International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

December 2013 | Issue 17 | Volume 5 | Number 4 | Pages 42-48

# CHAOTIC-PSO APPROACH FOR COORDINATED DESIGN OF PSS AND SSSC BASED CONTROLLER

**E. Youhanna Eshagh [1] H. Lesani [2] M.R. Haghifam [3]**

*1. Department of Power Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran power66_90@yahoo.com*
*2. Department of Electrical and Computer Engineering, University of Tehran, Tehran, Iran, lesani@ut.ac.ir*
*3. Department of Electrical and Computer Engineering, University of Tarbiat Modarres, Tehran, Iran haghifam@modares.ac.ir*

**Abstract-** In this paper coordination scheme to improve the stability of a power system by optimal design of power system stabilizer and Static Synchronous Series Compensator (SSSC) based controller is presented. The coordinated design problem is formulated as an optimization problem and Chaotic Particle Swarm Optimization (CPSO) is employed to search for the optimal controller parameters. The performance of the proposed controllers is evaluated for both single-machine infinite-bus power system and multi-machine power system. It is observed that the proposed controllers provide efficient damping to power system oscillations under operating conditions and under disturbances. Further, simulation results show that, in a multi-machine power system, the modal oscillations are effectively damped by the proposed approach.

**Keywords:** Particle Swarm Optimization, Chaotic Particle Swarm Optimization, Power System Stability, Power System Stabilizer, Static Synchronous Series Compensator, Multi-Machine Power System.

## I. INTRODUCTION

A broad spectrum of electric machines is widely used in electromechanical systems. In addition to the required when large power systems are interconnected by relatively weak tie lines, low frequency oscillations are observed. These oscillations may sustain and grow to cause system separation if no adequate damping is available [1]. Power System Stabilizers (PSS) are now routinely used in the industry to damp out power system oscillations [2].

However, the use of PSSs only may not be, in some cases, effective in providing sufficient damping particularly with increasing transmission line loading over long distances, and other effective alternatives are needed in addition to PSS. Recent development of power electronics introduces use of Flexible AC Transmission System (FACTS) controllers in power systems. FACTS controllers are capable of controlling network condition in a very fast manner and this feature of FACTS can be exploited to improve the stability of a power system [3].

Static Synchronous Series Compensator (SSSC) is one of the important members of FACTS family, which can be installed in series in the transmission lines. SSSC is very effective in controlling power flow in a transmission line with the capability to change its reactance characteristic from capacitive to inductive [4]. An auxiliary stabilizing signal can also be superimposed on the power flow control function of SSSC to improve power system stability [5]. The application of SSSC for power oscillation damping and stability enhancement can be found in [6, 7].

The interaction among PSSs and SSSC-based controller may enhance or degrade the damping of certain modes of rotor's oscillating modes. To improve overall system performance, many researches were made on the coordination between PSSs and FACTS power oscillation damping controllers [8-10]. When there is a FACTS device present in a system, FACTS device being a transmission system device, is installed at several kilometers away from generator, where as a PSS is installed near the generator.

Hence, potential time delays due to signal transmission and sensors should be included in the design and analysis of FACTS/PSS-based damping controllers. However, the effects of time delays are no reported in above papers. In addition, there have been various publications proposing different techniques for designing PSSs and/or FACTS-based stabilizers for damping improvements. These methods include residue method, eigenvalue-distance minimization approach, and linear matrix inequality technique and multiple mode adaptive control approach. One of the key issues that should be addressed, in these coordinated design techniques, is verification of robustness of the controllers designed.

Effective and efficient techniques are needed for obtaining robust controllers, particularly with respect to changes in power system configurations. In recent years, one of most promising research field has been "Heuristics from Nature" and different nonlinear techniques, an area utilizing analogies with nature or social systems. These techniques are finding popularity within research community as design tools and problem solvers because of their versatility and ability to optimize in complex multi-modal search spaces applied to non-differentiable objective functions.

New artificial intelligence-based approaches have been proposed to design a FACTS-based supplementary damping controller. These approaches include Particle Swarm Optimization [7, 11], Genetic Algorithm [8], Differential Evolution [12], Multi-Objective Evolutionary Algorithm [6, 13], Robust Fuzzy [14, 15], etc. Chaotic Particle Swarm Optimization Algorithm (CPSO), proposed by R. Caponetto [16] is a new comer to the family of nature-inspired optimization algorithms.

In this paper, a comprehensive assessment of the effects of PSS and SSSC-based damping controller when applied coordinately has been carried out. The design problem of the proposed controllers to improve power system stability is transformed into an optimization problem. CPSO based optimal tuning algorithm is used to optimally and simultaneously tune the parameters of the PSS and SSSC-based damping controller. The proposed multiple and multi-type controller design approach has applied and evaluated for both single-machine infinite-bus and a multi-machine power system.

Though, the example power systems studied in this paper are simple two-area examples, by studying these simple systems the basic characteristics of the controllers can be assed and analyzed and conclusions can be drawn to give an insight for larger systems. Further, since all the essential dynamics required for the power system stability studies have been included, and the results have been obtained using local signals, general conclusions can be drawn from the results presented in the paper to implement the proposed approach in a large realistic power system.

## II. PSO TECHNIQUE

PSO is a population based stochastic optimization method and a kind of evolutionary computation technique. It explores for optimal solution from a swarm population of moving particle vectors, based on a fitness function. The method has been found to be robust in solving problems featuring nonlinearity and non-differentiability, multiple optima, and high dimensionality through adaptation, which is derived from the social-psychological theory.

Each particle represents a potential answer and has a position ($X_i^k$) and a velocity ($V_i^k$) in the problem space. Each particle keeps a record of its individual best position ($P_i^k$), which is associated with the best fitness it has achieved so far, at any step in the solution. This value is known as $P_{best}$. Moreover, the optimum position between all the particles obtained at the current step in the swarm is stored as global best position ($P_g^k$). This location is called $G_{best}$. The velocity of particle and its new position will be updated according to the following equations:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{1}$$

$$V_i^{k+1} = wV_i^k + c_1 r_1 \left(P_i^k - X_i^k\right) + c_2 r_2 \left(P_g^k - X_i^k\right) \tag{2}$$

where, $w$ is an inertia weight that controls particles exploration during a search, $c_1$ and $c_2$ are positive numbers explaining the weight of the acceleration terms that guide each particle toward the individual best and the swarm best positions respectively. The $r_1$ and $r_2$ are uniformly distributed random numbers in the range of 0 to 1, and $N$ is the number of particles in the swarm. The inertia weighting function in Equation (2) usually calculated using following equation:

$$w = w_{\max} - \left(w_{\max} - w_{\min}\right) \times \left(\frac{iter}{iter_{\max}}\right) \tag{3}$$

where, $w_{\max}$ and $w_{\min}$ are initial and final weight, respectively, and $iter_{\max}$ and $iter$ are maximum and current iteration number, respectively [17].

## III. CHAOTIC PSO TECHNIQUE

PSO has gained much attention and wide spread applications in different fields. However, the performance of the simple PSO greatly depends on its parameters and it often suffers the problem of being trapped in local optima to prematurely converge. To enrich the searching behavior and to avoid being trapped into local optimum, chaotic dynamics is incorporated into the PSO. In this paper, the well-known logistic equation [17], which exhibits the sensitive dependence on initial conditions, is employed for constructing hybrid PSO. The Logistic equation, which used in this paper is described as:

$$q_k = \mu q_{k-1} \times (1 - q_{k-1}), \qquad k = 1, 2, \ldots q_0 \in (0,1) \tag{4}$$

where, $\mu$ is control parameter (real value between 0-4). Although Equation (4) is deterministic, it exhibits chaotic dynamics when $\mu = 4$ and $q_0 \notin \{0, 0.25, 0.5, 0.75, 1\}$.

That is, it exhibits the sensitive dependence on initial conditions, which is the basic characteristic of chaos. A minute difference in the initial value of the chaotic variable would result in a considerable difference in its long time behavior. To improve the performance of PSO, this paper introduces a new velocity update equation by applying chaotic sequence for weight parameter, $w$ in Equation (2). The new weight parameter is defined by multiplying Equations (3) and (4) in order to improve the global searching capability as follows [16]:

$$w_{new} = w \times q \tag{5}$$

Observe that the proposed new weight decreases and oscillates simultaneously for total iteration, whereas the conventional weight decreases monotonously from $w_{\max}$ to $w_{\min}$. As a result, the updated velocity formula will be assigned according to the following equation:

$$V_i^{k+1} = w_{new} V_i^k + c_1 r_1 \left(P_i^k - X_i^k\right) + c_2 r_2 \left(P_g^k - X_i^k\right) \tag{6}$$

whereas, the conventional weight decreases monotonously from $w_{\max}$ to $w_{\min}$, the proposed new weight decreases and oscillates simultaneously for total iteration as shown in Figure 1.

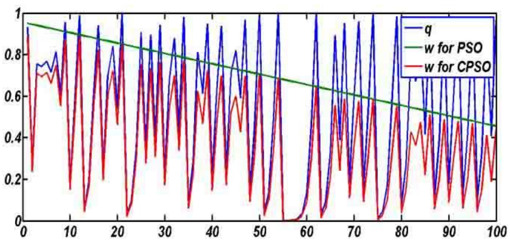



Figure 1. Comparison of inertia weights for all iterations ($iter_{\max}$ =100, $w_{\max}$ = 0.95, $w_{\min}$ = 0.45, $\mu$ = 4, $\theta_0$ = 0.63)

## IV. STRUCTURES OF THE PSS AND SSSC BASED DAMPING CONTROLLER

The structure of SSSC-based damping controller, to modulate the SSSC injected voltage $V_q$, is shown in Figure 2. The input signal of the proposed controller is the speed deviation ($\Delta\omega$), and the output signal is the injected voltage $V_q$. The structure consists of a gain block with gain $K_S$, a signal washout block, and two-stage phase compensation block as shown in Figure 2. The signal washout block serves as a high-pass filter, with the time constant $T_W$, high enough to allow signals associated with oscillations in input signal to pass unchanged. Without it, steady changes in input would modify the output.

From the viewpoint of the washout function, the value of $T_W$ is not critical and may be in range of 1-20 sec. The phase compensation blocks (time constants $T_{1S}$, $T_{2S}$, and $T_{3S}$, $T_{4S}$) provide appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals. In Figure 2, $V_{qref}$ represents the reference injected voltage as desired by the steady state power flow control loop. The desired value of compensation is obtained according to the change in the SSSC injected voltage $\Delta V_q$ which is added to $V_{qref}$.

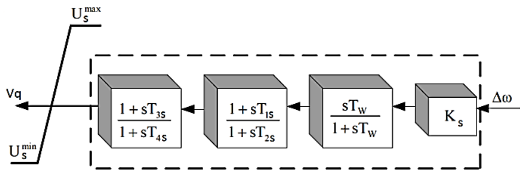



Figure 2. Structure of SSSC-based damping controller [11]

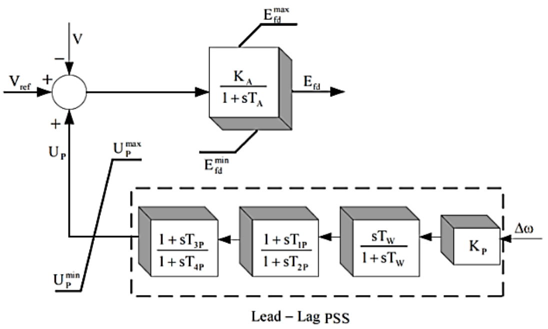



Figure 3. Structure of power system stabilizer [11]

Figure 3 shows the structure of the power system stabilizer used in the present study. It consists of a gain block with gain $K_{PS}$, a signal washout block, and two-stage phase compensation block. The input signal to the PSS is the speed deviation $\Delta\omega$ of generator where the PSS is installed and the output signal is the voltage setting $V_S$, which is added to excitation system reference voltage $V_{ref}$. The proposed controller must be able to work well under all operating conditions, while the improvement for the damping of the critical modes is necessary. Since the selection of SSSC-based damping controller parameters is a complex optimization problem. Thus, to acquire an optimal combination, this paper employs the CPSO algorithm to improve the optimization synthesis and find the global optimum value.

A performance index based on the system dynamics after an impulse disturbance alternately occurs in the system is organized and used as the objective function for the design problem. In this study, an ITAE is taken as the objective function. Since the operating conditions in the power systems are often varied, a performance index for a wide range of operating points is defined as follows [18], for single-machine infinite-bus power system:

$$J=\int_0^{t_{sim}}\left(|\Delta\omega|\right)t\,dt \tag{7}$$

For multi-machine power system:

$$J=\int_0^{t_{sim}}\left(\sum|\Delta\omega_L|+\sum|\Delta\omega_I|\right)t\,dt \tag{8}$$

where, $\Delta w$ is the speed deviation in single-machine infinite-bus system, $\Delta w_L$ and $\Delta w_I$ are the speed deviations of local and inter-area modes of oscillations respectively and $t_{sim}$ is the time range of the simulation.

For objective function calculation, the time-domain simulation of the power system model is carried out for the simulation period. It is aimed to minimize this objective function in order to improve the system response in terms of the settling time and overshoots. The problem constraints are the PSS and SSSC controller parameter bounds. Therefore, the design problem can be formulated as the following optimization problem:

minimize $J$

$$\text{subject to:}\quad\begin{cases}K_i^{\min}\le K_i\le K_i^{\max}\\ T_{1i}^{\min}\le T_{1i}\le T_{1i}^{\max}\\ T_{2i}^{\min}\le T_{2i}\le T_{2i}^{\max}\\ T_{3i}^{\min}\le T_{3i}\le T_{3i}^{\max}\\ T_{4i}^{\min}\le T_{4i}\le T_{4i}^{\max}\end{cases} \tag{9}$$

## V. CASE STUDY

In this paper, two systems are considered for study and are shown in Appendices 1 and 2.

### A. Single Machine Connected to Infinite Busbar

Synchronous machine connected to infinite bus bar shown in Figure 4 is considered for transient stability studies. As shown in Figure 5, for dynamic stability studies, it is linearized and considered [19]. In dynamic stability, studies excitation system and turbine governing system are represented along with the synchronous machine models that provide flux variation in the machine air gap. The solution technique of steady state and dynamic stability problem is to examine stability of system under incremental variation about an equilibrium point.

The equivalent generator parameters in per-unit and exciter constants and $k$ constants under nominal operating point are calculated and presented in Appendix 1. Figure 6 shows the typical convergence characteristics of PSO, CPSO algorithm. From Figure 6, it is quite clear that from among the four techniques the convergence of CPSO is the fastest. Hence, C-PSO optimized parameters are chosen as PSS and SSSC based controller parameters.

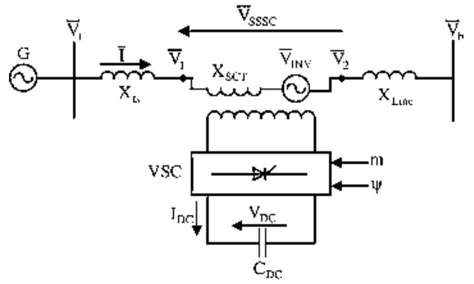



Figure 4. System considered for case study [19]

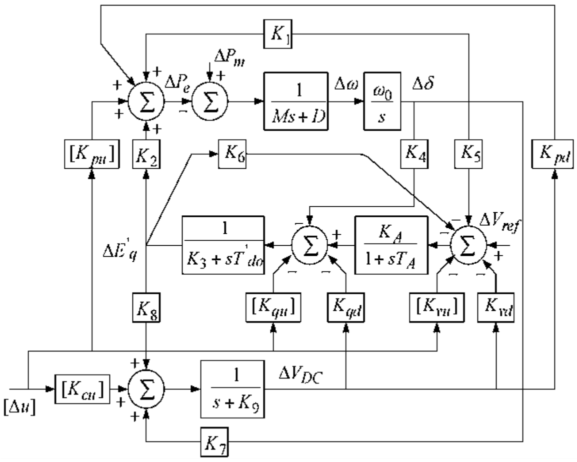


Figure 5. Linearized model of power system [19]

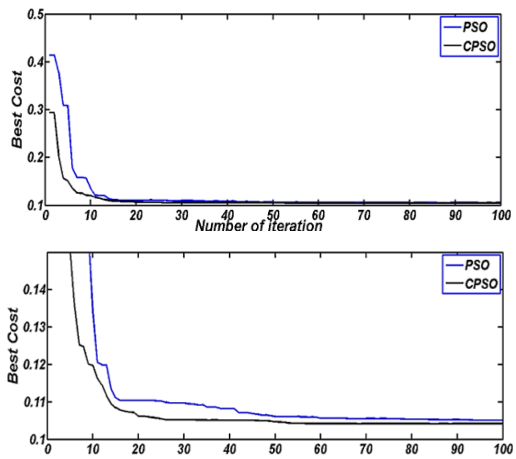



Figure 6. Convergence characteristics of PSO, CPSO algorithm

Table 1. The optimal parameter settings of the proposed controllers

| Controller parameters | Coordinated design | | |
|---|---|---|---|
| | PSS | SSSC | Min-Max Range |
| $K$ | 50 | 50 | 0.01-50 |
| $T_1$ | 1.0000 | 1.0000 | 0.01-1 |
| $T_2$ | 0.0331 | 0.3175 | 0.01-1 |
| $T_3$ | 1.0000 | 0.0100 | 0.01-1 |
| $T_4$ | 0.4173 | 0.3183 | 0.01-1 |

The behavior of the proposed controllers is verified at nominal loading condition ($P_e$ = 0.8 pu, $Q_e$ = 0.144 pu) under a severe disturbance. The system response under this severe disturbance is shown in Figure 7 and Figure 8. The objective function is evaluated by simulating the system dynamic model considering a 5% step increase in mechanical power input ($T_m$) at $t$ = 1.0 sec.

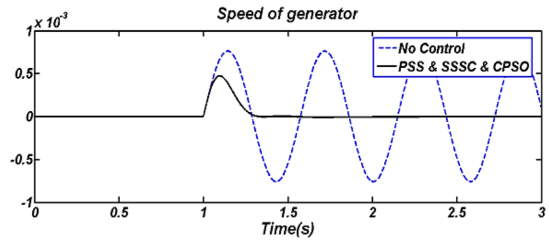



Figure 7. Speed deviation

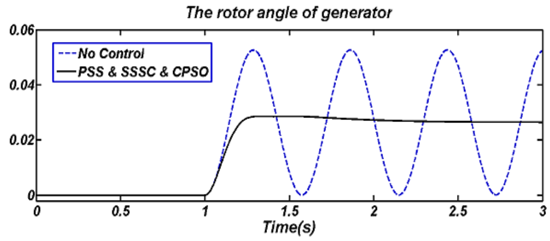



Figure 8. Power angle of the rotor

## B. Multi-Machine System

A four-machine, two-area study system, shown in Figure 9, is considered for the damping control design. Each area consists of two generator units. The rating of each generator is 900 MVA and 20 kV. Each of the units is connected through transformers to 230 kV transmission line. There is a power transfer of 400 MW from Area 1 to Area 2.

Each synchronous generator of the multi-machine power system is simulated using a third-order model and the FACTS device is considered using a current injection model. The detailed bus data, line data, and the dynamic characteristics for the machines, exciters, and loads are given in [1].

The loads are modeled as constant impedances. A first order model of a static type automatic voltage regulator was used, and its block diagram is shown in Figure 3. In Figure 3, $|V_t|$ is the terminal bus voltage magnitude and $V_{ref}$ is the reference voltage for the AVR. Limits of +5.0 pu and -5.0 pu. For the field voltage were used in the simulations. The dynamics of the machines are given in Appendix 2.The parameters of SSSC and system data are provided in Appendix 3.

Table 2. The optimal parameter settings of the proposed controllers

| Controller parameters | Coordinated design | | | |
|---|---|---|---|---|
| | PSS1 | PSS3 | SSSC | Min-Max Range |
| $K$ | 9.8850 | 9.8583 | 37.0843 | 0.01-50 |
| $T_1$ | 0.3847 | 0.8719 | 0.8789 | 0.01-1 |
| $T_2$ | 0.5710 | 0.9043 | 0.1692 | 0.01-1 |
| $T_3$ | 0.9464 | 0.4700 | 0.8262 | 0.01-1 |
| $T_4$ | 0.9217 | 0.7916 | 0.6102 | 0.01-1 |

The effectiveness and robustness of the performance of proposed controller under transient conditions is verified by applying a three-phase fault of 100 ms duration at the middle of one of transmission lines between bus 7 and bus 10. To evaluate performance of the proposed simultaneous design approach response with proposed controllers are compared with the response of the PSS and SSSC damping controller individual design. The inter-area and local mode of oscillations with coordinated and uncoordinated design of controllers is shown in Figure 10, respectively.

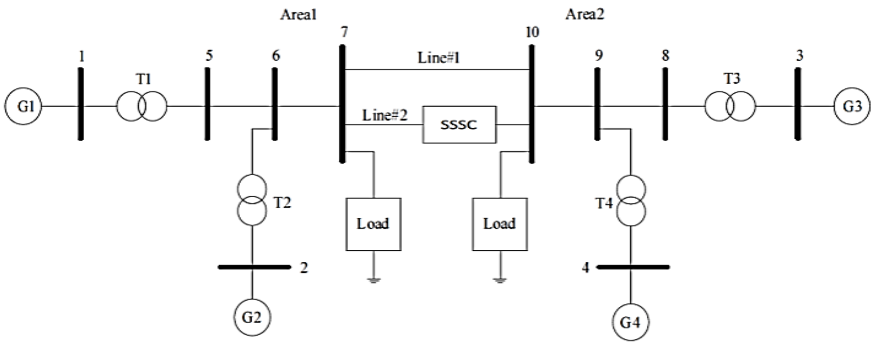
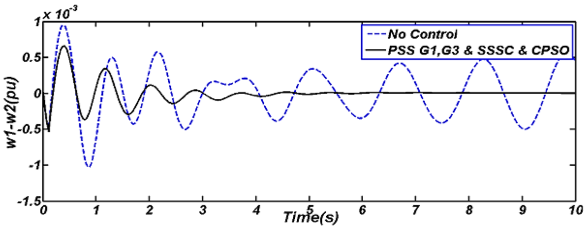
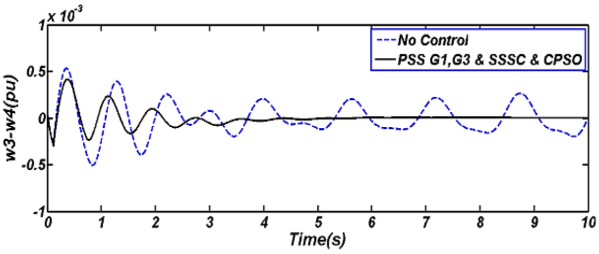


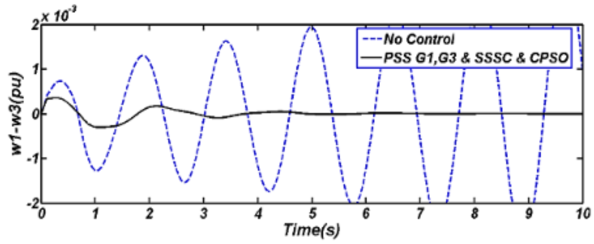

Figure 9. Four-machine two-area power system [1]



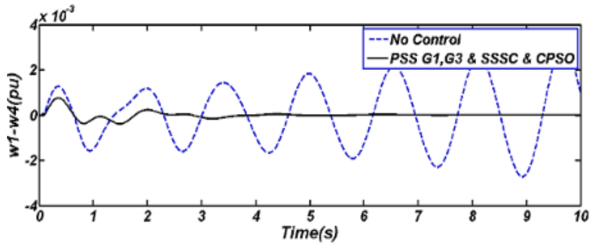

(a)



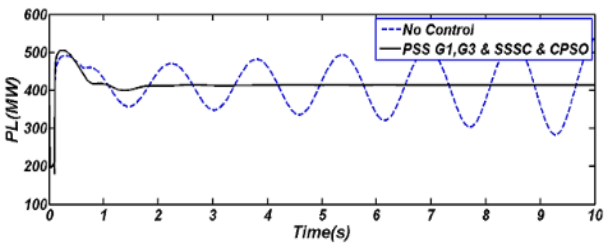

(b)



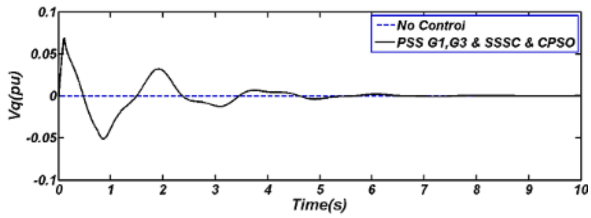

(c)




(d)




(e)




(f)

Figure 10. System response for 3-phase 3-cycle fault disturbance (a), (b) local mode of oscillations; (c), (d) inter-area mode of oscillations; (e) tie-line power flow; (f) SSSC injected voltage

It is clear from the figures that, the simultaneous design of the PSS and SSSC damping controller by the proposed approach significantly improves the stability performance of example power system and low frequency oscillations are well damped out.

## VI. CONCLUSIONS

In this study, power system stability enhancement by the coordinated application of multiple and multi-type damping controllers is thoroughly investigated. For the proposed controllers design problem, a time-domain simulation-based objective function to minimize the power system oscillations is used. Then, Chaotic Particle Swarm Optimization (CPSO) technique is employed to optimally and coordinately tune controller parameters. Simulation results are presented for nominal loading conditions and disturbances to show the effectiveness of the proposed coordinated design approach.

The proposed controllers are found to be robust to fault location and change in operating conditions and generate appropriate stabilizing output control signals to improve stability. Finally, proposed coordinated design approach is extended to a multi-machine power system and simulation results are presented to show effectiveness of the proposed controllers to damp modal oscillations in a multi-machine power system. The proposed control scheme is adaptive, simple to implement, yet is valid over a wide range of operating conditions.

## APPENDICES

### Appendix 1

### A. Nominal Operating Point

$P_e = 0.8$ pu, $Q_e = 0.144$ pu, $V_b = 1$ pu

**B. Power System Parameters**

Generator: $M = 2H = 6$ MJ/MVA; $D = 0$, $T'_{do} = 5.044$ sec.; $X_d = 0.1$ pu; $X_q = 0.06$ pu; $X'_d = 0.025$ pu; $f_0 = 60$ Hz.
Excitation system: $K_A = 5$; $T_A = 0.005$ sec.
Transmission line and transformer reactances:
$X_{Line} = 0.2$ pu; $X_{ts} = 0.2$ pu.
The SSSC Parameters: $C_{DC} = 1$ pu; $V_{DC} = 0.5$ pu; $m = 0.15$; $X_{SCT} = 0.1$ pu.
Heffron-Phillips Model Constants: $K_1 = 1.9014$; $K_2 = 0.6735$; $K_3 = 1.1429$; $K_4 = 0.0498$; $K_5 = -0.0127$; $K_6 = 0.9517$; $K_7 = -0.1759$; $K_8 = 0.0302$; $K_9 = 1.402\times10^{-4}$; $K_{DCm} = -0.4255$; $K_{pDC} = 0.0244$; $K_{qDC} = 0.0106$; $K_{vDC} = -0.0035$; $K_{pm} = 0.0839$; $K_{qm} = 0.0354$; $K_{vm} = -0.008$

**Appendix 2. The Dynamics of Each Synchronous Machine [1]**

$$\dot{\delta}_i = \omega_b\left(\omega_i - 1\right) \tag{10}$$

$$\dot{\omega}_i = \frac{1}{M}\left(P_{mi} - P_{ei} - D_i\left(\omega_i - 1\right)\right) \tag{11}$$

$$\dot{E}'_{qi} = \frac{1}{T'_{doi}}\left(E_{fdi} - \left(x_{di} - x'_{di}\right)i_{di} - E'_{qi}\right) \tag{12}$$

$$\dot{E}'_{fdi} = \frac{1}{T_A}\left(K_{Ai}\left(V_{refi} - V_i + u_i\right) - E_{fdi}\right) \tag{13}$$

$$T_{ei} = E'_{qi} i_{qi} - \left(x_{qi} - x'_{di}\right) i_{di} i_{qi} \tag{14}$$

**Appendix 3**

**A. Transmission Lines Data**

$V_{base} = 230$ kV; $S_{base} = 100$ MVA; $R = 0.0001$ (pu/km); $x_L = 0.001$ (pu/km); $b_C = 0.000175$ (pu/km).

**B. Generators Data**

Table A1. Generators data [1]

| Equivalent Gen. Type | $G_1$ Steam | $G_2$ Steam | $G_3$ Steam | $G_4$ Steam |
|---|---|---|---|---|
| Capacity (MVA) | 900 | 900 | 900 | 900 |
| $x_d$ | 1.8 | 1.8 | 1.8 | 1.8 |
| $x'_d$ | 3.0 | 3.0 | 3.0 | 3.0 |
| $x''_d$ | 0.25 | 0.25 | 0.25 | 0.25 |
| $x_q$ | 1.7 | 1.7 | 1.7 | 1.7 |
| $x'_q$ | 0.55 | 0.55 | 0.55 | 0.55 |
| $x''_q$ | 0.25 | 0.25 | 0.25 | 0.25 |
| $H$ | 6.5 | 6.5 | 6.175 | 6.175 |
| $T'_{do}$ | 8.0 | 8.0 | 8.0 | 8.0 |
| $T''_{do}$ | 0.03 | 0.03 | 0.03 | 0.03 |
| $T'_{qo}$ | 0.4 | 0.4 | 0.4 | 0.4 |
| $T''_{qo}$ | 0.05 | 0.05 | 0.05 | 0.05 |

**C. Loads Data**

Bus 7: $P_L = 967$ MW; $Q_L = 100$ MVAR; $Q_C = 200$ MVAR.
Bus 9: $P_L = 1767$ MW; $Q_L = 100$ MVAR; $Q_C = 350$ MVAR.

**D. AVR**

$K_A = 200$; $T_R = 0.01$.

**E. SSSC**

Converter rating: $S_{nom} = 100$ MVA;
System nominal voltage: $V_{nom} = 230$ kV;
Frequency: $f = 60$ Hz;
Maximum rate of changing reference voltage $V_{qref} = 3$ pu/s;
Converter impedances: $R = 0.00533$, $L = 0.16$;
DC link nominal voltage: $V_{DC} = 40$ kV;
DC link equivalent capacitance $C_{DC} = 375\times10^{-6}$ F;
Injected voltage regulator gains: $K_P = 0.00375$, $K_I = 0.1875$;
DC Voltage regulator gains: $K_P = 0.1\times10^{-3}$, $K_I = 20\times10^{-3}$;
Injected voltage magnitude limit: $V_q = \pm 0.2$.

**REFERENCES**


[1] P. Kundur, "Power System Stability and Control", McGraw-Hill, New York, 1994.
[2] E.A.H. Talaat, A. Abdennour, A.A. Al-Sulaiman, "Design and Experimental Investigation of A Decentralized GA-Optimized Neuro-Fuzzy Power System Stabilizer", International Journal of Electrical Power Energy System, Vol. 32, pp. 751-759, 2010.
[3] N.G. Hingorani, L. Gyugyi, "Understanding FACTS - Concepts and Technology of Flexible AC Transmission Systems", IEEE Press, New York, 2000.
[4] L. Gyugyi, C.D. Schauder, K.K. Sen, "Static Synchronous Series Compensator - A Solid State Approach to the Series Compensation of Transmission Lines", IEEE Trans. Power Delivery, Vol. 12, pp. 406-417, 1997.
[5] H.F. Wang, "Static Synchronous Series Compensator to Damp Power System Oscillations", Electrical Power System Research, Vol. 54, pp. 113-109, 2000.
[6] S. Panda, "Multi-Objective Evolutionary Algorithm for SSSC-Based Controller Design", Electrical Power System Research, Vol. 79, pp. 937-944, 2009.
[7] S. Panda, S.C. Swain, P.K. Rautray, R. Mallik, G. Panda, "Design and Analysis of SSSC-Based Supplementary Damping Controller", Simulation Modelling Practice Theory, Vol. 18, pp. 1199-1213, 2010.
[8] E.S. Ali, S.M. Abd-Elazim, "Coordinated Design of PSSs and TCSC via Bacterial Swarm Optimization Algorithm in a Multi-Machine Power System", International Journal Electrical Power Energy System, Vol. 36, pp. 84-92, 2010.
[9] S.M. Abd-Elazim, E.S. Ali, "Coordinated Design of PSSs and SVC via Bacteria Foraging Optimization Algorithm in a Multi-Machine Power System", International Journal Electrical Power Energy System, Vol. 41, pp. 44-53, 2012.
[10] L.J. Cai, I. Erlich, "Simultaneous Coordinated Tuning of PSS and FACTS Damping Controller in a Large Power System", IEEE Transactions on Power System, Vol. 20, pp. 294-300, 2005.
[11] S. Panda, N.P. Padhy, R.N. Patel, "Robust Coordinated Design of PSS and TCSC Using PSO Technique for Power System Stability Enhancement", Journal of Electrical System, Vol. 3, pp. 109-123, 2007.
[12] S. Panda, "Differential Evolution Algorithm for SSSC-Based Damping Controller Design Considering Time Delay", Journal of the Franklin Institute, Vol. 348, pp. 1903-1926, 2011.
[13] S. Panda, "Multi-Objective Non-Dominated Shorting Genetic Algorithm-II for Excitation and TCSC-Based Controller Design", Journal Electrical Engineering, Vol. 60, pp. 87-94, 2009.

[14] M. Nooshyar, H. Shayeghi, A. Talebi, A. Ghasemi, N.M. Tabatabaei, "Robust Fuzzy-PID Controller to Enhance Low Frequency Oscillation Using Improved Particle Swarm Optimization", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 14, No. 1, Vol. 5, pp. 17-23, March 2013.
[15] A.S. Kannan, R. Kayalvizhi, "A Novel Design of A Fuzzy Coordinated SSSC Controller for Integrated Power Systems", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 8, No. 3, Vol. 3, pp. 6-16, September 2011.
[16] R. Caponetto, L. Fortuna, S. Fazzino, M.G. Xibilia, "Chaotic Sequences to Improve the Performance of Evolutionary Algorithms", IEEE Transactions on Evolutionary Computation, Vol. 7, No. 3, pp. 289-304, June 2003.
[17] J. Kennedy, R. Eberhart, "Particle Swarm Optimization", IEEE Conferences, Vol. 4, pp. 1942-1948, December 1995.
[18] W.M. Korani, H.T. Dorrah, "Bacterial Foraging Oriented by Particle Swarm Optimization Strategy for PID Tuning", IEEE Int. Symp. on Computational Intelligence in Robotics and Automation, pp. 445-450, 2009.
[19] H.F. Wang, F.J. Swift, "A Unified Model for the Analysis of FACTS Devices in Damping Power System oscillations, Part I - Single-Machine Infinite-Bus Power Systems", IEEE Transactions on Power Delivery, Vol. 12, No. 2, pp. 941-946, 1997.

## BIOGRAPHIES

**Emanuel Youhanna Eshagh** was born in Tehran, Iran, 1987. He received the B.Sc. degree in Electrical Engineering from Qazvin Branch, Islamic Azad University, Qazvin, Iran in 2010. He is currently the M.Sc. student at Department of Power Engineering, South Tehran Branch, Islamic Azad University, Tehran, Iran. His research interests include FACTS, power system modeling, power system dynamic and control, power electronics, transient stability.

**Hamid Lesani** received the M.Sc. degree in Electrical Power Engineering from the University of Tehran, Tehran, Iran, in 1975 and the Ph.D. degree in Electrical Engineering from the University of Dundee, Dundee, UK, in 1987. He is currently the Professor in Department of Electrical and Computer Engineering, University of Tehran, Tehran, Iran. His teaching and research interests include design and modeling of electrical machines and power system dynamics. He is a member of IEEE, and a member of the Control and Intelligent Processing Center of Excellency at University of Tehran.

**Mahmoud Reza Haghifam** was born in Iran in 1967. He received the B.Sc., M.Sc., and Ph.D. degrees all in Electrical Engineering in 1989, 1992, and 1995, respectively. He joined Tarbiat Modares University, Tehran, Iran, as an Assistant Professor in 1995. He is now a Full Professor in the same university. In addition, he is a Research Fellow of Alexander Von Humboldt in Germany. He was as Visiting Professor in the University of Calgary, Calgary, AB, Canada in 2003. His main research interests are power system restructuring, power system reliability, and electric distribution system. He has published more than 300 technical papers in this areas. He is an IEEE Iran Section Industrial relationship officer. He has been awarded by DAAD and AvH in 2001, 2006, and 2009 for research stays in German universities.