IMPACT OF SLIDER GAIN ON LOAD FREQUENCY CONTROL USING FUZZY LOGIC CONTROLLER

Surya Prakash, Sunil Kumar Sinha, Ajay Shekhar Pandey and Brijesh Singh
Department of Electrical Engineering, Kamla Nehru Institute of Technology, Sultanpur, UP, India
E-mail: shekhar.ajay04@rediffmail.com

ABSTRACT

The interconnected two area systems are modeled and simulated by integration of Fuzzy controller with sliding gain for improved performance specifications like settling time and peak overshoot over the conventional PI controller. The paper investigates the impact of addition of slider gain with fuzzy logic controller for load frequency control of interconnected thermal-thermal and thermal-hydro interconnected power systems. The dynamic responses under small step load increase i.e. 1% (0.01p.u) is obtained with fuzzy logic controller and compared with that of a conventional integral controller, in MATLAB/SIMULINK environment.

Keywords: load frequency control, slider gain, two area interconnected system, fuzzy logic controller.

INTRODUCTION

Load Frequency Control (LFC) is being used for several years as part of the Automatic Generation Control (AGC) scheme in electric power systems. One of the objectives of AGC is to maintain the system frequency at nominal value (50 Hz). In actual power system operations, the load is changing continuously and randomly. The ability of the generation side to track the changing load is limited due to physical/ technical consideration, causing imbalance between the actual and the scheduled generation quantities. This action leads to a frequency variation, the difference between the actual and the synchronous frequency causes mal operation of sophisticated equipments like power converters by producing harmonics [1]. Automatic generation control (AGC) is the regulation of power output of controllable generators within a prescribed area in response to change in system frequency, tie-line loading, or a relation of these to each other, so as to maintain the schedules system frequency and / or the established interchange with other areas within predetermined limits [2]. Therefore, a control strategy is needed that not only maintains constancy of frequency and desired tie-power flow but also achieves zero steady state error and inadvertent interchange. Among the various types of load frequency controllers, the most widely employed is the conventional proportional integral (PI) controller.

A number of state feedback controllers based on linear optimal control theory have been proposed to achieve better performance [3]. Fixed gain controllers are designed at nominal operating conditions and failed to provide best control performance over a wide range of operating conditions. Fuzzy system has been applied [4] to the load frequency control problems with rather promising results. The fuzzy controller offers better performance over the conventional controllers, especially, in complex and nonlinearities associated system. In the steady state of power system, the load demand is increased or decreased in the form of Kinetic Energy stored in generator prime mover set, which results variation of speed and frequency accordingly.

Frequency is also a major stability criterion for large-scale stability in multi area power systems. To improve the stability of the power networks, it is necessary to design a load frequency control (LFC) systems that controls the power generation and active power at tie lines of interconnected system. In interconnected power networks with two or more areas, the generation within each area has to be controlled to maintain the scheduled power interchange. The active and reactive power demands are never steady and they continuously changes with the rising or falling trend of load demand. The proportional integral (PI) controllers do the regulation by taking care of small changes in load demand without frequency and voltage exceeding the prescribed limit (+ 49.5 Hz) [5].

The performance evaluation based on conventional integral controller (PI) and fuzzy controller for two area interconnected thermal-thermal and thermal-hydro power system is proposed, in this paper. Slider gain is included to enhance the performance of conventional and fuzzy controller. The sliding concept arises due to variable structure control (VSC). The objective of VSC [6] has been greatly extended from stabilization to other control functions. The most distinguished feature of VSC is its ability to result in very robust invariant control systems.

Two area control

A two area system consists of two single area systems, connected through a power line called tie-line, is shown in the Figure-1. Each area feeds its user pool, and the tie line allows electric power to flow between the areas. Information about the local area is found in the tie line power fluctuations. Therefore, the tie-line power is sensed, and the resulting tie-line power signal is fed back into both areas. It is conveniently assumed that each control area can be represented by an equivalent turbine, generator and governor system. Symbol used with suffix 1 refer to area 1 and those with suffix 2 refer to area 2.

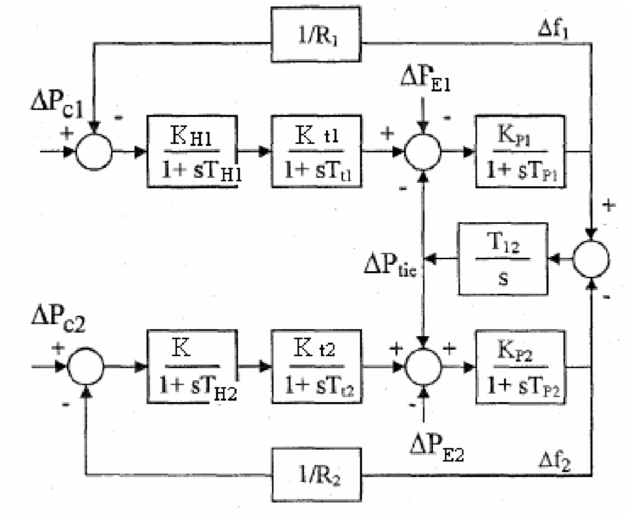


Figure-1. Basic block diagram of conventional two area system.

In an isolated control area case the incremental power $(\Delta P_{G} - \Delta P_{D})$ was accounted for by the rate of increase of stored kinetic energy and increase in area load caused by increase in frequency. Since a tie line transports power in or out of an area, this fact must be accounted for in the incremental power balance equation of each area [7].

Control of the tie-line

The power transfer equation through tie line is

$$P_{12} = \frac{|V_1||V_2|}{x} \sin(\delta_1 - \delta_2) \tag{1}$$

Where, δ_1 and δ_2 are Power angles of end voltages V_1, V_2. For small deviation in the angles , the tie line power changes with the amount i.e. small deviation in δ_1 and δ_2 lot by $\Delta\delta_1$ and $\Delta\delta_2$, Power P_{12} changes to $P_{12} + \Delta P_{12}$.

Therefore, Power transferred from Area 1 to Area 2 is

$$\Delta P_{12}(s) = \frac{2\pi T^{o}}{s}\left(\Delta f_1(s) - \Delta f_2(s)\right) \tag{2}$$

T^0 = Torque produced

In normal operation the power on the tie-line follows from the equation i.e.

$$\left[\Delta P_{T1}(s) - \Delta P_{E1}(s) - \Delta P_{12}(s)\right] = \frac{2H_1}{f_o} s\Delta f_1(s) + B_1\Delta f_1(s) \tag{3}$$

$$= \frac{2H_1}{f_o}\Delta f_1(s)\left(\frac{1}{B_1}s + 1\right) \tag{4}$$

If $$\frac{2H_1B_1}{f_o} = \frac{1}{K_{P1}} , \frac{1}{B_1} = T_{P1} \tag{5}$$

Due to the action of turbine controllers, the generator increases its output by the amount ΔP_T .The net surplus power $\Delta P_T - \Delta P_E$ will be absorbed by the system.

Tie line control has steady state error in frequency in tie-line power flow. To eliminate this, bias control is used.

Let ACE1 = area control error of area 1
ACE2 = Area control error of area 2

Now, $\Delta PR1$ and $\Delta PR2$ are mode integral of ACE1 and ACE2 respectively.

$$\Delta PR1 = -\mathrm{Ki}_1 \int_0^t (\Delta P_{12} + b_1\Delta f_1)\,dt \tag{6}$$

$$\Delta PR2 = -\mathrm{Ki}_2 \int_0^t (\Delta P_{21} + b_2\Delta f_2)\,dt \tag{7}$$

Taking Laplace transform of the Eq. (9),

$$\Delta PR1_{(s)} = -\frac{\mathrm{Ki}_1}{s}\left[\Delta P_{12}(s) + b_1\Delta f_1(s)\right] \tag{8}$$

$$\Delta PR2_{(s)} = -\frac{\mathrm{Ki}_2}{s}\left[\Delta P_{21}(s) + b_2\Delta f_2(s)\right] \tag{9}$$

The step changes ΔP_{D1} and ΔP_{D2} are applied simultaneously in control area 1 and 2 respectively. When steady state conditions are reached, the output signals of all integrating blocks will be constant and their input signal must become zero i.e.

$$\Delta P_{12} + b_1\Delta f_1 = 0 \tag{10}$$

$$\Delta P_{21} + b_2\Delta f_2 = 0 \tag{11}$$

$$\Delta f_1 - \Delta f_2 = 0 \tag{12}$$

$\Delta P_{12} = \Delta P_{tie,1}$ and $\Delta P_{21} = \Delta P_{tie,2}$

Therefore $$\frac{\Delta P_{tie,1}}{\Delta P_{tie,2}} = -\frac{T_{12}}{T_{21}} = -\frac{1}{a_2} = \text{constant} \tag{13}$$

Hence $\Delta P_{tie,1} = \Delta P_{tie,2} = 0$

$\Delta PR_1 = \Delta PR_2$,

And $\Delta f_1 = \Delta f_2 = 0$

Thus, under steady state condition, change in the tie- line power and frequency of each area converges to zero.

Conventional integral controller

When an integral controller is added to each area of the uncontrolled plant in forward path the steady state error in the frequency becomes zero. The task of load frequency controller is to generate a control signal u that maintains system frequency and tie-line interchange power at predetermined values [2].

The block diagram of PI controller is shown in Figure-2 where, the control input

$$\mathrm{ui} = -\mathrm{Ki}\int_0^{\tau}(\mathrm{ACEi})\,dt = -\mathrm{Ki}\int_0^{\tau}(\Delta P_{tie,i} + \mathrm{bi}\Delta \mathrm{fi})\,dt \tag{14}$$

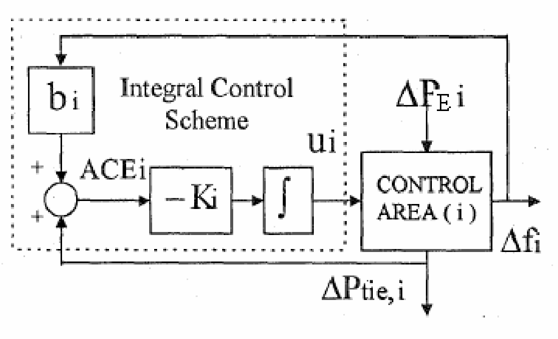


Figure-2. Conventional PI controller.

Conventional Proportional plus Integral controller (PI) provides zero steady state frequency deviation, but it exhibits poor dynamic performance (such as more number of oscillation and more settling time), especially in the presence of parameters variation and non-linearity [9]. In PI Controller Proportionality constant provides simplicity, reliability, directness etc. The disadvantage of offset in it is eliminated by integration but this system will have some oscillatory offset.

FUZZY LOGIC CONTROLLER

The Fuzzy logic control consists of three main stages, namely the fuzzification interface, the inference rules engine and the defuzzification interface [3]. For Load Frequency Control the process operator is assumed to respond to variables error (*e*) and change of error (*ce*).

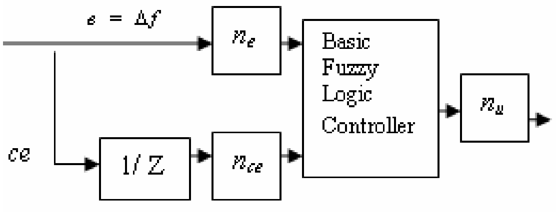


Figure-3. Block diagram of a fuzzy logic controller.

The variable error is equal to the real power system frequency deviation (Δf). The frequency deviation Δf is the difference between the nominal or scheduled power system frequency (f_N) and the real power system frequency (f).Taking the scaling gains into account, the global function of the FLC output signal can be written as.

$$\Delta Pc = F[n_c\, e(k),\ n_{ce}\, ce(k)] \tag{15}$$

Where, n_e and n_{ce} are the error and the change of error scaling gains, respectively, and F is a fuzzy nonlinear function. FLC is dependant to its inputs scaling gains [9]. The block diagram of FLC is shown in Figure-3. Output control gain is n_u and z is the maximum membership degree [3].

A label set corresponding to linguistic variables of the input control signals, *e (k) and* ce (k), with a sampling time of 0.01 sec is as follows:

L(*e*, *ce*) = { NB, NM, ZE, PM, PB},

Where, NB = Negative Big, NM = Negative Medium, ZE = Zero, PM = Positive Medium, PB= Positive Big

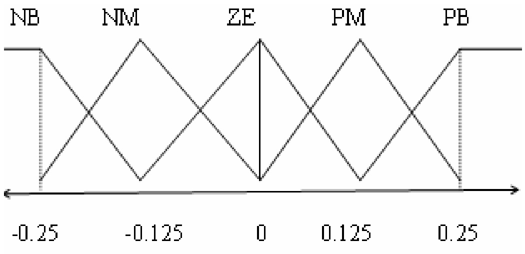


Figure-4. Membership function for the control input variables.

Fuzzy logic controller has been used in both the thermal-thermal and hydro-thermal interconnected areas. Attempt has been made to examine with five number of triangular membership function (MFs) which provides better dynamic response with the range on input (error in frequency deviation and change in frequency deviation) i.e. universe of discourse is -0.25 to 0.25. The numbers of rules are 25. The dynamic response are obtained and compared to those obtained with conventional integral controllers. Further, several inputs have been tried out and dynamic responses are examined in order to decide suitable inputs to the fuzzy logic controller (FLC) [10]. The membership functions (MFs) for the input variables are shown in Figure-4.

Table-1. Fuzzy inference rule for fuzzy logic controller.

Input		e(k)				
		NB	NM	ZE	PM	PB
ce(k)	NB	NB	NB	NM	NM	ZE
	NM	NB	NB	NM	ZE	ZE
	ZE	NM	NM	ZE	PM	PM
	PM	ZE	PM	PM	PB	PB
	PB	ZE	ZE	PM	PB	PB

SIMULATION AND RESULTS

In this work, Thermal-Thermal and Thermal-Hydro interconnected power system are considered with PI controller and fuzzy logic controller with and without sliding gain to illustrate the performance of load frequency control. The parameters are used for simulation [5] are as given in appendix. The various simulink models developed are shown in the Figures (Figure-5 to Figure-9).

For model given in Figure-5, frequency deviation (Δf) plots for both cases (thermal and hydro) are drawn separately for 1% step load increase (Figures 10 and 11). It indicates that the steady state error is zero in both thermal and hydro area with the settling time almost same (nearly

40 sec) as shown in Figures 10 and 11. But the transient response is different in both the cases because of the system complexity and unequal area parameters.

Due to inclusion of sliding gain in PI Controller (Figure-6), for two area thermal-thermal interconnected plants, the response shows that steady state error is reduced to zero with settling time nearly of 10 sec. The maximum peak overshoot in transient condition is nearly 0.027 pu absolute value. Hence, with the induction of slider gains the numbers of oscillations are reduced along with settling time (Figure-12).

With 1%(.01pu) step load increase in thermal-thermal, the areas with fuzzy controllers (Figure-7), the steady state error is minimized to zero with settling time nearly of 10 sec (Figure-13). The maximum peak overshoot in transient condition is nearly 0.030 pu absolute value.

Having 0.01pu step load increase in both thermal-thermal areas (Figure-8), the steady state error is minimized to zero with settling time nearly of 07 sec, as shown in Figure-14. The maximum peak overshoot in transient condition is nearly 0.031 pu absolute value.

Hence, the inclusion of slider gain not only reduces the number of oscillations but settling time as well. With same step load increase in Hydro-Thermal reheat areas, amalgamated fuzzy controller and slider gain (Figure-9), the steady state error is minimized to zero and settling time is nearly of 21 sec as shown in Figure-15. The maximum peak overshoot in transient condition is nearly 0.073 pu absolute value.

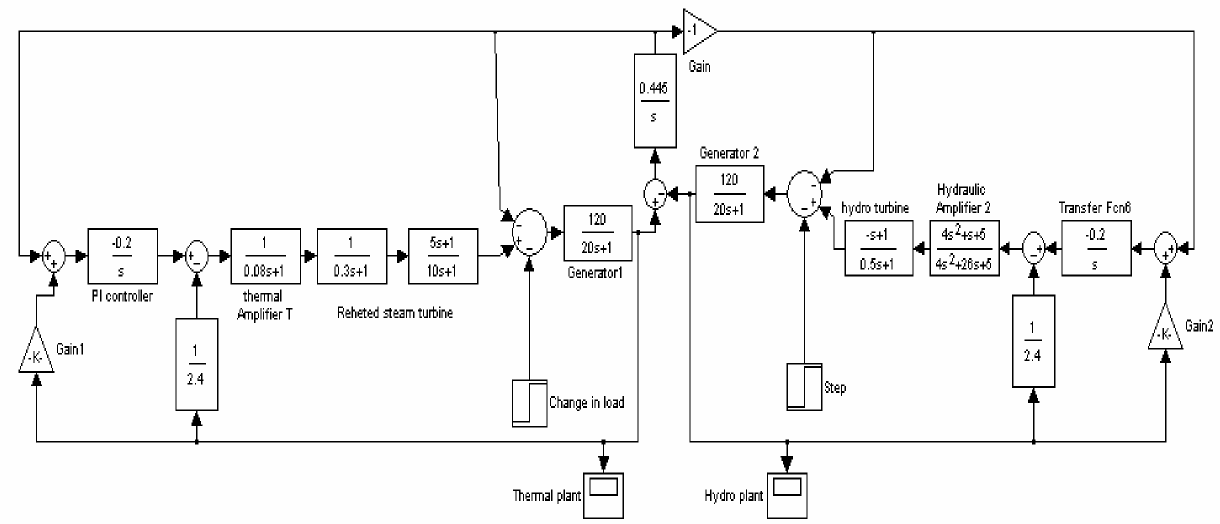


Figure-5. Simulink model of the two area hydro-thermal interconnected with PI controller.

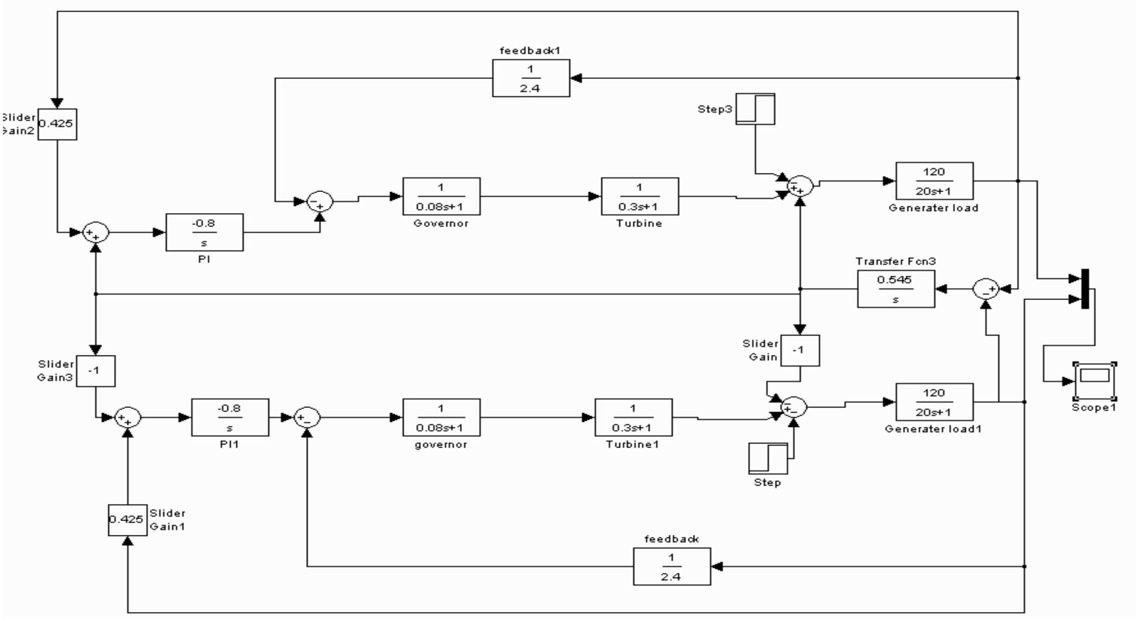


Figure-6. Simulink model of the two area thermal- thermal plant interconnected PI controller with slider gain.

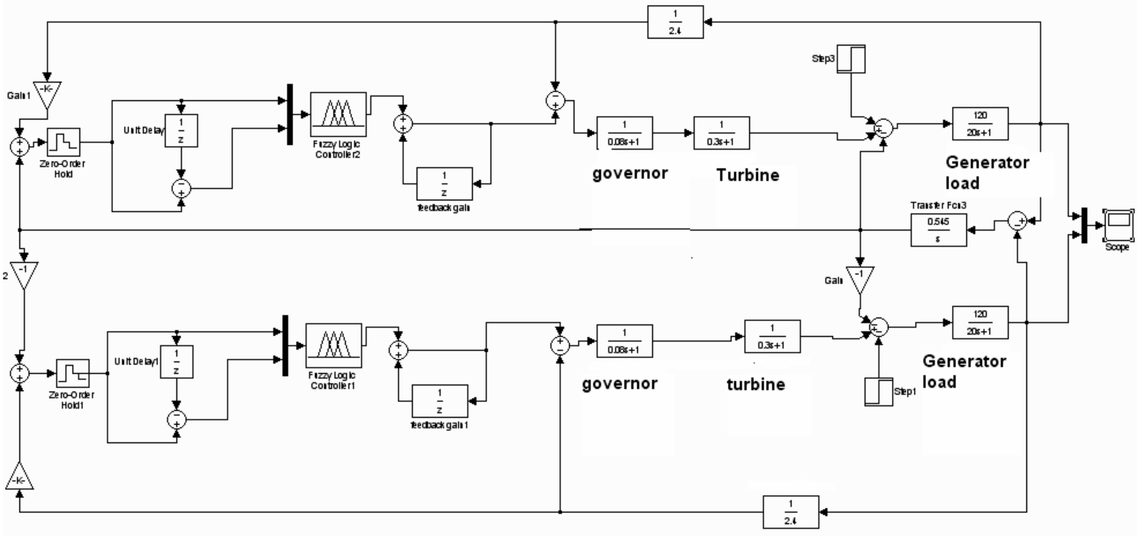


Figure-7. Simulink model of two area interconnected thermal-thermal interconnected system with fuzzy controller.

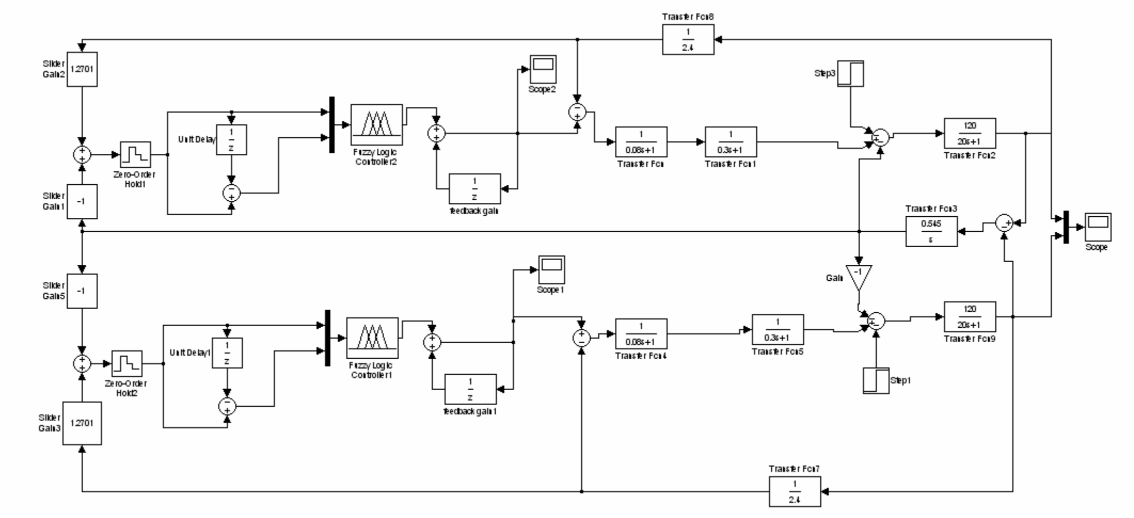


Figure-8. Simulink model of two area interconnected thermal-thermal plant with fuzzy controller and sliding gains.

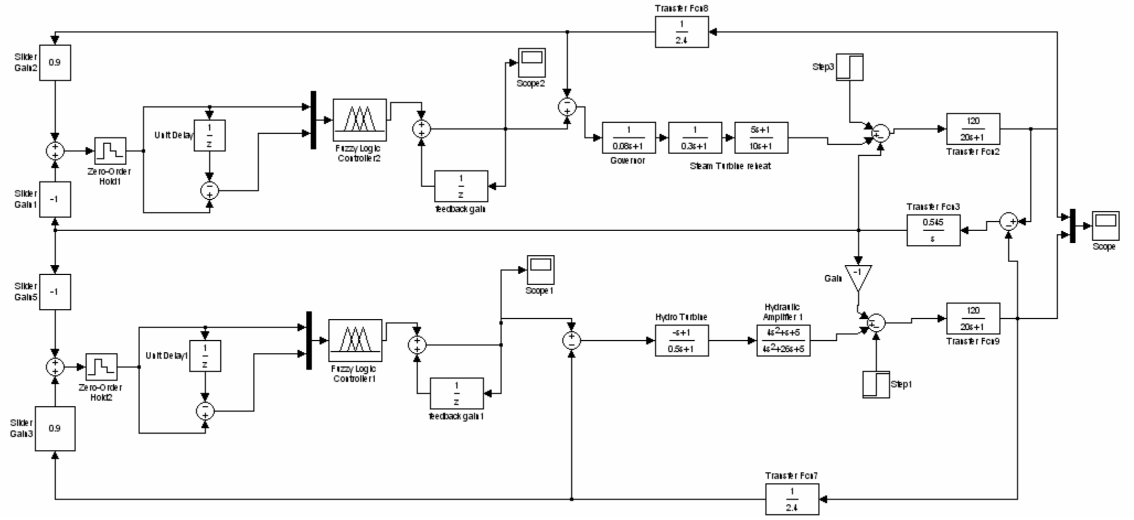


Figure-9. Simulink model of two area interconnected hydro-thermal reheat plant with fuzzy controller and sliding gains.

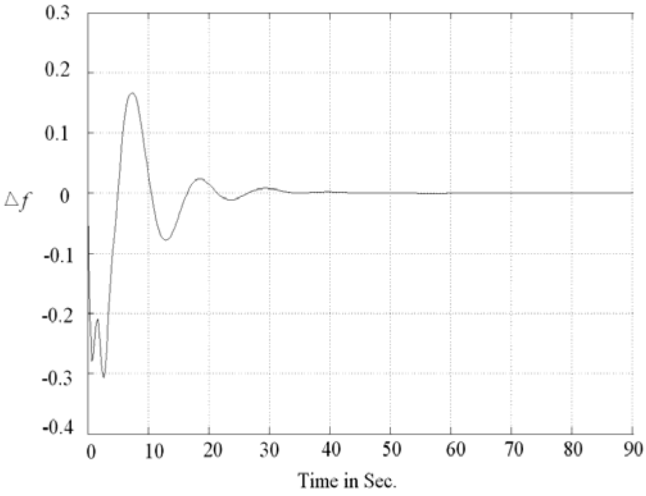


Figure-10. Response of thermal plant with PI controller.

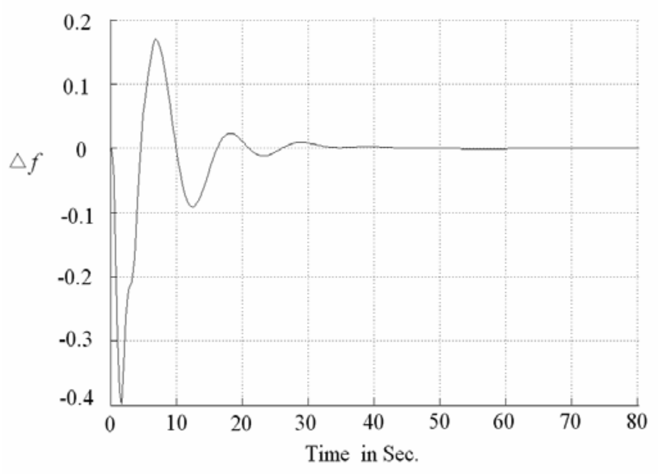


Figure-11. Response of hydro plant with PI controller.

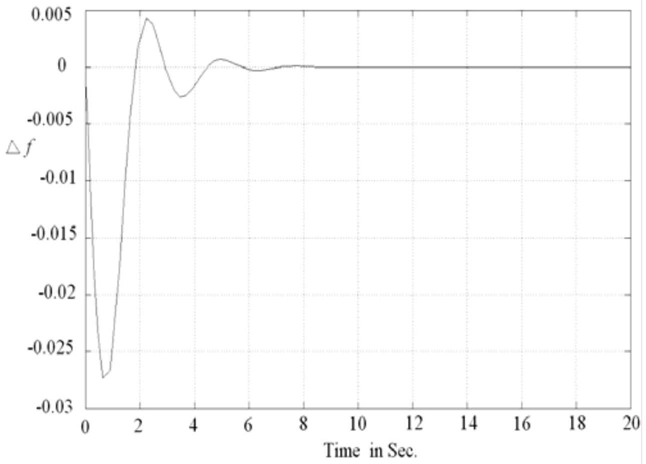


Figure-12. Response of the PI controller with slider gain for two area thermal-thermal interconnected plant.

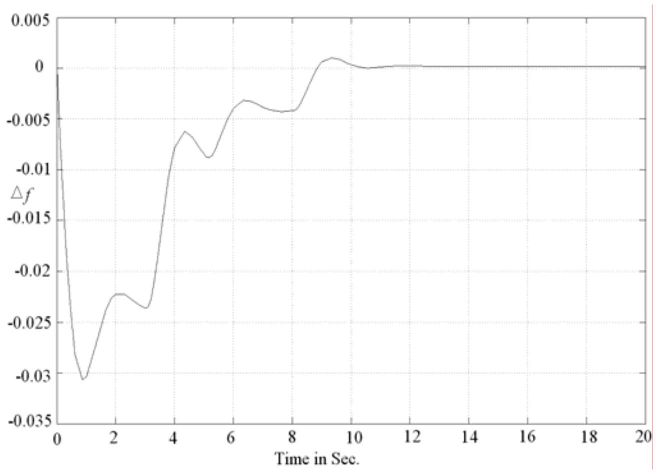


Figure-13. Response of fuzzy controller with two area thermal-thermal interconnected plant.

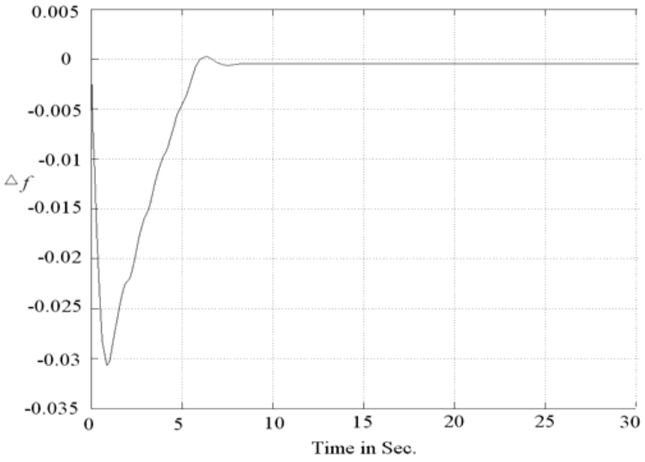


Figure-14. Response of two area thermal-thermal inter-connected plant with fuzzy controller and slider gain.

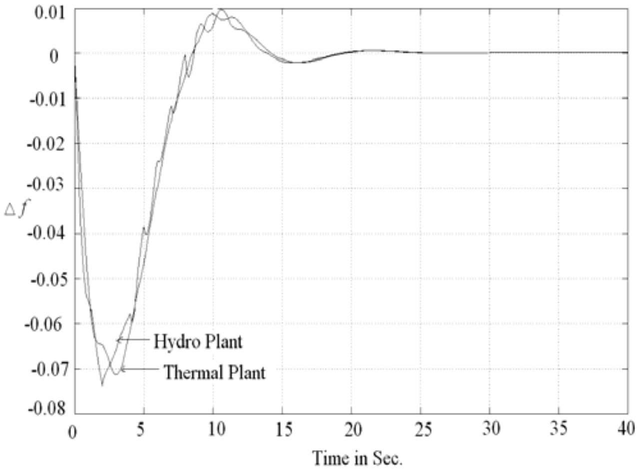
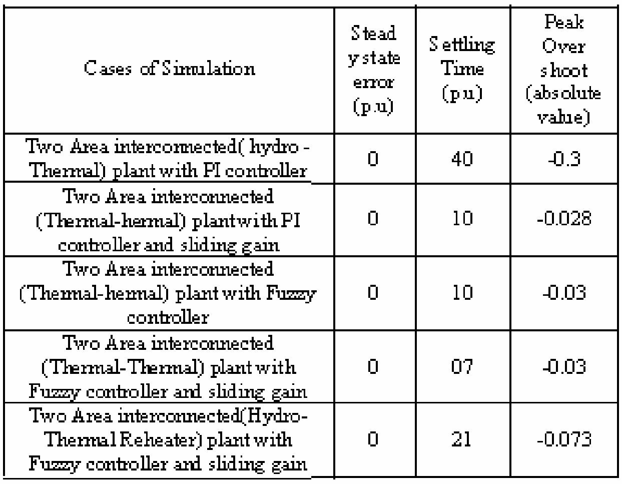


Figure-15. Response of two area interconnected hydro-thermal reheat plant with fuzzy controller and slider gain.

CONCLUSIONS

The integration of Fuzzy Controller with slider gain provides better dynamic performance and reduces the oscillation of the frequency deviation (Table-2) as compared to the conventional PI controller, which provides zero steady state frequency deviation with 1% (0.01p.u) step load increment in power system, and also exhibits poor dynamic performance (such as more number of oscillation and more settling time) in the presence of parameters variation and non-linearity.

Table-2. Comparative results.



Cases of Simulation	Steady state error (p.u)	Settling Time (p.u)	Peak Over shoot (absolute value)
Two Area interconnected(hydro -Thermal) plant with PI controller	0	40	-0.3
Two Area interconnected (Thermal-hermal) plantwith PI controller and sliding gain	0	10	-0.028
Two Area interconnected (Thermal-hermal) plant with Fuzzy controller	0	10	-0.03
Two Area interconnected (Thermal-Thermal) plant with Fuzzy controller and sliding gain	0	07	-0.03
Two Area interconnected(Hydro-Thermal Reheater) plant with Fuzzy controller and sliding gain	0	21	-0.073

Therefore, the integration of slider gain with fuzzy logic controller not only enhances the accuracy but also responsible for the better PI control action, even for complex dynamical systems

REFERENCES

[1] George Gross and Jeong Woo Lee. 2001. Analysis of Load Frequency Control Performance Assessment Criteria. IEEE transaction on Power Systems. 16(3): 520-525. August.

[2] Elgerd O. I. 1982. Electric Energy System Theory: An Introduction. Mc-Graw Hill.

[3] Jawad Talaq and Fadel Al- Basri. 1999. Adaptive Fuzzy gain scheduling for Load Frequency Control IEEE Transaction on Power Systems. 14(1): 145-150, February.

[4] J. Nanda and J.S Kakkarum. 200. Automatic Generation Control with Fuzzy logic controllers considering generation constraints. In: Proc. of 6th Intl. Conf on Advances in Power System Control Operation and managements. Hong Kong. November.

[5] A. Magla and J Nanda. 2004. Automatic Generation Control of an interconnected hydro- Thermal System Using Conventional Integral and Fuzzy logic Control. In: Proc. IEEE Electric Utility Deregulation, Restructuring and Power Technologies. April.

[6] John Y. Hung. 1993. Variable Structure Control: A Survey. IEEE Transaction on Industrial Electronics. 40(1). February.

[7] Kundur P. 1994. Power System Stability and Control. Mc-Graw Hill, New York.

[8] Timothy. J. Ross. 1995. Fuzzy logic with engineering application. Mc-Graw Hill.

[9] Q. P. Ha. 1998. A Fuzzy sliding mode controller for Power System Load Frequency Control. 2nd International Conference of Knowledge based Intelligent Electronic System. Adelaide, Australia. 21-23 April.

[10] M. Masiala, M. Ghnbi and A. Kaddouri. 2004. An Adaptive Fuzzy Controller Gain Scheduling for Power System Load-Frequency Control. lEEE International Conference on Industrial Technology (ICIT).

[11] D. P. Kothari, Nagrath. 2003. Modern Power System Analysis. Tata MC Gro Hill. 3rd Edition.

Appendix

Parameters are as follows:
f = 50 Hz,
R1 = R2 = 2.4 Hz/ per unit MW,
Tg = 0.08 sec,
Tp = 20 sec,
P tiemax = 200 MW,
Tr = 10 sec,
kr = 0.5,
H1 = H2 = 5 sec,
Pr1= Pr2 = 2000MW,
Tt = 0.3 sec ,
Kp1= Kp2 = 120 Hz.p.u/MW,
Kd = 4.0,
ki = 5.0,
Tw = 1.0 sec,
D1 = D2= 8.33 * 10^{-3} p.u MW/Hz.

Nomenclature

F	Nominal system frequency
P_{ri}	Area rated power,
$\mathrm{H_i}$	Inertia constant,
ΔP_{Di}	Incremental load change,
ΔPg_i	Incremental generation change,
$Di = \frac{\Delta P_{Di}}{\Delta fi}$	
T_{12}:	Synchronizing coefficient,
T_{g}:	Steam governor time constant,
K_r	Reheat constant,
T_{R}	Reheat time constant,
T_t	Steam turbine time constant,
$\mathrm{R_i}$	Governor speed regulation parameter,
B_i	Frequency bias constant
T_{pi}	2Hi / f * Di,
K_{pi}	1/ Di, Kj: Integral gain,
K_d, K_p, K_i	Electric governor derivative, proportional and integral gains,
K_{t}	Feedback gain of FLC,
T_{w}	Water starting time,
ACE	Area control error, *P*: Power,
E	Generated voltage,
V	Terminal voltage,
δ	Angle of the Voltage V,
$\Delta\delta$	Change in angle,
ΔP	Change in power,
Δf	Change in supply frequency,
Q	Reactive Power,
$\mathrm{V_F}$	Field voltage of generator field winding,
ΔPc	Speed changer position,
R	Speed regulation of the governor,
K_{H}	Gain of speed governor,
T_{H}	Time constant of speed governor,
K_1, $K2$, $K3$, $K4$, $K5$	Constants,
K_{p}	1/B = Power system gain,
T_{p}	2H / B f_0 = Power system time constant