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Load Frequency Control of Interconnected Hydro-Thermal Power System Using Fuzzy and Conventional PI Controller

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Abstract: ***This paper shows how to regulate the power supply from interconnected hydro thermal power system by load frequency control (LFC). Thus the LFC helps in maintaining the scheduled system frequency and tie-line power interchange with the other areas within the prescribed limits. The load frequency of hydro thermal power system is controlled by both conventional PI and fuzzy logic controllers but the peak overshoot and settling time of fuzzy controller is less than that of conventional PI controller and this is clear from their results. The control strategies guarantees that the steady state error of frequencies and interchange of tie-lines power are maintained in a given tolerance limitations. The performances of these controllers are simulated using MATLAB/SIMULINK package.***

KEYWORDS
Area Control error (ACE), Automatic generation control, Interconnected hydrothermal system, Load Frequency Control and Tie line power.

INTRODUCTION

To increase the reliable and uninterrupted power, there is a necessity to interconnect all the power systems. In this study, due attention is given to the interconnection of hydro-thermal system. Normally, thermal system consumes base load and hydro system for peak load, due to easiness in control. These two systems are interconnected through tie lines. These tie lines are utilised for contracted energy exchange between areas and provides inter-area support in case of abnormal conditions. India has the largest asset of more than 40,000 KM of 400 KV ac lines in the world. Presently most of the hydroelectric power plants are situated in southern, north eastern and Himalayan region in the country. These are possibilities to generate more power from these regions in future and power engineers may have to install interconnected hydroelectric and hydrothermal power plants (Ibraheem and Ahmad, 2004)

As the technology has so advanced that the every system should work with stability and accuracy in order to get the efficient response but at the same time due to complexity of systems and randomly changing load conditions sometimes the stability could not be maintained. In this paper the author has discussed about the load frequency control of interconnected hydro-thermal power systems The fluctuation of load in these systems are very common ,which can reduce their efficiency or may damage the system but it can be prevented by the use of different controllers in order to provide the automatic generation control or load frequency control. The most commonly used controllers are conventional PI and fuzzy logic controllers.

During the commencement of study it is observed that there is a lot of change in behaviour in the frequency response without controller, with conventional PI and fuzzy logic controller. Whenever the interconnected systems are working for longer time then a situation definitely arises when there fluctuation in frequency due to many causes such as by randomly load change, by environmental variance or load disturbance by the outer world. These entire situations are controlled by the automatic generation control or load frequency control. As the tie line transports the power in or out of an area so it is required to control the deviations of frequency and tie-line power of each control area. A control signal made up of tie line flow deviation added to frequency deviation weighted by a bias factor would accomplish the desired objective. This control signal is known as area control error (ACE).ACE serves to indicate when total generation must be raised or lowered in a control area. This objective can be easily achieved by the use of controllers (PI and fuzzy logic) in the interconnected power systems.

This paper is organized in five sections; the first section is the introduction part which is explained above. In section 2 how two areas are interconnected by tie line is shown. Section 3 describes the mathematical modelling of the interconnected thermal-hydro power systems. Section 4 presents the design procedure of controllers used, in which conventional PI and fuzzy logic controller are discussed in detailed. Section 5 is devoted to the simulation models and simulation results. Conclusion is given in section 6.

TWO-AREA LOAD FREQUENCY CONTROL

An extended power system can be divided into a number of load frequency control areas interconnected by means of tie lines. Without loss of generality we shall consider a two area connected by a single tie line is illustrated in figure1.The control area 1 is for thermal power system while the area 2 denotes the hydro power system and these two power systems are interconnected with the tie line.

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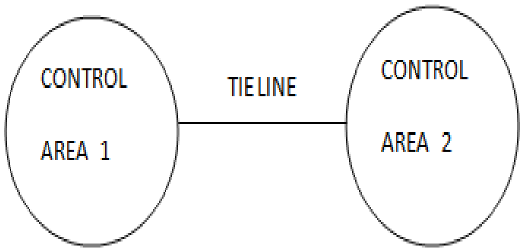

Figure 1: Two interconnected control areas

The control objective now is to regulate the frequency of each area and to simultaneously regulate the tie line power as per inter area power contracts. As in the case of frequency, proportional plus integral and fuggy logic controller will be installed so as to give zero steady state error in tie line power flow as compared to the contracted power.

MATHEMATICAL MODELLING OF POWER PLANTS

For analyzing the system performance, the mathematical model is required. Moreover, the control system can be designed only if the complete mathematical model of the system exits. The mathematical model of thermal, hydro and gas turbine power plants have been considered in this paper. The thermal and hydro power plants are modelled for small signal analysis

Interconnected Hydro-Thermal Plant-

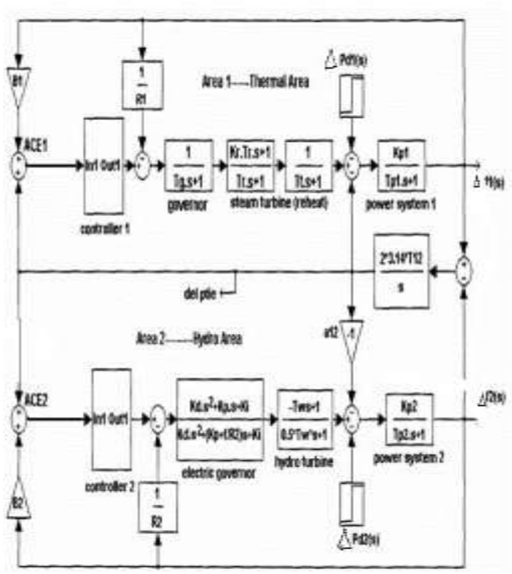

Figure 2: Composite block diagram of two area load frequency control

From the block diagram of thermal hydro interconnected power systems it is clear that the thermal power system consists of transfer functions of speed governor, Generator and steam turbine ,similarly hydro power system consists of transfer functions of electric generator ,Hydro turbine and Generator system. The blocks of controller 1 and controller 2 are replaced by PI and fuzzy controllers during their respective operations. Now let us derive the equations of two areas to decide the stability of frequencies at the output. The value of stabled frequency is taken as 50 Hz. 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.

Power transported out of area 1 is given by

$P_{tie,1} = (|v1|\,|v2|)/X12 \quad \sin(\delta 1 - \delta 2)$ 1.1

Where δ_1 δ_2 = power angles of equivalent machines of the two areas.

As the incremental power angles are integrals of incremental frequencies, we can write-

$\Delta P_{tie1} = 2\pi T_{12} (\int \Delta f_1 dt - \int \Delta f_2)$
1.2

Similarly the incremental tie line power for area 2 is given as

$\Delta P_{tie,1} = 2\pi T_{12} (\int \Delta f_2\, dt - \int \Delta f_1)$
1.3

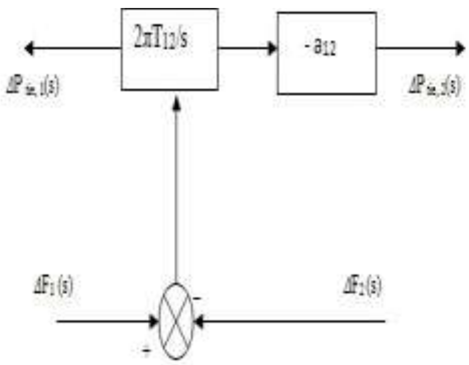

Figure 3: Transfer function of tie line power

As we know

$K_{ps1} = 1/B_1$

$T_{ps1} = 2H_1/B_1 f$ 1.4

Now by taking Laplace trans form of eq. 8.2 and 8.3,we get

$\Delta P_{tie,1}(s) = 2\pi T_{12}/s\,(\Delta f_1(s) - \Delta f_2(s))$ 1.5

And

$\Delta P_{tie,1}(s) = -2\pi a_{12} T_{12}/s\,(\Delta f_1(s) - \Delta f_2(s))$ 1.6

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Let us turn our attention to ACE (area control error) in the presence of a tie line. In case of interconnected control area when the ACE is connected to the PI and fuzzy logic controllers then it force the steady state frequency error to zero. This is accomplished by a single integrating block and by fuzzy logic controller by redefining ACE as a linear combination of frequency and tie line power. Thus, for control area 1

$$ACE = P_{tie,1} + b_1 \Delta f_1 \qquad 1.7$$

Where b_1 is the frequency bias

Now by Laplace transform, we get

$$ACE_1 = P_{tie,1}(s) + b_1 \Delta F_1(s) \qquad 1.8$$

Similarly for area 2

$$ACE_2 = P_{tie,2}(s) + b_2 \Delta F_1(s) \qquad 1.9$$

Let the step changes in the loads P_{D1} and ΔP_{D2} be simultaneously applied in control areas 1 and 2, respectively. When steady conditions are reached, the output signals from all PI and fuzzy logic controller blocks will become constant and in order for this to be so, their input signals must become zero. Thus

$$\Delta P_{tie,1} + b_1 \Delta f_1 = o$$

$$\Delta P_{tie,1} + b_1 \Delta f_2 = o$$

Hence $\Delta f_1 - \Delta f_2 = 0$

Or $\Delta f_1 = \Delta f_2$

Thus under steady conditions change in the tie line power and frequency of each area is zero. This has been achieved by the integration of ACEs in the feedback loop of each area and by applying the output from ACEs to the conventional PI and fuzzy logic controller.

CONTROLLERS USED

a) Conventional PI Controller
b) Fuzzy Logic Controller.

Conventional PI 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 figure4.

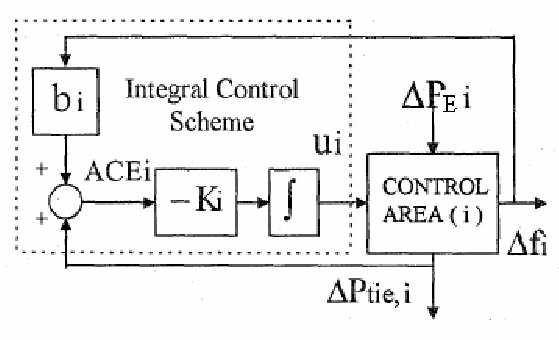

Figure 4: Conventional PI controller

Conventional Proportional plus Integral controller (PI) provides zero steady state frequency deviation, but it exhibits poor dynamic performance (such as number of oscillation and more settling time), especially in the presence of parameters variation and nonlinearity [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.

The control signals can be written as:

$$U_1 = K_p . ACE_1 - K_i \int ACE\, dt$$

$$U_2 = K_p . ACE_2 - K_i \int ACE_2\, dt$$

Where K_p and K_i are proportional and integral gains, respectively. For conventional PI controller, the gain K_p and K_i has been optimized using integral square error (ISE) criterion. For ISE technique, the objective function used is,

$$J = \int_0^t (\Delta F1 + \Delta F2 + \Delta Ptie)dt$$

Where

ΔF = Change in frequency

ΔP_{tie} = Change in tie line power

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*). In this study the purposed fuzzy controller takes the input as ACE_1 and ACE_2, which is given by:

$$ACE_i = F_i B_i + P_{tie}$$

Where Bi is the frequency bias

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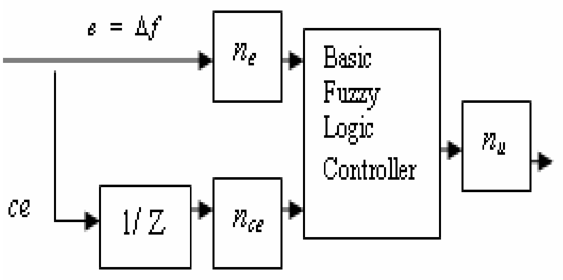

Figure 5: Block diagram of a fuzzy logic controller.

THE IMPLEMENTATION OF FUZZY LOGIC CONTROLLER

In puts and output Selection:

In this paper the author has taken two inputs and one output as shown below

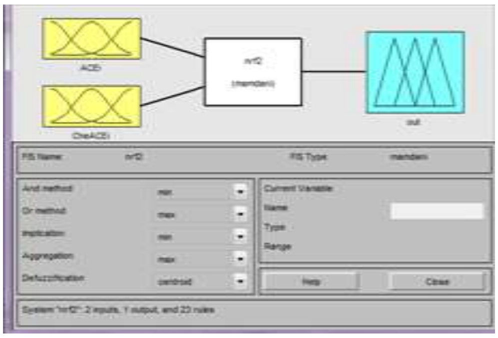

Figure 6: I/Os and O/P

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 7.

Membership Functions:

The following membership functions used for the designing the fuzzy controllers are-

NL- Negative Large
N- Negative Medium
NZ- Negative Zero
Z- Zero Change
PL- Positive Large
P- Positive Medium
PZ - Positive Zero

Table 1 Fuzzy inference rule for Fuzzy Logic Control

I/P	ΔACE					
ACE		NL	N	Z	P	PL
	NL	PL	PL	PL	-	-
	N	PL	P	P	-	-
	NZ	PL	P	P	-	-
	Z	P	P	Z	N	NL
	PZ	-	-	N	N	NL
	P	-	-	N	N	NL
	PL	-	-	NL	NL	NL

Simulink Model of Interconnected Thermal-Hydro Power System without Using Any Controller

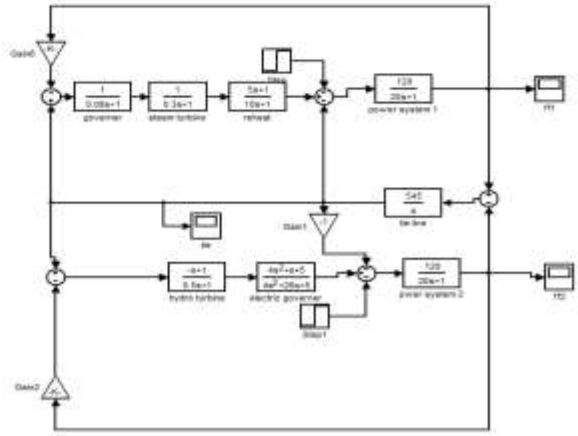

Figure 7: Interconnected systems without any controller

SIMULINK MODEL OF INTERCONNECTED THERMAL-HYDRO POWER SYSTEM USING FUZZY LOGIC CONTROLLER

In the simulink model the controller block of block diagram is replaced by fuzzy logic controller and rest of the blocks with their respective values as shown below:

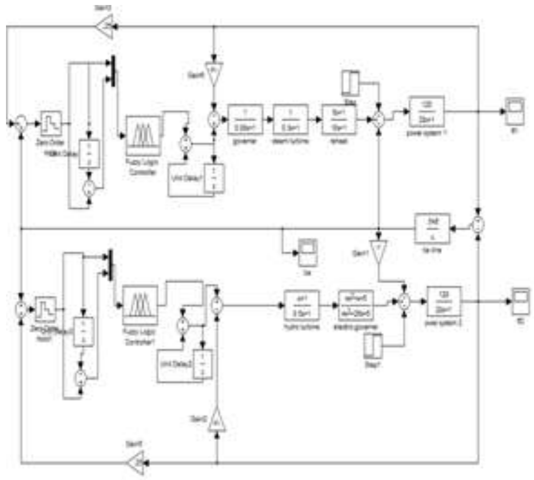

Figure 8: FLC using fuzzy logic controller

SIMULINK MODEL OF INTERCONNECTED THERMAL-HYDRO POWER SYSTEM USING CONVENTIONAL PI CONTROLLER

As in the previous simulink model here the controllers are replaced by the conventional PI controllers. The output of area control error is given to the input of conventional PI controller which consists of frequency deviation and the tie line deviation. The output is then given to interconnected areas to control the speed of turbines according to the needs of loads in order to keep the frequency of the system at some constant value.

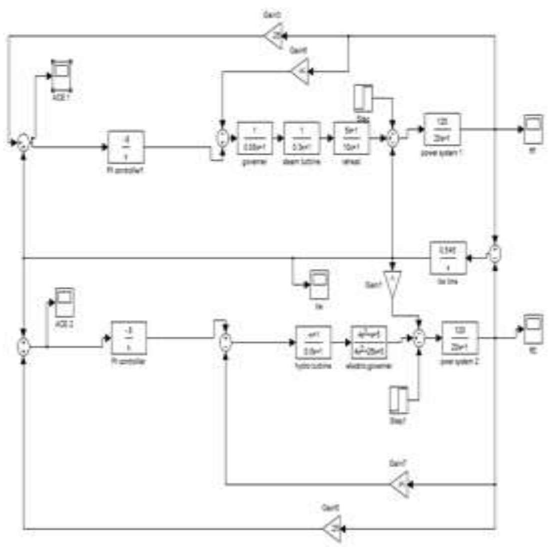

Figure 9: FLC using conventional PI controller

RESULTS AND DISCUSSION

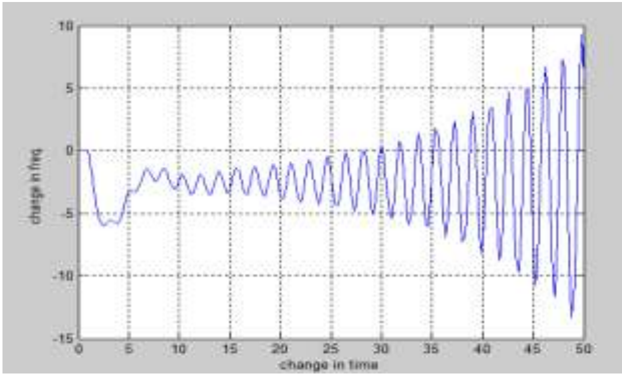

Figure 10: Frequency Response with out using controller in area 1

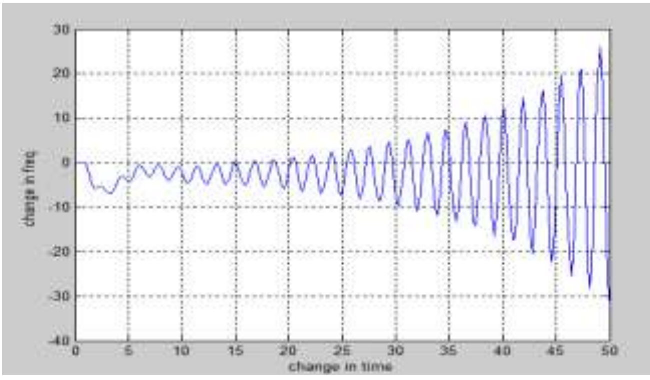

Figure 11: Frequency Response without using controller in area 2

From the above results it is clear due to absence of controllers in the interconnected power systems the oscillations in the frequency response is increasing with time and this finally lead to collapse or failure of power system.

Results are also being taken from both areas by considering load disturbance of 10% and 5% under the control of conventional PI and fuzzy logic controllers. Two performance criteria such as settling time and peak overshoots were considered in the simulation frequency and tie line deviation of both the areas. The results are shown below in which blue line is indicating the case of fuzzy logic controller while the red one indicates the usage of conventional PI controller in the power system. These results are taken by considering the step change of 10% in power system.

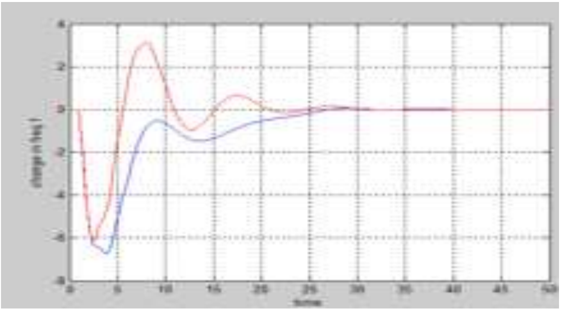

Figure 12: Frequency deviation in area 1 by using both PI and fuzzy logic controller

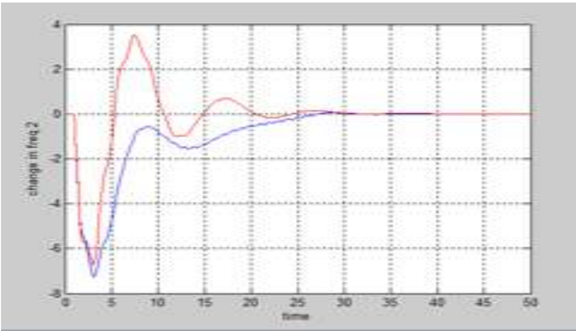

Figure 13: Frequency deviation of area 2 by both PI and fuzzy logic controller

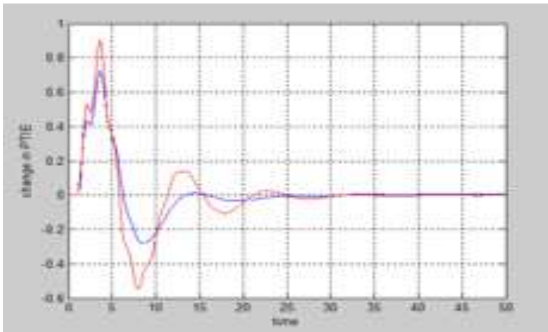

Figure 14: Tie line deviation by both PI and fuzzy logic controller

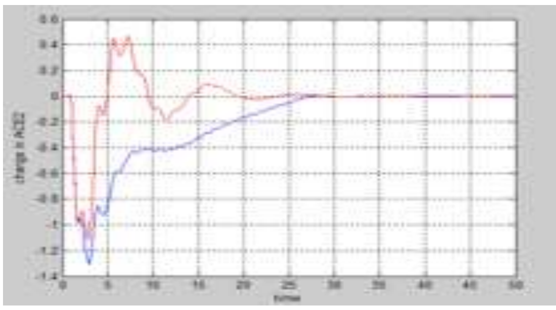

Figure 15: Area control error of area 2 by both PI and fuzzy logic controller

The comparision of conventional PI and fuzzy logic controller in tabular form for 10% step change in load is given below :

Table 2: Comparison between conventional PI and FLC (10%)

	Conventional PI Controller		Fuzzy Logic Controller	
For Step change of 10%	Setting Time (seconds)	Peak Overshoot	Settling Time	Peak Overshoot
Thermal Power Plant	35	-6.5 – 2	30	-6.4 – -.8
Hydro Power Plant	36	-7.5 – 2	32	-7.1 – -1

From the above results and comparison table it is clear that fuzzy logic controller have better response as conventional PI controller.

The response of simulink models at a step change of 5% are shown below:

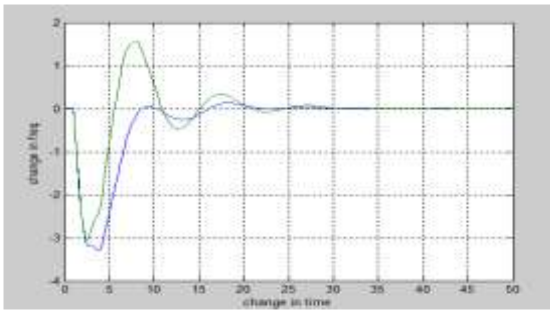

Figure 16: Frequency Response comparison using Conventional PI and FLC controller in area 1

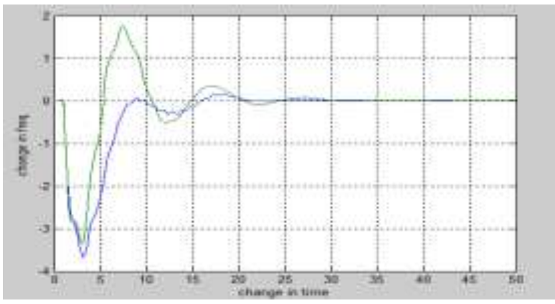

Figure 17: Frequency Response comparison using Conventional PI and FLC controller in area 2.

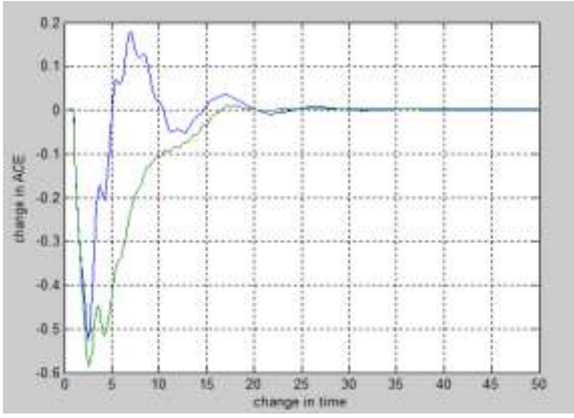

Figure 18: ACE Response comparison using Conventional PI and FLC controller in area 1

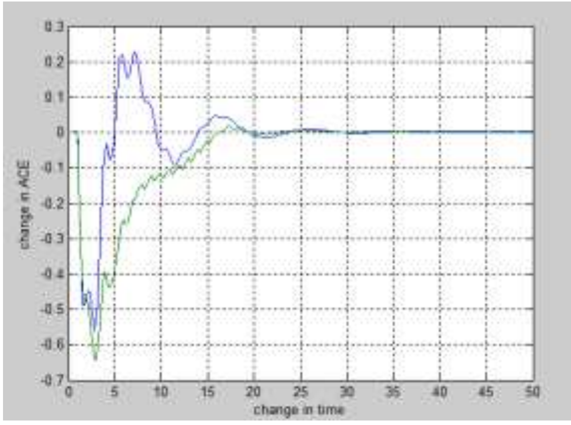

Figure 19: ACE Response comparison using Conventional PI and FLC controller in area 2

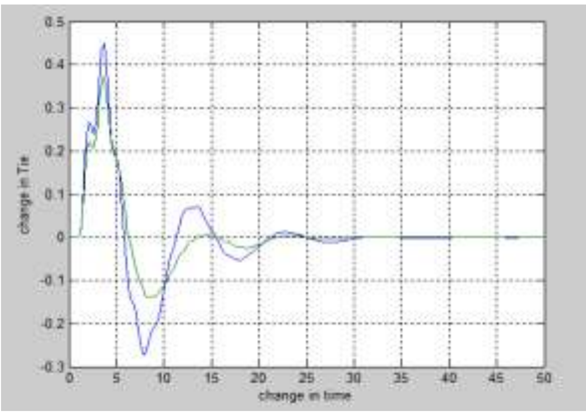

Figure 20: Tie Line Response comparison using Conventional PI and FLC controller.

Table 2: Comparison between conventional PI and FLC (5%)

	Conventional PI Controller		Fuzzy Logic Controller	
For 5% Step Change	Settling Time (Seconds)	Peak Overshoot	Settling Time	Peak Overshoot
Thermal Power Plant	31	(-3 - 1.5)	24	(-3.3 - 0.2)
Hydro Power Plant	31	(-3.3 – 1.7)	27	(-3.7 - 0.2)

After examining the results it is clear that conventional PI controller does not provide good control performance and it takes more time to settle down the steady state error and it is all due to fixed value of PI gains irrespective of changing error. But fuzzy logic controller provides satisfactory control performance, over conventional PI controller

CONCLUSIONS

From the above research it can be concluded that the transient response, settling time and peak overshoot in case of fuzzy logic controller is lesser as compared to the conventional PI controller. Thus simulation results of FLC have better control performance over conventional PI when some disturbance in load (10 % and 5%) is given or loaded into the interconnected hydro-thermal power system. In short we can say that the FLC is adequate for better quality and reliable electric power supply due to less settling time, less peak overshoot and quick rise time.

FUTURE SCOPES

- More than two areas such as thermal, hydro, gas etc can be interconnected and controlled for automatic generation of controlled power.
- New controllers can be designed for the better control performance in terms of frequency and tie line power deviation.
- More than one controller can be used such as conventional PI, PID, and FLC. Artificial neural network in serial or parallel for reducing the transient response and peak overshoot.

APPENDIX

The various Parameters are as follows:
f = 50 Hz, R1 =R2= 2.4 Hz/ per unit MW, Tg = 0.08 sec, Tp=20 sec
P tie, max = 200 MW

Tr = 10 sec kr = 0.5,
Pr1 = Pr2 =2000MW
Tt = 0.3 sec Kp1=Kp2 = 120 Hz.p.u/MW
Kd =4.0 ki = 5.0 Tw = 1.0 sec.
K_p = 26 , $B_1 = B_2$ = .25

NOMENCLATURE

F : Nominal system frequency
ΔP_D : Incremental load change
$\Delta Pg\ i$: Incremental generation change
T12 : Synchronizing coefficient,
Tg : Steam governor time constant
Kr : Reheat constant,
Tr : Reheat time constant
Tt : Steam turbine time constant
Ri : Governor speed regulation parameter
Bi : Frequency bias constant
Kj : Integral gain
Kt : Feedback gain of FLC
Tw : Water starting time,
ACE : Area control error
Δf : Change in supply frequency
ΔPc : Speed changer position
R : Speed regulation of the governor
*K*H : Gain of speed governor
*T*H : Time constant of speed governor

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