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Design of Genetic-Algorithm Based Robust Power System Stabilizer

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Abstract**—**This paper presents a systematic approach for the design of power system stabilizer using genetic algorithm and investigates the robustness of the GA based PSS. The proposed approach employs GA search for optimal setting of PSS parameters. The performance of the proposed GPSS under small and large disturbances, loading conditions and system parameters is tested. The eigenvalue analysis and nonlinear simulation results show the effectiveness of the GPSS to damp out the system oscillations. It is found tat the dynamic performance with the GPSS shows improved results, over conventionally tuned PSS over a wide range of operating conditions.

Keywords**—**Genetic Algorithm, Genetic power system stabilizer, Power system stabilizer, Small signal stability

I. INTRODUCTION

POWER systems are in general nonlinear and the operating conditions can vary over a wide range. Recently, small signal stability has received much attention. The increasing size of generating units, the loading of the transmission lines and the high-speed excitation systems are the main causes affecting the small signal stability.

Conventional fixed structure power system stabilizers (CPSS) are widely used by power system utilities to damp out small oscillations [1-3]. CPSS is designed using a liberalized model, which provides optimum performance around a nominal operating point. The tuned parameters of PSS are determined at this point only. However, the performance becomes sub-optimal following the variations in loading conditions and system parameters. The parameters of the power system stabilizer (PSS) must be re-tuned so that it can provide the desired performance. A self –tuning PSSs have been proposed to overcome such problem [6]. However, they are designed on the basis of parameter identification of the system model in real time, feedback gain computation and state observation, which are time consuming and results in computational burden.

Recently, the advanced numerical computation methods such as Artificial Neural Network (ANN), Fuzzy Logic systems (FLS) and Genetic Algorithms (GA) have been applied to various power system problems including PSS design [6-13]. Genetic algorithms are the global search techniques and provide the solution of optimization problem by miming the mechanism of natural selection and genetics.

In view of the above, the main 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 are as follows:

To present a systematic approach for the design of PSS for stability enhancement of power system using GA.

To study the dynamic performance of the system under different disturbances

To compare the performance of the GPSS with the conventionally tuned CPSS.

To investigate the effectiveness of the GPSS under the wide variations of loading conditions and system parameters.

II. SYSTEM MODEL

A single machine infinite bus (SMIB) system with synchronous generator provided with IEEE type-ST1 static excitation system is considered. The nominal operating conditions and system parameters are given in Appendix I & II.

III. DESIGN OF GA BASED PSS

The choice of suitable performance index is extremely important for the design of PSS. In this study, the PSS parameters are coded in a binary string and initial population is randomly generated. The proposed design algorithm employs GA to solve this optimization problem and search for the optimum set of PSS parameters.

A simple performance index that reflects small steady state error, small overshoots and oscillations is selected. GA search employs Integral Squared Time Square Error (ISTSE) optimization technique. The power system stabilizer (PSS) considered, is the conventional lead-lag network with gain Kc and lead-lag time constants T_1 , T_2 respectively as given by equation (1).

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$$Uc = \frac{sT_w.K_c.(1+sT_1)(1+sT_3)}{(1+sT_w)(1+sT_2)(1+sT_4)}\Delta w \qquad (1)$$

where $T_1 = T_3$, $T_2 = T_4$ 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. $\Delta\omega$ is the rotor speed deviation in p.u. following a small perturbation in the system. The performance index is defined as

$$J = \int_0^\infty [tw(t)]^2\, dt \qquad (2)$$

A. *General Structure of GA*

The sequential steps for searching optimal solution of PSS parameters using GA is shown in Fig. 1.

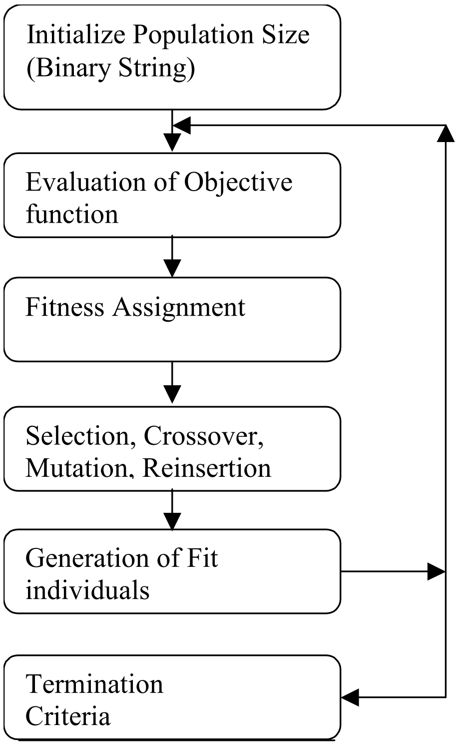

Fig. 1 Computational Flow Chart

B. *Design Methodology*

1) The design problem can be formulated as the following optimization problem:
Minimize J
Subjected to

$$\begin{aligned} K_{c_{\min}} &\le K_c \le K_{c_{\max}} \\ T_{1_{\min}} &\le T_1 \le T_{1_{\max}} \\ T_{2_{\min}} &\le T_2 \le T_{2_{\max}} \end{aligned} \qquad (3)$$

2) An initial population of individuals is randomly generated. A generation gap = 0.9 is assumed.
3) The optimization of PSS parameters is done by evaluating performance index J.
4) If the value of J obtained is minimum, then the optimum value of PSS parameters equal to those obtained in the current generation, otherwise go to step 5.
5) Based on the fitness, some individuals will be selected to populate the next generation. The selection is based on stochastic universal sampling method. Selected individuals will be then recombined through a crossover process by exchanging genetic information between the pairs of the individuals contained in the current population. After that, each individual in the population will be mutated with a given probability, through a random process of replacing one allele with another to produce a new genetic structure.

The GA stops when a pre-defined maximum number of generations are achieved or when the value returned by the objective function, being below a threshold, remains constant for a number of iterations. The optimum parameters of the CPSS and GPSS at nominal condition are shown in TABLE I.

TABLE I
OPTIMUM PSS PARAMETER

	K_C	T_1 (S)	T_2 (S)
CPSS	7.5563	0.3320	0.0727
GPSS	75.0183	0.11905	0.0276

The GA parameters used in this study are shown in TABLE-II.

TABLE II
GA PARAMETERS

Number of Individuals	100
Number of variables	3
Maximum Generation	80
Generation Gap	0.90
Pc	0.70
Pm	0.001

IV. SIMULATION STUDY

To evaluate the effectiveness of the proposed GA PSS to improve the stability of power system, the dynamic performance of the proposed PSS was examined under different loading conditions (heavy, light, nominal, leading p.f), small perturbation and large perturbation. The performance of the GA based PSS is compared with the CPSS whose parameters were optimized using phase compensation technique.

A. Small Perturbation Test

A small perturbation of 5 % step increase in mechanical torque was applied at nominal and heavy operating condition. The dynamic responses of GPSS are compared with the conventional power system stabilizer (CPSS). Fig. 2 and 3 shows that the GPSS has lower peak over-shoots and damps out low frequency oscillations very quickly as compare to CPSS. The GPSS has an overall better damped response.

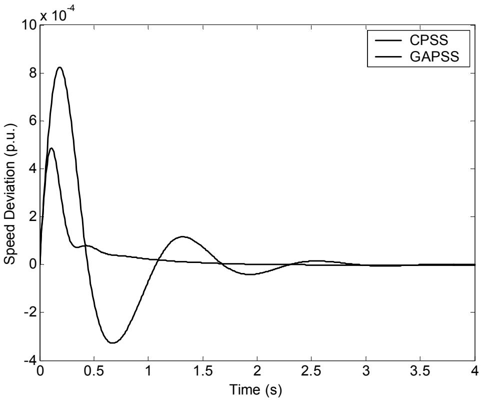

Fig.2 Dynamic response for Δω for small Perturbation at nominal load.

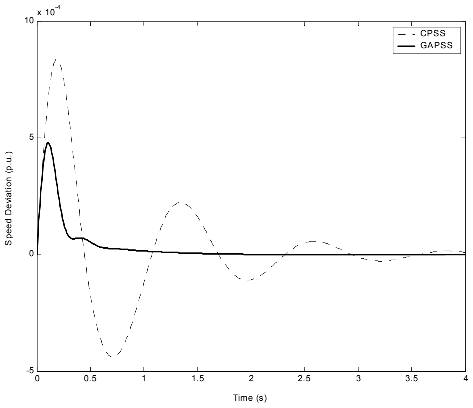

Fig.3 Dynamic response for Δω for small perturbation at heavy load

B. Large Perturbation Test

The performance of GPSS under severe disturbance was further verified by applying a 4-cycles, three-phase fault at the generator terminals at t = 0.25 sec .It can be seen from Fig.4 that the proposed GPSS minimizes the speed deviation and improves the settling time under the large perturbation also. Thus GPSS provide much superior performance as compare to conventionally tuned power system stabilizer.

C. Testing of GPSS under different operating conditions

The system dynamic performance with the GA based PSS is now examined considering the following different loading conditions as shown in TABLE - III for both small and large perturbation.

TABLE III
SYSTEM OPERATING CONDITIONS

Loading conditions	P (p.u.)	Q (p.u.)	Vt (p.u.)
Nominal	P_1=0.9	Q_1=0.2907	V_{t1}=1.0
Leading	P_2=0.6	Q_2= -0.1	V_{t2}=0.95
Heavy	P_3=1.1	Q_3=0.35	V_{t3}=1.0
Lagging	P_4=0.85	Q_4=0.27	V_{t4}=0.95

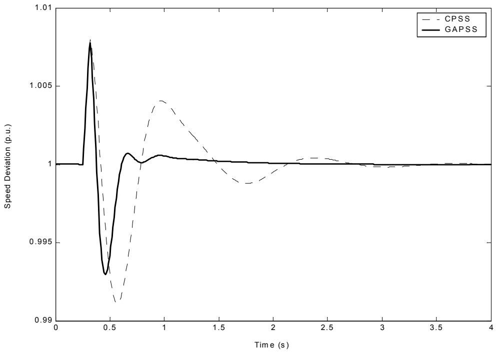

Fig.4 Dynamic response for Δω for 4-cycle fault at generator at nominal load.

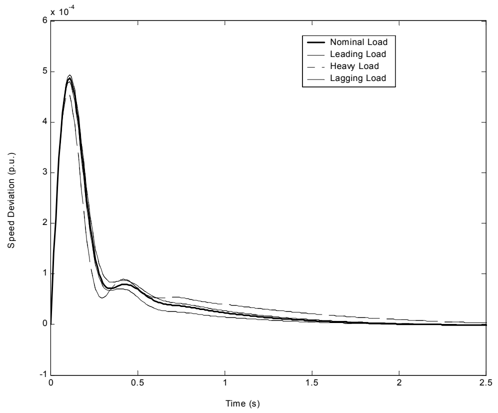

Fig.5 Dynamic response Δω for small perturbation at different loadings

1. *Testing under small disturbance*

To demonstrate the robustness of the proposed GPSS, a small perturbation of 5% step increase in the input mechanical torque was applied at various loading conditions.

The examination of simulation results (Fig. 5 and Fig.6) reveal that the proposed GPSS is quite robust to wide variations in loading conditions considering small perturbation.

2. *Testing under large disturbance*

A 3-phase transitory fault of 4 cycles duration is considered at the generator terminals. The simulation results are shown in Figs 7 and 8.The results clearly reveal that the GPSS is quite robust to wide variations in loading conditions for large perturbation.

The results clearly show the robustness of the GPSS and its

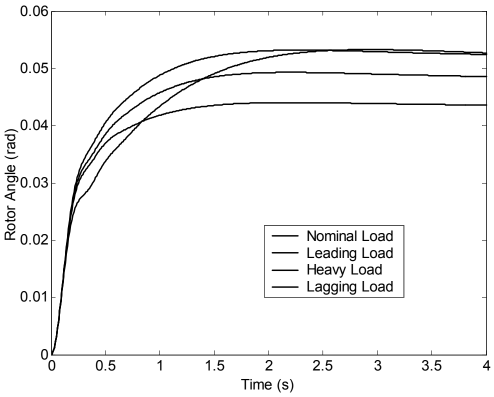

Fig.6 Dynamic response Δδ for small perturbation at different loadings

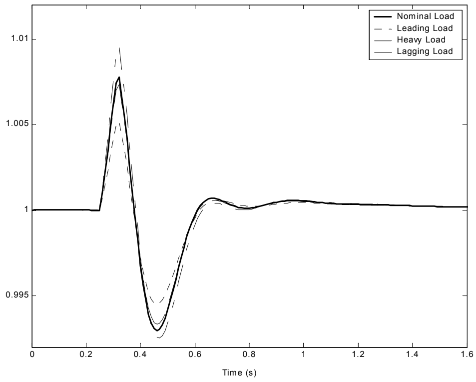

Fig. 7 Dynamic response for Δω for 4-cycle fault at different loadings

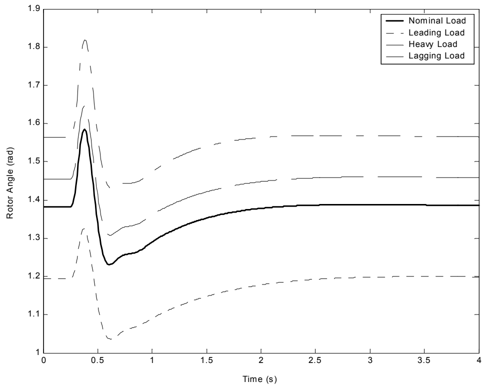

Fig. 8 Dynamic response for Δδ for 4-cycle fault at different loadings

ability to work over a wide range of operating conditions under small and large perturbation.

D. Effect of Change of System Parameter

To demonstrate the effectiveness of the proposed GPSS, the system inertia (h) has been varied in the range of ± 10% of its nominal value under the same torque disturbance at nominal load. The simulation results are shown in Fig. 9.

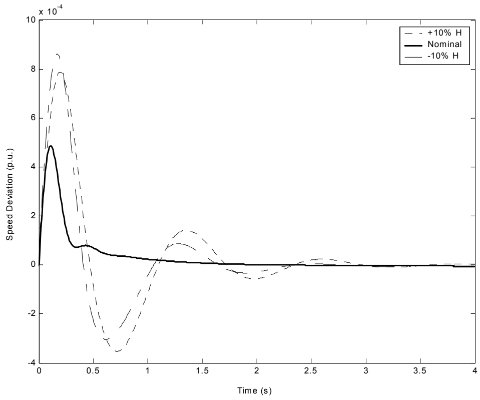

Fig.9 Dynamic response for Δω for ± 10% change in system inertia.

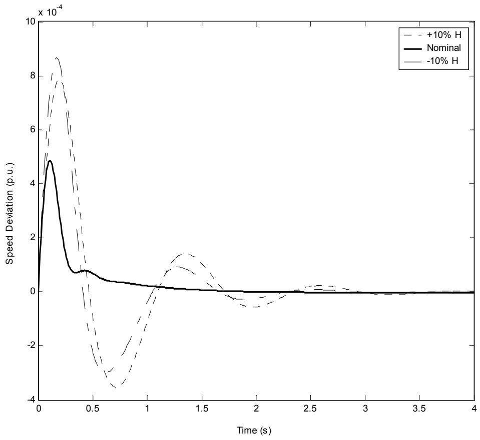

Fig.10 Dynamic response for Δω for ± 20% change in system reactance

E. Effect of Change of System Equivalent Reactance Xe

The system equivalent reactance Xe is changed by ± 20% of its nominal value. The system Dynamic performance with the GPSS is obtained under the variation of X_e. The simulation results shown in Fig. 10 verify the robustness of the GA based PSS.

V.CONCLUSIONS

A systematic approach for designing a power system stabilizer using genetic algorithm has been presented. The optimum values of the PSS are globally search by GA.

The dynamic performance of the GPSS is superior than the conventionally tuned PSS under small as well large perturbation. Simulation of the response of the proposed PSS to various disturbances, changes in network configuration and system loading have demonstrated the effectiveness of the GPSS.

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

Nominal System Parameters

The nominal parameters and operating conditions of the system are given below. All data are in per unit, except that M and the time constants are in seconds.

Generator :
$M = 2H = 7.0; X_d = 1.81; X_q = 1.76; X_d^{'} = 0.3$
$L_{adu} = 1.65; L_{aqu} = 1.60; L_l = 0.16;$
$R_a = 0.03; R_{fd} = 0.0006; L_{fd} = 0.153;$
$A_{sat} = 0.031; B_{sat} = 6.93; \Psi_{T1} = 0.8;$
Excitation System :
$K_{AVR} = 400; T_A = 0.05; T_B = 1.0; T_C = 8.0; T_R = 0.02;$
PSS :
$T_w = 1.4;$
Transmissi on Line
$X_e = 0.65; R_e = 0.0;$
Operating Condition
$P = 0.9; V_t = 1.0; E_B = 1.0; f = 60\,Hz$

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