Robust Tuning of the PSS Controller to Enhance Power System Stability

Saeid. Jalilzadeh and Mehdi. Azari

Abstract—It is the purpose of this paper to multi-objective design of a single-machine power system stabilizers (PSSs) using Modified Shuffled Frog Leaping Algorithm (MSFLA). The ability of the proposed approach for optimal setting of the widely used CPSSs has been attended. 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 which solved by the MSFLA 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, Modified shuffled frog leaping algorithm (MSFLA), Multi-objective optimization, Genetic algorithm (GA).

I. Introduction

ONE of the most important aspects in electric system operation is the stability of power systems. This issue form 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 devises for damping low frequency oscillations and increasing the stability of the power systems [5]. 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 (CPSS) structure [6,7]. CPSSs still are widely being used in the power systems and this may be because of some difficulties behind the using new methods.

New intelligent control design methods such as fuzzy logic controllers [8,9] and artificial neural network controllers [10] have been used as PSSs. Recently, intelligent optimization methods like genetic algorithms (GA) [11-14], simulated annealing [15], evolutionary programming [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 [11, 12] and [15, 16] the robust PSS design was formulated as a single objective function problem, and not all PSS parameter were considered adjustable. In order to dominate these disadvantages, the modified shuffled frog leaping algorithm (MSFLA) based PSS (MSFLAPSS) is proposed in this paper. The MSFLA technique is used for optimal tuning of PSS parameter to improve optimization synthesis and the speed of algorithm convergence.

In this paper, the problem of PSS design is formulated as a multi-objective optimization problem and MSFLA 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 MSFLA 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.

This paper is set out as follows: Section II presents problem formulation, Section III sets out the proposed solution method for solving the problem, the case study is presented in Section IV, and finally, the simulation results and the conclusion are presented in Section V and VI, respectively.

II. Problem Statement

For this purpose, a multi-objective function comprising the damping factor and the damping ratio is considered [14, 18] as follows:

$$J=\sum_{j=1}^{n_p}\sum_{\sigma_{i,j}\geq\sigma 0}[\sigma_0-\sigma_{i,j}]^2+a\sum_{j=1}^{n_p}\sum_{\xi_{i,j}\leq\xi_0}[\xi_0-\xi_{i,j}]^2 \qquad (1)$$

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where n_p is the number of operating points considered in the design process, and $\sigma_{i,j}$ is the real part of the i[th] eigenvalue of the j[th] operating point. Moreover, $\xi_{i,j}$ is the damping ratio of the i[th] eigenvalue of the j[th] operating point. This method's performance is shown in Fig.1.

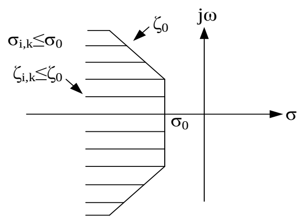


Fig. 1 Objective performance

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 k[th] mode and γ is defined according to system specifications.

For all other modes, including the original natural modes and the new modes:

3) $\xi_i \geq \xi_{mmdr}$. While ξ_{mmdr} is minimum marginal damping ratio. The performance of this technique has been shown in Fig.2.

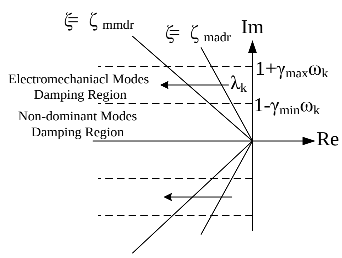


Fig. 2 Objective performance

In this paper, in order to use advantages of the above mentioned references, objectives are considered as follow:

$Minimize : \lambda_1 = (Min(abs(\sigma_k)))$, σ_k is the real part of the k[th] electromechanical modes.

$Minimize : \lambda_2 = (Min(\xi_k))$, ξ_k is the damping ratio of the k[th] 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 systems.

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 I
CPSS BOUNDARIES

Parameters	T_1	T_2	T_3	T_4	V_{Smax}	K_{PSS}
Maximum	1	1	10	10	0.5	100
Minimum	0.01	0.01	0.01	0.01	0.05	10

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

$$OF = (r_1 \times \lambda_1 + r_2 \times \lambda_2)^{-1} \quad (2)$$

Where λ_1 and λ_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. Modified Shuffled Frog Leaping Algorithm

In the natural memetic evolution of a frog population, the ideas of the worse frogs are influenced by the ideas of the better frogs, and the worse frogs tend to jump toward the better ones for the possibility of having more foods [2]. The frog leaping rule in the shuffled frog leaping algorithm (SFLA) is inspired from this social imitation, but it performs only the jump of the worst frog toward the best one. According to the original frog leaping rule presented above, the possible new position of the worst frog is restricted in the line segment between its current position and the best frog's position, and the worst frog will never jump over the best one (see Fig.3). Clearly, this frog leaping rule limits the local search space in each memetic evolution step.

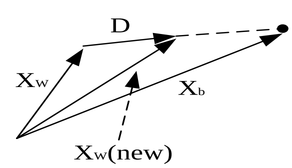


Fig. 3 The original frog leaping rule

This limitation might not only slow down the convergence speed, but also cause premature convergence. In nature, because of imperfect perception, the worst frog cannot locate exactly the best frog's position, and because of inexact action, the worst frog cannot jump right to its target position. Considering these uncertainties, we argue that the worst frog's new position is not necessary restricted in the line connecting its current position and the best frog's position. Furthermore, the worst frog could jump over the best one. This idea leads to a new frog leaping rule that extends the local search space as illustrated in Fig.4 (for 2-dimensional problems). The new frog leaping rule is expressed as:

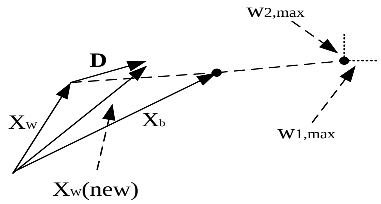


Fig. 4 The new frog leaping rule

$$D = r.c(X_b - X_w) + W \quad (3)$$

$$W = [r_1 w_{1,\max}, r_2 w_{2\max}, ..., r_s w_{s,\max}]^T \quad (4)$$

$$X_w(new) = \begin{cases} X_w + D & if \|D\| \le D_{\max} \\ X_w + \frac{D}{\sqrt{D^T D}} D_{\max} & if \|D\| > D_{\max} \end{cases} \quad (5)$$

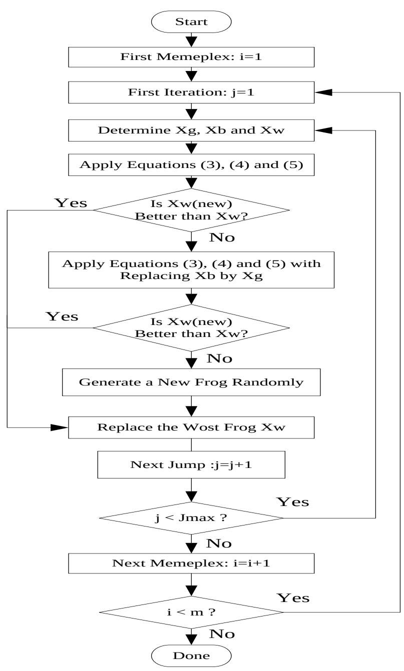


Fig. 5 The MSFLA flowchart

where r is a random number between 0 and 1; c is a constant chosen in the range between 1 and 2; r_i (1<i<S) are random numbers between -1 and 1; $w_{i,max}$ (1<i<S) are the maximum allowed perception and action uncertainties in the i_{th} dimension of the search space; and D_{max} is the maximum allowed distance of one jump. The flow chart of the local memetic evolution using the proposed frog leaping rule is illustrated in Fig.5.

The new frog leaping rule extends the local search space in each memetic evolution step; as a result it might improve the algorithm in term of convergence rate and solution performance provided that the vector $W_{max}=[w_{1,max},\ldots, w_{S,max}]^T$ is appropriately chosen. However, if $||W_{max}||$ is too large, the frog leaping rule will loss its directional characteristic, and the algorithm will becomes more or less random search. Therefore, choosing a proper maximum uncertainty vector is an issue to be considered for each particular optimization problem.

B. Genetic Algorithm

It is well known that GAs work 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. 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 bits 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 [19]. More details of proposed GA are shown in Fig. 6.

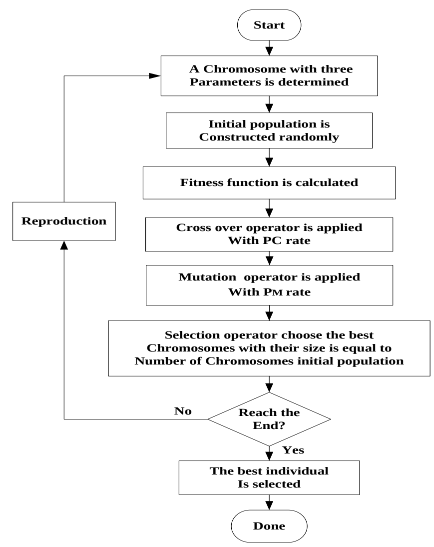


Fig. 6 The GA flowchart

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 assumed. 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 [20]. This system has been shown in Fig. 7.

Fig. 7 Single Machine Infinite Bus (SMIB) System

B. PSS Structure

The model of the CPSS is illustrated in Fig. 8. This model consists of two phase-lead compensation blocks, a signal washout block, and a gain block. The value of the T_w is usualy 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 (i.e:T_1, T_2, T_2, T_3, V_{Smax}, K_{PSS}) should be designed properly.

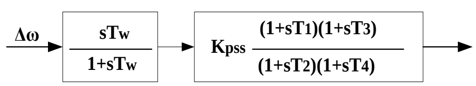


Fig. 8 Power system stabilizer

V. Experimental Result

The MSFLA and GA algorithms are simulated and tested on the single machine infinite bus (SMIB) model of a power system by regulating the various parameters as depicted in Fig. 7. After a number of careful experimentation, following optimum results of MSFLA and GA have finally been reported as follow. The minimum fitness value evaluating process is shown in Fig. 9.

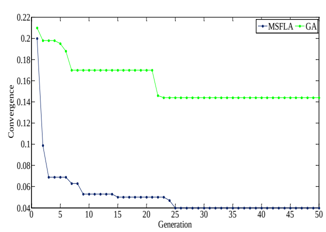


Fig. 9 Variations of Objective Function for SMIB System

The MSFLA and GA algorithms are run several times and then optimal set of PSS parameters is selected. The set value of PSSs' parameters using both the proposed MSFLA and GA method are given in Table 2.

TABLE II
OPTIMAL PSSs PARAMETERS USING MSFLA AND GA ALGORITHM FOR SMIB SYSTEM

Algorithm	T_1	T_2	T_3	T_4	V_{Smax}	K_{PSS}	MT(Sec)
GA	0.8	0.5	1.3	6.4	0.34	33.2	6534
MSFLA	0.6	0.1	1	7	0.3	21.4	5406

Execution time (MT) complexity of each optimization method is very important for its application to real systems. The execution time of the proposed MSFLA is compared with GA is tabulated in the last column of the Table II.

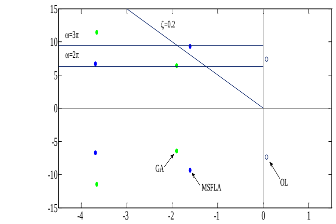
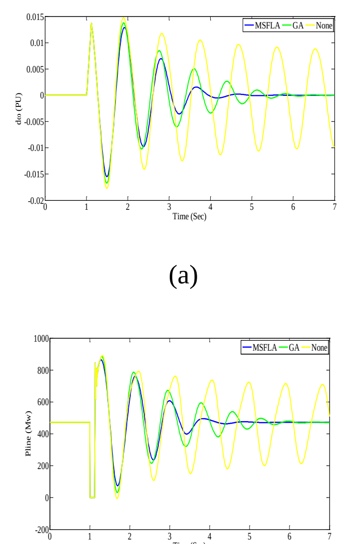


Fig. 10 Dominant Modes of SMIB System

As it can be seen from the Fig.9 the convergence of MSFLA algorithm is faster and less the time consuming as compared to the case where either method is applied alone. Because the proposed algorithm (MSFLA) provides the correct answers with high accuracy in the initial iterations which make the responding time of this algorithm extremely fast. In addition, the average value of objective function in the proposed MSFLA method is less than GA. This means that the MSFLA is more robust compared to GA.

To have a better understanding, dominant oscillatory poles' maps of the system, comprising some optimum PSSs are shown in Fig.10. This figure shows that the electro-mechanical modes are close together, but there is a higher difference in the other oscillatory mode of some PSSs. Also, instability of the open-loop system is obvious. Additionally the constraints which have been satisfied are illustrated in this figure.



(a)

(b)

Fig. 11 SMIB: a) Rotor speed deviation b) Active power

To evaluate the performance of the MSFLA based tuned PSSs under fault condition, a 6-cycle three phase ground fault disturbance has been applied to the system. The fault is then cleared by line tripping without reclosure. 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 shown in Fig.11. This figure presents large signal stability of the test system with optimum PSSs. Also it can be seen that the MSFLA based tuned PSSs using the multi-objective function achieves good robust performance and provides superior damping in comparison with GA. It can be concluded that the proposed MSFLAPSS provides much proper control signals than the GAPSSs and CPSSs.

VI. Conclusion

In this paper a multi-objective design of single-machine power system stabilizers (PSSs) using modified shuffled frog leaping algorithm (MSFLA) is presented. The stabilizers are optimally tuned with optimization a multi-objective function including the damping factor, and the damping ratio of the power system modes. The proposed MSFLA algorithm for tuning PSSs is easy to implement without additional computational complexity. The ability to jump out the local optima, providing the correct answers with high accuracy in the initial iterations and speed are astonishing increased and thereby the high accuracy is achieved. The capability of the proposed approach is tested on a single-machine power system under different operating conditions and disturbances. Compared with the GA methods in different operating conditions, the MSFLA technique provides robust performance, superior damping and much proper control signals which demonstrates its superiority in computational complexity, success rate and solution quality.

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