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ROBUST DESIGN OF FUZZY LOGIC POWER SYSTEM STABILIZER USING MULTIOBJECTIVE GENETIC ALGORITHM

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Abstract: - Optimal multiobjective design of robust fuzzy logic power system stabilizer is presented in this paper. The fuzzy logic power system stabilizer is designed using GA. The proposed controller enhances both small and large perturbation stabilities. A multiobjective problem is formulated to optimize a set of objective functions comprising the speed deviation error subjected to small and large perturbation. The problem of selection of optimal parameters of fuzzy logic power system stabilizer is converted into an optimization problem and which is solved by genetic algorithm with the Integral of square time square error (ISTSE) based multiobjective function. Simulation results reveal the effectiveness of the proposed controller over a wide range of loading conditions under small as well as large perturbation.

Key-Words: - Genetic algorithms, Multiobjective optimization, Dynamic stability, Fuzzy logic power system stabilizer.

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 [6-8].

Recently, fuzzy logic power system stabilizers have been proposed for effective damping of power system oscillations due to their robustness. Fuzzy logic controllers (FLC) are suitable for systems that are structurally difficult to model due to naturally existing non-linearities and other model complexities [8].

Exact mathematical model is not requiring in designing a fuzzy logic controller. In contrast to conventional power system stabilize which is designed in frequency domain, a fuzzy logic power system stabilizer is designed in the time domain.

Fuzzy logic controllers have successfully applied in control applications, they are subjective and heuristic. Although, fuzzy logic control introduces a good tool to deal with complex, non-linear and ill-defined systems, it suffers from the drawback of tuning of parameters of FLPSS. The generation of membership functions (MFs) and the tuning of scaling factors for FLC are done either iteratively by trial and error or by human expert

Therefore, the tuning of the FLPSS parameters is a time consuming task. It necessitates the need for an effective method for tuning the parameters of FLPSS.

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 [11]- [13].

In view of this fuzzy logic and genetic algorithms have been combined and applied to control problems. The application of GA to determine the optimal parameters for neuro-fuzzy PSS has been discussed in [14]. The single objective function based on one of the system outputs, i.e. the changes in the rotor speed of the synchronous generator has been used in the GA. A novel approach to design fuzzy logic power system stabilizer using genetic algorithm for multimachine power system has been presented in [15]. In this paper the robust PSS design was formulated as a single objective function problem.

Stability enhancement of a multimachine power system using FPSSs whose parameters are tuned through GA has been presented in [16]. In this paper, only width of the triangular membership function and gain of the FPSS are tuned through CGA (Crowding Genetic Algorithm). Optimal multiobjective design of robust multimachine power system stabilizers has been described in [19]. In this paper multiobjective function comprising the damping factor, and damping ratio of lightly damped electromechanical modes have been used to find the optimum parameters of PSSs in mutimachine power system.

The GA based controllers were either designed considering small disturbance or large perturbation as reported in the literature. The controller designed on linearized model provide adequate dynamic performance on small disturbances and their performance on large perturbation are not up to the mark while the controller designed on large perturbation work satisfactory for large disturbance. Recently, multiobjective GAs are used to solve optimization problems.[17].No efforts seem to have been made to design genetic algorithm based fuzzy logic power system stabilizer , which enhances both small and large perturbation stabilities. In this paper, the problem of robust fuzzy logic PSS design is formulated as multiobjective optimization problem and GA is applied to find the all optimal parameters of FLPSS including centers and variable of gaussian membership functions as shown in Fig.1.

The proposed design algorithm has been applied to a SMIB powers system as shown in Fig. 2. Non-linear simulation results have been carried out to test the effectiveness of the proposed FPSS under small disturbance, large disturbance and different 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, $x = [\Delta\omega \ \Delta\delta \ \Delta E'_q \ \Delta E_{fd}]^T$ and U is the PSS output signal. The nonlinear model of the SMIB system is given in the Appendix A. The small perturbation dynamic in state-space can be expressed as

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

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

where x and p is the state are perturbation vector respectively and **A, Γ** is the system matrix and perturbation matrix respectively.

2.2 Configuration of genetic based Fuzzy Logic Power System Stabilizer(FLPSS)

The FLPSS based stabilizer has two inputs .The input are measured as the speed deviation (error) from the steady state and the rate of change of the error. The speed can be easily measured from the shaft speed. In actual practice, the signals coming to the FPSS are not covering the entire domain of the universe of discourse. It is imperative to scale the signals to cover the entire domain of the FPSS. If somehow, the input signal goes beyond the desired limit of universe of discourse, then it is limited by the numerical value of maximum value of the degree of membership function. In addition to this, the internal parameter of the fuzzy logic controller is also optimized to attain the effectiveness of the stabilizer. In this problem, the internal parameters are centers of each membership function (this will decide the boundary to which each of the membership function (MF) goes to its neighborhood, e.g. Negative Big (NB) cannot comes in the region of Positive Small (PS), Positive Big (PB) as this also acts as a constraint to boundary of MF's).

2.3 Objective Function Formulation

The problem is divided into main three sub-groups.

(i) Design based on optimizing the parameters of FLPSS under small perturbation (FLPSSA)

In this design the parameters of FLPSS are optimized under small disturbance of magnitude of 5% change in input mechanical torque. (Linearized model at nominal operating point is used)

$$J_1 = \int_0^{t_s} t^2 \cdot e^2 dt \qquad (3)$$

where, t_s is settling time for speed deviation (e) and e (t) is $\Delta\omega(t)$ i.e. speed deviation of the generator following 5% step increase in mechanical input torque i.e., $\Delta T_m = 0.05$ p.u. Thus objective function J_1 is computed under small disturbance.

The optimization problem (J_1) needs to be minimized subjected to the following external constraints.

$$0 \le N_{err} \le 1300$$
$$0 \le N_{derr} \le 300$$
$$0 \le D_u \le 1$$

where, N_{err}, N_{derr} are the normalization factors and D_u is denormalization factor.

(ii) Design based on Optimizing the parameters of FLPSS under large perturbation (FLPSSB)

The parameters of the FLPSS are optimized using J_2 under a severe disturbance of 3-phase fault of three cycles duration at the terminals of the generator. (Non-linear model is used as given in Appendix I). J_2 is similar as J_1 but computed under large disturbance.

The following are the external constraints under large disturbance.

$$0 \le N_{err} \le 500$$
$$0 \le N_{derr} \le 200$$
$$0 \le D_u \le 1$$

(iii) Design based on optimizing the parameters of FLPSS using multiobjective GA (FLPSSC)

Now in this case there are two objectives which are to be simultaneously optimized and is defined by *J*.

$$J = J_1 + \alpha J_2 \qquad (4)$$

The following optimization problem needs to be minimized subjected to the following constraints.

External Constraints

$$0 \le N_{err} \le 1000$$
$$0 \le N_{derr} \le 300$$
$$0 \le D_u \le 1$$

Internal Constraints are same for all FLPSS structures.

$$-1.0 \le C_{NB} \le -0.6$$
$$-0.6 \le C_{NS} \le -0.2$$
$$-0.2 \le C_{ZO} \le +0.2$$
$$+0.2 \le C_{PS} \le +0.6$$
$$+0.6 \le C_{PB} \le +0.1$$
$$+0 \le \sigma_{i=1:5} \le 0.8$$

where, C_{NB} ,C_{NS},C_{ZO},C_{PS},C_{PB} are the centers of the negative big, negative small, zero, positive small and positive big gaussian membership function and $\sigma_{i=1:5}$ is the variance of gaussian function. The guassian membership function is defined as:

$$f(x,\sigma,c) = \frac{e^{-(x-c)^2}}{2\sigma^2} \qquad (5)$$

2.4 Design Algorithm

The problem reduces to the optimization of three different objective functions subjected to the given constraints. The solution of the problem is obtained by using the search technique based on genetic algorithm. The initial population consisting of a large number of chromosomes is generated to cover entire region of the sub-population. The chromosomes are coded in the binary. The first phase includes the selection of such individuals, which have potential to generate fit offspring in the future.. The final selected individuals based on fitness value are subjected to the genetic operators. The proposed multiobjective GA based method for tuning of fuzzy logic PSS uses Integral of square time square error (ISTSE) criterion. The GA parameters used in this study are given in Table I.

Table II System operating conditions used for testing

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

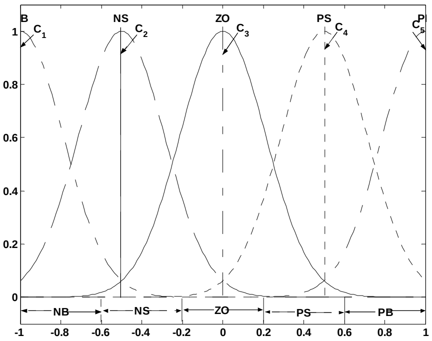

Fig. 1 Fuzzy Variables used in the Genetic Algorithm search.

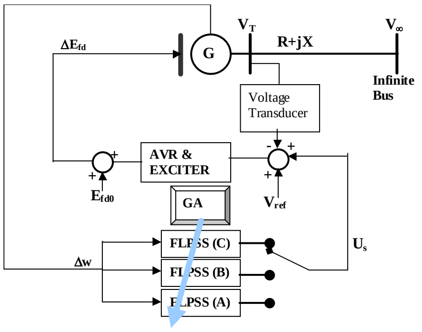

Fig. 2 Block diagram of SMIB with GA based FLPSS.

3 Test System

A single machine infinite bus (SMIB) system with synchronous generator provided with IEEE type-ST1 static excitation system is considered. The machine model used in this simulation is a two-axis model as described in [3]. The nominal system parameters are given in Appendix B.

Table I GA Parameters

Number of individuals (N_{ind})	220
Number of variables (N_{var})	13
Generation gap (G_{gap})	0.90
Probability of crossover (P_c)	0.85
Probability of mutation (P_m)	0.001
Number of maximum generation	100

4 Simulation Results

To demonstrate the effectiveness of the FPSS tuned using proposed multiobjective function over a wide range of operating conditions, the nonlinear time-domain simulation have been carried out under small disturbance, large disturbance. The system loading conditions are given in Table II.

4.1 Small Perturbation Test

A 5% step increase in T_m i.e. ΔT_m = 0.05 p.u. was applied at nominal, heavy and leading p.f. loading conditions as per Table II. The performance of the fuzzy logic power system stabilizer FLPSS(C) with the proposed multiobjective function J is compared with FLPSS (A) and FLPSS (B) designed using single objective functions J_1 or J_2 respectively. Simulation responses are shown in Figs.3-6.It is clear from the results that with the proposed multiobjective design FLPSS (C), the system returns to its previous operating point much faster than the single objective design FLPSS (A) and FLPSS (B). The simulation results clearly show that the FLPSS(C) damp out system oscillations very quickly as compare to FLPSS (A) and FLPSS (B). It can be concluded that the proposed design provides very good damping over a wide range of operating conditions under small perturbation.

4.2 Large Disturbance Test

To investigate the effectiveness of the FLPSS under more severe conditions, a three phase fault of 4-cycle duration was applied at the generator terminals at t = 1sec under nominal, heavy, leading p.f. and lagging p.f. loading conditions. It can be clearly seen from Figs.7-10 that the proposed FLPSS (C) minimize the speed deviation and improve the settling time under the large disturbance of fault also. The dynamic performance of the proposed FLPSS (C) is superior to the other two single objective function based designs i.e. FLPSS (A) and FLPSS (B). The results shown in Fig.11 reveal that the multiobjective function design provide more efficient stabilizing signals as compare to the other two single objective function based design. The PSS designed with multiobjective function provide much superior performance as compare to PSS designed using single objective function J_1 or J_2.

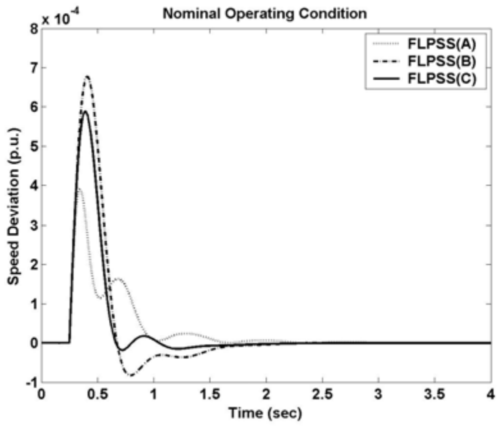

Fig.3 Dynamic response for Δω for small perturbation of $\Delta T_m = 0.05$ p.u at nominal load.

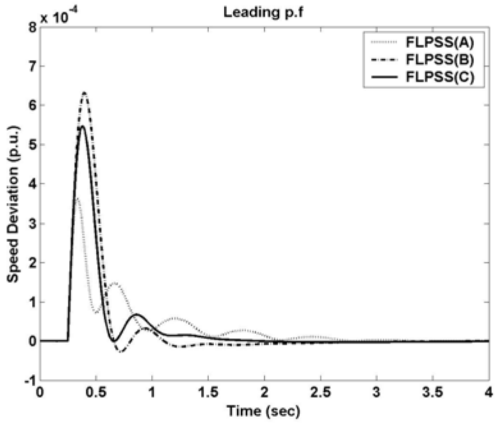

Fig. 4 Dynamic response for Δω for small perturbation of $\Delta T_m = 0.05$ p.u at leading p.f. load.

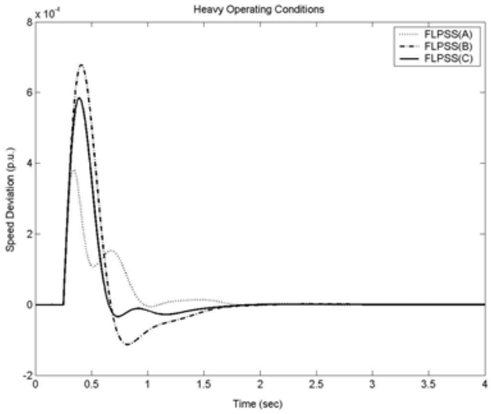

Fig. 5 Dynamic response for Δω for small perturbation of $\Delta T_m = 0.05$ p.u at heavy load.

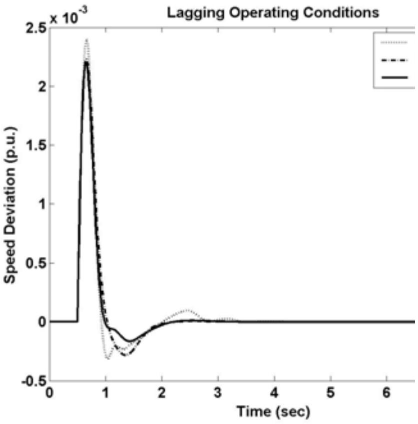

Fig. 6 Dynamic response for Δω for small perturbation of $\Delta T_m = 0.05$ p.u at lagging p.f load.

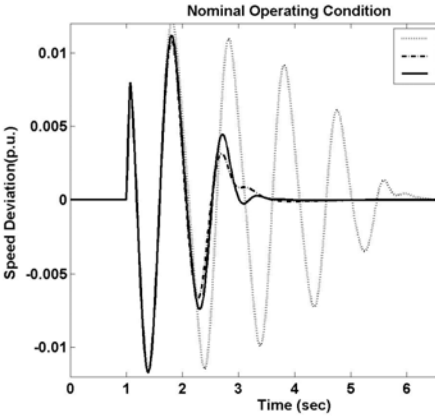

Fig. 7 Dynamic response for Δω for 4-cycle fault at the generator terminals at nominal load.

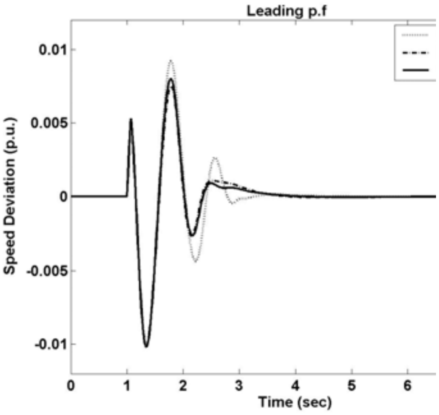

Fig. 8 Dynamic response for Δω for 4-cycle fault at the generator terminals at leading p.f. load.

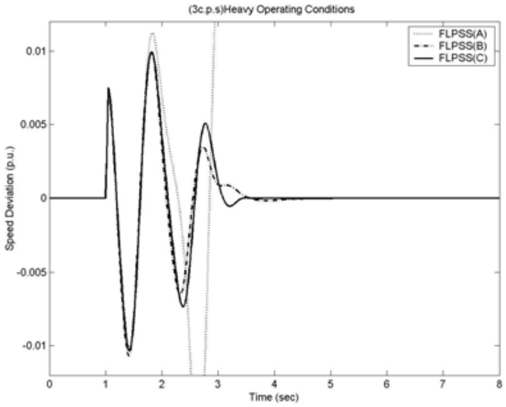

Fig. 9 Dynamic response for Δω for 3-cycle fault at the generator terminals at heavy load.

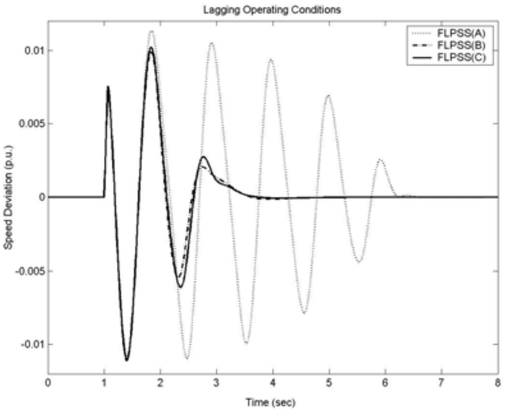

Fig. 10 Dynamic response for Δω for 3-cycle fault at the generator terminals at lagging p.f. load.

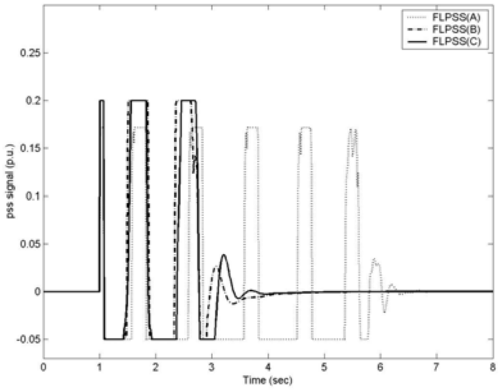

Fig. 11 Stabilizing signal under large perturbation.

5 Conclusions

In this paper, the design of robust fuzzy logic power system stabilizer using multiobjective GA is proposed. A multiobjective optimization problem is formulated to optimize two single objective functions. The problem of optimum selection of all the parameters of the fuzzy logic power system stabilizer is converted into an optimization problem which is solved by a GA incorporating speed deviation based multiobjective function. The dynamic performance of multiobjective function based FLPSS (C) is superior to that of the single objective function based design of FLPSS. The nonlinear time domain simulation responses to small perturbation, large perturbation and large disturbance in input mechanical torque have demonstrated the effectiveness of the multiobjective function based FLPSS. The investigations reveal that the dynamic performance of the system based on multiobjective function using genetic algorithm is quite robust to the wide variations in system loading conditions for both small and large perturbations.

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Appendix I

System Non-linear Dynamic Model

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 :

$T_w = 1.4;$

Transmission Line

$X_e = 0.65; R_e = 0.0;$

Operating Condition

$P = 0.9; V_t = 1.0; E_B = 1.0; f = 60\,Hz$

$$\dot{\omega} = (T_m - T_e)/2H$$
$$\dot{\delta} = \omega_0(\omega - 1)$$
$$\dot{E}_q^{'} = (E_{fd} - (E_q^{'} + (x_d - x_d^{'})i_d)/T_{do}^{'}$$
$$\dot{E}_{fd} = (K_A(V_{ref} - V_t + U_s) - E_{fd})/T_a$$

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.