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Design of Genetic Algorithm Based Power System Damping Controller

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Abstract: - This paper presents a Genetic based optimization technique towards the optimum design of power system damping controller in a multi-machine power system. In this approach, GA incorporates an objective function, which is based on integral of squared time squared error (ISTSE) technique. The parameters of the stabilizers are tuned through simulation of non-linear model of the power system using Genetic Algorithm (GA). The dynamic performance of the system has been investigated under small disturbances as well as large perturbation. The GA based PSS is compared with the CPSS optimized using phase compensation. Simulation studies reveal that the GA based PSS enhances system dynamic performance over a wide range of operating conditions and effective in damping local and interarea modes of oscillations.

Key-Words: - Dynamic stability, Power system stabilizer, Genetic algorithms, Genetic algorithm based power system stabilizer, Power system control

1 Introduction

The application of power system stabilizers for improving dynamic stability of power systems and damping out the low frequency oscillations due to disturbances has received much attention [1-3]. The conventional PSS comprising a cascade connected lead-lag network with rotor speed deviation as input has made great contribution in enhancing system stability. However, the performance of the CPSS becomes sub-optimal following variations in system parameters and loading conditions [2]. Power system is a highly nonlinear system and it is difficult to obtain exact mathematical model of the system. In recent years, adaptive self tuning, variable structure, artificial neural network based PSS, fuzzy logic based PSS have been proposed to provide optimum damping to the system oscillations under wide variations in operating conditions and system parameters**.** Genetic algorithms (GAs) are search methods rooted in the mechanics of natural selection and genetics. GAs are iterative procedures that maintain population of candidate solutions to optimize a fitness function. The advantage of the GA technique is that it is independent of the complexity of the performance index considered. Recently, the application of GAs to tune the parameters of PSS have been reported [13]- [15].

In view of the above, the thrust of the research work presented in this paper is to design a robust power system stabilizer whose parameters are tuned through GA. The main objectives of the research work presented in this paper is to present a systematic approach for the design of damping controller for stability enhancement of multi-machine power system using GA and compare the performance of the proposed GPSS with conventional PSS.The effectiveness of the GA based damping controller has been investigated under wide variations in loading conditions.

2 Problem Statement

2.1 Power System Model

A power system can be modeled by a set of nonlinear differential equations expressed as

$$\dot{X} = f(X,U) \qquad (1)$$

where X is the state vector and U is the input vector. In this study,
$X = [\delta\ \omega\ E'_q\ \Psi''_d\ E'_d\ \Psi''_q]^T$ and U is the PSS output signal.

The small perturbation dynamic in state-space can be expressed as

$$\dot{X} = AX + \Gamma p \qquad (2)$$

2.2 Structure of PSS

The power system stabilizer (PSS) considered, is the conventional lead-lag network with gain K_c and lead-lag time constants T_1, T_2, T_3, T_4 respectively and T_w is the washout time constant, which is used to washout d.c. signals and without it, steady changes in speed would modify the terminal voltage. It can be described as

$$Uc = \frac{sT_W.K_C.(1+sT_1)(1+sT_3)}{(1+sT_W)(1+sT_2)(1+sT_4)}\Delta w \qquad (3)$$

where, $\Delta\omega$ is the rotor speed deviation in p.u. following a small perturbation in the system. The optimization problem namely the selection of PSS parameters are accurately determined using GA.

2.3 Objective Function

To formulate the optimization problem, a simple objective function that reflects small steady state error, small overshoots and oscillations is selected. The performance index J is defined as

$$J = \int_0^\infty [tw(t)]^2\,dt \tag{4}$$

2.4 Design Constraints

The problem constraints are the parameter bounds. Thus the design problem can be formulated as the following optimization problem:

Minimize J

Subject to $K_C^{min} \leq K_C \leq K_C^{max}$

$T_1^{min} \leq T_1 \leq T_1^{max}$

$T_2^{min} \leq T_2 \leq T_2^{max}$

$T_3^{min} \leq T_3 \leq T_3^{max}$

$T_4^{min} \leq T_4 \leq T_4^{max}$

3 Test System

In this study a two area, eleven-bus-four-system is considered. Each synchronous machine is represented by non-linear sixth-order model as in the [3]. The nominal system parameters and data are given in Appendix. All the four generators are provided with simple exciters and turbine governors.

4 Design Algorithm

The proposed genetic algorithm is initiated by generating randomly an initial population of binary coded individuals, where each individual represents a possible solution of PSS parameters. Each individual of current population is evaluated for J and a basis for the biased selection process is then established. The objective values obtained for each individual are mapped into fitness values through a ranking process. The higher the individual 's fitness is, the higher is its chance to pass-on genetic information to successive generations. The next generation populated with offspring, obtained from selected parents.

The entire population is replaced by offsprings using crossover and mutation in standard genetic algorithm [9], whereas in proposed Genetic Algorithm the parents are selected on the basis of fitness value and the best parent chromosome is retained, comparing the fitness values of both the parents and the children, the best stings will go for the next generations. The GA stops when a pre-defined maximum number of generations is achieved or when the value returned by the objective function, being below a threshold, remains constant for a number of iterations.

5 Analysis

5.1 Optimum location of PSS in multi-machine power system

In a multi-machine power system, the participation factor technique [16] is used for finding the optimum PSS placement. The participation factors are computed using the left and right eigenvectors of the system matrix at the given operating condition. The optimum location of PSS is identified by comparing the participation factor of each generator corresponding to critical modes in order to stabilize the inter-area mode and also to improve damping of poorly damped local modes.

(5)
(6)
(7)

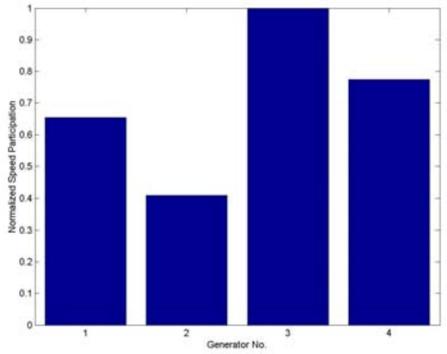

Fig. 1 Real speed participation factor for most critical mode.

The participation of each generator to the most critical modes is shown in Fig.1. It is clear from the Fig.1 that the optimum location of PSS is at machine No.3 for enhancing damping of the mode. The above investigations were repeated after installing optimum PSS at generator 3 (the PSS parameters were optimized using Phase Compensation technique). The PSS are optimized in the sequence 3,2,4,1.

The parameters of PSS are tuned sequentially using genetic algorithm employing Integral of Squared Time Squared Error criterion.

The performance index J of the best individuals in each generation has been selected and plotted over the generations to show its convergence rate.

The variations of performance index J over generations during sequential tuning of PSSs are shown in Figs 2-5.The values of GA parameters used for the design of PSS are shown in Table1.

Table 1 Values of GA Parameters

Number of Individuals	40
Number of Variables	4x4
Generation gap	0.8
Maximum generation	100

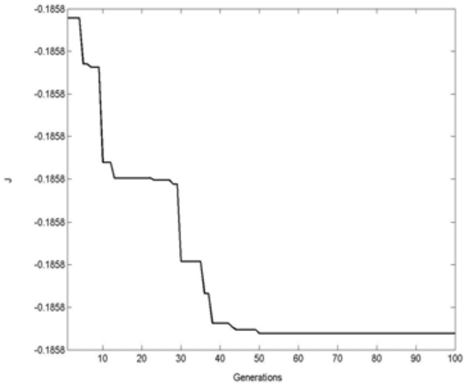

Fig. 2 Performance index during genetic search for tuning of PSS at generator 3.

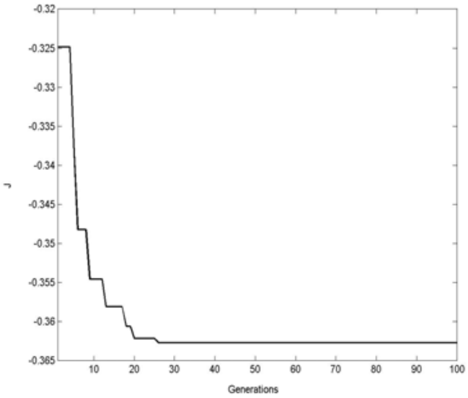

Fig. 3 Performance index during genetic search for PSS at generator 3,2.

The PSS are tuned sequentially using GA based algorithm. The performance of GPSS has been compared with CPSS under small perturbation and three phase fault for various loading conditions.

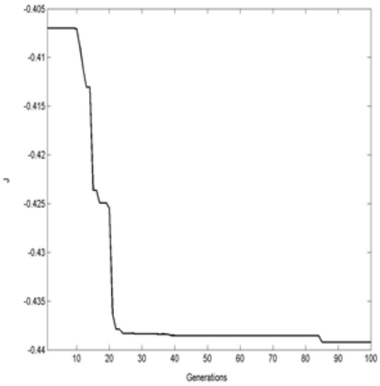

Fig. 4 Performance index during genetic search for PSS at generator 3, 2 and 1.

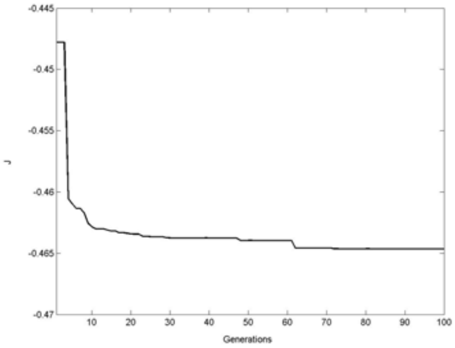

Fig. 5 Performance index during genetic search for PSS at generator 3,2,1and 4.

5.2 Comparison with conventional PSS

The performance of the GA based PSS are compared with the Conventional Power System Stabilizer (CPSS). The CPSS were installed at all four machines and tuned sequentially in the sequence of 3,2,4,1 using Phase Compensation technique [4]. The washout time constant is chosen equal to 10 sec.

6 Simulation Results

To evaluate the effectiveness of the proposed GA PSS to improve the stability of multi-machine power system, the dynamic performance of the system has been analysed with proposed GPSS under small perturbation and large three phase fault for different loading conditions as shown in Table 2.

Table 2 System operating conditions used for testing

Operating conditions (in per unit)				
Loading	Gen-1		Gen-2	
	P	Q	P	Q
Nominal	7.00	1.79	7.00	2.20
Heavy	8.89	3.07	6.99	3.97
Light	2.24	0.28	7.00	0.01
Loading	Gen-3		Gen-4	
	P	Q	P	Q
Nominal	7.18	1.68	7.00	1.85
Heavy	7.18	2.04	7.00	2.71
Light	7.18	1.21	7.00	0.70

6.1 Small Perturbation Test

A 5%step decrease in V_{ref1} i.e. $\Delta V_{ref1} = -0.05$ p.u. and 5% step increase in $V_{ref3} = 0.05$ p.u. was applied at nominal, heavy, light loading conditions as per Table 2.

The dynamic responses of the sequentially tuned GPSS at all machines are compared with the conventionally tuned CPSS. Simulation responses are shown in Figs. 6-9.It is clear from the results that with the proposed GPSSs, the system returns to its previous operating point much faster than the CPSSs . It can be concluded that the proposed GPSS provide very good damping over a wide range of operating conditions under small perturbation.

6.2 Large Disturbance Test

A 3-cycle, three phase fault was applied at bus 7 at t = 0.5 sec at nominal, heavy and light loadings. The fault is cleared by tripping the faulty line. It can be clearly seen from Figs.10-12 that the proposed GPSSs minimize the speed deviation and improve the settling time under the large perturbation also. The GPSSs provide much superior performance as compare to conventionally tuned power system stabilizer

The simulation results reveal that the proposed GPSSs are quite robust to wide variations in loading conditions, provide better damping and the settling time is very less as compare to CPSS.

The results shown in Fig 13-14 clearly reveal that the proposed GPSS provide effective stabilizing signal under small disturbance and three-phase fault. Investigations reveal that the system dynamic performance enhances with the proposed genetic algorithm based PSS.

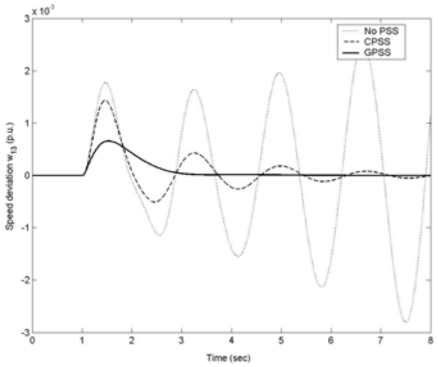

Fig. 6 Dynamic response for $\Delta\omega_{13}$ under small perturbation for nominal load

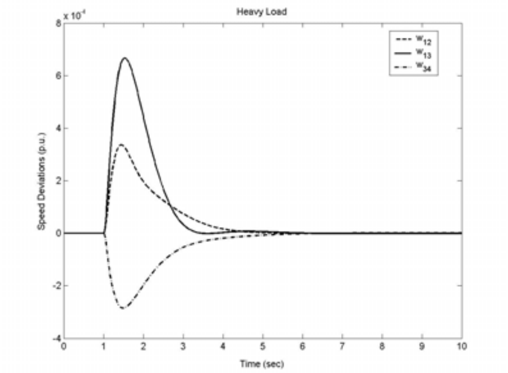

Fig. 7 Dynamic response for $\Delta\ \omega_{12}$, $\Delta\ \omega_{34}$, $\Delta\ \omega_{13}$ under small perturbation at heavy load with GPSS.

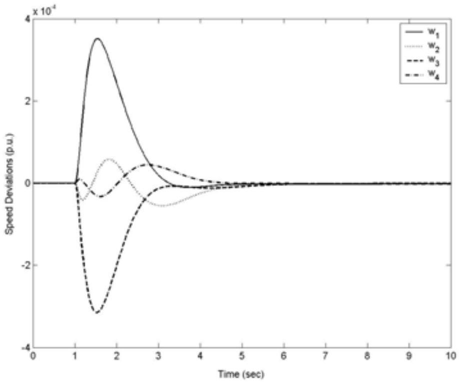

Fig. 8 Dynamic response for $\Delta\ \omega_1$, $\Delta\ \omega_2$, $\Delta\ \omega_3$ and $\Delta\ \omega_4$ under small perturbation at heavy load with GPSS.

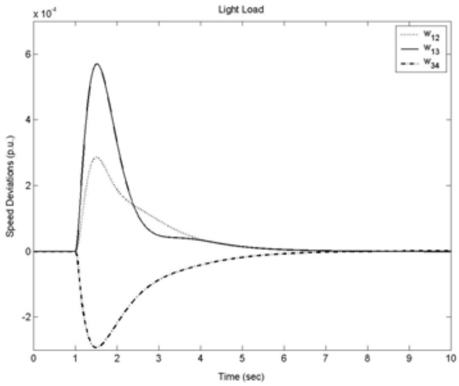

Fig. 9 Dynamic response for $\Delta\ \omega_{12}$, $\Delta\ \omega_{34}$, $\Delta\ \omega_{13}$ under small perturbation at light load with GPSS.

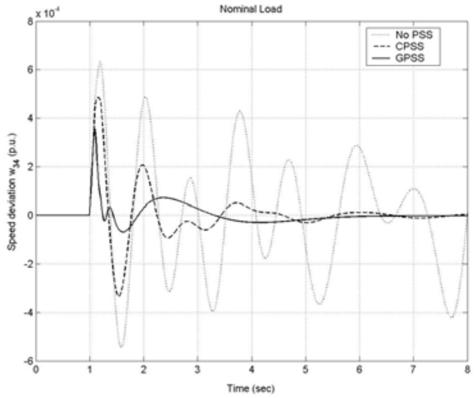

Fig. 10 Dynamic response for $\Delta\ \omega_{34}$ considering transitory 3-phase fault at bus-7 of three cycles duration for nominal load.

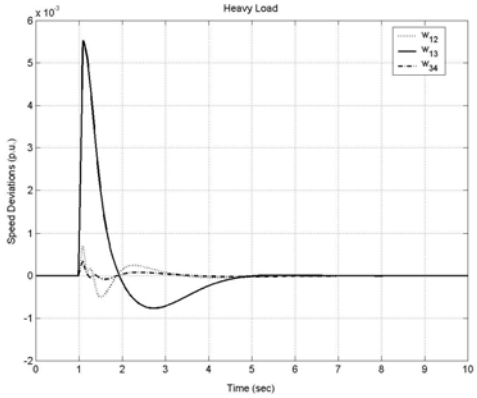

Fig. 11 Dynamic response for $\Delta\omega_{12,}$ $\Delta\omega_{34,}$ $\Delta\omega_{13}$ considering a transitory 3-phase fault at heavy load with GPSS.

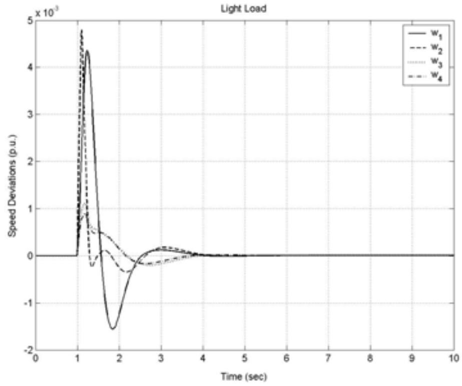

Fig. 12 Dynamic response for $\Delta\ \omega_{12}$, $\Delta\ \omega_{34}$, $\Delta\ \omega_{13}$ considering a transitory 3-phase fault at light load with GPSS.

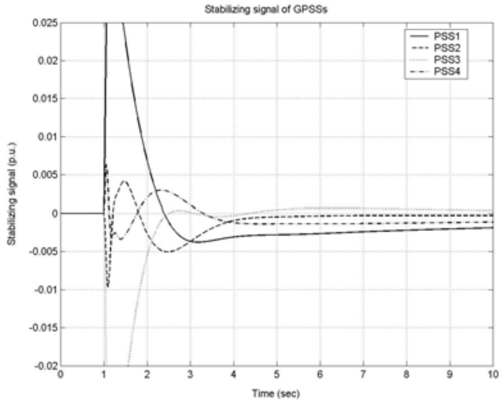

Fig. 13 Stabilizing signals of GPSS under small perturbation at nominal load.

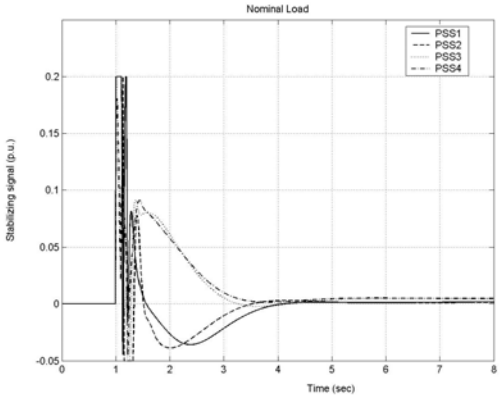

Fig. 14 Stabilizing signals of GPSS under large disturbance for nominal load.

7 Conclusions

This paper presents a systematic design procedure for locating power system stabilizers in a multi-machine power system. The parameters of the stabilizers are sequentially tuned using GA. The dynamic performance of GA based PSS is superior to the conventionally tuned PSS. Simulation of the responses to small perturbation, large perturbation and system loadings have demonstrated the effectiveness of the GPSS. The proposed method employs two genetic algorithm based PSSs to provide adequate damping to multimachine power system, therefore it reduces computational burden. Simulation studies also reveal that the proposed GPSS can damp both local and interarea modes of oscillations effectively.

Appendix I

System Non-linear Dynamic Model

$$\dot{\omega} = (T_m - T_e)/2H$$

$$\dot{\delta} = \omega_0(\omega - 1)$$

$$\dot{E}_q^{'} = (E_{fd} - (E_q^{'} + (x_d - x_d^{'})i_d))/T_{do}^{'}$$

$$\dot{E}_{fd} = (K_A(V_{ref} - V_t + U_s) - E_{fd})/T_a$$

where,

$$T_e = V_{td}I_d + V_{tq}I_q$$

$$V_t = \sqrt{V_{td}^2 + V_{tq}^2}$$

$$V_{td} = X_q I_q$$

$$V_{tq} = E_q^{'} - X_d^{'} I_d$$

$$I_d = [(X_e + X_q)(E_q^{'} - E_B\cos\delta) - E_B R_E \sin\delta]/Z_e^2$$

$$I_q = [R_e(E_q^{'} - E_B\cos\delta) + (X_e + X_d^{'})E_B\sin\delta]/Z_e^2$$

$$E_q^{'} = V_{tq} + X_d^{'} I_d$$

$$Z_e^2 = R_e^2 + X_e^2 + X_e(X_q + X_d^{'}) + X_q X_d^{'}$$

$$E_B = \sqrt{[(V_{to} - I_d R_e + I_q X_e)^2 + (I_q R_e + I_d X_e)^2]}$$

Appendix II

The generator parameters in perunit on the rated MVA and kV base are as follows:

X_d=1.8	X_q=1.7	X_l=0.2	X_d'=0.3
X_d"=0.3	X_q"=0.55	R_a=0.0025	T_{do}'=8.0 sec.
T_{do}"=0.03 sec.	T_{qo}" = 0.05 sec.	A_{sat}=0.015	B_{sat}=9.6
X_q'=0.55	T_{qo}' = 8.0 sec.	Ψ_{T1}=0.9	K_D=0
H=6.5 (for G_1 and G_2)		H=6.175 (for G_3 and G_4)	

The generation and terminal voltage of generator buses are as follows:

G_1	P_e=700MW	Q_e=185 VA	$V_{t.}$=1.03∠20.2°
G_2	P_e=700 MW	Q_e=235 VA	Vt=1.01∠10.5°
G3	Pe=719MW	Qe=176 VA	Vt=1.03∠-6.8°
G4	Pe=700MW	Qe=202 VA	Vt=1.03∠- .0°

The loads and reactive power supplied (Q_C) by the shunt capacitors at buses 7 and 9

Bus 7: P_L=967 MW Q_L=100 MVAr, Q_C = 200 MVAr

Bus 9: P_L=1767 MW Q_L=100 MVAr, Q_C = 350 MVAr

Excitation system K_A=50 T_R=0.01 sec.

Turbine-governor system Kg =25 Tg=0.5

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