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Optimal Power System Stabilizer Parameters Tuned by Cuckoo Search Algorithm

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***Abstract*—This paper presents the application of the Cuckoo Search algorithm (CS) to optimize the PSS parameters. PSS input is the speed deviation, the output signal to supply the automatic voltage regulators (AVR). The data to train is implemented in all the different operating conditions of the analysis model. The simulations are performed using the tool Simulink/Matlab. The results were compared with the PSS optimum algorithm (PSO), which showed that the performance of the proposed PSS was better than the PSS-PSO [10].**

***Keywords*— Power system stabilizer; Automatic voltage regulators; Simulink/Matlab;Cuckoo Search algorithm.**

I. INTRODUCTION

Power System Oscillations deals with the analysis and control of low frequency oscillations in the 0.2-3 Hz range which are a characteristic of interconnected power systems. These oscillations tend to die out automatically, but some of these may persist for a longer time causing power transfer impossible over the weak transmission lines.[1]

In early phase of 1960s, the fast acting, high-gain automatic voltage regulators (AVR) were applied to the generator excitation system which in-turn invites the problem of low frequency electromechanical oscillations in the power system. The device connected to generator excitation to control the oscillations were termed as power system stabilizer. It adds a stabilizing signal to AVR for modulating the generator excitation such as to create an electric torque component in phase with rotor speed deviation, which increases the generator damping [2]. Conventional PSS are designed using the theory of phase compensation in frequency domain and it can provide effective damping performance only for a particular operating condition and system parameters. [3].

Recently, optimization algorithms have been applied to PSS design such as Genetic Algorithm(GA)[6],Simulated Annealing (SA) [7], Tabu Search (TS) [8] and Particle Swarm Optimization (PSO) [9].The applications of these methods provide some degree of robustness to variation in system parameters, configurations and wide range of loading conditions. These methods have problem of premature convergence, slow convergence and to be trapped in local optima to obtain the optimum solution.

CS is a metaheuristic search algorithm which is recently developed by Yang and Deb in 2009 [11, 12]. This novel algorithm has been shown to be very effective in solving continuous optimization problems.

In this paper, CS algorithm is proposed for optimal designing of PSSs parameters. A single machine power system is considered as case study and embedded with PSS. The parameters of the proposed PSS are tuned by using the proposed algorithms. Simulation results and performance indices demonstrate the robustness and relative stability of the CS-PSS, which is promising with No-PSS and PSO-PSS over a different operating condition to reduce low frequency oscillations.

The structure of the article: In Section 2, the modeling of power system under study, which is a SMIB power system with a PSS, is presented. The Cuckoo search algorithm which is used to optimize the PSS controller parameters is introduced in section 3. Part 4 presents the research results and conclusions are given in Section 5.

II. POWER SYSTEM UNDER STUDY

The SMIB power system shown in Fig. 1 is considered in this study. The synchronous generator is delivering power to the infinite-bus through a transmission line . In Fig. 1, V_t and E_b are the generator terminal and infinite bus voltage respectively.

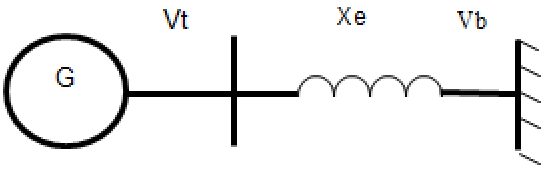

Fig. 1. *Single-machine infinite-bus power system*

Modelling the Synchronous Generator Infinite-bus Power System.

The synchronous generator is represented by model 1.1, i.e. with field circuit and one equivalent damper on q-axis. The machine equations are [10]:

$$\frac{d\delta}{dt} = \omega_B (S_m - S_{mo}) \tag{1}$$

$$\frac{dS_m}{dt} = \frac{1}{2H}\left[-D(S_m - S_{mo}) + T_m - T_e\right] \tag{2}$$

$$\frac{dE_q^{'}}{dt} = \frac{1}{T_{do}^{'}}\left[-E_q^{'} + (x_d - x_d^{'})i_d + E_{fd}\right] \tag{3}$$

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$$\frac{dE'_d}{dt} = \frac{1}{T'_{qo}}\left[-E'_d + (x_q - x'_q)i_q\right] \quad (4)$$

The electrical torque *Te* is expressed in terms of variables *E' d* , *E' q* , *id* and *iq* as:

$$T_e = E'_d i_d + E'_q i_q + (x'_d - x'_q) i_d i_q \quad (5)$$

For a lossless network, the stator algebraic equations and the network equations are expressed as:

$$E'_q + x'_d i_d = v_q \quad (6)$$

$$E'_d + x'_q i_q = v_d \quad (7)$$

$$v_q = -x_e i_d + E_b \cos\delta \quad (8)$$

$$v_d = x_e i_q + E_b \sin\delta \quad (9)$$

Solving the above equations, the variables *id* and *iq* can be obtained as:

$$i_d = \frac{E_b \cos\delta - E'_q}{x_e + x'_d} \quad (10)$$

$$i_q = \frac{E_b \sin\delta + E'_q}{x_e + x'_q} \quad (11)$$

NOMENCLATURE

δ	Rotor angle of synchronous generator in radians
S_m	Generator slip in p.u.
S_{mo}	Initial operating slip in p.u.
ω_B	Rotor speed deviation in rad/sec
T_m	Mechanical power input in p.u.
T_e	Electrical power output in p.u.
E_{fd}	Excitation system voltage in p.u.
V_t	Generator terminal voltage
E_b	Infinite-bus voltage
H	Inertia constant
D	Damping coefficient
T'_{do}	Open circuit d-axis time constant in sec
T'_{qo}	Open circuit q-axis time constant in sec
x_d	d-axis synchronous reactance in p.u.

III. OPTIMIZATION OF CPSS PARAMETERS USING CUCKOO SEARCH

Figure. 2 shows the typical block diagram of CPSS recommended by IEEE [3]. Usually the parameters of the two lead lag compensator blocks are the same *(T1= T3, T2=T4)*, thus the tunable parameters of CPSS are *T1*, *T2*, *T5*, *T6*, and *Kpss*. To design a CPSS with good damping performance, the above parameters need to be fine-tuned, which is a time-consuming job. To compare the proposed PSO controller design with the best possible performance of CPSS, inspired by [10], Cuckoo search (CS) is used in this paper to find a good CPSS design.

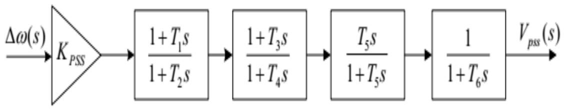

Fig. 2. Structure of CPSS suggested by IEEE Std. 421.5

A. *Objective Function*

The system electromechanical oscillations are reflected in terms of rotor speed deviations.

$$Fitness = \int_0^{\infty} e^2(t)dt \quad (12)$$

Here, e (t) represents the error deviations in generator speed (Δω). The objective is to minimize, so that the integral of the squared error deviations are minimized for better stability of the system.

B. *Proposed Meta-heuristic CS algorithm*

Cuckoo search (CS) is a Bio inspired optimization algorithm proposed by (Yang and Deb, 2009). It is inspired by the obligate brood parasitism nature of cuckoo species along with the Levy flight behavior of birds and flies in nature. Levy flight represents the flight behavior of animals and birds for food search . The cuckoo species lay their eggs in the nests of other host birds. If a host bird discovers the eggs are not its own, it will throw away these eggs or build a new nest elsewhere.

The following rules will describe the CS algorithm effectively.

(a). Each cuckoo lays one egg at a time, and will put its egg in the nests, chosen randomly.

(b). The best nests with good quality of eggs (potential solutions) will be carried over to next generations.

(c). The number of host nests is fixed, and a host bird will discover an egg with a probability Pa (between 0 and 1).

When generating new solutions x(t+1) ,a Levy flight is performed based on the equation(14).

$$x_i^{(t+1)} = x_i^t + \alpha \oplus Levy(\lambda) \quad (13)$$

where a > 0 is the step size which should be proportional to the scales of the optimization problem. The product means entry wise walk during multiplications. Lévy flights essentially provide a random walk while their random steps are drawn from a Lévy distribution for large steps.

$$Levy:\ u = t^{-1-\beta}, (1 < \beta < 3) \quad (14)$$

This has an infinite variance with an infinite mean. Here the steps essentially form a random walk process with a power law step-length distribution with a heavy tail. Some of the new solutions should be generated by Lévy walk around the best solution obtained so far, this will speed up the local search.

However, a substantial fraction of the new solutions should be generated by far field randomization and the locations should be far enough from the current best solution, this will make sure the system will not be trapped in a local optimum.

The proposed CS algorithm implemented in this paper to obtain the optimal damping controller parameters is given as follows:

Step 1: Specify the various parameters involved for CS algorithm implementation (i.e.) number of nests, minimum and maximum limits for PSS parameters (Ks,T1 and T2), number of generations, worst nests probability, termination criteria etc.

Step 2: Initialize a population of n host nests in the problem space.

Step 3: Evaluate the fitness function (Pi) for the randomly selected cuckoo (i) by Levy flights.

Step 4: Choose a nest j among available nests randomly and replace j by new solution, if the fitness (Pi) is greater than fitness (P_j).

Step 5: If the termination condition is reached, then optimal value of PSS parameters is equal to those obtained in current generation, otherwise go to step 6.

Step 6: Abandon a fraction of worse nests with probability Pa.

Step 7: Repeat steps 3-6, until the termination criterion is met.

The cuckoo search algorithm is easier to implement and it provides the global solution required for parameter optimization in complex engineering problems. In this paper, the cuckoo search algorithm provides an optimal solution for the damping controller parameters, so that the system stability is enhanced to a greater extent possible.

TABLE I. OPTIMIZED PARAMETERS CS- PSS AND PSO- PSS [10]

Structure	K_{pss}	T1	T2	T5	T6
CS-PSS	4.705	4.174	0.259	1.336	4.259
PSO-PSS[10]	0.812	2.022	0.231	0.458	0.411

IV. RESULTS AND SIMULATIONS

In order to simultaneously tune the parameters of the PSS, as well as to assess their performance and robustness under wide range of various fault disturbances, the MATLAB/SIMULINK model of the example power system shown in Fig. 1 is developed using equations (1)–(11). The developed MATLAB/SIMULINK model of synchronous generator with PSS is shown in Fig. 3. The SIMULINK model for calculation of *id* , *iq* , *E' d* , *E' q* and *Pe* is shown in Fig. 4.

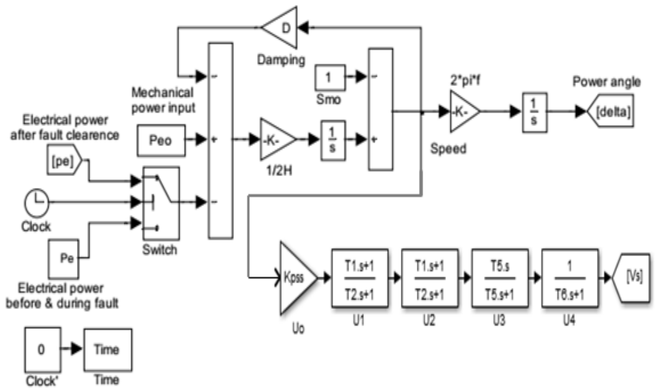

Fig. 3. SIMULINK model of SMIB with PSS

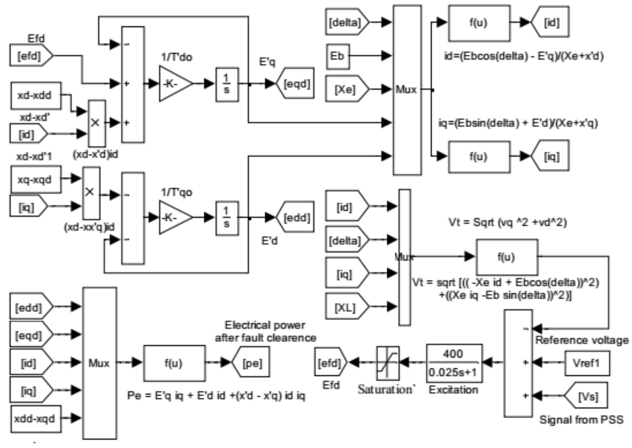

Fig. 4. SIMULINK model for calculation of id , iq , E' d , E' q , E fd and P

TABLE II. PSO AND CSO PARAMETERS IMPLEMENTED FOR CONTROLLER DESIGN

No	PSO Parameters		CS Parameter	
1	Swarm Size (n)	70	Number of nests (n)	30
2	No of Generations	10	No of Generations	10
3	No of variables (nd)	5	No of variables (nd)	5
4	rand1 and rand2	rand(nd,n)	Worst nests probability	0.5
5	Weighting function Wmax and Wmin	0.2	Step size	Variation
6	Weighting factor C1,C2	0.1, 0.1	Levy flight(β,α)	1.5, 0.01
7	Termination Method	Maximum Generations	Termination Method	Maximum Generations

In the following section, the CS-optimized CPSS is compared with optimized PSS with PSO and CPSS under two kinds of operating conditions, which are

Case 1, A three phase fault is applied at the generator terminal busbar at t = 1 sec and cleared after 5 cycles the impedance of the transmission line between the generator and infinite buses changes from X_{ep}=0.6 to X_{ep}=0at 1s.

Case 2, the operating point changes from Pg=0.6p.u.to Pg=0.3p.u.at 1s and Pg=0.3p.u. to Pg=0.5p.u. at 10s.

The comparisons of simulation results for the two cases are shown in Figs 5 - 10. In these figure, the "redline" represents the simulation results without stabilizing control "No PSS", the "black line" represents the simulation results for PSO based power system stabilizer "PSO-PSS", and "blue line" for the proposed CS based power system stabilizer "CS-PSS".

System data: All data are in pu unless specified otherwise.

Generator: H = 3.542, D = 0, Xd=1.7572, Xq=1.5845,X'd =0.4245, X'q =1.04, T'do = 6.66, T'qo=0.44, Ra=0, Pe=0.6,Qe=0.02224, δ0=44.370.

Exciter: KA=25, TA=0.025 s

Transmission line: Xe=0.6, G=0, B=0;

A. Comparison of system response for Case 1

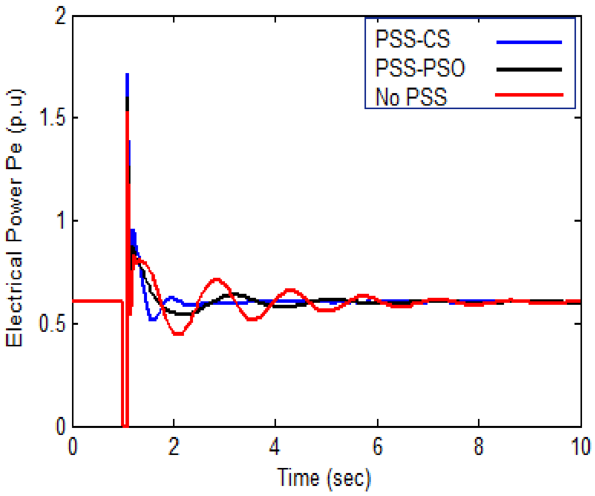

Fig. 5. Variation of electrical power Pe : Case-1

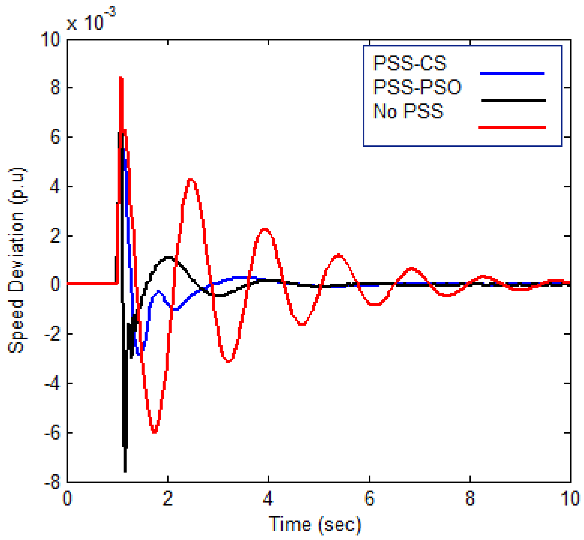

Fig. 6. Variation of speed deviation Δω : Case-1

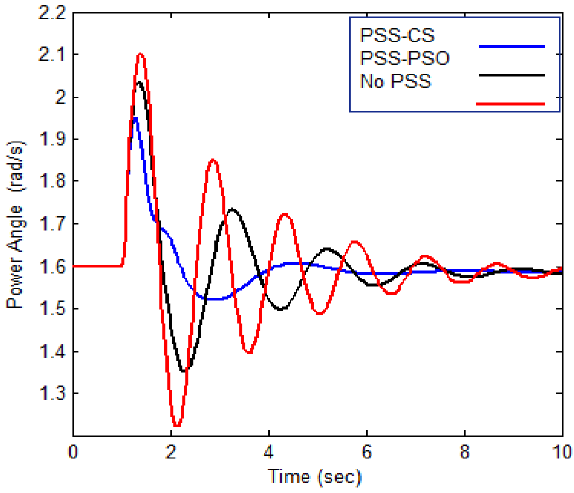

Fig. 7. Variationof power angle δ:Case-1

B. Comparison of system response for Case 2

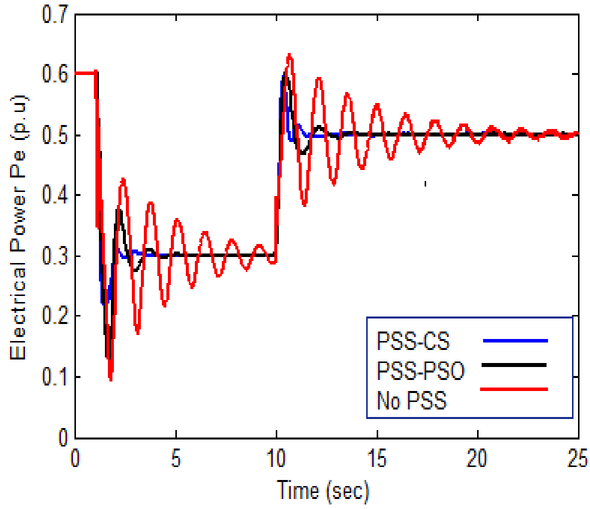

Fig. 8. Variation of electrical power Pe : Case-2

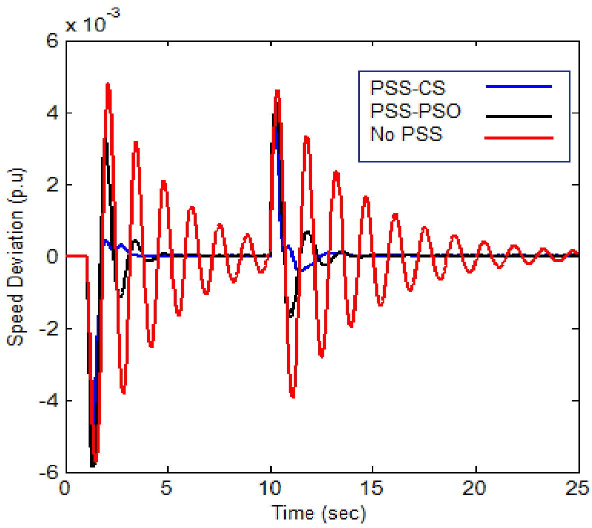

Fig. 9. Variation of speed deviation Δω : Case-2

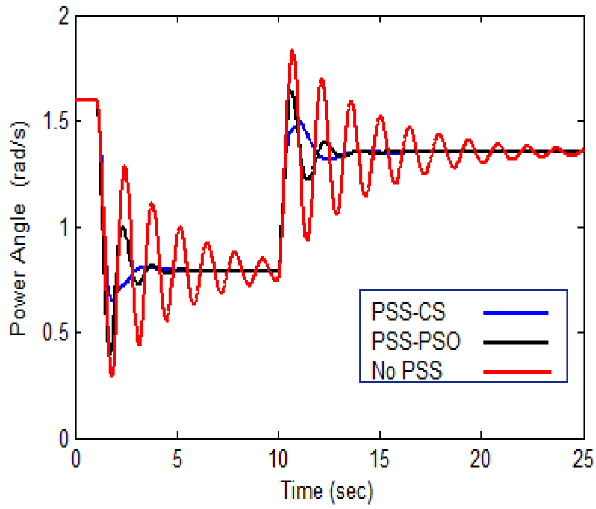

Fig. 10. Variationof power angle δ: Case-2

V. CONCLUSION

In this paper, CS algorithm is proposed for optimal designing of PSSs parameters. The PSSs parameters tuning problem is formulated as an optimization problem and CS algorithm is used to seek for optimal parameters. Simulation results confirm the robustness and superiority of the proposed controller in providing good damping characteristic to system oscillations over a wide range of loading conditions and short circuits. Moreover, the proposed CS-PSS demonstrates its effectiveness than others via different performance indices.

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