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An Adaptive Neuro-Fuzzy Logic Controller for a Two Area Load Frequency Control

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ABSTRACT

This paper presents the design and analysis of Neuro-Fuzzy controller based on Adaptive Neuro-Fuzzy inference system (ANFIS) architecture for Load frequency control of interconnected areas, to regulate the frequency deviation and power deviations. Any mismatch between generation and demand causes the system frequency to deviate from its nominal value. Thus high frequency deviation may lead to system collapse. This necessitates a very fast and accurate controller to maintain the nominal system frequency. This newly developed control strategy combines the advantage of neural networks and fuzzy inference system and has simple structure that is easy to implement. So, In order to keep system performance near its optimum, it is desirable to track the operating conditions and use updated parameters near its optimum. This ANFIS replaces the original conventional proportional Integral (PI) controller and a fuzzy logic (FL) controller were also utilizes the same area criteria error input. The advantage of this controller is that it can handle the non- linearities at the same time it is faster than other conventional controllers. Simulation results show that the performance of the proposed ANFIS based Neuro-Fuzzy controller damps out the frequency deviation and attains the steady state value with less settling time and reduces the overshoot of the different frequency deviations and also reduces the interchanged tie power.

***Keywords* -** Adaptive Neuro-Fuzzy Inference System, Conventional PI Controller, Fuzzy Logic Controller, Load Frequency Control, Neuro-Fuzzy Controller.

I. INTRODUCTION

Nowadays, electricity generation is very important because of its increasing necessity and enhanced environmental awareness such as reducing pollutant emissions. The dynamic behavior of the system depends on changes in the operating point. The quality of generated electricity in power system in dependent on the system output, which has to be of constant frequency and must maintain the scheduled power and voltage. Therefore, load frequency control, LFC, is very important in order to supply reliable electric power with good quality for power systems. Large-scale power systems are composed of control areas or regions representing coherent groups of generators. These various are interconnected through tie lines. The tie lines are utilized for energy exchange between areas and provide inter-area support in case of abnormal condition [1-5]. Load changes in area and abnormal conditions, such as outages of generation, leads to mismatch in scheduled power interchanges between areas. These mismatches have to be corrected via supplementary control. In recent years, large tie-line power fluctuations have been observed as a result of increased system capacity and very close interconnection among power systems [1-2].This observation suggests a strong need of establishing a more advanced load frequency control (LFC) scheme. An effective controller for stabilizing frequency oscillations and maintaining the system frequency within acceptable range and to maintain the interchange power between control areas at scheduled values by adjusting the MW output power of the selected generators so as to accommodate changing in load demands [4-5].The load Frequency control (LFC) or Automatic Generation control (AGC) has been one of the most important subjects concerning power system engineers in the last decades. Many investigations in the area of LFC problem have been reported and a number of control strategies have been employed in the design of load frequency(LF) controller in order to achieve better dynamic performance[6-8].In recent years, fuzzy system applications have received increasing attention in power system operation and control[8,9,10,11,12].Among the various types of load frequency controllers, The most widely employed is the conventional proportional integral(PI) controller [5-6].Conventional controller is simple for implementation but takes more time and gives large frequency deviation. A number of state feedback controllers based on linear optimal control theory have been proposed to achieve better performance [6].Fixed gain controllers are designed at nominal operating conditions and fail to provide best control performance over a wide range of operating conditions. So, to keep system performance near its optimum, it is desirable to track the operating conditions and use updated parameters to compute the control. Recently, fuzzy-logic control application to power system are rapidly developing especially power system stabilization problem [8,10,14,15] as well as load frequency control problem. The basic feature of fuzzy logic controllers (FLCs) is that the control strategy can be simply expressed by a set of rules which describe the behavior of the controller using linguistic terms. Proper control action is then inferred from this rule base. In additional, FLCs are relatively easy to develop and simple to implement. The required fuzzy rules knowledge is usually provided by a control engineer who has analyzed extensive mathematical modeling and development of control algorithms for various power systems. In addition, the design of the conventional FLC is inefficient in the ability of self-tuning. This paper proposes a new ANFIS based Neuro-fuzzy controller that grasps the merits of adaptive control and Neuro-fuzzy techniques and overcomes their drawbacks [12-14]. With the help of MATLAB, simulations are performed for load frequency control of two area system by the proposed ANFIS based Neuro-Fuzzy controller and also with conventional PI and Fuzzy logic controller for comparison. The proposed adaptive Neuro-Fuzzy inference system trains the parameters of the Fuzzy logic controller and improves the system performance. Simulation results shows the superior performance of the proposed Neuro-fuzzy controller in comparison with the conventional PI controller and Fuzzy logic controller in terms of the settling time, overshoot against various load changes.

II. MODEL OF TWO POWER AREA

The block diagram for each area of interconnected areas is shown in Fig.1, where Δf_1 and Δf_2 are the frequency deviations in area1 and area2 respectively in Hz. ΔP_{d1} and ΔP_{d2} are the load demand increments. A dynamic model with Δf_1, Δf_2 & $\Delta\dot{f}_1, \Delta\dot{f}_2$ & $\Delta\ddot{f}_1, \Delta\ddot{f}_2$ as state variables is derived .The dynamic equations are represented in equation(1).

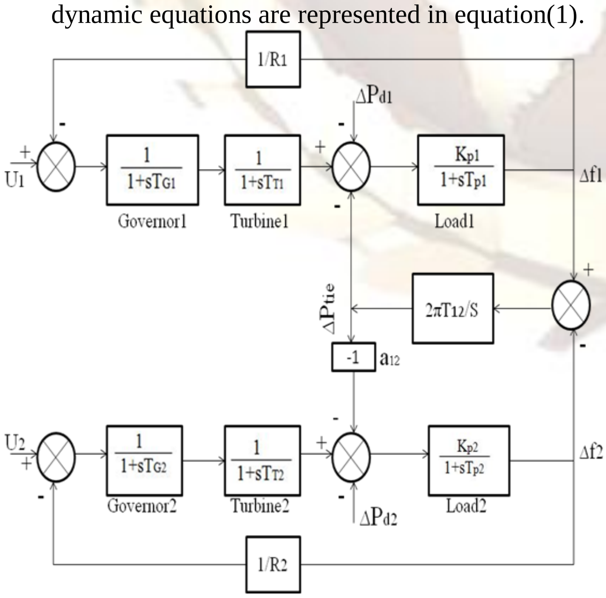

Fig.1 Two area interconnected system.

$$\left.\begin{array}{l}
\dot{X}_1 = X_2 \\
\dot{X}_2 = X_3 \\
\dot{X}_3 = \dfrac{1}{T_2}\left\{\begin{array}{l} -(K_1+2\pi T_{12}K_{P1}(T_{G1}+T_{T1}))X_1 - \\ (T_1+2\pi T_{12}K_{P1}T_{G1}T_{T1})X_2 - T_2X_3 + \\ 2\pi T_{12}K_{P1}(T_{G1}+T_{T1})X_4 \\ +2\pi T_{12}K_{P1}T_{G1}T_{T1}X_5 + \\ K_{P1}(u_1-\Delta P_{d1}-X_T) \end{array}\right\} \\
\dot{X}_4 = X_5 \\
\dot{X}_5 = X_6 \\
\dot{X}_6 = \dfrac{1}{T_6}\left\{\begin{array}{l} -(K_2+2\pi a_{12}T_{12}K_{P2}(T_{G2}+T_{T2}))X_4 - \\ (T_4+2\pi a_{12}T_{12}K_{P2}T_{G2}T_{T2})X_5 - T_5X_6 + \\ 2\pi a_{12}T_{12}K_{P2}(T_{G2}+T_{T2})X_1 \\ +2\pi a_{12}T_{12}K_{P2}T_{G2}T_{T2}X_2 + \\ K_{P1}(u_2-\Delta P_{d2}-a_{12}X_T) \end{array}\right\} \\
\dot{X}_7 = 2\pi T_{12}\left(X_1 - X_4\right)
\end{array}\right\} \quad (1)$$

Where

$$X_1 = f_1, X_2 = \dot{f}_1, X_3 = \ddot{f}_1, X_4 = f_2, X_5 = \dot{f}_2, X_6 = \ddot{f}_2$$

and $X_7 = P_{tie}$

$$K_2 = \frac{K_{P2}+R_2}{R_2}; T_4 = T_{P2}+T_{G2}+T_{T2};$$

$$T_5 = T_{P2}T_{G2}+T_{G2}T_{T2}+T_{T2}T_{P2};$$

$$T_6 = T_{P2}T_{G2}T_{T2}$$

$$K_1 = \frac{K_{P1}+R_1}{R_1}; T_1 = T_{P1}+T_{G1}+T_{T1};$$

$$T_2 = T_{P1}T_{G1}+T_{G1}T_{T1}+T_{T1}T_{P1};$$

$$T_3 = T_{P1}T_{G1}T_{T1}$$

III. CONTROL TECHNIQUES

3.1 CONVENTIONAL PI CONTROLLER

Among the various types of load-frequency control, the PI controller is most widely used to speed-governor systems for LFC schemes [7].One advantage of the PI controller is that it reduces the steady-state error to zero. Fig.3 shows the block diagram of conventional PI controller.

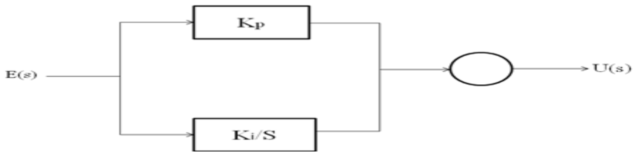

Fig.3 Conventional PI controller

Mathematically it is represented as

$$U(s) = K_p E(s) + K_i \int E(s) \qquad (2)$$

However, since the conventional PI controller with fixed gains has been designed at nominal operating conditions, but it fails to provide best control performance over a wide range of operating conditions and exhibits poor dynamic

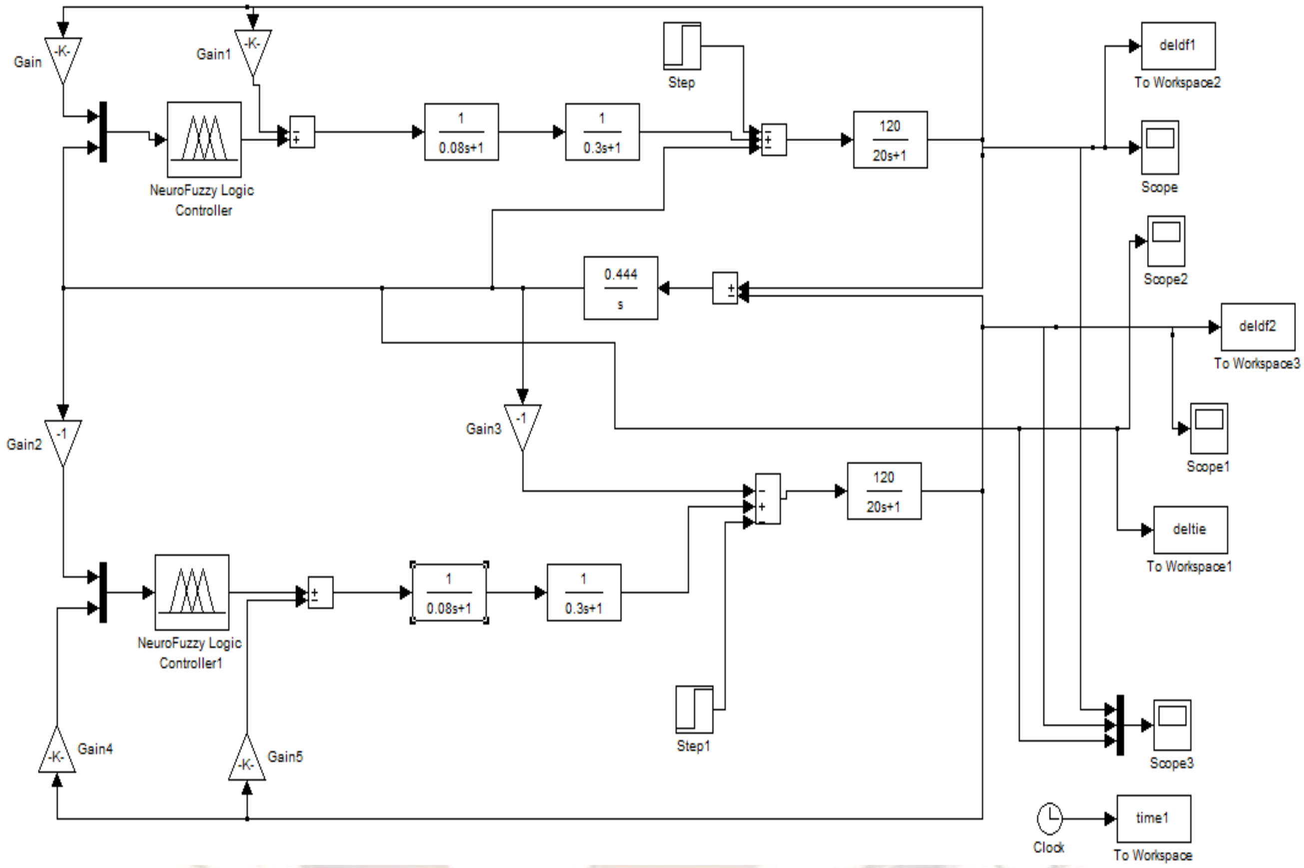

Fig.2 Simulink model of Two area system with ANFIS based Neuro-Fuzzy Controller.

Performance (such as more number of oscillation and more settling time), especially in the presence of parameters variation and non-linearity [4,6].To solve this problem, Fuzzy Logic techniques have been proposed in [8-10].System operating conditions are observed and used as inputs to a fuzzy system whose output signal controls the inputs to governor for increasing or decreasing the generation for maintaining the system frequency.

3.2 FUZZY LOGIC CONTROLLER

Recently, the fuzzy logic based control has extensively received attentions in various power systems applications[9].Fuzzy logic controllers(FLC) are knowledge based controllers derived from a knowledge acquisition process or automatically synthesized from self-organizing control architectures. It typically defines a non-linear mapping from the system's state space to the control space. A fuzzy system knowledge base consists of fuzzy IF-THEN rules and membership functions characterizing the fuzzy sets. The Fuzzy Logic Controller considered here for comparison is based on Mamdani inference model. The basic configuration of fuzzy logic control consists of three main stages, namely the fuzzification, knowledge base and the de-fuzzification.A universal mamdani type fuzzy controller has been simulated for the LFC to damp out the oscillations due to instantaneous perturbation as fast as possible. The parameters that affect the system performance is considered as the inputs and they are variable error (Δf) and change of error ($\dot{\Delta f}$).

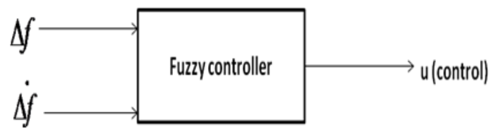

Fig.4 Simple Fuzzy Controller

The variable error is equal to the real power system frequency deviation(Δf).The frequency deviation is the difference between the nominal or scheduled power system frequency(f_n) and the real power system frequency(f).A simple fuzzy controller is shown in Fig.4.The first step is Fuzzification, It is the process of transforming real-valued variable into a fuzzy set variable. Next step is knowledge base; It is the heart of the fuzzy system .It consisting of fuzzy subsets. A fuzzy rule may contain fuzzy variables and fuzzy subsets characterized by membership function. Final step is De-fuzzification, It is used to convert the output fuzzy variable to a crisp value, So that it can be used for control purpose. It is used because crisp control action is required in practical applications. The rules of the knowledge base are used to determine the fuzzy controller action. The membership functions, knowledge base and method of de-fuzzification determine the controller performance. The membership functions with 5 linguistic variables(NB,NS,ZE,PS,PB) for two input and one output variable and rule base are shown in Fig.5 and Table-1 for the designed fuzzy logic controller for comparison with the proposed controller.

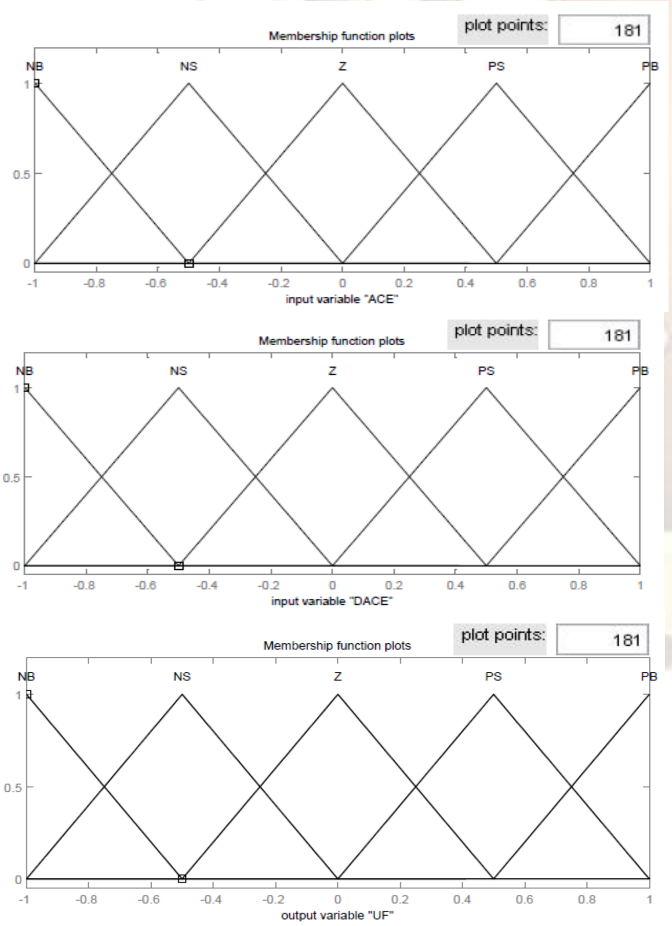

Fig.5 Membership functions of input and output variable

Table-1 Rule base (with 5 membership functions)

Input	E					
ΔE		NB	NS	ZE	PS	PB
	NB	NB	NB	NB	NS	ZE
	NS	NB	NB	NS	ZE	PS
	ZE	NB	NS	ZE	PS	PB
	PS	NS	ZE	PS	PB	PB
	PB	ZE	PS	PB	PB	PB

3.3 ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM (ANFIS)

ANFIS is a multi-layer adaptive neural network-based fuzzy inference system [13-16].ANFIS algorithm consists of fuzzy logic and neural networks with 5 layers to execute different node functions to learn and tune parameters in a fuzzy inference system (FIS) structure using a hybrid learning mode. Adaptive Neuro-Fuzzy Inference Systems are fuzzy Sugeno models put in the framework of adaptive systems to facilitate learning and adaptation [13].This framework makes FLC more systematic and less dependent on expert knowledge. To show the ANFIS architecture, let us take two-fuzzy rules based on a first order Sugeno model:

Rule 1: if(a is P_1)and(b is Q_1) then($f_1=p_1a+q_1b+r_1$)

Rule 2: if(a is P_2)and(b is Q_2)then($f_2=p_2a+q_2b+r_2$)

Where a and b are the inputs, P_i and Q_i are the fuzzy sets, f_i are the outputs within the fuzzy region specified by the rule, $p_{i,}$,q_i and r_i are the design parameters that are computed during the training process. Among the five layers, the first and fourth layers consists of adaptive nodes while the second, third and fifth layers consist of fixed nodes. The adaptive nodes are associated with their respective parameters, get updated with each subsequent iteration while the fixed nodes are devoid of any parameters. The ANFIS architecture to implement these two rules is shown in Fig.6.

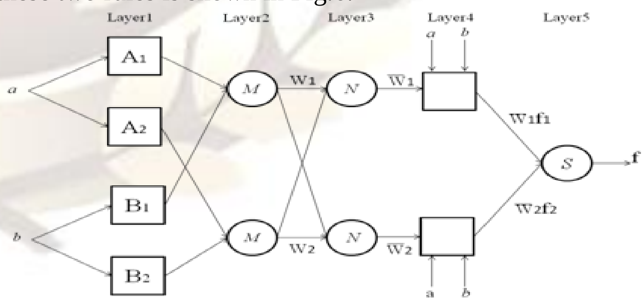

Fig.6 ANFIS Architecture

Layer 1: Every node in the layer 1 is an adaptive node. The outputs of layer 1 are the fuzzy membership grade of the inputs, which are given by:

$O\,i^1 = \mu A_i(a)$, For i=1,2 (3)

$Oi^1 = \mu B_{i-2}(b)$, For i=3,4 (4)

Where a and b are the inputs to node i, where A is a linguistic label (large, small) and where

$\mu A_i(a)$, $\mu B_{i-2}(b)$ can adopt any fuzzy membership function.

Layer 2: It is a rule layer, A fixed node labelled Mw hose output is the product of all the incoming signals, The outputs of this layer can be represented as:

$$O\, i^2 = W_i = \mu A_i(a)\, \mu B_i(b) \quad i=1,2 \qquad (5)$$

Layer 3: It is normalization layer in this also fixed node is a circle node labled N.

$$O\, i^3 = \overline{w}_i = w_i / (w_1 + w_2) \quad i=1,2 \qquad (6)$$

Layer 4: It is defuzzification layer an adaptive node with a node, The output of each node in this layer is simply the product of the normalized firing strength and a first order polynomial.

$$O\, i^4 = \overline{w}_i\, f_i = \overline{w}_i\, (f_i = p_i a + q_i b + r_i) \quad i=1,2 \qquad (7)$$

Layer 5: It is Summation neuron a fixed node which computes the overall output as the summation of all incoming signals.

$$O\, i^5 = \Sigma\, \overline{w}_i\, f_i = w_i f_i / (w_1 + w_2) \quad i=1,2 \qquad (8)$$

3.4. NEURO-FUZZY CONTROLLER

The development of the control strategy to control the frequency deviation of the two area system using the concepts of ANFIS control scheme is presented here. The neuro-fuzzy method grabs the advantages of neural networks and fuzzy theory to design a model that uses fuzzy theory to represent knowledge in an interpretable manner and the learning ability of a neural network to optimize its parameters. ANFIS is a separate approach in neuro-fuzzy development which was first introduced by Jang [14]. The model considered here is based on Takagi-Sugeno Fuzzy inference model. The block diagram of the proposed ANFIS based Neuro-Fuzzy controller for two area power system consists of parts, i.e fuzzification, knowledge base, neural network and de-fuzzification blocks, shown in Fig.7

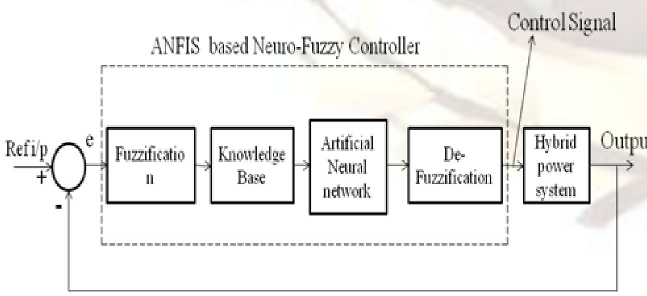

Fig.7 Block diagram of ANFIS based Neuro-fuzzy Controller.

ANFIS uses a hybrid learning algorithm to identify consequent parameters of Sugeno type fuzzy inference systems. It uses a combination of the back propagation gradient descent method and least squares method for training fuzzy inference system membership function parameters to equal the given training data set.FIS under consideration has two inputs. In the proposed paper, inputs to the ANFIS considered are error (Δf) and change in error ($\dot{\Delta f}$) whereas the output is the corresponding signal to the governor. Fig.8 shows the ANFIS structure for the designed Neuro Fuzzy controller.

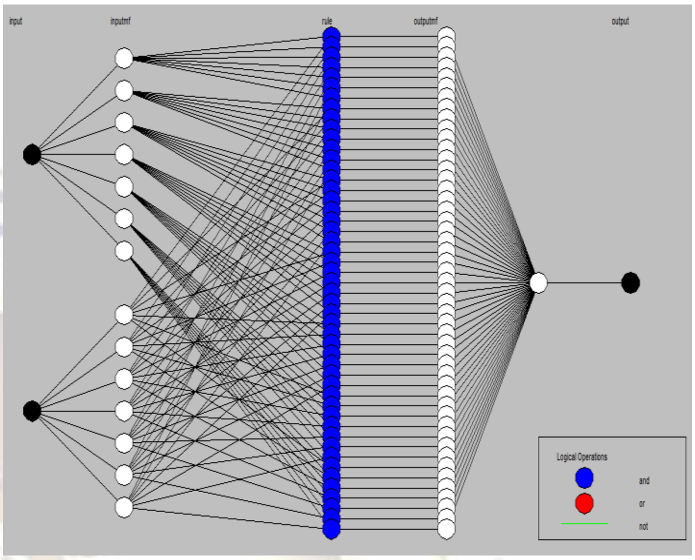

Fig.8 ANFIS structure for the designed Neuro-Fuzzy controller

IV. SIMULATION AND ANALYSIS

Simulations were performed using the conventional PI controller, Fuzzy Logic controller (FLC-Mamadani model) and proposed ANFIS based Neuro-Fuzzy controller for the two area system. The overshoot and settling time of proposed ANFIS based Neuro-Fuzzy controller is lower than that of conventional PI controller, Fuzzy Logic controller. The change in frequency of area1 and area2 and tie-line power deviation for 0.01p.u step load change in area1 and area2 is shown in Fig.9(a),9(b),9(c). It is observed that the proposed ANFIS based Neuro-Fuzzy controller damps out the deviations with less settling time for a 0.01p.u load disturbance. Simulation results explicitly show that the performance of the proposed ANFIS based Neuro-Fuzzy controller is superior to conventional PI controller, Fuzzy Logic controller.

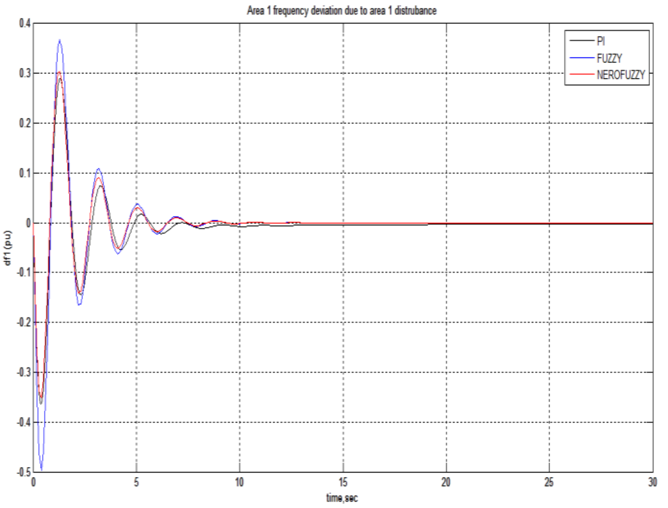

Fig.9(a) Area 1 frequency deviation due to area1 disturbance.

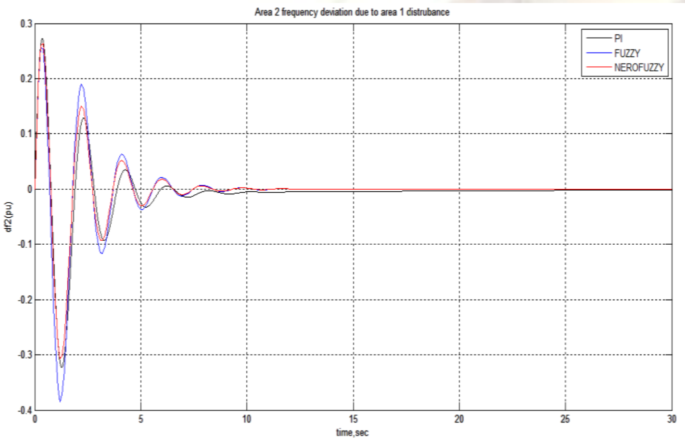

Fig.9(b) Area 2 frequency deviation due to area1 disturbance.

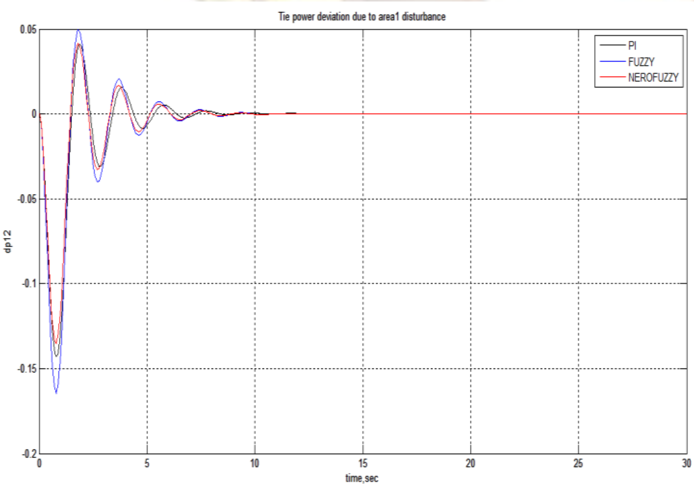

Fig.9(c) Tie power deviation due to area 1 disturbanance

V. CONCLUSION

The Neuro-fuzzy controller is designed for Load frequency control of two area system, To regulate the frequency deviations and tie-line power deviation, based on Adaptive Neuro-Fuzzy inference system(ANFIS architecture).The results obtained by using ANFIS based Neuro-fuzzy controller in this paper is more improved than those of conventional PI controller, Fuzzy Logic controller by its hybrid learning algorithm. It mainly controls the frequency deviation and tie-line power deviation of two area system and to increase the dynamic performance. It has been shown that the proposed controller is effective and provides significant improvement in system performance by combing the benefits of Fuzzy logic and neural networks. The overshoot and settling time of proposed ANFIS based Neuro-Fuzzy controller is lower than that of conventional PI controller, Fuzzy Logic controller.

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