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ROBUST TUNING OF PSS CONTROLLER BASED ON IMPERIALIST COMPETITIVE ALGORITHM

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Abstract- It is the purpose of this paper to multi-objective design of the single-machine Power System Stabilizers (PSSs) using Imperialist Competition Algorithm (ICA). The ability of the proposed approach for optimal setting of the widely used Conventional Power System Stabilizers (CPSSs) has been attended. The PSSs parameters designing problem is converted to an optimization problem with a multi-objective function including the desired damping factor and the desired damping ratio of the power system modes, which are solved by the ICA algorithm. The capability of the proposed approach is confirmed on a single-machine power system under different operating conditions and disturbances. The results of the proposed approach are compared with the Genetic Algorithm (GA) based tuned PSS through some performance indices to reveal its strong performance.

Keywords: PSS Design, Imperialist Competition Algorithm, Genetic Algorithm, Multi-Objective Optimization.

I. INTRODUCTION

One of the most important aspects in electric system operation is the stability of power systems. This issue forms from the fact that the power system must maintain frequency and voltage levels, 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]. Power systems face low frequency oscillations (in order of 0.1-2.5 Hz) during and after a large or small disturbance has happened to a system, especially for middle to heavy loading conditions [2, 3]. These oscillations may sustain and grow to cause system separation if there is not an adequate damping [4].

PSSs are the most effective devices for damping low frequency oscillations and increasing the stability of the power systems [5, 6]. A PSS provides additional feedback stabilizing signals in the excitation system. In spite of the capability of modern control techniques with different structures, power system utilities still prefer the conventional power system stabilizer structure [7, 8]. CPSSs still are widely being used in the power systems may be due of difficulties behind using new methods.

New intelligent control design methods such as fuzzy logic controllers [9,10] and artificial neural network controllers [11] have been used as PSSs. Recently, intelligent optimization methods like genetic algorithms (GA) [12-15], simulated annealing [16] and rule based bacteria foraging [17] have been applied for PSS parameter optimization. These evolutionary algorithms are heuristic population-based search procedures that incorporate random variation and selection operators. Even though, these methods seem to be good methods for the solution of 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 efficiency to obtain global optimum solution and also simulation process use a lot of computing time.

Moreover, in [12, 13] and [16, 17] the robust PSS design was formulated as a single objective function problem, and not all PSS parameters were considered adjustable. In order to dominate these disadvantages, the imperialist competition algorithm (ICA) based PSS (ICAPSS) is proposed in this paper for optimal tuning of PSS parameters.

In this paper, the problem of PSS design is formulated as a multi-objective optimization problem and ICA is used to solve this problem. The PSSs parameters designing problem is converted to an optimization problem with the multi-objective function including the desired damping factor and the desired damping ratio of the power system modes. The capability of the proposed ICA is tested on a single-machine power system under different operating conditions in comparison with the GA based tuned PSS (GAPSS) through some performance indices. Results show that the proposed method achieves stronger performance for damping low frequency oscillations under different operating conditions than other methods and is superior to them.

II. DESIGN OF OBJECTIVE FUNCTION

For this purpose, a multi-objective function comprising the damping factor and the damping ratio is considered as follows [15, 18]:

$$J = \sum_{j=1}^{n_p} \sum_{\sigma_{i,j} \geq \sigma_0} [\sigma_0 - \sigma_{i,j}]^2 + a \sum_{j=1}^{n_p} \sum_{\xi_{i,j} \leq \xi_0} [\xi_0 - \xi_{i,j}]^2 \quad (1)$$

where n_p is the number of operating points considered in the design process. This method's performance is shown in Figure 1.

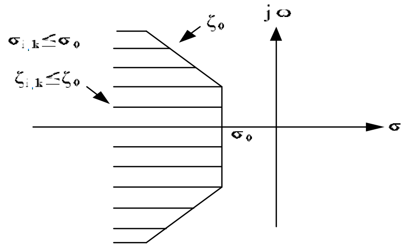


Figure 1. Objective performance

1) $\xi_k \geq \xi_{madr}$, where $k = (1,2,...,n-gen-1)$ and ξ_{madr} is the minimum acceptable damping ratio.
2) $(1-\gamma_{\min})\omega_k \leq \omega_k + \mathrm{Im}(\Delta\lambda_k) \leq (1+\gamma_{\max})\omega_k$, where ω_k is the frequency of kth mode and γ is defined according to system specifications.

For all other modes, including the original natural modes and the new modes we have:
3) $\xi_i \geq \xi_{mmdr}$, while ξ_{mmdr} is minimum marginal damping ratio. The performance of this technique has been shown in Figure 2.

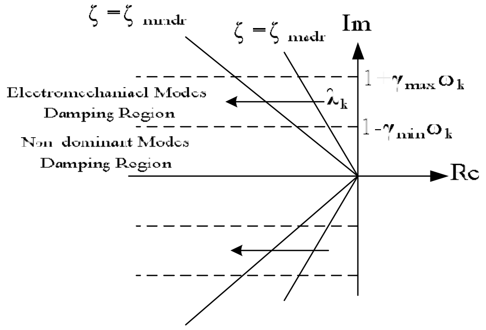


Figure 2. Objectives' performance

In this paper, in order to use advantages of the above mentioned references, objectives are considered as follow:
minimize $y_1 = (\min(\mathrm{abs}(\sigma_k)))$, where σ_k is the real part of the kth electromechanical modes.
minimize $y_2 = (\min(\xi_k))$, where ξ_k is the damping ratio of the kth electromechanical modes.
subject to:
1) $\sigma_i < 0$, for all eigenvalues. This condition guarantees system small signal stability.
2) For the electro-mechanical modes: $a \leq \omega_k \leq b$, while a and b are the empirically considered limits of frequency, presented in related figures.
3) For all other modes: $\xi_i \geq \xi_{mmdr}$, whereas ξ_{mmdr} is considered experimentally 0.2 for SMIB system.

No pre-specified value is considered $\sigma_{\min}$ or $\xi_{\min}$. For CPSS $x = (T_1, T_2, T_3, T_4, V_{S\max}, k_{PSS})$. The CPSS parameters bounds are shown in Table 1.

Table 1. CPSS boundaries

	Parameters					
	T_1	T_2	T_3	T_4	$V_{S\max}$	K_{PSS}
Maximum	1	1	10	10	0.5	100
Minimum	0.01	0.01	0.01	0.01	0.05	10

The main object here is to minimize the following objective function:

$$OF = (r_1 \times y_1 + r_2 \times y_2)^{-1} \quad (2)$$

where y_1 and y_2 are objective functions. In order to have comprehensive investigation, different values for weights, r_1 and r_2 are assumed.

III. HEURISTIC OPTIMIZATION METHOD

A. Imperialist Competitive Algorithm

The ICA was first proposed in [19-21]. It is inspired by the imperialistic competition. It starts with an initial population called colonies. The colonies are then categorized into two groups, namely, imperialists (best solutions) and colonies (rest of the solutions). The imperialists try to absorb more colonies to their empire. The colonies will change according to the policies of imperialists. The colonies may take the place of their imperialist if they become stronger than it (propose a better solution). The flow chart of the proposed algorithm is shown in Figure 3. The steps of the proposed ICA are described as follows:

Step 1. Generate an initial set of colonies with the size of N_C.

Step 2. Set iteration = 1.

Step 3. Calculate the objective function for each colony and set the power of each colony as follows:

$$CP_C = OF \quad (3)$$

Step 4. Keep the best N_{imp} colonies as the imperialists and set the power of each imperialist as follows:

$$IP_i = OF \quad (4)$$

Step 5. Assign the colonies to each imperialist according to the calculated IP_i. This means the number of colonies owned by each imperialist $\left(\left(IP_i / \sum_{j=1}^{N_{imp}} IP_j\right) \times \left(N_C - N_{imp}\right)\right)$ is proportional to its power that is, IP_i.

Step 6. Move the colonies towards their relevant imperialist using crossover and mutation operators.

Step 7. Exchange the position of a colony and the imperialist if it is stronger $CP_C > IP_i$.

Step 8. Compute the empire's power, that is, EP_i for all empires as follows:

$$EP_i = \frac{1}{N_{E_i}} \times (\chi_1 \times IP_i + \chi_2 \times \sum_{c \in E_i} CP_C) \quad (5)$$

where χ_1 and χ_2 are weighting factors that are adaptively selected.

Step 9. Pick the weakest colony and give it to one of the best empires (select the destination empire probabilistically based on its power, EP_i).

Step 10. Eliminate the empire that has no colony.

Step 11. If more than one empire remained then go to Step 6.

Step 12. End.

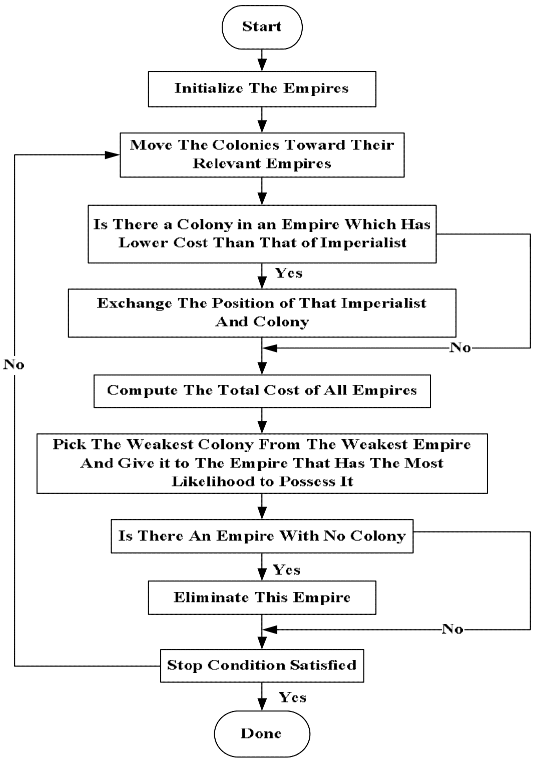


Figure 3. Flowchart of the proposed ICA

B. Genetic Algorithm

It is well known that GAs works according to the mechanism of natural selection - stronger individuals are likely to be the winners in a competitive environment. In practical applications, each individual is codified into a chromosome consisting of genes, each representing a characteristic of one individual for identification of the unknown parameters of a model, parameters are regarded as the genes of a chromosome, and a positive value, generally known as the fitness value, is used to reflect the degree of goodness of the chromosome [22].

Typically, a chromosome is structured by a string of values in binary form, which the mutation operator can operate on any one of the bits, and the crossover operator can operate on any boundary of each two bit in the string. Since in our problem the parameters are real numbers, a real coded GA is used, in which the chromosome is defined as an array of real numbers with the mutation and crossover operators. Here, the mutation can change the value of a real number randomly, and the crossover can take place only at the boundary of two real numbers. More details of proposed GA are shown in Figure 4.

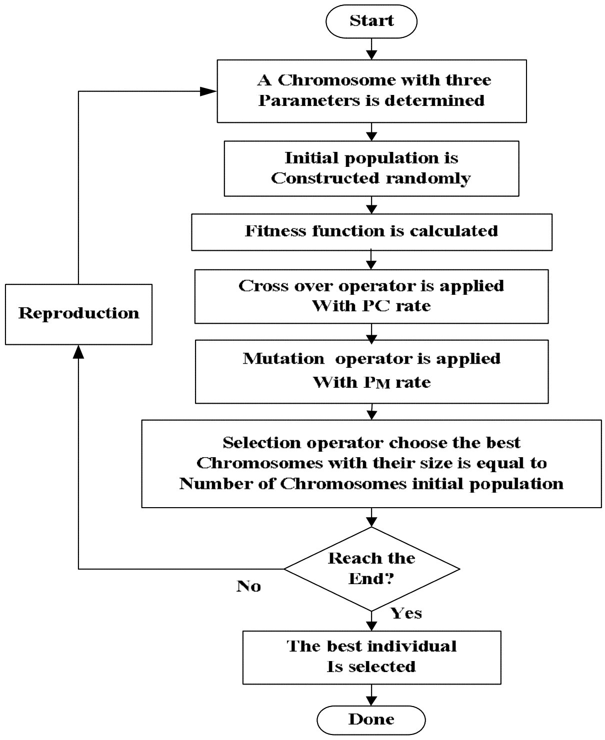


Figure 4. Flowchart of the GA

IV. CASE STUDY

A. Single Machine Infinite Bus

A single machine infinite bus (SMIB) model of a power system for evaluating the proposed method is supposed. In SMIB model, a typical 500MVA, 13.8 kV, 50Hz synchronous generator is connected to an infinite bus through a 500MVA, 13.8/400KV transformer and 400KV, 350 Km transmission line [23]. This system has been shown in Figure 5.

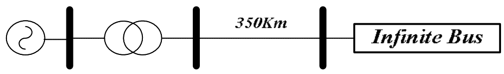


Figure 5. Single machine infinite bus (SMIB) system

B. PSS Structure

The model of the CPSS is illustrated in Figure 6. This model consists of two phase-lead compensation blocks, a gain block and a signal washout block. The value of T_W is usually not critical and it can range from 0.5 to 20 s. In this paper, it is fixed to 10 s. The six other constant coefficients of the model (T_1, T_2, T_3, T_4, $V_{S\max}$ and K_{PSS}) should be designed properly**.**

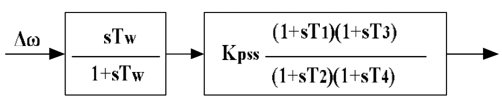


Figure 6. Power system stabilizer

V. SIMULATION RESULT

The proposed ICA methodology and GA are programmed in Matlab running on an Intel w Core TM2 Duo Processor T5300 (1.73 GHz) PC with 1 GB RAM. It is applied on SIMB system to demonstrate its abilities.

A. Determined Parameters of ICA

In this section the effect of ICA parameters on average objective function is investigated (after 100 trials). The following procedure has been adopted to calculate optimum value of the mutation and crossover probabilities. The colony size, (N_C) was selected 100 based on trial. The crossover and mutation probabilities are increased from 0.1 to 0.9 in steps of 0.1 as described in Table 2. The performance of the proposed ICA is evaluated for all the above-mentioned combinations. Hundred independent trials have been made with 100 iterations per trial.

The performance of the ICA also depends on the number of colonies. In Table 2 the performance of the ICA is checked also for different number of colonies. The parameters of ICA are selected based on the average total objective function obtained for different values of parameters given in Table 2. After a number of careful experimentation, following optimum values of ICA parameters have finally been settled: $N_C = 100$; crossover probability = 0.6, mutation probability = 0.4. Additionally, the other simulation parameters are provided as shown in Table 3.

Table 2. Influence of ICA parameters on average total objective function (after 100 trials)

N_C	Mutation probability	Crossover probability								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
100	0.1	0.04320	0.04301	0.04286	0.04277	0.04312	0.04278	0.08463	0.0428	0.04275
	0.2	0.04350	0.04262	0.04290	0.04299	0.04306	0.08023	0.04343	0.04322	0.04311
	0.3	0.04361	0.04279	0.04259	0.04262	0.04281	0.04294	0.04314	0.04313	0.04333
	0.4	0.04282	0.04275	0.04347	0.04308	0.04260	0.04210	0.04315	0.04352	0.04266
	0.5	0.04429	0.04344	0.04318	0.0440	0.04293	0.04256	0.04338	0.04253	0.04291
	0.6	0.04272	0.04280	0.04288	0.04277	0.04310	0.04287	0.04317	0.04273	0.04323
	0.7	0.04254	0.04253	0.04268	0.04260	0.04332	0.04330	0.04264	0.04238	0.04422
	0.8	0.04274	0.04256	0.04286	0.04312	0.04342	0.04354	0.04301	0.04289	0.04388
	0.9	0.04306	0.04283	0.04271	0.04288	0.04277	0.04307	0.04264	0.04256	0.04341

Table 3. ICA and GA simulation parameters

Method	Parameters			
	N_C	Selection method	Crossover	Mutation
		Normalized geometric selection	Simple Xover	Binary mutation
GA	100	χ_1=0.85	V_{max}=1.05	N_{imp}=3
ICA	100	χ_2=0.25	V_{min}=0.95	N_{imp}=3

B. Comparing the Result

The ICA algorithm is run several times and then optimal set of PSS parameters is selected. The optimal value of PSSs parameters of each method are given in Table 4. This table presents a comparison among the results of the ICA and GA confirming the effectiveness of the proposed method.

Table 4. Optimal PSSs parameters using ICA and GA schemes for SMIB system

Method	Parameters							
	T_1	T_2	T_3	T_4	V_{Smax}	K_{PSS}	AOF	MT
ICA	0.8	0.5	1.3	6.4	0.34	33.2	0.042	976
GA	0.68	0.09	1	6.7	0.33	17	0.05	1346

Additionally, Table 4 provides the average value of the objective function, based on the proposed method and the other one. This would show the convergence characteristics of the ICA compared with other method. The average value of objective function in the proposed ICA method is less than GA. This means that the ICA is more robust compared to GA. Execution time of each optimization method is very important factor for its application to real systems.

The execution time of the proposed ICA compared with other methods is given in the last row of Table 4. One of the main advantages of the proposed method is that the convergence of ICA algorithm is faster and less time consuming (Table 4) as compared to the other applied methods. Because the proposed algorithm (ICA) provides the correct answers with high accuracy in the initial iterations which make the responding time of this algorithm extremely low.

To have a better understanding, dominant oscillatory poles' maps of the system, comprising some optimum PSSs are depicted in Figure 7. As it can be seen from the figure, the open-loop system is unstable. To evaluate the performance of the ICA based tuned PSSs under fault condition, a 6-cycle three phase- ground fault disturbance has been applied to the system. Rotor speed deviation of a generator located close to the fault position and variations of active power of a selected line are plotted against time for various PSSs and the faulty operating condition as depicted in Figure 8. The major disadvantage of the proposed method is that there is no evidence for finding the global optimum solution in present problem. This can also be seen in classical methods because of their sensitivity to the starting point of the decision variables (initial values). According to figure 8 the preference of proposed scheme is demonstrated by having better damping in comparison with GA.

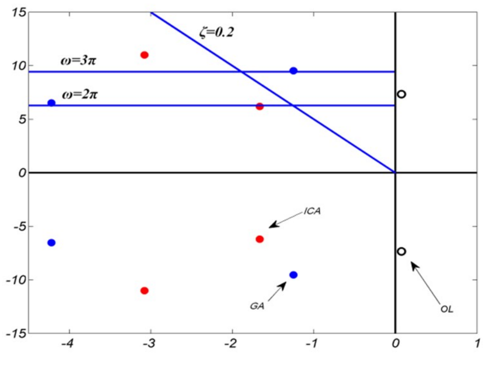
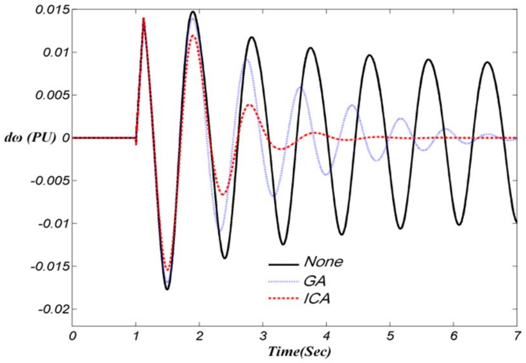
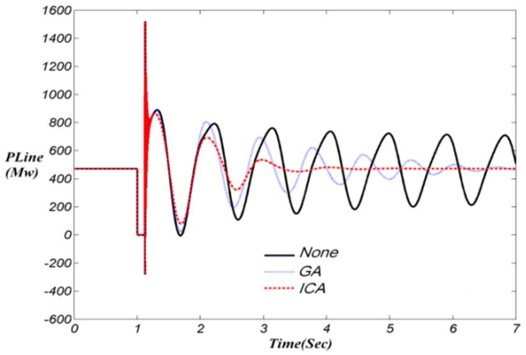


Figure 7. Dominant modes of SMIB system



(a)



(b)

Figure 8. SMIB: (a) Rotor speed deviation, (b) Active power

VI. CONCLUSIONS

The power system must maintain frequency and voltage levels, under any disturbance and oscillation. In such a case PSS is the most effective devices for damping low frequency oscillations and increasing the stability of the power systems. Therefore, in this paper a multi-objective design of single-machine power system stabilizers (PSSs) using imperialist competition algorithm (ICA) is presented. The stabilizers are optimally tuned with optimization a multi-objective function including the desired damping factor, and the desired damping ratio of the power system modes. The proposed ICA algorithm for tuning PSSs is easy to implement without additional computational complexity. The proposed method is applied on a single-machine power system to verify its robust performance under different operating conditions and disturbances. The effectiveness of proposed scheme compared with other method can be summarized as follow:

- Damping out local as well as inter area modes of oscillations.
- The faster convergence and less time consuming.
- The less fitness function which shows its robust preference than other method.
- The ability to jump out the local optima.
- Providing the correct answers with high accuracy in the initial iterations.
- Superiority in computational simplicity, success rate and solution quality.

NOMENCLATURES

OF : Objective function

CP_C : Power of cth colony

IP_i : Power of ith imperialist

EP_i : Power of ith empire

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BIOGRAPHIES

Abolfazl Jalilvand was born in Takestan, Iran in 1972. He received B.Sc. in Electrical and Electronic Engineering from Electrical and Computer Engineering Faculty, Shahid Beheshti University, Tehran, Iran, in 1995. He received M.Sc. and Ph.D. degrees from Electrical and Computer Engineering Faculty, University of Tabriz, Tabriz, Iran, in Power Engineering and Control Engineering in 1998 and 2005, respectively. After completing his Ph.D., he joined the Electrical Engineering Department of University of Zanjan, Zanjan, Iran, as an Assistant Professor where he was head of Electrical Engineering Department from 2008 to 2010. Also, he was Dean of Faculty of Engineering from 2010 to 2012. Currently, he is an Associate Professor at the same university. He has more than 100 papers in journals and conferences proceedings. His main research interests include the hybrid control systems, Petri nets, intelligent control, modeling and control of power electronic converters, control and stabilization of power systems, and application of intelligent methods in power systems. He is a member of the institute of electrical and electronics engineers (IEEE).

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