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Multi-machine power system stabilizer adjustment using genetic algorithms

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Abstract

In this paper, the problem of tuning lead-lag power system stabilizer parameters of a multi machine power system is considered. This problem is formulated as an optimization problem, which is solved using Genetic Algorithms (GA). Simulation results show the effectiveness of the proposed Genetic Algorithms-based lead-lag power system stabilizer to damp the oscillation of multimachine system and work effectively under variable loading and fault conditions. The proposed GA-PSS is evaluated on the IEEE 14 bus test system as a multi machine electric power system.

Keywords: Multi machine electric power system, Power system stabilizer, Genetic Algorithms

Introduction

Power systems are inherently nonlinear and undergo a wide range of transient conditions, which results in under damped low frequency speed as well as power oscillations that are difficult to control. The generator excitation system maintains generator voltage and controls the reactive power flow using an automatic voltage regulator (AVR). The role of an AVR is to hold the terminal voltage magnitude of a synchronous generator at a specified level. Hence, the stability of the AVR system would seriously affect the security of the power system. AVR helps to improve the steady-state stability of power systems, but transient stability became a concern for the power system operators. In transient stability the machine is subjected to large impact, usually a fault, which is maintained for a short time and cause a significant reduction in the machine terminal voltage and ability to transfer synchronizing power (El-Zonkoly *et al*., 2009; Nikzad *et al.,* 2011)

To enhance system damping, the generator is equipped with power system stabilizer (PSS) that provides supplementary feedback stabilizing signal in the excitation system. The problem of the PSS design is a multimodal optimization problem (i.e., there exists more than one local optimum). Hence, conventional optimization techniques are not suitable for such a problem. Moreover, there is no criterion to decide whether a local solution is also the global solution. Therefore, conventional optimization methods that make use of derivatives and gradients, in general, not able to locate or identify the global optimum (El-Zonkoly *et al*., 2009).

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. 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 (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 by Gupta *et al.* (2005), Mocwane and Folly (2007), Sil *et al.* (2009) and Bouhamida *et al.* (2005). In this paper an optimization method based on GA 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 a multi machine power system is considered as case study. Fig. 1 shows the IEEE 14 bus test system considered for evaluating the proposed method. 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:

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

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,

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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

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, Δω 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. 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}.

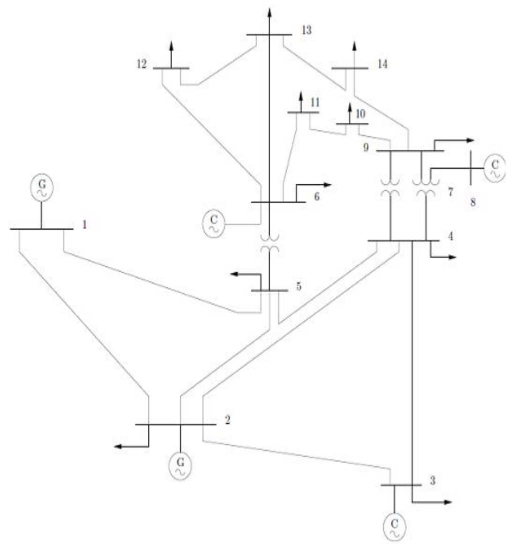
$$U = K_{DC} \frac{ST_W}{1+ST_W} \frac{1+ST_1}{1+ST_2} \frac{1+ST_3}{1+ST_4} \Delta\omega \quad (2)$$

The major point in the PSS design is to find the optimal values of K_{DC} and T1-T4. 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 GA.

Genetic algorithms

Genetic algorithms (GA) are global search techniques, based on the operations observed in natural selection and genetics (Randy & Sue, 2004). They operate on a population of current approximations-*the individuals*-initially drawn at random, from which improvement is sought. Individuals are encoded as strings (Chromosomes) constructed over some particular alphabet, e.g., the binary alphabet {0.1}, so that chromosomes values are uniquely mapped onto the decision variable domain. Once the decision variable domain representation of the current population is calculated, individual performance is assumed according to the objective function which characterizes the problem to be solved. It is also possible to use the variable parameters directly to represent the chromosomes in the GA solution. At the reproduction stage, a fitness value is derived from the raw individual performance measure given by the objective function and used to bias the selection process. Highly fit individuals will have increasing opportunities to pass on genetically important material to successive generations. In this way, the genetic algorithms search from many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance. The selected individuals are then modified through the application of genetic operators. In order to obtain the next generation Genetic operators manipulate the characters (genes) that constitute the chromosomes directly, following the assumption that certain genes code, on average, for fitter individuals than other genes. Genetic operators can be divided into three main categories: Reproduction, crossover and mutation (Randy & Sue, 2004).

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



Design methodology

In this section the proposed optimization method (GA) is used to find optimal values of PSS parameters. The power system has five synchronous generators, but just only one PSS is incorporated on the generator 1. In order to optimization, the performance index is considered as (3). Where, 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, $\Delta\omega$ 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 8 and the performance index is minimized using GA. The ranges of the PSS parameters for design procedure are as follows:

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

The genetic algorithm parameters used were: Number of Chromosomes: 5; Population size: 48; Crossover rate: 0.5; Mutation rate: 0.1.

Table 1 Optimal parameters of stabilizers using GA

Generator	Genetic algorithms				
	K_{DC}	T_1	T_2	T_3	T_4
G_1	6.7127	0.214	0.012	0.214	0.012

The PSS parameters are accuracy calculated using GA and the results are listed in Table 1.

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

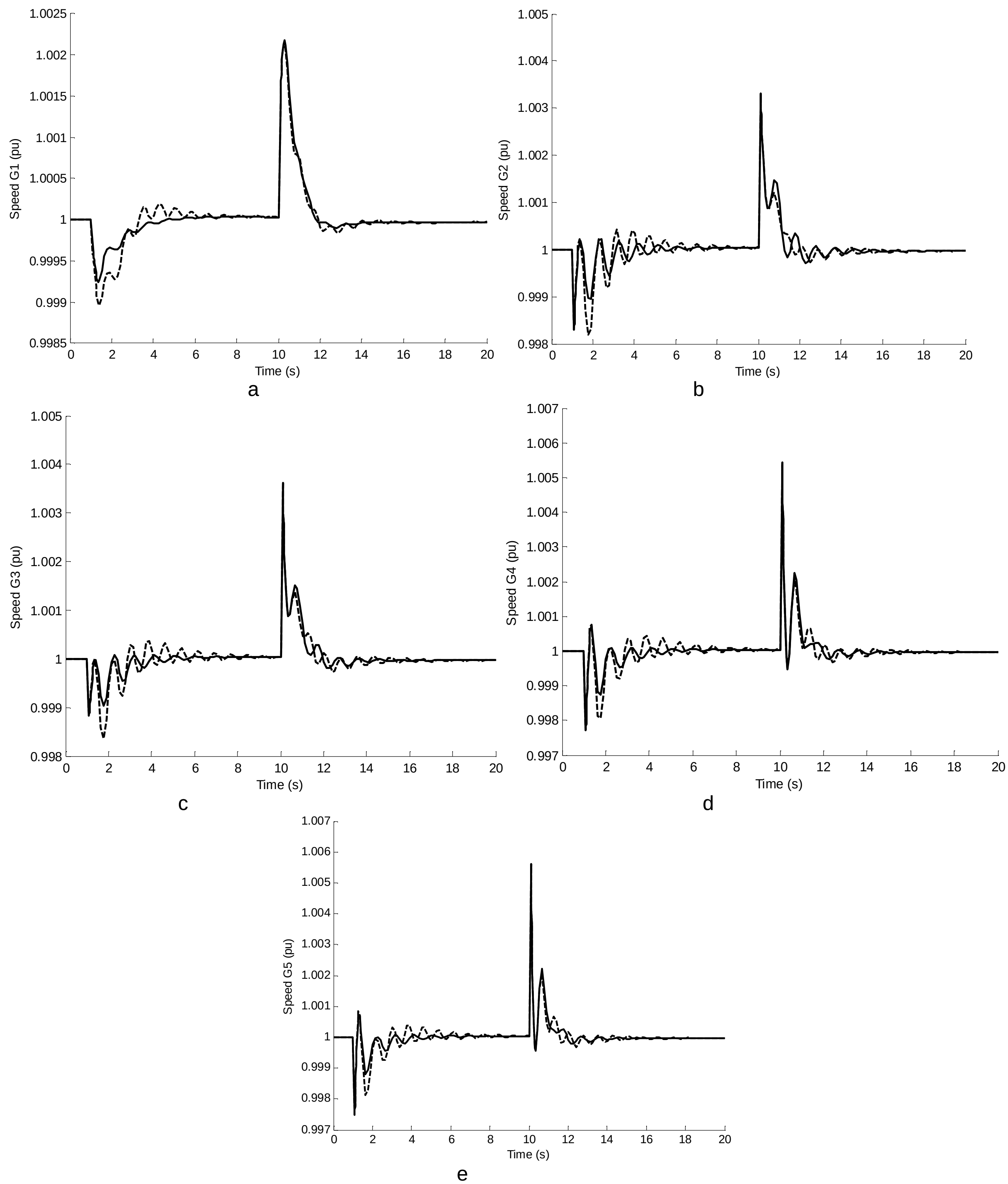

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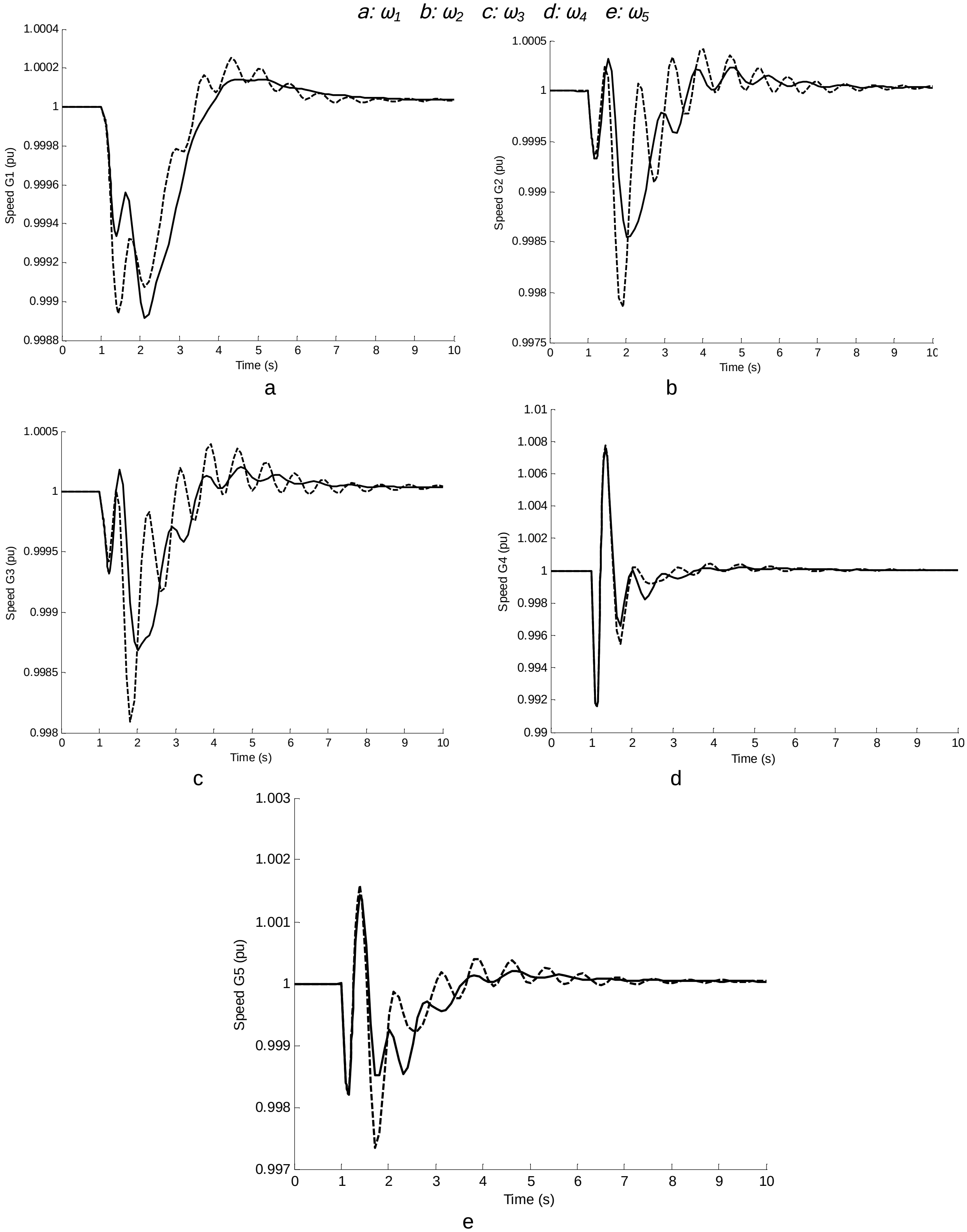
Fig. 3. System responses under scenario 2, Solid (GA-PSS)Dashed (without PSS)
a: ω_1 b: ω_2 c: ω_3 d: ω_4 e: ω_5



Simulation results

To evaluate the system performance under different disturbances, two scenarios of fault disturbances are considered as follows:

Scenario 1: a 5% load change
Scenario 2: a 10-cycle three-phase short circuit in bus 8.

It should be noted that in scenario 1, there is two load changes. In first the load is increased by 5% in second 1 and driven back to the nominal load at second 3. Then the load is decreased at second 10 and driven back to the nominal load at second 12. The simulation results are presented in Figs. 2-3. Each figure contains two plots for GA-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

This paper presented a Genetic algorithm method (GA) as a design method for determining the optimal values of control parameters of the lead-lag power system stabilizer (PSS). Simulation results showed the effectiveness of the proposed GA-PSS to damp out the multimachine (inter-area) modes of oscillations and work effectively over a wide range of loading conditions and fault conditions. Furthermore, in multimachine system, the GA-PSS has given a good response at different types of test conditions considering the speed deviation. The case study was a multi machine electric power system which is near to the real world applications.

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