LOAD FREQUENCY CONTROL OF MULTI-AREA POWER SYSTEM

A DISSERTATION

Submitted in partial fulfillment of the requirement for the award of the degree of

MASTER OF TECHNOLOGY
in
ELECTRICAL ENGINEERING
(With Specialization in System and Control)

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CANDIDATE'S DECLARATION

I hereby certify that this report which is being presented in the Dissertation seminar entitled **"LOAD FREQUENCY CONTROL IN MULTIAREA POWER SYSTEMS"** in partial fulfilment of the requirement of award of Degree of **Master of Technology** in **Electrical Engineering** with specialization in **SYSTEM AND CONTROL**, submitted to the Department of Electrical Engineering, Indian Institute of Technology, Roorkee, India, is an authentic record of the work carried out under the supervision of **Dr. Rajendra Prasad, Professor**, Department of Electrical Engineering, Indian Institute of Technology, Roorkee. The matter presented in this seminar has not been submitted by me for the award of any other degree of this institute or any other institute.

Date : 20/5/2016

Place : Roorkee **NALIN MISHRA**

CERTIFICATE

This is to certify that the statement made by the candidate is correct to best of my knowledge.

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My heartiest gratitude goes to my father, mother and sister for constantly supporting me, which allowed me to concentrate on my research work. I would like to dedicate this work to my family.

Nalin Mishra

ABSTRACT

Power systems is the backbone of electrical distribution. Power systems is interconnected in nature. Various single areas are connected together to make a bigger system called the multi-area system. There are various disturbances in Power System like change of load, short circuit, open circuit occurring time to time in the system. Any type of these disturbances in this system causes deviation in the system frequency. The electrical equipment that are used in daily life are highly dependent on system frequency. If there is any frequency change the equipment gets affected and will cause mal-operation of the whole system. So it is highly important to maintain the deviations within limits as soon as possible after the disturbances.

This thesis presents the problem of load frequency control in power systems. Load Frequency Control is very important in Power Systems for safe and reliable power supply. Load Frequency Control restores the balance between generation and end load demand. This causes stabilization of system frequency. This thesis gives the solution to this problem by the designs of various controllers. Work is done to get faster and better response for Load Frequency Control. In this thesis, conventional PID controllers, fuzzy controllers, HVDC link, and Particle Swarm Optimization based controllers are used to study Load Frequency Control in Multi-area power systems. It shows the effectiveness of using these controllers for Load Frequency Control. By the use of these controllers the frequency of the system stabilizes. In this thesis the controllers were used to obtain the response of the system after disturbance in multi-area systems. The results obtained by these controllers are compared with each other and conclusion is obtained at the end.

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LIST OF ABBREVIATION

PS : Power Systems

LFC : Load Frequency Control

PID : Proportional Integral Derivative

FLC : Fuzzy Logic Controller

HVDC : High Voltage Direct Current

PSO : Particle Swarm Optimization

CHAPTER 1
INTRODUCTION

1.1 General Introduction to LFC

Power Systems is the interconnection of many different control areas. They are connected to each other with the help of tie-lines. Disturbance in any of these control area can cause the frequency to deviate from its normal value. It is important to maintain the frequency constant for the proper working of Power Systems. This is maintained with the help of Load Frequency Control. Load Frequency Control is the process of controlling the real power output of the generating unit with the change in the frequency of the system in the event of a disturbance. Disturbance can be in any side. It can be in the generating part or the load part. Disturbance can also be due to the disturbance in any other area of the power systems. This maintains the frequency at 50Hz in India. Rated value for frequency is 50Hz in India. It is different in different parts of the world. Like in USA it is 60Hz.

The disturbances which occurs in any other part of the network connected to the existing power system network have effects on the frequency of the whole network. For example, if there are two areas connected to each other and in case any of the internal faults occurs in the area one the turbine is tripped and a generation from area one stops functioning. This decreases the network frequency in the system. So if the lost power generation in area 1 is not recovered by area two generation unit, by increasing a generated power, the frequency protection in area 2 will be activated and will trip the unit which is causing the loss of generation in any of the two units. If these two defined areas are well connected to any of the other areas the similar reactions will occur. Frequency stability in any system can be defined by the ability of power system to maintain steady state frequency in any acceptable range (example ± 0.5%). It mainly depends on the ability to keep balance between the generated power and the end user load demand.

For the successful operation of a connected power system require match in the total generation to the total load demand and its related system losses. The load is highly fluctuating in its basic nature which adversely affects the system frequency so the electricity generation to be controlled had become more increasingly important in today's world of increasing in load demand & the reduced generation means. The increase in load demands is posing very serious ill threats to the reliable operations of power systems network. To maintaining this constant frequency in power system is too much important for the healthiness of the power equipment and the other utilization equipment at the other end of the customers. To regulate the frequency in certain specified range, it is much important to maintain the balance with the demand and the supply in real time.

Load frequency control is an important issue in the power system. It ensures reliable and safe power supply to the end consumers. Objectives of load frequency control can be listed as follow:

1. to ensure there is zero power deviation in steady state after a disturbance in the system.
2. to minimize the tie-line power flow between neighboring areas.
3. to maintain acceptable levels of overshoot and undershoot in frequency and power deviations
4. to maintain minimum settling time for frequency deviations

In today's world, there is an increase in the power demand. To increase the reliability of power supply to the consumers there is a need to connect various power system arears together so that they can share the power whenever required by them. There is also a new concept of smart grid. In smart grids the renewable energy areas are connected with the conventional energy areas. These advanced thinking about our future power network has given rise to non-linearity and high complexity to the system. Earlier when there was no concept of interconnections of the power systems network, only conventional ways of control like PID control was sufficient in control of load frequency. But due to the rise in complexity and non-linearity, new methods are being proposed. These methods are based on artificial intelligence which are capable of making automatic decisions with any load changes or disturbances in the power system network. This has made possible the detection of disturbances quickly and making effective control in a smaller frame of time.

1.2 Literature Survey

The single and multi-area systems contain the problems of LFC in PS [1,2]. In early times frequency of PS was controlled with the help of flywheel governor. It was found to be unsatisfactory. So conventional controllers like PID controllers were used to keep frequency in limits. It was required to correct the frequency deviation by the use of LFC of the system [3]. Effects of non-linearities was also realized in LFC [4,5]. LFC was carried out in single area system [6]. LFC is extended to multi-area systems [7]. LFC using PID controllers is performed on various single and multi-area systems [8]. PID controllers and Fuzzy controllers are used for LFC in multi-area systems [9,10,11]. Intelligent methods like Fuzzy controllers were helpful in LFC of multi-area systems [12]. Fuzzy logic controllers give better results as compared to conventional controllers [13]. HVDC link proves to be better in LFC as compared with the HVAC link [15,16,17,18,19]. HVDC link makes the settling of frequency deviation faster. Particle Swarm Optimization is a good optimization technique [20,25]. PSO stabilizes the frequency deviation fast and quickly [21]. PSO optimization was studied in multi-area system [22,23,24]. PSO proved to be the best in controlling frequency deviation in multi-area power systems.

1.3 Objective of thesis

Frequency of the power system is the important parameter. All equipment depends on frequency of the system. So this should be maintained within limits. This helps to protect the components of the power systems from getting damaged.

The main objective of this thesis is:

1. to build a two, three and four area system consisting of different power system areas in MATLAB/Simulink platform.
2. to use PID controller to stabilize the frequency deviations occurring during disturbances.
3. after using PID controller, fuzzy controller with HVDC link and with prolonged disturbance is studied. It is compared with above obtained results.
4. finally using PSO based PID controller and then using that controller to study the effects of communication delays in the channel.
5. a comparison between all these controllers is finally presented.

1.4 Organization of thesis

Chapter 1: This chapter gives a brief description of LFC in Power Systems. It contains the literature survey, objective of thesis, and Organization of thesis.

Chapter 2: This chapter describes LFC in single and multi-area systems.

Chapter 3: This chapter gives the details of single area system and multi-area system along with their performance without controllers during disturbance.

Chapter 4: This chapter gives the details of multi area system and their performance with the use of PID controllers. Here we compared I, PI, and PID controller performances in multi-area systems.

Chapter 5: This chapter describes Fuzzy logic controller used for multi-area systems. Fuzzy logic controller is used to determine the performances of multi-area systems.

Chapter 6: This chapter describes the effect of using HVDC in Load frequency control. this shows how the response improves with the addition of HVDC link.

Chapter 7: This chapter also includes HVDC link in LFC for multi-area system but it simulates the effect of load fluctuations in the system.

Chapter 8: This chapter describes the use of PSO in LFC in multi-area system. It is used to get the optimized results in LFC.

Chapter 9: This chapter uses the PSO algorithm described in previous chapter to simulate the effect of communication delays in the system.

Chapter 10: The conclusions drawn from the results and the future scope of work on this topic is given in this chapter.

CHAPTER 2

LOAD FREQUENCY CONTROL IN MULTI-AREA SYSTEM

2.1 Introduction

Load frequency control is an important part of the Power Systems. To understand it properly, it is required to study about the basic components of Power Systems. This chapter gives information about various parts of Power Systems. This chapter describes this by using the block diagram of each part with their related equations. After this the study of Load Frequency Control will be performed. Finally, this chapter includes the details about the types of turbines used in the project and their transfer functions.

2.2 Power Systems: Overview

The objective in electrical power systems is to transform the available natural forms of energy into electrical energy by the use of electric generators and then transferring it to the end consumers located far away from the generating unit. Generating unit may be a thermal, a hydro plant, a nuclear plant, etc. after generation this is transferred to the consumers via transmission lines. An electrical power system is an interconnected system and a complex structure which is divided into many different subsystems that are called the Generation subsystem, the Transmission subsystem and the Distribution subsystem. These systems are described in the coming following paragraphs given below. It is important for the study of this project to include the understanding of these topics described below.

2.2.1 Generation

It is the most important components in power systems. It is comprised of the AC generators known as popularly the Synchronous Generators or in shorts Alternator. Synchronous generators are consisting of synchronous rotate fields inside of them. One produced in the rotor which is excited by DC incoming current and rotates at a speed called the synchronous speed and the other field is develops in the 3-phase AC windings in the stator of the generator. The DC current which is supplied to the excitation systems for the rotor windings. The excitation system in a normal generator is used to maintain generator voltage and it regulates flow of the reactive power in the generator.

The prime-movers was the source of the mechanical powers to the thermal station generators, and the steam turbines obtains its energy from burning of fossil fuels like coal, natural gases and the nuclear fuel. Steam turbines are running at very high rpm of 3000 and 1500 rpm in India. They are attached to cylindrical rotor generators with 2-poles for 3000 rpm and 4 poles for 1500 rpm operations. Hydraulic turbines are operating at low speed as compared to the steam turbines. Their generators are the salient rotor type with too many poles.

In the existing power systems network, the several generators works in parallel in coherent way supplying power to the power grid to supply the power for end user load demand. They are all connected to the common point known as the Bus. With reference to today's environmental conservation theory, many other useful alternate sources of energy are considered for power generation which are as follows: the Solar power, the wind power, the geothermal power, the tidal power and the biomass.

2.2.2. Transmission and sub transmission

This is that part of the power system which acts as an interconnection with generation side to the distribution side for following purposes:

i. to supply the power generated from the generators to the end loads connected to distribution side in power systems.

ii. for interconnection with the neighboring power utilities for the economic load dispatch of power and for the inter-area power transfer during the power emergencies.

Industrial consumers with very large power requirement might be supplied directly with the existing transmission power system. The part of transmission power system that is connecting high voltage substations with the distribution substations are known as the Sub-transmission power network. Capacitor and reactors banks were usually placed inside of the substations to maintaining the required amount of the voltage in the transmission line.

2.2.3. Distribution

The Distribution system is also the part of a power system that is linking the different distribution substations to the end consumers in the network. The secondary distributions called the sub-stations lines supply reduces the level of voltage for the utilization by the commercial and the residential end consumers of electric power. The power requirement for any ordinary home is fulfilled by a transformer which steps down the incoming voltage to the required Voltage level.

2.2.4. Loads

The loads in power systems are categorized as given here: the industrial load, the commercial load and the residential load. The very large industrial loads are being supplied directly from the transmission system. The big industrial loads are being provided power supply directly from the sub-transmission system, and the small industrial loads are being fed from the primary distribution network via transformers. Those industrial loads are mostly composite forms of loads, and mainly induction motors are forming a large proportion in these types of loads. The commercial loads and the residential loads are consisting largely of the lightening, the heating loads and the cooling loads. These types of loads are mainly independent from frequency and consume very negligible small reactive power.

2.3 Working System Description

The real power system network comprises of many elements such as the generators, the transmission lines, the loads, the controllers and the protection devices. The dynamics of a system is the function of its constituent elements. So, if we want to study any system, it is very important to have the information about its various elements involved in it. In this section, introduction to the elements of the power system model to be used in the thesis in single area and multi-area systems is given with their respective transfer function models. First one is the generator model.

2.3.1. Generator model

In this model, turbine's mechanical power is transformed to electrical power by the generator set unit. In the study of our topic of LFC, the target is to obtain the output speed of rotor as the frequency in the power systems depends on it. So rotor speed is used in LFC instead of the energy transformation. It is very difficult to store such a huge amounts of electrical energy that is generated in the generator, so it is important to maintain the balance with power generated in the generator and the end load demand in real time basis.

If the load changes at any time, the mechanical power output of turbine don't match with the generated electrical power in the generator. The difference of the mechanical power from turbine (ΔPm) and generated electrical power (ΔPel) is integrated with the deviations in the rotor speed ($\Delta \omega r$), which is specified in the terms of the frequency system changes (Δf) and multiply it with 2π. The relations in the terms of ΔPm and Δf is shown in Fig. 2.1, where *M is* denoting the generator's inertia constant.

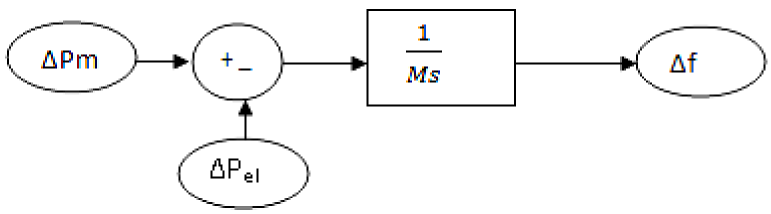

Fig. 2.1 Generator's block diagram

2.3.2. Load model

The loads in our study are categorized as:

1. resistive loads (ΔP_L), they remains unchanged when the rotor speed changes,
2. motor loads which vary with the load speed.

If the mechanical power input to the generator remains constant, the motor loads balances the change in load by changing the rotor speed to another value which is different from the fixed value as shown here in the figure given below.

where D is the load damping constant.

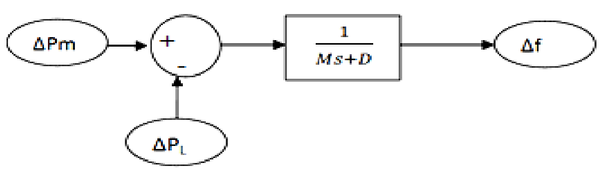

Fig. 2.2 Load's block diagram

2.3.3. Prime mover model

The model of the prime mover keeps track of the input steam supply to the generator and keeps track of the boiler's control system in a steam turbine in the case of a hydro-generator turbine. The model of the prime mover system is shown below.

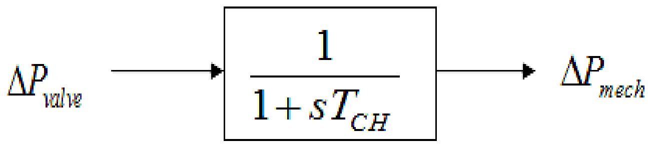

Fig 2.3 Prime mover's model

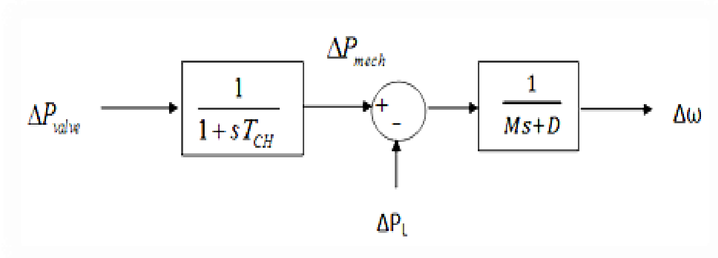

Fig 2.4 Prime mover-load model

Fig. 2.4 give the relation between the turbine supply to the power output of the turbine.

Where,

TCH = "charging time" time constant.

ΔPvalve = per unit change in valve position from nominal.

2.3.4. The Governor model

Governor is that part of the system which is connected in the system to sense the frequency deviations that are due to the variations in the load and it regulates it by controlling the inputs to the turbines. The block diagram of the governing unit is given in Fig. 2.5.

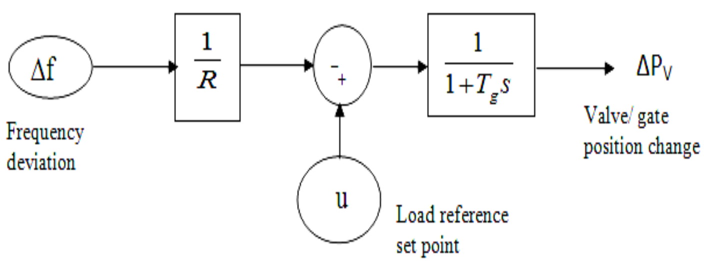

Fig 2.5 the governor model

here, *R* is the speed regulation characteristic and *Tg* is the time constant of the governor.

If there is any change in the load occurring without load reference, then a part of the change in load is balanced by the adjustment in the valve position, and the rest of the change is in the form of frequency change.

The main objective in LFC study is to control the frequency deviations due to the varying of active power load.

2.3.5 Turbines

Function of a turbine is to convert any form of energy available to it in mechanical energy. This mechanical energy produces electricity inside a generator. In this project on LFC, main focus in on three types of turbines, i.e. reheat turbines, non-reheat turbines and hydraulic turbines.

1) Reheat Turbines

They are of second order in nature due to separate stages of low and high pressure. Their transfer function can be written as,

$$G_R = \frac{F_{hp}T_{rh}s + 1}{(T_{ch}s + 1)(T_{rh}s + 1)}$$

Where

T_{rh}= low pressure turbine reheat time

T_{ch} = switching valve time

2) Non-reheat Turbines

They are single order in nature due to the absence of any other stages like the reheat turbines. Their transfer model function can be shown like:

$$G_{NR} = \frac{1}{(T_{ch}s + 1)}$$

$$T_{ch} = \text{switching valve time}$$

3) Hydraulic Turbines

They are non-minimum type turbines. Inertia of the water introduces a zero lying in the right hand side of the jw axis in the transfer function model of the hydraulic turbines. The transfer function of the hydraulic turbine is given as below,

$$G_H(s) = \frac{-T_w s + 1}{0.5T_w s + 1}$$

Where

T_w = time constant

2.4 Load frequency control in single area systems

In a single area system there is no interconnections with any other area. So there is no problems related to the exchange of power between two areas of the power systems. In the single area power systems, the main aim is to maintain the system frequency to normal desired value. Constant frequency is maintained in a single area network by using an integrator which acts as a reference for the governor units. This integral component ensures zero frequency error in the steady state condition.

Block diagram for load frequency control in single area system is given below.

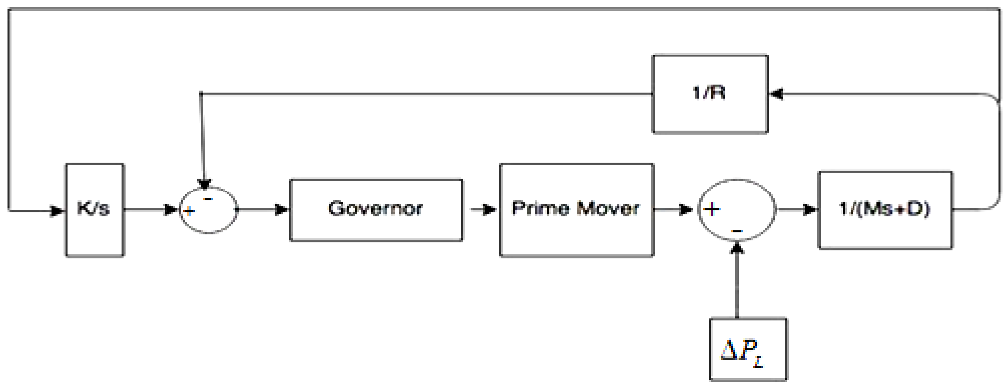

Fig 2.6 Load frequency control in single area system.

2.5 Load Frequency control in multi-area systems

For successful control of power and frequency in a multi-area network, the generated power should be matching with respect to the end load demand power. Nature of the load is changing in nature, this causes the system frequency to be changing at every point of time. It has an undesirable effect on the operation of the power systems.

In single area network, there are two quantities on which the focus remains. One is the change in frequency, and other one is the change in the tie-line power exchanges. These two quantities are clubbed together to form a new term called the ACE. ACE is defined by the equation given below.

$$ACE_i = \Delta P_{12} + b_i \Delta f_i$$

Here,

ACE=Area Control Error of ith area

ΔP_{12}=changed in tie-line power between area 1 and area 2

b_i = frequency bias constant of ith area

Δf_i= frequency deviation of ith area

Multi-area systems is the interconnection of two or more areas with the help of tie-lines. Generalized block diagram of a two area network is given in the below figure.

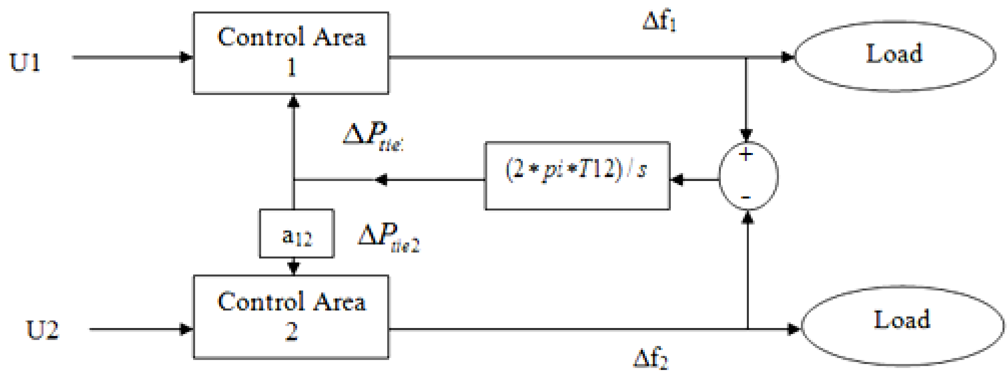

Fig 2.7 Block diagram of generalized two area system.

In multi-area system the generators are assumed to be working in synchronism. Load deviation in any of the control area results in frequency deviation in all the area and change in tie-line power deviation between various areas of the network. This change of frequency is of small value but it is required to correct this in the shortest period of time. Different areas of the system are connected to each other with the help of tie-lines. If the frequency of the area are not the same then there is power exchange in the system through the tie-lines. Tie-line arrangement in any two area system is modelled as shown below.

$$\Delta P_{tie,ij} = \frac{1}{s} T_{ij} [\Delta F_i(s) - \Delta F_j(s)]$$

Where,

$\Delta P_{tie,ij}$= tie-line power exchange between area 1 and area 2

T_{ij}= tie-line synchronization torque co-efficient

This equation can be shown in a model as shown below.

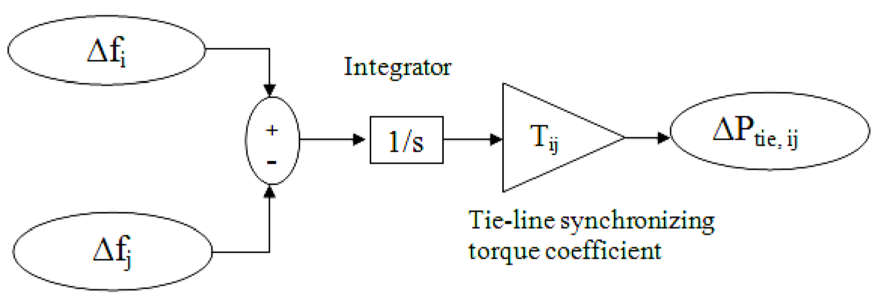

Fig 2.8 two area tie-line model

CHAPTER 3
LOAD FREQUENCY CONTROL WITHOUT ANY CONTROLLER

3.1 Introduction

In the previous chapter we became familiar with various components in the power systems. In this chapter we will perform load frequency control study on single area and multi-area power system using MATLAB/SIMULINK model. Model of the power system is realized with the help of block diagrams. A disturbance to the system is given in the form of a unit step input. The system reacts to the unit step disturbance and we get the change in frequency at the output. In this chapter, there is no controller involved to compensate the change in load. In this chapter we will first perform the load control study on single area after that we will proceed towards multi-area systems. In the next chapter the developed models of this chapter will be used to study frequency control with controllers.

3.2 Single Area System

It is an electrical area independent from any other area in the power system network, in which there is one or more than one generating units, which distributes the electricity in the same area. In this single area it is the responsibility of the single generating unit in the area to maintain the normal frequency in case of any disturbance to the system. These single area systems are the building blocks of the larger multi-area power systems. The characteristics of a single area network is very simple and easy to determine. This helps us to study the more complex multi-area networks. Now we describe various single area networks in the coming sections.

3.2.1 Thermal Systems

Modelling of a single area thermal system is performed in MATLAB/Simulink as shown in Fig. 3.1 below.

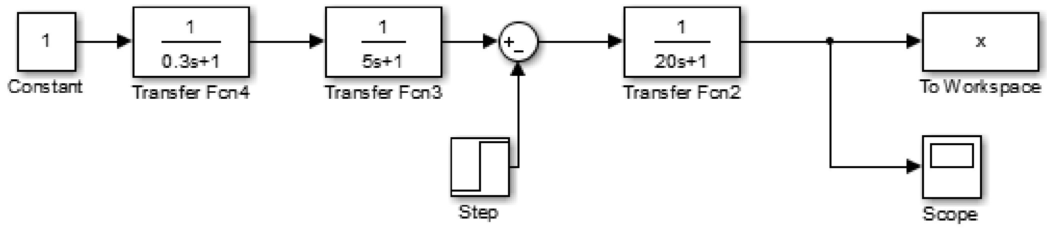

Fig 3.1 Single Area Thermal System

Fig 3.2 shows the step disturbance response in a single area thermal system without governor.

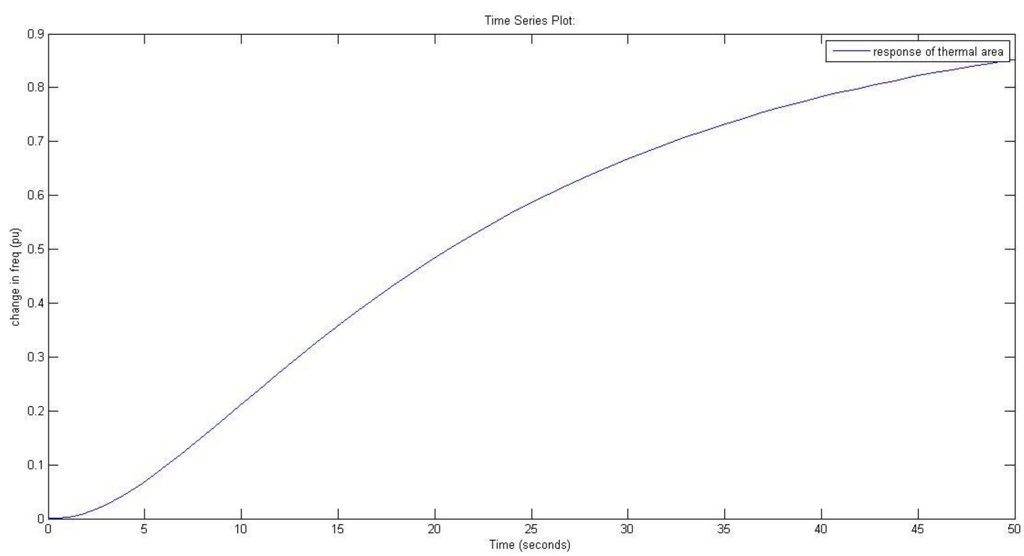

Fig 3.2 Response of a single area thermal system without generator

After analyzing the system without a speed governor, now we add a speed governor to the single area system. It is shown below in Fig 3.3. Fig 3.4 gives the response of the system with a unit step disturbance in the single area thermal system.

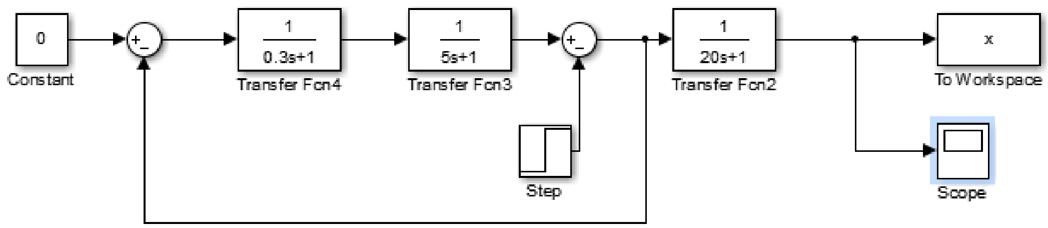

Fig 3.3 Single area thermal system with governor

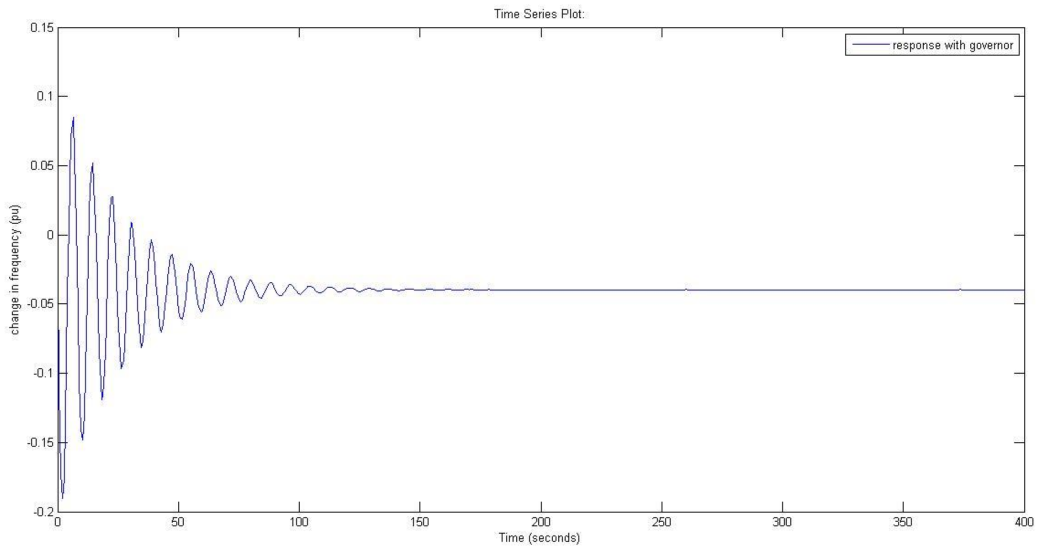

Fig 3.4 Response of a single area thermal system with generator

From the above results we come to know that the governor is very essential in the load frequency control. in the case when there was no governor, the response don't settle down to zero. If we add a governor then we see that the response has settled down to zero.

3.2.2 Hydro Systems

Modelling of a single area hydro system is performed in MATLAB/Simulink as shown in Fig. 3.5 below.

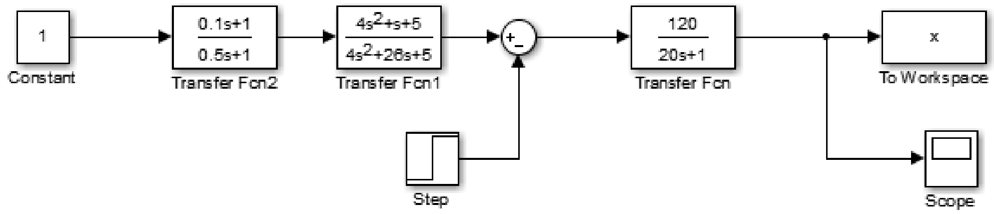

Fig 3.5 Single area hydro system without governor

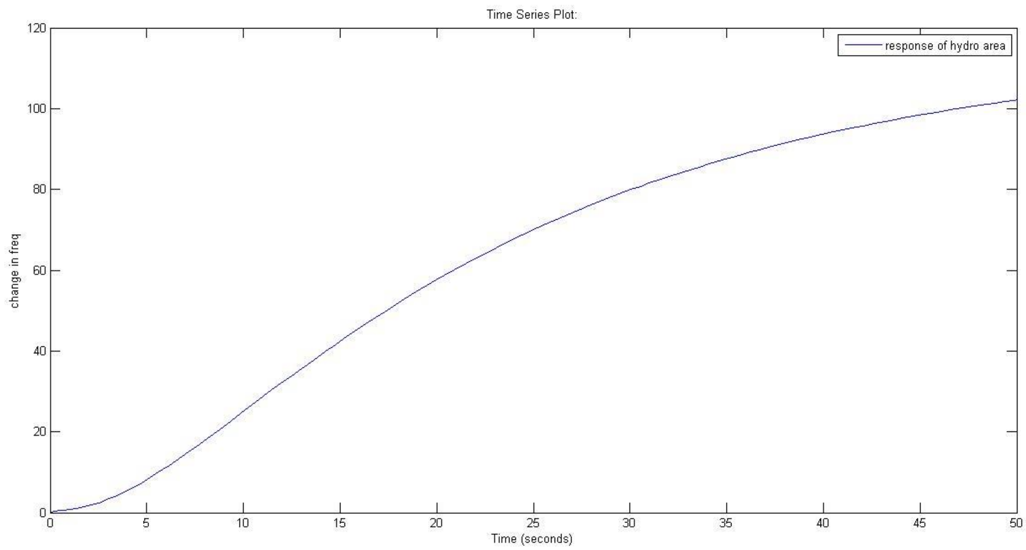

Fig 3.6 response in a single area hydro system without governor.

After analyzing the hydro system without a speed governor, now we add a speed governor to the single area hydro system. It is shown below in Fig 3.7. Fig 3.8 gives the response of the system with a unit step disturbance in the single area hydro system.

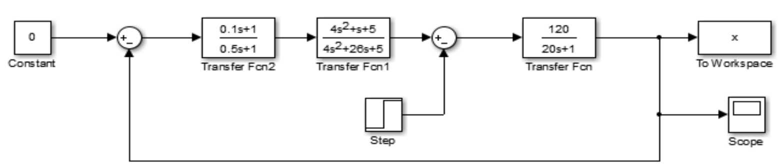

Fig 3.7 Single area hydro system with governor

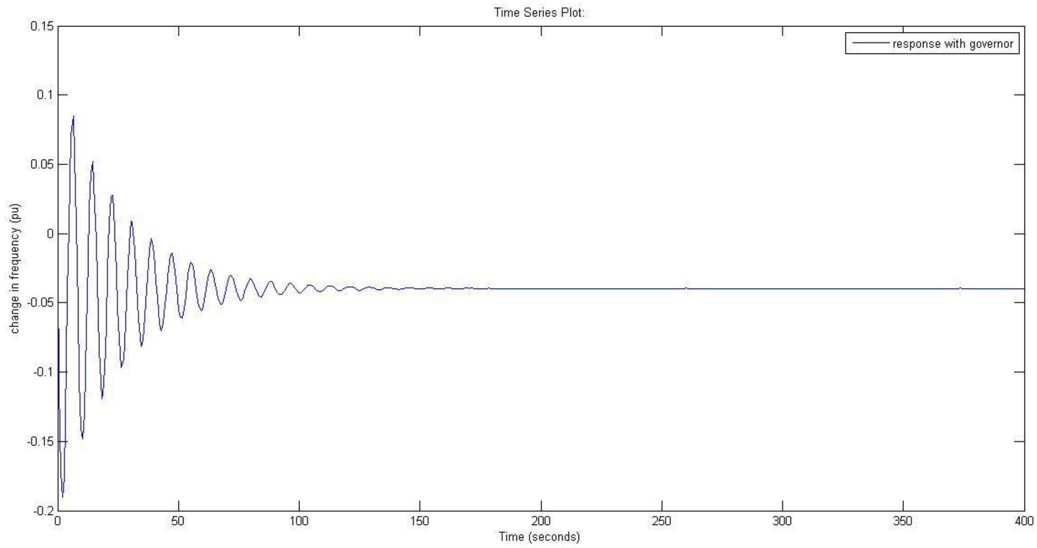

Fig 3.8 Response of a single area hydro system with generator

From the above result we come to know that the governor is very essential for the stability in LFC. Governor helps the system to settle down to zero using feedback.

In the above part of this chapter we studied about single area thermal and hydro systems with and without speed governors involved. We noticed that the response of the system improved when there was governor present in the system. In the latter part of the chapter we will discuss multi-area systems.

3.3 Multi-area systems

In real the power system is made up of many single areas connected together to form a larger multi-area system. They are connected with each other through tie-lines. Thus in a multi-area system, load variation or disturbance in any area causes frequency change and change in power exchange in the tie-lines. This mismatch in power and frequency must be rectified by the governor action of the generators. In this section we will discuss two area system with disturbance. General representation of a two area system is given in the Fig 3.9.

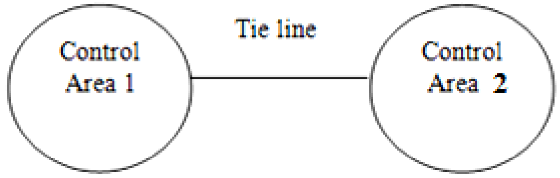

Fig 3.9 two area system

In two area system any variations should be met by the generators in both the areas. Moreover the tie-line power change should also be made to be zero. This is made possible by using an integrator which integrates the power from the tie-line and feedbacks it to the governors. For this we define a term called ACE. ACE stands for Area Control Error. It is a combination of incremental of frequency and the tie-line power change. In the Fig 3.10 the two area system is realized on MATLAB/SIMULINK model.

ACE is defined as

$$ACE_i = P_i + b_i \Delta f_i$$

Where,

b_i = biasing factor

Δf_i = change in frequency of area1

In two area system there are two areas dependent on each other. Thus the ACE for a two area system can be defined as given below.

ACE for area 1 is given by,

$$ACE_1(s) = P_1(s) + b_1 \Delta f_1(s)$$

ACE for area 2 is given by,

$$ACE_2(s) = P_2(s) + b_2 \Delta f_2(s)$$

Similarly equations can be made for three and four area systems.

CHAPTER 4

LOAD FREQUENCY CONTROL USING PID CONTROLLER

4.1 Introduction

From the previous chapter we conclude that there is a need of controllers for stable operation after any disturbance in the system. In this chapter we will study about the components of the PID controller and will use them to study the load frequency control in single and multi-area systems. PID controllers are popularly used in the load frequency studies of power systems. In this chapter conventional I, PI, PID controllers are used for load frequency control in single and multi-area systems. Result obtained from these controllers will be used to study with the controllers to be used in next coming chapters.

4.2 PID controllers

PID controllers are the commonly used controllers for many control actions. In this chapter we are using them for the load frequency control in single and multi-area systems. PID controllers are made up of three controllers called the Proportional (P), Integral (I), and the Derivative (D) controllers. These controllers are discussed in the section below.

4.2.1 Proportional controller

Proportional controller is given by the P controller in the PID controllers. In this controller the output is proportional to the input error to the controller. That is why this controller is called the proportional controller. The representation for this controller is as given below in the equation.

$$U_c(t) = K_p e(t)$$

The above representation is in the form of time domain. For representing it in laplace domain we represent it as given below,

$$U_c(s) = K_p E(s)$$

$K_p\ is\ the\ proportional\ gain\ of\ the\ controller$

Fig 4.1 shows the block diagram of P controller in both time and laplace domains

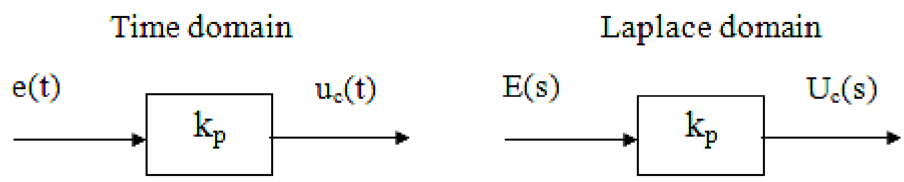

Fig 4.1 Block diagram of proportional controller

4.2.2 Integral Controller

Integral controller is given by the I controller in the PID controllers. In this controller the output is proportional to the integration of the input error to the controller. That is why this controller is called the integral controller. The representation for this controller is as given below in the equation.

$$U_c(t) = K_i \int e(t)\, dt$$

The above representation is in the form of time domain. For representing it in the laplace domain we represent it as given below,

$$U_c(s) = K_i E(s)/s$$

K_i *is the integral gain of the controller*

Fig 4.2 shows the block diagram of I controller in both time and laplace domains

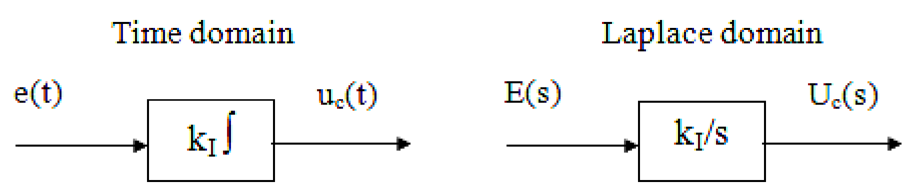

Fig 4.2 Block diagram of I controller

4.2.3 Derivative Controller

Derivative controller is given by the D controller in the PID controllers. In this controller the output is the derivative of the input error to the controller. That is why this controller is called the derivative controller controllers. The representation for this controller is as given below in the equation.

$$U_c(t) = K_d \frac{d}{dt} e(t)$$

The above representation is in the form of time domain. For representing it in the laplace domain we represent it as given below,

$$U_c(s) = K_d s E(s)$$

K_d *is the integral gain of the controller*

Fig 4.3 shows the block diagram of I controller in both time and laplace domains

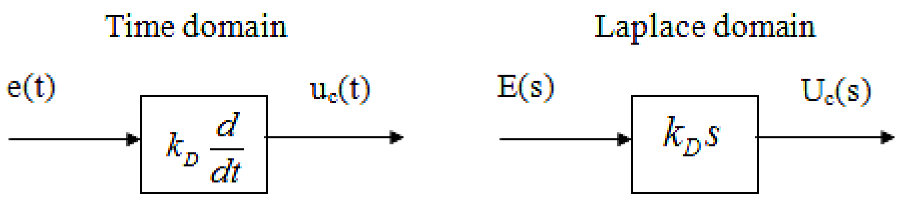

Fig 4.3 Block diagram of D controller

One must be careful in using this derivative controller as compared to the proportional and the integral controllers. This is because the derivative controller causes noise amplification in the system. So this is to be considered if we are using this derivative controller in our system.

4.3 PID controller

PID controller is the combination of proportional, integral and derivative controllers in either series or parallel configuration. Equation of a normally used PID controller is

$$U_c(s) = \left[k_P + \frac{k_I}{s} + k_D s\right] E(s)$$

Structure of the PID controller used in the thesis is given in the Fig 4.4 below.

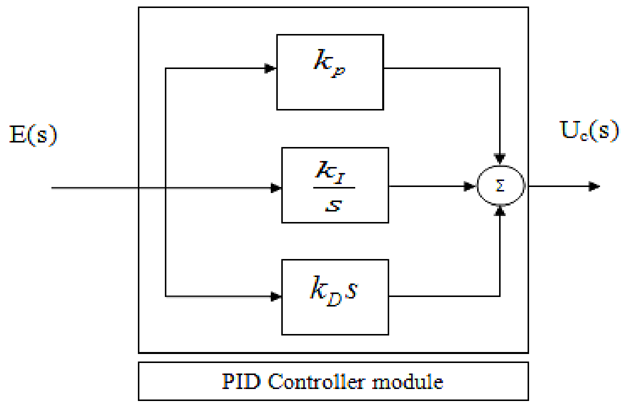

Fig 4.4 PID controller block diagram

In the coming section of this chapter various parts of the PID controller are discussed in brief.

1. Proportional gain (Kp): Larger value of proportional gain in the PID controller gives faster response to the system. But a larger value of this gain can result in instability of the whole system and can cause prolong oscillations in the system. This is highly undesirable in the system. So it is important to choose the value of proportional gain wisely.

2. Integral gain (Ki): Large value of this controller causes high steady state errors. This controller is meant to reduce the steady state error in the system. In this project this controller is used alone and also with the PI and PID controllers. This proves its effectiveness in reducing the steady state error of the system.

3. Derivative gain (Kd): Large value of this controller decreases overshoot in the system. This makes the system respond faster to the incoming disturbances to the system.

4.4 PID Tuning method

Tuning method used is Ziegler-Nichols method. The Ziegler-Nichols continuous cycling method is among the best known closed loop tuning methods. This is a manual method of tuning. The gain of the controller is gradually varied (increased or decreased) until the process output continuously cycles after a small step change or disturbance. Table for calculating PID parameters is given below:

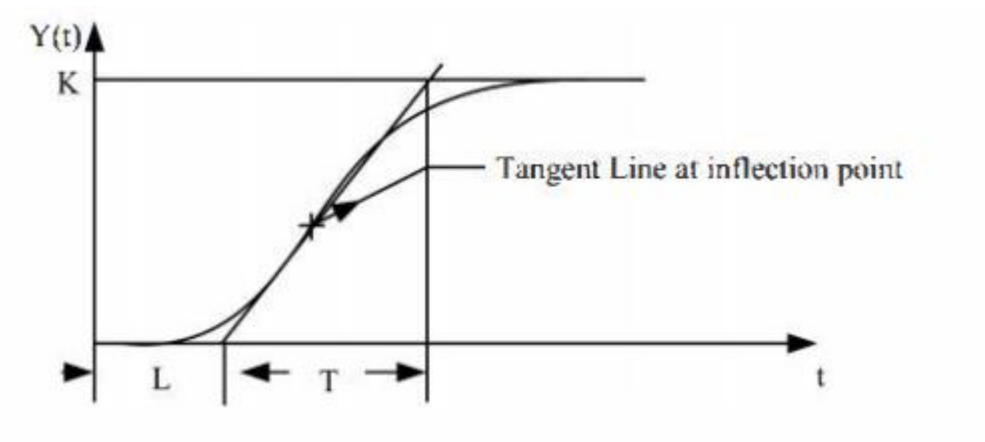

Fig.4.5 Ziegler-Nichols method

Table 4.1 - Ziegler-Nichols Method

Controller		**K_p**	**T_i**	**T_d**
Ziegler-Nichols Method (Closed loop)	**P**	**T/L**	**-**	**-**
	PI	**0.9T/L**	**L/0.3**	**-**
	PID	**1.2T/L**	**2L**	**0.5L**

4.5 PID controller in two area system

Performance of single area system was analyzed in the previous chapter. It was concluded that the governor is necessary for stabilization of frequency. In this chapter we will use PID controller to stabilize frequency in two, three and four area systems. Figure below shows the effect of PID controllers in a two area system.

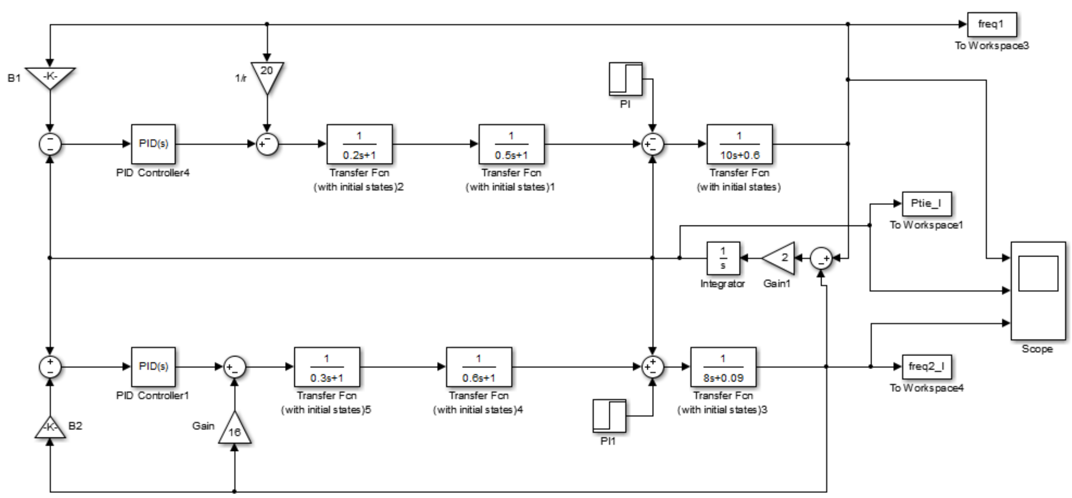

Fig. 4.6 PID controller in two area system

Response of the two area thermal system with I, PI and PID controllers is shown in the figures below.

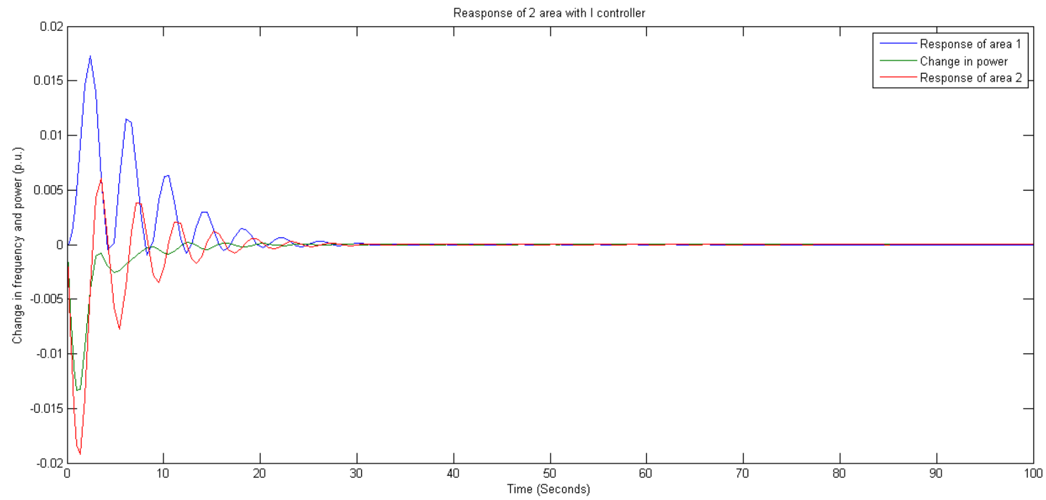

Fig 4.7 Response of two area system with I controller

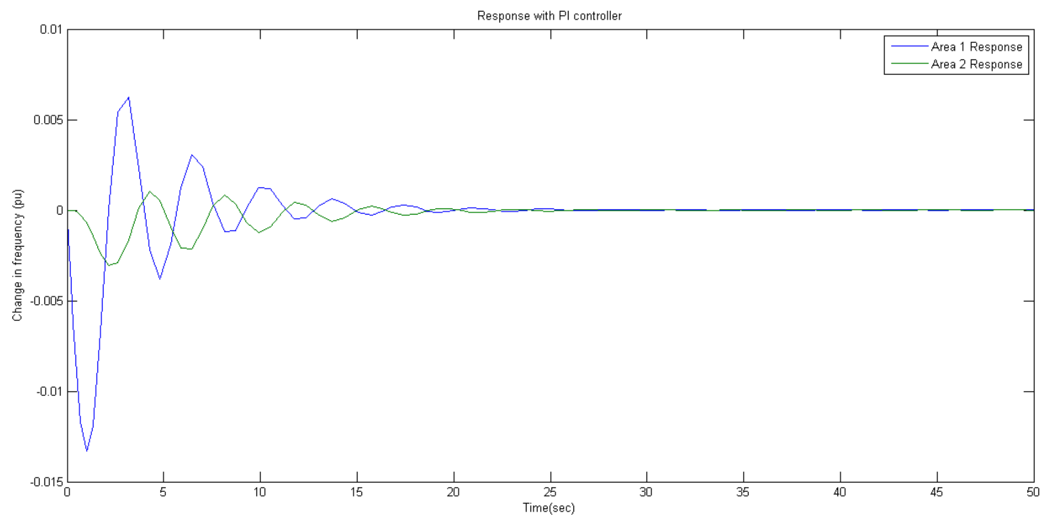

Fig 4.8 Response of two area system with PI controller

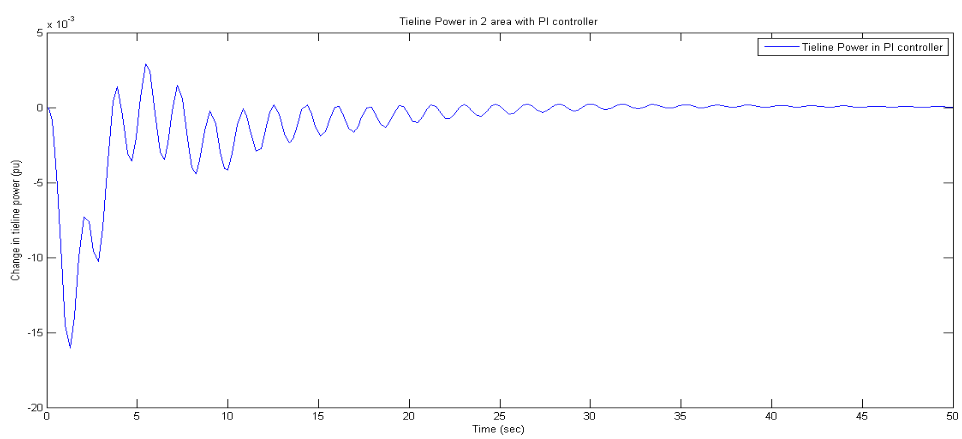

Fig 4.9 Tie-line power in two area system with PI controller

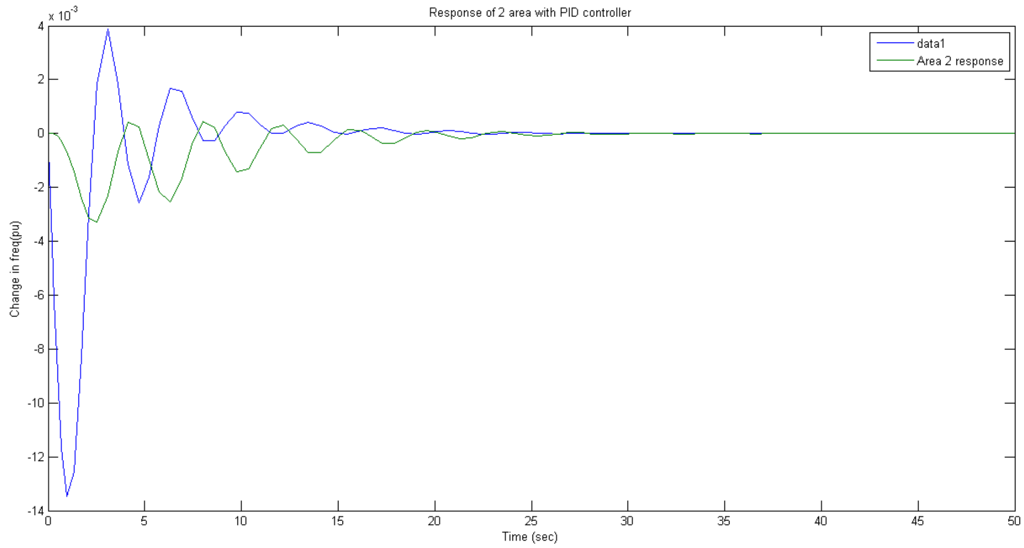

Fig 4.10 Response of two area system with PID controller

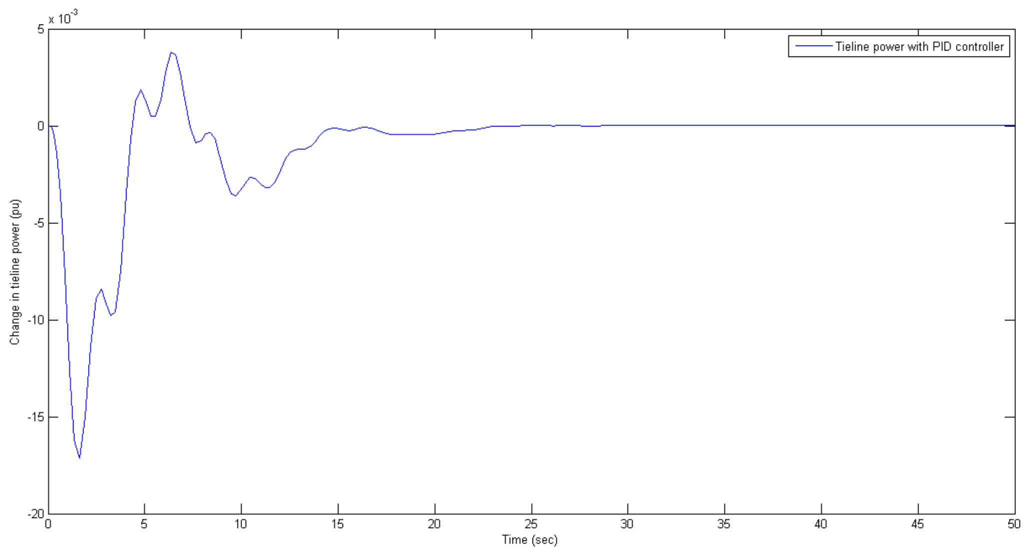

Fig 4.11 Tie-line power with PID controller

Table 4.2 given below shows the response with the PID controllers in the two area thermal system.

Table 4.2 Area-wise response of two area system

Controller	**Settling time (in seconds)**		**Overshoot (in p.u.)**		**Undershoot (in p.u.)**		**Tieline power (in p.u.)**
	Area1	**Area 2**	**Area 1**	**Area 2**	**Area1**	**Area 2**	**On steady state**
I	32	31	0.017	0.007	0.01	0.019	30
PI	25	25	0.006	0.002	0.013	0.002	38
PID	22	25	0.004	0.001	0.013	0.002	25

4.6 PID Controller in three-area system

In the previous section we studied about the PID controllers in two area system. In this section we proceed to analyze the three-area systems. The three area system is analyzed with the help of PID controllers. The performance of each area in the system is analyzed separately. After analyzing three area system we will proceed to four area system analysis. Figure below gives the MATLAB model of three area system used in this section with PID controller.

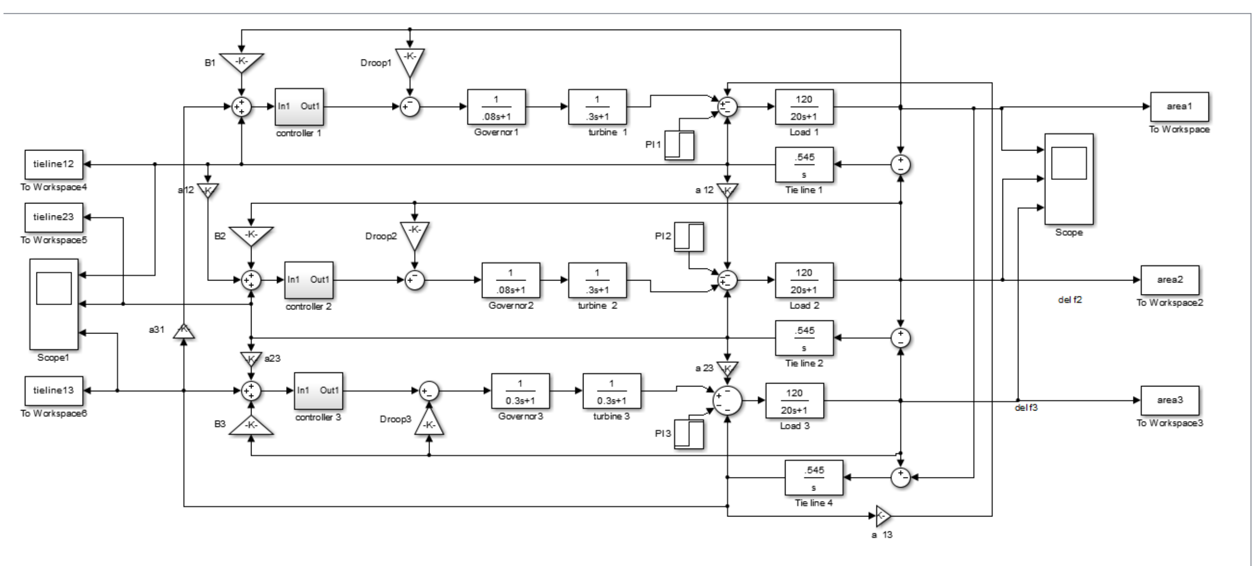

Fig 4.12 MATLAB model of three area system

In the figures given below we can see the changes in frequency of all the areas and also the change in tie-line power can be observed.

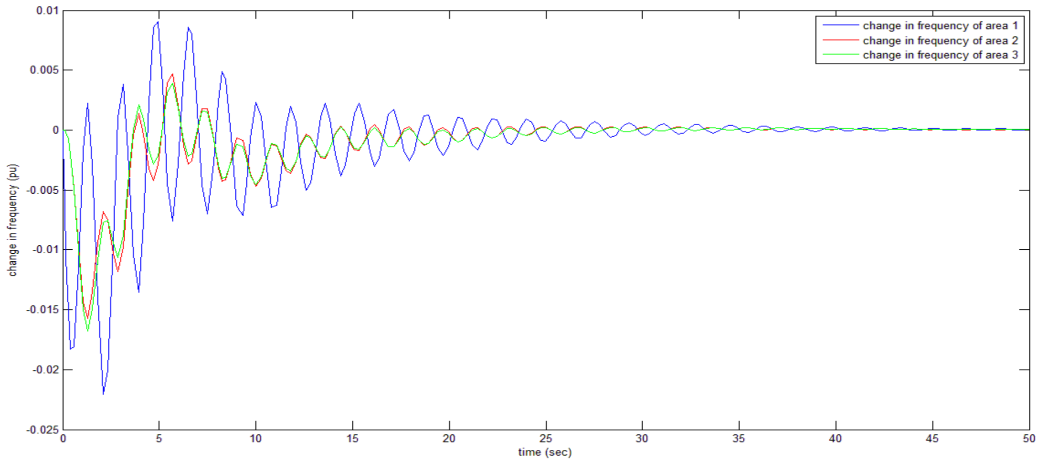

Fig 4.13 Response of three area system with I controller

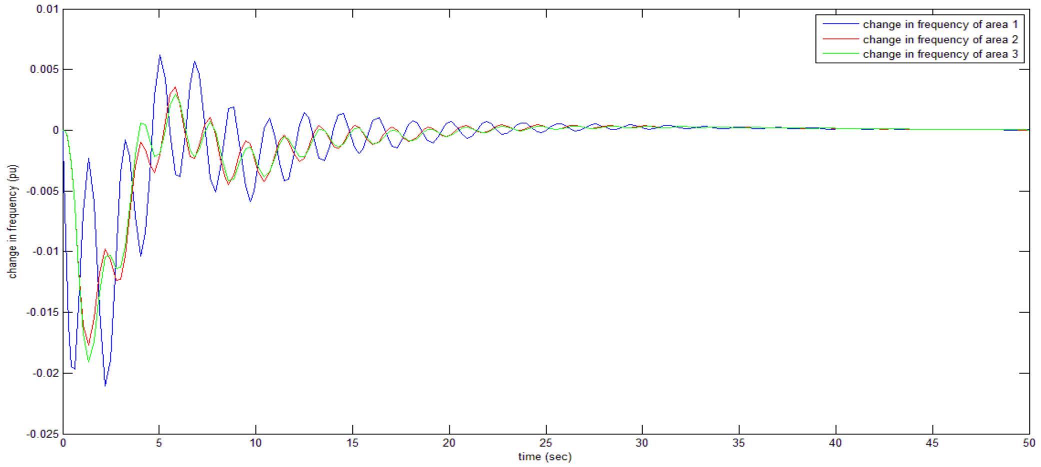

Fig 4.14 Response of three area system with PI controller

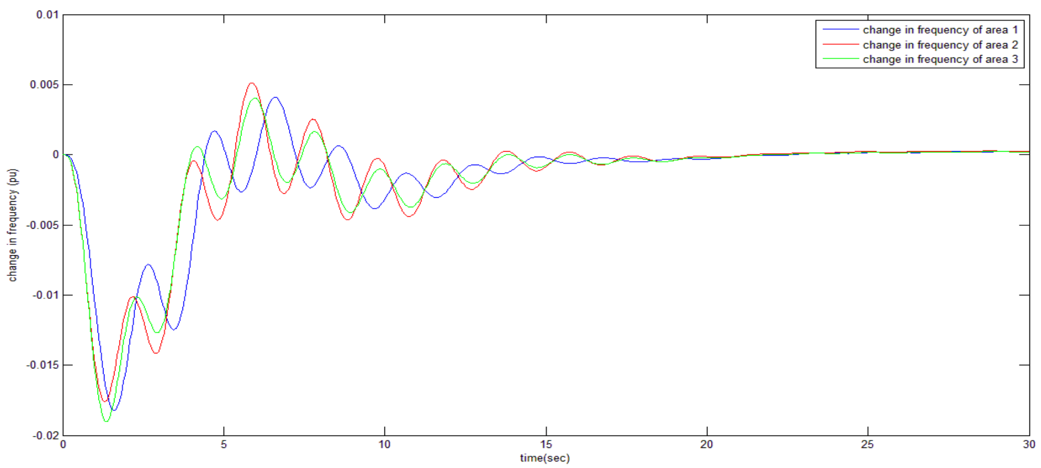

Fig 4.15 Response of three area system with PID controller

Table 4.3 Area-wise response of three area system

Controller	Settling time (in seconds)			Overshoot (in p.u.)			Undershoot (in p.u.)		
	Area1	Area2	Area3	Area1	Area2	Area3	Area1	Area2	Area3
I	40	30	35	0.01	0.005	0.005	-0.023	-0.015	-0.015
PI	32	30	28	0.005	0.004	0.004	-0.021	-0.018	-0.019
PID	23	23	22	0.004	0.005	0.004	-0.018	-0.017	-0.019

4.7 PID controller in four-area system

In this section we will study LFC in four area system. In the figure given below the MATLAB model of a four area system is presented. Response of the four area system with PID controller is shown below the figure.

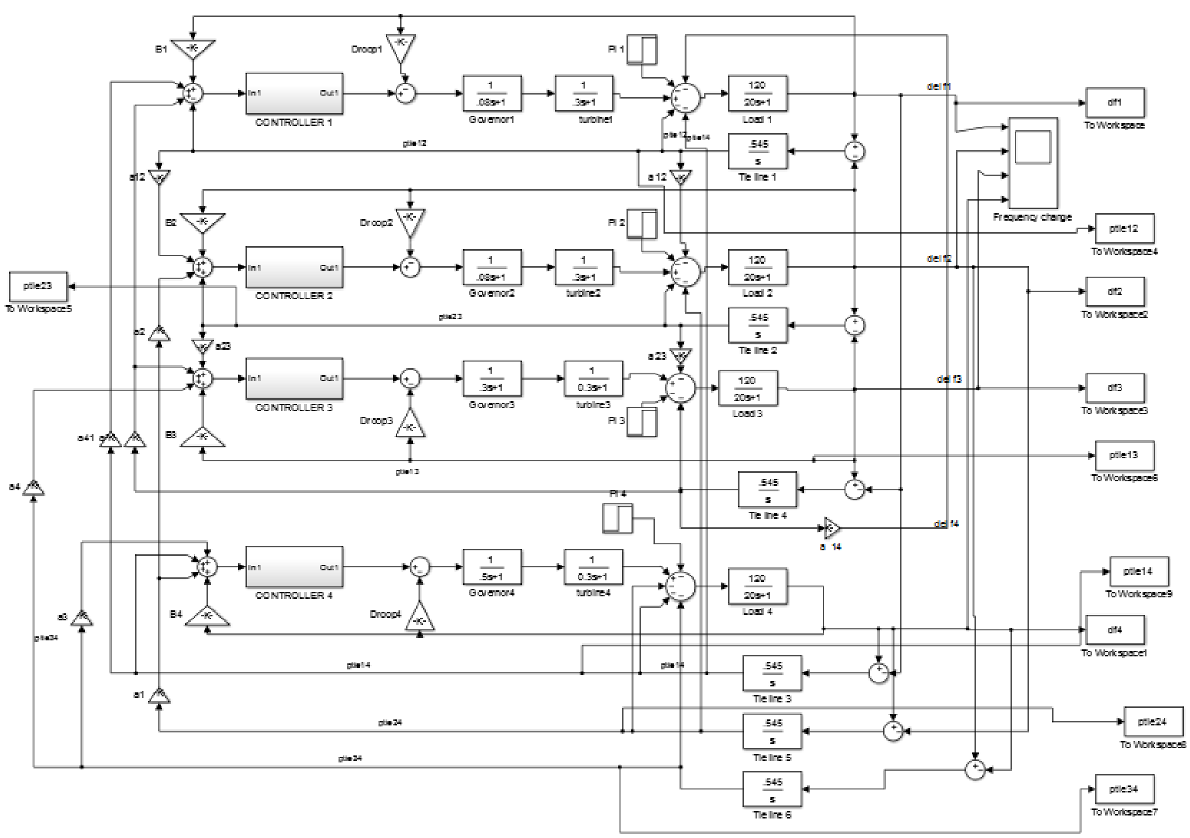

Fig 4.16 MATLAB model of the four area system

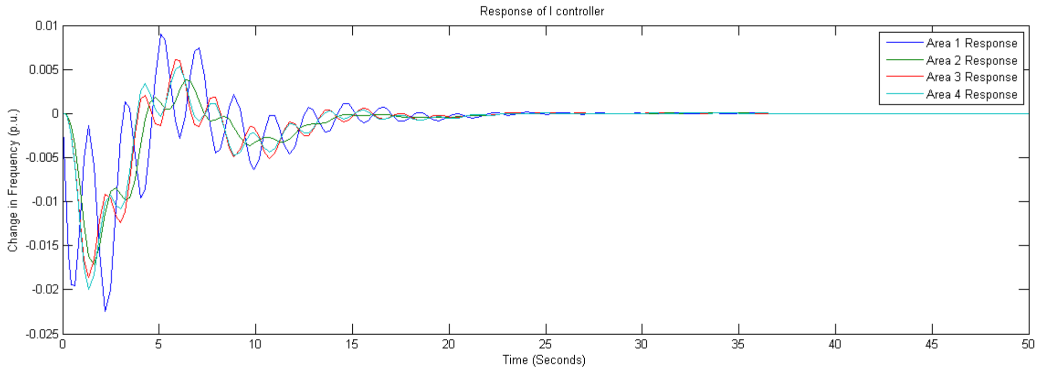

Fig 4.17 Response of four area system with I controller

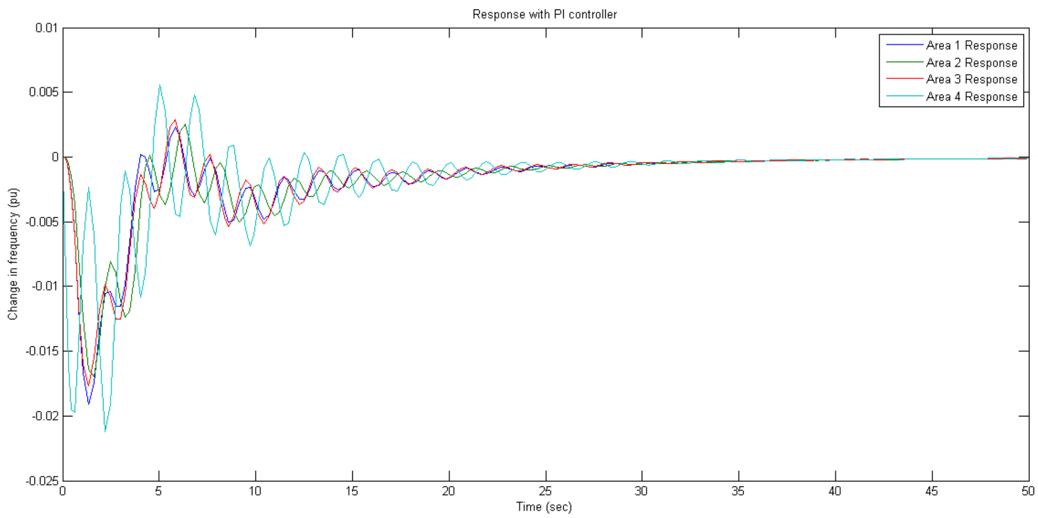

Fig 4.18 Response of four area system with PI controller

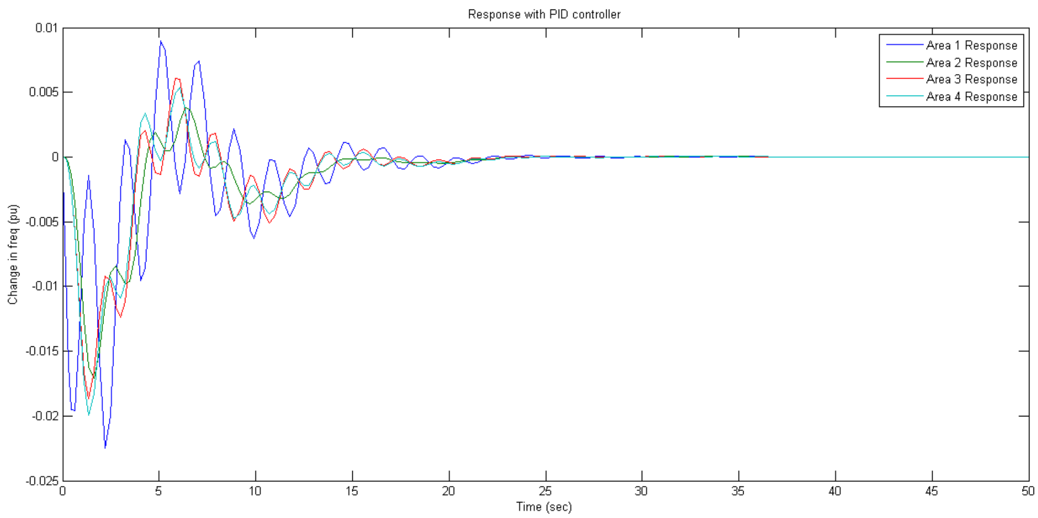

Fig 4.19 Response of four area system with PID controller

Table 4.4 Area-wise response of four area system

Controller	**Settling time (in seconds)**				**Overshoot (in p.u.)**				**Undershoot (in p.u.)**			
	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4
I	30	31	32	31	0.009	0.004	0.005	0.004	-0.022	-0.017	-0.017	- 0.02
PI	35	37	38	34	0.001	0.004	0.004	0.005	-0.02	-0.017	-0.017	-0.02
PID	25	26	26	25	0.008	0.005	0.006	0.005	-0.022	-0.017	-0.019	-0.02

From the above results it is shown that PID controller is better than the I and PI controller in multi-area system.

CHAPTER - 5

LOAD FREQUENCY CONTROL USING FUZZY LOGIC CONTROLLER (FLC)

5.1 Introduction

In the previous chapter we saw the working of PID controllers in case of any disturbance on the system. The PID controllers were able to stabilize the system after the disturbances. In this chapter we will study the fuzzy logic controllers and will implement the fuzzy logic on multi-area system under disturbance. Fuzzy logic controller is an intelligent controller which has defined some rules. On the basis of these rules the fuzzy logic controller makes decisions. Thus it can help in the stability of the system under disturbances. This chapter gives the implementation of Fuzzy logic controller on single and multi-area systems.

5.2 Fuzzy Logic Controller

With the advancements in technology, fuzzy logic has played a significant role. Fuzzy logic was proposed by A. Zedah in 1965. This logic was similar to human thinking and logical reasoning. Since then it is being used in many parts of the world. Fuzzy logic controller works on the principle of Fuzzy set. It is a set of values between [0,1] as compared to conventional logic where only two values (0 and 1) are considered. Fuzzy logic controller has also proved to be useful in Power Systems. Conventional methods are not able to give satisfactory results as compared to fuzzy logic. In this chapter, fuzzy logic controller is designed to minimize the variations in frequency in the output. In this study first two area system is considered and after that four area system is considered. Fuzzy logic is used to design the controller for load frequency control.

5.3 Structure of Fuzzy Logic Controller

The FLC works on the basis of four parts. They are: -

1. **Fuzzification:** It is the first part of fuzzy logic. In this part the crisp values are converted to corresponding fuzzy values. Selection of control variables is dependent on the system configuration and the type of output required. In this project, we have used ACE and derivative of ACE as the input to the controller.

2. Membership functions: The membership function maps the crisp values into fuzzy variables. In our project we will use the triangular membership function because it is simple in calculation of the output of the fuzzy function. Another reason is that due to the smooth nature of the function computational burden is less on the computer.

3. Rules: Fuzzy logic works on various rules which are in the form of “if and then” format.

4. Defuzzification: It is used to convert the output of the fuzzy set to a number. This number is used as a control signal. This is known as defuzzification in fuzzy logic. In this thesis centroid method is used for defuzzification.

Thus a fuzzy set based controller is used to design a controller for LFC in multi-area systems. This fuzzy logic developed is used in single and multi-area systems. Performance of this controller will be compared with the conventional controllers.

5.4 FLC in two area system

In previous chapters we studied about the conventional controllers for the LFC in multi-area systems. In this chapter we will use the FLC for the study in multi-area systems. First we will consider a two area system, and then other multi-area systems. Here we are considering the thermal system for LFC. Inputs to the controller are ACE and derivative of ACE (change in ACE). The figure below shows the two area thermal system.

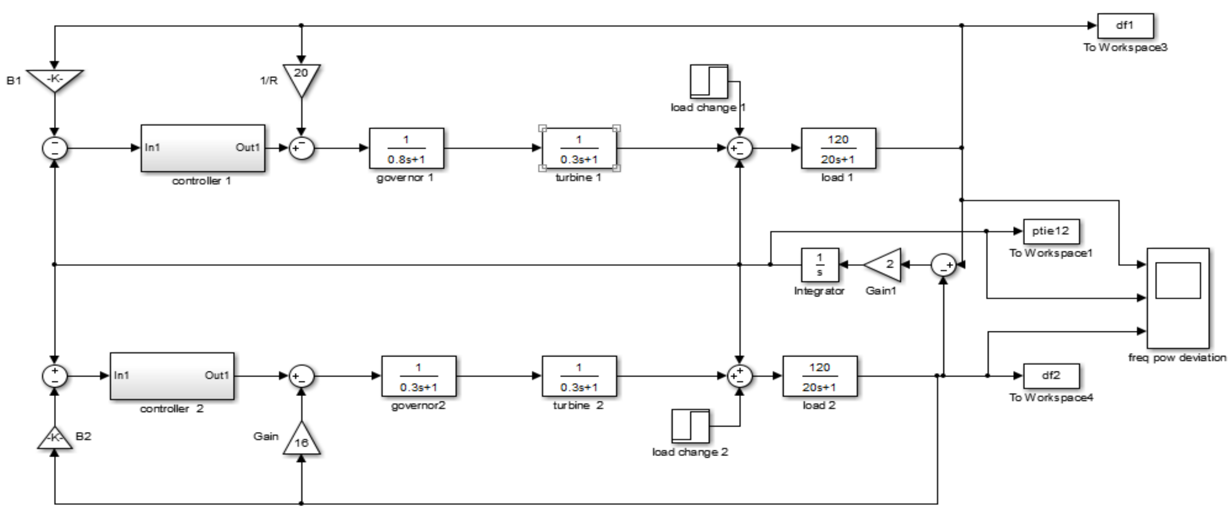

Fig 5.1 Two area system with LFC

Figure below shows the response of two area system with FLC. From the figure we conclude that the steady state error in frequency is reduced to zero.

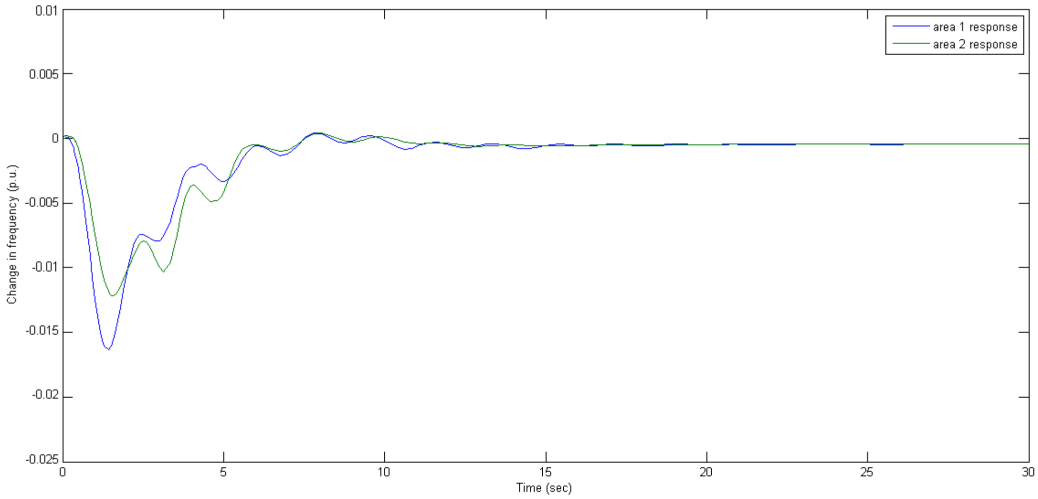

Fig. 5.2 Response of two area system with FLC

Table 5.1 Response of two area system with FLC

Settling time (in seconds)		**Overshoot (in p.u.)**		**Undershoot (in p.u.)**	
Area1	**Area 2**	**Area 1**	**Area 2**	**Area1**	**Area 2**
20	20	0.001	0.001	-0.016	-0.012

5.5 FLC in three-area system

The MATLAB/Simulink model of a three area system is shown in the figure given below. FLC is used in the model. A disturbance of 0.05 pu is given to the area 1 and the change in frequency and tie-line power is noticed in the figures given below. Table given below contains the details about results in a three area system.

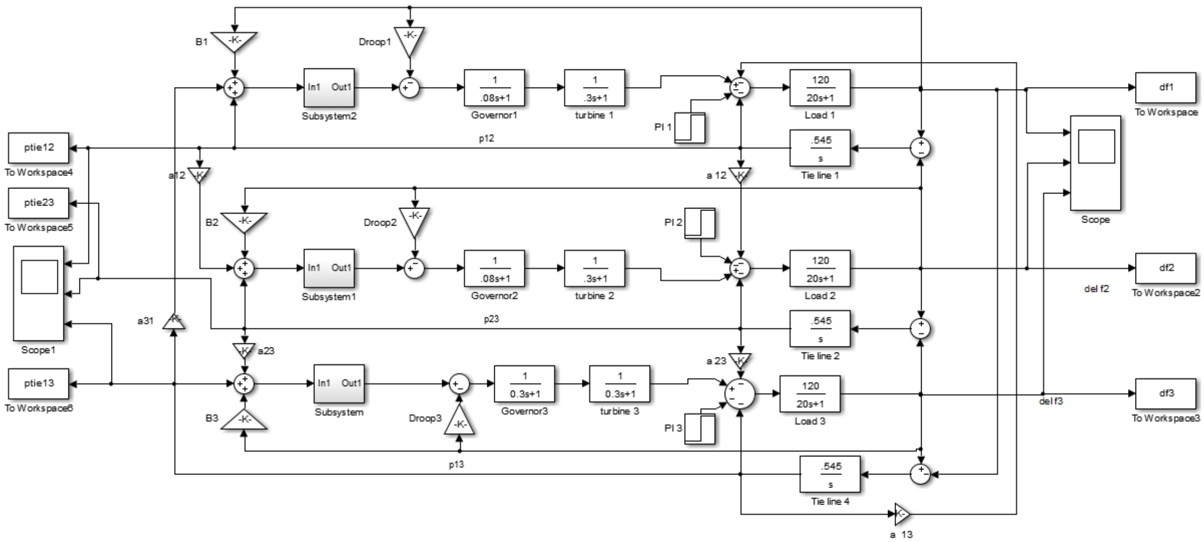

Fig. 5.3 Three-area system model with FLC

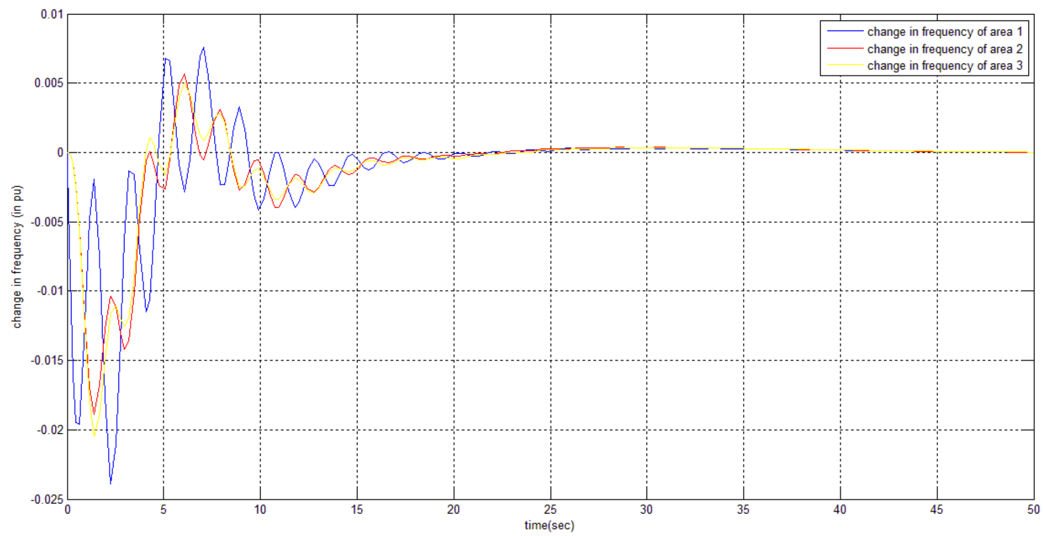

Fig. 5.4 Response of three-area system with FLC

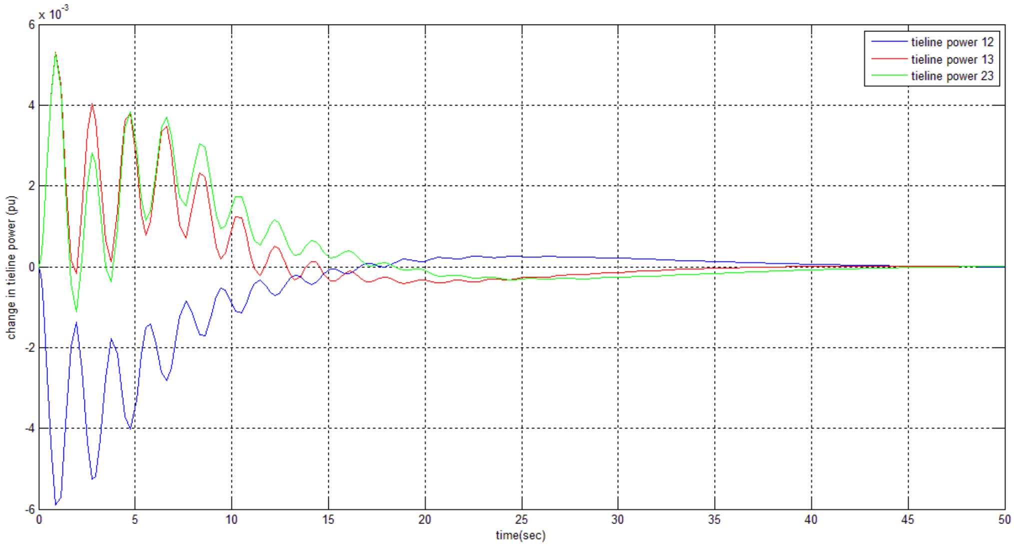

Fig. 5.5 Tie-line power in three-area system with FLC

Table. 5.2 Response of three-area system with FLC

Settling time (in seconds)			**Overshoot (in p.u.)**			**Undershoot (in p.u.)**		
Area1	Area2	Area3	Area1	Area2	Area3	Area1	Area2	Area3
22	20	21	0.007	0.005	0.005	-0.022	-0.018	-0.02

5.6 FLC in four-area system

The MATLAB/Simulink model of a four area system is shown in the figure given below. FLC is used in the model. A disturbance of 0.05 pu is given to the area 1 and the change in frequency and tie-line power is noticed in the figures given below. Table given below contains the details about results in a four area system.

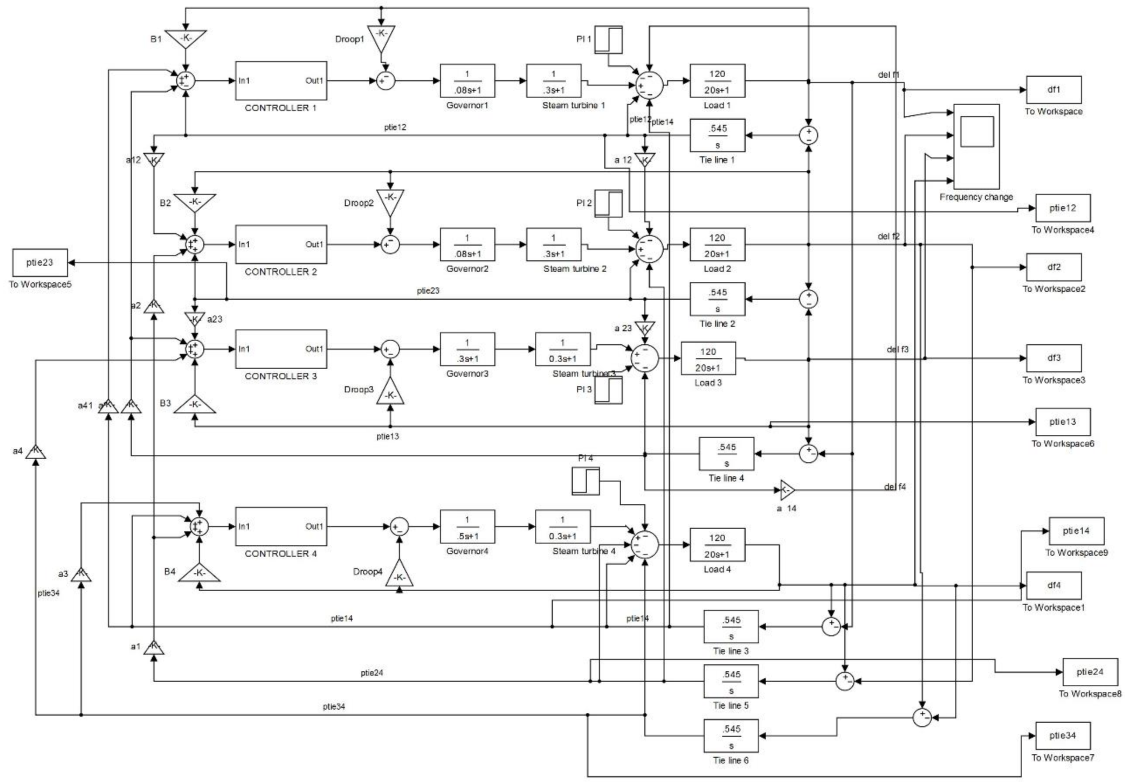

Fig. 5.6 Four-area system MATLAB/SIMULINK model with FLC

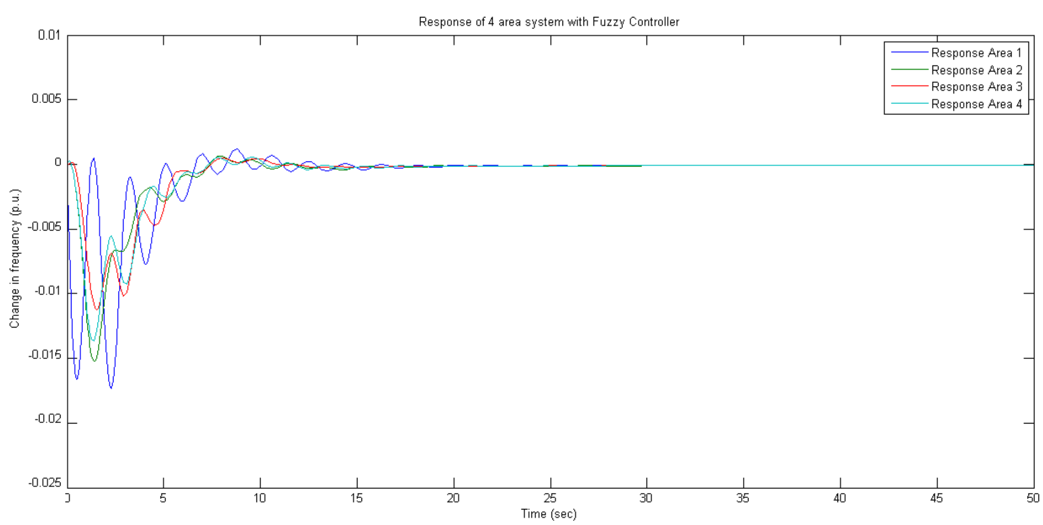

Fig. 5.7 Response of four-area system with FLC

Table. 5.3 Response of four-area system with FLC

Settling time (in seconds)				**Overshoot (in p.u.)**				**Undershoot (in p.u.)**			
Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4
19	20	20	19	0.001	0.001	0.001	0.001	-0.017	-0.015	-0.013	- 0.011

From the above results it is concluded that the Fuzzy Logic controller performs better than the conventional PID controller.

CHAPTER 6

EFFECT OF HVDC LINK ON LOAD FREQUENCY CONTROL

6.1 Introduction

There have been considerable advancements in the power electronics. These advancements had led to the development of HVDC systems. HVDC links is very helpful in reducing the frequency oscillations in the systems. This chapter compares the effect of HVDC link in Load Frequency Control of multi-area systems. HVDC interconnection lines is used with the conventional HVAC lines in the systems. Thyristor based HVDC had proved to include many positive features for this implementation. This further proposes to improve the stability of the system in case of any disturbance to the systems. This chapter simulates the effect of HVDC link in load frequency control in multi-area system using MATLAB/Simulink. First we will go through the basics of the HVDC links and then we will study its effect on the load frequency control in multi-area power systems.

6.2 HVDC

HVDC stands for High Voltage Direct Current. Due to the advancements in recent years in the field of Power Electronics, HVDC has become available. HVDC system had improved the efficiency of Power Systems which is attributed to the developments in Power Electronics field. In future Power Electronics based HVDC transmission systems will offer better control over the frequency.

Conventional AC transmission systems have many limitations. They can be used only in case of the synchronized AC systems, and in case of asynchronous systems they fail to be of any help. HVAC systems have many other disadvantages like the effect of earth capacitance, Ferranti effect, corona and Skin effect, etc. in comparison to the AC systems HVDC have many advantages which help it to increase the stability of the power systems during the disturbances. It had the ability to connect two different unsynchronized systems which is absent in case of the AC systems.

The main requirement in case of Load Frequency Control is to maintain the deviation in frequency of the system and the deviations in tie-line power of the system within specified limits by adjusting the power output of the generating units of each and every area with the change in frequency.

6.3 HVDC link in multi area system

In case of load frequency control using HVDC link active power from HVDC lines should continuously sense the change in frequency deviations. The active power change of the generating units is in proportion with the change in frequency deviations.

In case there is any type of frequency deviation in the system, the deviation acts as a control signal to the HVDC unit which senses the deviation and controls the power output of it accordingly. The HVDC link is represented as a first order system as shown below.

$$\Delta P_{DC} = \frac{1}{1 + sT_{DC}} \Delta X_{DC}$$

Where

T_{DC}= time constant of HVDC unit

So,

$$\Delta P_{12} = \Delta P_{DC} + \Delta P_{AC}$$

$$\Delta P_{AC} = \frac{2\pi T_{12}}{s} [\Delta f_1 - \Delta f_2]$$

Where

$\Delta P_{AC} = AC\ tieline\ power\ deviation$

$\Delta P_{DC} = power\ by\ the\ HVDC\ link$

$T_{12} = tieline\ synchronizing\ co - efficient$

The Area Control Error (ACE) of the system is defined by,

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{12}$$

$$ACE_2 = B_2 \Delta f_2 + \Delta P_{12}$$

$$\Delta P_{12} = \Delta P_{DC} + \Delta P_{AC}$$

Where

$\Delta f = f_{actual} - f_{scheduled}$

$P_{12} = net\ tieline\ power\ flow$

$B_i = frequency\ bias$

In case of load frequency control using HVDC link active power from HVDC lines should continuously sense the change in frequency deviations. The active power change of the generating units is in proportion with the change in frequency deviations.

In case there is any type of frequency deviation in the system, the deviation acts as a control signal to the HVDC unit which senses the deviation and controls the power output of it accordingly. The HVDC link is represented as a first order system as shown below.

$$\Delta P_{DC} = \frac{1}{1 + sT_{DC}} \Delta X_{DC}$$

Where

T_{DC}= time constant of HVDC unit

So,

$$\Delta P_{12} = \Delta P_{DC} + \Delta P_{AC}$$

$$\Delta P_{AC} = \frac{2\pi T_{12}}{s} [\Delta f_1 - \Delta f_2]$$

Where

$\Delta P_{AC} = AC\ tieline\ power\ deviation$

$\Delta P_{DC} = power\ by\ the\ HVDC\ link$

$T_{12} = tieline\ synchronizing\ co - efficient$

6.4 LFC on two area system with HVDC link

In this section the effect of HVDC link on load variations in two area system is performed for only one scenario. In this scenario possible operating conditions and end load demand is considered. The performance of developed HVDC link is compared to that of the conventional HVAC tie-line systems. A load change of 0.04pu is given to the area 1. All the simulations are performed on MATLAB/Simulink. The model of HVDC link is given in the figure below.

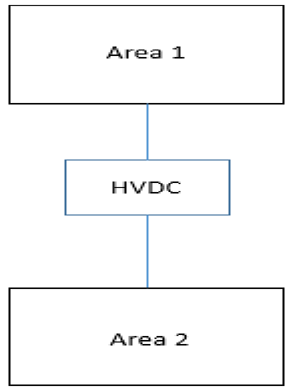

Fig. 6.1 Block diagram of two area system with HVDC link

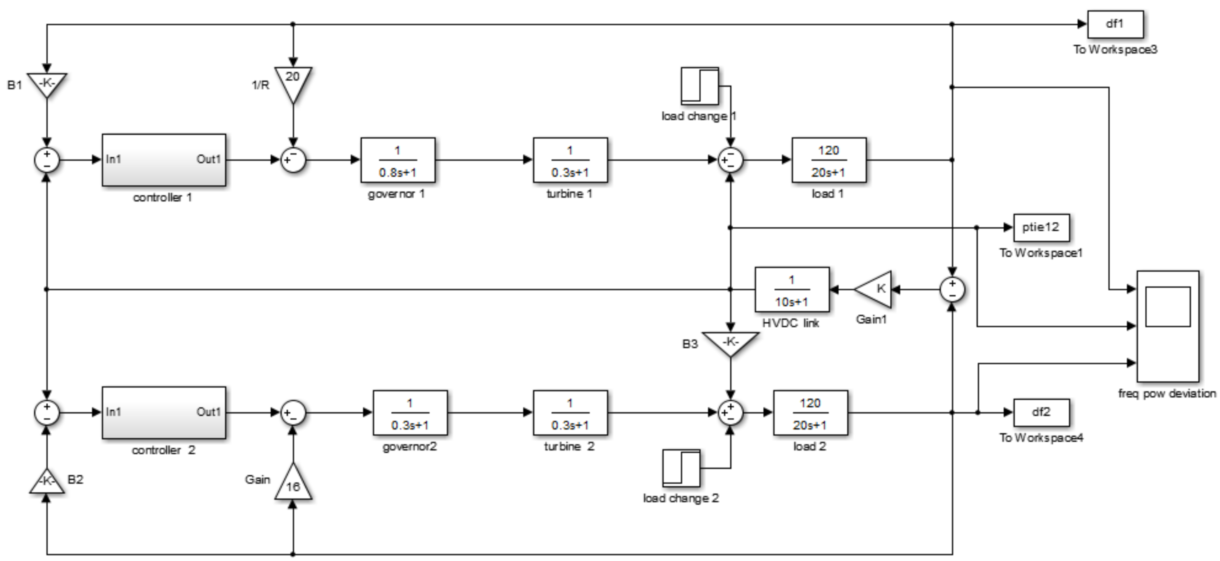

Fig 6.2 Two area Simulink model with HVDC link

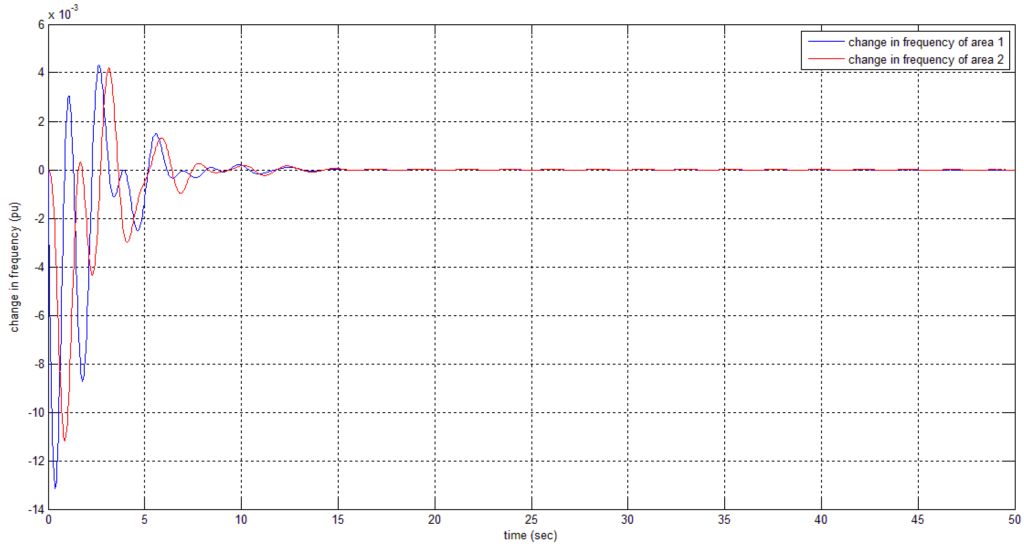

Fig. 6.3 Frequency response in two area system

Table 6.1 Response of two-area system with HVDC link

Settling time (in seconds)		**Overshoot (in p.u.)**		**Undershoot (in p.u.)**	
Area1	**Area 2**	**Area 1**	**Area 2**	**Area1**	**Area 2**
14	15	0.004	0.004	-0.0133	-0.011

6.5 HVDC link in three area system

In this section we will study the power system containing three areas. The block diagram of this three area LFC is shown in the figure below. In this section the effect of HVDC link on load variations in a three area system is performed for only one scenario. In this scenario possible operating conditions and end load demand is considered. The performance of developed HVDC link is compared to that of the conventional HVAC tie-line systems. A load change of 0.05pu is given to the area 1. All the simulations are performed on MATLAB/Simulink. The model of HVDC link is given in the figure below.

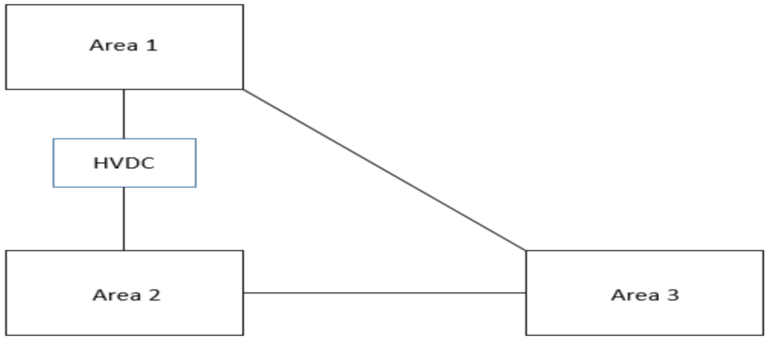

Fig. 6.4 Block diagram of HVDC link in three area system

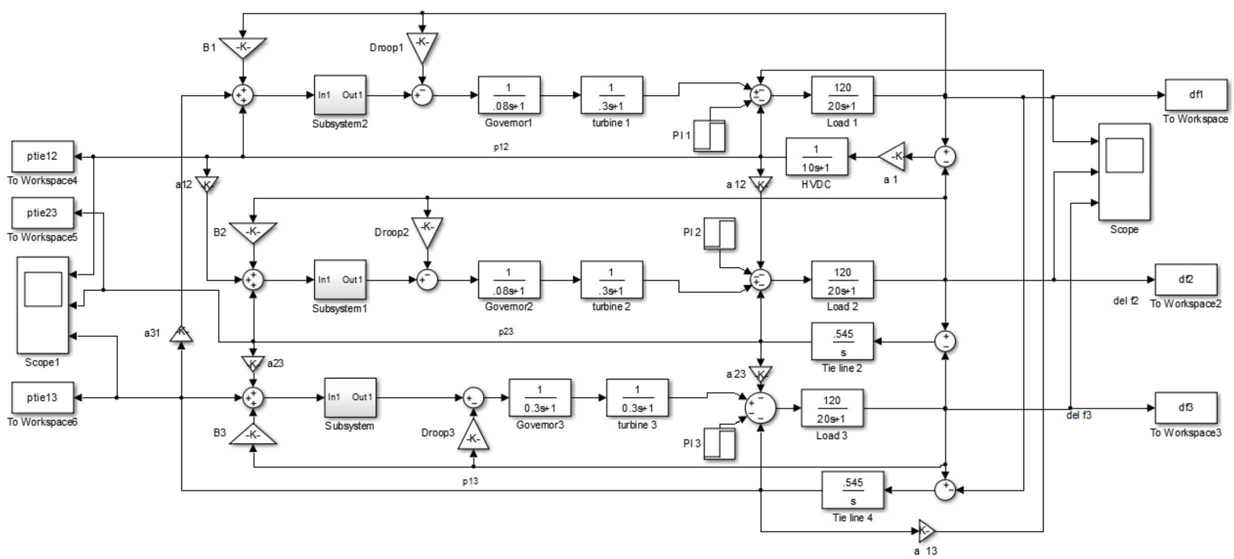

Fig. 6.5 Three area Simulink model with HVDC link

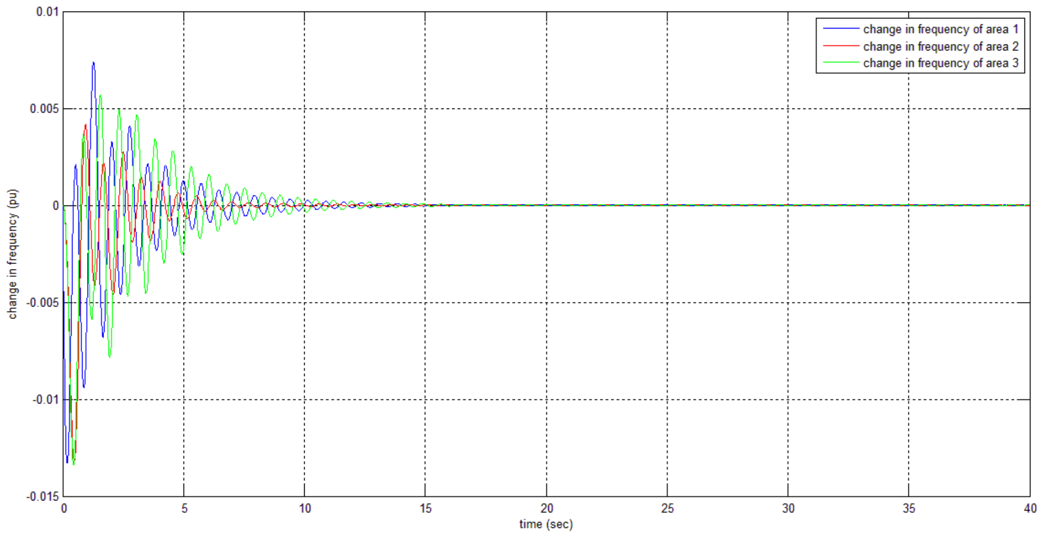

Fig. 6.6 Frequency response in three area system with HVDC link

Table 6.2 Response of three-area system with HVDC link

Settling time (in seconds)			**Overshoot (in p.u.)**			**Undershoot (in p.u.)**		
Area1	Area2	Area3	Area1	Area2	Area3	Area1	Area2	Area3
14	15	14	0.007	0.004	0.005	-0.013	-0.013	-0.013

6.6 HVDC link in four area system

In this section we will study the power system containing four areas. The block diagram of this four area LFC is shown in the figure below. In this section the effect of HVDC link on load variations in a four area system is performed for only one scenario. In this scenario possible operating conditions and end load demand is considered. The performance of developed HVDC link is compared to that of the conventional HVAC tie-line systems. A load change of 0.04pu is given to the area 1. All the simulations are performed on MATLAB/Simulink. The model of HVDC link is given in the figure below.

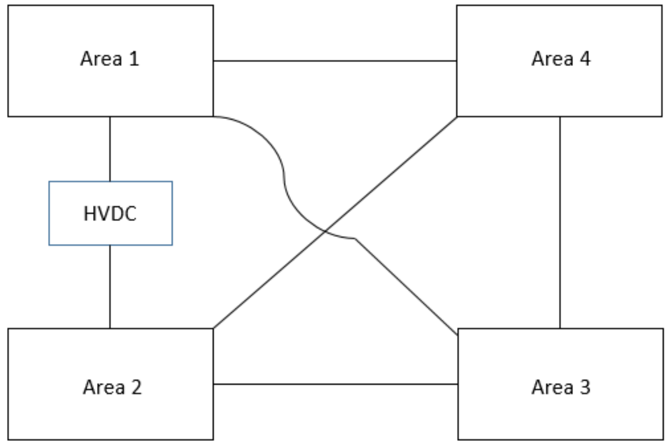

Fig. 6.7 Block diagram of four area system with HVDC link

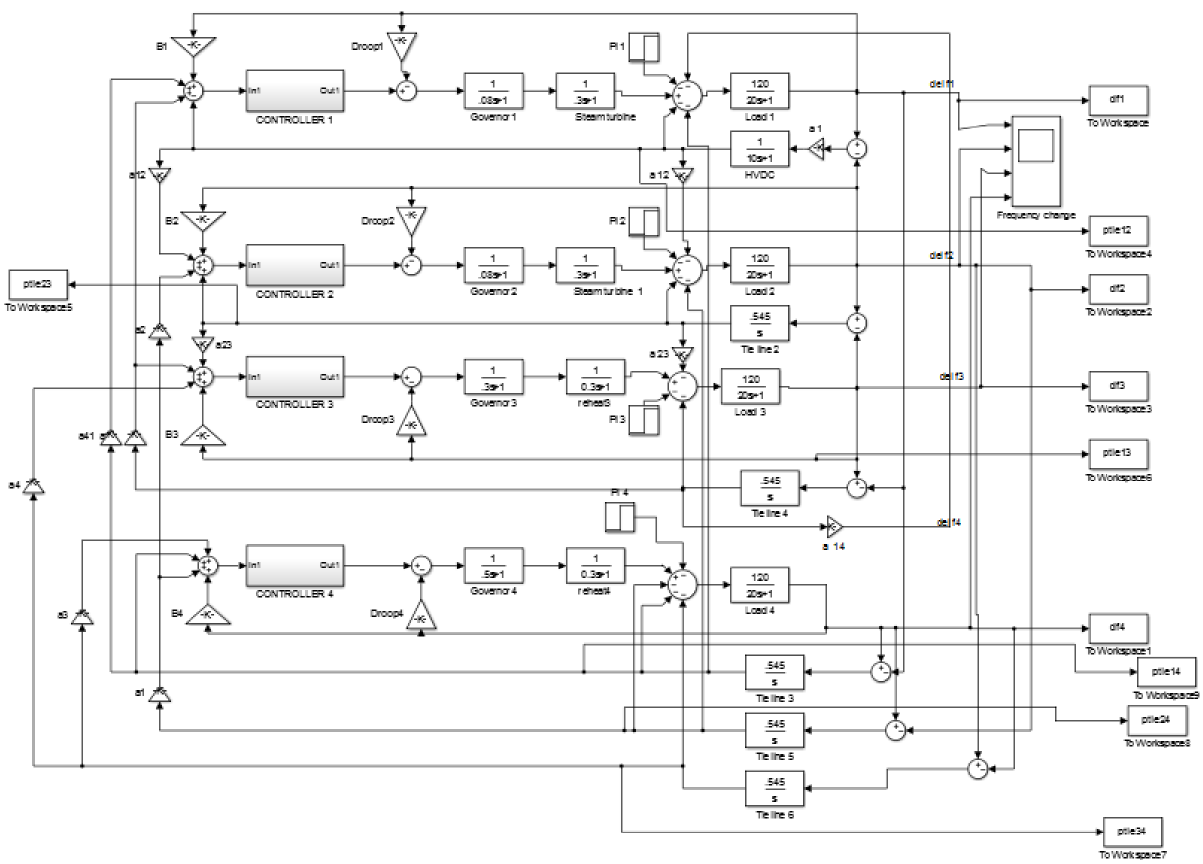

Fig. 6.8 Four area Simulink model with HVDC link

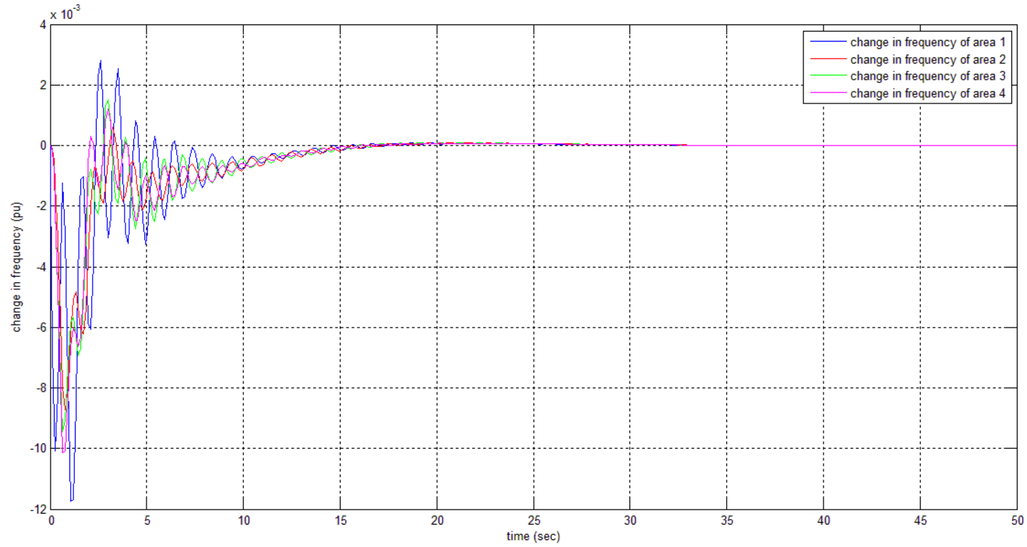

Fig. 6.9 Frequency response in four area system with HVDC link

Table 6.3 Response of four-area system with HVDC link

Settling time (in seconds)				**Overshoot (in p.u.)**				**Undershoot (in p.u.)**			
Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4
18	18	19	20	0.003	0.002	0.0015	0.0015	-0.012	-0.008	-0.01	- 0.01

From the above results we conclude that by adding a HVDC link in multi-area system the response improves. That is why HVDC lines are used for maintaining Load frequency to desired levels.

CHAPTER 7
LOAD FREQUENCY CONTROL WITH LOAD FLUCTUATION

7.1 Introduction

In the previous chapter we saw the usefulness of HVDC link in LFC. Earlier we used a step input for LFC but in this chapter we will demonstrate the actual case of load fluctuations on the system. We will use a random load fluctuation model. HVDC system will be used to improve the effects of the load fluctuations which will be demonstrating the actual load change on the system. If two AC systems are interconnected, the HVDC link plays an important role to sustain the frequency deviation due to load disturbances.

7.2 Random load fluctuation model

Random load disturbance is used to demonstrate the effect of actual load disturbance on the system. Fig 7.1 shows the model of random load generator used for the study of LFC in a system. The load consists of base and fringe components. It is obtained from the white noise generator. Low frequency and high frequency components are neglected from the load fluctuations. Fig. 7.2 gives the fluctuations in the load. To study these fluctuations, the standard deviation is used. Standard deviation of frequency and power is calculated by the model shown in the figure given below.

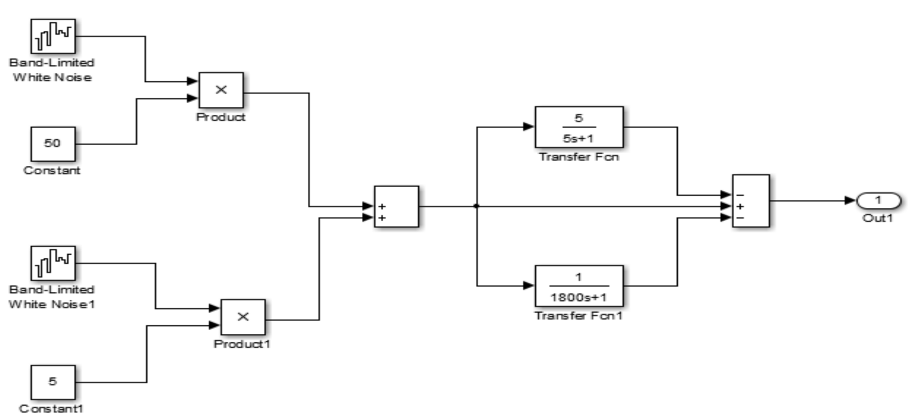

Fig. 7.1 Random load generator

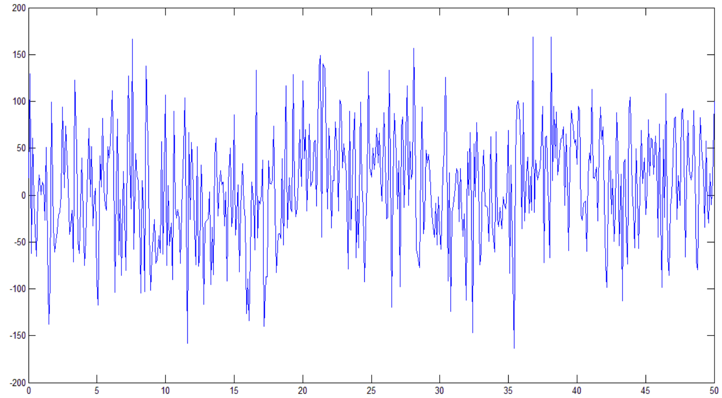

Fig 7.2 Load fluctuations model

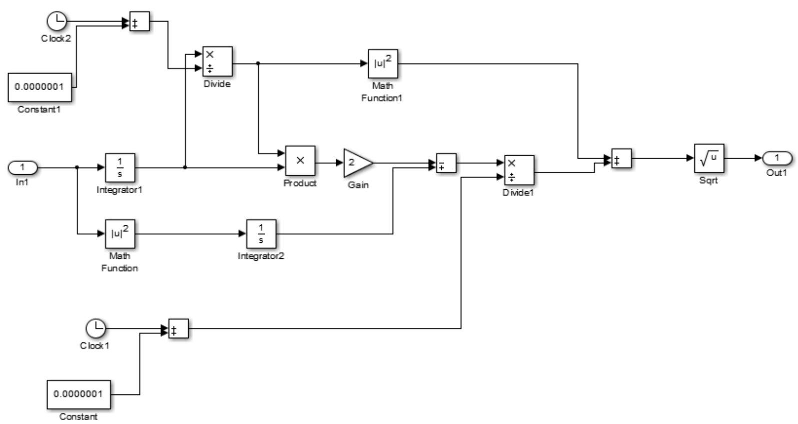

Fig 7.3 Standard deviation analysis block

In this chapter standard deviation model is used for the study of frequency deviations the equations for standard deviation model is given below.

$$\mathrm{STD}:\sigma=\sqrt{\frac{1}{n}\sum\left(x_i-\bar{x}\right)^2 dt}\cong\sqrt{\frac{1}{T}\int\left(x(t)-\bar{x}\right)^2 dt}$$
$$=\sqrt{\frac{1}{T}\int\left(x(t)^2-2x(t)\cdot\bar{x}+\overline{x^2}\right)dt}$$
$$=\sqrt{\frac{1}{T}\int x(t)^2\,dt-\frac{2}{T}\int x(t)\cdot\bar{x}dt+\frac{1}{T}\int\bar{x}dt}$$

STD = standard deviation

7.3 LFC on two area system

First a two area network model is considered. It is connected through a HVDC link. It is shown in the figure below. It is demonstrated through the model how effective the HVDC link is in the LFC. The gain of the HVDC link is changed and the effect is studied. Fig 7.5 shows the frequency and power response of the two area system with HVDC link.

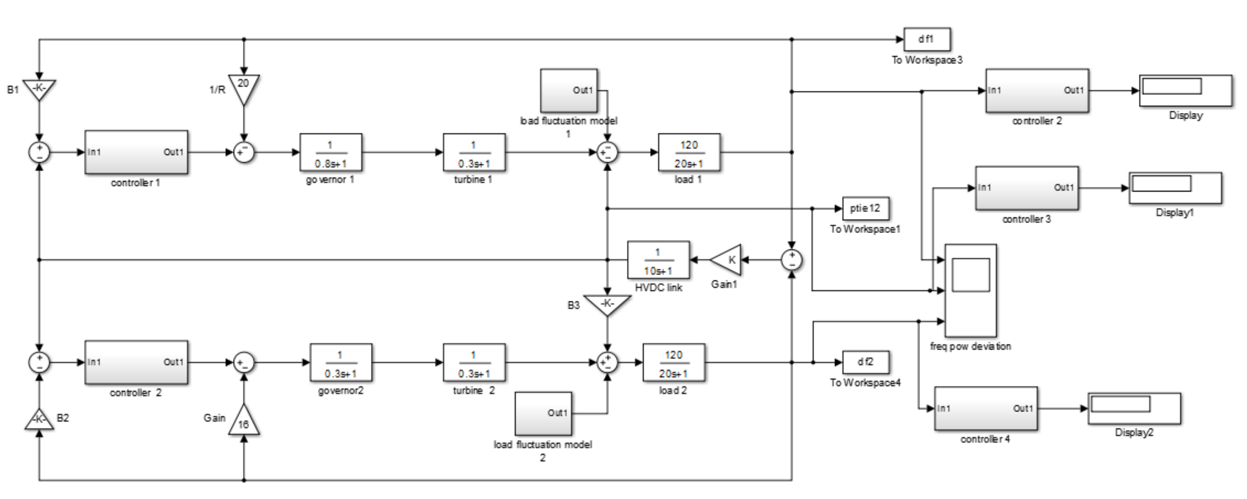

Fig 7.4 Two area system with HVDC model

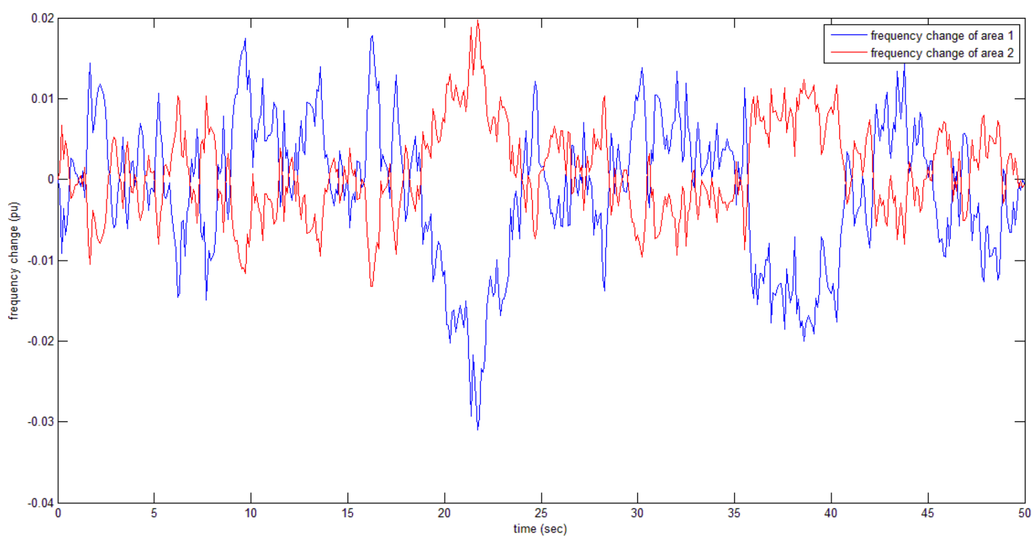

Fig 7.5 Frequency response of two area system

Table 7.1 Standard deviations for two area system

K	DF1	DF2
100	0.011653	0.009322

7.4 LFC on three area system

Now a three area model is considered. It is connected through a HVDC link. It is shown in the figure below. It is demonstrated through the model how effective the HVDC link is in the LFC. The gain of the HVDC link is changed and the effect is studied. Fig 7.5 shows the frequency and power response of the three area system with HVDC link.

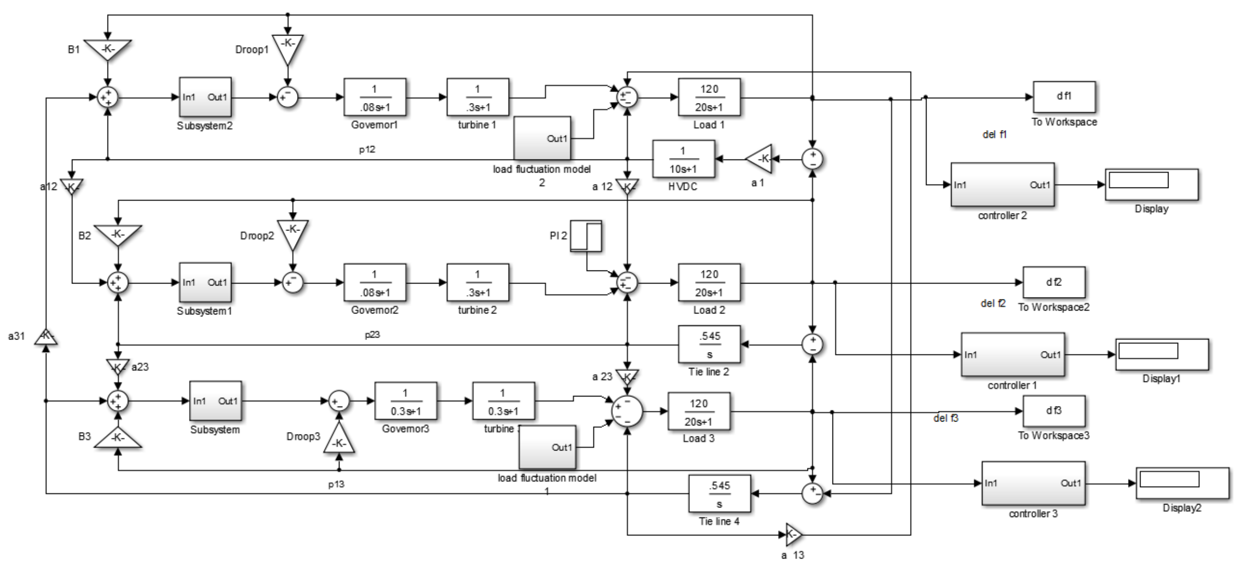

Fig 7.6 Three area system with HVDC link

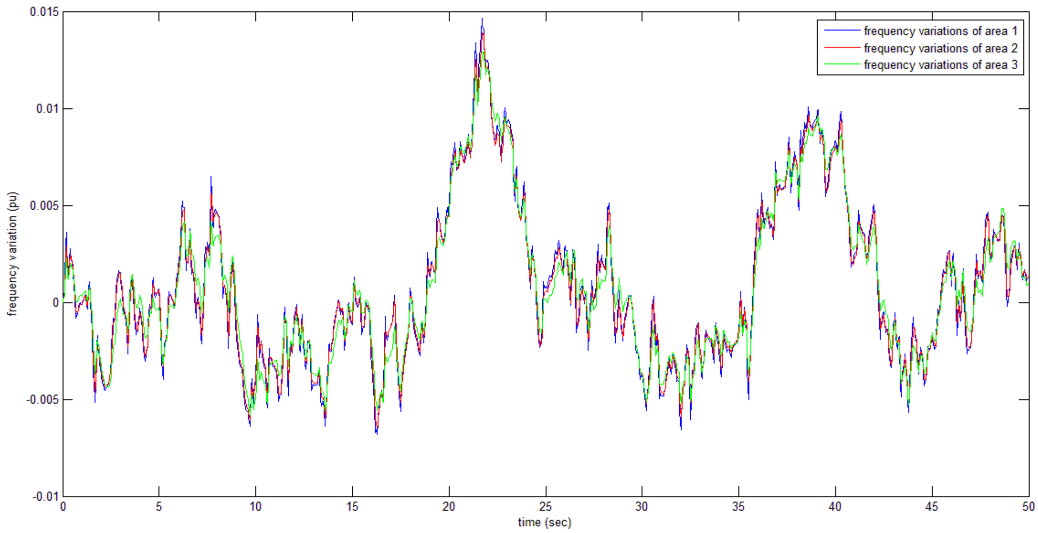

Fig 7.7 Frequency response of three area system

Table 7.2 Standard deviations for three area system

K	DF1	DF2	DF3
100	0.004165	0.004331	0.004294

Table 7.3 Standard deviations for four area system

K	DF1	DF2	DF3	DF4
100	0.004183	0.003973	0.004038	0.003483

HVDC link provides improvement in frequency response thus contributing towards Load Frequency Control in Power Systems.

CHAPTER 8

LFC USING PARTICLE SWARM OPTIMIZATION

8.1 Introduction

In this chapter the study of load frequency control is done with the help of Particle Swarm Optimization technique. MATLAB/Simulink model is used to study the LFC in multi-area system. In the earlier chapter I, PI, PID and Fuzzy logic controllers have been used to study LFC in multi-area systems. The conventional controllers like I, PI, PID are frequently used in LFC problems but it is very hard to compute their parameters in the huge multi-area system. To solve this problem we use different optimization tools. In this chapter we will use the PSO optimization technique. PSO is more effective in controlling the deviation in frequency of the models and reaches to the steady state in minimum time. The parameters of the PID controller will be modified with the help of PSO to give optimal solution to the LFC problem.

8.2 Particle Swarm Optimization

PSO optimization is one of the best optimization technique in LFC. It was developed in 1995 and it is based on the mapping of bird flocking and fish schooling. It is based on the population of the swarms. It requires very short computational time and less memory for the optimization problems. Bird flocking is the technique which is based on how the birds go to search for their food. They use the shortest path to reach to their destination. In this technique, the population of swarms is randomly generated and the best solution in their position is find out with the help of the fitness value. Another best value is the global value. In every iteration the particle's position is updated to its best value. The particles update their velocity with every iteration.

8.3 LFC in two area system

A two area system is employed in MATLAB/Simulink. It is shown in the figure below. PSO algorithm is applied to the system and values of PID parameters is evaluated. These values are applied to the PID block and the resultant response is given in the figure below.

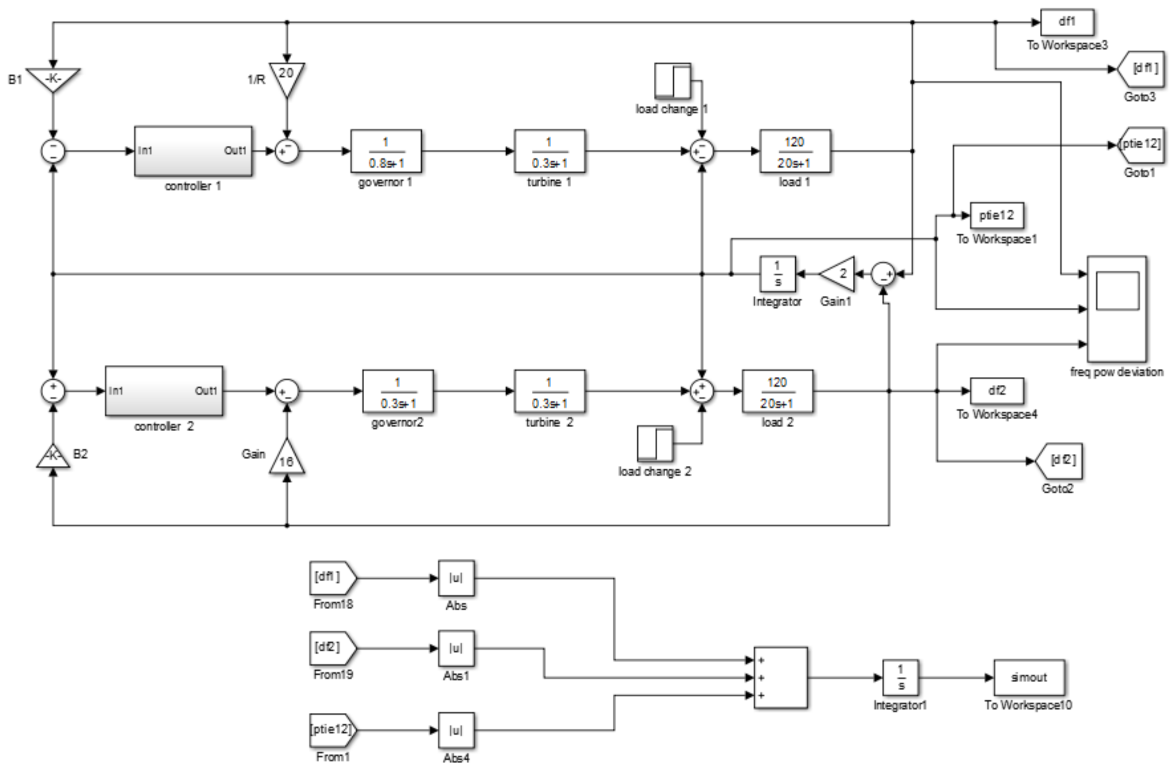

Fig 8.1 Block diagram of two area system with PSO

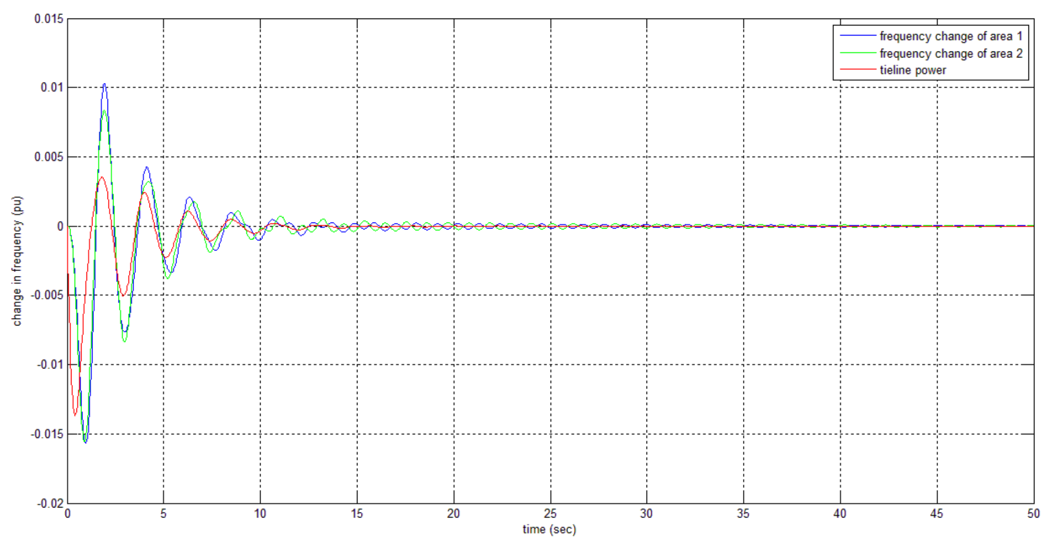

Fig 8.2 Response of two area system with PSO

Table 8.1 Response of two area system with PSO

Settling time (in seconds)		**Overshoot (in p.u.)**		**Undershoot (in p.u.)**	
Area1	**Area 2**	**Area 1**	**Area 2**	**Area1**	**Area 2**
13	14	0.01	0.008	-0.015	-0.015

8.4 LFC in three area system

A three area system is employed in MATLAB/Simulink. It is shown in the figure below. PSO algorithm is applied to the system and values of PID parameters is evaluated. These values are applied to the PID block and the resultant response is given in the figure below.

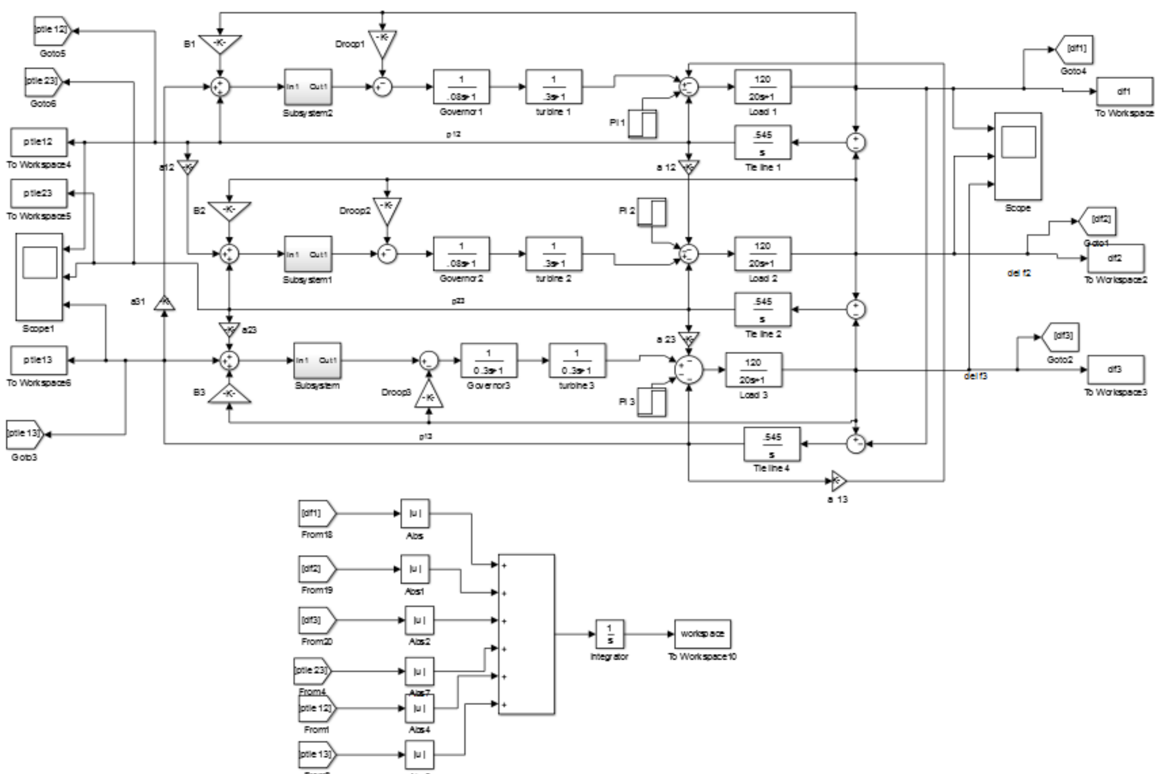

Fig 8.3 Block diagram of three area system with PSO

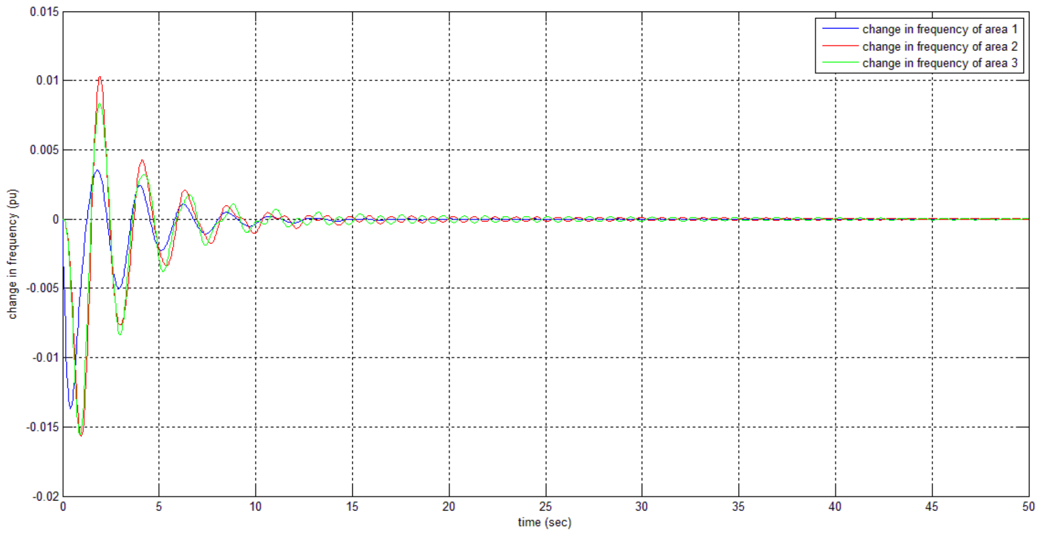

Fig 8.4 Response of three area system with PSO

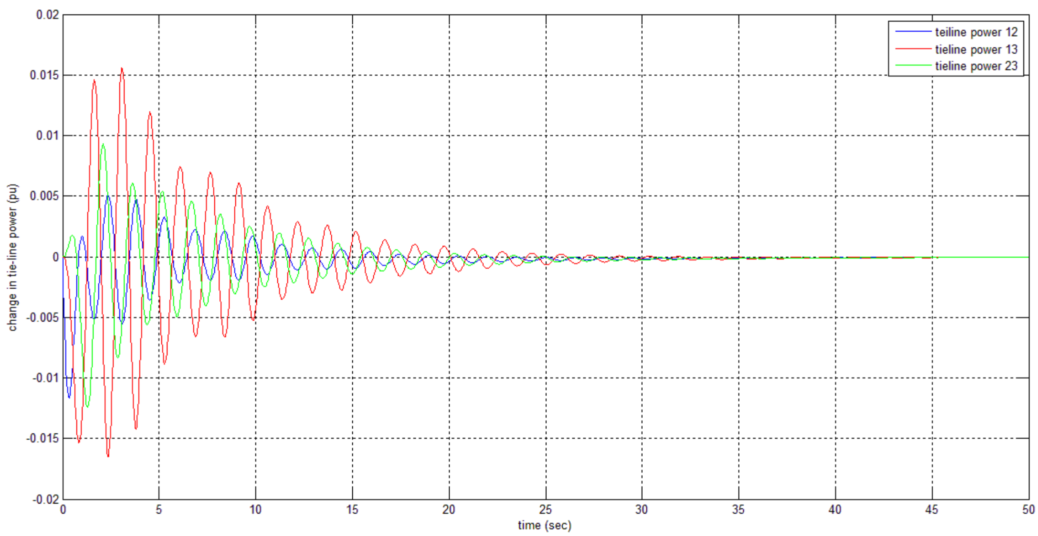

Fig 8.5 Tie-line response of three area system with PSO

Table. 8.2 Response of three-area system with PSO

Settling time (in seconds)			**Overshoot (in p.u.)**			**Undershoot (in p.u.)**		
Area1	Area2	Area3	Area1	Area2	Area3	Area1	Area2	Area3
14	18	19	0.01	0.004	0.008	-0.013	-0.015	-0.015

8.5 LFC in four area system

A four area system is employed in MATLAB/Simulink. It is shown in the figure below. PSO algorithm is applied to the system and values of PID parameters is evaluated. These values are applied to the PID block and the resultant response is given in the figure below.

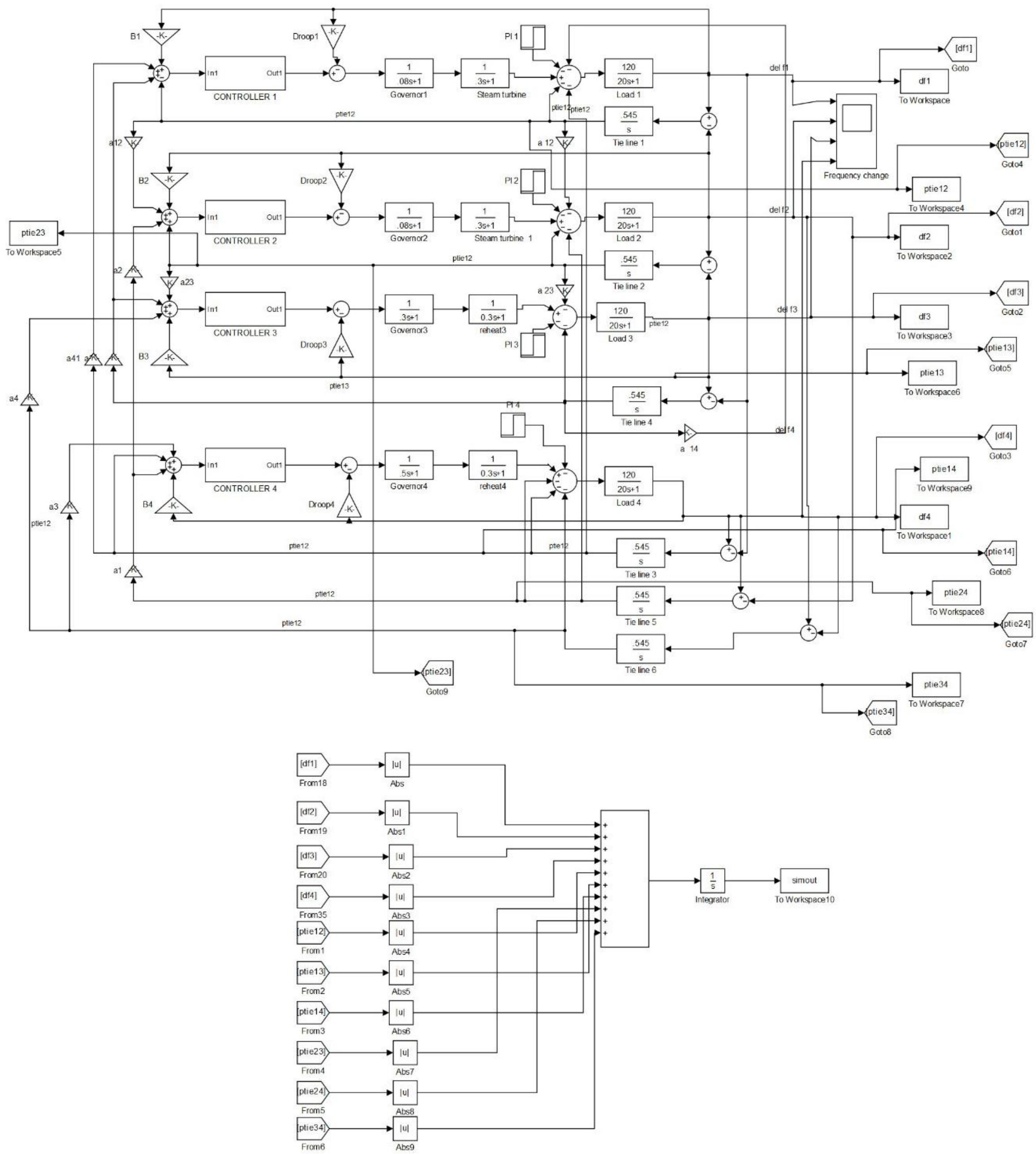

Fig 8.6 Block diagram of four area system with PSO

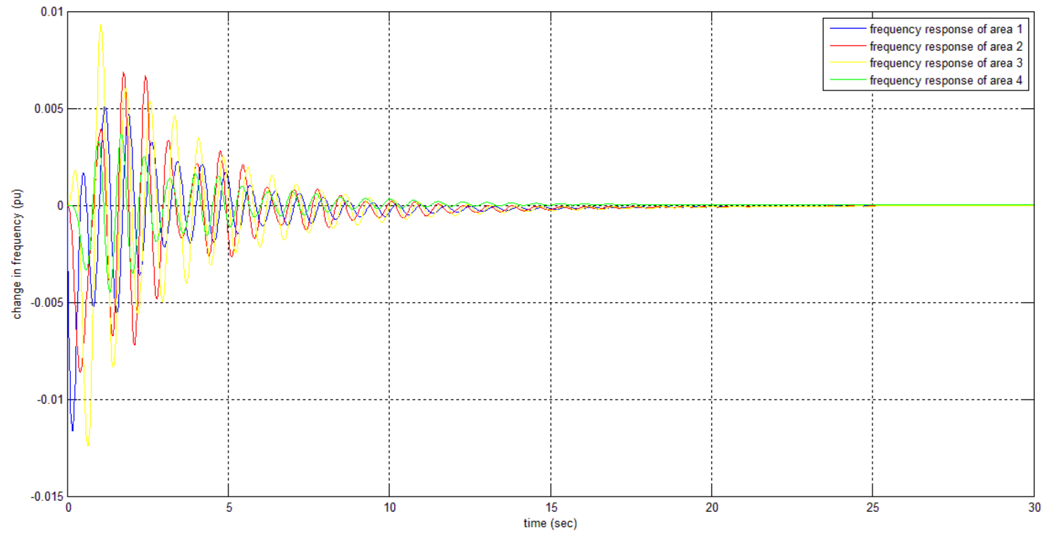

Fig 8.7 Response of four area system with PSO

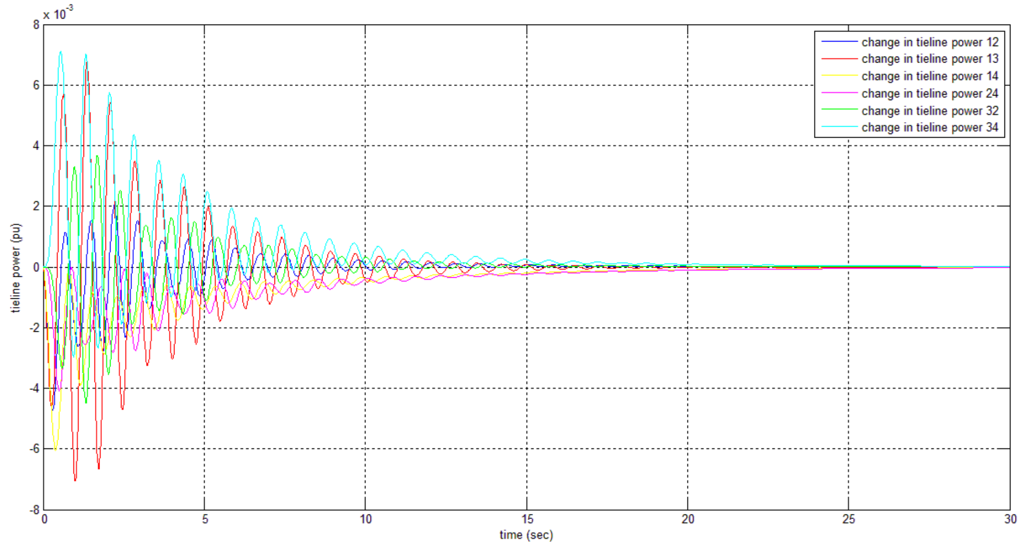

Fig 8.8 Tie-line response of four area system with PSO

Table. 8.3 Response of four-area system with PSO

Settling time (in seconds)				**Overshoot (in p.u.)**				**Undershoot (in p.u.)**			
Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4
15	16	14	14	0.005	0.007	0.009	0.003	-0.012	-0.008	-0.013	- 0.004

From the above results it is clear that the PSO algorithm improves the performance of the system in case of a disturbance. It provides optimal solution to the load frequency control problem.

CHAPTER 9

LFC WITH COMMUNICATION DELAY IN THE SYSTEM

9.1 Introduction

In the previous chapter the ability of PSO in minimizing disturbance in LFC was observed. The results obtained were better than that obtained with other controllers used in previous chapters. In this chapter the effect of communication delay is illustrated in the multi-area systems. There exists communication links in every system. In this system also various single areas are connected with each other through the tie-lines. These links can cause unreliable time delays and communication failures. Thus it is important to study about these communication delays in LFC study. In this chapter the design of LFC is studied with the inclusion of communication delays in the system. This study is done on two-area, three-area and four-area systems.

9.2 LFC in two-area systems

The two-area model of LFC is shown in the figure below. This model is used to study LFC with communication delay in two-area system. The simulations are carried out in MATLAB/Simulink. Transport delay is used to simulate communication delay in the system. Here two types of delays are present. One is in the feed forward channel and other in the feedback channel. Thus in two area network we are using a total of three delay elements.

Now three conditions are simulated.

1) LFC without any delay. In this condition the delay units are set to a value of zero and the results can be seen from previous chapter.

2) LFC with delay only in the feedback channel. In this condition a delay of 1 unit is given in the feedback channel. The results of this simulation can be seen in the figure given below.

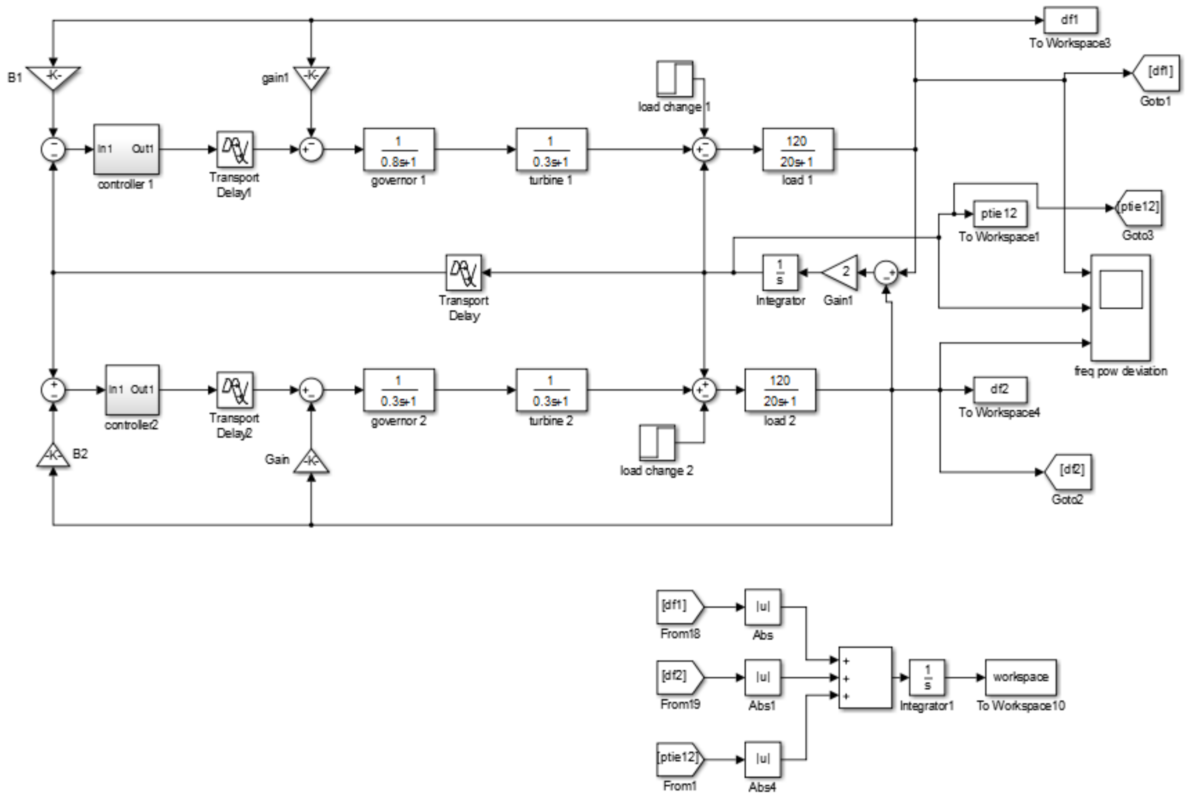

Fig 9.1 MATLAB/Simulink model of two area system with communication delay

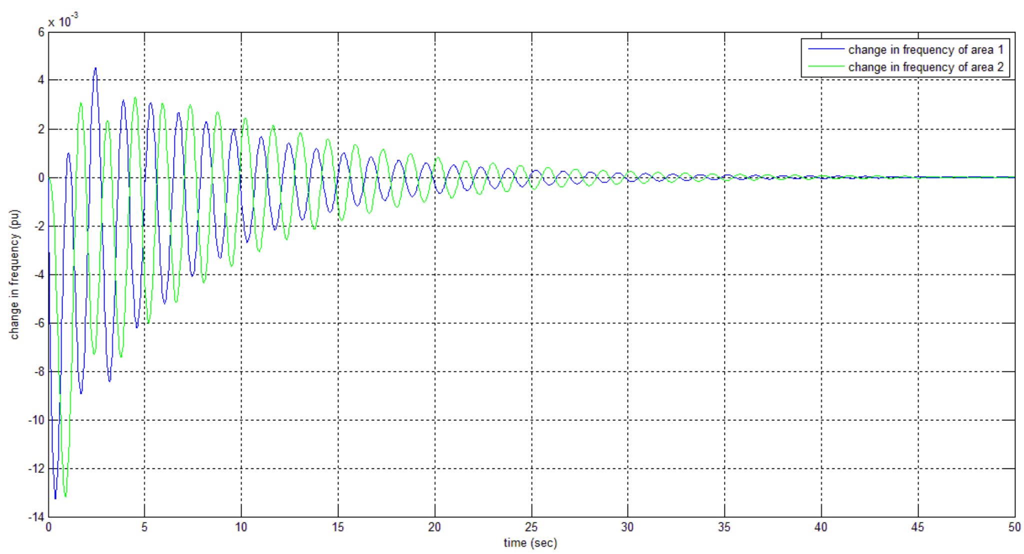

Fig 9.2 LFC with delay in feedback channel

3) LFC with delay in both feed forward channel and the feedback channel. In this condition a delay of 1 unit is given in both the channels. The results of this simulation can be seen in the figure given below.

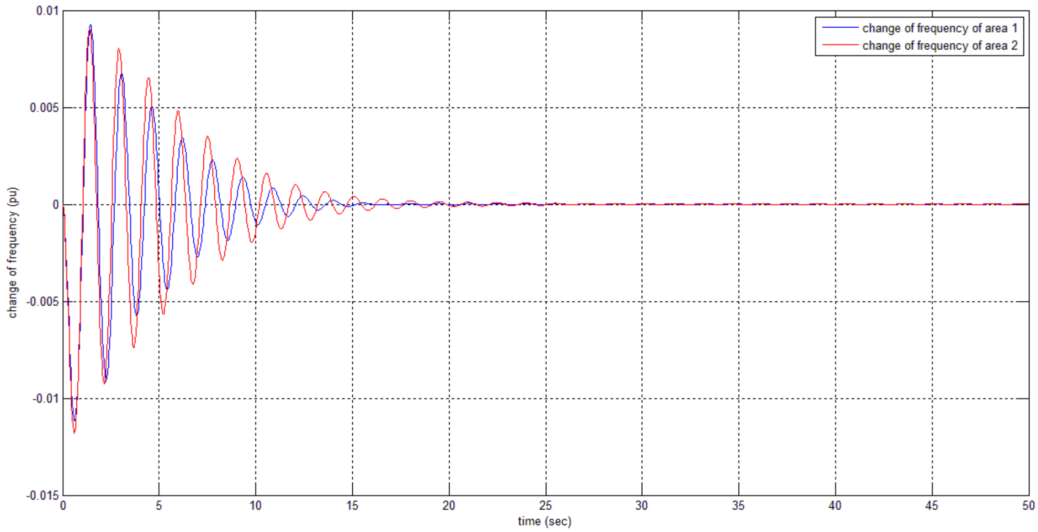

Fig 9.3 LFC with delay in both channel

Table 9.1 LFC with delay in two area system

Condition	**Settling time (in seconds)**		**Overshoot (in p.u.)**		**Undershoot (in p.u.)**	
	Area1	**Area 2**	**Area 1**	**Area 2**	**Area1**	**Area 2**
Without delay	13	14	0.01	0.008	-0.015	-0.015
Delay in feedback	34	36	0.004	0.003	-0.013	-0.013
Delay in both	15	18	0.009	0.009	-0.012	-0.012

9.3 LFC in three-area systems

The three-area model of LFC is shown in the figure below. This model is used to study LFC with communication delay in three-area system. The simulations are carried out in MATLAB/Simulink. Transport delay is used to simulate communication delay in the system. Here two types of delays are present. One is in the feed forward channel and other in the feedback channel. Thus in three area network we are using a total of six delay elements.

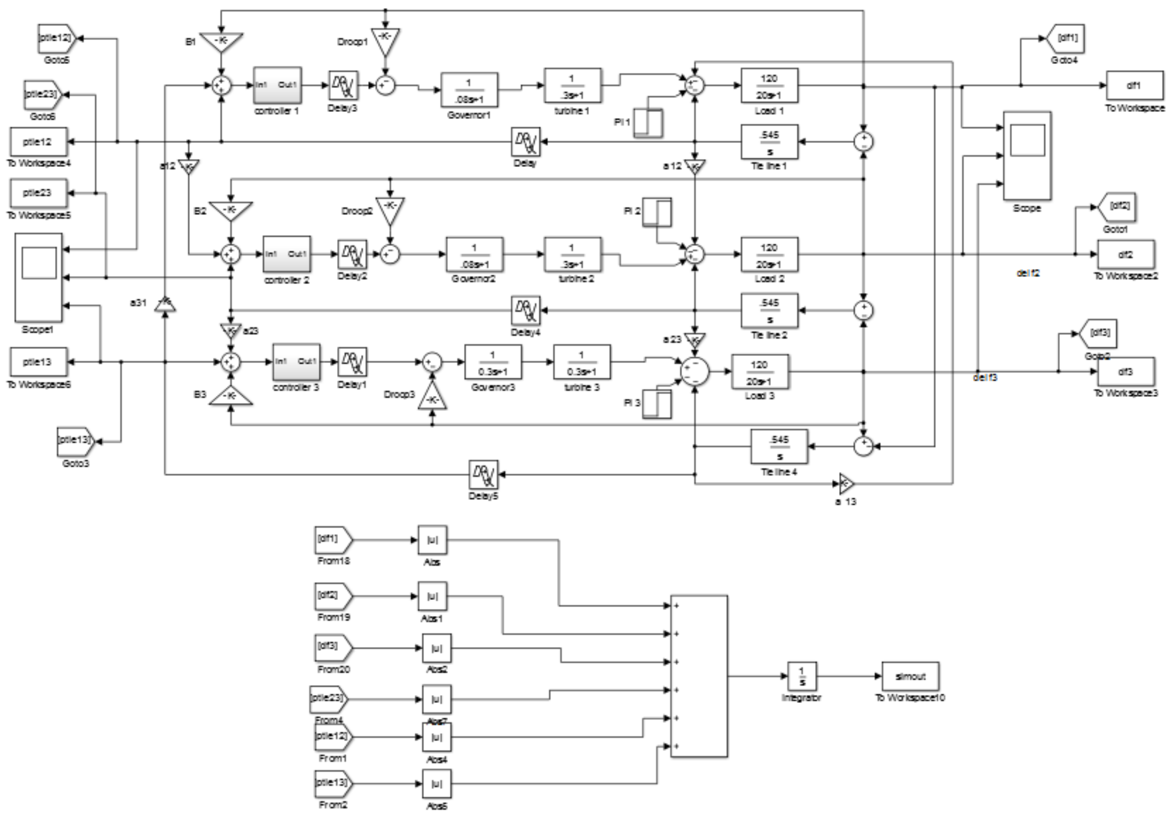

Fig 9.4 MATLAB/Simulink model of three area system with communication delay

Now three conditions are simulated in this three area system.

1) LFC without any delay. In this condition the delay units are set to a value of zero and the results can be seen from previous chapter.

2) LFC with delay only in the feedback channel. In this condition a delay of 1 unit is given in the feedback channel. The results of this simulation can be seen in the figure given below.

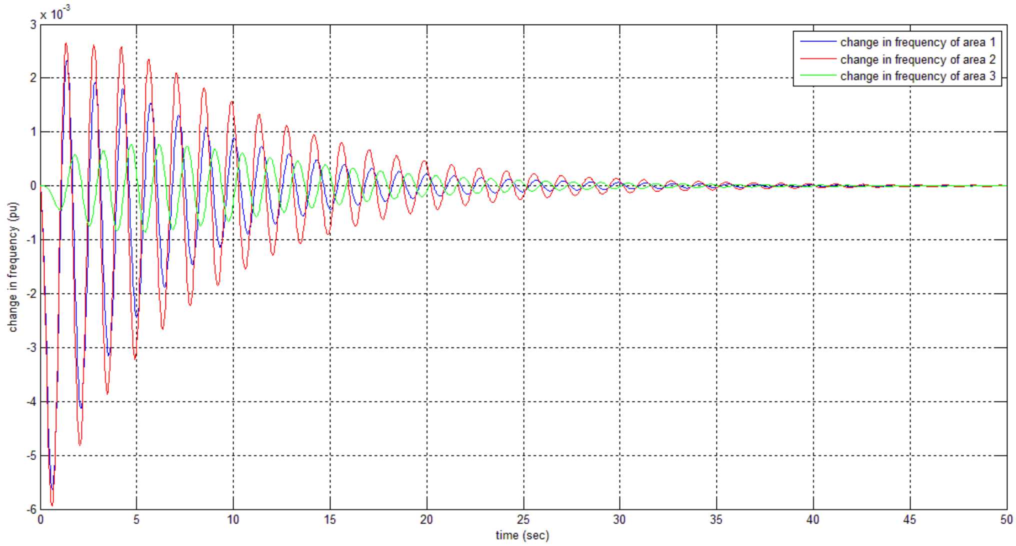

Fig 9.5 LFC in three area system with delay in feedback channel

3) LFC with delay in both feed forward channel and the feedback channel. In this condition a delay of 1 unit is given in both the channels. The results of this simulation can be seen in the figure given below.

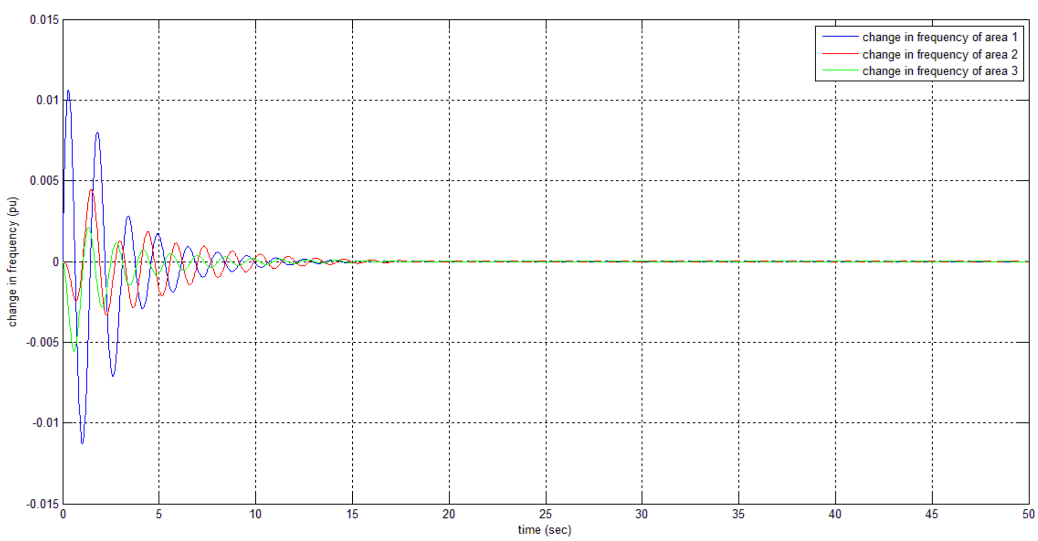

Fig 9.6 LFC in three area system with delay in both channel

Table 9.2 LFC with delay in three area system

Condition	Settling time (in seconds)			Overshoot (in p.u.)			Undershoot (in p.u.)		
	Area1	Area2	Area3	Area1	Area2	Area3	Area1	Area2	Area3
Without delay	14	18	19	0.01	0.004	0.008	-0.013	-0.015	-0.015
Delay in feedback	34	37	33	0.003	0.003	0.001	-0.006	-0.0055	-0.001
Delay in both channel	14	16	19	0.01	0.004	0.003	-0.011	-0.003	-0.006

9.4 LFC in four-area systems

The four-area model of LFC is shown in the figure below. This model is used to study LFC with communication delay in four-area system. The simulations are carried out in MATLAB/Simulink. Transport delay is used to simulate communication delay in the system. Here two types of delays are present. One is in the feed forward channel and other in the feedback channel. Thus in four area network we are using a total of ten delay elements.

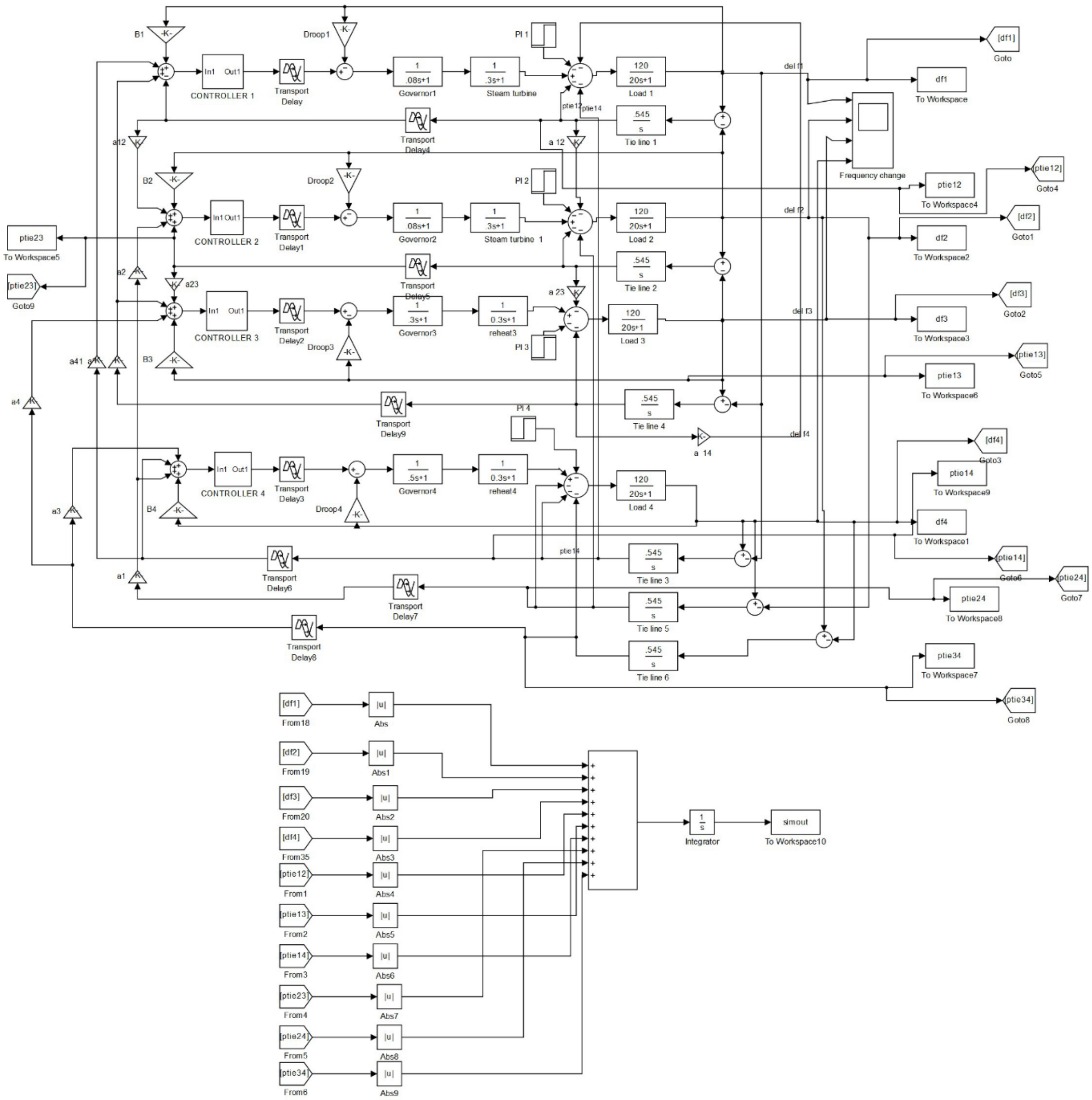

Fig 9.7 MATLAB/Simulink model of four area system with communication delay

Now three conditions are simulated in this four area system.

1) LFC without any delay. In this condition the delay units are set to a value of zero and the results can be seen from previous chapter.

2) LFC with delay only in the feedback channel. In this condition a delay of 1 unit is given in the feedback channel. The results of this simulation can be seen in the figure given below.

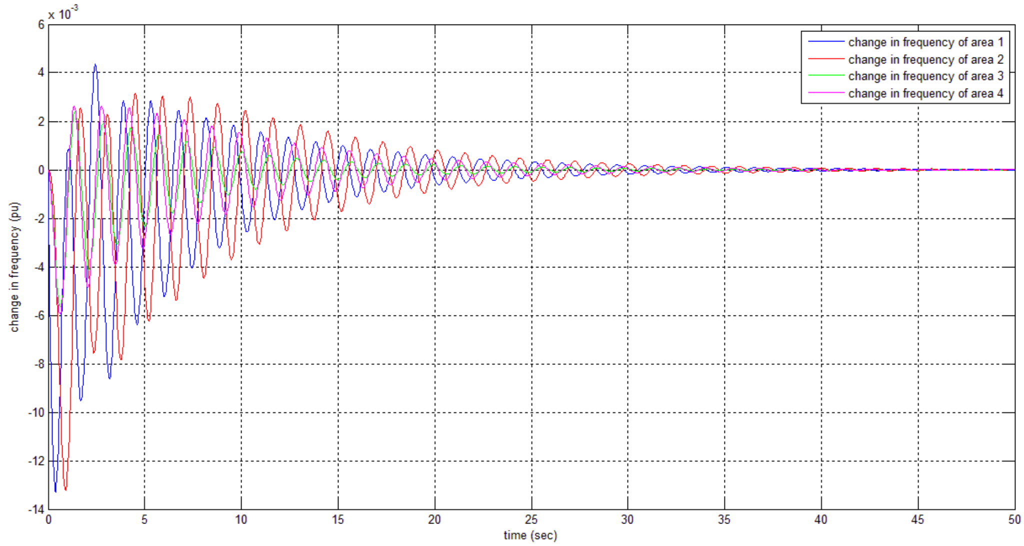

Fig 9.8 LFC in four area system with delay in feedback channel

3) LFC with delay in both feed forward channel and the feedback channel. In this condition a delay of 1 unit is given in both the channels. The results of this simulation can be seen in the figure given below.

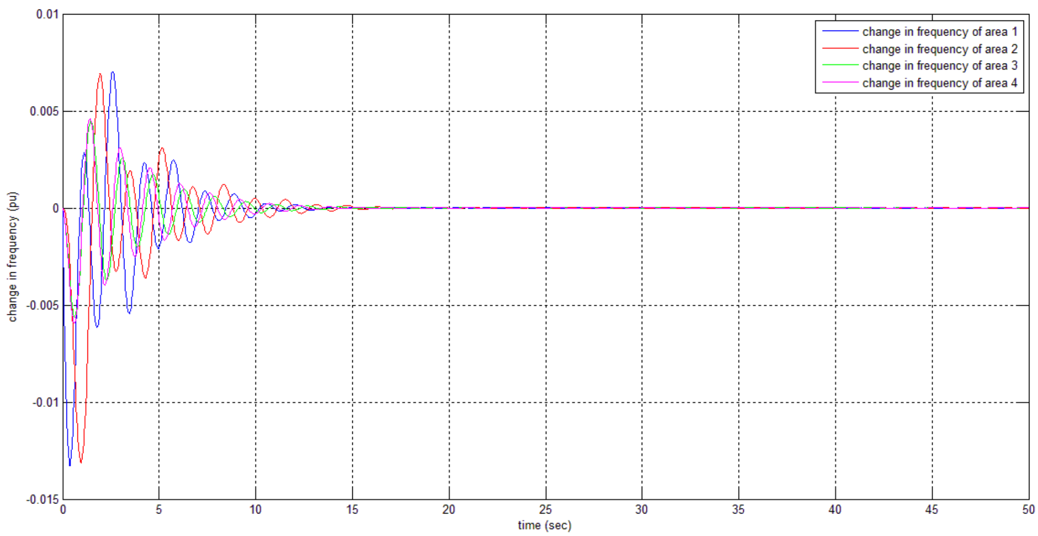

Fig 9.9 LFC in four area system with delay in both channel

Table 9.3 LFC with delay in four area system

Condition	Settling time (in seconds)				Overshoot (in p.u.)				Undershoot (in p.u.)			
	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4
Without delay	15	16	14	14	0.005	0.007	0.009	0.003	-0.012	-0.008	-0.013	- 0.004
Delay in feedback	36	38	34	35	0.004	0.003	0.003	0.003	-0.012	-0.012	-0.006	-0.006
Delay in both	14	16	14	14	0.006	0.006	0.004	0.003	-0.013	-0.013	-0.004	-0.004

From the above results it is clear that the communication delay in the system makes the system to take more time to settle down to desired frequency. It is improved by taking delays in both the channels. This improves the frequency response of the multi area system.

CHAPTER 10
CONCLUSIONS AND FUTURE SCOPE

10.1 Conclusions

This thesis is a contribution for the Load Frequency Control in multi-area power system with the help of conventional and intelligent controllers. Conventional controllers consist of PID controllers. Intelligent controllers consist of Fuzzy and PSO controller. HVDC link was also used to study the effect of HVDC link on the LFC in multi-area system.

These controllers were used to control the load frequency with disturbance in area 1. The power systems consisted of thermal and hydro systems. First PID controller was used with different values of I, PI, PID. Better result was obtained when PID controller was involved as a controller in multi-area system.

Fuzzy Logic control was used to control the frequency deviations. Its performance depends on the accuracy of fuzzy rules. Increase in number of fuzzy rules improves the response of the system. On the other hand, as the size of rules increases the computational time, and computational effort increases. The performance of Fuzzy controller was compared with that of the PID controllers and the response was improved in this case. HVDC link was added in place of AC link and then the performance of Fuzzy controller was evaluated. It was noted that the HVDC link improved the response of the system.

Particle Swarm Optimization technique was used for optimization of the parameters of PID controller. Optimized parameters gave best result for the system. It was concluded that PSO optimization was better than the optimization by Fuzzy logic controller.

PSO was also studied with delay in communication channels. It was noted that the delay causes the frequency to take more time to settle down to desired frequency. It was corrected by allowing delays in both the channels. After allowing delays in both the channels, the frequency response of the system improved.

10.2 Future Scope

Work done in this thesis can be extended to following directions:

1. The Fuzzy logic controller developed can be used in more complex systems to obtain the optimum performance.

2. PSO can be integrated with Fuzzy controller to obtain better results.

3. LFC of renewable energy sources can be performed with the help of the PSO algorithm to obtain optimal results.

4. PSO can be used to study the case of load fluctuations in power systems.

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