CHAPTER-1

INTRODUCTION

1.1 INTRODUCTION

Electrical power is generated at generating stations, which are usually at remote locations and far away from the load centers. Power transmission lines are the link for transmitting electrical power from generating station to the load centre. During the transmission of power the active power and the reactive power balance between generation and load must be maintained. These two balances correspond to two equilibrium points: frequency and voltage. When either of the two balances is broken and reset at a new level, the equilibrium points will float. A good quality of the electric power system requires both the frequency and voltage to remain at standard values during operation. However, the users of the electric power change the loads randomly and momentarily. It will be impossible to maintain the balances of both the active and reactive powers without any form of control. As a result of the imbalance, the frequency and voltage levels will be varying with the change of the loads. Thus a control system is essential to cancel the effects of the random load changes and to keep the frequency and voltage at the standard value.

Although the active power and reactive power have combined effects on the frequency and voltage, the control problem of the frequency and voltage can be decoupled. The frequency is highly 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. One is about the active power and frequency control while the other is about the reactive power and voltage control. In an interconnected system with two or more independently controlled areas, in addition to control the frequency, the generation within each area has to be controlled so as to maintain scheduled power interchange. The control of generation and frequency is commonly referred to as load frequency control (LFC).

1.2 LOAD FREQUENCY CONTROL

Electric energy is required to be supplied to the consumers within permissible limits of voltage and frequency around the rated value. As the demand changes, the system voltage and frequency deviates from the initial value, which causes a change in the state of the system. Also, in any interconnected system, deviation of the state of the system may disturb the state of economic operation and may even cause the overloading of the tie lines. Hence, Load frequency control is an integral component of the power system. It helps in smooth operation and control for supplying sufficient and reliable electric power with good quality. The foremost task of LFC is to keep the frequency constant against the randomly varying active power loads, which are also referred to as unknown external disturbance. Another task of the LFC is to regulate the tie-line power exchange error. A typical large-scale power system is composed of several areas of generating units. In order to enhance the fault tolerance of the entire power system, these generating units are connected via tie-lines. The usage of tie-line power imports a new error into the control problem, i.e. tie-line power exchange error. When a sudden active power load change occurs to an area, the area will obtain energy via tie-lines from other areas. But eventually, the area that is subject to the load change should balance it without external support. Otherwise there would be economic conflicts between the 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 differently. Another problem is that the interconnection of the power systems results in huge increases in both the order of the system and the number of the tuning controller parameters. As a result, when modeling such complex high-order 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 reality.

Thus, the LFC has two major assignments, which are

- To maintain the standard value of frequency.
- To keep the tie-line power exchange under schedule in the presence of any load changes in case of multi-area power system.

In addition, the LFC has to be robust against unknown external disturbances and system model and parameter uncertainties.

1.3 CONTROLLERS FOR LOAD FREQUENCY CONTROL

A number of control strategies have been employed in the design of load frequency controller in order to achieve better dynamic performance. In this thesis, most widely employed conventional controllers- PI and PID along with the intelligent controllers are considered.

Conventional controllers are simple for implementation but take more time and give large frequency deviation. These controllers are mature and well understood by practitioners. For these reasons, they are often the first choice for new controller design. However PID controller gives better results than PI controller. There are many methods for the tuning of these controllers out of which Ziegler-Nicholes method is the most widely used. These conventional controllers are discussed in detail later in this thesis.

Intelligent control describes the discipline where control methods are developed that attempt to emulate important characteristics of human intelligence. These characteristics include adaptation and learning, planning under large uncertainty and coping with large amounts of data. Today, the area of intelligent control tends to encompass everything that is not characterized as conventional control. Intelligent control is interdisciplinary as it combines and extends theories and methods from areas such as control, computer science and operations research. It uses theories from mathematics and seeks inspiration and ideas from biological systems. Intelligent control methodologies are being applied to power systems, robotics and automation, communications, manufacturing, traffic control, to mention but a few application areas. Neural networks, fuzzy control, genetic algorithms, planning systems, expert systems, and hybrid systems are all areas where related work is taking place. Intelligent control attempts to build upon and enhance the conventional control methodologies to solve new challenging control problems. Intelligent control can address control problems that cannot be formulated in the language of conventional control.

Intelligent controllers can be seen as machines which emulate human mental faculties such as adaptation and learning, planning under large uncertainty, coping with large amounts of data etc. in order to effectively control complex processes; and this is the justification for the use of the term intelligent in intelligent control, since these mental faculties are considered to be important attributes of human intelligence.

Two intelligent controllers- Fuzzy tuned PID controller and Neuro- fuzzy controller are designed for LFC. The dynamic responses of LFC with both of these controllers are studied. The responses obtained with the conventional and intelligent controllers are analyzed comparatively. Intelligent controllers are described at length later in this thesis.

1.4 OBJECTIVE & MOTIVATION FOR THE WORK

In this thesis, load frequency control in power system is considered. Load frequency control is an integral component of the power system. It helps in smooth operation and control for supplying sufficient and reliable electric power with good quality. By choosing a suitable controller the dynamic performance of the LFC can be improved to a great extent. It is therefore required that, various controllers for the LFC should be studied, modeled and simulated to identify the suitable controller for appropriate conditions. The objective of this thesis is to construct the LFC in MATLAB/SIMULINK environment, then simulation studies are carried out for LFC using intelligent controllers like Fuzzy-PID and Hybrid Neuro-fuzzy and the results are compared with the conventional controllers i.e. PI and PID controllers.

1.5 THESIS OUTLINE

The contents of the thesis are organized in the following chapters:

Chapter 1

This chapter introduces the topic of the dissertation i.e. Load frequency control of power system following which the controllers used for LFC are discussed in brief.

Chapter 2

This chapter deals with the literature review. Different control techniques for LFC using various controllers developed so far are discussed in an elaborate manner.

Chapter 3

In this chapter, LFC, reasons for the limit on frequency along with the mathematical modeling of each component of LFC is presented in detail. AGC for single area and two area are also discussed.

Chapter 4

In this chapter, conventional controllers are discussed at length. The block diagrams and the transfer functions for P, PI and PID controllers are presented. Comparison of these conventional controllers is also included.

Chapter 5

This chapter discusses the intelligent controllers like Fuzzy, Fuzzy-PID and hybrid Neuro-Fuzzy controllers that are applied on the LFC problem.

Chapter 6

This chapter presents the MATLAB/SIMULINK models of LFC with all the controllers discussed in previous chapters. The model of two-area LFC with PID controller is also developed. The results of PI, PID, Fuzzy logic, Fuzzy tuned PID and Neuro-Fuzzy controllers in terms of rise time, settling time etc are presented. The comparative analysis of the result of the controllers for single area is also included.

Chapter 7

This chapter contains the main conclusions based on the investigations carried out on this work. It also enlists the scope of further investigations and improvements in the controllers and the LFC model.

CHAPTER-2

LITERATURE REVIEW

In modern large interconnected power systems, power demands are never steady and they are continually changing. In thermal plants, steam input to turbo-generators must, therefore, be continuously regulated to match the power demands, failing which the machine speed will vary with the consequent change in frequency which is highly undesirable [1]. To keep the frequency changes within limits, load-frequency control technique is used. Load frequency control has become an integral part of the modern power systems. LFC provides smooth operation and control for supplying sufficient and reliable electric power with good quality [1-3]. The main goal of LFC in single area is to keep the frequency within limits and to give zero steady state error and in multi-area interconnected power system is to give zero steady state errors of tie-line exchanges and frequency deviations [4]. Along with this, in multi-area interconnected power system, it also ensures optimal transient behavior.

Various researches have been reported in the past pertaining to load frequency control of a single isolated and multi-area interconnected power system. In industry, proportional-integral (PI) controllers have been broadly used for decades as the load frequency controllers. A PI controller design on a three-area interconnected power plant is presented in [5], where the controller parameters of the PI controller are tuned using trial-and-error approach. The conventional LFC with PI controller doesn’t yield adequate control performance with the consideration of the singularities of the speed-governor such as rate limits on valve position and generation rate constraints. This drawback is overcome by using an extended integral control for the PI control of speed governor in the presence of GRC [6]. This scheme also helps in getting rid of overshoot of the conventional PI control. PI controllers are very basic controllers for LFC but are rarely used now because of their poor performance [7]. More focus is now on PID controller and many PID controllers for LFC have been developed in the past [7-10]. The tuning of the PI and PID controller is quite exasperating process and requires a lot of labor. A lot of research has been done to make the tuning of the controllers easier [11-13].

The LFC design based on an entire power system model is considered as centralized method. In [14] and [15], this centralized method is introduced with a simplified multiple-area power plant in order to implement such optimization techniques on the entire model. However, the simplification is based on the assumption that all the subsystems of the entire power system are identical while they are not. The assumption makes the simulation model in the paper quite different from the real system. Another problem for the centralized methods is that even if the method works well on a low-order test system, it would face an exponentially increasing computation problem with the increase of the system size.

Since the tie-line interfaces give rise to weakly coupled terms between areas, the large-scale power system can be decentralized into small subsystems through treating tie-line signals as disturbances. In large-scale power systems, classical centralized control approaches may fail due to geographically distribution of information and decentralized controllers result in sub-optimal solution for LFC problems and also reduce the computational complexity of centralized controllers. Numerous control techniques have been applied to the decentralized power systems. In [16–19], decentralized PI or proportional-integral-derivative (PID) controller is reported.

PI and PID controllers are the conventional controllers and are designed for the constant operating conditions in power system. In reality, the operating conditions change with the variations in the load demand. The controllers apt for such conditions can be obtained with the fuzzy logic.

Fuzzy logic control is a method based on fuzzy set theory, in which the fuzzy logic variables can be any value between 0 and 1 instead of just true and false. When the variables are selected, the decision will be made through specific fuzzy logic functions. The fuzzy logic controllers are much closer in spirit to human thinking and natural language than classical logical systems [20].The technique referred here is fuzzy gain scheduling. The effectiveness of fuzzy gain scheduling lies in the quick changes in control parameters as parameter estimation is not required and thus the system provides faster response as compared to the conventional controllers [21]. In [21], a fuzzy gain scheduled PI controller for four area interconnected power system with control dead bands and generation rate constraints has been proposed. Same technique has been reported with small alterations from many researchers [22-23]. A comparison between the fuzzy-gain-scheduled PI controller and the traditional PI controller was also included in [22].

A systematic LFC design methodology for uncertain nonlinear power systems is reported in [24]. The typical nonlinearity—the valve position limits on the governor and the parametric uncertainties are concerned, which are important under the deregulated operation of power systems. The designed fuzzy-model-based LFC provides a robust control performance. A novel method of quenching transients of load frequency of a single area power system using fuzzy logic control is proposed in [25]. The fuzzy gain scheduling technique reported earlier has now been extended to conventional PID controller. The methods of tuning of PID parameters using fuzzy logic controller are discussed in [26-27]. By using these techniques, fuzzy PID controller for a single area load frequency control has been developed and the dynamic response is also compared with PI and PID controllers in [28].

Fuzzy systems are more favorable as their behavior can be explained based on fuzzy rules and thus their performance can be adjusted by tuning the rules. But since, in general, knowledge acquisition is difficult, applications of fuzzy systems are restricted to the fields where expert knowledge is available and the number of input variables is small. To overcome the problem of knowledge acquisition, neural networks are extended to automatically extract fuzzy rules from numerical data. Cooperative approaches use neural networks to optimize certain parameters of an ordinary fuzzy system, or to preprocess data and extract fuzzy rules from data. A Neuro-Fuzzy system is a fuzzy system that uses a learning algorithm derived from neural network theory to determine fuzzy sets and fuzzy rules by processing data samples [29]. ANFIS based Neuro-Fuzzy model for LFC of an isolated hybrid power system is developed and the results are also compared with conventional PI and Fuzzy logic controller [30].

Most of the reported solutions of the LFC problem have been tested for their robustness against large step load change. A control technique with a notable robustness against not only parameter uncertainties but also model uncertainties and external load change will be preferred by the power industry.

CHAPTER-3

LOAD FREQUENCY CONTROL [1-3]

3.1 INTRODUCTION

In inter-connected control areas of large scale power systems, it is important to keep the frequency and inter area tie power near to the scheduled values. The input mechanical power is used to control the frequency of the generators and the change in the frequency and tie-line power are sensed, which is a measure of the change in rotor angle. A well designed power system should be able to provide the acceptable levels of power quality by keeping the frequency and voltage magnitude within tolerable limits. Changes in the power system load affects mainly the system frequency, while the reactive power is less sensitive to changes in frequency and is mainly dependent on fluctuations of voltage magnitude. So the control of the real and reactive power in the power system is dealt separately. The load frequency control mainly deals with the control of the system frequency and real power. It is the basis of many advanced concepts of the large scale control of the power system.

Reasons for the Limits on Frequency:

- The speed of the alternating current motors depends on the frequency of the power supply. There are situations where speed consistency is expected to be of high order.
- The electric clocks are driven by the synchronous motors. The accuracy of the clocks is not only dependent on the frequency but also is an integral of the frequency error.
- If the normal frequency is 50 Hertz and the system frequency falls below 47.5 Hertz or goes up above 52.5 Hertz then the blades of the turbine are likely to get damaged so as to prevent the stalling of the generator.
- The under frequency operation of the power transformer is not desirable. For constant system voltage if the frequency is below the desired level then the normal flux in the core increases. This sustained under frequency operation of the power transformer results in low efficiency and over -heating of the transformer

windings.

- The most serious effect of subnormal frequency operation is observed in the case of Thermal Power Plants. Due to the subnormal frequency operation the blast of the ID and FD fans in the power stations get reduced and thereby reduce the generation power in the thermal plants. This phenomenon has got a cumulative effect and in turn is able to make complete shutdown of the power plant if proper steps of load shedding technique is not engaged. It is pertinent to mention that, in load shedding technique a sizable chunk of load from the power system is disconnected from the generating units so as to restore the frequency to the desired level.

3.2 LFC AND ITS MATHEMATICAL MODELLING

If in a power system, any system is connected to a number of different loads, then for that system, as load changes frequency changes. If constant frequency is not required by a system then operator need not change the settings of the generator. But if constant frequency is required the operator can adjust the speed of the turbine by changing the governor characteristic as and when required. If a change in load is taken care by two generating stations running at parallel then the complexity of the system increases. The possibility of sharing the load by two machines is as follow:

- Suppose there are two generating stations that are connected to each other by tie line. If the change in load is either at A or at B and the generation of A is alone asked to regulate so as to have constant frequency then this kind of regulation is called Flat Frequency Regulation.
- The other possibility of sharing the load the load is that both A and B would regulate their generations to maintain the constant frequency. This is called parallel frequency regulation.
- The third possibility is that the change in the frequency of a particular area is taken care of by the generator of that area thereby the tie-line loading remains the same. This method is known as flat tie-line loading control.
- In Selective Frequency control each system in a group is takes care of the load changes on its own system and does not aid the other systems and the group for changes outside its own limits.
- In Tie-line Load-bias control all the power systems in the interconnection

aid in regulating frequency regardless of where the frequency change originates. The equipment consists of a master load frequency controller and a tie line recorder measuring the power input on the tie as for the selective frequency control.

The error signal i.e. Δf and ΔP_{tie} are amplified, mixed and transformed to real power command signal ΔP_V which is sent to the prime mover to call for an increase in the torque. The prime mover shall bring about a change in the generator output by an amount ΔP_G which will change the values of Δf and ΔP_{tie} within the specified tolerance. The first step to the analysis of the tie control system is the mathematical modeling of the system's various components and control system techniques.

3.2.1 Mathematical Modeling of Generator

Applying the swing equation of a synchronous machine to small perturbation, we have eqn 3.1 as shown below.

$$\frac{2H}{\omega} d^2 \frac{\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \tag{3.1}$$

Or in terms of small deviation in speed, the above equation changes to eqn 3.2.

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \tag{3.2}$$

Taking Laplace Transform, we obtain eqn 3.3.

$$\Delta\Omega(s) = \frac{1}{2Hs}[\Delta P_m(s) - \Delta P_e(s)] \tag{3.3}$$

Fig. 3.1 shows the block diagram for generator.

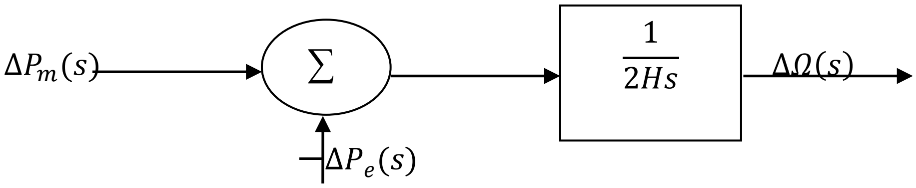


Fig.-3.1: Block diagram for generator

3.2.2 Mathematical Modeling of Load

The load on the power system consists of a variety of electrical drives. The equipments used for lighting purposes are basically resistive in nature and the rotating devices are basically a composite of the resistive and inductive components. The speed-load characteristic of the composite load is approximated by eqn 3.4:

$$\Delta P_e = \Delta P_L + D\Delta\omega \tag{3.4}$$

where

ΔP_L is the non-frequency- sensitive load change,

$D\Delta\omega$ is the frequency sensitive load change.

D is expressed as percent change in load by percent change in frequency.

Including the load model in the generator block diagram, results in the block diagram of fig. 3.2.

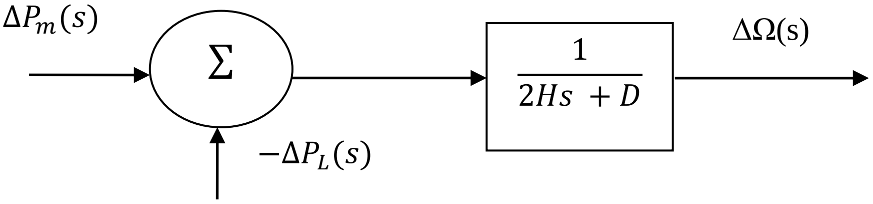


Fig.-3.2: Block diagram for generator and load

3.2.3 Mathematical Modeling for Prime Mover:

The source of mechanical power is commonly known as the prime mover. It may be hydraulic turbines at waterfalls, steam turbines whose energy comes from burning of the coal, gas and other fuels. The model for the turbine relates the changes in mechanical power output ΔP_m to the changes in the steam valve position ΔP_v. The eqn 3.5 shows turbine transfer function.

$$G_T = \frac{\Delta P_m(s)}{\Delta P_V(s)} = \frac{1}{1+\tau_T(s)} \tag{3.5}$$

Where

τ_T , the turbine constant is, in the range of 0.2 to 2.0 seconds.

The block diagram for a simple turbine is shown in Fig. 3.3.

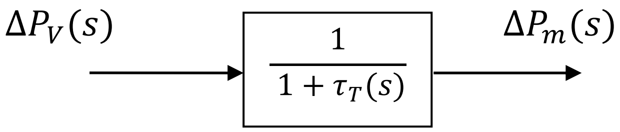


Fig.-3.3: Block diagram for turbine

3.2.4 Mathematical Modeling for Governor

When the electrical load is suddenly increased then the electrical power exceeds the mechanical power input. As a result of this, the deficiency of power in the load side is extracted from the rotating energy of the turbine. Due to this reason the kinetic energy of the turbine i.e. the energy stored in the machine is reduced and the governor sends a signal to supply more volumes of water or steam or gas to increase the speed of the prime- mover so as to compensate speed deficiency. For stable operation, the governors are designed to permit the speed to drop as the load is increased. The steady state characteristics of such a governor are shown in fig. 3.4.

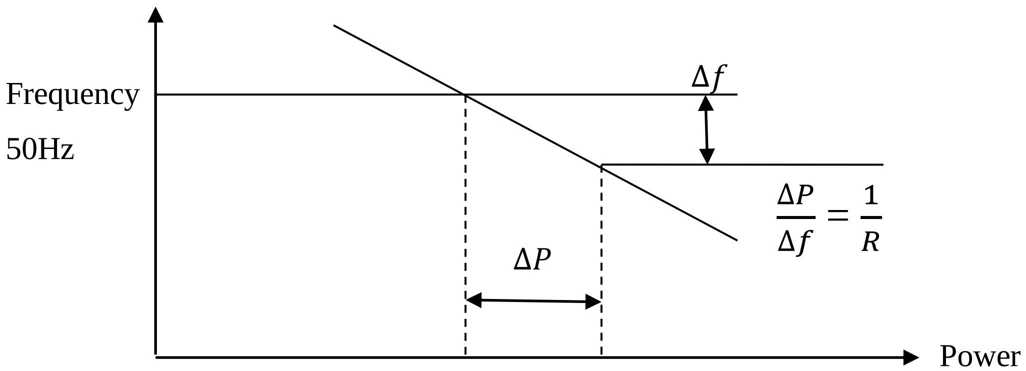


Fig.-3.4: Graphical Representation of speed regulation by governor

The slope of the curve represents speed regulation R. Governors typically have a speed regulation of 5-6 % from no load to full load. The speed governor mechanism acts as a comparator whose output is as given in eqn. 3.6.

$$\Delta P_g \;=\; \Delta P_{ref} - \frac{1}{R}\Delta f \tag{3.6}$$

Or in s-domain, it becomes as in eqn. 3.7.

$$\Delta P_g(s) \;=\; \Delta P_{ref} \;-\; \frac{1}{R}\,\Delta \Omega(s) \tag{3.7}$$

The command ΔP_g is transformed through hydraulic amplifier to the steam valve position command ΔP_v. We assume a linear relationship and consider simple time constant τ_g. So, we have the following s-domain relation given by eqn. 3.8:

$$\Delta P_V(s) \;=\; \frac{1}{1+\tau_g}\Delta P_g(s) \tag{3.8}$$

Combining all the block diagrams we get the single area system as shown in fig. 3.5

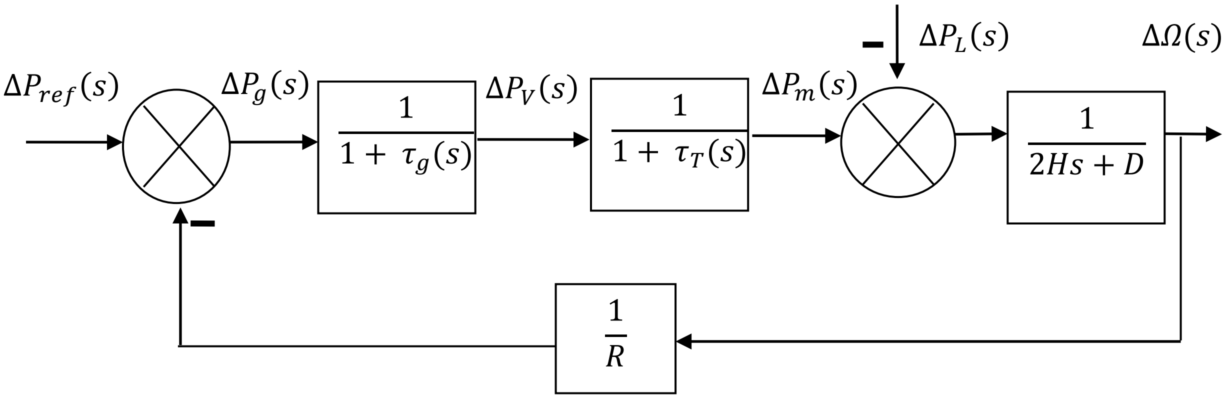


Fig.-3.5: Block Diagram of single area system.

3.3 AUTOMATIC GENERATION CONTROL

If the load on the system is increased suddenly then the turbine speed drops before the governor can adjust the input of the steam to the new load. As the change in the value of speed diminishes the error signal becomes smaller and the position of the governor and not of the fly balls gets closer to the point required to maintain the constant speed. One way to restore the speed or frequency to its nominal value is to add an integrator on the way. The integrator unit shall monitor the average error over a period of time and will overcome the offset. Thus as the load of the system changes continuously the generation is adjusted automatically to restore the frequency to the nominal value. This scheme is known as automatic generation control. In an interconnected system consisting of several pools, the role of the AGC is to divide the load among the system, stations and generators so as to achieve maximum economy and reasonably uniform frequency.

3.3.1 AGC in A Single Area

With the primary LFC loop a change in the system load will result in a steady state frequency deviation, depending on the governor speed regulation. In order to reduce the frequency deviation to zero we must provide a reset action by introducing an integral controller to act on the load reference setting to change the speed set point. The integral controller increases the system type by 1 which forces the final frequency deviation to zero. The integral controller gain must be adjusted for a satisfactory transient response. The LFC system is shown in fig. 3.6.

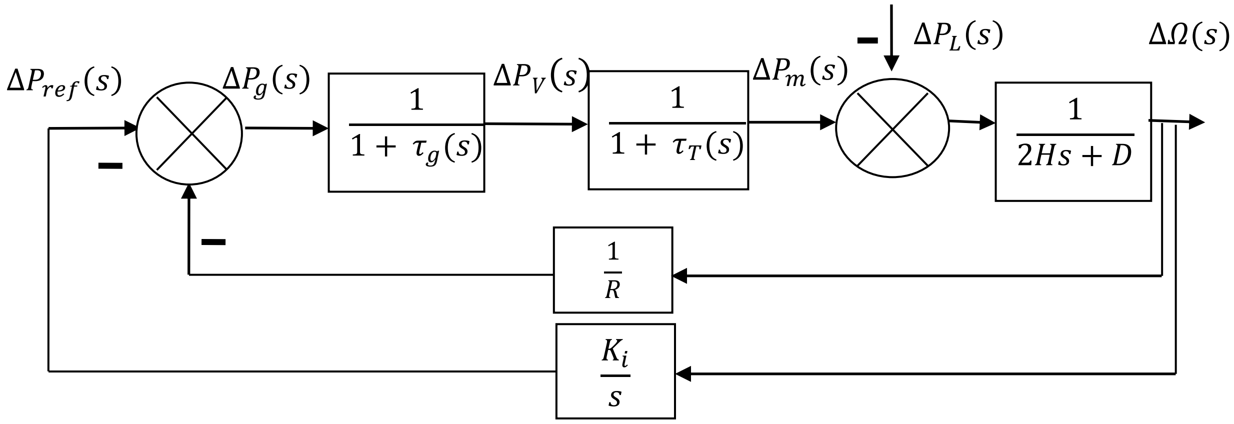


Fig.-3.6: Block Diagram of AGC for an isolated power system.

The closed loop transfer function of the control system is given by eqn. 3.9.

$$\frac{\Delta\Omega(s)}{-\Delta P_L} = \frac{s(1+\tau_g s)(1+\tau_T s)}{s(2Hs+D)(1+\tau_g s)(1+\tau_T s)+K_i+{}^{s}/_{R}} \quad (3.9)$$

3.3.2 Agc In The Multiarea System

In many cases a group of generators are closely coupled internally and swing in unison. Furthermore, the generator turbines tend to have the same response characteristics. Such a group of generators are said to be coherent. Then it is possible to let the LFC loop represent the whole system and the group is called the control area.

In an interconnected power system, different areas are connected with each other via tie-lines. When the frequencies in two areas are different, a power exchange occurs through the tie-line that connected the two areas. For a two area system, during normal operation the real power transferred over the tie line is given by eqn. 3.10.

$$P_{12} = \frac{|E_1||E_2|}{X_{12}} \sin\delta_{12} \quad (3.10)$$

Where

X_{12} = X_1 + X_{tie} + X_2 and δ_{12} = δ_1 - δ_2

For a small deviation in the tie- line flow from the nominal value, the eqn. 3.11 can be shown as:

$$\Delta P_{12} = \left.\frac{dP_{12}}{d\delta_{12}}\right|_{\delta 12o} \Delta\delta_{12} = P_s\, \Delta\delta_{12} \tag{3.11}$$

The quantity P_s is the slope of the power angle curve at the initial operating angle. Thus, we have P_s as given by eqn. 3.12.

$$P_s = \left.\frac{dP_{12}}{d\delta_{12}}\right|_{\delta 12o} = \frac{|E_1||E_2|}{X_{12}} \cos \Delta\, \delta_{12o} \tag{3.12}$$

The tie-line power deviation then takes on the form

$$\Delta P_{12} = P_s\, (\Delta\delta_1 - \Delta\delta_2) \tag{3.13}$$

The tie-line power flow appears as a load increase in one area and a load decrease in the other area, depending on the direction of the flow. The direction of the flow is dictated by the phase angle difference.

If LFCs are equipped with only the primary control loop, a change of power in area1 is met by the increase in generation in both areas associated with a change in the tie-line power, and a reduction in frequency. In the normal operating state, the power system is operated so that the demands of areas are satisfied at the nominal frequency. A simple control strategy for the normal mode is

- To keep frequency approximately at the nominal value.
- To maintain the tie-line flow at scheduled value.

- That each area should absorb its own load changes.

Conventional LFC is based upon tie-line bias control, where each area tends to reduce the area control error (ACE) to zero. The control error for each area consists of a linear combination of frequency and tie-line error as shown in eqn. 3.14.

$$ACE_i = \sum_{j=1}^{n} \Delta P_{ij} + K_i \, \Delta\omega \tag{3.14}$$

The area bias K_i determines the amount of interaction during a disturbance in the neighboring areas. An overall satisfactory performance is achieved when K_i is selected equal to the frequency bias factor of that area. Thus, the ACEs for a two-area system are given by the following eqns.

$$ACE_1 = \Delta P_{12} + B_1 \, \Delta\omega_1 \tag{3.15}$$

$$ACE_2 = \Delta P_{21} + B_2 \, \Delta\omega_2$$

ACEs are used as actuating signals to activate changes in the reference power set points, and when steady-state is reached, ΔP_{12} and $\Delta\omega$ will be zero. The block diagram of a simple AGC for a two-area system is shown in fig. 3.7.

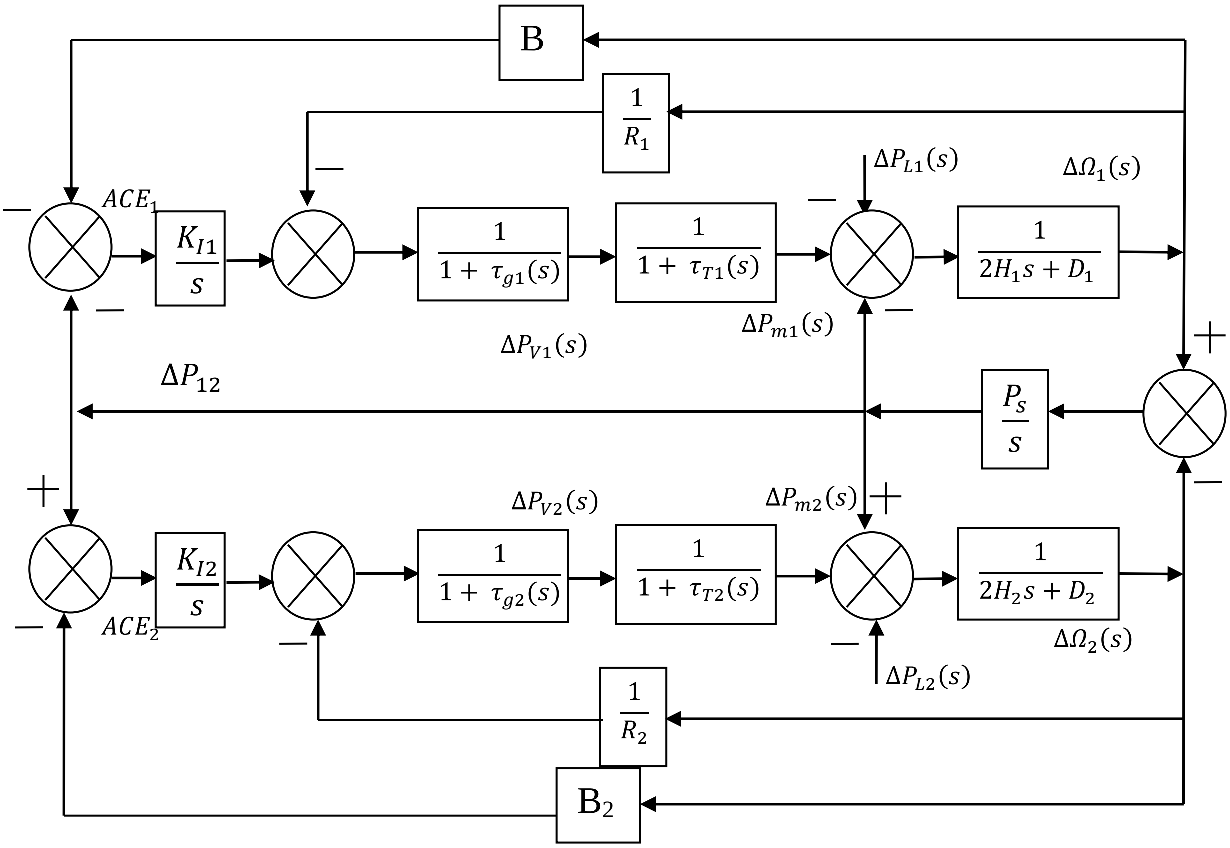


Fig.-3.7: Block Diagram of AGC for a two-area system.

In this chapter, Load frequency control has been discussed in detail for single area and two-area system. The controllers for LFC are covered in the coming chapters.

CHAPTER-4

CONVENTIONAL CONTROLLERS FOR LFC [6-10]

4.1 PARADIGM AND THEORY OF CONTROLLERS

A physical system is primarily characterized by its dynamic behavior. The dynamic behavior of the system depends on the system parameters, input variables, output variables and operating conditions. The parameters of the system have a tendency to vary under a variety of changing conditions, these parameter variations have adverse affect on system performance. The system performance can be improved and the effect of parameter variation can be nullified by using controllers.

The controller maintains the output at desired value by means of a control action. Any deviation of output from the reference input is detected by an error detector. The error thus detected is used as actuating signal for control action through a controller. The various control methods differ from each other depending on the factors based on which action is taken. The conventional controllers that are availed and employed are discussed in this section. Various kind of intelligent controllers are introduced in the next chapter.

4.2 CONVENTIONAL CONTROLLERS

4.2.1 P Controller

A proportional controller is a type of linear feedback controller. With this controller, the controller output (control action) is proportional to the error signal which is the difference between the desired value (setpoint) and the current value (measured) as shown in fig. 4.1.

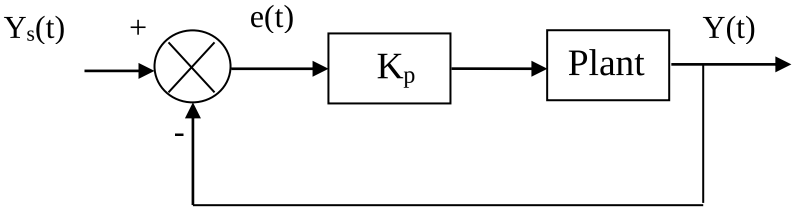


Fig. - 4.1: Basic block diagram of a conventional P controller

If the error is large, then the control action is large. Mathematically, the controller output can be shown as in eqn. 4.1:

$$\mathrm{U(t)} = K_p e(t) \; + U_o \tag{4.1}$$

where

$U(t)$ represents the control action i.e. controller output,

$e(t) = \; Y_s(t) - \; Y(t)$ represents the error,

K_P represents the controller's gain, and

U_o represents the steady state control action (bias) necessary to maintain the variable at the steady state when there is no error.

In a proportional controller, the steady state error depends inversely upon the proportional gain, so if gain is made larger steady state error goes down. Although proportional control is simple to understand, it has drawbacks. The largest problem is that for most systems it will never entirely remove error. This is because when error is 0 the controller only provides the steady state control action so the system will settle back to the original steady state which is probably not the new set point that we want the system to be at. To get the system to operate near the new steady state, the controller gain, K_p, must be very large so the controller will produce the required output when only a very small error is present. Having large gains can lead to system instability or can require physical impossibilities like infinitely large valves.

4.2.2 PI Controller

The limitation of a DC offset in ‘P’ control can be overcome by adding an integral term of error signal that provides desired DC stiffness to the system. The integral gain represented as ‘K_i’, increased value gives more stiffness at the cost of large overshoot. A sufficient value of ‘K_i’ gain in the controller will eliminate the DC offset, as the presence of even a small value of DC offset will make the integral term large. Although integral gain adds precision to the close loop control but it lacks in the wind up function that is needed to control the gain value during saturation. An improvement in the steady state error is introduced by ‘PI’ controller in the system dynamics. The basic block diagram of PI controller is as shown in fig. 4.2.

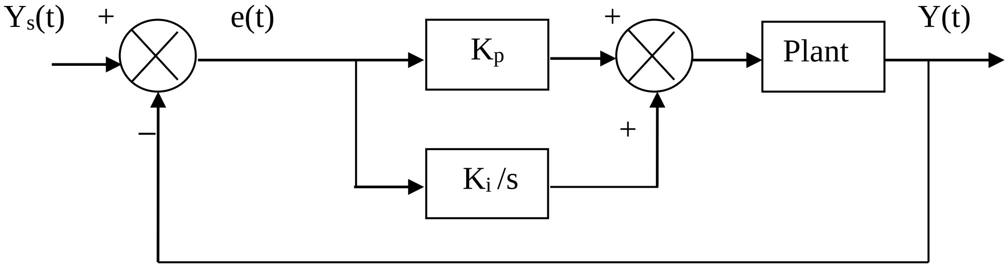


Fig. - 4.2: Basic block diagram of a conventional PI controller

The output of PI controller can be represented mathematically by eqn. 4.2.

$$U(t) = K_p e(t) + K_i \int_0^t e(t)dt \qquad (4.2)$$

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller.

PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when:

- fast response of the system is not required.
- large disturbances and noise are present during operation of the process.

- there is only one energy storage in process (capacitive or inductive).
- there are large transport delays in the system.

4.2.2 PID Controller

PID controller has all the necessary dynamics: fast reaction on change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control error area to eliminate oscillations (P mode). Derivative mode improves stability of the system and enables increase in gain K and decrease in integral time constant Ti, which increases speed of the controller response.

PID controllers are the most widely-used type of controller for industrial applications. They are structurally simple and exhibit robust performance over a wide range of operating conditions. In the absence of the complete knowledge of the process these types of controllers are the most efficient of choices.

The three main parameters involved are Proportional (P), Integral (I) and Derivative (D). The proportional part is responsible for following the desired set-point, while the integral and derivative part account for the accumulation of past errors and the rate of change of error in the process respectively. Each of the control action has different effect on the system and weighted sum of all the three actions is used by the PID controller. The PID control action can be divided in two zone based on the frequency, at lower frequency the 'K_p' gain dominated and at high frequency there is contribution from two gains 'K_p' and 'K_i'. The derivative action helps in setting 'K_p' at higher side then that can be set generally. All this actions work in tandem with in the close loop, depending on the command and the feedback signal of the system.

Although the PID is superior to the P, PI, PD controller in term of system dynamics response but it comes with an expense of increased sensitivity towards the changes in plant model. The rigorous task of tuning a PID controller is also a matter of great concern. The basic block diagram of a conventional PID controller is shown in fig.-4.3.

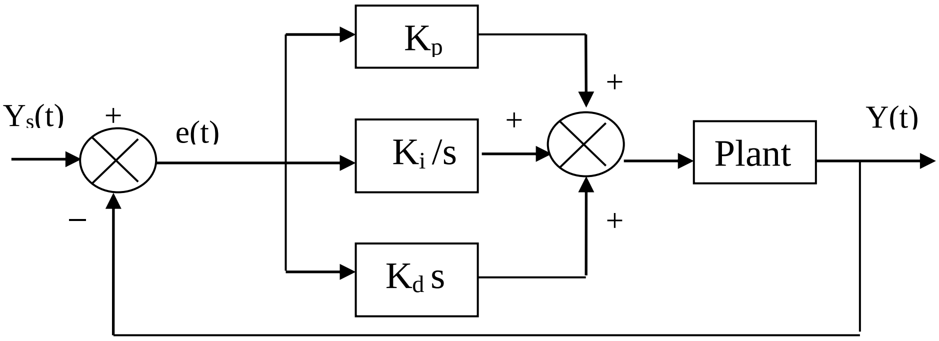


Fig.- 4.3: Basic block diagram of a conventional PID controller

Output of the PID controller is expressed mathematically in equation 4.3.

$$U(t) = K_p e(t) \; + \; K_i \int_0^t e(t)dt \; + \; K_d \frac{d\,e(t)}{dt} \tag{4.3}$$

4.2.3 Tuning Of PID Parameters

Tuning of a PID controller refers to the tuning of its various parameters (P, I and D) to achieve an optimized value of the desired response. The basic requirements of the output will be the stability, desired rise time, peak time and overshoot. Different processes have different requirements of these parameters which can be achieved by meaningful tuning of the PID parameters. If the system can be taken offline, the tuning method involves analysis of the step-input response of the system to obtain different PID parameters. But in most of the industrial applications, the system must be online and tuning is achieved manually which requires very experienced personnel and there is always uncertainty due to human error. Another method of tuning can be Ziegler-Nichols method. While this method is good for online calculations, it involves some trial-and-error which is not very desirable and this gives way to tuning using various soft computing techniques..

4.2.3.1 PID Controller Tuning Using Various Soft-Computing Techniques

PID controller model structure needs to be very precise. But in practical applications, to a different extent, most of the industrial processes exist to be nonlinear, the variability of parameters and the uncertainty of model are very high, thus using conventional PID control the precise control of the process cannot be achieved. The common methods known for tuning require the process model to be of a certain type. These methods require the process model to be reduced if it’s too complicated originally. The above problems can be well addressed by the application of soft-computing methods for tuning of the PID controller. These are especially useful for solving problems of computationally complicated and mathematically untraceable. This is due to the convenience of combining natural systems with intelligent machines effectively with the help of soft-computing methods. Among all these soft-computing methods available Neural network, Fuzzy logic and Genetic algorithm are the most important ones

Fuzzy logic mainly employs the mechanisms that are based on verbal power. Due to this fact it is responsible for dealing with the uncertainties present in the system. By the implementation of the knowledge of fuzzy logic in PID controller, the system response of the plant can be improved. The overshoot and the rise time of the response can be decreased and the dynamic performance of the system can also be improved.

These soft computing techniques are dealt in detail in the next chapter. The steps to develop Fuzzy logic controller, Fuzzy tuned PID controller and Hybrid neuro-Fuzzy controller for LFC are also discussed.

CHAPTER-5

INTELLIGENT CONTROLLERS FOR LFC [20-30]

5.1 INTELLIGENT CONTROLLERS

The concepts of intelligence and control are closely related and the term "Intelligent control" has a unique and distinguishable meaning. An intelligent system must define and use goals. Control is then required to move the system to these goals and to define such goals. Consequently, any intelligent system will be a control system. Conversely, intelligence is necessary to provide desirable functioning of systems under changing conditions, and it is necessary to achieve a high degree of autonomous behavior in a control system. Since control is an essential part of any intelligent system, the term "intelligent control systems" is sometimes used in engineering literature instead of "intelligent systems" or "intelligent machines".

An intelligent system has the ability to act appropriately in an uncertain environment, where an appropriate action is that which increases the probability of success, and success is the achievement of behavioral sub-goals that support the system's ultimate goal. In order for a man-made intelligent system to act appropriately, it may emulate functions of living creatures and ultimately human mental faculties. Intelligent controllers can be seen as machines which emulate human mental faculties such as adaptation and learning, planning under large uncertainty, coping with large amounts of data etc. in order to effectively control complex processes; and this is the justification for the use of the term intelligent in intelligent control, since these mental faculties are considered to be important attributes of human intelligence.

The word control in "intelligent control" has different, more general meaning than the word control in "conventional control". The processes of interest are more general and the control objectives can also be more general. To attain control goals for complex systems over a period of time, the controller has to cope with significant uncertainty that fixed feedback robust controllers or adaptive controllers cannot deal with. Since the goals are to be attained under large uncertainty, fault diagnosis and control reconfiguration, adaptation and learning are important considerations in intelligent controllers. It is also clear that task planning is an important area in intelligent control design. So the control problem in intelligent control is an enhanced version of the problem in conventional control. It is much more ambitious and general. It is not surprising then that these increased control demands require methods that are not typically used in conventional control. The area of intelligent control is in fact interdisciplinary, and it attempts to combine and extend theories and methods from areas such as control, computer science and operations research to attain demanding control goals in complex systems.

The intelligent controllers which are discussed in this chapter are: Fuzzy logic controller, Fuzzy tuned PID controller and Neuro- Fuzzy controller. These controllers are designed and applied to LFC and the dynamic responses of LFC with these controllers are studied.

5.2 FUZZY LOGIC CONTROLLER AND ITS BACKGROUND

Fuzzy logic is a logic having many values. Unlike the binary logic system, here the reasoning is not crisp, rather it is approximate and having a vague boundary. The variables in fuzzy logic system may have any value in between 0 and 1 and hence this type of logic system is able to address the values of the variables those lay between completely truths and completely false. The variables are called linguistic variables and each linguistic variable is described by a membership function which has a certain degree of membership at a particular instance. System based on fuzzy logic carries out the process of decision making by incorporation of human knowledge into the system. Fuzzy inference system is the major unit of a fuzzy logic system. The decision making is an important part of the entire system. The fuzzy inference system formulates suitable rules and based on these rules the decisions are made. This whole process of decision making is mainly the combination of concepts of fuzzy set theory, fuzzy IF-THEN rules and fuzzy reasoning. The fuzzy inference system makes use of the IF-THEN statements and with the help of connectors present (such as OR and AND), necessary decision rules are constructed. The basic Fuzzy inference system may take fuzzy inputs or crisp inputs depending upon the process and its outputs, in most of the cases, are fuzzy sets.

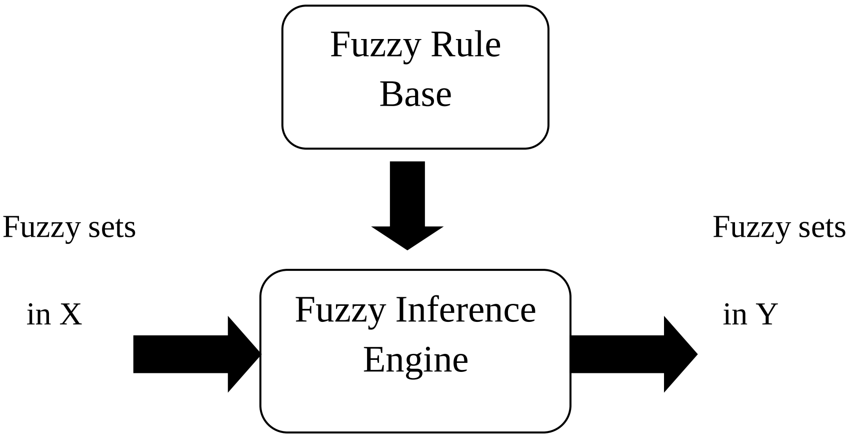


Fig.-5.1 A pure fuzzy system

The fuzzy inference system in Fig.-5.1 can be called as a pure fuzzy system due to the fact that it takes fuzzy sets as input and produces output that are fuzzy sets. The fuzzy rule base is the part responsible for storing all the rules of the system and hence it can also be called as the knowledge base of the fuzzy system. Fuzzy inference system is responsible for necessary decision making for producing a required output. In most of the practical applications where the system is used as a controller, it is desired to have crisp values of the output rather than fuzzy set values. Therefore a method of defuzzification is required in such case which converts the fuzzy values into corresponding crisp values. In general there are three main types of fuzzy infernece systems such as: - Mamdani model, Sugeno model and Tsukamoto model. Out of these three, Mamdani model is the most popular one. There are also various defuzzification techniques such as: - Mean of maximum method, Centroid of area method, Bisector of area methd etc. In this work Mamdani fuzzification technique is used. There are two types of Mamdani fuzzy inference system such as, “min and max” and “product and max”. In our example, the “min and max” Mamdani system is used. For this type of system, min and max operators are used for AND and OR methods respectively.

The fuzzy rules for the system are like as follows:

- If x is A1 and y belongs to B1, then z is C1.
- If x is A2 and y belongs to B2, then z is to C2.

Generally the procedure for constructing a FLC consists of the following mechanism:

- **Choosing the fuzzy controller inputs and outputs**: The frequency error 'e' and the change in frequency error 'ce' are selected as the input variables. Triangular type of the membership functions has been chosen. Membership functions for both the inputs are shown in fig.5.2 and the output is shown in fig. 5.3.

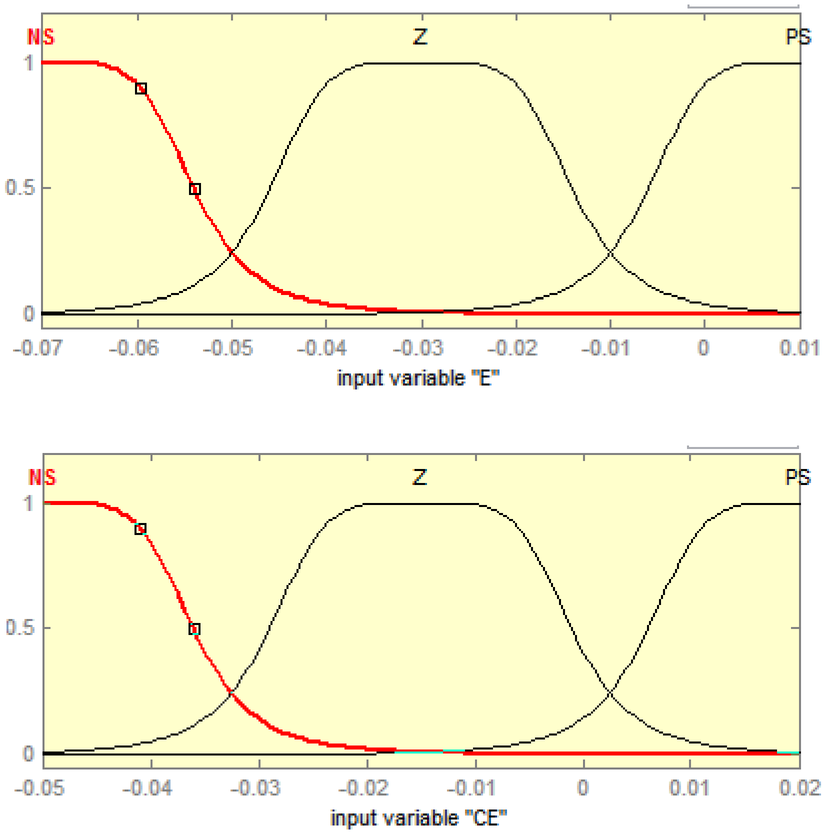


Fig.-5.2 Membership functions for both the inputs of fuzzy logic controller

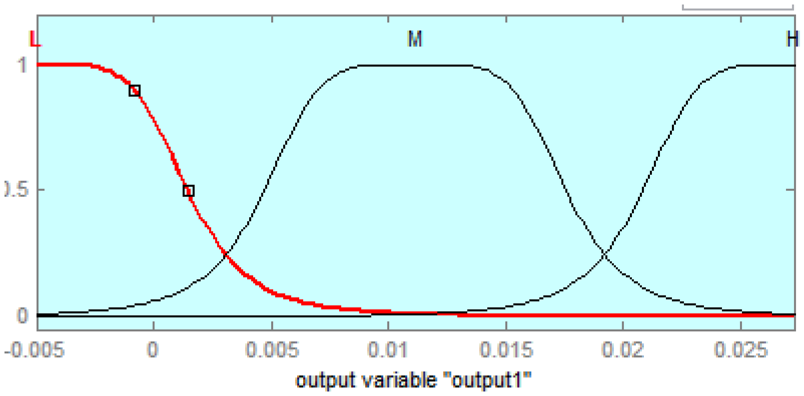


Fig.-5.3 Membership functions for the output of fuzzy logic controller

- **Putting control knowledge into rule base**: “Linguistic variables” that describe each of the time varying fuzzy controller inputs and outputs is defined. Each input and the output variables are described using the variables {L, M, H}. Proper control rules are written using the variables in the “if-then” format and rule base is prepared. The rule base is as shown in table 5.1.

Table.-5.1 Rule base for fuzzy logic controller

E **CE**	**NS**	**Z**	**PS**
NS	**H**	**M**	**L**
Z	**H**	**M**	**M**
PS	**H**	**L**	**L**

- **Inference Mechanism**: It leads to determination of conclusions. This emulates the expert’s decision making in interpreting and applying knowledge. The rules are read as “if error is ‘NB’ and change in error is ‘PB’ then the reference torque is ‘ZE’”. Where the part after if called antecedent i.e. ‘NB’ and change in error is ‘PB’ and part after then is called consequent i.e. reference torque is ‘ZE’. The conjunction of the rule antecedent is evaluated by the fuzzy operation intersection, which is implemented by the *min* operator. The rule strength presents the degree of membership of the output variables for a particular rule. Defining the rule strength of a particular rule as in eqn 5.1.

$$\xi_{\mathbf{i,j}} = \mathit{min}\,(\mu_{Fi}\,, \mu_{Fj}) \qquad (5.1)$$

where

i ϵ [NB, NM, NS, ZE, PS, PM, PB] is associated with the fuzzy variable e(n) and *j* ϵ [NB, NM, NS, ZE, PS, PM, PB] is associated with the fuzzy variable Δe(n).

The fuzzy inference engine uses the appropriate designed knowledge base to evaluate the fuzzy rules and produce the output of each rule. Fig 5.4 shows the control surface generated after the inference mechanism based on the rule base.

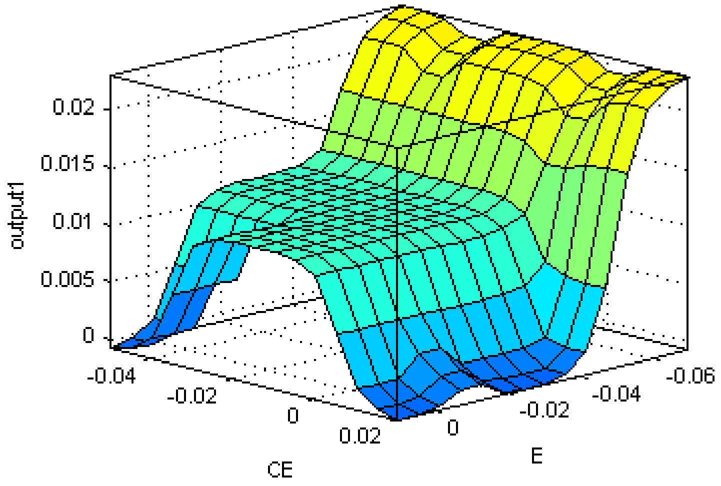


Fig.-5.4 control surface

- **Converting decisions into actions:**

De-fuzzification is the final component of the fuzzy controller, operates on the implied fuzzy sets produced by the inference mechanism and combines their effects to provide the “most certain” controller output. The centriod method is used for defuzzification. Centroid method that is used for defuzzifcation, returns the centre of area. The output is obtained using eqn. 5.2 in general.

$$\Delta S = \frac{\sum_{K=1}^{N} \mu\,(dS_K).dS_K}{\sum_{K=1}^{N} \mu\,(dS_K)} \qquad (5.2)$$

where

ΔS = the output of fuzzy logic

dS_K = discrete value of 'dS'

dS = the input to fuzzy and

$\mu(dS_K)$ = the degree of membership function associated with each 'dS_K' belonging to the active region.

To summarize the working of fuzzy functioning, the necessary inputs are applied to relative blocks by knowledge base, possessing the rule based and the data base as its sub- blocks. The fuzzifier converts crisp data into linguistic format. The decision maker decides in linguistic format with the help of logical linguistic rules supplied by the rule base and the relevant data supplied by the data base. The decision making block uses the rules in the format of "If-Then". The rule is to be read as if error is 'NB' and change in error is 'PB' then the reference torque is 'ZE'. It is defined by understanding the behavior of the system, such that rise time is low and the required torque is catered. The output of the decision-maker passes through the defuzzifier where in the linguistic format signal is converted back into the numeric form or crisp form. The denormalization is done (if required) to put the values back in physical domain.

5.3 FUZZY TUNED PID CONTROLLER

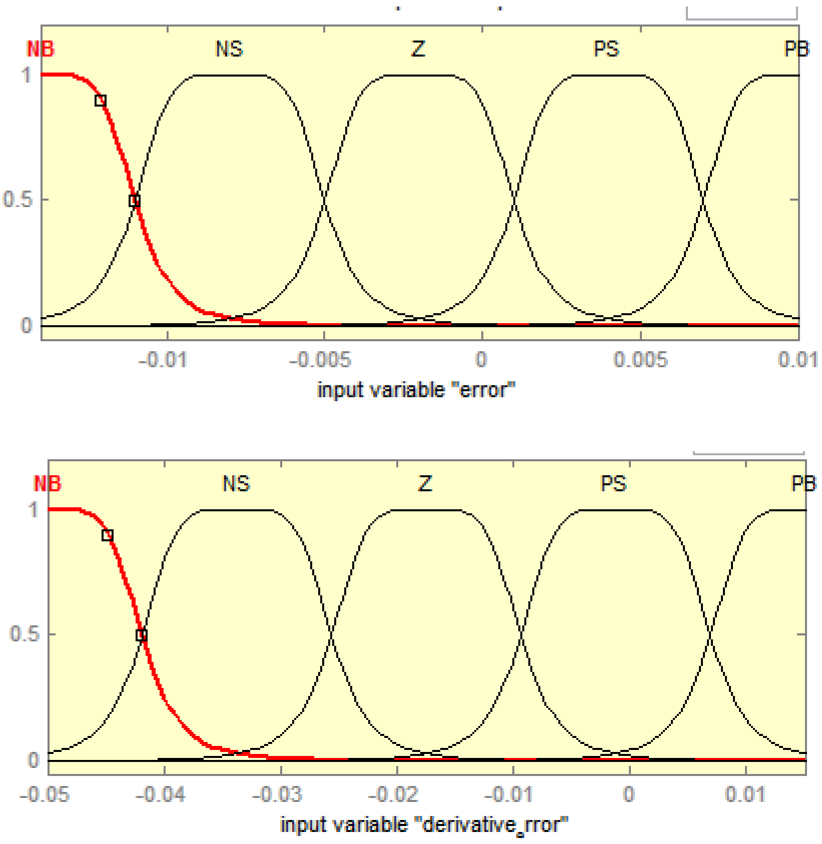
5.3.1 Principle of Fuzzy tuned PID Controller

Fuzzy logic has been useful in recent years to formalize the ad-hoc approach of PID control. A fuzzy PID controller takes the conventional PID controller as the foundation which uses the fuzzy reasoning and variable universe of discourse to regulate the PID parameters. The characteristics of a fuzzy system such as robustness and adaptability can be successfully incorporated into the controlling method for better tuning of PID parameters.

The term self-tuning refers to the characteristics of the controller to tune its controlling parameters on-line automatically so as to have the most suitable values of those parameters which result in optimization of the process output. Fuzzy tuned PID controller works on the control rules designed on the basis of theoretical and experience analysis. Therefore, it can tune the parameters K_p, K_i, and K_d by adjusting the other controlling parameters and factors on-line. This, in result makes the precision of overall control higher and hence gives a better performance than the conventional PID controller or a simple fuzzy PID controller without self-tuning ability.

5.3.2 Design and Structure of the Fuzzy tuned PID Controller

The Fuzzy tuned PID controller, which takes error "e" and rate of change-in-error "ce" as the input to the controller makes use of the fuzzy control rules to modify PID parameters on-line. The tuning of the Fuzzy tuned PID controller refers to finding the fuzzy relationship between the three parameters of PID, K_p, K_i, and K_d and "e" and "ce", and according to the principle of fuzzy control modifying the three parameters in order to meet different requirements for control parameters when "e" and "ce" are different and making the control object produce a good dynamic and static performance. The language variables of “e” ,”ce”, K_p, K_i, and K_d can be selected as 3, 5 or 7 membership functions. Here 5 linguistic variables are chosen. The region of these variables is then selected. The membership functions for e, ce, K_p, K_i, and K_d are as shown in fig. 5.5.



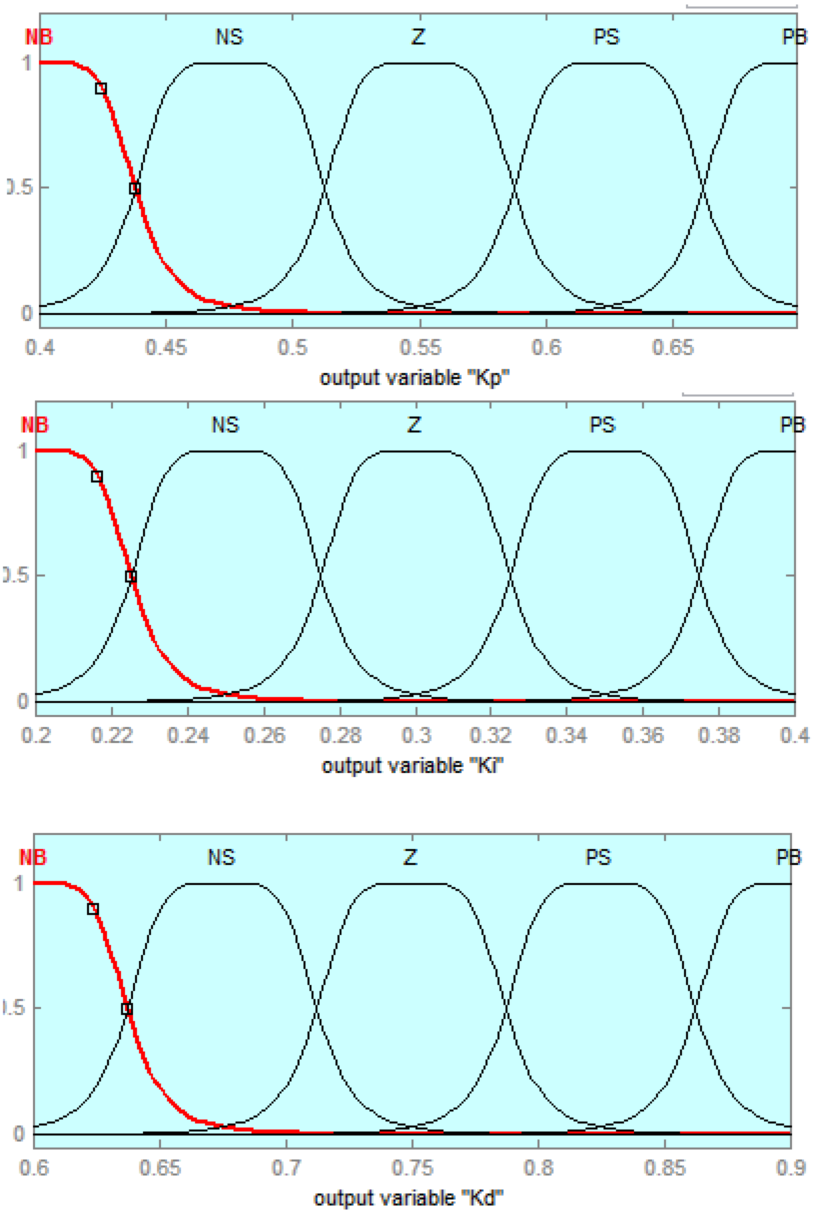


Fig.-5.5 Membership functions for inputs and outputs of Fuzzy-tuned PID controller

The block diagram of a fuzzy self-tuned PID controller is shown in fig. 5.6. As it can be seen from the block diagram, the fuzzification takes two inputs (e and ce) and gives three outputs K_p, K_i and K_d.

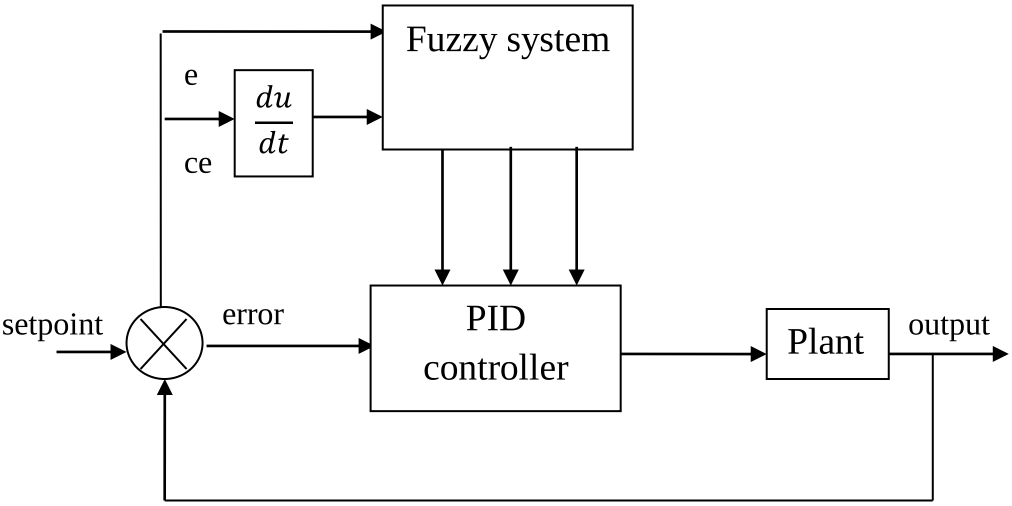


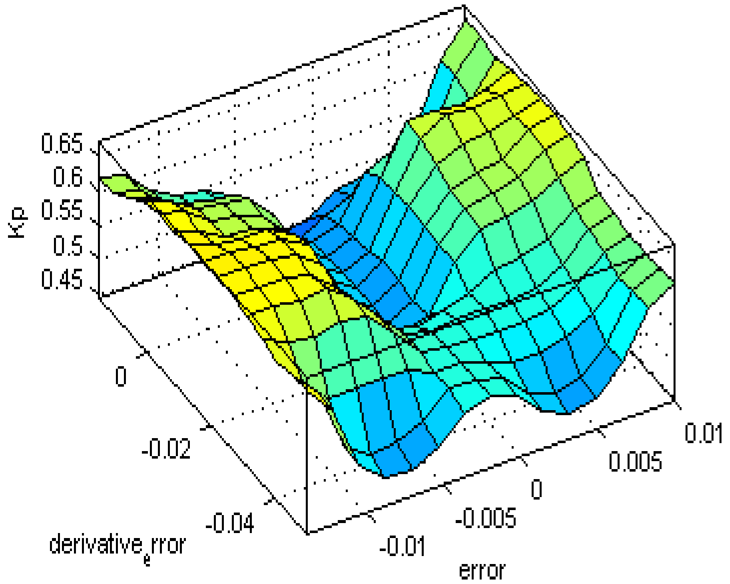
Fig.- 5.6 Basic structure of a fuzzy-tuned PID controller

The set of linguistic rules is the essential part of a fuzzy controller. In many cases it's easy to translate an expert's experience into these rules and any number of such rules can be created to define the actions of the controller. In the designed fuzzy system, conventional fuzzy conditions and relations such as: - "If e is A and ec is B, then K_p is C, K_i is D and K_d is E." are used to create the fuzzy rule table as shown in table 5.2.

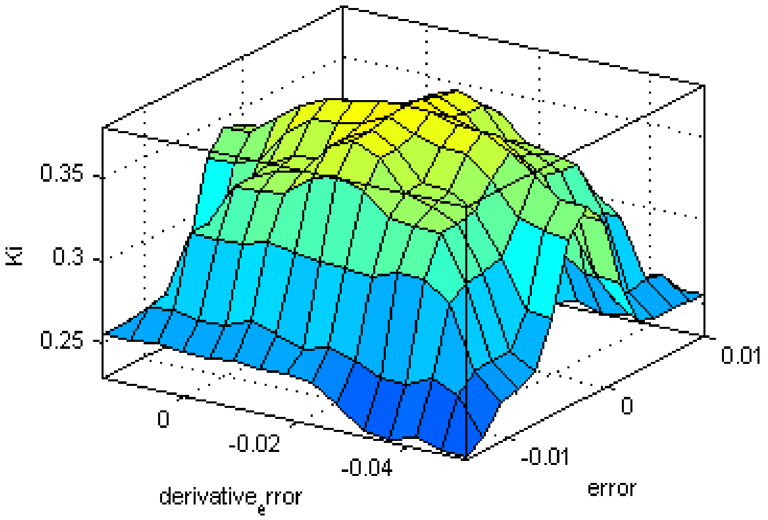
Table.-5.2 Rule base for K_p, K_i, and K_d of fuzzy tuned PID controller

E CE	NB	NS	Z	PS	PB
NB	PB,NB,NS	NS,NS,NS	Z,PS,Z	NS,NS,PS	PS,NS,PB
NS	PB,NB,PS	PB,PS,PS	Z,PB,Z	Z,PS,PS	PS,NB,PB
Z	PB,NS,PB	PB,PB,PS	NS,PB,Z	PS,PB,PS	PB,NB,PB
PS	PB,NS,PB	PS,PS,PS	NS,PB,Z	PB,PS,PS	PB,NS,PB
PB	PS,NS,PB	Z,NS,Z	NB,PS,NS	NS,Z,PS	PB,NS,PB

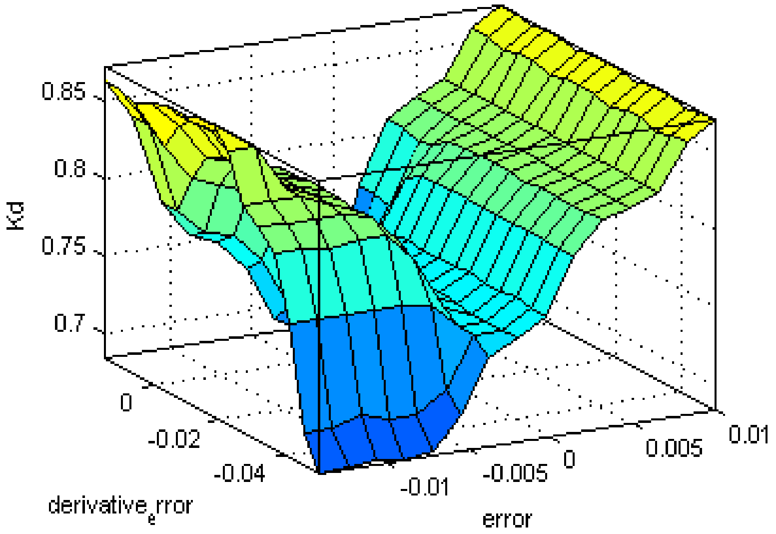
The control surfaces for K_p, K_i, and K_d after the inference mechanism based on the above rules are shown in fig. 5.7.



(a)



(b)



(c)

Fig.-5.7 control surfaces for (a) K_p,(b) K_i, and (c) K_d using fuzzy-tuned PID controller

5.3.3 Advantages of fuzzy-tuned PID controller

The followings are the advantages of fuzzy-tuned PID controller over the conventional PID controller:

- The traditional PID controller cannot self-tune parameters K_p, K_i and K_d while operating.
- Combining fuzzy inference with traditional PID method, PID parameters can be realized.
- By designing a fuzzy-tuned PID controller based on conventional PID, the decisions can be made through fuzzy reasoning rules according to the size, the direction and the changing tendency of the system error together with the dynamic changing of process characteristics.
- In practical applications, to different extent, most of the industrial processes exist to be nonlinear, the variability of parameters and the uncertainty of model are very high, thus, using conventional PID control the precise control of the process cannot be achieved.
- The dependence of fuzzy control on the mathematical model is weak, so it isn't necessary to establish the precise mathematical model of the process, and the fuzzy control has a good robustness and adaptability.

- The simulation results shows that: compared with the traditional PID controller, fuzzy tuned PID controller has a better dynamic response curve, shorter response time, small overshoot, high steady precision, good static and dynamic performance.

5.3.4 Shortcomings of fuzzy-tuned PID controller

Although fuzzy-tuned PID controller gives a better output response than the conventional PID controller, it also has some problems with its design and tuning methods. These problems are mainly due to the vagueness associated with the fuzzy method. Followings are the disadvantages of a PID controller based on fuzzy logic method:

- It uses the mode of approximate reasoning and decisions are made on vague and incomplete information similar to that of human beings.
- The choice of overall control structure can also be a big problem in some cases.
- In designing of the fuzzy logic controller not only the structural parameters need to be designed but also the gain of the conventional controller need to be tuned.
- Because of its complicated cross-effects analytical tuning algorithm for these parameters are really difficult.

5.4 HYBRID NEURO-FUZZY CONTROLLER

Every intelligent technique has particular computational properties e.g. ability to learn, explanation of decisions that make them suited for particular problems and not for others. It has been observed, while neural networks are good at recognizing patterns, they are not good at explaining how they reach their decisions and Fuzzy logic systems, which can reason with imprecise information, are good at explaining their decisions but they cannot automatically acquire the rules they use to make those decisions. These limitations have been a central driving force behind the creation of intelligent hybrid systems where two or more techniques are combined in a manner that overcomes the limitations of individual techniques. The use of intelligent hybrid systems is growing rapidly with successful applications in many areas including process control, engineering design, financial trading, credit evaluation, medical diagnosis, cognitive simulation, pattern recognition and image processing, etc.

Neural networks are used to tune membership functions of fuzzy systems that are employed as decision- making systems for controlling equipment. Although fuzzy logic can encode expert knowledge directly using rules with linguistic labels, it usually takes a lot of time to design and tune the membership functions which quantitatively define these linguistic labels. Neural network learning techniques can automate this process and substantially reduce development time and cost while improving performance. In theory, neural networks, and fuzzy systems are equivalent in that they are convertible, yet in practice each has its own advantages and disadvantages.

For neural networks, the knowledge is automatically acquired by the back propagation algorithm, but the learning process is relatively slow and analysis of the trained network is difficult. Neither is it possible to extract structural knowledge (rules) from the trained neural network, nor can we integrate special information about the problem into the neural network in order to simplify the learning procedure.

Fuzzy systems are more favorable as their behavior can be explained based on fuzzy rules and thus their performance can be adjusted by tuning the rules. But since, in general, knowledge acquisition is difficult and also the universe of discourse of each input variable needs to be divided into several intervals, applications of fuzzy systems are restricted to the fields where expert knowledge is available and the number of input variables is small. To overcome the problem of knowledge acquisition, neural networks are extended to automatically extract fuzzy rules from numerical data. Cooperative approaches use neural networks to optimize certain parameters of an ordinary fuzzy system, or to preprocess data and extract fuzzy rules from data.

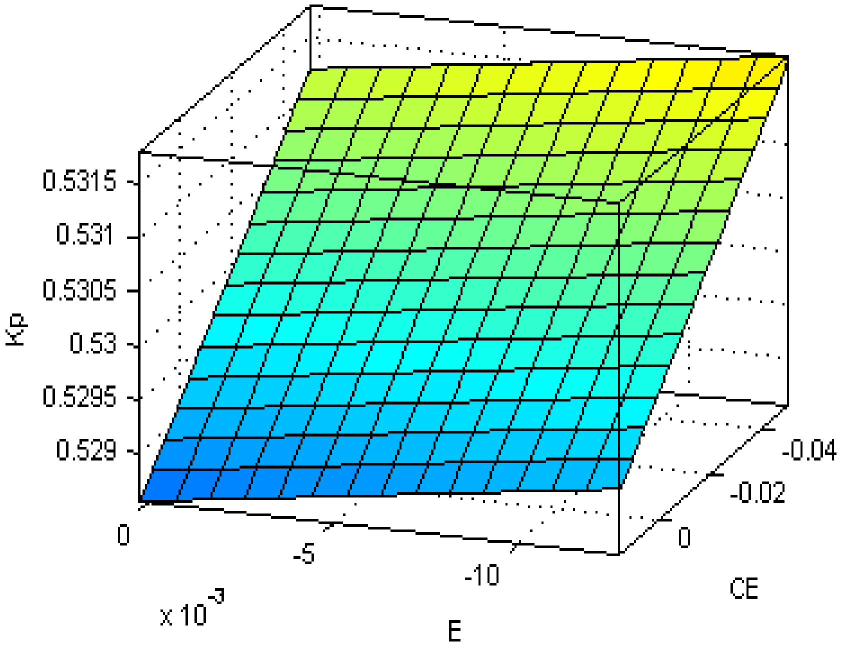
In brief, a Neuro-Fuzzy system is a fuzzy system that uses a learning algorithm derived from neural network theory to determine its parameters (fuzzy sets and fuzzy rules) by processing data samples.

The Steps to design HNF Controller are as follows:

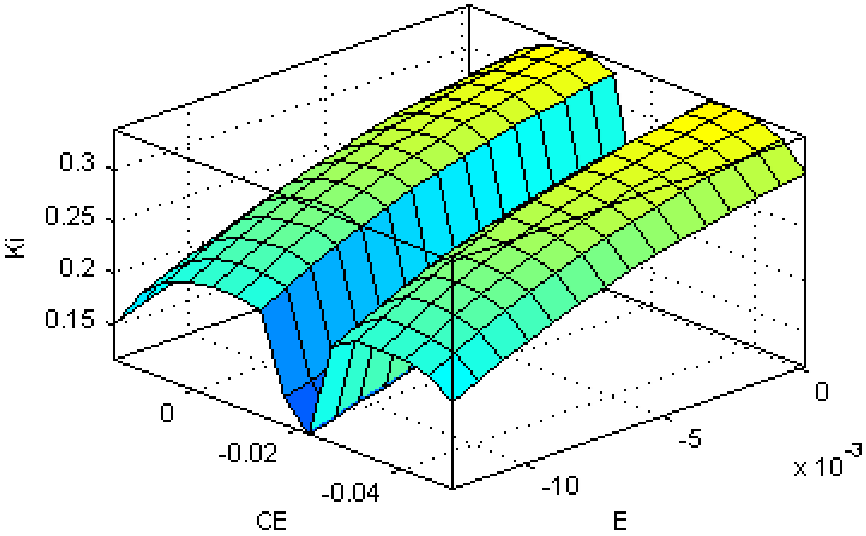
- Draw the SIMULINK model with FLC and simulate it with the given rule base.
- The first step to design the HNF controller is collecting the training data while simulating with FLC.
- The two inputs, i.e., ACE and d(ACE)/dt and the output signal gives the training data.

- Use anfisedit to create the HNF .fis file.
- Load the training data collected in Step.1 and generate the FIS with gbell MF's.
- Train the collected data with generated FIS upto a particular no. of Epochs.

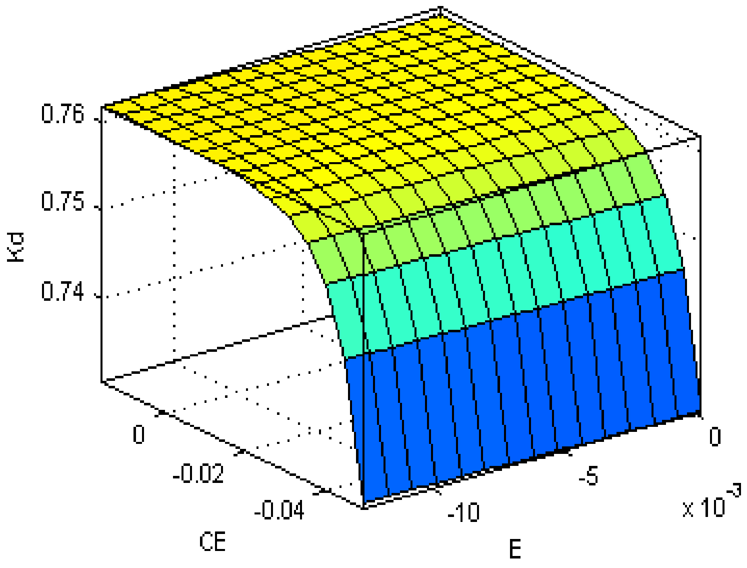
These steps are followed in order to develop HNF tuned PID controller. The optimized control surfaces given by the HNF controller are shown below in fig. 5.8.



(a)



(b)



(c)

Fig.-5.8 control surfaces for (a) K_p, (b) K_i, and (c) K_d using Hybrid Neuro-fuzzy controller

All the controllers discussed so far are modeled for load frequency control using MATLAB/SIMULINK environment in the next chapter. These controllers include PI, PID, Fuzzy, Fuzzy tuned PID and Hybrid Neuro- Fuzzy controllers. These controllers are developed for single area LFC. To understand the complexity of a multi-area LFC, a two-area LFC is also developed using PID controller.

CHAPTER-6

SIMULINK MODELING AND RESULTS

6.1 INTRODUCTION

In order to perform real simulation of load frequency control, the model is developed in MATLAB environment using SIMULINK. The simulations are carried out in the following section with the various controllers for single area, already discussed in the previous chapters. For realistic understanding of LFC, the problem is also extended to two area power system using PID controller only. The results of each model are also shown in the next section. At the end of this chapter, comparative analysis of the result is provided for better understanding of the performance of the controllers in terms of overshoot, settling time etc.

6.2 SIMULINK MODELING OF LFC

The controllers for LFC realized using the SIMULINK toolbox are namely, proportional integral (PI) controller, proportional integral derivative (PID) controller, Fuzzy logic controller, Fuzzy-tuned PID controller and Hybrid Neuro-Fuzzy controller.

6.2.1 Single Area LFC Using PI Controller

The LFC model is developed using PI controller as shown in fig.-6.1. The PI controller produces the required control signal. The controller’s operation has been discussed in the previous sections. The parameters of the controller i.e. the gains Kp and Ki are tuned for better result using Ziegler-nicholes method. The specifications of speed governor, turbine, speed regulation, load demand change and the parameters of the controller are provided in the appendix.

Some of this work has already been published under the title of “Comparative analysis of single area load frequency control using PI, PID and Fuzzy tuned PID controllers” in International Journal of Applied Engineering Research, Vol. 8 No. 8, 2013, (68-71).

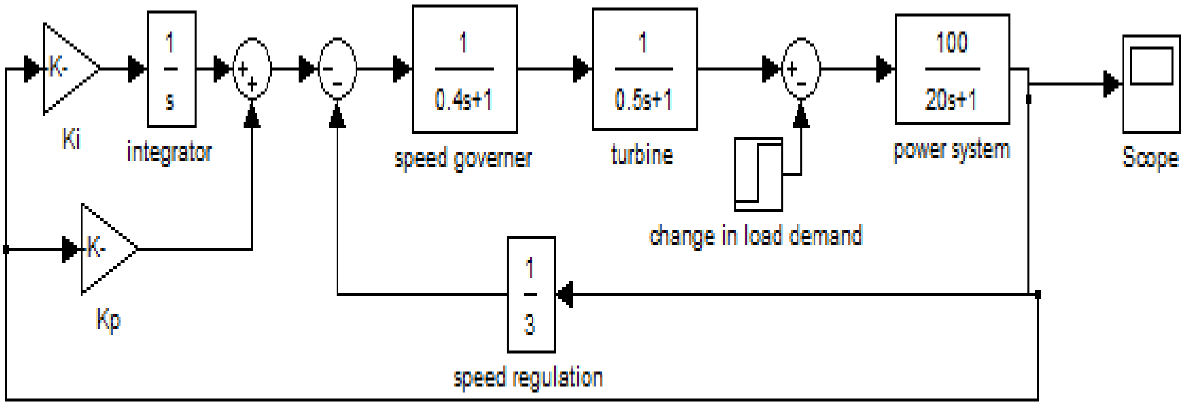


Fig.-6.1 SIMULINK model of LFC using PI controller

6.2.2 Single Area LFC Using PID Controller

In PID, three parameters need to be tuned, KP, Ki and Kd. So, it's difficult to tune as compared to PI. But when this controller is best tuned, it gives great results. The basic operating equations have been stated in the previous sections. Using the proportional (Kp), the Integral (KI) and the Derivative (KD) gain parameters the reference signal is generated by the PID controller, hence the desired output is achieved. PID controlled LFC is shown in fig. 6.2

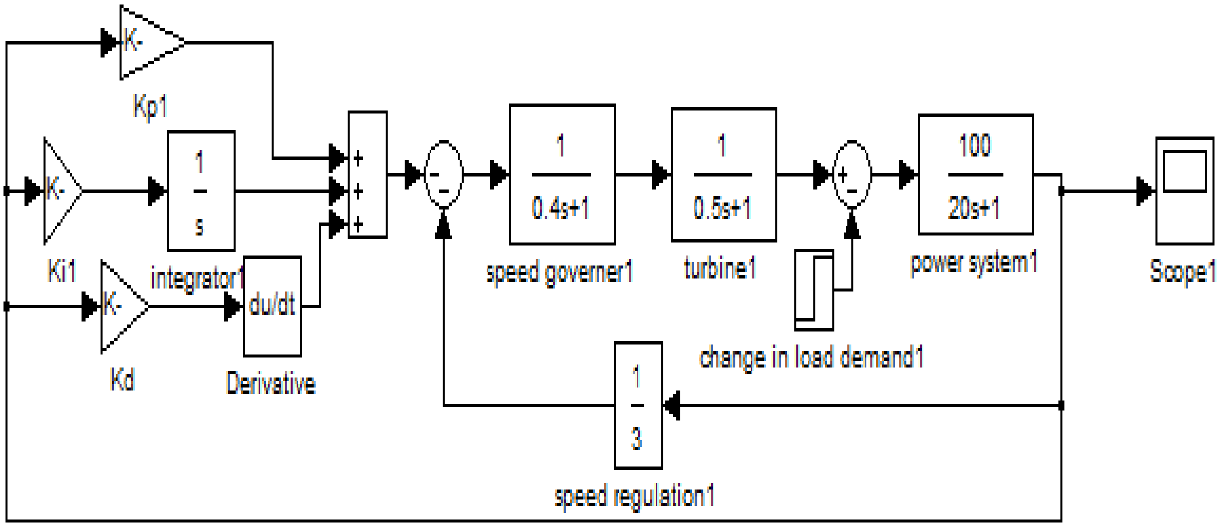
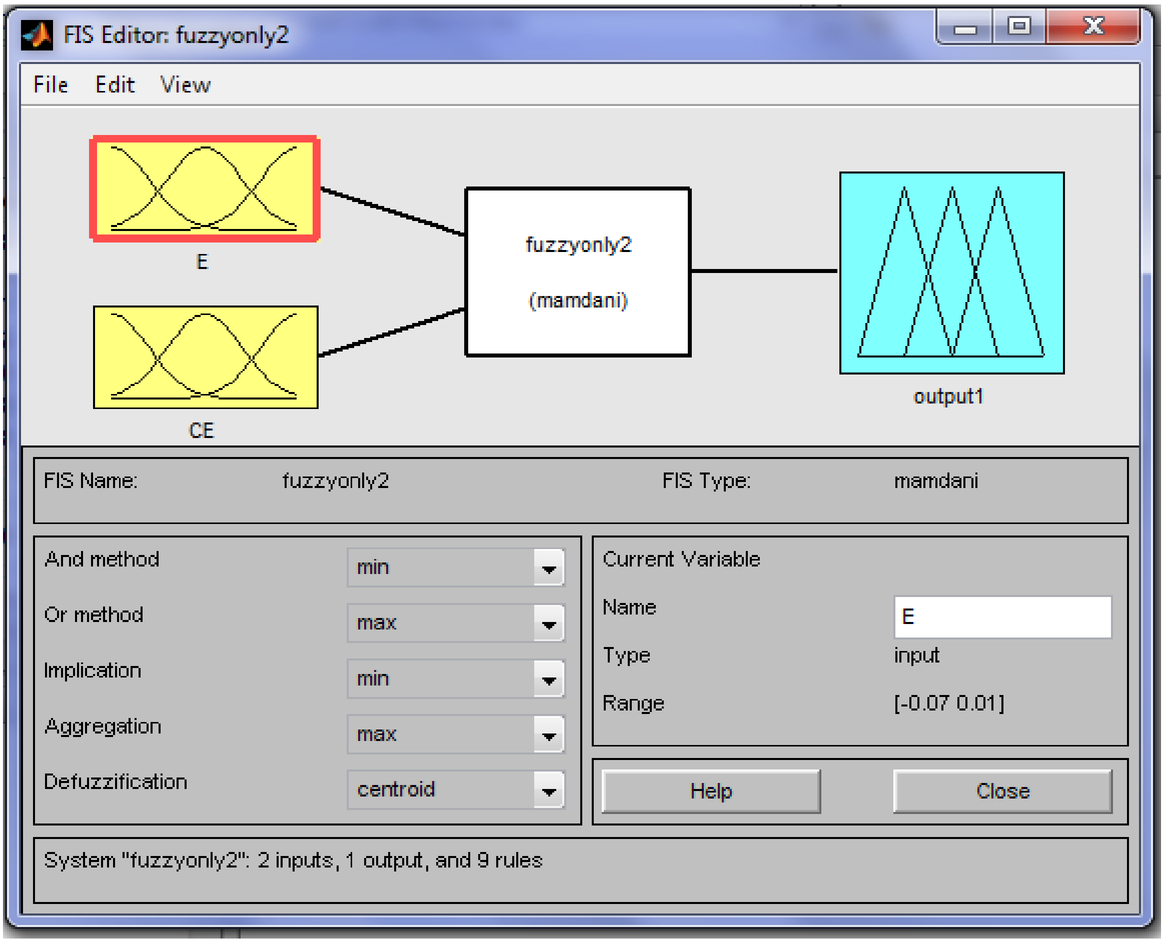


Fig.-6.2 SIMULINK model of LFC using PID controller

6.2.3 Single Area LFC Using Fuzzy Logic Controller

To design Fuzzy logic controller, Fuzzy rule base needs to be formulated. Fuzzy rule base depends upon the knowledge of the system. The better the knowledge of the system and experience, the better is the rule base and the better is the performance. The controller takes two inputs and gives one output. In this controller, three membership functions are taken for two inputs i.e. change in frequency taken as error (e) and its derivative taken as change in error (ce) and controller output. Mamdani type of inference system is considered as can be seen in the fig. 6.3.



FIS Name: fuzzyonly2
FIS Type: mamdani

And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid

Current Variable
Name: E
Type: input
Range: [-0.07 0.01]

System "fuzzyonly2": 2 inputs, 1 output, and 9 rules

Fig.-6.3 FIS editor of Fuzzy logic controller

The model of Fuzzy logic controlled LFC is shown in fig. 6.4.

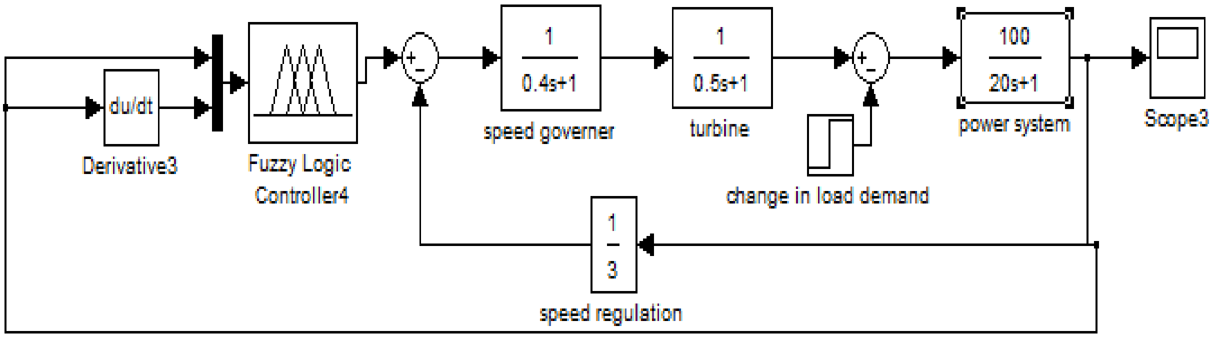


Fig.-6.4 SIMULINK model of LFC using Fuzzy logic controller

6.2.4 Single Area LFC Using Fuzzy-Tuned PID Controller

Fuzzy tuned PID controller works on the control rules designed on the basis of theoretical and experience analysis. It can tune the parameters Kp, Ki, and Kd by adjusting the other controlling parameters and factors on-line. This, in result makes the precision of overall control higher and hence gives a better performance than the conventional PID controller or a simple fuzzy controller. In this controller, five membership functions (NB, NS, Z, PS, PB) are taken for input i.e. e and ce as well as for outputs i.e. KP, Ki and Kd. The range is decided with the prior knowledge of variables. The membership functions and the control surfaces along with the rule base have been revealed in the previous chapter. The SIMULINK model of Fuzzy tuned PID controller is shown in fig. 6.5.

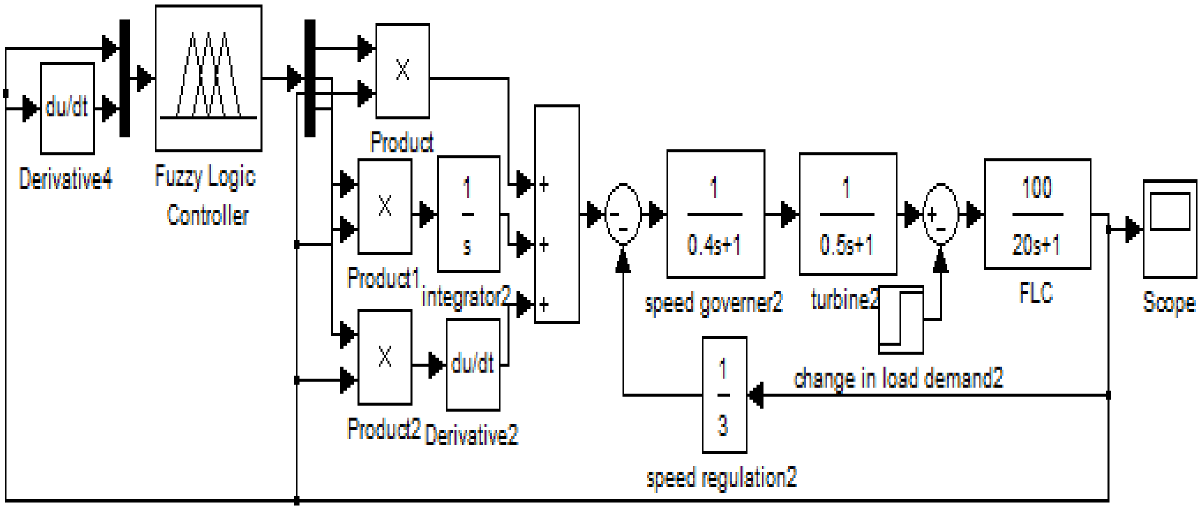
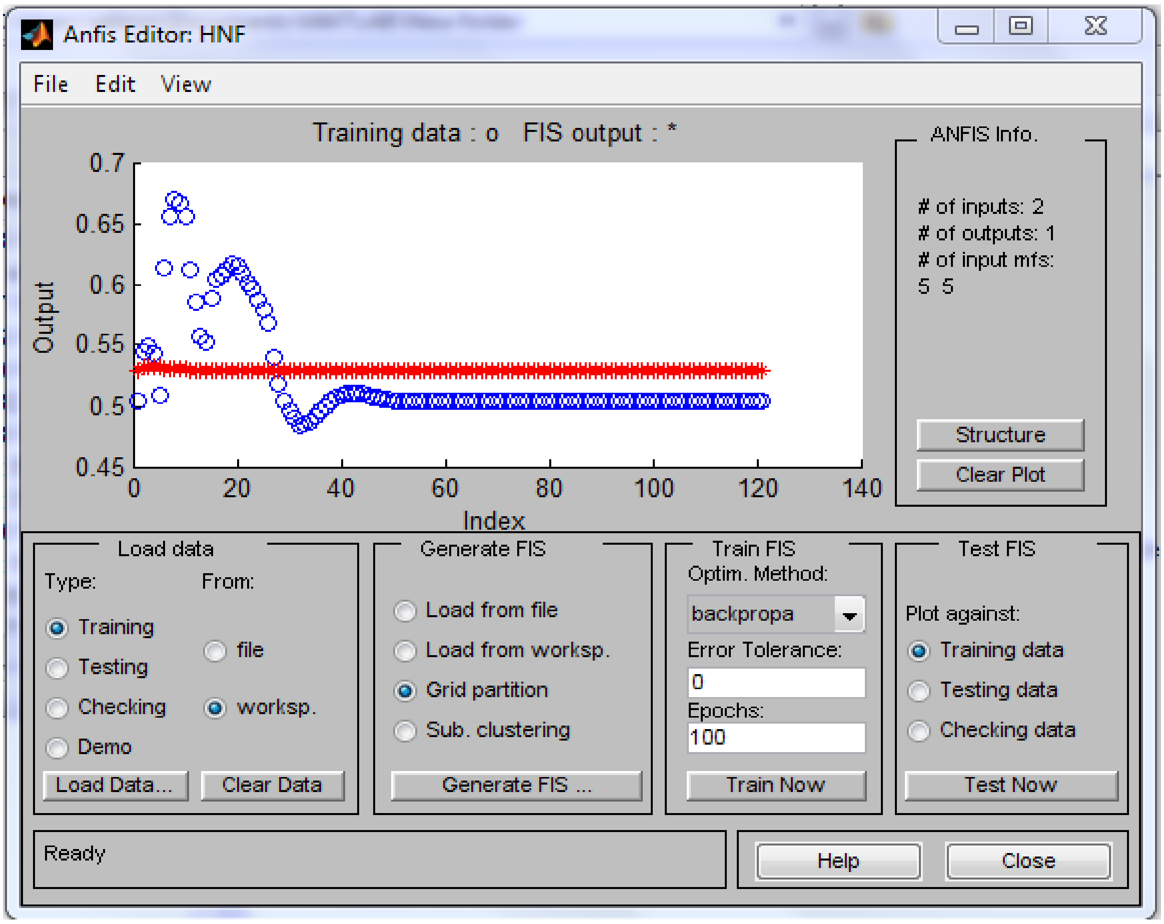


Fig.-6.5 SIMULINK model of LFC using Fuzzy-tuned PID controller

6.2.5 Single Area LFC Using Hybrid Neuro-Fuzzy Controller

This controller is a hybrid combination of fuzzy logic and neural network. Neural networks are used to tune membership functions of fuzzy systems that are employed as decision- making systems for controlling equipment. Although fuzzy logic can encode expert knowledge directly using rules with linguistic labels, it usually takes a lot of time to design and tune the membership functions which quantitatively define these linguistic labels. Neural network learning techniques can automate this process and substantially reduce development time and cost while improving performance.

The HNF controller is realized using ANFIS editor in MATLAB/SIMULINK. The ANFIS editor is shown in fig. 6.6.



Anfis Editor: HNF

ANFIS Info.

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

Load data
Type:
● Training
○ Testing
○ Checking
○ Demo
From:
○ file
● worksp.

Generate FIS
○ Load from file
○ Load from worksp.
● Grid partition
○ Sub. clustering

Train FIS
Optim. Method: backpropa
Error Tolerance: 0
Epochs: 100

Test FIS
Plot against:
● Training data
○ Testing data
○ Checking data

Ready

Fig.-6.6 ANFIS editor of Hybrid Neuro-Fuzzy controller

This editor takes the training input and based upon the data provided it trains the neural network which regulates the parameters of the fuzzy controller. In this, the controller only provides one output for every two input. Therefore, three controllers are used. The

The MATLAB model diagram for the HNF controller is shown in fig. 6.7.

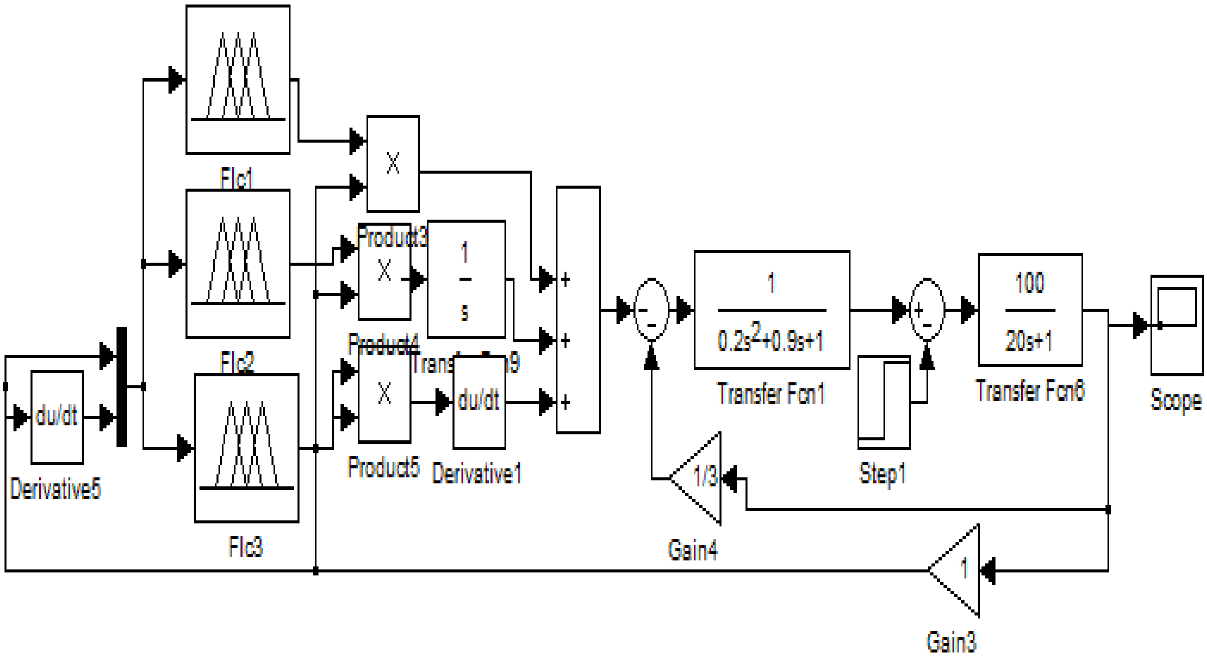


Fig.-6.7 SIMULINK model of LFC using Hybrid Neuro-Fuzzy controller

6.2.6 Two Area LFC Using PID Controller

In an interconnected power system, different areas are connected with each other via tie-lines. When the frequencies in two areas are different, a power exchange occurs through the tie-line that connected the two areas. The goals of LFC in two area are to keep frequency approximately at the nominal value, to maintain the tie-line flow at scheduled value and that each area should absorb its own load changes. The model of LFC of two are power system is shown in fig. 6.8. For simplicity, both the areas are taken as equivalent. The step changes in the load in both the areas are applied simultaneously and are equal to 0.01 pu.

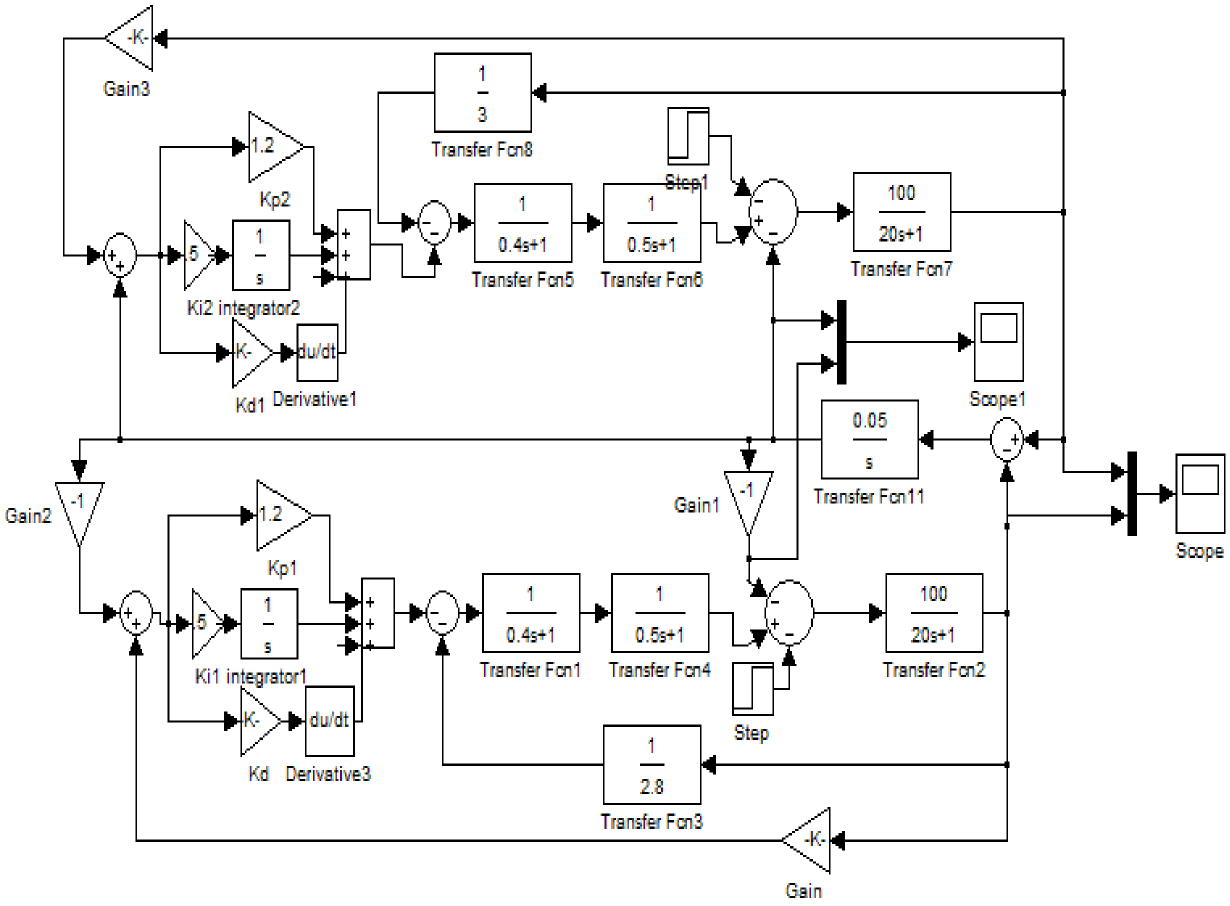


Fig.-6.8 SIMULINK model of two area LFC using PID controller

The detailed modeling, analysis, design and simulation of the PI controller, the PID controller, the Fuzzy logic controller, Fuzzy-tuned PID controller and Hybrid Neuro-Fuzzy controller have been described in this section. The simulation results of these models are presented in the next section.

6.3 RESULTS

In the following section, the simulation models developed so far are simulated for a fixed step load perturbation. It is considered as 1% or 0.01 pu. The simulation time for each model is kept same and is 50 sec. The results obtained are plotted to depict their effectiveness. Finally the results obtained from the different controllers are compared in terms of performance –good rise time and settling time.

6.3.1 Response of the Single Area LFC with a PI controller

The simulation model of the LFC is simulated using the developed PI controller and the response is observed as shown below in fig. 6.9.

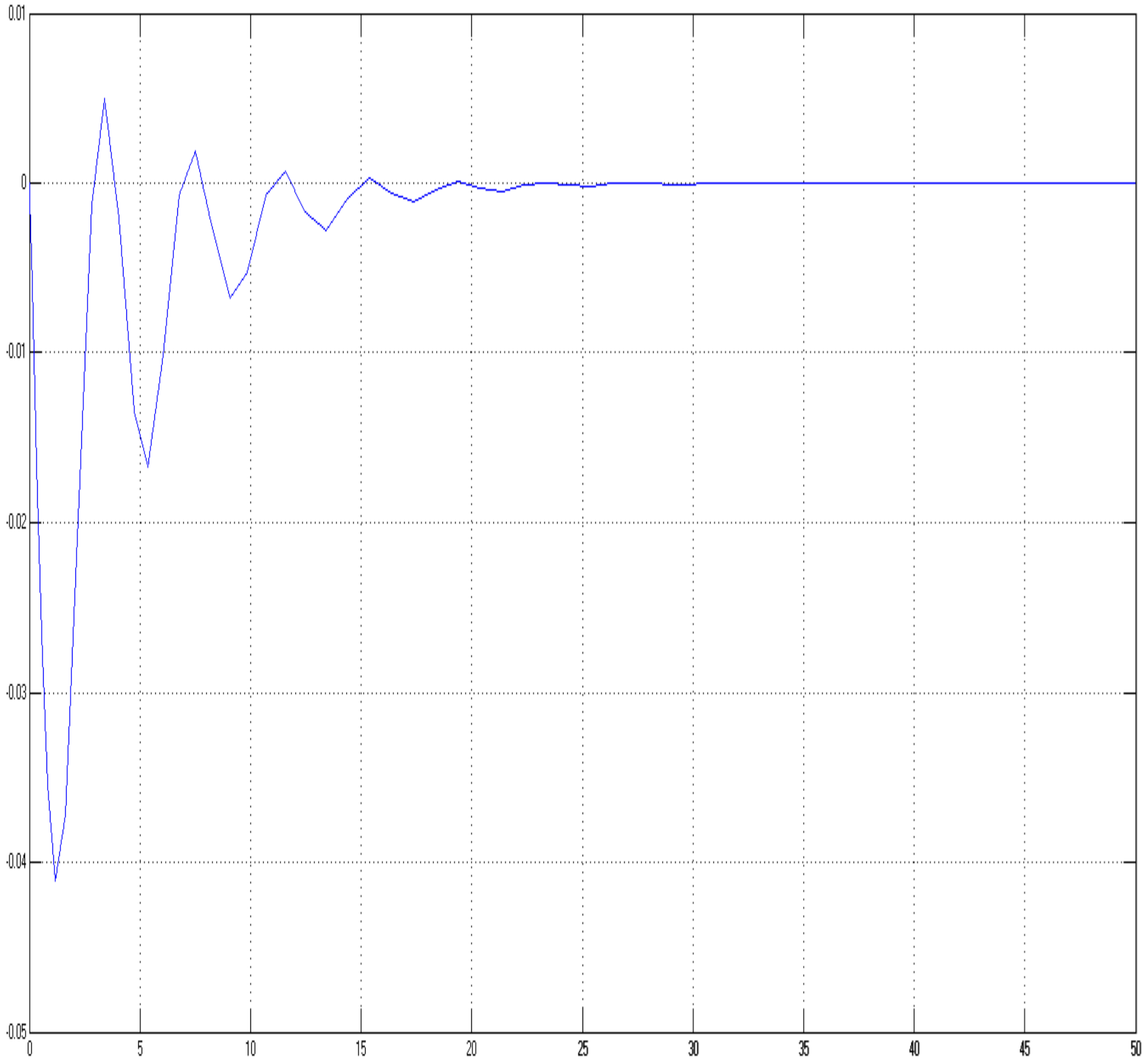


Fig.-6.9 Response of single area LFC using PI controller

The response of LFC with PI controller is very sluggish in nature as can be seen from the figure. It takes 21.7 sec to settle down to its steady state value i.e. zero. The maximum undershoot of the response is also very high which is not at all desirable.

6.3.2 Response of the Single Area LFC with a PID controller

PID controller is the most widely used controller as it gives satisfactory response as can be seen in the fig. 6.10. The response has low rise time and also settles down very quickly as compared to the response attained with PI controller. It takes 7.4 sec for frequency to settle down due to the load perturbation. The undershoot has also reduced by using PID controller but the overshoot has slightly increased.

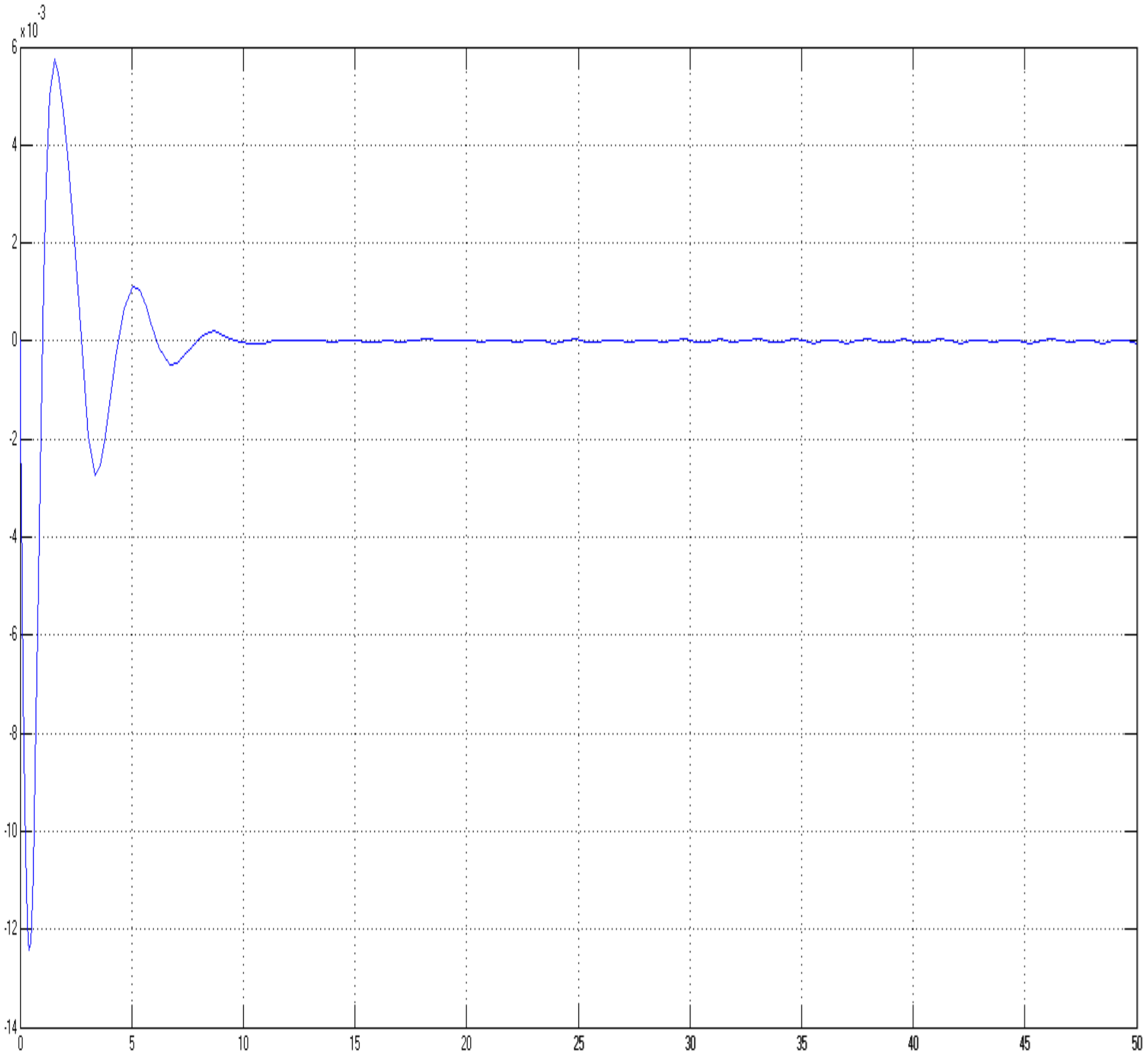


Fig.-6.10 Response of single area LFC using PID controller

6.3.3 Response of the Single Area LFC with a Fuzzy logic controller

The response attained with Fuzzy logic controller is shown in fig. 6.11. The overshoot vanishes with the fuzzy logic controller but the undershoot has increased from the response achieved with PID controller. The response of frequency deviation settles after 11 sec. The steady state error is also present. The response can be improved to a great extent by using Fuzzy-tuned PID controller.

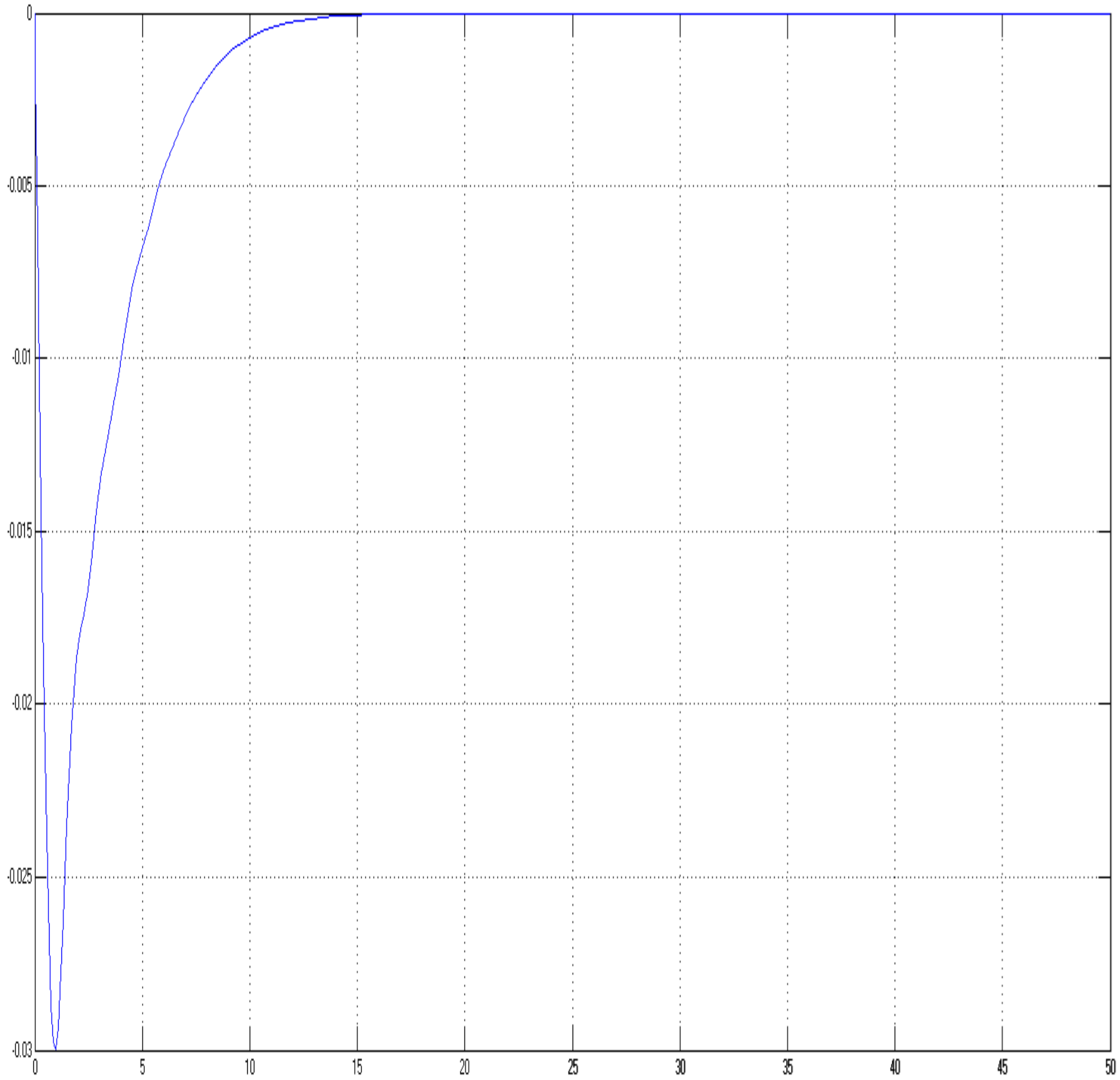


Fig.-6.11 Response of single area LFC using Fuzzy logic controller

6.3.4 Response of the Single Area LFC with a Fuzzy-Tuned PID controller

The fuzzy tuned PID controller uses the intelligence of Fuzzy logic controller to tune the gains of the PID controller and hence gives optimum results. This fact can be validated by the response shown in fig. 6.12. The rise time and the settling time have improved immensely to give an excellent response. The undershoot also have been reduced as compared with the previous controller output. There is also no offset present in the response.

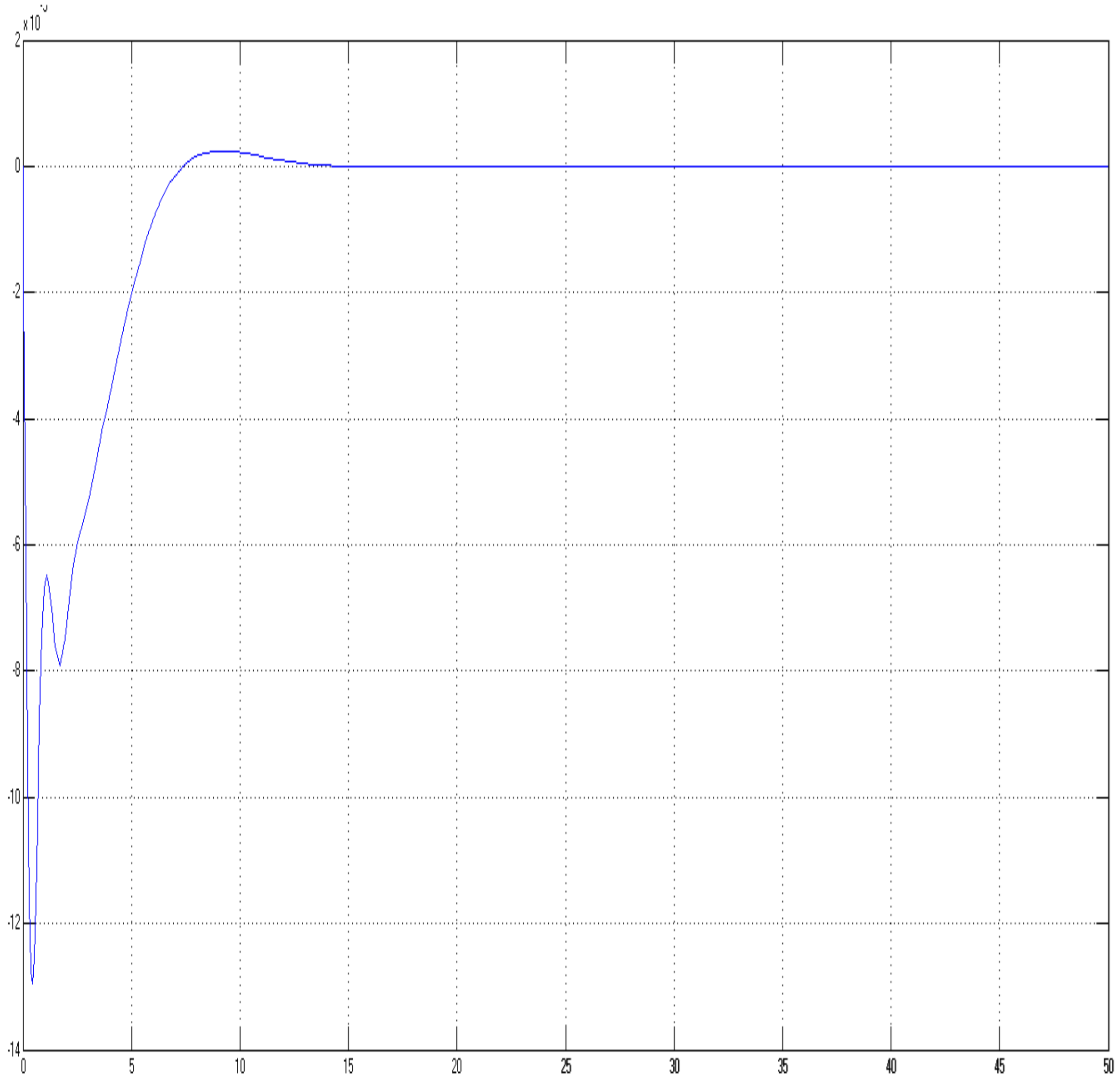


Fig.-6.12 Response of single area LFC using Fuzzy-Tuned PID controller

6.3.5 Response of the Single Area LFC with a Hybrid Neuro-Fuzzy controller

In this controller, Sugeno type of Fuzzy inference system (FIS) is used. This controller is realized using ANFIS editor. The response obtained is very much analogous to the response from Fuzzy-tuned PID controller with very slight variations. This controller is however, very easy to realize with minimal effort from the designer. The response of HNF controller is as shown in fig. 6.13.

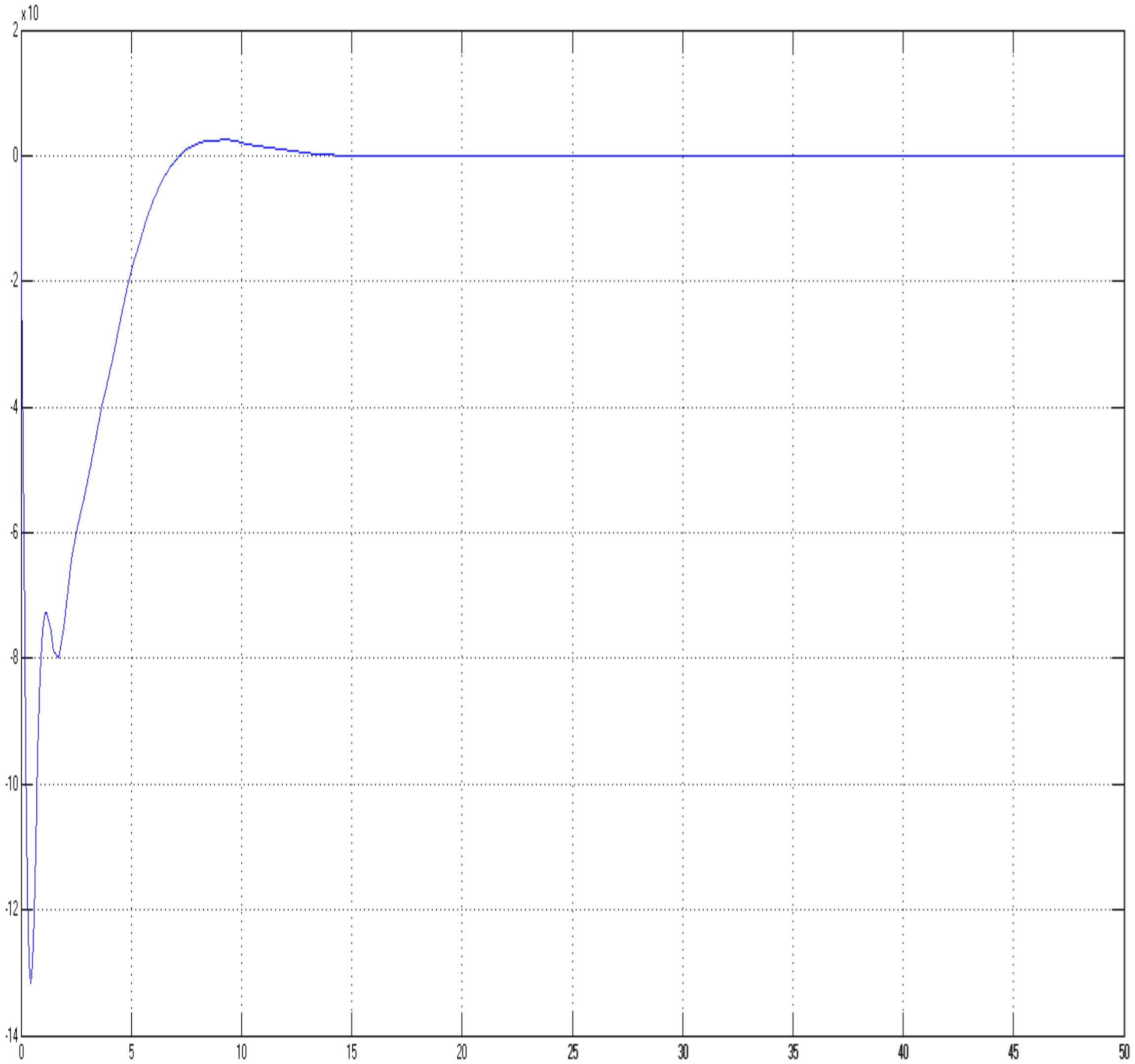


Fig.-6.13 Response of single area LFC using Hybrid Neuro-Fuzzy controller

6.3.6 Response of the all the Controllers for Single Area LFC

The response of the frequency variation of all the controllers developed so far is compiled on a single graph as shown in fig. 6.14. It helps in better evaluation and understanding of the results on a comparative basis. From the response, it can be seen that Fuzzy tuned PID controller have the no overshoot, lowest undershoot and also the settling time is the lowest, while the response of the PI controller is the most sluggish.

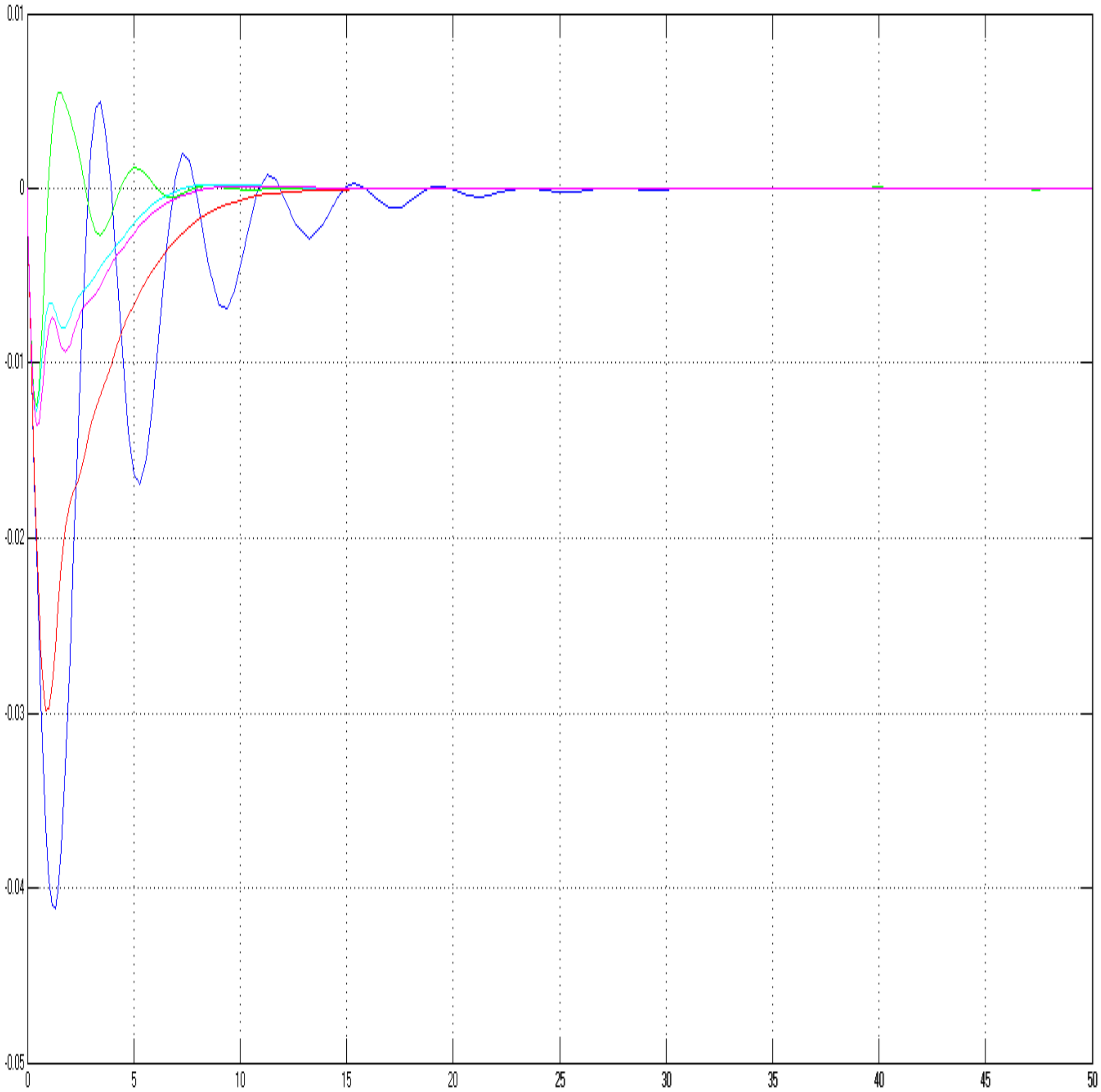


Fig.-6.14 Response of all the controllers (-----PI),(-----PID),(-----Fuzzy logic), (----- Fuzzy-tuned PID) and (-----HNF) for single area LFC

All the facts mentioned before can be visualized easily with the comparison provided in table 6.1 in terms of rise time and settling time. From all the response, Fuzzy tuned PID controller takes only 6.5 sec to settle down. In terms of good rise time we can rely on PID controller.

Table 6.1. The comparison of PI, PID Fuzzy logic, Fuzzy tuned PID and HNF controller

Controller used	Rise Time (sec)	Settling Time (sec)
PI	2.67	21.7
PID	0.80	7.4
Fuzzy logic	5.73	11
Fuzzy tuned PID	3.2	6.52
HNF	3.65	7.3

6.3.7 Response of the Two Area LFC with A PID Controller

After developing all the controllers for single area LFC, two area LFC is also developed with two equivalent areas. The parameters specification for the two area LFC is also provided in the appendix. By evaluating the response of the controllers designed for single area, it is found that PID controller gives comparable results with the intelligent controllers. If a little compromise can be made with the settling time, it gives great result with the advantage of its simplicity.

The results of frequency variation in area-1 and area-2 are shown in Fig. 6.15 and 6.16 respectively. The response is fast as it settles down quickly. The tie-line power variations for area-1 and area-2 are very low as depicted in fig. 6.17 and 6.18 respectively.

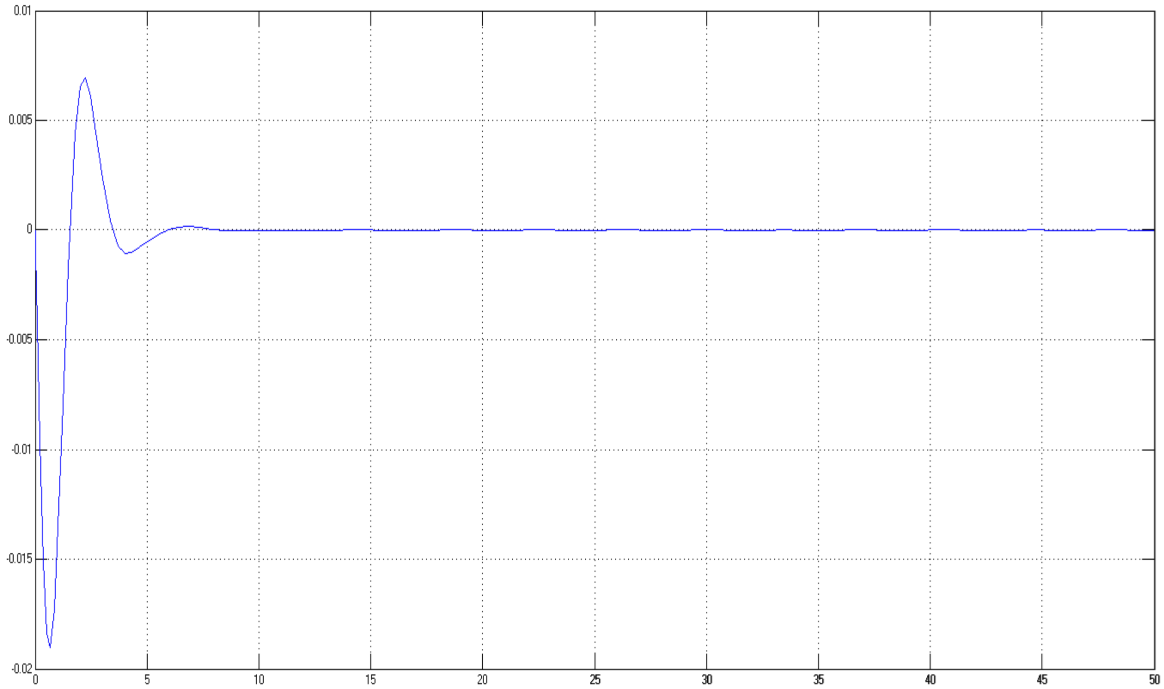


Fig.-6.15 Response of frequency variation in area-1 of two area LFC

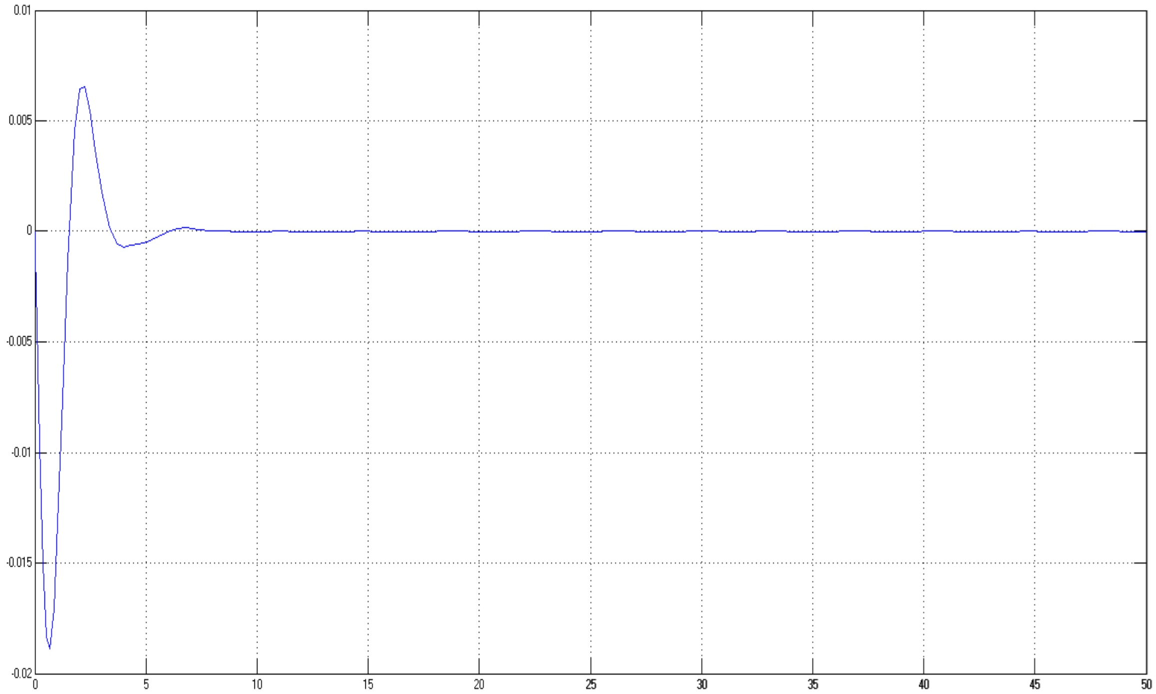


Fig.-6.16 Response of frequency variation in area-2 of two area LFC

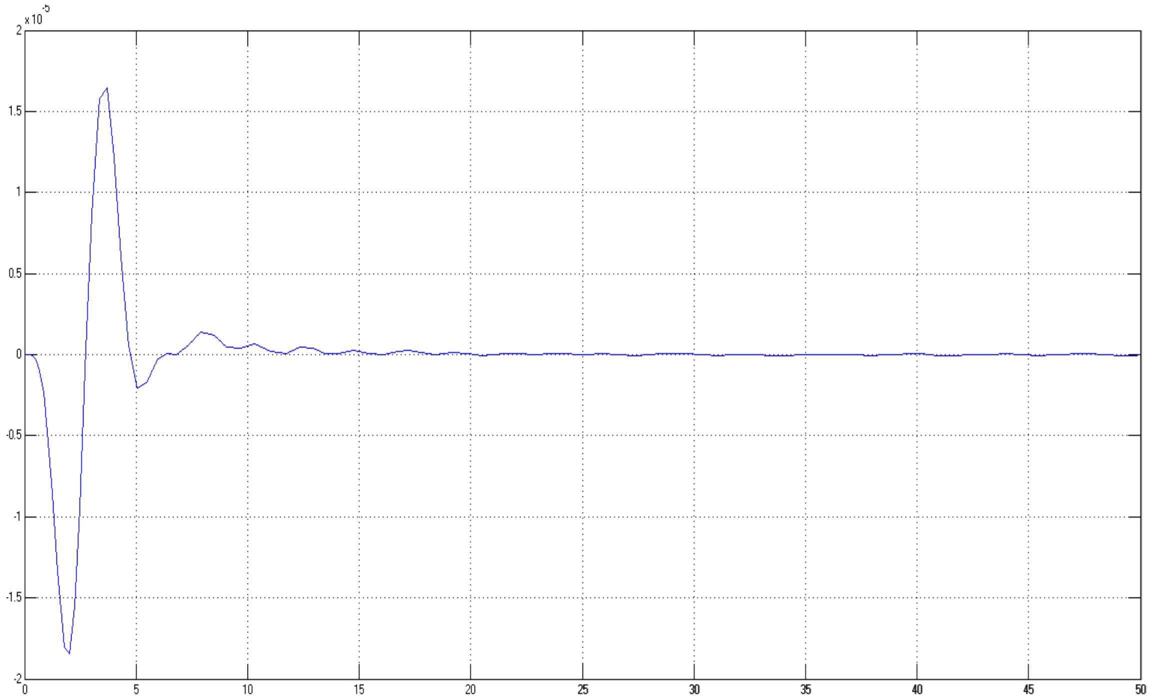


Fig.-6.17 Response of Tie-line power in area-1 of two area LFC

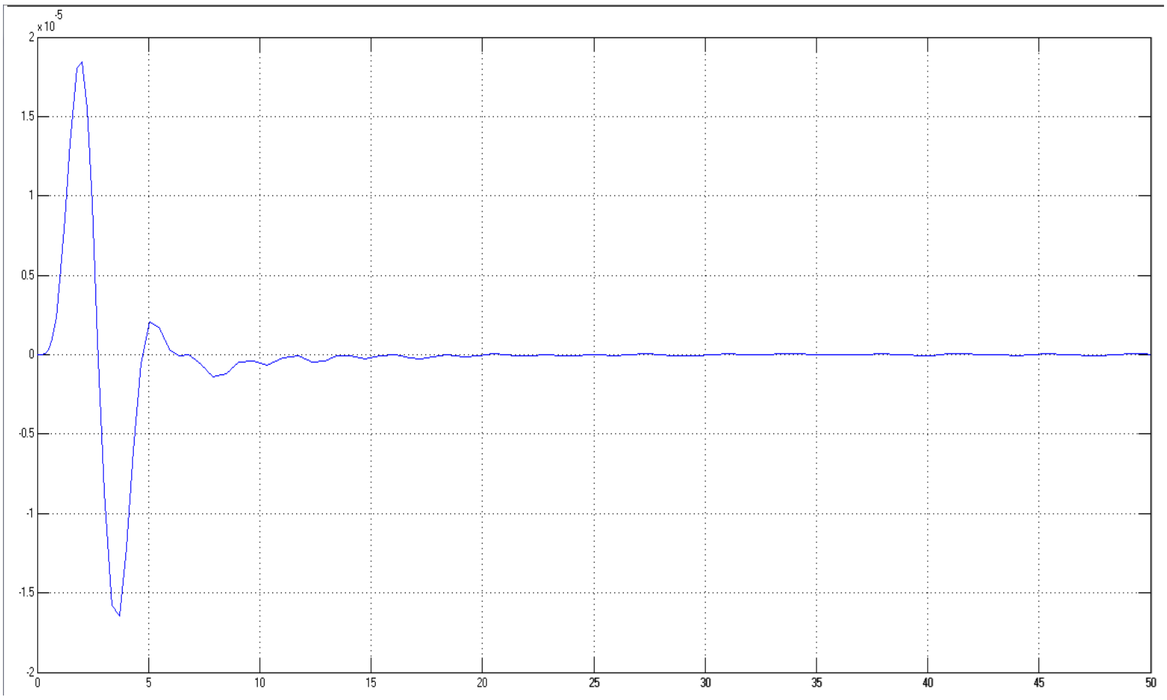


Fig.-6.18 Response of tie-line power in area-2 of two area LFC

After complete analysis of the results obtained with the various controllers, the result is concluded in the next chapter.

CHAPTER-7

CONCLUSION AND SCOPE OF FUTURE WORK

7.1 CONCLUSION

The modeling of load frequency control with different type of controllers has been successfully carried out using MATLAB/SIMULINK environment. Different controllers i.e. PI controller, PID controller, Fuzzy logic controller, Fuzzy tuned PID controller, and hybrid Neuro-Fuzzy controller are used for simulation study for assessment of the dynamic performance of LFC.

In MATLAB/SIMULINK environment, the Sim Power Systems, Fuzzy logic tool box and ANFIS tool box have been extensively used to carry out simulations of LFC using various controllers.

The conventional PI and PID controllers for LFC are very simple in designing but the tuning of their gains is a cumbersome problem. These controllers are widely used because of their maturity and simplicity. But the dynamic response obtained with these controllers can be improved to a great extent by using intelligent controllers.

To further improve the response, Fuzzy logic is applied to tune the gains of PID controller in Fuzzy tuned PID controller. The integration of both PID and FLC is done in such a way in Fuzzy tuned PID controller, so as to reap the advantages of both and avoiding their short comings.

In hybrid Neuro-Fuzzy controller, the controller is designed using ANFIS tool box. By using this tool box, the complexity of designing rule base for fuzzy logic controllers is ruled out. Not only the rule base but the shape of membership functions also is decided by the controller itself based on the learning data provided by the developed Fuzzy controller.

A successful implementation of all these controllers for the LFC is done and a comparison has been drawn between conventional PI controller, PID controller, Fuzzy logic controller, fuzzy tuned PID controller and hybrid Neuro-Fuzzy controller on the basis of rise time, settling time, maximum overshoot. The observed performance of the controllers have demonstrated the ability of the proposed controllers to track the command faster than the prevalent PI and PID controllers for the similar conditions with lesser overshoot and better settling time. The simulation study has been conducted for evaluation of effectiveness of the controllers for LFC.

7.2 FUTURE SCOPE

The proposed controllers for LFC displayed excellent simulation results. The advancement in the field of soft computing techniques and other methods useful for designing of the controllers has carved a way for vast improvements. An effort to further reduce the complexity may also be investigated in the future.

7.2.1 Improvement in Controllers

As a popular practical control method, Fuzzy logic controller and Neuro-Fuzzy controllers have the advantage of requiring little information from the plant and notable robustness against parameter and model uncertainties. But as a novel control technique, it could be improved in the following aspect. In the thesis, the designed intelligent controllers can guarantee the fast response of the ACE with small overshoot. However, during the process of simulating, the magnitude of the control effort shows a big peak value at the initial stage of the simulation. In the future, more focus can be laid upon obtaining the optimal ACE response.

The controller parameters are obtained manually with some hit and trial approach. To improve the response some quantitative method is needed to determine the controller parameters of LFC. The optimization algorithms such as GA could be applied to tune the parameters of the controllers of LFC.

7.2.2 Improvement of the Model

For the LFC problem, some of the plant limits such as generation rate constraints and dead bands are disregarded in this thesis. However, in reality, they exist in power systems. In the future, we plan to include the plant limits in the model of the power system to make the model more practical. Accordingly, we will also modify controllers so as to successfully apply them to the new model.

In this thesis, the general engineering tool MATLAB/SIMULINK is used to simulate load frequency control. In the future, we plan to construct the power system in the special software like DIgSILENT power factory or Simplorer®, which are very powerful tools in modeling real systems with power electronics and electro-mechanics. They could provide more realistic power generating units just like the ones in the real world. The successful implementation of LFC on such a software based power system model will ensure its feasibility in power industries.

APPENDIX

The nominal system parameters for single area LFC are as follows [1]:

$f = 50Hz$

$R = 3,$

$\Delta P_D(s) = 0.01$ p.u.

$K_g = 1$

$\tau_g = 0.4$ sec

$K_T = 1$

$\tau_T = 0.5$ sec

$K_{PS} = 100$ Hz/p.u.

$\tau_{PS} = 20$ sec.

For two-area LFC, all the parameters for both the areas are equivalent except from speed regulators.

$f = 50Hz$

$R_1 = 3$

$R_2 = 2.8$

$\Delta P_D(s) = 0.01$ p.u.

$K_g = 1$

$\tau_g = 0.4$ sec

$K_T = 1$

$\tau_T = 0.5$ sec

$K_{PS} = 100$ Hz/p.u.

$\tau_{PS} = 20$ sec.

$b = 0.425$

$2\Pi T_{12} = 0.05$

$A_{12} = -1$

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