International Journal of Information Technology and Knowledge Management
July-December 2010, Volume 2, No. 2, pp. 217-221

A SWARM INTELLIGENCE BASED ROBUST EXCITATION CONTROLLER DESIGN IN POWER SYSTEM DYNAMIC STUDIES

R. Shivakumar[1] & R. Lakshmipathi[2]

In the Modern Power System Scenario, Power System damping controllers are widely used in industry to damp the Low Frequency Inertial Oscillations experienced due to disturbance in the System. In this paper, an Swarm intelligence based Algorithm namely Particle Swarm Optimization algorithm (PSO) is implemented to compute the Optimal value of the damping controller parameters to enhance Small signal stability of the Power system.The Excitation Controller design is formulated as an Eigen value based Optimization problem and the damping controller parameters are optimized to shift the system closed loop Eigen values to the left in the complex s- plane for System Stability. In this work, the Single Machine infinite bus system (SMIB) model is taken into account for Modeling, Analysis and Simulation. To validate the Robustness of the proposed controller, Non linear Simulations have been carried out under various loading conditions of the system operation. The important feature of this paper is the Computation and Analysis of Eigen values and the Comparative study of the system model between Conventional Lead lag stabilizer and the PSO based Damping Controller.

Keywords: Particle Swarm Optimization, Low Frequency Oscillations, Power System Stability.

---

1. INTRODUCTION

The Phenomenon of Stability of Power Systems has received a great deal of attention in recent years. Low frequency oscillations of the order of 0.2 to 3 Hz are observed when large power systems are interconnected by weak tie lines [1].These low frequency oscillations may sustain and grow to cause system separation if adequate damping is not available. To enhance system damping, the generators are equipped with Power System Stabilizers (PSS) or Power System Damping Controllers.Power System Stabilizers are used to generate Supplementary Control Signals for the Excitation System in order to damp the Low frequency Power System Oscillations [2].

2. DAMPING CONTROLLER DESIGN TECHNIQUES

The Problem of PSS parameter tuning is a complex exercise. In recent years, several approaches based on optimal control, adaptive control, variable structure control and intelligent control have been applied to PSS design problem. Despite the potential of modern control techniques with different structures, Power system utilities still prefer the Conventional Lead Lag Controller(CPSS) design[3].The gain settings of these stabilizers are determined based on the linearized model of the power system around a nominal operating point. Since Power systems are highly nonlinear and the operating conditions can vary over a wide range, CPSS performance is degraded when the operating point changes from one to another because of fixed parameters of the stabilizer. Also, the other conventional techniques namely mathematical programming, gradient procedure, modern control theory etc are time consuming as they are iterative and require complex computation procedures and slow convergence.

Recently Metaheuristic Optimization technique like Genetic Algorithms,Tabu search, Simulated annealing, Bacteria Foraging, Particle Swarm optimization [4-6] have been applied for PSS parameter optimization. In this paper, Particle Swarm Optimization algorithm has been implemented to calculate the Optimum value of PSS Parameters. PSO is a population based stochastic Optimization technique inspired by social behavior of bird flocking or fish schooling[6]. PSO shares many similarities with Genetic algorithm like initialization of population of random solutions and search for the optimal solution by updating generations.

The main aim of this paper is to find the Optimum value of PSS parameters for a Single Machine Infinite Bus Power system (SMIB) to damp the low frequency inertial oscillations, thus improving system stability.

To show the Robustness of the proposed PSO based controller, the controller has been applied and tested on a weakly connected Power system under wide range of operating conditions. Also the Eigen value analysis and simulation results are compared between the Conventional Lead lag stabilizer and the PSO based PSS.

3. SYSTEM MODEL INVESTIGATED

Fig(1) represents a Single Synchronous Alternator connected to an infinite bus through a Transmission line having an

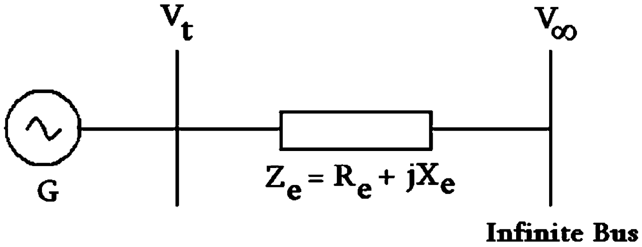
---

[1] Assistant Professor / EEE, Sona College of Technology, Salem, India

[2] Professor / EEE, St. Peters Engineering College, Chennai, India.

Email: mukil2005@gmail.com, drrlaksmipathi@yahoo.com.

impedance Ze. For analysis and simulation, the Transfer function block diagram for Low frequency Oscillation studies [7] was used. All the relevant system parameters [8] used for the simulation are given in Appendix.



Fig(1) SMIB Power System Model

4. THE PROPOSED APPROACH

4.1. Power System Damping Controller Structure

The Power System Stabilizer model consists of the Gain block, Washout block and the Phase compensation block. The input to the PSS is the Rotor Speed deviation and the Output is the Auxiliary Excitation signal given to the Generator Excitation system.

The Transfer function of the PSS model is given by

$$\left[\frac{\Delta U}{\Delta\omega}\right] = Ks\left[\frac{(1+sT_1)}{(1+sT_2)}\right]\left[\frac{(sTw)}{(1+sT_w)}\right] \quad (1)$$

where ΔU = Auxiliary Signal output from PSS

$\Delta\omega$ = Rotor Speed deviation

Ks = PSS gain

T_1, T_2 = PSS Time Constants.

Ks, T_1, T_2 are the PSS parameters which should be computed using the Conventional Lead lag method and PSO based Stabilizer design.

The Signal washout function is a high pass filter which removes dc signals and without it steady changes in speed would modify the terminal voltage. The washout time constant is in the range of 1 to 20 seconds and in this paper, Tw is taken as 15 seconds.

4.2. Proposed Optimization Criterion Formulation

For Low frequency oscillations damping, the Optimal PSS Parameters are to be Computed. For this requirement, in this work, an Eigen value based objective function as in equation (2) is taken.

$$[J] = \mathrm{Max}\{\,\mathrm{Re}[\lambda i]\},\ (\lambda i) \in (\lambda_T) \quad (2)$$

where (λi) belongs to the group of Electromechanical mode Eigen values(λ_T).

Re[λi] represents the Real part of the i^{th} electromechanical mode Eigen value. The Maximum real part value of the Eigen value indicate that the system is unstable, as it is located in right hand side of the complex s-plane. The Main aim is to Minimize this objective function J in order to shift the poorly damped Complex Eigen values to the left hand side of the s-plane for System Stability.

The Design problem including the constraints imposed on the various PSS parameters is given as follows:

Optimize J

Subject to $Ks^{min} \le Ks \le Ks^{max}$ (3)

$T_1^{min} \le T_1 \le T_1^{max}$ (4)

$T_2^{min} \le T_2 \le T_2^{max}$ (5)

Typical ranges selected for Ks, T_1 and T_2 are as follows: For Ks [1 to 50], for T_1 [0.1 to 1] and for T_2 [0.1 to 1].

5. AN OVERVIEW OF PARTICLE SWARM OPTIMIZATION

PSO is an Evolutionary Computation technique developed by Eberhart and Kennedy in 1995,which was inspired by the social behavior of bird flocking and fish schooling [9].

It utilizes a population of particles that fly through the problem hyperspace with given velocities. Each particle has a memory and hence it is capable of remembering the best position in the search space ever visited by it. The position corresponding to the best fitness is known as Pbest and the overall best out of all the particles in the population is called gbest [10-12].

At each iteration, the velocities of the individual particles are updated according to the best position for the particle itself and the neighborhood best position.

The velocity of each agent can be modified by the following equation:

$$V_i^{k+1} = W.V_i^k + C_1 rand_1 * (Pbest_i - S_i^k) + C_2 rand_2 * (gbest - S_i^k) \quad (6)$$

where V_i = Velocity of agent i at iteration k.

W = Weighting Function.

C_j = Weighting factor.

rand = random number between 0 and 1.

Si^k = Current position of agent i at iteration k.

Pbest = Pbest of agent i.

gbest = gbest of the group.

The following Weighting Function is usually utilized in equation (6).

$$W = [W_{\max}] - \left\{ \frac{w_{\max} - w_{\min}}{iter_{\max}} \right\} * iter \tag{7}$$

Where w_{max} = Initial Weight

w_{min} = Final Weight.

$iter_{max}$ = Maximum Iteration number

iter = Current iteration number.

Using the above equation, a certain velocity, which gradually gets close to Pbest and gbest can be calculated.

The Current position can be modified by the following equation

$$Si^{k+1} = Si^{k} + Vi^{k+1} \tag{8}$$

The following Computational Steps are implemented in this work for Computation of Optimum PSS Parameters.

Step 1: Select the Initial parameters of PSO algorithm.

Step 2: Initialize the Particle swarm by assigning a random position in the problem space to each particle.

Step 3: Evaluate the Fitness function for each Particle.

Step 4: For each Individual particle, Compare the fitness value of the particles with its Pbest. If the current value is better than the pbest value, then set this value as the Pbest for agent i.

Step 5: Identify the particle that has the best Fitness value. The value of its fitness function is identified as gbest.

Step 6: Update the Velocities and Positions of all the particles using equations (6) and (8).

Step 7: Repeat Steps 3-6 until the Stopping Criterion is met.

6. SIMULATION AND TEST RESULTS

The Linearized Space model of Single machine infinite bus system [fig (1)] was formulated and the open loop Eigen values was computed for various operating conditions, listed in Table III. The open loop Eigen values reveal that the system is unstable; having poorly damped electromechanical modes of oscillations located in right half of complex s-plane.

Table I
Parameters Selected for PSO Algorithm

PSO Parameters	Typical Values Selected
C_1, C_2	2,1.5
Wmax, Wmin	1, 1
Size of Particle Swarm	30
No of Generations	20

Also fig (2), (3) shows the Speed deviation and Power angle deviation oscillations having huge overshoots and large settling time.

For this drawback, the PSS parameters are computed using Conventional lead lag method and PSO algorithm based design.

Table II
Damping Controller Parameters (Optimal Value)

S. No	*Operating Conditions [P,Q]*	*Conventional PSS [Ks, T_1, T_2]*	*PSO based PSS [Ks, T_1, T_2]*
1	[0.9, 0.1]	[3.5808, 0.6432, 0.1]	[26.3519, 0.5467, 0.1481]
2	[0.85, 0.1]	[3.7564, 0.6612, 0.1]	[21.3459, 0.6345, 0.1536]
3	[0.9, 0.06]	[3.5618, 0.6994, 0.1]	[40.8727, 0.4982, 0.1578]

The Optimized PSS parameters play a vital role in shifting the poorly damped electromechanical modes of oscillations to left half of complex s-plane.

Table III shows that the Conventional PSS aid in shifting the poorly damped eigen values to left plane, also it is clear that the PSO based PSS is best suited in shifting the poorly damped modes to left half of s-plane better than the Conventional method, thus enhancing system stability.

Fig (4), Fig(5) shows that the speed deviation and Power angle deviation oscillations are damped in a better manner by PSO based PSS in comparison with the Conventional PSS.

The Overshoots and settling time are reduced to a greater extent compared to the open loop response without PSS.

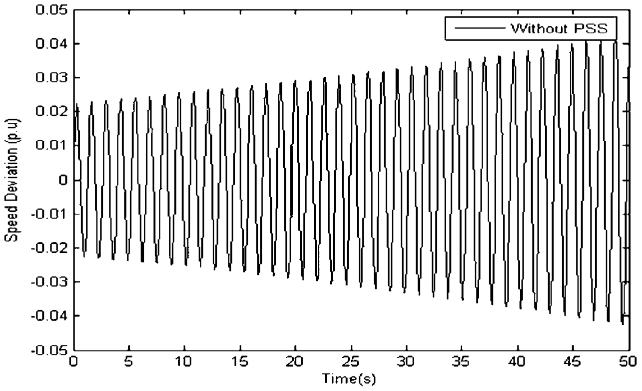


Fig. (2) Response of Rotor Speed Deviation without Damping Controller

Table III
Eigen Values Computed

S.No	*Operating Point[P,Q]*	*Eigen Values without Controller*	*Eigen Values with Controller*	
			Conventional PSS	*PSO based PSS*
1	[0.9, 0.1]	0.0419 ± j 4.8282	-14.7141	-14.5042
		-10.1423 ± j 3.7078	-0.0013 ± j 3.9086	-5.6587 ± j 4.8627
			-0.0495	-0.5636 ± j 5.0335
			-7.7453 ± j 6.0887	-0.0501
2	[0.85, 0.1]	0.0254 ± j 4.8177	-14.7041	-14.7326
		- 10.1227 ± j 3.7399	-7.7377 ± j 6.1142	-0.4049 ± j 5.0131
			-0.0149± j 3.8938	-6.0726 ± j 4.4325
			-0.0497	-0.0501
3	[0.9, 0.05]	0.0345 ± j 4.8838	-14.7085	-15.4312
		-10.1336 ± j 3.6979	-0.0217 ± j 3.9448	-4.3516 ± j 5.4466
			-0.0497	-1.0796 ± j 5.2561
			-7.7225 ± j 6.0907	- 0.0501

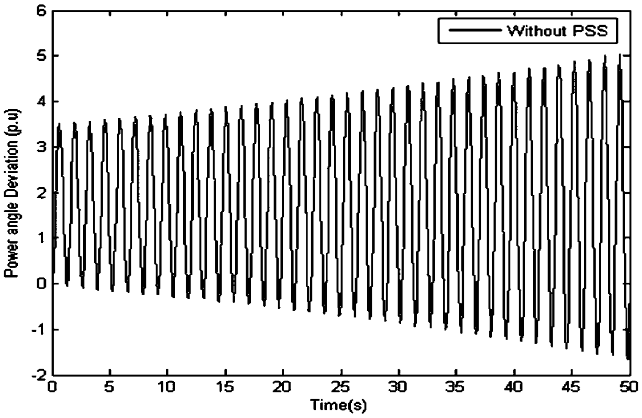


Fig. (3) Response of Power Angle Deviation without Damping Controller

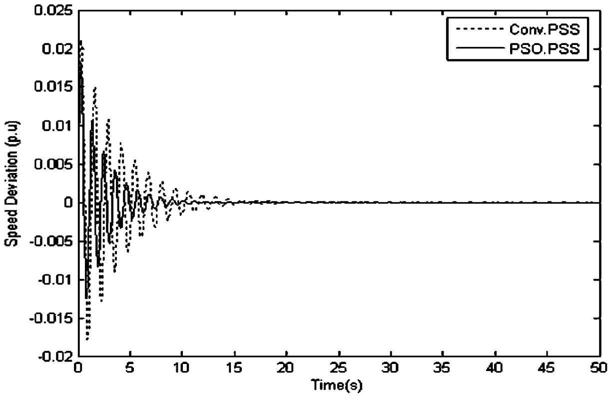


Fig. (4): Response of Rotor Speed Deviation with Damping Controllers

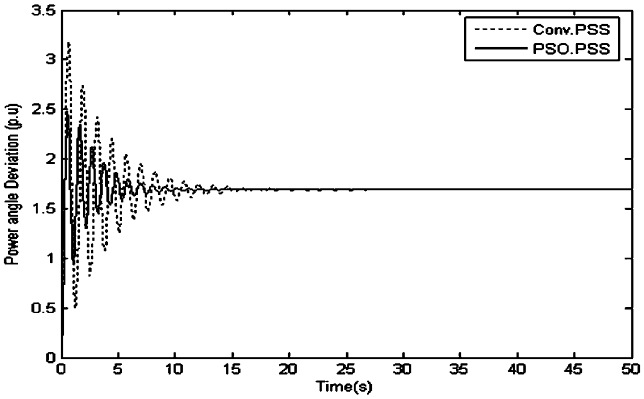


Fig. (5): Response of Power Angle Deviation with Damping Controllers

7. CONCLUSION

In this paper, the Low frequency Oscillations experienced in a Single Machine Infinite Bus System was damped by implementing the Particle Swarm Optimization Algorithm.

- The Optimum value of PSS parameters was computed by the PSO algorithm to shift the poorly damped closed loop Eigen values to better positions in left half of s-plane compared to the conventional PSS, thus enhancing Power System stability
- The Non linear simulation results under various system operating conditions shows that the Rotor speed and Power angle deviation oscillations are damped out with reduced overshoots and quick settling time.

APPENDIX

Data of SMIB System

Alternator : M = 9.26, Tdo' = 7.76 Secs, D = 0
xd = 0.973, xd' = 0.190, xq = 0.550

Excitation : $K_A = 50$, $T_A = 0.05$, $K_F = 0.025$,
$T_F = 1$Sec.

Line and Load : R = 0.034, X = 0.997

Loading Conditions : Initial State (0.9,0.1)

REFERENCES

[1] C.Y.Chung, K.W.Wang,C.T.Tse, X.Y.Bian and A.K.David "Probabilistic Eigen Value Sensitivity Analysis and PSS Design in Multimachine Systems", IEEE Transactions on Power Systems, 18, No.4, 2008, pp.1439-1445.

[2] H, Ping,Y.W.Kewen, T.Chitong, B.Xiaoyan, "Studies of the Improvement of Probabilistic PSSs using Single Neuron Model", Electrical Power and Energy Systems, 29, 2007, pp.217-221.

[3] M.A.Abido, "Pole Placement Technique for PSS and TCSC based Stabilizer Design using Simulated Annealing,", Electrical Power and Energy Systems, 22, 2000, pp.543-554.

[4] M.A.Abido, "Robust Design of Multimachine Power System Stabilizers using Simulated Annealing," IEEE Transactions on Energy Conversion, 15, No.3, 2003, pp.297-304.

[5] S.Mishra,M.Tripathy,J.Nanda," Multimachine Power System Stabilizer Design by Rule based Bacteria Foraging", Electric Power Systems Research, 77, 2007, pp.1595-1607.

[6] B.Zhao,Y.Cao, "A Multiagent based Particle Swarm Optimization Approach for Optimal Reactive Power Dispatch", IEEE Transactions on Power Systems, 20, No.2, 2005, pp.1070-1078.

[7] Bikash Pal,Balardo Chaudhuri, Robust Control in Power Systems", Springer Series, 2005.

[8] Yao.Yan Yu, "Electric Power System Dynamics", Academic Publishers, 1983.

[9] Yamille del Valle, Ganeshkumar Venayagamoorthy, Salman Mohagheghi, Jean Carlos Hernandez, Ronald G.H. Harley, Particle Swarm Optimization:Basic Concepts, Variants and Applications in Power Systems", IEEE Transactions on Evolutionary Computation, 12, No.2, April 2008, pp.171-195.

[10] R.Eberhart and J.Kennedy, "A New Optimizer using Particle Swarm Theory", 6th International Symposium, Micromachine and Human Science(NHS), Oct 1995, pp. 39-43.

[11] Kennedy and R.Eberhart, "Particle Swarm Optimization" in Proceedings of IEEE International conference on Neural Networks(ICNN), 4, Nov 1995, pp.1942-1948.

[12] Jong Bae Park, Ki Song Lee, Joong in Shin and Kwang Y.Lee, "A Particle Swarm Optimization for Economic Dispatch with Non Smooth Cost functions", IEEE Transactions on Power Systems, 20, No.1, Feb 2005, Pp.34-42.