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Multi-machine power system stabilizer design by using cultural algorithms

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ABSTRACT

Conventional power system stabilizer (CPSS) has been widely used as a supplementary controller to damp out the low frequency oscillations. The tuning of CPSS parameters for nonlinear power systems in a robust way in order that the overall system stability can be improved is a major drawback of CPSS. Several meta-heuristic optimization techniques have been tried out to overcome this shortcoming. This paper presents a new technique named cultural algorithms (CAs) to tune the PSS parameters. This technique is robust and computationally efficient as compared with other meta-heuristic algorithms. Simulations are carried out on two typical multi-machine electric power systems. The results clearly verify that the proposed method improves the dynamic stability of the system, especially when the operating point changes.

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1. Introduction

Power system stabilizers have been commonly employed to damp out the electromechanical oscillations of the generators in power systems. The conventional PSS (CPSS) is usually designed based on a linear model of the plant for a particular operating point [1]. However, power systems are inherently nonlinear and the operating point frequently changes. Therefore, the CPSS performance may deteriorate under variations that result from nonlinear and time variant characteristics of the controlled plant.

To develop a high-performance PSS for a wide range of operating conditions many different methods have been developed. The application of robust control methods [2–4] and adaptive control algorithms [5–7] for designing PSS has been reported by authors. In these methods a linearized dynamic model of the system in a state space or transfer function form is needed for designing the PSS. However, in large electric power systems, it is very complex and troublesome to find a linearized dynamic model of the system. Moreover, in the real electric power systems whose parameters are time varying, the application of an online controller for adaptive techniques in which the parameters of the system are to be estimated, may not be easy and a fixed controller is more suitable and feasible. In order to solve this drawback, different techniques including optimization methods, which do not need a linear model, have been widely used in recent years.

Artificial intelligence approaches such as fuzzy logic [8–10], artificial neural networks [11], neuro-fuzzy [12,13] and meta-heuristic optimization methods [14–19] have been presented to design power system stabilizers. In artificial intelligence methods the PSS structure changes and a nonlinear PSS is usually obtained. This kind of PSS may not be easy to be implemented. However, in the optimization methods, the tuning of a fixed parameter conventional PSS is easily accomplished. The tuning process is converted to a constrained optimization problem which is solved by using an optimization algorithm.

A multi-objective design of multi-machine power system stabilizers (PSSs) using Particle Swarm Optimization (PSO) has been reported in [14,15]. In these papers, an eigenvalue-based multi-objective function comprising the damping factor and the damping ratio of the lightly damped electromechanical modes has been used for optimization process. Multi objective design of the multi-machine power system stabilizers (PSSs) using chaotic optimization algorithms (COAs) has been given in [16]. In this paper, the tuning of the PSS is converted to a constrained optimization problem which is solved by using chaotic optimization algorithm based on Lozi map. Also, in this paper, two objective functions are considered which comprise eigenvalue and time domain specifications. In [17] the optimal locations and the design of robust multi machine power system stabilizers (PSSs) using genetic algorithms have been reported. In this paper the PSS parameters and locations are computed so that the maximum damping performance under different operating conditions is achieved. A PSS design using the multi-objective optimization approach named Strength Pareto has been given in [18] in which two objective functions are considered for maximizing the damping factor and the damping ratio of power system modes. Also a new method for tuning the PSS parameters using improved ant direction hybrid differential evolution has been presented in [19]. The application of different optimization algorithms for tuning the PSS parameters shows that the scope for finding better algorithms still remains.

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Nomenclature

δ	rotor angle
ω	rotor speed (pu)
ω_i	rotor speed of generator *i*th (pu)
$\Delta\omega$	the frequency deviation
P_m	mechanical input power
T_m	mechanical torque (pu)
P_e	electrical output power (pu)
Te	electric torque (pu)
M	system inertia (Mj/MVA)
E'_q	internal voltage behind x'_d (pu)
E_{fd}	equivalent excitation voltage (pu)
X'_d	transient reactance of *d* axis (pu)
X_q	steady state reactance of *q* axis (pu)
X_d	steady state reactance of *d* axis (pu)
T'_{do}	time constant of excitation circuit (s)
K_a	regulator gain
T_a	regulator time constant (s)

This paper presents a new design method for the stability enhancement of multi-machine power systems using PSSs in which their parameters are tuned by cultural algorithm (CA). This technique is robust and computationally efficient when compared with other meta-heuristic algorithms [20,21]. CA is a branch of evolutionary computation which has three major components as population space, belief space and communication protocol where the belief space is a knowledge component. In CA there is a "dual evolution-dual improvement" unlike other evolutionary based algorithms. This improvement can lead to have a faster convergence and also a robust performance [20,21]. To show the effectiveness of this new technique for PSS design, this method is compared with genetic algorithms (GAs). Nonlinear time domain simulations are carried out on two multi-machine electric power systems. The results show that the proposed method guarantees to have a robust performance for a wide range of operating conditions and different disturbances.

2. Illustrative test cases and PSS

Two typical multi-machine electric power systems are considered to evaluate the proposed method.

2.1. Two-area four-machine power system

Fig. 1 shows a two-area four-machine electric power system. The nominal system parameters are given in [22]. In simulations three loading conditions are considered as heavy, nominal and light and are listed in Table 1.

2.2. IEEE 10-generator 39-bus power system

Fig. 2 depicts the IEEE 39-bus system which is well known as 10-machine New-England power system. Generator 1 represents the aggregation of a large number of generators. All generators except G_1 are equipped with PSS. The system data can be found in [23]. The heavy and light loads are also given in Table 1.

2.3. Dynamic model of the system

In this study, each generator is modelled as a two-axis, three-order model. For all operating conditions, the power system can be modelled by a set of nonlinear differential equations as (1),

$$\dot{x} = f(x, u) \tag{1}$$

where $x = [\delta, \omega, E'_q]$ and u are the vector of state variables and the vector of the PSS output signals, respectively. The nonlinear dynamic model of the system can be rewritten as (2).

$$\begin{cases} \omega_i = \frac{(P_m - P_e - D\omega)}{M} \\ \delta_i = \omega_0(\omega - 1) \\ E'_{qi} = \frac{(-E_q + E_{fd})}{T'_{do}} \\ E_{fdi} = \frac{-E_{fd} + K_a(V_{ref} - V_t)}{T_a} \end{cases} \tag{2}$$

2.4. Power system stabilizer

The CPSS configuration is given in (3), where $\Delta\omega$ is the speed deviation in pu. This type of PSS consists of a washout filter and a dynamic compensator [14]. The output signal is fed as a supplementary input signal to the excitation system. The washout filter, which is a high pass filter, is used to reset the steady state offset in the PSS output. In this paper, the value of the time constant (T_w) is fixed as 10 s. The dynamic compensator is made up with two lead–lag stages with time constants, T_1–T_4 with an additional gain K_{DC}.

$$U = K_{DC} = \frac{ST_W}{1 + ST_W} \frac{1 + ST_1}{1 + ST_2} \frac{1 + ST_3}{1 + ST_4} \Delta\omega \tag{3}$$

The CA optimization method is used to find the best optimal values of the parameters K_{DC} and T_1–T_4.

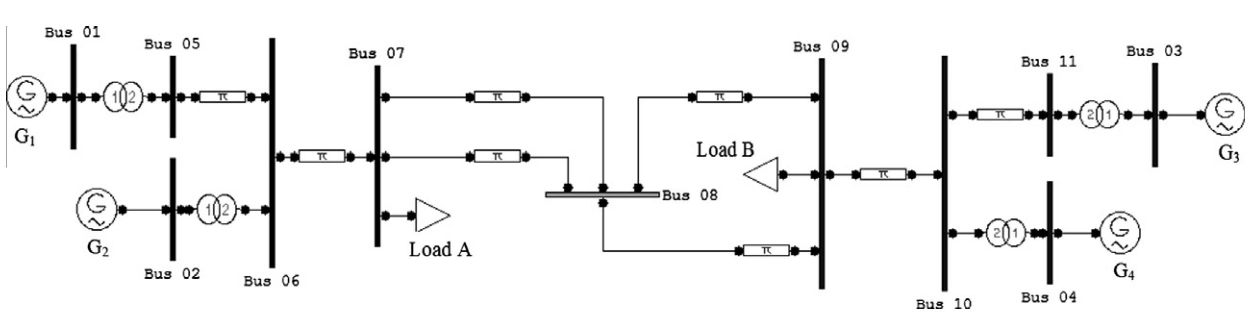

Fig. 1. Four-machine 11-bus power system.

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