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Design Fuzzy-PI Based Controller for Load Frequency Control of Thermal - Thermal Area Interconnected Power System

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ABSTRACT
This paper presents how to design proportional integral controller and Fuzzy-PI based controller for efficiently load frequency control. Loads on the electrical system always vary in relation to that time, which results in diversity of frequency, causing frequency control problems to be loaded. The frequency difference is highly undesirable and the maximum allowable difference in frequency is ± 0.5 Hz. This paper load frequency control is done by PI controller, which is a conventional controller. This type of controller is slow and the controller does not allow the designer to keep in mind the potential change in operating conditions and non-linearity in the generator unit. To overcome these flaws, new intelligent controllers like Fuzzy-PI Controller are presented to extinguish tie-line power due to deviation in frequency and various load disturbances.

The effectiveness of the proposed controller has been confirmed using the MATLAB / SIMULINK software. The results show that the PI-fuzzy controller provides fast response, little undershoots and negligible overshoot with small state transfer time to reach the final stable position.

KEY WORDS: *PI controller, Fuzzy controller, two area power system, load frequency control*

1. INTRODUCTION

For large power systems consisting of interconnected control areas, load frequencies, it is important to keep the frequency and the inter-area energy close to the planned values. The mechanical input power is used to control the frequency of the generators, and the change in frequency and line voltage is measured, which is a measure of the change in rotor angle. A well designed power system should be able to guarantee the acceptable quality of the power supply by keeping the frequency and voltage levels within tolerable limits.

Changes in the network load mainly affect the system frequency, while the reactive power is less sensitive to frequency changes and depends mainly on voltage fluctuations. Thus, the control of the active and reactive power in the power grid is treated separately. The load frequency control is mainly concerned with the control of the system frequency and the active power, while the automatic voltage regulator loop regulates the changes of the reactive power and voltage magnitude. Load frequency control is the basis of many advanced concepts of large scale control of the power system.

The load frequency control (LFC) controls the actual power and frequency. MATLAB provides an excellent environment for modeling and programming. It has great flexibility and utility for engineering applications. SIMULINK is a visual modeling tool, which works on MATLAB shell. The goal of the load frequency control (LFC) is to maintain zero steady state errors in a multi area interconnected power system. The change in voltage and frequency from the nominal values, when there is any mismatch in real power and reactive power generations and demands. It can be provided by sensitivity analysis that mismatches in the real power balance affects primarily the system frequency, but leaves the bus voltage essentially unaffected. So, a control system is essential to cancel the effects of the sudden load changes and to keep the frequency at the nominal value [3–5]

1.1 Two-area power system model

A two-area interconnected thermal power system as shown in Fig. 1 is considered. The system is widely used in literature for the design and analysis of AGC [7]. In Fig. 1, $B1$ and $B2$ are the frequency bias parameters; $ACE1$ and $ACE2$ are area control errors; X1 and X2 are the control outputs from the controller; $R1$ and $R2$ are the governor speed regulation parameters in p.u. Hz; T_{H1} and T_{H2} are the speed governor time constants in seconds; ΔP_{H1} and ΔP_{H2} are the governor output command (p.u.); T_{T1} and T_{T2} are the turbine time constant in seconds; $\Delta PT1$ and $\Delta PT2$ are the change in turbine output powers; ΔP_{E1} and ΔP_{E2} are the load demand changes; K_{P1} and K_{P2} are the power system gains; T_{P1} and T_{P2} are the power system time constant in seconds; ΔP_{Tie} is the incremental change in tie line power (p.u.); Δf_1 and Δf_2 are the system frequency deviations in Hz. The relevant parameters are given in Appendix A.

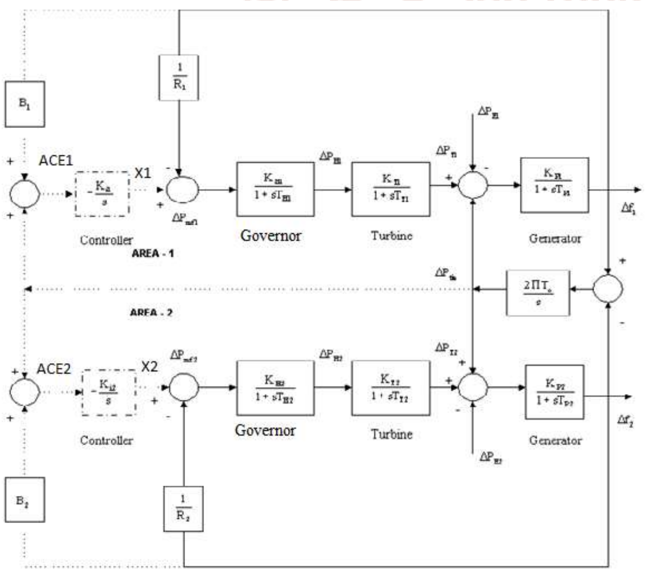

Figure 1: Two area Thermal–Thermal plant with conventional PI controller

1.2 Modeling of the tie-line

The well known power transfer equation is

$$P_{12}^{\,o} = \frac{|V_1||V_2|}{x}\sin(\delta_1 - \delta_2) \qquad (1)$$

Where δ_1 and δ_2 are the angles of end voltages V_1 and V_2 respectively. The sequence of subscript indicates that the tie line defines positive in power direction 1 to 2.

For tiny deviation in the angles and the tie line changes with the power amount

$$\Delta P_{12} \approx \frac{|V_1||V_2|}{x}\cos(\delta_1 - \delta_2)(\Delta\delta_1 - \Delta\delta_2) \qquad (2)$$

In accordance with the concept of "electrical stiffness" of synchronous machines, we define "synchronizing coefficient" of a line

$$T^o = \frac{|V_1|\,|V_2|}{x}\cos(\delta_1 - \delta_2) \quad (3)$$

Thus the equation (2) can be written as

$$\Delta P_{12} = T^o(\Delta\delta_1 - \Delta\delta_2) \qquad (4)$$

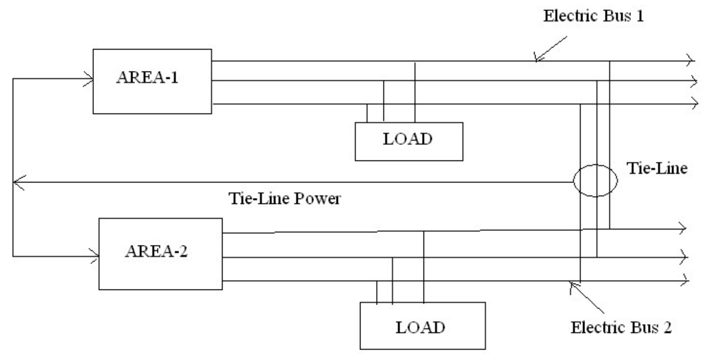

Figure 2: Conventional Two Area System: Basic Block Diagram

The frequency deviation is related to the reference angle by the formula

$$\Delta f = \frac{1}{2\pi}\frac{d(\delta + \Delta\delta)}{dt} = \frac{1}{2\pi}\frac{d(\Delta\delta)}{dt}$$

$$\text{or } \frac{d(\Delta\delta)}{dt} = 2\pi\Delta f$$

$$\text{or } \Delta\delta = 2 \cdot 2\pi \int_0^t \Delta f\,dt$$

Thus the equation (3.4) can be written as

$$\Delta P_{12} = 2\pi T^o\left(\int_0^t \Delta f_1 dt - \int_0^t \Delta f_2 dt\right)$$

Taking Laplace transformation of equation

$$\Delta P_{12}(s) = \frac{2\pi T^o}{s}\left(\Delta f_1(s) - \Delta f_2(s)\right) \qquad (5)$$

The above equation can be represented as in figure (3)

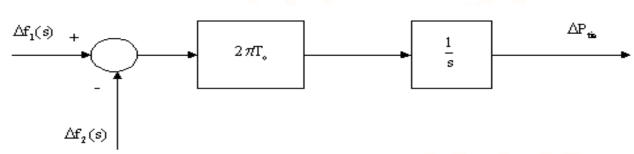

Figure 3: Block Diagram Representation of a Tie – Line

Similarly the incremented tie line power expected from area 2 is given by

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

The power balance equation for single area can be given by

So for the double area, the equation should be modified as follows

$$\Delta P_{T1} - \Delta P_{E1} = \frac{2H_1}{f_o}\frac{d(\Delta f_1)}{dt} + B_1\Delta f_1 + \Delta P_{12}$$

$$\left[\Delta P_{T1}(s) - \Delta P_{E1}(s) - \Delta P_{12}(s)\right] = \frac{2H_1}{f_o} s\Delta f_1(s) + B_1\Delta f_1(s) \quad (6)$$

$$\text{If } T_{P1} = \frac{2H_1}{B_1 f_0} \quad K_{P1} = \frac{1}{B_1}$$

Equation (6) can be written as

$$\Delta f_1(s) = G_{P1}(s)\left[\Delta P_{T1}(s) - \Delta P_{E1}(s) - \Delta P_{12}(s)\right]$$

$$G_{P1}(s) = \frac{K_{P1}}{1 + sT_{P1}}$$

Thus the complete block diagram representation of two area load frequency control is given in figure (1).

2. Ziegler -Nichols Rule Based Tuning

For comparison the PID controller was tuned using conventional Ziegler –Nichols tuning rule based on the critical gain K_u and critical period P_u. Values of Ku and P_u were calculated from the sustained oscillations of the output by employing only proportional controller. The sustained oscillation response with proportional controller under critical gain is shown in Figure (4). As per the Ziegler-Nichols rule the settings for PID controller parameter are given in the following table [1]. Controller parameters calculated for conventional controller are given in Table [2].

Table 1: Ziegler-Nichols tuning rules

Type of control	$G_c(s)$	K_c	T_i	T_d
Proportional (P)	K_c	0.5 K_u	-	-
Proportional–Integral(PI)	$K_c\left(1+\frac{1}{sT_i}\right)$	$0.45K_u$	$\frac{P_u}{1.2}$	-
Proportional-Integral-Derivative (PID)	$K_c\left(1+\frac{1}{sT_i}+sT_d\right)$	$0.6K_u$	$\frac{P_u}{2}$	$\frac{P_u}{8}$

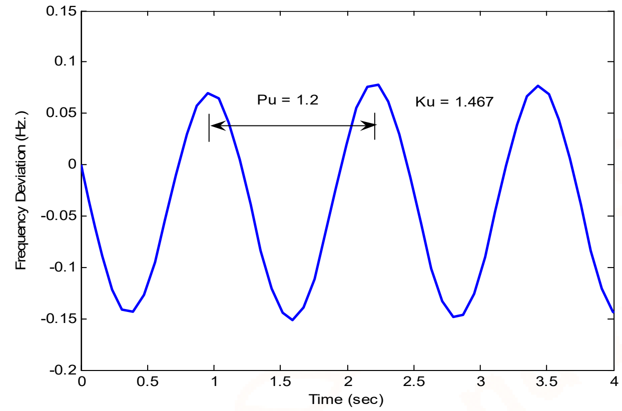

Figure 4: System response with proportional controller under critical gain

Table 2: Controller Parameters for conventional controller

K_c	T_i	K_i
$0.45.K_u = 0.66$	$P_u/1.2 = 1$	$K_c/T_i = 0.66$

3. Different types of controllers

3.1 PI - Controller

The 'PI' controller will eliminate forced oscillations and steady state error, which will result in the operation of the on-off controller and the 'P' controller, respectively. However, starting an integral mode has a negative impact on the response speed and overall stability of the system.

Therefore, the PI controller does not increase the reaction rate. It can be expected because the PI controller has no means of predicting what will happen to the bug in the near future. This problem can be solved by introducing a derivative mode that is able to predict what will happen to the error in the near future and thus reduce it [13]

3.2 Fuzzy Controller

The general architecture of a fuzzy controller is depicted in Figure (5) [14]. The origin of a fuzzy controller is an fuzzy inference engine (FIS), which includes fuzzification,, knowledge base evaluation and defuzzification in the data flow. The inputs to the systems are the error and the change in the error of the feedback loop, while the output is the control action. There are 7 trapezoidal membership functions in each input i.e.NB (Negative Big), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium), PB (Positive Big). The mamdani rule base adopted here and the defuzzification process is centroid method. The fuzzy rules are shown in Table [3].

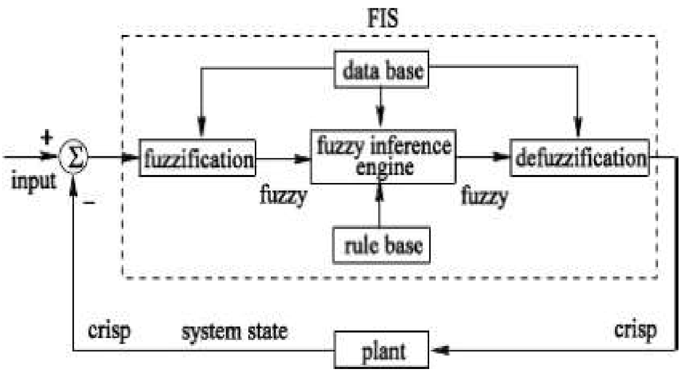

Figure 5: Structure of fuzzy logic controller

Table 3: Fuzzy Rule Base

E / ΔE	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PB	PB	PM	PM	PS
NM	PB	PM	PM	PM	PS	PS	PS
NS	PM	PM	PS	PS	PS	PS	ZE
ZE	NS	NS	NS	ZE	PS	PS	PS
PS	ZE	NS	NS	NS	NS	NM	NM
PM	NS	NS	NM	NM	NM	NB	NB
PB	NS	NM	NB	NB	NB	NB	NB

A fuzzy system is described by a set of IF-THEN rules and uses diverse membership functions. To solve the load-frequency control problem in fuzzy controller, controller inputs are Area Control Error and derivative of Area Control Error and its output are considered as the control signal. The member ship function uses in fuzzy logic controller for Error, change in Error and output is shown in figure (5).

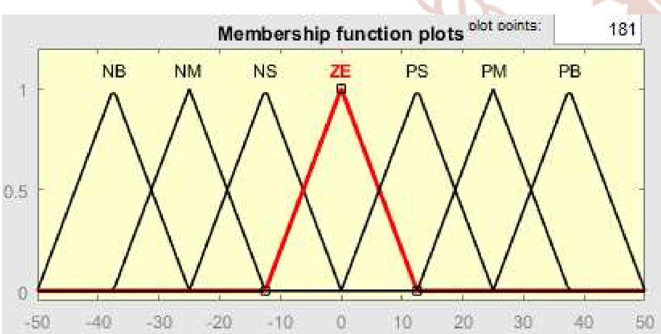

Figure 5: Membership functions of inputs (E, ΔE) and output

3.3 PI- Fuzzy Logic Controller

A Fuzzy-PI controller designed based on a linear model of power system under the loading condition FLC designed to eliminate the need for continuous operator attention and used automatically to adjust some variables the process variable is kept at the reference value. A FLC consists of three sections Namely, fuzzifier, rule base, and defuzzifier. The Fuzzy-PI controller structure is shown in Figure (6).

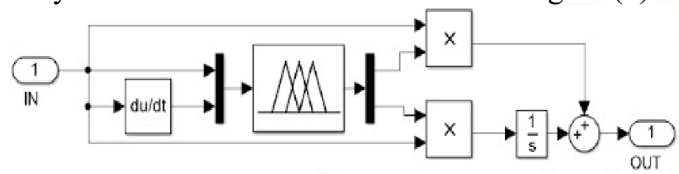

Figure 6: PI-Fuzzy Logic controller in Simulink

4. Results and Simulation

Performed simulations using PI and Fuzzy-PI controllers applied to a two area interconnected power systems. The developed system is simulated with 10 % step load disturbance in area 1. Due to this the change in dynamic responses of the system has been observed, as shown in below Figures. It is examine from the output responses that the proposed Fuzzy-PI Controller is stable and less oscillations and the settling time also improved considerably. Also this output justified that this interconnection is valid for Thermal-Thermal systems. For conventional PI controller and Fuzzy-PI controller, the main objective is to improve the control performance

4.1 Uncontrolled case

The frequency changes in area-1 and area-2 for the 10% step load perturbation is shown in figure (7). There is a steady state error in the response.

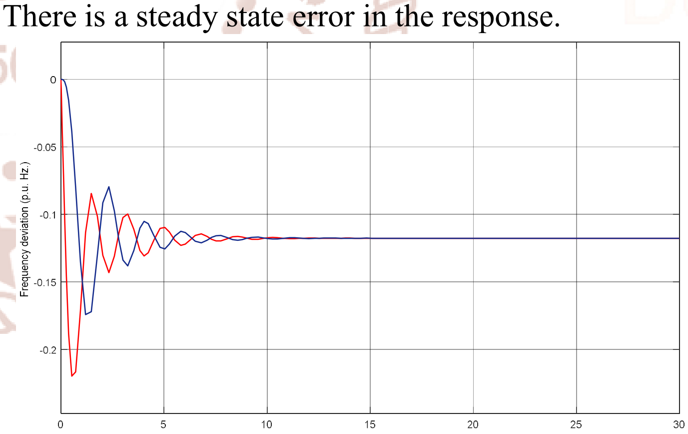

Figure 7: Two area Thermal-Thermal plant (Uncontrolled) with a disturbance of 10 % in area-1: Frequency deviation of area -1 and area – 2

4.2 Controlled Case with Proportional plus Integral Controller

The frequency changes in area-1 and area-2 for the 10% step load perturbation is shown in figure (8) and (9). (10% step load perturbation is given in area -1).

The steady state error is zero in this case. The frequency deviation of area-1 is much more

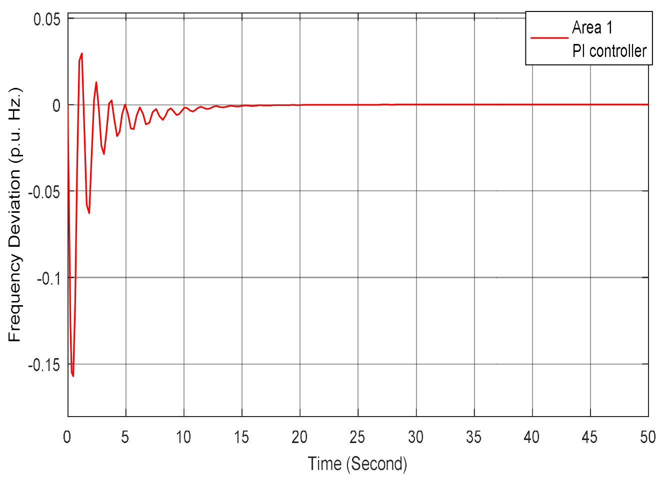

Figure 8: Two area Thermal-Thermal plant (Controlled with PI) with Disturbance of 10 % in area-1: Frequency deviation of area -1

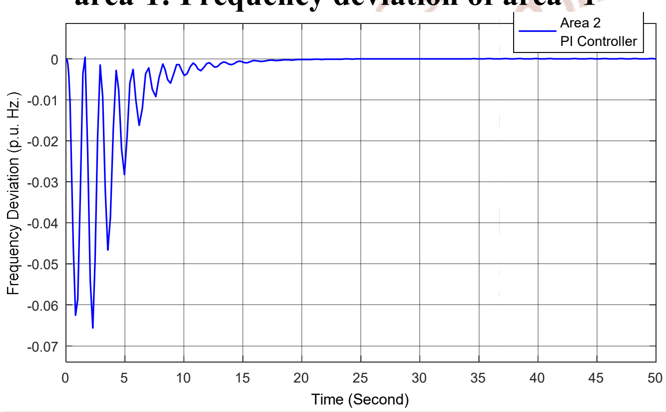

Figure 9: Two area Thermal-Thermal plant (Controlled with PI) with a Disturbance of 10 % in area-1: Frequency deviation of area -2

4.3 Controlled Case with Fuzzy-PI Controller

The frequency changes in area-1 and area-2 for the 10% step load perturbation is shown in figure (10) and (11). (10% step load perturbation is given in area -1). The steady state error is zero in this case. The frequency deviation of area-1 is much more

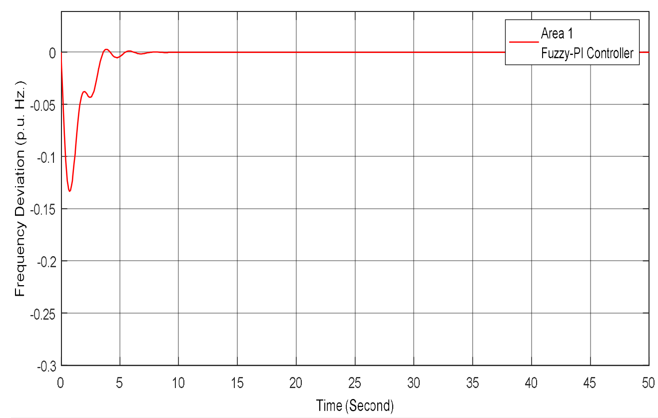

Figure 10: Two area Thermal-Thermal plant (Controlled with Fuzzy-PI) With disturbance of 10 % in area-1: Frequency deviation of area -1

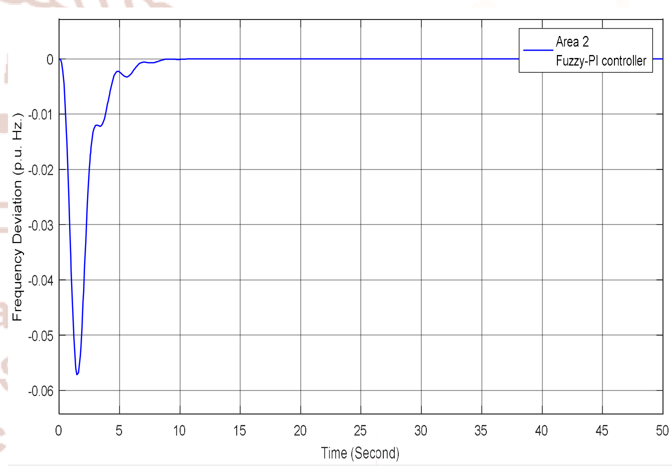

Figure 11: Two area Thermal-Thermal plant (Controlled with Fuzzy-PI) With Disturbance of 10 % in area-1: Frequency deviation of area -2

4.4 Comparison between PI and Fuzzy-PI Controller

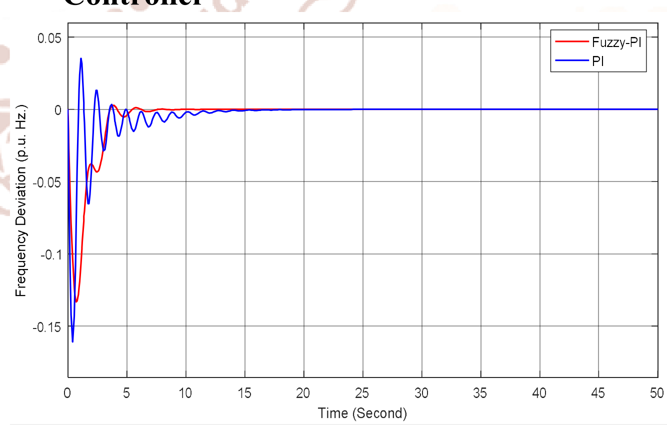

Figure 12: Comparison result between Fuzzy-PI and PI controller with Disturbance of 10 % in area-1: Frequency deviation of area -1

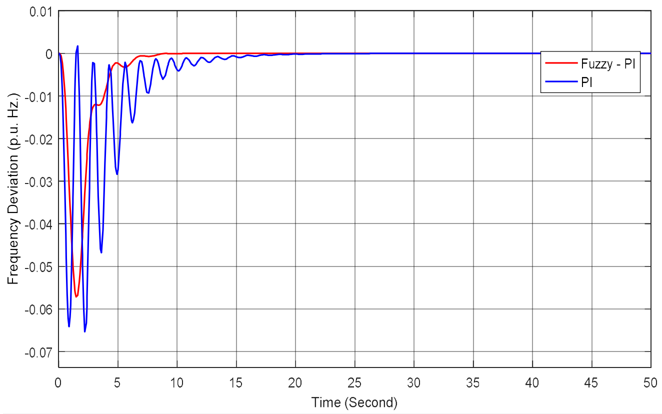

Figure 13: Comparison result between Fuzzy-PI and PI controller in with Disturbance of 10 % in area-1: Frequency deviation of area -2

The comparison of peak undershoots; Peak Overshoot and Settling Time via PI controller and Fuzzy-PI controller are given in Table [3].

Table 3: Thermal-Thermal plant: PI Controller Vs Fuzzy-PI Controller

	Peak Undershoot		Peak Overshoot		Settling Time(Sec)	
Two Area	Area -1	Area -2	Area -1	Area -2	Area-1	Area-2
PI Controller	-0.1557	-0.0629	0.0297	0.0003	12.88	14.85
PI-Fuzzy Controller	-0.1320	-0.0562	0.0027	0.0000	7.25	8.55

5. Conclusion

In this paper a new technique Fuzzy-PI controller is designed for automatic load frequency control of interconnected Thermal - Thermal systems. The controller performances Fuzzy-PI approach is in work for a Load Frequency Control for Generation of Interconnected Power System. The proposed controller can handle the non-linearity and at the same time faster than other conventional controllers. Also the simulation results are compared with a conventional other controller. From the Result shown in figure (8) to figure (13). The results obtained for double area Thermal-Thermal plant shows the superiority such controllers over the conventional PI controllers. In Fuzzy-PI Controller the settling time has been reduced in area1 and area 2 are 5.63 sec and 6.30 sec respectively. It is explicit that the performance in term of settling time and overshoot of fuzzy-PI controller is better. There is no steady state error. So fuzzy-PI controller shows its effectiveness over the conventional PI controller.

The result shows that the proposed intelligent controller is having improved dynamic response and at the same time faster than conventional controller

APPENDIX

Parameter	Value
$K_{P1} = K_{P2}$	120 Hz. / p.u. MW
$K_{H1} = K_{H2}$	1 Hz. / p.u. MW
$K_{T1} = K_{T2}$	1 Hz. / p.u. MW
$T_{P1} = T_{P2}$	20 Sec.
$T_{H1} = T_{H2}$	0.08 Sec.
$T_{T1} = T_{T2}$	0.3 Sec.
$B_1 = B_2$	0.425 p.u. MW / Hz.
$R_1 = R_2$	2.4 Hz. / p.u. MW
T_o	0.0867 p.u. MW/Hz

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