Load Frequency Control of Four-Area Hydro-thermal Inter-connected Power System through ANFIS Based Hybrid Neuro-Fuzzy Approach

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***Abstract*- This paper presents an ANFIS based intelligent load frequency control approach for a hybrid power system with four thermal-hydro control areas. The merit of the proposed controlling technique is that it is faster than the automatic conventional control techniques and is able to handle the non-linearities simultaneously. Also the maximum overshoot and the settling time of ANFIS based controller are lesser when compared to the conventional controllers, thereby reducing the oscillations locally and of inter-area. This effectiveness of the proposed controller in improving the dynamic response is shown and validated in four area inter-connected system. Thermal control areas (1 and 2) have reheat turbines and areas 3 and 4 comprises hydro-power plants. Comparison in performances of PI ,PID control technique and ANFIS control approach is carried out in MATLAB/SIMULINK software. The results validates that the ANFIS based intelligent controller is faster than the conventional controller and have improved dynamic response.**

Keywords-Generator load frequency control, PI,PID and hybrid neuro fuzzy controllers, ANFIS.

I. INTRODUCTION

A large power system generally consists of several control areas or regions representing a coherent group of machines. In a practical interconnected power system with interconnection of thermal, nuclear, gas and hydro power generating areas, the net power generation is a mix of these different power generating areas. However, nuclear power plants due to their high efficiency are mostly used for base loads and hence do not participate in Automatic generation control(AGC).Gas plants are highly suitable for variable load demands. They are used for meeting the peak demands only. Therefore the most usual choices for AGC are Thermal and Hydro plants.[4][8][11]

There are two main targets of the load frequency control - i) to maintain the frequency deviations in each control area within specified limits and ii) to maintain the tie line power exchanges between the control areas within the specified limits.[1][2][8] Any imbalance between the generated power and load demand can lead to subsequent deviations in the plant freq.(f) from the value specified.[2][3][8] This deviation in frequency is undesirable and can lead to system failure. Automatic generation control(AGC) methodology consists two parts ,i.e, a load frequency control loop (LFC loop) and a Automatic Voltage control loop (AVR loop).Load Frequency Control system provides the zero steady state error in frequency deviations for controlling the generator load model.[8][11] Therefore, a controlling methodology or technique is required which keeps freq. and nominal tie-line power exchange fixed but also assures zero steady state error and uninterrupted exchange.[5][10]

There are different kinds of LFC controllers such as PI controller, PID controller, slide mode controller and intelligent controllers. Conventional PI controller is the most widely employed LFC controller. LFC in a power system with multi areas aims at optimal transient behaviors.[2][3] The conventional controllers PI and PID provides good dynamic response and also are very easy to implement. But due to variations in load , boiler dynamics and other disturbances the performance of the conventional controllers degrades when the complexity of the system rises.[2][8] Slide mode controllers with fixed gain at scheduled operating situations provides good performance but fails to provide required control.[2][6][9] Therefore, it is necessary that performance of the plant remains close to its optimum, and consequently it becomes

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necessary to trace and tarck the operating conditions and utilize updated values of the parameters to calculate the control gains.[4][7] Hence the requirement of a LFC controller that can remove these drawbacks arises. Intelligent controlling technique uses controllers namely fuzzy logic controllers and neural controllers and they are much more adequate for this field. Key feature of the intelligent controllers is well known i.e. gives a model-free description of the control systems and there is no need of model identification in suchtechniques.[6][10]

In this paper a task to apply artificial neuro –fuzzi control technique for generator load-frequency control of power network with four interconnected locale has been undertaken. In MATLAB, an adoptive network that is similar to fuzzy based inference system is used. The framework of ANFIS architecture has been used. The performances of the ANFIS based controller and the conventional automatic PI and PID control are compared to highlight the supremacy of hybrid controller over conventional controllers.

II. CONTROL METHODOLOGY

The objective of Automatic generation control can be fulfilled by using either of the following controllers: PI,PID controller, Fuzzy logic based controller, ANFIS based controller. In this paper, PI PID and ANFIS based controller for Load frequency control has been discussed in the sections below:

A. Conventional Controllers:

The objective of any controller of load frequency is to produce a controlling signal which keeps the frequency of given system constant and power exchange between control areas at predetermined values.Fig.1shows the typical scheme of conventional control on i^{th} control area. The area control error(ACE_i) is input to the PI controller with proportional gain (K_i).$b_{i:}$bias;ΔP_{Di}: change in load;ΔF_i:change in frequency and K_F =(2*Π*T_{12})/s, where T_{12} is tie line constant which depends on the system voltages of two control areas connected through the tie line and its reactance.

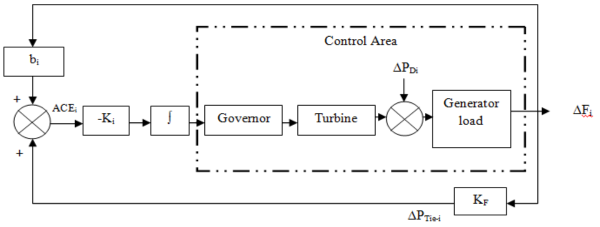

Fig.1. Automatic conventional control scheme using PI on ith area

B. Intelligent controller:

(i)Fuzzy inference Systems.

Researchers recently have proposed different neural and fuzzy applications for different purposes and fields. Due to their vast uses in the area such as image processing, pattern recognition, control, etc, the HNF technique have drawn considerable attention. The results of a HNF system are acquired from the combination of ANN learning with fuzzy based logic.[5][6][10] There are basically two main fuzzy inference styles which are also available in MATLAB are:

Mamdani-type inference system, based on paper by Zadeh in the year 1973 for decision procedures & complex system which assumes membership functions for output as fuzzy sets. It has been widely accepted worldwide, and is adequate to manual input.[6] But it has a drwaback that the calculation time for the defuzzification process is large.[7][10]

Sugeno-type inference is derived from Sugeno-Takagi proposed methodology of fuzzy inference, in attempt to explain a systematically better approach for generating fuzzy knowledge bases from a set of input and output data.[6] It is suitable for control techniques which are linear (e.g. PID control, etc.), adaptive and optimal techniques, assures that the output surface is continuous, and is very much adequate for mathematical study.[10] The outcomes of Sugeno type inference system are highly resembling to Mamdani - type inference.. If the requirements include learning abilities then it would be appropriate to set the fuzzy based model into a structure of ANN with supervised learning that can be useful to calculate gradient vectors accordingly.Sugeno-type is more favoured over Mamdani type inference .A standard rule in fuzzy logic is:If p is measured as X and q is measured as Y then it impiles that r=f(p,q) , where X and Y are fuzzy sets in the prior and r=f(p, q) is defined as real function in the later. Mostly, ‘r’ is a function of order one or zero.[7][10]

ii). Modelling: ANFIS based System

Any fuzzy system can be designed by the steps explained as follows:

- Fuzzyfication of crisp values

1. Extraction and normalization of crisp values for input fuzzy vectors and output fuzzy vectors.
2. Selection of the membership functions (mFs)-number and shape, for input fuzzy vectors and output fuzzyvectors .
3. Conversion of crisp values into Fuzzy inputs by calculating membership grades.

- Rule base and Fuzzy Inference

1. Form a rule base using control observations.
2. Find out the rule bases that are stored.
3. The rule base consists of easy to form simple if-then conditional statements that decide the control objectives and

control policy of the domain experts.

- Defuzzification

1. Calculate the crisp values for corresponding fuzzy output vector, applying a suitable defuzzification process.
2. Results are procured after simulation.

iii)ANFIS based designed controller (Adaptive NeuroFuzzy Inference System)

This is a kind of artificial neural network which is based on Sugeno type FIS. It has higher complexity than FIS. This can be used only for Sugeno type models.[6][7] But user can define no. of input & out put membership functions(num Mfs, the MF's type (mfType) , the no. of model validation sets of data(numPts) and the criterion for optimization for minimizing the measure of error(characterized by the number of the squared differences of true N-curve & its linearized form). There are several types of membership functions. The choice of a membership function depends on the parameters of the model.[7][10]

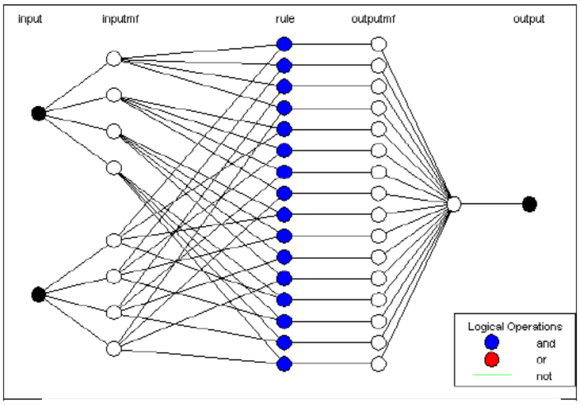

Fig.2.Rulebases Formed ANFIS

The main advantage that ANFIS has over the fuzzy based designing is that it requires lesser membership functions(mFs) to represent input as well as output, implying the identical maximum number of rules.[5][7] Therefore, the memory requirement & rules base reduces considerably.

In the presented model, there are two inputs to the ANFIS based controller are frequency (ACE(t)) and change in frequency error (ΔACE(t)) with 4 membership functions. Fig.2 shows 16 rules have been made with 16 output mFs. and then defuzzification provides only one output which has been taken out..

iv).Model validation using training and checking data sets: ANFIS

Model validation is the procedure by which we see how effectively the developed FIS model predicts the output values when the inputs from the data set on which the FIS model was not trained are fed to the FIS model. The number of epochs is deduced with help of mentioned parameters and anticipated error which is usually preset by the user. The model validation data is given below:

S.NO.	Validation Data	Number
1.	Nodes	53
2.	Linear parameters	16
3.	Non-linear parameters	24
4.	Epochs	40
5.	Training data pair	51
6.	Checking data pair	51

In this model, generalized bell membership functions have been considered.

.III. SIMULINK MODEL

The typical power system with 4 control areas interconnected using transmission lines called tie-lines is shown in fig.3.Area 1 and 2 are thermal areas and Area 3 and 4 are hydro power control areas.

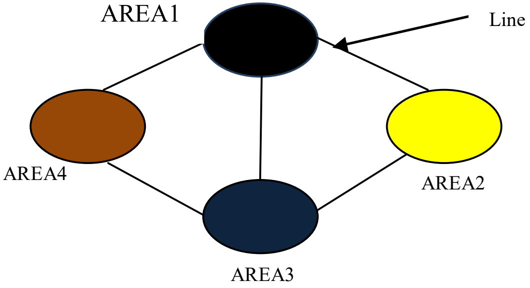

Fig 3. Block diagram of four area plant connected with tie line

The aim of the frequency control scheme is that each control area should be able to feed its own demand and must be suitable for frequency control at the same time.[1][2][8] In a power system with isolated area , the rate of rise of kinetic energy stored provides for the increase$(\Delta P_g - \Delta P_d)$ in power and increment in system load caused due to increment in system frequency.[1-4]

To get rid of steady state error of freq. & in tie-line power exchange, a gain called bias can be used. It implies that the each one of the controlling areas must contribute to frequency control and should also take care of their own net exchange. In this control, the error of each area is kept a linear function of frequency error and tie line power error[2].

$ACE_{a1} = \Delta P_{21}+B_{1}.\Delta f_{1}$ (6)

$ACE_{a2} = \Delta P_{32}+B_{2}.\Delta f_{2}$ (7)

$ACE_{a3} = \Delta P_{34}+B_{3}.\Delta f_{3}$ (8)

$ACE_{a4} = \Delta P_{41}+B_{4}.\Delta f_{4}$ (9)

where ACE is the area control error, $B_{1.}$, $B_{2.}$, $B_{3.}$ & $B_{4.}$ are fixed gains defined as frequency bias for their respective areas. Now ΔP_{c1}, ΔP_{c2}, ΔP_{c3}, ΔP_{c4} are definite integral of their respective area control errors.[2-5]. The simulink models of the plant system with four control (thermal-hydro) areas interconnected through tie lines are shown in fig.4 and fig.5 using different control methodology i.e., conventional and intelligent respectively.

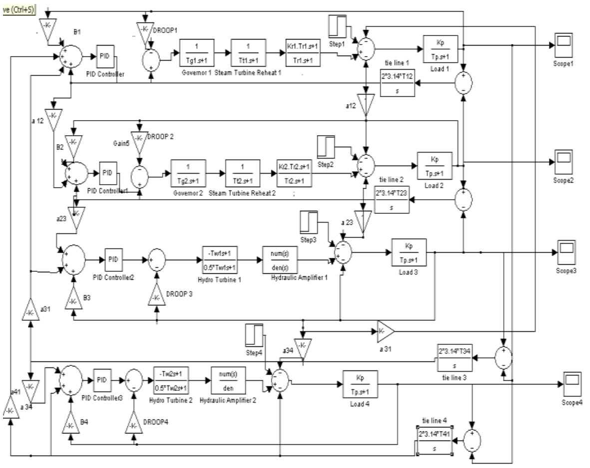

Fig.4 Simulink Model For Four Area LFC Control incorporating conventional controller.

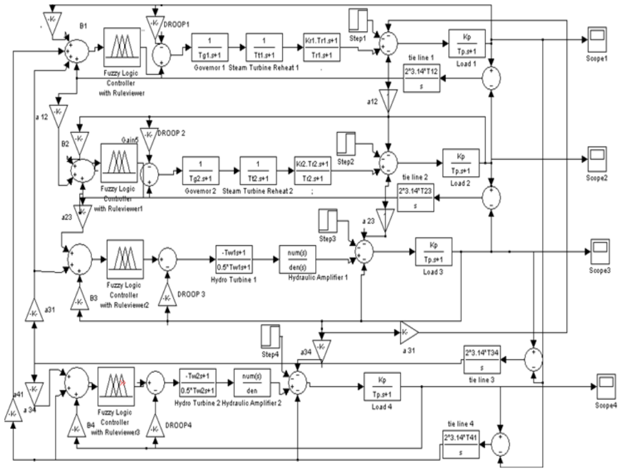

Fig.5 Simulink Model For Four Area LFC Control incorporating intelligent controller(ANFIS).

IV. RESULTS AND DISCUSSION

A Load frequency control effort using adaptive nuero–fuzzy (ANFIS) technique has been constructed. In this hybrid scheme, first the ANFIS is fed by the error & derivative of error in the frequency as the input. With these inputs and using nueral network back propagation method, ANFIS generates the parameters to be used in the FIS controller of type-sugeno. The value of various constants used for simulation are given in appendix. With 0.01 change in step load(or disturbance) in the systim frequency(f) and tie-power,the various freq. deviation plots are obtained for hydro-thermal plant separately using PI, PID and ANFIS controllers. For simplicity, simulation results of only one of the thermal and one of the hydro control areas is shown.

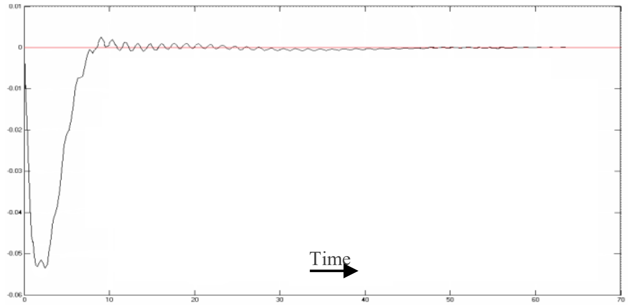

Fig6.freq. deviation of Area-1(thermal) with PI Control

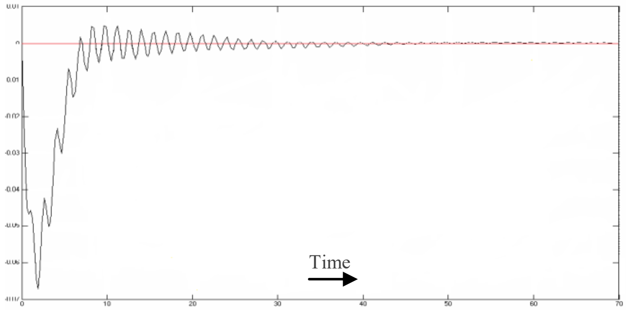

Fig7.freq. deviation of Area-3(hydro) with PI Control

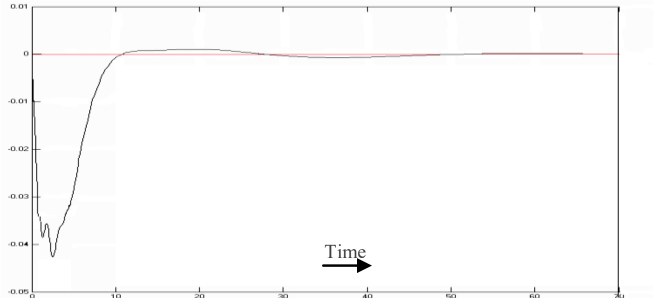

Fig8.freq. deviation of Area-1(thermal) with PID Control

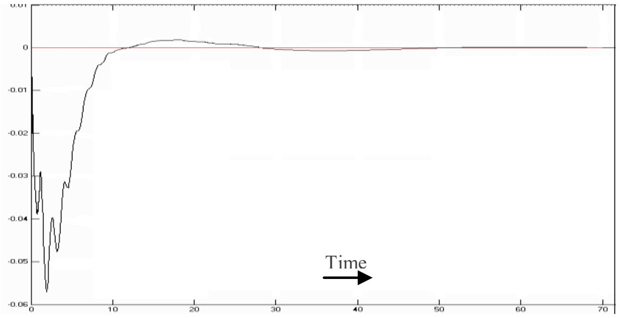

Fig9. freq. deviation of Area-3(hydro) with PID Control

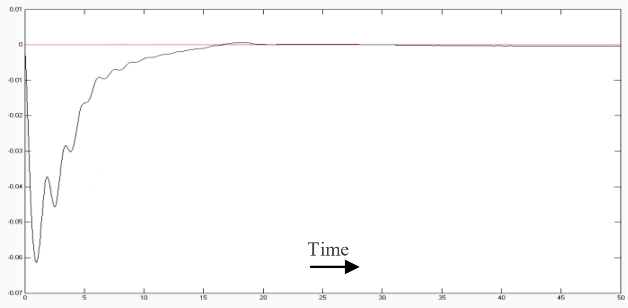

Fig10.freq. deviation of Area-1(thermal) with ANFS Control

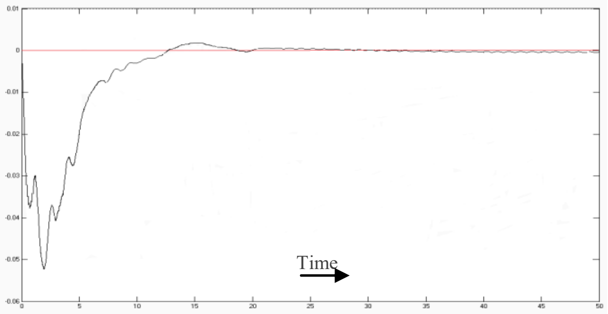

Fig11. freq. deviation of Area-3(hydro) with ANFIS Control

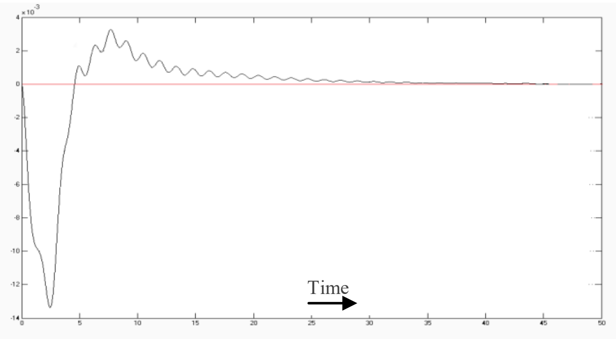

Fig12.Tie line power of Area1(thermal)-Area2(thermal) with PI Control

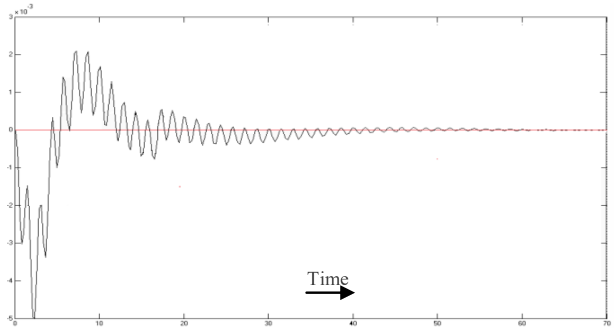

Fig13.Tie Line Power of Area1(thermal)-Area3(hydro) with PI Control

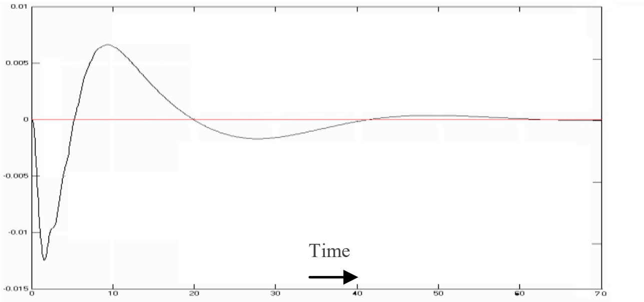

Fig14.Tie Line Power of Area1(thermal)-Area2(thermal) with PID Control

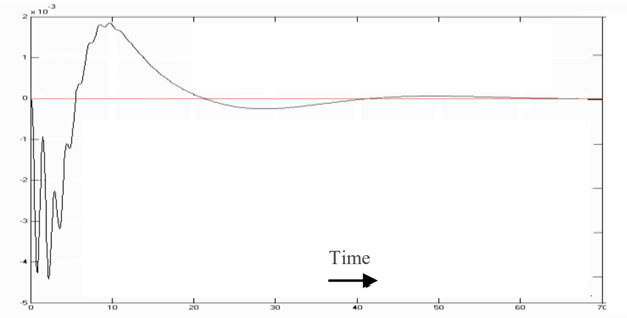

Fig15.Tie Line Power of Area1(thermal)-Area3(hydro) with PID control

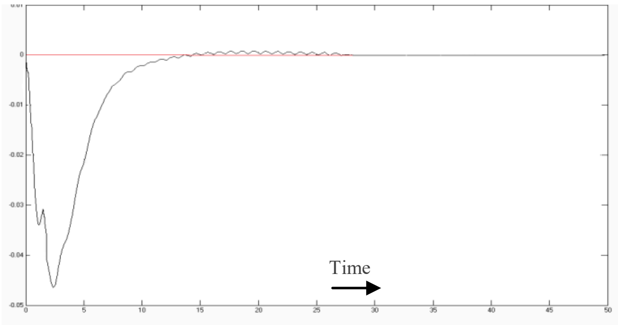

Fig16.Tie Line Power of Area1(thermal)-Area2(thermal) with ANFIS Control

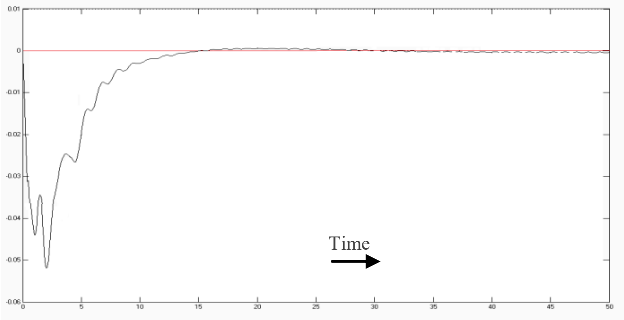

Fig17.Tie Line Power Of Area1(thermal)-Area3(hydro) with ANFIS Control

From the above results it becomes apparent that the adaptive and intelligent ANFIS based control provides far better dynamic response of the system as compared to the conventionally used PI and PID based controllers. It is very clearly observed in the above plots that the maximum overshoot and the time taken to reach steady state is comparatively reduced using ANFIS controllers for change both in plant frequency as well as in the power exchange between areas are shown in tables below :

Table no 1. Settling time comparison

Controllers	PI	PID	ANFIS
Δf(area 1)(sec)	65	59	17
Δf(area 2)(sec)	65	59	17
Δf(area 3)(sec)	69	59	16
Δf(area 4)(sec)	68	50	16
$\Delta P_{tieline}$ power(A1-A2)(sec)	66	62	14
$\Delta P_{tieline}$ power(A1-A3)(sec)	69	60	28

Table no 2. Maximum overshoot comparison

Controllers	PI	PID	ANFIS
Δf(area 1)p.u.	-0.053	-0.060	-0.061
Δf(area 2)p.u.	-0.053	-0.059	-0.061
Δf(area 3)p.u.	-0.067	-0.068	-0.055
Δf(area 4)p.u.	-0.066	-0.065	-0.055
$\Delta P_{tieline}$ power(thermal)p.u.	-0.0051	-0.005	-0.0051
$\Delta P_{tieline}$ power(hydro)p.u.	-0.0056	-0.012	-0.044

V. CONCLUSIONS:

From the above tabulated and plotted simulation results for the change in plant frequency and the tie line power, it is clear that the intelligent nuero-fuzzy based controller(ANFIS) minimizes the settling time and maximum overshoot of anomalies in system frequency (f) and tie-power. Also it is clear from the results that the oscillations in the two responses have also been minimized using the proposed controller. Thus the nuero-fuzzy control methodology is faster and accurate as compared to conventionally used PI and PID controllers.

VI. ACKNOWLEDGEMENT:

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VII.APPENDIX:

f=50 Hz, R_i=2.5 Hz/p.u. Megawatts, T_{pi}=20s, P_{tiemax}==200 Megawatts, T_r=10s, H_i=5 s, K_r=0.499, P_{ri}==2000 MegaWatts, $T_{t\text{-}i}$=0.299s, T_{gi}=0.081 s,K_{pi}=120 Hertz/p.u. MegaWatts, K_i=4, K_d=5, T_w=1 s, D_i=8. $331*10^{-3}$ p.u MegaWatt/ Hz, B_i=0.4254 p.u MegaWatt/Hz, a_i=0.515, a= (2* pi*T_i), del P_{di}= 0.01.

REFERENCES

[1] Yousuf, KAL-Kharausi.Albadi and Hosseinzadeh, "Load Frequency Control of a Multi-Area Power Systims: An Adaptive Fuzzy Logic Approach", *IEEE Transactions of Power Systems*.

[2] Kothari, D.P. and Nagrath (2012), *Modern Power System Analysis*, Tata Macgraw Hiil, Fourth Edetion.

[3] Wadhawa, C.L. (2007), *Electric Pover Systms*, New Age International Publication Edition.

[4] Sinha, S.K. and Surya, P. (2012), "Four Area Load Frequenci Control of Interconnected Hybrid Power System by Intelligent PID Controlling Technique", 978-1-4673-0455-9/12/$31.00, IEEE.

[5] Panda, Gayadhar, Panda, Sidharth and Ardil, Cemal (2009), "AGC of Interconnected Power System with Generation Rate Constraints by Hybred Neuro Fuzzy Approach", *World Academy of Science, Engineering and Technologies,* Vol. 52, pp. 54–548.

[6] Panda, Gayadhar, Panda, Sidharth and Ardil, Cemal (2009), "Hybrid Neuro-Fuzzi Approach for Automatic Generation Control of Two Area Interconnected Pover System", *International Journal of Computational Intelligence,* Vol. 5(1), pp. 80–84.

[7] Jang, J.R. (1993), "Anfis: Adaptive Network Based Fuzy Inference System", *IEEE Trans. On Systems, Man and Cybernetics*, Vol. 23, May 1993, pp. 665–685.

[8] Ibraheem, Prabhat Kumar and Kothari, D.P. (2005), "Recent Phlosophies of AGC Strategies in Power Systems", *IEEE Trans. On Pover System*, Vol. 20, No. 1, pp. 346–357.

[9] Prakash, Surya and Sinha, S.K. (2009), "Impact of Slider Gain in LFC using FLC", *ARPN Journal of Engineering & Applied Science*, Vol. 4, No. 7, Sep. 2009.

[10] Prakash, Surya, Bhardwaj, A.K. and Sinha, S.K. (2012), "Neuro Fuzzy Hybrid Intelligent Approach for Four Area Load Frequency Control in Interconnected Power System", *2nd International Conference on Power,Control & Embedded Systems*.

[11] Magla, A. and Nanda, J. (2004), "AGC of an Interconnected Hydro-Thermal Systims Using Conventional Integral and Fuzzy Logic Control", *Proc. IEEE Electric Utility Deregulation, Restructuring and Power Technologies*, Apr. 2004.