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Multi Area Power Control System Load Frequency Analysis Using Modern Control Techniques

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ABSTRACT: Interconnected transmission networks delivering the national power balance and synchronize the various kinds of facilities are needed to work. Regions that may occur in one of the failures that take place due to any load change and also affect other regions. One of the most necessary aspects of this kind of system is to exchange of bus voltage and mains frequency. Electric power transmission systems used to provide high quality and constant power load changes provided by oscillation frequency and voltage values must be removed as early as possible. Fixed frequency is an important factor for power system's quality. Users connected to the energy system at a frequency of changes in energy demand lead to some of the harmonics. Load frequency control system should identify these changes and should not be considered a distortion.

Two different regions of Load Frequency control of power systems using fuzzy logic-based controllers are examined. With a load of any change in the frequency of the power system investigated how affected. Then Fuzzy Logic Controller (FLC) changes, so that it is observed in using the system. The system has two different control area power systems small-signal model in MATLAB /Simulink computer simulation program was created. FLC in the control and Integral Controller has been using the system. This produces two different results are compared with the controller. The artificial neural network controller is used in place of the fuzzy logic controller for better results.

KEYWORDS: Load Frequency Control (LFC), Interconnected power systems, Tie-lines power deviation, Area control Error, Frequency deviation, PI controller, Fuzzy inference system (FIS), Artificial Neural Networks (ANN)

I. INTRODUCTION

Modern electric power system is a complex network of synchronous generators, transmission lines and loads. The characteristics of the system vary with changes in load and generation schedules. Electric utilities first grew as isolated systems, and then gradually neighboring utilities began to join highly interconnected systems. The overall reliability has improved through interconnection but disturbances in such system propagate through, leading to system instability and possible blackouts.

Systems, which have, long transmission distances between the load centers and generating stations may exhibit under damped or even negatively damped oscillations. If the magnitude of disturbance is more, such as three-phase fault, major line or load switching, the system could even become transiently unstable. A good power system should possess the ability to regain the normal operating condition after a disturbance. Since ability to supply uninterrupted electricity determines the quality of electric power supplied to the load, stability is regarded as one of the important topics of power system research.

II. MODELING OF REHEAT THERMAL POWER SYSTEM

2.1 Modeling of steam turbine

Before we develop the model of a complete turbine, let us first derive the transfer function of a steam vessel and the expressions for power developed by a turbine stage.

The continuity equation for vessel is

$$\frac{dw}{dt} = V \frac{d\rho}{dt} = Q_{in} - Q_{out} \quad (2.1)$$

W=Weight of steam in the vessel

V=Volume of the vessel

ρ = Density of steam

Q = Steam mass flow rate

T = time(s)

Assuming the flow out of the vessel to be proportional to pressure in the vessel,

$$Q_{out} = \frac{Q_0}{P_0} P \quad (2.2)$$

Where P = pressure of steam in the vessel

P_0 = rated pressure

Q_0 = rated flow out of vessel

The change in density of steam with respect to pressure at given temperature may be determined from steam

$$\begin{aligned} Q_{in} - Q_{out} &= V \frac{dP}{dt} \frac{\partial \rho}{\partial P} \quad (2.3) \\ &= V \frac{\partial \rho}{\partial P} \frac{P_0}{Q_0} \frac{dQ_{out}}{dt} \\ &= T_V \frac{dQ_{out}}{dt} \end{aligned}$$

$$T_V = \frac{P_0}{Q_0} V \frac{\partial \rho}{\partial P} \quad (2.4)$$

$$Q_{in} - Q_{out} = T_V S Q_{out} \quad (2.5)$$

$$\frac{Q_{out}}{Q_{in}} = \frac{1}{1 + T_V S} \quad (2.6)$$

The transfer function of the steam vessel and T_V is its time constant. In modern steam turbines the force on each rotor blades and hence the turbine torque is proportional to steam flow rate.

$$T_M = K Q \quad (2.7)$$

Where, k is proportional constant

III. LOAD FREQUENCY CONTROL

3.1 Two Area Power System

Large scale power systems are normally composed of control areas or regions representing coherent groups of generators. Area load changes and abnormal conditions lead to mismatches in frequency and scheduled power interchanges between areas. These mismatches have to be corrected by Governor Control, which is defined as the regulation of the power output of generators within a prescribed area. The key assumptions in the classical Governor control problem are:

- The steady state frequency error following a step load change should vanish. The transient frequency and time errors should be reduced.
- The static change in the tie power following a step load in any area should be zero, provided each area can accommodate its own load change.
- Any area in need of power during an emergency should be assisted from other areas.

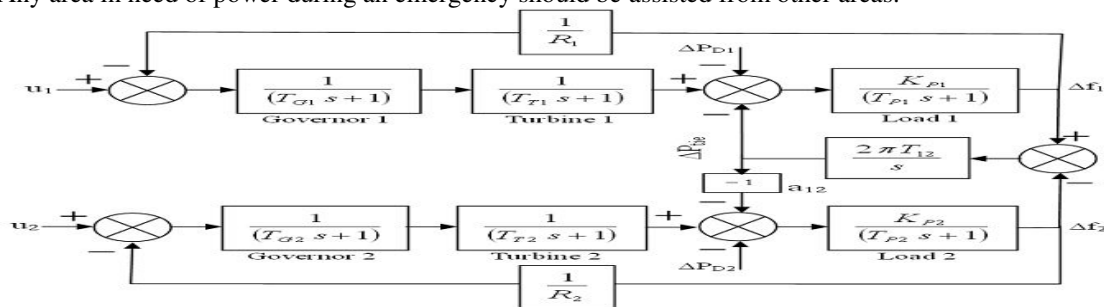


Figure 3.1 Two area power system



IV. CLASSIFICATION OF CONTROLLER

4.1 Proportional-plus-integral controllers.

A PI Controller (proportional-integral controller) is a feedback controller which drives the plant to be controlled by a weighted sum of the error (difference between the output and desired set-point) and the integral of that value

4.2 Proportional-plus-derivative controllers:

Proportional-Derivative or PD controller combines proportional control and derivative control in parallel. Derivative action acts on the derivative or rate of change of the control error. This provides a fast response, as opposed to the integral action, but cannot accommodate constant errors (i.e., the derivative of a constant, nonzero error is 0). Derivatives have a phase of +90 degrees leading to an anticipatory or predictive response.

4.3 Proportional-plus-integral-plus-derivative controllers:

A PID controller (Proportional, Integral and Differential) is used to control devices, such as Drives to maintain control of a varying system. This is in most cases done through the Examination of signals from sensors placed in the system, called feedback signals. When the feedback signal is received, it is compared with the desired value, or set point based on this comparison a calculation is made of what the necessary response is, in order to make the feedback signal match the setpoint. This calculation is performed by a P, a PI or a PID controller. The main difference between a P, a PI and a PID controller is the accuracy at which it is possible to control the feedback according to the set point. The four major characteristics of the closed loop step response are:

- Rise time: the time it takes for the plant output y to rise beyond 90% of the desired Level for the first time.
- Overshoot: how much the peak level is higher than the steady state, normalized against the steady state.
- Settling time: the time it takes for the system to converge to its steady state.
- Steady state error: the difference between the steady state output and the desired output

V. FUZZY LOGIC CONTROLLER

5.1 Unique features of Fuzzy logic

The unique features of fuzzy logic that made it a particularly good choice for many control problems are as follows, It is inherently robust since it does not require precise, noise – free inputs and can be programmed to fail safely if a feedback sensor quits or is destroyed. The output control is a smooth control function despite a wide range of input variations.

5.2 Fuzzification and Normalization

Fuzzification is related to the vagueness and imprecision in a natural language. It is a subjective valuation, which transforms a measurement into a valuation of an objective input space to fuzzy sets in certain input universes of discourse. The fuzzification module (FM) performs the following functions:

5.3 Membership functions

Generally, in fuzzy system used '4' different shapes of MF's., those are Triangular, Gaussian, Trapezoidal, sigmoid, etc.,

5.3.1 Triangular membership function

The simplest and most commonly used membership functions are triangular membership functions, which are Symmetrical and asymmetrical in shape

5.3.2 Gaussian membership function

Two membership functions Triangular and Trapezoidal are built on the Gaussian curve and two sided composite of two different Gaussian curves.

5.4 Fuzzy Inference System

The fuzzy inference system Fuzzy system basically consists of a formulation of the mapping from a given input set to an output set using Fuzzy logic. The mapping process provides the basis from which the interference or conclusion can be made.

A Fuzzy interface process consists of following steps

Step 1: Fuzzification of input variables.

Step 2: Application of Fuzzy operator (AND, OR, NOT) In the IF (antecedent) part of the rule.

Step 3: Implication from the antecedent to the consequent (Then part of the rule).

Step 4: Aggregation of the consequents across the rules.

Step 5: Defuzzification.

Generally, there will be a matrix of rules similar to the ES rule matrix for Ex: There are 7MF for input variables 'x' and MF for input variable 'y' then there will be all together 35 rules.

5.4.1 Implication method

The implication Methods are introduced for the evaluation of rules: 1) MAMDANI 2) SUGENO 3) LUSING LARSON.

5.5 Defuzzification and Denormalization

A defuzzification strategy is aimed at producing a non-fuzzy control action that best represents the possibility of an inferred fuzzy control action.

5.6 Design of the fuzzy logic controller

The design of a fuzzy logic controller is a three stage processes. It comprises of Fuzzification, inference mechanism and defuzzification. "Fuzzy controllers have got a lot of advantages compared to the classical controllers such as the simplicity of control, low cost and the possibility to design without knowing the exact mathematical model of the process. A fuzzy logic controller is based on a set of control rules called as the fuzzy rules among the linguistic variables. Our basic structure of the fuzzy logic controller to control the speed of the induction motor consists of 4 important parts, viz., Fuzzification, knowledge base, decision-making logic and the defuzzification.

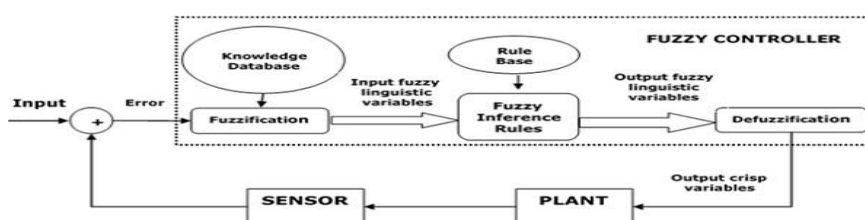
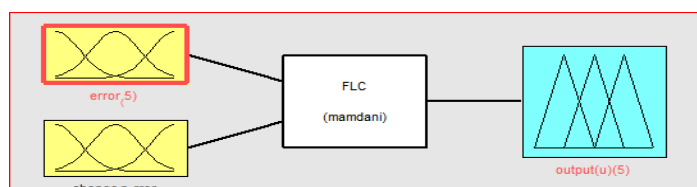


Figure.5.6. Basic Stage of Fuzzy Logic Controller Design

5.7 Mamdani fuzzy inference system

Defuzzification convert the conclusion reached by the inference mechanism into the input to the plants. The continuity of input membership functions, reasoning method, and defuzzification method for the continuity of the mapping u fuzzy ($e, \Delta e$) is necessary.



System FLC: 2 input, 1 output, 25 rules

Figure 5.7 (Recall): Mamdani Fuzzy Inference System (FIS) and Membership Function Edit

VI. ARTIFICIAL NEURAL NETWORKS

6.1 Artificial Neurons

Artificial Neural Networks are based on the neural structure of the brain. The brain basically learns from experiences. It is natural proof that are beyond the scope of current computers are indeed solvable by small energy efficient packages. This brain modelling also promises a less technical way to develop machine solutions.

Figure 6.1 shows the relationship of these four parts. Within humans there are many variations on this basic type of neurons, further complicating man's attempts at electrically replicating the process of thinking. Yet, all natural neurons have the same four basic Components. These components are known by their biological names – dendrites, soma, axon, and synapses. Dendrites are hair-like extensions of the soma which act like input channels. These input channels receive their input through the synapses of other neurons. The soma then processes these incoming signals over time.

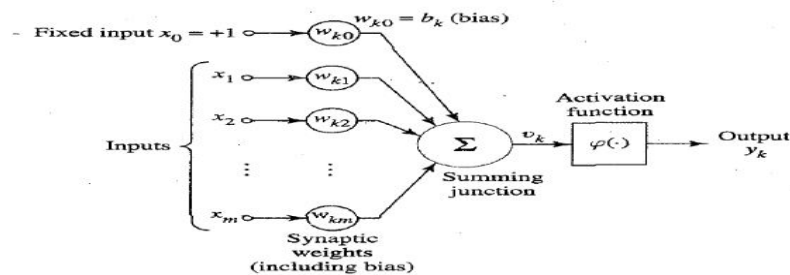


Figure 6.1. Artificial Neural Networks

Where x_1, x_2, \dots, x_m are the m inputs

$w_{k1}, w_{k2}, \dots, w_{km}$ are weights attached to the input links

For the above model

$$U_k = \sum_{j=1}^m (w_{kj} x_j) \quad (6.1)$$

$$v_k = U_k + b_k \quad (6.2)$$

The bias b_k has the effect of increasing or lowering the input of the activation function.

$$y_k = \phi(U_k + b_k) \quad (6.3)$$

6.2 Creating a Network (NEWFF)

The first step in training a feed forward network is to create the network object. The function newff creates a trainable feed forward network. It requires four inputs and returns the network object. The first input is an R by 2 matrixes of minimum and maximum values for each of the r elements of the input vector. The second input is an array containing the sizes of each layer. The third input is a cell array containing the names of the transfer functions to be used in each layer. The final input contains the name of the training function to be used.

SYNTAX: NEWFF (PR, [S1 S2 ... SN1], {TF1 TF2 ... TFN1}, BTF, BLF, PF) takes,

PR – Rx2 matrix of min and max values for input elements

Si – Size of i^{th} layer, for N1 layers

TFi – Transfer function of i^{th} layer, default = 'tansig'

BTF – Back prop network training function, default = 'trainlm'

BLF – Back prop weight/bias learning function, default = 'learnsgdm'

PF – Performance function, default = 'mse' and returns an N layer feed – forward back prop network

Initializing Weights (INIT, INITNW, RANDS)

6.2.1 Training

There are two types of training procedures according to the way in which the inputs are applied to the network. They are 'incremental training' where each training pair will be applied one after the other and 'batch training' in which entire set of training pairs will be applied at once. The syntaxes for them are as below:

SYNTAX: Batch Training : net = train (net, p, t);

Incremental Training : [net, a, e] = adapt (net, p, t);

Where 'p' and 't' together constitute the training set. 'P' is input vector and 't' is target vector presented to the feed forward network. With these functions the network will be trained according to the training algorithm mentioned in 'newff'.

6.2.2 Simulation

The function sim simulates a network. Sim takes the network p, and the Network objects net, and returns the network outputs 'k'.

SYNTAX: K = sim (net, p);

6.2.3 Training Parameters

SYNTAX

net.trainparam.epochs
net.trainparam.lr
net.trainparam.goal
net.trainparam.show

DESCRIPTION

indicates maximum number of epochs for training
specifies the learning rate
specifies the performance goal
specifies number of epochs between Showing progress

VII. SIMULATION RESULTS

7.1 Simulation of two area lfc using modern control techniques

The Two area power system load frequency analysis is simulated in MATLAB environment when applying to the different control techniques using PI, Fuzzy and Artificial neural network controllers.

7.1.1 PI controller:

In this control, proportional control action tends to stabilize the system, while the integral control action tends to eliminate or reduce steady-state error in response to various inputs. Simulation is done in MATLAB environment as shown in Fig 7.1

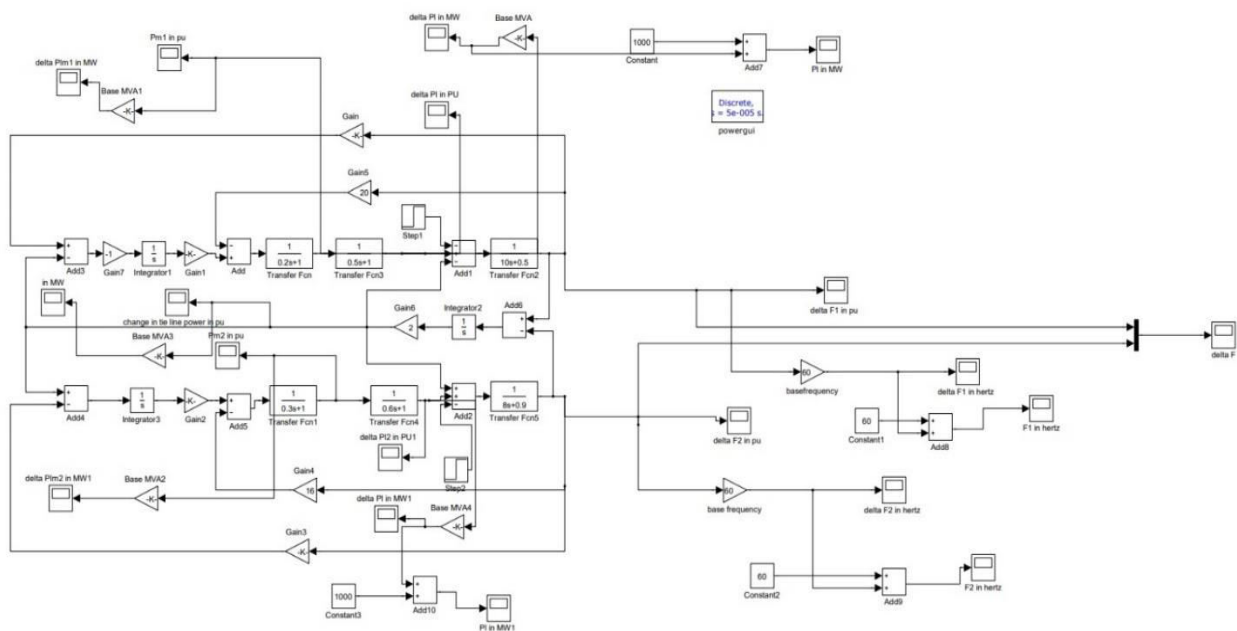
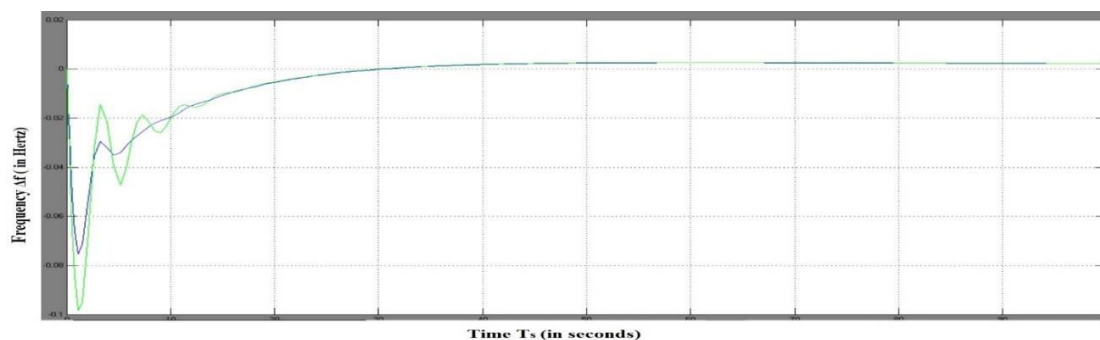
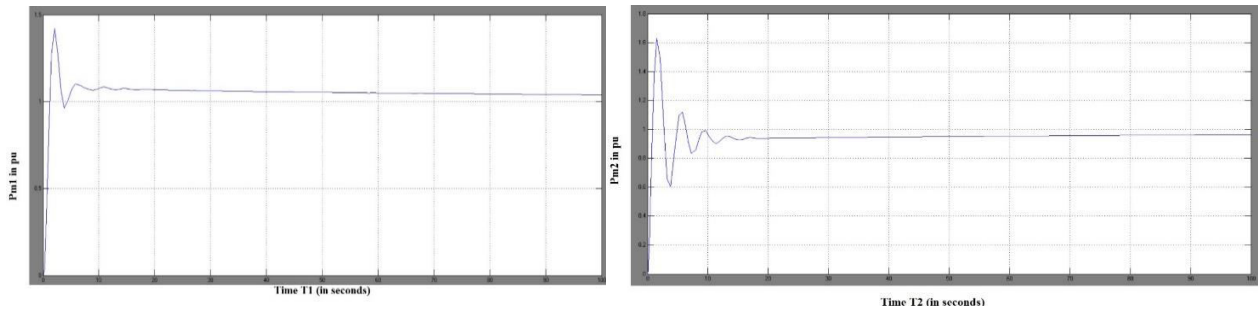


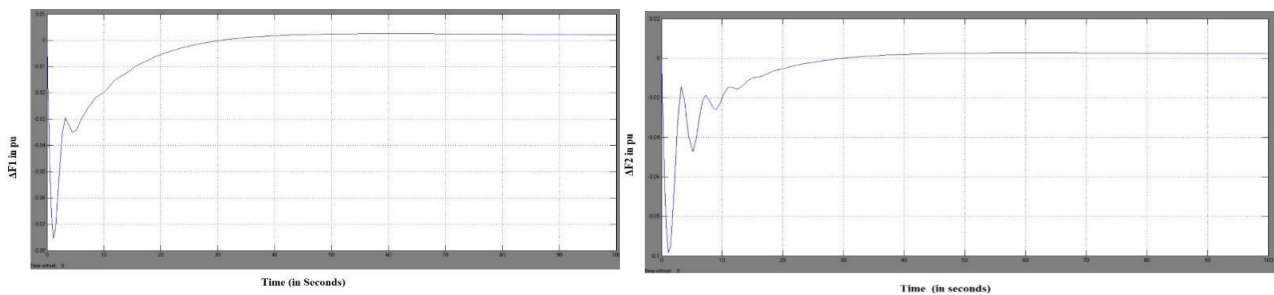
Figure:7.1 Two area load frequency control using PI controller



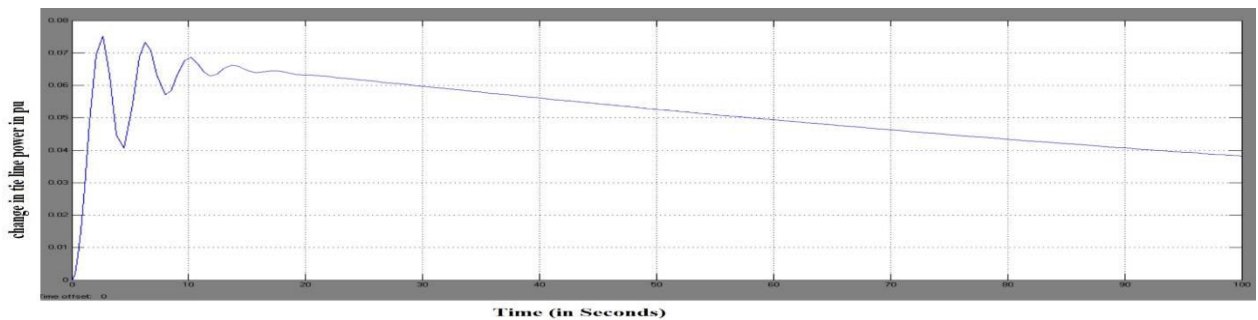
(a) Frequency deviation Δf versus Settling time T_s waveform



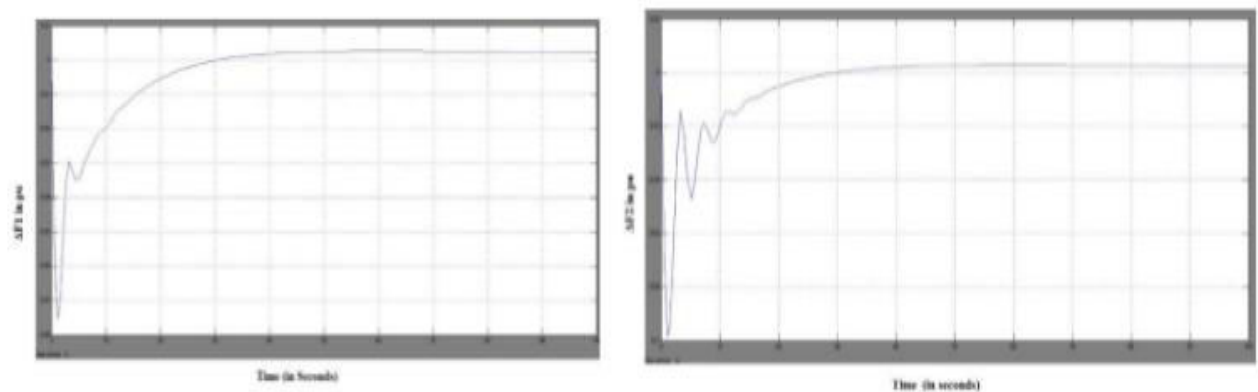
(b) Change in mechanical power pm1 & pm2 waveform



(b) Change in frequency Δf_1 & Δf_2 waveform



(c) Change in tie line power waveform



(e) Frequency F1 and F2 waveform

- From Figure 7.1. (a), Since PI controller is present in the two area system even if there is a change in load (at area-1), the change in frequency is settled to zero $\Delta f=0$ i.e., the system reached its steady state position. Its settling time $T_s=27\text{sec}$.
- From Figure.7.1. (b), The conventional PI controller gives change in mechanical power pm1 of area-1 at 1.039 in pu and pm2 of area-2 at 0.9639 in pu & time T1 of area-1 at 10 sec and time T2 of area-2 at 14 sec.

- From Figure 7.1.(c) The conventional pi controller gives frequency change Δf_1 of area-1 at 0.002128 in pu and Δf_2 of area-2 at 0.002248 in pu & Time of both area-1 and area-2 at 27 sec. From Figure.7.1.(d), Change in tie line power in pu ΔP_{12} is obtained at a value of 0.03816 in pu.
- From Figure.7.1.(e) Frequency oscillations are varied with respective to time and frequency of area-1 at 60.13 Hz and frequency of area-2 at 60.14 Hz & Time T1 of area-1 at 30 sec and Time T2 of area-2 at 28 sec.

7.1.2 Fuzzy Logic Cotroller:

Fuzzy logic controller is a multi valued logic used to reduce study state error and simulation is done in MATLAB environment as shown in figure.7.3.

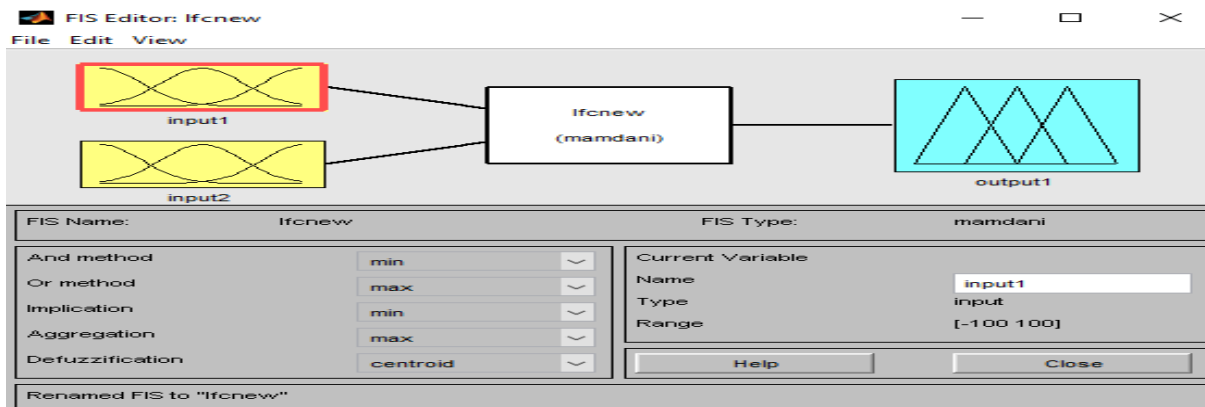


Figure.7.2. Fuzzy inference system

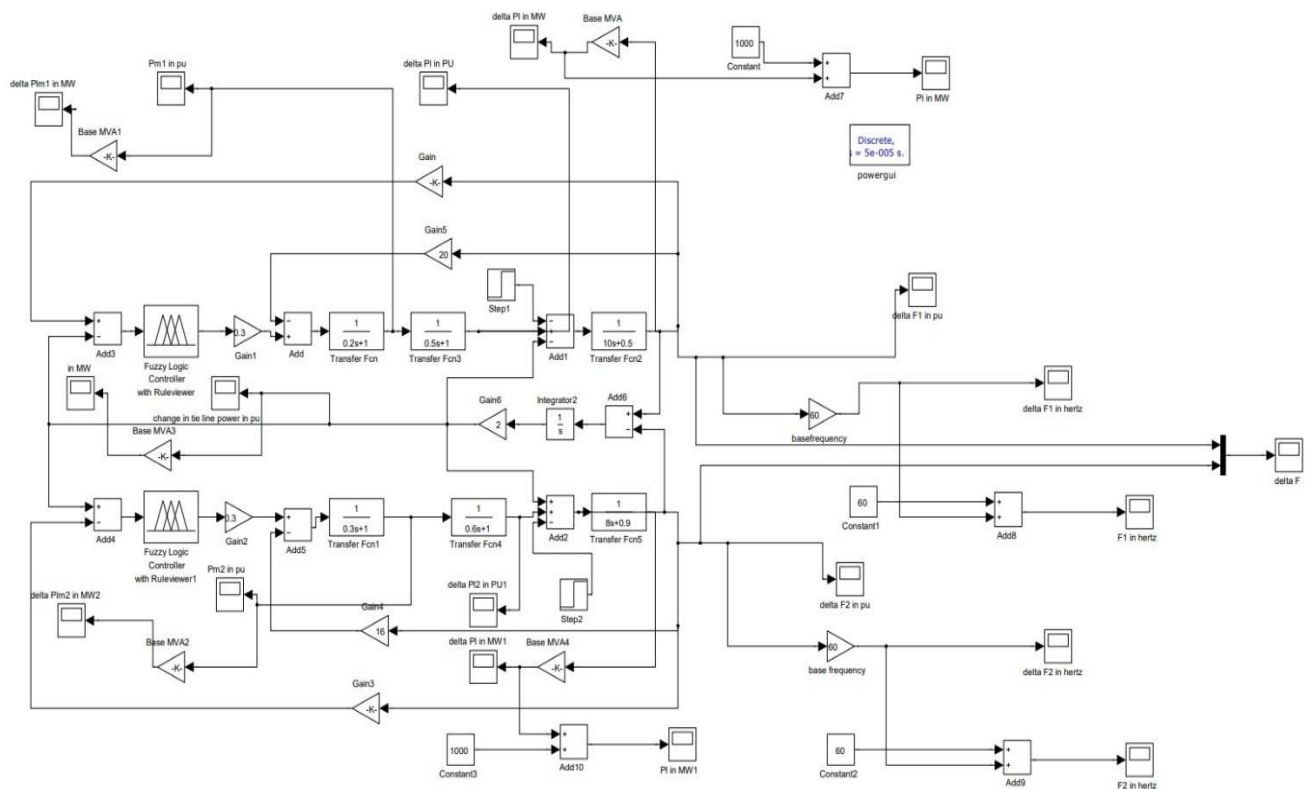
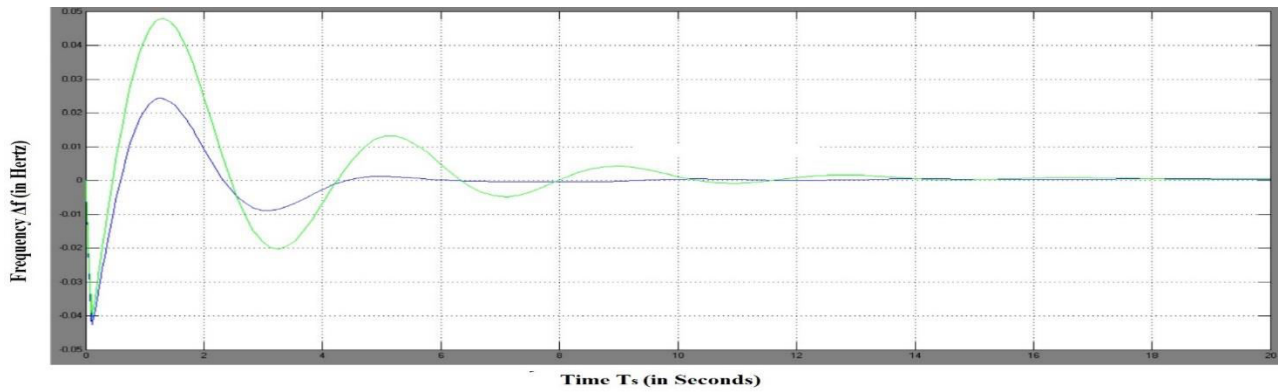
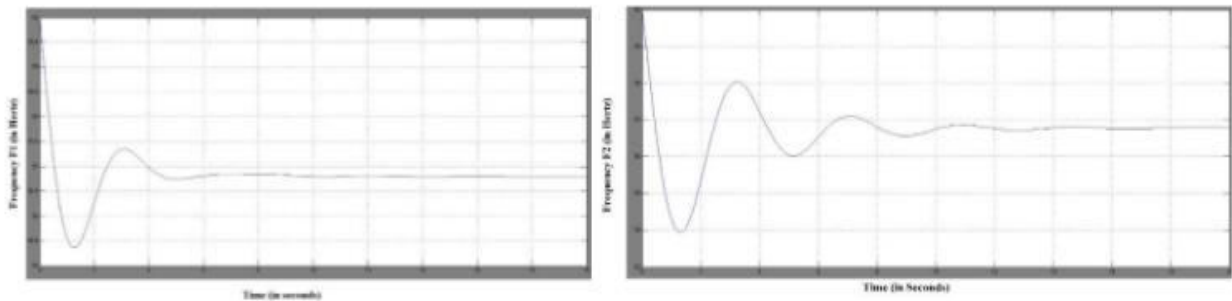


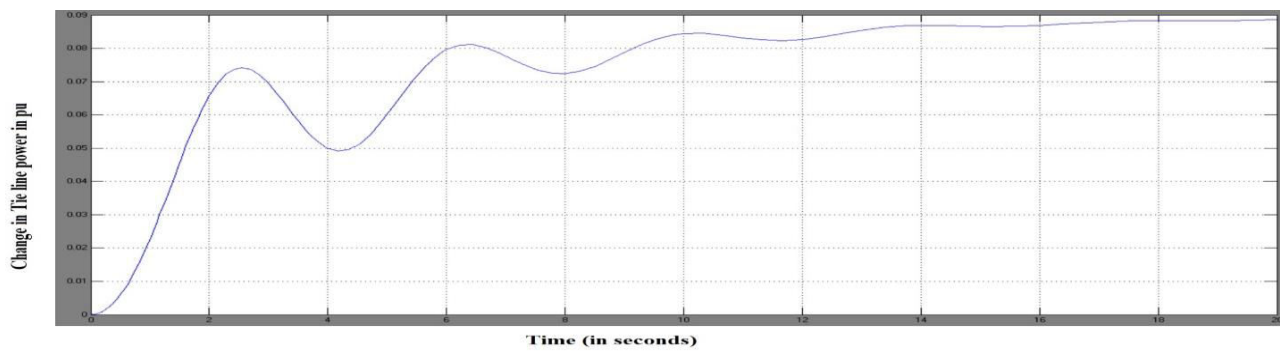
Figure:7.3. Two area load frequency control using FUZZY Logic Controller



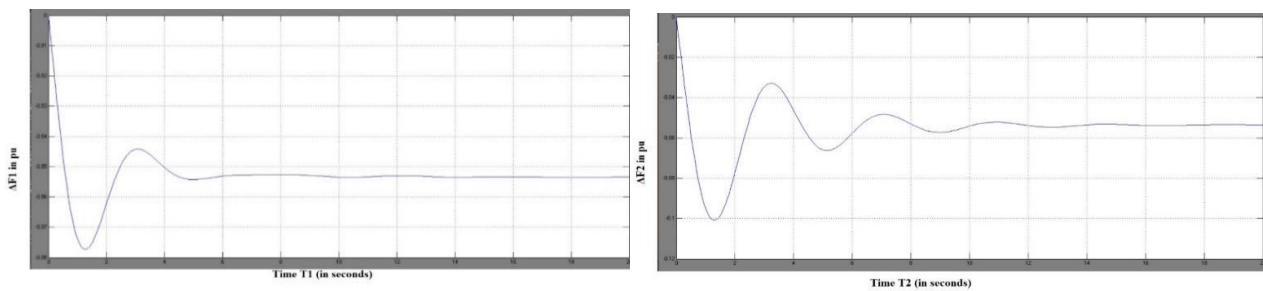
(a) Frequency deviation Δf versus Settling time T_s waveform



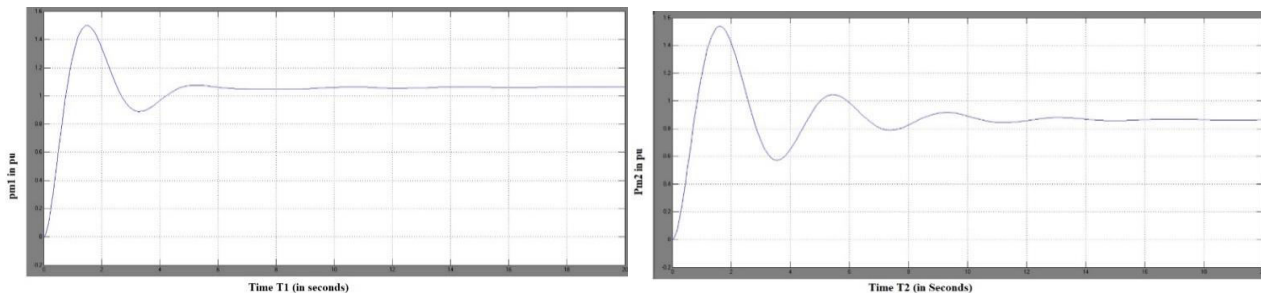
(b) Frequency F_1 and F_2 waveform



(c) Change in tie line power waveform



(d) Change in frequency Δf_1 & Δf_2 waveform



(e) Change in mechanical power pm1 and pm2 waveform

- From Figure.7.3.(a) Fuzzy controller is present in the two area system even if there is a change in load (at area-1) the change in frequency settled to zero $\Delta f=0$ i.e. the system reached its steady state position. It's settling time $T_s=14$ sec. and the peak over shoot is at 0.05 Hz.
- From the simulation result it is observed that the Fuzzy controller are adjusted for a satisfactory response and frequency deviation returns to zero with settling time of approximately 14 seconds which is less than PI controller.
- From 7.3. (b) Fuzzy controller present in two area system with Frequency F1 of area -1 at 59.86 Hz and frequency F2 of area-2 at 59.82 Hz and time of area-1 and area-2 at 14 sec respectively.
- From Figure7.3 (c) Change in tie line power in pu ΔP_{12} is obtained at a value of 0.08854 p.u
- From Figure 7.3. (d) It is observed that frequency change in area-1 of i.e., Δf_1 at 0.05343 in pu and change in area-2 i.e., Δf_2 at 0.5362 in pu and time T1 of area-1 at 10 sec and time T2 of area-2 at 12 sec.
- From Figure7.3. (e) Fuzzy controller present in two area power system obtained at change in mechanical power pm1 of area-1 at 1.061 in p.u and pm2 of area-2 at 0.8631 in p.u and Time T1 of area-1 at 10 sec and Time T2 of area-2 at 14 sec.

7.1.3 Artificial Neural Networks:

An ANN is based on a collection of connected units or nodes called artificial neurons, which loosely model the neurons in a biological brain. Simulation is done in MATLAB environment as shown in figure

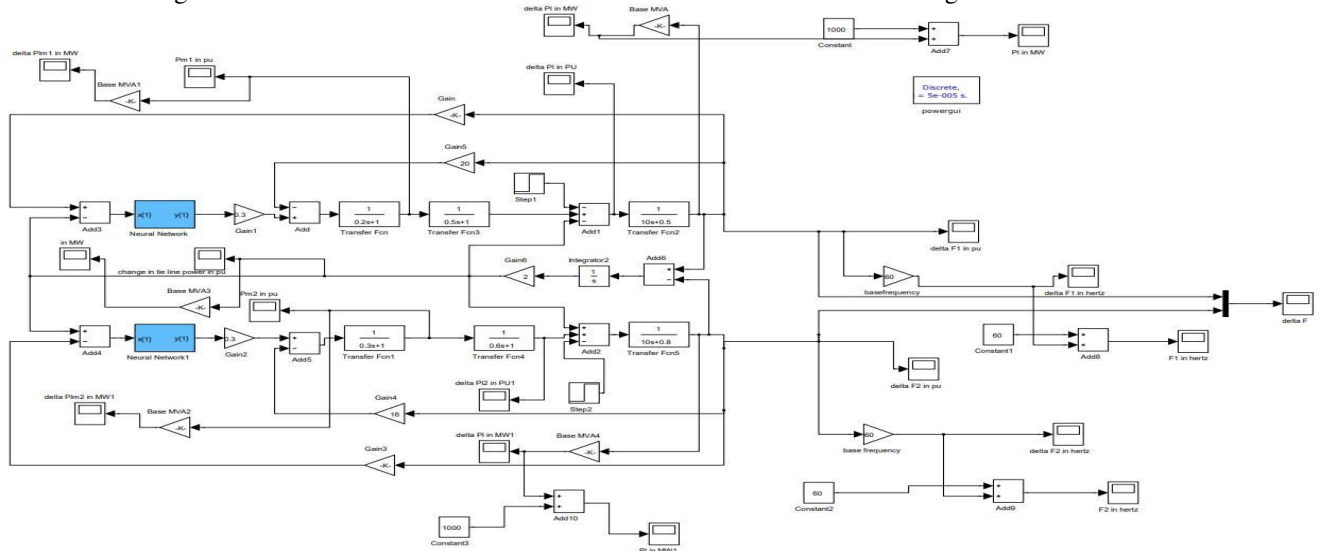
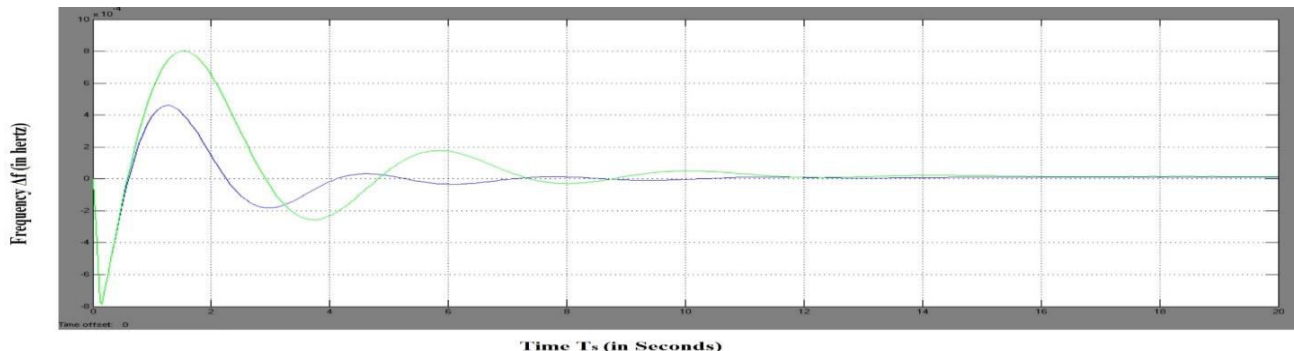
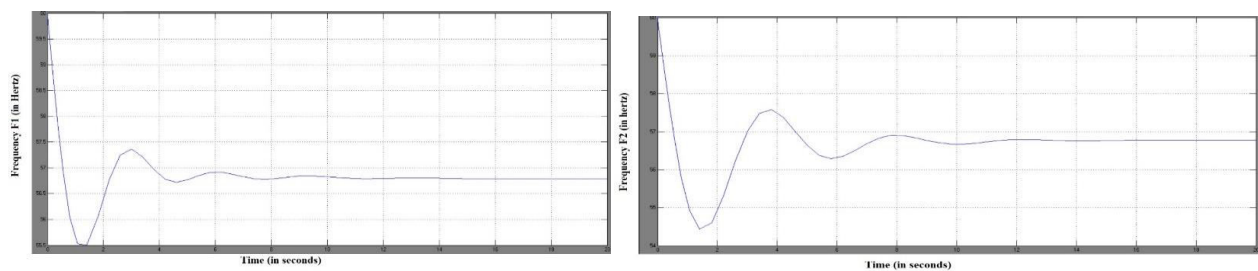


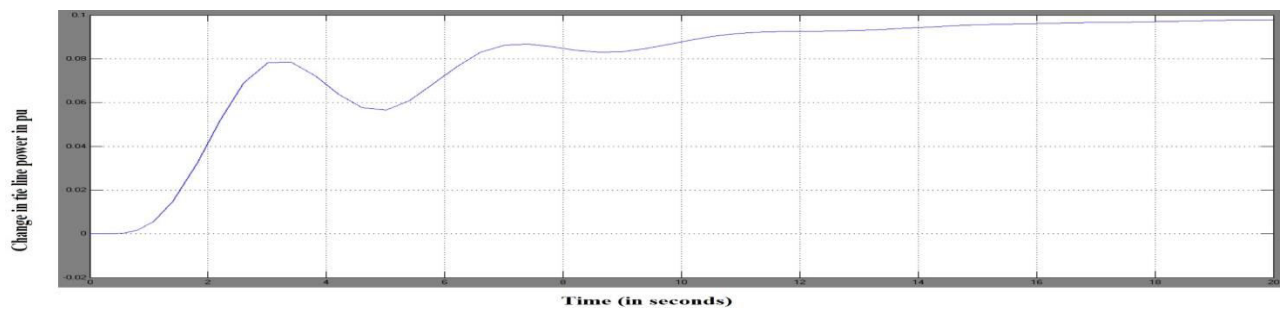
Figure:7.5. Two area load frequency control using ANN



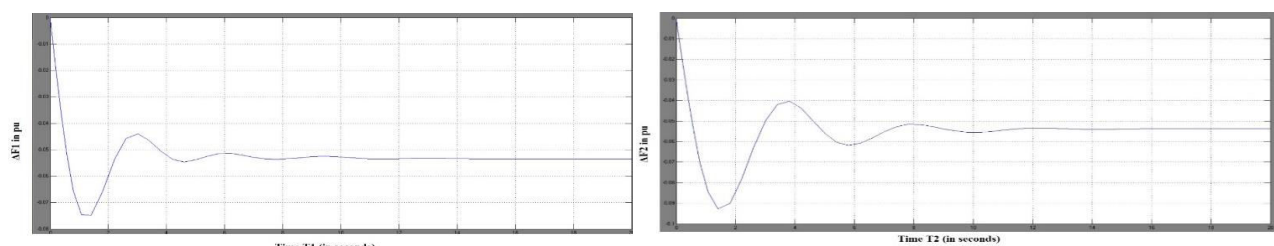
(a) Frequency deviation Δf versus Settling time T_s waveform



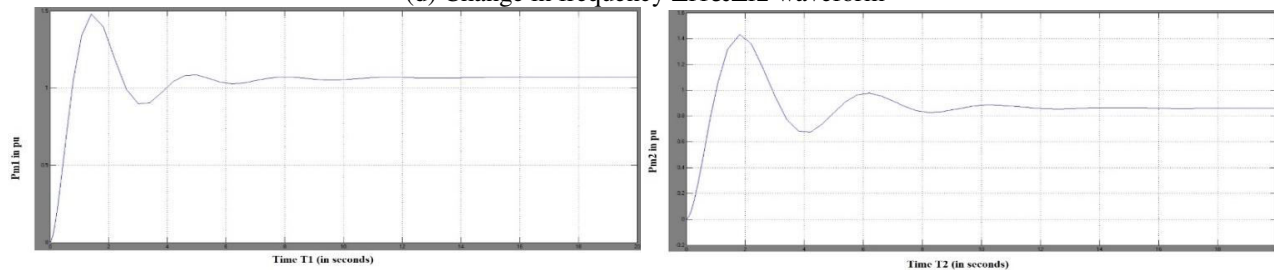
(b) Frequency F_1 and F_2 waveform



(c) Change in tie line power waveform



(d) Change in frequency Δf_1 & Δf_2 waveform



(e) Change in mechanical power p_{m1} and p_{m2} waveform

- From Figure 7.5. (a) ANN controller is used in the power system, the frequency of the two areas reached its steady state position ($\Delta f=0$) after change in load. Here we can also observe that steady state is reached

quickly compare to PI controller and peak undershoots are reduced. The settling time $T_s=12\text{Sec}$ and the peak over shoot is at 0.008 Hz

- From figure 7.5.(b), Artificial neural network obtained at two area system due to frequency F1 of area-1 at 59.74 Hz and frequency F2 of area-2 at 59.74 Hz and time of area-1 and area-2 at 8 sec and 10 sec respectively.
- From figure 7.5.(c), It is observed that change in tie line power i.e., ΔP_{12} is obtained at a value of 0.09782 in p.u. and from 7.5.(d), Artificial neural network present in two area system due to change in frequency of area-1 i.e., Δf_1 at 0.05356 in pu and area -2 i.e., Δf_2 at 0.05369 in pu and time T1 of area-1 at 8 sec and time T2 of area-2 at 10 sec.
- With the proposed ANN controller, it is clearly observed that from figure 7.5.(e), the change in mechanical power of area-1 i.e., p_{m1} at 1.071 in pu and area-2 i.e., p_{m2} at 0.8593 in pu and time T1 of area-1 around 8 sec and time T2 of area-2 around 12 sec.

TABLE I. Two Area LFC Modeling Parameters

Frequency, F	60Hz
Synchronizing power coefficient, P_s	$2\text{pu} = 0.02\text{p.u}$
Load change in MW	$\Delta P_{L1}=187.5\text{ MW}$
Load change	$\Delta P_{L1}=0.1875\text{ p.u}$
Base Power	1000 MVA

Parameters	Area-1	Area-2
Speed regulation (R)	0.05	0.0625
Frequency Sensitive Load Coefficient (D)	0.6	0.9
Inertia Constant (H)	5	4
Governor Time Constant (T_g)	$T_{g1}=0.2\text{ Sec}$	$T_{g2}=0.3\text{ Sec}$
Turbine Time Constant (T_t)	$T_{t1}=0.5\text{ Sec}$	$T_{t2}=0.6\text{ Sec}$

TABLE II .Comparing the Overall Parameters between PI, FUZZY & ANN controllers

S.NO	PARAMETERS	PI	FUZZY	ANN
1.	Maximum Peak overshoot in pu, Δf	-0.02	0.05	0.0008
2.	Settling Time, T_s in Seconds	27	14	12
3.	ΔF_1 in Pu	0.002128	0.05343	0.05356
4.	ΔF_2 in Pu	0.002248	0.05362	0.05369
5.	P_{m1} in Pu	1.039	1.061	1.071
6.	P_{m2} in Pu	0.9639	0.8631	0.8593
7.	F1 in Hertz	60.13	59.86	59.78



8.	F2 in Hertz	60.14	59.82	59.74
9.	Change in Tie- line power in Pu, ΔP_{12}	0.03816	0.08854	0.09782

VIII. CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

For supplying stable and reliable electric power, load frequency control is an important issue in power system operation and control. Automatic load frequency control is used to maintain the generator power output and frequency within the prescribed values.

In this project, two control area power system with frequency oscillations caused by load changes with the reduction of FLC and ANN are investigated. Power system modeling and FLC Matlab / Simulink program was carried out using Simpower toolbox function. ANN technique is developed using programming. FLC's and ANN performance compared with conventional integral controller.

The results with PI controller has more peak overshoot and it takes 27sec time to reach steady state. In case of fuzzy controller, it has less peak overshoot is 0.05Hz and takes 14sec time to reach steady state. In case of ANN controller, it has less peak overshoot is 0.009Hz and takes 12sec time to reach steady state.

8.2 Future Scope

This project future scope may include,

- The proposed two controllers each for the steam turbine and boiler by using coordinated control system (CCS).
- By using Multiple areas in the power system, we can reduce the tie line power error.

IX. ACKNOWLEDGMENT

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