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Automatic Load Frequency Control of Three Area Power System Using ANFIS Based Controller

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Abstract-*Load frequency control (LFC) is critical for the task and outline of current electric power frameworks. Corresponding necessary (PI) and relative basic subsidiary (PID) controllers are utilized to control the different parameters of multi zone control framework. Because of high pinnacle overshoot and settling time, ordinary PI and PID controllers are not favoured for extensive power framework. The principle inspiration of this task is to control the yield recurrence reaction with least pinnacle overshoot and settling time. This task introduces an ANFIS based wise load recurrence control approach for three region control framework with three control territories. The value of the proposed controlling method is that it is speedier than the programmed traditional control systems and can deal with the non linearities all the while. Additionally the most extreme overshoot and the settling time of ANFIS based controller are lesser when contrasted with the ordinary controllers, subsequently decreasing the motions locally and of between region. This adequacy of the proposed controller in enhancing the dynamic reaction is appeared and approved in three region between associated frameworks. Examination in exhibitions of PI, PID control system and ANFIS control approach is done in MATLAB/SIMULINK programming. The outcomes approves that the ANFIS based smart controller is quicker than the customary controller and have enhanced dynamic reaction.*

Keywords- *Load Frequency Control (LFC), Area Control Error (ACE), Proportional-Integral (PI), Proportional-Integral Derivative (PID), Adaptive Neuro-Fuzzy Inference System (ANFIS), Membership Functions (mFs).*

I. INTRODUCTION

Power system is system of electricity generation, transmission and distribution. Due to increasing the enormous load demand, power system has become more and more complex. Now generation is not sufficient to full fill the load demand. Therefore due to mismatch between load demand and generation, frequency control has become a very important issue. Today many researchers are trying to find out the best solution for frequency control because synchronism of all generators in a particular control area and the proper matching between load demand and generation in power system greatly depend on the frequency.Frequency is function of active power and voltage is a function of reactive power [1]. Therefore two control loop are used in power system. One is active power-frequency (P-f) control loop. Second is reactive power-voltage (Q-V) control loop. Attention of active power frequency (P-f) control is very important in comparison to reactive power-voltage (Q-V) control because of mechanical inertia constant. For any power system, reliability and quality are two important factors.Load frequency control plays an important role to maintain the reliability and quality of power system. Manually control of large power system is not feasible. So therefore automatically generation and voltage controller equipment's are installed on each generator.

For small load, they tackle the change in load demand without changing in frequency limits but if change in load demand is very large then controller should be retune either manually or automatically. For automatically control of active power and frequency in power system, controllers are used. 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. Any imbalance between the generated power and load demand can lead to subsequent deviations in the plant frequency (f) from the value specified. This deviation in frequency is undesirable and can lead to system failure.

II. EXPLAINATIONS BEHIND THE LIMITS ON FREQUENCY

Following are the explanations behind keeping a strict cut off on the framework recurrence variety:

1. The speed of the substituting current engines relies upon the recurrence of the power supply. There are circumstances where speed consistency is required to be of high request.
2. The electric timekeepers are driven by the synchronous engines. The precision of the timekeepers are reliant on the recurrence as well as is an indispensable of this recurrence mistake.
3. On the off chance that the typical recurrence is 50 Hertz and the framework recurrence falls beneath 47.5 Hertz or goes up over 52.5 Hertz then the cutting edges of the turbine are probably going to get harmed in order to keep the slowing down of the generator.

4. The under recurrence task of the power transformer isn't attractive. For steady framework voltage if the recurrence is underneath the coveted level than the ordinary transition in the centre increments. This managed under recurrence task of the power transformer brings about low effectiveness and over-warming of the transformer windings.
5. The most genuine impact of subnormal recurrence task is seen on account of Thermal Power Plants. Because of the subnormal recurrence activity the impact of the ID and FD fans in the power stations get decreased and in this way diminish the age control in the warm plants. This wonder has a combined impact and thusly can influence finish shutdown of the ability to plant if legitimate strides of load shedding procedure isn't locked in. It is relevant to say that, in stack shedding method a sizable piece of load from the power framework is detached from the producing units in order to re-establish the recurrence to the coveted level.

III. EXISTING SYSTEM FOR LOAD FREQUENCY CONTROL OF POWER SYSTEM AND ITS DISADVANTAGES

In industry, proportional integral (PI) controllers have been comprehensively utilized for quite a long time as the heap recurrence controllers. A PI and PID controller's outline on a three-zone interconnected power plant is exhibited in [3], where the controller parameters of the PI controller are tuned utilizing experimentation approach. The corresponding increase gives steadiness and high recurrence reaction. So as to defeat the unfaltering state blunder caused in P controller we are utilizing the PI controller. This sort of controllers is for the most part utilized where speed parameter isn't considered in the framework. The vital term safeguards that the normal mistake is headed to zero. The normal for the PI controller is limitless pick up at zero recurrence.

PI controller is a standout amongst the most mainstream controllers in the business. A controller in the forward way, which changes the controller yield relating to the corresponding in addition to essential of the mistake flag is called PI controller. The corresponding increase gives security and high recurrence reaction. Keeping in mind the end goal to beat the unfaltering state blunder caused in P controller we are utilizing the PI controller.

This kind of controllers is fundamentally utilized where speed parameter isn't considered in the framework. The necessary term guarantees that the normal mistake is headed to zero. The normal for the PI controller is limitless pick up at zero recurrence. Points of interest of PI incorporate that it wipe out constrained motions the main detriment in PI controllers is that it deliver intemperate overshoot time to a stage summon [4]. The PI controller is portrayed by the exchange work given underneath [5].

$$G_{C(S)} = K_P\left(1 + \frac{1}{ST_i}\right)$$

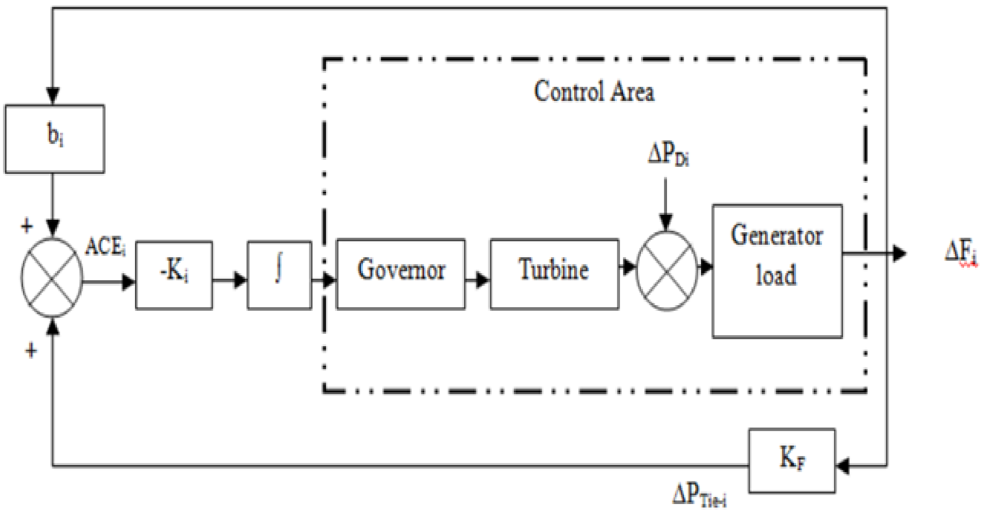


Figure 1. Automatic conventional control scheme using PI on i[th] area.

Fig.1 shows 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 (Ki). Bi: bias;ΔP_{Di}: change in load;ΔF_i: change in frequency and KF =(2*Π*T12)/s, where T12 is tie line constant which depends on the system voltages of two control areas connected through the tie line and its reactance.Disadvantage in PI controllers is that it produce excessive overshoot time to a step command, sensitivity to controller gains and sluggish response to sudden disturbances in load frequency control of interconnected power systems [2].Load frequency control of multi area interconnected power system using PID controller having more settling time and less robustness in controlling.

IV.PROPOSED INTERCONNECTED THREE AREA POWER SYSTEM WITH ANFIS BASED CONTROLLER

A power system can be considered as a group of control areas which are connected via tie lines. In each group, generators are considered in synchronized form. The block diagram of three area interconnected power system with ANFIS based controller is shown in fig.2. Where three control area1 having non-reheating thermal power unit, area2 having gas turbine unit and area3 having hydraulic unit are connected through tie- lines. The movement of valve due to load disturbance of three area are given by

$$\Delta X_{E1}(s) = [\Delta P_{C1} - \frac{1}{R_1}\Delta F_1(S)\left[\frac{1}{1+T_{g1}}\right]$$
$$\Delta X_{E2}(s) = [\Delta P_{C2} - \frac{1}{R_2}\Delta F_2(S)\left[\frac{1}{1+T_{g2}}\right]$$
$$\Delta X_{E3}(s) = [\Delta P_{C3} - \frac{1}{R_3}\Delta F_3(S)\left[\frac{1}{1+T_{g3}}\right]$$

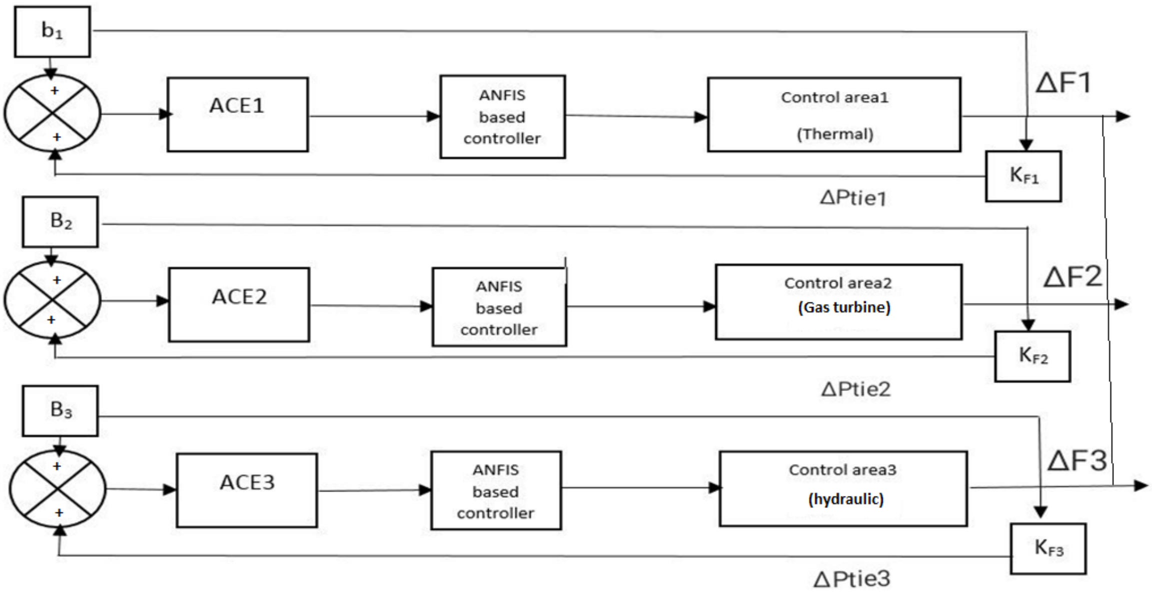


Figure 2. The block diagram of three area interconnected power system with ANFIS based controller

The change in turbine power are given by,

$$\Delta P_{C1} = \Delta X_{E1}(S)\left[\frac{1}{1+ST_{t1}}\right]$$
$$\Delta P_{C2} = \Delta X_{E2}(S)\left[\frac{1}{1+ST_{t2}}\right]$$
$$\Delta P_{C3} = \Delta X_{E3}(S)\left[\frac{1}{1+ST_{t3}}\right]$$

The tie line power deviation of three area are given by,

$$\Delta F_{1(S)} = \left[\frac{K_{PS1}}{1+ST_{P1}}\right][\Delta P_{g1(S)} - \Delta P_{D1(S)} - \Delta P_{tie\,1(S)}]$$
$$\Delta F_{2(S)} = \left[\frac{K_{PS2}}{1+ST_{P2}}\right][\Delta P_{g2(S)} - \Delta P_{D2(S)} - \Delta P_{tie\,2(S)}]$$
$$\Delta F_{3(S)} = \left[\frac{K_{PS3}}{1+ST_{P3}}\right][\Delta P_{g3(S)} - \Delta P_{D3(S)} - \Delta P_{tie\,3(S)}]$$

Area control error (ACE) for three area are given by,

$$ACE_1 = \Delta P_{tie\,1} + B_1\Delta F_1(S).$$
$$ACE_2 = \Delta P_{tie\,2} + B_2\Delta F_2(S).$$
$$ACE_3 = \Delta P_{tie\,3} + B_3\Delta F_3(S).$$

Where,

$$K_{12} = 2\pi T_{12}^0 \quad \text{And} \quad K_{21} = 2\pi T_{21}^0$$
$$K_{23} = 2\pi T_{23}^0 \quad \text{And} \quad K_{32} = 2\pi T_{32}^0$$
$$K_{31} = 2\pi T_{31}^0 \quad \text{And} \quad K_{13} = 2\pi T_{13}^0$$

T_{12}^0 And T_{21}^0 = synchronizing coefficient of tie line between area1 and area2.
T_{23}^0 And T_{32}^0 = synchronizing coefficient of tie line between area2 and area3.

T_{31}^{0} And T_{13}^{0}= synchronizing coefficient of tie line between area3 and area1.
$\Delta X_{E1}(s), \Delta X_{E2}(s)$ And $\Delta X_{E3}(s)$are movement of valve in area1, area2 and area3 respectively.
ΔP_{c1}, ΔP_{c2} and $\Delta P_{c3}$are commanded increase in power for area1, area2 and area3 respectively.
$\Delta P_{g1}, \Delta P_{g2}$, And $\Delta P_{g3}$are incremental power output for area1, area2 and area3 respectively.

IV.PROPOSED ANFIS BASED CONTROLLER DESIGN

ANFIS remains for Adaptive Neuro-Fuzzy Inference System. The ANFIS controller joins the upsides of fuzzy controller and in addition speedy reaction and flexibility nature of ANN Fundamentally, ANFIS is tied in with taking a fuzzy inference system (FIS) and tuning it with a back spread calculation in view of some gathering of info yield information. The Neuro fuzzy strategy blends the upsides of neural networks and fuzzy hypothesis to design a model that uses a fuzzy hypothesis to speak to information in an interpretable way and the learning capacity of a neural network to advance its parameters. The proposed controller utilizes fuzzy rationale calculation with a structure of artificial neural networks (ANN) in five layers in order to receive the rewards of the two techniques. ANFIS is an imperative approach in Neuro-fuzzy development which was presented by Jang. The block outline of the proposed ANFIS based load recurrence control comprises of four sections specifically fuzzification, information base, neural network and de-fuzzification.

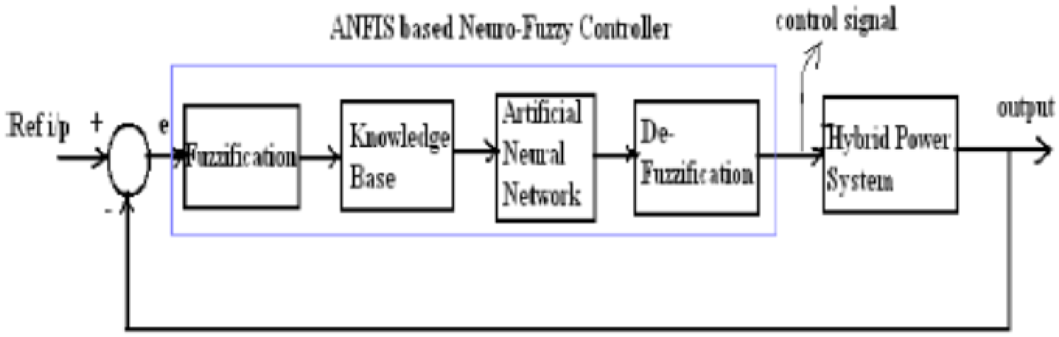


Figure 3. Block Diagram of ANFIS Based Load Frequency Control

1. Fuzzy inference Systems

Analysts as of late have proposed diverse neural and fuzzy applications for various purposes and fields. Because of their tremendous uses in the region, for example, picture preparing, design acknowledgment, control, and so on. The HNF procedure have drawn considerable consideration. The consequences of a HNF system are procured from the mix of ANN learning with fuzzy based rationale. [6][8] There are fundamentally two primary fuzzy inference styles which are additionally accessible in MATLAB are: Mamdani-type inference system, in light of paper by Zadeh in the year 1973 for decision strategies and complex system which accept enrolment capacities for yield as fuzzy sets. It has been widely acknowledged worldwide, and is adequate to manual information. Yet, it has a downside that the count time for the defuzzification procedure is huge. [7][8] Sugeno-type inference is derived from Sugeno-Takagi proposed strategy of fuzzy inference, in endeavour to clarify a systematically better approach for creating fuzzy information bases from an arrangement of info and yield information. [6] It is appropriate for control methods which are direct (e.g. PID control, and so forth.), versatile and ideal strategies, guarantees that the yield surface is constant, and is particularly adequate for numerical investigation. [8] The results of Sugeno write inference system are exceedingly taking after to Mamdani – type inference. On the off chance that the necessities include learning capacities then it is fitting to set the fuzzy based model into a structure of ANN with directed discovering that can be valuable to ascertain slope vectors as needs be. Sugeno-type is more supported over Mamdani compose inference .A standard administer in fuzzy rationale is: If p is estimated as X and q is estimated as Y then it suggests that r=f (p, q), where X and Y are fuzzy sets in the earlier and r=f (p, q) is defined as genuine capacity in the later. Generally, 'r' is an element of order one or zero. [7][8]

2. Modelling: ANFIS based System
Any fuzzy system can be designed by the means clarified as takes after:
• Fuzzyfication of fresh esteems
1. Extraction and standardization of fresh esteems for input fuzzy vectors and yield fuzzy vectors.
2. Determination of the participation capacities number and shape, for input fuzzy vectors and yield fuzzyvectors.
3. Transformation of fresh esteems into Fuzzy contributions by computing enrolment grades.
• Rule base and Fuzzy Inference
1. Shape agovern base utilizing control perceptions.
2. Discover the decide bases that are put away.
3. The administer base comprises of simple to frame basic if-then restrictive articulations that decide the control goals and control strategy of the area specialists.
• Defuzzification

1. Compute the fresh esteems for comparing fuzzy yield vector, applying a reasonable defuzzification process.
2. Results are acquired after reproduction.
3. ANFIS based designed controller (Adaptive Neuro Fuzzy Inference System)

This is a sort of artificial neural network which depends on Sugeno compose FIS. It has higher unpredictability than FIS. This can be utilized just for Sugeno compose models. [6][7] But client can define no. of information and yield enrolment works, the no. of model approval sets of information and the paradigm for streamlining for limiting the measure of blunder (described by the quantity of the squared contrasts of genuine N-bend and its linearized frame). There are a few sorts of participation capacities. The decision of an enrolment work depends on the parameters of the model. [6][7]

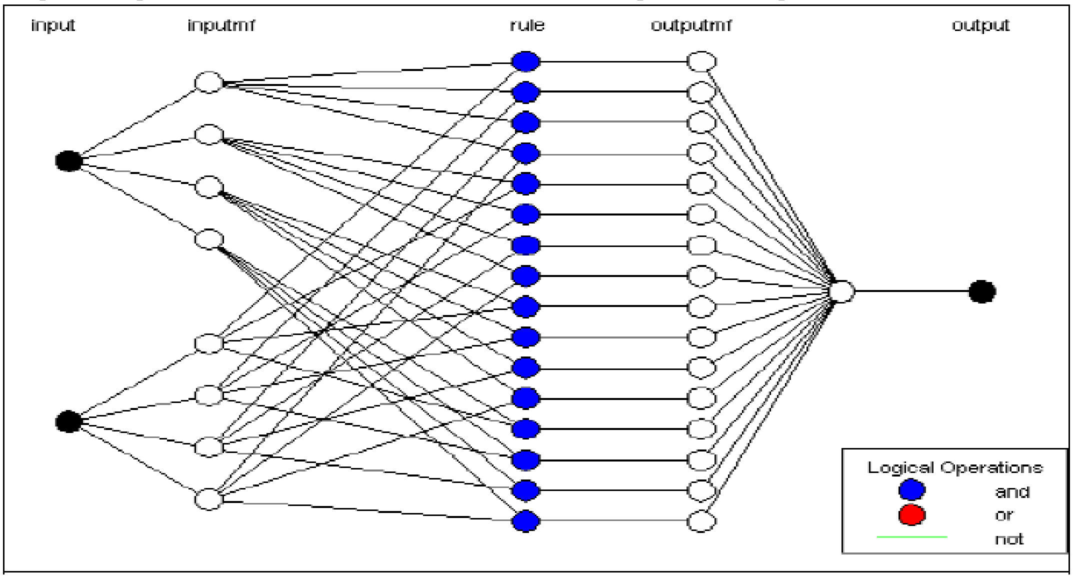


Fig.4. Base Rules Formed ANFIS

The principle advantage that ANFIS has over the fuzzy based designing is that it requires lesser enrolment capacities (mFs) to speak to include and additionally yield, suggesting the identical most extreme number of rules.[7] Therefore, the memory necessity and tenets base lessens considerably. In the introduced model, there are two contributions to the ANFIS based controller are recurrence (ACE (t)) and change in recurrence mistake (ΔACE (t)) with 4 enrolment capacities. Fig.4 indicates 16 rules have been made with 16 yield mFs. And after that defuzzification provides just a single yield which has been taken out.

3. Strategy for the ANFIS controller

1. Design and develop the required Simulink model under indicated conditions with fuzzy rationale controller and balance the guidelines inside the constrained scope of factors.
2. Assemble the required preparing information from the working devices while designing the FLC. The two info capacities, for example, programmed age control (AGC) and change in mistake flag AGC/dt with a yield flag of the controller from the prepared information. The preparation information will gives us the much data about conceivable power system conduct for various working dynamic aggravations.
3. Utilize anfisedit order in the MATLAB charge window for to make the .fis document.
4. Load the preparation information work stage 2and create the FIS document with adaptable upheld enrolment capacities.
5. Produce the FIS record from the loaded flag and prepared the created fis document at various ages in the controller.

4. Model approval utilizing preparing and checking informational collections:

ANFIS Model approval is the strategy by which we perceive how adequately the developed FIS model predicts the yield esteems when the contributions from the informational collection on which the FIS model was not prepared are encouraged to the FIS model. The quantity of ages is deduced with help of said parameters and foreseen mistake which is typically pre-set by the client. The model approval information is given beneath:

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

VI. SIMULATION AND RESULTS

Three area of interconnected non-reheating thermal, gas turbine and hydraulic power plant powersystem was used to analysis the dynamic behaviour for 1% or 0.01 pu step load disturbance in all three area.Figure 7 shown MATLAB/SIMULINK block diagram of three Areas interconnected power system with ANFIS based controller.

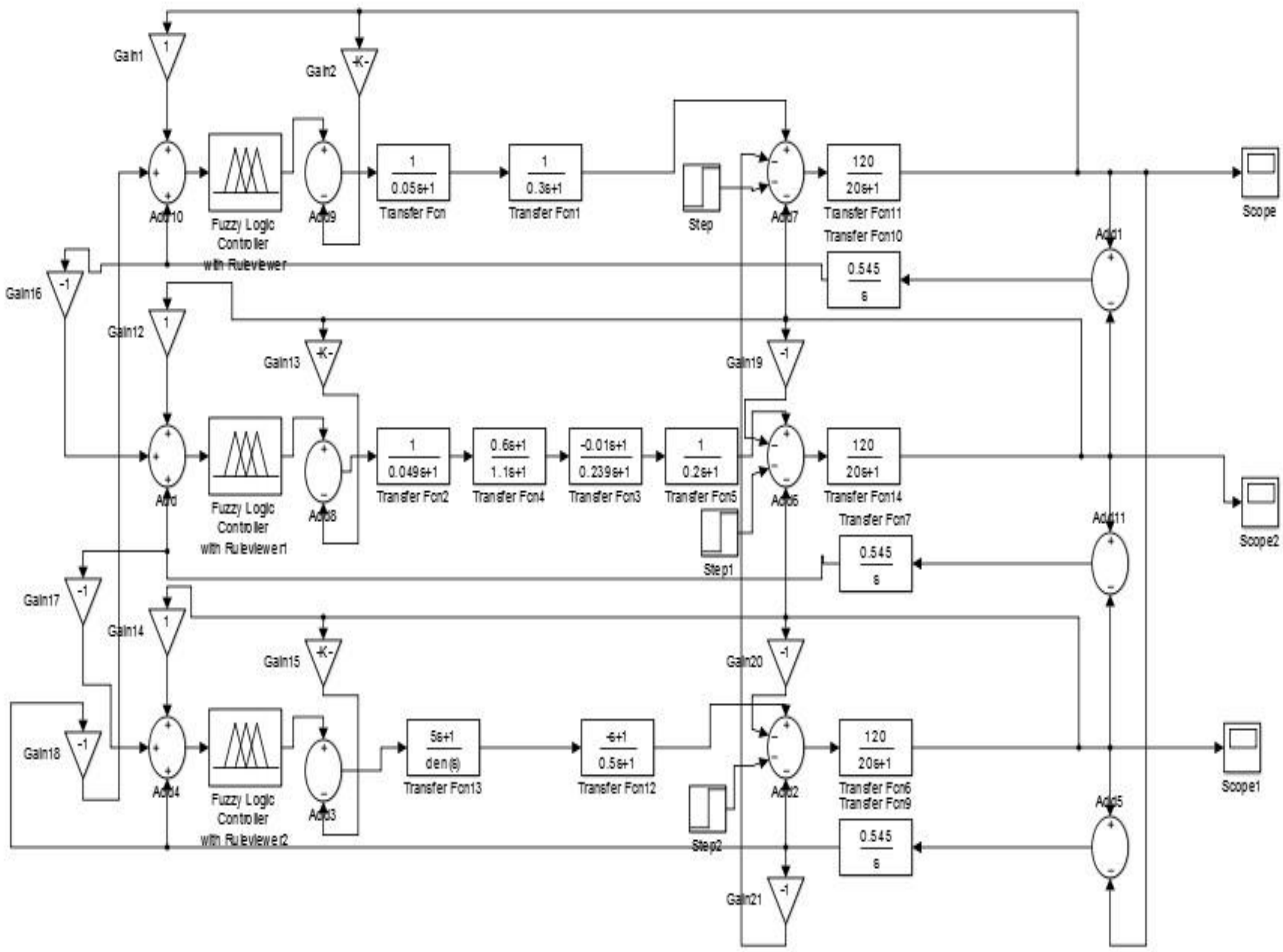
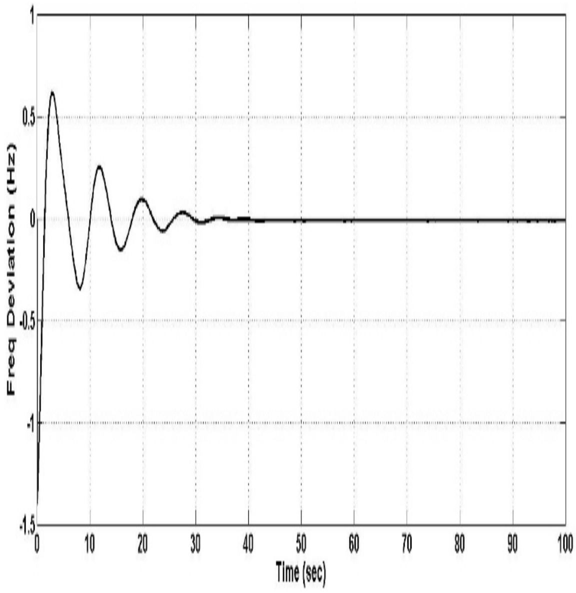


Figure.5 MATLAB/SIMULINK block diagram of three Areas interconnected power system with ANFIS based controller.



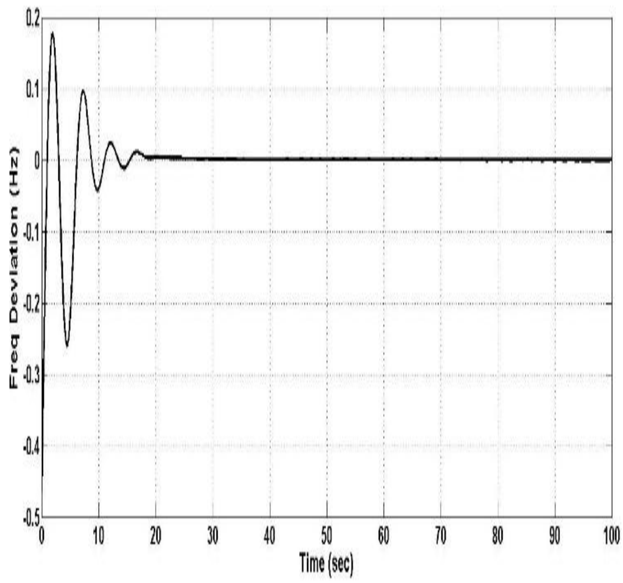
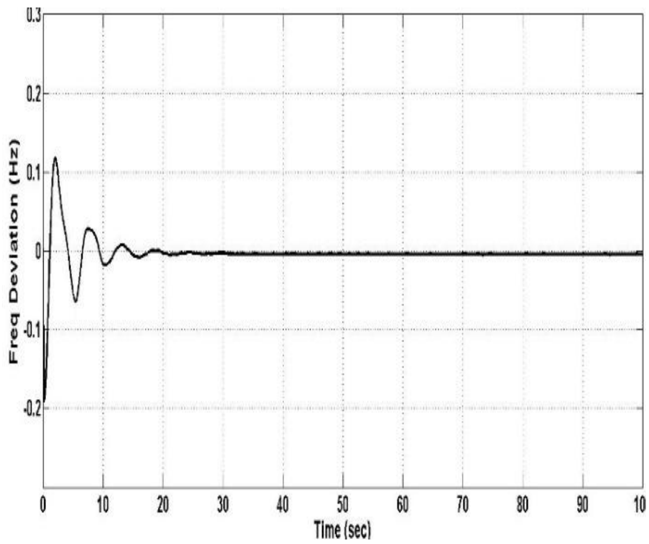


Fig.6.Simulation result of area1 with PI controller

Fig.7.Simulation result of area2 with PI controller



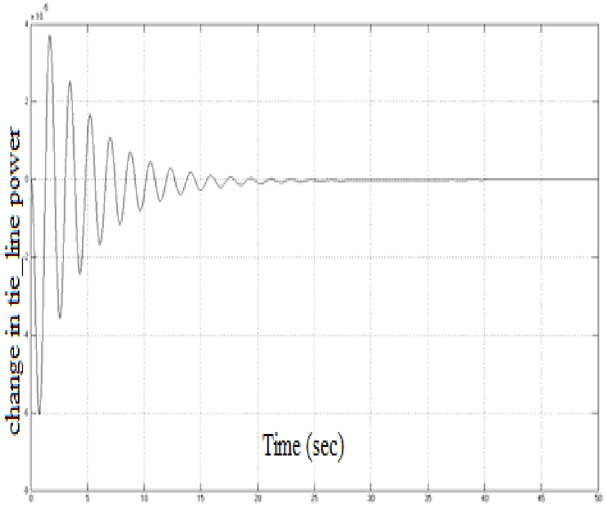


Fig.8.Simulation result of area3 with PI controller Fig. 9.Simulation result of Change in Tie-line powerbetweenthree areas with PI controller

The developed model with PI controller has been simulated and responses shown in Fig. 6-9. The developed model with ANFIS controller has been simulated and responses shown in Fig. 10-13, reveal that ANFIS based controller further reduces the steady state error in frequency deviation and also maximum peak over shoot in all the three areas.

The comparative study of results for frequency deviation using PI, PID and ANFIS based controller is given in Table 1 and 2. The performances are analysed on the basis of maximum peak over shoot and settling time.

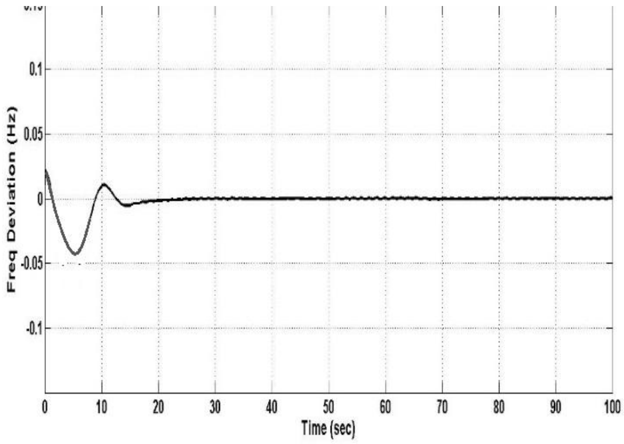


Fig.6.Simulation result of area1 with ANFIS based controller

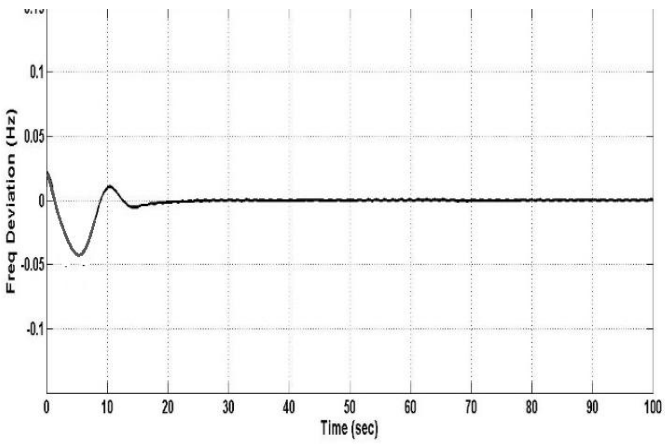


Fig.7.Simulation result of area2 with ANFIS based Controller

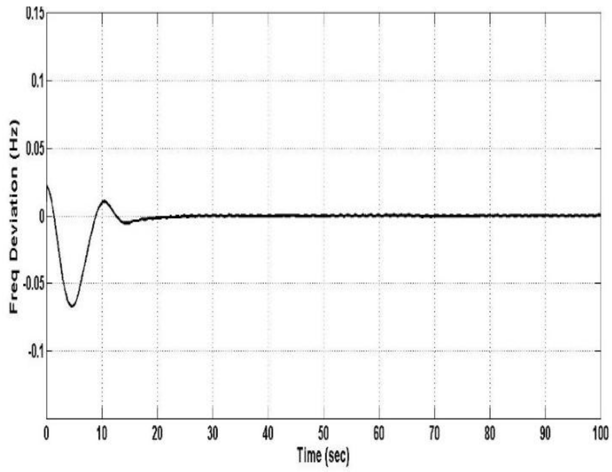


Fig.8.Simulation result of area3 with ANFIS based controller

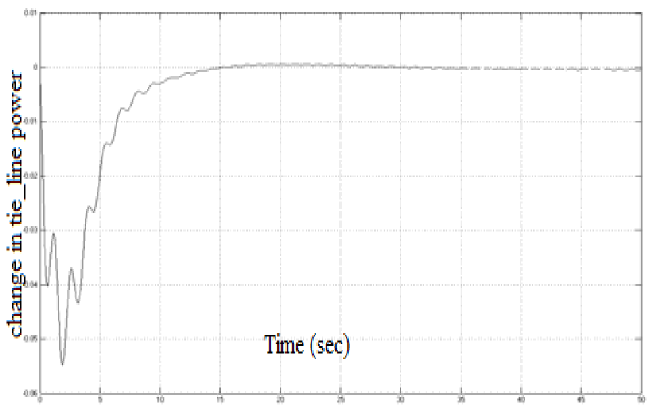


Fig.9.Simulation result of Change in Tie-line power between three areas with ANFIS based controller

Table 1: Comparison of settling time

Controlareas	PI	PID	ANFIS based controller
Area1(sec)	64	60	19
Area2(sec)	64	60	17
Area3(sec)	70	60	20

Table 3: Comparison of peak overshoot

Controlareas	PI	PID	ANFIS based controller
Area1(Δf_1)	-0.056	-0.049	-0.062
Area2(Δf_3)	-0.056	-0.049	-0.062
Area3(Δf_3)	-0.061	-0.058	-0.064
Change in tie-line power	-0.0145	0.005	-0.046

V.CONCLUSION

In this paper, the Adaptive Neuro Fuzzy Inference System based Load Frequency Control is proposed for a three area interconnected power system in each control area. The results have been compared with without controllers, conventional PI controller & PID controller. The results proved that the Adaptive Neuro Fuzzy Inference System based LFC gives fast and better response as compared to conventional PI controller & PID controller in terms of maximum peak overshoot, settling time and steady sate error. The results show that the proposed ANFIS controller is having improved dynamic performance and at the same time faster than conventional controllers.

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