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Optimal Power System Stabilizers design via Cuckoo Search algorithm

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ABSTRACT

Cuckoo Search (CS) algorithm is introduced in this paper for optimal Power System Stabilizers (PSSs) design in a multimachine power system. The PSSs parameter tuning problem is formulated as an optimization problem which is solved by CS Algorithm. An eigenvalues based objective function involving the damping ratio, and the damping factor of the lightly damped electromechanical modes is considered for the PSSs design problem. The performance of the proposed CS based PSSs (CSPSS) has been compared with Genetic Algorithm (GA) based PSSs (GAPSS) and the Conventional PSSs (CPSS) under different operating conditions and disturbances. The results of the developed CSPSS are verified through time domain analysis, eigenvalues and performance indices. Also, the effectiveness of the proposed algorithm in providing good damping characteristics is confirmed.

Introduction

Power systems may experience sustained oscillations. These oscillations may lead to partial or total power interruption [1]. One of the famous types of oscillations is referred to inter-area modes resulted from swinging of one generation area with respect to other areas. The other one is related to 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 provide an auxiliary control signal to excitation system in order to alleviate both types of oscillations [3].

In last few years, Artificial Intelligence (AI) techniques have been discussed to solve problems associated with PSS design. Artificial Neural Network (ANN) for designing PSS is discussed in [4–6]. It enhances the system performance, but the main problem of this controller is the long training time and the selecting number of layers and neurons in each layer. Another AI approach likes Fuzzy Logic Control (FLC) has attracted much attention in control applications [7–12]. 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. However, it gives better results than the conventional controllers; a hard work is inevitable to get the effective signals when designing FLC. Robust techniques such as H_∞ [13–17], H_2 [18,19] and μ-synthesis [20] have been also used for PSS design. These methods are iterative 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. Pole shifting technique is illustrated in [21–23] to design PSS but this technique suffers from complexity of computational algorithm and memory storage problem and assumes full state availability.

Recently, optimization algorithms have been applied to PSS design problem. Simulated Annealing (SA) is presented in [24] for parameters tuning of PSS but it might fail by getting trapped in local optimum. Another technique like Tabu Search (TS) is introduced in [25,26] to design PSS. In spite of the effectiveness of the optimization tool in designing PSS, the efficiency is reduced by using highly epistatic objective functions, and the large number of optimized parameters. Also, it is time consuming method. Genetic Algorithm (GA) is developed in [27,28] for optimal design of PSS. It requires a very long run time depending on the size of the system under study. Also, it gives rise to repeat revisiting of the same suboptimal solutions. Particle Swarm Optimization (PSO) for the design of the PSS parameters is discussed in [29–32]. PSO pains from the partial optimism that causes the less exact

Abbreviations: PSS, Power System Stabilizer; AI, Artificial Intelligence; ANN, Artificial Neural Network; FLC, Fuzzy Logic Control; SA, Simulated Annealing; TS, Tabu Search; GA, Genetic Algorithm; PSO, Particle Swarm Optimization; BF, Bacteria Foraging; CS, Cuckoo Search; CPSS, Conventional PSSs; GAPSS, Genetic Algorithm based PSSs; CSPSS, Cuckoo Search based PSSs; BATPSS, BAT Search based PSSs; IAE, The Integral of Absolute value of the Error; ITAE, The Integral of the Time multiplied Absolute value of the Error.

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Nomenclature

δ and ω	the rotor angle and speed respectively
E'_q, E_{fd} and V_f	the internal, the field, and excitation voltages respectively
X	the vector of the state variables
U	the vector of input variables
K_i	the stabilizer gain
T_W	the washout time constant and it is equal at 10 s
K_A, T_A	gain and time constant of the excitation system respectively
K_f, T_f	gain and time constant of the field system respectively
P_a	the probability to abandon a nest
n	number of nests
x_i^t	the current solution
x_i^{t+1}	a new solution
J_t	objective function
T_s	the settling time
np	the number of operating points investigated in the design
σ and ξ	the real part and the damping ratio of the eigenvalue
Δ	the deviation from nominal values
Δw_{12}	equal to $(\Delta w_1 - \Delta w_2)$
Δw_{23}	equal to $(\Delta w_2 - \Delta w_3)$
Δw_{13}	equal to$(\Delta w_1 - \Delta w_3)$

regulation of its speed and direction. Moreover, the algorithm cannot work out the problems of scattering and optimization. Furthermore, it suffers from slow convergence in refined search stage, weak local search ability and this may lead to possible entrapment in local minimum solutions. A relatively newer evolutionary computation algorithm, called Bacteria Foraging (BF) scheme has been illustrated by [33] and further established recently by [34–38]. The BF algorithm depends on random search directions that may lead to delay in reaching the global solution.

A new metaheuristic algorithm known as CS algorithm, based on the life of a bird family, is investigated for optimal design of PSS parameters. The PSS design problem is established as an optimization task using CS algorithm. The stabilizers are tuned to shift all electromechanical modes to a predefined zone in the S-plane to confirm the relative stability. The validation of the developed CSPSS is applied on a multimachine power system under multiple operating conditions in comparison with GAPSS and CPSS through time domain analysis, eigenvalues and performance indices. Results evaluation assure that the proposed algorithm provides good robust performance for attenuating the oscillations under different loading conditions and disturbances.

Problem formulation

Power system model

A power system in general can be formalized by a set of nonlinear differential equations as:

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

where $X = [\delta, \omega, E'_q, E_{fd}, V_f]^T$ and U is the output signals of PSSs.

In the tuning problem of PSS, the linearized incremental models around an equilibrium point are usually used. Therefore, the state equation of a power system with n machines and 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

CPSS structure is favorable due to the ease of online tuning. A comprehensive analysis of the effects of different CPSS parameters on the overall dynamic performance of the power system is investigated in [39]. It indicates that the appropriate selection of the CPSS parameters results in satisfactory performance during system disturbances. The structure of the ith PSS is given by:

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

This structure consists of a gain, a washout filter, a dynamic compensator and a limiter as given in Fig. 1. The output signal is fed as an auxiliary 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. Two lead-lag circuits are used to compensate the phase lag 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 [2]. In this paper, the value of the washout time constant T_W is kept at 10 s, the values of time constants T_{2i} and T_{4i} are fixed at a reasonable value of 0.05 s. The stabilizer gain K_i and time constants T_{1i}, and T_{3i} are remained to be determined.

System under study

In this paper, the 3-machine, 9-bus shown in Fig. 2 is considered. The system data in detail is given in [40]. Three different operating conditions are taken into account and named as light, normal, and heavy load to show the superiority of the proposed algorithm in designing robust PSS. The generator and loading level are given in Table 1 for these loading conditions.

Optimization techniques

Overview of Cuckoo Search algorithm

The breeding behavior of cuckoo species and the basic items of the proposed algorithm are discussed below.

Cuckoo breeding behavior

CS is a metaheuristic search algorithm which has been introduced recently by Yang [41]. The algorithm is inspired by obligating brood parasitism of some cuckoo species by laying their eggs in the nests of other host birds, which may be of different species. At the appropriate moment, the cuckoo hen flies down to the host's nest, pushes one egg out of the nest, lays an egg and flies off. The whole process takes about 10 s. A female may visit up to 50 nests during a breeding season. The host birds may detect that the eggs are not their own and either throw them away or abandon the nest and build a new one elsewhere. This has resulted in the evolution of