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MULTIMACHINE POWER SYSTEM OSCILLATION DAMPING: PLACEMENT AND TUNING PSS VIA MULTIOBJECTIVE HBMO

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Abstract- In this paper a Multi-objective Honey Bee Mating Optimization (MOHBMO) technique is applied to damp power system oscillation by tuning the Power System Stabilizer (PSS) parameters. Selecting the parameters of PSS which simultaneously stabilize system oscillations is converted to a simple optimization problem which is solved by a HBMO. In the proposed syndicate tuning technique, two performances indicates as ITAE and FD are computed for the stability and performance at each of the given set of operating conditions of the system simultaneously, which leads to use multi objective technique. This newly proposed controller is more efficient because it cope with oscillations and different operating points. The effectiveness of proposed controller is tested in two case studies. The first one is single machine infinite bus system which is compared with Strength Pareto Evolutionary Algorithm (SPEA) and robust PSS that is tuned by Genetic Algorithm (GA). The second case study is the Two Area Four Machine (TAFM) system of Kundur in comparison with the SPEA, GA and Quantitative Feedback Theory (QFT) based tuned PSS under different load conditions. Also in this case the placement of PSSs is presented. Simulation results show the effectiveness of the proposed PSS to damp the oscillation of multi-machine system and work effectively under variable loading and fault conditions.

Keywords: Multiobjective HBMO, PSS, Oscillation, Multi-Machine Power System.

I. INTRODUCTION

In the past, many utilities took small-signal stability for granted and carried out no studies at all to reveal problems related to small-signal performance. This was primarily because a system that remained stable for the first few seconds following a severe disturbance was very likely to remain stable for small perturbations about the post fault system condition. This is not true for present day systems. As power systems have been in continuous development, the need for small-signal studies and measures to ensure sufficient stability margins has been recognized [1-2].

Power System Stabilizers (PSSs) are auxiliary control devices on synchronous generators, used in conjunction with their excitation systems to provide control signals toward enhancing the system damping and extending power transfer limits, thus maintaining reliable operation of the power system [3]. A PSS model is viewed as an additional control block to enhance system stability. This block is added to the Automatic Voltage Regulator (AVR), and uses stabilizing feedback signals such as shaft speed, terminal frequency and/or power to change the input signal of the AVR.

In recent decades, a lot of techniques have been introduced for deigning PSSs. Conventionally lead-lag control is one of the traditional methods. The conventional fixed structure PSS, designed using a linear model obtained by linearizing nonlinear model around a nominal operating point provides optimum performance for the nominal operating condition and system parameters. However, the performance becomes suboptimal following deviations in system parameters and loading condition from their nominal values [4]. The main problem encountered in the Conventional PSS (CPSS) design is the power system constantly experiences changes in operating conditions due to variation in generation and load patterns, as well as changes in transmission networks. Therefore, the achieved results of this technique present poor dynamic performance [5]. To overcome these problems, a number of techniques have been developed for designing PSSs.

Genetic algorithm (GA) is a powerful optimization algorithm which is independent on the complexity of problems where no prior knowledge is available. In recent years, this technique is used for tuning PSS parameters [6]. In [7] 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. Although 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 size of system under study [8]. That is why for this kind of application it could not be applied on-line.

Ant Colony Optimization (ACO) is a powerful technique which is based on the behavior of the artificial ants is inspired from real ants [9]. This algorithm works concurrently and independently and collective interaction via indirect communication leads to good solutions. The greedy heuristic helps find acceptable solution in the early solution in early stages of the search process [10]. This algorithm has some disadvantage points as slower convergence than other heuristics and no centralized processor to guide the ACO towards good solutions. To overcome the drawbacks of above methods, MOHBMO is proposed to implement optimization in this research.

In PSS optimization problems there are several objective functions to optimize. For such multi-objective problems, there is not usually a single best solution but a set of solutions that are superior to others when considering all objectives. This multiplicity of the solutions is explained by the fact that the objectives are generally conflicting ones [11]. Hence, in this research the multi objective functions as a Time multiplied Absolute value of the Error (ITAE) and Figure of Demerit (FD) are considered to find the optimum parameters of the PSS using the advantages of HBMO. The effectiveness of the proposed technique is applied on two case studies. The first one is single machine infinite bus system which is compared with Strength Pareto Evolutionary Algorithm (SPEA) [12] and robust PSS that is tuned by GA [12] through the mentioned performance indicates. And the second case study is the Two Area Four Machine (TAFM) system of Kundur in comparison with the SPEA [12], GA [12] and Quantitative Feedback Theory (QFT) [13] based tuned PSS under different load conditions. The numerical results demonstrate that the proposed multi-objective technique using HBMO is effective and alternative to other compared techniques.

II. PROBLEM STATEMENT

A. Single-Machine Infinite Bus System

The Single Machine Infinite Bus system considered for small-signal performance study which is shown in Figure 1. The generator is represented by the third-order model comprising of the electromechanical swing equation and the generator internal voltage equation [12]. The swing equations of this system are:

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

$$\dot{\omega} = \frac{1}{M}(P_m - P_e - D(\omega - 1)) \tag{2}$$

where, P_m is the input and P_e is the output powers of the generator, M and D are the inertia constant and damping coefficient, respectively, d is the rotor angel and v is the speed and r is the derivative operator d/dt. The output power of the generator can be expressed in terms of the d-axis and q-axis components of the armature current, i, and terminal voltage, v, as:

$$P_e = v_d i_d + v_q i_q \tag{3}$$

The internal voltage equation is:

$$\rho E'_q = (E_{fd} - (x_d - x'_d)i_d - E'_q) / T'_{do} \tag{4}$$

where, E_{fd} is the field voltage, i_d is the open circuit field time constant, x_d and x'_d are d-axis reactance and d-axis transient reactance of the generator, respectively.

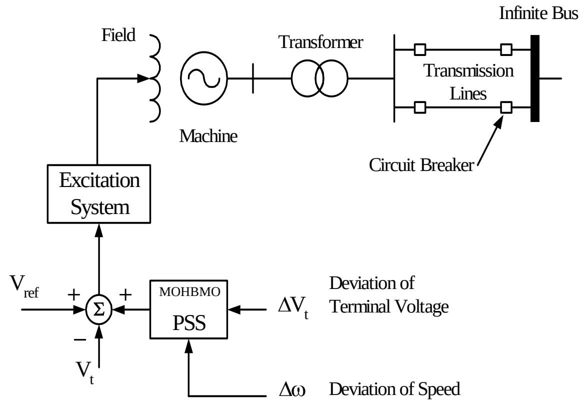


Figure 1. Schematic diagram of one machine infinite bus system and MOHBMO PSS

B. Two-Area Four-Machine System

Kundur's Two-Area Four-Machine (TAFM) system consisting of two fully symmetrical areas linked together by two 220 km, 230 kV transmission lines [13] is considered as a second case study in this research. This power system typically is used to study the low frequency electromechanical oscillations of a large interconnected system. Figure 2 shows the system and its data which is available for everybody in Matlab software's demo.

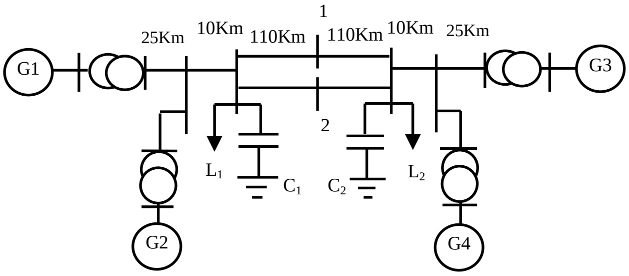


Figure 2. TAFM system

C. PSS Design

The CPSS consists of two phase-lead compensation blocks, a signal washout block, and a gain block. The PSS parameters construct the decision vector. To optimize, these parameters are experimentally limited. These limitations reduce the computation time significantly. Table 1 shows the up and down boundaries of the parameters [12-13]. The block diagram of PSS is presented in Figure 3.

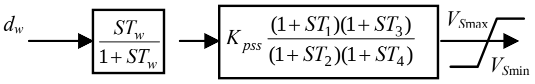


Figure 3. Power system stabilizer

Table 1. PSS parameters limitations

Parameters	T_1	T_2	T_3	T_4	K_{pss}
Lower limit	0.001	0.001	0.001	0.001	0.1
Upper limit	10	10	10	10	100

D. Honey Bee Mating Optimization

The honey bee is a social insect that can survive only as a member of a community or colony. The colony inhabits an enclosed cavity. A colony of honey bees consist of a queen, several hundred drones, 30,000 to 80,000 workers and broods during the active season. A colony of bees is a large family of bees living in one bee-hive. 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 [14].

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. The HBMO Algorithm is the combination of several different methods corresponded to a different phase of the mating process of the queen. In the marriage process, the queen(s) mate during their mating flights far from the nest. 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. When the queen mates successfully, the genotype of the drone is stored. 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 [15]:

$$P_{rob}(Q,D) = e^{-\frac{\Delta(f)}{s(t)}} \tag{5}$$

where $P_{rob}(Q,D)$ is the probability of adding the sperm of drone D to the spermatheca of queen Q (that is, the probability of a successful mating); Δf 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:

$$S(t+1) = \alpha \times 2S(t) \tag{6}$$

$$E(t+1) = E(t) - \gamma \tag{7}$$

where α is a factor and γ is the amount of energy reduction after each transition. Also, Algorithm and computational flowchart of HBMO method to optimize the PSS parameters is presented in Figure 4.

Thus, HBMO algorithm may be constructed with the following five main stages [16]:

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 creation of broods.
2. Creation of new broods by crossoverring the drones’ genotypes with the queen’s.
3. Use of workers (heuristics) to conduct local search on broods (trial solutions).
4. Adaptation of workers’ fitness based on the amount of improvement achieved on broods.
5. Replacement of weaker queens by fitter broods.

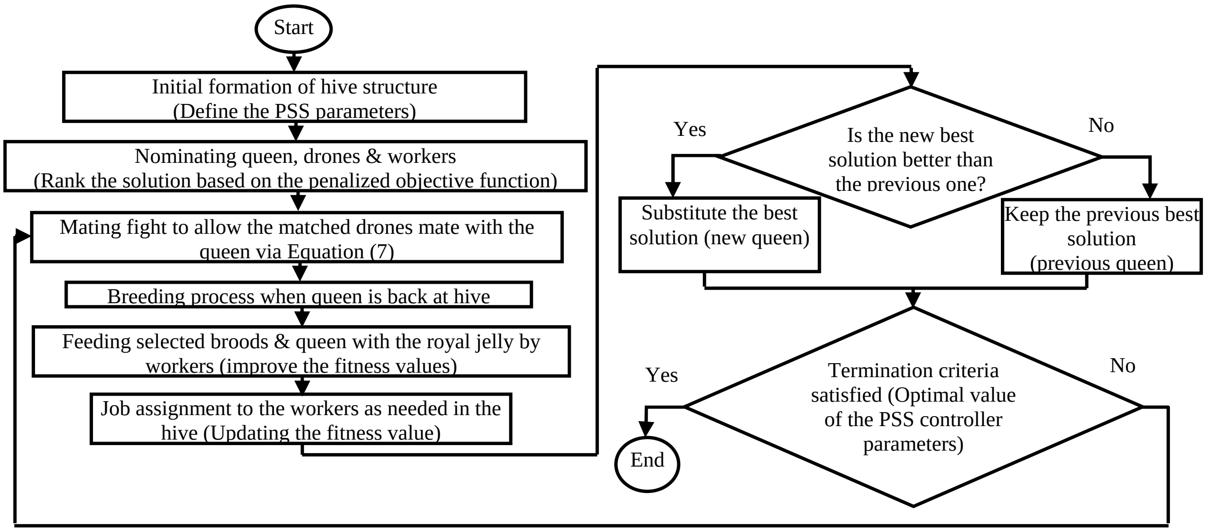


Figure 4. Algorithm and computational flowchart of HBMO

Table 2. The optimized parameters of case 1

method	Gen	K_{pss}	T_1	T_2	T_3	T_4
CPSS	G_1	12.5	0.073	0.028	0.073	0.028
GA	G_1	13.01	0.093	0.009	0.082	0.011
MOHBMO	G_1	25.56	0.097	0.019	0.088	0.010

III. APPLYING MOHBMO TECHNIQUE TO POWER SYSTEM

A. Single-Machine Infinite Bus System Results

For simplicity, a conventional PSS is modeled by two identical stages, lead/lag network which is represented by a gain K_s and four time constants T_1, T_2, T_3 and T_4 for two case studies [6]. In this research the *FD* and *ITAE* for both case studies are presented by f_1 and f_2, respectively. The simulation operated with multi objective with HBMO algorithm and the objective functions for optimization are as follow:

$$f_1 = \sum_{j=1}^{N_l}\sum_{i=1}^{N_g}(200\times OS_{ij})^2 + (500\times US_{ij})^2 + 0.08\times T_{s,ij}^2 \qquad (8)$$

$$f_2 = 100\times\sum_{j=1}^{N_l}\sum_{i=1}^{N_g}\int_0^{t_{sim}} t(|\Delta\omega_{ij}|).dt \qquad (9)$$

The numerical results for PSS parameters in first case study are presented in Table 2. This case study is tested in different load conditions. The details of load conditions are presented in Table 3 and the numerical results for these load conditions for *FD* and *ITAE* are presented in Table 4. The convergence trend of proposed algorithm is shown in Figure 5.

It is very important that, the performance of the proposed controller is tested under transient conditions by applying a 6-cycle three-phase fault or increasing the mechanical torque. For this purpose the response of system for the mentioned conditions are presented in Figures 6-8. It can be seen that the overshoot, undershoot, settling time and speed deviations of machine is greatly reduced by applying the proposed MOHBMO PSS.

B. TAFM System Results

In this part, the proposed technique to find the PSS parameters is applied with finding the optimum location of PSSs in TAFM system simultaneously. Consequently, two PSSs with different settings are installed at G_2 and G_4. However, in [12] the best locations of PSSs are indicated in G_1 and G_4 with similar settings. Anyway, G_2 and G_4 are considered as best locations for installation of the PSSs in this research. Figure 9 shows the trend of objective function’s variation of PSSs locations. Also the optimum parameters of PSSs are presented in Table. 5. Also the objective function variation for TFAM system is presented in Figure 10.

Table 3. Condition for compare simulation

Case No	*P*	*Q*	X_e	*H*
1	0.8	0.4	0.3	3.25
2	0.5	0.1	0.3	3.25
3	1.0	0.5	0.3	3.25
4	0.8	0.4	0.6	3.25
5	0.5	0.1	0.6	3.25
6	1.0	0.5	0.6	3.25
7	0.8	0.0	0.6	3.25
8	1.0	-0.2	0.3	3.25
9	0.5	-0.2	0.6	3.25
10	1.0	0.2	0.3	0.81

Table 4. Calculation of *FD* and *ITAE* for 10 point in to design MOHBMO with three faults in 1 sec.

No	MOHBMO		SPEA		GA	
	ITAE	*FD*	*ITAE*	*FD*	*ITAE*	*FD*
1	0.672	2.410	1.424	4.543	1.508	4.838
2	1.122	2.624	1.713	5.019	1.895	5.747
3	0.800	2.582	1.501	4.682	1.578	4.945
4	0.672	2.491	1.472	4.672	1.418	4.738
5	1.122	2.687	1.809	5.123	1.455	5.647
6	0.800	2.542	1.356	4.673	1.388	4.955
7	0.672	2.491	1.378	4.398	1.418	4.748
8	0.800	2.582	1.398	4.709	1.579	4.933
9	1.122	2.687	1.788	4.909	1.795	5.202
10	0.800	2.542	1.404	3.784	1.579	4.901

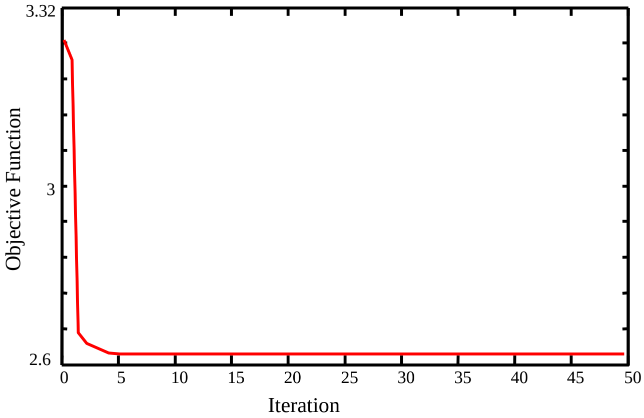


Figure 5. Objective function variation of PSS design

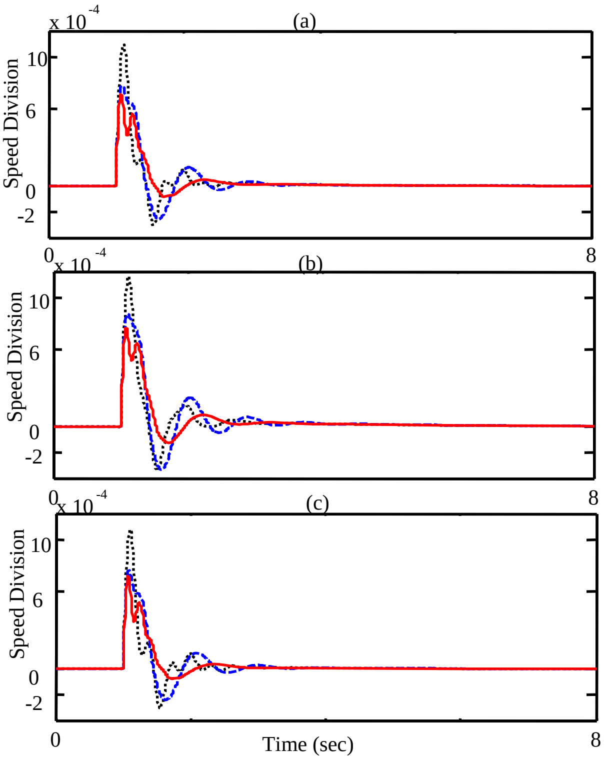


Figure 6. System response by 0.2 p.u. step increasing the mechanical torque in t=1:
Solid (MOHBMO-PSS), Dashed (SPEA-PSS) Doted (GA-PSS)
(a) P=0.8, Q=0.4, X_e=0.3 (b) P=0.5, Q=0.1, X_e=0.3
(c) P=1.0, Q=0.5, X_e=0.3

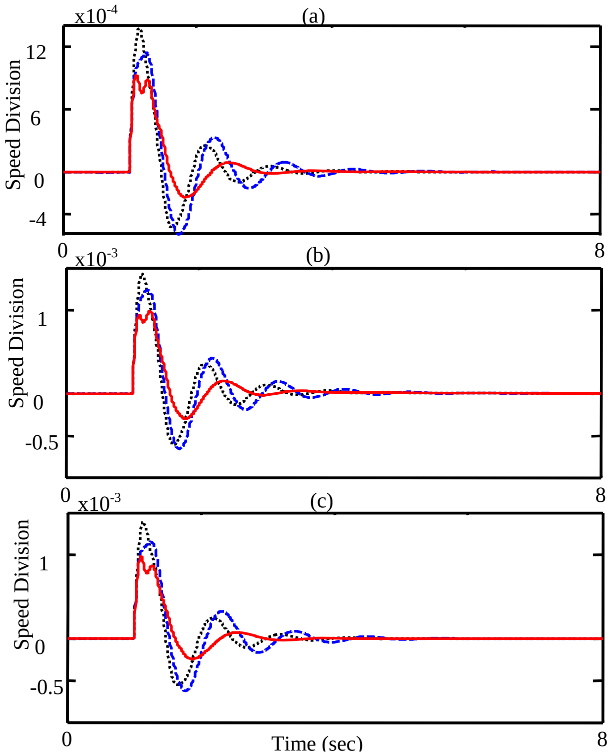


Figure 7. System response by 0.2 p.u. step increasing the mechanical torque in t=1:
Solid (MOHBMO-PSS), Dashed (SPEA-PSS) Doted (GA-PSS).
(a) P=0.8, Q=0.4, X_e=0.6 (b) P=0.5, Q=0.1, X_e=0.6
(c) P=1.0, Q=0.5, X_e=0.6

Table 5. Optimal PSSs’ Parameters of TAFM System

Method		K_{pss}	T_1	T_2	T_3	T_4
MOHBMO	G_1	-	-	-	-	-
	G_2	20.5	0.13	0.01	0.05	0.05
	G_3	-	-	-	-	-
	G_4	15.01	0.01	0.05	0.5	12.2
SPEA	G_1	45	0.26	0.01	4.2	10
	G_2	-	-	-	-	-
	G_3	45	0.26	0.01	4.2	10
	G_4	-	-	-	-	-
GA	G_1	100	0.52	0.04	0.65	5.8
	G_2	-	-	-	-	-
	G_3	100	0.52	0.04	0.65	5.8
	G_4	-	-	-	-	-
QFT	G_1	24.5	0.13	0.01	-	-
	G_2	10.0	0.13	0.01	-	-
	G_3	12.2	0.09	0.01	-	-
	G_4	8.0	0.2	0.02	-	-

- **Scenario 1:** In this scenario the PSSs are installed in G_2 and G_4. To investigate the performance of the PSSs under fault conditions, 9-cycle three phase fault ground fault at bus 1 cleared without equipment have been applied to the robustness of the controllers. The variations of ω for generators in heavy operating condition are presented in Figure 11. Also, the variation of system at nominal operating condition is shown in Figure 12. It is clear that the PSSs by proposed technique have a better performance rather than other controllers of [12] in different load conditions.

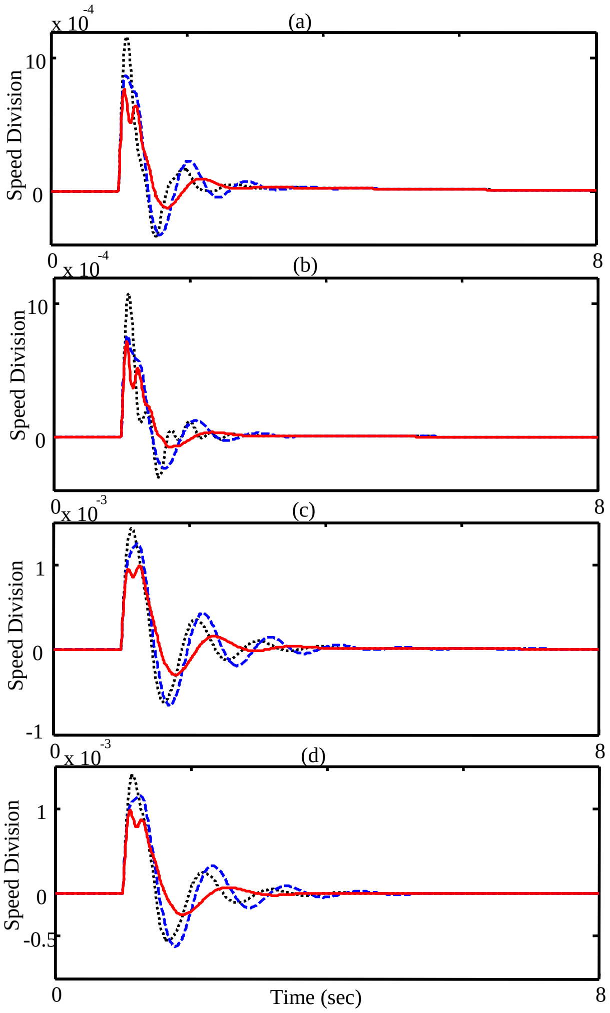


Figure 8. System response by applying a 6-cycle three-phase fault at t=1 sec.: Solid (MOHBMO-PSS), Dashed (SPEA-PSS) Doted (GA-PSS)
(a) P=0.5, Q=0.0, X_e=0.3 (b) P=1.0, Q=0.0, X_e=0.3
(c) P=0.5, Q=0.0, X_e=0.6 (d) P=1.0, Q=0.0, X_e=0.6

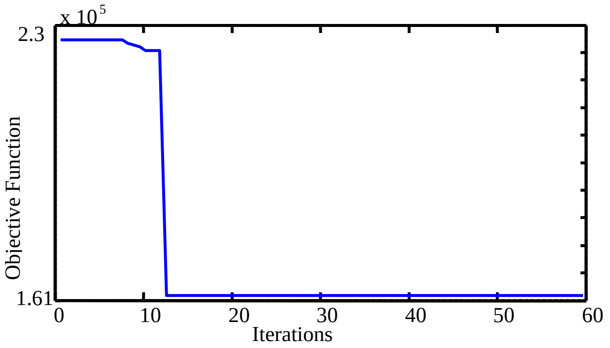


Figure 9. Objective function variation of PSSs location

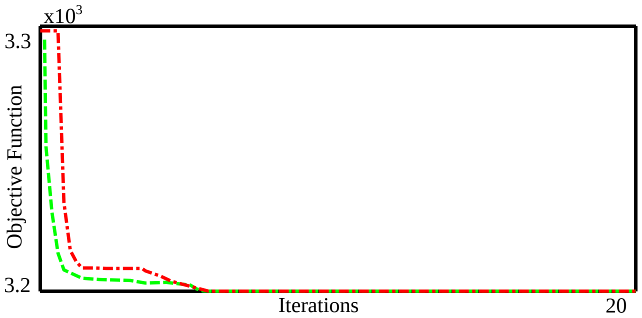


Figure 10. Objective function variation of PSSs optimization in two scenarios

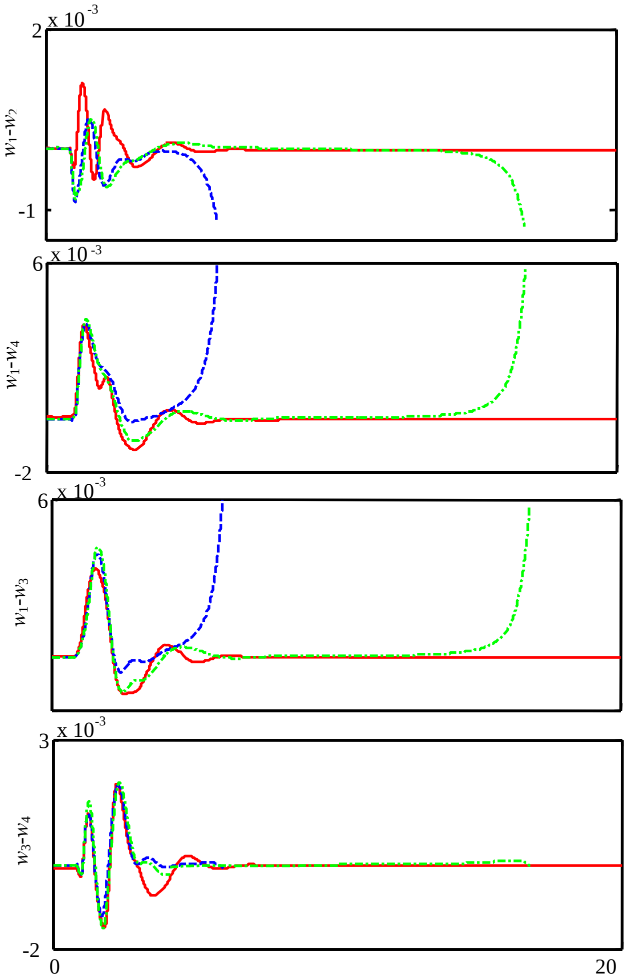
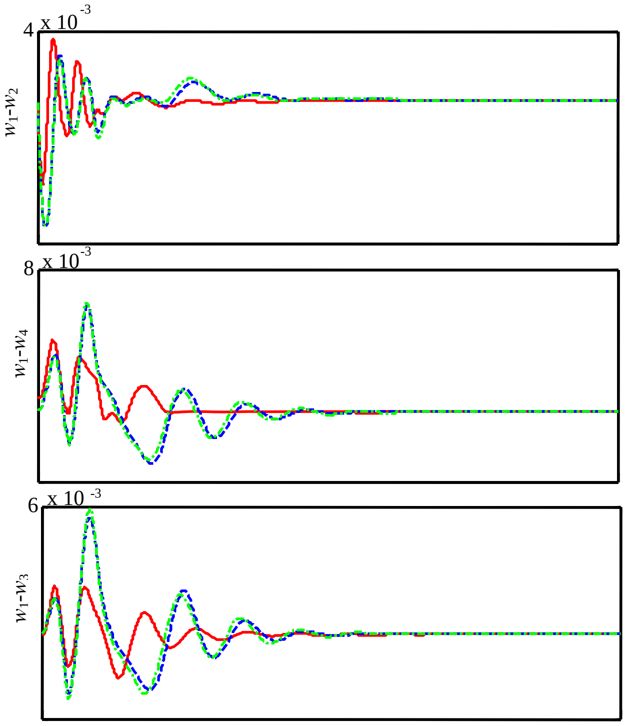


Figure 11. System response under scenario 1 with heavy loading condition: Solid (MOHBMO-PSS), Dashed (SPEA-PSS), Doted (GA-PSS)



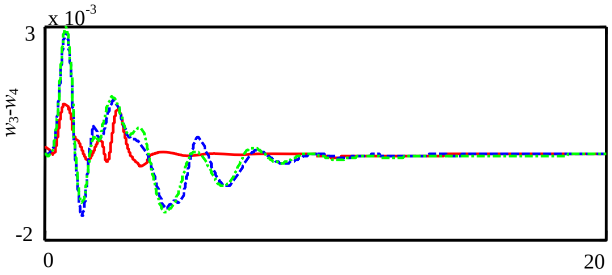


Figure 12. System response under scenario 1 with nominal loading condition: Solid (MOHBMO-PSS), Dashed (SPEA-PSS), Doted (GA-PSS)

- **Scenario 2:** In this scenario the TAFM system is compared with QFT technique [13]. For this purpose, four PSSs are installed in the proposed system. Time responses of the resulting closed-loop system with all four generators fitted with stabilizers were simulated for various disturbances and operating conditions. The system response in nominal, light and heavy load conditions is presented in Figures 13-15, respectively. The numerical results of ITAE and FD for different load condition are presented in Table 6 and Table 7, respectively.

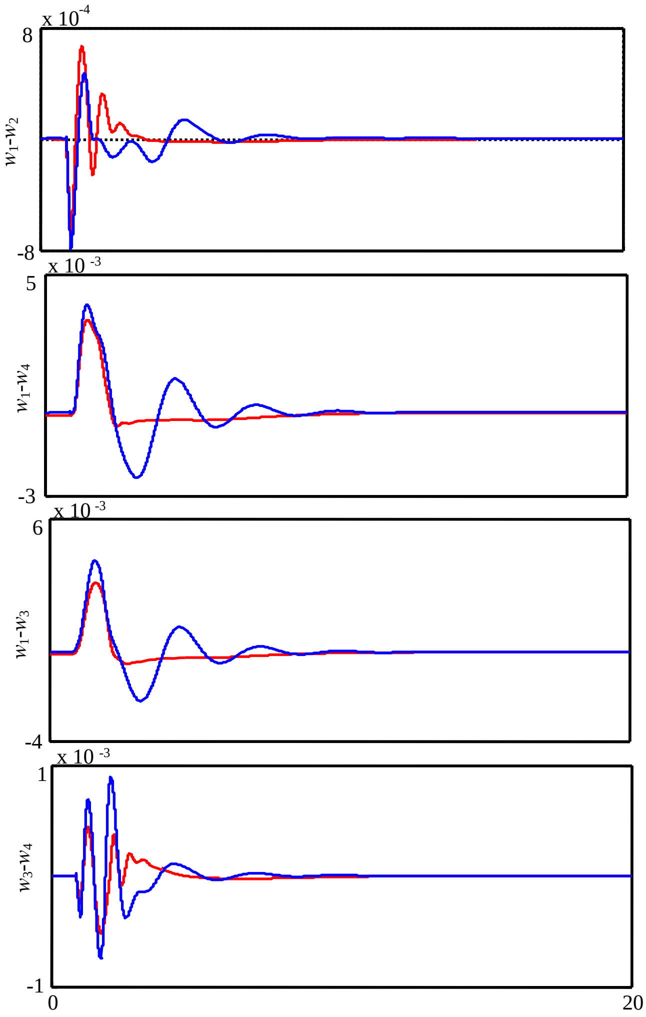


Figure 13. System response under scenario 2 with nominal loading condition: Solid (MOHBMO-PSS), Dashed (QFT-PSS)

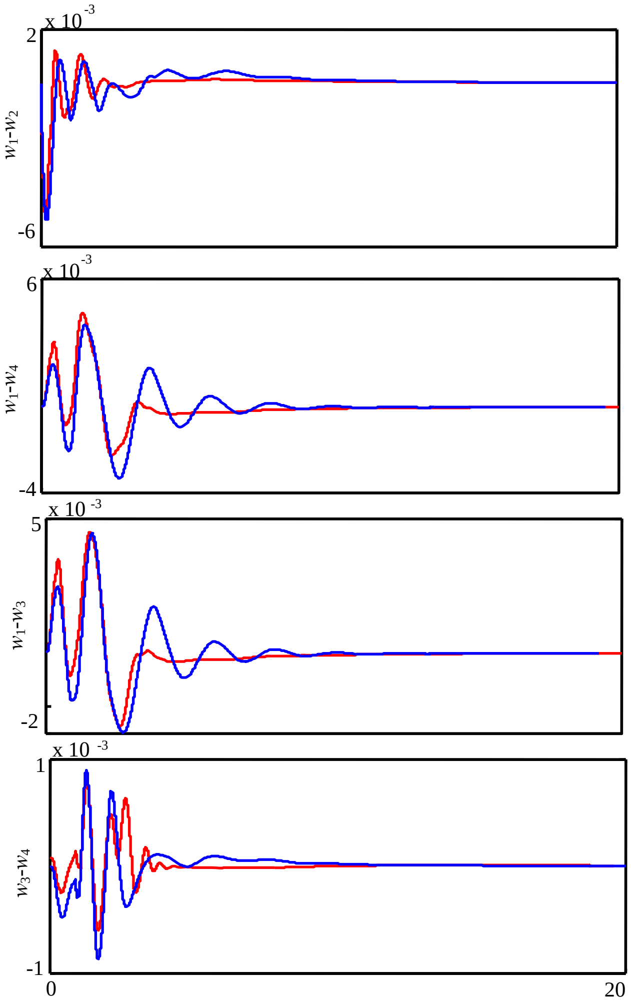
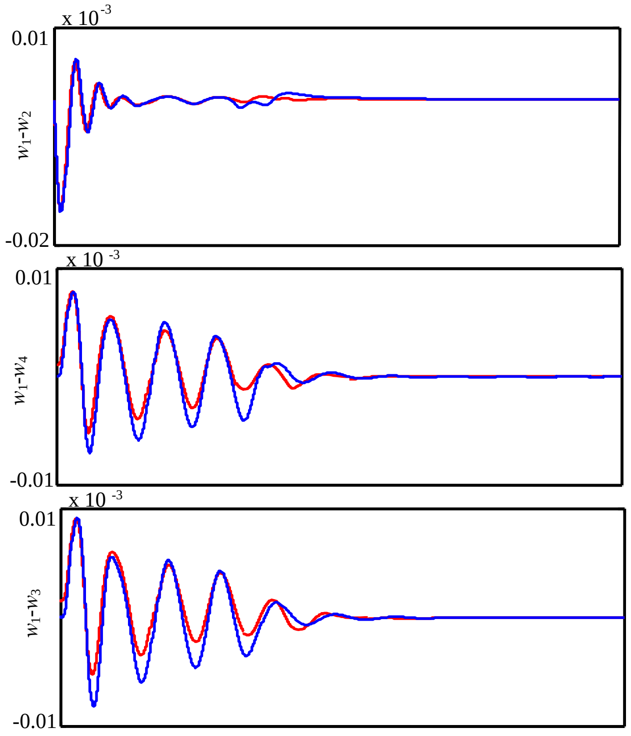


Figure 14. System response under scenario 2 with light loading condition: Solid (MOHBMO-PSS), Dashed (QFT-PSS)



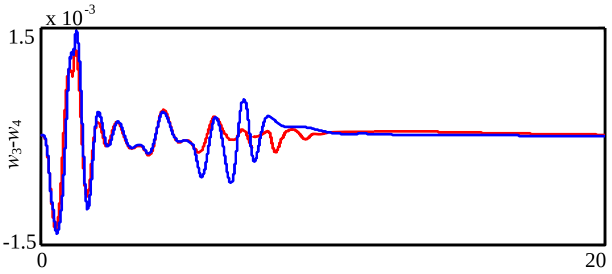


Figure 15. System response under scenario 2 with heavy loading condition: Solid (MOHBMO-PSS), Dashed (QFT-PSS)

Table 6. Value of ITAE in different techniques

	Scenario 1			Scenario 2		
Method	Nominal	Light	Heavy	Nominal	Light	Heavy
MOHBMO	4.27	4.63	4.77	3.14	3.71	3.49
SPEA	5.81	6.13	6.31	-	-	-
GA	6.31	6.62	6.77	-	-	-
QFT	-	-	-	3.84	4.21	3.43

Table 7. Value of FD in different techniques

	Scenario 1			Scenario 2		
Method	Nominal	Light	Heavy	Nominal	Light	Heavy
MOHBMO	12.21	12.56	13.04	10.35	10.63	11.02
SPEA	14.82	14.90	15.72	-	-	-
GA	16.30	16.42	16.82	-	-	-
QFT	-	-	-	12.22	13.03	11.33

IV. CONCLUSIONS

In this research, a design scheme of robust PSS for single machine connected to an infinite bus and tow area four machine of Kundur using multi-objective technique have been developed. The slip signal is taken as output of simulation. For optimization problem the HBMO technique is applied to find the appropriate parameters of PSSs in optimum location through some performance indicates as *FD* and *ITAE*. This method is stronger than other methods which considered with single objective in particular the lack of reliability in what concerns succeeded, and valid convergence, and the failures in attempts to reduce the time. The proposed technique is tested in various load condition for the solution of the low frequency oscillation problem in power system. The single machine infinite bus system is compared with SPEA and robust PSS that is tuned by GA through the mentioned performance indicates. The second case study is compared with the SPEA, GA and QFT based tuned PSS under different load conditions. Achieved numerical results of power systems demonstrate that the proposed MOHBMO is superior to other compared methods.

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