Adaptive Neuro-Fuzzy based Load Frequency Controller for Three Area Inter-Connected Hydro-Thermal Power System

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***Abstract*- This paper presents an intelligent load frequency control approach for a power system with three thermal-thermal-hydro control areas using ANFIS technique. The merit of this controlling technique is that it is faster than the conventional controllers. 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 three area inter-connected system.Areas1 & 2 comprises of thermal reheat plants and area 3 comprises of hydro power plant. Comparison in performances of PID control technique, Fuzzy based controller and ANFIS control approach is carried out in MATLAB/SIMULINK package. The results validates that the ANFIS based controller is faster than the conventional controller and have improved dynamic response.**

Keywords- Generator load frequency control, PID,FLC(Fuzzy Logic controller) and hybrid neuro fuzzy controllers, ANFIS, AGC(Automatic Generation Control)

I. INTRODUCTION

With the increasing non-linearities and the complexities of the power systems, the industrial sector has been severely affected by the operating point variations which has increased the concern about power quality. Any power system network consists of many interconnected areas and any type of fault, interruptions or disturbances adversely affects the power quality. Any mismatch between generation and demand leads to severe frequency deviations which may even lead to black-outs. Thus, power system controllers are need to be designed in order to regulate power flows between the tie lines and frequency in the interconnected areas through AGC. AGC consists of a feedback control loop to adjust the frequency in limits. AGC has two parts namely LFC (Load frequency control)and AVR(automatic voltage regulator). LFC provides zero steady state errors alongwith optimisation of transient behaviour. There are different kinds of LFC controllers such as PI controller , PID controller, slide mode controller and intelligent controllers.

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, the most usual choices for AGC are Thermal and Hydro-plants.[4][11]

In Literature, dynamic response has been analysed using PI,PID, Fuzzy and Nueral network based controllers[1][4][7] which suggest various control techniques with various advantages and disadvantages. In reference[10], a LFC using conventional controllers and intelligent ANFIS controllers are proposed and their performances in improving dynamic responses are compared[.9]

In this paper a task to apply artificial neuro –fuzzy controller for load frequency control of three plant area interrelated power system has been undertaken. I The framework of ANFIS architecture has been used. The performances of the ANFIS based controller,

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,FLC and the conventional automatic PID control are compared to highlight the supremacy of hybrid controller over conventional controllers.

II. THREE AREA POWER SYSTEM MODELING

Any power system network consists of many interconnected control areas which increases its complexities and non-linearities. These control areas are connected by tie lines which require controllibility of power flow and freq. deviation.

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. 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 frequency error and tie line power error [2].

$ACE_{a1} = P_{21}+B_{1.}\ f_1$ (1)

$ACE_{a2} = P_{32}+B_{2.}\ f_2$ (2)

$ACE_{a3} = P_{34}+B_{3.}\ f_3$ (3)

where ACE stands for the area control error, $B_{1.}$, $B_{2.}$ & $B_{3.}$ are fixed gains defined as frequency bias for their respective areas. Now P_{C1},P_{C2},P_C3 are definite integral of their respective area control errors[2-5].The simulink models of the power plant system with three control(thermal-thermal-hydro)areas interconnected through tie lines are shown below with different control methodology.

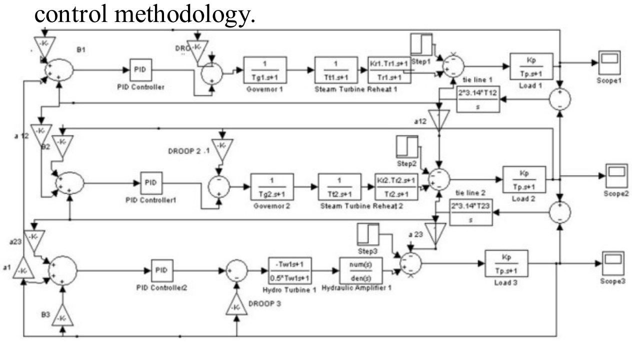

Fig. 1 model for three area power system(hydel-thermal-thermal)using PID Controller

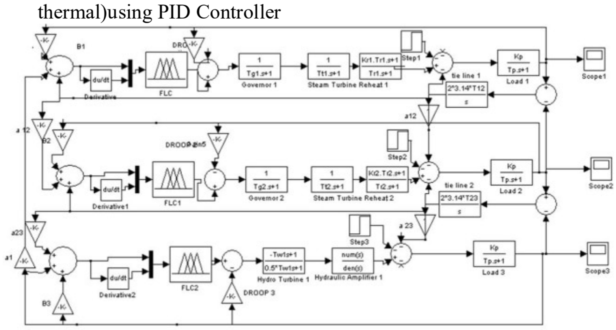

Fig.2 model for three area power system(hydel-thermal-thermal)using fuzzy logic controller

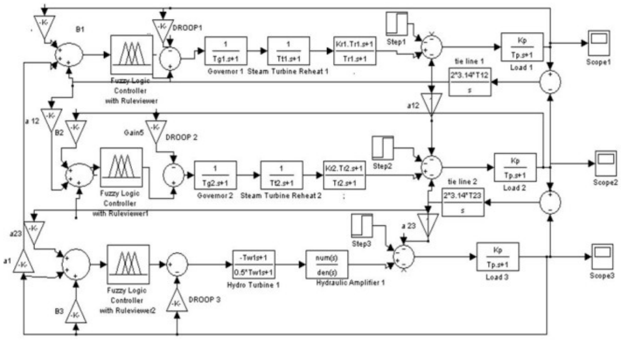

Fig.3 model for three area power system(hydel-thermal-thermal)using ANFIS based Controller

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,PID,Fuzzy 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 is equal to($2*\Pi*T_{12}$)/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.

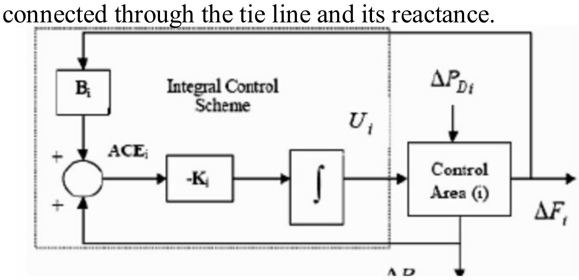

Fig.4. Automatic conventional control scheme using PI on ith area

B. *Intelligent Controllers*

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 ANFIS technique have drawn considerable attention. The results of a ANFIS system are acquired from the combination of ANN learning with fuzzy based logic.[5][6][10] The controller designed in our work consists of a fuzzy algorithm which represents the knowledge in analytical form followed by the nueral structure for learning process for the optimisation of the parameters

i. *Fuzzy Logic Algorithm*

For fuzzy based controller, first step is to decide the type of inference system. In MATLAB, there are basically two types of inference system explained below briefly:

Mamdani-type inference system is for decision procedures & complex system which assumes membership functions for output as fuzzy sets respectively. Table I shows the rule base for three membership functions, which gives the best result for the present problem. Defuzzification to obtain crisp value of FL controller output is done by centre of maximum method [14]. The fuzzy rule base proposed by trial and error study of control are used for tuning FLC are shown below:

Table I. Rule Base for 3 Membership Functions

(del_ACE→) (ACE↓)	NL	ZE	PL
NL	NL	NL	ZE
ZE	NL	ZE	PL
PL	ZE	PL	PL

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 to calculate gradient vectors accordingly.Sugeno-type is more favoured over Mamdani type inference

The basic steps in modelling fuzzy based controller after deciding the type of inference system are:

- 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 fuzzy vectors .
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 and are .
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.

ii)ANFIS based designed controller

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, methods- AND:prod, OR:maximum, of membership functions. The choice of a membership function depends on the parameters of the model.[7]

The main advantage that ANFIS has over the fuzzy based designing is that it requires lesser membership functions(mFs) for same number of rules.[5][7]Therefore, the memory requirement and 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. After developing the FIS, 16 rules have been made with 16 output mFs and then defuzzification provides only one output which has been taken out. MATLAB /SIMULINK representation of rule bases in a FIS is shown below

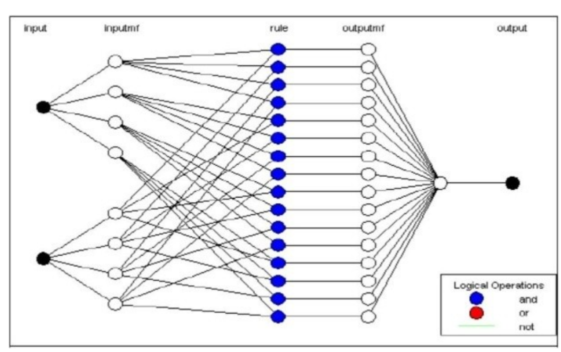

Fig 5- Rulebases in ANFIS

iii). *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:

Table II:Validation data

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

Below given is error range :
1 0.000527878 0.00471299
2 0.000612469 0.00492600

In this model, gbell membership functions have been considered. The deviation in frequency f ¸ may be defined as the difference of real system frequency (f) and nominal or predefined system frequency (f_N).

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 PID , FLC and ANFIS controllers.

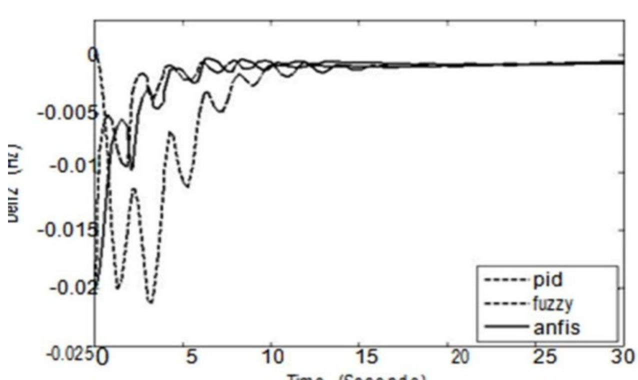

Fig 6. Change in Freq. of Area 1(thermal)

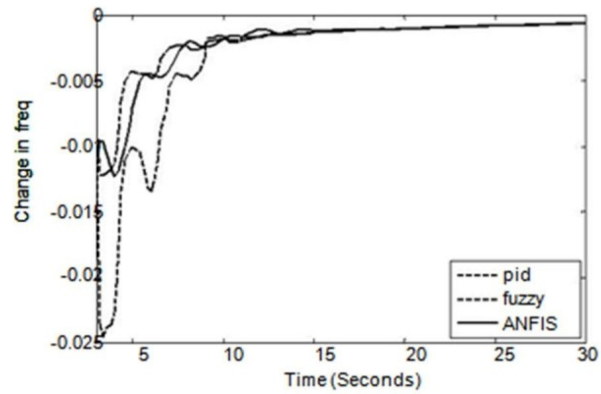

Fig 7. Change in Freq. of Area 2(thermal)

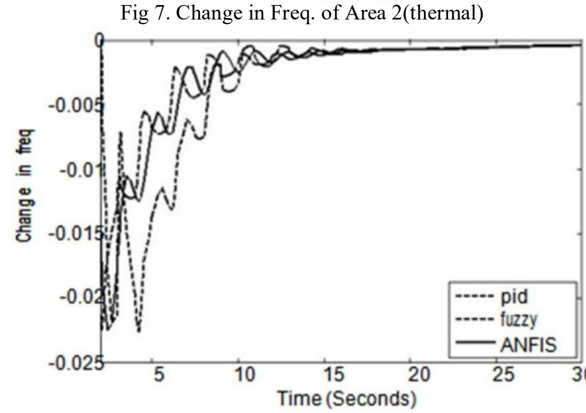

Fig 8. Change in Freq. of Area 3(hydro)

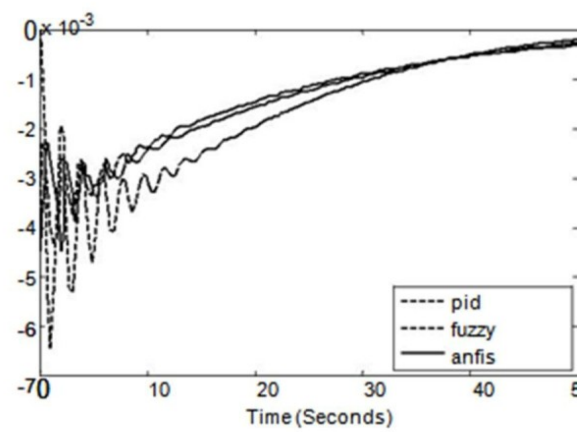

Fig 9. Change in Power of Ptie(tie line power)

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 as shown below.

Table III. Settling time comparison

Controllers	del f(area 1) pu(sec)	Del f(area 2) pu(sec)	Del f(area 3)pu (sec)	Del f(area 4) pu(sec)	Del $P_{tie\ line}$ thermal(sec|)	Del $P_{tie\ line}$ hydro (sec)
PI	29.99	29	28	49	71	67
PID	27	25	24	44	39	44
ANFIS	15	15	16	16	14	26

Table no IV. Maximum overshoot comparison

Controllers	Del f(area 1)pu(sec)	Del f(area 2)pu(sec)	Delf (area 3)pu(sec)	Del f(area 4)pu(sec)	DelP$_{tieline}$ power(thermal)(sec)	DelP$_{tieline}$ hydro(sec)
PI	-0.025	-0.025	-0.023	-0.06	-0.0064	-0.0056
PID	-0.02	-0.012	-0.02	-0.04	-0.0042	-0.012
ANFIS	-0.01	-0.01	-0.015	-0.02	-0.0031	-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 for change in system freqeuncy (f) and tie- line power that is for 1% change in input power;1%change in frequency is observed in case of ANFIS controller which is minimum.Thus the nuero-fuzzy control methodology is faster and accurate as compared to conventionally used PI and PID controllers and hence steady state is achieved faster in case of ANFIS controllers for LFC of four area system.

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-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,Kp=0.05,Ki=-0.5,Kd=0.01

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