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Robust control of Multi Machine Power System Using Intelligent Control methods and their Performance Comparison

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Abstract: This paper is deals with the robustness property of various intelligent control methods namely Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Bacterial Foraging Algorithm (BFA), and Harmony Search Algorithm (HSA) for the design of Power system stabilizer for multi machine power system. The problem of robustly tuning of PID based stabilizer design is formulated as an optimization problem according to the time domain-based objective function with some performance indices which is solved by intelligent control methods that have a strong ability to find the most optimistic results. To demonstrate the effectiveness and robustness of the proposed stabilizers, the design process takes a wide range of operating conditions and system configuration into account. The comparison is carried out in terms of robustness, peak over shoot and settling time of the system dynamic response. For completeness, the performance of conventional controllers is also included. The results of these studies show that the proposed intelligent control methods based PID type stabilizers have an excellent capability in damping power system oscillations and enhance greatly the dynamic stability of the power system in addition to maintaining robustness for a wide range of loading conditions.

Keywords: Intelligent Controllers, Power System Stabilizer, PID Controller, Power System Stability

INTRODUCTION

Desirable features of electric power system are stable operation, voltage regulation, and maximum power transfer capability. These requirements are achieved by providing efficient excitation controllers on synchronous machines. An excitation controller consists of voltage regulator and power system stabilizer (PSS). The voltage regulator keeps the terminal voltage reasonably constant for different load conditions. Because of poorly damped mechanical modes of oscillations which are inherently present in the system, voltage regulator alone is not adequate to stabilize the power system without oscillations. Therefore, it is essential to install power system stabilizers on all or some of the synchronous machines to improve overall system damping characteristics. Several methods have been proposed in the past for the design of power system stabilizer [1-8]. These methods incorporate traditional methods of controller design [1-5] as well as the application of recently developed intelligent control methods such as Artificial Neural Networks(ANN) [6], Fuzzy logic principles [7], and Genetic Algorithms(GA) [8]. It was shown that the intelligent control methods are more optimistic than traditional methods.

The aim of the present work is to make a comprehensive comparative study and evaluation of the application of intelligent control methods on the design of PSS. Four types of intelligent controllers namely GA, PSO, BFA and HSA based controllers have been designed and tested in multi machine power system. For completeness conventional controller such as Lead-Lag has been developed for multi machine system. The performances of the system employing these controllers have been computed for different operating points of the power system. Comparison is then carried out in terms of controller robustness as well as peak overshoot and settling time of the system dynamics. The merits and demerits of different control strategies are compared and presented. Further, it is observed that in all the above cases HSA based PID-PSS gives better dynamic response curves in terms of overshoot, rise time and settling time in comparison with conventional and other soft computing methods.

Power system model studied

A four-machine, two-area study system, shown in Fig. 1, is considered for the damping controller 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 the 230 kV transmission line. There is a power transfer of 400 MW from Area 1 to Area 2. The detailed bus data, line data, and the dynamic characteristics for the machines, exciters, and loads are given in [18]. The loads are modeled as constant impedances. For the power system stability analysis, a reasonably accurate mathematical model which takes into account the nonlinear ties in the system is highly essential. The two-axis model (fourth order) given in [18] is used for the time domain simulations study for each machine. The loads are modeled as constant impedances. A first order model of a static type automatic voltage regulator is used. Nonlinear dynamic equations of each machine can be summarized as follows:

$$\dot{\delta}_i = \dot{\omega}_b(\omega_i - 1) \qquad (1)$$
$$\dot{\omega}_i = \frac{1}{M_i}(P_{mi} - P_{ei} - D_i(\omega_i - 1)) \qquad (2)$$
$$\dot{E}'_{qi} = \frac{1}{T'_{doi}}(E_{fdi} - (X_{di} - X'_{di})\, i_{di} - E'_{qi}) \qquad (3)$$
$$\dot{E}'_{fdi} = \frac{1}{T'_{Ai}}(K_{Ai}(V_{refi} - V_i + U_i\,) - \ E_{fdi} \qquad (4)$$
$$T_{ei} = E'_{q\,i}\, i_{qi} - (X_{qi} - X'_{di})\, i_{di} i_{qi} \qquad (5)$$

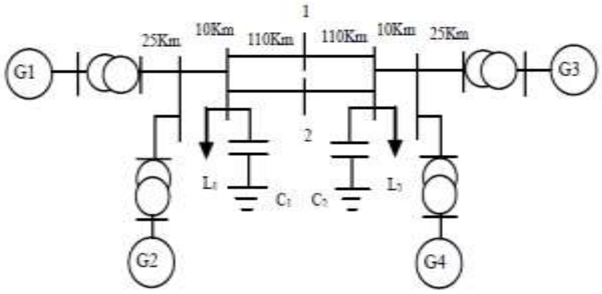

Fig-1: Single Line Diagram of Two Area Power System

Design of pidpss for multi machine power system

This section describes how the intelligent control methods are employed to tune the PID type PSS parameters for the two-area multi-machine power system which is shown in Fig.1. The operating function of a PID type 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 supplementary stabilizing signal considered is one proportional to speed. A widely used speed based PIDPSS is considered throughout the study. The transfer function of the *i*th PID type stabilizer is given by:

$$U_i = \frac{T_W S}{1+T_W S}\left(K_{Pi} + \frac{K_{ii}}{s} + \frac{K_{Di}\, S}{1+T_D\, S}\right) \Delta\boldsymbol{\omega}_{\mathrm{i}}(\mathrm{s}) \qquad (6)$$

where, T_D<<1 and usually is considered as $K_D/100$. $\Delta\omega_i$ is the speed deviation of the *i*th generator and U_i is the output signal fed as a supplementary input signal to the regulator of the excitation system. This type of PSS consists of a washout filter and a PID compensator. The washout filter, which really is a high pass filter, is regarded as to reset the steady-state offset in the output of the stabilizer. The value of the time constant *Tw* is usually not critical and it can range from 1 to 20 s. Just like any other optimization problem, an objective function (performance index) needs to be formulated to determine optimal parameters of PIDPSSs. The optimal values of these parameters depend upon the cost function used for optimization. Each individual in the intelligent control methods has an associated performance index (PI) value. The performance indices [14] used here are of the following form:

I. The integral of the square of the error criterion (ISE) which is given by

$$\mathrm{ISE}=10^4\, X \int_0^{tsim} (\,\Delta\omega_{12}^2 + \Delta\omega_{13}^2 + \Delta\omega_{14}^2 + \Delta\omega_{34}^2\,) \qquad (7)$$

The integral of time-multiplied absolute value of the error Criterion (ITAE). The criterion penalizes long-duration transients and is much more selective than the ISE. A system designed by use of this criterion exhibits small overshoot and well damped oscillations. It is given by

$$ITAE = 10^4 \int_0^{tsim} t(|\Delta\omega_{12}| + |\Delta\omega_{13}| + |\Delta\omega_{14}| + |\Delta\omega_{34}|) \qquad (8)$$

IAE integrates the absolute error over time. It doesn’t add weight to any of the errors in a systems response. It tends to produce slower response than ISE optimal systems, but usually with less sustained oscillations. It is given by

$$IAE = 10^4 \int_0^{tsim} (|\Delta\omega_{12}| + |\Delta\omega_{13}| + |\Delta\omega_{14}| + |\Delta\omega_{34}|) \qquad (9)$$
$$F = ISE + ITAE + IAE \qquad (10)$$

The optimal tuning of the PSS parameters is carried out by evaluating the fitness function (F) as given in equations (7)-(10) for the operating conditions as given in Table1.A 6-cycle three-phase fault is applied at the middle of one of the transmission lines between bus-7 and bus-8. In this study, the intelligent control methods work offline. For each PSS, the optimal setting of three parameters is determined by the intelligent control methods, i.e. 12 parameters are to be optimized.

Operating conditions of multi machine power system

To illustrate the performance of the proposed techniques, it is assumed that conventional PSSs are installed in generators 1-4. The main objective is to estimate the optimal parameters (K_p,K_i,K_d) using the proposed techniques associated with the PIDPSSs under the operating conditions listed in table 1 by minimizing the performance index given in equations (6-10).

Table-1: Operating conditions of multi machine power system

Condition	Case 1 Base case	Case 2 20% increase for system load in case1	Case 3 20% decrease for system load in case 1
P1	0.7778	1.084	0.7778
Q1	0.1021	0.3310	0.0502
P2	0.7777	0.7778	0.7777
Q2	0.1308	0.4492	0.0371
P3	0.7879	0.7879	0.7989
Q3	0.0913	0.1561	0.0794
P4	0.7778	0.7778	0.7778
Q4	0.0918	0.2501	0.0704

Intelligent control methods used

Genetic Algorithm (GA)

Genetic Algorithms are adaptive methods which may be used to solve search and optimization problems. Over many generations, natural populations evolve according to the principles of natural selection and *survival of the fittest*. By mimicking the process, genetic algorithms are able to `evolve' solutions to real world problems, if they have been suitably encoded. Detailed discussion on genetic Algorithm for the design of PSS is given in [8].

Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is a population based stochastic optimization technique developed by Eberhart and Kennedy [10,11]. It shares many similarities with evolutionary computation techniques such as Genetic Algorithms. Application of PSO for the design of PIDPSS parameters is discussed in [11]. The system is initialized with a population of random particles where each particle is a candidate solution. The particles fly through the problem space by following the current optimum particles and searches for optima by updating their positions. However, unlike GA, PSO has no evolution operators such as crossover and mutation. The advantages of PSO over GA are that programming can be written with ease while the convergence of the objective function is very fast.

Bacterial Foraging Algorithm (BFA)

Recently, bacterial foraging algorithm (BFA) has emerged as a powerful technique for solving optimization problems. The detailed operation and steps of BFA can be known form [10] BFA mimics the foraging strategy of *E. coli* bacteria which try to maximize the energy intake per unit time. From the very early days it has drawn attention of researchers due to its effectiveness in the optimization domain. To improve its performance, a large number of modifications have already been undertaken. The Bacterial Foraging Algorithm consists of four principal mechanisms, namely chemotaxis, swarming, reproduction and elimination-dispersal.

Harmony Search Algorithm (HSA)

Harmony Search Algorithm (HSA) is based on the musical process of searching for the perfect state of harmony. Musicians, during a rehearsal or a performance, try to create pleasing sounds and approach the ideal state of harmony. HSA is inspired from the artificial phenomenon of creating sounds, imitating musicians' behavior. Just as the musicians try to improve their music (based on aesthetic and acoustic criteria), the algorithm seeks for certain values that optimize the objective function and at the same time satisfy the problem's constraints. And in the same way a music band improves rehearsal after rehearsal, HSA improves iteration after iteration. Design of PIDPSS parameters using HSA is well explained in [9,13].

Performance comparison of robust control methods

In order to validate the effectiveness and performance of the employed algorithms, it is necessary to comparethe results obtained by these techniques. In power system, operating condition changes very fast. It is a well-known fact that when the load increases the performance of the power system stabilizer becomes poorer and poorer. If the designed PIDPSS works effectively for the increase in loading condition it is understood that it can work effectively in the remaining operating conditions. The operating condition 2 (20% increase in load) is chosen for the comparative study. The comparisons of different algorithms are based on the convergence with the objective function and speed response curves. PIDPSSs parameters obtained for case 2 by all the intelligent control methods are used for the simulation of the power system. The convergence characteristics of different intelligent control methods with number of iterations are depicted in figure 3. This figure shows the variation of objective function value at each iterative step with each optimization algorithm. From figure 3, it is noticed that BFA converges fast when compared to all the other algorithms. It starts to converge to optimal solution from 30 iterations than the remaining algorithms. The speed response curves obtained for all the generators with the intelligent control techniques based PIDPSSs are shown in figure 3-6. Time domain specifications of speed response curves are measured and listed in table 2.

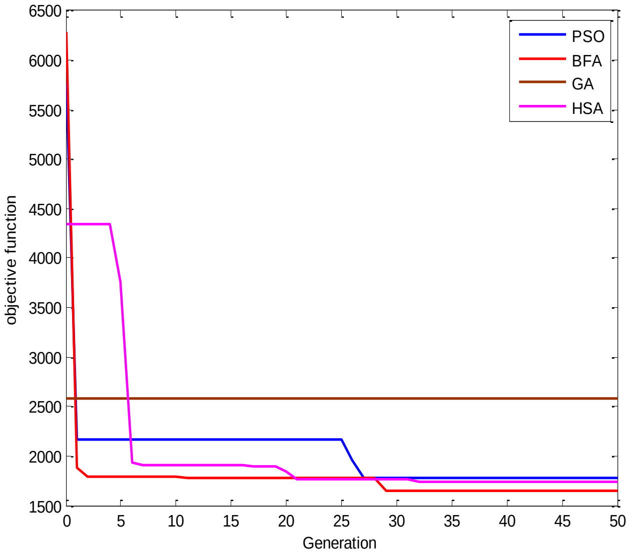

Fig-2: Variation of Objective function value for case 2

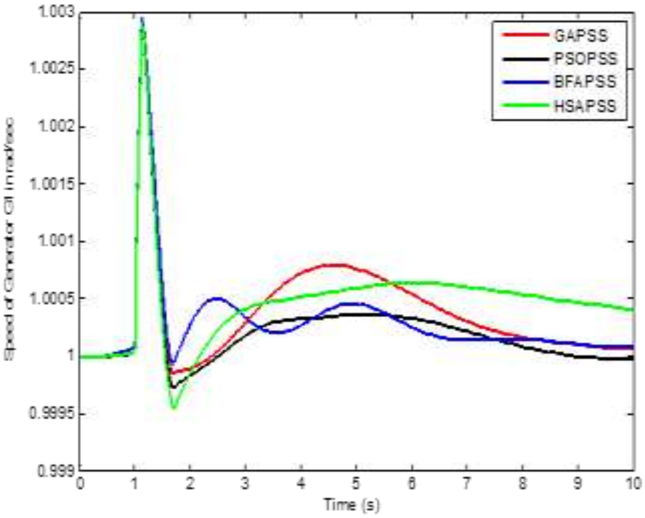

Fig-3: Inter area- Local mode oscillations of Generator 1 for operating condition 2 with different types of PIDPSSs

Table-2: Comparison of time domain specifications of intelligent control methods

Operating Condition	**Type of PSS**	**Generator**	**% Under shoot**	**% Over shoot**	**Settling time in Sec**	**Steady state error**
OP2 (20% Increase in Load case 1)	GAPSS	G1	0	0.29	7	0
		G2	0.06	0.35	8	0
		G3	0.43	0.22	6	0
		G4	0.43	0.25	5.5	0
	PSOPSS	G1	0.1	0.27	8.4	0
		G2	0.2	0.34	9.4	0
		G3	0.6	0.22	9.4	0
		G4	0.6	0.20	5.6	0
	BFAPSS	G1	0.1	0.24	7.2	0
		G2	0.06	0.37	6.9	0
		G3	0.05	0.23	4.4	0
		G4	0.43	0.24	4.6	0
	HSAPSS	G1	0.12	0.27	7.2	0
		G2	0.13	0.34	6.4	0
		G3	0.48	0.22	4.2	0
		G4	0.4	0.25	4.3	0

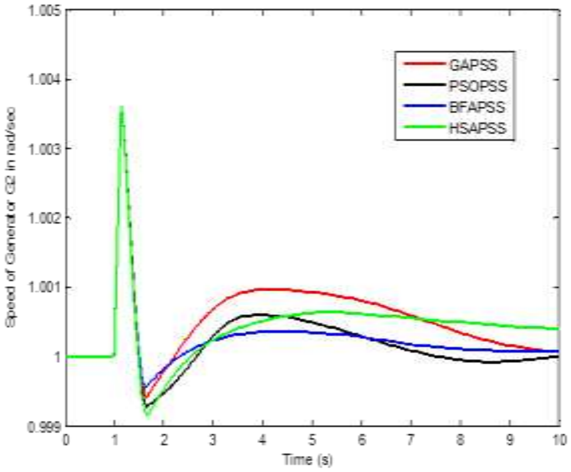

Fig-4: Inter area- Local mode oscillations of Generator 2 for operating condition 2 with different types of PIDPSSs

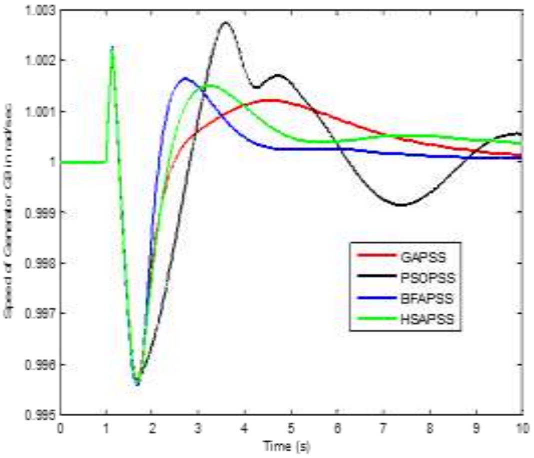

Fig-5: Inter area- Local mode oscillations of Generator 3 for operating condition 2 with different types of PIDPSSs

From the dynamic response curves obtained using the intelligent control methods it is observed that the steady state error is zero for all the controllers. It is further observed that the undershoots, overshoots and settling time are all more or less same for all the generators at all operating conditions. However, the convergence of objective function for BFA method is faster (30 iterations) followed by HSA, PSO and GA.

Robustness analysis of algorithms

In power system the operating condition changes very fast. The controller designed for one operating condition may not give satisfactory performance to other operating conditions. Therefore, it becomes necessary that the controller parameters need to be tuned according to the changes in the operating condition which is very difficult to accomplish online even using very fast computer. Therefore, it is necessary to design a PSS which is robust in behavior. Simulation is carried out for the power system with the parameters obtained for case 2 (20% increase in load) operating condition and retaining it for the remaining operating conditions. The response curves obtained with intelligent control methods based PIDPSS of the power system considered are shown in figure 7-10. From Figure 7-10, it is therefore possible to choose the PSS parameters obtained by intelligent control methods at any one operating condition which can be chosen and retained for other operating conditions also. Further, from the simulation results it is observed that, when the system is subjected to internal and external disturbances by retaining the same structure and parameter of the controller which was obtained for any one operating condition works effectively over a wide range of loading conditions which is otherwise very difficult to accomplish on line. This shows the robustness of the controller designed using intelligent control methods.

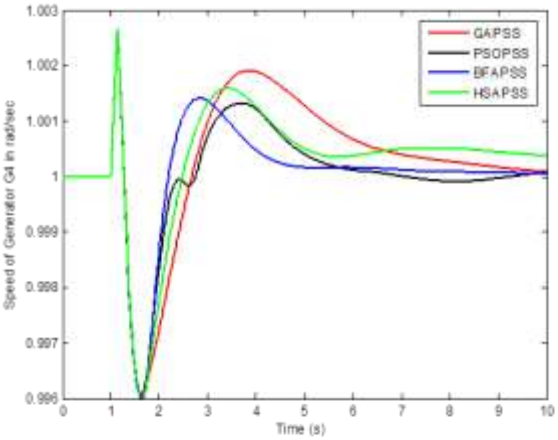

Fig-6: Inter area- Local mode oscillations of Generator 4 for operating condition 2 with different types of PIDPSSs

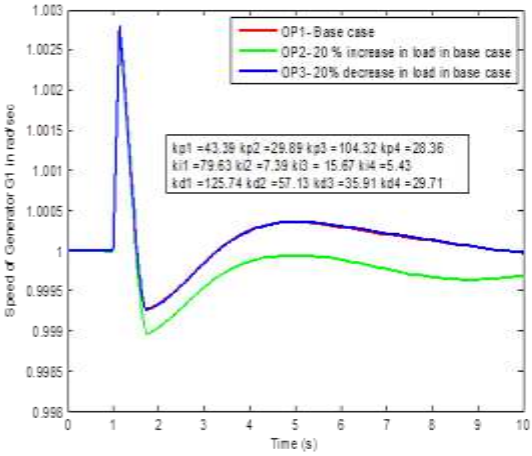

Fig-7: Inter area- Local mode oscillations of Generator 1 for different Operating conditions with Robust GAPSS

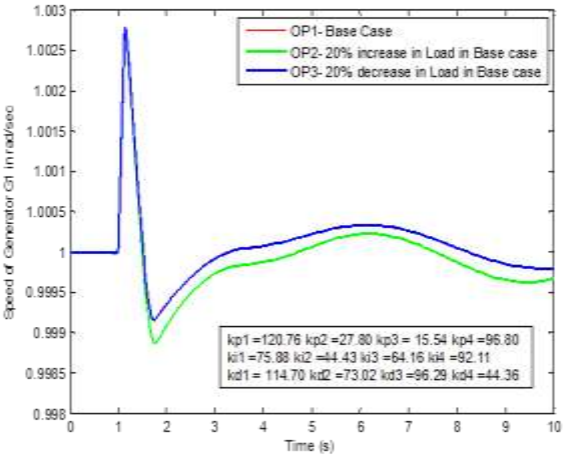

Fig-8: Inter area- Local mode oscillations of Generator 1 for different Operating conditions with Robust PSOPSS

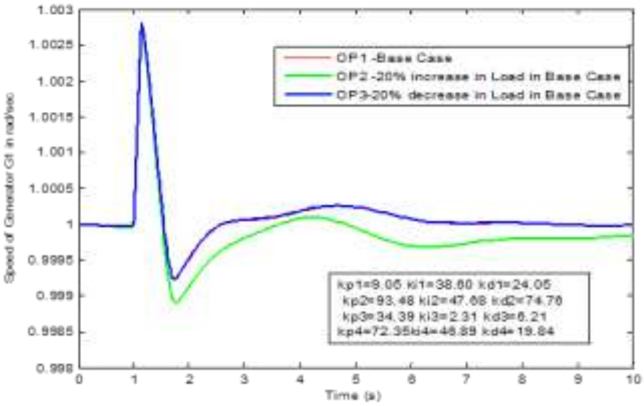

Fig-9: Inter area- Local mode oscillations of Generator 1 for different Operating conditions with Robust BFAPSS

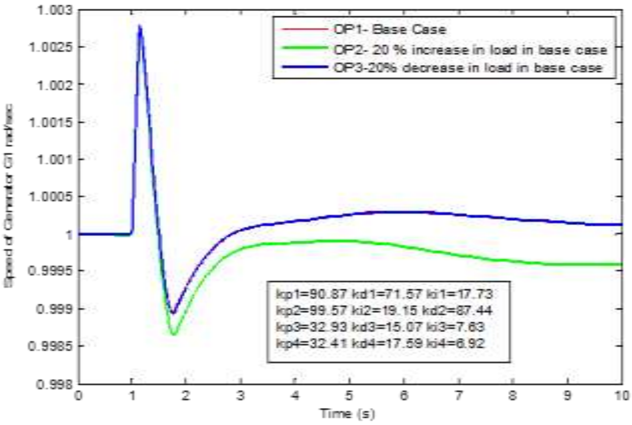

Fig-10: Inter area- Local mode oscillations of Generator 1 for different Operating conditions with Robust HSAPSS

The robustness property of the PIDPSS parameters designed based on GA, PSO,BFA and HSA are tested with all the four generator's dynamic characteristics. The PSS parameters for this purpose are chosen for the case 2 and simulation is carried out with the designed PIDPSSs. For Generator 1 there will be three graphs for three operating conditions. There are four intelligent control methods based PIDPSSs and thus the figure has 12 response curves which is shown in figure 11. From this figure it is evident that dynamic characteristics of the generator G1 do not vary appreciably when the operating conditions change. It has also been observed that this is true for the other three generators which are not included in this paper. Thus it approves that the intelligent control methods could optimize the parameters of power system stabilizer of multi machine system. Therefore, the proposed methods of tuning the PIDPSSs can be an attractive alternative to conventional fixed gain stabilizer design as it retains the simplicity of the conventional PSS and at the same time guarantees a robust acceptable performance over a wide range of operating and system condition.

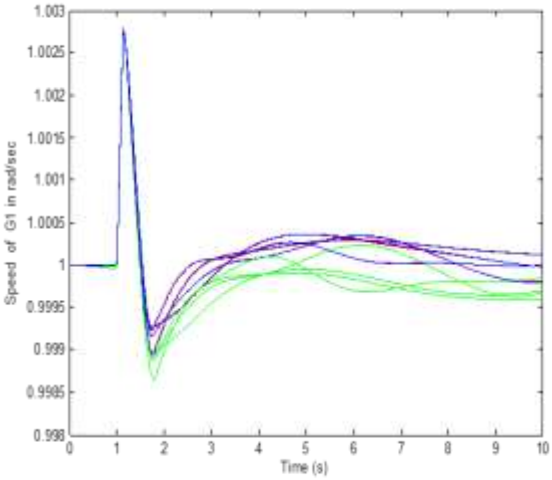

Fig-11: Inter area- Local mode oscillations of Generator 1 for operating condition 2 with different robust parameters.

CONCLUSION

This paper investigates the performance of different intelligent control methods for the design of PID Power System Stabilizer connected to two area four machine power systems. The design problem of the proposed controller is formulated as an optimization problem and GA, PSO, BFA and HSA are employed to search for optimal controller parameters. Simulation results assure the effectiveness and robustness of the proposed controller in providing good damping characteristic to system oscillations over a wide range of loading conditions. Thus it is concluded that a multi machine power system can be well stabilized using PIDPSS. Further, the optimum values of PID parameters can be determined by the application of intelligent control methods such as GA, PSO, BFA and HSA. Furthermore, due to robustness property of the PID parameters designed for any one operating condition of the power system can be retained for a wide range and there is no need to tune the PID parameters according to the change in the operating condition. Although the robustness property of all the four controllers do not differ much , it is observed that the objective function for BFA converges faster followed by HSA,PSO and GA.

REFERENCES

1. Anderson, P.M. and Fouad, A. A.(1977) - Power System Control and Stability- The Iowa State University Press, Ames, Iowa.
2. Yao-nan YU and Qiang-hua Li (1990), Pole placement power system stabilizers design of an unstable nine- machine system, *IEEE Trans. on power systems*.
3. Subramanya Sarma A.V.R.(1993), An efficient algorithm for the Co-ordinated synthesis of Power system stabilizers in multi machine power systems, *Ninth National convention of Electrical Engineers, Bangalore.*
4. Chen, C. L., & Hsu, Y. Y. (1987). Coordinated synthesis of multimachine power system stabilizer using an efficient decentralized modal control (DMC) algorithm. *IEEE Transactions on Power Systems*, *2*(3), 543-550.
5. Yuan-Yih Hsu and Chen-Hsing Cheng ,(1993),“A fussy based controller for Generator Excitation Control”,*IEEE Transactions on Systems*, *Man and Cybernetics*, Vol 23, No.2, MARCH/APRIL 1993.
6. ZhangY, Chen GP, Malik OP, Hope GS., “An artificial neural network based adaptive power system stabilizer,” IEEE Transactions on Energy Conversion 1993; 8:71-77.
7. Hsu YY, Cheng CH, (1993), A fuzzy controller for generation excitation control, *IEEE Transaction on Systems* , Man and Cybernetics ;23(2):532-539.
8. .K. Sundareswaran and S. Razia Begum (2004), Genetic tuning of a Power system stabilizer, *European transaction on electrical power*; 14:151-160.
9. Kalifullah Abdul Hameed, Sankaran Palani,(2014),Robust Design of Power System Stabilizer using Harmony Search Algorithm, *Automatika*, Atkaff 55(2), 162–169.
10. Abd-Elazim, S. M., & Ali, E. S. (2013). A hybrid particle swarm optimization and bacterial foraging for optimal power system stabilizers design. *International Journal of Electrical Power & Energy Systems*, *46*, 334-341.
11. Soliman, H. M., Bayoumi, E. H., & Hassan, M. F. (2008). PSO-based power system stabilizer for minimal overshoot and control constraints. *Journal Of Electrical Engineering-Bratislava-*, *59*(3), 153.
12. Shayeghi, H., Ghasemi, A., & Shayanfar, H. (2011). PID type stabilizer design for multi machine power system using IPSO procedure. *Computer Science and Engineering*, *1*(2), 36-42.
13. Sambariya, D. K., & Gupta, R. (2016, March). Effective PID-PSS design using bat algorithm for SMIB power system. In *Power Systems (ICPS), 2016 IEEE 6th International Conference on* (pp. 1-6). IEEE.