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Power System Stabilizer Parameters Tuning Based On Tabu Search in a Multi Machine Power System

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Abstract: Power system stabilizers (PSSs) are used to enhance damping of power system oscillations through excitation control of synchronous generator. The objective of the PSS is to generate a stabilizing signal, which produces a damping torque component on the generator shaft. Conventional Power system stabilizers (CPSSs) are designed with the phase compensation technique in the frequency domain and include the lead-lag blocks and related parameters are determined according to a linearized power system model. The performance of CPSSs depends upon the generator operating point and the system parameters, but a reasonable level of robustness can be achieved depending on the tuning method. To overcome the drawbacks of CPSS, numerous techniques have been proposed in literatures. In this paper an optimization method based on Tabu search (SA) is used for tuning the PSS parameters. The performance of proposed SA-PSS is evaluated at IEEE 14 bus test system as a multi machine electric power system. The simulation results clearly indicate the effectiveness and validity of the proposed method.

Key words: Multi Machine Electric Power System, Power System Stabilizer, Low Frequency Oscillations, Tabu search

INTRODUCTION

Large electric power systems are complex nonlinear systems and often exhibit low frequency electromechanical oscillations due to insufficient damping caused by adverse operating. 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. For tuning the CPSS, linear model of power system is considered and so it has not good damping effect over a wide operating range. Since power systems are highly nonlinear, with configurations and parameters which alter through time, the CPSS design based on the linearized power system model cannot guarantee its performance in a practical operating condition. It means that CPSSs haven't robustness in response to disturbances or operation conditions .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 (Linda and Nair, 2010; Yassami *et al*., 2010; Sumathi *et al*., 2007; Jiang *et al*., 2008; Sudha *et al*., 2009) and Fuzzy logic method (Hwanga *et al*., 2008; Dubey, 2007). Also the application of robust control methods for designing PSS has been presented by Gupta *et al*. (2005), Mocwane and Folly (2007), Sil *et al*. (2009) and Bouhamida *et al*. (2005).

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In this paper an optimization method based on TS is used to adjust the PSS parameters. A multi machine electric power system is considered as case study. Simulation results show that the proposed method greatly enhances the dynamic stability of multi machine power system.

This paper is structures as follows. Section 2 describes the power system modeling. The power system stabilizers are briefly introduced in section 3. Section 4 is devoted to the tabu search and the design methodology is presented in section 5. Eventually the simulation results are presented in section 6.

2. System under Study:

In this paper IEEE 14 bus test system is considered to evaluate the proposed method. The system data are completely given in IEEE standards.

2.1. Dynamic Model of the System:

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

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

where i=1, 2, 3, 4,5 (the generators: 1 to 5); 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.

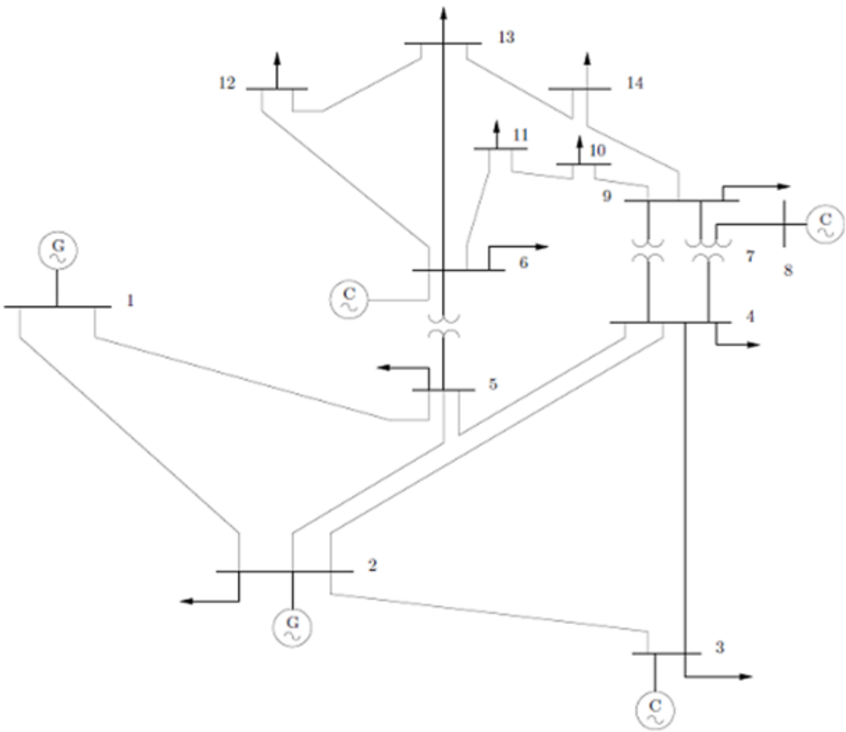


Fig. 1: The schematic of IEEE 14 bus test system.

3. 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 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 *et al*., 1993). The PSS configuration is given in as (2). where, ?ω 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}.

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

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 TS. in the next section a brief introduction about the TSis presented.

4. Tabu Search:

Tabu search (TS) was first presented in its present form by [Glover, 1986]; Many computational experiments have shown that TS has now become an established optimization technique which can compete with almost all known techniques and which - by its flexibility - can beat many classical procedures. Up to now, there is no formal explanation of this good behavior. Recently, theoretical aspects of TS have been investigated [Faigle and Kern, 1992].

The success with TS implies often that a serious effort of modeling be done from the beginning. In TS, iterative procedure plays an important role: for most optimization problems no procedure is known in general to get directly an "optimal" solution.

The general step of an iterative procedure consists in constructing from a current solution x_i a next solution x_j *and* in checking whether one should stop there or perform another step.

In other hand, a neighborhood $N(x_i)$ is defined for each feasible solution x_i, and the next solution x_j is searched among the solutions in $N(x_j)$.

In this part we summarize the discrete TS algorithm in four steps. Assume that X is a total search space and x is a solution point sample and f (x) is cost function:

1- Choose $x \in X$ to start the process.
2- Create a candidate list of non-Tabu moves in neighborhood. (x_i, i=1,2,...,N)
3-Find $x_{winner} \in N(x)$ such that $f(x_{winner}) > f(x_i),\ i \neq winner$.
4- Check the stopping criterion. If satisfied, exit the algorithm.
If not, winner $x = x_{winner}$, update Tabu List and then go to step 2.

In order to exit from algorithm, there are several criterions that are considered in our research.

1- by determining a predetermined threshold: If the value of cost function was less, algorithm would be terminated.
2- Determination of specific number of iterations.
3- If the value of the cost was remained invariable or negligible change for several iterations, algorithm would be terminated.

A didactic presentation of TS and a series of applications have been collected in [Glover *et al*., 1992].

5. Design Methodology:

In this section the PSS parameters tuning based on the Tabu search is presented. The test system has five generators and it is possible to install five PSSs. In this paper just one PSS is considered to install on generator 1. In this study the performance index is considered as (3). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (*ITAE*).

$$ITAE = \int_0^t t|\Delta\omega_1|dt + \int_0^t t|\Delta\omega_2|dt + \int_0^t t|\Delta\omega_3|dt + \int_0^t t|\Delta\omega_4|dt + \int_0^t t|\Delta\omega_5|dt \quad (3)$$

Where, *Dw* 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 8 and the performance index is minimized using TS. The ranges of the PSS parameters for design procedure are as follows:

1> K_{DCi} >100 and 0.01> T > 1

The following TS parameters have been also used in present research.
Number of Chromosomes: 5
Population size: 48
Crossover rate: 0.5
Mutation rate: 0.1
The PSS parameters are accuracy calculated using TSand the results are listed in Table 1.

Table 1: Optimal parameters of stabilizers using TS

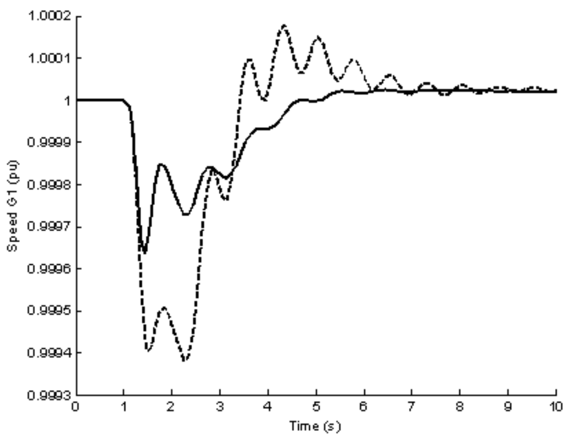
Generator	parameters				
	K_{DC}	T_1	T_2	T_3	T_4
G_1	8.1102	0.377	0.01	0.377	0.01

6. 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 15-cycle three-phase short circuit in bus 14
Scenario 2: 10% load change

It should be noted that, in scenario 2, the load has two step changes. In first it is increased at 1 second and then driven back to the nominal load at 4th second; then the load is reduced at 20th second and driven back to the nominal load at 24th second.

The simulation results are presented in Figs. 2-3. Each figure contains two plots for TS-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.



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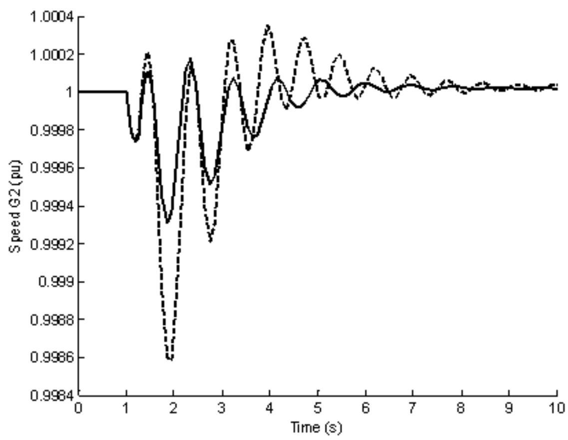

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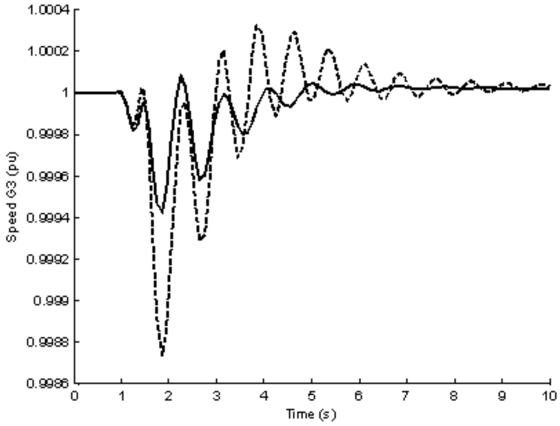

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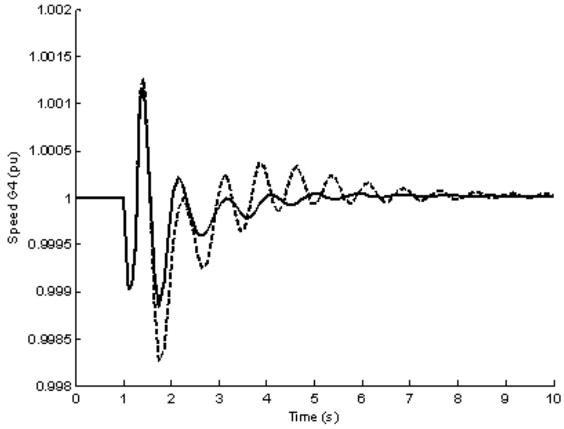

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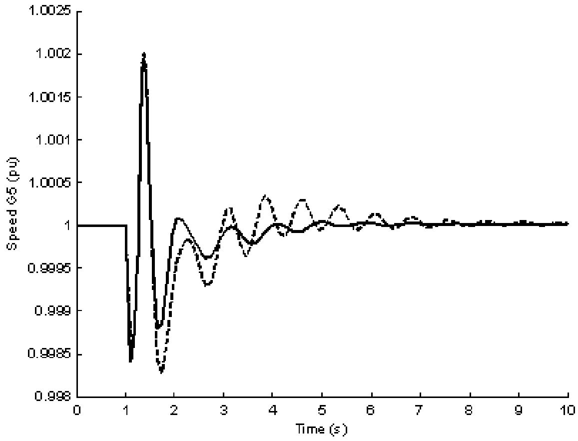

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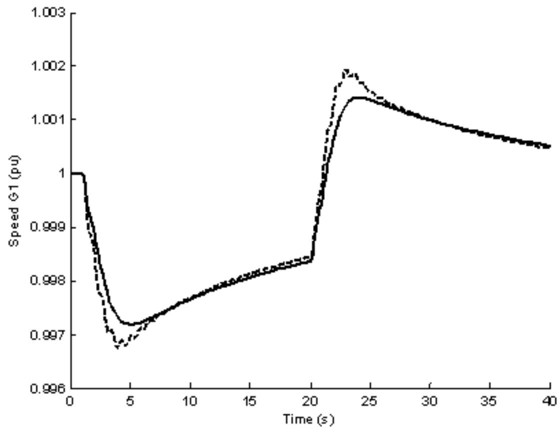
Fig. 2: System responses under scenario 1 Solid (TS-PSS), Dashed (without PSS).
a: ω_1 b: ω_2 c: ω_3 d: ω_4 e: ω_5



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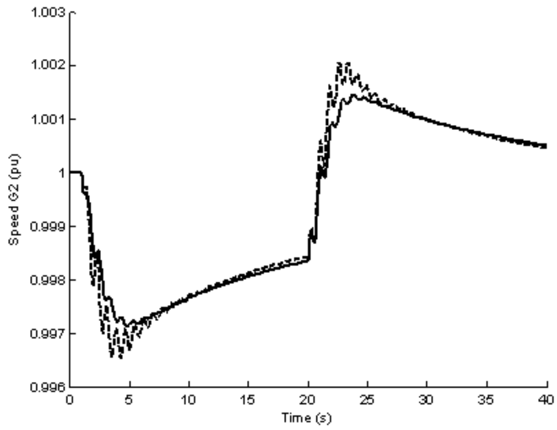

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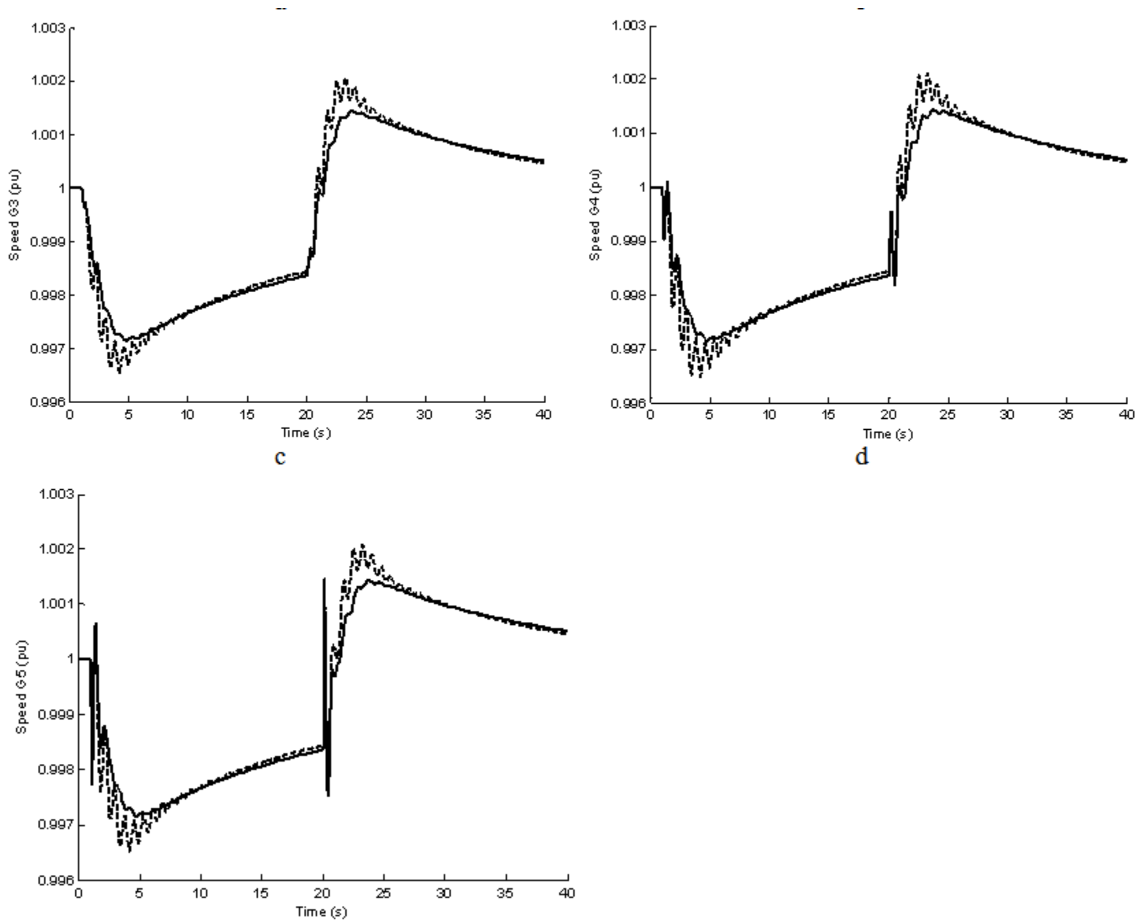

Fig. 3: System responses under scenario 2 Solid (TS-PSS), Dashed (without PSS).
a: ω_1 b: ω_2 c: ω_3 d: ω_4 e: ω_5

Conclusions:

In this paper dynamic stability of a multi machine electric power system has been successfully improved by using Power System Stabilizer. The PSS parameters were obtained by using tabu search optimization method. The power system has been installed with just one PSS. This application of just one PSS is near to real world applications. The simulation results on a multi machine electric power system showed that PSS can greatly enhance damping of power system oscillations in large electric power systems. Therefore the proposed method is a feasible and appropriate method to enhance dynamic stability of large multi machine electric power systems. The proposed PSS is very feasible and easy to implementation.

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