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A Comparison of Several Approaches to Load Frequency Control of Multi Area Hydro-Thermal System

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ABSTRACT

The main contribution of Load Frequency Control (LFC) is preserving frequency constant against the varying active power loads. System has several generating units in which the notion of fault/load tolerance has to be enhanced. For this purpose tie-lines are made between these interconnected units. In this paper, a fuzzy controller has been suggested for LFC of multi unequal area hydro-thermal interconnected power system. Simulation has been performed on a test system with four areas. First and second areas have thermal reheat power plant and third and fourth areas consists of hydro power plant with electric governor. Simulation has been carried out by Matlab / Simulink software and capability of the proposed technique confirmed by comparing its results with related values of PI and PID controllers.

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Load frequency control, Fuzzy controller, Controller design, Area hydro-thermal, Tie-line.

Introduction

Load Frequency Control (LFC) is of importance in electrical power system design and operation. The objective of the LFC, in an interconnected power system, is to maintain the frequency of each area and to keep tie-line power flows within some pre-specified tolerances by adjusting the MW outputs of the LFC generators so as to accommodate the fluctuating load demands [1].

Ref.[2] presents a new population based parameter free optimization algorithm as Teaching Learning Based Optimization (TLBO) and its application to automatic LFC (ALFC) of multi-source power system having thermal, hydro and gas power plants. In [3], a new method is presented to solve the load-frequency control of non-linear power systems. In the proposed methodology, a two-area interconnected hydrothermal power system is considered to optimal adjustment parameters of Proportional-Integral-Derivative (PID) controller. The proposed intelligent strategy in [4] is based on a combination of a novel heuristic algorithm named Self-Adaptive Modified Bat Algorithm (SAMBA) and the Fuzzy Logic (FL) which is used to optimally tune parameters of Proportional–Integral (PI) controllers which are the most popular methods in this context.

Ref.[5] presents an optimal method to tune the PID controller for a hydraulic turbine coupled with the corresponding Transient Droop Compensator (TDC). Fractional-order proportional-integral-derivative (FOPID) controllers have been designed in [6] for LFC of two interconnected power systems. In [7], a hybrid gravitational search algorithm (GSA) and pattern search (PS) technique is proposed for LFC of multi-area power system. In [8], a novel hybrid Differential Evolution (DE) and Pattern Search (PS) optimized fuzzy PI/PID controller is proposed for LFC of multi-area power system. In [9], a Fractional Order PID (FOPID) is designed for single area LFC for all three types of turbines i.e., non-reheated, reheated and hydro turbines.

Ref.[10] presents an application of the novel artificial intelligent search technique to find the parameters optimization of nonlinear LFC considering PID controller for a power system. In [11], design and performance analysis of DE algorithm based parallel 2-Degree Freedom of PID (2-DOF PID) controller for LFC of interconnected power system is presented. Ref.[12] presents controller parameters tuning of DE algorithm and its application to LFC of a multi-source power system having different sources of power generation like thermal, hydro and gas power plants.

In this paper, a fuzzy controller has been suggested to control LFC in multi unequal area hydro-thermal interconnected power system. This context is consists of five sections. Concept of multi area power system has been introduced in Section 2. The proposed fuzzy controller has been designed in third sections. Simulation results are visible in Section 4. This work is concluded in 5th section.

2. Multi area power system

2.1 Modeling of the Tie-Line

Power transferred from area 1 to 2 through tie line. Then power transfer equation through tie-line is given by

$$P_{12} = \frac{V_1 . V_2}{X_{12}} \sin(\delta_1 - \delta_2) \qquad (1)$$

Where, δ_1 and δ_2 are power angles of end voltages $V1$ and V_2 of equivalent machine of the two areas respectively. X_{12} is reactance of tie line.

The order of the subscripts indicates that the tie line power is define positive in direction 1 to 2.For small deviation in the angles and the tie line power changes with the amount i.e. small deviation in δ1 and δ2 changes by Δδ1 and$\Delta\delta_2$, Power P_{12} changes to $P_{12} + \Delta P_{12}$

Therefore, Power transferred from Area 1 to Area 2 as given in [13] is

$$\Delta P_{12}(s) = \frac{2\pi T^0}{s}(\Delta f_1(s) - \Delta f_2(s)) \qquad (2)$$

Where, T^0 is torque produced.

2.2 Objective of control areas

The main purpose of automatic control, regulate and maintain system frequency at nominal value can be exchanged between the areas controlled by regulating the amount of planned elective generator output

In an isolated control area case the incremental power ($\Delta PG - \Delta PD$) was accounted for by the rate of increase ofstored kinetic energy and increase in area load caused by increase in frequency. The state variable for each of areas are ΔP_i $(i=1,....,4)$ and state space equation related to the variables are different for each areas.

$$\Delta P_1(k) = \Delta P_{12}(k) + A_{41}\Delta P_{41}(k) \qquad (3)$$

$$\Delta P_2(k) = \Delta P_{23}(k) + A_{12}\Delta P_{12}(k) \qquad (4)$$

$$\Delta P_3(k) = \Delta P_{34}(k) + A_{23}\Delta P_{23}(k) \qquad (5)$$

$$\Delta P_1(k) = \Delta P_{12}(k) + A_{41}\Delta P_{41}(k) \qquad (6)$$

Tie-line bias control is used to eliminate steady state error in frequency in tie-line power flow. This states that the each control area must contribute their share to frequency control in addition for taking care of their own net interchange.

Let *ACE1*=area control error of area1
ACE2=area control error of area2
ACE3=area control error of area3
ACE4 =area control error of area4

In this control, *ACE1*, *ACE2* and*ACE3* are made linear combination of frequency and tie line power error [13]

$$ACE1 = \Delta P_{12} + b_1\Delta f_1 \qquad (7)$$

$$ACE2 = \Delta P_{23} + b_2\Delta f_2 \qquad (8)$$

$$ACE3 = \Delta P_{34} + b_3\Delta f_3 \qquad (9)$$

$$ACE4 = \Delta P_{41} + b_4\Delta f_4 \qquad (10)$$

where, the constant b_1, b_2, $b_3$andb_4 are called area frequency bias of area1, area2, area3 and area4 respectively.Now ΔPR_1, ΔPR_2, ΔPR_3 and ΔPR_4 are mode integralof *ACE1*, $2ACE_3$ and ACE_4, respectively.

3. Fuzzy controller system

The method of fuzzification has found increasing applications in power systems. The applications of fuzzy sets signify a major enhancement of power systems analysis by avoiding heuristic assumptions in practical cases. This is because fuzzy sets could be deployed properly to represent power system uncertainties [14]. The design of FLC can be normally divided into three areas namely allocation of area of inputs, determination of rules and de fuzzifying of output into a real value. In this paper the proposed fuzzy controller takes the input as ACE and ACĖ, which is given as [15],

$$ACE_i = \Delta P_{tie} + b_i\Delta F_i \qquad (11)$$

The parameter Bi may be optimized, but here, chosen as

$$\frac{1}{k_{pi}} + \frac{1}{R_i} \qquad (12)$$

where, K_{pi} and R_i are power system gain and governor speed regulation parameter, res pectively.The Block diagram of Fuzzy Logic Controller is shown in Fig. 1. [16] A label set corresponding to linguistic variables of the input control signals, *e(k)* and *Ce*(k), with a sampling time of ۰.۰1 sec is given Attempt has been made to examine with Seven number of triangular membership function (MFs) namely Negative Big(NB), Negative Medium(NM), Negative Small (NS), Zero(ZO), Positive Small(PS), Positive Medium (PM) and Positive Big(PB) are used.Fuzzy rules are conditional statement that specifies the relationship among fuzzy variables. These rules help us to describe the control action in quantitative terms and have been obtained by examining the output response to corresponding inputs to the fuzzy controller. Rules are given in Table 1. The rules are interpreted as follows, If ACE is NB and ACĖ is NS then output is PM.

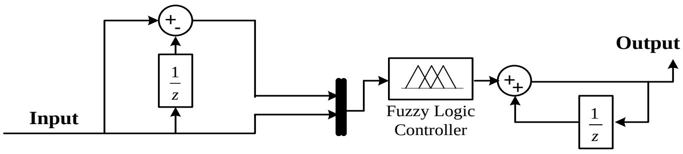
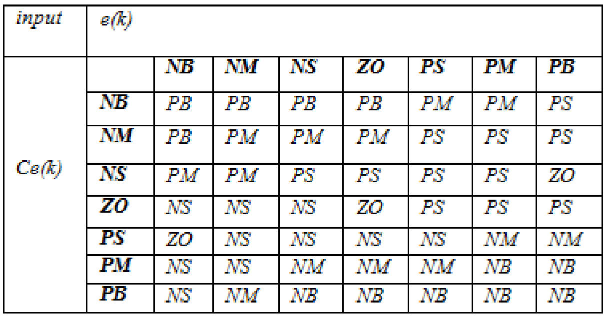


Fig. 1 Model of Fuzzy Logic Controller

Table 1. Fuzzy inference rule for fuzzy logic controller



input	*e(k)*							
Ce(k)		**NB**	**NM**	**NS**	**ZO**	**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	ZO
	ZO	NS	NS	NS	ZO	PS	PS	PS
	PS	ZO	NS	NS	NS	NS	NM	NM
	PM	NS	NS	NM	NM	NM	NB	NB
	PB	NS	NM	NB	NB	NB	NB	NB

4. Case study

4.1 Implementing the simulation

Fig.2 illustrate the simulated structure in Simulink/Matlab software. This structure consists of three loads (Load1, Load2 and Load3), two tie-lines (tie line 1 and tie line2), two stream sources (Stream Turbine reheat1 and Stream Turbine reheat2) and two hydro sources (Hydro amplifier1and Hydro amplifier1). System outputs for four sources have been extracted from Scope1 (S1), Scope2 (S2), Scope3 (S3) and Scope4 (S4). The initial values of simulation parameters have been listed in Table 2.

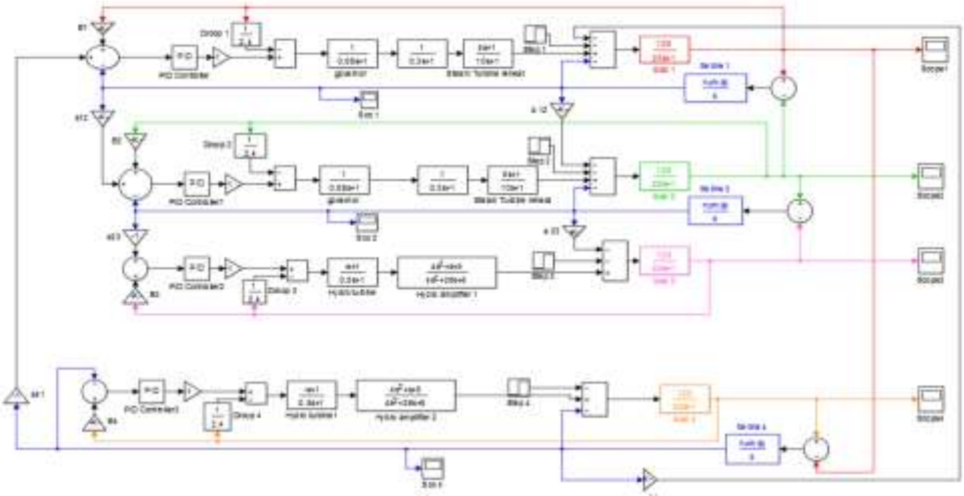


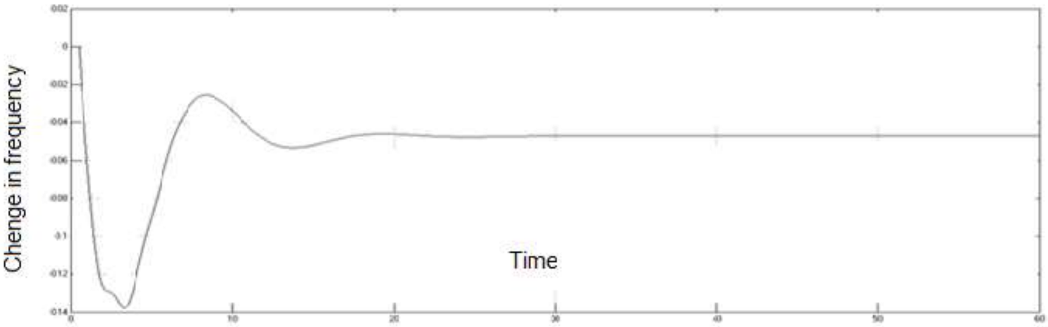
Fig.2 Simulation structure in Simulink/Matlab software

Table 2. Simulation parameters

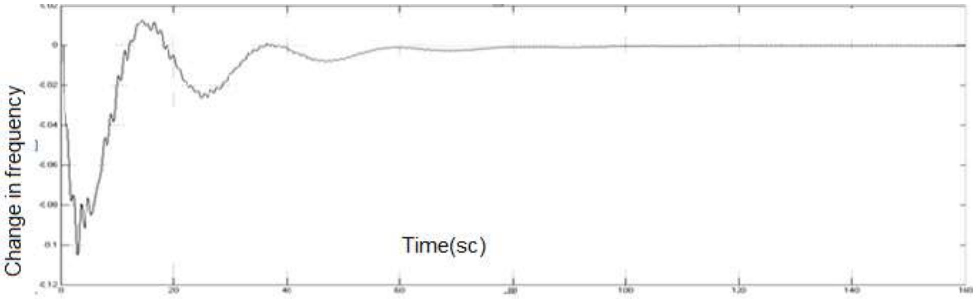
Parameter	Symbol	Value	Unit
Frequency	f	50	Hz
Governor speed regulation parameter	R_1,R_2,R_3,R_4	2.4	*Hz/p.u. MW*
Steam governor time constant	T_{gi}	0.08	*sec*
	T_{pi}	20	*sec*
Maximum tie line power	$P_{tie,max}$	200	*MW*
Reheat time constant	Tr	10	*sec*
Reheat constant	K_r	0.5	-
Inertia constant	H_1=H_2=H_3= H_4	5	*Sec*
Steam turbine time constant	T_{ti}	0.3	*sec*
Proportional gain	K_{p1}=K_{p2}=K_{p3}=K_{p4}	20	*Hz.p.u/MW*
Derivative time constant	K_d	0.4	-
Integral time constant	K_i	0.5	-
Water starting time	T_w	0.1	*sec*

4.2 Simulation results

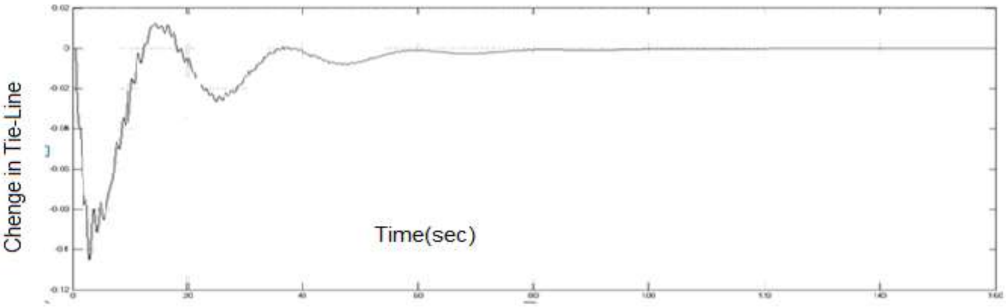
In this section, simulation results from four power sources based on three controllers are presented. These controllers are: PI, PID and fuzzy controllers. Fig.3 shows the outpour of stream turbine Scope.



a. Fuzzy controller



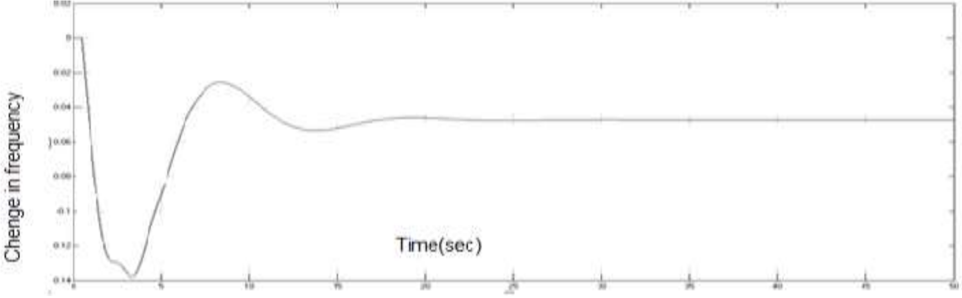
b. PID controller



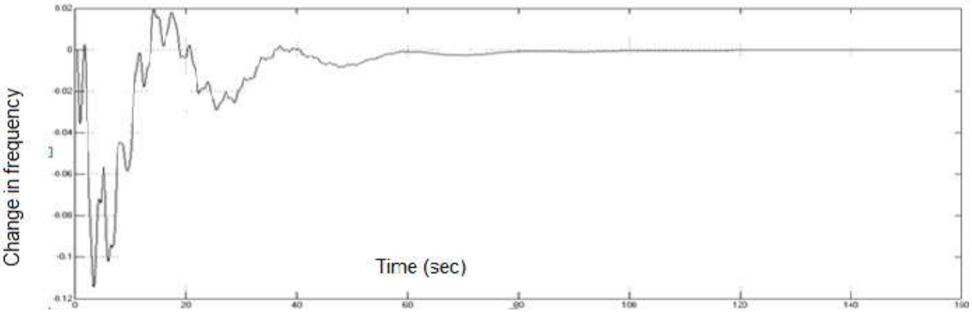
c. PI controller

Fig.3 Output of first power Scope

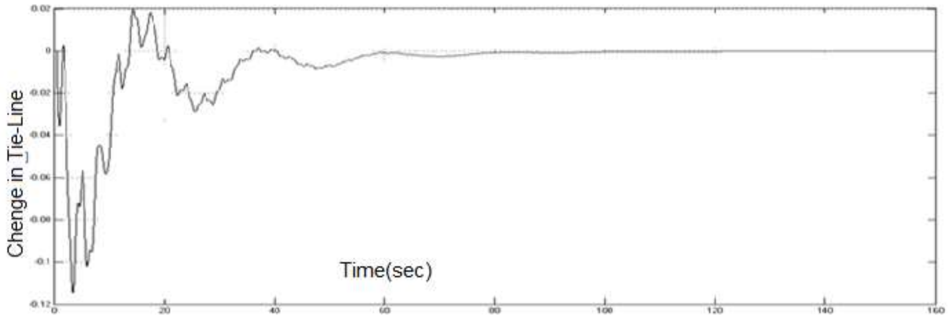
By considering results of Fig.3, PI and PID controllers have considerable distortion respect to fuzzy controller. The curve of fuzzy controller after 30 sec is damped while this damping occurs after 80 sec by PI and PID controller. Output curves of three controllers from second scopes are visible in Fig.4.



a. Fuzzy controller



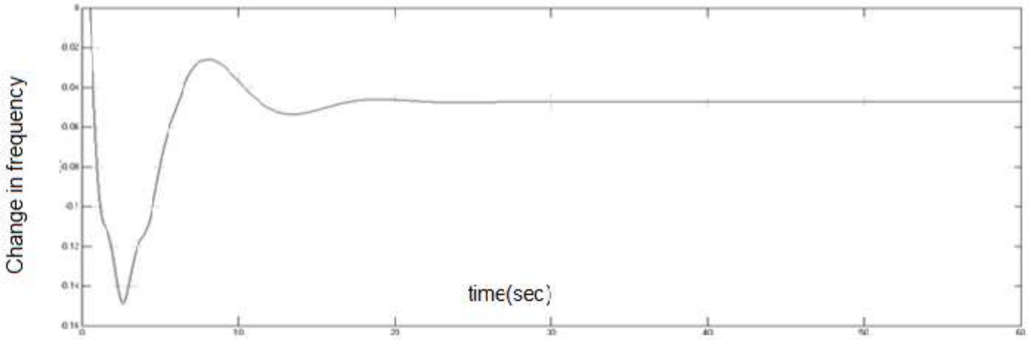
b. PID controller



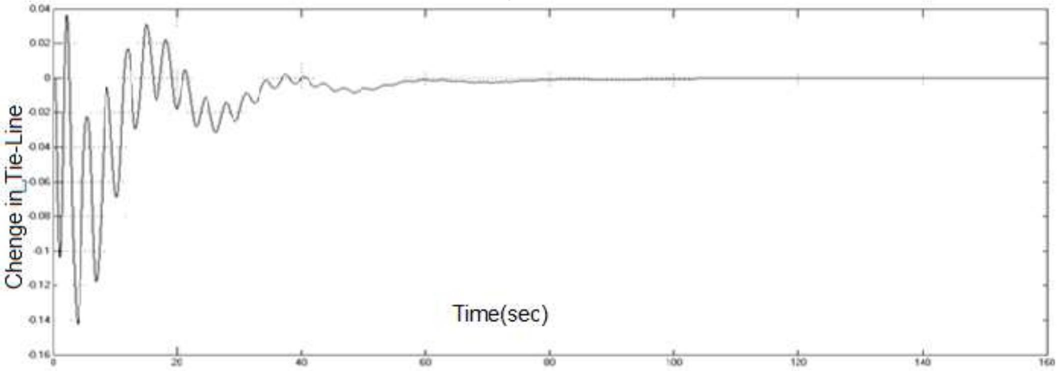
c. PI controller

Fig4. Output of second Scopes

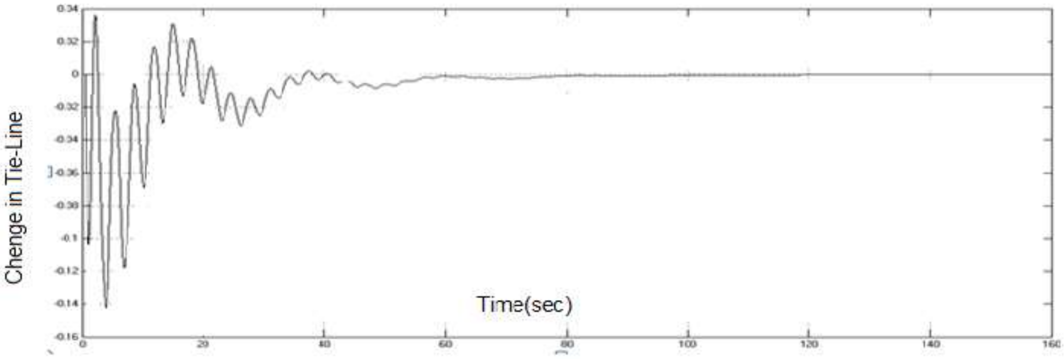
Based on Fig.4, distortion amplitude of PI and PID controller respect prior scopes increased while fuzzy controller presents similar behavior. In this case, peak value of two traditional controller is considerable. Fig.5 shows simulation results of third scopes.



a. Fuzzy controller



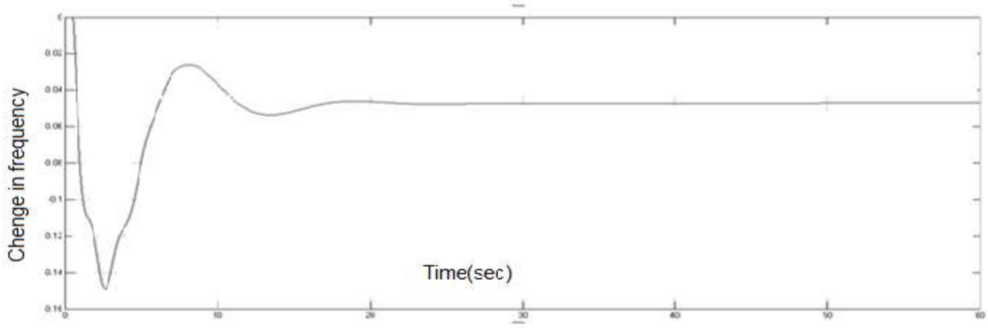
b. PID controller



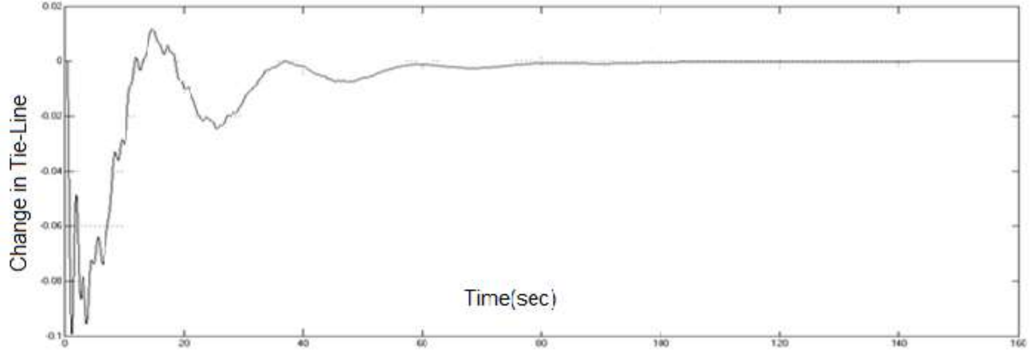
c. PI controller

Fig5. Output of third Scopes

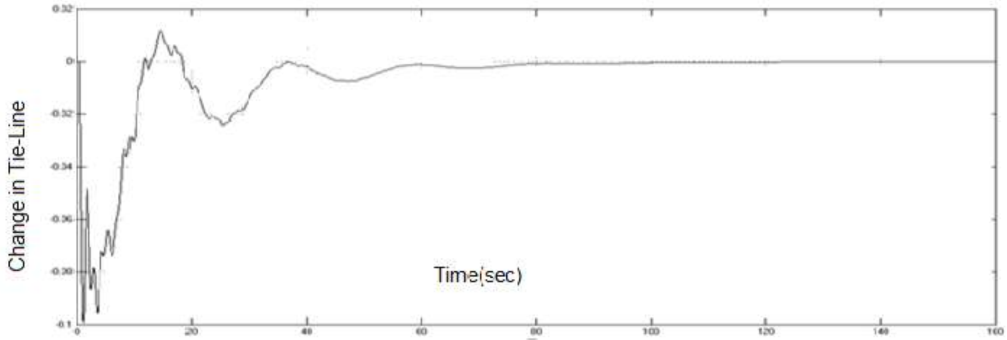
By comparing results of Fig5., we can claimed that fuzzy controller present better response respect to PI and PID controllers. Distortion of two traditional controllers is more than related parameter of fuzzy controller. Results of fourth sources based on three controllers have been presented in Fig.6.



a. Fuzzy controller



b. PID controller



c. PI controller

Fig6. Output of fourth Scopes

5. Conclusion

Main contribution of this work is designing a novel controller based on fuzzy logic for LFC of multi unequal area hydro-thermal interconnected powersystem. Results of the proposed algorithm have been compared with related values of two traditional controllers; i.e. PI and PID controllers. From simulation results, in all case we can claim our proposed controller has minimum peak value, minimum fall value, minimum settle time. The results substantiate that fuzzy controller has ability for LFC better than PI and PID controllers. Also, third source presents the maximum distortion among four scopes.

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