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Coherency Identification in Multi-machine Power System

Nisha Pilple* **and Dr. Malaya Saurava Dash**
Technocrats Institute of Technology, Bhopal, Madhya Pradesh, India.
*Corresponding author email id: nisha23piple@gmail.com

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Abstract **– This paper analyzes four different test systems for defining coherent generators in the multi machine power systems based on the Eigen properties of the linearized model of the inter connected power system. The disruption is measured to be dispersed in the network by smearing small signal disturbance in each case. For finding the coherent areas and their tolerances in the inter-connected power system, no generator buses are allocated to each cluster of coherent generator using similar coherency recognition methods. The technique is assessed with four test schemes, and coherent generators and zones are acquired for diverse functioning points to render a more precise consortium approach, which is effective through a wide array of naturalistic functioning points of the network.**

Keywords **– Power System Stabilizer (PSS), Coherency Identification, Small Signal Stability, Eigen Value Analysis.**

I. Introduction

Power system stability problem has been and continues to receive a great deal of attention over the years. For convenience in analysis, gaining a better understanding of the nature of stability problems, and developing solutions to problems, power system stability problems are classified into following three categories:

- *Rotor angle stability* – ability of the system to maintain synchronism.
- *Voltage stability* – ability of the system to maintain steady acceptable voltage.
- *Frequency stability* – ability of the system to maintain frequency within an acceptable variation range.

Power systems are steadily growing with ever larger capacity. Formerly separated systems are interconnected to each other. In large interconnected power systems small signal stability, especially inter-area oscillations, become an increasing importance. Many electric systems world-wide are experiencing increased loading on portions of their transmission systems, which can, and sometimes do, lead to poorly damped, low frequency (0.2-0.8 Hz) inter-area oscillations. These oscillations can also lead to widespread system disturbances if cascading outages of transmission lines occur due to oscillatory power swings, like during the black out in following regions:

1. In 1960's, Ontario Hydro (OH) – Hydro Quebec (HQ) interconnections.
2. In 1969, Finland-Sweden (and Norway) – Denmark interconnections.
3. In 1975, unstable oscillations of 0.6 Hz, New South Wales and Victoria.
4. Blackout in Western North America on August 10, 1996.

The power system stability can be classified into differ0ent categories and sub-categories as shown in figure 1.1.

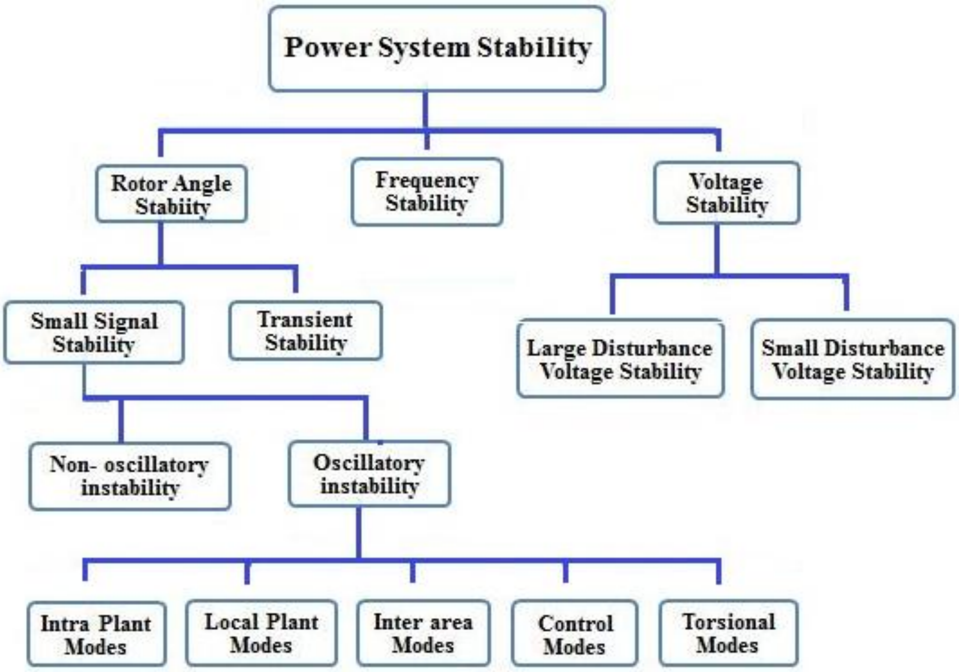

Fig. 1. Classification of Power System Stability.

Rotor angle stability is one of the classified categories of the power system stability which refers to the ability of the synchronous machines to maintain synchronism after a disturbance. Looking at the characteristics of the disturbances, rotor angle stability analysis can be sorted out as below:

Dynamic Stability:

Dynamic stability refers to the stability of a power system subjected to small and sudden perturbations. A system is said to be dynamically stable if the oscillations do not acquire more than certain amplitude and die out quickly. If the system is dynamically stable it is expected that after a temporary small disturbance, the System will return to its initial state, while for a permanent small disturbance the system will acquire a new operating point after a transient period [Anderson, 1977].

Transient Stability:

Transient stability or Large-disturbance rotor angle stability is the ability of the power system to maintain synchronism when subjected to a severe disturbance, such as a three-phase faults or transmission line switching, loss of generation or loss of a large load. However, transient stability of the system depends very much on the initial operating condition of the system and the nature (i.e., the type, magnitude, duration, and location, etc.) of the large disturbances that are applied to the system [Anderson, 1977] as well as on the post-fault system configuration.

The disturbances occurring in power system include electromechanical oscillations of electrical generators. Interconnected power systems exhibit several kinds of oscillations when subjected to a perturbation. Some of the oscillations are related to a single unit, some others are related to a closely attached power generation units and some other oscillations are related to a group of generators that are associated through weak connections such as tie-lines. These oscillations are also named as power swings and to maintain the system stability these oscillations must be effectively damped. Oscillations in power systems are separated by the System Factors that they affect.

The energy demand is vastly growing and the network expansion is not following the pace of load growth in power systems. This has led the inter-connected power systems to operate very close to their operation limits, which makes them more vulnerable to any possible disturbance. Therefore there is increasing value for enhancement methods to maintain the stability of power systems. In the case of disturbance in multi-machine power systems, some of the machines exhibit similar responses to the disturbance which means the difference between their swing curves is so small that they can be considered to be oscillating together and coherently. In power system dynamic performance, coherency between generators is an important factor which has several applications including dynamic reduction of power systems and emergency protection and control schemes.

Defining coherent generators is an essential part of some emergency protection methods such as controlled islanding when the system is subjected to a severe disturbance and the conventional control systems are unable to keep the system stable [7]. The stability of islands created in the aftermath of the disturbance is dependent on the coherency of the generators inside the islands which shows the importance of correctly detecting coherent generators.

Owing to the importance of coherency detection in transient stability and control studies, several methods have been introduced to define the coherent groups of generators and areas in inter-connected power systems. Some of these methods use time-domain analysis on the linear dynamic model of power systems [8] and also frequency response analysis has been implemented in some papers [9]. Direct stability analysis methods such as unstable equilibrium point have also been applied for solving the generator coherency detection problem [10]. In these methods using the linearised dynamic model such as slow coherency method, the coherency between generators is obtained for the specific operating point and the change in the operating conditions may change the coherency indices between the generators which should be investigated. Therefore methods such as continuation method [11] have been applied to trace the coherency characteristics in the network. In [12] a method is proposed to use the phase of the oscillations to determine coherency using Hilbert-Huang transform. Application of wide area angle and generator speed measurement is another helpful tool in tracking the generator coherency in inter-connected power systems [13].

The classical approach to damp low frequency oscillations is the use of power system stabilizer (PSS) forming a part of excitation system and FACTS controller employing locally available signals such as generator speed, power generated by alternator etc. PSS with local signal lack the global observation and has not enough ability to damp inter-area oscillation [14]. Wide Area Damping controller employing remote signal as input to the controller, such as generator's speed, tie-line active power, rotor angle deviation etc., effectively damp poorly damped critical inter-area modes. In contrast time delay caused by transmission of global signals is one of the significant factors influencing the whole power systems stability and damping performance.

II. System Description

The system represents a three phase four wire system main components of system are Source followed by a VI measurement, nonlinear load for balance and unbalanced system and there is a DSTATCOM connected in parallel for which gating signals are provided by the pulse generator also including subcomponents as, Voltage source inverter, Capacitor at dc link, Reference current generator and Current Controller shown in Fig. 1.

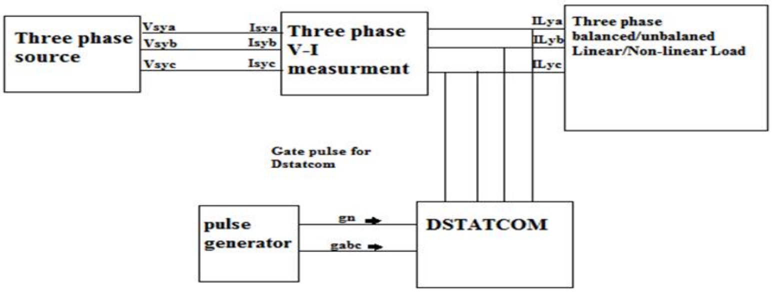

Fig. 2. Block diagram of system.

DSTATCOM consists of a typical three-phase Insulated Gate Bipolar Transistor (IGBT) based four leg VSC bridge with the dc bus capacitor. An extra leg is added to control the current in neutral wire [3]. DSTATCOM is used for instant monitoring of load current, improvement of power factor, regulation of voltage along with, elimination of harmonics, current compensation and maintaining the linear and nonlinear loads also generation of reference compensating current [4]. The gate pulse of generator used for giving the gate pulses to the VSC of DSTATCOM also as well as for the neutral. In this block all the control pulses exists and also consist Reference current generation, PI controllers, HBCC, PLL etc [5] Algorithm of PI controller involves two separate parameters: The Proportional parameter determines equation of the current error; Integral parameter determines the equation based on the sum of recent errors. Correct regulation of proportional controller's value plays an important role in DC voltage control system's response. Too much increase in proportional gain may results in unsteadiness (fluctuations) on top of system and an excessive amount of much reduction decreases the responding speed system. Further the Integral gain of controller modifies the steady state error. Hence the system becomes stable only at a particular regulated value of PI controller [8, 12]. Many techniques of generation of gating pulses but the most widely used technique is hysteresis controller because of this simplicity and quick response. In hysteresis controller the reference current which was obtained by SRF technique is compared with the filter current and provides the gate pulses for DSTATCOM [11-14].

III. Methodology

This concerns with the detailed modelling of Power System dynamic components such as synchronous generator, exciter, governor and power system stabilizer. In addition to this modelling of load has been presented. Linearization of the given system to form state space model for analyzing small signal stability is then performed. The designing procedure of proposed Controller employing Coherency is then described. Power System Component Dynamic Models.

Model of Synchronous Generator

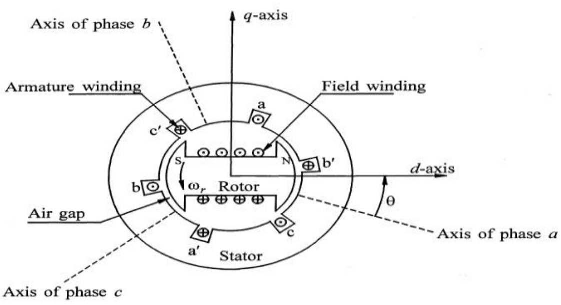

Fig. 3. Schematic diagram of a three phase synchronous machine.

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In electrical power system synchronous generators are the main source electrical energy. The stability in power system arises from the fact that in steady state or under normal conditions the average electrical speed of all generators must remain the same anywhere in the system i.e. they must remain in synchronism. Therefore, an understanding of the characteristics and accurate modelling of the dynamic performance of synchronous machines are of fundamental importance to the study of power system stability. This section gives only brief idea of modelling of synchronous generator. For detail study of synchronous generator refer [18]. In this thesis a two axis classical model synchronous generator, as described in [18], has been used. The dynamic equations of the synchronous generator which is shown in the Fig. 3.1 are

$$p\delta = \omega_0 \Delta\omega_r$$

$$p\Delta\omega_r = \frac{1}{2H}(P_m - P_e - K_D \Delta\omega_r)$$

$$pE_q^{'} = \frac{1}{T_{do}^{'}}\left(E_{fd} - E_q^{'} - (X_d - X_d^{'})i_d\right)$$

Where

p operator of differentiation.

δ generator rotor angle,

ω_0 base rotor electrical speed (rad/sec),

$\Delta\omega_r$ speed deviation per unit,

$E_q^{'}$ internal quadrature axis voltage,

E_{fd} voltage output exciter,

H generator inertia constant,

P_m generator input mechanical power,

P_e generator output electrical power,

K_D damping coefficient,

$T_{do}^{'}$, $T_{qo}^{'}$ direct and quadrature axis transient field winding time constant,

X_d, X_q direct axis and quadrature axis synchronous reactance,

$X_d^{'}$, $X_q^{'}$ direct axis and quadrature axis transient reactance.

The per unit power equation on the base three phase VA = $(3/2)e_{s\,base}\, i_{s\,base}$ can be expressed as

$$P_t = e_d i_d + e_q i_q$$

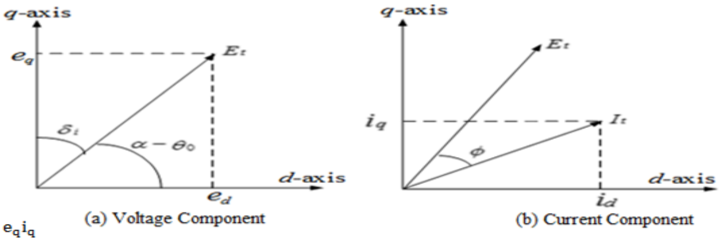

Fig. 4. d-q component of armature voltage and current.

Where

e_d, e_q park's transformation voltage of terminal voltage E_t.

i_d, i_q park's transformation current of terminal current I_t.

$e_{s\,base}$ peak value of rated line to neutral voltage.

$i_{s\,base}$ peak current of rated line current.

Similarly the per unit torque equation on the base torque = $\frac{3}{2}\left(\frac{p_f}{2}\right)\psi_{s\,base}\, i_{s\,base}$ can be written as $T_e = \psi_d i_q - \psi_q i_d$.

Where

p_f no. of poles of synchronous machine.

$\psi_{s\,base}$ stator flux linkage due to $i_{s\,base}$,

ψ_d, ψ_q park's transformation component of stator flux linkage.

Park's coordinate frame is rotating synchronously with the rotor. The effect of Park's transformation is simply to transform all stator quantities from phases a, b and c into new variables, the frame of reference of which moves with the rotor. This leads to great simplification in the mathematical description of the synchronous machine.

Phasor equation and Phasor diagrams

In order to determine the performance character tics of the machine in actual machine in actual machine axes, i.e. a-b-c co-ordinates, the transformation from d, q, o to abc variables can be used.

I_d, I_q and E_f are only magnitude and not in complex notation. In order to express them as a phasors, refer to fig. 3.3, where d-axis is taken as the reference or real-axis.

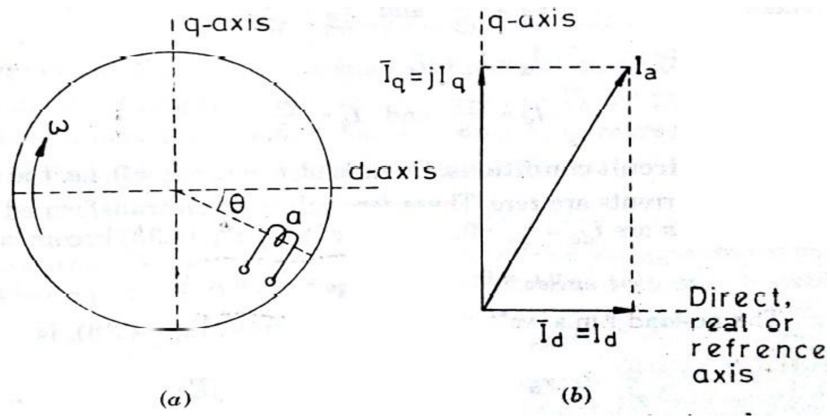

Fig. 5. (a) Phase-a axis at an angle $\theta = \omega t$ from d-axis and (b) Phasor component of I_a.

The phasor notation for armature currentI_a, in terms of phasors $\overline{I_d}$ and $\overline{I_q}$ can be written as $\overline{I_a} = \overline{I_d} + \overline{I_q}$, $\overline{I_a} = \overline{I_d} + \overline{I_q} = I_d + jI_q$, $\overline{I_d} = I_d$ and $\overline{I_q} = jI_q$ or $I_q = -j\overline{I_q}$

With these changes, Eq. (7.15) becomes $V_a = V_t = r_a\overline{I_a} + jX_d\overline{I_d} + jX_q\overline{I_q} + jE_f$

V_t is the terminal voltage of any one phase for a salient-pole type synchronous motor.

For a generator, the voltages are generated and the currents are output currents. In view of this, the generator voltage equation can be obtained from motor voltage equations by writing $(-\overline{I_a})$ in place of $\overline{I_a}$. Therefore, the generator voltage equation is $jE_f = \overline{V_t} + r_a\overline{I_a} + jX_d\overline{I_d} + jX_q\overline{I_q}$, phasor diagram for a salient-pole synchronous generator as shown in figure 3.4.

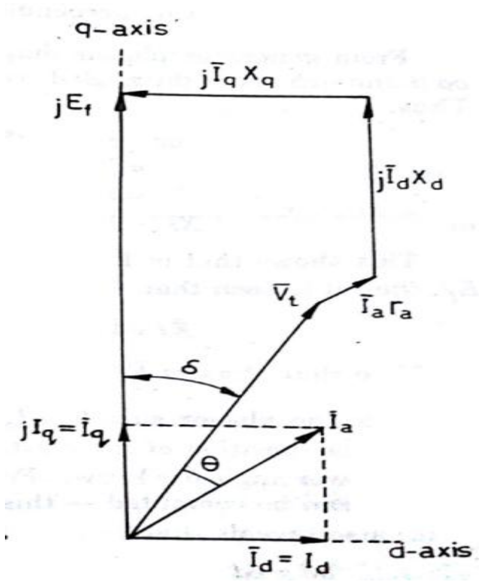

Fig. 6. Phasor diagram for synchronous generator.

Constant Flux Linkage Model (Classical model):

For studies in which the period of analysis is small as compared to T'_{do} the machine model is often simplified by assuming E'_q (or Ψ_{fd}) constant throughout the study period. The assumption eliminates the only differential equation associated with the electrical characteristics of the machine.

A further approximation to simplify the machine model is to ignore transient saliency by assuming $X'_d = X'_q$, and to assume that the flux linkage Ψ_{1q} also remains constant. With these assumptions, the voltage behind the transient impedance $R_a + jX'_d$ has a constant magnitude.

The per unit flux linkages identified in the d-axis are given by , $\Psi_{ad} = -L_{ad}i_d + L_{ad}i_{fd}$, $\Psi_d = \Psi_{ad} - L_l i_d$, $\Psi_{fd} = \Psi_{ad} + L_{fd}i_{fd}$, $i_{fd} = \frac{\Psi_{fd} - \Psi_{ad}}{L_{fd}}$

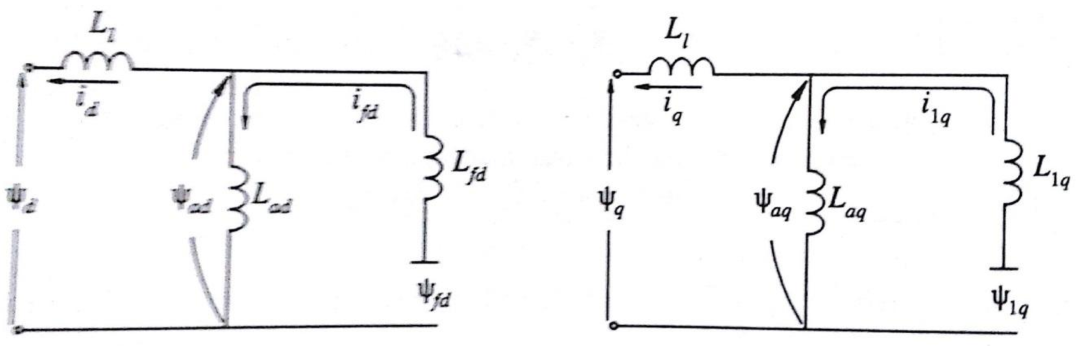

Fig. 7. The *d*- and *q*-axis equivalent circuits with one rotor circuit in each axis.

The corresponding equivalent is shown in figure (8.3)

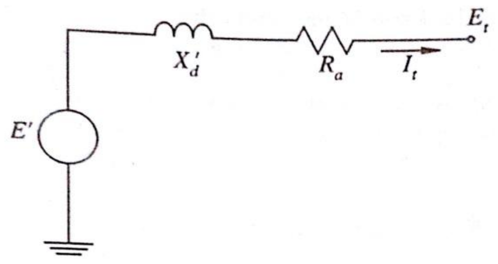

Fig. 7. Simplified transient model.

With rotor flux linkages Ψ_{fd} and Ψ_{1q} constant, $E_d^{'}$ and $E_q^{'}$ are constant. Therefore the magnitude of E' is constant. As the rotor speed changes, the d- and q-axes move with respect to any general reference coordinate system whose R-I axes rotate at synchronous speed, as shown in figure (3.6). Hence, the components $E_R^{'}$ and $E_I^{'}$ change.

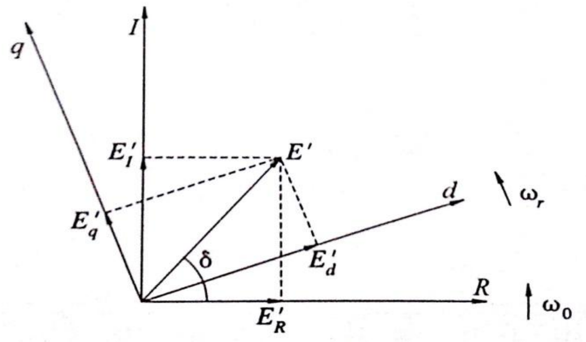

Fig. 8. The *R-I* and *d-q* coordinate system.

This model offers considerable computational simplicity; it allows the transient electrical performance of the machine to be represented by a simple voltage source of fixed magnitude behind an effective reactance. It is commonly referred to as the classical model, since it was used extensively in early stability studies.

Modelling of Governor

The main function of prime mover is to deal with the mechanism for controlling the synchronous machine speed and hence voltage frequency. Hence a device must be required to since either speed or frequency in such a way that comparison with a desired value can be used to create an error signal to take corrective action, so that the speed and frequency is automatically controlled. The block diagram of this model for a time constant governor TG with speed regulation R is shown in Fig. 3.7. The mathematical model of this governor is as per the following equations

$$T_G \dot{P_m} = -P_m + P_{ref} - \frac{1}{R}(\omega - 1) \tag{5.6}$$

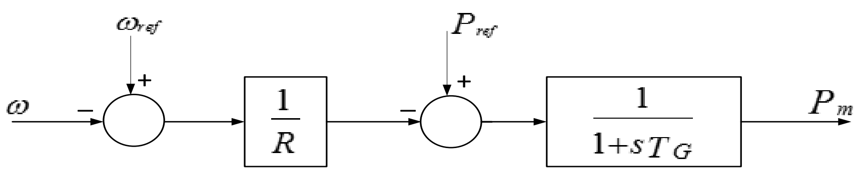

Fig. 8. Block diagram of governor model.

Modelling of Exciter

The exciter model used in this study is the standard IEEE type ST1A exciter. Its block diagram is shown in figure-(9).

The type ST1A exciter model represents a potential-source controlled-rectifier system. The excitation power is supplied through a transformer from generator terminals; there the exciter ceiling voltage is directly proportional to the generator terminal voltage. The effect of rectifier regulation on ceiling voltage is represented by KC. The model provides flexibility to represent series lag-lead or rate feedback stabilization. Because of the very high field-forcing capability of the system, a field current limiter is sometimes employed; the limiter is defined by ILR and the gain by KLR.

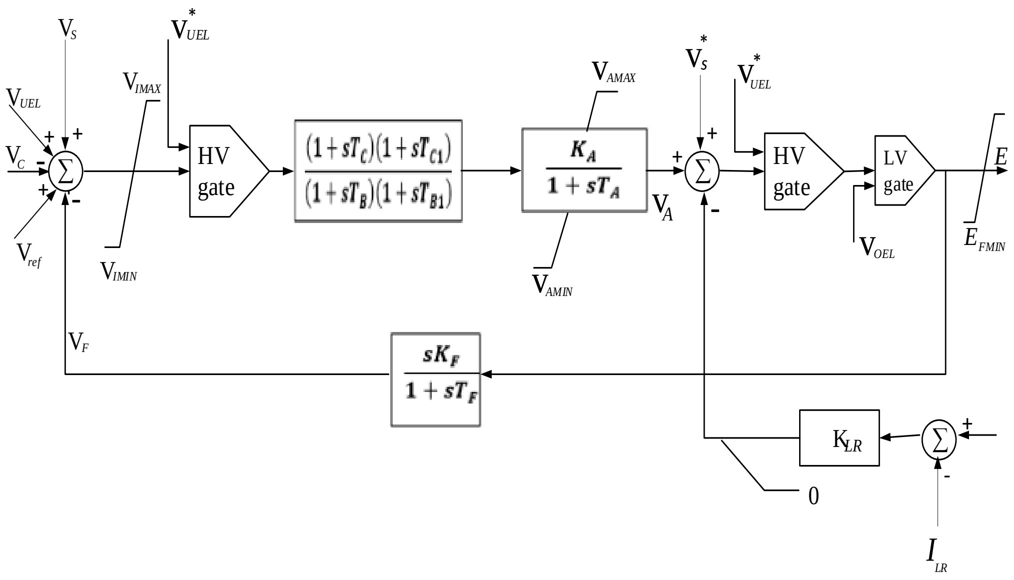

Fig. 9. IEEE type ST1A excitation system model.

The governing equations for the IEEE-ST1A type excitation system are given by [2]:

$$\frac{dV_{tri}}{dt} = \frac{1}{T_{ri}}[-V_{tri} + V_{ti}] \quad (5.7)$$

$$E_{fdi} = K_{ai}(V_{refi} - V_{tri}) \quad (5.8)$$

Modelling of PSS

The basic function of a power system stabilizer (PSS) is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signals. A PSS is added to the automatic voltage regulator (AVR), which controls the generator stator terminal voltage. PSS uses stabilizing feedback signals such as shaft speed, terminal frequency and/or power to change the input signal. But, since we want to produce a torque in phase with speed deviation, therefore the most suitable input signal to the PSS is the speed deviation i.e. Δω. Hence in the literature this type of PSS with input as speed deviation is called delta-omega PSS. Power system dynamic performance is improved by the damping of system oscillations. To provide damping, PSS must produce a component of electrical torque in phase with the rotor speed deviations. The general block diagram representation of a delta-omega PSS is shown in Fig. 3.9

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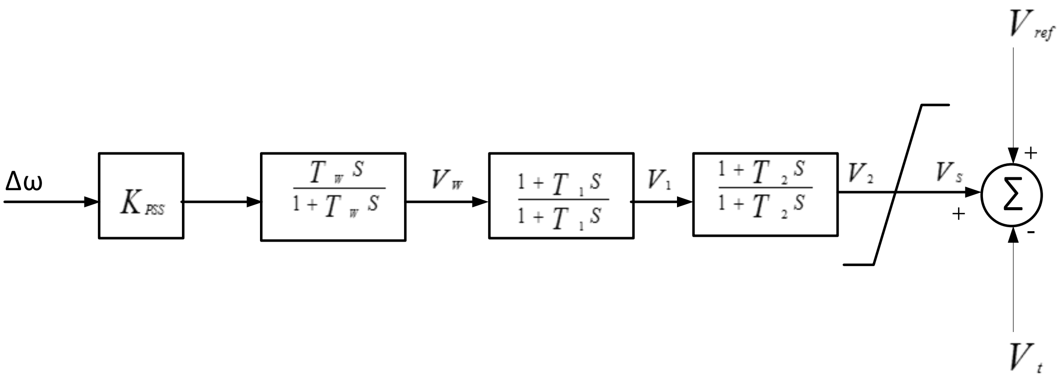


Fig. 10. Block diagram representation of power system stabilizer.

It consists of three blocks: a gain block, a signal washout block and a phase compensation block. The stabilizer gain kpss determines the amounts of damping introduced by the PSS. Ideally the gain should be set at a value corresponding to maximum damping; however it is often limited by other considerations. The signal washout block serves as a high pass with the time constant TW high enough to allow signals associated with oscillations in rotor speed to pass unchanged. Without it, steady changes in speed would modify the terminal voltage. It allows the PSS to respond only to changes in speed. From the viewpoint of the washout function, the value of TW is not critical and may be in the range of 1 to 20 seconds. The main consideration is that it be long enough to pass stabilizing signals at the frequencies of interest unchanged, but not so long that it leads to undesirable generator voltage excursions during system-islanding conditions. The lead/lag phase compensation blocks provides the appreciate phase lead characteristic to compensate for the phase lag between the exciter input and the generator electrical (air-gap) torque. Normally, the frequency range of interest is 0.1 to 2.0 Hz, and the phase-lead network should provide compensation over this entire frequency range. Generally some under-compensation is desirable so that the PSS, in addition to significantly increasing the damping torque, results in a slight increase of the synchronizing torque. The differential equations describing a PSS shown in Fig. 3.9 are: $T_W\dot{V}_W = -V_W + K_{PSS}(T_W\Delta\dot{\omega})$, $T_2\dot{V}_1 = -V_1 + \left(V_W + T_1\dot{V}_W\right)$, $T_4\dot{V}_2 = -V_2 + (V_1 + T_3\dot{V}_1)$.

Modelling of Load

Stable operation of power system depends on the ability to continuously match the electrical output of generating units to the electrical load on the system. Consequently, load characteristics have an important influence on system stability. The modeling of loads is complicated because a typical load bus represented in stability studies is composed of a large number of devices such as fluorescent and incandescent lamps, refrigerators, heaters, compressors, motors, furnaces and so on. The exact composition of load is difficult to estimate. Also the composition changes depending on many factors including time (hour, day, and season), weather conditions and state of the economy. The load models are traditionally classified into two broad categories: static models and dynamic models. The loads can be modeled using constant impedance, constant current and constant power static load models. The constant impendence type loads are static loads where the active and reactive power is directly proportional to the square of voltage magnitude. Constant current loads are also static loads but the active and reactive power are directly proportional to voltage magnitude. Similarly constant power loads are also static loads but the only difference is that active and reactive power has no relation with voltage magnitude. The load models described in can be defined as $P_L = kP_0\left[A_1 + A_2\frac{V}{V_0} + A_3\left(\frac{V}{V_0}\right)^2\right]$, $Q_L =$

$kQ_0\left[B_1 + B_2\frac{V}{V_0} + B_3\left(\frac{V}{V_0}\right)^2\right])$

Where

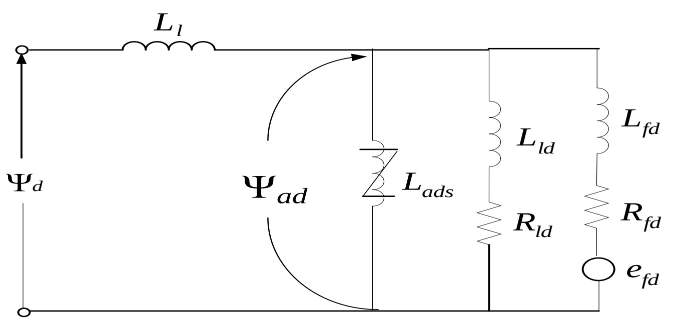
$A_1 + A_2 + A_3 = B_1 + B_2 + B_3 = 1$; P_0 and Q_0, are called nominal powers. The nominal real and reactive powers consumed by the load is under nominal condition i.e at nominal voltage $V_0$and nominal frequencyf_0.The actual consumed load powers P_L and Q_L are under the current condition of voltage V and frequency f. The variable k used in the equation is known as loading factor. These kind loads are often called as ZIP model.

Small Signal Stability Analysis:

Small signal stability is the ability of the power system to maintain synchronism when subjected to small disturbance. The small perturbation continuously occurs in any power system n due to small changes in load and generation. For analyzing the small signal stability of any system the system model can be linearized around an operating point i.e. the disturbances are considered to be so small or incremental in nature so that we can develop a linear model of the system around an operating point. Once we develop the linear model of the system we can understand behavior of the system under small perturbation, various parameter of the system which affect the stability of the system. Further the moment we have linear model of the system we can apply the linear control system theory for designing the controllers. The controllers particularly are excitation control system (i.e. voltage regulator) and power system stabilizer. But as we can see that in any power system the actual system is somewhat complex and it is not as simple as a machine connected to an infinite bus. In multi machine system there are different modes of oscillations such as control mode of oscillation, local modes of oscillations, inter area modes of oscillations. Primary requirement of the system to have stability is that system should have the positive synchronizing torque, positive damping torque. The system stability gets affected if any of these two torques becomes negative.

So to start with we should first study a simple model considering the constant flux linkages in the field winding. Next we will include field dynamics i.e. changes of flux linkage in the field winding. It is here first considered that the field winding is manually controlled. Then we will include the automatic field voltage regulator (AVR) and we will study the parameter of the excitation system and gain setting of the automatic voltage regulator on stability of the system. Then next step will be we include the auxiliary control of the controller that is the power system stabilizer (PSS). Then we will extend the model with amortisseurs. So that the step by step study will give the complete insight into the small signal stability of the system.

When generator amortisseurs are included, the system equations will be changed. We will assume that the model includes one d- axis amortisseur and two q-axis amortisseurs, as shown in figure.



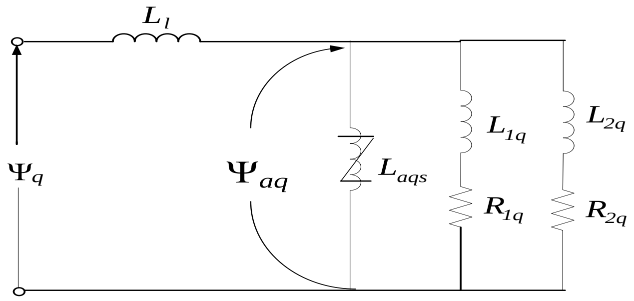


Fig. 11. Synchronous machine equivalent circuits.

Eigen Value and Modal Analysis

The state space model of the power system has been written in its general form in Equations. This representation is used to calculate and analyze the small signal stability of the system. State matrix A gives the eigenvalue λ_i, which is a very significant vector for determining the stability of system. The eigenvalues of state matrix are given by the values of the scalar parameter λ, for which there exist non-trivial solution to equation: The eigenvalues are obtained from the characteristic equation of state matrix A as follow:

There are n numbers of eigenvalues for state matrix of size $(n \times n)$, or in other words, the number of state vectors are equal to the number of eigenvalues. The general form of eigenvalues can be written as follow:

The real component of eigenvalue, i.e. σ, given the damping and the imaginary component gives the frequency of oscillation. Negative real part of the eigenvalue represents that the mode with corresponding eigenvalue is placed at left side of imaginary axis in the complex plane, which represents the damped oscillations whereas positive real part of eigenvalue represents the mode at left side of imaginary axis in the complex plane that indicates negative damping which may lead to oscillations of increasing amplituade. Therefore, eigenvalues are the significant factor for analyzing the stability of the system. The frequency of oscillations in Hz is given by;

The dynamics of any linear system can be viewed as a collection of modes. A mode is characterized by its damping ratio and frequency of oscillation. If the damping to a critical mode is poor, like in a case of electromechanical modes or swing modes of power system, they can be considered as resonances. Many engineering areas are considered as complex coupled system which can be decoupled for simplicity of computation. The coordinates of the modes may be changed by diagonalization. In order to implement this concept, the state matrix A can be diagonalized by the square right modal matrix $\emptyset$ as follow: The left and right modal matrices are normalized for the sake of convenience, so we get;

Eigen-property Based Coherent Machine Identification:

The practical significance of eigenvectors is that it can be used to distinguish the type of oscillation with reference to generator's rotor oscillation. It can be either of relative motion type or centre of inertia type motion for a selected critical mode corresponds to a eigenvalue. The imaginary sign of the eigenvector can determine the type of oscillation among several generators' rotor position. It is also significantly used for the coherent area identification which can graphically represent using compass plot. In order to eliminate the cross-coupling between the state variables, a new state vector z needs to be considered, related to the original state vector Δx as follow:

Therefore, ODE system represented in Equations 3.38 and 3.39 can be transformed into new model coordinate With these equations, the dynamics of the system are represented by the un-coupled first order differential equation. The response of a particular state variable Δx_k, may be examined in the ith mode in the right eigenvector $\emptyset$. This response is called mode shape of particular oscillatory mode. Participation factor analysis is also used to provide the information about the association between the state variable and the oscillatory modes [19].

IV. Results and Discussion

Achieving adequate acceptable damping for this mode.

Area Identification Using Compass Plot

In addition to the critical mode identification, modal analysis was also performed for coherent machine identification where the one group of generators forms one area and oscillating with another group of generators. Compass plot shows the coherent areas in the studied system as shown in figure. 4.2.

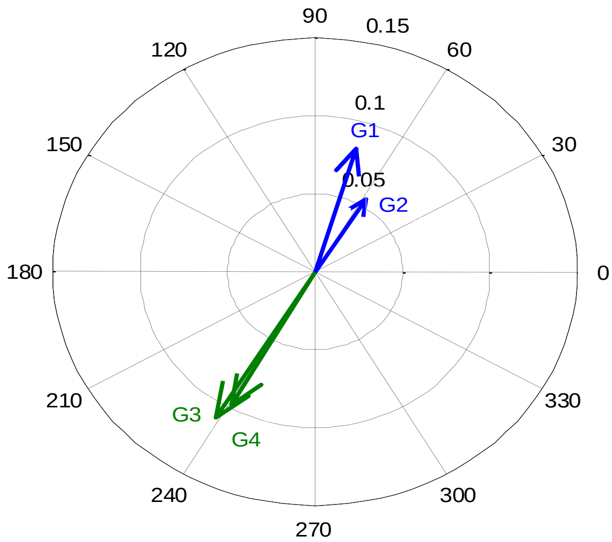


Fig. 12. Compass Plot for Two Area Four Machine System.

There are four arrows representing the four generators. The length and direction of each arrow is corresponding to the magnitude and phase angle of respective eigenvector for the critical mode of machine. In the compass plot, it is clear that generator 1 and generator 2 forms area 1, and generator 3 and generator 4 forms another area so that the studied system termed as two area system when area 1 is oscillating with respect to area 2. The small signal stability analysis is performed under no fault condition and by applying small disturbance of 0.05 to the voltage reference of exciter in generator 1 of area 1.

Closed Loop Verification and Non-Linear Time Domain Simulation

The performance of the proposed power system stabilizer is first verified by small signal analysis. A small disturbance (1 + 0.05) to the voltage reference input of exciter of generator 1 is applied. Time response analysis of the proposed close loop control system is performed for the verification of the expected outcomes.

Fig. 4.9 shows the response of field voltage of generator voltage with respect to time under small signal performance assessment of the test systems.

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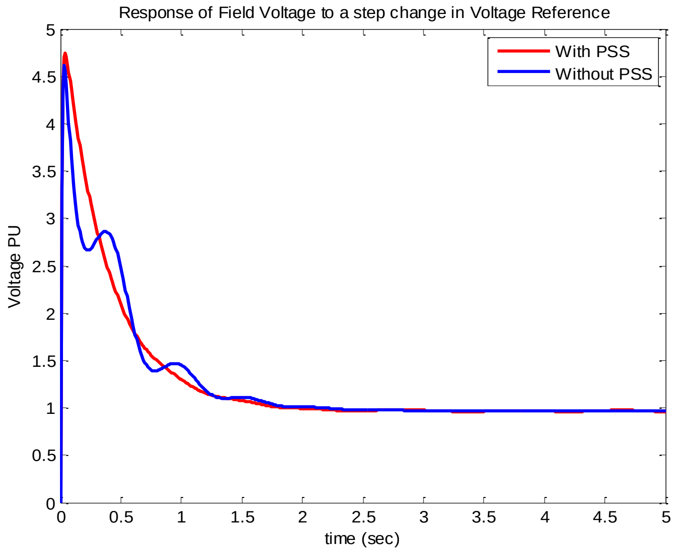
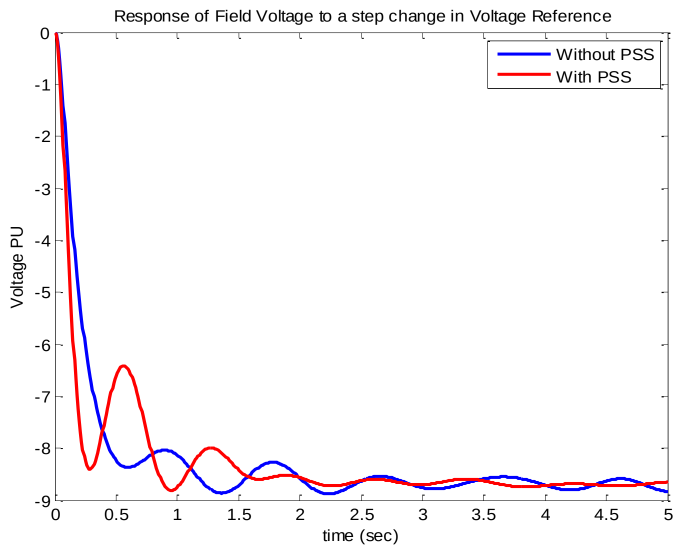
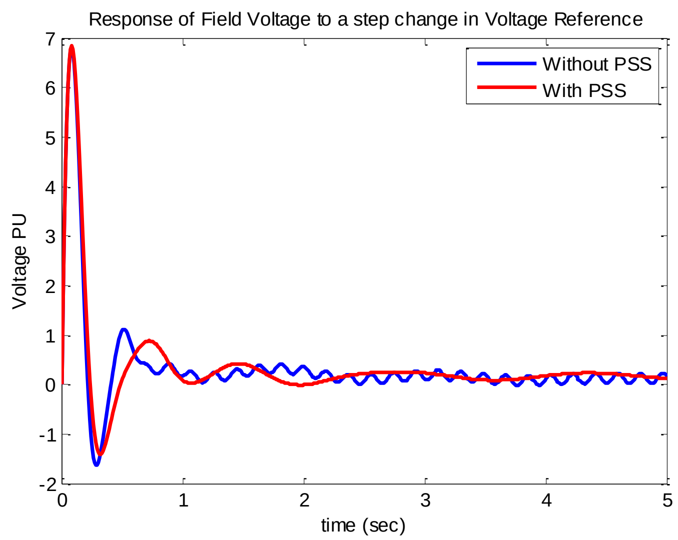


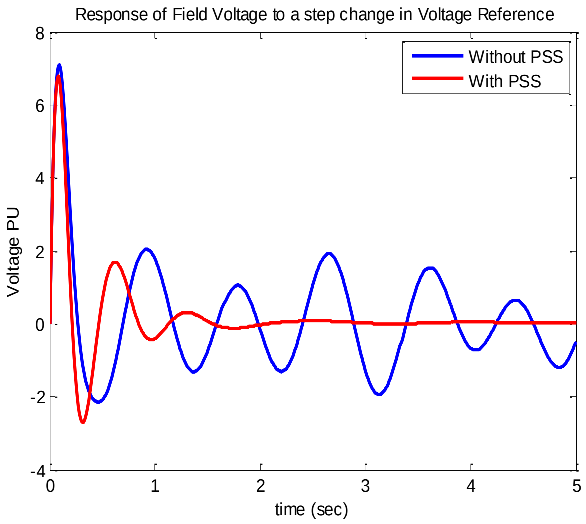
NPCC 16 machine 68 bus system.



IEEE 50 machine system.



NPCC 48 machine 140 bus test system.



Kundur's two area four Machine System.

Fig. 12. Response of field voltage of generator voltage with respect to time under small signal performance for test systems.

V. Conclusion

By analyzing the above obtained simulation results of the proposed PSS, it is hence concluded that the proposed controller really proves its effectiveness in damping the critical low frequency inter-area oscillations and provides a much better performance as compared to the conventional controller without PSS. A eigen-properties based coherency identification approach in interconnected multi machine power system is proposed. The main advantage of the proposed coherency analysis is that it obtains the coherency analysis directly without the knowledge of solutions as consequence the technique is suitable for real time application. The methodology was tested in four different test systems.

Appendix

Table I. Simulation output performance parameters.

Three phase supply voltage = 415V, 50Hz.
Supply Impedance: Rs = 0.01Ω,
Ls = 1mH Unbalanced/ Balanced Linear and non-linear loads: Three single phase diode bridge rectifier R = 25Ω and L = 8mH C=100 µF
DC bus Capacitor Cdc = 4500 µF DC bus PI Controller: Kp = 0.9, Ki = 0.08
AC bus PI controller : Kp = 0.5, Ki = 0.9
Low pass filter : 20Khz pf :0.707

References

[1] Real-Time Applications of Synchrophasors for Improving Reliability, North American Electric Reliability Corporation, Oct. 2010.
[2] Wu, H., "The Impact of time delay on robust control design in power systems," in Proc. of IEEE PES Winter Meeting, 2002, vol. 2, pp. 27-31.
[3] Mitra, P., "Performance of a fuzzy power system stabilizer with Tie-line active power deviation Feedback", IEEE, 2006, pp. 884-889.
[4] Wu, H.X.; Tsakalis, K.S.; and Heydt, G.T., "Evaluation of time delay effects to wide-area power system stabilizer design," IEEE Trans. Power Syst., vol. 19, no. 4, Nov. 2004, pp. 1935–1941.
[5] Naduvathuparambil, B.; Valenti, M. C.; and Feliachi, A.; "Communication delays in wide area measurement systems," in Proc. 34th Southeastern Symp. System Theory, Mar. 2002, pp. 118–122.

[6] Zhang, Y. and Bose, A., "Design of wide-area damping controllers for inter area oscillations", IEEE Trans. Power Syst., Vol. 23, no. 3, Aug. 2008, pp.1136–1143.
[7] You, H., Vittal, V., Wang, X.: 'Slow coherency-based islanding', IEEE Trans. Power Syst., 2004, 19, (1), pp. 483– 491.
[8] Pires de Souza, E.J.S., Leite da Silva, A.M.: 'An efficient methodology for coherency-based dynamic equivalents [power system analysis], IEE Proc. C, Gener. Transm. Distrib., 1992, 139, (5), pp. 371–382
[9] Hiyama, T.: 'Identification of coherent generators using frequency response', IEE Proc. C, Gener. Transm. Distrib., 1981, 128, (5), pp. 262–268.
[10] Haque, M.H.: 'Identification of coherent generators for power system dynamic equivalents using unstable equilibrium point',IEE Proc. C, Gener. Transm. Distrib., 1991, 138, (6), pp. 546 –552.
[11] Wang, X., Vittal, V., Heydt, G.T.: 'Tracing generator coherency indices using the continuation method: a novel approach', IEEE Trans. Power Syst., 2005, 20, (3), pp. 1510–1518.
[12] Senroy, N.: 'Generator coherency using the Hilbert-Huang transform', IEEE Trans. Power Syst., 2008, 23, (4), pp. 1701–1708.
[13] Alsafih, H.A., Dunn, R.: 'Determination of coherent clusters in a multi machine power system based on wide-area signal measurements'. IEEE Power and Energy Society General Meeting, Minneapolis, USA, July 2010, pp. 1 –8.
[14] IEEE Task Force Report, "Load Representation for Dynamic Performance Analysis", Paper 92WM126-3 PWRD, Presented at the IEEE PES Winter Meeting, New York, January 26-30, 1992.
[15] K. Anaparthi, B. Chaudhuri, N. Thornhill, and B. Pal, "Coherency identification in power systems through principal component analysis," IEEE Trans. Power Syst., vol. 20, no. 3, pp. 1658–1660, Aug. 2005.
[16] N. P. Patidar, M. L. Kolhe, N. P. Tripathy, B. Sahu, A. Sharma, L. K. Nagar and A. N. Azmi, "Optimized Design of Wide-Area PSS for Damping of Inter-Area Oscillations", 2015 IEEE 11th International Conference on Power Electronics and Drive Systems IEEE PEDS 2015, Session PQHS-III, pp-88, Sydney, Australia, June 12, 2015.
[17] Padhy B.; Srivastava S. C; Verma N. K.; - 'A Coherency Based Approach for Signal Selection for Wide Area Stabilizing Control in Power Systems', IEEE Sys. J., vol. 7, no.4, Dec 2013, pp. 807-816
[18] KundurPrabha, 'Power System Stability and Control', TATA McGRAW-HILLEdition,1994.
[19] Perez-Arriaga, I. J., Verghese G. C. and Schweppe F. C., "Selective modal analysis with applications to electric power systems, Part I: Heuristic Introduction," IEEE T-PAS, Vol. 101, No. 9, pp 3117-3125, 1982.
[20] Tarokh, M., "Measures for Controllability, Observability and Fixed Modes, IEEE Transaction on Automatic Control, pp. 1286-1273, August, 1992,

AUTHOR'S PROFILE

First Author
Nisha piple, Reserch scholar in Department of Electrical and Electronics Engineering, Technocrats institute of Technology; Bhopal Madhya Pradesh, India. He has received his B.E. (Electrical and Electronics) from Oriental Institute of Science Technology, Bhopal, Presently pursuing M.tech (power system) from Technocrats Institute of Technology, Bhopal, Madhya Pradesh, India.

Second Author
Dr. Malaya Saurava Dash, Prof. (Dr). Malaya Saurava Dash has received his B.E. (Electrical Engineering) from N.I.T. Rourkela and Ph.D. from the same university in 2003 and 2009 respectively. In 2014 he joined as Associate Professor in the Department of Electrical & Electronics Engineering, Technocrate Institute of Technology, Bhopal. His areas of interest are Power Electronics, Power Systems, Solid Dielectrics, Bhopal, Madhya Pradesh, India.