Analysis of Load Frequency Control for Multi Area System Using PI and Fuzzy Logic Controllers

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***Abstract*— Transmission of power from one area to other area in interconnected power system causes variations in both the system frequency and tie line power interchange. Load frequency control is one of the efficient ways to solve these kinds of problems. In this paper a three area system is considered i.e., area-1with thermal power plant, area-2 with hydro power plant and area-3 with nuclear power plant. These areas are combined together in three ways to get two area systems and two types of three area linear system models are also developed in MATLAB Simulink environment. In order to analyze the performance of a multi area system we are comparing the values of undershoot and settling time for each case using conventional control and Fuzzy logic control techniques separately for 1% disturbance in either area. Simulation result shows that the fuzzy logic controller gives efficient results for the LFC problem.**

Keywords—Load Frequency Control, Fuzzy Logic Controller, Interconnected Power System, Hydro Model, Nuclear Model

I. INTRODUCTION

Due to rapid growth of population all over the world the demand of the power is also increasing, but with the use of single conventional source in the power system the demand can't be reached. This can be done by using interconnection of conventional energy source through which they can share the load and automatically demand can be easily fulfilled. Interconnection of systems with tie lines can cause frequency fluctuations, so LFC method is used to reduce the transitions and make the steady state error to zero. The interconnected power system consists of control areas namely single-area, two-area and multi-area connected system. In a control area, in order to maintain the frequency constant the speed of all the generators need to be either increased or decreased.

In single area control the change in the system load will create the change in generation of the power which in turn results in a deviation in steady state frequency. In order to maintain frequency deviation to zero we need to use the integral controller. The integral controller gain need to be calibrated for obtaining transient response without any deviations but in case of complex and variable dynamic characteristics fuzzy logic control gives the good dynamic response when compared to the integral controller in load frequency problems

In multi area control system the load is shared between many areas. A multi area system consists of two or more single area systems, connected through a power line called tie-line. Each control area can be represented by an equivalent generator, turbine and governor system. In an isolated control area case the incremental power (ΔPG -ΔPD) was accounted for the rate of increase of stored kinetic energy and increase in area load caused by increase in frequency. Since a tie line transports power into the area or outside the area, this fact must be considered for the incremental balance equation of power for each control area [2].

II. MODELLING

A. Two Area Thermal-Hydro Power Plant

Turbine and generator set in the thermal power system are used to convert the temperature and steam pressure into mechanical energy. The parameters for this model are considered from thermal and hydro power systems are considered [3].Mathematical modeling of thermal speed governer is given as

$$\Delta Y_E(S) = [\Delta P_C(S) - \frac{1}{R}\,\Delta F(S)] \text{ x } \left(\frac{K_{gS}}{1+sT_{gS}}\right) \quad (1)$$

Modelling equation of thermal generator is given as

$$\Delta F(S) = [\Delta P_G(S) - \Delta P_D(S)] \times \left(\frac{K_{pS}}{1+sT_{pS}}\right) \quad (2)$$

Transfer function of thermal load model is given as

$$\Delta F(s) = \Delta P_m(s) - \Delta P_D(s)\left(\frac{1}{2Hs+D}\right) \qquad (3)$$

As for the requirement of hydro-electric power system modeling for load frequency control, speed governor, turbine and generator should be modeled. In order to represent the hydraulic turbine and water column to be stable few assumptions are to be done i.e., maintaining negligible resistance and considering penstock pipe to be inelastic and water incompressible.

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Transfer function model of hydro turbine is

$$\frac{\Delta P_{Th}}{\Delta Y_{eh}} = \frac{1-sT_W}{1+0.5sT_W} \qquad (4)$$

Model of hydroelectric speed governer

$$T_{Gh} = \left(\frac{K_{gh}}{1+sT_{gh2}}\right)\left(\frac{1+sT_{h2}}{1+sT_{h4}}\right) \qquad (5)$$

The generator dynamics is modeled by swing equation and given in equation

$$\frac{2H}{\omega}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \qquad (6)$$

Load model for hydro system

$$\Delta P_e = \Delta P_L + D\Delta w \qquad (7)$$

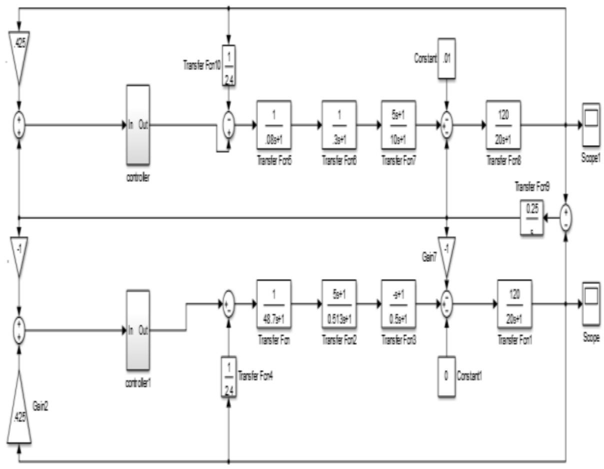

Figure 1: Simulink model of controlled two area Thermal-Hydro System

B. *Two Area Thermal Nuclear Model*

As for the requirement of nuclear power system modeling for load frequency control, speed governor, turbine and generator should be modeled. These are modeled as follows: The transfer function block diagram model of governor is shown as in Figure

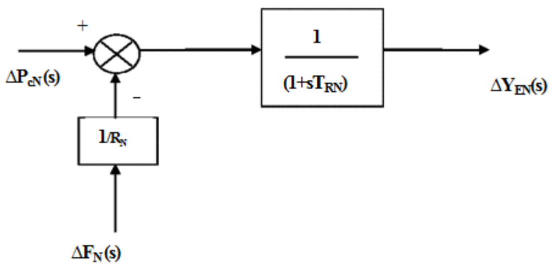

Figure 2: Transfer function of governer

Model Development of Turbine of Nuclear Power Plant

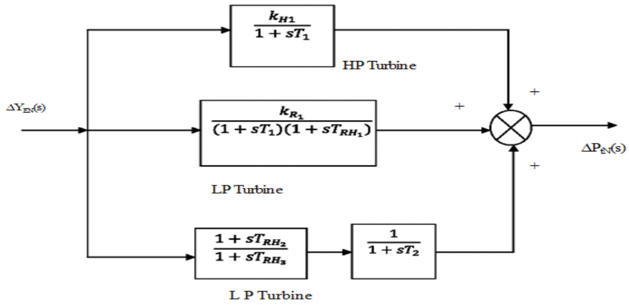

Figure 3: Turbine model of Nuclear power plant

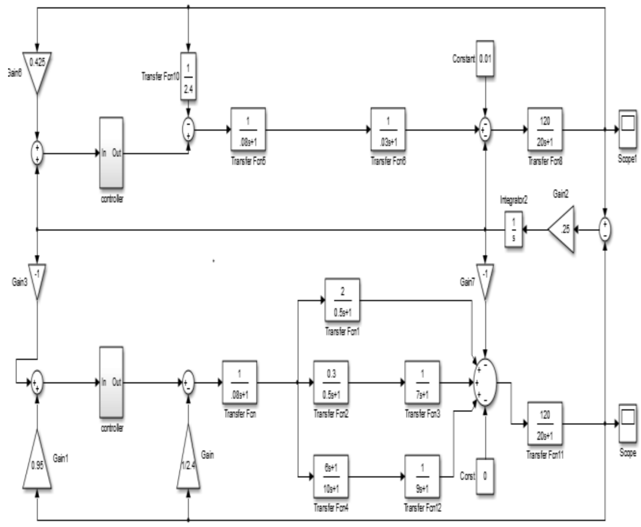

Figure 4: Simulink model of two area thermal-nuclear system

III. Three Area Hydro-Nuclear-Thermal System

Three-area interconnected hydro-nuclear-thermal system model is shown below:

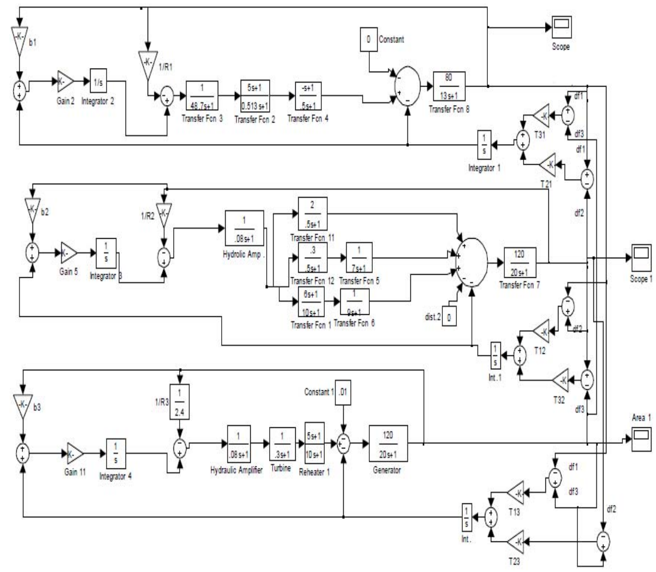

Figure 5: Simulink model of three area system.

IV. CONTROL TECHNIQUES

A. Conventional PI Controller

PI controller is one of the most popular controllers in the industry. The proportional gain provides stability and high frequency response. In order to overcome the steady state error caused in P controller we are using the P-I controller. This type of controllers is mainly used where speed parameter is not considered in the system. The integral term insures that the average error is driven to zero. The characteristic of the PI controller is infinite gain at zero frequency. Advantages of PI include that it eliminate forced oscillations the only disadvantage in PI controllers is that it produce excessive overshoot time to a step command [4].

The PI controller is characterized by the transfer function given below [5]

$$G_c(s) = K_p(1 + \frac{1}{sT_i}) \qquad (8)$$

B. Fuzzy logic controller

The idea behind the Fuzzy Logic Controller (FLC) is to fuzzify the controller inputs, and then infer the proper fuzzy control decision based on defined rules. Fuzzy knowledge based system is shown in Figure. The FLC output is then produced by defuzzifying this inferred fuzzy control decision [6]. Thus, the FLC processes contain following main components:

- Fuzzification
- Rules Definition
- Inference Engine
- Defuzzification

C. Rule Base for Fuzzy Logic System

Working of fuzzy logic controller is based on 49 rules. These fuzzy logic rules are in ‘‘if and then‟ format. These rules can be placed in form of table (as in table 1). Here error and cumulative error are two inputs of fuzzy logic controller and we have only one output [7], [8]. Fuzzy rule table is given in table-1, input and output membership functions are given

Table 1: FAM Table

		Cumulative Error						
		nb	**nm**	**ns**	**Z**	**ps**	**pm**	**pb**
	nb	pb	pb	pm	Pm	ps	ps	z
	nm	pb	pb	pm	Pm	ps	z	z
	ns	pb	pb	pm	Pm	z	ns	ns
Error	**z**	pb	pm	pm	z	ns	nm	nb
	ps	pm	pm	ns	ns	nm	nb	nb
	pm	ps	ps	ns	nm	nb	nm	nb
	pb	ns	ns	nm	nm	nm	nm	nb

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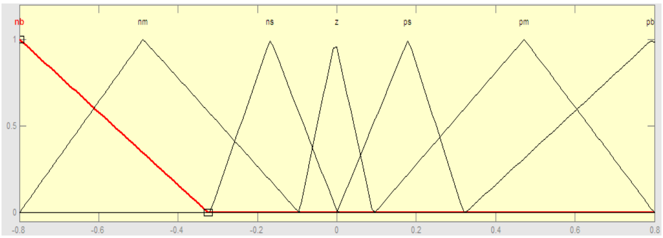

Figure 6: Error Input Membership Function

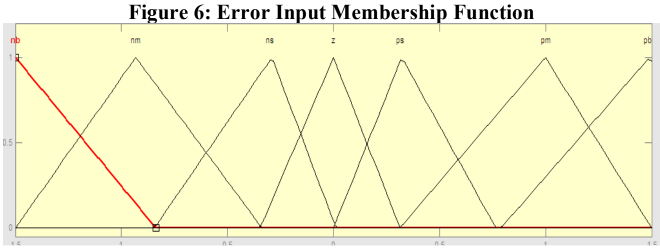

Figure 7: Cumulative Error Input Membership Function

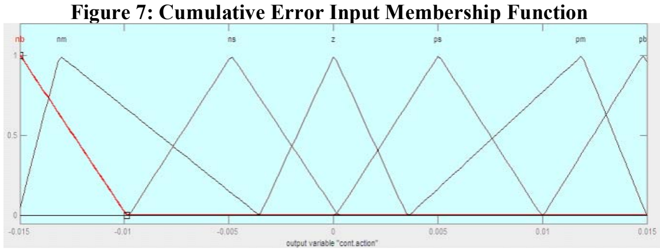

Figure 8: Output Membership Function

V. SIMULATION

The following simulations were performed on two areas with thermal-thermal, thermal-nuclear and thermal-hydro and three area hydro-nuclear-thermal systems with namely two controllers i.e., PI and FUZZY LOGIC controller with 1% disturbance in either area.

Simulation is carried out in two area system for the following cases:

- Simulated result parameters of area 2 when disturbance in area 1
- Simulated result parameters of area 1 when disturbance in area 2

Simulation is carried out in three area system for the following cases:

- Simulated result parameters of area 1 when disturbance in area 1
- Simulated result parameters of area 2 when disturbance in area 1
- Simulated result parameters of area 3 when disturbance in area 1

A. Two Area Thermal-Thermal:

Case-1: Simulated result parameters of area 2 when disturbance in area 1

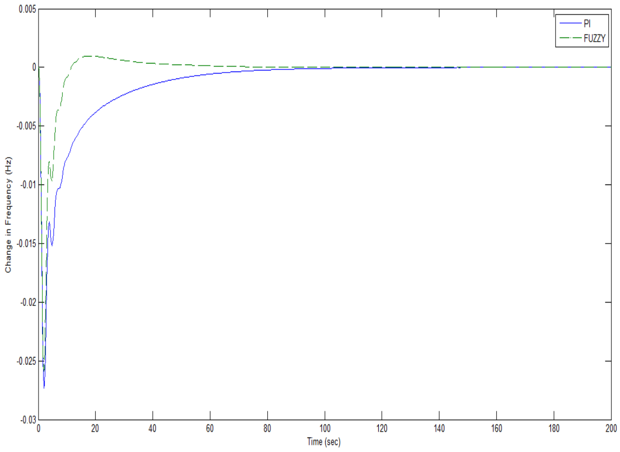

Figure 9: Simulated Result area 2 of two area Thermal System when disturbance in area1with reheat unit

Table 2: Time analysis parameters of simulations of area 2 for Thermal-Thermal system when disturbance in area 1

Parameters	System with PI controller	System with FUZZY controller
Undershoot(Hz)	0.027	.026
Settling time(sec)	96	64

Case-2: Simulated result parameters of area 1 when disturbance in area2

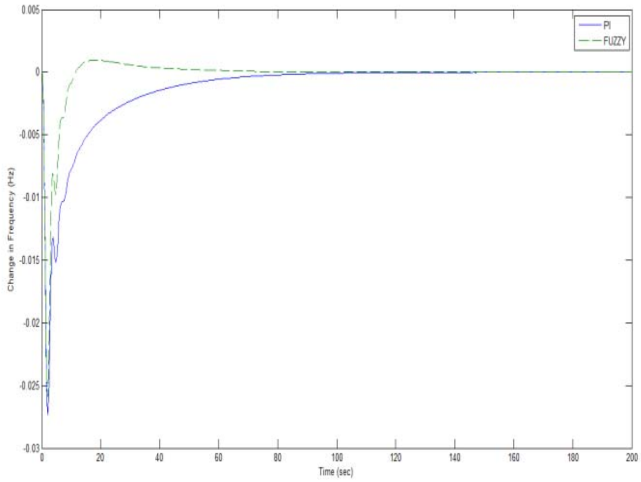

Figure 10: Simulated Result of area 1 of two area Thermal system when disturbance in area 2with reheat unit

Table 3: Time analysis response parameters of simulations for Thermal-Thermal system for area-1when disturbance in area 2

Parameters	System with PI controller	System with FUZZY controller
Undershoot(Hz)	0.027	.026
Settling time(sec)	96	64

B. Two Area Thermal-Hydro System

Case-1: Simulated result parameters of area 2 when disturbance in area1

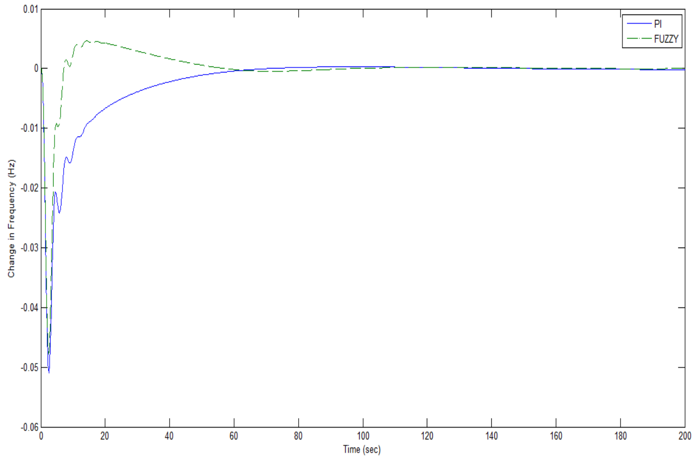

Figure 11: Simulated Result of area 2 of two area Thermal-Hydro System when disturbance in area1

Table 4: Time analysis parameters of simulations of area2 for Thermal-Hydro system when disturbance in area 1

Parameters	System with PI controller	System with FUZZY controller
Undershoot(Hz)	0.051	.047
Settling time(sec)	110	68

Case-2: Simulated result parameters of area 1 when disturbance in area2

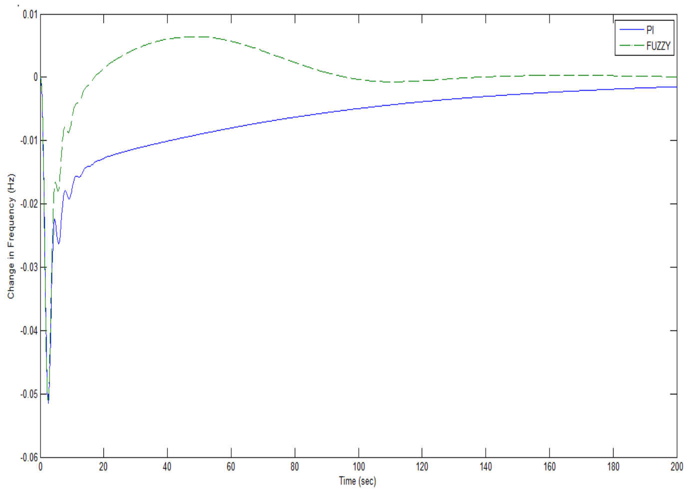

Figure 12: Simulated Result of area 1 of two area Thermal-Hydro System when disturbance in area 2

Table 5: Time analysis parameters of simulations of area1 for Thermal-Hydro system when disturbance in area 2

Parameters	System with PI controller	System with FUZZY controller
Undershoot(Hz)	0.051	.047
Settling time(sec)	>200	140

C. Two Area Thermal-Nuclear System with Controller

Case-1: Simulated result parameters of area 2 when disturbance in area1

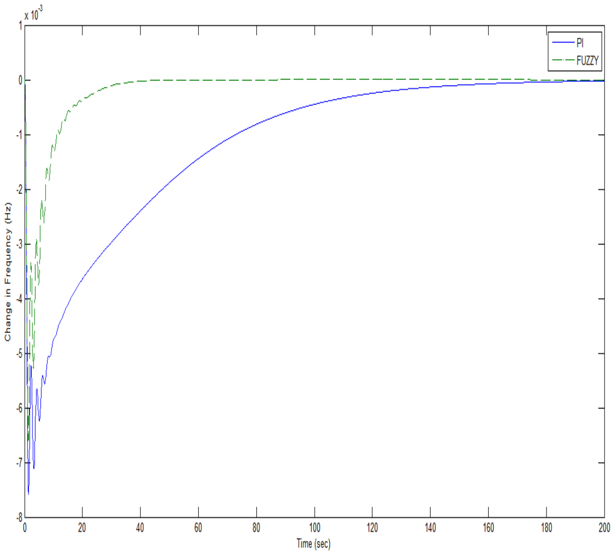

Figure 13: Simulated Result of area 2 of two area Thermal-Nuclear System when disturbance in area1

Table 6: Time analysis response of simulations of area 2 for Thermal-Nuclear system when disturbance in area 1

Parameters	System with PI controller	System with FUZZY controller
Undershoot(Hz)	0.0075	.0072
Settling time(sec)	200	47

Case-2: Simulated result parameters of area 1 when disturbance in area2

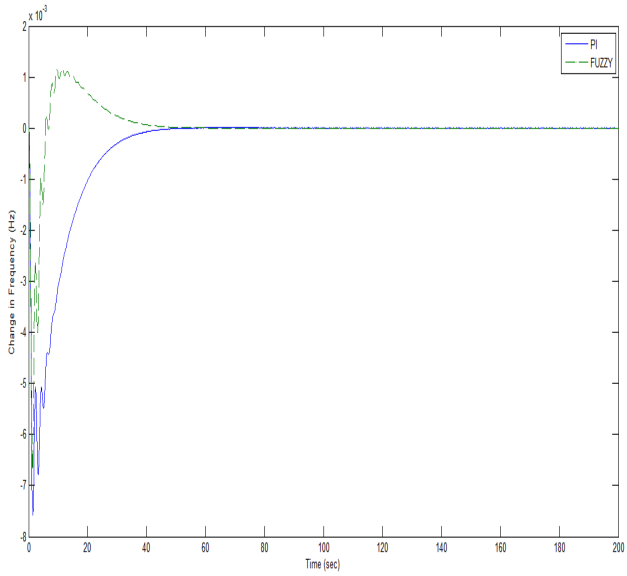

Figure 14: Simulated Result of area 1 of two area Thermal-Nuclear System when disturbance in area2

Table 7: Time analysis parameters of area1 for Thermal-Nuclear system when disturbance in area-2

Parameters	System with PI controller	System with FUZZY controller
Undershoot(Hz)	0.0075	.0071
Settling time(sec)	100	54

D. Three Area Hydro-Nuclear- Thermal Systems:

Case-1: Simulated result parameters of area 1 when disturbance in area1

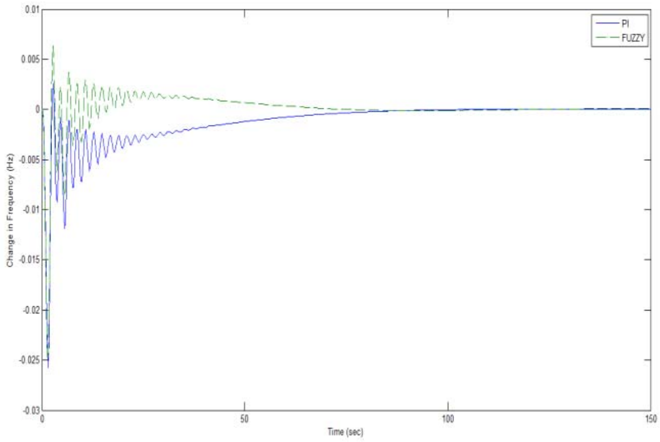

Figure 15: Simulated Result of Hydro system for three area Hydro-Nuclear-Thermal System when disturbance in area 3

Table 8: Time analysis parameters of simulations of Hydro system for Hydro-Nuclear- Thermal system when disturbance in area 3

Parameters	System with PI controller	System with FUZZY controller
Undershoot(Hz)	0.026	0.025
Settling time(sec)	104	73

Case-2: Simulated result parameters of area 2 when disturbance in area1

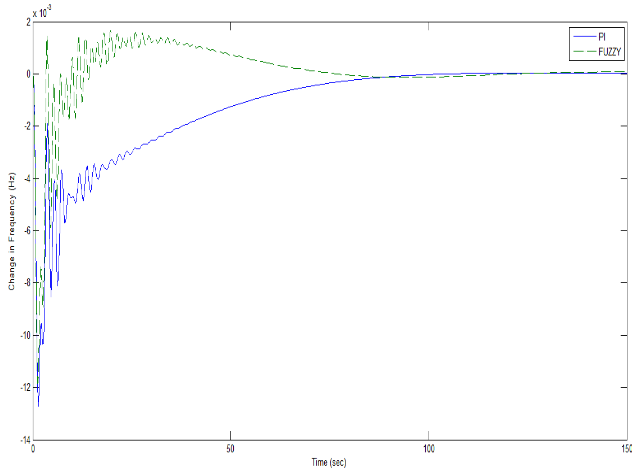

Figure 16: Simulated Result of Nuclear system for three area Hydro-Nuclear-Thermal System when disturbance in area 3

Table 9: Time analysis parameters of simulations of Nuclear system for Hydro-Nuclear- Thermal system when disturbance in area 3

Parameters	System with PI controller	System with FUZZY controller
Undershoot(Hz)	0.0013	0.0012
Settling time(sec)	85	80

Case-3: Simulated result parameters of area 3 when disturbance in area1

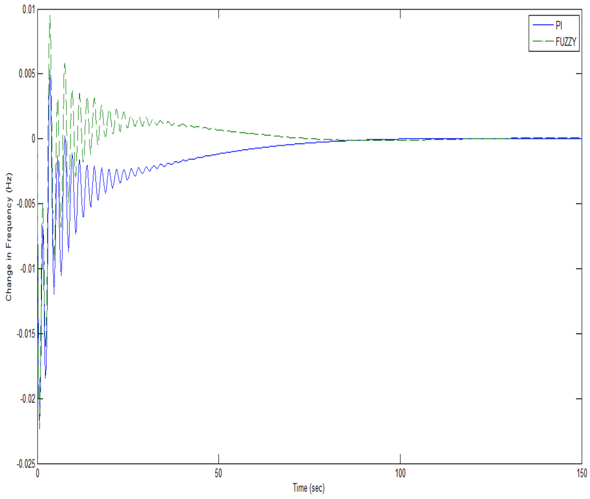

Figure 17: Simulated Result of Thermal system for three area Hydro-Nuclear-Thermal System when disturbance in area 3

Table 10: Time analysis parameters of simulations of Thermal system for Hydro-Nuclear- Thermal system when disturbance in area 3

Parameters	System with PI controller	System with FUZZY controller
Undershoot(Hz)	0.0225	0.022
Settling time(sec)	80	76

VI. Conclusion

Investigation of two area and three area systems has been done with PI and fuzzy logic controllers. Considering the disturbance as 1%, the result for different cases are compared and it shows that fuzzy logic controller gives improved dynamic response than PI controller. With the aid of fuzzy controller the transients in the frequency response reduced to a great extent.

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