Hybrid Neuro-Fuzzy Controller based Adaptive Neuro-Fuzzy Inference System Approach for Multi-Area Load Frequency Control of Interconnected Power System

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Abstract-

This paper concentrated on the design and analysis of Neuro-Fuzzy controller based 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. So there is necessity robust controller required to maintain the nominal system frequency. The proposed ANFIS controller combines the advantages of fuzzy controller as well as quick response and adaptability nature of artificial neural network however the control technology implemented with sugeno rule to obtain the optimum performance. 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- linarites 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 reduces the overshoot of the different frequency deviations.

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 behaviour 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

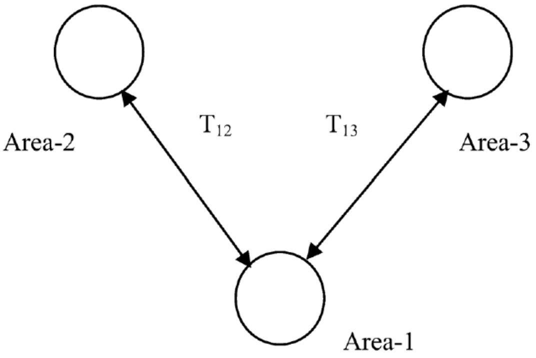


Fig 1: Representation of Three Area Interconnected System.

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 behaviour 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 modelling 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.

The main objectives of Load frequency control are

i) To maintain constant frequency throughout the system,

ii) To preserve the tie-line power at scheduled level irrespective of load changes in any area

iii) To diminish Area Control Error(ACE)

iv) To minimize Peak time, Peak overshoot and settling time.

II. MULTI AREA POWER SYSTEM

A. Load Frequency Problems:

If the system is connected to numerous loads in a power system, then the system frequency and speed change with the characteristics of the governor as the load changes. If it’s not required to maintain the frequency constant in a system then the operator is not required to change the setting of the generator. But if constant frequency is required the operator can adjust the velocity of the turbine by changing the characteristics of the governor when required. If a change in load is taken care by two generating stations running parallel then the complex nature of the system increases.

The ways of sharing the load by two machines are as follow: 1) suppose there are two generating stations that are connected to each other by tie line. If the change in load is either at A or at B and the generation of A is regulated so as to have constant frequency then this kind of regulation is called as Flat Frequency Regulation. 2) The other way of sharing the load is that both A and B would regulate their generations to maintain the frequency constant. This is called parallel frequency regulation. 3) The third possibility is that the change in the frequency of a particular area is taken care of by the generator of that area thereby maintain the tie-line loading. This method is known as flat tie line loading control. 4) In Selective Frequency control each system in a group is taken care of the load changes on its own system and does not help the other systems, the group for changes outside its own limits. 5) In Tie-line Load-bias control all the power systems in the interconnection aid in regulating frequency regardless of where the frequency change originates.

B. Dynamics Of The Power System

The automatic load frequency control loop is mainly associated with the large size generators. The main aim of the automatic load frequency control (ALFC) can be to maintain the desired unvarying frequency, so as to divide loads among generators in addition to managing the exchange of tie line power in accordance to the scheduled values.

Various load frequency control loop are as given away in the Fig. 2.1 components of the

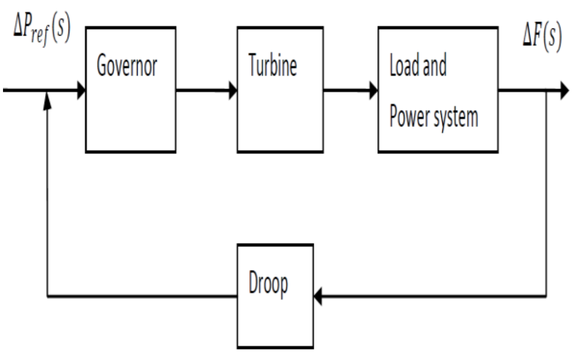


Fig.2: Block Diagram of Automatic Load Frequency Control

i)*TURBINES* **:** Turbines are used in power systems for the conversion of the natural energy, like the energy obtained from the steam or water, into mechanical power (*Pm*) which can be conveniently Supplied to the generator.

The mathematical model representation of the turbine is,

$$\frac{\Delta P_T(s)}{\Delta P_v(s)} = \frac{K_T}{1 + sT_T}$$

Where $\Delta P_V(s)$ = the input to the turbine
ΔP_T =the output from the turbine

ii) *GOVERNOR*: - The governors are used in the Power system to control the speed.

The mathematical model representation of the turbine is,

$$\Delta P_V = \frac{1}{1+\tau g}\Delta P_g(s)$$

Where Δ Pg= governor output

GENERATORS

Generators receive mechanical power from the turbines and then convert it to electrical Power. However our interest concerns the speed of the rotor rather than the power Transformation

$$\frac{\Delta P_v(s)}{\Delta P_g(s)} = \frac{1}{1 + sT_g}$$

The mathematical model representation of the generator is

Where $\Delta P_V(s)$ = the output from the generator
$\Delta P_g(s)$ = the input to the generator
T_g= time constant of the generator

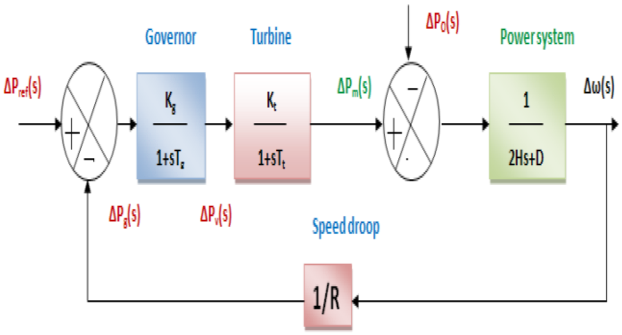


Fig.3: complete block diagram of single area system

The closed loop transfer function that relates the load change ΔP_D to the frequency deviation $\Delta F(S)$ is

$$\Delta F(s) = \frac{-K_p \Delta P_D(s)/s(1 + sT_p)}{(K_T K_p/R)/(1 + sT_H)(1 + sT_T)(1 + sT_p)}$$

C. Dynamic Model Of A Multi-Area Power System

The block diagram for each area of interconnected areas is shown in Fig.4, where Δf1 and Δf2, Δf3 are the frequency deviations in area1 and area2, area3 respectively in Hz. ΔPL1 and ΔPL2, ΔPL3 are the load demand increments.

The Three area power system connected by tie-line is shown in Fig. 4.

a. Modelling of the Tie-Line

Considering area 1 has surplus power and transfers to area 2.

P12 = Power transferred from area 1 to 2 through tie line.

Then power transfer equation through tie-line is given by

$$P_{12} = \frac{|V_1|.|V_2|}{X_{12}} . \mathrm{Sin}(\delta 1 - \delta 2)$$

Where
δ and 2 δ = Power angles of end voltages V1 and V2 of equivalent machine of the two areas respectively.
X12 = reactance of tie line.

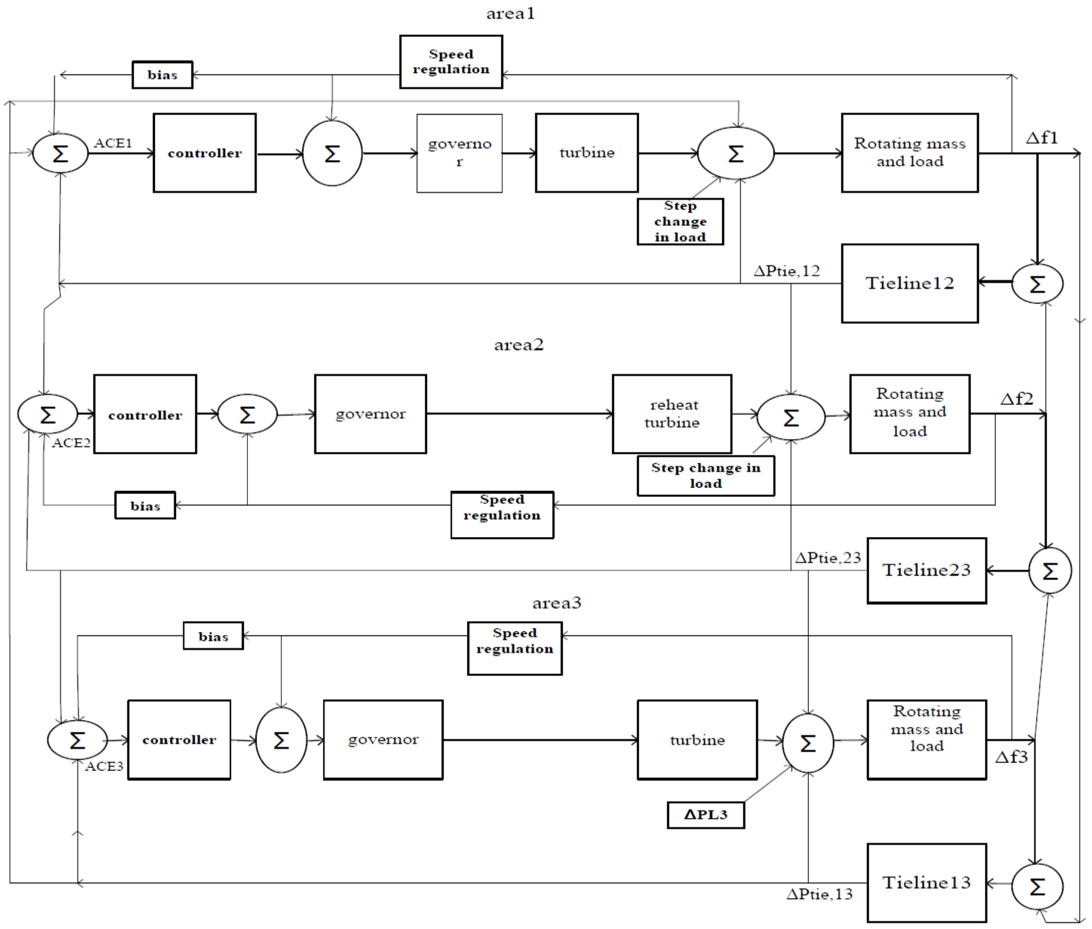


Fig4: Dynamic Model of Three Area Power System

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 Δδ 2, Power P12 changes to P12 + Δ *P*12

Therefore, Power transferred from Area 1 to Area 2 as given in [11] is

$$\Delta P_{12}(s) = \frac{2\pi T^{o}}{s}\left(\Delta f_1(s) - \Delta f_2(s)\right)$$

T0 = Torque produced

In this paper, the performance evaluation based on ANN, Fuzzy and ANFIS control technique for four areas interconnected thermal-hydro power plant is proposed. The sliding concept arises due to variable structure concept. The objective of VSC has been greatly extended from stabilization to other control functions. The most distinguished feature of VSC is its ability to result in very robust control systems and external disturbances [12], [13].

b. objective of Control Areas

The main objective of the control areas are as follows:

1. Each control area as for as possible should supply its own load demand and power transfer through tie line should be on mutual agreement.
2. Each control areas should controllable to the frequency control. [11]

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

$\Delta P1\ (k) = \Delta P12\ (k) + a41\Delta P41\ (k)$
$\Delta P2\ (k) = \Delta P23\ (k) + a12\Delta P12\ (k)$
$\Delta P3\ (k) = \Delta P34\ (k) + a23\Delta P23\ (k)$

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 area 1
ACE2 = Area control error of area 2
ACE3 = Area control error of area 3

In this control, ACE1, ACE2 and ACE3 are made linear combination of frequency and tie line power error [11].

$$ACE1 = \Delta P_{12} + b_1 \Delta f_1$$
$$ACE2 = \Delta P_{23} + b_2 \Delta f_2$$
$$ACE3 = \Delta P_{31} + b_3 \Delta f_3$$

Where the constant b1, b2, b3 are called area frequency bias of area 1, area 2, area 3 respectively.

Now ΔPR_1 , ΔPR_2 , $\Delta PR_3$and are mode integral of ACE1, ACE2, ACE3 respectively.

III.PROPOSED SIMULINK MODEL

The implemented Simulink model worked with the versatile nuero fuzzy interface framework is proposed. The fuzzy logic controller which is used to give required preparing information. The functions are controlled by neuron process.

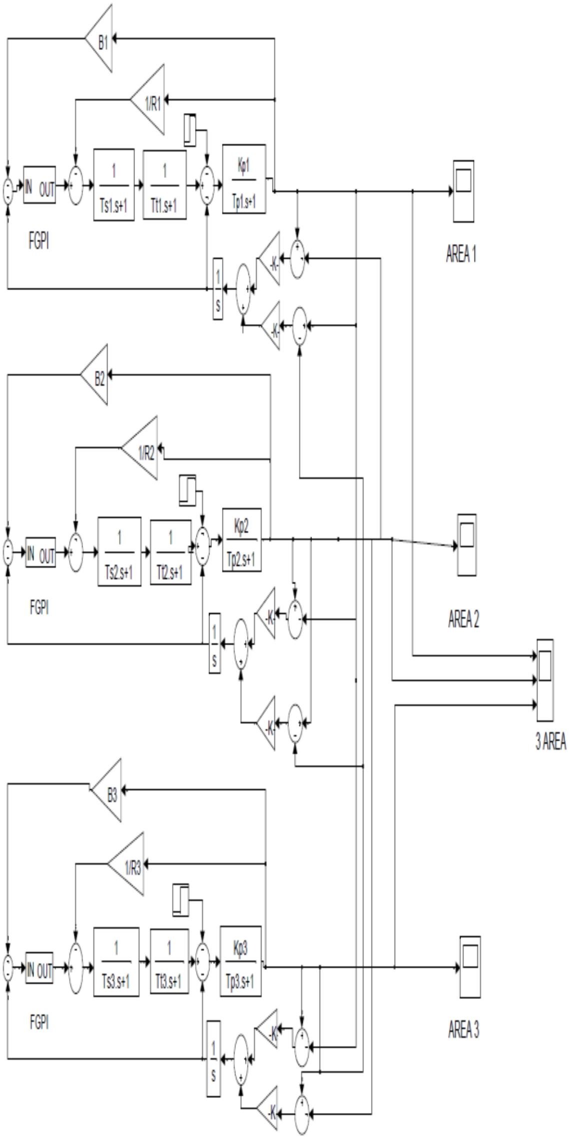


Fig 5: Proposed Simulink Model

The Simulink model developed with dynamic representations. The proposed controller can arranged to reduce the disturbances in power system even at number of operating devices in areas.

The basic steps followed for designing the ANFIS Controller in MATLAB/Simulink is outlined:

1. Draw the Simulink model with fuzzy controller and Simulate it with the given rule base.
2. The first step for designing the ANFIS controller is collecting the training data while simulating the model with fuzzy controller.
3. The two inputs, i.e., ACE and d (ACE)/dt and the output signal gives the training data.
4. Use anfisedit to create the ANFIS .fis file.
5. Load the training data collected in Step 2 and generate the FIS with gbell MF's.
6. Train the collected data with generated FIS up to a Particular no. of Epochs.
7. Save the FIS. This FIS file is the neuro-fuzzy enhanced

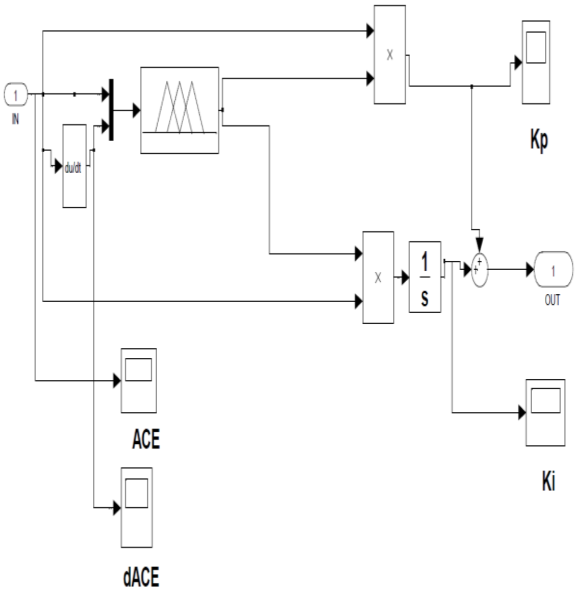


Fig 6: Proposed Anfis Control Strategy by Fuzzy

Fuzzy Logic Controllers:

Since power system dynamic characteristics are complex and variable, conventional control methods cannot provide desired results. Intelligent controller can be replaced with conventional controller to get fast and good dynamic response in load frequency problems.

Fuzzy Logic Controller (FLC) can be more useful in solving large scale of controlling problems with respect to conventional controller are slower. Fuzzy logic controller is designed to minimize fluctuation on system outputs.

There are many studied on power system with fuzzy logic controller. A fuzzy logic controller consist of three section namely fuzzier, rule base and defuzzifier as shown in fig

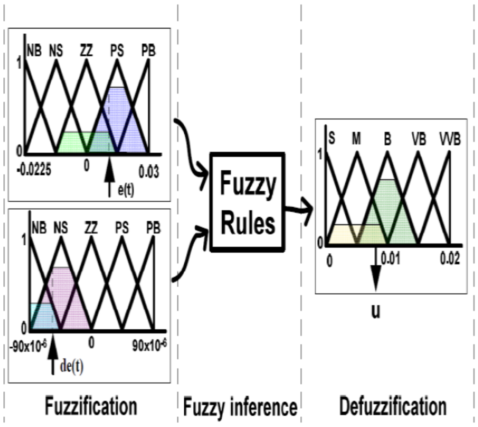


Fig.7 Fuzzy Inference system for FLC

The idea of fuzzy logic was produced to address instability and imprecision which broadly exists in building issues. Fuzzy logic controllers are principle based controllers. The configuration of fluffy rationale controllers includes four stages i. Fuzzification ii. Knowledge base iii. Inference engine iv.Defuzzificaion

Fuzzification: The procedure of changing over a genuine number into a fuzzy number is called Fuzzification.

Knowledge base: This incorporates, characterizing the participation capacities for every data to the fuzzy controller and outlining vital standards which determine fuzzy controller yield utilizing fuzzy variables.

Inference engine: This is component which simulates human choices and impacts the control activity in light of on fuzz logic.

Defuzzification: This is a procedure which changes over fuzzy controller output, fuzzy number, to a genuine numerical quality.

This is a mixed method of Conventional fundamental integral controller and Fuzzy controller. For the proposed controller the mamdani fuzzy derivation engine is utilized and the deduction instrument is acknowledged by five trapezoidal enrollment capacities (MFs) for each of the three semantic variables AGC and AGC/dt and yield capacity C.

The inputs of the fuzzy logic controllers and C are the yield of fuzzy logic controller. The quantity of semantic terms utilized for each phonetic variable decides the nature of control which can be accomplished utilizing fuzzy logic controller.

Generally as the number of phonetic variable increases, the quality of control improves but this improvement comes at a cost of increased complexity on account of computational time and memory requirements due to increased number of rules.

		$\dot{e}$				
		NB	NS	ZZ	PS	PB
e	NB	S	S	M	M	B
	NS	S	M	M	B	VB
	ZZ	M	M	B	VB	VB
	PS	M	B	VB	VB	VVB
	PB	B	VB	VB	VVB	VVB

Table-1: Fuzzy Rule

Artificial Neural Networks:

The proposed model membership functions are controlled by the ANN. It can reduce the steady state errors in frequency disturbances from the turbines. It can also compensate the over shoot errors in the three areas. The settling time and peak overshoot losses are minimized very effectively than the P, PI, PID controllers.

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.8

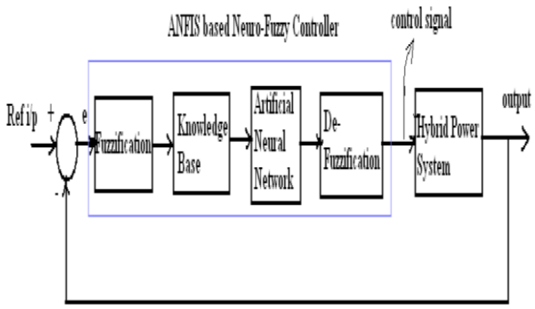


Fig.8 Block diagram of ANFIS based Neuro-fuzzy Controller.

The figure 8 gives the structure of the ANN network. It consisted five membership functions of two inputs. These can maintain the rules to identify the error effectively by logic layer 1 and logic layer2 and output layer. Logic layers are provided to calculate the errors and back propagation techniques from the input variables. Finally the output layer which generates the error less signal to Anfis controller.

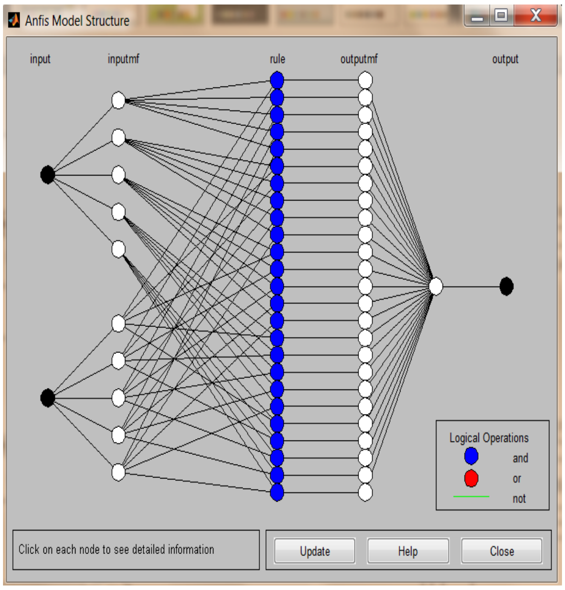


Fig 9: ANN structure for the proposed Model

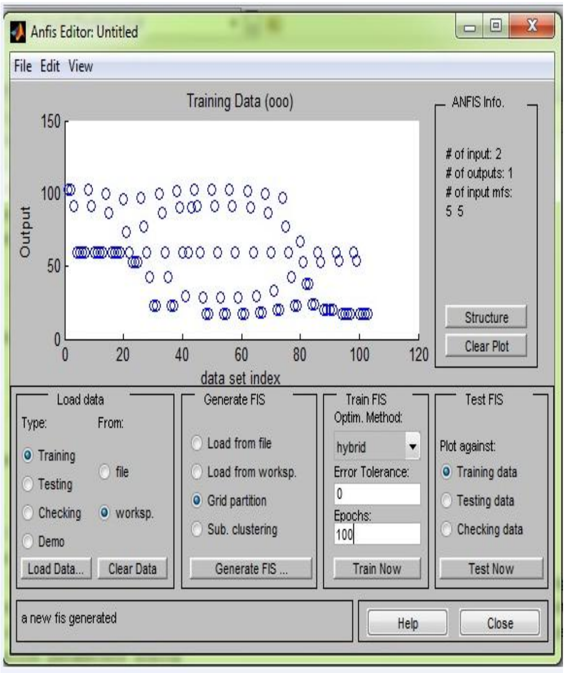
Anfis Controller:

The developed input and output variables can detect the variable limits and membership functions and then simulate or adopt by Anfis structure. The automatic generation control (AGC) and rate of change of its error signal and with a generated output signal C.

Procedure for the ANFIS controller:

- Design and develop the required Simulink model under specified conditions with fuzzy logic controller and modulate the rules within the limited range of variables.
- Gather the required training data from the operating devices while designing the FLC. The two input functions such as automatic generation control (AGC) and change in error signal AGC/dt with an output signal of the controller from the trained data. The training data will gives us the much information about possible power system behaviour for different operating dynamic disturbances.
- Use anfisedit command in the MATLAB command window for to create the .fis file.
- Load the training data operate step 2and produce the FIS file with flexible supported membership functions.
- Generate the FIS file from the loaded signal and trained the generated fis file at different epochs in the controller.

The Anfis controller operated under back propagation approachment with 100epchos.

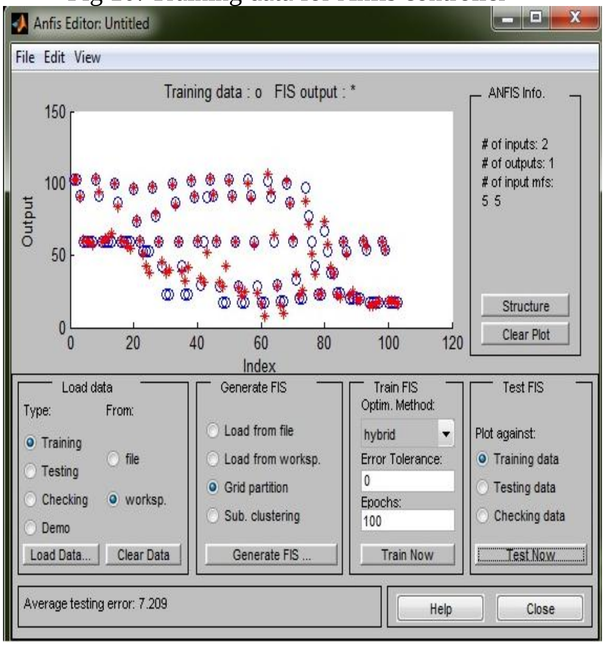


# of input: 2
# of outputs: 1
# of input mfs:
5 5

Type: ● Training
From: ● worksp.
● Grid partition
Optim. Method: hybrid
Error Tolerance: 0
Epochs: 100
Plot against: ● Training data

a new fis generated

Fig 10: Training data for Anfis controller



# of inputs: 2
# of outputs: 1
# of input mfs:
5 5

Type: ● Training
From: ● worksp.
● Grid partition
Optim. Method: hybrid
Error Tolerance: 0
Epochs: 100
Plot against: ● Training data

Average testing error: 7.209

Fig 11: Generated Output after testing process from ANFIS

The Simulated results are shown in below figures. The fig 12 gives us the information regarding area-1 response. Fig 13 represents the area-2 related dynamic behaviour. Fig 14 gives the area-3 oscillations in the power system.

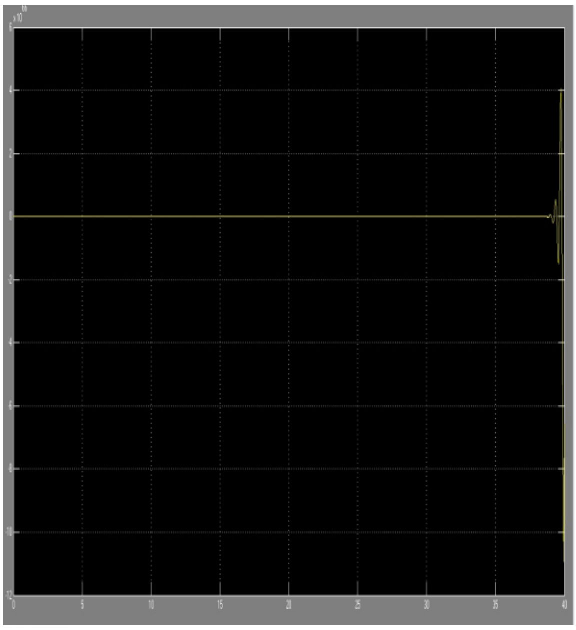


Fig 12: Output response of area-1 from Anfis controller

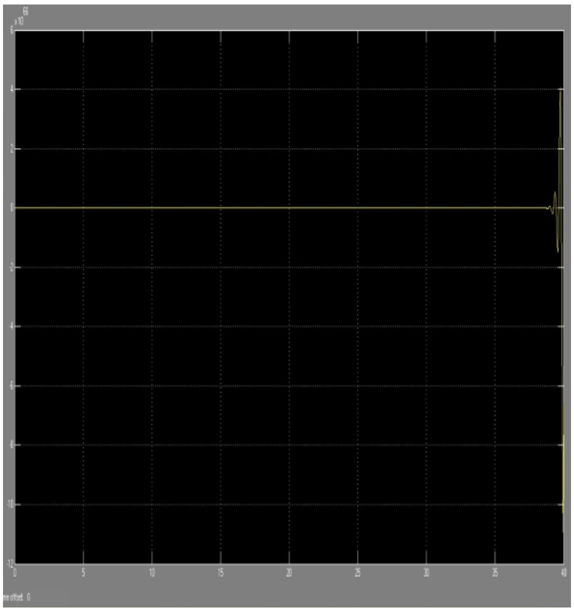


Fig 13: Output response of area-2 from Anfis controller

The table II gives the information and comparison related to the existed models such as DIAFLC, Type-II Fuzzy and PID controllers with proposed model ANFIS.

	$\lvert\Delta f1ss\rvert$ (10e-3)			
TYPE	DIAFLC	TYPE-II FUZZY	PID	ANFIS
	0	0	2	0

	$\lvert\Delta fmax\rvert$ (10e-3)			
TYPE	DIAFLC	TYPE-II FUZZY	PID	ANFIS
	8	6.5	8	4

Table II: Frequency Variation for different existed models with proposed Anfis controller

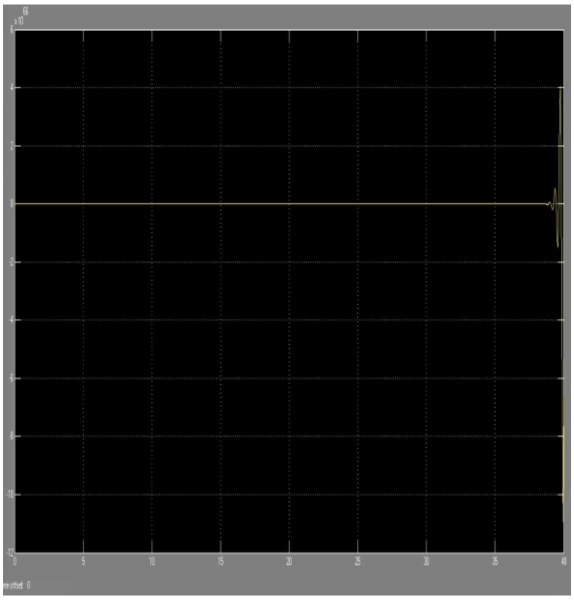


Fig 14: Output response of area-3 from Anfis controller

The proposed model reduces the dynamic disturbances very effectively by detecting the errors and it can reduces the overshoot effectively by neural networks finally the three area power system stability improves.

IV.CONCLUSION

The Neuro-fuzzy controller is designed for Load frequency control of three area system, to regulate the frequency deviations 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 of three 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.

An advanced control algorithm which is designed to compensate the disturbances by improving the steady stare responses and transient response in the multi area networks.

The designed Simulink models are testes and verified within MATLAB/SIMULINK with reduced fluctuations in the networks.

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