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Optimization of Power System Stabilizers using BAT search algorithm

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ABSTRACT

A new metaheuristic method, the BAT search algorithm based on the echolocation behavior of bats is proposed in this paper for optimal design of Power System Stabilizers (PSSs) in a multimachine environment. The PSSs parameter tuning problem is converted to an optimization problem which is solved by BAT search algorithm. An eigenvalues based objective function involving the damping factor, and the damping ratio of the lightly damped electromechanical modes is considered for the PSSs design problem. The performance of the proposed BAT based PSSs (BATPSS) has been compared with Genetic Algorithm (GA) based PSSs (GAPSS) and the Conventional PSSs (CPSS) under various operating conditions and disturbances. The results of the proposed BATPSS are demonstrated through time domain analysis, eigenvalues and performance indices. Moreover, the results are presented to demonstrate the robustness of the proposed algorithm over the GA and conventional one.

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Introduction

One problem that faces power systems is the low frequency oscillations arising due to disturbances. These oscillations may sustain and grow to cause system separation if no adequate damping is providing [1]. In analyzing and controlling the power system's stability, two distinct types of system oscillations are recognized. One is referred to inter-area modes resulted from swinging one generation area with respect to other areas. The second one is associated with swinging of generators existed in one area against each other and is known as local mode [2,3]. Power System Stabilizer (PSS) is used to generate supplementary control signals for the excitation system in order to mitigate both types of oscillations [4].

In last few years, Artificial Intelligence (AI) techniques have been discussed in literatures to solve problems related to PSS design. Artificial Neural Network (ANN) for designing PSS is addressed in [5–8]. The ANN approach has its own merits and demerits. The performance of the system is improved by ANN based controller but, the main problem of this controller is the long training time, the selecting number of layers and the number of neurons in each layer. Another AI approach likes Fuzzy Logic Control (FLC) has received much attention in control applications. In contrast with the conventional techniques, FLC formulates the control action of a plant in terms of linguistic rules drawn from the behavior of a human operator rather than in terms of an algorithm synthesized from a model of the plant [9–15]. It offers the following merits: it does not require an accurate model of the plant; it can be designed on the basis of linguistic information obtained from the previous knowledge of the control system and gives better performance results than the conventional controllers. However, a hard work is inevitable to get the effective signals when designing FLC. Also, it requires more fine tuning and simulation before operational. Robust techniques such as H_∞ [16–20], H_2 [21,22] and μ-synthesis [23] have been also used for PSS design. However, these methods are iterative, sophisticated and, the system uncertainties should be carried out in a special format. On the other hand, the order of the stabilizers is as high as that of the plant. This gives rise to complex structure of such stabilizers and reduces their applicability. Another technique like pole shifting is illustrated in [24,25] to design PSS. However, this technique suffers from complexity of computational algorithm, heavy computational burden, memory storage problem and non-adaptive tuning under various system operating conditions and configurations. Also, this design approach assumes full state availability.

Recently, global optimization techniques have been applied to PSS design problem. Simulated Annealing (SA) is presented in [26] for optimal tuning of PSS but this technique might fail by getting trapped in one of the local optimal. Another heuristic technique like Tabu Search (TS) is introduced in [27–28] to design PSS. Despite this optimization method seems to be effective for the design problem, the efficiency is reduced by the use of highly epistatic objective functions, and the large number of parameters to be optimized. Also, it is time consuming method. Genetic Algorithm (GA) is developed in [29,30] for optimal design of PSS. Despite this optimization technique requires a very long run time

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depending on the size of the system under study. Also, it suffers from settings of algorithm parameters and gives rise to repeat revisiting of the same suboptimal solutions. A Particle Swarm Optimization (PSO) for the design of the PSS parameters is illustrated in [31]. However, PSO pains from the partial optimism, which causes the less exact at the regulation of its speed and the direction. Moreover, the algorithm cannot work out the problems of scattering and optimization. Furthermore, the algorithm suffers from slow convergence in refined search stage, weak local search ability and algorithm may lead to possible entrapment in local minimum solutions. A relatively newer evolutionary computation algorithm, called Bacteria Foraging (BF) scheme has been developed by [32] and further established recently by [33–39]. The BF algorithm depends on random search directions which may lead to delay in reaching the global solution. In order to overcome these drawbacks, a BAT search optimization algorithm is proposed in this paper.

A new metaheuristic algorithm known as BAT search algorithm, based on the echolocation behavior of bats, is proposed in this paper for the optimal design of PSS parameters. The problem of a robust PSS design is formulated as an objective optimization problem and BAT algorithm is used to handle it. The stabilizers are tuned to shift all electromechanical modes to a prescribed zone in the S-plane in such a way that the relative stability is confirmed. The effectiveness of the proposed BATPSS is tested on a multimachine power system under various operating conditions in comparison with GAPSS and CPSS through time domain analysis, eigenvalues and performance indices. Results evaluation show that the proposed algorithm attains good robust performance for suppressing the low frequency oscillations under various operating conditions and disturbances.

Mathematical problem formulation

Power system model

The complex nonlinear model related to n machines interconnected power system, can be formalized by a set of nonlinear differential equations as:

$$\dot{X} = f(X, U) \tag{1}$$

where X is the vector of the state variables and U is the vector of input variables. $X = [\delta, \omega, E'_q, E_{fd}, V_f]^T$ and U is the output signals of PSSs in this paper. δ and ω are the rotor angle and speed, respectively. Also, E'_q, E_{fd} and V_f are the internal, the field, and excitation voltages respectively.

The linearized incremental models around an equilibrium point are usually used in the design of PSS. Therefore, the state equation of a power system with m PSSs can be formed as:

$$\dot{X} = AX + BU \tag{2}$$

where A is a $5n \times 5n$ matrix and equals $\partial f/\partial X$ while B is a $5n \times m$ matrix and equals $\partial f/\partial U$. Both A and B are estimated at a certain operating point. X is a $5n \times 1$ state vector and U is a $m \times 1$ input vector.

PSS controller structure

Power system utilities still prefer CPSS structure due to the ease of online tuning and the lack of assurance of the stability related to some adaptive or variable structure techniques. On the other hand, a comprehensive analysis of the effects of different CPSS parameters on the overall dynamic performance of the power system is investigated in [40]. It is shown that the appropriate selection of the CPSS parameters results in satisfactory performance during the system disturbances. The structure of the i^{th} PSS is given by:

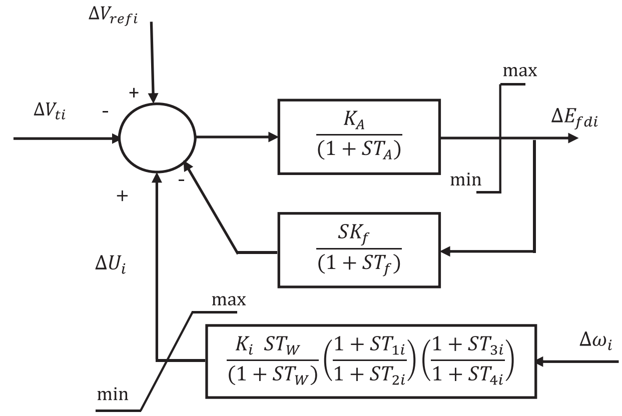

Fig. 1. Block diagram of i^{th} PSS with excitation system.

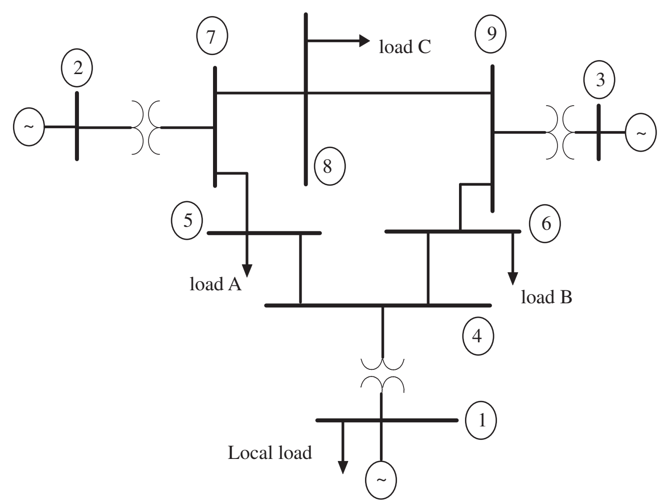

Fig. 2. Multimachine test system.

Table 1
Loading conditions for the system (in p.u).

	Light		Normal case		Heavy	
	P	Q	P	Q	P	Q
Generator						
G1	0.9649	0.223	1.7164	0.6205	3.5730	1.8143
G2	1.00	−0.1933	1.630	0.0665	2.20	0.7127
G3	0.45	−0.2668	0.85	−0.1086	1.35	0.4313
Load						
A	0.7	0.35	1.25	0.5	2.0	0.9
B	0.5	0.3	0.9	0.3	1.8	0.6
C	0.6	0.2	1.0	0.35	1.6	0.65
Local load at G1	0.6	0.2	1.0	0.35	1.6	0.65

$$\Delta U_i = K_i \frac{ST_W}{(1+ST_W)}\left[\frac{(1+ST_{1i})}{(1+ST_{2i})}\frac{(1+ST_{3i})}{(1+ST_{4i})}\right]\Delta\omega_i \tag{3}$$

This structure consists of a gain, washout filter, a dynamic compensator and a limiter as it is shown in Fig. 1. The output signal is fed as a supplementary input signal, ΔU_i to the regulator of the excitation system. The input signal $\Delta\omega_i$ is the deviation in speed from the synchronous speed. The stabilizer gain K_i is used to determine the amount of damping to be injected. Then, a washout filter makes it just act against oscillations in the input signal to avoid steady state error in the terminal voltage. In addition, two lead–lag circuits are included to eliminate any delay between the excitation and the electric torque. The limiter is included to prevent the output signal of the PSS from driving the excitation system into heavy saturation

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