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Adjustment of PSS in a multi machine power system based on particle swarm optimization technique

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Abstract

The tuning of the PSS parameters for a multi-machine power system is usually formulated as an objective function with constraints consisting of the damping factor and damping ratio. A novel Meta heuristic optimization method, called particle swarm optimization method (PSO), is proposed to solve this kind of problem. An objective function based on the integral of the error is incorporated. The IEEE 14 bus standard power system, under various system configurations, is employed to illustrate the performance of the proposed method. Nonlinear time domain simulation results demonstrate the effectiveness of the proposed algorithm and the objective function with a remote signal.

Keywords: Multi machine electric power system, Power system stabilizer, Particle swarm optimiza.

Introduction

The dynamic stability of power systems is an important factor for secure system operation. Low-frequency oscillation modes have been observed when power systems are interconnected by weak tie lines. The low-frequency oscillation mode, which has poor damping in a power system, is also called the electromechanical oscillation mode and usually occurs in the frequency range of 0.1-2.0 Hz. The power system stabilizer (PSS) has been widely used for mitigating the effects of low-frequency oscillation modes. The construct and parameters of PSS have been discussed in many studies. Currently, many plants prefer to employ conventional lead-lag structure PSSs, due to the ease of online tuning and reliability. The widely used conventional power system stabilizers (CPSS) are designed using the theory of phase compensation in the frequency domain and are introduced as a lead-lag compensator. The parameters of CPSS are determined based on the linearized model of the power system. In order to provide perfect damping over a wide operation range, the CPSS parameters should be fine tuned in response to both types of oscillations. Since power systems are highly nonlinear systems, with configurations and parameters which alter through time, the CPSS design based on the linearized model of the power system cannot guarantee its performance in a practical operating environment. Therefore, an adaptive PSS which considers the nonlinear nature of the plant and adapts to the changes in the environment is required for the power system (Liu *et al.,* 2005). In order to improve the performance of CPSSs, numerous techniques have been proposed for designing them, such as intelligent optimization methods (Sumathi *et al.,* 2007; Jiang *et al.,* 2008; Sudha *et al.,* 2009; Linda & Nair, 2010; Yassami *et al.,* 2010) and Fuzzy logic method (Dubey, 2007; Hwanga *et al.,* 2008). Also the application of robust control methods for designing PSS has been presented earlier (Bouhamida *et al.,* 2005; Gupta *et al.*, 2005; Mocwane & Folly, 2007; Sil *et al.*, 2009).

This paper presents the application of a Meta heuristic optimization method named PSO in order to finding global optimal solution of the proposed optimization method. A standard 14 bus IEEE power system is considered to illustrative the proposed method.

System under study

As referred before, a multi machine electric power system is considered to clarify the proposed method. IEEE 14 bus test system with five machines is shown in Fig.1. The system data are completely given in IEEE standards.

Dynamic model of the system

The nonlinear dynamic model of the system is given as follows:

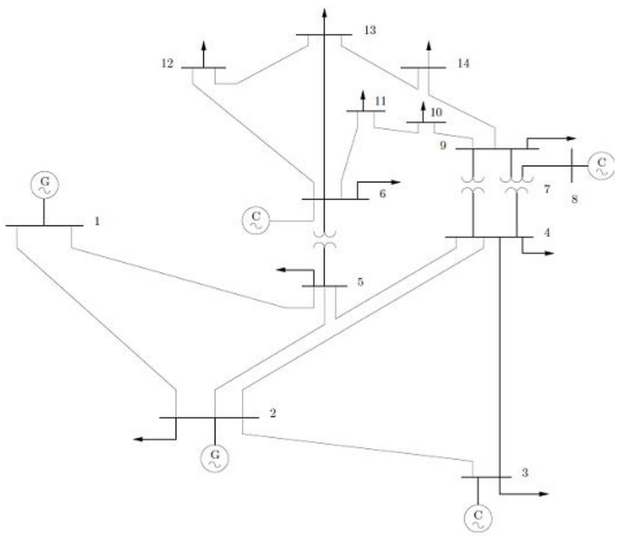
$$\begin{cases} \dot{\omega}_i = \dfrac{\left(P_m - P_e - D\omega\right)}{M} \\ \dot{\delta}_i = \omega_0\left(\omega - 1\right) \\ \dot{E}'_{qi} = \dfrac{\left(-E_q + E_{fd}\right)}{T'_{do}} \\ \dot{E}_{fdi} = \dfrac{-E_{fd} + K_a\left(V_{ref} - V_t\right)}{T_a} \end{cases} \quad (1)$$

where i=1, 2, 3, 4,5 (the generators: 1 to 4); δ, rotor angle; ω, rotor speed; P_m, mechanical input power; P_e, electrical output power; E'_q, internal voltage behind x'_d; E_{fd}, equivalent excitation voltage; Te, electric torque; T'_{do}, time constant of excitation circuit; K_a, regulator gain; T_a, regulator time constant; V_{ref}, reference voltage; V_t, terminal voltage.

Power system stabilizer

As mentioned before, in large interconnected power systems, the damping torque of system is reduced and system need to PSS for stability. The basic function of

Fig.1. IEEE 14 bus test system



PSS is to add damping torque to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal. To provide damping, the stabilizer must produce a component of electrical torque in phase with the rotor speed deviations (Kundur,1993). The dynamic model of PSS is given in as (2). Where, $\Delta\omega$ is the speed deviation in p.u. This type of PSS consists of a washout filter, a dynamic compensator. The output signal is fed as a supplementary input signal to the excitation of generator. 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 (Tw) is fixed to 10 s. The dynamic compensator is made up to two lead-lag stages with time constants, T1-T4 and an additional gain K_{DC}.

$$U = K_{DC} \frac{ST_W}{1+ST_W} \frac{1+ST_1}{1+ST_2} \frac{1+ST_3}{1+ST_4} \Delta\omega \quad (2)$$

The major point in the PSS design is to find the optimal values of K_{DC} and T1-T4. In this paper an optimization method is used to find the best values of the proposed parameters. Where, the optimum values of K_{DC} and the time constants of T1-T4 are obtained by using PSO. In the next section a brief introduction about the PSO is presented.

Particle swarm optimization

PSO was formulated by Edward and Kennedy in 1995. The thought process behind the algorithm was inspired by the social behavior of animals, such as bird flocking or fish schooling. PSO is similar to the continuous genetic algorithms (GA) in that it begins with a random population matrix. Unlike the GA, PSO has no evolution operators such as crossover and mutation. The rows in the matrix are called particles (same as the GA chromosome). They contain the variable values and are not binary encoded. Each particle moves about the cost surface with a velocity. The particles update their velocities and positions based on the local and global best solutions as shown in (3) and (4) (Randy & Sue, 2004):

$$V_{m,n}^{new} = w \times V_{m,n}^{old} + \Gamma_1 \times r_1 \times (P_{m,n}^{local\ best} - P_{m,n}^{old}) + \Gamma_2 \times r_2 \times (P_{m,n}^{global\ best} - P_{m,n}^{old}) \quad (3)$$

$$P_{m,n}^{new} = P_{m,n}^{old} + \Gamma\, V_{m,n}^{new} \quad (4)$$

Where:
$V_{m,n}$ = particle velocity
$P_{m,n}$ = particle variables
W = inertia weight
r_1, r_2 = independent uniform random numbers
$\Gamma_1 = \Gamma_2$ = learning factors
$P_{m,n}^{local\ best}$= best local solution
$P_{m,n}^{global\ best}$= best global solution

The PSO algorithm updates the velocity vector for each particle then adds that velocity to the particle position or values. Velocity updates are influenced by both the best global solution associated with the lowest cost ever found by a particle and the best local solution associated with the lowest cost in the present population. If the best local solution has a cost less than the cost of the current global solution, then the best local solution replaces the best global solution. The particle velocity is reminiscent of local minimizes that use derivative information, because velocity is the derivative of position (Randy & Sue, 2004).

Design methodology

The IEEE 5-machine, 14-bus system is used to illustrate the performance of the proposed method. Fig. 1 presents the one-line diagram of the system. This system, which is unstable without PSS, has been widely used as a benchmark system for PSS parameter tuning problems. In the test system, generator 1 is equipped with PSS and the performance index is considered as (5). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (*ITAE*).

$$TAE = \int_0^t t|\Delta\omega_1|dt + \int_0^t t|\Delta\omega_2|dt + \int_0^t t|\Delta\omega_3|dt + \int_0^t t|\Delta\omega_4|dt + \int_0^t t|\Delta\omega_5|dt \quad (5)$$

Where, $\Delta\omega$ is the frequency deviation and parameter "*t*" is the simulation time. It is clear to understand that the controller with lower performance index is better than the other controllers. To compute the optimum values of parameters, a 10-cycle three-phase short circuit is assumed in bus 9 and the performance index is minimized using PSO. The ranges of the PSS parameters for design procedure are as follows:

$1 < K_{DCi} < 100$ and $0.01 < T < 1$

In order to acquire better performance, number of particle, particle size, number of iteration, Γ_1, Γ_2, and Γ are chosen as 12, 5, 50, 2, 2 and 1, respectively. Also, the inertia weight, w, is linearly decreasing from 0.9 to 0.4. It should be noted that PSO algorithm is run several times and then optimal set of PSS parameters is

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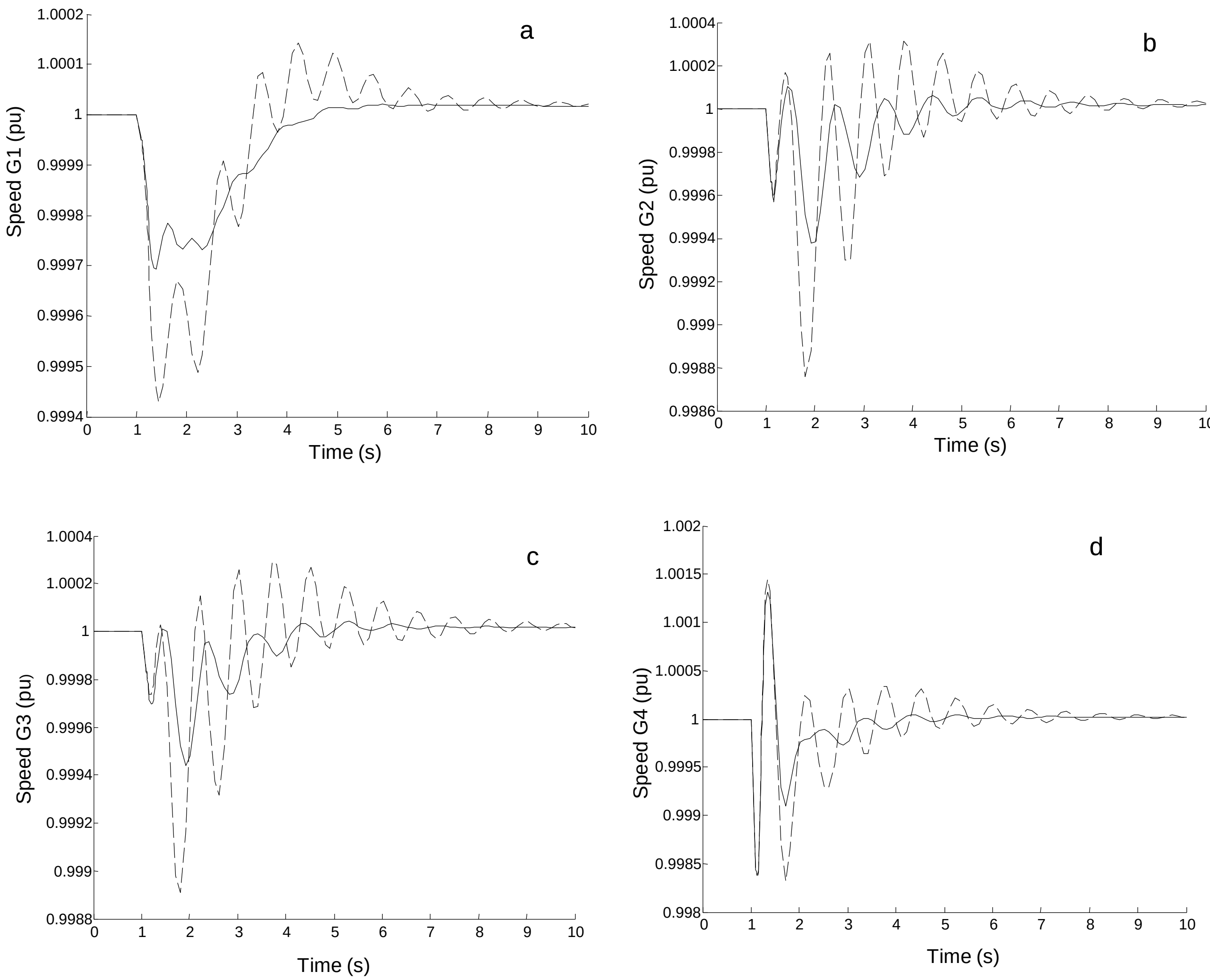
Fig. 2. System responses under scenario 1. Solid (PSO-PSS), Dashed (without PSS)
a: ω_1 b: ω_2 c: ω_3 d: ω_4 e: ω_5



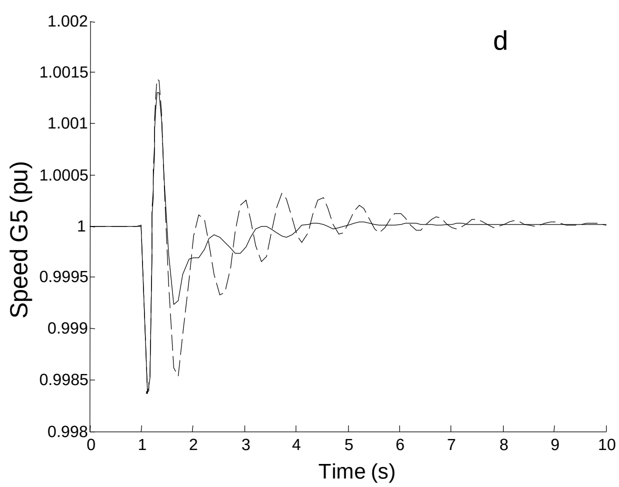


Table 1. Optimal parameters of stabilizers using PS

Generator	PSO				
	K_{DC}	T_1	T_2	T_3	T_4
G_1	5.8821	0.3917	0.0234	0.3917	0.0234

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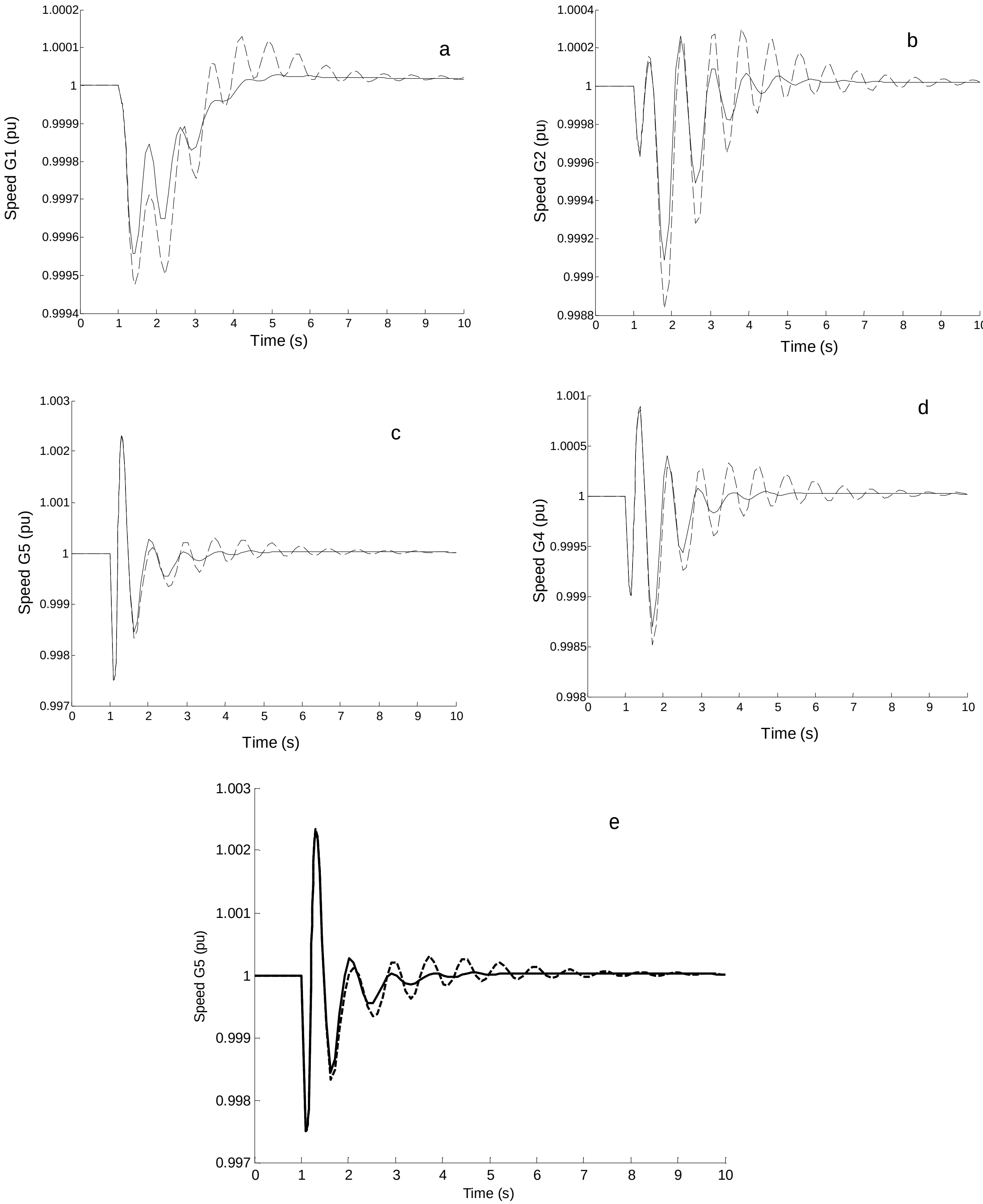
Fig. 3. System responses under scenario 2. Solid (PSO-PSS), Dashed (without PSS)
a: ω_1 b: ω_2 c: ω_3 d: ω_4 e: ω_5



selected. The optimum values of the PSS parameters are obtained using PSO and summarized in the Table 1.

Simulation results

Simulations are carried out on the test system given in section 2. To evaluate the system performance under different disturbances, two scenarios of fault disturbances are considered as follows:

Scenario 1: a 10-cycle three-phase short circuit in bus 9
Scenario 2: a 10-cycle three-phase short circuit in bus 12
Figs. 2-3 show the simulation results under proposed scenarios. Each figure contains two plots for PSO-PSS (solid line) and without PSS (dashed line). It is clearly seen that under different conditions, PSS can enhance power system stability. The oscillations are extremely damped out by PSS. The auxiliary injected signal of PSS improves system damping and consequently the LFO are successfully damped out. Also the system responses in the case of without PSS show the system insufficient damping. Where, the oscillation are visible in the responses.

Conclusions

A novel Meta heuristic optimization method named PSO has been proposed to determine the optimal tuning of power system stabilizers. The PSO algorithm searches for the optimal PSS parameters, which can include remote feedback of speed deviation measurement signals. Nonlinear time domain simulation results demonstrate the effectiveness of the proposed algorithm. We believe the PSO can serve as a better alternative to the problem of optimal tuning of power system stabilizers using the other optimization methods.

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