International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 4, Number 2 (2011), pp.209-226

http://www.irphouse.com

Stability Enhancement using Hybrid Power System Stabilizer Auto Tuned by Breeder Genetic Algorithm

M. Mary Linda[1*] and N. Kesavan Nair[2]

[1]Assistant Professor, Department of EEE
Ponjesly College of Engineering, Nagercoil, Tamilnadu, India.
**Corresponding Author E-mail: mm.linda2002@gmail.com*
[2]Professor, Department of EEE
Noorul Islam College of Engineering, Kumaracoil, Tamilnadu, India.

Abstract

The design and implementation of Power System Stabilizer (PSS) in a multimachine power system based on innovative evolutionary algorithm plainly as Breeder Genetic Algorithm (BGA) with Adaptive Mutation is described in this paper. For the analysis purpose a Conventional Power System Stabilizer and a Conventional Genetic Algorithm based Power System Stabilizer are designed and implemented in the same system. Simulation results on multimachine system subjected to small perturbation and three phase fault radiates the effectiveness and robustness of the proposed PSS over a wide range of operating conditions and system configurations. The results have shown that Adaptive Mutation BGAs are well suited for optimal tuning of PSS and they work better than Conventional Genetic Algorithm, since they have been designed to work on continuous domain. The effectiveness and feasibility of the proposed Power System Stabilizer is demonstrated through a three machine nine bus WSCC system and New England 10-machine system which shows better results when compared to the Conventional Genetic Algorithm.

Keywords: Adaptive Mutation Breeder Genetic Algorithm (ABGA), Conventional Genetic Algorithm (CGA), Conventional Power System Stabilizer (CPSS), Power System Stabilizer (PSS).

Introduction

In power systems, reliability and transfer capability are often limited by stability constraints like transient, oscillatory and voltage stabilities [1]. Stability of power systems is one of the most important aspects in electric power system operation. With the increasing electrical power system demand and need to operate power systems closer to their limits of stability, faster and more flexible manner in the deregulated competitive environment, modern power systems can reach stressed conditions more easily than the past. These unstable or poorly damped oscillations have been observed more often in today's power systems. Spontaneous system oscillations at very low frequencies in the order of 0.2 to 2.5 Hz that occur due to weak interconnections of large electric power systems are therefore becoming more significant. Once started, they would continue to grow, causing system separation if inadequate damping is available. Damping of these oscillations in interconnected power system is essential for secure and stable operation of the system. Power System Stabilizer is the most widely used device for resolving oscillatory stability problems [2].PSS have long been regarded as an effective way to enhance the damping of electromechanical oscillations in electrical power systems[3].

Conventional power system stabilizers are designed based on eigen value analysis which utilizes two basic tuning techniques phase compensation and root locus .Phase compensation is widely used and compensates for the phase lags by providing a damping torque component. Root locus involves shifting of eigen values related to the power system modes of oscillation by shifting the poles and zeros of the stabilizer [4].Power systems utilities have been using the CPSS over the past four decades due to its simplicity [5]. CPSS are normally tuned to perform optimally at and around the nominal operating conditions. However, as the system loading conditions or operating conditions change, the CPSS may not be able to provide adequate damping to the system and results in degradation of the performance of the system [6].

Genetic Algorithm (GA) which is a part of Artificial Intelligence has received increased attention in recent years. GAs are biologically motivated adaptive systems based on natural selection and genetic recombination [6].GA is a stochastic global search and optimization method that mimic the metaphor of natural biological evolution and are closely modeled on evolution in the biological world.

The main theme of GA is robustness, the balance between efficiency and efficacy necessary for survival in many different environments. On the other hand GA provides an alternative to traditional optimization techniques by using directed random searches to locate optimal solutions in complex power system problems [7]. Thus the performance of the power system stabilizer can be significantly enhanced by operating genetic based learning mechanism.

However GA has some limitations like premature convergence, difficulties in selecting optimal genetic operators and high computational capacity required to solve complex optimization problems. To overcome some of these limitations, Breeder Genetic Algorithm have recently been proposed to increment the capability of GAs [5, 8].BGAs employ the same concept of survival of the fittest as employed in CGAs. However unlike GA, BGA uses artificial breeding similar to the one being practiced by animal breeders. The resultant is an extremely versatile and effective function optimizer with very few parameters to be selected by the user.

A slightly different version of BGA known as the Adaptive Mutation Breeder Genetic Algorithm whereby the mutation rate changes according to the nature of the fitness values is proposed in [9]. Recently the application of BGA to optimal PSS design has gained momentum, but the performance of the controllers is designed using computer simulations only [5, 8].This paper presents the experimental results of the above cited ABGA optimizer when implemented in a three-machine nine- bus WSCC system and New England 10-machine system. For the results presented in this paper, a simple AVR were implemented using analogue devices with a time constant regulator but no filter. The simulation results of the proposed optimization based PSS is compared with the CPSS and CGA based PSS. All the experimental studies for machine performance were recorded using MATLAB/ Simulink software.

Modeling of Power System Stabilizer

The main function of a PSS is to produce a proper torque on the rotor of the machine involved in such a way that the phase lag between the exciter input and the machine electrical torque is compensated. The basic PSS consists of four controllers which are the gain, washout filter, phase lead compensator and output limits. The transfer function of the i^{th} PSS of a multimachine power system is

$$U_{PSSi} = \frac{K_s\, sT_w}{1+sT_w}\left[\frac{(1+sT_{1i})(1+sT_{3i})}{(1+sT_{2i})(1+sT_{4i})}\right].\Delta\omega i(s) \tag{1}$$

As matters stand, the output signal is fed as a supplementary input signal U_i to the habitual excitation system. Generally, the gain K_s is set within the values between 2 to 10 to meet the requirements of amplifying the input (Δw). The washout filter is employed as a high pass filter that removes dc component existing in the input signal. Typically T_w is initially set to 10 sec in this paper. The dynamic compensator is made up of two lead-lag stages .Fig.1 provides the block diagram of a typical lead-lag PSS [2] together with a thyristor type excitation system, where the input signals for PSS, $\Delta\omega = \omega - \omega_r$, is the deviation of the generator rotor speed 'ω' from the system synchronous speed ω_r. It is assumed that in the PSS parameter design, the time constant of the washout filter Tw, and the bounds of PSS output signals V_{smax} and V_{smin} are prespecified parameters and the gain factor K_s, the phase lead- lag time constants T_1, T_2, T_3, and T_4 are the parameters to be designed [10]. The thyristor type excitation system [11] as shown in Fig.1 is used throughout this paper with the parameters listed in [12]. The block TGR stands for Transient Gain Reduction.

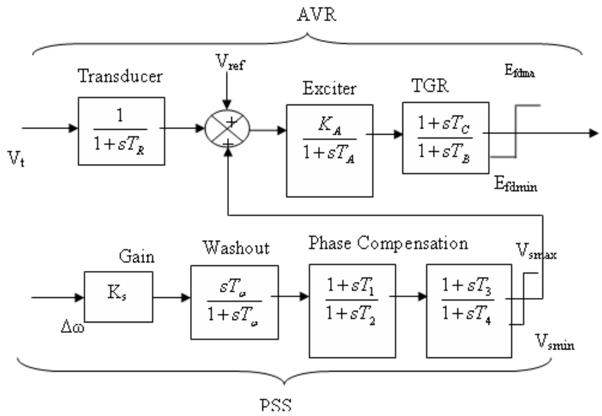

Figure 1: Thyristor type excitation system and PSS.

Breeder Genetic Algorithm

GA is a four step process involving evaluation, reproduction, recombination and mutation [13]. Since in classical GA, selection is stochastic and works in discrete coding, a truncation selection, deterministic procedure breeding mechanism is originally created by Heinz Muhlenbein [14].

BGA is a relatively new evolutionary algorithm that is based on artificial selection. This work uses a modified version of BGA called the Adaptive Mutation BGA [5]. This BGA usually uses real-valued representation as opposed to simple GA which mainly uses binary and sometimes floating or integer representation. This BGA uses truncation selection method, whereby a selected top T% (where T% is called truncation rate and its typical values are 10% to 50%) of the fittest individuals, chosen from the current generation, go through recombination and cross over to form the next generation [15]. The rest of the individuals are discarded. In truncation method, the fittest individual called an *ellist* is guaranteed a place in the next generation. The other top (T-1) % goes through recombination and mutation to form the rest of the individuals in the next generation.

Recombination

ABGA allows various possible recombination processes to be used, each of them searching the space with a particular bias. The recombination processes that were used are volume and line recombination. In volume recombination, a random vector r equal to the parents in length is generated and the child Zi is produced by the following expression [5, 9].

$$Z_i = r_i x_i + (1-r) y_i \tag{1}$$

In other words, the child can be said to be located at a point inside the hyper box defined by the parents. In line recombination a single uniformly random number r is generated between 0 and 1, and the child is obtained by the following expression.

$$Z_i = r\ x_i + (1-r) y_i \tag{2}$$

In light of this, a child can be said to be located at a randomly chosen point on a line connecting the two parents.

Adaptive Mutation process

One problem that has been of concern in GA is premature convergence, where the search might converge on local optima rather than the desired global one. This has been minimized by preserving the diversity of the population by adding small injection of randomness or mutation [9]. This is achieved by adding a small vector of normally distributed zero mean random numbers to each child before inserting it into the population. The standard deviation r of the vector is very critical, as small r might lead to premature convergence or big r might impair the search and reduce its ability to converge optimally. Therefore, it is better to use an adaptive approach whereby the rate is modified during the course of the search. The population is divided into two halves X and Y. A mutation rate of 2r is applied to X while a mutation of ½r to Y. The mutation r is adjusted depending on the population (X or Y) that is producing better and fitter solutions on average. If X individuals are fitter that the mutation rate, r is increased by l0%, while if Y is fitter that the mutation rate, r is reduced by a similar amount.

ABGA based Power System Stabilizer

Though these stabilizers have simple robust structures tuning them either by computer simulation modeling or by actual field tests is an involved process which requires considerable expertise and also the knowledge of system parameters external to the generating station [21]. Thus by the implementation of the proposed algorithm the performance of CPSS can be improved.

Optimization of CPSS using ABGA

The controllers were designed offline and discretized to an equivalent digital controller for implementation on a digital computer for the experiment. For this optimization problem, an eigenvalue based multi objective function with the combination of damping factor and damping ratio is considered as follows [11]:

$$Objective\,Function\,J = \sum_{j=1}^{NP} \sum_{\sigma_i \geq \sigma_0} (\sigma_0 - \sigma_i)^2 + \alpha \times \sum_{j=1}^{NP} \sum_{\varsigma_i \leq \varsigma_0} (\varsigma_0 - \varsigma_i)^2 \tag{2}$$

Subjected to the constraints

$$\left.\begin{aligned} K_{si}^{\min} &\leq K_{si} \leq K_{si}^{\max} \\ T_{1i}^{\min} &\leq T_{1i} \leq T_{1i}^{\max} \\ T_{2i}^{\min} &\leq T_{2i} \leq T_{2i}^{\max} \\ T_{3i}^{\min} &\leq T_{3i} \leq T_{3i}^{\max} \\ T_{4i}^{\min} &\leq T_{4i} \leq T_{4i}^{\max} \end{aligned}\right\} \tag{3}$$

To the extent of degree of relative stability, the parameters of the PSS may be selected to minimize the damping factor σ.To limit the maximum overshoot, the parameters of the PSS may be selected to minimize the damping ratio term ς. Where σ_{ij} and ς_{ij} are the real part and the damping ratio of the ith eigenvalues of the jth operating point. The value of 'α' is chosen as 10. NP is the total number of operating points for which the optimizations are carried out. The main objective of this metaheuristic technique is to find the best parameter combination that minimizes the objective function J, where the constraints are the PSS parameter bounds, such that all the closed loop poles lie within a 'D' shaped sector as in [19], in the negative half plane of the jω axis.

Typical ranges selected for K_{si}, T_{1i}, T_{2i}, T_{3i} and T_{4i} are as follows K_{si} = [5 to 50]; $T_{1i} = T_{2i} = T_{3i} = T_{4i}$= [0.1 to 1.0]. The proposed approach makes use of ABGA to solve this optimization problem and search for optimal or near optimal set of PSS parameters {K_{si}, T_{1i}, T_{2i}, T_{3i}, T_{4i}}; i= {1, 2, 3,……..m}, where *m* is the number of machines.

Results and Discussion

The performance of the proposed technique on the CPSS is evaluated by applying them to two different multimachine systems.

Test Systems

In the proposed work two different multimachine systems are considered under different operating conditions.

Test System I

In this work, a three machine nine bus WSCC system is considered as shown in Fig.2. Details of the system data are given in [18]. The generator and system loading levels at these cases are given in [9].

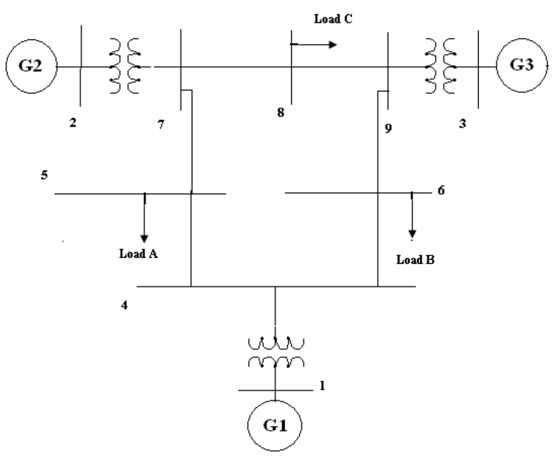

Figure 2: Three Machine Nine Bus WSCC System.

Test System II
In the second phase, to show the robustness of the proposed PSS, a 10-machine, 39-bus New England system as shown in Fig.3 is considered. G_1 is an equivalent power source representing parts of the U.S. Canadian interconnection system. Details of this test system are given in [16]. For comparison purpose, it is assumed that all the generators except G_1 are equipped with PSS's.

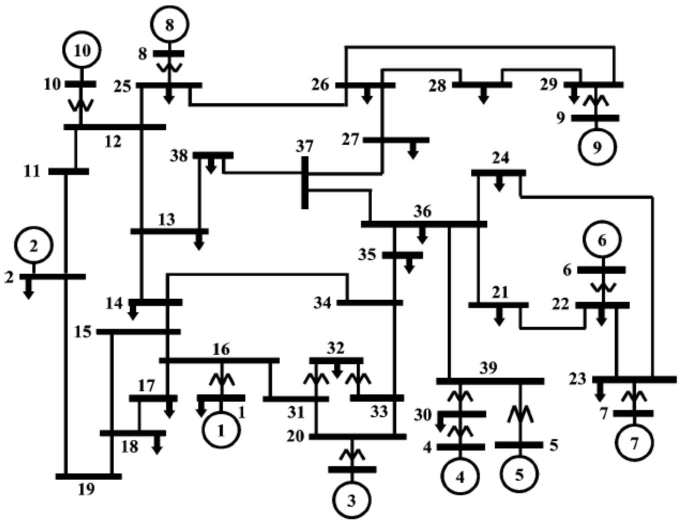

Figure 3: New England 10 Machine System.

Testing Strategy
The Conventional GA and ABGA techniques are applied to tune CPSS problem and the coding are written on MATLAB 7.4 packages and executed on Core2Duo, 2.1 GHz, and 3GB RAM processor.

Parameter Selection of ABGA
The parameters for the ABGA design were configured in the following way: Table I gives the parameters used for ABGA optimization compared with the Conventional Genetic Algorithm.

Table I: Parameters used for optimization.

Parameters	CGAPSS	ABGAPSS
Chromosome representation	Binary	Real
Population	100	100
Generation	80	60
Mutation	0.01	0.01(Adaptive)

Stopping Criteria
The algorithm is stopped based on the maximum number of iterations.

Simulation Results of Test System 1
To demonstrate the robustness of the proposed approach the following scenarios are considered.

- The base operating condition
- Outage of line between bus 7 and 8
- Shift in generation of 50 MW in G_2

In order to facilitate comparison with CPSS, the method in [18] was adopted for the design of the CPSS for this multimachine power system. The ultimate values of the optimized parameters of the ABGAPSS, CGAPSS and the CPSS parameters are given in Table II.

Table II: Optimized parameters of Test system I.

Techniques	Generator	K_s	T_1	T_2	T_3	T_4
CPSS	G_2	14.78	0.2425	0.4547	0.1861	0.1787
	G_3	19.83	0.5465	0.5675	0.1392	0.1473
CGAPSS	G_2	20.78	0.6687	0.2325	0.2324	0.1343
	G_3	36.09	0.6338	0.4576	0.2623	0.2321
ABGAPSS	G_2	21.87	0.4876	0.3657	0.1523	0.1100
	G_3	39.63	0.6567	0.4554	0.1301	0.1048

The electromechanical modes and the damping ratios obtained from all operating conditions, both with CGAPSS, ABGAPSS and without PSS in the system are specified in Table III. When PSS is not mounted, we can conclude that some of the modes are poorly damped and in rare cases they are unstable (highlighted in Table III). From the Table III, it makes public that the damping ratio and negative real part is prominent compared to the conventional techniques.

Table III: Eigenvalues and damping ratios of the electromechanical modes.

Scenarios	Without PSS	CPSS	GAPSS	ABGAPSS
Case1	-0.025± 8.912,0.098 -0.026 ± .239,0.165	-1.54 ± j4.44,0.327 -1.35± j2.51,0.473	-3.656 ± j8.454,0.397 -3.547 ± j18.653,0.48	-3.978 ± j2.768,0.367 -3.916 ± j4.234,0.487
Case2	-0.107± 5.887,0.037 -0.042 ±8.967,0.036	-1.64 ± j4.07,0.373 -1.23 ± j3.12,0.366	-2.389 ± j7.543,0.378 -4.786 ± j19.587,0.39	-4.888± j4.664,0.378 -4.768 ± j6.765,0.498

Case3	0.045 ± j6.867,0.09 -0.023 ± 9.856,0.63	-1.92 ±j4.63,0.383 -1.01 ±j4.28,0.227	-2.856 ±j8.659,0.385 -3.666±j18.868,0.23	-4.869 ± j4.789,0.297 -3.843 ± j7.639,0.465

Nonlinear Time- Domain Simulation

To access the success and strength of the proposed controller, the performance of the projected controller under transient conditions is established by pertaining a 6 cycle three phase fault at t=1 sec, at bus 7 at the end of the line 5-7 is considered [18]. The fault is cleared by permanent tripping of the faulted line. The speed deviations of the Generator G_2 under the three scenarios are shown in Figures 4, 5 and 6.

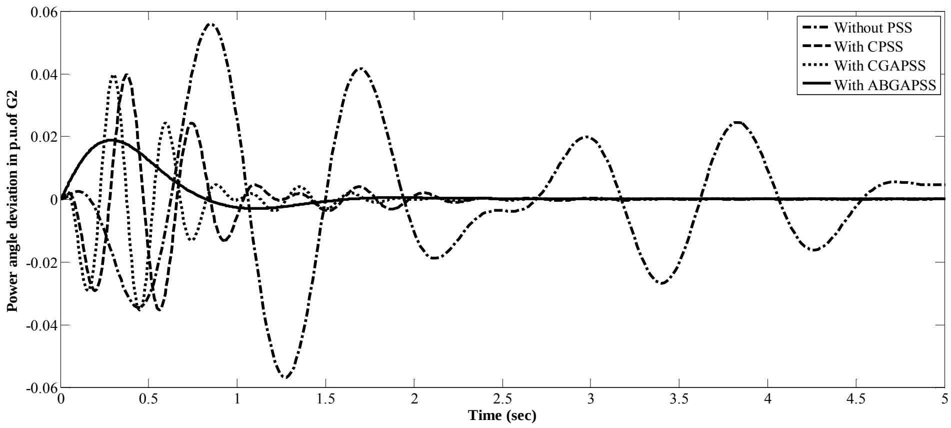

Figure 4: Power angle deviation of G_2 under scenario 1.

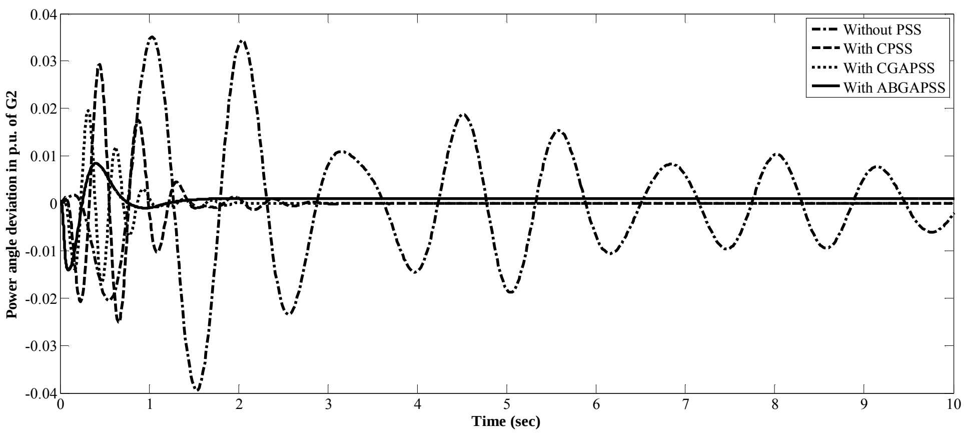

Figure 5: Power angle deviation of G_2 under scenario 2.

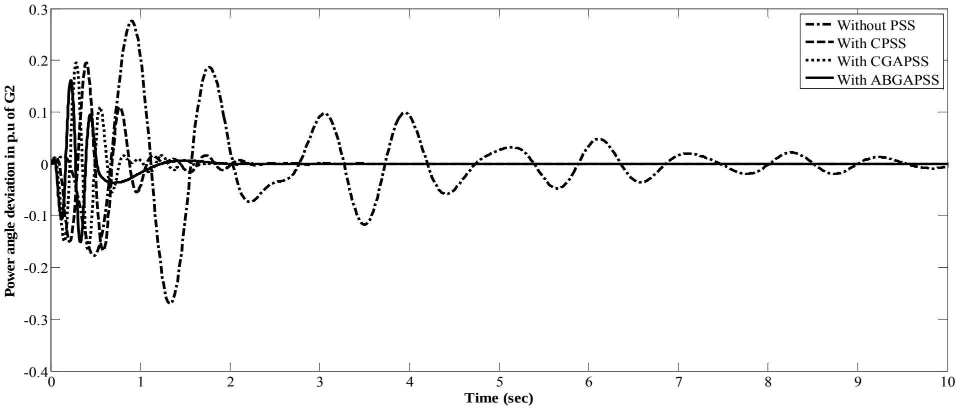

Figure 6: Power angle deviation of G_2 under scenario 3.

The results show that the system was adequately damped when equipped with the ABGAPSS. The performance is poor for CPSS and obviously with open loop. Performance of the CGA proposed in [19] and ABGA is close, even though the ABGA outperforms the CGA just slightly in all three operating conditions considered. Also it can be inferred that the maximum overshoot has been reduced by the proposed ABGAPSS. Thus for diverse operating conditions the projected technique functions fabulously within short duration in damping.

Convergence Test

Since ABGAPSS is a population based technique, to test the performance 50 trials were conducted. Out of 50 trails, the success rate (best damping) of the proposed algorithm is very high (93% for ABGAPSS) compared to CGAPSS (90%).Also from Fig.7 it can be inferred that CGAPSS takes around 100 iterations [19] to converge whereas ABGAPSS takes only about 60 iterations.

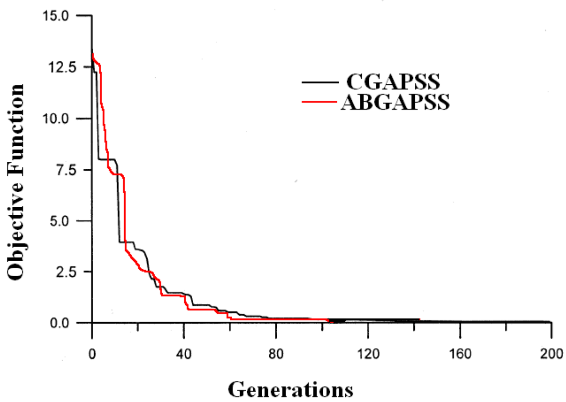

Figure 7: Convergence Characteristics.

Simulation Results of Test System II

To demonstrate the stiffness of the proposed emerging technology under brutal conditions and decisive line outages, two unusual operating conditions in accumulation to the base case is considered [20]. They can be specified as

- The base operating condition
- Outage of line 21-22
- Outage of line 14-15

The final values of the optimized parameters of the ABGAPSS are given in Table IV.

Table IV: Optimized parameters of ABGAPSS for Test System II.

Gen	K_s	T_1	T_2	T_3	T_4
G_2	49.0065	0.4325	0.0234	0.5455	0.0146
G_3	31.9876	0.7878	0.0281	0.6764	0.0456
G_4	43.4535	0.6576	0.0523	0.5678	0.5421
G_5	45.9876	0.2434	0.0654	0.3545	0.0345
G_6	49.5775	0.7665	0.0214	1.5456	0.0675
G_7	1.2478	0.4566	0.0227	0.5346	0.2314
G_8	26.8757	0.8766	0.0154	0.6875	0.2130
G_9	5.7895	0.2456	0.0567	0.2768	0.3045
G_{10}	20.9941	1.6465	0.0453	1.2331	0.3213

Nonlinear Time- Domain Simulation

The ABGAPSS is placed at all the generators except G_1 which is connected to the reference bus. The swing curves of all the generators with and without the ABGAPSS are shown in Figs.8 and 9. From the simulation results it is apparent that, the proposed approach finally directs all the 10 generators to stable condition when the system is installed with the proposed ABGAPSS. Therefore the proposed approach can be used to perk up the solution quality of classical methods.

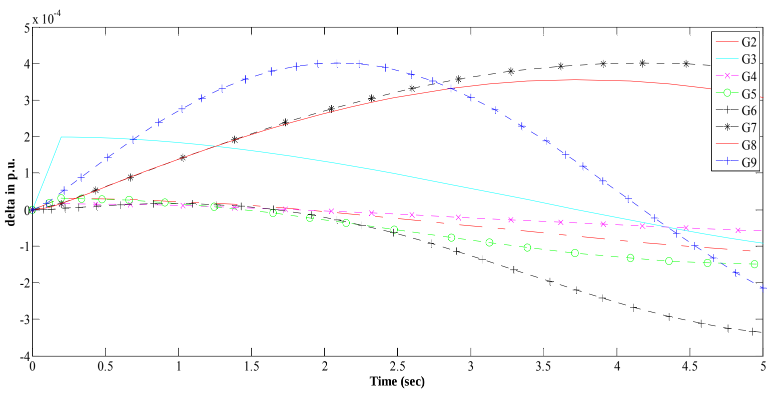

Figure 8: Swing curves for Test System II without PSS.

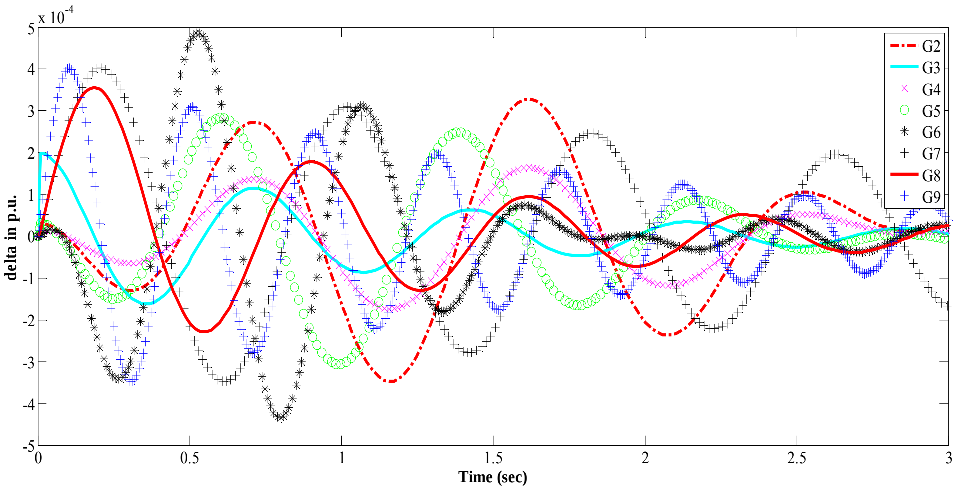

Figure 9: Swing curves for Test System II with ABGAPSS.

Stability analysis using Bode plot for Test System II

The closed loop frequency response for the compensated test system II is shown in Fig.10. From the simulation results it is clear that the performance indices associated with the frequency response are generally accepted values and the system is highly stable if the above outlined PSS is mounted on the system.

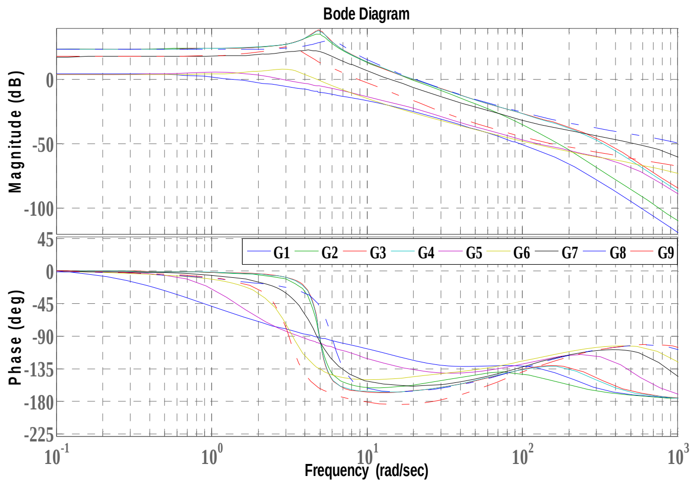

Figure 10: Closed loop frequency response of Test System II with ABGAPSS.

Comparison of critical clearing time of different techniques

In a three phase fault of 100ms duration at bus 29, followed by tripping of 29-26 or 29-28, the system is unstable with either of the PSS [11]. For these cases, the critical clearing times (which is determined by solving the swing equation given in Appendix 2) beyond which the system losses synchronism are given in Table V.

Table V: Comparison of critical clearing time (in ms).

Faulty Bus	Line	CPSS	CGAPSS	ABGAPSS
29	29-28	83	90	92
29	29-26	86	92	96
26	29-26	81	87	90
28	29-28	76	82	86

When the ABGAPSS is incorporated in the system it is observed that the critical clearing time has increased.

Comparison of performance indices of time response

The performance indices associated with the closed – loop frequency responses are given in Table VI. From the table it is clear that the performance indices are generally accepted values and characterizes the system as a very good damping system.

Table VI: Performance indices of Test system II.

S.No.	P_L (p.u.)	Q_L (p.u)	Type	Settling time (T_s),s	Rise time (T_r),s	Over shoot ($\times 10^{-3}$)	Peak Value	Stead y state error ($\times 10^{-5}$)
1	0.9	0.3	Conventional PSS	2.1	0.4124	8.969	1.75	2.432
			Existing GAPSS	1.8	0.3747	8.58	1.64	1.765
			Proposed ABGAPSS	1.3	0.3434	7.889	1.21	1.35
2	0.97	0.69	Conventional PSS	1.9	0.33	7.989	2.04	9.234
			Existing GAPSS	1.5	0.2876	7.089	1.55	8.569
			Proposed ABGAPSS	1.3	0.2674	6.9	1.15	7.896
3	1.05	0.7	Conventional PSS	2.2	0.4233	7.624	1.93	6.356
			Existing GAPSS	1.8	0.3245	6.986	1.51	5.67
			Proposed ABGAPSS	1.2	0.27	7.012	1.23	4.876
4	1.11	0.8	Conventional PSS	1.9	0.3243	7.124	2.03	9.934
			Existing GAPSS	1.5	0.2435	6.788	1.48	9.018
			Proposed ABGAPSS	1.0	0.2123	5.98	1.22	8.686
5	1.25	0.5	Conventional PSS	2.0	0.342	5.345	1.80	3.99
			Existing GAPSS	1.3	0.2323	4.745	1.62	3.445
			Proposed ABGAPSS	1	0.21	4.81	1.32	3.119

Conclusion

A new adaptive breeded genetic optimization approach for designing power system stabilizer for multi machine systems has been presented. The designed PSS attains near optimal overall power system stability performance, including oscillation stability performance and transient stability performance. The problem of selecting the PSS parameters is converted to a new breed optimization problem which simultaneously improves the damping at various operating conditions. Simulated results have demonstrated the effectiveness of this robust algorithm. It is shown that the proposed robust optimization provides very good damping characteristics and enhances the dynamic stability of the system. Its level of robustness to system load variations is better than conventionally tuned GAPSS. Also it is more superior and positive response generator when compared to the conventional Genetic Algorithm.

Appendix 1: Modeling of power system components

Generator

The generator is represented by third order model comprising the electromechanical swing equation and the generator internal voltage equations given by

$$\dot{\delta} = \omega_0 \omega$$

$$\dot{\omega} = \frac{1}{M}(P_m + G + K_d \omega - P_e)$$

$$\dot{E}_q^{'} = \frac{1}{T_{d0}^{'}}[E_{fd} - (x_d - x_d^{'})i_d - E_q^{'}]$$

$$\dot{E}_{fd} = \frac{1}{T_e}\left[-E_{fd} + K_e(V_{ref} + V_{PSS} - V_t)\right]$$

$$T_e = E_q^{'} i_q + (x_d^{'} - x_q^{'}) i_d i_q$$

The stator algebraic equations are given by

$$E_q^{'} + x_d^{'} i_d - R_a i_q = V_q$$

$$-x_d^{'} i_d - R_a i_d = V_d$$

The expressions for δ_s, $E_q^{'}$, i_d, and i_q can be derived from the phasor diagram [21]

$$\delta_s = \tan^{-1}\left[\frac{P_s(x_t + x_q) - Q_s(R_a + R_t)}{P_s(R_a + R_t) + Q_s(x_t + x_q) + V_s^2}\right]$$

Where

$P_s = V_s I_a \cos\Phi$

$Q_s = V_s I_a \sin\Phi$

From stator algebraic equation, $E_q^{'}$ is given by

$$E_q^{'} = \frac{(x_t + x_d^{'})}{x_t}\sqrt{V_t^2 - \left(\frac{x_d}{(x_t + x_q)} V_s \sin\delta_S\right)^2} - \frac{x_d^{'}}{x_t} V_S \cos\delta_S$$

The expression for i_d and i_q are as follows:

$i_d = BE_q' - YV_s\cos(\delta_S + \alpha)$

$i_q = GE_q' - YV_s \sin(\delta_S + \alpha)$

Where

$\dot{\delta}$ = Rotor angle in degrees

ω = angular speed in rad/s

P_m = Mechanical power developed by the generator

K_d= Damping constant of the generator

P_e = Electrical Power delivered in p.u.

x_d ,x_q= Direct and quadrature axis reactance of the generator in p.u.

E_d, E_q = Direct and quadrature axis voltages behind the transient reactance in p.u.

Exciter and PSS

The block diagram representing the thyristor type excitation system and PSS accommodated with the generator is shown in Fig.1 which is modeled with the following equations

$$\dot{E}_{fd} = \frac{K_A}{T_A}(V_{ref} - V_t - U_{PSS}) - \frac{E_{fd}}{T_A}$$

$$P_e = v_d i_d + v_q i_q$$

and $$V_t = (v_d^2 + v_q^2)^{\frac{1}{2}}$$

$$with\ v_d = E\sin\delta - (x_q i_q)D_s, v_q = E_q' - x_d' i_d\ and$$

$$G = \left(K_{G1} + \frac{K_{G2}}{1+sT_G}\right)$$

$$U_{PSSi} = \frac{K_s sT_w}{1+sT_w}\left[\frac{(1+sT_{1i})(1+sT_{3i})}{(1+sT_{2i})(1+sT_{4i})}\right].\Delta\omega i(s)$$

Where K_A and T_A = gain and time constants of the exciter

V_{ref} = reference voltage in p.u.

V_t= Terminal voltage in p.u.

E_{fd} = Field Voltage of the Generator in p.u.

K_{G1} and K_{G2} are the gain constants of the Governor

K_{p} = Gain of the PSS

T_1, T_2, T_3, T_4 = Time constants of the PSS

D_s = Damping Coefficient of PSS

U_{PSS} = Output of PSS in p.u.

T_w = Washout Time Constant

Appendix 2: Swing Equation of multimachine systems

In the multimachine system model, the loads are assumed to be constant impedance and converted into admittances as

$$\bar{Y}_{Li} = \frac{-(P_{Li} - jQ_{Li})}{V_i^2} \text{ where i = 1 to m}$$

The network equations for the new augmented network can be written as

$$\begin{bmatrix} \bar{I}_A \\ 0 \end{bmatrix} = \begin{bmatrix} \bar{Y}_A & \bar{Y}_B \\ \bar{Y}_C & \bar{Y}_D \end{bmatrix} \begin{bmatrix} \bar{E}_A \\ \bar{V}_B \end{bmatrix}$$

This can be reduced to

$$\bar{I}_A = \left(\bar{Y}_A - \bar{Y}_B \bar{Y}_B \bar{Y}_D^{-1} \bar{Y}_C \right) \bar{E}_A = \bar{Y}_{\text{int}} \bar{E}_A$$

Where the elements of $\bar{I}_A$ and $\bar{E}_A$ are

$$\bar{I}_i = (I_{di} + jI_{qi}) e^{j(\delta_j - \Pi/2)}$$

$$\bar{E}_i = E_i \angle \delta_i$$

The elements of $\bar{Y}_{\text{int}\,i}$ are $\bar{Y}_{iji} = \bar{G}_{iji} + \text{j}\,\bar{B}_{iji}$

For the simulation of the multimachine system, first the admittance matrix (Y) of the system is calculated and the complexity of transient stability analysis is reduced by considering all the rotor angles of synchronous machines coincides with angle of the voltage behind the transient reactance and all the machines are assumed to swing at coherent. The power flow equation of ith machine is calculated by

$$P_{ei} = \sum_{j=1}^{m} \left| E_i^{'} \right| \left| E_j^{'} \right| \left| Y_{ij} \right| \cos(\theta_{ij} - \delta_i + \delta_j)$$

and the Swing equation is

$$\frac{H}{\pi f}\frac{d^2\delta_i}{dt^2} = P_{mi} - \sum_{j=1}^{m} |E_i^{'}||E_j^{'}||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j)$$

References

[1] Tridip Kumar Das, Ganesh Kumar Venayagamoorthy, Usman O. Aliyu, "Bio-Inspired Algorithms for the Design of Multiple Optimal Power System Stabilizers: SPPSO and BFA", IEEE Transactions on Industry Applications, 44(2008), 1445-1457.

[2] P.Kundur,"Power System Stability and Control "McGraw Hill Inc.1993.

[3] N.S.D. Arrifona, V.A.Oliviera, R.A.Ramos N.G.Bretas, and R.V .Oliviera, " Fuzzy Stabilization of Power Systems in a Co-Generation Scheme Subject to Random Abrupt Variations of Operating Conditions", IEEE Transactions on Control System Technology,15(2007),384-393.

[4] E.V.Larsen and D.A.Swann "Applying Power System Stabilizers Part-I: General Concepts ", IEEE Transactions on Power Apparatus and Systems, 100, (1981), 3017-3024.

[5] A. Phiri , K.A.Folly , " Application of Breeder GA to Power System Controller Design" IEEE Swarm Intelligence Symposium 2008, St Louis , MO, September 21-23,2008.

[6] Severus Sheetekela, Komla Folly, Om P Malik , " Design and Implementation of Power System Stabilizers based on Evolutionary Algorithms" IEEE AFRICON 2009, September 23-25,2009.

[7] M.A.Abido and Y.L.Abdel Magid, "A Genetic- Based Power System Stabilizer", IEEE Transactions on Electric Machines and Power Systems, 26(1998), 559-571.

[8] S. PN Sheetekala, K.A Folly, "Optimization of Power System Stabilizer using Genetic Algorithm Techniques Based on Eigenvalue Analysis", SAUPEC 2009, 28-29 January 2009.

[9] John Greene, "The Basic Idea behind the Breeder Genetic Algorithm", Department of Electrical Engineering, Technical Report, University of Cape Town, 23 August 2005.

[10] S.Q.Yuan and D.Z. Fang, Robust PSS Parameter Design Using a Trajectory Sensitivity Approach, IEEE Transactions on Power Systems, 24(2009), 1011-1018.

[11] Seung - Mook Baek , Jung- Wook Park and Ian A. Hiskens, Optimal Tuning for Linear and Non Linear Parameters of Power System Stabilizers in Hybrid System Modeling, IEEE Transactions on Industry Applications, 45 (2009) 87-97.

[12] [On line]. Available: http:// psdyn.ece.wise. edu / IEEE_bench marks/ index.html.

[13] D.E.Goldberg,"Genetic algorithm in Search, Optimization and Machine Learning", Addison-Wesley, 1989.

[14] Heinz Muhlenbein, Dirk Schlierkamp-Voosen, “The Science of Breeding and its Application to the Breeder Genetic Algorithm BGA, Evolutionary Computation, 1(1994), 335-360.
[15] I. De Falco, R.Del Balio, A. Della Cioppa and E.Tarantino, “Breeder Genetic Algorithms for Airfoil Design Optimization”, IEEE International Conference on Evolutionary Computation, (1996), 71-75.
[16] M.A.Pai, Energy Function Analysis for Power System Stability, Norwell, MA: Kluwer 1989.
[17] E.V.Larsen and D.A.Swann “Applying Power System Stabilizers Part-II: Performance Objectives and Tuning Concepts “, IEEE Transactions on Power Apparatus and Systems, 100 (1981), 3024-3033.
[18] P.M.Anderson and Fouad, A.A, Power System Control and Stability,Ames IA: Iowa State Univ. Press, 1977, First Edition.
[19] Y.L.Abdel Magid and M.A.Abido, Optimal Multiobjective Design of Robust Power Systems Stabilizers Using Genetic Algorithms, IEEE Transactions on Power System, 18(2003), 1125-1132.
[20] M.A.Abido, Optimal Design of Power System Stabilizers Using Particle Swarm Optimization, IEEE Transactions on Energy Conversion 17(2002), 406-413.
[21] Gurunath Gurrala and Indraneel Sen, Power System Stabilizers Design for Interconnected Power Systems, IEEE Transactions on Power Systems, 25(2010) 1042-1051.

VITAE

M. Mary Linda received her B.E(Electrical and Electronics Engg;) degree from Noorul Islam College of Engineering, Kumaracoil in the year 2002 and her M.E (Power Systems) from Arulmigu Kalasalingam College of Engineering, Srivilliputhur in the year 2005. She has achieved the Gold Medal in P.G Degree from Anna University, Chennai in the year 2005. She has the teaching experience of six years. Her current research interests are AI techniques and power system stability.

Dr. N. Kesavan Nair obtained his B.Sc (Engg) and M.Sc (Engg) in Power Systems from Kerala University and Ph.D from I.I.T Kharagpur. He started his career in 1965 as Lecturer in Electrical Engineering in College of Engineering, Trivandrum and retired from government service as Professor in 1997. In between he has worked as Joint Director in LBS Centre for Science and Technology, Trivandrum coordinating the consultancy works of the centre. Since 1997 he has been working as visiting Professor of Electrical Engineering in various Engineering Colleges. He is actively engaged in teaching and research in the fields of Electrical Machines and Power Systems. Dr Nair has to his credit a few publications also in this area at National and International level.