Gazi University Journal of Science
GU J Sci
24(4):805-816 (2011)

GUJS

Fuzzy PI Control with Parallel Fuzzy PD Control for Automatic Generation Control of a Two-Area Power Systems

Yüksel OĞUZ♠

Department of Electrical Education, Faculty of Technical Education, Afyon Kocatepe University, Afyonkarahisar / TURKEY

Received:21/01/2011 Accepted:07/04/2011

ABSTRACT

This paper presents an efficient method based on a modified fuzzy PI control with parallel fuzzy PD (fuzzy-PI + fuzzy-PD) control for automatic generation control (AGC) of a two-area power system. This paper describes the control schemes required to operate the two-area power system in the steady state. The model of a two-area power system is established using the equations describing dynamic behavior of a two-area power system and control schemas in Matlab-Simulink program respectively. In this paper, typical responses to real power demand are illustrated using the latest simulation technique available by the MATLAB/SIMULINK program. Results of simulation show that the proposed a modified fuzzy-PI+fuzzy-PD control offers better performance than PID controllers at different operating conditions.

Keywords: Fuzzy PI control with parallel fuzzy PD control, automatic generation control, Power Systems, Matlab/Simulink

1. INTRODUCTION

In recent years, the analysis and design of power systems have been affected dramatically by the widespread use of personal computers. Personal computers have become so powerful and advanced that they can be used easily to perform steady-state and transient analysis of large interconnected power systems. One of the difficulties of teaching power systems analysis training is not having a real system with which to experiment in the laboratory. Therefore, computer-simulated systems are used to supplemented the teaching of power system analysis [1].

Changes in real power affect mainly the system frequency, while reactive power is less sensitive to changes in frequency and is mainly dependent on changes a voltage magnitude. Thus, real and reactive powers are controlled separately. The load frequency control (LFC) loop controls the real power and frequency and the automatic voltage regulator (AVR) loop regulates the reactive power and voltage magnitude. Load frequency control (LFC) has gained in importance with the growth of interconnected systems and has made the operation of interconnected systems possible [2,3]. One of the principle aspects of automatic generation control (AGC) of power system is the maintenance of frequency and power change over the tie-lines at their scheduled values. Therefore, automatic generation control (AGC) or in other words, load frequency controller (LFC), is designed and implemented to automatically balance generated power and load demand in each control area so that the quality of the power delivered is maintained at the requisite level [2-5. In literature, for AGC, some control strategies based on classical control theory have been proposed [6,7]. Unfortunately, because of operating point continuously changes depending on demand of consumers, the selected fixed controller can unsuitable other operating points. Therefore, many of controller with variable structure is proposed in literature [8,9].

♠Corresponding author, e-mail: yukseloguz@aku.edu.tr

The proportional-integral and derivative (PID) decentralized controller is widely used in power industry for load frequency controller. This gives adequate system response considering the stability requirements and the performance of its regulating units. Conventional PID controllers of fixed structure and constant parameters are usually tuned for one operating condition. As the characteristics of the power system elements are non-linear, these controllers may not be capable of providing the desired performance for other operating conditions [10,11]. Therefore, the response of this controller is not satisfactory enough and large oscillations may occur in the system [12]. Moreover, the dynamic performance of the system is highly dependent on the selection of the PI controller gain.

The adaptive control techniques have been applied to cope with the variation of the system parameters but they require information on the system states or an efficient on-line identifier [13]. The model reference approach may be also difficult to apply since the order of the power system is large.

Fuzzy logic control has emerged as an alternative or complement to conventional control strategies in many engineering areas. Fuzzy control theory usually provides nonlinear controllers that are capable of performing various nonlinear control actions. If the parameters of the fuzzy controllers are chosen appropriately, it is also possible for them to work for uncertain nonlinear systems [14-17]. In addition, fuzzy controllers are capable of handling many complex situations such as some control systems with large uncertainties in process parameters and/or systems structures, as well as some ill-modeled or linguistically described physical systems.

In this paper, we design and implement a modified fuzzy PID (proportional-integral-derivative) controller (FPIC) based on the successful fuzzy PI and fuzzy PD controller developed by using a practical approach of the conventional PID controller design method. Fuzzy PID type method based on fuzzy system is chosen to improve the performance of controller for automatic generation control of a two-area power system. The linearized models of the essential components used in control systems are described in this paper. Modeling of a two-area power system is established using the equations describing dynamic behavior of a two-area power system and control schemas in MATLAB/Simulink program respectively.

2. AUTOMATIC GENERATION CONTROL IN A TWO-AREA POWER SYSTEM

Automatic generation control (AGC) is very important factor in the operation of power systems to supply sufficient and reliable electric power with good quality [18]. AGC is a generic term used to designate the automatic regulation of the mechanical power input to the synchronous generators within a pre-defined control area [19, 20]. The generic functions of AGC include the following aspects:

- Load frequency control
- Economic load dispatch

In power systems, load frequency control were equipment with only the primary control loop, a change of power in area 1 was met by the increase in generation in both areas associated with a change in the tie-line power, a reduction in frequency. In the normal operating state, the power system is operated so that the demands of areas are satisfied at the nominal frequency. A simple control strategy for the normal mode is keep frequency approximately at the nominal value, and maintains the tie-line flow at about schedule. Also, each area should absorb its own load schedule.

In practice the adjustment of ΔP_{ref1} and ΔP_{ref2} is done automatically by the tie-line bias control or secondary control. The control loop drive the so-called area control errors (ACE) to zero. The control error for each area consists of a linear combination of frequency and tie-line error.

$$ACE_i = \sum_{j=1}^{n} \Delta P_{ij} + K_i \Delta\omega \tag{1}$$

The area bias K_i determines the amount of interaction during a disturbance in the neighboring areas. As applied to the two-area power system, the two ACEs are given by

$$\begin{aligned} ACE_1 &= \Delta P_{12} + B_1 \Delta\omega_1 \\ ACE_2 &= \Delta P_{21} + B_2 \Delta\omega_2 \end{aligned} \tag{2}$$

$$\Delta P_{12} = P_s (\Delta\delta_1 - \Delta\delta_2) \tag{3}$$

$$B_1 = \frac{1}{R_1} + D_1 \qquad B_1 = \frac{1}{R_1} + D_2 \tag{4}$$

where ΔP_{12} and ΔP_{21} are departures from scheduled interchanges. The constants B_1 and B_2 are called frequency bias settings and are positive. ACEs are used as actuating signal to activate changes in the reference power set point, and when steady state is reached, ΔP_{12} and $\Delta\omega$ will be zero. ΔP_{12} is the increase in power transferred from area 1 to area 2, in response to an increase in the center of angle difference $\Delta\delta_1$-$\Delta\delta_2$. From a control theory point of view the integrator has the merit that it drives the ACE_i to zero in the steady state. Of course, we are implicitly assuming the system is stable, so the steady state is achievable. Thus, in the steady state ACE_1=ACE_2 is zero. Applying equation (2), we find $\Delta P_{12} = \Delta P_{21} = 0$. Thus, there is return to nominal frequency and the scheduled interchanges. Furthermore, since both areas are in energy balance, any load changes must have been absorbed within each area. The block diagram of a simple AGC for a two-area power system is shown in Fig 1.

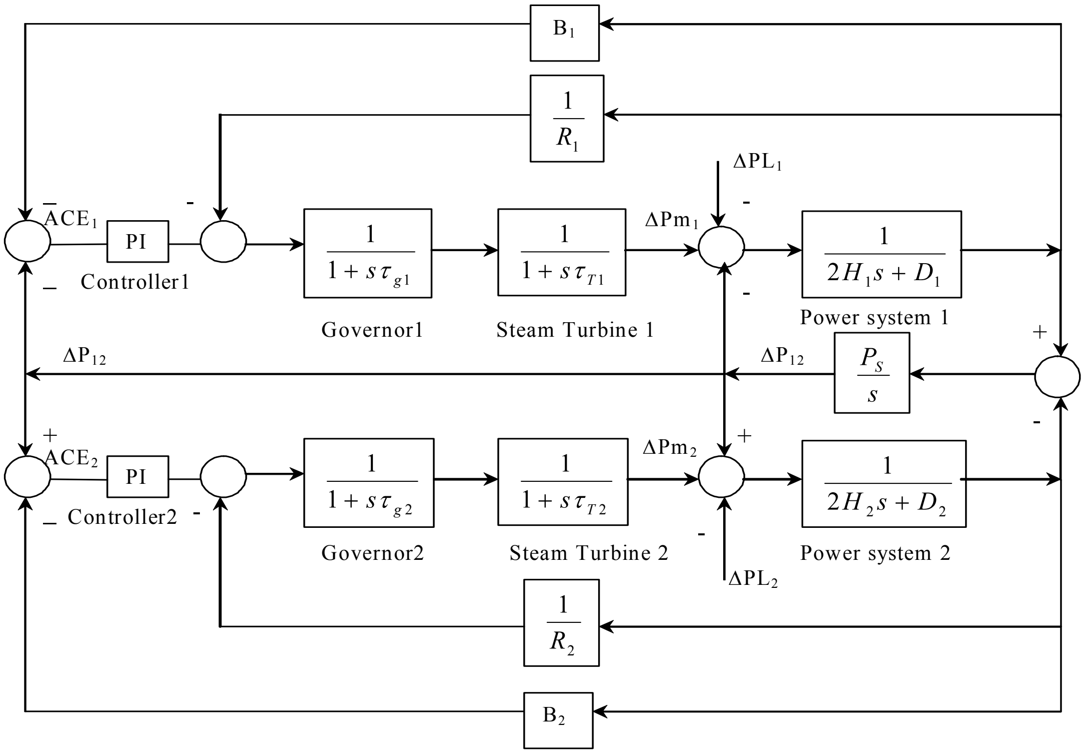

Figure 1. AGC block diagram for a two-area power system.

3. FUZZY PID CONTROLLER

The proportional, integral and derivative part of the conventional linear PID controller is modified by the two-input fuzzy system. Through the fuzzy control rules and membership functions, some non linearities are implemented on the output surface of the fuzzy system. The nonlinearities add varying gains on the proportional, integral and derivative in the PID controller [21, 22]. The weight of the proportional, integral and derivative actions are vary with the error by using the varying gains. The varying gains make system performance less sensitive to the variations of PID gains. Through the simulation, the performance of the fuzzy PID controller is analyzed in comparison with the linear PID controller [23].

There have been many applications of fuzzy logic controller in control areas. Basically there are three types of structure of fuzzy logic controllers. One is a PD type fuzzy controller. It generates control signal from error and change rate in error. PD type fuzzy logic controller is position type control. The other one is PI type fuzzy logic controller, which generates incremental control action (Δu) from error and change rate in error. Fuzzy PI controller is velocity type fuzzy control. The third one is PID type fuzzy control which generates control action (u) from error, change in error and sum of the accumulative error (Σe). Fuzzy PID controller generates incremental control action (Δu) from error, change in error and acceleration error ($\Delta^2 e$). The difficulties of fuzzy PID controller are that they three inputs, which will expand the rule base greatly and make the design more complicated. Therefore such types of fuzzy PID control are rarely used. Fuzzy PID controller cannot eliminate the steady state error. Fuzzy PD controller is more practical than fuzzy PD controller. But fuzzy PI controller has poor performance in the system transient response [24].

3.1 Design of fuzzy PI controller and fuzzy PD controller

To implement a fuzzy PI and PD controller, we first need the digital version of the conventional analog PI and PD controller in frequency domain. The output of the conventional analog PI controller in frequency s-domain;

$$U_{PI}(s) = \left(K_P + \frac{K_I}{s} \right) \cdot E(s) \tag{5}$$

Where E(s) is the error signal in s-domain. The bilinear formula can be used to digitize an analog PI controller. Equation (5) can be transformed into the discrete version for computer aided control systems by applying the bilinear transformation

$$s = \frac{2}{T}\left(\frac{z-1}{z+1}\right) \tag{6}$$

In equation (6), T>0 is the sampling time. Using the bilinear formula in the PI controller, we obtain the following form;

$$U(z) = \left(K_P - \frac{K_I \cdot T}{2} + \frac{K_I \cdot T}{1-z^{-1}}\right) \cdot E(z) \tag{7}$$

It then follows from the inverse z-transform, we obtain the following solution forms;

$$u(nT) - u(nT-T) = K_P\left[e(nT) - e(nT-T)\right] + K_I e(nT) \tag{8}$$

$$\frac{u(nT)-u(nT-T)}{T} = K_P \frac{e(nT)-e(nT-T)}{T} + \frac{K_I}{T} e(nT) \tag{9}$$

$$\Delta u(nT) = \frac{u(nT)-u(nT-T)}{T} \tag{10}$$

where Δu(nT) is the incremental control output of the PI controller, $e_p(nT)$ the error signal, and the rate of change of the error signal $e_v(nT)$. The rate of change of the error signal (e_v) is given by

$$e_V(nT) = \frac{e_V(nT) - e(nT-T)}{T} \,. \tag{11}$$

The control output signal of the digital PI controller is written as

$$u_{PI}(nT) = u(nT-T) + T\Delta u(nT) \tag{12}$$

$$\Delta u_{PI}(nT) = K_P \cdot e_v(nT) + \frac{K_I}{T} \cdot e(nT) \tag{13}$$

The digital PI controller can be implemented as shown Fig 2. Also, The fuzzy PI controller is shown in Fig 3.

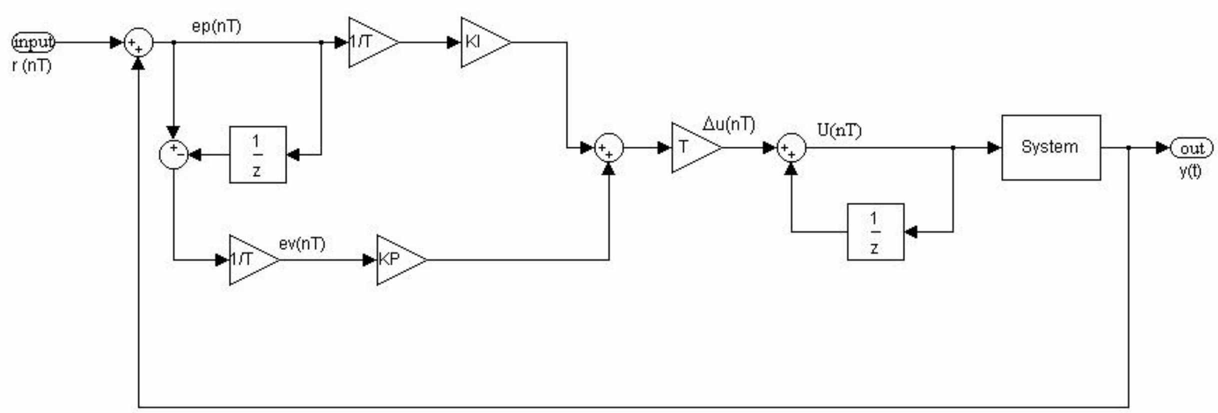

Figure 2. The digital PI controller

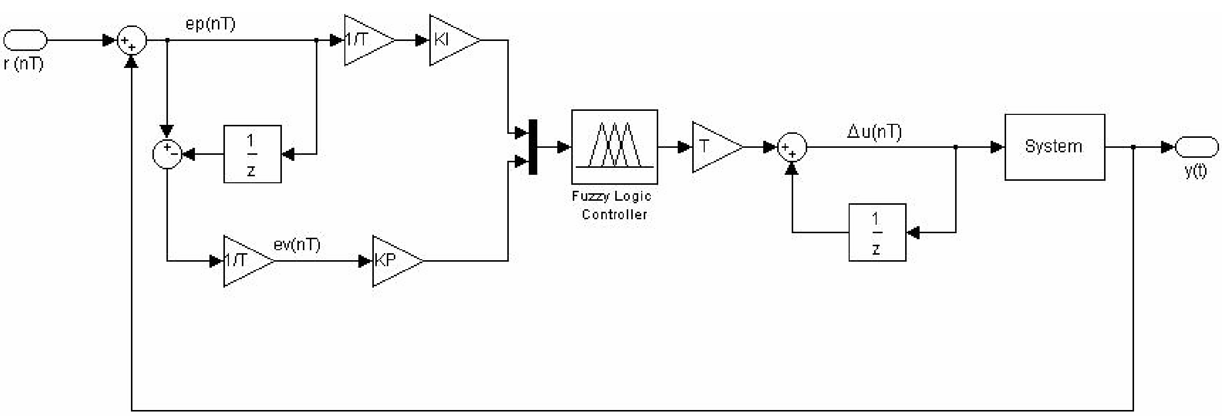

Figure 3. The fuzzy PI controller

Similarly, we describe the design and basic structure of the fuzzy PD controller. The output of the conventional analog PD controller in frequency s-domain, is given by

$$U_{PD(s)} = \left(K_P + sK_D\right) \cdot E(s) \tag{14}$$

Equation (14) can be transformed into the discrete version using the bilinear formula (6) in the continuous-time PD controller which result in the following form:

$$U_{PD}(s) = \left(K_P + \frac{2}{T}\frac{1 - z^{-1}}{1 + z^{-1}} K_D \right) E(z) \tag{15}$$

$$\left(1 + z^{-1}\right) \cdot U(z) = \left(1 + z^{-1}\right) K_P \cdot E(z) + K_D \left(1 - z^{-1}\right) \cdot E(z) \tag{16}$$

It then follows from the inverse z-transform, we obtain the following form:

$$\Delta u(nT) = K_P e_p(nT) + K_D e_V(nT) \tag{17}$$

Where,

$$e_p = \frac{e(nT) - e(nT - T)}{T} \tag{18}$$

$$e_V = \frac{e(nT) - e(nT - T)}{T} \tag{19}$$

The digital PD controller can be implemented as shown Fig 4. Also, the fuzzy PD controller is shown in Fig 5.

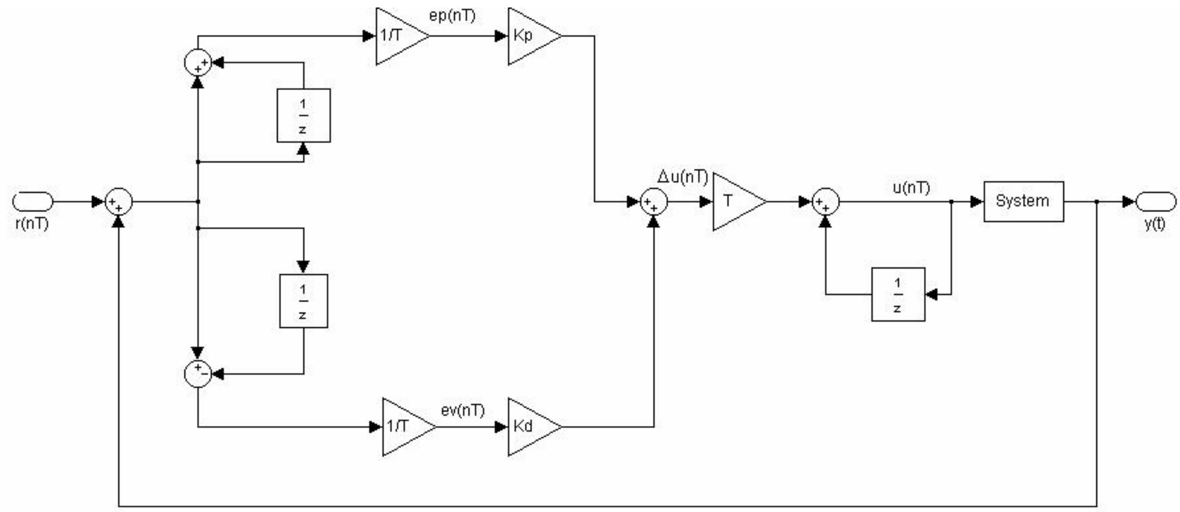

Figure 4. The digital PD controller

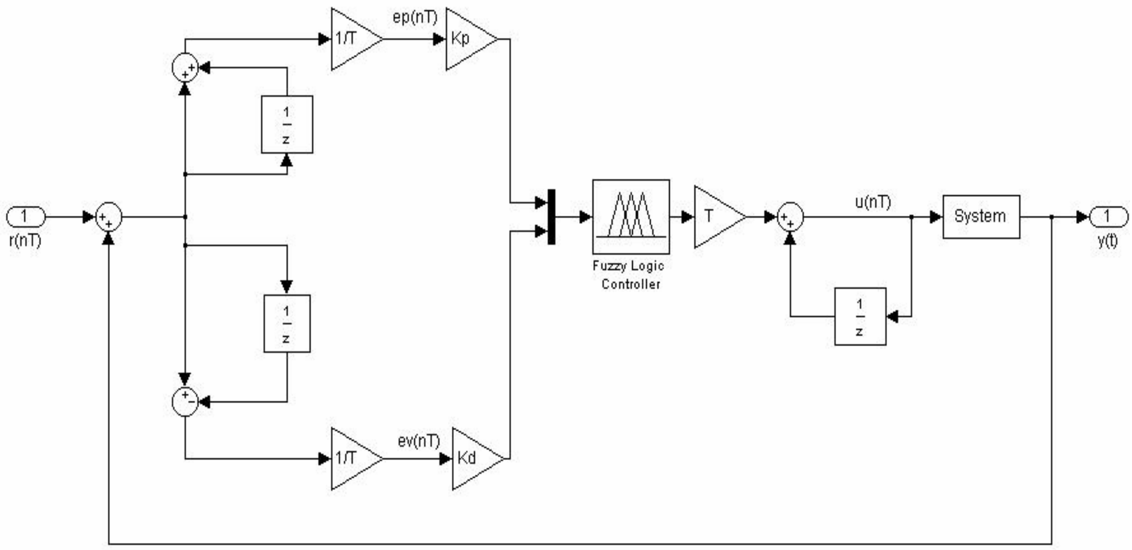

Figure 5. The fuzzy PD controller

4. FUZZY-PI CONTROLLER WITH PARALLEL FUZZY-PD CONTROLLER FOR AUTOMATIC GENERATION CONTROL OF A TWO-AREA POWER SYSTEM

In interconnected power networks with two or more area, the generation within each area has to be controlled so as to maintain scheduled power interchange. Load frequency control consists of two main control loops. These are primary control loop and secondary control loop. Primary control loop is achieved by turbine-governing system. Maintaining the frequency at scheduled value cannot be succeeded. Power system with the primary LFC loop, a change in the system load will result in a steady state frequency error. In order to reduce the steady state frequency deviation, a secondary control loop is provided in addition to the primary control loop. This control loop can be realized by introducing a PI controller, fuzzy logic controller, neuro-fuzzy controller and fuzzy PID controller to act on the load reference setting to change the speed set point. This control scheme is known as AGC.

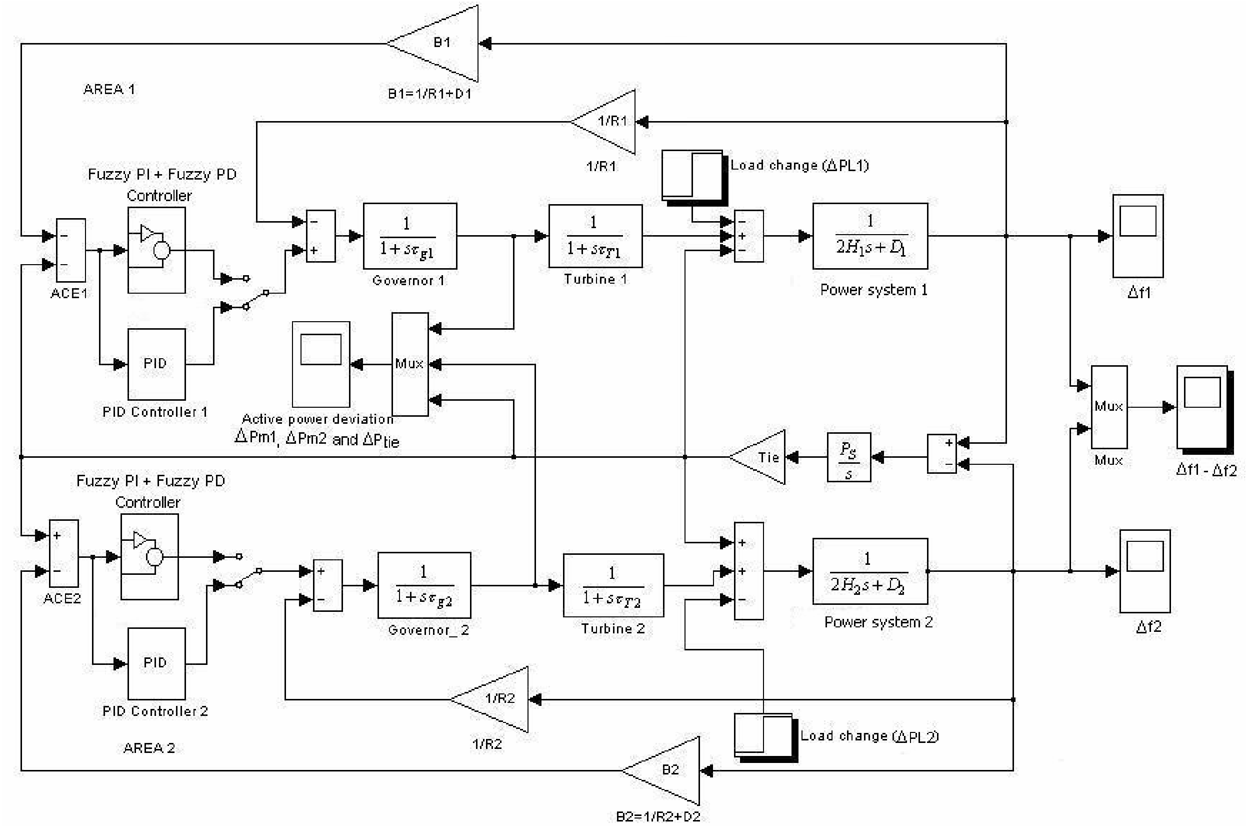

Figure 6. The simulation block diagram for automatic generation control of a two-area power system with Fuzzy PI+ Fuzzy PD controller

In this paper, a power flow is occurred between area 1 and area 2 though a tie-line in the power system with two areas. The control of power flow can be achieved by secondary control loop. Also damping of oscillations at tie-line is another requirement for control of steady state frequency deviation and active power generation. The automatic generation control based on fuzzy PI controller with parallel fuzzy PD controller (fuzzy PI controller +fuzzy PD controller) is proposed in this paper. The simulation block diagram of the two-area power system with fuzzy PID controller and the conventional PID controller is shown in Fig.6 and system parameter values are given in Table 1. This simulation study is implemented by using MATLAB/Simulink Toolbox and Fuzzy Logic Toolbox.

Table 1. The parameter values of a two-area power system [3]

Parameter Names	Area 1	Area 2
The apparent power	500 MVA	500MVA
Nominal frequency	60 Hz	60Hz
Speed regulation	R_1=0.05	R_2=0.0625
Frequency sensitive load coefficient	D_1=0.6	D_2=0.9
Inertia constant	H_1= 5	H_2= 4
Governor time constant	τ_{g1}= 0.2s	τ_{g2} = 0.3s
Turbine time constant	τ_{T1}= 0.5s	τ_{T2} = 0.6s
The synchronizing power coefficient	τ_{ie} = 2 s	

The automatic generation control based on fuzzy PI controller with parallel fuzzy PD controller (fuzzy PI controller +fuzzy PD controller) is proposed in this paper. The simulation block diagram of the two-area power system with fuzzy PID controller and the conventional PID controller is shown in Fig.6 and system parameter values are given in Table 1. This simulation study is implemented by using MATLAB Simulink Program and Fuzzy Logic Toolbox.

In this paper, the proposed fuzzy PID controller consists of fuzzy PI and fuzzy PD controllers, as shown in Fig.7. The simulation block diagrams of fuzzy PI controller and fuzzy PD controller are shown in Fig 3 and Fig 5. The both the fuzzy PI and fuzzy PD controller can use the same membership functions and the same rule base. Only the gains for the input and output signals have to be tuned with appropriate coefficients. The final control action can be expressed as a sum of both control actions:

$$u(nT) = u_{PI}(nT) + u_{PD}(nT) \tag{20}$$

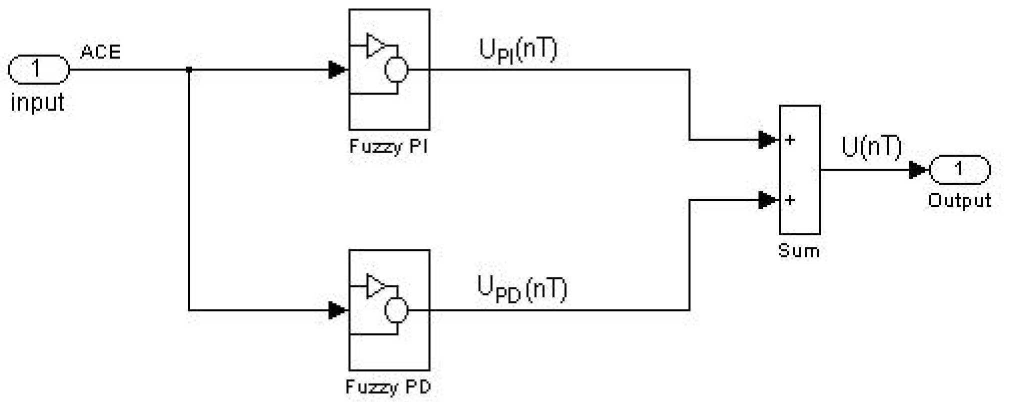

Figure 7. The simulation block diagram of the fuzzy PI+ fuzzyPD controller

For tuning gain of fuzzy-PI+fuzzy-PD controller, the gain of fuzzy PI controller without the fuzzy PD controller is needed to tune according to desired output of the plant. Then keep the gains for input signals unchanged after adding fuzzy PD controller and adjust the gains for output signals to obtain an appropriate result [25].

The input signals of the proposed fuzzy-PI+fuzzy-PD controller are e_p the error signal (ACE) and e_v the rate of change of the error signal (ΔACE). The output signal of fuzzy PI controller is Δu_{PI} and the output signal of fuzzy PD controller is Δu_{PD}. The input and output membership functions of the proposed fuzzy-PI+fuzzy-PD controller are shown in Fig. 8 and Fig.9, respectively.

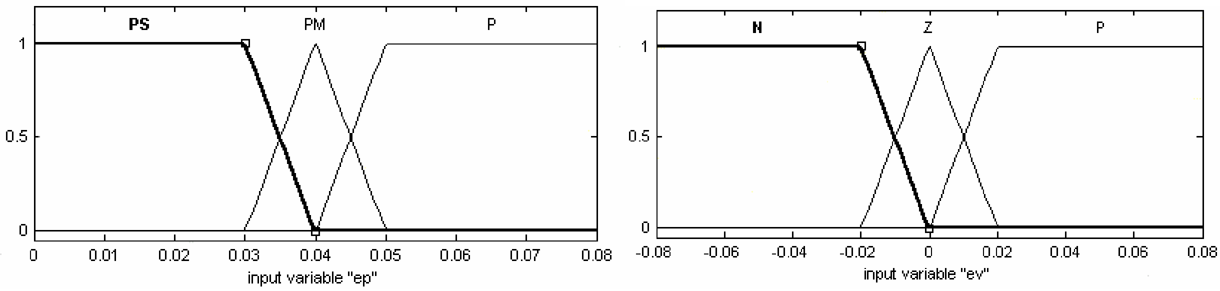

Figure 8. The membership functions for input variable “ep”, “ ev” of the fuzzy PI+PD controller

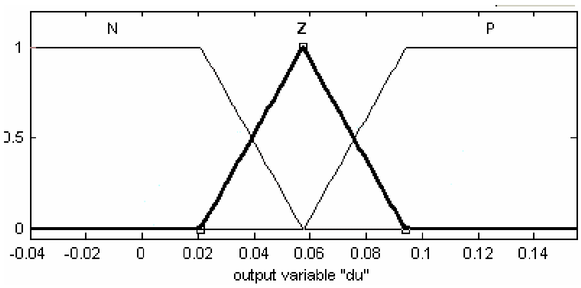

Figure 9. The membership functions for output variable “du” of the fuzzy PI+PD controller

The membership functions are the control gains K_P,K_I, K_D to be large or small, as shown in Fig.8 and Fig 9. Hence, the fuzzy-PI+fuzzy-PD controller becomes a parameter time-varying PI and PD controller. The input membership functions “e_p” of the fuzzy-PI+fuzzy-PD controller is divided into three areas based on magnitude and sign. These are positive small (PS), positive middle (PM) and positive (P). Also, the input membership functions “e_v” and the output membership functions “du” of the fuzzy-PI+fuzzy-PD controller are divided into three areas based on magnitude and sign. There are negative (N), zero (Z) and positive (P).

Fuzzy control rules are constructed by using the control experience of operator having experiences about automatic generation control of the interconnected power system. The input variables “e_p and e_v” have three membership functions, as shown in Fig 8. Using the combinations of the input membership functions, total nine fuzzy control rules can be generated:

1. If (e_p is PS) and (e_v is N) then (du is N)
2. If (e_p is PS) and (e_v is Z) then (du is N)
3. If (e_p is PS) and (e_v is P) then (du is Z)
4. If (e_p is PM) and (e_v is N) then (du is N)
5. If (e_p is PM) and (e_v is Z) then (du is Z)
6. If (e_p is PM) and (e_v is P) then (du is P)
7. If (e_p is P) and (e_v is N) then (du is Z)
8. If (e_p is P) and (e_v is Z) then (du is P)
9. If (e_p is P) and (e_v is P) then (du is P)

The mathematical formula applied is the “min/max” rule for “and” and “or”. This was to reduce the calculation complexity and time. The type of fuzzy logic controller obtained is called Mamdani type fuzzy rules.

5. SIMULATION RESULTS

In this paper, the application of the fuzzy-PI+fuzzy-PD controller to AGC of a two-area power system is investigated. In the simulation, firstly, a step load increase in area 1 and then step load increase in area 1 and area 2 of the same power system are applied. The per-unit load changes from 0.01p.u.MW to 0.3 p.u.MW are applied to the power system with obtained the fuzzy-PI+fuzzy-PD controller. In this case, the frequency oscillations and tie-line power flow are investigated by using the simulation block diagrams. AGC is implemented to damp out the oscillations by using the fuzzy-PI+fuzzy-PD controller and conventional PID controller in each area in the power system.

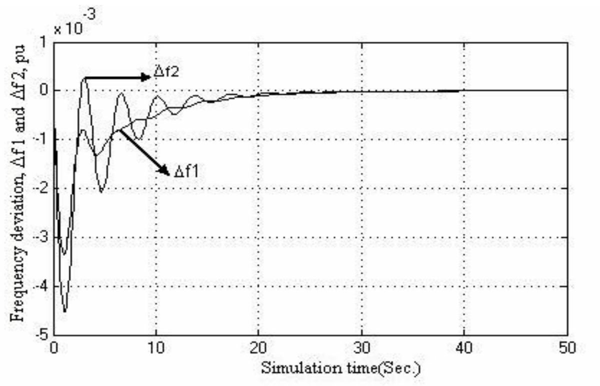

Figure 10. Frequency deviations in response to a step load change of $\Delta P_{L1}=\Delta P_{L2}=0.05$p.u.MW in a two-area power system with PID controller.

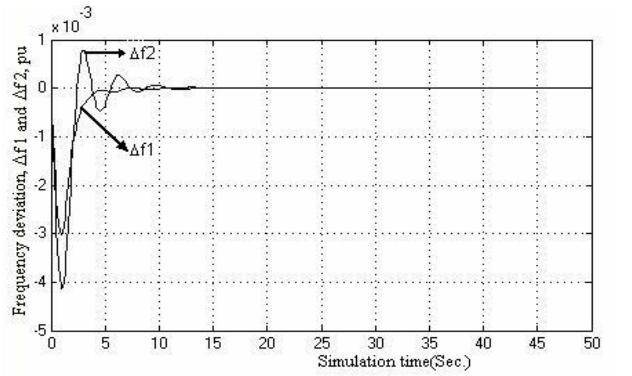

Figure 11. Frequency deviations in response to a step load change of $\Delta P_{L1}=\Delta P_{L2}=0.05$p.u.MW in a two-area power system with fuzzy PI + fuzzy PD controller.

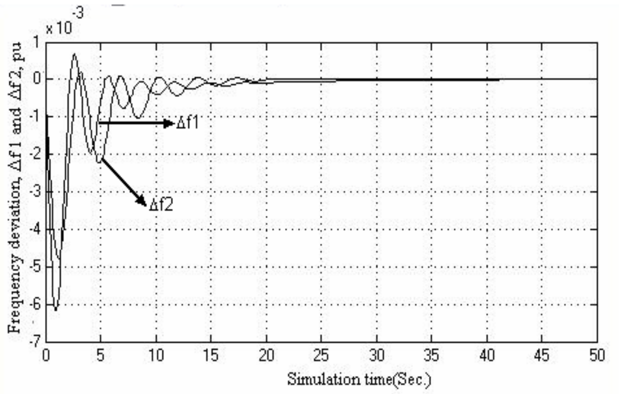

Figure 12. Frequency deviations in response to a step load change of $\Delta P_{L1}=0.1$pu and $\Delta P_{L2}=0.05$p.u.MW in a two-area power system with PID controller

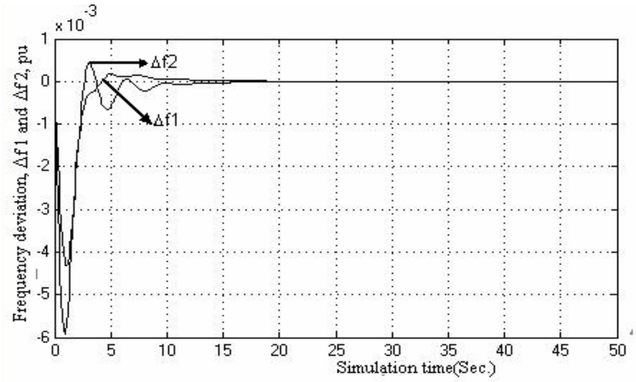

Figure 13. Frequency deviations in response to a step load change of $\Delta P_{L1}=0.1$pu and $\Delta P_{L2}=0.05$p.u.MW in a two-area power system with fuzzy-PI+fuzzy-PD controller.

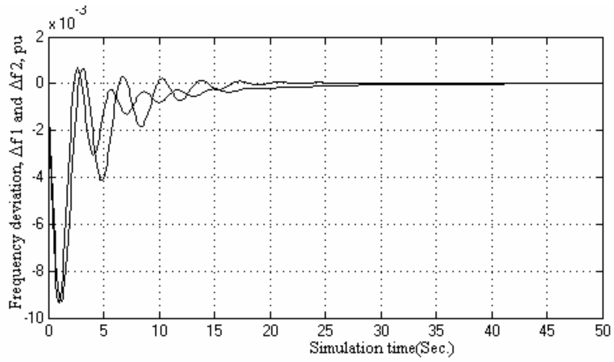

Figure 14. Frequency deviations in response to a step load change of $\Delta P_{L1}=0.15$pu and $\Delta P_{L2}=0.1$p.u.MW in a two-area power system with PID controller.

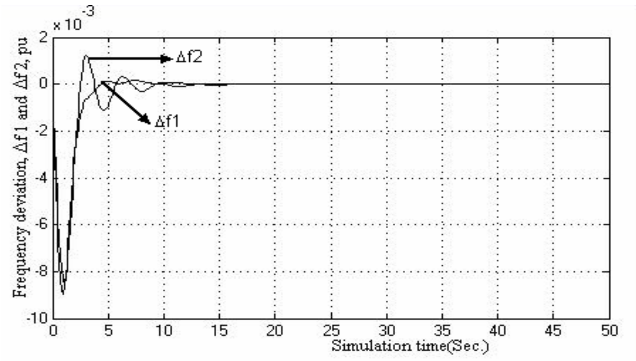

Figure 15. Frequency deviations in response to a step load change of $\Delta P_{L1}=0.15$pu and $\Delta P_{L2}=0.1$p.u.MW in a two-area power system with fuzzy-PI+fuzzy-PD controller.

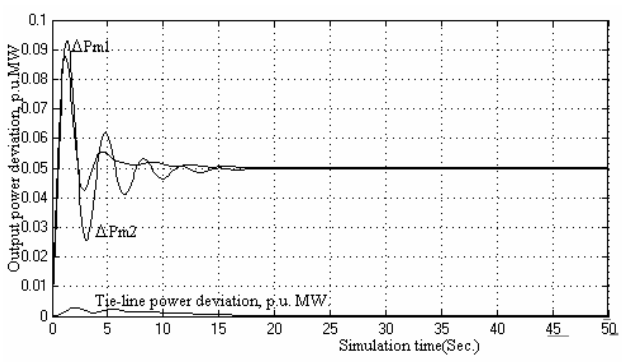

Figure 16. Output power deviations in response to a step load change of $\Delta P_{L1}=\Delta P_{L2}$=0.05p.u.MW in a two-area power system with PID controller.

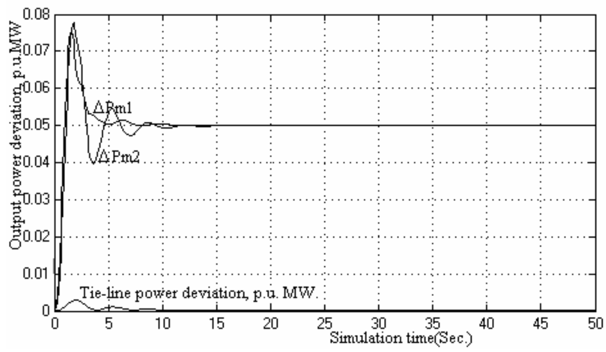

Figure 17. Output power deviations in response to a step load change of $\Delta P_{L1}=\Delta P_{L2}$=0.05p.u.MW in a two-area power system with fuzzy-PI+fuzzy-PD controller.

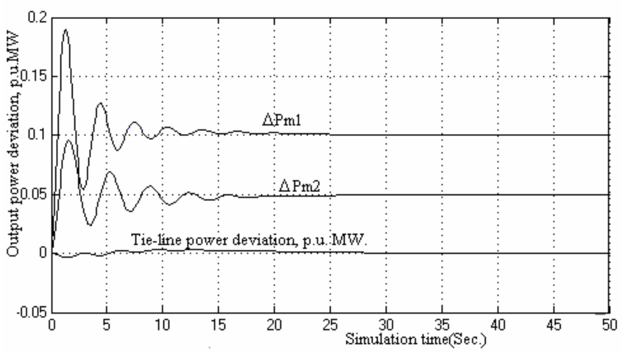

Figure 18. Output power deviations in response to a step load change of ΔP_{L1}=0.1pu and ΔP_{L2}=0.05p.u.MW in a two-area power system with PID controller.

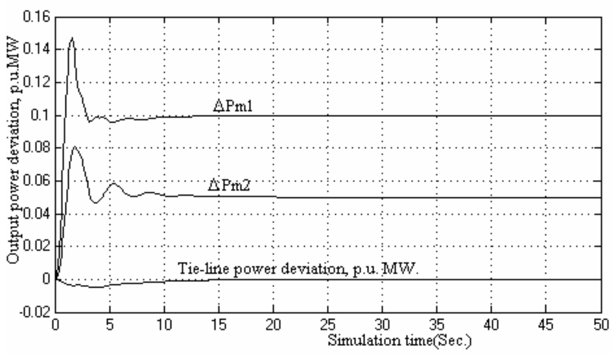

Figure 19. Output power deviations in response to a step load change of ΔP_{L1}=0.1pu and ΔP_{L2}=0.05p.u.MW in a two-area power system with fuzzy-PI+fuzzy-PD controller.

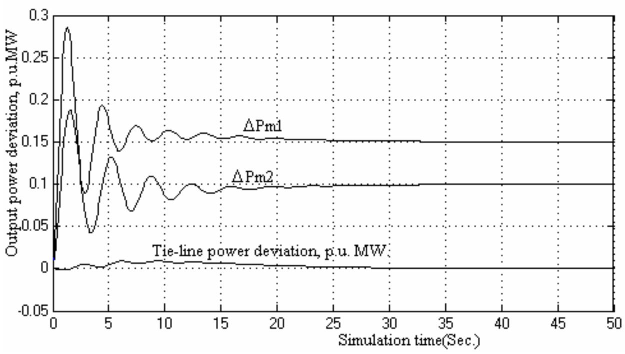

Figure 20. Output power deviations in response to a step load change of ΔP_{L1}=0.15pu and ΔP_{L2}=0.1p.u.MW in a two-area power system with PID controller.

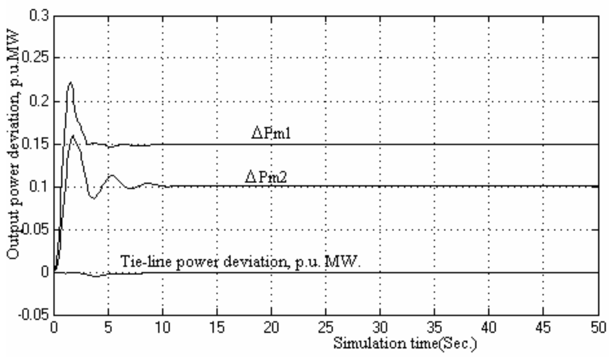

Figure 21. Output power deviations in response to a step load change of ΔP_{L1}=0.15pu and ΔP_{L2}=0.1p.u.MW in a two-area power system with fuzzy-PI+fuzzy-PD controller.

In our simulation study, we chose the gain values of the conventional PID controller according to step load deviations in the power system with two areas. This gain values are K_{Pmax}= 0.3, K_{Imax}= 0.5 and K_{Dmax}=0.15. The changes in frequency, output power and tie-line power flows in response to step load changes in a two area power system with conventional PID controller are shown respectively in Fig.10, 12, 14, 16, 18 and 20. At the same time, the changes of frequency and output power of each area and the changes of tie-line power flow for the same load changes in a two area power system with the fuzzy-PI+fuzzy-PD controller are shown respectively in Fig.11, 13, 15, 17, 19 and 21.

The simulation results of a two area power system according to step load deviations are given as compare with the conventional PID controller and the fuzzy-PI+fuzzy-PD controller. The simulation results demonstrate show that the fuzzy-PI+fuzzy-PD controller improves effectively the damping of the oscillations after the load variation in one of the areas in the power system with two steam turbines. It can be observed that the responses with our proposed the fuzzy-PI+fuzzy-PD controller give better performance than the conventional PID controller.

6. CONCLUSION

In this paper, we have described the design and an application of the fuzzy-PI+fuzzy-PD controller computer aided control system. At the same time, we have presented an efficient approach to the automatic generation control problem of a two-area power system using the fuzzy-PI controller with parallel fuzzy-PD controller. Transient behaviours of the frequency and output power of each area and deviations of tie-line power flows in a two area power system are investigated in accordance with load deviations using MATLAB/Simulink and Fuzzy Logic Toolbox. MATLAB/Simulink Program presents a large resource for investigating AGC in power systems for educational purposes. In the simulation work, the simulation results show that the performance of the fuzzy-PI controller with parallel fuzzy-PD controller is better than conventional PID controller at automatic generation control in a two-area power system.

REFERENCES

[1] Allen E., White N.La, Yoon Y., Chapman J. and Ilic M., "Interactive Object-Oriented Simulation of Interconnected Power Systems Using SIMULINK" ***IEEE Transactions on Education***, 44(1): 87-95 (2001).

[2] Kundur P., Power system stability and control, ***McGraww-Hill*** (1994).

[3] Saadat H., Power System Analysis, ***McGraw-Hill, New York*** (1999).

[4] Khodabakhshian A., Hooshmand R. "A new PID controller design for automatic generation control of hydro power systems" ***Electrical Power and Energy Systems*** 32, 375–382 (2010).

[5] Sabahi K., Teshnehlab M., Shoorhedeli M.A., "Recurrent fuzzy neural network by using feedback error learning approaches for LFC in interconnected power system" ***Energy Conversion and Management*** 50: 938–946 (2009).

[6] Lu C-F, Liu C-C, Wu C., "Effect of battery energy storage system on load frequency control considering governor deadband and generation rate constraints" ***IEEE Trans Power Syst*** 10(3):555–61 (1995).

[7] Cavin JK, Budge MC, Rosmunsen P. "An optimal linear system approach to load-frequency Control" ***IEEE Trans Power Apparatus Syst***, PAS-90:2472–82 (1971).

[8] Ai-Homouz ZM, Abdel-Magid YL. "Variable structure load frequency controllers for multiarea power systems", ***Int J Electr Power Energy Syst***, 15(5):293–300 (1993).

[9] Chang CS, Fu W, "Area load frequency control using fuzzy gain scheduling of PI controllers", ***Electr Power Syst Res***, 42:145–52 (1997).

[10] Hiyama T., "Application of rule based stabilizing controller to power systems", ***IEE Proc C*** 136:175–81 (1989).

[11] Dash PK, Liew AC, Mishra BR, "An adaptive PID stabilizer for power systems using fuzzy Logic", ***Electr Power Syst Re,*** :213–22 (1998).

[12] Kumar A, Malik OP, Hope GS., "Variable structure system control applied to AGC of an interconnected power system", ***IEE Proc,*** 132(C-1):23–9 (1985).

[13] Zribi M, Al-Rashed M, Alrifai M., "Adaptive decentralized load frequency control of multi-area power systems", ***Int J Electr Power Energy Syst,*** 27:573–83 (2005).

[14] Chen G., "Conventional and Fuzzy PID Controller: an overview", ***Int. J. Intell. Control Systems***, 1:235-246 (1996).

[15] Malki H.A., Li H., Chen G., "New Design and Stability Analysis of Fuzzy Proportional Derivative Control System", ***IEEE Trans.Fuzzy System,*** 245-254 (1994).

[16] Wang L.X., A Course in Fuzzy System and Control, Englewood Cliffs, NJ: ***Prentice-Hall***, (1997).

[17] G.K.I. Mann, B.G.Hu and R.G.Gosine, "Analysis of direct action fuzzy PID controller structures", ***IEEE Trans.Syst., Man,*** Cybern. 29(3)371-388 (1999).

[18] Abraham R. J., Das D. and Patra A., "Automatic generation control of an interconnected hydrothermal power system considering superconducting magnetic energy storage", ***International Journal of Electrical Power & Energy Systems,*** 29(8):574-579 (2007).

[19] Bergen A.R., Power System Analysis, ***Prentice Hall***, Second Edition, New Jersey (2000).

[20] Iracleous D.P. and Alexandridis A.T., "A Multi-Task Automatic Generation Control For Power Regulation", ***Electric Power Systems Researc***h, 73(3):275-285 (2005).

[21] Quao W. Z., Mizumoto M., "PID type fuzzy controller and parameter adaptive method", ***Fuzzy Sets Sys,.*** 78:23-25 (1996).

[22] Bhattacharya S., Chatterjee A. and Munshi S., "A new self-tuned PID-type fuzzy controller and a combination of two-term controllers", ***ISA Transactions,*** (43)3:413-426 (2004).

[23] Mann G.K.I., Gosine R.G., "Three-dimensional min–max-gravity based fuzzy PID inference analysis and

tuning", ***Fuzzy Sets and Systems,*** 156(2): 300-323 (2005).

[24] Li H.X., Gatland H.B., "Conventional fuzzy control and its enhancement", ***IEEE Trans.Syst., Man Cybern,*** 26:791-797 (1996).

[25] Malki H.A., Feigenspan D., Misir D., Chen G., " Fuzzy PID control of a flexible joint robot arm with uncertainties for time-varying load", ***IEEE Trans. Control System Technol.,*** 371-378 (1997).