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OPTIMAL PID POWER SYSTEM STABILIZER TUNING VIA ARTIFICIAL BEE COLONY

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Abstract- This paper presents a hybrid Proportional Integral Differential (PID) and Power System Stabilizer (PSS) controller based Artificial Bee Colony (ABC) techniques to damp low frequency oscillation. The recent studies in artificial intelligence demonstrated that the ABC optimization is strong intelligent method in complicated stability problems. The optimal PID and PSS parameters are applied on a Single-Machine Infinite-Bus (SMIB). The nonlinear problem formulated as an optimization problem for wide ranges of operating conditions using the ABC algorithm. The simulation results illustrate the effectiveness, good robustness and validity of the proposed method through some performance indices such as ITAE, FD, IAE, T_s, ISE and eignvalues under wide ranges operating conditions in comparison with PSO-TVAC, PSO-TVIW and classical PSO techniques. The results of tuning and installing the PID power system stabilizers by ABC strategic on SMIB shows that damping is improved significantly in the system and has better outperforms than the other algorithms.

Keywords: PID Controller, Artificial Bee Colony Algorithm, SMIB, Power System Stabilizer.

I. INTRODUCTION

The Power System Stabilizer (PSS) controller design, methods of combining the PSS with the excitation controller (AVR), investigation of many different input signals and the vast field of tuning methodologies are all part of the PSS topic [1]. The action of a PSS is to extend the angular stability limits of a power system by providing supplemental damping to the oscillation of synchronous machine rotors through the generator excitation. This damping is provided by an electric torque applied to the rotor that is in phase with the speed variation [2, 3]. In the recent years, a large number of research papers have been appeared in the area of PSS. Also they directed towards obtaining such a PSS that can provide an optimal performance for a wide range of machine and system parameters [4].

Currently, many literatures used Conventional PSS (CPSS) to damped low frequency oscillations [2]. However, these controllers don't have appropriate revenue in different load conditions. Consequently, a lot of intelligent methods have been introduced to optimal tuning of the PSSs parameters [5].

Abedinia, et al [6] proposed Genetic Algorithm (GA) to optimal PSS parameters tuning in multi machine power system. This paper improved the dynamic stability of power systems by increasing the damping speed division of the synchronous machine in the system. The advantages of GA technique for tuning the PSS parameters show that it is independent of the complexity of the performance index.

Ghasemi, et al [7] is presented multi objective Particle Swarm Optimization with Time-Varying Acceleration Coefficients (PSOTVAC) for optimal design of PSS in multi-machine power system through some performance indicates. The 3-machine, 9-bus standard power system, under various system configurations and loading conditions, is employed to illustrate the performance of the proposed method.

Artificial Neural Network (ANN) is successful heuristic method for optimal PSS tuning. The advantages for ANN expressed to put forward for using ANN and the high level of interest is the ability of ANN to realize complicated nonlinear models. ANN is based on the concept of parallel processing and has great ability in realizing complicated non-linear mappings from the input space to the output space, thus providing an extremely fast processing facility for complicated non-linear problems [8, 9].

Hence, in this paper to overcome these problems, an ABC technique is applied for the solution of the PID power system stabilizer problem. Therefore, the ABC method is used for the optimal tuning of the PID parameters according to the single objective functions to improve the optimization synthesis and damping low frequency oscillations following disturbances in the power systems.

The effectiveness of the proposed ABCPID is tested on a Single-Machine Infinite-Bus (SMIB) power system under different operating conditions which is compared with the other version of PSO [7] through nonlinear time simulation and some performance indices. The simulation results show that the proposed ABC algorithm for design PID controller can modified low frequency oscillations of the power system under different load conditions.

II. POWER SYSTEM MODEL

For stability assessment of power system adequate mathematical models describing the system are needed. The system behaviour following such a disturbance is critically dependent upon the magnitude, nature and the location of fault and to a certain extent on the system operating conditions. The stability analysis of the system under such conditions, normally termed as `Transient-stability analysis' is generally attempted using mathematical models involving a set of non-linear differential equations. A schematic diagram for the test system is shown in Figure 1. The generator is equipped with the excitation system and a power system stabilizer. Furthermore, the data of system are given in the Appendix A. The nonlinear dynamic equations of the SMIB system considered can be summarized as [10]:

$$\dot{\delta}_i = \omega_b(\omega_i - 1) \tag{1}$$

$$\dot{\omega}_i = \frac{1}{M_i}(P_{mi} - P_{ei} - D_i(\omega_i - 1)) \tag{2}$$

$$\dot{E}'_{qi} = \frac{1}{T'_{doi}}(E_{fdi} - (x_{di} - x'_{di})i_{di} - E'_{qi}) \tag{3}$$

$$\dot{E}_{fdi} = \frac{1}{T_{Ai}}(K_{Ai}(v_{refi} - v_i + u_i) - E_{fdi}) \tag{4}$$

$$T_{ei} = E'_{qi}i_{qi} - (x_{qi} - x'_{di})i_{di}\, i_{qi} \tag{5}$$

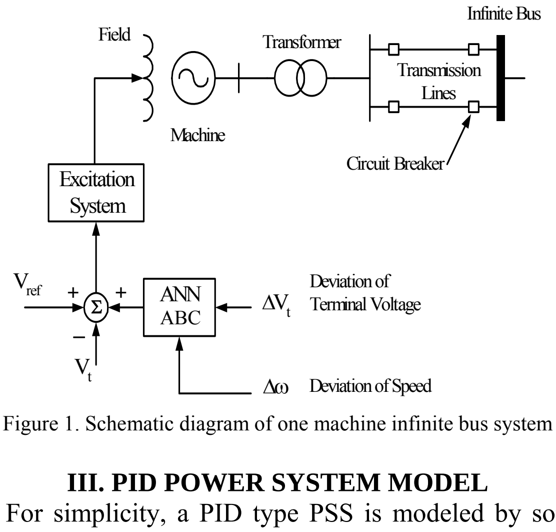

Figure 1. Schematic diagram of one machine infinite bus system

III. PID POWER SYSTEM MODEL

For simplicity, a PID type PSS is modeled by some identical stages, PID which is represented by a gain K_P, K_I and K_D, washout function, the value of T_W is not critical and may be in the range of 1 to 20 seconds and output limits ($V_{s\max}$ and $V_{s\min}$). The structure of the PID type power system stabilizer, to modulate the excitation voltage is shown in Figure 2.

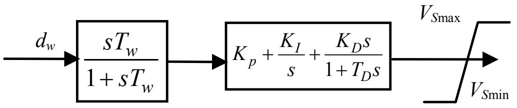

Figure 2. The structure of PID type PSS

IV. ARTIFICIAL BEE COLONY (ABC) ALGORITHM

Intelligence artificial optimization techniques are receiving great interests these days. Honey bee colony structure is taking the spotlight in the field of function optimization. In this research our attention centers on the food foraging behavior of honey bees. A behavioral model of self-organization is proposed for a colony of honey bees by Seeley (1995). Foraging bees visiting flower patches return to the hive with nectar as well as a profitability rating of respective patches in the behavioral model. Recently, Karaboga and Basturk [11] have described an Artificial Bee Colony (ABC) algorithm based on the foraging behavior of the honey-bees for numerical optimization problems. The algorithm simulates the intelligent foraging behavior of the honey bee swarms. It is a very simple, robust and population based stochastic optimization algorithm [12].

All bees that are currently exploiting a food source are known as employed. The employed bees exploit the food source (NFS) and they carry the information about food source back to the hive and share this information with onlooker bees. Onlookers bees are waiting in the hive for the information to be shared by the employed bees about their discovered food sources and scouts bees will always be searching for new food sources near the hive. Employed bees share information about food sources by dancing in the designated dance area inside the hive. The nature of dance is proportional to the nectar content of food source just exploited by the dancing bee. Onlooker bees watch the dance and choose a food source according to the probability proportional to the quality of that food source. Therefore, good food sources attract more onlooker bees compared to bad ones. Whenever a food source is exploited fully, all the employed bees associated with it abandon the food source, and become scout. Scout bees can be visualized as performing the job of exploration, whereas employed and onlooker bees can be visualized as performing the job of exploitation [8].

In the ABC algorithm, the number of employed bees is equal to the number of food sources which is also equal to the number of onlooker bees. There is only one employed bee for each food source whose first position is randomly generated. Each employed bee, at each iteration of the algorithm determines a new neighboring food source of its currently associated food source by Equation (6), and computes nectar amount of this new food source:

$$v_{ij} = z_{ij} + \theta_{ij}(z_{ij} - z_{kj}) \tag{6}$$

where, $k \in \{1, 2, ..., BN\}$ and $j \in \{1, 2, ..., D\}$ are randomly chosen indexes. Although k is determined randomly, it has to be different from *i*. The θ_{ij} is a random number between [−1, 1]. It controls the production of a neighbor food source position around z_{ij} and the modification represents the comparison of the neighbor food positions visually by the bee. Equation (6) shows that as the difference between the parameters of the z_{ij} and z_{kj} decreases, the perturbation on the position z_{ij} decreases, too. If the nectar amount of this new food source is higher than that of its currently associated food source, then this employed bee moves to this new food source, otherwise it continues with the old one.

After all employed bees complete the search process; they share the information about their food sources with onlooker bees. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount by Equation (7). This method, known as roulette wheel selection method, provides better candidates to have a greater chance of being selected:

$$p_i = fit_i / (\sum_{n=1}^{SN} fit_i) \qquad (7)$$

where fit_i is the fitness value of the solution i 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. Figure 2 presents the flowchart of the proposed technique. The pseudo code for ABC algorithm looks as follows:

- Initialize
- Repeat
- Move the employed bees onto their food source and evaluate the fitness
- Move the onlookers onto the food source and evaluate their fitness
- Move the scouts for searching new food source
- Memorize the best food source found so far
- Until (termination criteria satisfied)

V. ABC BASED PID TYPE SMIB

The ABC technique is global and local search techniques equipped with powerful tools used to solve optimization problems. Figure 3 shows the block diagram of ABC based tuned PID type PSS controller to solve the power system problem. Proposed method consists of two parts, in first part, the PID parameters are obtained by solving the constraint optimization problem (figure 3) using ABC method. Once parameters are obtained they are tested for the robustness and D-stability in the second part. The proposed method of tuning essentially involves the following steps.

Step 1: Start with an initial operating condition for speed input PID.

Step 2: Solve the constrained optimization problem (Typical ranges of the optimized parameters are [0.1-50] for K_P, K_I and K_D and [0.1-20] for T_w and [0.05-0.5] for $V_{s\max}$ and -$V_{s\min}$).

Step 3: Once PID parameters are obtained check for robustness with these parameters. For this generate a set of loading/system condition (which considers a multiple of operating conditions are given in Table 1).

Step 4: Run load flow for each loading/system condition.

Step 5: For each operating condition evaluate J given by Equation (8).

$$J = \sum_{j=1}^{Np} \int_0^{t_{sim}} t.\omega dt + 0.07 \times OS^2 \qquad (8)$$

where, N_P is number of operating conditions, t_{sim} is total simulation time and OS is the Overshoot for speed division.

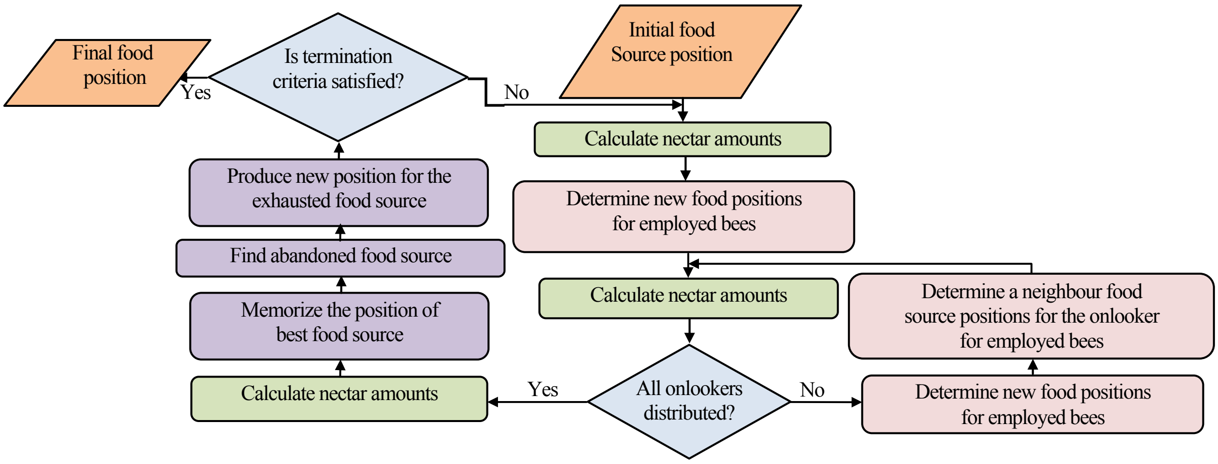

Figure 2. The flowchart of the proposed ABC algorithm

Table 1. Operation conditions

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

To demonstrate performance robustness of the proposed method, two performance indices: the Integral of the Time multiplied Absolute value of the Error ($ITAE$) and Figure of Demerit (FD) based on the system performance characteristics are defined as [7]:

$$FD = (500 \times OS)^2 + (8000 \times US)^2 + 0.01 \times T_s^2 \qquad (9)$$

$$ITAE = 100 \times \int_0^{t_{sim}} t(|\Delta\omega|).dt \qquad (10)$$

where, Overshoot (OS), Undershoot (US) and settling time of the rotor angle deviation of the machine is considered for evaluation of the FD. Actually the T_s, is the settling time which is considered in numerical results. Furthermore, this proposed technique, is applied for SMIB through the Integral of Absolute value of the Error (IAE) and Integral of the Signal Error (ISE) which are described as:

$$IAE = 100 \times \int_0^{t_{sim}} (|\Delta\omega|)dt \qquad (11)$$

$$ISE = 100 \times \int_0^{t_{sim}} (|\Delta\omega|^2)dt \qquad (12)$$

Results of the PID 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 ABC and PSO-TVAC, PSO-TVIW and CPSO algorithms based PID are given in Table 2. Also the initial value for algorithms gives in Table 3. Figure 4 shows the minimum fitness functions evaluating process.

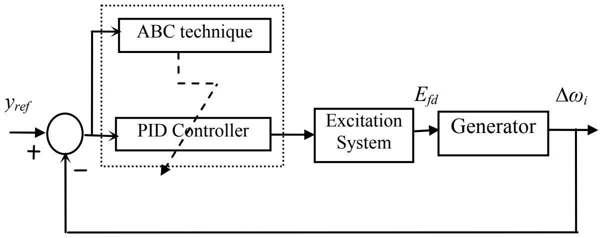

Figure 3. The ABC-PID controller design

VI. SIMULATION RESULTS

The behavior of the proposed ABC algorithm based designed PID power system stabilizer under transient conditions is verified by applying disturbance and fault clearing sequence under different operating conditions. In comparison with the PSO-TVAC, PSO-TVIW and PSO based tuned PID. 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 [10].

- *Scenario* 1: A step change of 0.1 pu in the input mechanical torque.
- *Scenario* 2: A three phase-to-ground fault for 100 ms at the generator terminal.

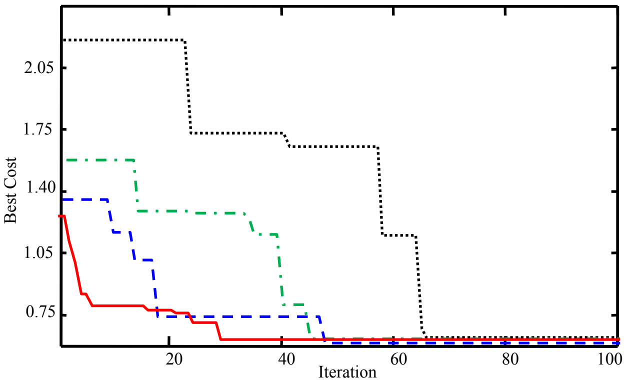

Figure 4. Fitness convergence, Dashed (CPSO), Dashed-Doted (PSO-TVIW), Dashed (PSO-TVAC) and Solid (ABC)

Table 2. The achieved results from optimization

Method	T_W	K_P	K_I	K_D	$V_{\max}$	$V_{\min}$
PSO	18.84	17.954	6.645	1.029	0.077	- 0.091
PSO-TVIW	9.398	14.435	3.249	3.209	0.189	-0.283
PSO-TVAC	12.81	12.817	2.817	2.245	0.195	-0.298
ABC	11.92	10.019	2.153	2.109	0.116	- 0.233

Table 3. Parameters for proposed algorithms

ABC		PSO-TVAC		PSO-TVIW		PSO	
limit	200	C_{1f}	0.2	C_1	2.1	C_1	2.1
Pop.	40	C_{1i}	2.5	C_2	2.1	C_2	2.1
limit	200	C_{2f}	2.5	φ	4.1	$w_{\min}$	0.4
		C_{2i}	0.2	$w_{\min}$	0.4	$w_{\max}$	0.9
		φ	4.1	$w_{\max}$	0.9	Pop.	40
		$w_{\min}$	0.4	Pop.	40	Iteration	100
		$w_{\max}$	0.9	Iteration	100		
		Pop.	40				
		Iteration	100				

Figure 5 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 CPSO is highly oscillatory. ABC and all version of PSO algorithm based tuned stabilizers are able to damp the oscillations reasonably well and stabilize the system at all operating conditions.

Figure 6 depicts the responses of same operating conditions but with strong transmission system. System is more stable in this case, following any disturbance. All PID improve their dynamic stability considerably and ABCPID shows its superiority over PSOPID, PSO-TVIWPID and PSO-TVACPID. Also, Figure 7 refers to a three-phase to ground fault at the generator terminal.

Figure 8 depicts the system response in scenario 1 with inertia H'=H/4. It can be seen that the proposed ABC based PID has good performance in damping low frequency oscillations and stabilizes the system quickly. Moreover, it is superior to the PSO based methods tuned stabilizer.

The numerical values of PID parameters are shown in Tables 4-5 (based scenario 1). Also to demonstrate the robustness performance of the proposed method, in the some operating condition for scenario 1, the Eigen values of the system with PSO, SPEA, PSO-TVIW and PSO-TVAC are obtained and listed in Table 6. It is clear to see that the eignvalues of the system with ABCPID are farther than the imaginary axis and the system stability margin is more than other methods.

For more information about ABC algorithm the computational results which are used in this paper through several runs of proposed technique. The computational results are shown in Table 7. There are no significant differences amongst the standard deviations of the solutions. Thus, the proposed ABC technique is a robust optimization algorithm.

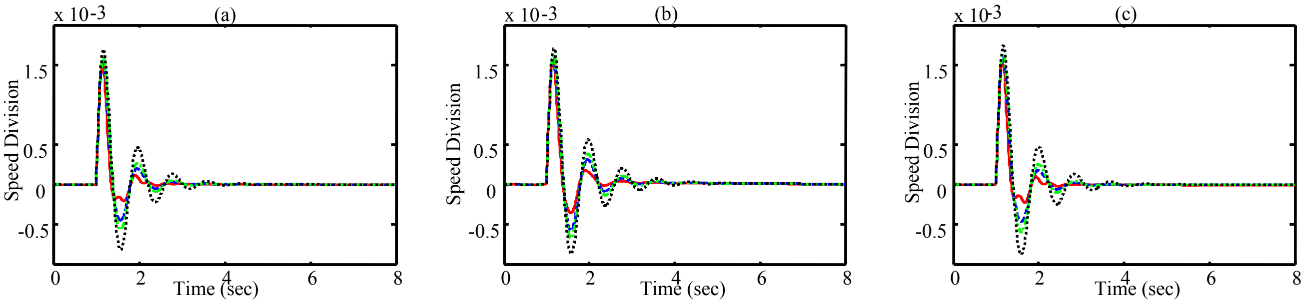

Figure 5. ΔT_m=0.1 (p.u.) under X_e=0.3; PSO (Dotted), PSO-TVIW (Dashed-Doted), PSO-TVAC (Dashed) and ABC (Solid)
(a) P=0.8, Q=0.4 (b) P=0.5, Q=0.1 (c) P=1.0, Q=0.5

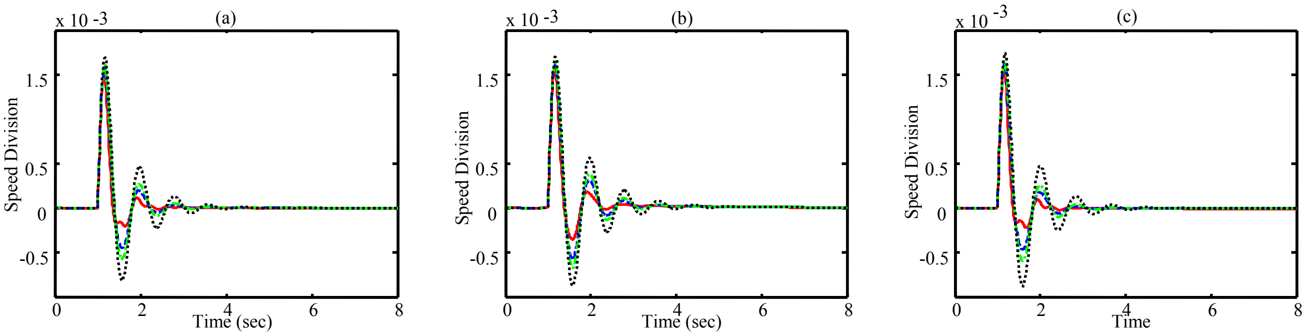

Figure 6. ΔT_m=0.1 (p.u.) under X_e=0.6; PSO (Dotted), PSO-TVIW (Dashed-Doted), PSO-TVAC (Dashed) and ABC (Solid)
(a) P=0.8, Q=0.4 (b) P=0.5, Q=0.1 (c) P=1.0, Q=0.5

Table 4. Performance indices for scenario 1

No	ABC					PSO-TVAC				
	ITAE	*FD*	T_s	*IAE*	$ISE\times10^{-4}$	*ITAE*	*FD*	T_s	*IAE*	$ISE\times10^{-4}$
1	0.6519	4.1621	1.3000	0.2773	4.2068	0.8291	4.6513	1.3200	0.2972	4.9163
2	1.0551	4.5080	1.3100	0.3876	4.7878	1.2814	5.5916	1.6500	0.3976	5.6239
3	0.7708	4.2743	1.3000	0.2355	4.4200	0.8894	4.8243	1.3300	0.2630	5.2244
4	0.6519	4.1621	1.3000	0.2773	4.2068	0.8291	4.6513	1.3200	0.2972	4.9163
5	1.0551	4.5080	1.3100	0.3876	4.7878	1.2814	5.5916	1.6500	0.3976	5.6239
6	0.7708	4.2743	1.3000	0.2355	4.4200	0.8894	4.8243	1.3300	0.2630	5.2244
7	0.6519	4.1622	1.3000	0.2773	4.2070	0.8291	4.6516	1.3200	0.2972	4.9166
8	0.7711	4.2743	1.3000	0.2354	4.4204	0.8897	4.8250	1.3300	0.2630	5.2253
9	1.0550	4.5081	1.3100	0.3876	4.7880	1.2813	5.5918	1.6500	0.3976	5.6241
10	0.7709	4.2743	1.3000	0.2355	4.4202	0.8895	4.8246	1.3300	0.2630	5.2248

Table 5. Performance indices for scenario 1

No	PSO-TVIW					PSO				
	ITAE	*FD*	T_s	*IAE*	$ISE\times10^{-4}$	*ITAE*	*FD*	T_s	*IAE*	$ISE\times10^{-4}$
1	0.9739	5.5438	1.6500	0.2976	5.5087	1.4198	7.2647	1.7000	0.3021	7.3052
2	1.4209	6.1693	1.6800	0.3974	6.2354	1.8382	7.9926	2.0500	0.3991	7.9512
3	1.0590	5.8241	1.6800	0.2639	5.9139	1.5814	7.8534	1.7300	0.2704	8.0752
4	0.9739	5.5438	1.6500	0.2976	5.5087	1.4198	7.2647	1.7000	0.3021	7.3052
5	1.4209	6.1693	1.6800	0.3974	6.2354	1.8382	7.9926	2.0500	0.3991	7.9512
6	1.0590	5.8241	1.6800	0.2639	5.9139	1.5814	7.8534	1.7300	0.2704	8.0752
7	0.9740	5.5442	1.6500	0.2976	5.5091	1.4199	7.2650	1.7000	0.3020	7.3056
8	1.0594	5.8250	1.6800	0.2639	5.9149	1.5819	7.8544	1.7300	0.2704	8.0765
9	1.4209	6.1696	1.6800	0.3973	6.2356	1.8382	7.9929	2.0500	0.3990	7.9514
10	1.0592	5.8245	1.6800	0.2639	5.9143	1.5816	7.8539	1.7300	0.2704	8.0757

Table 6. The Eigen values of system with different PID for scenario 1

Case No	*P*	*Q*	X_e	*H*	PSO	PSO-TVIW	PSO-TVAC	ABC
1	0.8	0.4	0.3	3.25	-1.0097 -0.0070 + 0.1577i -0.0070 - 0.1577i -0.1573 -0.0242 -0.0005	-1.0054 -0.1287 -0.0192 + 0.0715i -0.0192 - 0.0715i -0.0326 -0.0008	-1.0077 -0.1065 -0.0277 + 0.0728i -0.0277 - 0.0728i -0.0355 -0.0010	-1.0051 -0.1275 -0.0184 + 0.0686i -0.0184 - 0.0686i -0.0356 -0.0008
2	0.5	0.1	0.3	3.25	-1.0088 -0.0096 + 0.1480i -0.0096 - 0.1480i -0.1584 -0.0188 -0.0005	-1.0049 -0.1298 -0.0228 + 0.0659i -0.0228 - 0.0659i -0.0249 -0.0008	-1.0069 -0.1099 -0.0312 + 0.0672i -0.0312 - 0.0672i -0.0260 -0.0010	-1.0046 -0.1287 -0.0223 + 0.0629i -0.0223 - 0.0629i -0.0272 -0.0008

3	1.0	0.5	0.3	3.25	-1.0106 -0.0054 + 0.1620i -0.0054 - 0.1620i -0.1565 -0.0273 -0.0005	-1.0059 -0.1277 -0.0171 + 0.0739i -0.0171 - 0.0739i -0.0373 -0.0008	-1.0084 -0.0260 + 0.0752i -0.0260 - 0.0752i -0.1026 -0.0420 -0.0010	-1.0056 -0.1264 -0.0162 + 0.0710i -0.0162 - 0.0710i -0.0407 -0.0008
4	0.8	0.4	0.6	3.25	-1.0077 -0.0090 + 0.1309i -0.0090 - 0.1309i -0.1362 -0.0422 -0.0005	-1.0042 -0.0125 + 0.0524i -0.0125 - 0.0524i -0.0874 + 0.0267i -0.0874 - 0.0267i -0.0008	-1.0061 -0.0827 + 0.0465i -0.0827 - 0.0465i -0.0163 + 0.0492i -0.0163 - 0.0492i -0.0011	-1.0040 -0.0894 + 0.0304i -0.0894 - 0.0304i -0.0106 + 0.0509i -0.0106 - 0.0509i -0.0008
5	0.5	0.1	0.6	3.25	-1.0069 -0.0120 + 0.1297i -0.0120 - 0.1297i -0.1388 -0.0343 -0.0005	-1.0038 -0.0168 + 0.0487i -0.0168 - 0.0487i -0.0833 + 0.0219i -0.0833 - 0.0219i -0.0008	-1.0054 -0.0791 + 0.0439i -0.0791 - 0.0439i -0.0202 + 0.0447i -0.0202 - 0.0447i -0.0011	-1.0036 -0.0856 + 0.0267i -0.0856 - 0.0267i -0.0146 + 0.0472i -0.0146 - 0.0472i -0.0008
6	1.0	0.5	0.6	3.25	-1.0084 -0.0067 + 0.1293i -0.0067 - 0.1293i -0.1339 -0.0484 -0.0005	-1.0046 -0.0904 + 0.0292i -0.0904 - 0.0292i -0.0093 + 0.0535i -0.0093 - 0.0535i -0.0008	-1.0066 -0.0856 + 0.0485i -0.0856 - 0.0485i -0.0131 + 0.0507i -0.0131 - 0.0507i -0.0011	-1.0044 -0.0924 + 0.0325i -0.0924 - 0.0325i -0.0074 + 0.0521i -0.0074 - 0.0521i -0.0008
7	0.8	0.0	0.6	3.25	-1.0098 -0.0051 + 0.1443i -0.0051 - 0.1443i -0.1445 -0.0395 -0.0005	-1.0054 -0.0121 + 0.0621i -0.0121 - 0.0621i -0.1052 -0.0690 -0.0008	-1.0077 -0.0791 + 0.0342i -0.0791 - 0.0342i -0.0191 + 0.0596i -0.0191 - 0.0596i -0.0011	-1.0051 -0.0103 + 0.0599i -0.0103 - 0.0599i -0.0975 -0.0807 -0.0008
8	1.0	-0.2	0.3	3.25	-1.0147 0.0029 + 0.1753i 0.0029 - 0.1753i -0.1534 -0.0427 -0.0005	-1.0082 -0.1295 -0.0057 + 0.0825i -0.0057 - 0.0825i -0.0560 -0.0008	-1.0117 -0.0152 + 0.0838i -0.0152 - 0.0838i -0.0815 + 0.0127i -0.0815 - 0.0127i -0.0011	-1.0077 -0.1276 -0.0045 + 0.0797i -0.0045 - 0.0797i -0.0609 -0.0008
9	0.5	-0.2	0.6	3.25	-1.0092 -0.0094 + 0.1432i -0.0094 - 0.1432i -0.1489 -0.0271 -0.0005	-1.0051 -0.1108 -0.0209 + 0.0592i -0.0209 - 0.0592i -0.0463 -0.0008	-1.0072 -0.0311 + 0.0561i -0.0311 - 0.0561i -0.0673 + 0.0191i -0.0673 - 0.0191i -0.0010	-1.0048 -0.1075 -0.0191 + 0.0559i -0.0191 - 0.0559i -0.0536 -0.0008
10	1.0	0.2	0.3	0.81	-1.0440 0.0103 + 0.3371i 0.0103 - 0.3371i -0.1531 -0.0287 -0.0005	-1.0260 -0.0256 + 0.1867i -0.0256 - 0.1867i -0.0890 -0.0390 -0.0008	-1.0363 -0.0328 + 0.2094i -0.0328 - 0.2094i -0.0516 + 0.0069i -0.0516 - 0.0069i -0.0010	-1.0245 -0.0272 + 0.1817i -0.0272 - 0.1817i -0.0816 -0.0447 -0.0008

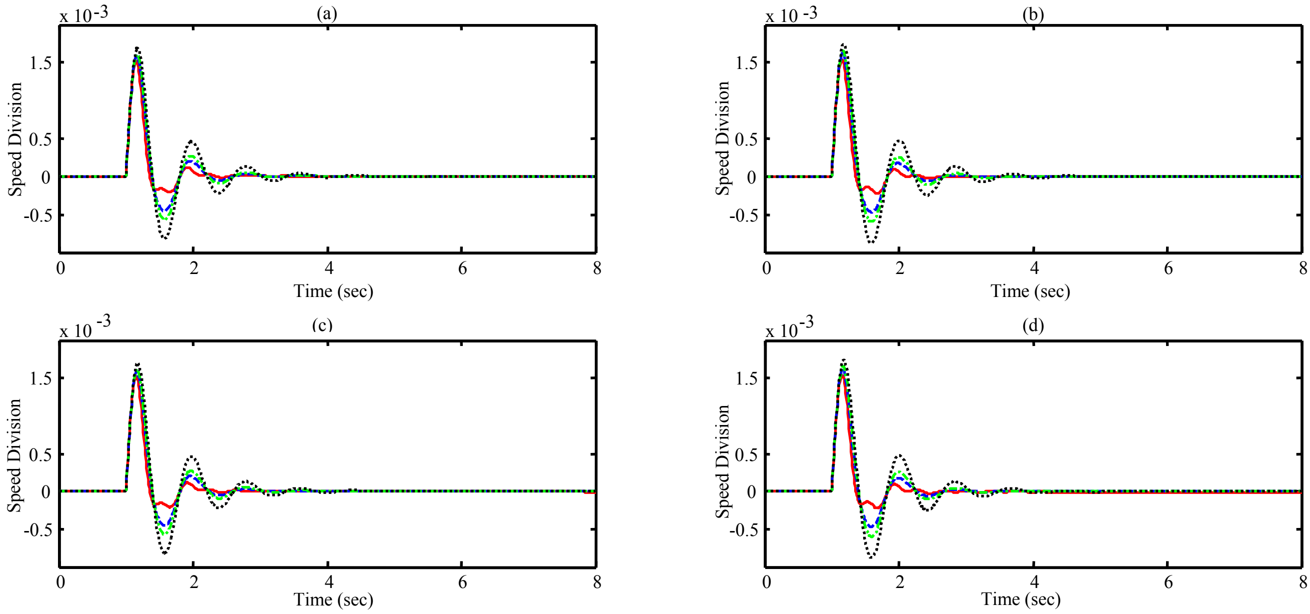

Figure 7. 3-φ to ground fault 100 ms for X_e=0.3; PSO (Dotted), PSO-TVIW (Dashed-Doted), PSO-TVAC (Dashed) and ABC (Solid)
(a) P=0.8, Q=0.4 (b) P=1.0, Q=0.5 (c) P=0.8, Q=0.0 (d) P = 0.8, Q = -0.2

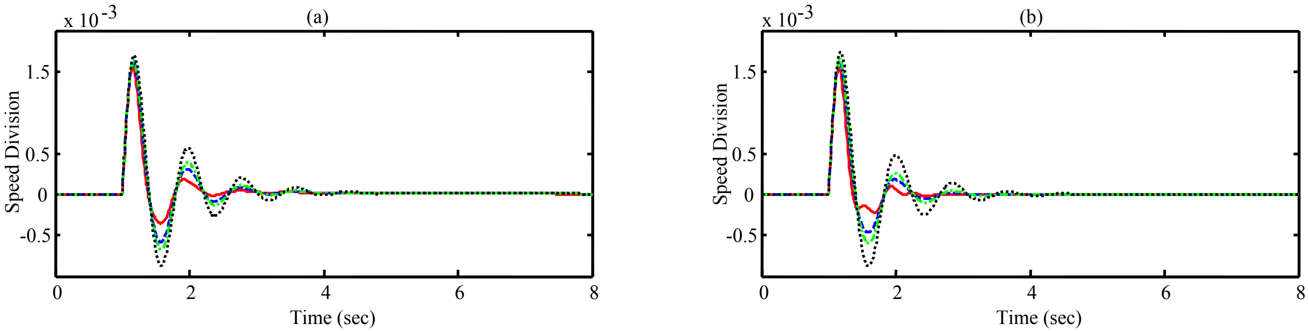

Figure 8. ΔT_m=0.1 (p.u.) under X_e=0.6 and H'=H/4; PSO (Dotted), PSO-TVIW (Dashed-Doted), PSO-TVAC (Dashed) and ABC (Solid)
(a) P=1.0, Q=0.5 (b) P=0.6, Q=0.0

Table 7. The average results over many runs of ABC

Run	PSO				PSO-TVIW				PSO-TVAC				ABC			
	Min	Mean	Max	Iter	Min	Mean	Max	Iter	Min	Mean	Max	Iter	Min	Mean	Max	Iter
1	0.456	1.465	2.154	85	0.409	0.721	1.565	53	0.401	0.675	1.321	36	0.402	0.611	1.132	24
2	0.412	1.479	2.024	65	0.401	0.719	1.570	61	0.406	0.678	1.326	30	0.401	0.621	1.129	25
3	0.466	1.514	2.012	89	0.415	0.722	1.569	57	0.402	0.669	1.330	41	0.403	0.631	1.131	27
4	0.419	1.496	2.063	91	0.412	0.723	1.566	62	0.401	0.675	1.327	35	0.401	0.632	1.131	29
5	0.455	1.488	2.130	76	0.401	0.731	1.568	63	0.403	0.671	1.326	29	0.405	0.632	1.127	30
6	0.401	1.506	2.114	85	0.422	0.725	1.563	59	0.409	0.669	1.325	25	0.401	0.631	1.128	25
7	0.462	1.502	2.213	78	0.431	0.719	1.561	64	0.401	0.673	1.332	32	0.404	0.640	1.125	31
8	0.476	1.479	2.006	69	0.411	0.711	1.562	59	0.410	0.665	1.331	31	0.401	0.633	1.126	23
9	0.486	1.486	2.136	92	0.408	0.722	1.564	65	0.401	0.652	1.327	24	0.401	0.632	1.129	29
10	0.445	1.462	2.116	56	0.413	0.720	1.562	58	0.406	0.662	1.331	26	0.403	0.633	1.128	25
SD	0.026	0.016	0.064	11.48	0.008	0.004	0.003	3.44	0.003	0.007	0.003	5.06	0.001	0.007	0.002	2.63

VII. CONCLUSIONS

This paper presents a hybrid PID and PSS controller based Artificial Bee Colony techniques to damp low frequency oscillation. The ABC algorithm is a search algorithm that is inspired by the intelligent foraging behavior of a honey bee swarm process and has emerged as a useful tool for engineering optimization. It incorporates a flexible and well-balanced mechanism to adapt to the global and local exploration and exploitation abilities within a short computation time. Hence, this method is efficient in handling large and complex search spaces. The proposed control strategy in this contribution combines the advantage of the PID control system and PSS controller by ABC techniques for achieving the desired level of robust performance under different operating conditions and load disturbances. The effectiveness of the proposed ABCPID is tested on a SMIB power system under different operating conditions which is compared with the other version of PSO through nonlinear time simulation and different performance indices. Also, beside the parameters of PSS, the Eigen-values of the power system are considered for test the flexibility of the proposed technique in different situation. The presented results in this paper, demonstrate that in a SMIB system, fixed-structure damping controllers can be tuned to provide satisfactory damping performance over a pre-specified set of operating conditions. The ABC algorithm based tuning process has shown robustness in achieving controllers satisfying the design criteria in a large-scale realistic power system. The computational time required by algorithm can be considered adequate for a design study.

APPENDIX

SMIB Data for Simulation

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, $E_{fd\max}$=7.0, $E_{fd\min}$=-7.0

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