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ROBUST DESIGN OF POWER SYSTEM STABILIZER FOR A SINGLE GENERATOR-INFINITE BUS POWER SYSTEM

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Key words: Power system stabilizer (PSS), Genetic algorithm (GA), Fuzzy proportional-integral-derivative PSS controller design (FPID-PSS).

In interconnected power system, the stability is influenced by the oscillations. The safe functioning of these systems depends on the damping of these oscillations. The development of the damping controllers is a constraint based on a multimodal optimization problem. The use of conventional optimization methods is relatively difficult. In this paper, a power system stabilizer that generates an additional control signal for the excitation system provides the improvement of the stability of the single machine infinity bus system (SMIB). To overcome the disadvantages of conventional power system stabilizers (CPSS), a PSS controller is designed. The structure of a conventional controller PID is used, where the gains are adapted on-line based on parameter estimation using fuzzy gain scheduling. A genetic algorithm (GA) is used to determine the range of the controller parameters. The simulation results show the high performance of the proposed controller, to improve the stability of the power system compared to conventional PSS.

1. INTRODUCTION

Nowadays, the consumption of electrical energy has increased. This significant demand of energy requires the interconnection of power systems in long transmission lines. In the case of a large demand for energy, the functioning of electrical systems is in their maximum limits. The safe functioning of these systems is a great challenge in the presence of small and large disturbances in power networks [1–3]. These disturbances are the source of electromechanical oscillations and strong variations in rotor angles of the generator. These oscillations are with low frequencies in the range of 0.2 and 3 Hz. They can be the consequences of tripping the generator from the grid, participating to major system blackouts, and so on [4, 5].

The stability consists in keeping the operating equilibrium when the system undergoes disturbances. Power system stability is an issue to achieve safe and reliable operation. The automatic voltage regulator and the power system stabilizer (PSS) can both contribute to the stability of a power system [6].

The PSS can be used to damp the oscillations with low frequencies and improve the power system stability. The classic power system stabilizer are designed to tune parameters of systems with linear models and with some functioning conditions. A change in the functioning conditions influence the control output of the power system and then on its stability [7, 8]. Different techniques based on artificial intelligence (AI) are used to solve the problems of low frequency oscillations [9 –14].

In this paper, we propose to apply a nonlinear controller to a power system, which is single machine-infinity bus (SMIB) system, in the presence of disturbances. A PID controller is applied using fuzzy gain scheduling based on on-line parameter estimation. The performances are evaluated in two cases: the first case is a three-phase short-circuit fault and the second case is a sudden increase of 10 % in mechanical power input.

The organization of the paper is as follow; we begin with SMIB model; next the power stabilizer system is presented. We then propose a fuzzy gain scheduling PID controller. The simulation results are shown after. Finally, we give some conclusion remarks on the performance of proposed.

2. POWER SYSTEM MODEL (SMIB)

A synchronous generator and a fast excitation system are part of the investigated system, which is connected to the network via a transmission line.

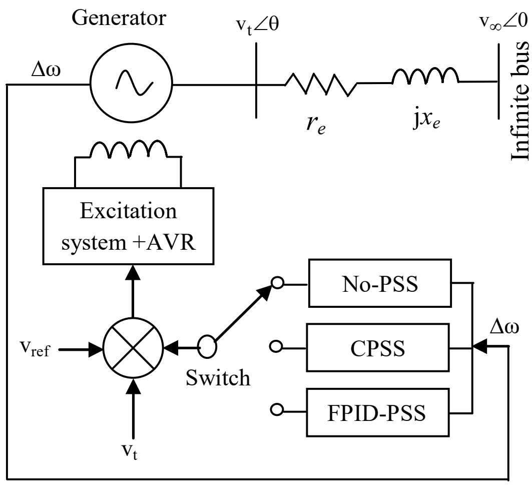

Fig. 1 – SMIB system the excitation of the generator.

Figure1 presents SMIB with the excitation of the generator. The considered system can be defined in a two-axis model by the following equations [6]:

$$\frac{\mathrm{d}\delta}{\mathrm{d}t} = \omega - \omega_s , \tag{1}$$

$$\frac{\mathrm{d}\omega}{\mathrm{d}t} = \frac{\omega_s}{2H}\left[T_m - \left(e_q' i_q + \left(x_q - x_d'\right) i_d i_q + D(\omega - \omega_s)\right)\right], \tag{2}$$

$$\frac{\mathrm{d}e_q'}{\mathrm{d}t} = \frac{1}{T'_{d0}}(e'_q + (x_d - x'_d) i_d - e_{fd}) , \tag{3}$$

$$\frac{\mathrm{d}e_{fd}}{\mathrm{d}t} = -\frac{1}{T_a} e_{fd} + \frac{K_a}{T_a}(v_{ref} - v_t) , \tag{4}$$

$$x_q i_q - v_d = 0 \tag{5}$$

$$e_q' - v_q - x_d' i_d = 0 , \tag{6}$$

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$$r_e i_d - x_e i_q = v_d - v_\infty \sin(\delta)\,, \tag{7}$$

$$x_e i_d + r_e i_q = v_q - v_\infty \cos(\delta)\,, \tag{8}$$

$$v_t^2 = v_d^2 + v_q^2\,. \tag{9}$$

Equations: (1) – (4) are the differential equations of the power system;

(5) – (6) are algebraic stator equations;

(7) – (9) are the network equations,

where: δ – rotor angle; ω – rotor speed; ω_s – synchronous speed; T_m – mechanical torque input; T_e – electromagnetic torque; D – damping coefficient ; H – inertia constant; e_{fd} – excitation voltage; e'_q – q-axis transient voltage; T'_{d0} – d-axis transient time constant; x_d – d-axis synchronous reactance; x_q – q-axis synchronous reactance; x'_d – d-axis transient reactance; v_t – generator terminal voltage; v_{ref} – reference voltage; K_a – gain of excitation voltage; T_a – time constants of excitation voltage; i_q – q-axis armature current, i_d – d-axis armature current, x_e – equivalent reactance of transmission lines, r_e – equivalent resistance of transmission lines, v_∞ – infinitive bus voltage.

3. **POWER SYSTEM STABILISER (PSS)**

The studied system is equipped with automatic voltage regulator (AVR) and PSS, as shown in Fig. 2.

The AVR is utilized in the excitation system to maintain the desired terminal voltage.

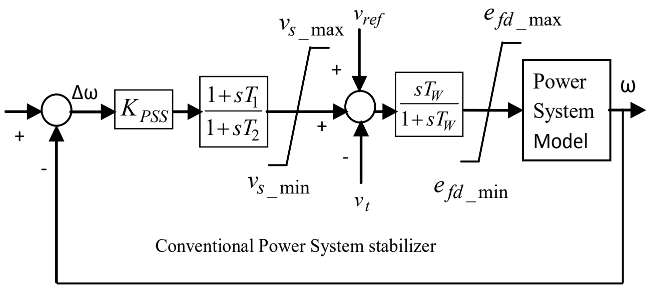

Fig. 2 – Block diagram of the PSS and the excitation system.

A first order voltage regulator model is employed in this study – equation (4). The AVR parameters to adjust are the K_a and T_a. The exciter gain is K_a, and the exciter time constant is T_a.

The PSS is used to attenuate oscillating signals with low frequency especially the generator rotor oscillations. Rotor oscillations are produced mainly by rotor speed deviations.

The generator speed deviation is the PSS's input. The PSS model contains the phase compensating block and a gain block. The PSS output is transmitted to the excitation of the generator, where T_1, T_2 are PSS time constants, T_W is the wash out time constant and K_{PSS} is the PSS gain. K_{PSS} is typically in the range of 0.1 to 50; T_1 is the lead time constant, which ranges from 0.2 to 1.5 s; and T_2 is the lag time constant, which ranges from 0.02 to 0.15 s [7, 8].

4. **PROPOSED CONTROLLER**

The basic task of the PID-type power system stabilizer is to compensate the phase delay between the machine electrical torque and the excitation input to create an appropriate torque in the generator's rotor. The PID stabilizer consists of P proportional, I integral, D differential gains, T_W high-pass filter circuit time constant and output limitations ($v_{pss\_\max}$ and $v_{psss\_\min}$). The value of T_W is between 1 to 20 seconds [9]. The structure of the PID controller is shown in Fig. 3.

In the design of the PID, it is necessary to determine the limits of the PID parameters and these restrictions are shown below.

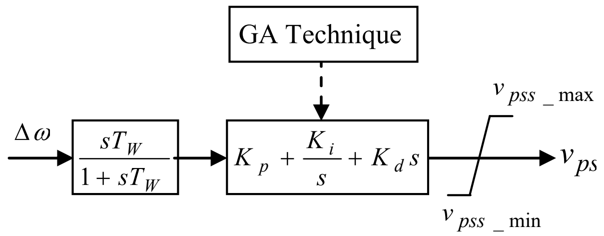

Fig. 3 – Structure of PID type PSS.

$$K_{p\_\min} \langle K_p \langle K_{p\_\max}\,, \tag{10}$$

$$K_{i\_\min} \langle K_i \langle K_{i\_\max}\,, \tag{11}$$

$$K_{d\_\min} \langle K_d \langle K_{d\_\max}\,. \tag{12}$$

4.1. OBJECTIVE FUNCTION

The performance indices integral absolute error (IAE) is utilized in this study to minimize the error signal and subsequently to decrease the settling time and overshoots in power system oscillations.

These oscillations are influenced by the power angle (δ), rotor speed ($\Delta\omega$), and deviations in T_e). To find the best suitable one, GA algorithm has been applied to minimize the values provided by the objective functions of the system, that is given by [10-12]:

$$J_{IAE} = \int_0^{t_s} |\Delta\omega(t)|\,\mathrm{d}t\,. \tag{13}$$

The PSS parameters are optimized using genetic algorithms tool under MATLAB environment.

Table 1 shows the PSS parameters optimized by GA.

Table1

The parameter values of system

Method GA	PID Controller		
	K_P	K_i	K_d
MAX	15	3	10
MIN	4	0.001	4

The maximum generation is 100, the number of individuals is 100, the crossover probability is 0.7, and the mutation probability is 0.3.

The lower limit of the K_P, K_i and K_d is 0.001 and the upper limit is 15. By utilizing the proposed approach, this optimization problem is solved by running the GA technique coded in MATLAB and the most appropriate PSS parameters are obtained.

4.2. FUZZY GAIN SCHEDULING PID CONTROLLER

The PID control system with a fuzzy gain scheduler is shown in Fig. 4. The strategy employed here is to generate controller parameters using fuzzy rules and reasoning.

K_p and K_d are assumed to be in the prescribed ranges $[K_{p\_min}, K_{p\_max}]$ and $[K_{d\_min}, K_{d\_max}]$, respectively.

A following equations is used to determine the parameters K_p, K_i and K_d [13, 14].

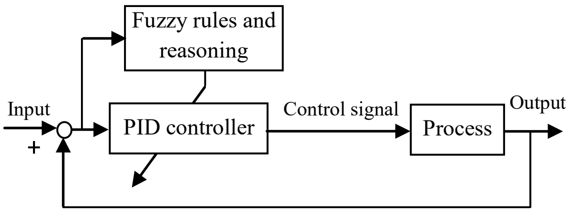

Fig. 4 – PID control system with a fuzzy gain scheduler.

$$K_p = \left(K_{p\_max} - K_{p\_min}\right)K'_p + K_{p\_min}, \tag{14}$$

$$K_d = \left(K_{d\_max} - K_{d\_min}\right)K'_d + K_{d\_min}, \tag{15}$$

$$K_i = K_p^2 / \left(\alpha K_d\right). \tag{16}$$

The parameters K'_p, K'_d and α are determined by a set of fuzzy rules: if $e(k)$ is A_i and $\Delta e(k)$ is B_i, then K'_p is C_i, K'_d is D_i, and $\alpha = \alpha_i$,

$$i = 1, 2, \ldots, m. \tag{17}$$

The membership functions are presented in Fig. 5.

5. **RESULTS AND DISCUSSIONS**

The simulation is performed using MATLAB-Simulink. In simulation studies, two types of dysfunctions are considered. Table 2 shows the parameter values of system.

Table 2

The parameter values of system

Generator	$H = 7/2$ s ; $T'_{d0} = 5$ s; $r_s = 0.005$ p.u ; $x_q = 0.78$ p.u; $x_d = 1.18$ p.u; $x'_d = 0.2951$ p.u; $D = 0$ p.u; $f = 60$ Hz; $\omega_s = 2\pi f$ rad/s; $e_{fd\_max} = 7$ p.u; $e_{fd\_min} = 0$ p.u.
Transmissi on line	$x_e = 0.15$ p.u; $r_e = 0$ p.u; $v_t = 1.05$ p.u; $\theta = 0.0715$ rad; $v_\infty = 1$ p.u.
The AVR	$K_a = 200$; $T_a = 0.01$ s.

i. Large fault type: three-phase short-circuit fault on generator terminals at $t = 1$ s.

ii. Small fault type: A sudden increase of 10 % in mechanical power input at $t = 1$ s ($\Delta P_m = 0.10$ p.u).

The FPID–PSS controller is designed for this type of fault since the three-phase fault has a very serious effect on the system behavior.

Large fault condition: A three-phase fault was applied to the generator terminal bus at $t = 1$ s and it was assumed that the fault was cleared after 6 periods (range = 0.1 s).

The system was returned to its old operating conditions by correcting the fault.

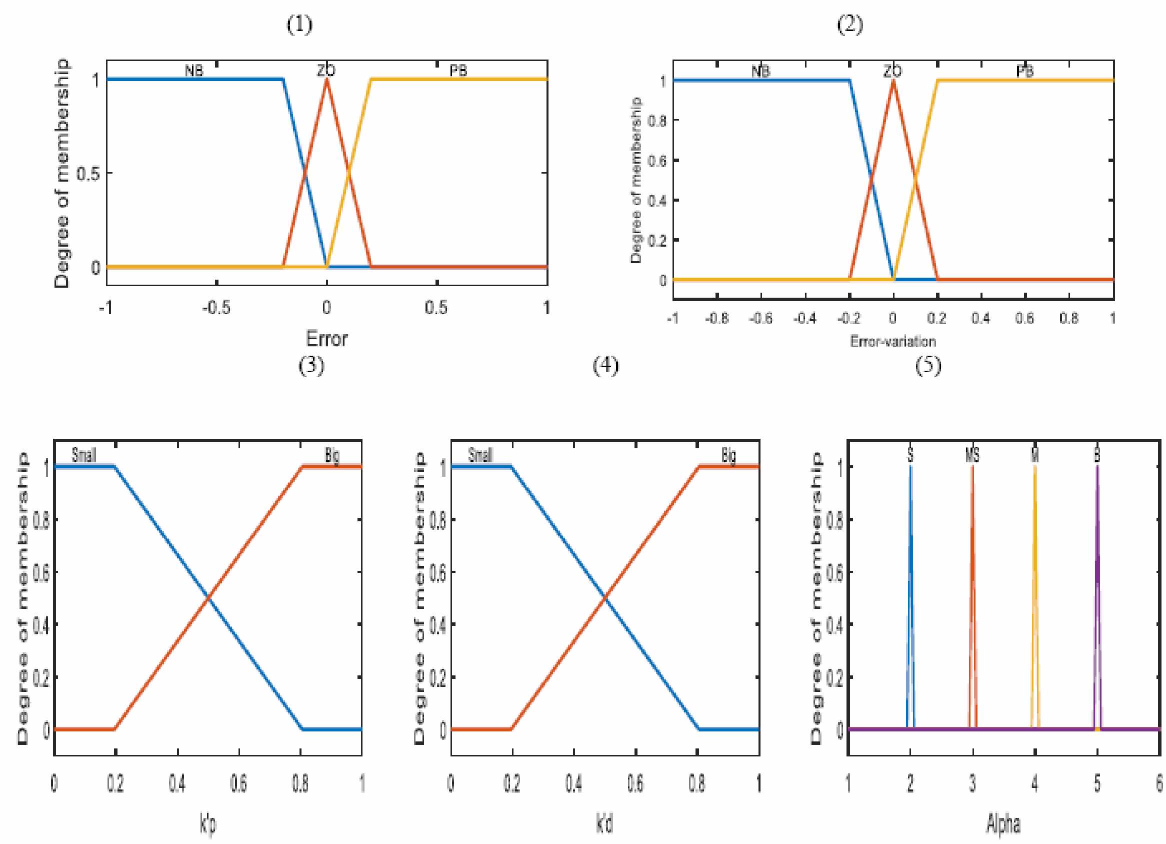

Fig. 5 – Membership functions used.
Inputs: memberships 1 and 2; outputs memberships: 3, 4 and 5,
B – big, M – medium, MS – medium small, S – small.

In the case of this three-phase fault, the evolution of v_∞ and x_e is depicted in Fig. 6. The speed deviation (Δω), the rotor angle (δ) and the electromagnetic torque T_e of the single-machine endless bus system are shown in Fig. 7a.

Figure 8 shows the PID parameters of the fuzzy gain scheduler for the control of the system.

As can be understood from the responses in these figures, compared to the algorithm-based FPID-PSS, it has shorter settling time, providing the best damping characteristics to low-frequency oscillations and stabilizing the system more quickly.

Small fault condition: the performance of the proposed controller was confirmed by applying a 10 % T_m increase in mechanical power input at t = 1 s. In the event of a minor failure, in Fig. 7b, shows the responses of Δω, δ and T_e, respectively.

P_o = 0.8 pu and Q_o = 0.6 pu are considered the generator's nominal operating points. Responses corresponding to disturbance in turbine torques are observed for 0.1 pu step change in the turbine torque. The FPID-PSS has stabilised the system with a smaller settling time and overshoot compared to CPSS.

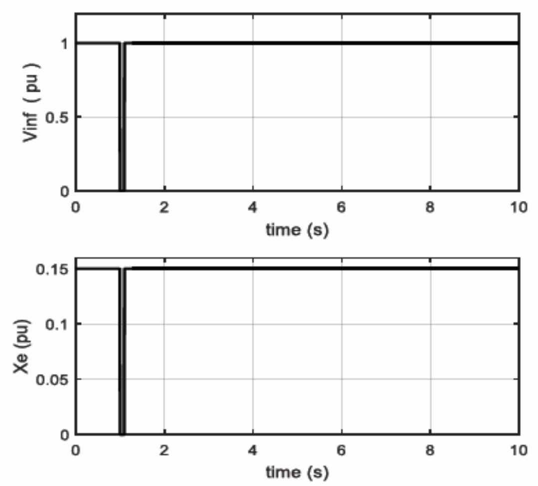

Fig. 6 – The evolution of v_∞ and x_e.

The time domain simulation results are presented in Fig. 7.

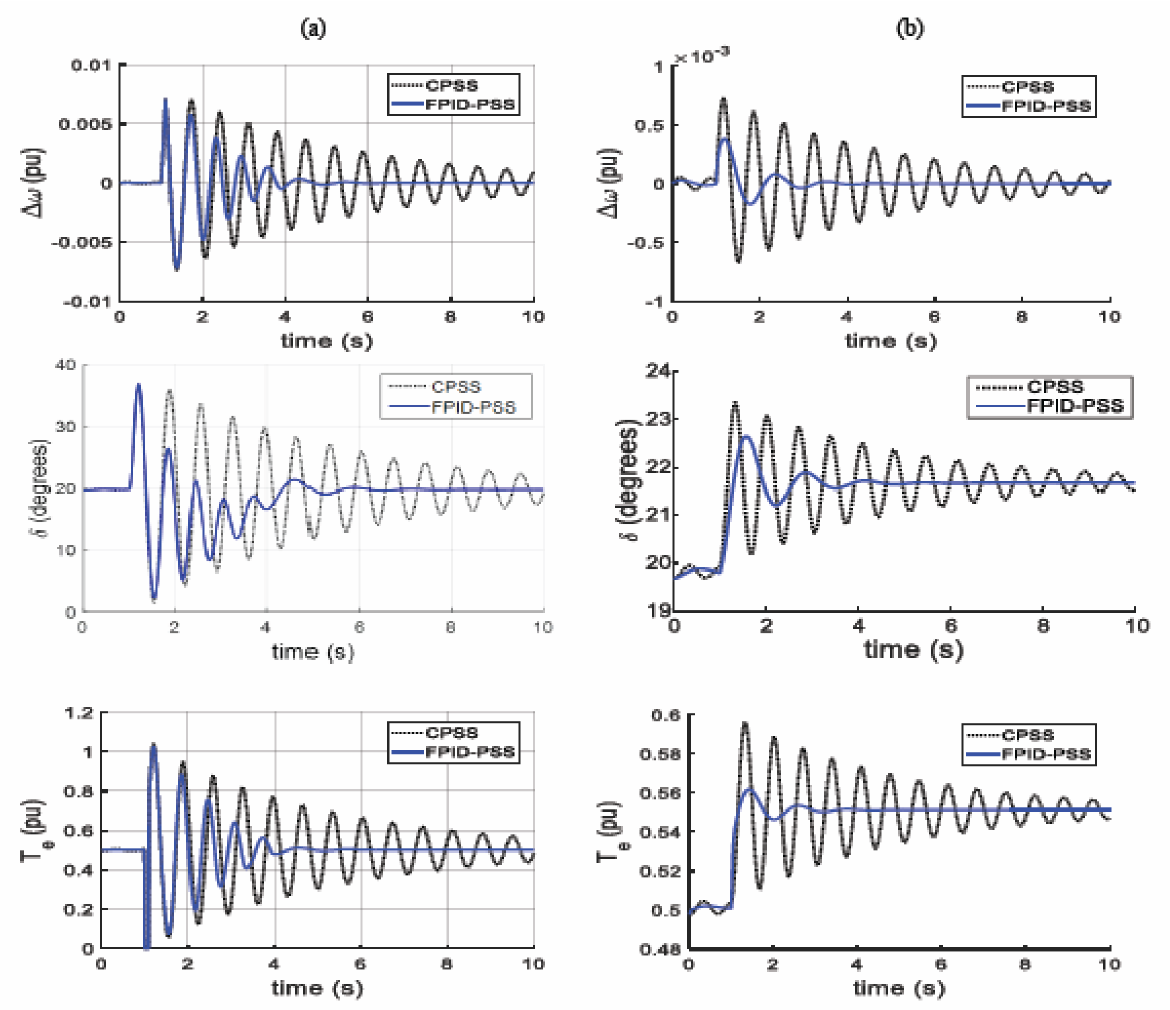

Fig. 7 – System responses for Δω, δ and Te:
a) large fault condition;
b) small fault condition.

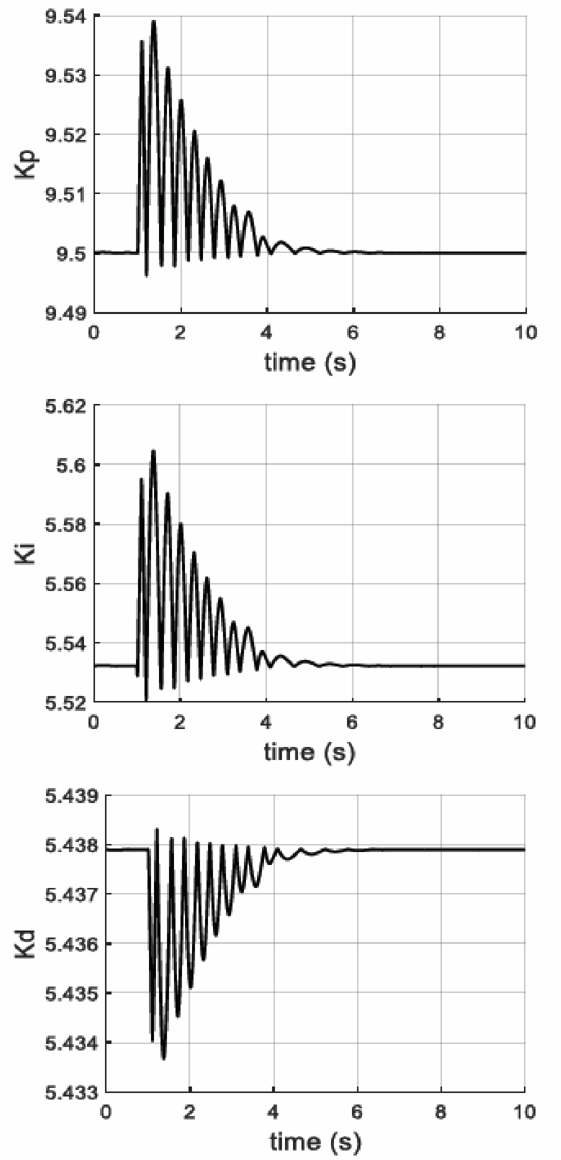

Fig. 8 – PID parameters of the fuzzy gain scheduler for the control of the system.

6. **CONCLUSION**

In this paper, the optimization of a PSS controller design of power system stabilizer based on a PID controller using Fuzzy gain scheduling which is adapted on-line based on parameter estimation is presented. IAE performance index was selected as the objective function in GA which is used to determine the range of the controller parameters.

The design was applied to a typical single-machine endless bus bar power system. The simulation results of the system for rotor angle and speed deviation show that. The FPID-PSS based on the GA optimization method increases the stability and performance of the power system compared to CPSS.

The results showed that the suggested power system stabilizer controller, which is based on a PID controller using fuzzy gain scheduling which is adapted on-line based on parameter estimation, can ensure the robust stability and performance under a wide variety of operating situations.

The results are promising, indicating the algorithm's potential for optimal AVR and PSS design coordination.

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