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

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

September 2012 Issue 12 Volume 4 Number 3 Pages 24-31

OPTIMAL DESIGN OF POWER SYSTEM STABILIZER USING IMPROVED ABC ALGORITHM

H. Shayeghi **A. Ghasemi**

Technical Engineering Department, University of Mohaghegh Ardabili, Ardabil, Iran
hshayeghi@gmail.com, ghasemi.agm@gmail.com

Abstract- This paper presents an Improved Artificial Bee Colony (IABC) algorithm to optimal tune of the Power System Stabilizer (PSS). In the IABC algorithm an interactive strategy is introduced by considering the universal gravitation to the movement of onlooker bees in the original Artificial Bee Colony (ABC) to enhance exploration ability of the ABC algorithm. The robustly PSS tuning problem is formulated as an optimization problem according to the time domain-based objective function for a wide range of operating conditions. It is solved by the IABC technique to reduce PSS design effort and find the best system damping characteristics. The proposed Improved ABC based PSS is tested on a in a Single-Machine connected to Infinite-Bus (SMIB) power system through the nonlinear time domain simulation and some performance indices. The results is compared with the original ABC based tuned stabilizer and conventional PSS to illustrate its robust performance. Results evaluation show that the optimized PSS using the proposed IABC algorithm achieves good damping of low frequency oscillations for wide range of system operation conditions and is superior to the other PSSs.

Keywords: PSS Design, IABC Algorithm, Low Frequency Oscillations, SMIB.

I. INTRODUCTION

Stability of power systems is one of the most important aspects in electric system operation .This arises from the fact that the power system must maintain frequency and voltage levels at the nominal values, under any disturbance, like a sudden increase in the load, loss of one generator or switching out of a transmission line during a fault [1]. By the development of interconnection of large electric power systems, there have been spontaneous system oscillations at very low frequencies in order of 0.2-3.0 Hz .Once started, they would continue for a long period of time. In some cases, they continue to grow, causing system separation if no adequate damping is available. Moreover, low frequency oscillations present limitations on the power-transfer capability. To enhance system damping, the generators are equipped with Power System Stabilizer (PSS) that provide supplementary feedback stabilizing signals in the excitation system. PSS augment the power system stability limit and extend the power-transfer capability by enhancing the system damping of low frequency oscillations associated with the electromechanical modes [2].

The lead compensator based stabilizers with fix parameters have practical applications and generally provide acceptable dynamic performance. However, the problem of PSS parameter tuning is a complex exercise. A number of the conventional techniques have been reported in the literature pertaining to design PSS namely: the eigenvalue assignment, mathematical programming, gradient procedure for optimization and also the modern control theory [2-5]. Unfortunately, the conventional techniques are time consuming as they are iterative and require heavy computation burden and slow convergence.

In addition, the search process is susceptible to be trapped in local minima and the solution obtained may not be optimal [4]. Also, a set of controller parameters which stabilize the system under a certain operating condition may no longer yield satisfactory results when there is a drastic change in power system operating conditions and configurations [5]. A more reasonable design of the PSS is based on the gain scheduling and adaptive control theory as it takes into consideration the nonlinear and stochastic characteristics of the power systems [6-7]. This type of stabilizer can adjust its parameters on-line according to the operating condition. Many years of intensive studies have shown that the adaptive stabilizer can not only provide good damping over a wide operating range but more importantly, it can also solve the coordination problem among the stabilizers. Many random heuristic methods, such as genetic algorithms, chaotic optimization algorithm, rule based bacteria foraging, honey bee mating optimization and particle swarm optimization (PSO) [8-13] have recently received much interest for achieving high efficiency and search global optimal solution in the problem space and they have been applied to the problem of PSS design.

These evolutionary based methods are heuristic population-based search procedures that incorporate random variation and selection operators. Although, these methods seem to be good approaches for the solution of the PSS parameter optimization problem, however, when the system has a highly epistatic objective function (i.e. where parameters being optimized are highly correlated), and number of parameters to be optimized is large, then they have degraded effectiveness to obtain the global optimum solution. Recently, the Artificial Bee Colony (ABC) technique is used for the optimal design of PSS [14]. However, the effectiveness of the original ABC greatly depends on the suitable movement of onlooker bees. The onlooker bee is designed to move straightly to the picked coordinate indicated by the employed bee and evaluates the fitness values near it in the original ABC algorithm in order to reduce the computational complexity.

Hence, the exploration capacity of the ABC is constrained in a zone. In order to overcome this drawback an interactive strategy for ABC algorithm called Improved ABC (IABC) technique is developed and proposed for optimal tune of PSS parameters to improve power system low frequency oscillations damping in this paper. Hence, to enhance exploration ability in the ABC, the concept of universal gravitation is introduced into the consideration of the affection between employed bees and the onlooker bees in the IABC. The main advantage of the IABC algorithm is simple concept, easy implementation, robustness to control parameters and computational effort.

The proposed method has been applied and tested on a weakly connected power system under wide range of operating conditions to show the effectiveness and robustness of the proposed IABC based tuned PSS and their ability to provide efficient damping of low frequency oscillations . To show the superiority of the proposed design approach, the simulations results are compared with the ABC based designed and classical PSS under different operating conditions through some performance indices. The results evaluation shows that the optimized PSS using the IABC algorithm achieves good robust performance for wide range of load changes in the presence of very highly disturbance and is superior to the other stabilizers.

II. POWER SYSTEM DESCRIPTION

A power system model consisting of a Single Machine connected to an Infinite Bus (SMIB) through a circuit transmission line is used in the simulation studies. A schematic diagram for the model is shown in Figure 1. The generator is equipped with excitation system and a power system stabilizer. All the relevant parameters are given in Appendix.

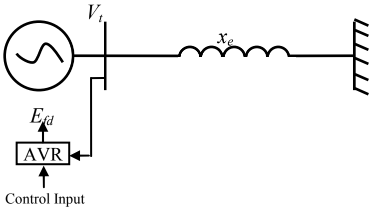


Figure 1. SMIB power system

The synchronous generator is represented by model 1.1, i.e. with field circuit and one equivalent damper winding on q axis. The dynamic equations of the SMIB system considered can be summarized as [15, 11].

$$\begin{aligned}
&\dot{\delta} = \omega_B S_m \\
&\frac{dS_m}{dt} = \frac{1}{2H}(-DS_m + T_m - T_e) \\
&\dot{E}'_q = \frac{1}{T'_{do}}(E_{fd} + (x_d - x'_d)i_d - E'_q) \\
&\dot{E}_{fd} = \frac{1}{T_A}(k_A(v_{ref} - v_t + V_s)) - E_{fd})
\end{aligned} \tag{1}$$

$$T_e = E'_q i_q + (x'_d - x'_q) i_d i_q \tag{2}$$

A. Structure of PSS

The structure of PSS, to modulate the excitation voltage is shown in Figure 2. The structure consists a gain block with gain K, a signal washout block and two-stage phase compensation blocks. The input signal of the proposed method is the speed deviation ($\Delta\omega$) and the output is the stabilizing signal V_S which is added to the reference excitation system voltage. The signal washout block serves as a high-pass filter, with the time constant T_W, high enough to allow signals associated with oscillations in input signal to pass unchanged. From the viewpoint of the washout function, the value of T_W is not critical and may be in the range of 1 to 20 seconds [14]. The phase compensation block (time constants T_1, T_2 and T_3, T_4) provides the appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals.

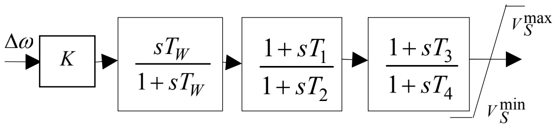


Figure 2. Structure of power system stabilizer

III. IMPROVED ABC ALGORITHM

A. Overview of the ABC algorithm

Karaboga and Basturk [16] described an artificial bee colony algorithm based on the foraging behavior of honey-bees for numerical optimization problems. It is a very simple, robust and population based stochastic optimization algorithm [17]. In the ABC algorithm, the colony of artificial bees contains of three groups of bees: employed bees, onlookers and scouts. The food source represents a possible solution of the optimization problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution. Every food source has only one employed bee. Thus, the number of employed bees or the onlooker bees is equal to the number of food sources (solutions).

An onlooker bee chooses a food source depending on the probability value associated with that food source, p_i, calculated by the following expression:

$$p_i = fit_i \,/\, \sum_{n=1}^{SN} fit_n \tag{3}$$

where, fit_i is the fitness value of the solution i evaluated by its employed bee, which is proportional to the nectar amount of the food source in the position i and SN is the number of food sources which is equal to the number of employed bees (BN), and p_i is the probability of selecting the ith employed bee. In this way, the employed bees exchange their information with the onlookers.

In order to produce a candidate food position from the old one, the ABC uses the following expression:

$$v_{ij}(t+1) = x_{ij} + \phi_{ij}(x_{ij}(t) - x_{kj}(t)) \tag{4}$$

where, v_i denotes the position of the ith onlooker bee, t denotes the iteration number, x_k is the randomly chosen employed bee, j represents the dimension of the solution, $k \in \{1, 2, ..., BN\}$ and $\phi_{ij}(\cdot)$ produces a series of random variable in the range [0, 1]. It controls the production of a neighbour food source position around x_{ij} and the modification represents the comparison of the neighbor food positions visually by the bee. Equation (4) shows that as the difference between the parameters of the x_{ij} and x_{kj} decreases, the perturbation on the position x_{ij} decreases, too. Thus, as the search approaches to the optimum solution in the search space, the step length is adaptively reduced. Also, x_{ij} is given as follows:

$$x_{ij} = x_{ij}^{\min} + \mathrm{rand}() \times (x_{ij}^{\max} - x_{ij}^{\min}) \tag{5}$$

The food source whose nectar is abandoned by the bees is replaced with a new food source by the scouts. In the ABC algorithm this is simulated by randomly producing a position and replacing it with the abandoned one. If a position cannot be improved further through a predetermined number of cycles called *limit* then that food source is assumed to be abandoned.

After each candidate source position v_{ij} is produced and then evaluated by the artificial bee, its performance is compared with that of x_{ij}. If the new food has equal or better nectar than the old source, it is replaced with the old one in the memory. Otherwise, the old one is retained. In other words, a greedy selection mechanism is employed as the selection operation between the old and the current food sources.

The main steps of the algorithm are given by [14]:

i) Initialize population of solutions and evaluate them.
ii) Produce new solutions for the employed bees, evaluate them and apply the greedy selection mechanism.
iii) Calculate the probabilities of the current sources with which they are preferred by the onlookers.
iv) Assign onlooker bees to employed bees according to probabilities, produce new solutions and apply the greedy selection mechanism.
v) Stop the exploitation process of the sources abandoned by bees and send the scouts in the search area for discovering new food sources, randomly.
vi) Memorize the best food source found so far.
vii) If the termination condition is not satisfied, go to step 2, otherwise stop the algorithm.

It is clear from the above explanation that there are three control parameters used in the basic ABC: The number of the food sources which is equal to the number of employed or onlooker bees (SN), the value of *limit* and the Maximum Cycle Number (MCN).

B. IABC Algorithm

In general, the ABC algorithm works well on finding the better solution of the object function. However, the original design of the onlooker bee's movement only regards as the relation between the employed bee, which is chosen by the roulette wheel mechanism, and the one selected randomly. Thus, it is not strong enough to maximize the exploitation capacity. In order to overcome this drawback, the Interactive strategy is introduced for ABC algorithm which called Improved ABC technique. By applying the Newtonian law of universal gravitation, the universal gravitations between the onlooker bee and the selected employed bees are exploited. Thus, by considering the gravitation between the picked employed bee and n selected employed bees, the Equation (4) can be rewritten as follows [18]:

$$v_{ij}(t+1) = x_{ij} + \sum_{t=1}^{n} \tilde{F}_{ik}(x_{ij}(t) - x_{kj}(t)) \tag{6}$$

where, $\tilde{F}_{ik}$ is the normalized gravitation of F_{ik} and is expressed as follows:

$$\begin{aligned} \tilde{F}_{ik} &= |F_{ik}| / \sum_{k=1}^{n} F_{ik} \\ F_{ik} &= G\frac{F(x_i)\cdot F(x_k)}{(x_{ij} - x_{kj})^2}\,\frac{x_{ij} - x_{kj}}{|x_{ij} - x_{kj}|} \end{aligned} \tag{7}$$

Accordingly, the gravitation $\tilde{F}_{ik}$ plays the role of a weight factor controlling the specific weight of [x_i-x_k]. The normalization process is taken in order to ensure that $\tilde{F}_{ik} \in [0, 1]$. Through the normalization, the constant G can be eliminated.

The procedure of the IABC algorithm can be summarized as follows:

i) **Initialization:** Spray n_e percentage of the populations into the solution space randomly, and then calculate their fitness values, which are called the nectar amounts, where n_e represents the ratio of employed bees to the total population. Once these populations are positioned into the solution space, they are called the employed bees.
ii) **Move the Onlookers:** Calculate the probability of selecting a food source by Equation (3), select a food source to move to by roulette wheel selection for every onlooker bees and then determine the nectar amounts of them. The movement of the onlookers follows the Equation (6).
iii) **Move the Scouts:** If the fitness values of the employed bees do not be improved by a continuous predetermined number of iterations, which is called *limit*, those food sources are abandoned, and these employed bees become the scouts. The scouts are moved by the Equation (5).
iv) **Update the Best Food Source Found So Far:** Memorize the best fitness value and the position, which are found by the bees.

v) **Termination Checking:** Check if the amount of the iterations satisfies the termination condition. If the termination condition is satisfied, terminate the program and output the results; otherwise go back to the Step 2.

IV. PROBLEM FORMULATION

In case of the lead-lag structured PSS, the washout time constants is usually specified. In the present study, washout time constant T_W =10 sec is used. The controller gain K and the time constants T_1, T_2, T_3 and T_4 are to be determined. It is worth mentioning that the PSS is designed to minimize the power system oscillations after a large disturbance so as to improve the power system stability. These oscillations are reflected in the deviations in power angle, rotor speed and line power. Minimization of any one or all of the above deviations could be chosen as the objective. In this study, an Integral Square Time of Square Error (ISTSE) of the speed deviations is taken as the objective function expressed as follows:

$$J = \sum_{i=1}^{NP} \int_{t=0}^{t=tsim} t^2 (\Delta\omega)^2 \, dt \, dt \tag{7}$$

where, $\Delta\omega$ denotes the rotor speed deviation for a set of PSS parameters, t_{sim} is the time range of the simulation and NP is the total number of operating points for which the optimization is carried out. It is aimed to minimize this objective function in order to improve the system response in terms of the settling time and overshoots under different operating condition. The design problem can be formulated as the following constrained optimization problem, where the constraints are the controller parameters bounds [12, 14]:

$$\begin{aligned} &\text{minimize } J \text{ subject to :} \\ &K^{\min} \le K \le K^{\max} \\ &T_1^{\min} \le T_1 \le T_1^{\max} \\ &T_2^{\min} \le T_2 \le T_2^{\max} \\ &T_3^{\min} \le T_3 \le T_3^{\max} \\ &T_4^{\min} \le T_4 \le T_4^{\max} \end{aligned} \tag{8}$$

Typical ranges of the optimized parameters are [0.01-50] for K and [0.01-1] for T_1, T_2, T_3 and T_4. The proposed approach employs IABC algorithm to solve this optimization problem and search for an optimal or near optimal set of PSS parameters. The optimization of the PSS parameters is carried out by evaluating the objective cost function as given in Equation (7), which considers a multiple of operating conditions are given in Table 1. The operating conditions are considered for wide range of output power at different power factors.

Table 1. Operation conditions

Case No.	P	Q	x_e	H
Case 1 (Base case)	0.8	0.4	0.3	3.25
Case 2	0.5	0.1	0.3	3.25
Case 3	1	0.5	0.3	3.25
Case 4	0.8	0.4	0.6	3.25
Case 5	0.5	0.1	0.6	3.25
Case 6	1	0.5	0.6	3.25
Case 7	0.8	0	0.6	3.25
Case 8	1	-0.2	0.3	3.25
Case 9	0.5	-0.2	0.6	3.25
Case 10	1	0.2	0.3	0.81

Results of the PSS parameter set values based on the objective function J, by applying a three phase-to-ground fault for 100 ms at generator terminal at t=1 sec using the proposed IABC and ABC algorithms [14] are given in Table 2. The Classical PSS (CPSS) is design using the tuning guidelines given in [15] for nominal operating point. Figure 3 shows the minimum fitness functions evaluating process.

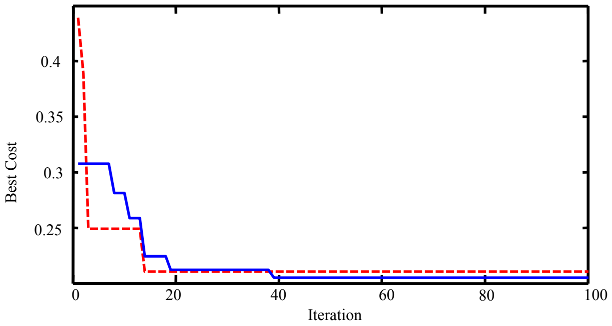


Figure 3. Fitness convergence, Dashed (ABC) and Solid (IABC)

Table 2. Optimal PSS parameters

Method	K_{pss}	T_1	T_2	T_3	T_4
CPSS	0.0280	0.0738	0.0280	0.0738	12.5
ABC	0.0111	0.0653	0.0543	0.0760	21.3200
IABC	0.0280	0.0738	0.0280	0.0738	12.5

V. SIMULATION RESULTS

The behavior of the proposed IABC based designed PSS (IABCPSS) under transient conditions is verified by applying disturbance and fault clearing sequence under different operating conditions in comparison with the original ABC based tuned PSS (ABCPSS) and classical PSS. The disturbances are given at t=1 sec. System responses in the form of slip (S_m) are plotted. The following types of disturbances have been considered.

- Scenario 1: A step change of 0.1 pu in the input mechanical torqueof machine.

- Scenario 2: A three phase-to-ground fault for 100 ms at the generator terminal.

Figure 4 shows the system response at the lagging power factor operating conditions with weak transmission system for scenario 1. It can be seen that the system with CPSS is highly oscillatory. Both IABC and ABC based tuned stabilizers are able to damp the oscillations reasonably well and stabilize the system at all operating conditions. Figure 5 depicts the responses of same operating conditions but with strong transmission system. System is more stable in this case, following any disturbance. Both PSSs improve its dynamic stability considerably and IABCPSS shows its superiority over ABCPSS and CPSS. System response at the ohmic operating conditions is shown in Figure 6 with the weak and strong transmission system for scenario 1. The proposed Improved ABC based PSS is effective and achieves good system damping characteristics.

Also, Figure 7 shows the system response at the leading power factor operating conditions with the weak and strong transmission system for scenario 1. Figure 8 refers to a three-phase to ground fault at the generator terminal. Figure 9 depicts the system response in scenario 1 with inertia $H' = H/4$. It can be seen that the proposed IABC based PSS has good performance in damping low frequency oscillations and stabilizes the system quickly. Moreover, it is superior to the original ABC and classical based methods tuned stabilizer.

To demonstrate performance robustness of the proposed method, four performance indices based on the system performance characteristics are defined as [12]:

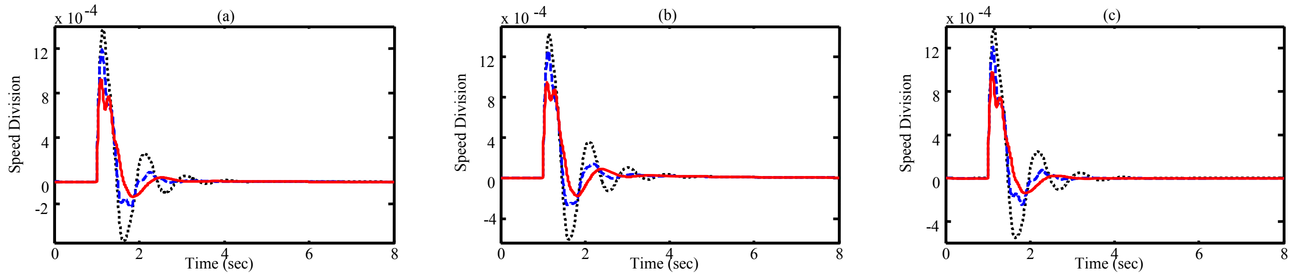
$$ITAE = 1000 \int_{0}^{t_{sim}} t.\omega.dt \tag{9}$$

$$FD = (1000 \times OS)^2 + (2000 \times US)^2 + T_s^2 \tag{10}$$

$$IAE = 1000 \int_{0}^{t_{sim}} \omega.dt \tag{11}$$

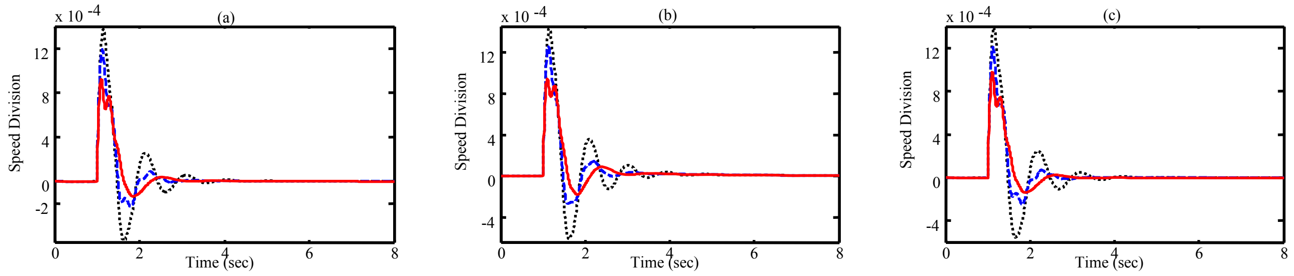
$$ISE = 1000 \int_{0}^{t_{sim}} \omega^2.dt \tag{12}$$

where, Overshoot (*OS*), Undershoot (*US*) and settling time of rotor angle deviation of machine is considered for evaluation of the *FD*. It is worth mentioning that the lower values of these indices are, the better the system response in terms of time domain characteristics. Numerical results of performance robustness for all operating conditions as given in Table 1 for scenario 1 are listed in Table 3. It can be seen that the values of these system performance characteristics with the proposed IABC based tuned PSS are much smaller compared to that original ABC and classical based designed PSS. This demonstrates that the overshoot, undershoot, settling time and speed deviations of machine is greatly reduced by applying the proposed stabilizer.



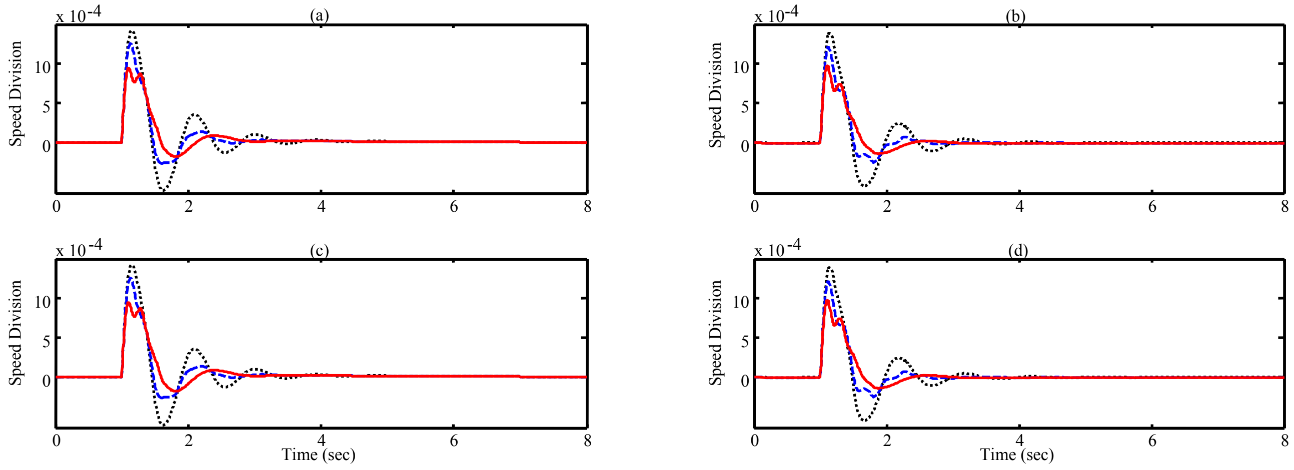
(a) P=0.8, Q=0.4 (b) P=0.5, Q=0.1 (c) P=1.0, Q=0.5

Figure 4. ΔT_m=0.1 (p.u.) under X_e=0.3; CPSS (Dotted), ABCPSS (Dashed) and IABCPSS (Solid)



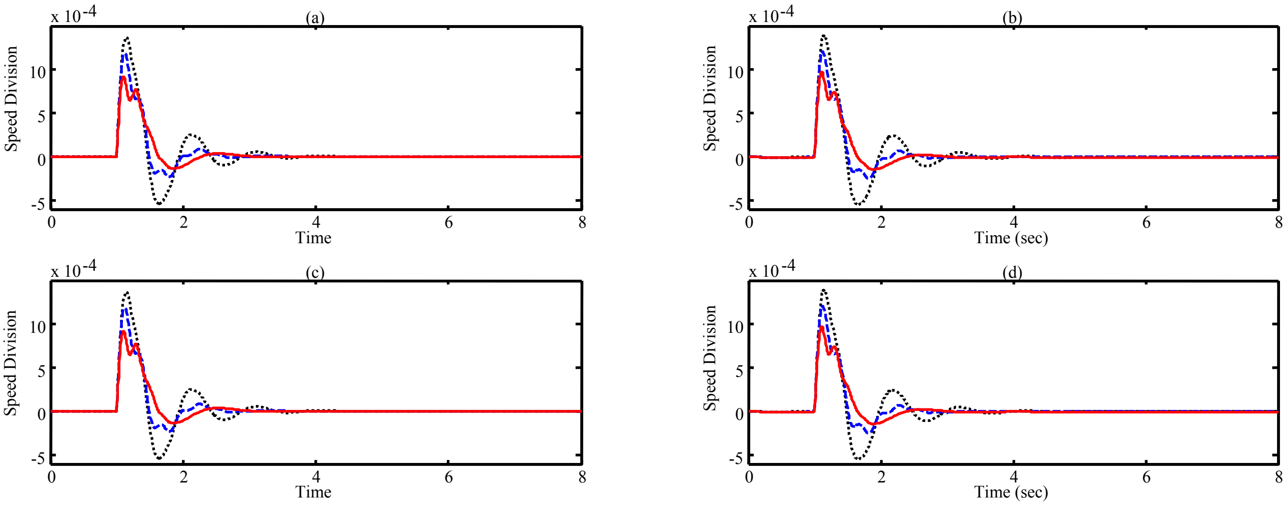
(a) P=0.8, Q=0.4 (b) P=0.5, Q=0.1 (c) P=1.0, Q=0.5

Figure 5. ΔT_m=0.1 (p.u.) under X_e=0.6; CPSS (Dotted), ABCPSS (Dashed) and IABCPSS (Solid)



X_e=0.3; (a) P=0.5, Q=0.0 (b) P=1.0, Q=0 X_e=0.6; (c) P=0.5, Q=0.0 (d) P=1.0, Q=0

Figure 6. ΔT_m=0.1 (p.u.); CPSS (Dotted), ABCPSS (Dashed) and IABCPSS (Solid)



X_e=0.3;   (a) P=0.8, Q=-0.2   (b) P=1.0, Q=-0.2 X_e=0.6;   (c) P=0.8, Q=-0.2   (d) P=1.0, Q=-0.2

Figure 7. ΔT_m=0.1 (p.u.); CPSS (Dotted), ABCPSS (Dashed) and IABCPSS (Solid)

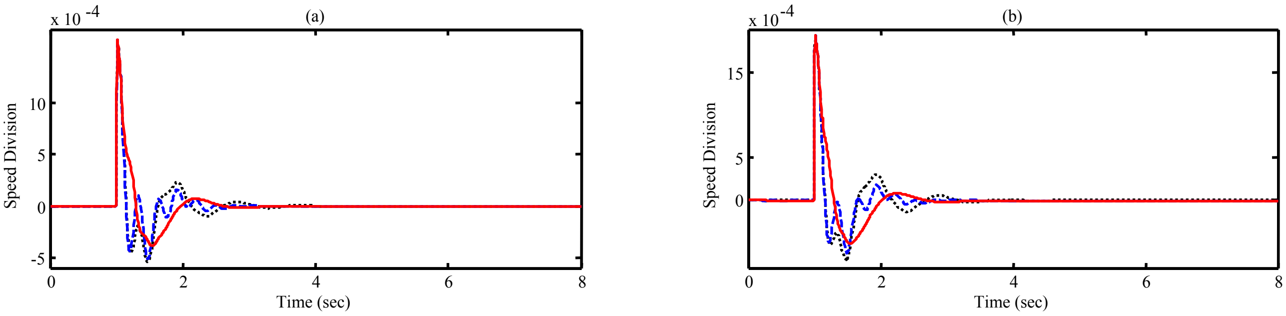
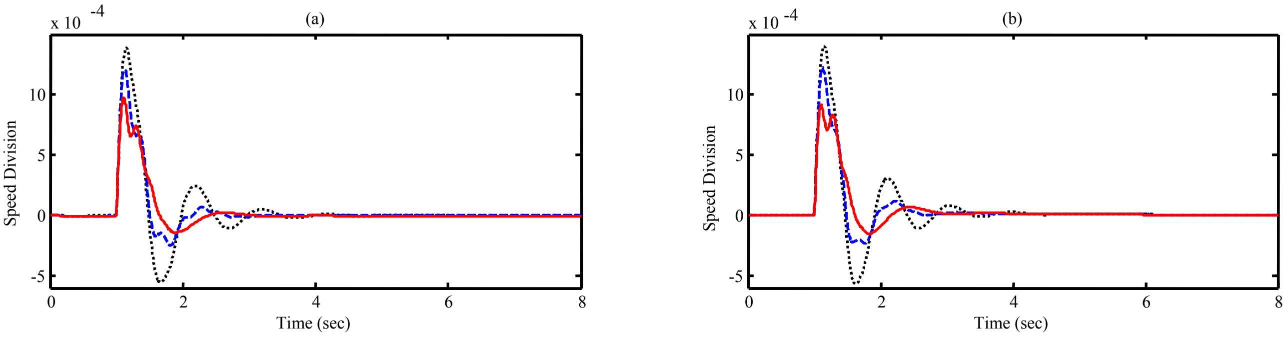


Figure 8. 3-φ to ground fault 100 ms for X_e=0.3, CPSS (Dotted), ABCPSS (Dashed) and IABCPSS (Solid)



(a) P=1.8, Q=0.5   (b) P=0.6, Q=0.0

Figure 9. ΔT_m=0.1 (p.u.) under X_e=0.6 and H'=H/4, CPSS (Dotted), ABCPSS (Dashed) and IABCPSS (Solid)

Table 3. Performance indices value using different stabilizers

No	IABC					ABC					CPSS				
	ITAE	*FD*	T_s	*IAE*	*ISE*	*ITAE*	*FD*	T_s	*IAE*	*ISE*	*ITAE*	*FD*	T_s	*IAE*	*ISE*
1	0.590	2.309	1.390	0.298	2.170	0.658	3.037	1.410	0.304	2.973	1.118	4.738	1.700	0.309	4.868
2	0.981	2.414	1.400	0.402	2.610	1.056	3.260	1.400	0.402	3.561	1.495	5.247	1.730	0.403	5.616
3	0.645	2.422	1.390	0.262	2.298	0.671	3.130	1.420	0.272	3.101	1.178	4.915	1.760	0.279	5.218
4	0.590	2.309	1.390	0.298	2.170	0.658	3.037	1.410	0.304	2.973	1.118	4.738	1.700	0.309	4.868
5	0.981	2.414	1.400	0.402	2.610	1.056	3.260	1.400	0.402	3.561	1.495	5.247	1.730	0.403	5.616
6	0.645	2.422	1.390	0.262	2.298	0.671	3.130	1.420	0.272	3.101	1.178	4.915	1.760	0.279	5.218
7	0.590	2.309	1.390	0.298	2.171	0.658	3.038	1.410	0.304	2.973	1.118	4.738	1.700	0.309	4.868
8	0.645	2.422	1.390	0.262	2.299	0.672	3.130	1.420	0.272	3.101	1.179	4.916	1.760	0.279	5.219
9	0.981	2.414	1.400	0.402	2.610	1.056	3.261	1.400	0.402	3.561	1.495	5.247	1.730	0.403	5.616
10	0.645	2.422	1.390	0.262	2.299	0.671	3.130	1.420	0.272	3.101	1.179	4.916	1.760	0.279	5.218

VI. CONCLUSIONS

In this paper, an improved ABC optimization technique has been successfully applied for power system stabilizer design in a SMIB power system. To design PSS problem, a nonlinear time domain based objective function is developed to increase the system damping and then IABC technique is implemented to search for the optimal stabilizer parameters. The proposed algorithm is easy to implement without additional computational complexity. Thereby experiments this algorithm gives quite promising results. The ability to jump out the local optima, the convergence precision and speed are remarkably enhanced and thus the high precision and efficiency are achieved. The effectiveness of the proposed stabilizer, for power system stability improvement, is demonstrated by a weakly connected example power system subjected to severe disturbance. The dynamic performance of IABC based tuned PSS has also been compared with original ABC and classical methods based designed PSS to show its superiority. The nonlinear simulation results under wide range of operating conditions show the robustness of IABC based stabilizer ability to provide efficient damping of low frequency oscillations and its superiority to the other methods. The system performance characteristics in terms of some performance indices reveal that the optimized stabilizer by the proposed IABC demonstrates that the overshoot, undershoot, settling time and speed deviations of the machine are greatly reduced under severe disturbance conditions.

APPENDIX

System Data

Generator: R_a=0, x_d= 2.0, x_q = 1.91, x'_d=0.244, x'_q=0.244, f = 50 Hz, T'_{do}=4.18, T'_{qo}=0.75, H=3.25
Transmission line: R= 0, x_e = 0.3
Exciter: K_A=50, T_A=0.05, E_{fdmax}=7.0, E_{fdmin}=-7.0

REFERENCES

[1] M. Anderson, A.A. Fouad, "Power System Control and Stability", Ames, IA, Iowa State Univ. Press, 1977.

[2] P. Kundur, "Power System Stability and Control", McGraw-Hill Inc., New York, 1994.

[3]Y. Hsu, C.Y. Hsu, "Design of Proportional Integral Power System Stabilizer", IEEE Trans. on Power Systems, Vol. 1, No. 2, pp. 46-53, 1986.

[4] P. Kundur, M. Klein, G.J. Rogers, M.S. Zywno, "Application of Power System Stabilizers for Enhancement of Overall System Stability", IEEE Trans. on Power Systems, pp. 614-626, 1989.

[5] M.J. Gibbard, "Robust Design of Fixed-Parameter Power System Stabilizers over a Wide Range of Operating Conditions", IEEE Trans. on Power Systems, Vol. 6, pp. 794-800, 1991.

[6] D.A. Pierre, "A Perspective on Adaptive Control of Power Systems", IEEE Trans. on Power Systems, Vol. 2, pp. 387-396, 1987.

[7] Y. Zhang, G.P. Chen, O.P. Malik, G.S. Hope, "An Artificial Neural Network Based Adaptive Power System Stabilizer", IEEE Trans. on Energy Conversion, Vol. 8, No. 1, pp. 71-77, 1993.

[8] Z. Wang, C.Y. Chun, K.P. Wong, P. Gan, Y. Xue, "Probabilistic Power System Stabilizer Design With Consideration of Optimal Sitting Using Recursive Genetic Algorithm", European Transactions on Electrical Power, Vol. 21, pp. 1409-1424, 2011.

[9] H. Shayeghi, H.A. Shayanfar, S. Jalilzadeh, A. Safari, "Multi-Machine Power System Stabilizers Design Using Chaotic Optimization Algorithm", Energy Conversion and Management, Vol. 51, pp. 1572-1580, 2010.

[10] S. Mishra, M. Tripathy, J. Nanda, "Multi-Machine Power System Stabilizer Design by Rule Based Bacteria Foraging", Electric Power Systems Research, Vol. 77, pp. 1595-1607, 2007.

[11] H. Shayeghi, A. Ghasemi, "Multiple PSS Design Using an Improved Honey Bee Mating Optimization Algorithm to Enhance Low Frequency Oscillations", International Review of Electrical Engineering, Vol. 6, pp. 3122-3133, 2011.

[12] H. Shayeghi, A. Ghasemi, "Application of PSO-TVAC to Improve Low Frequency Oscillations", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 9, Vol. 3, No. 4, pp. 36-44, December 2011.

[13] H. Shayeghi, A. Ghasemi, "Improved Time Variant PSO Based Design of Multiple Power System Stabilizer", International Review of Electrical Engineering, Vol. 6, pp. 2490-2501, 2011.

[14]H. Shayeghi, H.A. Shayanfar, A. Ghasemi, "A Robust ABC Based PSS Design for a SMIB Power System", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 8, Vol. 3, No. 3, pp. 86-92, September 2011.

[15] K.R. Padiyar, "Power System Dynamics-Stability and Control", Second Edition, BS Publications, Hyderabad, India, 2008.

[16] D. Karaboga, B. Basturk, "A Powerful and Efficient Algorithm for Numerical Function Optimization: Artificial Bee Colony (ABC) Algorithm", Journal of Global Optimization, Vol. 37, pp. 459-471, 2007.

[17] H. Shayeghi, A. Ghasemi, "Market Based LFC Design Using Artificial Bee Colony", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 6, Vol. 3, No. 1, pp. 1-10, March 2011.

[17] C. Zhang, D. Ouyang, J. Ning, "An Artificial Bee Colony Approach for Clustering", Expert Systems with Applications, Vol. 37, pp. 4761-4767, 2010.

[18] P.W. Tsai, J.S. Pan, B.Y. Liao, S.C. Chu, "Enhanced Artificial Bee Colony Optimization", International Journal of Innovative Computing, Information and Control, Vol. 5, No. 12, pp. 1-11, 2009.

BIOGRAPHIES

Hossein Shayeghi received the B.S. and M.S.E. degrees in Electrical and Control Engineering in 1996 and 1998, respectively. He received his Ph.D. degree in Electrical Engineering from Iran University of Science and Technology, Tehran, Iran in 2006. Currently, he is an Associate Professor in Technical Engineering Department of University of Mohaghegh Ardabili, Ardabil, Iran. His research interests are in the application of robust control, artificial intelligence and heuristic optimization methods to power system control design, operation and planning and power system restructuring. He has authored and co-authored of five books in Electrical Engineering area all in Farsi, two book chapters in international publishers and more than 190 papers in international journals and conference proceedings. Also, he collaborates with several international journals as reviewer boards and works as editorial committee of six international journals. He has served on several other committees and panels in government, industry, and technical conferences. He was selected as distinguished researcher of the University of Mohaghegh Ardabili several times and in 2007, 2010 and 2011. He was elected as distinguished researcher in engineering field in Ardabil province of Iran. Also, he is a member of Iranian Association of Electrical and Electronic Engineers (IAEEE) and IEEE. Currently, he is the head of Ardabil Technology Incubation Center (ATIC) at University of Mohaghegh Ardabili since 2008.

Ali Ghasemi received the B.Sc. and M.Sc. (Honors with first class) degrees in Electrical Engineering from Esfahan University of Technology, Esfahan, Iran in 2009 and Technical Engineering Department of the University of Mohaghegh Ardabili, Ardabil, Iran in 2011. His areas of interest in research are power system control and operation, and applications of heuristic techniques in power systems. He has authored of more than 50 papers in reputable international journals and conference proceedings. Also, he collaborates with several international journals as reviewer boards and works as editorial committee of two international journals. He is the recipient Excellence in thesis award of 4th Electric Power Generation Conference, Iran, 2012.