LOAD FREQUENCY CONTROL OF MULTI AREA SYSTEM USING ARTIFICIAL INTELLIGENCE TECHNIQUES

DISSERTATION

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By

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ABSTRACT

The power system is interconnected to enhance the security and reliability. With large interconnected system, unexpected external disturbances, parameter uncertainties and the model uncertainties make big challenges for stability of system. Load Frequency Control (LFC) deals with the control of real power and frequency of the system. The LFC is used to reduce the transient deviations in the power system. It limits the frequency within limits and controls the tie-line exchange power. Various controllers are used for this purpose. Recently Artificial Intelligence Techniques such as Artificial Neural Network (ANN), fuzzy logic, Genetic Algorithm etc. are used for the designing of controllers. These controllers provide a faster response and are flexible to adjust according to system conditions.

In this dissertation work, I have designed controllers such as integral controller which is conventional method for Load Frequency Control and Artificial Intelligence Technique based Fuzzy Logic controller to deal with the Load Frequency Control Problem for Multi-area System. The simulation of the system is done with MATLAB. The requirement of these controllers is to provide a robust system which is more stable and reliable and helps the system to regain its normal value after any disturbance.

CERTIFICATE

This is to certify that Surbhi Pandebearing Registration no.11301735 has completed objective formulation of Dissertation titled **"LOAD FREQUENCY CONTROL OF MULTI AREA SYSTEM USING ARTIFICIAL INTELLIGENCE TECHNIQUES"** under my guidance and supervision. To the best of my knowledge, the present work is the result of his original investigation and study. No part of the report has ever been submitted for any other degree at any university.

The dissertation is fit for submission and the partial fulfilment of the conditions for the award of degree of Master of Technology in Electrical and Electronics Engineering.

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“No duty is more urgent than that of returning thanks”.

A formal statement of acknowledgement to express my gratitude to **Ms. ROOHI KANSAL ,** Assistant professor, School of Electrical and Electronics Engineering, Lovely Professional University for his sincere efforts, valuable guidance and constant encouragement that helped me throughout the course of research and preparation of this Dissertation. I am greatly obliged to all teachers of my department who directly and indirectly helped me to do my dissertation successfully. I am thankful to my parents who helped and encouraged me to work hard during my work.

It will be incomplete without expressing whole hearted thanks to my friends who has been the constant resource of encouragement and support throughout my dissertation. Above all, it is the grace of God, which has led and blessed me all the way in my life to make this work a fruitful one.

Surbhi Pande

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DECLARATION

I, Surbhi Pande, student of Master of Technology inElectrical and Electronics Engineering under Department of Electrical and Electronics Engineeringof lovely professional university, Punjab, hereby declare that all the information furnished in this Dissertation report is based on my own intensive research and is genuine.

This Dissertation does to the best of my knowledge; contain part of my work which has been submitted for the award of my degree either of this university or any other university without proper citation.

SURBHI PANDE

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Date:

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CHAPTER 1

INTRODUCTION

A power system consists of many generating units which are interconnected to each other to fulfill the load demand. The interconnection between various area are done through tie lines. In an interconnected power system as the power load demand i.e. active and reactive power demand varies randomly, both area frequency and tie-line power interchange also vary. This change should be balanced as soon as possible to maintain the system stability and reliability. The process of maintaining frequency and tie line power under balanced condition is known as Load Frequency Control (LFC). The objectives of LFC are to minimize the transient deviations in these variables (area frequency and tie-line power interchange) and to ensure their steady state errors to be zeros. When dealing with the LFC problem of power systems, unexpected external disturbances, parameter uncertainties and the model uncertainties of the power system pose big challenges for controller design. Artificial intelligence techniques such as neural network, fuzzy logic, genetic algorithm etc. are increasingly popular practical techniques for controller design for load frequency control. This study presents a solution to the LFC problem based on fuzzy logic with integral control. The controller is constructed for a multiple area power system. The dynamic model of the power system and the controller design based on the model will be simulated and programmed using MATLAB.

1.1 LOAD FREQUENCY CONTROL

Power systems convert natural energy into electric power and transmit this power to load centers. The alternating current is generally used to transmit the electricity. For optimized performance of electrical equipment, good quality of power is required which means a nearly constant voltage and frequency of the supply. During the transportation of electrical power through transmission lines, both the active power and the reactive power balance must be maintained between generating end and load end. Thus the input to the generators must be continuously maintained according to the varying demand of active power so that the frequency is balanced in the system. Also, generator excitation should be regulated to maintain the reactive power demand of the system which in turn balances the voltage in the bus within limits. Thus the balancing of active and reactive power corresponds to two equilibrium points:

(1) Frequency
(2) Voltage.

When any one of the two balances is disturbed and reset at a new level, the equilibrium points will float. A good quality of the electric power requires both the frequency and voltage to remain at nominal values during operation. The consumers of the electric power change the loads randomly. It is almost impossible to maintain the balances of both the active power and reactive powers without control. Due to this imbalance, the frequency and voltage will be changing with the change of the loading condition. Thus a control system is essential to cancel the effects of the random load changes and to keep the frequency and voltage at the nominal values. This control can be provided either manually or automatically. The controllers are designed to take care of changes in load variation so that the frequency and voltage can be maintained within the prescribed limits of system.

Although the active and reactive power has combined effects on the frequency and voltage, the control problem of the frequency and voltage can be decoupled. As we see that the frequency is dependent on the active power while the voltage is highly dependent on the reactive power. Thus the control issue in power systems can be decoupled into two independent problems.

1. The active power and frequency control.
2. The reactive power and voltage control.

The first problem of controlling active power and so the frequency of the system is known as "Load Frequency Control". It is also known as generation control or *P-f* control.

The load frequency control controls the loading of the generators of the system at normal frequency. The frequency of a system remains constant or under nominal conditions when active power generation and its demand remain in balanced condition. Due to change in load, there is a deviation in the frequency of the system from the nominal frequency, known as frequency error Δf. this error signal is used by the load frequency control system to change the generation to bring the system under normal condition. The LFC system control the inlet valve opening of the prime movers according to change in loading condition of the system. For large systems and multi area systems automatic control devices or controllers are used in loop of LFC system.

The first and foremost task of LFC is to keep the frequency constant against the randomly varying active power loads, which are also known as unknown external disturbance. The frequency must be maintained constant for the following reasons:

- Speed of AC motors varies with frequency which is undesirable.
- Synchronism is maintained between various generating units by having constant and same frequency.
- Induction motors and transformers produce high magnetizing currents due to drop in frequency.
- Power transmission capability between interconnected lines of the system also depends on frequency.
- The electrical equipment's are designed to work on constant frequency.

1.1.1 MECHANISM OF LFC

When the load demand varies on generating unit, unbalance between the real power input and output occurs. This difference between input and output of real power is supplied by the stored kinetic energy of rotating parts of that unit.

$$\text{Kinetic Energy (KE)} = \frac{1}{2}\, I\, \omega^2 \quad \ldots(1)$$

Where, I = moment of inertia of rotating part.

ω = angular speed of rotating part.

The kinetic energy, angular speed and frequency are directly proportional to each other. The frequency change is given by Δf and is sensed by a speed-governor system. This value is fed back through a feedback control system to control the position of inlet valve of prime mover so as to maintain balance between input and output of real power. Thus in this way frequency variation is controlled in the system.

Another task of the LFC is to regulate the tie-line power exchange error. A typical large-scale power system consists of several areas of generating units. In order to improve the fault tolerance limit of the whole power system, these different areas of generating units are connected through tie-lines. The tie-line power induces a new error into the control problem of tie-line power exchange error. When a sudden active power load changes in an area, the area gets this power via tie-lines from other areas. But the area that is subjected to the load change should balance it on its own and without external support. Otherwise there would be economic conflicts between the GENCOS and TRANSCOS of areas. Hence each area requires a separate load frequency controller to regulate the tie-line power exchange error so that all the areas in an interconnected power system can set their set-points accordingly. A major problem with the interconnection of the power systems results in huge increase in both the order of the system and the number of the tuning controller parameters. Thus when we model such complex power systems, the model and parameter approximations cannot be avoided. Therefore, the requirement of the LFC is to be robust against the uncertainties of the system model and the variations of system parameters in real.

So the Load frequency control loop senses the change in frequency Δf and change in tie line power ΔP_{tie} which gives the change in rotor angle of the system δ and the change in this angle due to change in loading conditions i.e. $\Delta\delta$ is need to be corrected for the balance of system. These error signals are given to prime mover for an increment in torque. The prime mover changes the generator output by ΔP_g which in turn bring the values of Δf and ΔP_{tie} within the specified limits.

The schematic diagram of a Load Frequency Control is shown in figure 1 as shown

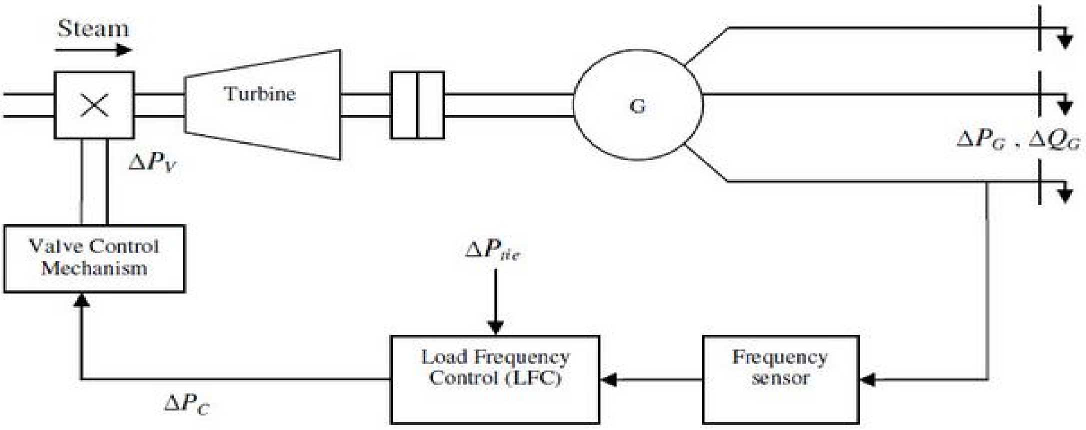


Fig.1. Schematic Diagram of LFC

In short, the LFC has two major tasks -

1. Maintain the standard value of frequency and
2. To keep the tie-line power exchange under schedule in the presences of any load changes.

In addition, the LFC has to be robust against unknown external disturbances and system model and parameter uncertainties. The high-order interconnected power system also increases the complexity of the controller design for the LFC.

1.1.2 EXISTING LFC METHODS

In an interconnected power system consisting of many areas, following controller designing and tuning techniques which includes use of Conventional and Artificial Intelligence Techniques are used for the purpose of load frequency control.

- Integral controllers are being used from decades for the purpose of LFC. Conventionally Proportional Integral (PI) controllers are used. The Proportional Integral Derivative (PID) Controllers were also designed with enhanced properties for LFC. This controller attempts to minimize the error by adjusting the process control output.
- Fuzzy logic based controllers are widely used for the LFC. These are based on the fuzzy set theory which takes fuzzy variables. This controller analyzes the system based on some rule base defined and gives the corresponding output. The output is much improved by using fuzzy logic.
- Artificial Neural Network based controllers are also used widely these days for the purpose of LFC. These controllers are based on pattern recognition and classification. The algorithms used are back propagation, orthogonal least square etc.
- Genetic algorithm is a much widely used computer intelligence algorithms. It is very effective in solving complex optimization problems for load frequency control.
- There are controllers based on the combination of above mentioned techniques such as Neuro-Fuzzy based controllers, PID-Fuzzy based controllers etc. the output performance of the system is much improved after the application of such controllers in the system.

1.2 ISOLATED AREA SYSTEM

A single area power system or an isolated area consists of a single generation unit (a turbine, speed governor, generator) and the load. The load demand of that area is supplied by that generator unit itself. The frequency of this system is assumed to be constant in both the static and dynamic condition of system. This single area is the smallest unit of a power system. First we will consider a single area and its modeling.

1.3 DYNAMICS OF GENERATION SYSTEM

For understanding the load frequency control of single area system, its analysis and design, the first step to do is its mathematical modeling. The system is linearized by taking proper assumptions and approximations for the mathematical equations which describes the system and transfer functions of the components is obtained accordingly.

1.3.1 GENERATOR MODEL

A generator is used to convert mechanical power into electrical power. For LFC consideration, we focus on the rotor speed output (frequency of the systems) of the generator instead of the energy transformation.

For small disturbance, Swing equation for synchronous machine is-

$$\frac{2H}{\omega_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \qquad \ldots (2)$$

For small speed change,

$$\frac{d\Delta\frac{\omega}{\omega s}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \qquad \ldots (3)$$

Taking Laplace transformation of above equation, we get

$$\Delta\Omega(s) = \frac{1}{2Hs}\left(\Delta P_m(s) - \Delta P_e(s)\right) \qquad \ldots (4)$$

The block diagram representing the above equation is given in figure 2 as shown

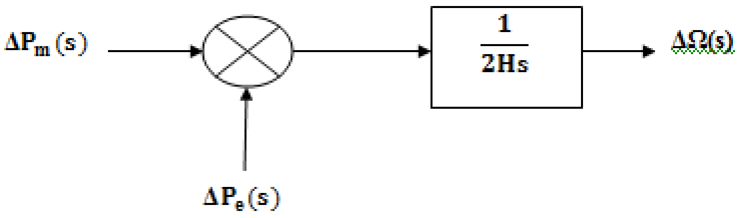


Fig.2. Block Diagram of Generator Block

1.3.2 LOAD MODEL

Various types of electrical devices form load in power system. Inductive and capacitive types of loads are dependent on frequency but resistive loads are independent of frequency. The Speed-Load characteristics of a device show its sensitivity towards frequency variation. For a composite load, the speed-load characteristics is given by the equation

$$\Delta P_e = \Delta P_L + D\Delta\omega \qquad \dots (5)$$

Where, $\Delta P_L(S)$= Load change independent of frequency

$D\Delta\omega$ = Load change dependent on frequency

And $D = \frac{\% changeinload}{\% changeinfrequency}$

Thus, the block diagram for generator – load model is given in figure 3.

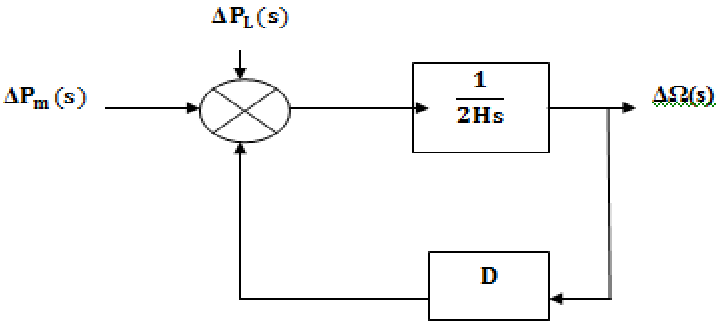


Fig.3. Block Diagram of Generator – Load Block

On simplifying the above model, we get the block diagram of load for the mathematical modeling as shown in figure 4

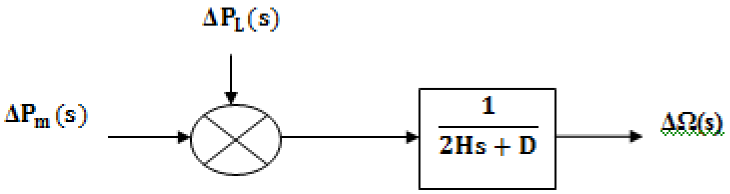


Fig.4. Block Diagram of Load

1.3.3 TURBINE MODEL

Prime mover is the source of mechanical power in the system. In hydel power plants it is the hydraulic turbine and for thermal power plant it is steam turbine. The mechanical power output ΔP_m is converted into steam valve position ΔP_v through a turbine. Different types of turbines are used in power system such as non-reheat type, reheat type and hydraulic type.

The non-reheat type turbines are simplest type of turbine of first order. The transfer function of such turbine is given by

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{\tau_t s} \qquad \dots (6)$$

Where $\tau_t s$ = Time constant. Its value lies between 0.2 to 2 seconds.

The block diagram representing above equation for non-reheat turbine is shown in figure 5 .

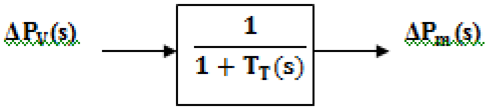


Fig.5. Block Diagram for Simple Non Reheat Steam Turbine

Reheat turbines have more than one stage of high steam pressure and low steam pressure and so these are modeled as second order units. The transfer function of reheat turbine is given by equation

$$G_{RS}(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{F_{hp}T_{rh}s + 1}{(T_t s + 1)(T_{rh}s + 1)} \qquad \dots (7)$$

Where F_{hp} = high pressure stage rating

T_{rh} = Low pressure reheat time.

1.3.4 SPEED GOVERNERNING SYSTEM MODEL

The speed governor is most important part of Load Frequency Control as it handles the controlling of the inlet valve of prime mover and controls the speed of the system. The frequency of the system is dependent on the speed. The change in speed is sensed by governor and it adjusts the valve of turbine to change mechanical power output to keep the speed in new steady state.

From speed governor characteristics,

$$\Delta P_g = \Delta P_{ref} - \frac{1}{R}\Delta\omega \qquad \dots (8)$$

This equation can be given in S domain as

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta\Omega(s) \qquad \dots (9)$$

Let us consider a linear relationship and simple time constant τ_g, we get the relation between ΔP_g and ΔP_v as

$$\Delta P_v = \frac{1}{1 + \tau_g}\Delta P_g(s) \qquad \dots (10)$$

The block diagram of speed governor system based on the above transfer function is given in figure 6 as

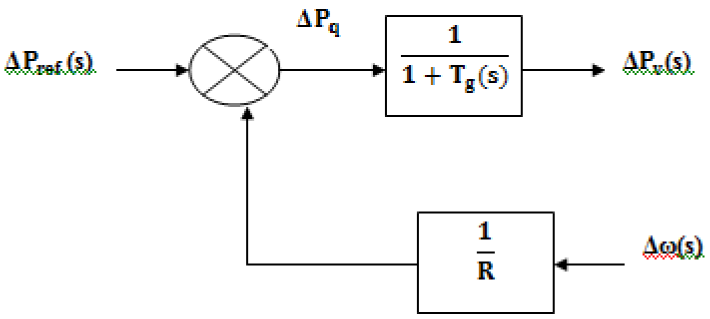


Fig.6. Block Diagram Representation of Speed Governing System

1.3.5 DYNAMIC MODEL OF AN ISOLATED SYSTEM

By combining the block diagrams of generator model, load model, turbine model and speed governing system, we get the complete block diagram for Load Frequency Control of an isolated area or a single area power system is shown in figure 7 as

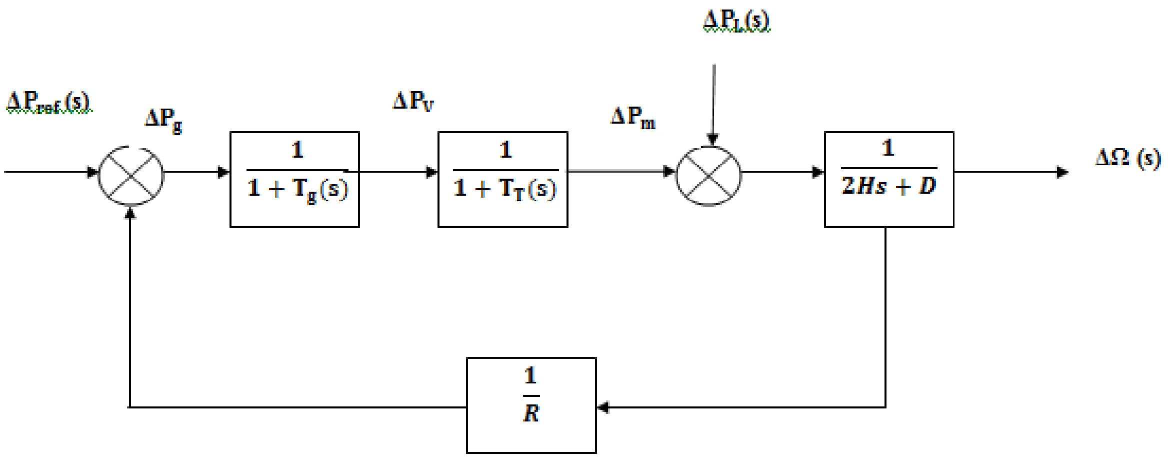


Fig.7. Block Diagram of Load Frequency Control of an Isolated System

The open loop transfer function of this block diagram after simplification and taking load change $-\Delta P_L(s)$ as input and frequency deviation $\Delta\Omega(s)$ is given as

$$K\,G(s)H(s) = \frac{1}{R}\frac{1}{(2Hs + D)(1 + \tau_g s)(1 + \tau_t s)} \qquad \text{... (11)}$$

The closed loop transfer function relating load change ΔP_L to frequency deviation $\Delta\Omega$ is given by

$$\frac{\Delta\Omega(s)}{-\Delta PL(s)} = \frac{(1 + \tau_g s)(1 + \tau_t s)}{(2Hs + D)(1 + \tau_g s)(1 + \tau_t s) + 1/R} \qquad \ldots (12)$$

1.4 MULTIAREA POWER SYSTEM

Generally a power system is comprised of various composite and multi-level systems having linear and non-linear characteristics. A multi area power system is formed by interconnecting more than one single area system. The block diagram of a two rea interconnected system is shown in figure 8.This interconnection is done via tie-lines. The system is interconnected to enhance the stability and reliability of the power system. But due to interconnections, the complexity of the system also increases. The frequency and voltage of each area have to be regulated and maintains in prescribed limits else the complete system could be damaged. Also the system should be protected for any fault condition too. For the purpose of Load Frequency Control, each area in an interconnected system is provided with a controller to balance and maintain the frequency in the prescribed values and to maintain tie line power so that system remains in stable state and continuous and reliable supply can be provided.

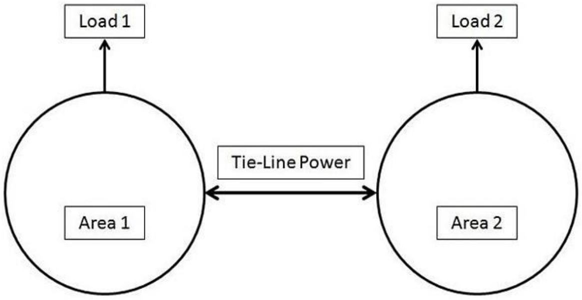


Fig.8. Block Diagram of Interconnected System

1.4.1 INTERCONNECTION OF POWER SYSTEM

A large power system can be divided into number of control areasbased on the principle of coherency. These areas are connected with each other by tie lines. With the interconnection of these Load Frequency Control Areas, we can pool the generation of power and demand of the consumer. Such operation is known as pool operation. The successful operation of interconnected power systems requires the matching of total generation with total load demand and associated system losses. As power systems expanded out from their urban cores, interconnections among neighboring systems became increasingly common. Groups of utilities began to form power pools, allowing them to trade electricity and share capacity reserves. One of the great engineering achievements of the last century has been the evolution of large synchronous alternating current (AC) power grids, in which all the interconnected systems maintain the same precise electrical frequency. There are several economical and other advantages of this power pool which can be given as

- An interconnected system provides bulk transfer of power from generation to demand center efficiently.
- The interconnected system makes it possible to select the cheapest generation available by linking together all participants across the transmission system.
- Interconnected transmission circuits are more reliable than individual generating units. They enhance the security of supply as they are capable to make use the diversity among individual generation sources and load demand in a better way.
- With an interconnected transmission system, the surplus generation of one area can be used to provide power in other area where there is requirement of it. Hence it reduce the requirement of additional installed generation capacity and can provide sufficient generation security for the complete interconnected power system.
- In an isolated area, the frequency variation due to load variation of the system is maintained by that system itself. But with interconnection of system, the overall system has to meet the highest of individual system requirement to take care of largest potential loss of power generation.

In India the north, west, east and north east grids are operating synchronously and all four regions are interconnected with AC as well as HVDC links. The Southern region is connected to East and West by HVDC links. Each regional grid is divided further into state grids which form the respective control areas. Within a region the various control areas are interconnected by AC links [23].

1.4.2 TIE-LINES

Tie lines are used for the interconnection of different control areas of power system. When the frequency of the two areas are different then power is exchanged between those these areas through tie lines. The equation representing tie line is given as

$$\Delta P_{tie}(s) = \frac{1}{s} T_{ij} \left(\Delta F_i(s) - \Delta F_j(s)\right) \dots (13)$$

Where ΔPtie = tie line exchange power between two areas

T_{ij} = tie line synchronizing torque between area i and j.

The block diagram for tie line representing the above equation is shown in figure 9 as

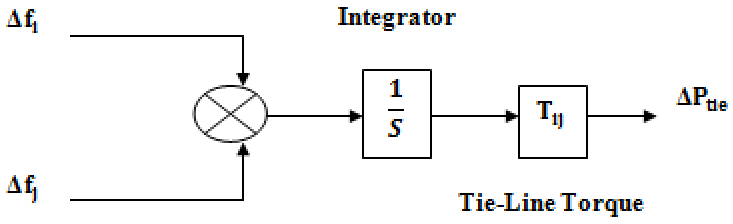


Fig.9. Block Diagram of Tie Line

Figure shows that the tie-line power error is the integral of the frequency difference between the two areas i and j.

1.4.3 AREA CONTROL ERROR

The aim of Load Frequency Control is to maintain the frequency and the tie line exchange power within the limits so that the stability of the system can be maintained. The tie line power error is integral of frequency difference between the interconnected areas. If the frequency error of a system can be controlled and made to zero then only the tie line power error will constitute the steady state errors in a system. So for the modeling of an interconnected area tie line power deviation is included in control input. Thus, Area Control Error (ACE) can be defined as

$$ACE_i = \sum_{j=1\ldots n, j\neq i} \Delta P_{tieij} + B_i \Delta F_i \ldots \ (14)$$

Where B_i = frequency response characteristic for area i

And $$B_i = D_i + \frac{1}{R_i} \ldots \ (15)$$

The output of each generation area is given by ACE. All the frequency errors and tie line power errors will be zero if we can make the ACE as zero.

1.4.4 PARALLEL OPERATION

The power generating units are connected in parallel for their operation. The equivalent generator is considered for one area generating units. The equations related to such condition are given as

$$M_{eq} = \sum_{i=1\ldots n} M_i \ldots \ (16)$$

$$D_{eq} = \sum_{i=1\ldots n} D_i \ \ldots (17)$$

$$B_{eq} = \sum_{i=1\ldots n} \frac{1}{R_i} + \sum_{i=1\ldots n} D_i \ldots (18)$$

Where M_{eq} = Equivalent generator inertia constant

D_{eq} = Load damping constant

B_{eq} = Frequency Response characteristic

1.4.5 CONTROL OF AN INTERCONNECTED AREA

The control of an area is maintained by three control layers. These are primary control, secondary control and tertiary control. These can be explained as:

1.4.5.1 PRIMARY CONTROL:

Primary control is used to balance the system generation and load demand in the network. The balance is maintained by exerting the control locally in the system. When frequency deviation occurs, the turbine speed governors are made to adjust the generator output according to the variation so that system remains in balanced state. During large disturbances, primary control balances the generated power and consumed power by adjusting the system to a new set-point value other than the pre-disturbance value so that the system remain in stablestate.

1.4.5.2 SECONDARY CONTROL:

Secondary control basically has two functions to perform:

1. The secondary control maintains the interchange power between the control area and interconnected area is maintained according to predefined value. When large frequency drop occurs in the system.
2. Secondary control restores the frequency to a new set point so that system remain stable.

The secondary control is an automatic centralized process of control block.

1.4.5.3 TERTIARY CONTROL:

It is the automatic or the manual control setting or adjustment of generator and load set point. The two main functions of tertiary control are:

1. The reserve for an accurate secondary control is provided sufficiently, and
2. Area wise objectives should get maintained while distributing the power.

1.4.6 DYNAMIC MODEL OF MULTI AREA POWER SYSTEM

Interconnecting various individual power systems, the model for a multi area power system is developed. The system developed is shown in figure 9.

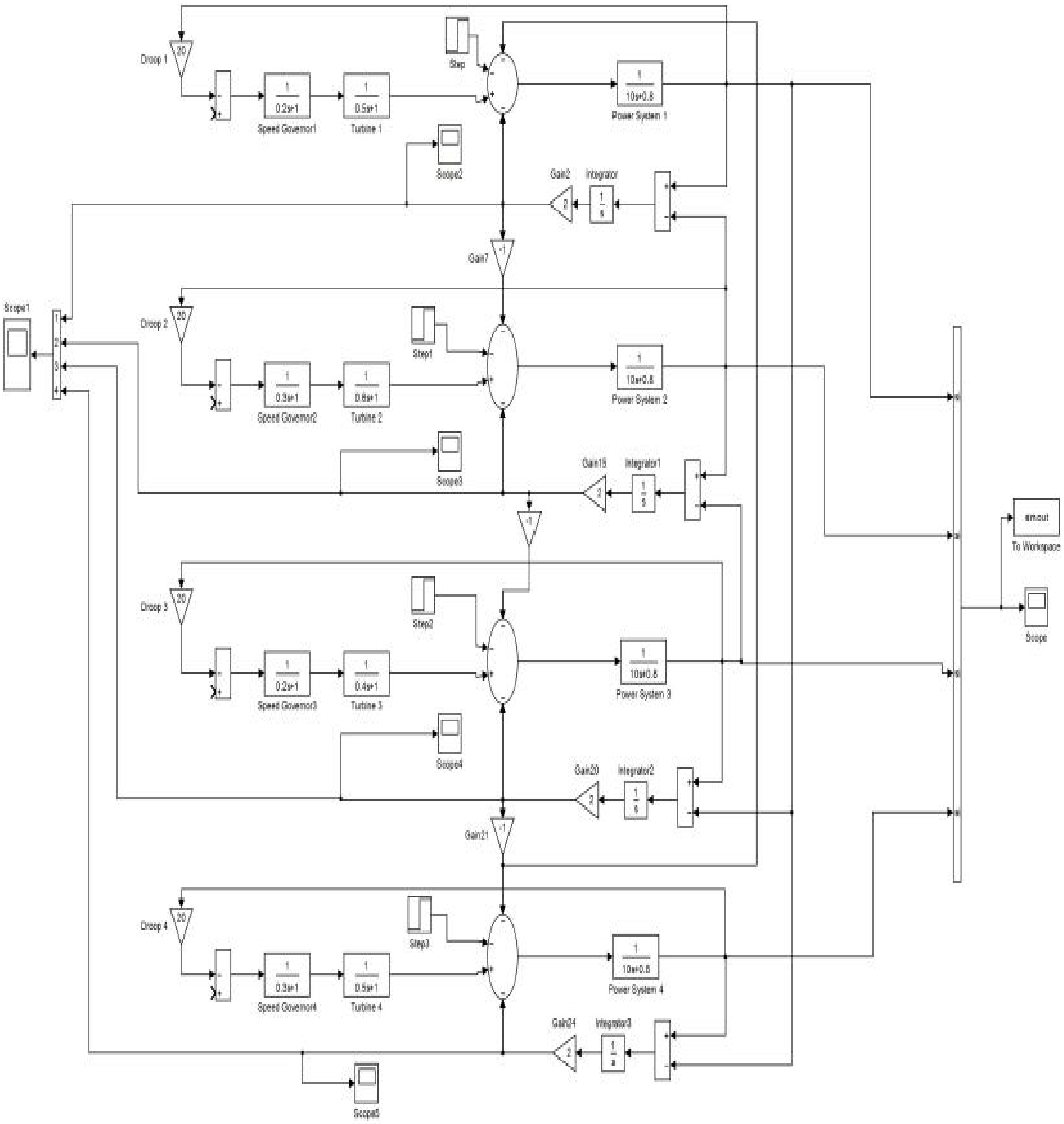


Fig.10. Block Diagram of Four Area Interconnected System

CHAPTER 2

REVIEW OF LITERATURE

2.1 Hassan A. Yousef, Khalfan Mohammed Al Kharusi, "Indirect adaptive fuzzy logic frequency control of multi-area power system", 8th IEEE GCC conference and exhibition, Muscat, Oman, 1-4 February, 2015.

The multi area power system is considered to be consists of a gas turbine and steam turbine. The Load Frequency Control of multi-area system is achieved by designing an approximation based adaptive fuzzy logic controller. The controller depends on the local state of each area i.e frequency, tie-line power change and the tracking error. The system is modeled based on the specifications and an indirect adaptive fuzzy logic control (IAFLC) is used in each area to control the system stability. A three area system is considered in which area 1 and area 2 are having both the gas turbines and steam turbines and area 3 consist of only gas turbine. For designing the fuzzy logic based controller, 5 Gaussian membership functions are taken for frequency change and tie-line power change. Fuzzy system having center average defuzzifier and singleton fuzzifier approximates the unknown functions in control law. A conventional PID controller is also designed by Ziegler-Nichols method and is simulated with the IAFLC. A Lyapunov function shows the closed-loop system boundedness for the tracking error and parameter error. The result shows that each area is capable of handling its own load demand as well as LFC is achieved in terms of zero steady state frequency and tie-line error. The designed controller is superior to the conventional PID controller.

2.2 G.T. Chandra Sekhar, Sahu Rabindra Kumar, Panda Sidhartha, "Load frequency control with fuzzy-PID controller under restructured environment", International conference on control, instrumentation, communication and computational technologies (ICCICCT), 2014.

In this study two control areas are considered having power capacity of 2000 MW and nominal loading as 1640 MW. Both areas consist of reheat thermal system, gas system and hydro-power system. For each generating station a Fuzzy-PID controller having derivative filter coefficient is designed. The performance criteria for modern heuristic optimization technique based controller are Integral of Time multiplied Absolute Error (ITAE), Integral of Squared Error (ISE), Integral of Time multiplied, Squared Error (ITSE) and Integral of Absolute Error (IAE). ITAE is used to reduce the settling time and peak overshoot. The case of POOLCO based transaction, Bilateral based transaction, Contract violation based transaction are considered. It is seen that for the two area six unit power system consist of hydro, thermal and gas power plant the constraints like Time Delay (TD) and Generation Rate Constraint (GRC) gives ability of system handling the nonlinearities of model. Differential Evolution (DE) is used to optimize the gain of the fuzzy and PID controller. As result the performance of the system such as peak overshoot and settling time are improved in case of Fuzzy-PID controller than the conventional PID controller.

2.3Roohi Kansa1, Balwinder Singh Surjan, "Study of Load Frequency Control in an interconnected system using conventional and fuzzy logic controller", International journal of science and research (IJSR), Volume 3 Issue 5, May 2014

The frequency drift of the power system due to load variations are discussed in this paper. Better improvements are achieved on minimizing the frequency fluctuations. An Automatic Generation Control (AGC) is used for this purpose here. This AGC technique uses here is a maintenance of demand and supply of power in real time. The comparison of conventional PI controller and fuzzy controller is also discussed here in this paper. The Frequency control in interconnected system is done by two automatic controllers connected each other. They are primary and secondary. The system is stabilized on a disturbance by the primary controller and the secondary controller is used to restore the system frequency and the power exchanged by the interconnected system. The dynamic response is studied in MATLAB/SIMULINK software and the whole system was mathematically modeled.

2.4 Prakash Surya , Bhardwaj A. K. , Sinha S. K. "Neuro Fuzzy hybrid intelligent approach for Four -area Load Frequency Control of interconnected power system", 2nd International conference on power, control and embedded systems, IEEE, 2012.

An interconnected four area power system is considered where area 1 and 2 consist of reheat type thermal power plant and area 3 and 4 consist of hydro power plant. The control techniques used for Load Frequency Control of the system are PI, Fuzzy and ANFIS (Adaptive Neuro-Fuzzy Interface System). The Variable Structure Concept (VSC) is the reason for using sliding concept. VSC provides the robust control system for external disturbances and for the stabilization of control functions. Hybrid Neuro-Fuzzy (HNF) is a mix of neural network and fuzzy logic. Four numbers of input and output MFs are used i.e. only 16 rules are defined for ANFIS. This controller provides a faster response and can handle the nonlinearities of the system. It damps out the oscillations in the system very effectively. Sugeno type fuzzy interface system controller is proposed by the author with the parameters inside fuzzy are decided by back propagation method of neural network. The proposed model provides the better and faster response.

2.5 Zenk Hilmi, Zenk Osman, Akpinar Adem Sefa, "Two different power control system Load-Frequency analysis using Fuzzy Logic Controller", 978-1-61284-922-5, 2011 IEEE.

A two area system is taken for Load Frequency Control consideration. Fuzzy logic controller is designed for each area so that each area could handle the frequency change and the power exchange between two areas. Inputs to fuzzy logic controller are control error and sampling error change. Three MFs are taken and thus 9 rules are formed in rule base. When the integral controller is designed in the system, the system comes to its steady state but with increased number of oscillations and setting time. Fuzzy logic controller provides two zone protection in the system. When the fuzzy logic controller is used with the integral controller, the oscillations are substantially reduced and steady state comes in lesser time than the integral controller.

2.6 Mishra Padmagandha, Dr. Mishra S., Nanda J., Sajith K.V., "Multilayer Perceptron Neural Network (MLPNN) controller for automatic generation control of multi area Thermal system", IEEE, 2011.

A two unequal area and three unequal area are investigated for the purpose of Automatic Generation Control (AGC). These areas consist of single reheat turbines with generation rate constant of three percent. The integral controller is applied in this system and then is replaced by multilayer perceptron neural network (MLPNN) controller for each area. The MPLNN is designed such that there is a single neuron in each layer of the two area system and three area system. Non linearity in neural function is given by Log-sigmoid activation function. The connecting weights are adapted through reinforcement learning i.e. the weights are updated dynamically through back propagation updation technique with inputs as Area Control Error and tie line flow deviation. The performance of the MPLNN is much improved in system loading condition and magnitude of step change in load or simultaneous changes in load than the typical integral controller.

2.7 Mohamed. M .Ismail, M. A. Mustafa Hassan, "Load Frequency Control adaptation using artificial intelligent techniques for one and two different areas power system", International journal of control, automation and systems, Vol. 1, No. 1, January 2012.

A single area non reheat type thermal power system is considered with PID controller. This system is then interconnected via tie lines with a similar system to make a two area. The PID controller is used for the stabilization of frequency in the system. Then the PID controller is tuned with different adaptation techniques such as Fuzzy logic, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). For the fuzzy logic design, seven membership functions have been considered. For the design of Genetic Algorithm three variables are taken with double vector population type and 20 as population size. The Gaussian mutation function is taken. For the optimal tuning with PSO, three variables are taken with bird step of 50. The results are compared and it is seen that fuzzy with PID gives the better results than other two methods in terms of less settling time and peak overshoot.

2.8 K.P. Singh Parmar, S. Majhi, D.P. Kothari "Improvement of dynamic performance of LFC of the two area power system: An analysis using MATLAB", International journal of computer applications, (0975 – 8887), Volume 40– No.10, February 2012.

A two area power having reheat turbine thermal system, hydro system and gas units is considered. The interconnection is done by an AC tie line which is connected in parallel with a DC link to stabilize frequency oscillations in system. The optimal controller for Load Frequency Control compares the values for practical system with and without using DC tie line in the system. The dynamic response of the LFC is compared and improved with the feedback controller. The comparison shows that the systems dynamic response such as less settling time and lower overshoot with zero steady state error is much improved with the AC-DC combination of tie lines than just using AC tie line in the system. The simulation shows that the feedback controller is quite robust for wide range of frequency variation and gives effective performance and better results.

2.9 K.P. Singh Parmar, S. Majhi, D.P. Kothari, "LFC of an interconnected power system with thyristor controlled phase shifter in the Tie Line", International journal of computer applications (0975 – 8887), Volume 41– No.9, March 2012.

An interconnected two area power system considering Hydro, Thermal with Reheat turbines and gas units in each area is taken. A Thyristor Controlled Phase Shifter (TCPS) is used to stabilize the frequency of area and tie line power so as to provide better Load Frequency Control in the system. It is connected in series with the AC tie line. TCPS controls the phase angle (ϕ) to improve the stability of the system by damp the frequency oscillations. Twenty six state variables are taken as output feedback states. The simulation results shows that the feedback controller with TCPS in the system gives less settling time and small peak overshoot with zero steady state error in the response than the system without using TCPS.

2.10 Surya Prakash, S. K. Sinha, "Load frequency control of three area interconnected hydro-thermal reheat power system using artificial intelligence and PI controllers", International Journal of Engineering, Science and Technology, Vol. 4, No. 1, 2011.

An interconnected three area hydro thermal power system of reheat type is considered for the LFC analysis. Area 1 and 2 are reheat type thermal power plant and area 3 is hydro power plant. The control for frequency is done by using Proportional Integral (PI) controller. Artificial intelligence techniques such as fuzzy logic controller (FLC) and Artificial Neural Network (ANN) is used with the PI controller to provide better result and faster response of the system. Seven triangular membership functions are taken for defining rule base. For neural network log-sigmoid transfer function is taken to train the multilayer network using back propagation algorithm. A Non-linear Auto Regressive Model reference Adoptive Controller (NARMA-L2) type of architecture is used for ANN controller which consist of plant output, reference and control signal. In this, frequency deviation, tie line power change and load change of the area are taken as inputs to neural network controller. The ANN plant model is a three layer perceptron having four inputs and 10 neurons in hidden layer and one output. 300 epochs are trained by 300 training samples. A comparison of PI controller, Fuzzy logic based controller and ANN controller is given in the study which shows that ANN controller with sliding gain proves the better result that fuzzy and PI controllers for LFC.

2.11 Swasti R. Khuntia, Sidhartha Panda "A Novel approach for automatic generation control of a multi-area power system", IEEE CCECE 2011 – 001183.

Three power generation areas of equal size are considered. Area 1 and 2 are Reheat type Thermal Power System and area 3 is Hydro Power system. The Multilayer Layer Perceptron structure model having three layers is used in Artificial Neural Network (ANN) and this is applied in the system. An adaptive Neuro-Fuzzy inference system (ANFIS) controller is used which is advanced adaptive control of ANN and provides faster response than other controllers. The ANFIS controller combines the fast response and adaptability of ANN with advantages of fuzzy controller. The back propagation-through-time algorithm is used. The input signals are ACE and derivative of ACE with respect to time. Output signal to stabilize the system is decided by fuzzy logic having seven membership functions and 49 rules in its rule base. With the use of ANFIS controller, the system has small overshoot and settling time is also less irrespective of magnitude of disturbance. Thus we conclude that the ANFIS controller is superior than conventional optimized integral controller in stabilizing the system.

2.12 S.Ramesh, A.Krishnan, "Fuzzy rule based Load Frequency Control in a parallel AC – DC interconnected power systems through HVDC Link", International journal of computer applications, (0975 – 8887), Volume 1 – No. 4, 2010.

The interconnection of an AC-DC system with HVDC link is studied in this paper. A fuzzy controller is designed to control the oscillations in the interconnected system. The frequency of the system goes to oscillatory when a considerable disturbance is occurs in the system. A typical integral controller is not enough to give the optimized results in this situation. To overcome this issues, a new fuzzy controller is designed and proposed to the system in this paper. The analysis is done on two are non- reheat thermal systems and simulated using a MATLAB. Using this system, a more economical, stable and quality power is provided to the customers. The controller also plays a good role in Load Frequency Control (LFC). The proposed controller in this paper can also integrated with a typical integral controller for more optimized results.

2.13 A. H. Mazinan, M. F. Kazemi, “An Efficient solution to Load-Frequency Control using Fuzzy-Based predictive scheme in a Two-area interconnected power system”, Published by IEEE, 2010.

A new fuzzy based predictive scheme is discussed for the Load Frequency Controller in a two area interconnected power system. The power system is modelled in MATLAB environment and analysis is done using SIMULINK software. The results are compared with the conventional integral controller output. The LFC of the two area system is optimized using the new proposed fuzzy controller. The fuzzy rules are made on the analysis of the disturbance that occurs on the system and results are compared with traditional control. The new approach reduces the steady state errors of the system and results in a better stability of the power system. The results verify the controller output is in the proposed range of stability and comparatively better with conventional controller output.

2.14 K.Sabahi, M.A.Nekoui, M.Teshnehlab, M.Aliyari and M.Mansouri, “Load Frequency Control in interconnected power system using modified dynamicneural networks”, Mediterranean Conference on control and automation, Athens-Greece. 2007.

Amodified dynamic neural network controller is discussed in this paper in order to improve the load frequency controller. Various neural layers inside the controllers are discussed here. There are hidden layers and conventional layers in the network. The paper mentions the importance of controlling load frequency in a power system and the problems caused by improper handling of oscillating frequencies of power. Along with classical adaptive controllers, a fuzzy system is also being analyzed here for a better performance of the neural networks. The block diagram of uncontrolled two area interconnected system is modeled and the designed controller is applied on this model. A modified dynamic neural network is designed in this paper for the better result from all the analyzed parts. A detailed comparison of conventional neural networks is also discussed in this paper.

2.15 N. Yadaiah, P. Sai Srinivas, “Intelligent decentralized controllers for Multi area Power Systems”, Published by IEEE, 2006.

The design of decentralized controllers is discussed in this paper, based on conventional approach andintelligent approach using fuzzy concept. The stability analysis on linear timeinvariant continuous time system is also done on the new designed controller. In this paper a new fuzzy scheme for the load frequency control for a two area interconnected system is designed. The input used here are the change in frequency and the generator output and it generates a control signal as per the rule set. The inputs are analyzed and the decision is taken as per the rules. The output of the new system is compared with the conventional integral controller output. The whole power system is mathematically modeled for the analysis and the control equation is formulated from that. A new Linear Quadratic optimal regulator is also designed in this paper. This is a main tool in the new control theory. The frequency response of the system is also improved by this new scheme of control.

2.16 C.-F. Juang and C.-F. Lu., "Load-frequency control by hybrid evolutionary fuzzy PI controller", Published by IEEE, 2006.

A new combination of fuzzy- PI controller is proposed by the paper. The controller is used to control the load frequency and make the system more stabilized. Here the fuzzy controller is the main controller used to set even the proportional and integral parameters of the PI controller. The studies on the system are used to formulate the controller action

parameters . For a better and improved result, a new strategy called Fuzzy –Proportional - Integral controller by Hybridising a Genetic Algorithm and Particle-Swarm Optimisation, called FPI–HGAPSO, is proposed. The typical genetic algorithms are over written using the particle swarm optimization. The performance of a two area system with this new scheme of controlling strategy is considered and compared it with the conventional controlling strategy like proportional integral strategy. A linear model is considered here for the analysis. The system is modelled in MATLAB, considering the system to be controlled. The change in the load results in the system frequency and cause serious issues in the consumption side. The change in error in the area is the fuzzy input here. For forming the rule set, genetic fuzzy systems were also considered and the decisions were taken by this rule set. The combination of the PI and fuzzy controller is designed using hybrid of a genetic algorithm and particle swarm optimization.

2.17 R.Vijaya Santhi, K.R.Sudha, S. Prameela Devi, "Robust Load Frequency Control of Multi-Area Interconnected system Including SMES units Using Type-2 Fuzzy Controller", Published by IEEE.

The load frequency control of three area system is studied and a new fuzzy controller is proposed to the system. These are to be controlled include superconducting Magnetic Energy Storage (SMES). A type II fuzzy approach is executed here. A generation rate constraint is considered to make the fuzzy rules over here. The analysis of result shows that this method is good in making the system insensitive to the large changes in the load frequency change. The plant parameters also maintained in a steady value even in presence of non-linearity. The robustness of the system is improved by the type-2 fuzzy controller and the plant shows a better stability using this new controlling strategy. The uncertainties of the system is also considered as the parameter for the controller action. This new fuzzy type 2 controller works on a different technique that consider the value of membership is function but not a point value. The advantage of this strategy is the degree of freedom for handling the uncertainties in the system. The results are compared with the PI controller output and found that the new controller gives a high robust output and improved performance for the system.

[18]. Baqeev Tyagi and S.C.Srivastava, "A Fuzzy Logic based Load Frequency Controller in a competitive electricity environment", Published by IEEE, 2003

In this paper, the design of a fuzzy controller is explained on the basis of Automatic Gain Controller (AGC). An integral model for the general purpose of multi area control is also discussed here. Here, for AGC, a general-purpose fuzzy logic based controller has been developed. A multi area system is considered for the above mentioned. The proposed fuzzy logic based plan has been used to tune the integral controller. The advancement of the fuzzy logic based controller is that it doesn't oblige broad and thorough model for optimal tuning. To build up the standard base, Area Control Error (ACE) and rate of progress of ACE have been taken as input to the controller. The created fuzzy logic construct controller has been tried in light of a practical Indian power system network having 75- bus UPSEB system. A deregulated power market situation has been expected in the 75- bus system, which has been isolated into four control territories. MATLAB/SIMULINK software are used for the simulation and testing of the system.

CHAPTER 3

SCOPE OF STUDY

Load Frequency control is a very important aspect of power system stability in a multi area system of an isolated system. The system stability depends on voltage and frequency. These two quantities must remain under prescribed values for good power quality and reliability of system. As we know that Load Frequency Control deals with the regulation of the system frequency, the controllers must be designed in such a way that the system can attain steady state in the minimum time possible so that various electrical equipment connected in the system remain safe.

For this purpose, I have designed Load Frequency Controllers for an isolated area and multi area power system. These controllers are based on integral control action and fuzzy logic based control. These controllers are designed such that the system is able to attain its steady state as soon as possible without damaging the system.

Further, as the extension of this research, the system may be employed with other artificial intelligence techniques such as Artificial Neural Network(ANN), Genetic Algorithm(GA), Combined Fuzzy and Neural Network, Wavelet based System. The controllers based on these techniques or combination of these techniques can be applied in the interconnected power system for the enhancement of safety and reliability of the system.

The optimization techniques such as Particle Swarm Optimization (PSO) can also be used in solving the frequency control problems and getting the optimized solution. Controllers can be designed on these and employed in the system. The multi area interconnected system can be employed with HVDC links in parallel with the system. This system also enhances the system stability to much extent. The controllers based on artificial intelligence techniques can also be designed and employed for these systems.

As I have designed the multiple area power system using conventional integral controller and fuzzy logic and a combination of integral and fuzzy controller for the load frequency control, we can also use these controllers for the purpose of Grid Stability, Automatic Generation Control etc. using various artificial intelligence techniques and controllers.These controllers or the controller combination can be used with the optimization techniques such as Particle Swarm Optimization etc. to further enhance the system performance and a robust system. This multi area system can also be used with a DC system that is a DC tie line in parallel with AC tie line for giving the better performance.

CHAPTER 4

OBJECTIVE

In this dissertation work, I have study and design the load frequency control of an isolated area and multi area system using conventional integral controller, fuzzy logic and combination of these two controllers. A comparison between these controller systems is taken into consideration to provide the better response of the power system for Load Frequency Control. The power system under consideration is modeled and tested in MATLAB/Simulink and the response of the system is noted. After the application of the integral controller and the fuzzy logic controller in the system, we will be requiring the faster response of the system with less percent overshoot, less delay time, less settling time etc. The aim of these controllers is to restore the frequency to its nominal value in the shortest time possible whenever there is change in demand. It should be coupled with minimum frequency transients and zero- steady state error.

CHAPTER 5

RESEARCHMETHODOLOGY

For the study of Load Frequency Control in a multi area system, the controllers used are based on conventional integral control action i.e. integral controller and Fuzzy Logic Based controller to improve the performance of the system. These methods are given as-

5.1 INTEGRAL CONTROLLER

Integral control is used when the signal driving the controlled system is derived by integrating the error in the system. It is the most generally used controller for the thermal and hydro power station monitoring. The transfer function of the controller is K_i/s in terms of transfer functions and Laplace transforms. The main advantage of using an integral controller is that integral control will produce zero SSE (Steady State Error) in the system. The disadvantage of using an integral controller is that the integral control might produce a closed loop system with significantly slower response times.

The integral controller is used to gain the stable state condition rapidly by fast transient reaction of controller when some disturbance occurred in the system. In this, integral of an error signal is taken to produce zero steady state error. It is given as

$$u(t) = k_i \int e\,(t).dt \qquad \text{... (19)}$$

Where K_i = Integral gain.

When there is some error in the system, the integral controller increases the control action so that the output of generator is controlled to fulfill the demand of load by system. As the error is eliminated, the integral action is continued to bring the system in steady state condition. If the value of K_i gain is kept high, overshoot will increase sharply because it is a function of gain. This value is highly undesirable. If the value of K_i is kept low, the overshoot reduces but rise time of system in increased. Thu the system must be designed with the optimized values of $K_{i.}$

5.1.1 DESIGN OF INTEGRAL CONTROLLER

The integral controller used for the purpose of Load Frequency Control is comprised of a frequency sensor and an integrator. The work of frequency sensor is to sense the change in frequency or frequency error (Δf) of the system due to load change or fault condition. This frequency error signal is then fed to the integrator. This frequency error which is given as the input to integrator is known as "Area Control Error" (ACE). Thus we can say that ACE is the frequency change of an area which is given to integral control action loop to bring the system in steady state and keep frequency error as zero i.e. ACE = Δf.

Thus the integrator work as

$$\Delta P_c = -k_i \int \Delta f \,.\, dt \qquad \ldots (20)$$

$$\Delta P_c = -k_i \int (ACE) \,.\, dt \qquad \ldots (21)$$

Where ΔP_c = Power command signal

K_i = integral gain constant.

The signal ΔP_c is given as input to speed changer and makes it move according to the stability requirement. The integral gain constant controls the rate of integration and so the speed response of the control loop of the system. The block diagram for a system having integrator and frequency sensor is shown in figure 11 as

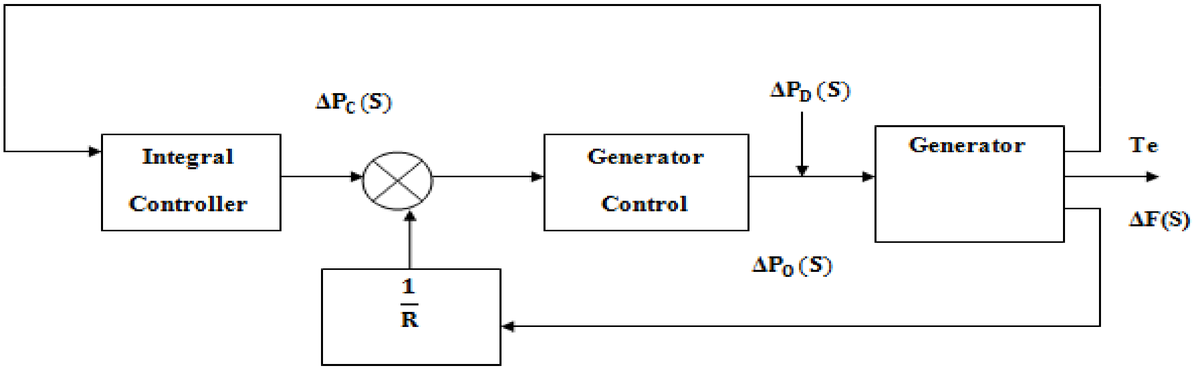


Fig 11Block Diagram of Integral Controller

In this figure,

R = speed regulation feedback parameter

$\Delta P_G(s)$ = incremental changes in generation

$\Delta P_D(s)$ = incremental changes in load

$\Delta F(s)$ = incremental changes in frequency

The integral controller is given with negative feedback which gives a negative or decrease command for a positive frequency error (ΔF). The integral control makes zero steady state frequency error ($\Delta f_{\text{steady state}} = 0$) for step load change. When there is error in system, the output of integrator increases which cause the speed changer to move. The integrator and the speed changer come to a constant value only after the frequency error becomes zero. Thus the system attains stability by integral control action.

5.2 FUZZY LOGIC

Artificial Intelligence (AI) based techniques such as Fuzzy Logic are very useful in designing controllers for non-linear and complex systems. Fuzzy Logic is a problem solving technique or control methodology for solving problems related to any field. It converts the human knowledge into mathematical formula. Fuzzy logic deals with the approximate reasoning than the exact value, it is multi valued logic. Fuzzy logic is used in the systems where the inputs are either imprecise or vague. Fuzzy logic describes and solves the fuzziness based on fuzzy set. As the large power systems are full of uncertainties, fuzzy logic has proved to be a very useful tool of mathematical approach for solving power system problems. The fuzzy controller is based on the fuzzy logic which is similar to human thinking and decision making based on approximate information. Thus fuzzy logic is used in all the fields these days for enhancing the performance of the process. One of this is Load Frequency Control. The fuzzy logic based controller is used in the system for the following reasons-

- Simple control design for complicated models
- Simple implementation and better result
- More robust than conventional controller algorithms

5.2.1 DESIGN OF FUZZY LOGIC CONTROLLER

The fuzzy logic controller works in a same way as human by adjusting the input signal to system based on the changes in output parameters. The fundamental fuzzy logic control approach consist of four elements-

1. Fuzzification
2. Interference system
3. Rule base
4. Defuzzification

The block diagram is given in figure 12 as-

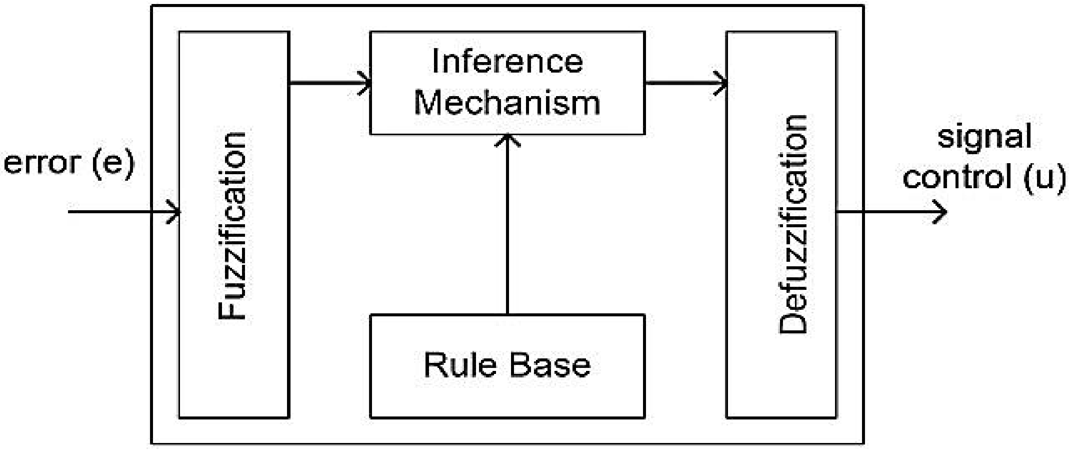


Fig 12Block Diagram of Fuzzy Logic

Fuzzification is the process of changing crisp value to a fuzzy value. This fuzzy value carriesuncertainty in it. This value is represented by membership functions. Fuzzy control loop consist of fuzzy reasoning and rule base to give the decisions. Knowledge Base defines the parameters and variables of the fuzzy set. Defuzzification is the process of changing the fuzzy values to a crisp value. It is basically interpreting fuzzy set membership degrees into decision or real value. There are many methods of defuzzification such as COG (center of gravity), COA (center of area), BOA (bisector of area), FCD (fuzzy clustering defuzzification), FM (fuzzy mean), LOM (last of maxima) etc.

The Fuzzy logic based Load frequency controller is designed with two inputs. One input is Area Control Error and second input is differential of ACE. The output signal is the change of the control signal. The fuzzy logic controller is shown in figure 13 as

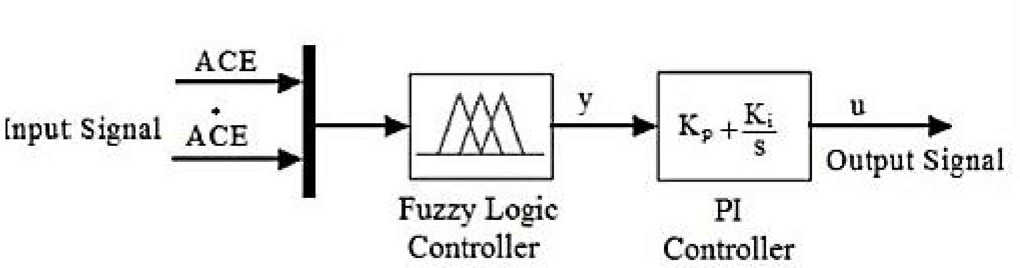
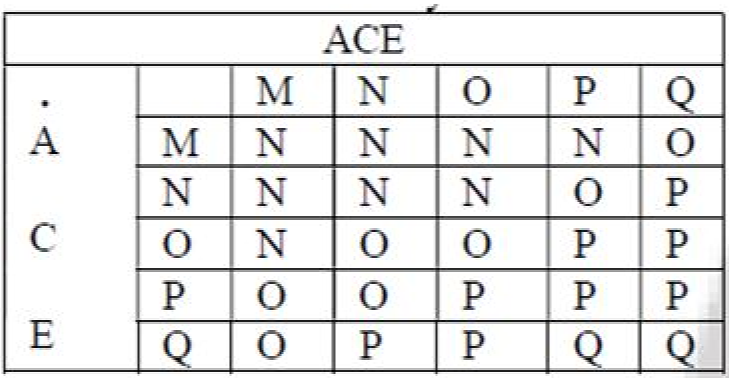


Fig 13 Fuzzy Logic Controller

For designing the controller, Mamdani type fuzzy interference engine has selected and centroid method is used for defuzzification. The membership function gives the range upto which an input belongs to a fuzzy set. We have use triangular membership functions are used for both input and output of the fuzzy logic controller. Five membership functions are being used with the set of 25 rule base to define the control problem of LFC. These are given in table 1.

TABLE 1: FUZZY RULES



	ACE					
		M	N	O	P	Q
$\dot{A}$	M	N	N	N	N	O
	N	N	N	N	O	P
C	O	N	O	O	P	P
	P	O	O	P	P	P
E	Q	O	P	P	Q	Q

Where NB : Negative Big ,

NS : Negative Small

Z : Zero

PS : Positive Small

PB : Positive Big

The membership functions for the controller are shown in figure 14 as

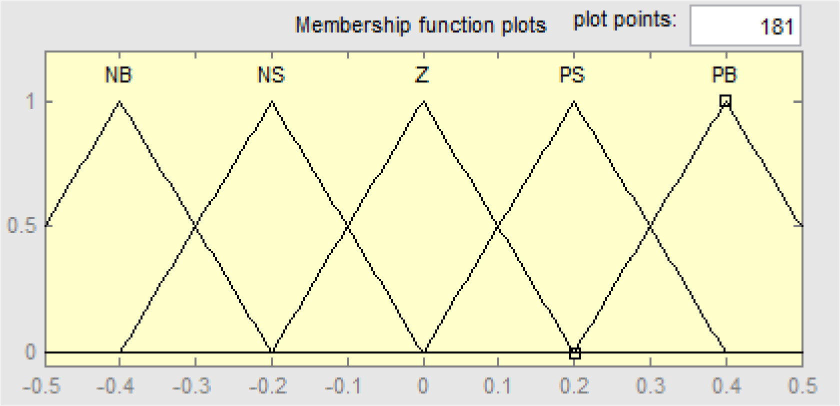


Fig 14 Membership Function Diagram of Fuzzy Controller

These membership functions are used to describe the linguistic variables. If-Then statement is used for designing the control rules. This system is then implemented in the actual system to enhance the performance of the system.

CHAPTER 6

RESULTS AND DISUSSION

The Load Frequency Control design for an isolated and multi area system is done. The basic system consists of a speed governor system, turbine and generating unit. The transfer functions of these units are connected accordingly. The controllers that are used for the LFC are conventional integral controller and the fuzzy logic based controller.

6.1EXPERIMENTAL WORK

First I have designed a single area network having a speed governor system, turbine and generator

This system is connected to power system and is modeled in MATLAB as shown in figure 15 as

.

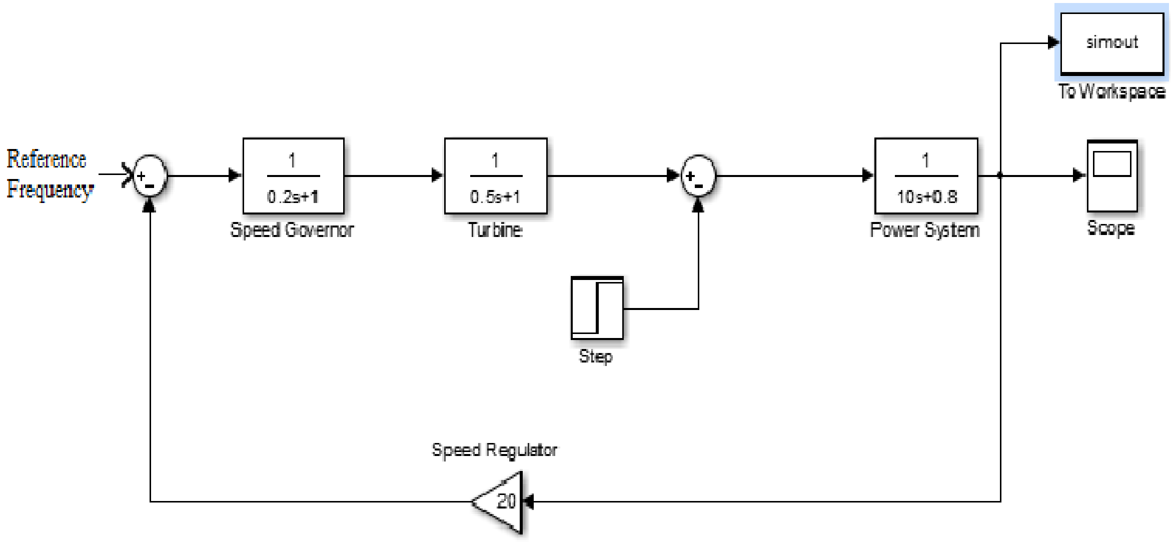


Fig15 Model of an Isolated System in MATLAB.

. The system parameters of this isolated system are

Turbine Time Constant $\tau_t = 0.5$ sec

Governor Time Constant $\tau_g = 0.2$ sec

Generator Inertia Constant H = 5 sec

Governor Speed Regulation R = 0.05 per unit

D = 0.8

$\Delta P_L = 0.01$

The feedback loop gives the value of speed regulator to the speed governor system. The output response of the system is taken from scope. The system response is observed at a disturbance (step input) of 0.01 from the frequency. Due to this the system frequency changes and this frequency error is given in feedback loop. The output of the system is given as shown in figure 16 as.

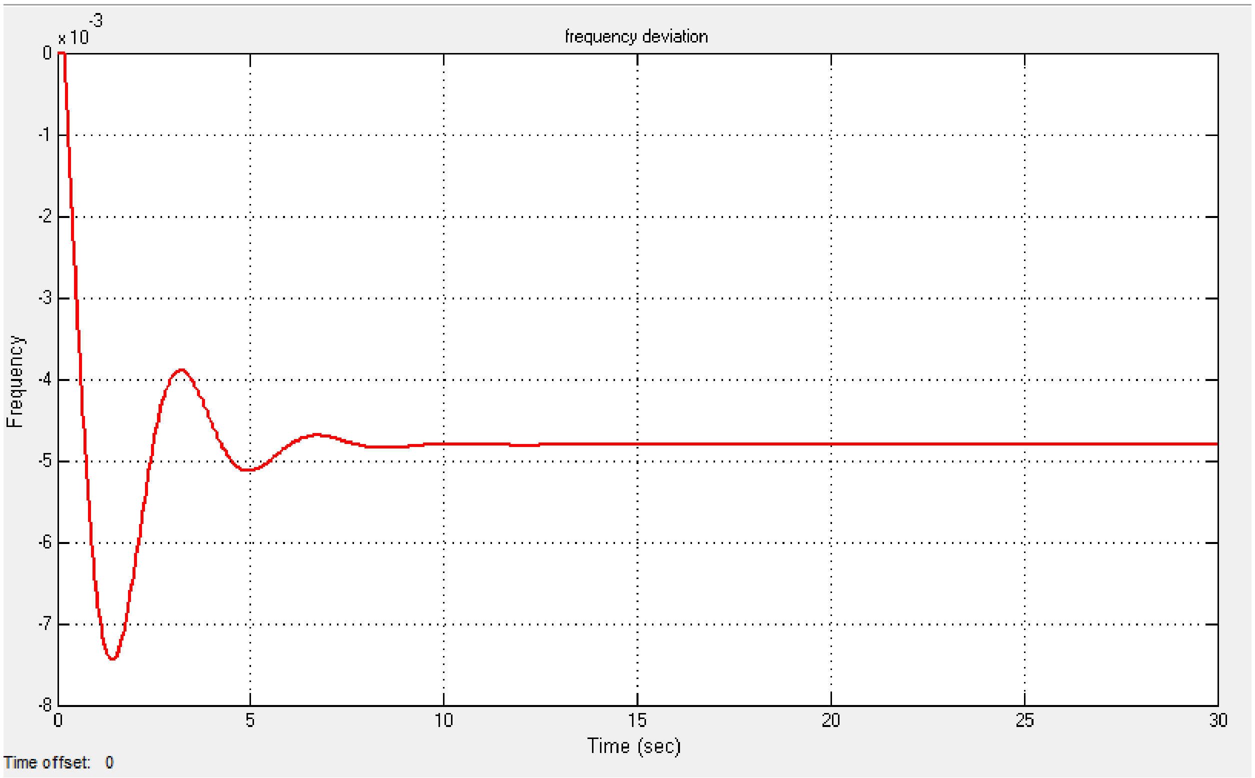


Fig 16: Frequency vs. Time graph for single area system.

From the frequency vs. time graph of single area system, we can see that when a step input is given to the system the system response change. The system stabilizes after approximate 10 sec and at a new frequency of the system varies from nominal frequency by 0.0048 Hz.

Then I have designed an integral controller for this system and applied it on the system. Integral control is used when the signal driving the controlled system is derived by integrating the error in the system. The transfer function of the controller is K_i/s in terms of transfer functions and Laplace transforms. The main thing is that integral control will produce zero SSE (Steady State Error). The disadvantage of an integral controller is that integral control might produce a closed loop system with significantly slower response times.

When we apply the integral controller in this system, the output is proportional to the amount of time the error is present. Integral action eliminates offset. The integral controller produces an output proportional with the summarized deviation between the set point. The integral controller eliminates the steady-state error. The MATLAB model is shown as-

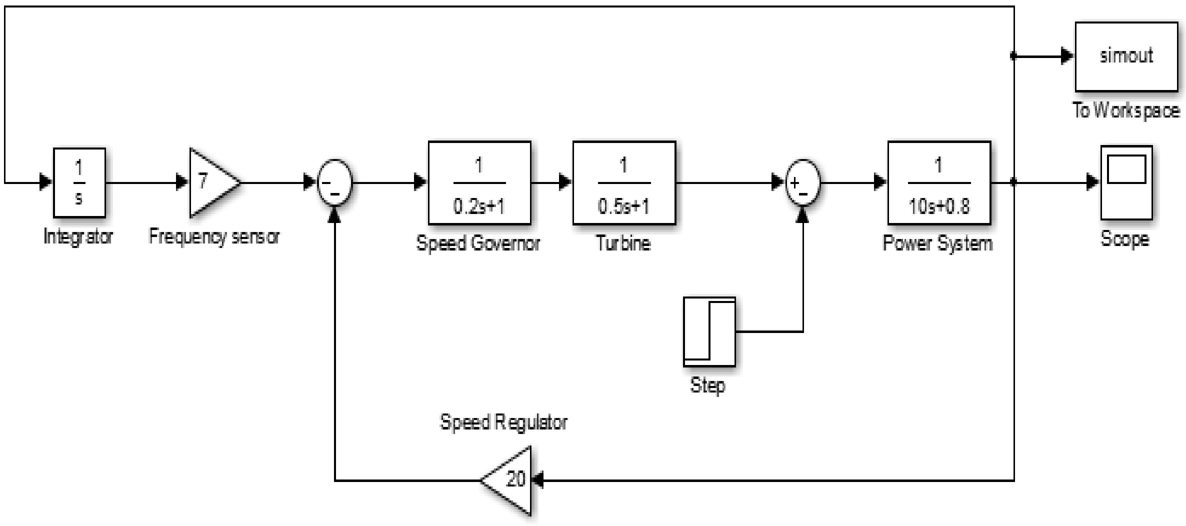


Fig 17 Model of an Isolated System with Integral Controller

In this figure, there are two feedback loops. One is frequency sensor block which provides feedback to the integral controller block. This input is given to the speed governor along with the speed regulator feedback so that the system adjusts its values back to the normal state. The output of the single area system with integral controller is shown in figure 18 as

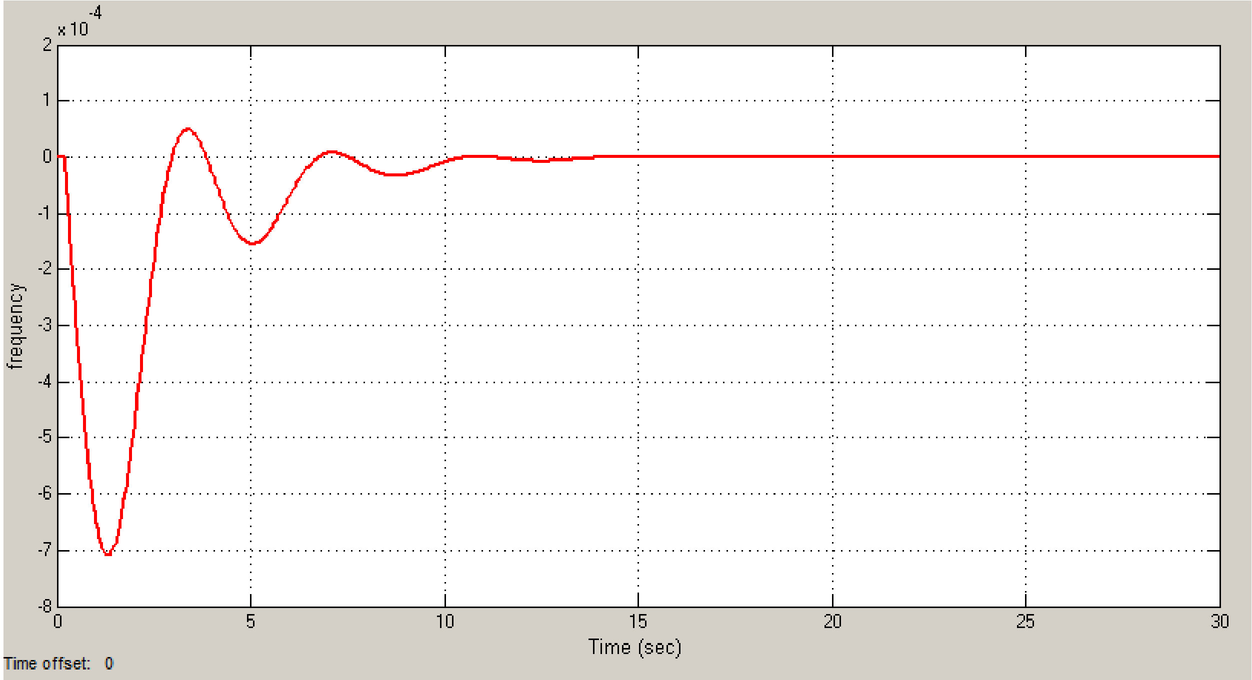


Fig. 18: Frequency vs. Time Graph for An Isolated System with Integral Controller.

We can see that the output response of the system is improved. The system is back to its original position in about 13 seconds from the time of disturbance. The system without the integral controller is not able to come to its normal state. After applying the integral controller the system becomes more stable and hence more reliable.

Then I tried to design a fuzzy logic controller for this single area network. A fuzzy logic based controller is designed using two inputs and five membership functions. Mamdani Fuzzy inference engine and Centroid method is used for defuzzification process and applied to analyze the effect on the system. The rules were taken from the reference paper [6]. The block diagram of single area network with fuzzy logic based controller model in MATLAB is shown in figure 19 as.

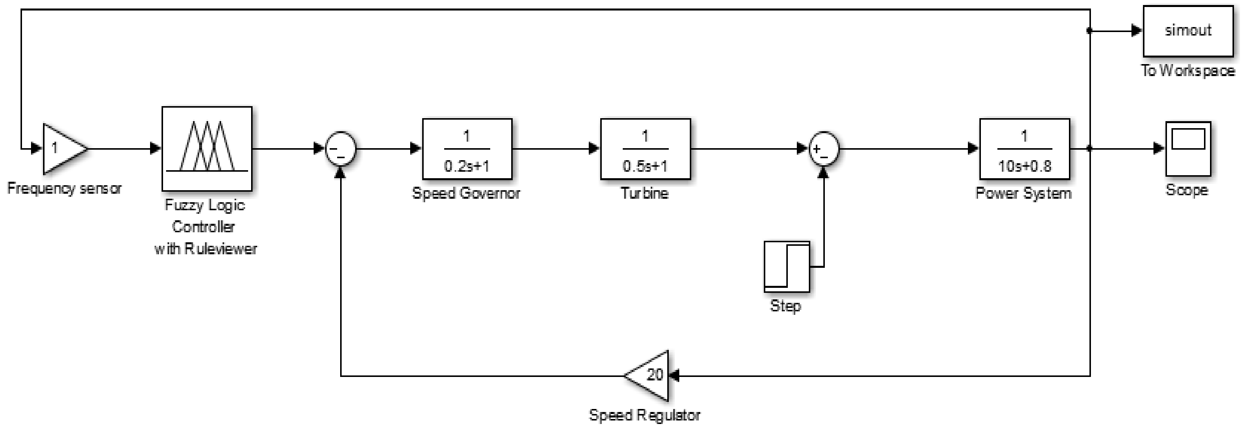


Fig 19 Model of An Isolated System With Fuzzy Controller.

The fuzzy logic based controller is used to makes the system stable in the minimum time possible. The output response of the system is shown in figure 20 as.

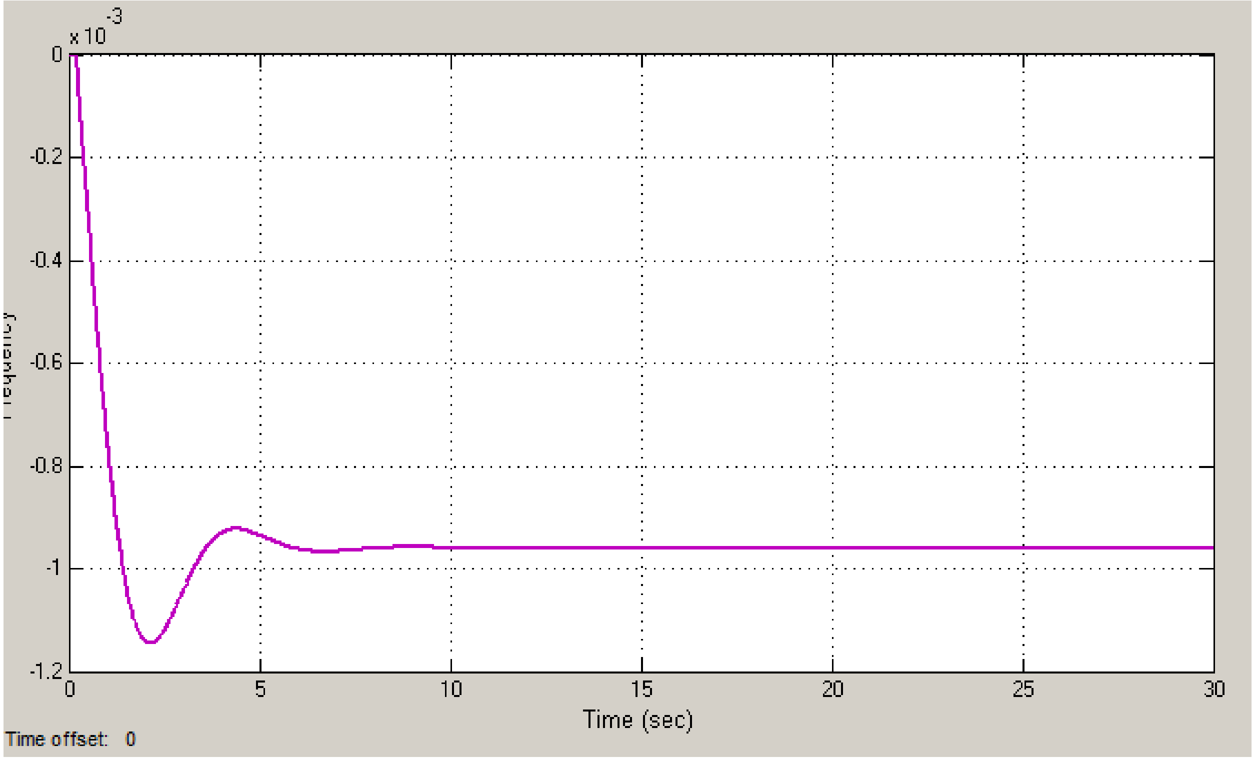


Fig 20 Frequency vs. Time graph for Fuzzy Logic Controller

From the output of the fuzzy logic based controller we can see that the system settling time is reduced to about 7 sec and there is little difference in frequency of 0.095 Hz from nominal frequency.

A combination of Integral controller with Fuzzy Logic based controller is designed to improve the efficiency of the system further. The system is shown in figure 21 as

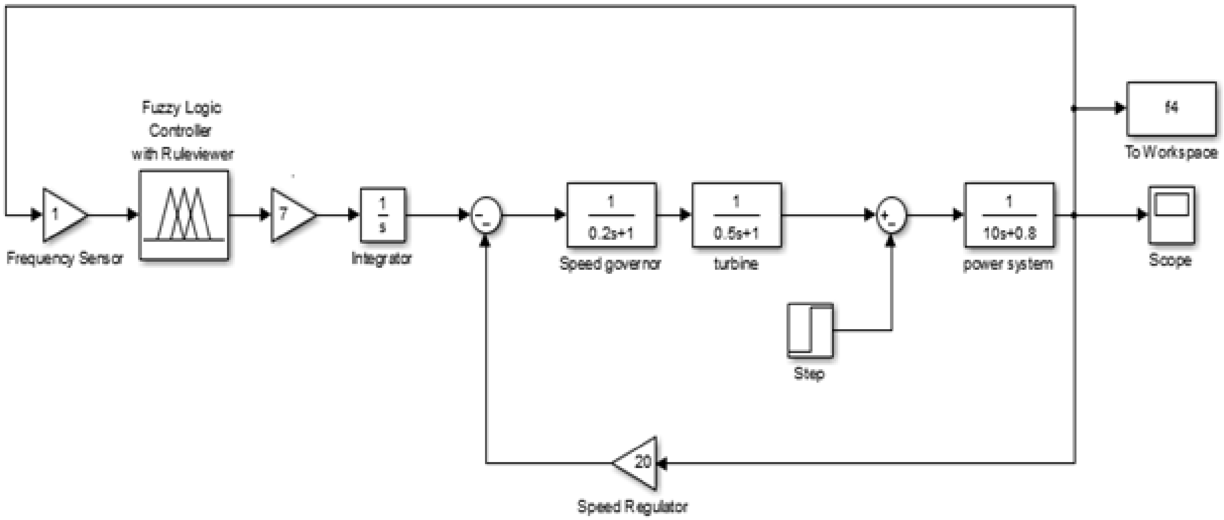


Fig 21Model of an Isolated System with Integral-Fuzzy based controller

Now the multi area power system is comprised of more than one single area system connected with each other via tie-lines. For my work I have consider a four area thermal power system. The block diagram of four area system connected via tie lines is shown in figure 22 is shown as

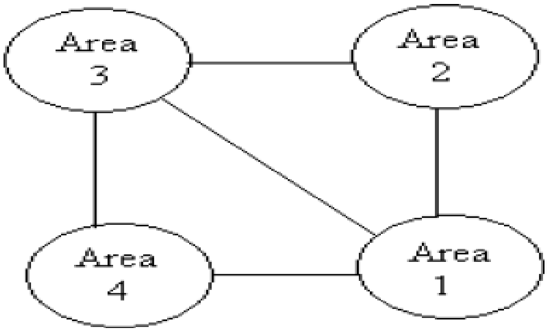


Fig 22 Block Diagram of Four Area Interconnected System

The transfer function model of Thermal four area interconnected system developed in MATLAB is shown in figure 23.

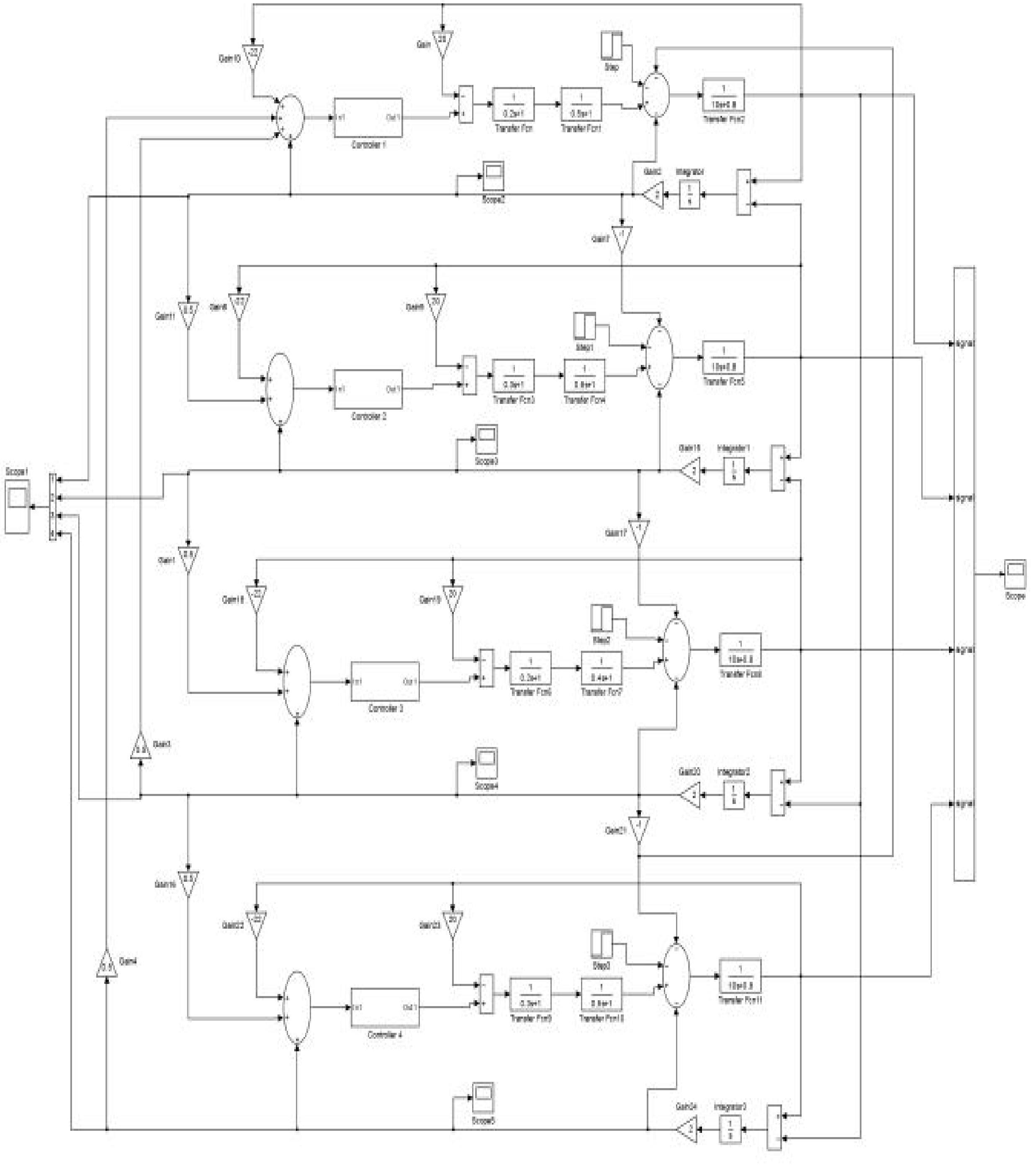


Fig 23 Transfer function model of Thermal four area interconnected system

The steady state error is eliminated in the system with Tie-Line Bias Control. The combination of tie line power error and frequency are used to make ACE linear.

Integral controller and fuzzy controller are used to evaluate the performance of the system shown in figure 23. The output of the two controllers and the system output are compared. We see that the performance of the system is much improved in case of combination of integral with fuzzy logic based controller.

6.2PERFORMANCE EVALUATION

The frequency response of the isolated thermal area for fault of 0.01 in the system, with integral controller, with fuzzy controller and with integral-fuzzy controller combination is shown in figure 24.

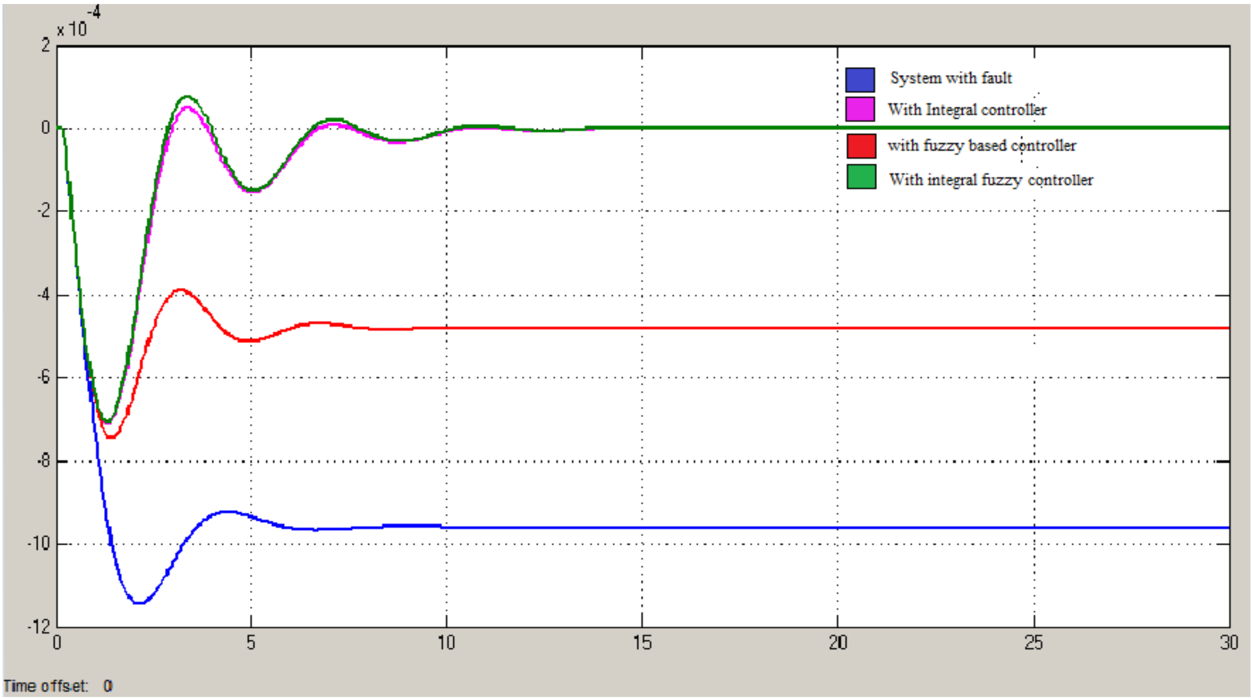


Fig. 24 Frequency Response of isolated system with controllers

From above figure, we see that the system gives best performance with combination of Integral-Fuzzy logic based controller. The settling time is reduces and system have zero steady state error after 12 sec.

In case of four area system, the response of the system with 1% of variation in frequency in each area is shown in figure 25 and the response of tie- line power is shown in fig 26.

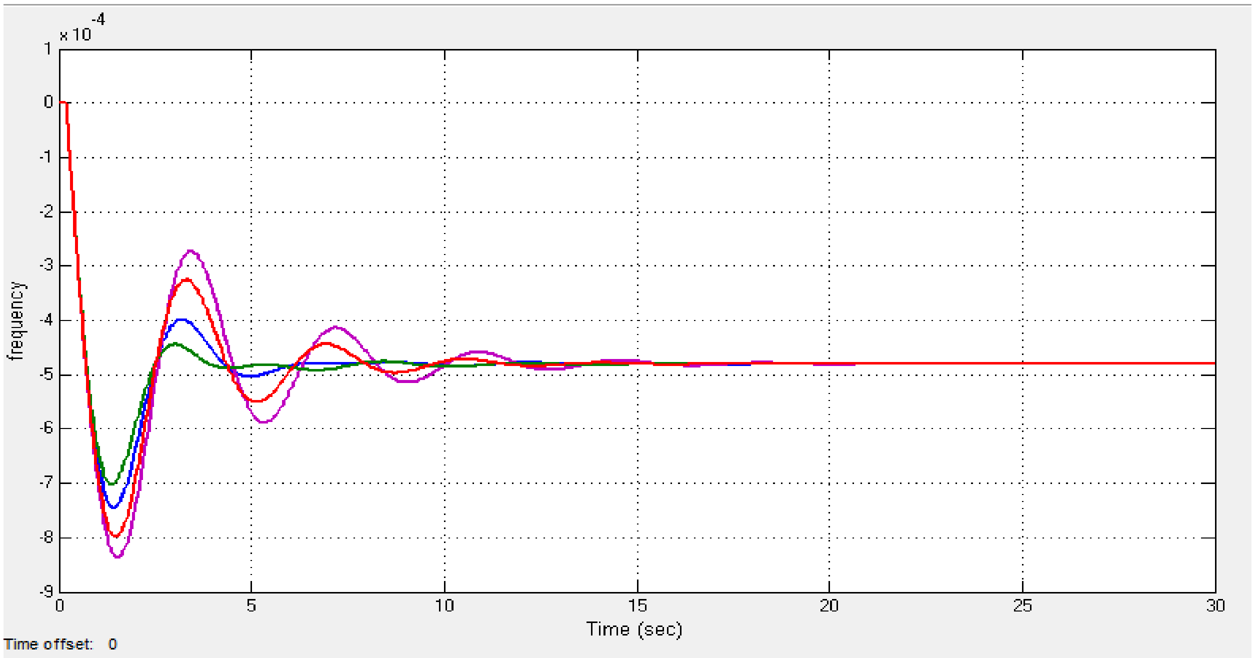


Fig 25 Frequency response of four area system

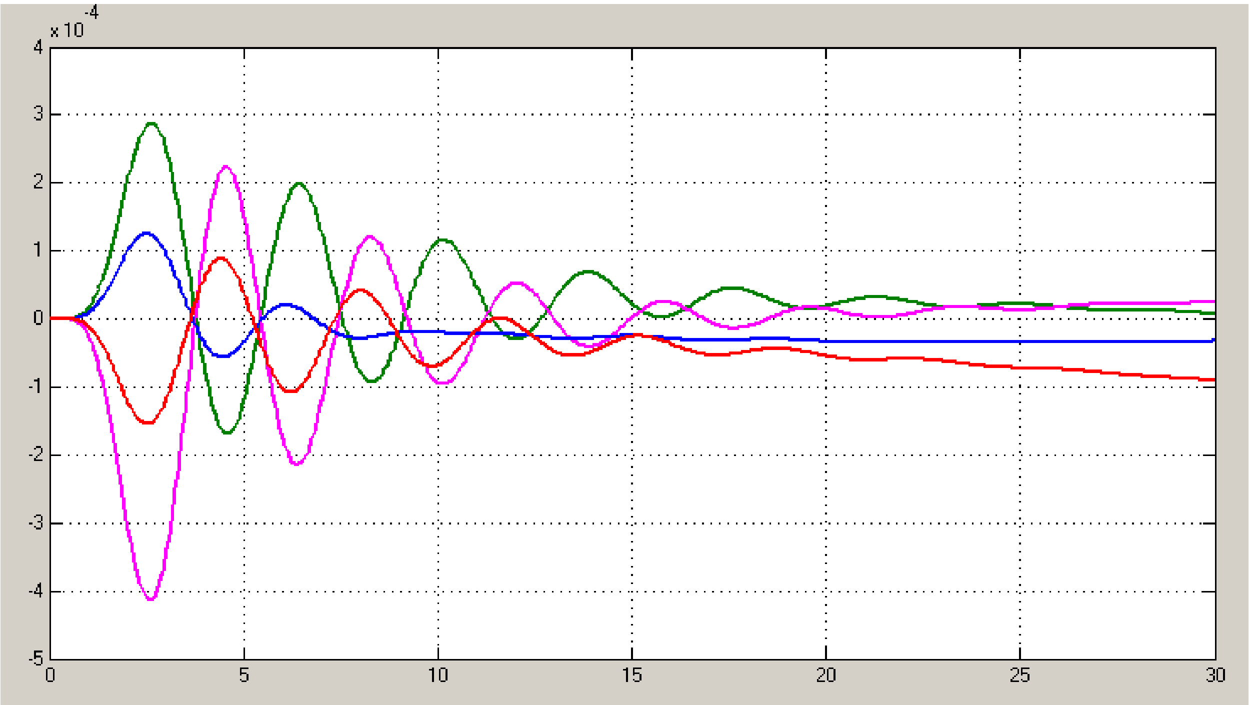


Fig26 Tie line power of four area system

When we apply the integral controller in this system, we get the frequency response of the system as shown in figure 27

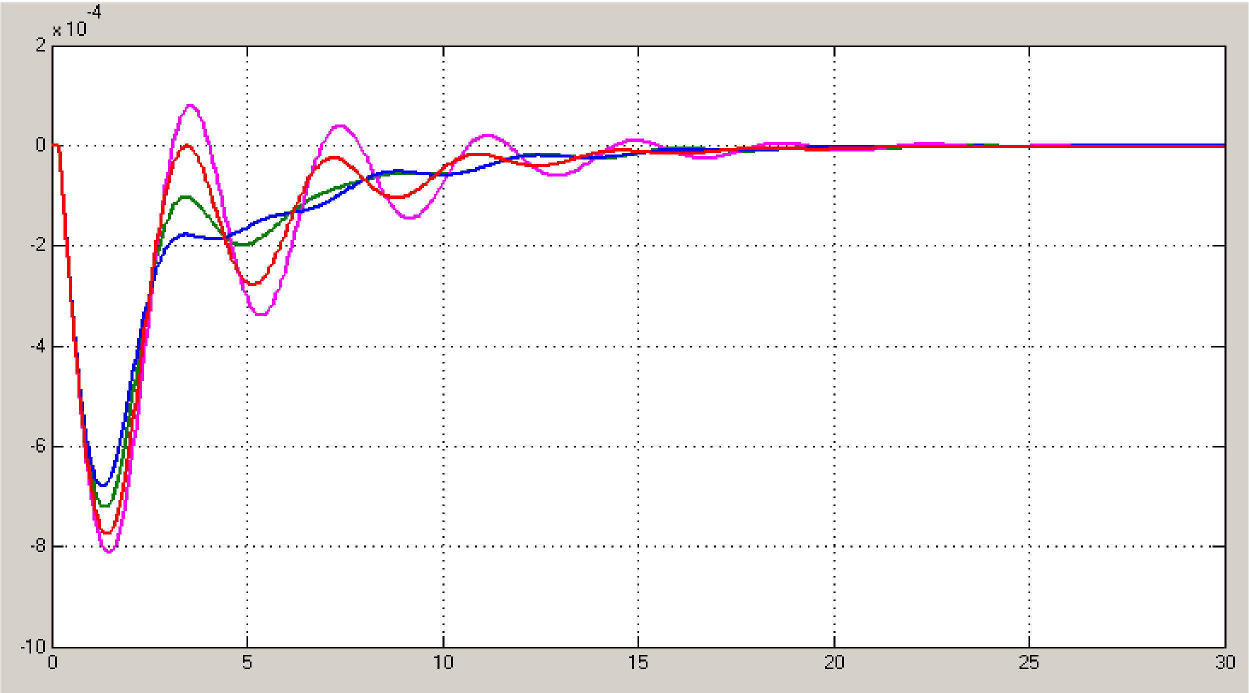


Fig 27 Frequency Response of Four Area System with Integral Controller

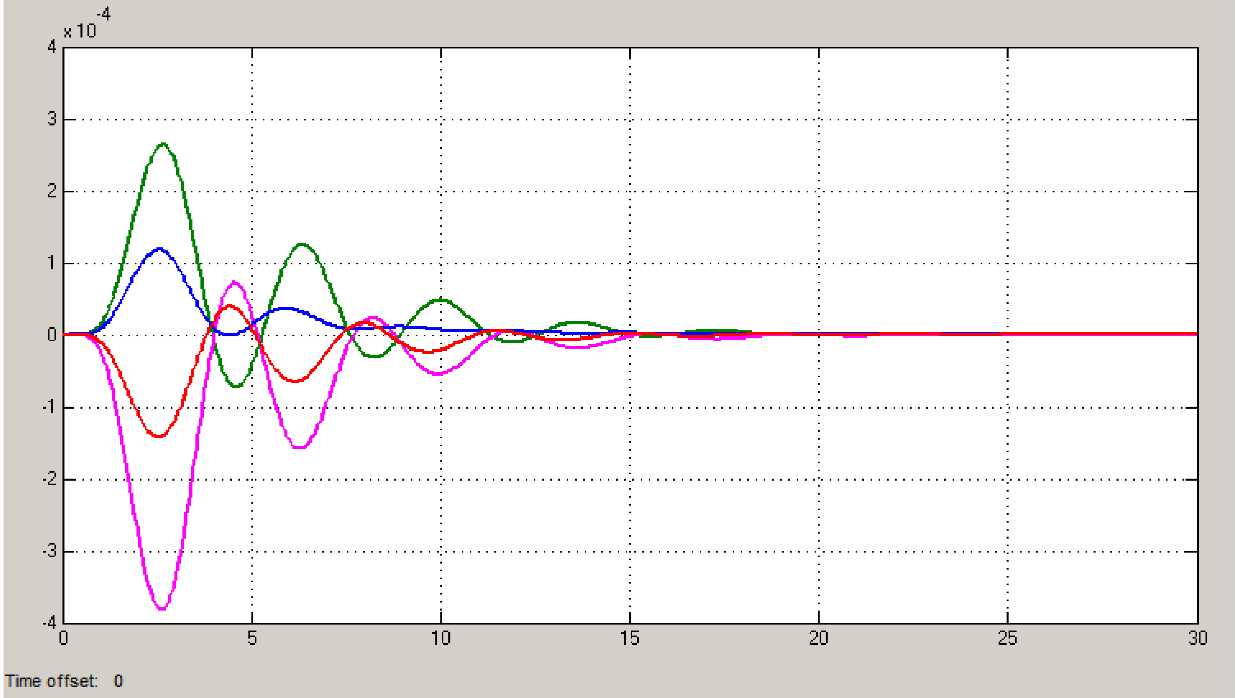


Fig 28 Tie Line Power of Four Are System with Integral Controller

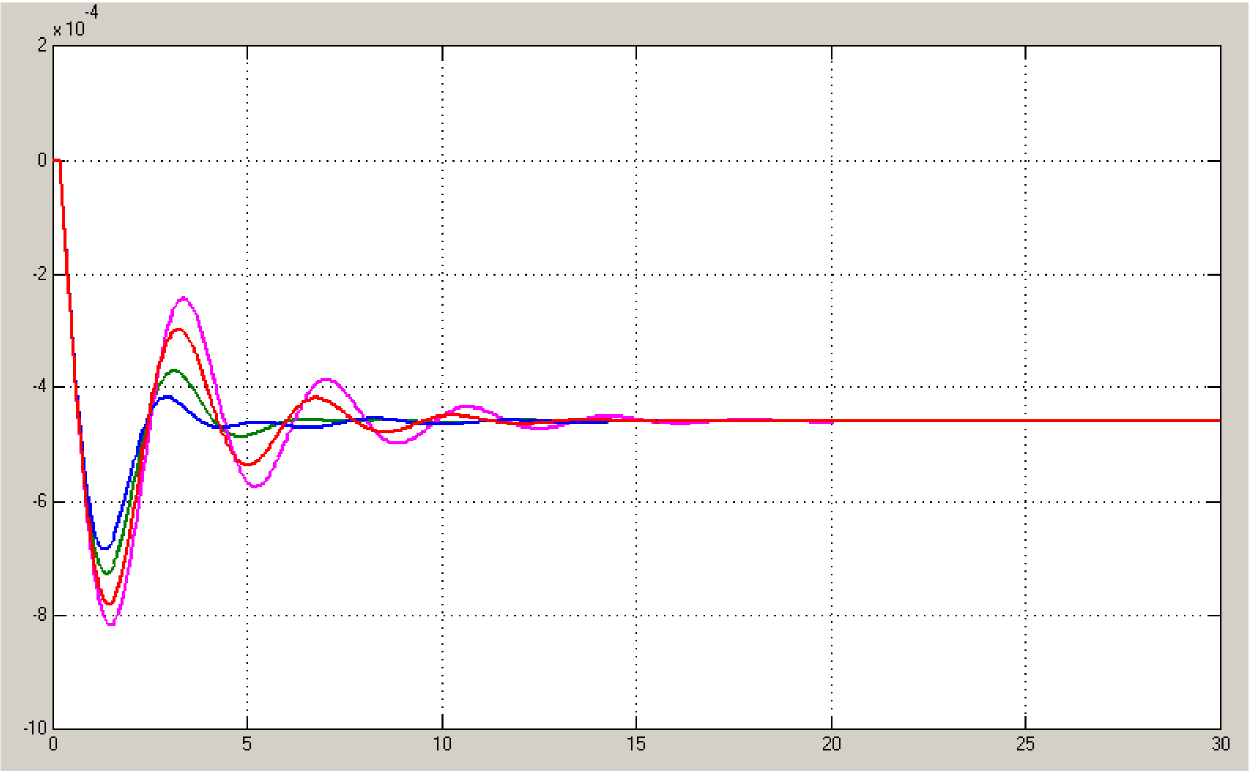


Fig 29 Frequency response of four area system with Fuzzy Controller

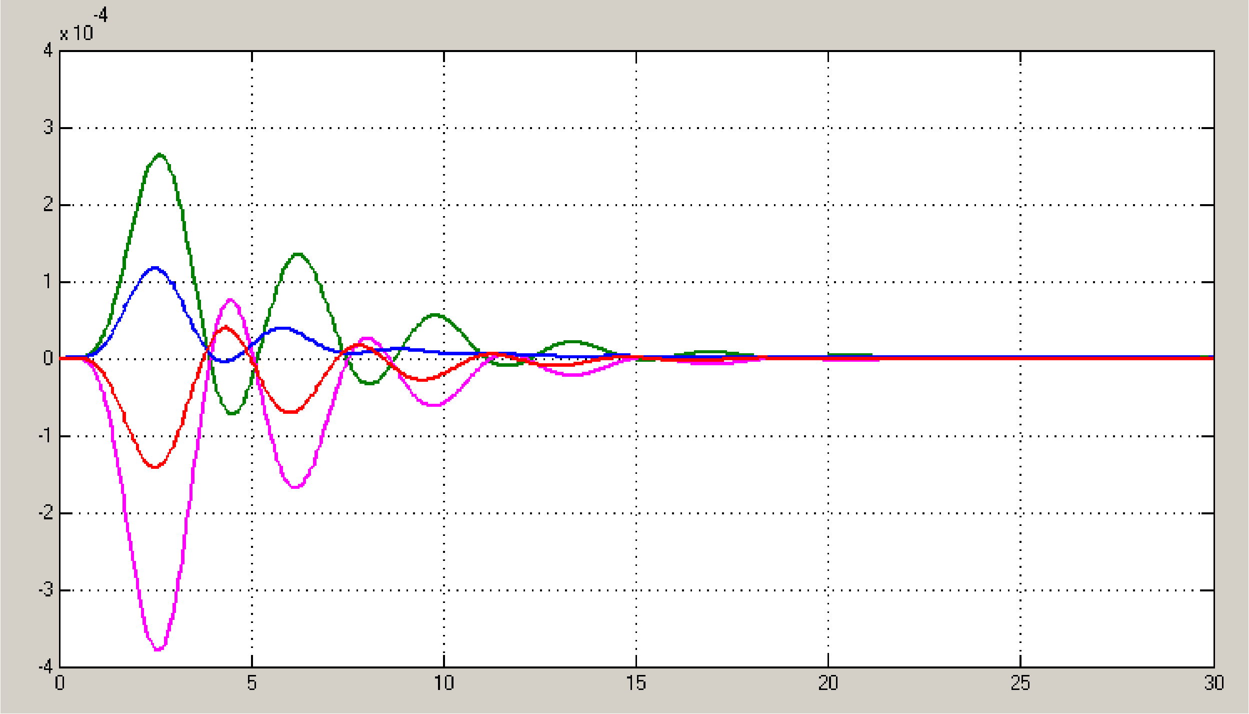


Fig 30 Tie Line Power of Four Area System with Fuzzy Controller

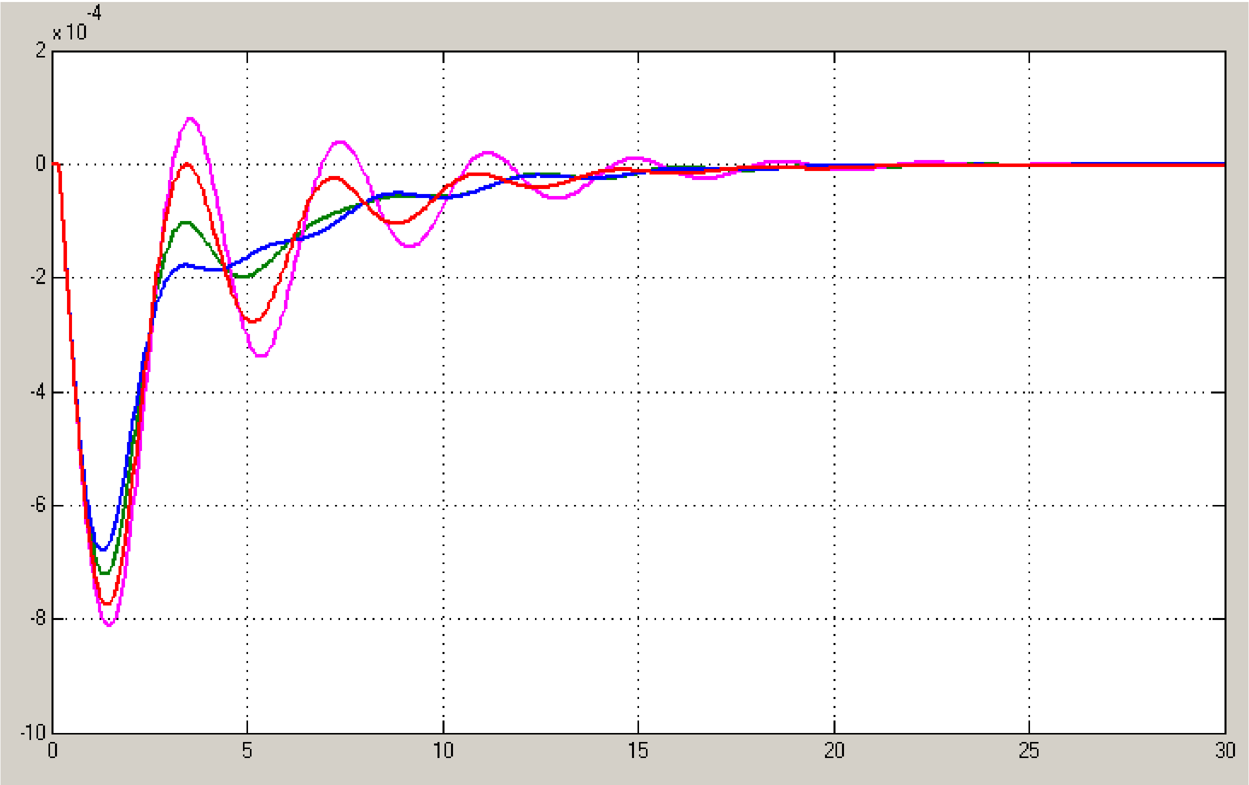


Fig 31 Frequency Response of Integral-Fuzzy Controller

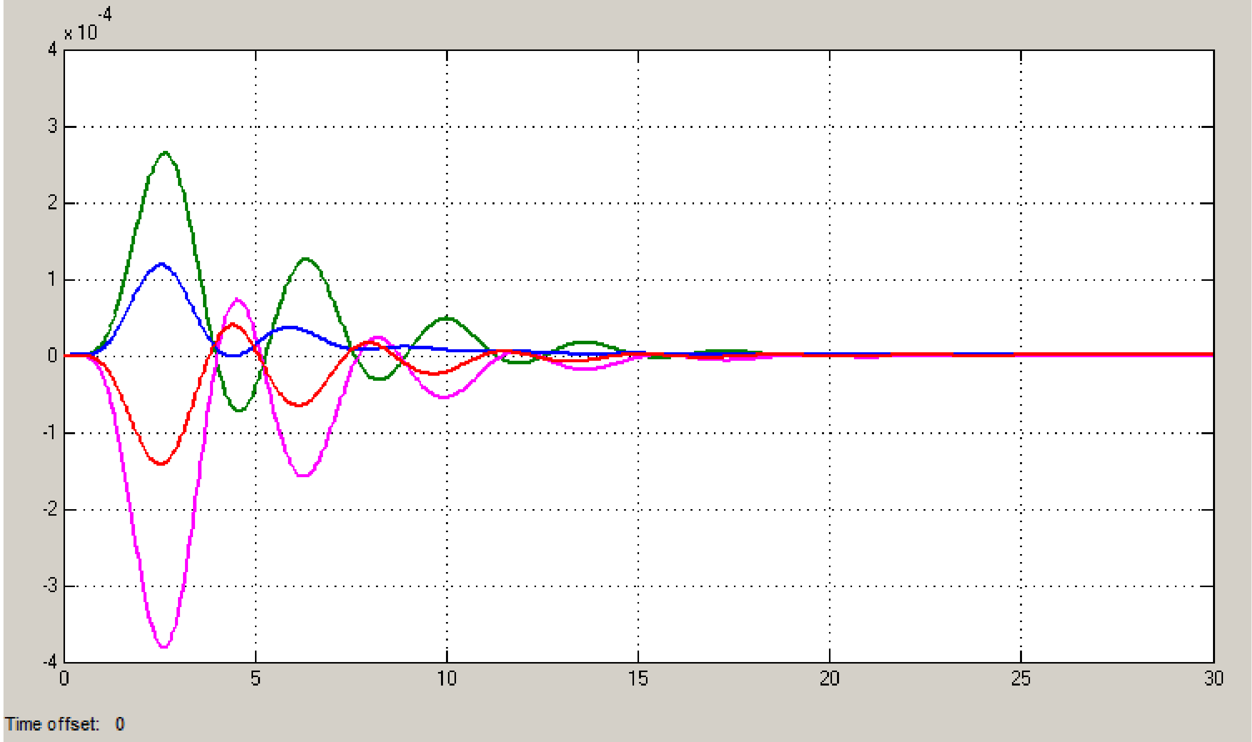


Fig 32 Tie line Power with Integral Fuzzy Controller

The comparative performance of integral controller, fuzzy controller and integral fuzzy controller for an isolated system are shown in Table II.

TABLE II

CONTROLLER	SETTLING TIME (sec)	PEAK OVERSHOOT $(1*10^{-4})$
INTEGRAL	13	0.8
FUZZY	8	-3.9
INTEGRAL-FUZZY	10	1

As we can see that, the response of the system is enhanced in case of integral-fuzzy controller combination than the conventional controller and fuzzy controller alone. In the combined Integral-Fuzzy controller the fuzzy helps in reducing the settling time and Integral controller makes the steady state error to zero.

In case of interconnected four area thermal power system, the frequency response and the tie line response with integral controller are shown in figure 27 and 28. The frequency response and tie line power of system with fuzzy logic based controller is shown in figure 29 and 30. The system response with combination of Integral-Fuzzy based controller is shown in figure 31 and 32. The comparison between these system response show that the system with combination of two controllers have better frequency response with less settling time and zero steady state error.

CHAPTER 7

CONCLUSION

In this dissertation work, I have designed the single area power system and multiple area power system. This area is simulated with the help of MATLAB. Then I have designed integral controller and fuzzy logic based controller for this system. The controllers are designed such that whenever some disturbance in frequency response or fault occurs in the system, then the system would be able to regain its original normal operating condition in least time. This makes the system more stable and reliable.

When the system is simulated with MATLAB, we observed that the system is not able to come to its normal operating condition. This may damage our system during practical operation. When the Integral controller is connected in the system, we observed that the system is able to regain its nominal operating condition with zero steady state error. This improves the safety of the system and makes system more reliable. Now, when the fuzzy logic controller is connected in the system, the system regains its normal operating condition in same duration. The advantage of using fuzzy logic controller is that it can adjust itself with the system operating conditions. This gives more flexibility in designing the system. With using fuzzy logic based controller, the system stabilizes with less settling time but there is a little deviation from the nominal frequency and with the application of integral with fuzzy controller, the system stabilizes in less settling time with zero steady state error. Hence the system response is improved and the objective of Load Frequency Control for single area and multi-area system has been achieved.

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APPENDIX

ABBREVIATIONS

LFC : Load Frequency Control

AGC : Automatic Generation Control

ACE : Area Control Error

HVDC : High Voltage Direct Current

GA : Genetic Algorithm

BFOA : Bacteria Foraging Optimization Algorithm

PI : Proportional Integral

FLC : Fuzzy Logic Controller

ACE : Area Control Error

ANN : Artificial Neural Network

MATLAB : MATrix LABoratory

NB : Negative Big

NM : Negative Medium

NS : Negative Small

ZO : Zero

PS : Positive Small

PM : Positive Medium

PB : Positive Big