Robust Optimal Controller Design for Multimachine Systems using Genetic Algorithms

R.Shivakumar[1], M.Panneerselvam[2], Dr.R.Lakshmipathi[3]

[1]Assistant Professor / EEE, Sona College of Technology, Salem, India
[2] Lecturer / EEE, Sona College of Technology, Salem, India
[3] Professor / EEE, St.Peters Engineering College, Avadi, Chennai, India

Abstract— **Power System Oscillation Controllers (PSOC) are added to Excitation systems to enhance the damping during Low frequency oscillations. This paper provides a systematic approach to damp the low frequency oscillations observed in Three Machine Nine Bus Multimachine Power Systems based on Genetic Algorithm(GA).The Optimal Controller design problem is formulated as an optimization criterion comprising of Time domain based objective function to compute the optimal controller parameters. The main objective is to minimize the integral squared error involving rotor speed deviation and power angle deviations. To validate the effective damping action of the proposed controller, Non linear Time domain simulations has been carried out in this work under wide variations in the system loading conditions. Also a comparative study has been done to show the robustness of the Genetic based controller over the conventionally designed Lead Lag controller.**

Keywords- Genetic Algorithm, Multimachine Power Systems, Time Domain Simulation, Low Frequency Oscillations.

I. INTRODUCTION

Power Systems experience Low frequency oscillations due to disturbances. These low frequency oscillations are related to the small signal stability of a Power System. These oscillations may sustain and grow to cause system separation if no adequate damping is available [1]. A Power System Oscillation Controller (PSOC) is one of the most cost effective method to damp the oscillations, thus enhancing Power System Stability [2]. Two fundamental problems associated with the application of PSOC are:

1. The Operating Condition and Parameters of a Power System vary over a wide range.
2. The Mathematical model of the Multimachine Power Systems are highly dynamic and Non linear in nature.

In recent years, several approaches based on Modern control theory have been applied to PSOC design problem. These include optimal control, adaptive control, variable structure control and intelligent control [3-4]. Despite the potential of modern control techniques, Power System utilities still prefer the conventional lead lag Controller structure[5].Conventional PSOC(Conv PSOC) are designed using the theory of phase compensation in the frequency domain and are introduced as a lead lag compensator.

The gain settings of these controllers are determined based on the linearized model of the power system around a nominal operating point to provide desired performance at this point. Since modern power systems are highly dynamic in nature, Conventional Controllers will not give the desired performance, as the operating point changes from one to another because of fixed parameters of the controller. Unfortunately, the conventional techniques are time consuming, as they are iterative and require heavy computation burden and slow convergence.

Modern Evolutionary optimization algorithms include a wide variety of population based algorithms which can be applied to different kinds of optimization problems. Recently, Bio inspired optimization techniques like Genetic algorithms, Tabu search, Evolutionary Programming, Simulated annealing, Bacteria foraging and Particle Swarm Optimization have been applied for PSOC parameter optimization [6-7].

In this work, Genetic Algorithm is implemented to compute the optimal controller parameters for enhancing Multi Machine Power System stability. Genetic Algorithms are computerized search and optimization algorithms based on the principles of Natural genetics and Natural selection [8].GA mimic the survival-of-the fittest principle of nature to make a search process. Genetic algorithm differ from more traditional optimization techniques in many ways: Genetic algorithm use objective function to guide the search, not derivative or other auxiliary information.

The main objective here is to minimize the integral squared error (Rotor speed deviation and Power angle deviation) to damp the low frequency oscillations. Non linear Time domain simulations under wide system operating conditions are being implemented to show the robustness of the proposed controller. The Complete design procedure is compared with the conventional lead lag Controller (Conv PSOC) design to validate the superiority of the Bio inspired Genetic algorithm based Controller (GAPSOC) design.

II. MULTIMACHINE POWER SYSTEM MODEL

Figure (1) represents the Multimachine Power System model involving Three Synchronous Alternators and Nine Bus network.

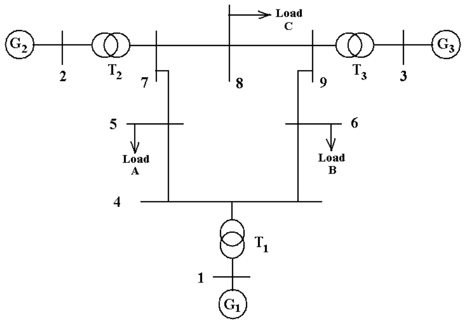

Figure (1). Multimachine Power System Model

The Dynamic model in State Space form is given by

$$\dot{x} = Ax + Bu \qquad (1)$$

where [x] = State Variable Vector
A,B = State Matrix and Input Matrix respectively.

For Analysis and Simulation, the Heffron-Phillips block diagram of Synchronous Generator System Model was used. All the relevant System Parameters [9] used for the Simulation are given in Appendix-I.

(A). Power System Oscillation Controller Structure

The Power System Oscillation Controller structure consists of the Gain Block, Cascaded identical Phase Compensation block and the washout block. The input to the controller is the Rotor speed Deviation (Δω) and output is the Supplementary Control signal (ΔU_E) given to Generator excitation system.

The Transfer function of the Controller Model is given by

$$\left[\frac{\Delta U_E}{\Delta\omega}\right] = Ks\left[\frac{(1+sT_1)}{(1+sT_2)}\right]\left[\frac{(1+sT_3)}{(1+sT_4)}\right]\left[\frac{(sT_w)}{(1+sT_w)}\right] \qquad (2)$$

Where Ks = PSOC gain
Tw = Washout Time constant.
T_1,T_2,T_3,T_4 = PSOC Time constants

Time Constants $T_1 = T_3$, $T_2 = T_4$ (Identical Phase Compensator Block).

Hence Ks, T_1, T_2 are the PSOC parameters which should be computed using Conventional Lead Lag Controller and optimally tuned using GAPSOC for Multimachine Power System Model.

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 work, Tw is taken as 20 seconds.

III. PROPSED OPTIMIZATION CRITERION FORMULATION

The Main objective of this criterion formulation is to compute the optimal value of PSOC parameters for system oscillations damping and thus enhancing the Multimachine Power System stability.

The Time Domain based Objective function is given by

$$[J] = \int_0^T e^2(t).dt \qquad (3)$$

Here e(t) is the error involving Rotor Speed deviation [Δω] and the Power angle deviation[Δδ].
T represents the Time of Simulation.

The objective here is to Minimize the objective function J, so that the integral of the squared error deviation is minimized thus enhancing the damping of the low frequency oscillations.

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

Optimize J
Subject to

$$K_S^{\min} \le K_S \le K_S^{\max} \qquad (4)$$

$$T_1^{\min} \le T_1 \le T_1^{\max} \qquad (5)$$

$$T_2^{\min} \le T_2 \le T_2^{\max} \qquad (6)$$

Various typical ranges selected for Ks, T_1 and T_2 are as follows: For Ks [1 to 40], for T_1 [0.1 to 1] and for T_2 [0.1 to 1]. The above mentioned Time domain based optimization criterion is being implemented in this work to compute the Optimal PSOC parameters namely Ks, T_1 and T_2 so that the Multimachine Power System Stability is enhanced to a greater extent.

IV. AN OVERVIEW OF GENETIC ALGORITHM

Genetic Algorithms are numerical optimization algorithms inspired by Natural selection and natural genetics [10-12].GA techniques differ from more traditional search algorithms in that they work with a number of candidate solutions rather than one candidate solution.

GA includes operators such as Reproduction, Crossover, Mutation and Inversion.

Reproduction is a process in which a new generation of population is formed by selecting the fittest individuals in the current population. *Crossover* is responsible for producing new offsprings by selecting two strings and exchanging portions of their structures. *Mutation* is a local operator which is applied with a very low probability of occurrence. Its function is to alter the value of a random position in a string. Finally, *Inversion* is a process which inverts the order of the elements between two randomly chosen points on the string.

The Proposed Computational Steps involved in Genetic Algorithm implementation are as follows:

Step 1. Specify the various parameters for GA Optimization.

Step 2. Create an Initial Population of individuals randomly.

Step 3. Evaluate the fitness of each individual (i.e) Evaluating the optimization criterion J.

Step 4. If value of J obtained is minimum, then Optimum value of PSS parameters is equal to those obtained in current generation, Otherwise Goto step 5.

Step 5. Based on the fitness, select the best Individuals and Perform recombination through a crossover process.

Step 6. Mutate the new generation with a given Probability.

Step 7. If termination condition (Maximum no of Generations) is not reached, go back to step(3).

V. SIMULATION RESULTS

The main objective of the dynamic simulation is to minimize the integral squared error involving Rotor speed deviation and Power angle deviations, thus enhancing the Multimachine Power System Stability.

In this work, MATLAB 7.0 / SIMULINK tool was used for all the simulation and analysis.

The State space modelling of the three machine Nine bus power system model was performed. In this work, the Power System Oscillation controllers are installed in the Synchronous Alternators 2 and 3 models except Alternator 1. The Coordinated design procedure involving three machines with oscillation controllers is a complex exercise. Figure (2) and Figure (3) represents the Speed Deviation responses of the system for Synchronous alternator 2 and 3 for the operating point (P=0.8, Q=0.034p.u).In this, the Open loop system without PSOC responses are having huge overshoots and larger settling time. Due to the implementation of the Conventional lead lag based controller and Genetic based controller design, the Speed deviation overshoots are reduced and the oscillations settle at a quicker time compared to the open loop response without controller. Also, it is evident that the Genetic based controller responses are better than the Conventional controller response. This shows the importance of Genetic Algorithm based controller design in damping the Low frequency oscillations.
Table 1 shows the various parameters selected for the Genetic Algorithm implementation.

TABLE 1. GENETIC ALGORITHM PARAMETERS

S.No	**Genetic Algorithm Parameters**	
1	Population Size	25
2	No of Generations	10
3	Selection Operator	Roulette Wheel Selection
4	Generation Gap	0.90
5	Cross over Probability	0.95
6	Mutation Probability	0.10

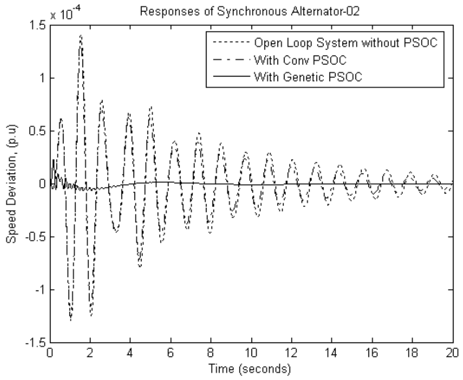

Figure (2) Dynamic Speed Deviation Response for system for Open loop, Conv. PSOC and Genetic PSOC for [P=0.8, Q=0.034 p.u] for Alternator 2.

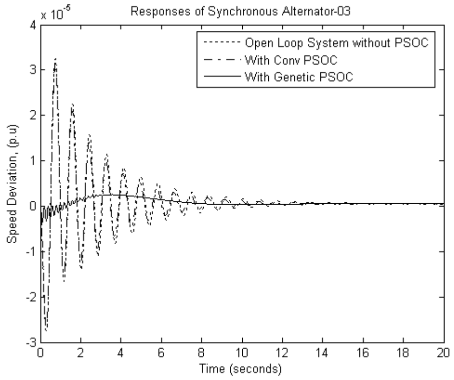

Figure (3) Dynamic Speed Deviation Response for system for Open loop, Conv. PSOC and Genetic PSOC for [P=0.8, Q=0.034 p.u] for Alternator 3.

Figure (4) and Figure (5) represents the Dynamic Power angle responses of the system for Synchronous alternators 2 and 3 for the operating point (P=0.8, Q= 0.034 p.u).These responses clearly indicate the better damping effect exerted by the Genetic Algorithm based controller compared to the open loop without controller and Conventional Lead lag controller.
Table (2) shows the Optimal controller parameters computed for both Conventional lead lag controller design and the Genetic based Controller design for [P=0.8, Q=0.034 p.u].

TABLE 2. OPTIMAL CONTROLLER PARAMETERS FOR [0.8, 0.034 p.u]

S. No	Synchronous Alternator	Controller	Computed Optimal Controller Parameters [Ks , T_1 & T_2]
1	G2	Conv.PSOC	[10.455 ,0.312, 0.14]
		Genetic PSOC	[25.9125 ,0.8993 ,0.7260]
2	G3	Conv.PSOC	[5.4213 ,0.1983 ,0.14]
		Genetic PSOC	[33.1034 ,0.7913, 0.2563]

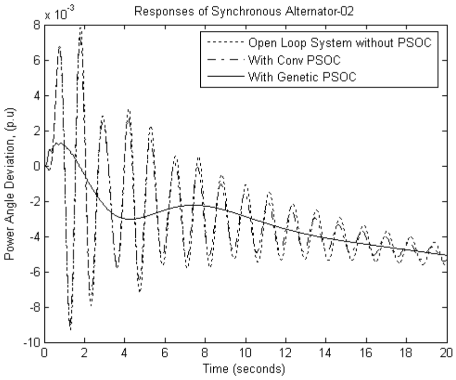

Figure (4) Dynamic Power Angle Deviation Response for system for Open loop, Conv. PSOC and Genetic PSOC for [P=0.8, Q=0.034 p.u] for Alternator 2.

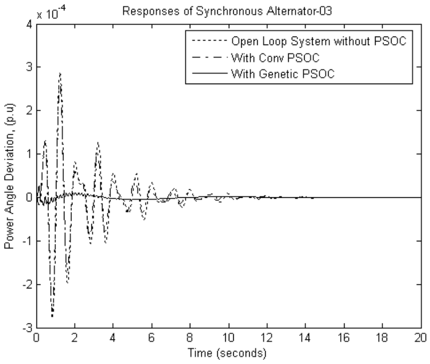

Figure (5) Dynamic Power Angle Deviation Response for system for Open loop, Conv. PSOC and Genetic PSOC for [P=0.8, Q=0.034 p.u] for Alternator 3.

Since Modern Power Systems are highly dynamic and Non linear in nature, the controller design should be effective under wide variations in system operating conditions. To show the robustness of the controller design under wide variation in operating conditions, the dynamic simulation has been done under another operating condition with [P = 0.75, Q =0.015 p.u].Figure (6), (7), (8) and (9) represents the dynamic Speed Deviation and Power Angle responses of the system with Conv. PSOC and Genetic based PSOC for [P = 0.75, Q =0.015 p.u].

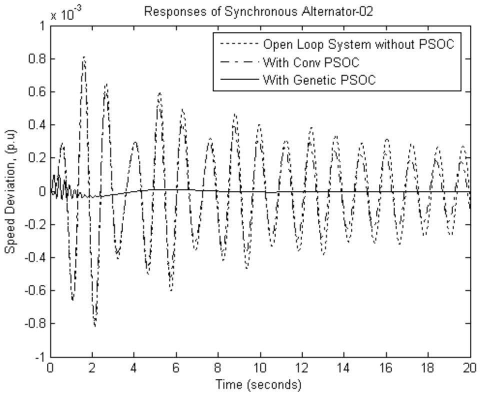

Figure (6) Dynamic Speed Deviation Response for system for Open loop, Conv. PSOC and Genetic PSOC for [P=0.75, Q=0.015 p.u] for Alternator 2.

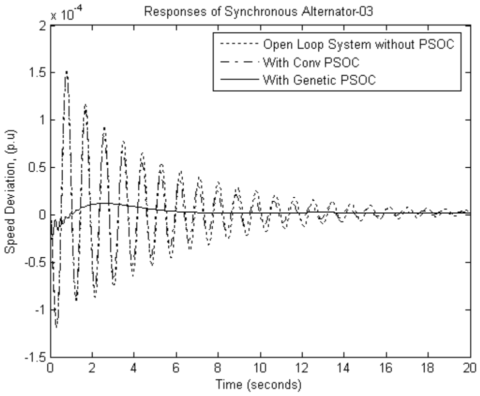

Figure (7) Dynamic Speed Deviation Response for system for Open loop, Conv. PSOC and Genetic PSOC for [P=0.75, Q=0.015 p.u] for Alternator 3.

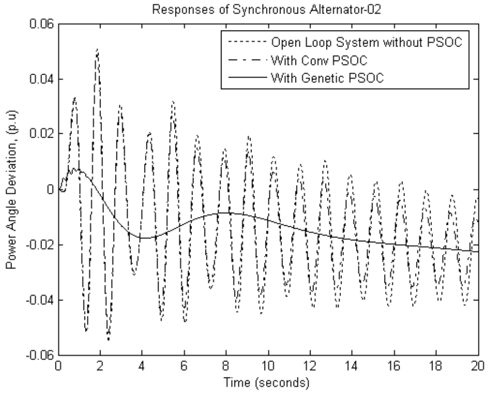

Figure (8) Dynamic Power Angle Deviation Response for system for Open Loop, Conv. PSOC and Genetic PSOC for [P=0.75, Q=0.015 p.u] for Alternator 2.

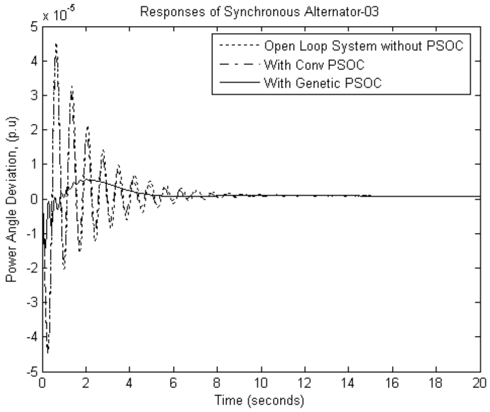

Figure (9) Dynamic Power Angle Deviation Response for system for Open loop, Conv. PSOC and Genetic PSOC for [P=0.75, Q=0.015 p.u] for Alternator 3.

Table (3) shows the Optimal controller parameters computed for both Conventional lead lag controller design and the Genetic based Controller design for [P=0.75, Q=0.015 p.u].

TABLE 3.OPTIMAL CONTROLLER PARAMETERS FOR [0.75, 0.015 p.u]

S. No	**Synchronous Alternator**	**Controller**	**Computed Optimal Controller Parameters [Ks , T_1 & T_2]**
1	G2	Conv.PSOC	[9.549, 0.1554, 0.12]]
		Genetic PSOC	[21.5412, 0.7134, 0.235]
2	G3	Conv.PSOC	[6.3020 , 0.2560, 0.12]
		Genetic PSOC	[27.3102,0.6166, 0.1663]

The dynamic responses in figure (6), (7), (8) and (9) clearly indicate the dominant damping exerted by the Genetic Algorithm based controller design in damping the Low frequency oscillations compared to the open loop system without controller and also with Conventional lead lag controller design, thus enhancing the Multimachine Power System Stability to a greater extent.

VI. CONCLUSION

This Paper provides an efficient solution to damp the Low frequency inertial oscillations experienced in the Three machine nine bus Multimachine Power System. The implementation of Time domain based optimization criterion for Conventional Lead Lag design and Genetic Algorithm based design provide better results, thus enhancing Power System Stability. Also, the robustness of the Genetic Algorithm based Controller design has been proved by the dynamic simulation responses of the Multimachine System under wide System operating conditions.

APPENDIX – 1.

Multimachine Power System Data for Simulation

Alternator 1: 125 MVA, 13.8 KV. Rated Power Factor = 0.9

X_d=1.05, X_d'=0.3, Xq=0.686, Xq'=0.686

Tdo'=6.170, D = 0, M= 8.

Alternator 2: 192 MVA, 18 KV. Rated Power Factor = 0.9

X_d=0.8958, X_d'=0.1198, Xq=0.8645,

Xq'=0.1969, T_{do}'=6, D =0, M= 12.

Alternator 3: 100 MVA, 13.8 KV. Rated Power Factor = 0.9

X_d=1.3125, X_d'=0.1813, Xq=1.2578,

Xq'=0.25, T_{do}'=5.89, D=0, M= 6.

Excitation System:
K_A= 200, T_A = 0.05, K_F =0.025, T_F=1.0
. Ke = 0.15, Te= 0.025
Operating Point: P=0.8, Q= 0.034 p.u.
All the Parameters are in (p.u) unless specified otherwise.

REFERENCES

[1] Adam Dysko, William E.Leithead and John O' Reilly, "Enhanced Power System Stability by Coordinated PSS Design", IEEE Transactions on Power Systems,Vol.25,No.1,February 2010,pp.413-422.

[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,Vol. 29,2007,pp.217-221.

[3] Wenxin Liu,Ganeshkumar Venayagamoorthy and Donald C.Wunsch, "A Heuristic Dynamic Programming based Power System Stabilizer for a Turbogenerator in a Single Machine Power System",IEEE Transactions on Industry Applications,Vol.41,No.5,Sep-October 2005,pp.1377-1385.

[4] D.K.Chaturvedi, O.P.Malik and K.Kalra, "Experimental Studies with a Generalized Neuron based Power System Stabilizer", IEEE Transactions on Power Systems, Vol.19, No.3, Aug 2004,pp.1445-1453.

[5] M.J.Gibbard, "Robust Design of Fixed parameter Power System Stabilizer", IEEE Transactions on Power Systems, Vol.6, 1991, pp.794-800.

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

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

[8] A.L.B.Do.Bomfin,G.N.Taranto and D.M.Falcao, "Simultaneous Tuning of Power System Damping Controllers using Genetic Algorithms",IEEE Transactions on Power Systems,Vol 15,No.1,pp.163-169,Feb 2000.

[9] Bikash Pal, Balarko Chaudhuri, "Robust Control in Power Systems",Springer Series, 2000.

[10] K.Sebaa, M.Boudour, "Optimal locations and Tuning of Robust Power System Stabilizer using Genetic Algorithms", Electric Power Systems Research, Vol.79, 2009, pp.406-419.

[11] Y.L.Abdel-Magid and M.A.Abido, "Robust Coordinated Design of Excitation and TCSC based stabilizers using Genetic Algorithms", International Journal of Electric Power and Energy systems, Vol.69, No.23, 2004, pp.129-141.

[12] S.Panda, S.C.Swain, C.Ardil, "Optimal Supplementary Controller design for TCSC employing RCGA", International Journal of Computational Intelligence, Vol.5:1, 2009, pp.36-45.