

Harmony search algorithm for power system stabilizer tuning

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Abstract

The problem of tuning Power system stabilizers (PSSs) is commonly formulated as a nonlinear optimization problem with some constraints. In this paper a new optimization technique based on Harmony Search (HS) to solve the proposed optimization problem is presented. This is a very complex nonlinear programming problem. A constructive heuristic algorithm aimed at obtaining an excellent quality solution for this problem is presented. Results of the tests, carried out with a multi machine electric power system, show the capabilities of the method and also the viability of using the HS to solve the problem.

Keywords: Multi Machine Power System, Power System Stabilizer, Low Frequency Oscillations, Harmony Search Algorithm

Introduction

Constantly increasing intricacy of electric power systems has enhanced interests in developing superior methodologies for Power System Stabilizers (PSSs). Transient and dynamic stability considerations are among the main issues in the reliable and efficient operation of power systems. Low Frequency Oscillation (LFO) modes have been observed when power systems are interconnected by weak tie-lines (Liu *et al.*, 2004). The LFO mode, with weak damping, is also called the electromechanical oscillation mode, and it usually happens in the frequency range of 0.1 to 2 Hz. PSSs are the most efficient devices for damping both local mode and inter-area mode small signal LFOs by increasing the system damping, thus enhancing the dynamic stability of the power systems. The generators are equipped with PSS, which provides supplementary feedback and stabilizes the signal in the excitation system. The problem of PSS design is to tune the parameters of the stabilizer so that the damping of the system's electromechanical oscillation modes is increased. This must be done without the adverse effects on other oscillatory modes, such as those associated with the exciters or the shaft torsion oscillations. The stabilizer must also be so designed, that it has no adverse effects on a system's recovery from a severe fault. The concept and parameters of PSS have been considered in various studies (Liu *et al.*, 2005). The classical PSSs (CPSS) have been widely used in power systems. But, 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).

In this paper, an optimization method based on HS 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.

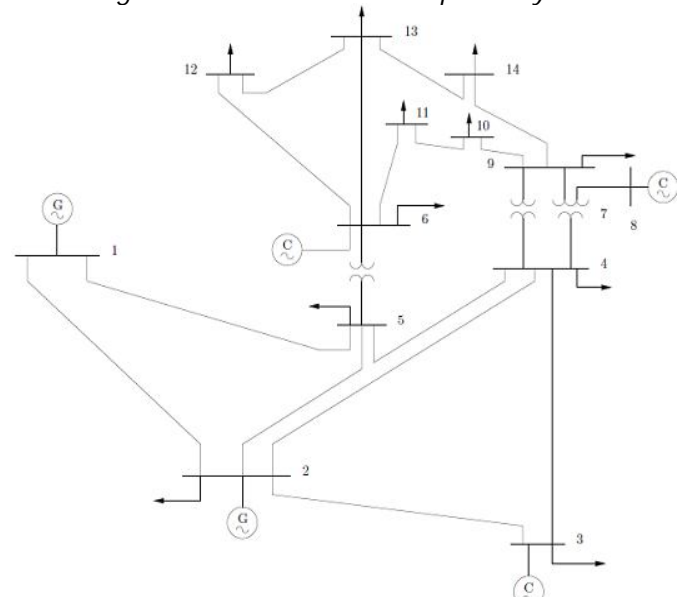
System under study

In this paper IEEE 14 bus system testing is considered to evaluate the proposed method. The system data are completely given in IEEE standards. Fig. 1 shows the proposed standard power system.

Dynamic model of the system

The nonlinear dynamic model of the system is given

Fig. 1. IEEE 14 bus standard power system



as (1).

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

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; T_e , 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 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 PSS configuration 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 (T_w) is fixed to 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} .

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

The major point in the PSS design is to find the optimal values of K_{DC} and T_1 - T_4 . We used an optimization method to find the best values of the proposed parameters. Where, the optimum values of K_{DC} and the time constants of T_1 - T_4 are obtained by using HS in the next section a brief introduction about the HS is presented.

Harmony search algorithm

Harmony search (HS) algorithm is based on natural musical performance processes that occur when a musician searches for a better state of harmony, such as during jazz improvisation. The engineers seek for a global solution as determined by an objective function, just like

the musicians seek to find musically pleasing harmony as determined by an aesthetic (Hong-qi *et al.*, 2008). In music improvisation, each player sounds any pitch within the possible range, together making one harmony vector. If all the pitches make a good solution, that experience is stored in each variable's memory, and the possibility to make a good solution is also increased next time. HS algorithm includes a number of optimization operators, such as the harmony memory (HM), the harmony memory size (HMS, number of solution vectors in harmony memory), the harmony memory considering rate (HMCR), and the pitch adjusting rate (PAR). In the HS algorithm, the harmony memory (HM) stores the feasible vectors, which are all in the feasible space. The harmony memory size determines how many vectors it stores. A new vector is generated by selecting the components of different vectors randomly in the harmony memory. For example, Consider a jazz trio composed of saxophone, double bass and guitar. There exist certain amount of preferable pitches in each musician's memory: saxophonist, {Do, Mi, Sol}; double bassist, {Si, Sol, Re}; and guitarist, {La, Fa, Do}. If saxophonist randomly plays {Sol} out of {Do, Mi, Sol}, double bassist {Si} out of {Si, Sol, Re}, and guitarist {Do} out of {La, Fa, Do}, that harmony {Sol, Si, Do} makes another harmony (musically C-7 chord). And if the new harmony is better than existing worst harmony in the HM, the new harmony is included in the HM and the worst harmony is excluded from the HM. This procedure is repeated until fantastic harmony is found. When a musician improvises one pitch, usually he (or she) follows any one of three rules: (1) playing any one pitch from his (or her) memory, (2) playing an adjacent pitch of one pitch from his (or her) memory, and (3) playing totally random pitch from the possible sound range (Hong-qi *et al.*, 2008). Similarly, when each decision variable chooses one value in the HS algorithm, it follows any one of three rules: (1) choosing any one value from HS memory (defined as memory considerations), (2) choosing an adjacent value of one value from the HS memory (defined as pitch adjustments), and (3) choosing totally random value from the possible value range (defined as randomization). The three rules in HS algorithm are effectively directed using two parameters, i.e., harmony memory considering rate (HMCR) and pitch adjusting rate (PAR). The steps in the procedure of harmony search are: Step1. Initialize the problem and algorithm parameters; Step2. Initialize the harmony memory (HM); Step3. Improvise a new harmony from the HM; Step4. Update the HM and Step5. Repeat Steps 3 and 4 until the termination criterion is satisfied. For better understanding, these steps are briefly described in the following subsections (Verma *et al.*, 2010).

Initialize the problem and algorithm parameters

Specify the optimization problem as (3).

$$\text{minimise } f(x) \tag{3}$$

Subject to $x_i \in X_i \quad i = 1, 2, \dots, N$

Where $f(x)$ is an objective function, x is set of decision variables x_i , N is the number of decision variables and X_i represents the possible range of values for each decision variables.

The HS algorithm parameters to be initialized as: Harmony memory size (HMS): this indicates the number of solution vectors in the harmony memory; HMCR; PAR and Number of improvisations (NI) or stopping criteria.

Initialize the harmony memory (HM)

The harmony memory is initialized with as many randomly generated vectors as the HMS as (4).

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \dots & x_{N-1}^1 & x_N^1 \\ x_1^2 & x_2^2 & \dots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \dots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \dots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \tag{4}$$

Improvise a new harmony from the HM

A new harmony vector $x^t = (x_1^t, x_2^t, \dots, x_N^t)$ is generated based on three rules as following: memory consideration, pitch adjustment and random selection as(5)

$$x_i^t \leftarrow \begin{cases} x_i^t \in \{x_i^1, x_i^2, \dots, x_i^{HMS}\} & \text{with probability HMCR} \\ x_i \in X_i & \text{with probability } (1 - \text{HMCR}) \end{cases} \tag{5}$$

A HMCR of 0.90 indicates that the HS algorithm will choose the decision variable from the stored values in the HM with 90% probability and from the entire range with (100-90%) probability (Verma *et al.*, 2010). Every component chosen by harmony consideration is examined for pitch adjustment based on the following rule: Pitch adjusting decision for x_i^t is given as (6).

$$x_i^t \leftarrow \begin{cases} \text{Yes with probability PAR} \\ \text{No with probability } (1 - \text{PAR}) \end{cases} \tag{6}$$

The value of $(1 - \text{PAR})$ sets the rate of doing nothing. If pitch adjustment decision for x_i^t is yes, x_i^t is modified as (7).

$$x_i^t = x_i^t + \text{rand}() * \text{bw} \tag{7}$$

Where bw is an arbitrary distance bandwidth and $\text{rand}()$ is a random number between 0 and 1.

The PAR and bw are adjusted as (8).

$$\text{PAR}(gn) = \text{PAR}_{\min} + \frac{\text{PAR}_{\max} - \text{PAR}_{\min}}{NI} \times gn \tag{8}$$

Where $gn = 1, 2, \dots, NI$, $\text{PAR}(gn)$ is the pitch adjusting rate for generation or improvisation of gn , PAR_{\min} is the minimum pitch adjusting rate and PAR_{\max} is the maximum pitch adjusting rate (Verma *et al.*, 2010).

To explore the search space, the control parameter bandwidth 'bw' is adjusted depending upon the variance of the population in each improvisation, and is given by (9).

$$\text{bw}(gn) = \sqrt{\text{var}(X)} \tag{9}$$

Update the HM

The new memory is judged in terms of the objective function (fitness function) value and if the new memory is better than the previous memory in the HM, then new harmony memory is included in the HM and the existing worst harmony is excluded from the HM.

Check for stopping criteria

If maximum number of improvisations is reached, then stop, otherwise steps 3 and 4 are repeated.

Design methodology

In this section the PSS parameters tuning based on the Harmony Search Algorithm is presented. The system testing 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 (10). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE).

$$ITAE = \int_0^t |\Delta\omega_1| dt + \int_0^t |\Delta\omega_2| dt + \int_0^t |\Delta\omega_3| dt + \int_0^t |\Delta\omega_4| dt + \int_0^t |\Delta\omega_5| dt \tag{10}$$

Where, $\Delta\omega$ is the frequency deviation and parameter "t" is the simulation time and is considered from zero to 20s. 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 HS. The ranges of the PSS parameters for design procedure are as follows: $1 < K_{DCI} < 100$ and $0.01 < T < 1$

The following Harmony search algorithm parameters have been used in present research.

Fig. 2. Speed of generators under scenario 1

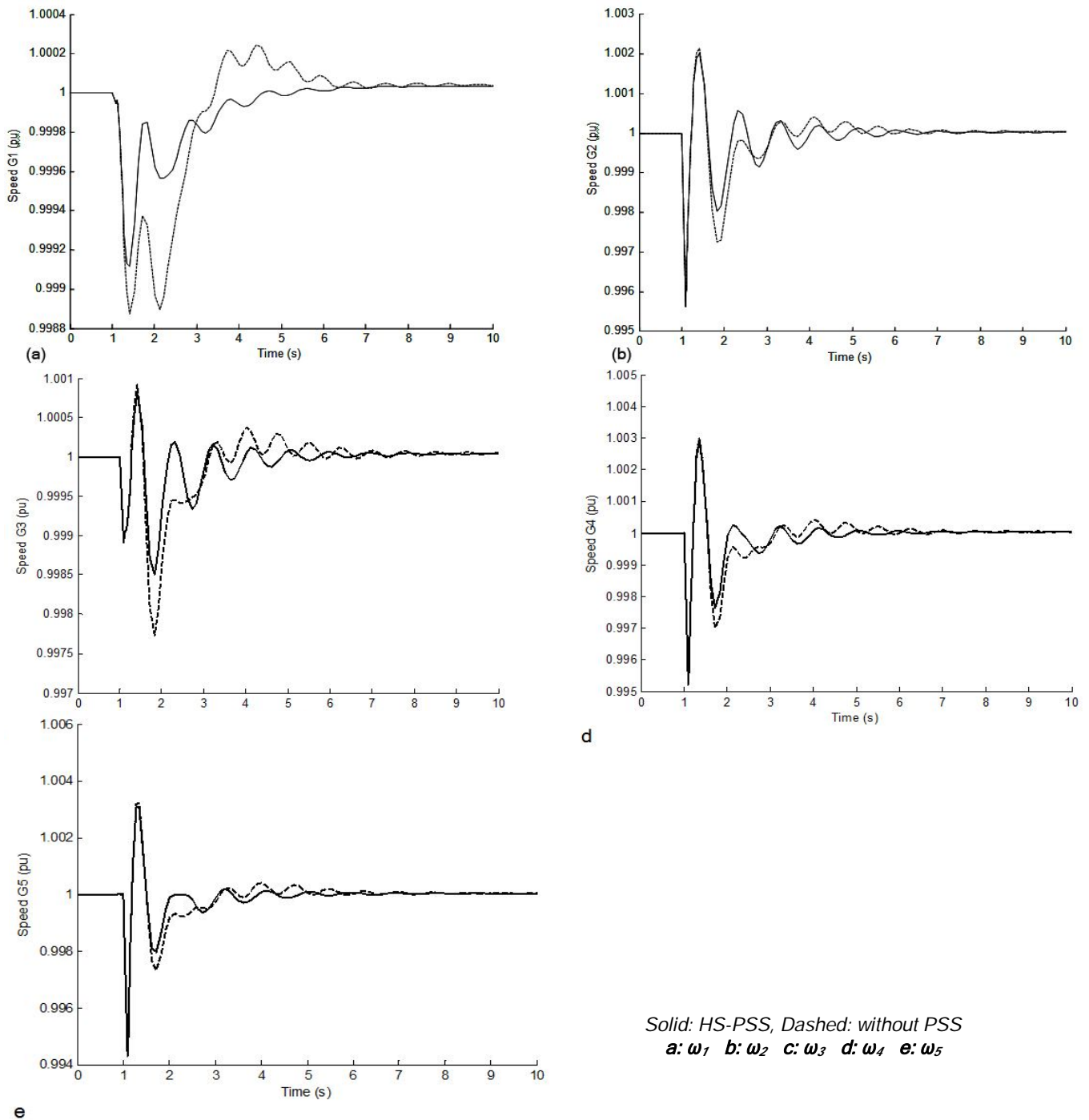
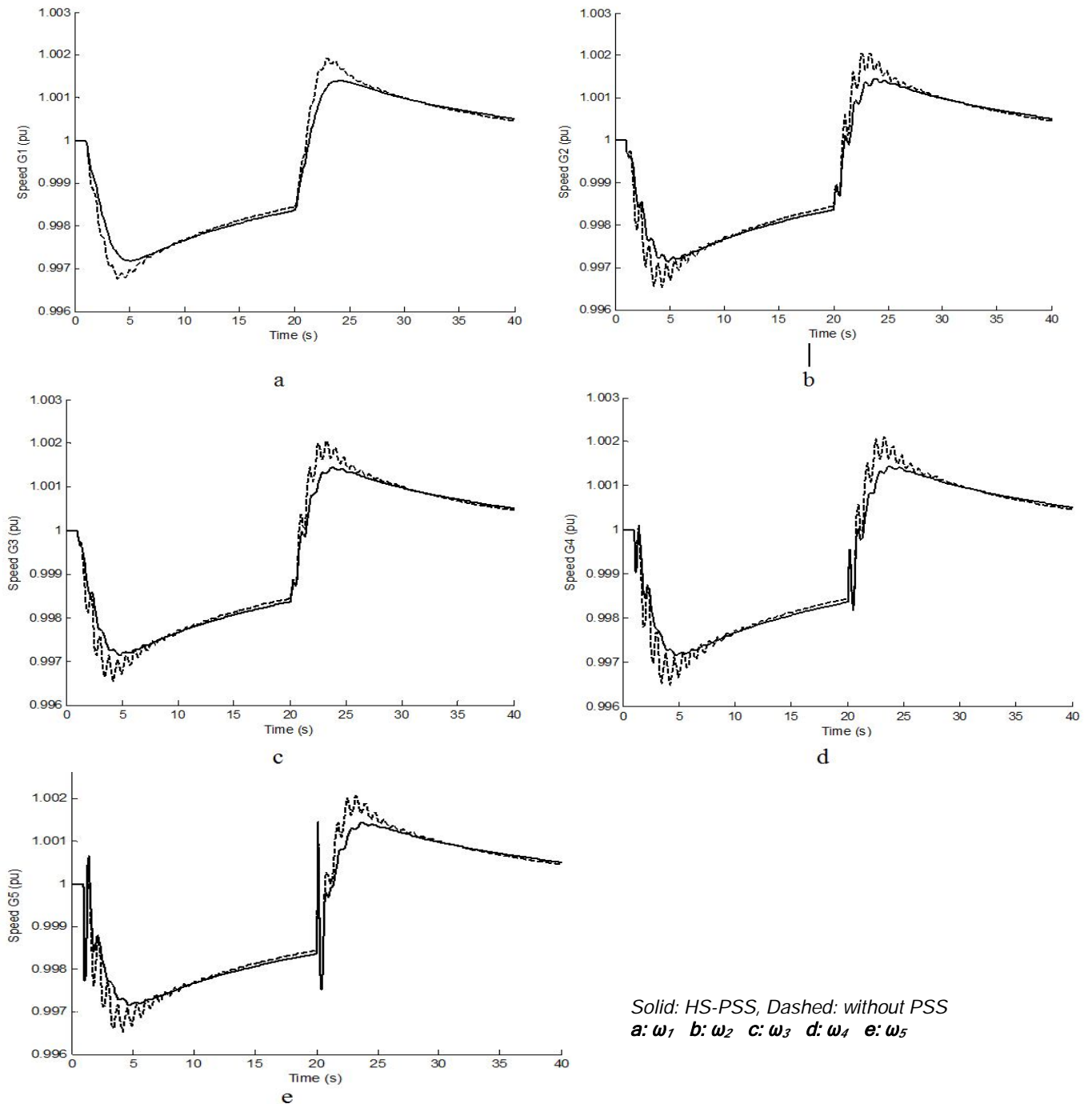


Fig. 3. Speed of generators under scenario 2



Number of decision variables (N): 5
 Harmony memory size (HMS): 60
 Number of improvisations (NI): 100
 HMCR: 0.9

Table 1. Optimal parameters of stabilizers using HS

Generator	Harmony search algorithm				
	K_{DC}	T_1	T_2	T_3	T_4
G ₁	8.223	0.199	0.01	0.199	0.01

The PSS parameters are accurately calculated using HS and the results are listed in Table 1.

Simulation results

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

Scenario 1: a 6-cycle three-phase short circuit in bus 4

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 Fig. 2-3. Each figure contains two plots for HS-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 the present paper, an application of HS algorithm to determine the optimal tuning of PSSs parameters is introduced. The design problem of PSSs parameters selection is converted into an optimization problem which is solved by HS technique with the integral of error based objective function. Time domain simulations also show that, the oscillations of synchronous machines can be rapidly damped for power systems with the proposed PSSs over a wide range of conditions. Simulation results indicate the efficiency of the proposed HS algorithm in tuning PSS and stabilizing the system under LFOs.

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