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Power system stabilizer tuning in multi machine electric power systems

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Abstract

Power System Stabilizers (PSS) are used to generate supplementary damping control signals for the excitation system in order to damp the Low Frequency Oscillations (LFO) of the electric power system. The PSS is usually designed based on classical control approaches but this Conventional PSS (CPSS) has some problems. The CPSS is usually designed based on a linear model of the plant for a particular operating point. However, power systems are inherently nonlinear and the operating point frequently changes. Therefore, CPSS performance may deteriorate under variations that result from nonlinear and time-variant characteristics of the controlled plant. In this paper, to develop a high-performance PSS for a wide range of operating conditions, meta-heuristic optimization methods such as Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) are used for tuning PSS parameters. The proposed optimization methods are evaluated against each other at a multi machine electric power system considering different loading conditions. The simulation results clearly indicate the effectiveness and validity of the proposed methods.

Keywords: Multi Machine Power System, Low Frequency Oscillations, Particle Swarm Optimization, Power System Stabilizer.

Introduction

Large electric power systems are complex nonlinear systems and often exhibit low frequency electromechanical oscillations due to insufficient damping caused by adverse operation. These oscillations with small magnitude and low frequency often persist for long periods of time and in some cases they even present limitations on power transfer capability (Liu *et al.,* 2005) In analyzing and controlling the power system's stability, two distinct types of system oscillations are recognized. One is associated with generators at a generating station swinging with respect to the rest of the power system. Such oscillations are referred to as "intra-area mode" oscillations.

The second type is associated with swinging of many machines in an area of the system against machines in other areas. This is referred to as "inter-area mode" oscillations. Power System Stabilizers (PSS) are used to generate supplementary control signals for the excitation system in order to damp both types of oscillations (Liu *et al*., 2005). 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. Providing good damping over a wide operating 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.

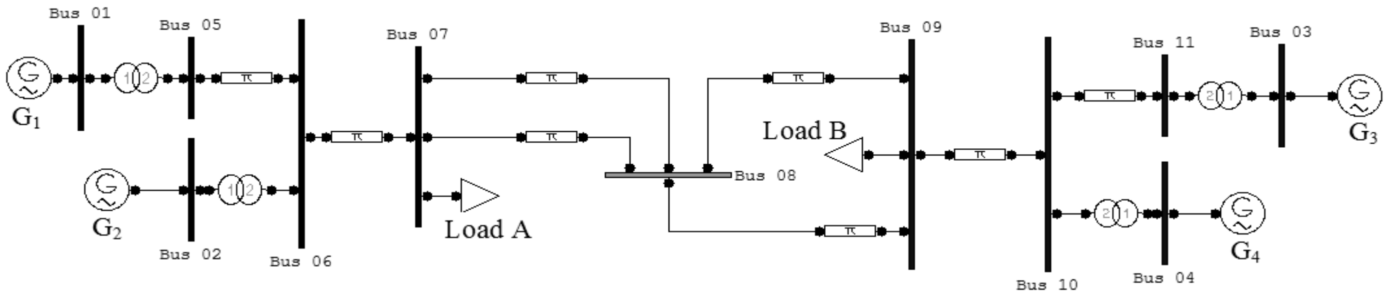
Therefore, an adaptive PSS which considers the nonlinear nature of the plant and adapts to the changes in the environment is required for the power system (Liu *et al*., 2005). In order to improve the performance of CPSSs, numerous techniques have been proposed for designing them, such as intelligent optimization methods (Sumathi *et al*., 2007; Jiang *et al*., 2008; Sudha *et al.,* 2009; Linda & Nair, 2010; Mehdi Nikzad *et al.*, 2011; Reza Hemmati *et al*., 2011;Sayed Mojtaba Shirvani Boroujeni *et al.*, 2011; Shoorangiz Shams Shamsabad Farahani *et al.*, 2011a,b Yassami *et al.,* 2010) and Fuzzy logic method (Dubey, 2007; Hwanga *et al.,* 2008). Also many other different techniques have been reported by Nambu Ohsawa (1996) and Chatterjee *et al*. (2009). 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 deals with a design method for the stability enhancement of a multi machine power system using PSSs which their parameters are tuned using PSO (PSO-PSS). Simulation results show that the proposed method guarantees robust performance under a wide range of operating conditions.

System under study

In order to consider real world constraints, a multi machine electric power system which exhibit a real world performance is considered here as case study. Fig.1 shows the proposed multi machine power system. The system data are completely given by Kundur (1993). In order to evaluate the performance of the proposed method over a wide range of loading conditions, three different cases as nominal, light and heavy loadings are considered and listed in Table 1. Also, turbine and excitation system have been incorporated. Excitation system model IEEE-ste1 is used.

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



Dynamic model of the system

The nonlinear dynamic model of the system is given as (1); where i=1, 2, 3, 4 show the number of generators and the other parameters are 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.

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

Power System Stabilizer

The PSS configuration is given in (2); where Δω is the speed deviation in p.u. This type of PSS consists of a washout filter, a dynamic compensator (Shayeghi *et al*., 2010). 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 to two lead-lag stages with time constants, T_1-T_4 and an additional gain K_{DC}.

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

In this paper PSO is used to find the best optimized values of the parameters K_{DC} and T_1-T_4. In the next subsection an introduction about PSO is briefly 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 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).

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

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

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
$P_{m,n}^{localbest}$= best local solution
$P_{m,n}^{globalbest}$= 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. The advantages of PSO are that it is easy to implement and there are few parameters to adjust. The PSO is able to tackle tough cost functions with many local minima (Randy & Sue, 2004).

Design methodology

In this section the proposed optimization algorithms (PSO) is used to design PSS parameters. First step in the design procedure is to define an objective function (performance index) for optimization. In this paper Integral of the Time multiplied Absolute Error (ITAE) is considered as objective function and is given as (5).

$$ITAE = \int_0^t t|\Delta\omega_1|dt + \int_0^t t|\Delta\omega_2|dt + \int_0^t t|\Delta\omega_3|dt + \int_0^t t|\Delta\omega_4|dt \qquad (5)$$

Where, the *Δω* shows the deviation of speed and *t* indicates the simulation time. 100 seconds time period is considered.

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Design procedure can be formulated as the following constrained optimization problem, where the constraints are the PSS parameter bounds (Shayeghi *et al*., 2010).

Minimize ITAE

Subject to

$$K_{DCi}^{min} \le K_{DCi} \le K_{DCi}^{max}$$

$$T_{1i}^{min} \le T_{1i} \le T_{1i}^{max}$$

$$T_{2i}^{min} \le T_{2i} \le T_{2i}^{max} \qquad K_{DCi}^{min}$$

$$T_{3i}^{min} \le T_{3i} \le T_{3i}^{max}$$

$$T_{4i}^{min} \le T_{4i} \le T_{4i}^{max}$$

The proposed approach employs PSO technique to solve this optimization problem and to search for optimal or near optimal set of PSS parameters (K_{DCi} and T_{1i} to T_{4i} for i = 1, 2, 3). It should be noted that PSSs are only designed for generators G_1, G_2 and G_4 because G_3 is the slack generator.

Parameters tuning using PSO

Table 2.Optimal parameters of stabilizers using PSO

Generator	PSO				
	K_{DC}	T_1	T_2	T_3	T_4
G_1	10.4421	0.0914	0.01	0.5988	0.01
G_2	33.9221	0.278	0.01	0.0291	0.01
G_4	57.0371	0.7744	0.01	0.0466	0.01

To compute the optimum values of parameters, a 6-cycle three-phase short circuit is assumed in bus 1 and the performance index is minimized using PSO. In order to acquire better performance, number of particle, particle size, number of iteration, Γ_1, Γ_2, and Γ are chosen as 48, 15, 100, 2, 2 and 1, respectively. Also, the inertia weight, w, is linearly decreasing from 0.9 to 0.4. The results are given in Table 2. Also in order to show the effectiveness of the PSO method, the parameters of stabilizers are also tuned using GA. In GA case, the performance index is considered the same as PSO case and the optimal parameters of stabilizers are listed in Table 3.

Table 3.Optimal parameters of stabilizers using GA

Generator	GA				
	K_{DC}	T_1	T_2	T_3	T_4
G_1	18.2088	0.128	0.0215	0.9210	0.0159
G_2	27.9147	0.4588	0.0255	0.0210	0.0499
G_4	53.6691	0.912	0.0150	0.0556	0.0141

Simulation results

In this section the proposed PSSs (PSO-PSS and GA-PSS) are evaluated on the testing system. Two different cases are considered to evaluate the performance of the proposed PSSs:

Case 1: a 6-cycle three-phase short circuit at bus 3

Case 2: a 10-cycle three-phase short circuit at bus 8

Simulation results are shown in Fig 2-9. Each figure contains two plots for PSO-PSS (solid line) and GA-PSS (dashed line). Results show the appropriate performance of the PSSs during post fault. With installation of PSSs, The system oscillations are extremely damped and system becomes stable. The both PSSs (PSO-PSS and GA-PSS) have suitable performance in stability enhancement and damping power system oscillations. But PSO-PSS has significantly better performance than GA-PSS. Also with changing operating conditions from the nominal to heavy, while the performance of GA stabilizers become poorer, the PSO stabilizers have a stable and robust performance.

Conclusions

In this paper a new PSS tuning based on PSO (PSO-PSS) was successfully presented. The proposed PSS was evaluated on a multi machine power system which in near to real world applications. Results clearly showed that the proposed PSSs greatly enhance power system.

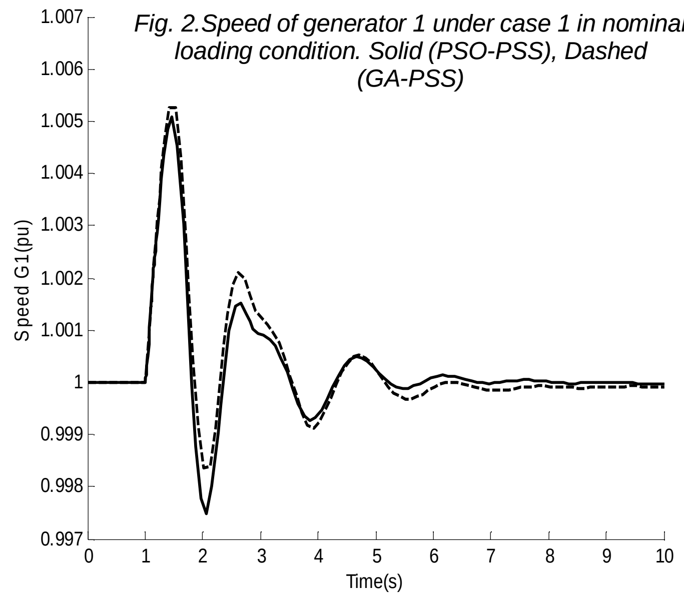

Fig. 2.Speed of generator 1 under case 1 in nominal loading condition. Solid (PSO-PSS), Dashed (GA-PSS)

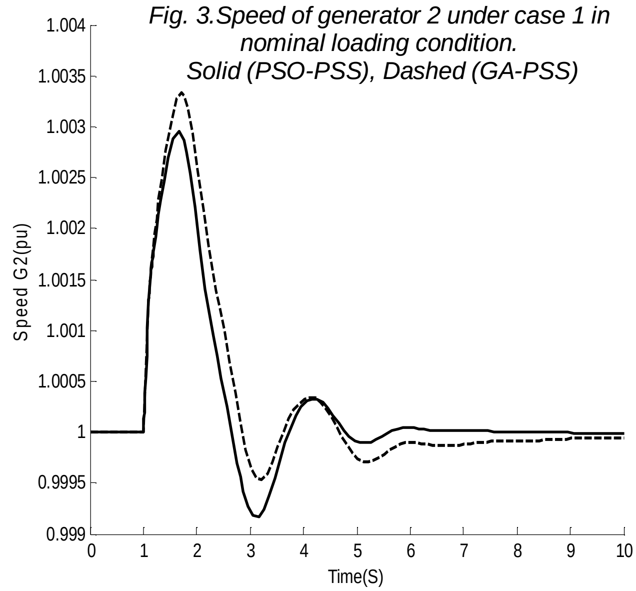

Fig. 3.Speed of generator 2 under case 1 in nominal loading condition. Solid (PSO-PSS), Dashed (GA-PSS)

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Fig. 4.Speed of generator 3 under case 1 in nominal loading condition. Solid (PSO-PSS), Dashed (GA-PSS)

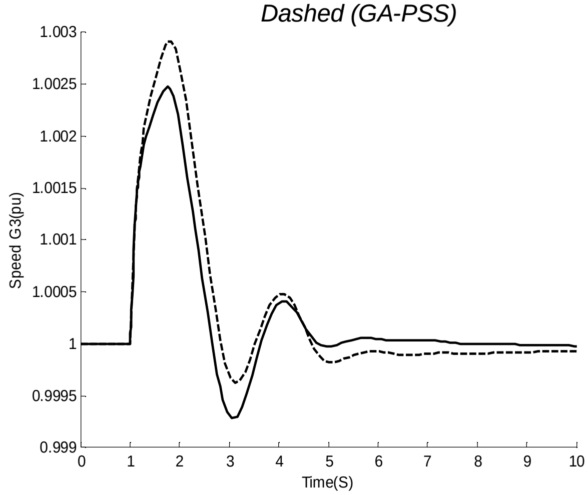


Fig. 7.Speed of generator 2 under case 2 in heavy loading condition. Solid (PSO-PSS), Dashed (GA-PSS)

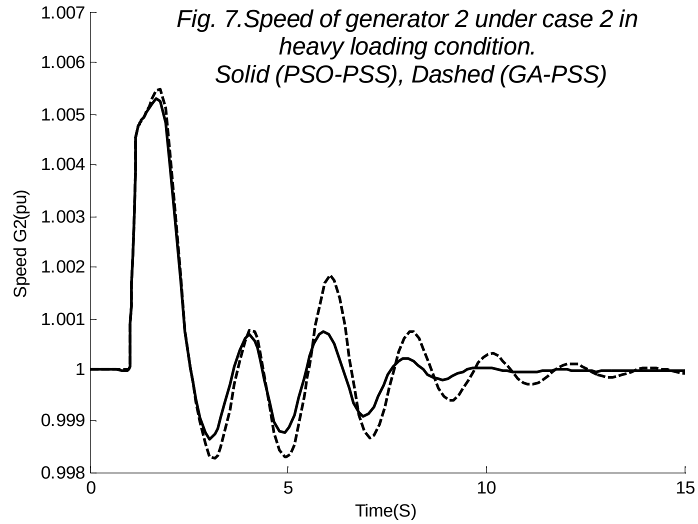


Fig. 5.Speed of generator 4 under case 1 in nominal loading condition. Solid (PSO-PSS), Dashed (GA-PSS)

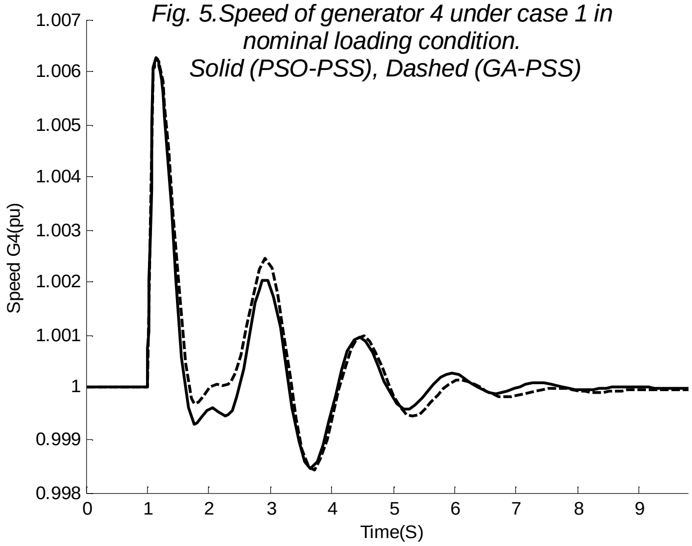


Fig. 8.Speed of generator 3 under case 2 in heavy loading condition. Solid (PSO-PSS), Dashed (GA-PSS)

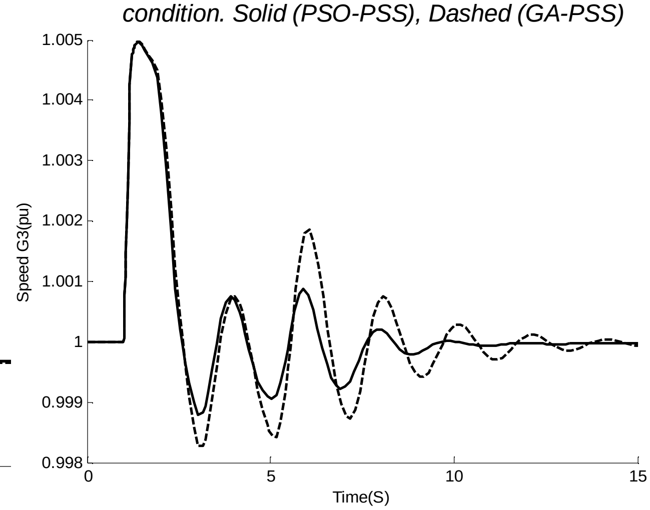


Fig. 6.Speed of generator 1 under case 2 in heavy loading condition

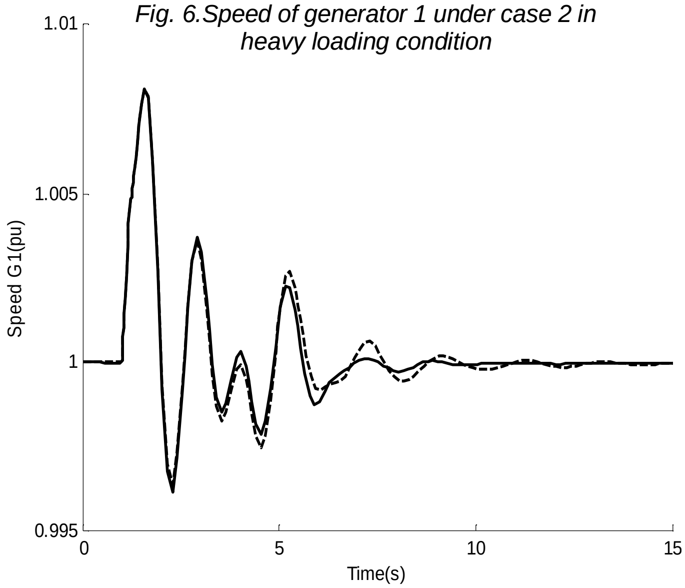
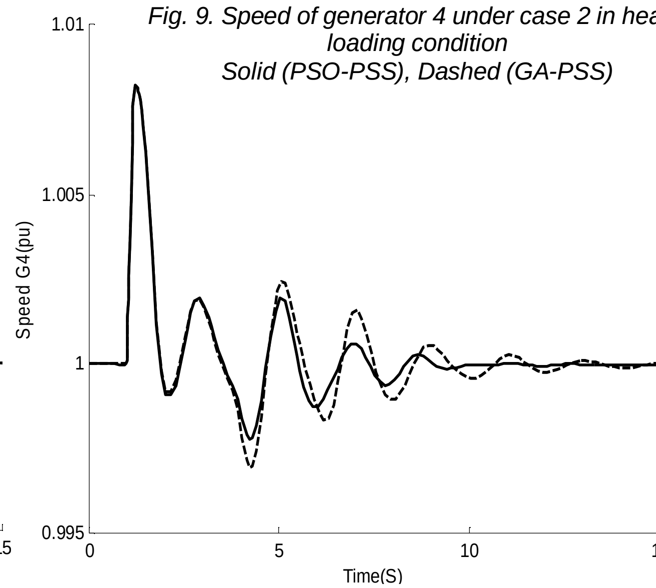


Fig. 9. Speed of generator 4 under case 2 in heavy loading condition Solid (PSO-PSS), Dashed (GA-PSS)



damping and the oscillations are extremely damped. Comparison with the other optimization method (GA-PSS) showed the validity of the PSO in finding optimal solution of a nonlinear optimization problem. Also the simulation results demonstrated that the designed PSO-PSS is capable of guaranteeing the robust performance of power system under a wide range of system loading conditions.

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