# DAMPING CONTROLLER DESIGN FOR POWER SYSTEM OSCILLATIONS USING GLOBAL SIGNALS

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**Abstract:** This paper describes a new power system stabilizer (PSS) design for damping power system oscillations focusing on interarea modes. The input to the PSS consists of two signals. The first signal is mainly to damp the local mode in the area where PSS is located using the generator rotor speed as an input signal. The second is an additional global signal for damping interarea modes. Two global signals are suggested; the tie-line active power and speed difference signals. The choice of PSS location, input signals and tuning is based on modal analysis and frequency response information. These two signals can also be used to enhance damping of interarea modes using SVC located in the middle of the transmission circuit connecting the two oscillating groups. The effectiveness and robustness of the new design are tested on a 19-generator system having characteristics and structure similar to the Western North American grid.

**Keywords:** Interarea oscillation, PSS design, stability.

## 1 INTRODUCTION

The stability of electro-mechanical oscillations between interconnected synchronous generators is necessary for secure system operation. The oscillations of one or more generators in an area with repect to the rest of the system are called *local modes*, while those associated with groups of generators in different areas oscillating against each other are called *interarea modes* [1]. Local modes are largely determined and influenced by local area states. Interarea modes are more difficult to study as they require detailed representation of the entire interconnected system and are influenced by global states of larger areas of the power network [2]. This has led to an increased interest in the nature of these modes and in methods of controlling them.

We are motivated to investigate more effective control schemes in order to increase transmission capability for systems limited by oscillatory instability. The most common control measures in use today for this problem employ power system stabilizers (PSSs) with local rotor speed as input. These PSSs are effective in damping local modes, and if carefully tuned [3] may also be effective in damping interarea modes up to a certain transmission loading. The effectiveness in damping interarea modes is limited because interarea modes are not as highly controllable and observable in the generator's local signals as the local modes.

We investigate using *global* signals obtained remote from the controller to damp interarea modes. The global signals studied are (1) difference between two generators speed deviations and (2) tie line active power flow. Although control using signals obtained remotely requires additional communication equipment, it is likely that the cost of such equipment would be offset by the additional operating flexibility gained by the control. In addition, we note that recent advances in the field of phasor measurements may enable use of remote signals transmitted via satellite for control purposes [4].

This paper extends investigation of using global control signals reported in [5,6] via development of two separate control strategies utilizing these signals. The first strategy utilizes a two-level PSS controller where the first level of control is derived from local signals and is designed to effectively deal with the local modes. The second level of control is supplied from a coordinator using selected global states to deal with the poorly damped interearea modes.

The second strategy utilizes a static var compensator (SVC) to enhance damping of interarea modes. Although SVCs are most often applied for the purpose of voltage support, they can also be used to increase damping of oscillations. We have observed that an SVC using local bus voltage inputs does not necessarily contribute significantly to system damping. However, a significant contribution to system damping can be achieved when an SVC is controlled by an appropriately chosen auxiliary signal superimposed over the voltage control loop [7].

## 2 DAMPING OF SYSTEM MODES

To identify the local and interarea modes of N-generator system, it is described by the linear state-space model as

$$\dot{x} = Ax + Bu = Ax + \sum_{j=1}^{N} B_j u_j \tag{1}$$

$$y_j = C_j x \tag{2}$$

where $B_j$ and $C_j$ are the column-vector input matrix and the row-vector output matrix corresponding to the jth machine, respectively. Eigenanalysis of the system A-matrix will produce system eigenvalues $\lambda_i$ and their corresponding right and left eigenvectors $t_i$, $v_i$, respectively. Some of the modes are defined as local modes and others as interarea modes. This is according to the frequency range and system states by which the modes are affected. For damping enhancement of the poorly damped modes, it is common to use PSS with local rotor-speed input signal at different machines. The location of these PSSs is determined by using participation factors (PF) or transfer function residues [8].

### 2.1 Location of PSS Using PF

PF indicates how much a certain state participates in a certain mode. The participation of state $s$ in the ith mode is given by [6]:

$$PF_{is} = t_{is} v_{is} \tag{3}$$

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Therefore, the machines with highest PF in the mode of interest are good candidates for applying control via PSS.

## 2.2 Location of PSS Using Residues

The open-loop transfer function for a certain input/output of the jth generator of the system is

$$G_j = \frac{y_j}{u_j} \tag{4}$$

It can also be expressed in terms of the modes and residues as

$$G_j = \sum_{i=1}^{n} \frac{R_{ij}}{(s-\lambda_i)} \tag{5}$$

where $R_{ij}$ is the residue associated with ith mode and the jth transfer function $G_j$. It is given by

$$R_{ij} = \lim_{s \to \lambda_i} (s - \lambda_i) G_j(s) \tag{6}$$

The residue is also given by [6]:

$$R_{ij} = C_j t_i v_j B_j \tag{7}$$

Additionally, the residue can be expressed in terms of mode controllability and observability.

Mode Controllability. The controllability of mode i from the j-th generator is given by

$$cont_{ij} = |v_i B_j| \tag{8}$$

Mode Observability. The measure of mode observability of a certain mode i from machine j can be defined as

$$obsv_{ij} = |C_j t_i| \tag{9}$$

From Equations (7), (8) and (9), it is clear that

$$|R_{ij}| = |C_j t_i v_i B_j| = cont_{ij} * obsv_{ij}, \tag{10}$$

The residue associated with an eigenvalue $\lambda_i$ and a feedback transfer function $f_j(s,K_j)$, where $K_j$ is the constant gain of the controller, are related by [8]

$$\frac{\partial \lambda_i}{\partial K_j} = R_{ij} \frac{\partial f_j(s,K_j)}{\partial K_j} \tag{11}$$

Figure 1 shows a PSS at the jth generator having a transfer function $H_{PSSj}(s)$ given by:

$$H_{PSSj}(s) = K_{PSSj} H_j(s) \tag{12}$$

Then, replacing $f_j(s,K_j)$ in Equation (11) by $H_{PSSj}(s)$, and for small values of gain, it gives

$$\frac{\Delta \lambda_i}{\Delta K_{PSSj}} = R_{ij} H_j(\lambda_i) \tag{13}$$

Adding the feedback to the system will cause a change in the i-th eigenvalue. Using Equations (12) & (13), this change is given by

$$\Delta \lambda_i = R_{ij} H_{PSSj}(\lambda_i) \tag{14}$$

Therefore, the PSS is located at the machine j having the largest residue for the i-th mode $R_{ij}$, giving the largest change of $\lambda_i$.

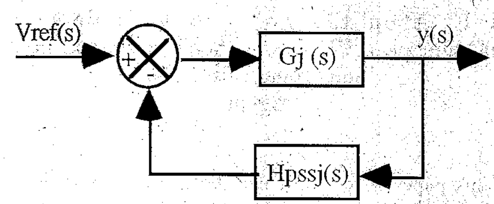


Figure 1 The jth Generator with PSS

It has been observed that even with several PSSs located at selected generators, some modes are still poorly-damped, i.e. conventional PSSs are not capable of damping all system modes under stressed operating conditions. Additional damping is required particularly for the interarea modes. Therefore, a new approach focusing on the selection of controlled generators and control signals with a goal of designing an efficient controller capable of damping all modes of oscillations is presented in the next section.

## 3 CONTROLLER DESIGN APPROACH

Equation (14) indicates that a controller at generator j is most effective in damping mode i if an input is chosen so that $R_{ij}$ is maximum; therefore the signal with highest observability is chosen as input to the controller. The change of eigenvalue must be directed towards the left half complex plane (LHP). This can be done by shaping the phase of $H_{PSSj}(s)$ using phase lead compensation. The amount of phase lead required $\Phi_{ij}$, shown in Figure 2, is given by [9] :

$$\phi_{ij} = 180^o - arg(R_{ij}) \tag{15}$$

If $H_j(s)$ is a static gain, i.e. $H_{PSSj}(s) = K_{PSSj}$, then

$$\Delta \lambda_i = \Delta \sigma_i + j \Delta \omega_i = K_{PSSj}\{Re(R_{ij}) + jIm(R_{ij})\} \tag{16}$$

Equation (16) shows that the change of damping and frequency of the i-th mode, due to the static feedback gain, is proportional to the real and imaginary parts of the residue, respectively.

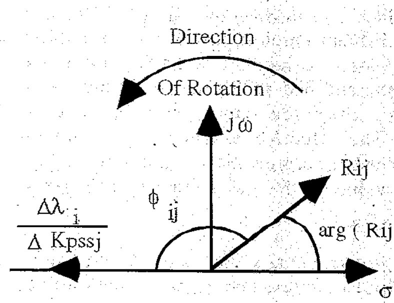


Figure 2 Effect of Residue Compensation at the jth Generator on the ith Mode

For local modes, the largest residue is always associated with the generator's local rotor speed state; hence, it is commonly used as an input signal to PSS. For interarea modes, the state with the highest observability may not be in the same area as the generator with the highest controllability. The state with the highest observability could be a system-wide state combining information from different areas rather than being a single state of one generator. Therefore, it will be called *global signal,* and it may be remotely transmitted. This signal will be used as input to a two-level PSS controller, described in Section 4, and also to an SVC controller, described in Section 5.

## 4 PROPOSED TWO-LEVEL PSS DESIGN

The new PSS design aims to enhance the damping of poorly damped local and interarea modes. This design provides a control signal which is a sum of two component control signals.

The first control signal $u^l$ is to provide damping for local modes using the local generator rotor speed signal as a PSS input. The angle of compensation is computed at the local mode frequency, and the controller time constants are chosen accordingly. Thus, the local mode will be very highly damped. This part of the controller is called **PSS1** and can be considered as a first-level controller in a two-level control scheme as shown in Figure 3. Each generator is considered as a subsystem. The interaction between subsystems, represented in the interarea modes, is neglected in this stage.

The second control signal $u^g$ is to provide damping for the interarea modes, controlled from the selected machines using a global input signal . The angle of compensation is computed at the interarea mode frequency, with PSS1 in service, and the controller time constants are chosen to give this angle. This part of the controller is called **PSS2**. It is the second-level controller or the coordinator as shown in Figure 3. The job of this controller is to obtain the measurements characterizing the global signals and send a control signal in terms of these measurements to the selected machines for controlling the interarea modes. Therefore the total control signal for the jth machine is

$$u_j = u_j^l + u_j^g \qquad (17)$$

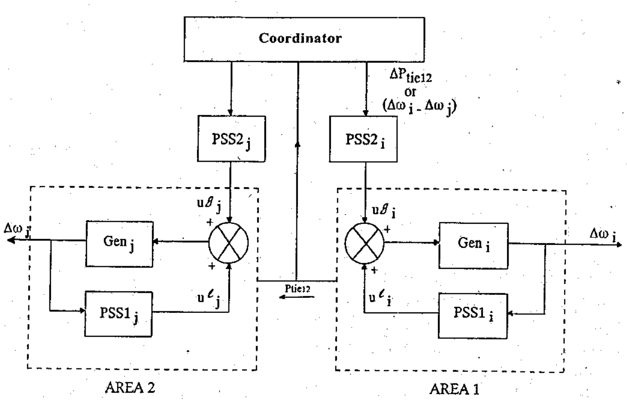


Figure 3: Proposed Two-Level PSS Design

### 4.1 Design of First-Level Controller, PSS1

Since PSS1 is intended for damping local modes of the controlled machines, a PSS1 is located at each machine with a poorly damped local mode. In this work, the amount of phase-lead required to shift the mode to the LHP is computed from Equation (15) which is based on full system representation. The parameters of the lead/lag network are calculated from:

$$H_{PSS1j}(s) = K_1 \frac{sT}{1+sT}\left[\frac{1+sT1_j}{1+sT2_j}\right]^m$$

where,

$$T2_j = \frac{1}{\omega l_j \sqrt{a_j}}, \quad T1_j = a_j\, T2_j$$

$$\alpha_j = \frac{T1_j}{T2_j} = \frac{1 - sin(\frac{\phi_{ij}}{m})}{1 + sin(\frac{\phi_{ij}}{m})}$$

and m is the number of compensating blocks, $T$ is a washout time constant (usually 5-10 sec.), and $\omega l_j$ is the frequency of the local mode in rad/sec. The gain $K_1$ is taken as one-third the instability gain $K_{inst}$ , i.e. $K_1 = K_{inst}/3$.

### 4.2 PSS2 Design Using Tie-Line Power Signal

Interarea modes typically have high observability in the active power of tie-lines between areas involved in these interarea oscillations. Therefore, the tie-line active power can be used as a stabilizing signal for damping the interarea modes associated with this tie-line. The selection of the controlled machine j and the tie-line signal x is such that the transfer function $Ptie_x/Vref_j$ has the largest residue magnitude for the interarea mode of interest. From Equation (6), this is given by:

$$\max_x \left\{ \lim_{s \to \lambda_i} (s - \lambda_i) \frac{P_{tie_x}}{V_{ref_j}} \right\} \qquad (18)$$

where j is the jth machine, and x is the tie-line number.

The modal analysis is performed with all PSS1s included, and the residues associated with the lightly damped interarea modes and several tie-lines are computed at the machines with the highest controllability. These tie-lines are the heavily loaded ties connecting the areas the generators of which are swinging against each other. The PSS2j transfer function is given by:

$$H_{PSS2j}(s) = K_2 \frac{sT}{1+sT} \frac{1+\tau 1 s}{1+\tau 2 s} \qquad (19)$$

where $T$ is the washout time constant, and $\tau 1$ , $\tau 2$ are the compensating network time constants. The time constants are found using the same method described in Section 4.1. To study the effect of this controller on system modes using EPRI Small Signal Stability Program (SSSP), a user defined block for simulation of this controller is built [10]. The gain K2 is chosen to provide sufficient damping to the interarea mode of concern.

From Equation (17) the total control signal (as shown in Figure 4) is given by:

$$V s_j = H_{PSS1j} * \Delta\omega j + H_{PSS2j} * \Delta Ptie_x \qquad (20)$$

### 4.3 PSS2 Design Using Speed Difference Signal

The residue $R_{ij}$, corresponding to the speed deviation signal of generator j to control mode i, may not be large enough to achieve satisfactory damping. To increase the residue magnitude either the observability or the controllability of these modes at particular machines must be increased, according to Equation

(10). Controllability can be increased by increasing the exciter forward gain, but this is not always good practice, as it can reduce the stability margin for the local mode.

We have observed that the right eigenvector elements corresponding to the speed, and hence the observability vectors of two machines j and k in generator groups oscillating against each other (in an interarea mode), are always about 180 degrees apart. This suggests that the observability of this mode from these two machines speed difference signal will be larger in magnitude than each of the individual observabilities. If interarea mode i is controlled from machine j using speed difference signal of machines j and k then:

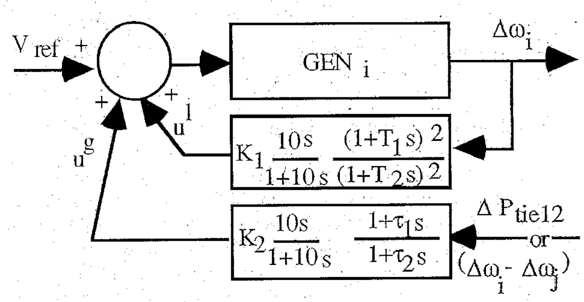


Figure 4 New PSS Design

$$\Delta\omega_{jk} = \Delta\omega_j - \Delta\omega_k \quad (21)$$

The observability index for this signal is given by

$$obsv(\Delta\omega_{jk}) = C_j v_i - C_k v_i = (C_j - C_k)v_i \quad (22)$$

and the total control signal becomes

$$V s_j = H_{PSS1j} * \Delta\omega j + H_{PSS2j} * \Delta\omega_{jk} \quad (23)$$

## 5 APPLICATION TO STATIC VAR COMPENSATOR (SVC)

The damping obtained depends on SVC location in the system and its control signal. It has been found that the mid-point of the transmission circuit, connecting the two oscillating groups of machines in the interarea mode, is the best SVC location for damping enhancement [2]. An SVC can alter the P-δ curve by changing its output $B_{SVC}$ (SVC suceptance) in such a way that damping is increased. For example, for a one machine infinite bus system, if the speed deviation of the machine is fed back as an auxiliary signal to the SVC input, then $B_{SVC}$ and subsequently the P-δ curve, will be altered such that the speed deviation is decreased, and therefore, damping can be increased. This control strategy has been called "Δω-Control" [11]. We use either tie-line active power signal or speed difference signal as input to the SVC for damping interarea modes.

### 5.1 Tie-Line Power Signal to SVC

The SVC is assumed to be located in the middle of a tie-line connecting two areas oscillating against each other in a lightly damped interarea mode. This interarea mode will be highly observable in such a tie line. Therefore, the tie-line power of this line is used as a stabilizing signal. A controller is designed in order to compensate the phase lag of the system at the frequency of interarea mode of interest. This SVC stabilizing controller is given by:

$$H_{SVC}(s) = K_{SVC} \frac{sT}{1+sT} \frac{1+\tau_{1S}s}{1+\tau_{2S}s} \quad (24)$$

where $\tau_{1S}$ , $\tau_{2S}$ are the time constants of the lead/lag compensation block of the SVC stabilizing controller, and T is the washout time constant.

The transfer function between $Ptie_x$ and Vref for the SVC, $\frac{\Delta Ptie_x}{Vref}$, and its residues for the modes of interest are calculated. The time constants of the compensation network is designed to shift the residue vector to the negative axis. The phase lead required is calculated from Equation (15). The gain Ksvc is calculated using the integrated system so that the overall system stability is maintained with a considerable stability margin. The SVC stabilizing signal is thus:

$$V_s = H_{SVC}\ \Delta Ptie_x \quad (25)$$

### 5.2 Speed Difference Signal To SVC

Speed difference signal is the vectorial difference between the speeds of the two machines whose right-eigenvector elements are the largest and are almost out of phase with each other. In this case, the speed difference signal will have an observability index for the interarea mode increased to about double of each of the individual speeds. Therefore, modulation of Bsvc when using this signal will be larger than just using one machine's speed signal, and hence damping will be significantly increased.

If the interarea mode i is controlled by the SVC using speed difference signal between machines j and k, the SVC stabilizing signal is given by:

$$V_s = H_{SVC}\ \Delta\omega_{jk} \quad (26)$$

Similarly, the transfer function $\frac{\Delta\omega_{jk}}{Vref}$ is found, and its residue for the mode of interest is computed. The amount of phase compensation is then computed from Equation (15), and the parameters of the $H_{SVC}$ are found so as to give the required phase compensation using the procedure explained in Section 4.1.

## 6 EXPANSION OF SECURE OPERATING REGION

In some North American power systems, the power flow in a tie-line may be constrained by the stability of the interarea mode associated with this flow. Therefore, it is expected that the capacity of the major tie-lines will significantly increase when damping of the interarea mode is improved, which is the case when PSS1+PSS2 are in service rather than with PSS1 only. To check that, the flows of the key tie-lines associated with the interarea modes are increased until the stability limit is reached, i.e., until a mode is critically stable or just becomes unstable. This value will be called "critical flow". Several critical flows are obtained and plotted, forming a region inside of which all operating points are stable, and on its boundaries lie all the critical points. This region can be called "secure operating region". The effectiveness of PSS2s is evaluated by how much the area of the secure region is increased due to PSS2s. This can also be considered as a measure for robustness, since the secure region determines the area of all stable operating points for the designed controller. This will be numerically shown for the test system in Section 9.

## 7 ROBUSTNESS OF THE DESIGNED CONTROLLERS

A robust controller is expected to perform satisfactorily at various operating conditions. However, since the proposed controller has been designed using linear analysis of the power system, it is important to check that it performs satisfactorily when disturbances occur. The robustness of the controller is evaluated in two different ways. The first is to evaluate the system performance and damping ratio of critical modes of the system under a heavily stressed operating condition compared to the original operating condition. The second way is to evaluate the system response to various disturbances using time domain simulation of the nonlinear power system model.

## 8 CASE STUDY

The single line diagram of the test system is shown in Figure 5. This system has characteristics and structure similar to the North American Western grid (WSCC) [12]. It consists of 46 buses and 19 machines in 7 areas. Each area contains two or three machines, one of which is represented by the classical model while the other one or two are represented by a detailed model (two-axis model with IEEE Type AC4 exciter, no governor, and a damping coefficient of 1.0pu).

Eigenanalysis, using the Small Signal Stability Program (SSSP), of the open-loop system with no PSSs included indicates there are 13 local and 5 interarea modes, all of which are poorly damped (Table 1). It is seen that all machines are participating in local modes. Therefore, a PSS1 is located at each of the 11 detailed machines. It is noted that modes 12 & 13 belong to two equivalent machines and are not of concern. The control parameters of PSS1s are computed and given in Table 2. With PSS1s included (the conventional case) the 5 interarea modes are still lightly damped. By adding PSS2s (proposed

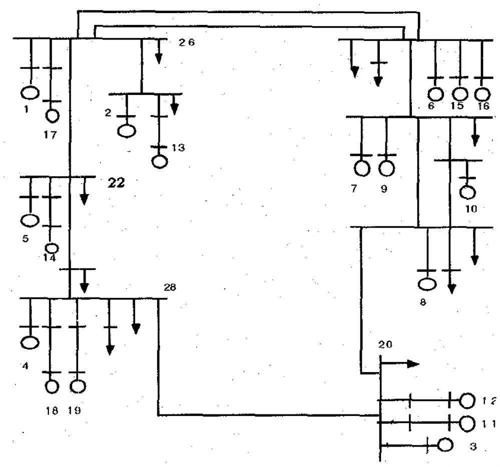


Figure 5: The Test System

control) to the selected machines having the largest residues, the damping is enhanced for all modes as shown in Table 1, when using either the tie-line active power or the speed difference signals as input signals. The control parameters of PSS2s are given in Table 3. The controllers' performance and robustness are tested by using the Extended Transient and Mid-term Stability Program (ETMSP). From Figure 6, it is clear that system damping is significantly improved.

To check controller robustness and their ability to stabilize the system, the system with all PSS1s included has been stressed until it is unstable by increasing the transfer in the major lines and changing the load model to constant power. Figure 7 shows the time simulation of this unstable point compared to the case when PSS2s are applied, using speed difference signal. It is clear that the addition of the PSS2s has stabilized the system under this unstable operating condition. Figure 8 illustrates the expansion of the secure operating region for the two major flows of the system due to the addition of PSS2.

Table 1: The Low Frequency Modes Of Oscillation With And Without Controllers

| MODE | NO PSS | | PSS1 | | PSS1 + PSS2 TIE-LINE | | PSS1 + PSS2 SPEED DIFF. | | PSS1+SVC1 Mid tie 28-20 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FREQ. | DAMP. | FREQ. | DAMP. | FREQ. | DAMP. | FREQ. | DAMP. | FREQ. | DAMP. |
| 1 | 1.1609 | -0.0148 | 1.1181 | 0.1832 | 1.0671 | 0.1792 | 1.1309 | 0.1640 | 1.1182 | 0.1832 |
| 2 | 1.8825 | -0.0018 | 1.7803 | 0.1538 | 2.0919 | 0.2186 | 2.0866 | 0.3138 | 1.7802 | 0.1537 |
| 3 | 1.7206 | 0.0519 | 1.4667 | 0.2988 | 1.4822 | 0.2132 | 1.4800 | 0.2031 | 1.5881 | 0.2726 |
| 4 | 2.0112 | 0.0539 | 1.3488 | 0.4822 | 1.5581 | 0.5150 | 1.3675 | 0.422 | 1.4571 | 0.1111 |
| 5 | 1.4562 | 0.0116 | 1.4123 | 0.1463 | 1.4231 | 0.1468 | 1.2728 | 0.2829 | 1.4122 | 0.1463 |
| 6 | 1.4397 | 0.0310 | 1.3280 | 0.2041 | 1.3593 | 0.1320 | 1.3275 | 0.2024 | 1.3249 | 0.2045 |
| 7 | 1.5141 | 0.0103 | 1.5923 | 0.0923 | 1.4540 | 0.2145 | 1.5906 | 0.0917 | 1.5922 | 0.0924 |
| 8 | 1.8566 | 0.0095 | 1.9869 | 0.0757 | 1.6918 | 0.2543 | 1.9867 | 0.0767 | 1.9868 | 0.0757 |
| 9 | 1.4917 | 0.0150 | 1.4198 | 0.1618 | 1.4194 | 0.1434 | 1.6979 | 0.3120 | 1.4188 | 0.1621 |
| 10 | 1.3650 | 0.0239 | 1.5093 | 0.1368 | 1.1911 | 0.1832 | 1.1711 | 0.1923 | 1.5881 | 0.2726 |
| 11 | 1.6178 | 0.0132 | 1.3303 | 0.2202 | 1.3185 | 0.2173 | 1.5093 | 0.1720 | 1.3434 | 0.2271 |
| 12 | 1.9700 | 0.0048 | 1.9605 | 0.0111 | 1.9601 | 0.0089 | 2.3846 | 0.0627 | 2.3850 | 0.0628 |
| 13 | 2.3241 | 0.0052 | 2.3850 | 0.0628 | 2.3465 | 0.0819 | 1.9581 | 0.0129 | 1.9604 | 0.0111 |
| 1 | 0.3496 | 0.0077 | 0.3395 | 0.0951 | 0.2116 | 0.1322 | 0.3250 | 0.1997 | 0.3487 | 0.1253 |
| 2 | 0.6552 | 0.0097 | 0.6477 | 0.0561 | 0.6426 | 0.1386 | 0.6984 | 0.1271 | 0.6473 | 0.1071 |
| 3 | 0.7070 | 0.0165 | 0.6959 | 0.0754 | 0.5081 | 0.2013 | 0.7006 | 0.4162 | 0.7209 | 0.1029 |
| 4 | 0.8185 | 0.0054 | 0.8071 | 0.0688 | 0.8070 | 0.1123 | 0.8795 | 0.2101 | 0.8134 | 0.1155 |
| 5 | 0.9510 | 0.0154 | 0.9545 | 0.0964 | 0.8489 | 0.1762 | 1.0199 | 0.1520 | 0.9562 | 0.1072 |

Table 2: The First-Level Controllers Design (PSS1)

| GEN. # j | Local Mode Controller Parameters (PSS1) | | | |
|---|---|---|---|---|
| | $\phi_{ij}$ | K1 | T1 | T2 |
| 9 | 51 | 5.0 | 0.218 | 0.086 |
| 10 | 51 | 5.0 | 0.135 | 0.053 |
| 11 | 59 | 5.0 | 0.158 | 0.054 |
| 12 | 81 | 5.0 | 0.172 | 0.036 |
| 13 | 74 | 5.0 | 0.219 | 0.055 |
| 14 | 48 | 5.0 | 0.171 | 0.072 |
| 15 | 49 | 5.0 | 0.164 | 0.068 |
| 16 | 41 | 5.0 | 0.124 | 0.060 |
| 17 | 75 | 5.0 | 0.216 | 0.052 |
| 18 | 35 | 5.0 | 0.159 | 0.086 |
| 19 | 39 | 5.0 | 0.139 | 0.070 |

Table 3: The Second-Level Controller Design (PSS2)

| GEN # j | TIE-LINE SIGNAL | | SPEED DIFF. SIGNAL | | | |
|---|---|---|---|---|---|---|
| | TIE | K2 | SPEED DIFF. | K2 | $\tau 1$ | $\tau 2$ |
| 10 | | | 10-15 | 10 | 0.455 | 0.133 |
| 11 | 28-20 | +0.02 | 11-10 | 10 | 0.386 | 0.157 |
| 13 | 25-23 | +0.03 | | | | |
| 17 | | | 17-13 | 10 | 0.400 | 0.151 |
| 18 | | | 18-17 | 10 | 0.476 | 0.082 |

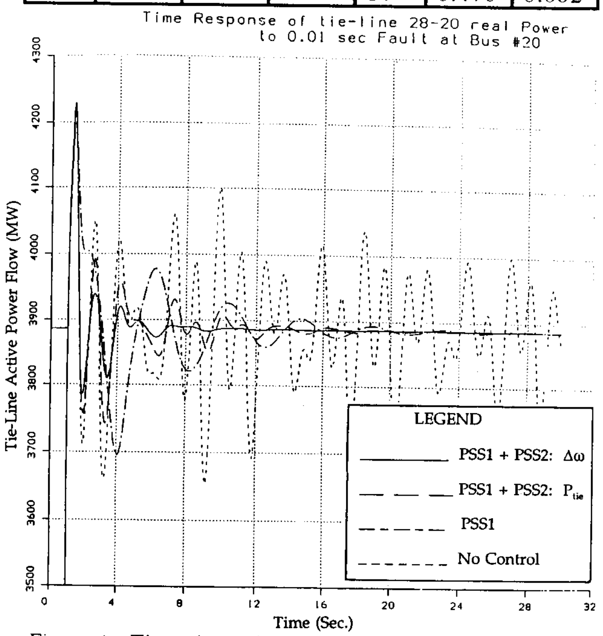


Figure 6: Time simulation comparison for tie-line 28-20 power

Table 4: Residues Of Interarea Modes For SVCs

| MODE | SVC1 | SVC2 |
|---|---|---|
| | Mid-line 28-20 (Ptie 28-20) | At Gen #22 (Ptie 22-26) |
| 1 | +0.02-j16.44 | +0.95+j8.1 |
| 2 | +0.99+j0.00 | -2.33+j5.60 |
| 3 | -2.78+j12.96 | +4.08+j8.88 |
| 4 | -3.51-j20.35 | +0.37-j2.40 |
| 5 | -1.54-j36.00 | -0.42+j78.6 |

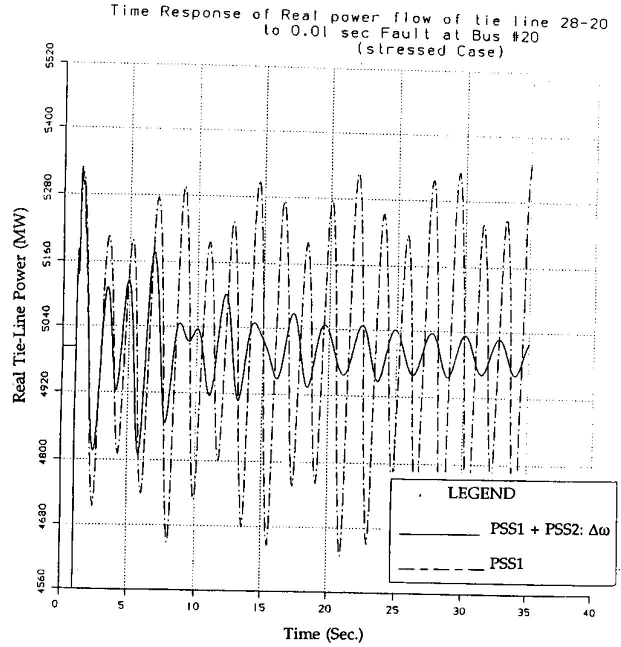


Figure 7: Stabilization effect of PSS2

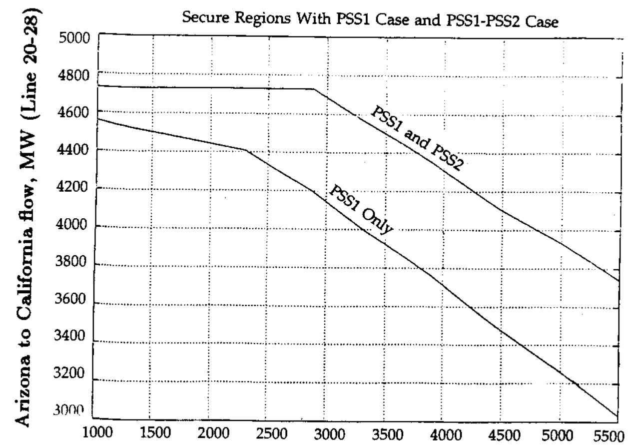


Figure 8: Expanded operating region due to PSS2

In addition, an SVC controller was designed, using tie-line active power signal as input, to enhance damping of interarea modes of the system. This controller was built in SSSP using user defined blocks as this is a non standard controller.

Two potential locations are studied for the SVC :

- Middle of line 28-20 (between Arizona and South California areas) and signal from Ptie 28-20 (SVC1)
- At Bus#22 (North California) and signal from Ptie 22-26 (SVC2)

Table 4 lists the residues for the interarea modes at SVC1 and SVC2. SVC1 is chosen as it has much higher residues for modes #1,3,4,5. The effect of SVC1 on damping of these modes, compared to PSS2 (of both types), is shown in Table 1. Figure 10 shows the block diagram of SVC1 and its stabilizing controller.

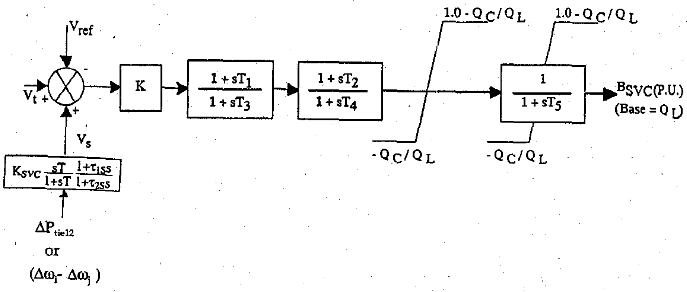


Figure 9: Block diagram of proposed SVC1 controller

## 10 CONCLUSIONS

In this paper, a two-level control scheme for PSS design has been proposed. The first level control is to provide damping for the local modes using the local speed signal as an input to the PSS. The second level is to enhance damping of interarea modes using global signals as additional inputs to the PSS. The proposed global signals are either the tie-line active power or the speed difference signal. With proper choice of these signals an increased residue magnitude for the interarea modes is obtained, and hence these modes are effectively damped. The proposed control scheme has been compared to the conventional techniques using a 19-Generator system. The results show that the proposed controller is more effective and robust. These global signals have also been applied to SVC in order to damp the interarea oscillations, and the damping was significantly increased.

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