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Fuzzy PID based PSS Design Using Genetic Algorithm

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***Abstract*—**This paper presents PSS (Power system stabilizer) design based on optimal fuzzy PID (OFPID). OFPID based PSS design is considered for single-machine power systems. The main motivation for this design is to stabilize or to control low-frequency oscillation on power systems. Firstly, describing the linear PID control then to combine this PID control with fuzzy logic control mechanism. Finally, Fuzzy PID parameters (K_p. K_d, K_I, *Kupd, Kui*) are tuned by Genetic Algorthm (GA) to reach optimal global stability. The effectiveness of the proposed PSS in increasing the damping of system electromechanical oscillation is demonstrated in a one-machine-infinite-bus system

***Keywords*—**Fuzzy PID, Genetic Algorithm, power system stabilizer.

I. INTRODUCTION

LOW -frequency oscillations are a common problem in large power systems. PSS (power system stabilizer) is one of alternative solution for this problem. PSS can provide auxiliary control signal to the excitation system and/or the speed governor system of the electric generating unit. This can also damp oscillation and improve its dynamic performance. PSSs have been extensively studied and used in power systems for many years.

Most PSSs employ the classical linear control theory. PSS design approach is based on a linear model in fixed configuration of the power system. This results in fixed-parameter of PSS. It is called a conventional PSS (CPSS) and widely used in power systems to damp out small oscillations [1-3].

In the conventional fixed-parameter spectrum controllers, the gains and other parameters may not ideally suit the entire spectrum of operation. Developments in digital technology have made it feasible to develop and implement improved controllers based on modern, more sophisticated techniques. Power system stabilizers based on adaptive control, artificial neural networks, and fuzzy logic are being developed. Each of these control techniques possesses unique feature and strength. Fuzzy logic-based PSS (FLPSS) shows great potential in increasing the damping of generator oscillations, especially when made adaptive. [4]-[5].

In this papers, an optimal PID fuzzy-based PSS is developed, which uses the post-disturbance value of the speed deviation as the input. Then this signal is used as the input of fuzzy PID controller. To reach optimal dynamic response, the fuzzy PID stabilizer is tuned by GA.

II. POWER SYSTEM MODEL

A single machine infinite bus (SMIB) system with synchronous generator provided with IEEE type-ST1 static excitation system is considered. A Linear model of power system is shown in fig. 1.[2] The nominal operating conditions and system parameters are given in Appendix.

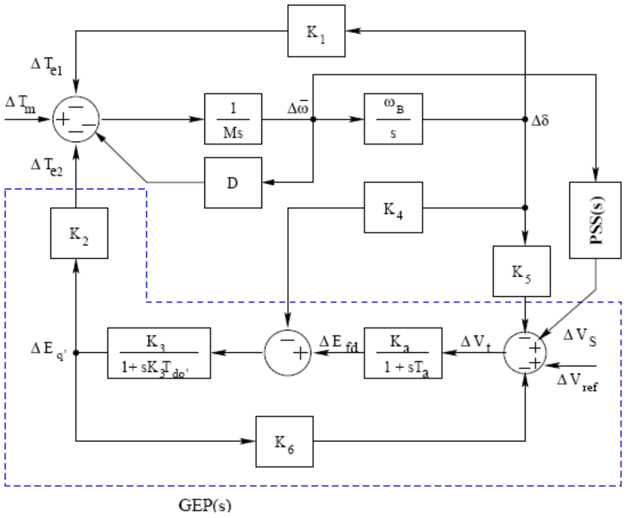

Fig. 1 A linear model of power system

III. FUZZY PID CONTROLLER

The basic principles underlying the design of the proposed fuzzy PID (Proportional Integral Derivative) based PSS can be illustrated by the block diagram in Fig.2, in which a synchronous generator with a static exciter is equipped with a fuzzy PID based PSS whose gain settings are tuned by GE. The generator speed deviation $\Delta\omega$ is as the input signal of the proposed stabilizer.

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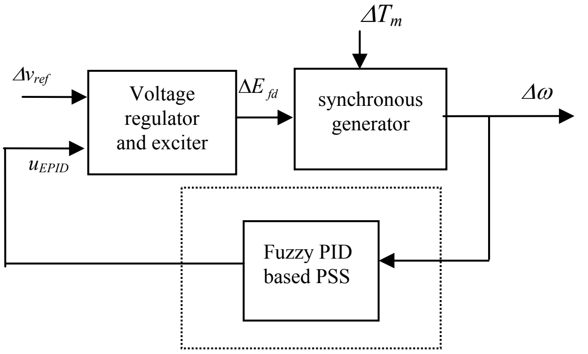

Fig. 2 Structure of the study system

The general continuous-time PID based PSS has the expression

$$u_{PID}(t)=K_p\Delta\omega(t)+K_I\int\Delta\omega(t)dt+K_D\frac{d\Delta\omega}{dt} \tag{1}$$

where *Δω* is speed deviation of machine and K_P, K_I, and K_D are PID based PSS parameters.

This is first converted into the frequency domain to get

$$u_{PID}(s)=(K_P+\frac{K_I}{s}+sK_D)\Delta\omega(s) \tag{2}$$

A. Derivation of the Fuzzy PD based PSS

The output of the conventional analog PD controller in the frequency-domain is given by

$$u_{EPD}=(K_P^c+sK_D^c)\Delta\omega(s) \tag{3}$$

Where K_P^c and K_D^c are the conventional proportional and derivative gains, respectively, and *Δω(s)* is the speed deviation signal. This equation can be transformed into the discrete version by applying the bilinear transformation

$$s=\frac{2}{T}\left[\frac{z-1}{z+1}\right]$$

Where is *T* the sampling period, which results in

$$u_{EPD}(z)=(K_P^c+K_D^c\frac{T}{2}\frac{1-z^{-1}}{1+z^{-1}})\Delta\omega(z) \tag{4}$$

Letting $K_P=K_p^c$ and $K_D=2K_D^c/T$, and then taking the inverse *z*-transform, we have

$$\begin{aligned}u_{EPD}(nT)+u_{EPD}(nT-T)&=K_P[\Delta\omega(nT)+\Delta\omega(nT-T)]\\&+K_D[\Delta\omega(nT)-\Delta\omega(nT-T)]\end{aligned} \tag{5}$$

Further dividing (5) by *T*, and using to mean from now on (4), we obtain

$$u_{EPD}(n)=K_Pd(n)+K_Dr(n) \tag{6}$$

where

$$u_{EPD}(n)=\frac{u_{PD}(n)+u_{PD}(n-1)}{T}$$

$$r(n)=\frac{\Delta\omega(n)-\Delta\omega(n-1)}{T}$$

$$d(n)=\frac{\Delta\omega(n)+\Delta\omega(n-1)}{T}$$

We can then rewrite (3) as

$$u_{EPD}(n)=-u_{EPD}(n-1)+T\Delta u_{EPD}(n) \tag{7}$$

Replacing the term $T\Delta u_{PD}(n)$ by a fuzzy control action gain, we finally arrive at

$$u_{EPD}(n)=-u_{EPD}(n-1)+K_{uPD}\Delta u_{EPD}(n) \tag{8}$$

where K_{uPD} is a fuzzy PD control gain.

B. Derivation of the Fuzzy I Controller

The output of the conventional analog I controller in the frequency-domain is given by

$$u_{EI}(s)=\frac{K_I^c}{s}\Delta\omega(s) \tag{9}$$

where K_I^c is the conventional integral control gain. Under the bilinear transformation, (9) becomes

$$u_{EI}(z)=\frac{T}{2}\frac{1-z^{-1}}{1+z^{-1}}K_i^c\Delta\omega(z) \tag{10}$$

so that

$$u_{EI}(z)=K_I^c\frac{T}{2}\left(1+\frac{2z^{-1}}{1-z^{-1}}\right)\Delta\omega(z) \tag{11}$$

then we have

$$u_{EI}(n)-u_{EI}(n-1)=\frac{K_I^cT}{2}[\Delta\omega(n)-\Delta\omega(n-1)]+K_I^cT\Delta\omega(n-1) \tag{12}$$

$$\Delta u_{EI}(n)=K_I\Delta\omega(n-1)+Kr(n) \tag{13}$$

where $K_I=K_I^c$ and $K=(T/2)K_I^c$, with

$$\Delta u_I(n)=\frac{u_I(n)-u_I(n-1)}{T}$$

and

$$r(n)=\frac{\Delta\omega(n)-\Delta\omega(n-1)}{T}$$

Letting K_{uI} be a fuzzy control gain, as was similarly done for the fuzzy PD controller case discussed above, we arrive at

$$u_{EI}(n)=u_{EI}(n-1)+K_{uI}\Delta u_{EI}(n) \tag{14}$$

C. Combination of the Fuzzy PD+ I Controller

Finally, the overall fuzzy PD+I control law can be obtained by algebraically summing the fuzzy PD control law (7) and fuzzy I control law (14) together. The result is

$$\begin{aligned}u_{EPID}(n)&=u_{EPD}(n)+u_{EI}(n)\\&=-u_{EPD}(n-1)+K_{uPD}\Delta u_{EPD}(n)\\&+u_{EI}(n-1)+K_{uI}\Delta u_{EI}(n)\end{aligned} \tag{15}$$

The overall fuzzy PID based PSS is shown in Fig. 3, where the fuzzy PD and I controllers will be inserted into the configuration.

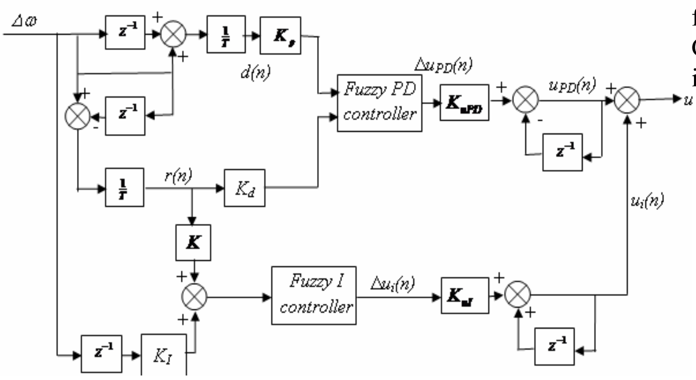

Fig. 3 The fuzzy PID based PSS block diagram

IV. DESIGN OF OFPID BASED PSS

The choice of suitable performance index is extremely important for the design of OFPID based 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. *Δω* is the rotor speed deviation in p.u. following a small perturbation in the system. The performance index (objective function) is defined as

$$J = \int_0^\infty (t\Delta\omega)^2\, dt \qquad (16)$$

General Structure of GA

The sequential steps for searching optimal solution of Fuzzy PID based PSS parameters using GA is shown in Fig. 4

Design Methology

1) An initial population of individuals is randomly generated
2) The optimization of Fuzzy PID based PSS parameters is done by evaluating performance index J.
3) 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 4.
4) 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 OFPID based PSS at nominal condition are shown in Table I.

TABLE I
FUZZY PID BASED PSS PARAMETERS

K_p	K_d	K_i	K_{upd}	K_{ui}	K
-18.9727	25.2521	81.8621	-10.2770	133.4178	4.0931

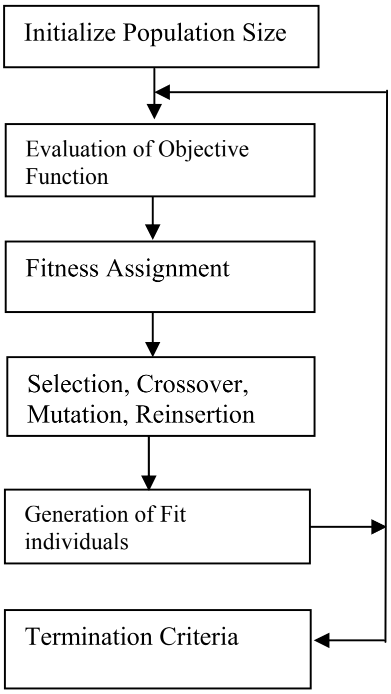

Fig. 4 Computational Flow Chart

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

TABLE-II
GA OPTIONS

PopulationSize	50
EliteCount	2
CrossoverFraction	0.9
MigrationInterval	20
MigrationFraction	0.2
Generation	100
StallGenLimit	50
StallTimeLimit	Inf
InitialPenalty	10
PenaltyFactor	100
Initial range	[0;20]

V. SIMULATION RESULT

To evaluate the effectiveness of the proposed PSS to improve the stability of power system, the dynamic performance of the proposed PSS was examined under different loading conditions, small perturbation and large perturbation. The performance of the Optimal Fuzzy PID based PSS is compared with the CPSS whose parameters were optimized using phase compensation technique.

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

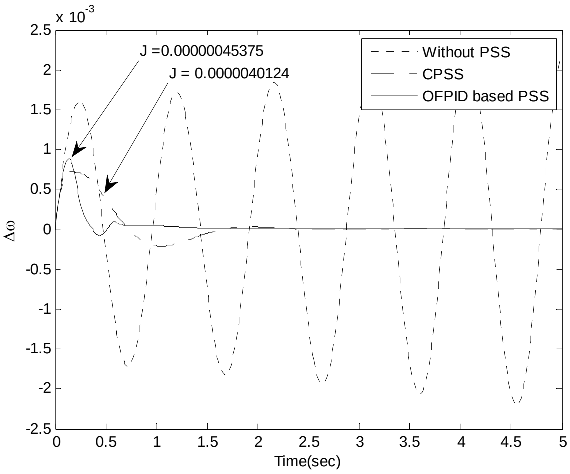

Fig. 5 Dynamic response for Δω for small Perturbation at nominal load

VI. CONCLUSION

A different approach for designing a power system stabilizer using optimal PID Fuzzy has been presented. The optimum values of the PSS are globally search by PSO. The dynamic performance of the OPIDF based PSS is superior than the no PSS and conventionally tuned PSS under small as well largeperturbation. Simulation of the response of the proposed PSS to small disturbances have demonstrated the effectiveness of the OPIDF based PSS.

APPENDIX

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 :

$M = 2H=4..74;\ X_d =1,7;\ x_q=1,64;\ x_d^{'} = 0.254$

$T_{d0}^{'} = 5.9$

Excitation System :

$K_A=400;\ T_A=0,05; K_F=0.025;\ T_F=1,0;$

PSS:

$T_W =1,4\ \ T_1=T_3= 0.3\ \ T_2 =T_4= 0.055$

Transmition on Line :

$X_e=0.4$; $R_e=0.02$

Operation Condition :

P=1; PF=0.85 $V_t=1,0$; f =60 Hz

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