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A Disturbance Source Location Method Based on the Initial Oscillation Period

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Abstract. In order to improve the accuracy and rapidity of the disturbance source location, a new method based on variational mode decomposition (VMD) for forced power oscillation disturbance source location is proposed. Using the active power and frequency of the transient phase of an oscillation, the dominant mode of electrical components is extracted by VMD. Then, the oscillation energy using the variation is calculated to achieve the disturbance source location. Taking the forced power oscillation accident caused by too strong primary frequency modulation as an example, the effectiveness and feasibility of the proposed method is verified.

1. Introduction

Existing research shows that there may be prime mover disturbance, excitation system disturbance and speed regulation system disturbance on the generator side. Besides, load disturbance may exist on the grid side. These disturbance sources may cause forced power oscillation of the system.

In [1], Wang T *et al.* study a low frequency oscillation accident different from the weak damping mechanism, and point out that if there is a disturbance in the power system, when the frequency of the disturbance is consistent with or close to the natural resonance frequency of the system, it may cause low frequency oscillation of resonance mechanism. Further to the literature [1], Tang Y. takes the case of a single-machine infinity system as an example. Through the small perturbation dynamic equation, the analytical expressions of transient forced oscillation and steady-state forced oscillation are derived, and the theoretical basis of forced power oscillation is established [2]. To identify the oscillation properties and take appropriate restrain measure, a second order differential method and discriminate criterion based on the initial period of oscillation waveform is proposed [3]. However, this method is not stable enough at the peak of the individual oscillation period when distinguishing between weakly damped oscillations and forced power oscillations. Currently, the disturbance source location method using energy functions has received extensive attention [4]-[7]. The literature [4]-[5] analyze the change relations and characteristics of internal and external energy during the oscillating process, and point out that the disturbance source can be located by using the energy conversion characteristics in the steady state phase of an oscillation. In [6], Yang D *et al.* conduct Prony analysis on the active power and frequency in the transient phase and steady state phase of oscillations, and calculate the energy flow direction factor by extracting the dominant component. Similarly, Chu X *et al.* extract the

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the dominant mode of electrical components by empirical mode decomposition (EMD), and calculate the empirical mode energy flow to realize the disturbance source location [7].

In engineering practice, combining measured data with signal processing technology is a common method for current power system oscillation identification. The Prony algorithm can directly extract the feature quantity of the signal, but the algorithm is sensitive to noise. EMD adopts an envelope method based on extreme points, which is prone to modal aliasing. In view of the fact that VMD can effectively separate modal signals and is not affected by noise [8], this paper proposes a VMD-based forced power oscillation disturbance source location method. Using the active power and frequency of the transient phase of an oscillation, the dominant mode of electrical components is extracted by VMD to calculate oscillation energy. Taking the forced power oscillation accident caused by too strong primary frequency modulation as an example, the effectiveness and feasibility of the proposed method is verified.

2. Variational mode decomposition

VMD is a method of signal decomposition using the variational principle, which is proposed by Dragomiretskiy *et al.* in 2014. The VMD assumes that each mode of the signal is a finite bandwidth with different center frequencies. In the process of acquiring the mode, the alternating direction multiplier method is used to search for the optimal solution of the variational model iteratively, and the frequency center of each component is determined to realize the frequency division and effective separation of the signal.

The construction of the variational problem mainly includes the following steps:

① The analytic signal of each modal function u_k(t) is obtained by Hilbert transform;

$$(\delta(t)+\frac{j}{\pi t})\cdot u_k(t) \tag{1}$$

② Add an estimated center frequency to the analytic signal of each mode, and modulate the modal spectrum to baseband;

$$\left[(\delta(t)+\frac{j}{\pi t})\cdot u_k(t)\right]\cdot e^{-j\omega_k t} \tag{2}$$

③ The squared L^2-norm of the above-mentioned demodulated signal gradient is calculated, and the bandwidth of each modal signal is estimated. The variational problem is expressed as follows

$$\begin{gathered}\min_{\{u_k\}\{\omega_k\}}\left\{\sum_{k=1}^{K}\left\|\partial_t\left[(\delta(t)+\frac{j}{\pi t})\cdot u_k(t)\right]\cdot e^{-j\omega_k t}\right\|_2^2\right\}\\ s.t.\ \sum_{k=1}^{K}u_k=f\end{gathered} \tag{3}$$

The specific solution method of the variational model is shown in the literature [8].

3. Disturbance source location method based on VMD

3.1. Energy Function Construction Using Deviations

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

$$W_{ij}=\int \Delta P_{ij}\,2\pi\Delta f_i dt \tag{4}$$

$$\Delta P_{ij} = P_{ij} - P_{ij,s} \tag{5}$$

$$\Delta f_i = f_i - f_{i,s} \tag{6}$$

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.

For the forced power oscillation, the variation of $\boldsymbol{P}$ and $\boldsymbol{f}$ can be expressed as a form of superposition of dominant component that reflect low frequency oscillation characteristics and non-dominant components:

$$\Delta P_{ij} = \Delta P_{ij}^{1} + \Delta P_{ij}^{else} \tag{7}$$

$$\Delta f_i = \Delta f_i^{1} + \Delta f_i^{else} \tag{8}$$

where ΔP_{ij}^{1} and Δf_i^{1} are the dominant component of power variation and frequency variation, respectively.

Bringing (7) and (8) into (4), the oscillation energy for the dominant mode becomes:

$$W_{ij}^{D(1)} = \int \Delta P_{ij}^{1} 2\pi \Delta f_i^{1} dt \tag{9}$$

3.2. Disturbance source location process

The main steps for applying VMD for disturbance source location are:

① Select the waveform of the initial phase of the forced power oscillation, and extract ΔP_{ij}^{1} and Δf_i^{1} by VMD;

② Calculate the oscillation energy according to (9);

③ Locate the disturbance source according to the rising or falling trend of the oscillation energy.

4. Case study

A low frequency oscillation accident 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 accident investigation, when the unit speed fluctuates around 3002r/min, a frequency adjustment action is triggered periodically. The excessive frequency adjustment function makes the DEH power control system lose stability. It is a typical forced power oscillation accident caused by abnormal speed control system.

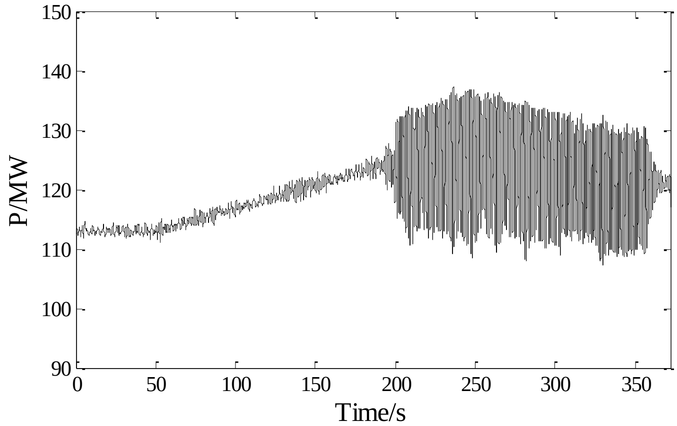


Figure 1. Active power oscillation waveform.

The initial oscillation period of 10s in the transient phase is extracted for analysis, which is shown in figure 2 and figure 4. As can be seen from figure 3 and figure 5, the VMD decomposes the power signal and frequency signal into four modes respectively, i.e., four Intrinsic Mode Functions (IMFs).

Among the four modes, IMF1 represents the steady state trend of electrical components, and the remaining modes are variations of electrical components. The amplitude of IMF2 is the highest, which is the dominant mode of this oscillation.

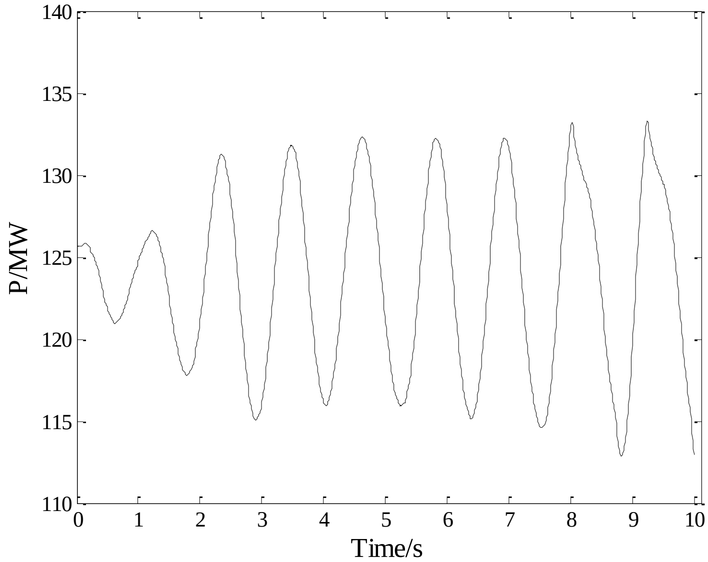
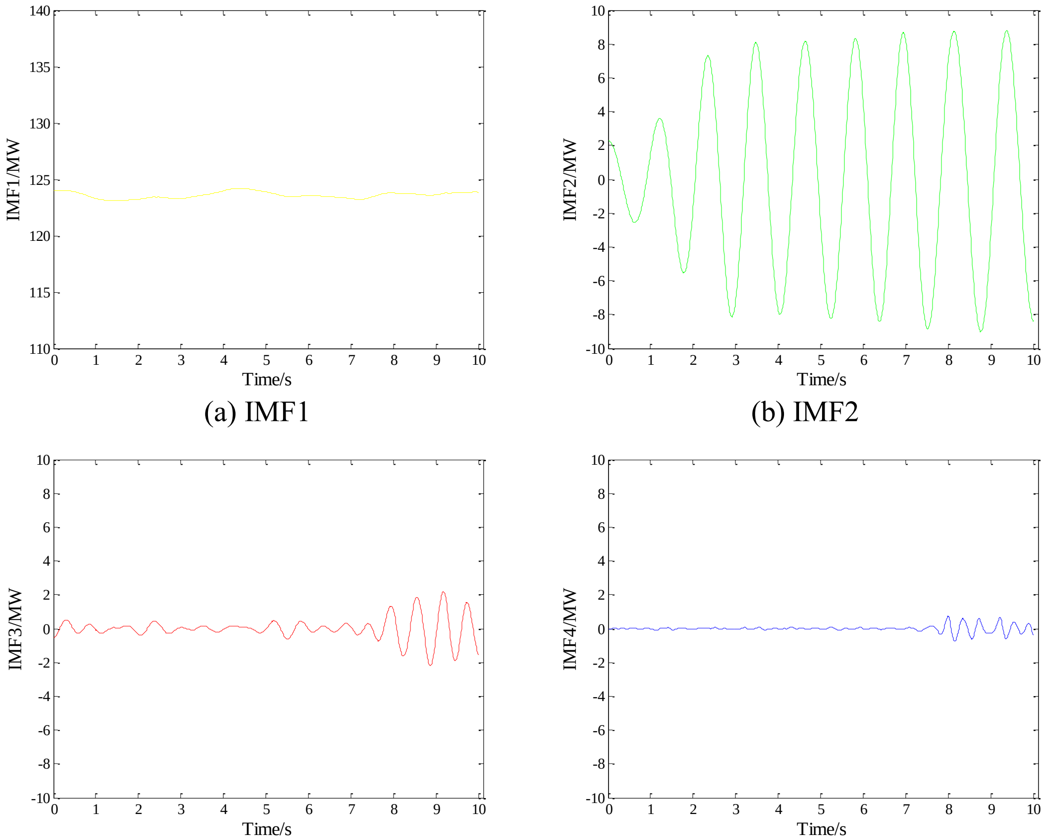


Figure 2. Active power in transient phase of the oscillation.



(a) IMF1 (b) IMF2

(c) IMF3 (d) IMF4

Figure 3. Mode decomposition of active power.

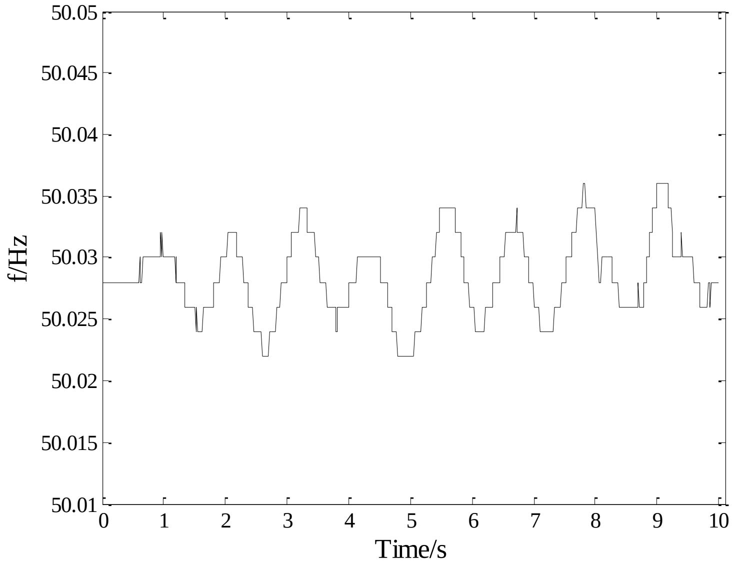


Figure 4. Frequency in transient phase of the oscillation.

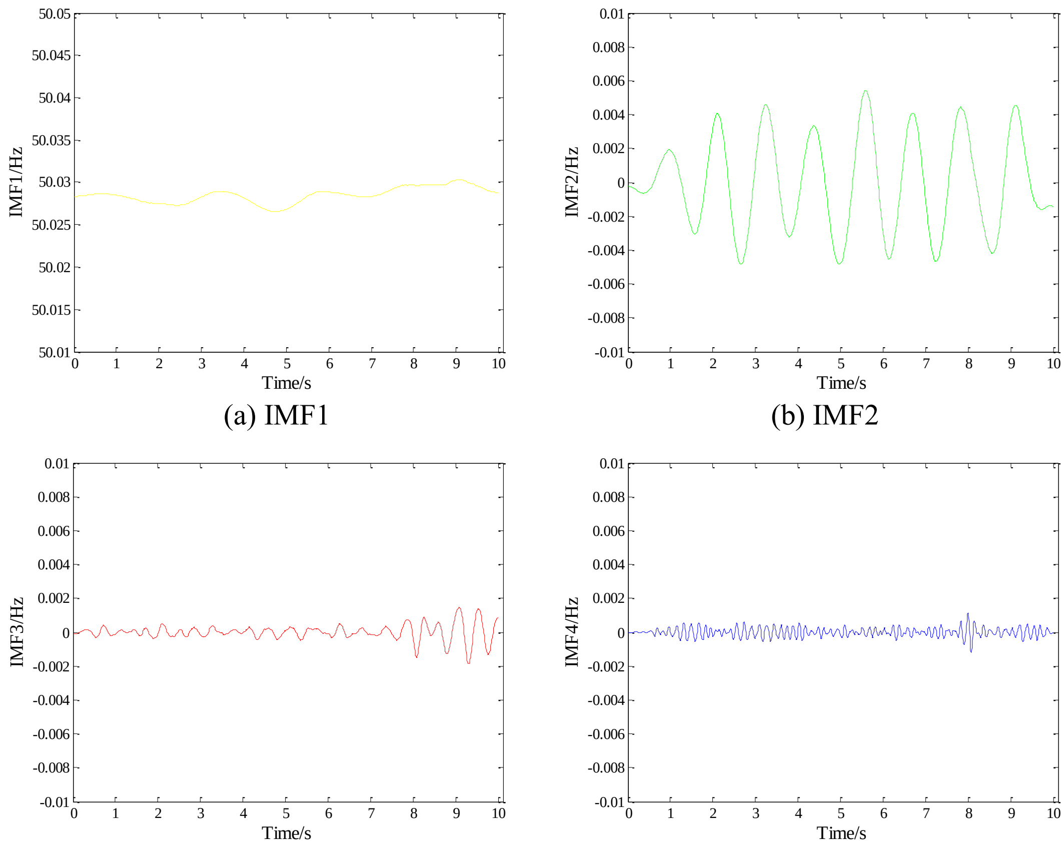


Figure 5. Mode decomposition of frequency.

The oscillation energy based on the dominant oscillation mode is shown in figure 6. On the generator terminal bus, the genset continues to inject positive energy into the system, so the genset is the source of disturbance. It can be seen that with the excellent modal decomposition capability of

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VMD, the energy flow characteristics of the dominant oscillation mode can be accurately reflected. The result of the disturbance source location analysis is consistent with the actual situation, which verifies the effectiveness of the proposed method.

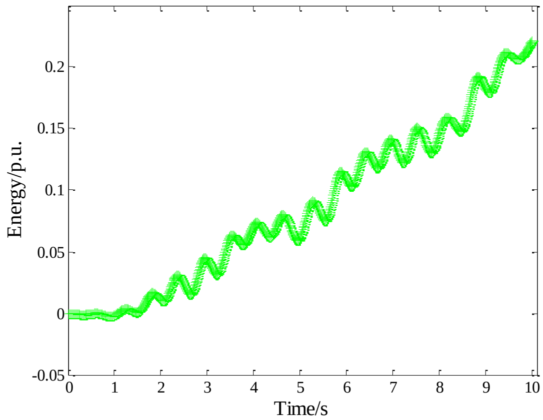

Figure 6. Oscillation energy for the dominant mode.

5. Conclusions

In this paper, a VMD-based forced power oscillation disturbance source location method is proposed. By performing VMD on the electrical components of the generator terminal bus in transient phase, the oscillation energy for the dominant mode is calculated to locate the disturbance source. Taking the forced power oscillation accident caused by abnormal speed control system as an example, the effectiveness and feasibility of the proposed method is verified.

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