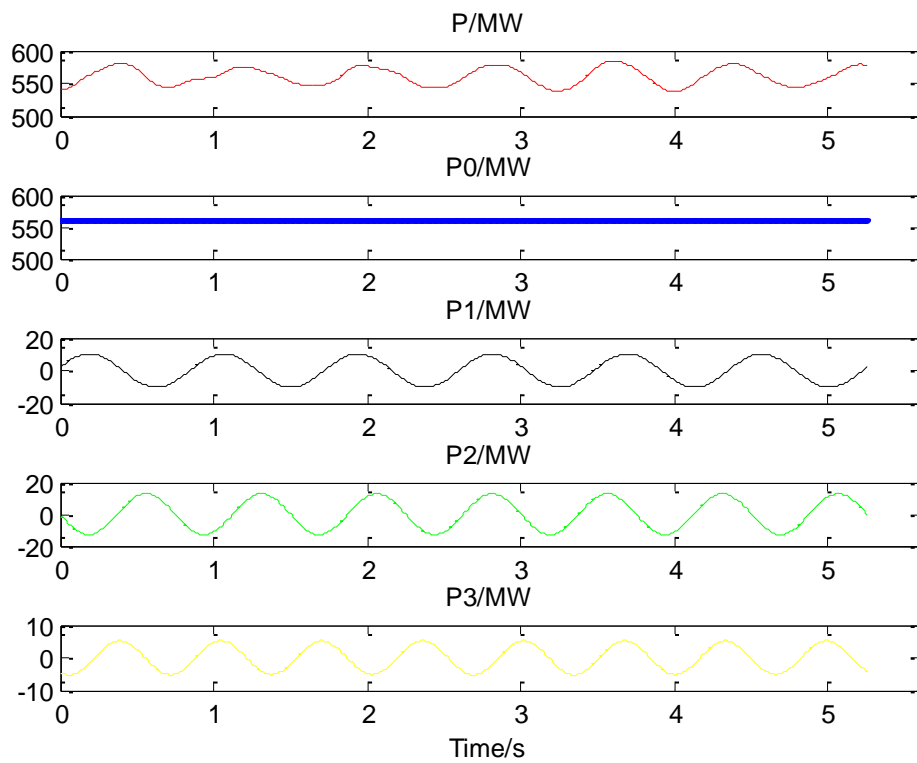
$$b_1 = \pi A_1 A_2 \cos(\phi_1 - \phi_2) \tag{8}$$

$$c_1 = \frac{\pi}{2\omega_1} A_1 A_2 \sin(\phi_1 + \phi_2) \tag{9}$$

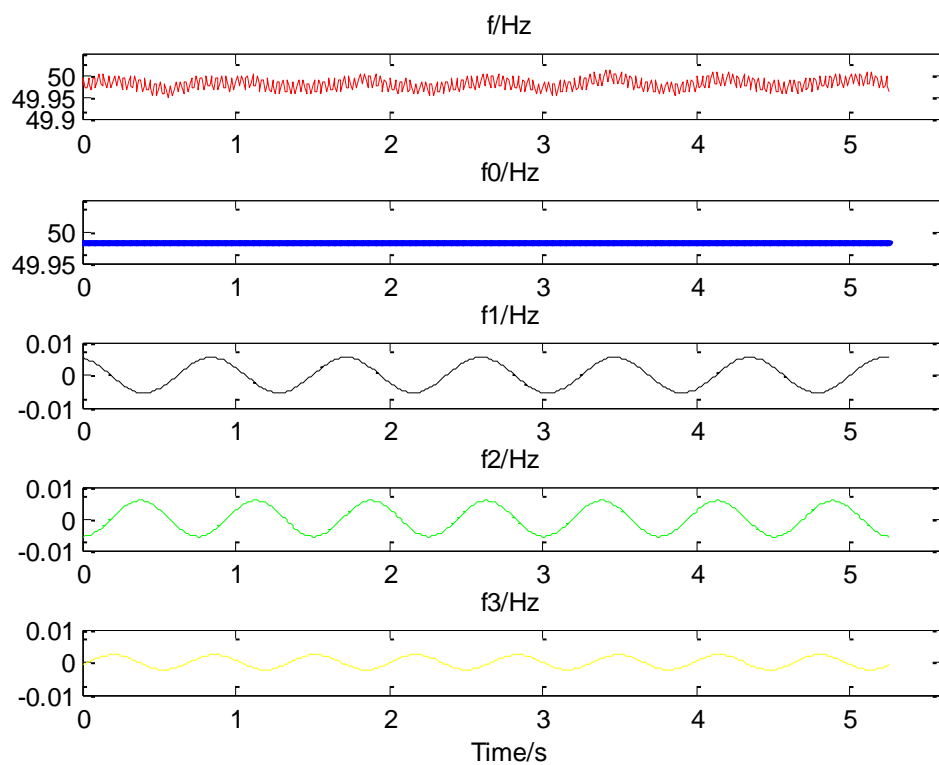In (6), the slope of the non-periodic component $b_1 t$ determines the direction of the energy flow in the network.

3.2. Disturbance source location

In order to verify the disturbance source, a waveform of 5.25s at steady state oscillation is extracted for FFT analysis. The FFT decomposition results for active power and frequency are shown in figure 3 and figure 4. It can be seen that in addition to the DC component, P and f contain three major harmonic components. The three harmonic components correspond to three dominant oscillation modes, and the corresponding oscillation frequencies are 1.1407Hz, 1.3308Hz and 1.5209Hz. In addition, the oscillation amplitudes of mode 1 and mode 2 are relatively close.
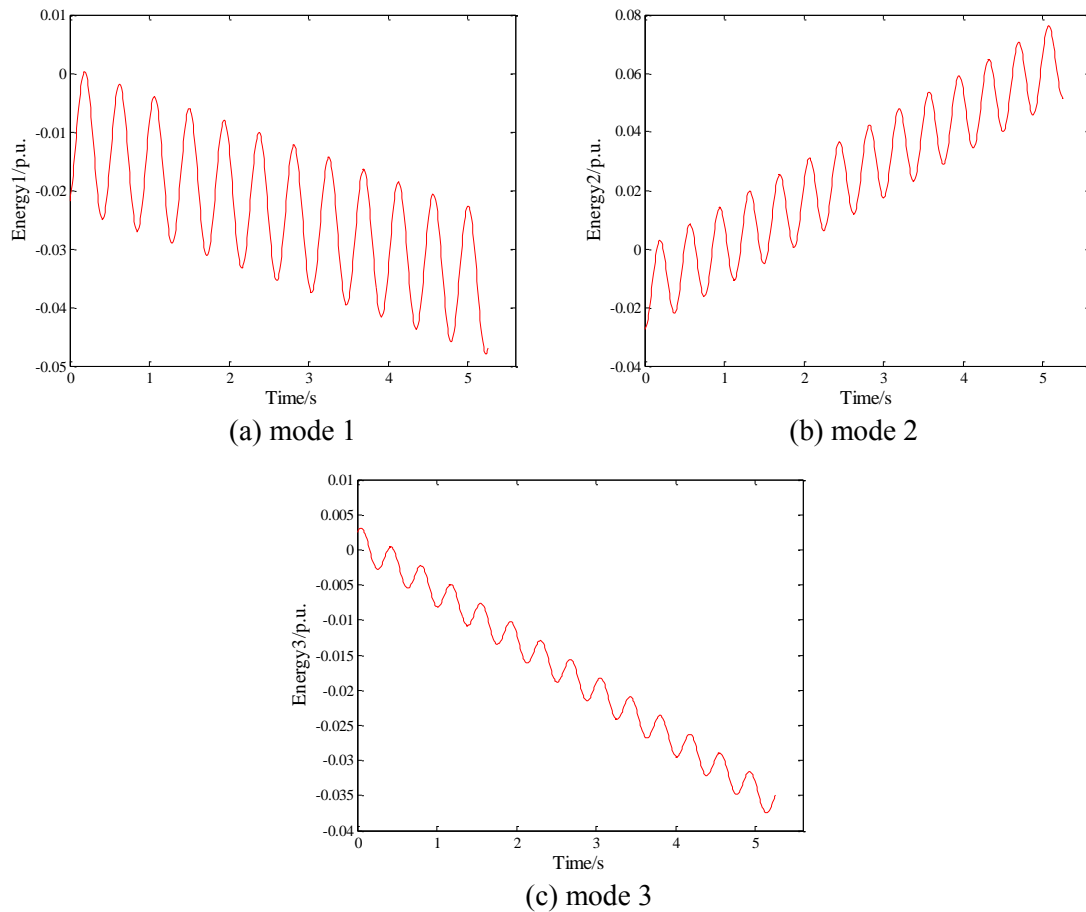
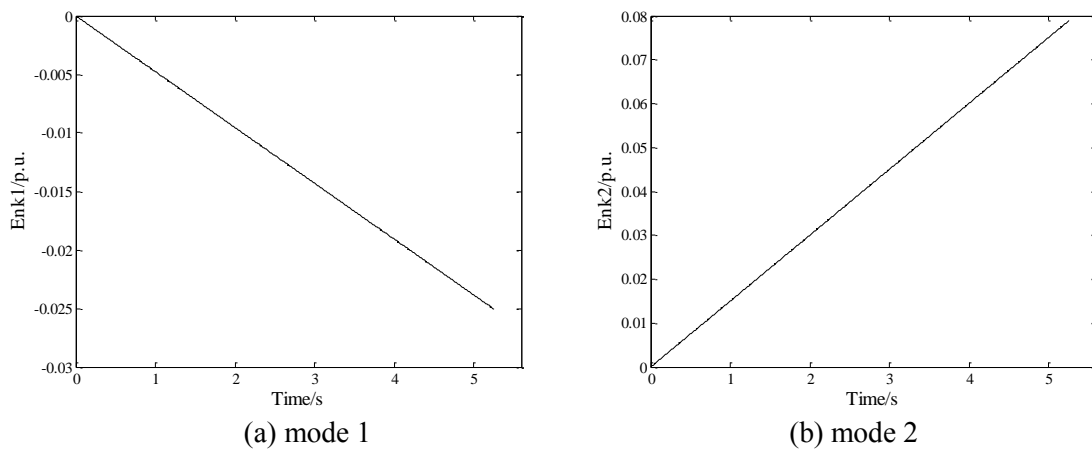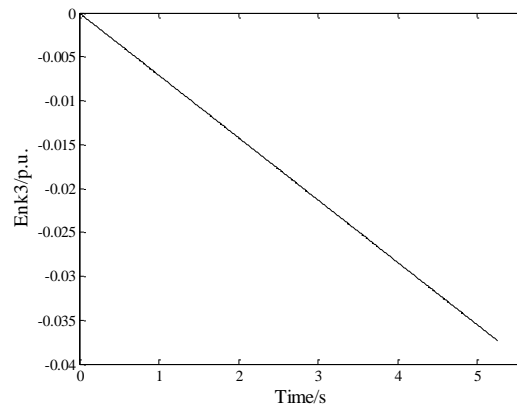**Figure 3.** FFT decomposition of active power in steady-state oscillation.

Figure 4. FFT decomposition of frequency in steady-state oscillation.

For the three dominant oscillation modes, the oscillation energy calculated by (6) is shown in figure 5, and the non-periodic component of the oscillation energy for three modes is shown in figure 6. It can be seen that the oscillation energy for each mode consists of a sine function, a straight line and a constant term. The potential energy flowing into the busbar in the network is defined as negative, and the potential energy flowing out of the busbar is positive. Since there are three oscillation modes with different flow directions in this case, it is impossible to locate the disturbance source according to one single oscillation mode.

(a) mode 1

(b) mode 2

(c) mode 3

Figure 5. Oscillation energy for three dominant modes.
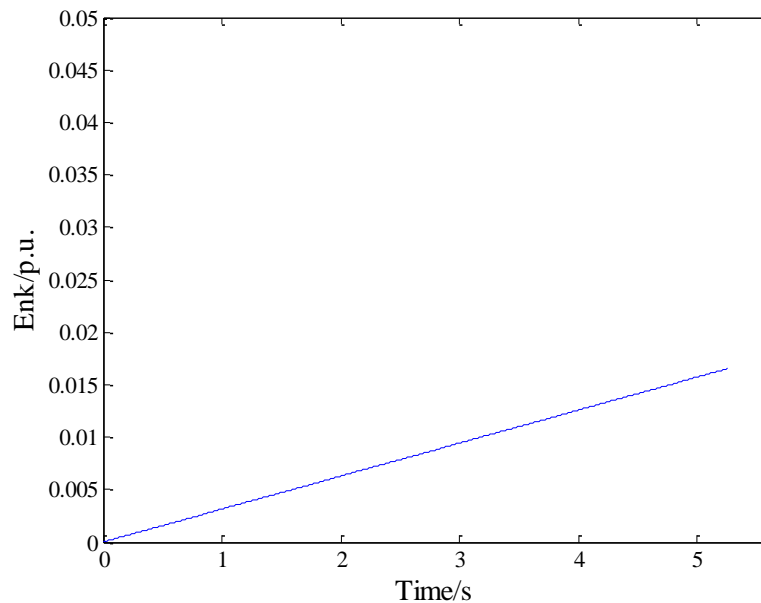

(a) mode 1

(b) mode 2

(c) mode 3

Figure 6. The non-periodic component of oscillation energy for three dominant modes.

The oscillatory energy is composed of two parts: one is the periodic energy change that accompanies the periodic oscillation; the other part is the energy consumed by the disturbance injected into the system and propagated in the network, namely the non-periodic component. Therefore, it is necessary to superimpose the non-periodic components of the three oscillation energy to show the cumulative effect in the oscillation event. The positive slope of total non-periodic component in figure 7 indicates that the branch potential energy flows from the generator to the system, which verifies that the white noise is disturbance source of the forced power oscillation accident.

Figure 7. The total non-periodic component for three dominant modes.

4. Conclusions

In this paper, a low frequency oscillation event caused by PSS field test is studied. Based on speculation about the cause of the accident, the oscillation energy method is used to locate the disturbance source accurately. In view of the existence of three dominant modes in this case, an improved measure is proposed to achieve the disturbance source localization. Based on FFT decomposition, the oscillation energy for three dominant modes is obtained. By superimposing the non-periodic components of the oscillation energy for three dominant modes, the disturbance source is determined and verified by field investigation.

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