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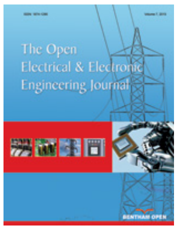

RESEARCH ARTICLE

The Online Identification of Dominated Inter-area Oscillations Interface Based on the Incremental Energy Function in Power System

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Abstract: The online identification of power system dominated inter-area oscillations interface based on the incremental energy function method is proposed in this paper. The dominant inter-area oscillations interface can be obtained by calculating branch oscillation potential energy, which is tie-line concentrated by oscillations energy. To get the oscillation energy caused by the different mechanism (free oscillation and forced oscillation), different fault position, different oscillation source. Power system dominated inter-area oscillations interface can be effectively obtained by proposed method, at the same time, dominated inter-area oscillations clusters also can be obtained. Finally, damping property of power system is effectively improved by configurating series damping controller in the dominant oscillation profile. The accuracy of the dominant oscillation interface identification is verified in this paper. At the same time, the proposed approach can also provides the basis for the configuration of damping control based on line.

Keywords: Dominated inter-area oscillations interface, Energy function, Online identification, Power system.

1. INTRODUCTION

With expansion of interconnected power grids, the possibility of power system oscillation increased gradually. The low frequency oscillation problem will seriously threaten the interconnected power grids [1, 2]. As one of the key technologies of online analysis of power system oscillation, it is the significance of online identification of dominant inter-area oscillations interface (DIOI) based on wide-area local measurement. Large interconnected power grid may also produce weak damping mode, and get worse and worse as the increasing of power flow of interregional dominant oscillations interface within area. Therefore, it is very important that dominant oscillations interface of power system can be fast recognized. Oscillations between different regions refer to oscillations within multi-generator, it provides the premise for suppressing inter-area oscillation by the key oscillation interface.

Based on the idea of oscillation group in [3, 4], the approximate estimation formula of frequency and damping of the low frequency oscillation are deduced. This method can provide us not only a clearly physical conception but also make the calculation simple and effective. At the same time, it is easy for mechanism analyzing. In [5], it shows that when total inertia of power grid is constant, the greater of difference of total inertia between the critical generators and remaining generators, the higher of the oscillation frequency (corresponding to the local oscillation mode). When the total inertia of them are almost same, the lower the frequency of oscillation (corresponding to the inter-area modes), and when the two the total inertia of them are equal, the frequency of the system reaches lowest.

Transient energy function method has a clearly physical concept, with online application potential, and it has been widely used in transient stability analysis of power system [6 - 11]. But it is not widely used in power oscillation. In [12], it is used for identifying oscillation path, and achieved ideal result. On the basis of it, the relationship between

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damping of generator and small signal characteristics of system are analyzed in [13]. At last, it also has obtained the good effect. But they rarely involves the rapid identification of the dominant oscillation interface.

The DIOI identification of interconnected power system based on the branch oscillation mode energy is proposed in this paper. The method is simple in structure, easy to be measured, and identifying dominant interface accurately. Through various examples and power oscillation caused by different mechanism, the proposed method can effectively identify the dominant oscillation interface. Finally, the accuracy of the critical oscillation interface identification is verified by setting reactive power compensation on different branch.

In addition, it is important for obtaining mode shape in the offline small signal analysis (SSA). The traditional method is eigenvalue analysis based on the mathematical model. Mode shape is obtained using the right eigenvector being approximate 180°. And the proposed energy method based on the disturbed trajectory can also be used to be clustering by identifying dominant oscillation interface. As shown in abovementioned, there are consistent. The oscillation energy can also distinguish mode shape.

Selection of oscillation interface is helpful to control power oscillation [14 - 18]. That is, through the critical lines be installed compensation device to control the active power of line, it can inhibit the power oscillation. Its effectiveness depends on the selection of the critical lines. Regional oscillation involves many group of generators, it provides a basis for suppressing inter-area oscillation by dominant oscillation interface judgment. The proposed energy method has online application potential. It also can proved more information, and get branch energy distribution, *etc*.

2. MATERIALS AND METHODOLOGY MECHANISM OF POWER OSCILLATION AND ENERGY CONVERSION PROCESS

2.1. The Mechanism of Power Oscillation

In Fig. (**1**), the two-area system is shown [19, 20]. P_t, P_{E1} and P_{E2} are the active powers of tie-line, G_1 and G_2, respectively.

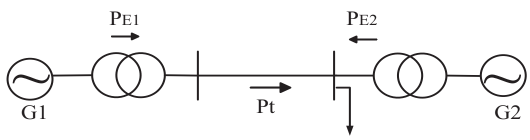

Fig. (1). The two-area system.

All generators are modeled classically and the load model is the constant impendence. Transient voltage E' is supposed invariable, the active powers of G_1 and G_2 are shown as follows [20]:

$$\begin{aligned} P_{E1} &= E_1'^2 G_{11} + E_1'E_2'(B_{12}\sin\delta_{12} + G_{12}\cos\delta_{12}) \\ P_{E2} &= E_2'^2 G_{22} + E_1'E_2'(-B_{12}\sin\delta_{12} + G_{12}\cos\delta_{12}) \end{aligned} \tag{1}$$

Then deviation of formula (1) are shown in the following:

$$\begin{aligned} \Delta P_{E1} &= \left.\frac{\partial P_{E1}}{\partial \delta_1}\right|_0 \Delta\delta_1 + \left.\frac{\partial P_{E1}}{\partial \delta_2}\right|_0 \Delta\delta_2 = K_{11}\Delta\delta_1 + K_{12}\Delta\delta_2 \\ \Delta P_{E2} &= \left.\frac{\partial P_{E2}}{\partial \delta_1}\right|_0 \Delta\delta_1 + \left.\frac{\partial P_{E2}}{\partial \delta_2}\right|_0 \Delta\delta_2 = K_{21}\Delta\delta_1 + K_{22}\Delta\delta_2 \end{aligned} \tag{2}$$

where,

$$\begin{aligned} K_{11} &= \left.\frac{\partial P_{E1}}{\partial \delta_1}\right|_0 = -\left.\frac{\partial P_{E1}}{\partial \delta_2}\right|_0 = -K_{12} = E_1'E_2'(B_{12}\cos\delta_{120} - G_{12}\sin\delta_{120}) \\ K_{21} &= \left.\frac{\partial P_{E2}}{\partial \delta_1}\right|_0 = -\left.\frac{\partial P_{E2}}{\partial \delta_2}\right|_0 = -K_{22} = E_1'E_2'(-B_{12}\cos\delta_{120} - G_{12}\sin\delta_{120}) \end{aligned}$$

Then swing equations are shown in formula (3),

$$\begin{aligned} \frac{d\Delta\delta_1}{dt} &= \Delta\omega_1\omega_n \\ \frac{d\Delta\delta_2}{dt} &= \Delta\omega_2\omega_n \\ M_1\frac{d\Delta\omega_1}{dt} &= \Delta P_{M1} - (K_{11}\Delta\delta_1 + K_{12}\Delta\delta_2) - D\Delta\omega_{12} \\ M_2\frac{d\Delta\omega_2}{dt} &= K_{21}\Delta\delta_1 + K_{22}\Delta\delta_2 \end{aligned} \tag{3}$$

Where D represents the damping coefficient, ΔP_{M1} represents the mechanical power deviation of G_1.

If $\Delta\delta_{12}$ is state variable, formula (4) can be obtained by formula (3),

$$\frac{d^2\Delta\delta_{12}}{dt^2} + \frac{D}{M_1}\frac{d\Delta\delta_{12}}{dt} + \omega_n(\frac{K_{11}}{M_1} - \frac{K_{22}}{M_2})\Delta\delta_{12} = \Delta P'_{M1} \tag{4}$$

Where, $\Delta P'_{M1} = \omega_n \frac{\Delta P_{M1}}{M_1}$

If there are $x = \Delta\delta_{12}$, $2\beta = \frac{D}{M_1}$, $\omega_n^2 = \omega_n(\frac{K_{11}}{M_1} - \frac{K_{22}}{M_2})$ frequency ω_r and a magnitude R are included in the mechanical power of G_1. So there is $\Delta P'_{M1} = R\cos\omega_r t$.

According to above mentioned, formula (4) can be transformed into:

$$\frac{d^2x}{dt^2} + 2\beta\frac{dx}{dt} + \omega_n^2 x = \Delta P'_m \tag{5}$$

The second order inhomogeneous differential equation with constant coefficients is show as formula (5). It is can be obtained by linearizing the rotor motion equation at working point.

The prime mover power change is often ignored, and rotor motion equation becomes the second order homogeneous differential equation with constant coefficients:

$$\frac{d^2x}{dt^2} + 2\beta\frac{dx}{dt} + \omega_n^2 x = 0 \tag{6}$$

Formula (6) is rotor motion equation, which is used to analyze power system low-frequency oscillation based on negative damping mechanism, the solution form is as follows:

$$\Delta\delta_1(t) = A_0 e^{-\beta t}\cos(\sqrt{\omega_n^2 - \beta^2}\,t + \varphi_0) \tag{7}$$

Where ω_n is natural oscillation angle frequency under system without damping; β is the damping factor; A_0 and ϕ_0 are two integral constants determined by initial conditions. $A_0 e^{-\beta t}$ can be seen as amplitude changing over time. If it is negative damping system, β is negative. The system will appear increase magnitude oscillation after it subjected to disturbance; If the system damping is good, β is positive. The system will appear attenuation oscillation.

When prime mover power can't be ignored, the generator rotor motion equation must be described with the second order inhomogeneous differential equation with constant coefficients. The solution contains the general solution and special solution. The general solution is the solution of the corresponding homogeneous equation, and the particular solution has a direct relationship with mechanical power as change ΔP_m. As assuming $\Delta P_m = R\cos\omega_r t$, the particular solution is as follows:

$$\Delta\delta_2(t) = \frac{r}{\sqrt{(\omega_n^2 - \omega_r^2)^2 + 4\beta^2\omega_r^2}}\cos(\omega_r t + \varphi) \tag{8}$$

where $r = \omega_n R/M$;ω_r is increment angular frequency of prime mover power. The angular frequency of the oscillation of the special solution is the same as increment angular frequency of prime mover power.

According to formula (7) and (8), solution of formula (5) can be shown as:

$$\Delta\delta(t) = \Delta\delta_1(t) + \Delta\delta_2(t) \tag{9}$$

When damping is positive, and after general solution the relevant with damping attenuating, the performance of the rest special solution is sustained oscillation. If the prime mover power frequency is close to the system inherent oscillation frequency, amplitude of persistent oscillation is very big. This is resonance mechanism of low frequency oscillation. As to amplitude of formula (8), the reached maximum amplitude corresponding angular frequency acquired with the extremum method:

$$\omega = \omega_r = \sqrt{\omega_n^2 - 2\beta^2} \tag{10}$$

This frequency slightly smaller than system without damping oscillating angular frequency.

The maximum value of amplitude is:

$$A_r = \frac{r}{2\beta\sqrt{\omega_n^2 - \beta^2}} \tag{11}$$

2.2. The Energy Conversion in Power Oscillation Process

If forced oscillation happened, the power angle deviation and rotor speed deviation are shown as follows respective

$$\Delta\delta = A\cos(\omega_r t + \varphi) \tag{12}$$

$$\Delta\omega = \frac{d\Delta\delta}{dt} = A\omega_r \cos(\omega_r t + \varphi + \pi/2) \tag{13}$$

The inter-area oscillation can be analyzed using energy function in [12, 13]. According to the rotor motion equations, energy function can be obtained for forced oscillation [19 - 21]:

$$\frac{1}{2}M\Delta\omega^2 \quad \frac{1}{2}K\Delta\delta^2 \quad \Delta_{\ m}\Delta\delta - D\Delta\omega\Delta\delta \tag{14}$$

where the kinetic energy is in the following:

$$\begin{aligned} V_{KE} &= \frac{1}{2}M\Delta\omega^2 = \frac{1}{2}M\omega_r^2 A^2 \cos^2(\omega_r t + \varphi + \pi/2) \\ &= \frac{1}{4}M\omega_r^2 A^2[1 + \cos(2\omega_r t + 2\varphi + \pi)] \end{aligned} \tag{15}$$

At the same time, the potential energy is shown as follows:

$$\begin{aligned} V_{PE} &= \frac{}{2}K\Delta\delta^2 = \frac{}{2}KA^2 \cos^2(\omega_r t + \varphi) \\ &= \frac{1}{4}M\omega_n^2 A^2[1 + \cos(2\omega_r t + 2\varphi)] \end{aligned} \tag{16}$$

The formula (17) shows total energy of generator:

$$V_E = V_{KE} + V_{PE} = \frac{1}{2}M\Delta\omega^2 + \frac{1}{2}K\Delta\delta^2 \tag{17}$$

According to above-mentioned, energy of generator are inconstant. Deal with the average value of energy in a periodic $\bar{V}_{KE} = \frac{1}{4}M\omega_r^2 A^2$ $\bar{V}_{PE} = \frac{1}{4}M\omega_n^2 A^2$, $\bar{V}_{KE} \neq \bar{V}_{PE}$, time, there is:

$$\bar{V}_E = \bar{V}_{KE} + \bar{V}_{PE} = \frac{1}{4}(1+v^2)M\omega_n^2 A^2 \tag{18}$$

According to formula (18), the average value of the kinetic energy is not the same as that of the potential energy. But the average value of total energy is constant. The above mentioned is the energy characteristic of forced oscillation [21].

3. DOMINATED INTER-AREA OSCILLATIONS INTERFACE IDENTIFICATED BASED ON THE INCREMENTAL BRANCH POTENTIAL ENERGY FUNCTION

3.1. The Branch Oscillation Increment Potential Energy Function

Each part energy of the system are shown as follows:

$$\begin{aligned} \Delta V_{KE} &= \int_0^t M\Delta\dot{\omega}\Delta\omega\omega_0 d\tau \\ \Delta V_{PE} &= \int_0^t \Delta P_E \Delta\omega\omega_0 d\tau \\ \Delta V_M &= \int_0^t \Delta P_M \Delta\omega\omega_0 d\tau \\ \Delta V_D &= \int_0^t D\Delta\omega\Delta\omega\omega_0 d\tau \end{aligned} \tag{19}$$

where incremental branch potential energy function is shown:

$$\Delta V_{pe} = \int_0^{\Delta\delta}(P_m \sin\delta - P^s)d\delta = \int_0^{\Delta\delta}(P_{ij} - P_{ij}^s)d\delta_{ij} = \int_0^t \Delta P_{ij}(\tau)\Delta\omega_{ij}(\tau)\omega_0 d\tau \tag{20}$$

Due to δ_{ij} , $\delta_{ij}$are disturbed trajectory, which contains nonlinear information of system.

The dominant oscillation interface located in the tie line contains small dominant oscillation frequency and damping. Frequency, damping ratio and mode shape are concerned in the traditional SSA.

But it is based on offline analysis, it do not analyze and evaluate real state of oscillation of the system. And according to the energy oscillation interface division, the dominant tie-line can be distinguished. The branch potential energy of dominant oscillation interface be analyzing by FFT, branch potential energy of dominant oscillation interface also contains dominant frequency. The oscillation amplitude of dominant oscillation interface is large. The mode shape is area divided by dominant oscillation interface.

According to different power oscillation caused by mechanism, the different mechanism can be divided into: 1). Free oscillation; Small disturbance degree of three phase short circuit is setting by different position. The time of remove fault is less, and small perturbation can be simulated. So the results can be approximately equivalent to the results calculated by small signal eigenvalue analysis. 2). Forced oscillation; The frequency of disturbance source such as load, generator are set the same as dominant oscillation frequency calculated by SSA, in order to stimulate the forced oscillation.

In this paper, dominant oscillation interface identification of power oscillation caused by different oscillation mechanism using formula (20).

3.2. Energy Analysis of Oscillation Center

DIOI should be a branch concentrated energy. Take oscillation center of two equivalent system for example, if multi-machine system subjected disturbance, it appears two machine oscillation mode. Assumption of ignore within generator incoherence, multi-machines can be simplified as two machine equivalent system, as shown in Fig. (**2**) [9 - 11].

Take potential $\dot{E}_2$ of equivalent machine G2 for reference, the electric potential $\dot{E}_1$ of equivalent machine G_1 around potential $\dot{E}_2$ counterclockwise in the process of change the rotor angle difference between the two equivalent δ, as shown in Fig. (**3**).

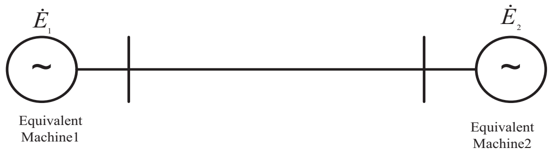

Fig. (2). Two equivalent machines system.

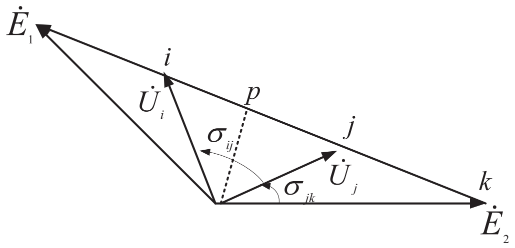

Fig. (3). Voltage of two machines system.

If $|\dot{E}_1|=|\dot{E}_2|$ oscillation center is always located in longitudinal impedance center of system augmented network. When δ is swing to 180°, oscillation center voltage is zero; If $|\dot{E}_1|=|\dot{E}_2|$, when electrical potential amplitude of two equivalent mechanical is constant in the process of oscillation, the oscillation center will be located in a fixed position, which is deviation of the longitudinal impedance center of system augmented network; If $|\dot{E}_1|$ and $|\dot{E}_2|$ changes in the process of system oscillation, oscillation center position is also changed [21].

For convenience of analysis, the following are all assumptions if don't be explained. $|\dot{E}_1|=|\dot{E}_2|$, and resistance of each component in system is ignored. Then the following is:

(1) If the oscillation center is located in one branch of two equivalent machine, the this branch is dominant oscillation branch.

(2) If a branch of two machine equivalent system is principal oscillation in the branch of system, and oscillation center is located in the center of branch reactance. Then this branch is called isometric main oscillation branch. Under the condition of above assumptions, for two machine equivalent system, main oscillation branch is one and only one. And the isometric dominant oscillation branch is a special case of the main oscillation branch. The diagram of oscillation center of two machine equivalent system is shown in Fig. (**4**).

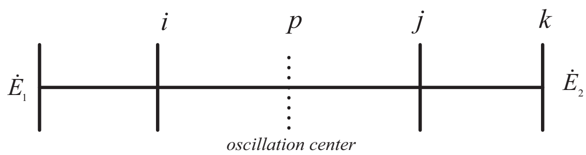

Fig. (4). Diagram of oscillation center in two equivalent machines system.

The temporary oscillation potential energy that shares by any place within a small neighborhood of circuit reactance in oscillation center is large than any branch in system. Thus when there is oscillation in system, branch potential energy mainly concentrated in the tiny local area network of the center. Then transient branch potential energy oscillation will further focus on main oscillation branch with stability of the system gradually decline. It will be losing stability on this branch.

In a multi-machine system, if two machine oscillation mode make caused by fault, no matter how complex, there must be oscillatory center in network. Due to the impedance angle of the various components is different and the generator voltage is not constant in the oscillation process, it may lead to oscillations center isn't located in a fixed position of network. However, there must be a cut set. It is the same as corresponding mode, which is mainly affected by oscillation center, and has the same features with dominant oscillation branch. The cut is called oscillation interface cut. In a multi-machine system, change of transient oscillation potential energy in oscillation interface cut set is the same as dominant oscillation branch in the two machine system.

4. DESIGN OF IDENTIFICATION OF DOMINANT OSCILLATION INTERFACE SCHEME

Based on the above principles, a novel adaptive dominant oscillation interface identification scheme using synchronous phase measurement unit is proposed. Eight steps are included in the developed technique depicted in Fig. (**5**).

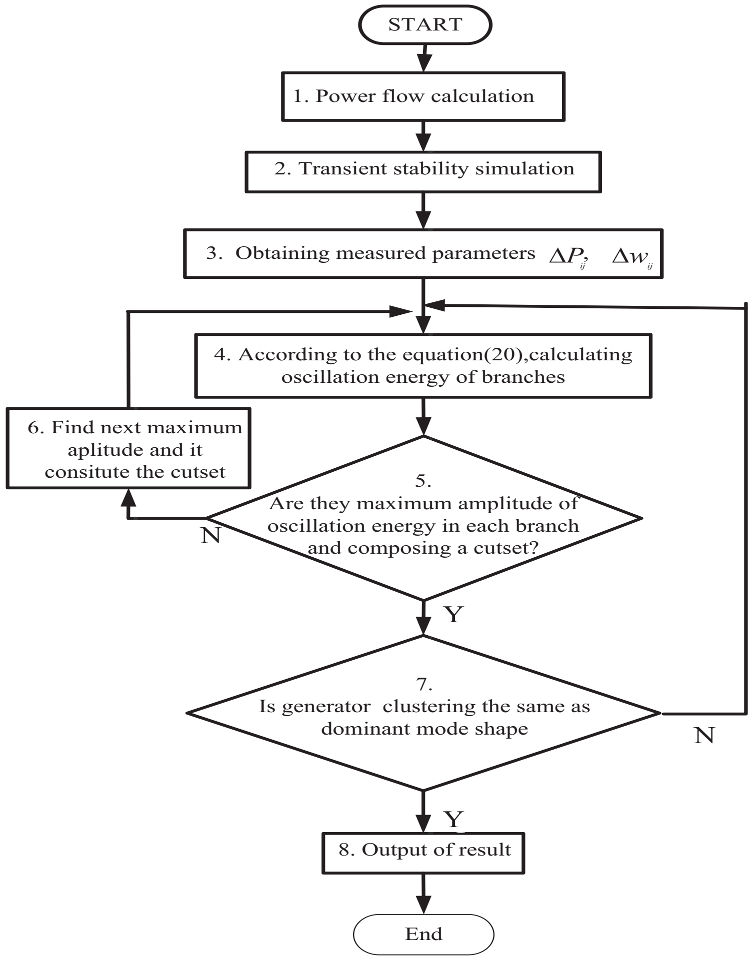

Fig. (5). The chart of identification of dominant oscillation interface scheme.

Step1. Power flow calculation

Step2. Transient stability simulation

Step3. Collecting the useful information (initial rate of active power deviation at the generator terminals and speed deviation) from the WAMS *via* PMU;

Step4. According to the formula (20), oscillation energy in each branches is calculated;

Step5. Comparing the maximum amplitude of oscillation energy in each branch. If amplitude of oscillation energy in some branch are largest and they can be composed a cutset, go to Step 7, else go to Step 6;

Step6. If amplitude of oscillation energy in some branch are not largest or they can't be composed a cutset. The next branch that has largest amplitude of oscillation energy in some branch and can be composed a cutset are selected in this step;

Step7. Making sure that generator is clustering the same as dominant mode shape.

Step8. Output of result.

5. COMPUTER SIMULATION TESTING

5.1. The Dominant Oscillation Interface Identification

Case 1 4-machine 2-area system

(1) The DIOI of power oscillation caused by negative damping mechanism

Take four-machine two-area system for example [1], as shown in Fig. (**6**). Only G_4 can be placed PSS in the system, the results of small signal stability calculation are shown in Table **1**. The damping ratio of system is 2.8439%, and system is in a weak damping mode. The power oscillation is easily caused by disturbance. Assuming three phase short circuit is set in BUS6 at 0-0.12 s, power oscillation is happened. According to proposed method, incremental oscillation branch potential energy is calculated, which is shown in Fig. (**7**). As shown in the above-mentioned, amplitude of oscillation potential energy of Line 7-8 is largest and energy is concentrated, under power oscillation caused by negative damping mechanism. Thus DIOI of system located on Line 7-8. As shown in Fig. (**7**), the branch potential energy in Area 1 (G1-G2) is negative. And in Area 2 (G3-G4) is positive. The generator group is divided into (G1, G2) *vs*. (G3, G4) by identified oscillation interface. As shown in Fig. (**8**), it is the same as ideal shape of dominant mode f=0.5524Hz, which is off-line calculated based on SSA. When DIOI is identified, mode shape is also can be obtained at the same time.

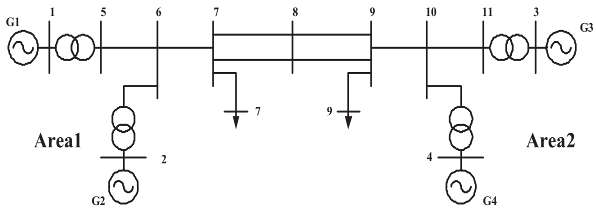

Fig. (6). Four machine two area system.

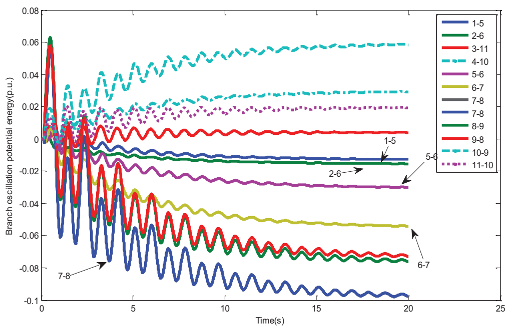

Fig. (7). The incremental oscillation branch potential energy of system.

Table 1. The results of small signal stability calculation.

Mode	Frequency (Hz)	Damping (%)	Mode shape	Mode type
1	0.5524	2.8439	{1,2} *vs*. { 3,4}	Inter-area oscillation mode
2	0.9649	10.8147	{1} *vs*. { 2}	Local oscillation mode
3	1.043	16.0699	{3} *vs*. { 4}	Local oscillation mode

(2) The dominant oscillation interface identification of power oscillation caused by forced oscillation mechanism

Take four-machine two-area system for example. All generators are configured PSS. As shown in the results of small signal stability calculation, the oscillation frequency f=0.5549Hz, and damping ratio of system is 8.5925%. The system is in a strong damping mode. General small disturbance is not easy to lead to the power oscillation, but if generator or load has the periodic small disturbance in the system, forced oscillation phenomenon is easily happened. In the following, Generator disturbance source is discussed:

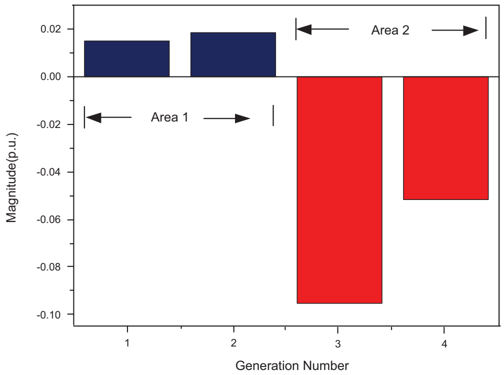

Fig. (8). The ideal mode shape of dominant mode.

Assuming periodic disturbance $y=0.1\sin(2\pi\times0.5549\times t)$ is set at G4, forced power oscillation happened. According to proposed method, incremental oscillation branch potential energy is calculated, which is shown in Fig. (**9**). As shown in the above-mentioned, amplitude of oscillation potential energy of Line 7-8 is largest and energy is concentrated, under the power oscillation caused by forced oscillation mechanism. Thus dominant oscillation interface of system located on Line 7-8. As shown in results of small signal stability calculation, generator group is divided into (G1, G2) *vs*. (G3, G4) by identified oscillation interface. Two section are Area 1 (G1-G2) and Area 2 (G3-G4).

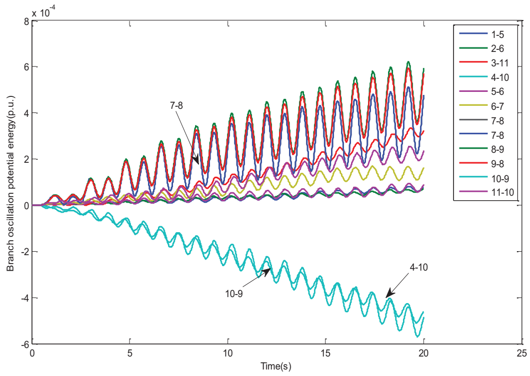

Fig. (9). The incremental oscillation branch potential energy of system.

As shown in Fig. (**8**), it is the same as ideal shape of dominant mode f=0.5549Hz,which is off-line calculated based on SSA. When DIOI is identified, mode shape is also can be obtained at the same time.

Assuming periodic disturbance $y=0.1\sin(2\pi\times0.5549\times t)$ is set at G1, forced oscillation happened. According to proposed method, incremental oscillation branch potential energy is calculated, which is shown in Fig. (**10**).

As shown in the above-mentioned, amplitude of oscillation potential energy of Line 7-8 is largest and the energy is concentrated, under the power oscillation caused by forced oscillation mechanism. Thus dominant oscillation interface of system still located on Line 7-8. As shown in Fig. (**10**), it is the same as ideal shape of dominant mode f=0.5539Hz, which is off-line calculated based on SSA. When DIOI is identified, mode shape is also can be obtained at the same time.

Case2 16-machine 68-bus system

(1) The free oscillation mechanism

The eigenvalue of 16-machine 68-bus system shown in Fig. (**11**) is calculated by SSA. There is a dominant negative damping oscillation mode, which its frequency is 0.403295 Hz and mode shape is (G14-G16) *vs*. (G1-G13). Assuming three phase short circuit is set in BUS44 at 0-0.02 s, power oscillation is happened. According to the result of incremental oscillation branch potential energy, dominant oscillation interface is 50-52,49-52,40-41. The generator group is divided into (G14-G16) *vs*. (G1-G13) by identified oscillation interface. As shown in Fig. (**12**), it is the same as ideal shape of dominant mode, which is off-line calculated based on SSA. In order to extract the oscillation information, active power of line $P_{49\text{-}52}$ is analyzed by FFT, as shown in Fig. (**13**).

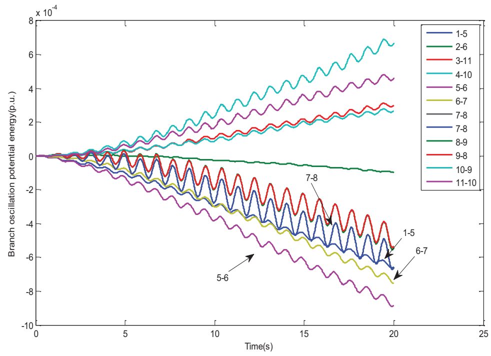

Fig. (10). The incremental oscillation branch potential energy of system.

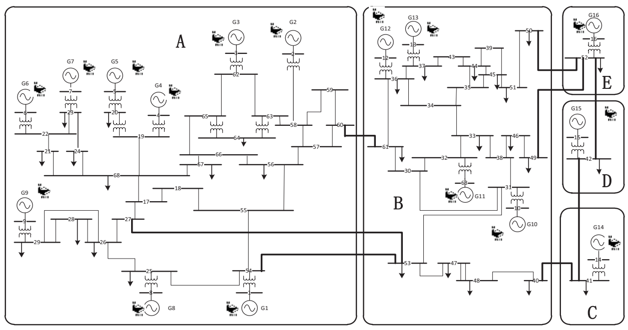

Fig. (11). 16-machine 68-bus system.

The active power of tie-line contains dominant oscillation frequency f = 0.39 Hz. Oscillation amplitude of 50-52,49-52,40-41 is bigger. As to oscillation caused by negative damping, dominant oscillation interface can be identified by proposed method.

(2) The forced oscillation mechanism

Assuming periodic disturbance $y = 0.1\sin(2\pi \times 0.4033 \times t)$ is set at Load 67, forced oscillation happened. According to proposed method, incremental oscillation branch potential energy is calculated, which is shown in Fig. (**14**). As shown in the above-mentioned, amplitude of oscillation potential energy of Line 50-52,49-52,40-41are largest and energy is concentrated, under the power oscillation caused by forced oscillation mechanism. Thus DIOI located on Line 50-52,49-52,40-41. As shown in Fig. (**14**), it is the same as ideal shape of dominant mode f=0. 4033Hz, which is off-line calculated based on SSA. When DIOI is identified, mode shape is also can be obtained at the same time.

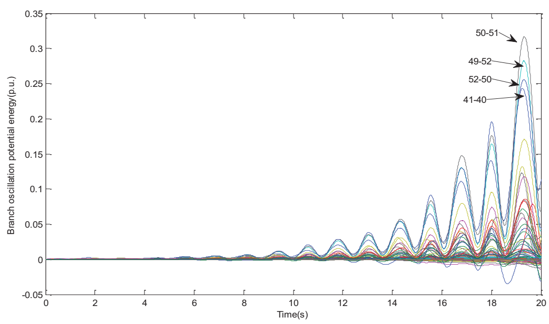

Fig. (12). The incremental oscillation branch potential energy of system.

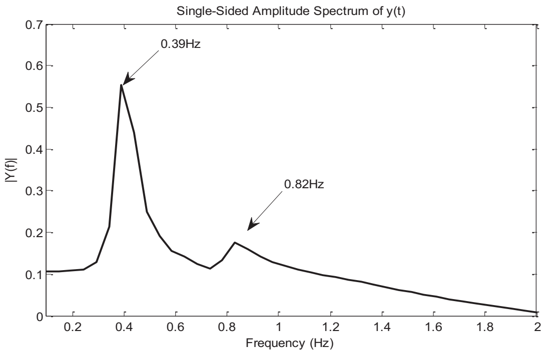

Fig. (13). The active power of line P49-52 is analyzed by FFT.

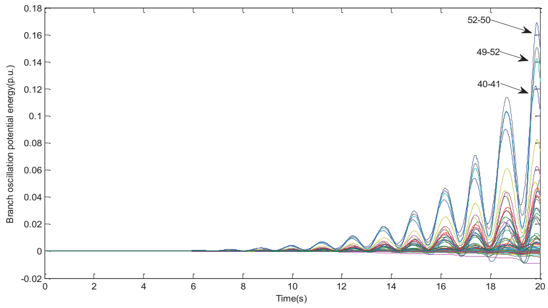

Fig. (14). The incremental oscillation branch potential energy of system.

In order to extract the oscillation information, active power of line P_{49-52} is analyzed by FFT, as shown in Fig. (**15**). The active power of tie-line contains dominant oscillation frequency f = 0.399Hz.

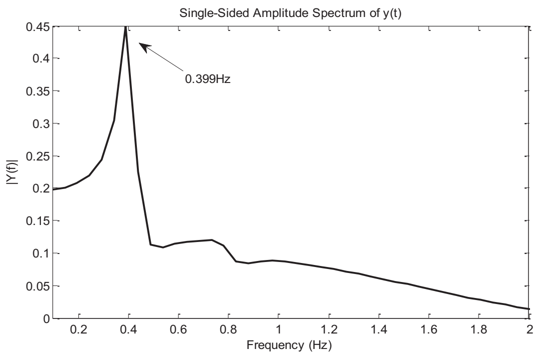

Fig. (15). The active power of line P49-52 is analyzed by FFT.

5.2. The Validation of Identified Dominant Oscillation Interface

In order to further verify the effectiveness of the identification of dominant oscillation interface, the DIOI is Line 7-8 in 4-machine 2-area system, which oscillation is caused by negative damping. So fix reactive power compensation by reactance is placed on Line 7-8 of dominant oscillation interface, the control effects can be compared with injected and without injected. Line 7-8, 9-10 and 10-11 are configurated fix reactive power compensation by reactance, power oscillation suppression are shown in Fig. (**16**).Compared with other lines, line 7-8 of dominant oscillation interface are configurated fix reactive power compensation. Thus the power oscillations of tie line is reduced, and power oscillation are effectively inhibited. The accuracy of identification of dominant oscillation interface is verified. It provides a theoretical basis for locating damping control based on line.

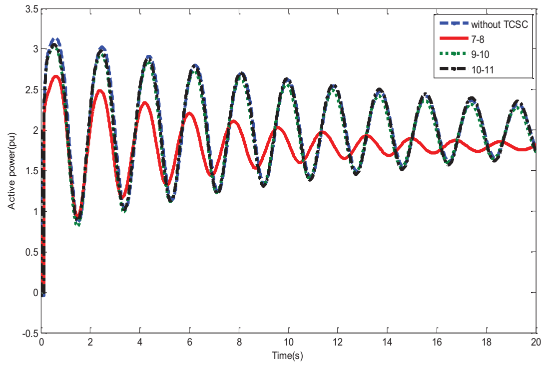

Fig. (16). The active power inhibited by TCSC on different position.

As shown in Fig. (**16**), after applying, after applying fix reactive power compensation, the system damping is obviously increasing and power oscillation is suppressed. when dominant oscillation interface line 7-8 are placed fix reactive power compensation, the system damping effect is much better than that other branch. In the Fig. (**16**), dominant oscillation section configurated damping control can effectively suppress interarea oscillation.

CONCLUSION

In this paper, the online identification of power system dominated inter-area oscillations interface based on the incremental energy function method is proposed. The dominant inter-area oscillations interface can be obtained by calculating branch oscillation potential energy, which is tie-line concentrated by oscillations energy. To get the oscillation energy caused by the different mechanism, different fault position, different oscillation source. Power system dominated Inter-Area oscillations interface can be effectively obtained by proposed method, at the same time, dominated inter-area oscillations clusters also can be obtained. Finally, damping property of power system is effectively improved by placing series damping controller in the dominant oscillation interface. The accuracy of the dominant oscillation interface identification is verified in this paper. The proposed approach can also provides the basis for the configuration of damping control based on series line.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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