International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-4, February 2020

A Robust Fuzzy Logic Controller Design for Load Frequency Control of Hydro Thermal Power Generating Stations

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Abstract*: This article analyses the contribution of Fuzzy logic controller in a two source two area hydro thermal system aimed at load frequency control of the system. The proposed two area two source hydro thermal system is observed for different system parameter change to realize the dynamic behavior of frequency along with the interchanged power through tie line. To begin with, hydro and thermal power plants in a single control area for a step load variation is reviewed and the results for PI along with fuzzy logic controller are compared. Additionally a two source two area system is considered and the frequency and tie line power deviation with fuzzy logic controller is matched with results of PI controller. To witness the superiority of fuzzy logic controller, the connected generating system is run for different system parameter change. Simulation outcomes revealed that the recommended fuzzy logic controller put in enhanced output response when compared with conventional PI controller. The offsets found with the conventional controller can be estimably fell off with the suggested fuzzy logic controller.

Keyword*: Fuzzy Logic Controller (FLC), Load Frequency Control (LFC), PI controller, Two source two area system (TSTA)

I. INTRODUCTION

The comfort of human being lies on consumption of electrical power which increases the load demand. The continuous change in the load requirement immensely influence efficient operation and control of the power system. Consequently, the control area frequency and exchange power through tie line, deviate from their nominal values. This ultimately makes the power system vulnerable [1]. Load frequency control implements an imperative place in the power system operation to endure the complexities found due to load variation [2]-[4].

A lot of research have been carried out for several possible combinations of single source multi area system. Many researchers have studied the LFC problem comparing the conventional control with numerous control approaches in the system [5]-[7].

Revised Manuscript Received on February 28, 2020.
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Differential Evolution (DE) optimization practice is employed to optimize the PI parameter gain for studying load frequency control considering non reheat turbine in thermal generating system [8]. Saikia and Nanda in their work [9] investigated the robustness of a newly designed Integral Double Derivative (IDD) controller in a single source interconnected power system.

Numerous analysis have been done for LFC in single source multi area system. But in actual practice, both the hydro and thermal power generating sources take part in power generation for individual control area. The LFC for an applied power system contains more than one generating source, is realized and the results found with optimal and full state feedback controller are compared by Parmar and Kothari in their work [10]. Mohanty et. al,[11] observed the Differential Evolution (DE) optimization to improve the PI gain parameter values for LFC in a multi-source generating system. Chandrakala et. al,[12] applied fuzzy gain scheduling in a multi-source system and the compared the results with ZN tuned PI controller. The variations attained in control area frequency and power through tie line, due to dynamic load variation can be controlled through different intelligent controllers [13]. Along with this, various optimization techniques can be applied to optimize control parameters [14]. But a few research is undergone for load frequency control considering fuzzy logic controller in the system [15]-[18]. However less work has been carried out for LFC in multi source multi area system taking FLC in to consideration.

With reference to all, it is intended to study and compare the robustness of the recommended fuzzy controller with conventional PI controller for LFC in a two area generating system. Primarily the two source single area hydro thermal system is studied with the proposed fuzzy logic controller. To look at the benefits of using FLC, the study is put through two source hydro thermal system and a comparison made with PI controller. Moreover superiority of the FLC approach is proved by varying the system parameter values.

II. MATERIALS AND APPROACHES

A. Multi source multi area scheme

The system under analysis comprises of two source two area combined system as represented in Fig.1. Each control area consists of hydro and thermal power plants. In thermal power generation, the variance in generation and requirement of load in the system is identified by the speed governor and the governor controlled the steam input to the turbine.

In a hydropower system, the turbine is driven by the mechanical force supplied, due to the kinetic energy of water. In Fig.1 the control area frequency bias parameters are B_1 and B_2; ACE1 and ACE2 symbolizes the area control errors; R_1 and R_2 are regulatory parameters of speed governing system.

İn a reheat thermal power plant, ΔP_g symbolizes the speed governor output power; Tg is the governor time factor; ΔP_{tg} is the regulated output power of reheat steam turbine; T_{rt} is the reheat steam turbine time factor.

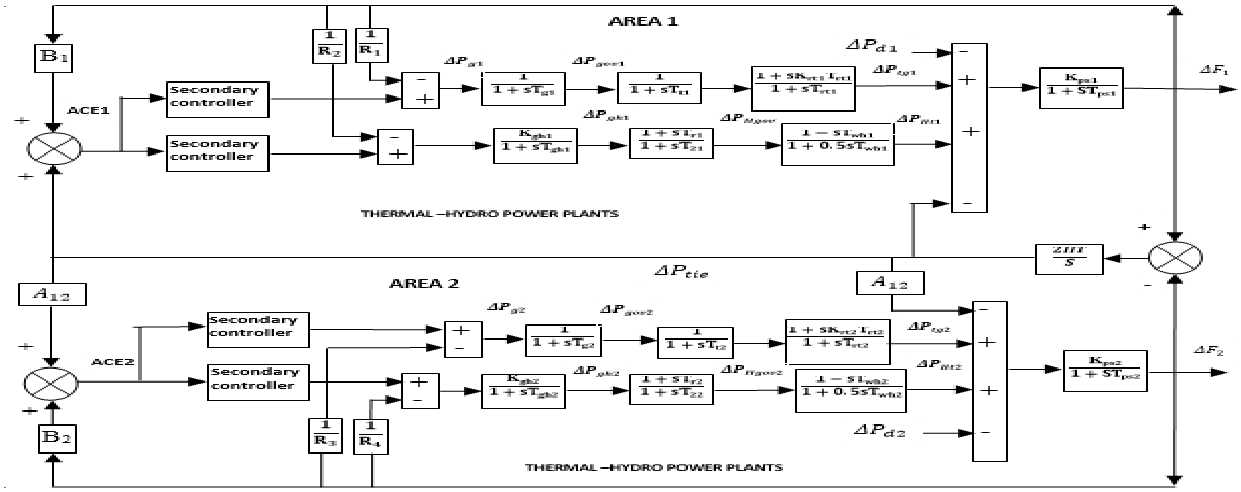

Fig.1. Two source two area power generating system

In hydro generation ΔP_{gh} denotes the power output of governor; T_{gh} is the time constant of hydro governor; ΔP_{Hgov} is the hydraulic valve output; ΔP_{Ht} presents the output power of hydro turbine. In this two area system, ΔP_{d1} and ΔP_{d2} are the incremental change in the control areas; K_{ps1} , K_{ps2} signifies the gain and T_{ps1},T_{ps2} are the time constants of the interconnected power system. The ΔF_1 and ΔF_2 are control area frequency change and ΔP_{tie} is variation in the tie line power. The appropriate parameters are furnished in Appendix A.The LFC in the connected power generating system regulate the generation to retain the change in frequency and the power exchange through tie line at a low value. With the purpose of maintaining the scheduled values of area frequency and tie line power at various loading conditions, secondary controller is incorporated in the system. Due to its reliability, simplicity and robustness, the PI controller is given preference to act as a derived controller for the power system operation and control. In view of the offsets found in control area frequency and power flow through tie line in the interconnected system and to meet a fairly stable system, the fuzzy logic intelligent controller used instead of PI.

B. Control approaches

Appropriate control techniques can be implemented with load frequency control to enhance the power system functioning.

a. Conventional PI controller

Owing to its simple and robust design, the conventional PI controller is mostly used in the industry applications. The block representation of PI controller is exhibited in Fig.2.

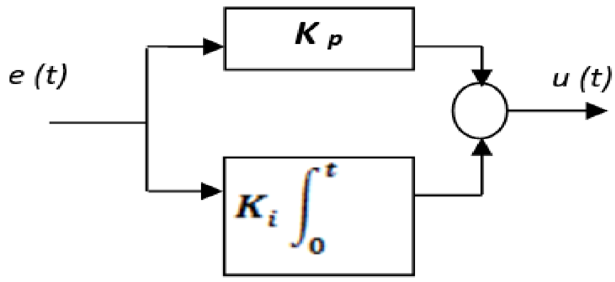

Fig. 2. Block representation of PI controller

The mathematical equation for controlled output (*u (t)*) of a PI controller can be represented as equation (1)

$$u(t) = K_p\, e(t) + K_i \int_0^t e(t) \qquad (1)$$

Where K_p and K_i are the coefficients of proportional and integral control action.

b. Fuzzy Logic Controller

The multi valued logics which is used by a fuzzy logic controller is the interpretation of human reasoning in form of fuzzy logic language. The elementary block for FLC is represented as Fig.3.

With different possible combination of the input variables in fuzzy logic language, more accurate results can be obtained. The suggested fuzzy logic controller consists of two input variables, the area control error and the change in area control error of the interconnected control areas. The input variables are represented by 7 membership functions.

NM- Negative more
NA- Negative average
NL- Negative less
NU -Null
PM- Positive more
PA- Positive average
PL- Positive less

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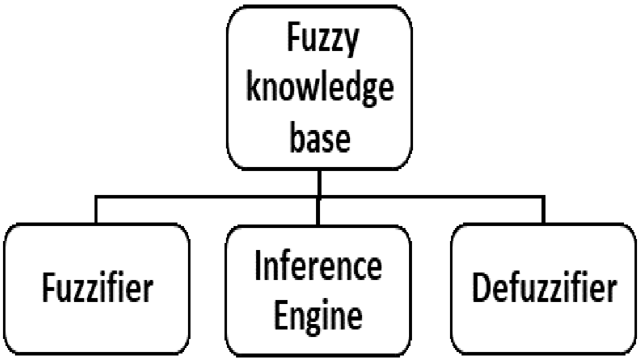


Fig. 3 Block representation of FLC

Table I. Fuzzy rule viewer

Error	**d(Error)**						
	NM	NA	NL	NU	PL	PA	PM
NM	NM	NM	NM	NM	NA	NL	NU
NA	NM	NM	NA	NA	NL	NU	PL
NL	NM	NA	NA	NL	NU	PL	PA
NU	NA	NA	NL	NU	PL	PA	PM
PL	NA	NL	NU	PL	PA	PA	PM
PA	NL	NU	PL	PA	PA	PM	PM
PM	NU	PL	PA	PM	PM	PM	PM

The possible combination of 7 membership functions are represented in Table I.

III. SIMULATION RESULTS AND DISCUSSION

The hydro and thermal power plants in two control areas for study as represented in Fig.1.is examined developing its simulation model and the values of system parameters used are provided in Appendix B.

a. Analysis of two source single area system

To identify the performance of frequency alteration for a two source single area system with 10% step load change, MATLAB/Simulation of system is done. The output of simulation results for PI and Fuzzy logic controllers are evaluated and the comparison of frequency deviation graph is exhibited in Fig. 4.

It can be examined from the Fig.4. that the two source hydro thermal system in a single control area run with PI controller, when subjected to 10% step load variation exhibits an overshoot and the system took 24.2 sec to settle down. Moreover the proposed fuzzy logic controller outperforms the PI controller in damping oscillation efficiently and the system attains stability in a reduced time of 6.2 sec.

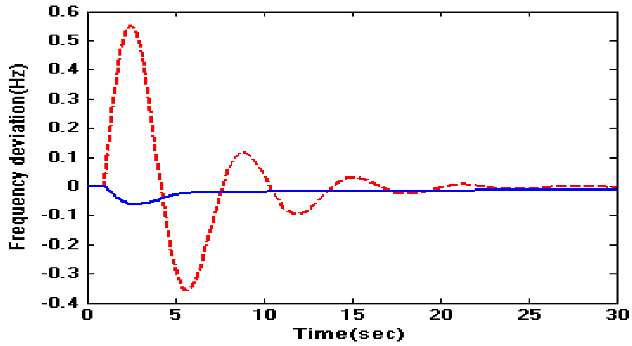


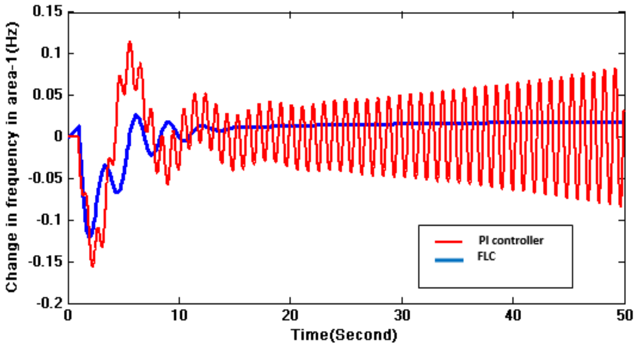
Fig.4. Frequency alteration in one area for 10% load variation

b. Analysis of two source two area generating system

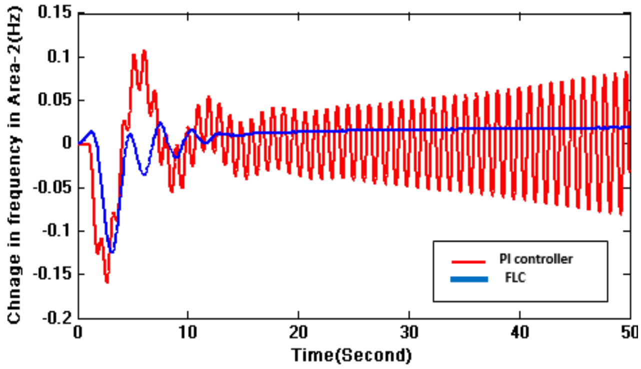
To figure out the efficacy of FLC, a two area system with hydro thermal generation is exposed to 5% increase in load requirement in area-1 only. A comparative analysis of frequency responses ΔF_1 in 1st control area, ΔF_2 in 2nd control area and interchange tie line power ΔP_{tie} with PI and FLC are presented as Fig.5. (a),(b),(c) .

The system frequency alteration in 1st area (ΔF_1) shows in Fig.5.(a) exhibits that with PI controller, the proposed system results an unstable and oscillatory output response .

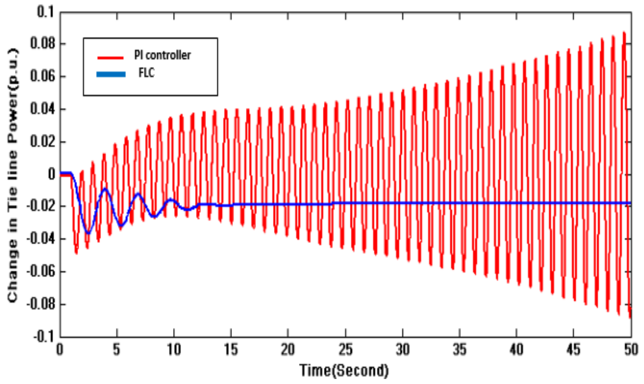
Whereas the damping oscillation can be found as effectively reduced with a faster settling time of 14.36 sec through fuzzy logic controller.



(a) Deviation in F_1 due to 5% load increase in 1st area



(b) Deviation in F_2 due to 5% load increase in 1st area

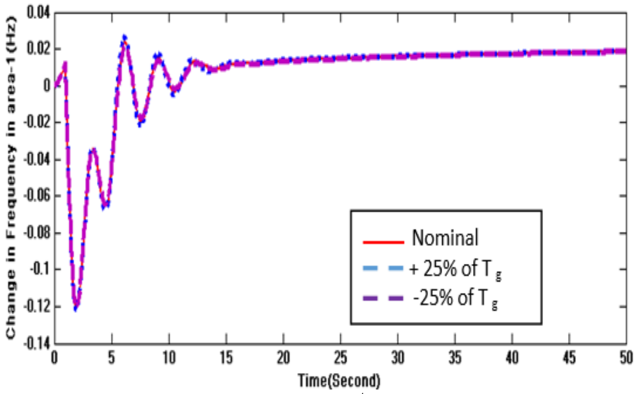


(c) Tie line power P_{tie} due to 5% load increase in 1st area

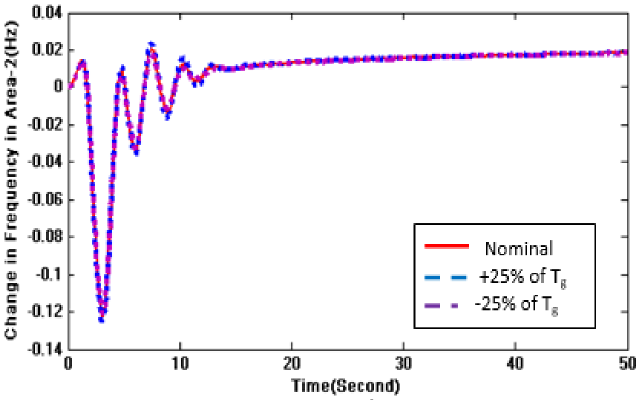
Fig.5. Dynamic behavior the two source two area hydro thermal generation

The frequency deviation in the second control area (ΔF_2) as exhibited in Fig.5 (b) presents the efficacy of FLC on PI controller, showing improved damping characteristics of the suggested system. The oscillations with PI controller is completely suppressed with FLC. The unstable response with PI controller is effectively decreased to 14.56 sec with FLC and adds to system stability.

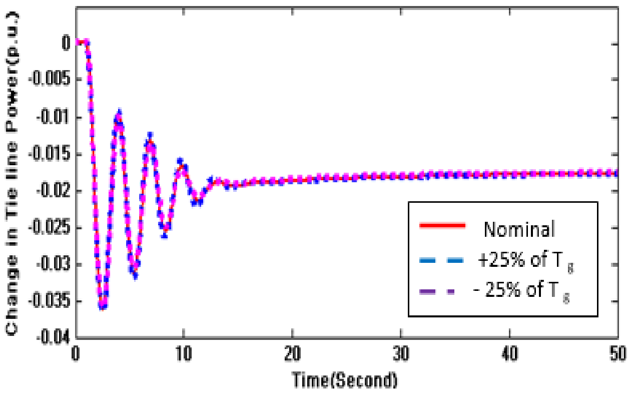
The change in power through tie line (ΔP_{tie}), as established in Fig.5 (c) demonstrated that PI controller cannot monitor the power exchange through the tie-line whereas FLC can effectively monitor it with minimum oscillation to settle the frequency variation in the control areas.



(a) Frequency alteration in 1st control area



(b) Frequency alteration in 2nd control area

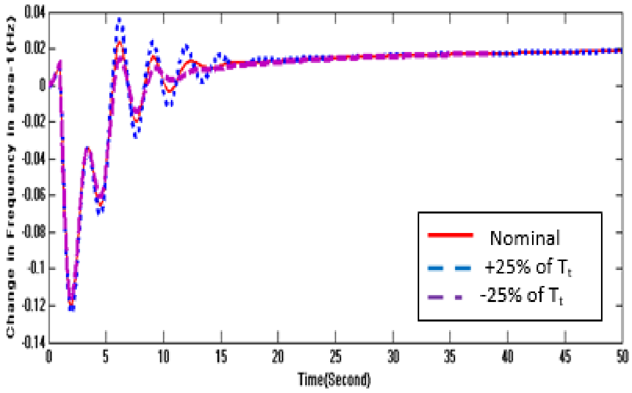


(c) Power exchange through tie line

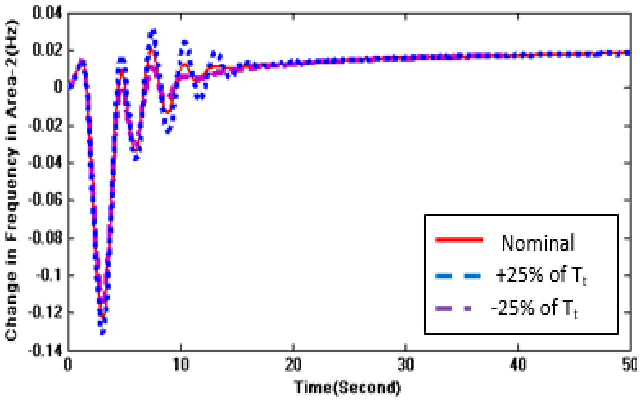
Fig.6. Dynamic behavior a TSTA system with variation of T_g

With a variation in the range of ±25% with respect to their suggested values, the operating load conditions, governor time coefficient (T_g),steam turbine time coefficient (T_t) and tie line power time constant (T_{12}), the robustness of fuzzy logic controller is verified and shown by the Fig.6-8. The comparative analysis with parameter variation is summarized in table II.

From the study it is concluded that, FLC can efficiently improve the deviations found in system frequency unlike PI controller.



(a) Frequency alteration in 1st control area



(b) Frequency alteration in 2nd control area

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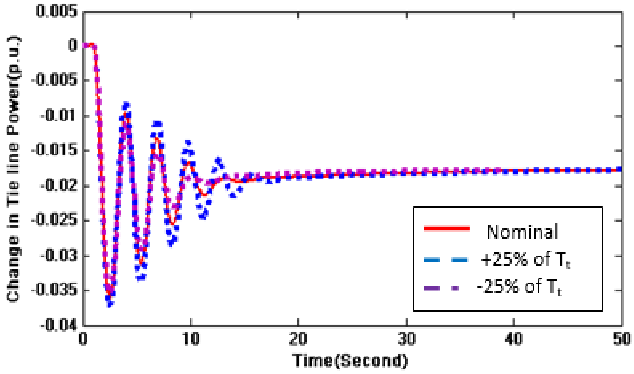
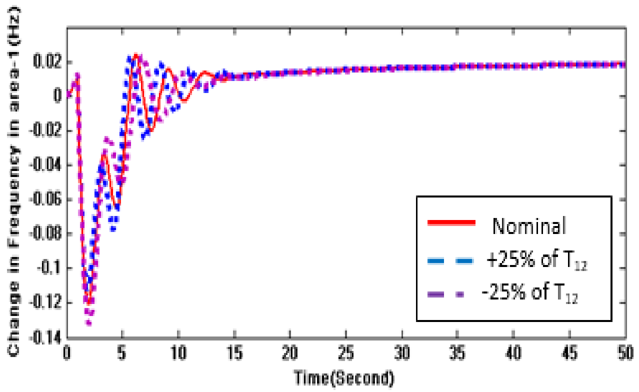
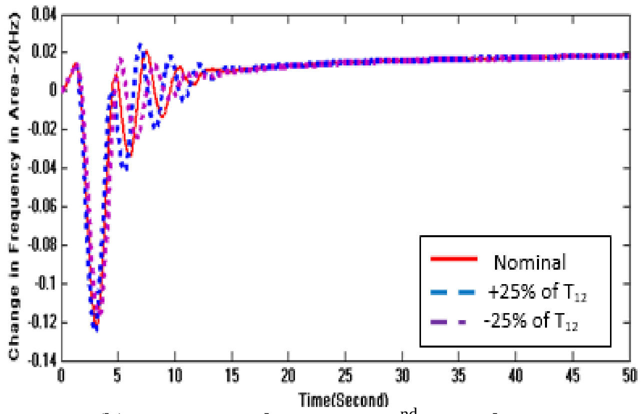


(c) Power exchange through tie line

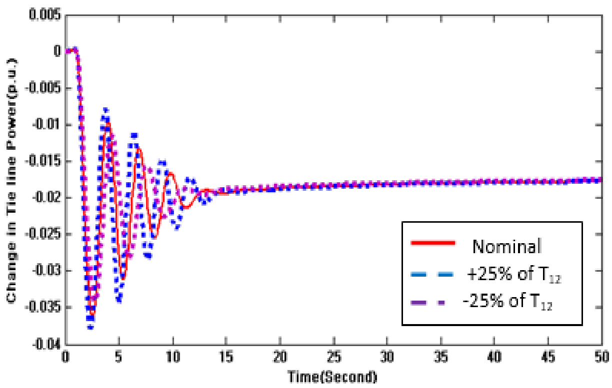
Fig.7. Dynamic behavior the TSTA system with variation of Tt



(a) Frequency alteration in 1st control area



(b) Frequency alteration in 2nd control area



(c) Power exchange through tie line

Fig.8. Dynamic response the TSTA hydro thermal system with variation of T_{12}

Table-II. Comparative analysis with parameter variation

Variation in parameter values	% change	Settling Time Ts(Second)		
		ΔF_1	ΔF_2	ΔP_{tie}
Nominal loading conditions	0	15.02	13.83	14.93
T_g	+25	15.00	14.07	14.84
	- 25	14.98	13.89	15.1
T_t	+25	15.23	14.12	14.96
	- 25	14.87	13.93	15.03
T_{12}	+25	15.12	14.11	15.07
	- 25	15.02	14.08	14.98

IV. CONCLUSION

This paper imparts the effectiveness of a rule based fuzzy logic controller to prevail over the problems found, considering PI controller in multi area power generating system when subjected to different parameter variations. The suggested system simulations are examined for PI and fuzzy logic controller and the results are compared. Moreover the deviation found in control area frequency and power flow through the control areas, for 5% load change in one control area are compared to look at the superiority of FLC on PI. The simulation results explain that, by implementing fuzzy logic controller in the system, the offsets found in frequency variation and power flow through tie-line, are improved and the response settles down quickly with a reduced settling time. The system parameter values of the connected plants have been changed in proportion and examined for FLC. From findings it is established that, the proposed fuzzy logic controller performs excellently with system parameter variations.

Appendix A

Single area hydro thermal system [8]

R_1 = 2.4Hz/per unit Megawatt
R_2= 2.4Hz/per unit Megawatt
T_g=0.08sec
K_{rt}=0.333
T_{rt} =10sec
T_t =10 sec
K_{gh} = 1
T_{gh} =48.7sec
T_r =5sec
T_2=0.513sec
T_{wh}=1 sec
K_{ps}=120Hz/p.u
T_{ps}= 20sec

Appendix B

Two source two area hydro thermal system [8]

R_1 = R_2=2.4Hz/ per unit Megawatt
B_1=B_2= 0.425 per unit Megawatt/Hz
Thermal power plant parameters
T_{g1} = T_{g2} =0.08sec
K_{rt1} = K_{rt2} = 0.333
T_{rt1} = T_{rt2} =10sec
T_{t1} = T_{t2}= 10 sec

Hydro power plant parameters

$R_3 = R_4 = 2.4$Hz/p.u MW

$K_{gh1}=K_{gh2}=1$

$T_{gh1} = T_{gh2} = 48.7$sec

$T_{r1} = T_{r2} = 5$sec

$T_{21} = T_{22} = 0.513$sec

$T_{wh1} = T_{wh2} = 1$ sec

$K_{ps1} = K_{ps2} = 120$Hz/p.u.

$T_{ps1} = T_{ps2} = 20$sec

$A_{12} = -1$

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