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Multi-machine power system stabilizer adjustment using Simulated Annealing

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Abstract

In this paper, the authors are willing to find the optimal and robust design for power system stabilizers (PSSs) in a multi-machine power system. In this regard a new Meta heuristic method as Simulated Annealing (SA) is used. The PSS parameters are computed to assure maximum damping performance under different scenarios. A multi machine electric power system is used to illustrative the performance of proposed method. The efficacy of this technique in damping local and inter-area modes of oscillations in multimachine power systems is confirmed through nonlinear simulation results. Simulation results are carried out by numerical simulations on MATLAB software.

Keywords: Multi Machine, Power System Stabilizer, Low Frequency Oscillations, Simulated Annealing

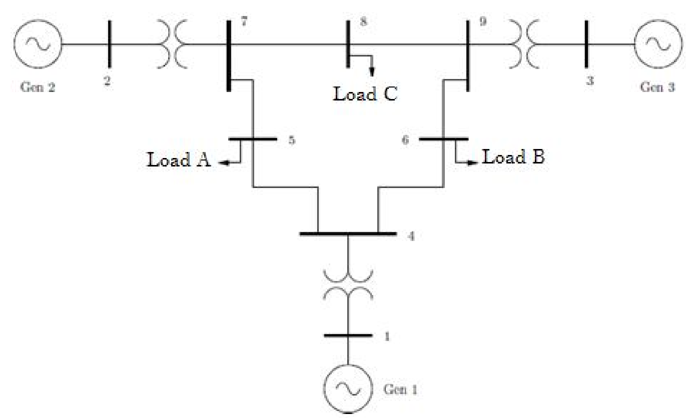
Introduction

With the increasing electrical power system demand and the need to operate power systems closer to their limits of stability, faster and more flexible manner in the deregulated competitive environment, modern power systems can reach stressed conditions more easily than the past. These cause unstable or poorly damped oscillations that are observed more often in today's power systems. The instability problems caused by low frequency inter-area oscillations that occur due to weak interconnected power systems are therefore becoming significant. Increasing the damping of these modes of oscillation by adequately tuning power system stabilizers (PSSs) has been the topic of many works. In the past, the PSS designs were based on a single machine infinite bus (SIMB) power system model, considering the concepts of synchronizing and damping torque coefficients (deMello & Concordia, 1996). However, the described procedure considered that the PSS parameters are chosen to ensure the damping performance for local modes. The simultaneous coordination of multiple PSSs for multi machine power systems was not attempted. In the last decades, PSS have been used by utilities in real power systems as they have proven to be the most cost-effective electromechanical damping control (Larsen & Swann, 1981; Abdel-Magid *et al*., 1999; Kundur, 1994).

Recently, several new techniques have been used to design different power system stabilizers; Such as Fuzzy method (Chaturvedi & Malik ,2008; El-Zonkoly *et al.,* 2009; Ghoshal *et al.,* 2009; Talaat *et al.,* 2010; Chatterje *et al.,* 2011;), robust methods (Rigatos & Siano, 2010; Soliman *et al.,* 2010) and adaptive methods (Hussein *et al.,* 2009; Hussein *et al.,* 2010). However, power systems companies prefer to choose lead-lag structure due to its simplicity and reliability in real power systems implementation. To increase the damping performance of the stabilizers, recent researchers have paid attention to tune these stabilizers simultaneously. In this scope, application of optimization methods has been widely carried out to PSS tuning (Wanga *et al.,* 2009; Shayeghi *et al.*, 2010a,b; Yassami *et al.,* 2010).

In this paper a new Meta heuristic optimization method based on SA is used to adjust the PSS parameters. The proposed method is evaluated on a multi machine electric power system. Simulation results, which are carried out on the proposed multi machine power system, show the viability of SA in parameters tuning of PSS.

Fig. 1. Three-machine nine-bus power system



Illustrative test system

Fig. 1 shows a multi machine electric power system (Sauer & Pai, 1997). In this study in order to frequency regulation of synchronous machines, the turbine-governor system is also incorporated. The system data are given in (Sauer & Pai, 1997). The nonlinear dynamic model of the system is given as (1). where i=1, 2, 3 (the generators: 1 to 3); 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.

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

Structure of power system stabilizer

The function of a PSS is to generate appropriate torque on the rotor of the machine, in such a way that, the phase lag between the exciter input and the machine electrical torque is compensated. In this study extensively used speed based PSS design is considered where the stabilizing signal is assumed to be proportional to the speed perturbation. The structure of PSS is as (2). It consists of a gain block with gain K_{DC}, a signal washout block and two-stage phase compensation blocks. The signal was hout block acts as a high-pass filter, with the time constant Tw that allows the signal associated with the oscillations in rotor speed to pass unchanged, and it does not allow the steady state changes to modify the terminal voltages. From the view of the washout function, the value of Tw is generally not critical and may be in the range of 0.5 to 20 s. In this study, it is fixed as 10 s. The phase compensation blocks with time constants T1, T2 and T3, T4 supply the suitable phase-lead characteristics to compensate for the phase lag between the input and the output signals. The five PSS parameters consisting of the four time constants T1 to T4 and the gain K_{DC} need be optimally chosen for each generator to guarantee optimal system performance under various system configurations and disturbances. In this paper SA is used to find the best values of the proposed parameters. In the next section a brief introduction about the SA is presented.

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

Simulated Annealing

In the early 1980s the method of simulated annealing (SA) was introduced in 1983 based on ideas formulated in the early 1950s. This method simulates the annealing process in which a substance is heated above its melting temperature and then gradually cooled to produce the crystalline lattice, which minimizes its energy probability distribution. This crystalline lattice, composed of millions of atoms perfectly aligned, is a beautiful example of nature finding an optimal structure. However, quickly cooling or quenching the liquid retards the crystal formation, and the substance becomes an amorphous mass with a higher than optimum energy state. The key to crystal formation is carefully controlling the rate of change of temperature.

The algorithmic analog to this process begins with a random guess of the cost function variable values. Heating means randomly modifying the variable values. Higher heat implies greater random fluctuations. The cost function returns the output, *f*, associated with a set of variables. If the output decreases, then the new variable set replaces the old variable set. If the output increases, then the output is accepted provided that:

$$r \le e^{[f(P_{old}) - f(P_{new})]/T} \quad (3)$$

Where, *r* is a uniform random number and *T* is a variable analogous to temperature. Otherwise, the new variable set is rejected. Thus, even if a variable set leads to a worse cost, it can be accepted with a certain probability. The new variable set is found by taking a random step from the old variable Set as (4).

$P^{new} = dP^{old}$ (4)

The variable *d* is either uniformly or normally distributed about p^{old}. This control variable sets the step size so that, at the beginning of the process, the algorithm is forced to make large changes in variable values. At times the changes move the algorithm away from the optimum, which forces the algorithm to explore new regions of variable space. After a certain number of iterations, the new variable sets no longer lead to lower costs. At this point the value of T and d decrease by a certain percent and the algorithm repeats. The algorithm stops when $T \simeq 0$.The decrease in *T* is known as the cooling schedule. Many different cooling schedules are possible. If the initial temperature is T_0 and the ending temperature is T_N, then the temperature at step *n* is given by (5).

$T_n = f(T_0, T_N, N, n)$ (5)

Where, *f* decreases with time. Some potential cooling schedules are as follows:

a. Linearly decreasing: $T_n = T_0 - n(T_0 - T_n)/N$
b. Geometrically decreasing: $T_n = 0.99\, T_{n-1}$
c. Hayjek optimal: $T_n = c/log(1+n)$, where *c* is the smallest variation required to get out of any local minimum.

Many other variations are possible. The temperature is usually lowered slowly so that the algorithm has a chance to find the correct valley before trying to get to the lowest point in the valley. This algorithm has been applied successfully to a wide variety of problems (Randy & Sue, 2004).

Design methodology

The PSSs tuning using SA is performed on the proposed test system. In the system, generator 1 is slack generator and thus the PSS is only installed on generators 2 and 3. The parameters of two proposed PSSs are simultaneously tuned by using SA. Also the performance index is considered as (6). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (*ITAE*).

$$ITAE = \int_0^t t|\Delta\omega_1|dt + \int_0^t t|\Delta\omega_2|dt + \int_0^t t|\Delta\omega_3|dt \quad (6)$$

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

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Fig. 2. Generator speeds under scenario 1
Solid (SA-PSS), Dashed (without-PSS)

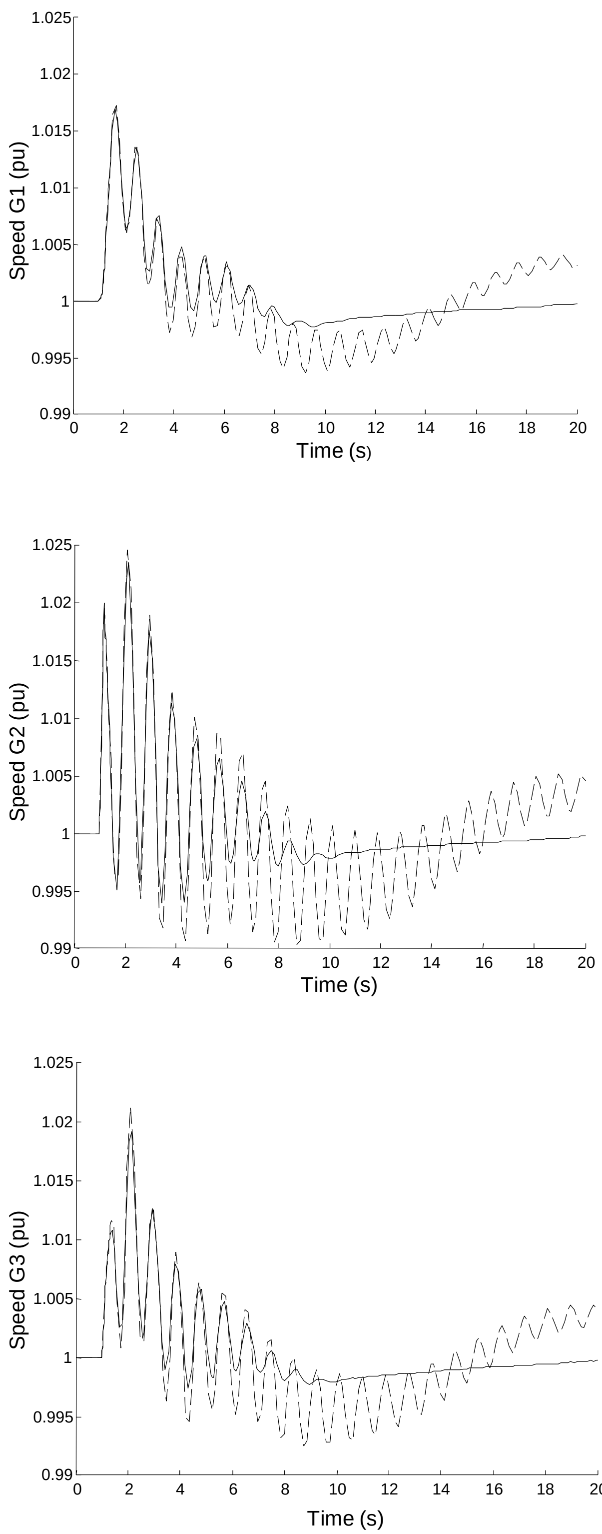
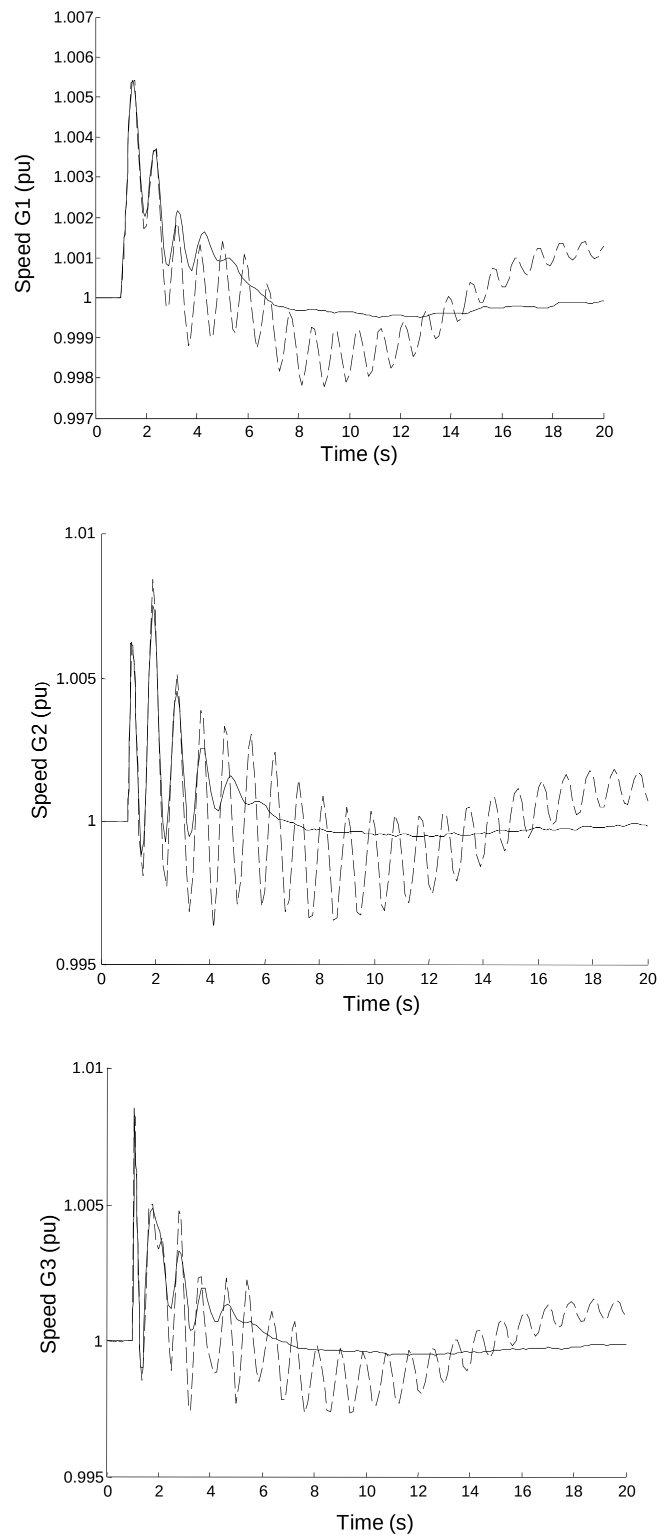


Fig. 3. Generator speeds under scenario 2
Solid (SA-PSS), Dashed (without-PSS)



assumed in bus 2 and the performance index is minimized using SA. The ranges of the PSS parameters for design procedure are as follows: 1< K_{DCi} <100 and 0.01< T < 1. It should be noted that SA algorithm is run several times and then optimal set of PSS parameters is selected. The optimum values of the PSS parameters are obtained using SA and summarized in the Table 1.

Table 1. Optimal parameters of PSS achieved using SA

Generator	SA				
	K_{DC}	T_1	T_2	T_3	T_4
G_2	31.02	0.451	0.022	0.772	0.0101
G_3	44.88	0.521	0.012	0.808	0.0124

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 2

Scenario 2: a 6-cycle three-phase short circuit in bus 6

The simulation results are presented in Figs. 2-3. Each figure contains two plots for SA-PSS (solid line) and without PSS (dashed line). The simulation results show that applying the supplementary stabilizer signal greatly enhances the damping of the generator angle oscillations. The results clearly show that in large electric power systems, PSS can successfully increase damping of power system oscillations. Also the responses without PSS clearly show that the system without PSS does not have enough damping torque and the responses go to fluctuate.

Conclusions

In this paper, a new simple SA-based optimization algorithm for tuning power system stabilizers was presented. The described algorithm allows simultaneously tuning PSSs and finding out their optimal parameters in large power systems. The procedure was tested for a multi machine interconnected power system with two numbers of PSSs, through two different scenarios. The obtained results show that the proposed technique can find the optimal and the best PSSs parameters simultaneously with an excellent global damping performance. Therefore, it is suitable for large scale power systems stability improvement.

Acknowledgement

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