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OPTIMAL DESIGN OF MULTI-MACHINE POWER SYSTEM STABILIZERS USING INTERACTIVE HONEY BEE MATING OPTIMIZATION

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ABSTRACT
This paper presents an enhanced Honey Bee Mating Optimization (HBMO) to solve the optimal design of multi machine power system stabilizers (PSSs) parameters, which is called the Interactive Honey Bee Mating Optimization (IHBMO).Power System Stabilizers (PSSs) are now routinely used in the industry to damp out power system oscillations. The design problem of the proposed controller is formulated as an optimization problem and IHBMO algorithm is employed to search for optimal controller parameters. The propose method is applied to multi-machine power system (MPS).The method suggested in this paper can be used for designing robust power system stabilizers for guaranteeing the required closed loop performance over a pre specified range of operating and system conditions. The simplicity in design and implementation of the proposed stabilizers makes them better suited for practical applications in real plants. The non-linear simulation results are presented under wide range of operating conditions in comparison with the PSO and CPSS base tuned stabilizer one through FD and ITAE performance indices. The results evaluation shows that the proposed control strategy achieves good robust performance for a wide range of system parameters and load changes in the presence of system nonlinearities and is superior to the other controllers.

KEYWORDS: power system stabilizer, IHBMO, multi-machine

INTRODUCTION
Power systems are inherently nonlinear and undergo a wide range of transient conditions, that results in under damped low frequency speed as well as power oscillations that are difficult to control. 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 (Basler, 2008). Since the development of interconnected 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].In recent decades, power-system stabilizers (PSSs) with conventional industry structure have been extensively used in modern power systems as an efficient means of damping power oscillations (Kundur, 1994).

The earlier stabilizer designs were based on concepts derived from classical control theory (Larsen and Swann, 1981) Conventional power system stabilizers (CPSSs) are designed based on linear models representing the system's generators operating at a certain operating point. The conventional, lead compensation type of PSS continues to be most popular with the industry due to its simplicity and well understood operational principles. The performance of these designed CPSSs is acceptable as long as the system is operating close to the operating point for which the system model is obtained. However, CPSSs are not able to provide satisfactory performance results over wider ranges of operating conditions.PSS design using this method involves some amount of trial and error and experience on part of the designer. Further these controllers are tuned for particular operating conditions and with change in operating conditions they require re-tuning. Robustness issues are also not adequately addressed in this classical setting. To overcome these difficulties of PSS design and location of that, intelligent optimization based techniques have been introduced (Abedinia *et al*., 2011). H∞ optimization techniques (Hardiansyah *et al.*, 2006) have been applied to robust PSS design problem. However, the additive and/or multiplicative uncertainty representation cannot treat situations where a nominal stable system becomes unstable after being perturbed. On the other hand, the order of the H∞ based stabilizer is as high as that of the plant. This gives rise to complex structure of such stabilizers and reduces their applicability.

Genetic algorithm (GA) is a powerful optimization technique, independent on the complexity of problems where no prior knowledge is available. Many PSS tuning methods use GA (Davis, 1987). These works investigated the use of genetic algorithms for simultaneously stabilization of multi-machine power system over a wide range of scenarios via power system stabilizers with fixed parameters. In (Zhang and Coonick, 2000) formulates the robust PSS design as a multi-objective optimization problem and employs GA to solve it. Improving damping factor and damping ratio of the lightly damped or un-damped electromechanical modes are two objectives. It has been shown that taking just one of the objectives into account may yield to an unsatisfactory result for another one. Also GA is very sufficient in finding global or near global optimal solution of the problem, it requires a very long run time that may be several minutes or even several hours depending on the size of the system under study (Barreiros *et al*., 2005).

Artificial Neural Network (ANN) is an intelligent method which is used for PSS tuning (Center *et al*., 2008). This technique has its own advantages and disadvantages. The performance of power system is improved by ANN based controller but, the main problem of these controllers are the long training time and selecting the number of layers and number of neurons in each layers (Center *et al*., 2008). Also, the proposed techniques are iterative and require heavy computation burden due to system reduction procedure. To overcome the backwashes of above methods, IHBMO is proposed to optimization in this paper.

In the honey bee mating optimization, with observing the operation and the structure of the honey bee mating optimization algorithm, the queen can only mating with several drone without considered other drones. Nevertheless, this characteristic may narrow down the mating with best drone for generate best child and may become a drawback of the honey bee mating optimization. Therefore, this paper presents an interactive strategy by considering the universal gravitation between the queen and drone to retrieve the disadvantages in generate Childs.

In this paper, a comprehensive assessment of the effects of PSS-based damping controller has been carried out. The design problem of the proposed PSS is transformed into an optimization problem and Interactive Honey Bee Mating Optimization (IHBMO) based optimal tuning algorithm is used to optimally tune the parameters of the PSS. The proposed method has been applied and tested on a weekly connected power system under wide range of operating conditions to show the effectiveness and robustness of the proposed IHBMO 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 Classic and PSO designed power system stabilizer.

Power system model

The complex nonlinear model related to an n-machine interconnected power system for case study, can be described by a set of differential-algebraic equations by assembling the models for each generator, load, and other devices such as controls in the system, and connecting them appropriately via the network algebraic equations. The synchronous machine is the most important part of power systems. This part of power system includes electromechanical system which is made of two parts as: electrical and mechanical parts. The model of power system in this paper is simulated by deferential equations that are presented below for this paper (Padyar, 2008; Ghasemi *et al*., 2011). Description of these parameters is presented in APPENDIX A.

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

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

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

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

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

Structure of PSS

The structure of PSS, to modulate the excitation voltage is shown in Fig .1. The structure consists a gain block with gain KP, a signal washout block and two-stage phase compensation blocks. The input signal of the proposed method is the speed deviation (Δω) and the output is the stabilizing signal VS which is added to the reference excitation system voltage. The signal washout block serves as a high-pass filter, with the time constant TW, high enough to allow signals associated with oscillations in input signal to pass unchanged. From the viewpoint of the washout function, the value of TW is not critical and may be in the range of 1 to 20 seconds (Ghasemi *et al*., 2011) The phase compensation block (time constants T1, T2 and T3, T4)provides the appropriate phase-lead characteristics to compensate for the phase lag between input and the output signals.

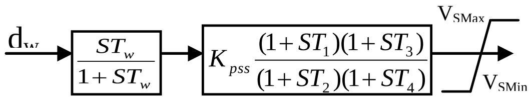

Fig 1. Structure of power system stabilizer

HBMO technique

The honey bee mating optimization is new evolution algorithm with good perspective and high ability for solving optimization problem (Abedinia *et al*., 2011). In the recent year, employed HBMO algorithm for solve multi-objective optimization problems and in many single objective optimization problems was successfully (Shayeghi *et al*., 2010).

3.1. basic HBMO

The honey bee is a social insect that can survive only as a member of a community, or colony. A honey-bee colony typically consists of a single egg laying long-lived queen, several thousand drones (depending on the season), workers and is a large family of bees living in one bee-hive and usually contains 10000 to 60000 workers (Abbas, 2011). The queen is the most important member of the hive because she is the one that keeps the hive going by producing new queen and worker bees. Drones' role is to mate with the queen. Tasks of worker bees are several such as: rearing brood, tending the queen and drones, cleaning, regulating temperature, gather nectar, pollen, water, etc. Broods arise either from fertilized (represents queen or worker) or unfertilized (represents drones) eggs. A mating flight starts with a dance performed by the queen who then starts a mating flight during which the drones follow the queen and mate with her in the air. In each mating, sperm reaches the spermatheca and accumulates there to form the genetic pool of the colony. The queen's size of spermatheca number equals to the maximum number of mating of the queen in a single mating flight is determined. Each time a queen lays fertilized eggs, she randomly retrieves a mixture of the sperm accumulated in the spermatheca to fertilize the egg and this task can only be done by the queen (Shayeghi *et al*., 2010; Abbas, 2001).

At the start of the flight, the queen is initialized with some energy content and returns to her nest when her energy is within some threshold from zero or when her spermatheca is full. In developing the algorithm, the functionality of workers is restricted to brood care, and therefore, each worker may be represented as a heuristic which acts to improve and/or take care of a set of broods. A drone mates with a queen probabilistically using an annealing function as (Shayeghi *et al*., 2010)::

$$prob(Q,D) = e^{\frac{-\Delta(f)}{S(t)}} \qquad (6)$$

Where Prob (Q, D) is the probability of adding the sperm of drone D to the spermatheca of queen Q (that is, the probability of a successful mating); Δ(f) is the absolute difference between the fitness of D (i.e., f (D)) and the fitness of Q (i.e., f (Q)); and S(t) is the speed of the queen at time t. It is apparent that this function acts as an annealing function, where the probability of mating is high when both the queen is still in the start of her mating–flight and therefore her speed is high, or when the fitness of the drone is as good as the queen's. After each transition in space, the queen's speed, S(t), and energy, E(t), decay using the following equations:

$$S(t+1) = \alpha \times S(t) \qquad (7)$$

$$E(t+1) = E(t) - \gamma \qquad (8)$$

where α(t) is speed reduction factor and γ is the amount of energy reduction after each transition ($\alpha, \gamma \in [0,1]$).

Thus, HBMO algorithm may be constructed with the following five main stages (Abbas, 2001; Bozorg *et al*., 2006):

1. The algorithm starts with the mating–flight, where a queen (best solution) selects drones probabilistically to form the spermatheca (list of drones). A drone is then selected from the list at random for the creation of broods.

2. Creation of new broods by cross-over ring the drones' genotypes with the queen's.

3. Use of workers (heuristics) to conduct local search on broods (trial solutions). it can transfer the genes of drones and the queen to the jth individual based on the Eq. (9).

$$(9)\; child = parent1 + \beta(parent2 - parent1)$$

Where β is the decreasing factor ($\beta \in [0,1]$).

4. Adaptation of workers' fitness based on the amount of improvement achieved on broods. The population of broods is improved by applying the mutation operators as follows:

$$(10)\; \begin{array}{l} Brood_i^k = Brood_i^k \pm (\delta + \varepsilon) Brood_i^k \\ \delta \in [0,1], 0 < \varepsilon < 1 \end{array}$$

5. Replacement of weaker queens by fitter broods.

In general, the whole process of HBMO algorithm as shown in Fig. 2. [13].

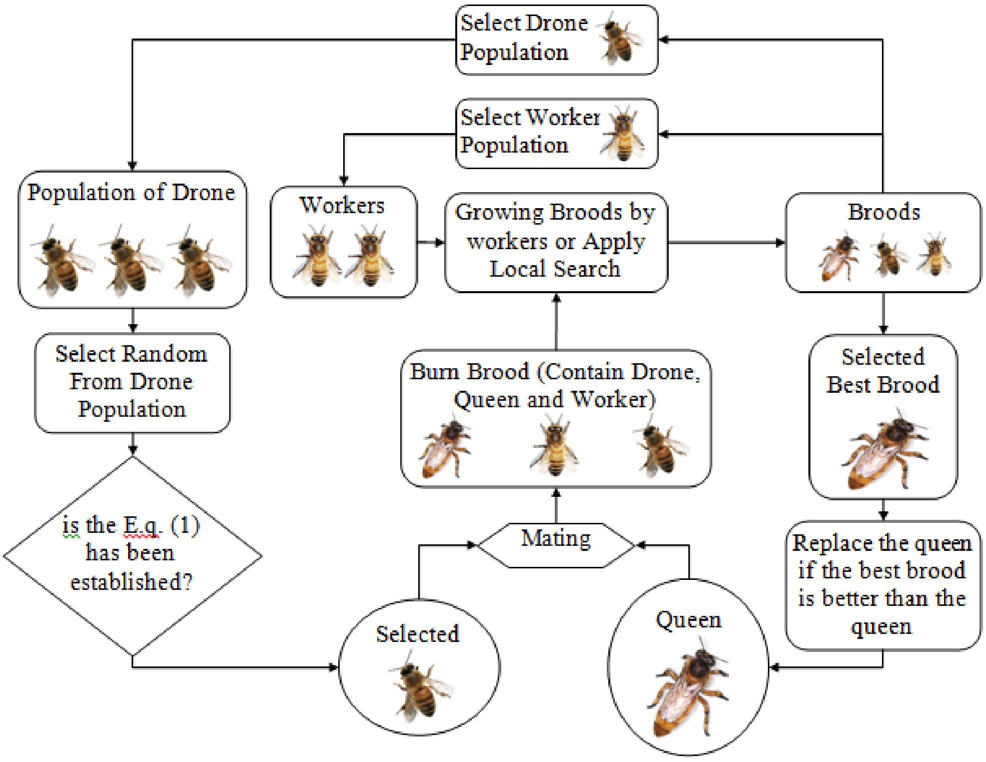

Figure 2. The proposed HBMO technique

Interactive Honey Bee Mating Optimizations

To solve the Dynamic Multi machine power system stabilizers (MPSS) problem, honey bee mating algorithm (HBMO) can be used. The basic disservice of the HBMO algorithm is the fact that itmay miss the optimum, not strong enough to maximize the exploitation capacity and provide a near optimum solution in a limited runtime period. Notwithstanding, the HBMO algorithm is prosperous for finding best answer in optimization problem, but only considers the relation of queen and selected drones by the mating wheel selection. The factor of this mathematics formulation is between (0,1). hence, it cannot used full exploitation capacity. to overcome this drawback, I propose a new method that enhances the mating process of Honey Bee Mating Optimization and increased HBMO with a by considering the universal gravitation between the queen and drone called Interactive Honey Bee Mating Optimization (IHBMO).The Interactive Honey Bee Mating Optimization (IHBMO) algorithm used the equation (11), the universal gravitations between the queen and drone bees are exploited by the mating wheel selection.

$$F_{12} = G\frac{m_1 m_2}{r_{21}^2}\hat{r}_{21} \qquad (11)$$

$$\hat{r}_{21} = \frac{r_2 - r_1}{|r_2 - r_1|} \qquad (12)$$

Where $m1$; $m2$, r21,ˆr21, F12 and G are masses of the objects, the separation between the objects, the unit vector defined with equation (12), the gravitational force heads from the object 1 to the object 2 and the universal gravitational constant, respectively. In the supposed algorithm, the mass m1 and $m2$ replaced by parameters: F(θi) and F(θk), they are fitness value of the queen and drone that picked by applying the mating wheel selection and of the randomly selected drone, respectively (Abedinia *et al*., 2012). We can drive similar formulation for universal gravitation. therefore can write:

$$F_{ik_j} = G\frac{F(\theta_i)\times F(\theta_k)}{(\theta_{kj}-\theta_{ij})^2}\cdot\frac{\theta_{kj}-\theta_{ij}}{|\theta_{kj}-\theta_{ij}|} \qquad (13)$$

$$x_{ij}(t+1) = \theta_{ij}(t) + F_{ik_j}.[\theta_{ij}(t) - \theta_{kj}(t)] \qquad (14)$$

Where Fik.[θi- θk] considered universal gravitation between the queen and drone, which is hand-picked by the queen, and more than one drones (Rashidi *et al*., 2009). Fik play factor controlling in the mating wheel selection (Rashidi *et al*., 2009). By developing and considering the gravitation between the picked queen and $n$selected drone, the results can writing with equation (15):

$$x_{ij}(t+1) = \theta_{ij}(t) + \sum_{k=1}^{n}\tilde{F}_{ik_j}.[\theta_{ij}(t) - \theta_{kj}(t)] \qquad (15)$$

Where $\tilde{F}_{ik_j}$ is the normalized gravitation. In general, the whole process of IHBMO algorithm can be summarized at the five main steps as follows (Rashidi *et al*., 2009):

1. Generate an initial population: In this step, an initial population based on state variable is generated, randomly. That is formulated as:

$$D = [D_1, D_2, D_3, ..., D_n] \qquad D_i = (d_i^1, d_i^2, ..., d_i^m) \qquad (16)$$

Where, d_i^j is the j-th state variable value of i-thdrone. For each individual (Di) the objective function values are evaluated. The queen was chosen according to the best solution (minimum objective function value). The other solutions generated during this phase became the drones to be used during the mating flight (trial solutions). The speed of queen at the start and the end of a mating flight is generated in this step.

2. Flight matting: At the start of the mating flight, the queen flies with her maximum speed. A drone is randomly selected from the population of drones. The mating probability is calculated based on the objective function values of the queen and the selected drone. If the mating is successful (i.e., the drone passes the probabilistic decision rule), the drone’s sperm is stored in the queen's spermatheca and the queen speed is decreased. Otherwise, the queen speed is

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decreased and another drone from the population of drones is selected until the speed of the queen reaches to her minimum speed or the queen's spermatheca is full.

3. Breeding process: In this step, a population of broods is generated based on mating between the queen and the drones stored in the queen's spermatheca. The generation of new broods occurs by cross-over ring the drones' genotypes with the queen's. The jthbrood is generated by using the equation (15).

4. Adaptation of worker's fitness: in this step, after new broods are generated, an attempt is made to improve both the new solutions and the best solution by use of a mutation procedure as equation (10):

5. Replacement of weaker queens by fitter broods and Check the termination criteria: If the new brood is better than the current queen, it takes the place of the queen. If the brood fails to replace the queen, then in the next mating flight of the queen this brood will be one of the drones. Meanwhile, If the termination criterion is satisfied then finish the algorithm, else discard the all previous trial solutions (brood set). Then generate new drones set and go to stage 2.

Case study 1

In this study, the 3-machine9-bus power system shown in Fig.3 is considered. To assess the effectiveness and robustness of the proposed method over a wide range of loading conditions, four different cases designated as nominal, light, heavy and other loading are considered. Details of the system data and operating condition are given in Ref (Abedinia *et al*., 2012)

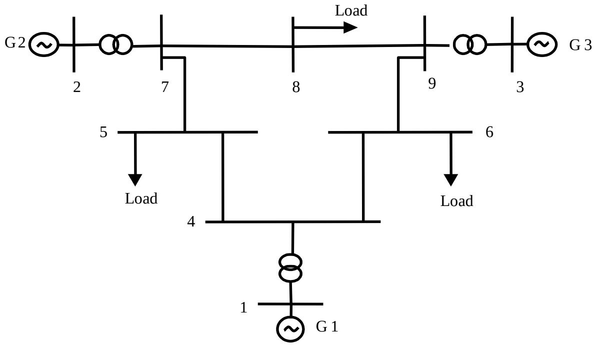

Fig. 3. Three-machine nine-bus power system.

Figure 4 shows the block diagram of IHBMO based tuned PSS controller to solve design the multi machine power system stabilizer problem for each generator (Figure 3) [20].

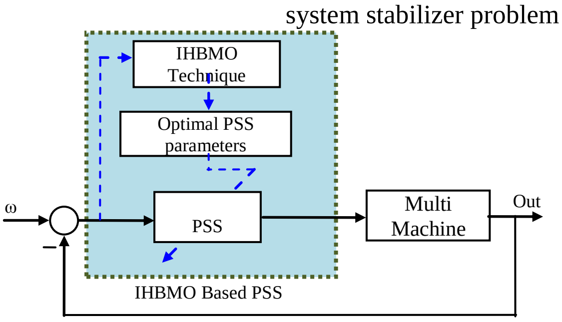

Figure 4. The proposed IHBMO based PSS controller structure.

Problem formulation

In case of the above lead-lag structured PSS, the washout time constants is usually specified. In the present study, washout time constant TW =10s is used. The controller gain KPand the time constants T1, T2, T3 and T4are 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 the this study, an ISTSE of the speed deviations is taken as the objective function expressed as follows:

$$f = \sum_{i=1}^{N_p} \int_0^{t_{sim}} t^2 (|\Delta\omega_{ij}|)^2 .dt \quad (17)$$

Where, Δω denotes the rotor speed deviation for a set of PSS parameters (note that here the parameters to be optimized is KP, T1, T2, T3 and T4; the parameters of the PSS), and tsimis 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 (Padiyar, 2008; Ghasemi *et al*., 2011)

$$\begin{aligned} &Minimize\ J\ Subject\ to: \\ &K^{\min} \le K \le K^{\max} \\ &T_1^{\min} \le T_1 \le T_1^{\max} \\ &T_2^{\min} \le T_2 \le T_2^{\max} \\ &T_3^{\min} \le T_3 \le T_3^{\max} \\ &T_4^{\min} \le T_4 \le T_4^{\max} \end{aligned} \quad (18)$$

Typical ranges of the optimized parameters are [0.01-50] for K and [0.01-1] for T1, T2, T3 and T4. The proposed approach employs IHBMO 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 Eq. (18), which considers a multiple of operating conditions. The operating conditions are given in Table 1 and other loading for simulation given in Table 2. Results of the PSS parameter set values based on the objective function using the proposed IHBMO, PSO and Classic algorithms are given in Table 3.

Table 1- Generator operating conditions (in Pu)

Gen	Nominal		Heavy		Light		Other Load		V_t(pu)
	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	
G_1	0.72	0.27	2.21	1.09	0.36	0.16	0.33	1.12	1.040
G_2	1.63	0.07	1.92	0.56	0.80	-0.11	2.00	0.57	1.025
G_3	0.85	-0.11	1.28	0.36	0.45	-0.20	1.50	0.38	1.025

Table 2- Loading conditions (in Pu)

Bus	Nominal		Heavy		Light		Other Load	
	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)	P(pu)	Q(pu)
5	1.25	0.5	2.0	0.80	0.65	0.55	1.50	0.90
6	0.90	0.30	1.80	0.60	0.45	0.35	1.20	0.80
8	1.0	0.35	1.50	0.60	0.50	0.25	1.00	0.50

Table 3- Optimal PSS parameters

Method	Num - Gen	K_{pss}	T_1	T_2	T_3	T_4
CPSS [21]	G1	18	0.09189	0.05	0.09189	0.05
	G2	16	0.10191	0.05	0.10191	0.05
	G3	20	0.08615	0.05	0.08615	0.05
PSO [22]	G1	46.21	0.06	0.05	0.2383	0.05
	G2	36.87	0.1097	0.05	0.185	0.05
	G3	16.66	0.2257	0.05	0.071	0.05
IHBMO	G1	36.890	0.0768	0.0671	0.981	0.1826
	G2	41.381	0.0671	0.0512	0.886	0.1901
	G3	39.891	0.0278	0.0498	0.906	0.1401

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Simulation results

The behavior of the proposed controller under transient conditions is verified by applying disturbance and fault clearing sequence under different operating conditions. The simulation studies are carried out for two scenarios.The numerical results of performance robustness for all cases are listed in Table 4-5. It can be seen that the values of this system performance characteristics with the proposed controller are smaller compared to that other compared methods.

Scenario 1

In this scenario, performance of the proposed controller under transient conditions is verified by applying a 3-cycle three-phase fault at t=1 sec, on bus 7 at the end of line 5-7. The fault is cleared by permanent tripping the faulted line. Speed deviations of the generators G1, G2 and G3 under Nominal, Heavy and Lightload condition are shown in Fig. 5, 6 and 7, respectively.

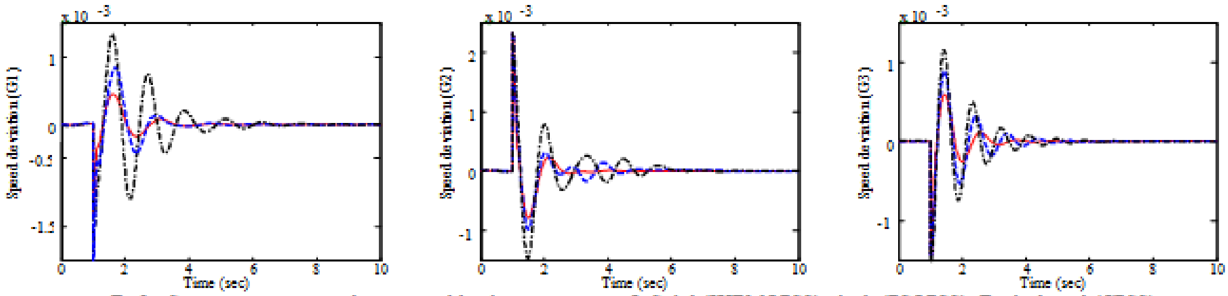

Fig5 - System response under nominal loading in scenario I; Solid (IHBMOPSS), dash (PSOPSS), Dash-dotted (CPSS)

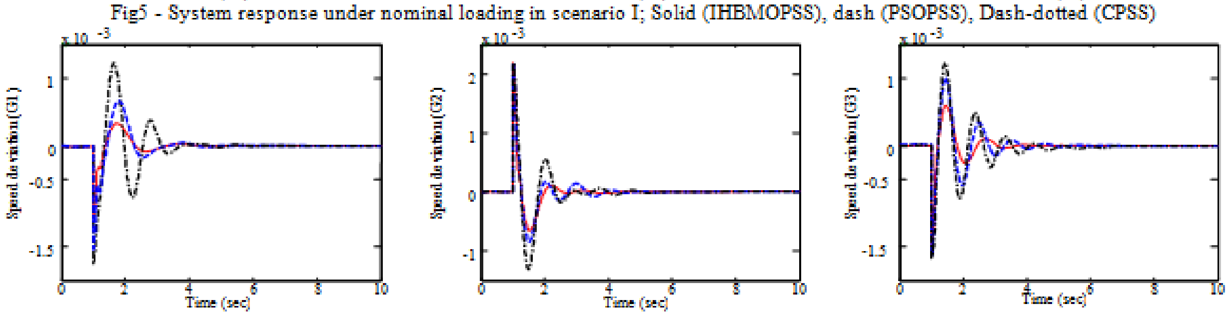

Fig6 - System response under heavy loading in scenario I; Solid (IHBMOPSS), dash (PSOPSS), Dash-dotted (CPSS)

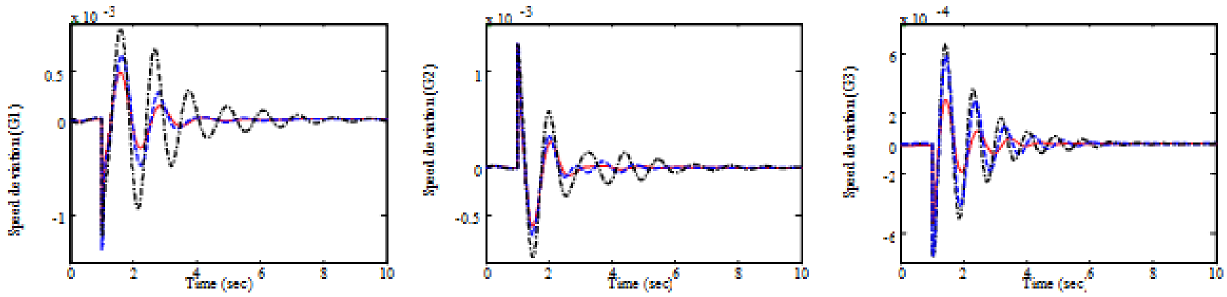

Figure 7 - System response under light loading in scenario I; Solid (IHBMOPSS), dash (PSOPSS), Dash-dotted (CPSS)

Scenario 2

In this scenario, another severe disturbance is considered for different loading conditions; while, a 3-cycle, three-phase fault is applied at the same location in scenario I but applied t=5.0. The fault is cleared without line tripping and the original system is restored upon the clearance of the fault and A 0.1p.u. step increase in the mechanical torque was applied at t=0.5. Speed deviations of the generators G1, G2 and G3 under Heavy, Nominal and Lightload condition are shown in Fig. 8,9 and 10, respectively.

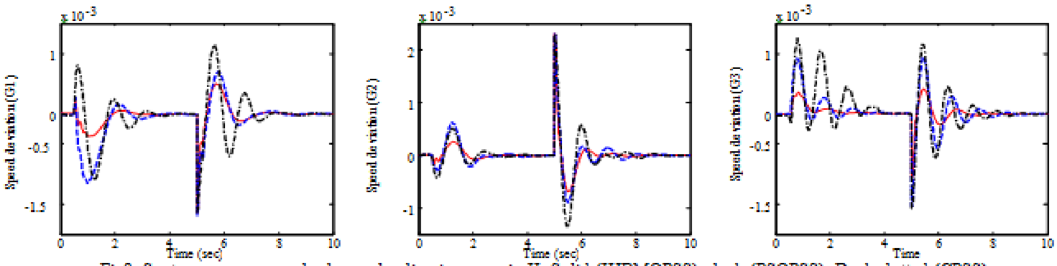

Fig8. System response under heavy loading in scenario II; Solid (IHBMOPSS), dash (PSOPSS), Dash-dotted (CPSS)

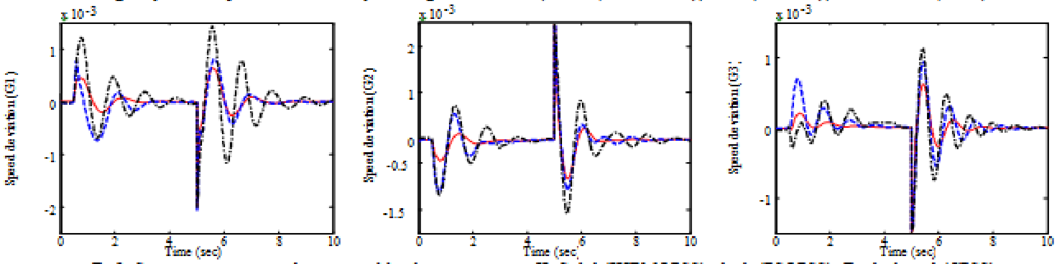

Fig9. System response under nominal loading in scenario II; Solid (IHBMOPSS), dash (PSOPSS), Dash-dotted (CPSS)

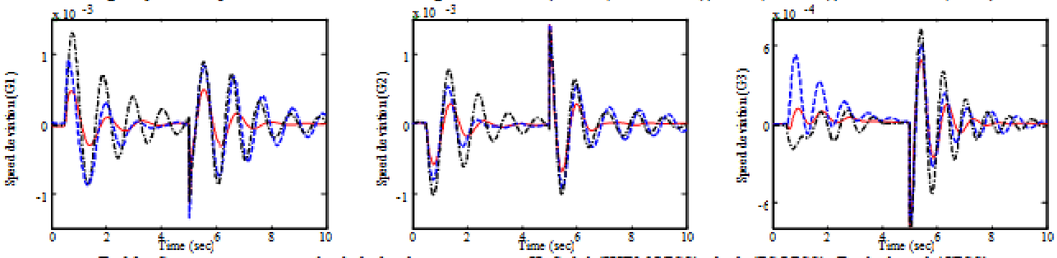

Fig10 - System response under light loading in scenario II; Solid (IHBMOPSS), dash (PSOPSS), Dash-dotted (CPSS)

In the figure 11, show variation of signal output after power system stabilizer. This figure is contain fault from scenario I.

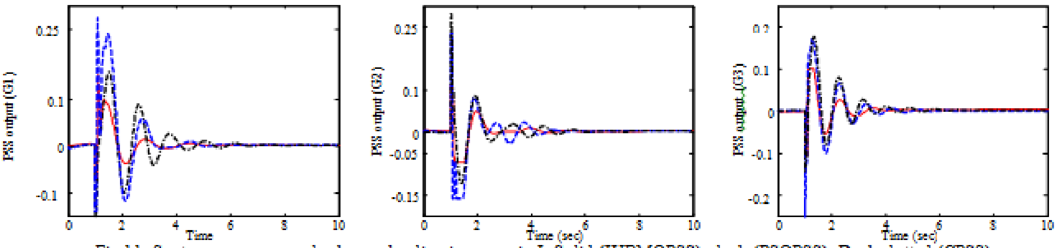

Fig 11. System response under heavy loading in scenario I; Solid (IHBMOPSS), dash (PSOPSS), Dash-dotted (CPSS)

Case study 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 (Ghasemi *et al*., 2011).

$$(19)\ ITAE = 100 \times \int_{0}^{t_{sim}} t.(|\Delta\omega_1| + |\Delta\omega_2| + |\Delta\omega_3|).dt$$

$$(20)\ FD = \frac{\sum_{i=1}^{N_G} 100 \times ((700 \times OS)^2 + (800 \times US)^2 + 0.001 \times T_s{}^2)}{N_G}$$

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 the value of these indices is, the better the system response in terms of time-domain characteristics. Numerical results of performance robustness for all cases are listed in Table 4 and Table 5. It can be seen that the values of these system performance characteristics with the proposed IHBMO based tuned PSSs are much smaller compared to that PSO and Classic based designed PSS. This demonstrates that the overshoot, undershoot settling time and speed deviations of machine is greatly reduced by applying the proposed IHBMO based tuned PSS. Also, Fig. 12 shows theminimum fitness functions evaluating process using the IHBMO method.

Table 4. Values of performance indices ITAE and FD for scenario I.

Change load	IHBMO		PSO		Classic	
	ITAE	FD	ITAE	FD	ITAE	FD
25%	0.2750	0.4332	0.4255	0.4978	0.6742	0.6032
20%	0.2798	0.4458	0.4312	0.5129	0.7080	0.6212
15%	0.2865	0.4610	0.4374	0.5293	0.7508	0.6420
10%	0.2934	0.5035	0.4435	0.5451	0.7994	0.6626
5%	0.3026	0.5223	0.4507	0.5621	0.8570	0.6833
Nominal	0.3135	0.5404	0.4591	0.5779	0.9269	0.7198
-5%	0.3265	0.5589	0.4718	0.5969	1.0138	0.7459
-10%	0.3425	0.5775	0.4880	0.6154	1.1246	0.8140
-15%	0.3627	0.5967	0.5120	0.6515	1.2553	0.8572
-20%	0.3888	0.6049	0.5492	0.6735	1.4268	0.9341
-25%	0.4241	0.6435	0.6009	0.6963	1.6484	0.9834

Table 5. Values of performance indices ITAE and FD for scenario II.

Change load	HBMO		PSO		Classic	
	ITAE	FD	ITAE	FD	ITAE	FD
25%	1.0941	1.0147	1.6316	1.1421	2.2890	1.2717
20%	1.1037	1.0270	1.6402	1.1573	2.3733	1.2899
15%	1.1211	1.0409	1.6464	1.1617	2.4842	1.3374
10%	1.1465	1.0530	1.6535	1.1769	2.6059	1.3614
5%	1.1847	1.0659	1.6654	1.1932	2.7483	1.3864
Nominal	1.2320	1.0891	1.6933	1.2312	2.9165	1.4124
-5%	1.2876	1.1177	1.7279	1.2500	3.1165	1.4391
-10%	1.3602	1.1485	1.7808	1.2687	3.3511	1.4657
-15%	1.4484	1.2015	1.8605	1.3057	3.6516	1.4998
-20%	1.5572	1.2530	1.9708	1.3429	3.9951	1.5362
-25%	1.7031	1.3156	2.1262	1.3840	4.4353	1.5839

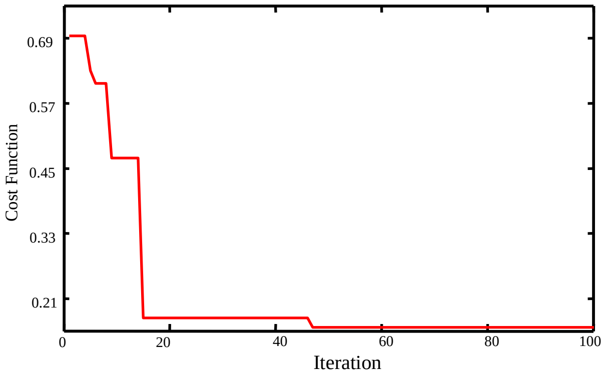

Fig12 – variation of fitness

CONCLUSIONS

In this paper, a novel Honey Bee Mating Optimization technique, which called Interactive Honey Bee Mating Optimization (IHBMO) is proposed for power system stabilizer design in a Multi Machine (MM). For the proposed PSS design problem, a non-liner simulation-based objective function to increase the system damping was developed and then, IHBMO techniques are implemented to search for the optimal controller parameters. The proposed IHBMO algorithm for tuning PSSs 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 IHBMO based tuned PSS has also been compared with a PSO and Classic designed PSS to show its superiority. The non-linear simulation results presented under wide range of operating conditions show the effectiveness and robustness of their ability to provide efficient damping of low frequency oscillations and its superiority to the other methods. The system performance characteristics in terms of ITAE and FD indices reveal that the proposed stabilizers demonstrates that the overshoot, undershoot, settling time and speed deviations of the machine are greatly reduced under severe disturbance conditions.

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