Sudan University of Sciences & Technology
College of Engineering
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Load Frequency Control of Multi area system

التحكم في تردد الحمل لنظام متعدد محطات التوليد

A Project Submitted In Partial Fulfilment for the Requirements of the Degree of B.Sc. (Honor) In Electrical Engineering

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October 2016

الآية

قال تعالى :

" اللَّهُ لَا إِلَهَ إِلَّا هُوَ الْحَيُّ الْقَيُّومُ لا تَأْخُذُهُ سِنَةٌ وَلَا نَوْمٌ لَهُ مَا فِي السَّمَاوَاتِ وَمَا فِي الْأَرْضِ مَنْ ذَا الَّذِي يَشْفَعُ عِنْدَهُ إِلَّا بِإِذْنِهِ يَعْلَمُ ما بَيْنَ أَيْدِيهِمْ وَمَا خَلْفَهُمْ وَلَا يُحِيطُونَ بِشَيْءٍ مِنْ عِلْمِهِ إِلَّا بِمَا شَاءَ وَسِعَ كُرْسِيُّهُ السَّمَاوَاتِ وَالْأَرْضَ وَلَا يَئُودُهُ حِفْظُهُمَا وَهُوَ الْعَلِيُّ الْعَظِيمُ " .

صدق الله العظيم

البقرة (255)

DEDICATION

Our whole hearted gratitude to our parents for their constant encouragement, love, wishes and support.

To our beloved friends who have special place on our hearts.

Above all, I thank Almighty Allah who bestowed his blessings upon us.

ACKNOWLEDGEMENTS

First of all, I thank Almighty Allah who bestowed his blessings upon us. We would like to thank our advisor, **Dr. Alfadil Zakaria Yahia**, for his directions, excellent guidance, and support. His enthusiasm and inspiration lightened the road of completing this work .We also thank him for his insightful comments and suggestions which continually helped us to improve our understanding.

Also we express our deep gratitude to the member's college in the Department of Electrical Engineering.

We would also like to express our heartfelt gratitude to our friends who have always inspired us and particularly helped us in our work.

ABSTRACT

In an interconnected power system, the power system load demand varies randomly. Variations in load bring about drifts in frequency and voltage which in turn leads to generation loss due to the line tripping and also blackout. These drifts might be reduced to the smallest possible value by automatic generation control (AGC) which constitutes of two sections are load frequency control (LFC) along with automatic voltage regulation (AVR).

The main objective of this research to maintain the real frequency and the desired power output (megawatt) in the interconnected power system and to control the change in tie line power between control areas.

The methodology of this research is used simulation to show how (LFC) work by building models in Simulink which helped to understand and evaluate the response by adding secondary control loop with simple integral controller. The simulation results in time-domain verified the effectiveness of secondary control loop through successfully regulating the area control error (ACE) outputs, frequency errors and tie-line power errors in the presences of load changes. The models involve single area, two areas and three areas.

المستخلص

في أنظمة القدرة المترابطة يتغير طلب الحمل بصورة عشوائية . التغيير في هذا الحمل يجلب إنحرافات في التردد والجهد والتي بدورها تؤدي إلي فقد الإمداد أو التوليد بسبب فقد أحد خطوط النقل أو إنهيار المنظومة بأكملها (Blackout) ، هذه الإنحرافات ربما تقل إلى أصغر قيمة ممكنة وذلك بالتحكم التلقائي في التوليد الذي يتكون من قسمين هما التحكم في تردد الحمل (LFC) ونظامية الجهد التلقائية (AVR).

الهدف الأساسي من هذا البحث الحفاظ على التردد وقدرة الخرج المطلوبة في أنظمة القدرة المترابطة في قيم محدودة ، وأيضا" التحكم في تغيير قدرة خط الربط بين المحطات في حالة حدوث تغيير في الحمل في إحدى المحطات.

المنهجية المتبعة هي إستخدام برنامج المحاكاة لتوضيح كيفية عمل (LFC) وذلك بإنشاء نماذج في (Simulink) التي ساعدت على فهم وتقييم إستجابة النظام وذلك بإضافة حلقة تحكم ثانوية بمتحكم تكاملي بسيط ؛ نتائج برنامج المحاكاة في حيز الزمن تثبت تأثير حلقة التحكم الثانوية وذلك من خلال نواتج خطأ تحكم المحطة(ACE) وأخطاء التغيير في التردد و أخطاء قدرة خط الربط وذلك في الحمل ، وهذة النماذج تضم تمثيل لمحطة واحدة ومحطتين وثلاثة محطات.

TABLE OF CONTENTS

CHAPTER THREE

DESIGN MODEL FOR VARIOUS SYSTEM

CHAPTER FOUR

SIMULATION RESULTS OF AUTOMATIC LOAD FREQUANCY

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

TABLE OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

ALFC	Automatic load frequency control
AVR	Automatic voltage regulation
AC	Alternating current
ACE	Area control error
LFC	Load frequency control
ΔP_{ref}	Incremental speed reference setting
$\Delta\omega$	Drift in frequency for step change in load or steady state frequency deviation
ΔP_m	Turbine output
P_{12}	Power due to tie line between area1and area2
ΔP_{12}	Power change in tie line between area1and area2
P_{13}	Power due to tie line between area1and area3
ΔP_{13}	Power change in tie line between area1and area3
P_{23}	Power due to tie line between area2and area3
ΔP_{23}	Power change in tie line between area2and area3
ΔP_{m1}	Turbine output of area 1
ΔP_{m2}	Turbine output of area2
ΔP_{01}	Increase of load in area 1
ΔP_{02}	Increase of load in area 2
ΔP_G	Active power generation
ΔP_D	Active power demand
β_1 and β_2	Composite frequency response characteristic of area 1 along with area 2
ΔP_v(s)	The input to the turbine
ΔP_T(s)	The output from the turbine

ΔP_v(s)	The output from the generator
ΔP_g(s)	The input to the generator
T_g	Time constant of the generator
T^0	Synchronizing coefficient
Δf_1	Frequency deviation in area1
Δf_2	Frequency deviation in area2
Δf_3	Frequency deviation in area3
D	Damping constant
R	Speed regulation

CHAPTER ONE

INTRODUCTION

1.1 Background

The modern power systems with industrial and commercial loads need to operate at constant frequency with reliable power. The load frequency control of an interconnected power system is being improved over the last few years. The goals of the LFC are to maintain zero steady state errors in a multi area interconnected power system [1], [2].

Power systems are very large and complex electrical networks consisting of generation networks, transmission networks and distribution networks along with loads which are being distributed throughout the network over a large geographical area [3]. In the power system, the system load keeps changing from time to time according to the needs of the consumers. So properly designed controllers are required for the regulation of the system variations in order to maintain the stability of the power system as well as guarantee its reliable operation.

The rapid growth of the industries has further lead to the increased complexity of the power system. Frequency is greatly depends on active power and the voltage greatly depends on the reactive power. So the control difficulty in the power system may be divided into two parts. One is related to the control of the active power along with the frequency whereas the other is related to the reactive power along with the regulation of voltage [4]. The active power control and the frequency control are generally known as the Automatic Load Frequency Control (ALFC).

Basically the Automatic Load Frequency Control (ALFC) deals with the regulation of the real power output of the generator and its frequency (speed). The primary loop is relatively fast where changes occur in one to several seconds. The primary control loop reacts to frequency changes through the speed governor and the steam (or hydro) flow is managed accordingly to counterpart the real power generation to relatively fast load variations. Thus maintain a megawatt balance and this primary loop performs a course speed or frequency control. The secondary loop is slower compared to the primary loop. The secondary loop maintain the excellent regulation of the frequency, furthermore maintains appropriate real power exchange among the rest of the pool members. This loop being insensitive to quick changes in load as well as frequency although it focuses on swift changes which occurs over periods of minutes. Load disturbance due to the occurrence of continuous and frequent variation of loads having smaller values always creates problem for ALFC. Because of the change in the active power demand/load in an area, tie-line power flows from the interconnected areas and the frequency of the system changes and thus the system becomes unstable. So we need Automatic Load Frequency Control to keep up the stability at the time of the load deviations. This is done by minimizing transient deviations of frequency in addition to tie-line power exchange and also making the steady state error to zero [5]. Inequality involving generation with demand causes frequency deviations. If the frequency is not maintained within the scheduled values then it may lead on the way to tripping of the lines, system collapse as well as blackouts.

1.2 Problem Statement

Load frequency control

In a system as the load changes, the frequency of the system also changes. No regulation control would be required if it was not important to keep the frequency of the system constant. Normally the frequency would vary by 5% approx. from light load to full load conditions.

Tie line power problem

In case of a two machine system having two loads, the change in load is to be taken care of by both the machines such that there is equal participation by both the machines in sharing the tie-line power and also maintaining the system stability by reducing the error to zero value.

1.3 Objectives

- To take care of the required megawatt power output of a generator matching with the changing load.
- To regulate the frequency of each area.
- To simultaneously regulate the tie line power as per inter-area power contracts.

1.4 Methodology

- Design modeling for multi area of load frequency control.
- Using commercial software (Matlab/Simulink) to investigate ALFC response.

1.5 Thesis Layout

Chapter 1: represents general introduction, project problem statements, and methodology and thesis layout.

Chapter 2: represents general literature to dynamics of the power system.

Chapter 3: introduces the design of single area and an interconnected power systems.

Chapter 4: shows the simulation results for single area without secondary loop and with secondary loop, two areas without secondary loop and with secondary loop and three areas without secondary loop and with secondary loop.

Chapter 5: represents conclusion and scope of future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Concept of Control Area

A control is interpreted as a system where we can apply the common generation control or the load frequency control scheme. Usually a self-governing area is made reference to as a control area. Electrical interconnection is very strong in every control area when compared to the ties in the midst of the adjoining areas. Within a control area all the generators move back and forth in logical and consistent manner which is depicted by a particular frequency. Automatic Load frequency Control difficulty of a bulky interrelated power system have been investigated by dividing the whole system into number of control areas and termed as multi-area.

In the common steady state process, power systems every control area must try to counter balance for the demand in power by the flow of tie-line power through the interconnected Lines . Generally the control areas encompass only restricted right to use to the information of the total grid: they are able to manage their own respective buses however they cannot alter the parameters at the unknown buses directly. But an area is alert of the dominance of its nearby Areas by determining the flow in and flow out of power by the side of its boundaries which is commonly known as the tie-line power. In every area the power equilibrium equations are computed at the boundaries, taking into consideration the extra load ensuing from the power that is being exported. Later on, the areas work out the optimization problem in accordance to their objective function which is local.

2.2 Types of Control

1) Primary control:

This type of control is endeavored locally to keep the balance Involving generation along with demand within the network. It is apprehended by speed of turbine governors that adjusts the generators output as a response to the frequency divergence in the area. If there is a major disturbance then the primary control permits the balance of generated as well as utilized power at a frequency distinguishable from the set-point quantity in order to make the network stable.

2) Secondary control:

This type of control is exerted by means of an automatic centralized procedure in the control building block. It has two purposes:

- It keeps the interchange power connecting the control block and its adjoining blocks according to the planned value
- In case of major frequency drop, it brings back the set point value of the frequency.

2.3 Importance of the Inter-connection of Areas

Earlier electric power systems were usually operated as individual units. But a need for the interconnection was realized due to the following reasons:

- There was a demand for larger bulk of power with increased reliability so there was interconnection of neighboring plants.
- It is also beneficial economically since fever machines are necessary as reserve for action at peak loads (reserve capacity) and also less machines are needed to be run without load to take care of sudden rise and fall in load(spinning reserve).

For that reason, several generating units are connected with each other forming state, regional and national grids respectively. Also for the control of power flow in these grids the Load dispatch centers are needed.

2.4 Dynamics of the Power System

The automatic load frequency control loop is mainly associated with the large size generators. The main aim of the automatic load frequency control (ALFC) can be to maintain the desired unvarying frequency, so as to divide loads among generators in addition to managing the exchange of tie line power in accordance to the scheduled values. Various components of the automatic load frequency control loop are as given away in the Figure (2.1)

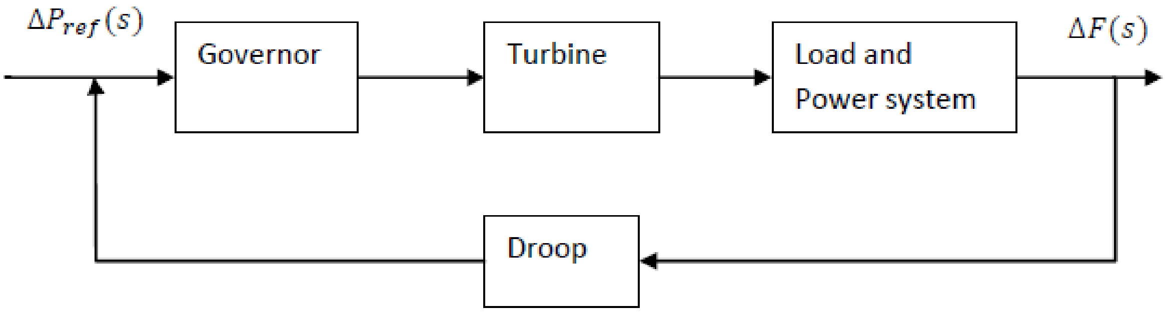

Figure 2.1: Block diagram of Automatic load frequency control

2.4.1 Turbine

Turbines are used in power systems for the conversion of the natural energy, like the energy obtained from the steam or water, into mechanical power (Pm) which can be conveniently supplied to the generator. There are three categories of turbines usually used in power systems: non-reheat, reheat in addition to hydraulic turbines, each and every one of which may be modeled and designed by transfer functions. We have non-reheat turbines which are represented as first-order units where the delay in time known as time delay (T_{CH}) takes place between the interval during switching of the valve and producing the torque in the turbine. Design of reheat turbines is done by using second-order units as there are different stage because of soaring and low down of the pressure of the steam. Because of the inertia of the water hydraulic turbines are treated as non-minimum phase units.

The turbine model represents changes in the steam turbines power output to variation in the opening of the steam valve. Here we have considered a non-reheat turbine with a single gain factor K and single time constant. In the model the representation of the turbine is,

$$\frac{\Delta P_T\ (s)}{\Delta P_v\ (s)} = \frac{K_T}{1+sT_T} \tag{2.1}$$

Where $\Delta P_v(s) =$ the input to the turbine

ΔP_T(s) = the output from the turbine

2.4.2 Generators

Generators receive mechanical power from the turbines and then convert it to electrical power. However our interest concerns the speed of the rotor rather than the power transformation. The speed of the rotor is proportional to the frequency of the power system. We need to maintain the balance amid the power generated and the power demands of the load because the electrical power cannot be stored in bulk amounts. When there is a variation in load, the mechanical power given out by the turbine does not counterpart the electrical power generated by the generator which results in an error which is being integrated into the rotor speed deviation ($\Delta\omega$). Frequency bias. The loads of the power can be divided into resistive loads (p_L) , which may be fixed when there is a change in the rotor speed due to the motor loads which change with the speed of the load. If the mechanical power does not change then the motor loads shall compensate the change in the load at a rotor speed which is completely dissimilar from the planned value.

Mathematically,

$$\frac{\Delta P_v(s)}{\Delta P_g(s)} = \frac{1}{1+s\, t_g} \qquad (2.2)$$

Where ΔP_v (s) = the output from the generator

ΔP_g (s) = the input to the generator

T_g= time constant of the generator

2.4.3 Prime Mover Model

The source of mechanical power, commonly Known as the prime mover, may be hydraulic turbine at waterfalls ,steam turbine whose energy comes from burning of coal, gas, nuclear fuel and gas turbine. The model for the turbine relates change in mechanical power output ΔP_m to change in steam valve position ΔP_v. Different type of turbine varies widely in characteristic.

The simplest prime mover model for non-reheat steam turbine can be approximated with a single time constant t_T resulting in following transfer function.

$$G_T(\mathrm{s})=\frac{\Delta P_m(s)}{\Delta P_v(s)}=\frac{1}{1+s\, t_T} \qquad (2.3)$$

Figure 2.2: Block diagram of simple non-reheat steam turbine

2.4.4 Governor

Governors are employed in power systems for sensing the bias in frequency which is the result of the modification in load and eliminate it by changing the turbine inputs such as the characteristic for speed regulation (R) and the governor time constant (T_g). If the change in load occurs without the load reference, then some part of the alteration can be compensated by adjusting the valve/gate and the remaining portion of the alteration can be depicted in the form of deviation in frequency. (LFC) aims to limit the deviation in frequency in the presence of changing active power load. Consequently, the load reference set point can be utilized for adjusting the valve/gate positions so as to cancel all the variations in load by controlling the generation of power rather than ensuing deviation in frequency.

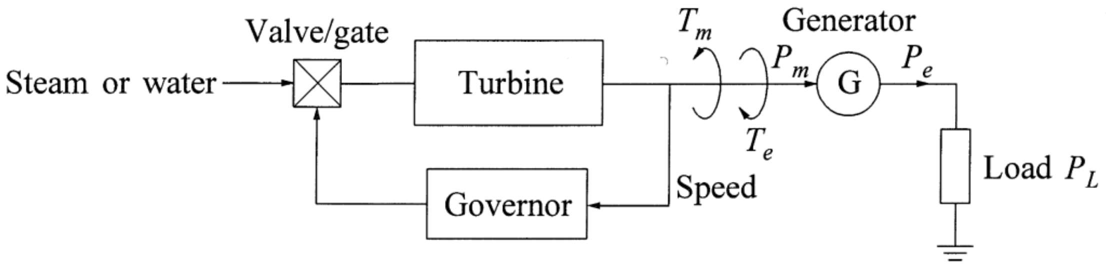

Figure 2.3: generator supply isolating load

Mathematically,

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta F(s) \quad (2.4)$$

Where $\Delta P_g(s)$ = governor output

$\Delta P_{ref}(s)$ = the reference signal

R = regulation constant or droop

$\Delta F(s)$ = frequency deviation due to speed

2.4.5 Load

The load on a power system consists of a variety of electrical devices. For resistive loads that are resistive such as lighting and also heating loads are not dependent on frequency. Motor load sensitive to change in frequency .How sensitive it is to frequency depend on the speed load characteristic of all driven devices. The speed load characteristics composite load by

$$\Delta P_e = \Delta P_l + D\,\Delta\omega \tag{2.5}$$

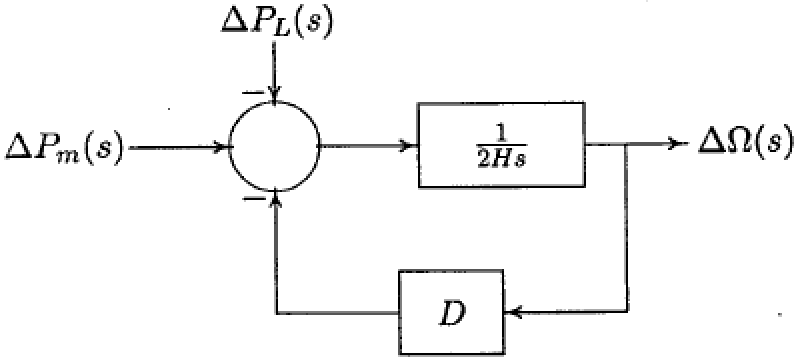

Figure 2.4: Generator and load block diagram.

2.4.6 Tie Line

Various areas can be connected with one another by one or more transmission lines in an interconnected power grid through the tie-lines. When two areas are having totally different frequencies, then there's an exchange of power between the two areas that are linked by the tie lines. The power due to tie-line trades in area *i* and area *j* (ΔP_{ij}) and the tie-line synchronizingtorque coefficient (T_{ij}). Thus we can also say that the integral of the divergence in frequency among the two areas is an error in the power due to tie-line.

The objective of tie-lines is to trade power with the systems or areas in the neighborhood whose costs for operation create such transactions cost-effective. Moreover, even though no power is being transmitted through the tie-lines to the neighborhood systems/areas and it so happens that suddenly there is a loss of a generating unit in one of the systems. During such type of situations all the units in the interconnection experience alteration in frequency and because of which the desired frequency is regained. Let there be two control areas and power is to be exchanged from area 1 to area 2.

Mathematically,

$$P_{1\,2} = \frac{|V_1|\,|V_2|}{X_{1\,2}} \sin(\delta 1 - \delta 2) \qquad (2.6)$$

Where 1 stands for control area 1 and 2 stands for control area 2

$X_{1\,2}$= series reactance involving area 1 and 2

$|V_1|$ And $|V_2|$ = magnitude of voltages of area 1 plus area

2.4.7 Area Control Error

The aim of (LFC) is not just to terminate frequency error in all areas, but as well to enable the exchange of the power due to tie-line as scheduled. In view of the fact that the error due to tie-line power will be the integral of the dissimilarity in frequency among every pair of areas, but when we direct frequency error back to zero, all steady state errors present in the system frequency will give rise to in tie-line power errors. For this reason it is necessary to consider the control input in the variation in the tie-line power. Consequently, an area control error (ACE) is stated. Each of the power generating area considers (ACE) signal to be used as the output of the plant. By making the (ACEs) zero in all areas makes all the frequency along with errors in the tie-line power in the system as zero.

In order to take care of the total interchange of power among its areas within the neighborhood, (ALFC) utilizes real power flow determinations of all tie lines as emanating through the area and there after subtracts the predetermined interchange to compute an error value. The total power exchange, jointly with a gain, B (MW/0.1Hz), known as the bias infrequency, as a multiplier with the divergence in frequency is known as the Area Control Error (ACE) specified by,

$$\text{ACE} = \sum_{k=1}^{k} P_k - P_s + B(F_{act} - F_0)\ \text{MW} \qquad (2.7)$$

Where,

P_k= power in the tie line (if out of the area then +ve)

P_s= planned power exchange

F_0= base frequency

F_{act} = actual frequency

Positive (+ve) ACE shows that the flow is out of the area.

2.4.8 Parallel operation

If there is several power generating units operating in parallel in the same area, an equivalent generator will be developed for simplicity. The equivalent generator inertia constant (M_{eq}), load damping constant (D_{eq}) and frequency response characteristic (B_{eq}) can be represented as follows:

$$M_{\mathrm{eq}} = \sum_{\mathrm{i}=1,\dots,\mathrm{n}} \mathrm{M_i} \tag{2.8}$$

$$D_{\mathrm{eq}} = \sum_{\mathrm{i}=1,\dots,\mathrm{n}} \mathrm{D_i} \tag{2.9}$$

$$B_{\mathrm{eq}} = \sum_{\mathrm{i}=1,\dots,\mathrm{n}} \frac{1}{\mathrm{R_i}} + \sum_{\mathrm{i}=1,\dots,\mathrm{n}} \mathrm{D_i} \tag{2.10}$$

2.5 Modeling of ALFC

2.5.1 Modeling for the change in frequency

Let consider an automatic load frequency control loop of a system which is isolated intended for the examination of the steady state and dynamic responses. The figure is as shown below in the Figure (2.5).

[1] Steady state analysis

Let ΔP_{ref}(s) be the setting for the speed changer and ΔP_D be the alteration in demand of the load. Considering a simple situation where the speed changer might have constant setting i.e. ΔP_{ref}(s) = 0 as well as there is change in the load demand. This may be known to be free governor operation

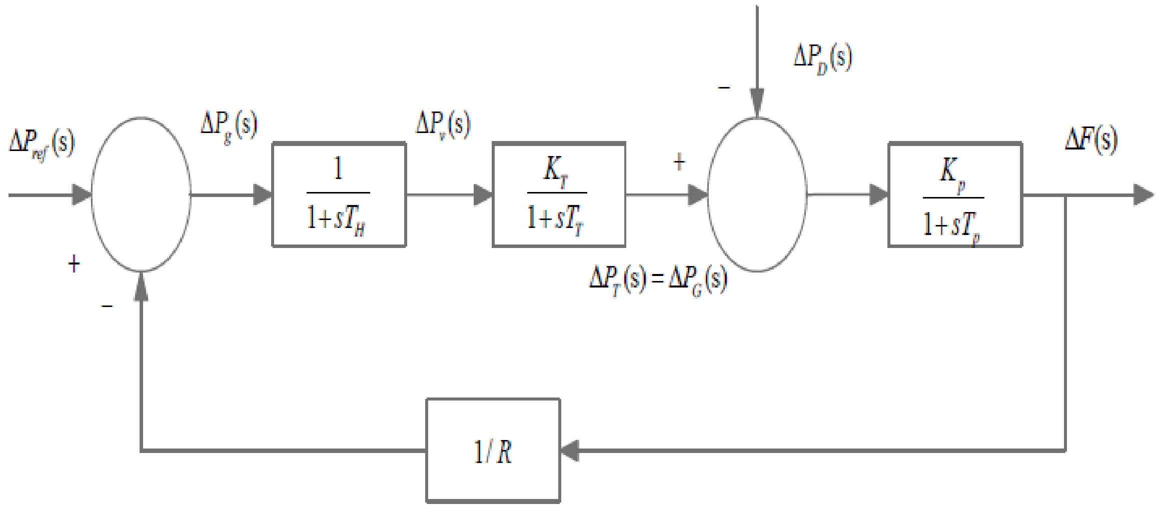

Figure 2.5: Automatic load frequency control loop

For such a process the steady modification in the system frequency for a step change in load i.e. $\Delta P_D(s) = \frac{\Delta P_D}{s}$ is obtained as follows:

$$[\{\Delta P_{ref}(s)-\frac{1}{R}\Delta F(s)\}\frac{K_T}{(1+sT_H)(1+sT_T)} - \Delta P_D(s)]\frac{K_P}{1+sT_P} \tag{2.11}$$

This implies that,

$$\Delta F(s) = \frac{-K_P \Delta P_D(s)/s(1+sT_P)}{\left(\frac{K_T K_P}{R}\right)(1+sT_H)(1+sT_T)(1+sT_P)} \tag{2.12}$$

After simplification we get,

$$\Delta F(s) = -\frac{\Delta P_D}{\beta} \tag{2.13}$$

Where β is the area frequency response characteristics

[2] Dynamic analysis

For a step change in load,

$$\Delta F(s) = \frac{-K_P \Delta P_D(s)/s(1+sT_P)}{\left(\frac{K_T K_P}{R}\right)(1+sT_H)(1+sT_T)(1+sT_P)} \tag{2.14}$$

Assuming amplifier and turbine response to be instantaneous i.e. T_T=T_H=0 and K_T=1, we have

$$\Delta \mathrm{F(s)} = \frac{-K_D}{(1+sT_P)K_{P/R}}\frac{\Delta P_D}{s} \tag{2.15}$$

After simplification we get,

$$\Delta F(s) = \frac{-RsK_P(1+sT_H)(1+sT_T)}{Rs(1+sT_H)(1+sT_T)(1+sT_P)+(s+RK_T)K_P}\frac{\Delta P_D}{s} \tag{2.16}$$

2.5.2 Modeling of the Tie-Line

Let us consider that area 1 is having surplus power and it transfers power to the area 2 by the tie-line.

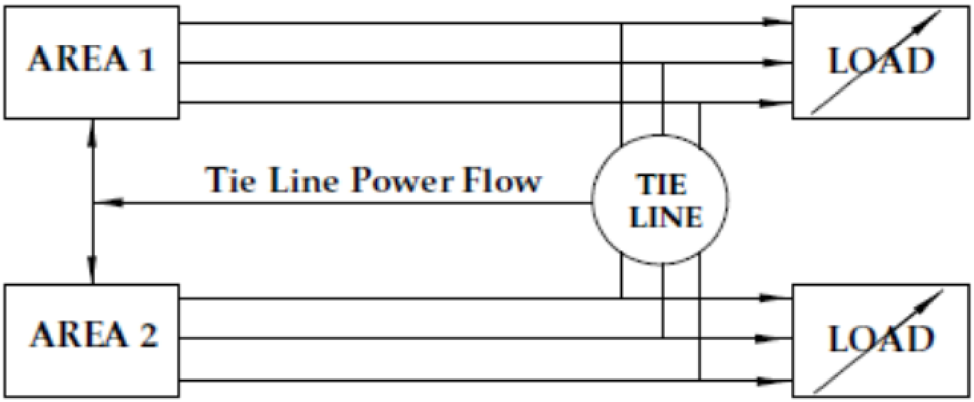

Figure 2.6 Power transfer through tie line

P12 = power exchanged from area 1 towards area 2 via tie lines.

Then the power transfer equation the tie-line is specified as follows:

$$P_{1\,2} = \frac{|V_1|\,|V_2|}{X_{1\,2}}\sin(\delta 1-\delta 2) \tag{2.17}$$

$$\Delta P_{1\,2} = \frac{|V_1|\,|V_2|}{X_{1\,2}} \cos(\delta 1-\delta 2)\,(\Delta\delta 1-\Delta\delta 2) \qquad (2.18)$$

Where δ1 and δ2 = power angles of end voltages V_1 and V_2 of corresponding machine of the two areas.

X_{12}= reactance of the tie line.

$|V_1|$ and $|V_2|$ = magnitude of voltages of area 1 and area 2 .

The sequence of the subscripts depicts that the flow of power due to the tie lines is positive in the direction from 1 to 2.

For little deviation in the angles δ1 and δ2 changes by Δδ1 and Δδ2, the tie line power changes as follow:

i.e. $$\Delta P_{1\,2} = \frac{|V_1|\,|V_2|}{X_{1\,2}} \cos(\delta 1-\delta 2)\,(\Delta\delta 1-\Delta\delta 2) \qquad (2.19)$$

$$\Delta P_{1\,2} = T^0(\Delta\delta 1-\Delta\delta 2) \qquad (2.20)$$

i.e.

$$\Delta P_{1\,2} = \frac{2\Pi T^0}{s}\left(\Delta f_1(s) - \Delta f_2(s)\right) \qquad (2.21)$$

Where $T^0 = \frac{|V_1|\,|V_2|}{X_{1\,2}} \cos(\delta 1-\delta 2)$ = Torque produced

In a control area which is isolated, the incremental power (ΔPG – ΔPD) is the rate of rise of preserved kinetic energy due to rise in the load followed by a rise in the frequency. The power due to the tie-lines for each area is as below:

$$\Delta P_1(s) = \Delta P_{12} + a_{31}\Delta P_{31}(s) \qquad (2.22)$$

$$\Delta P_2(s) = \Delta P_{23} + a_{12}\Delta P_{12}(s) \qquad (2.23)$$

$$\Delta P_3(s) = \Delta P_{31} + a_{23}\Delta P_{23}(s) \qquad (2.24)$$

Control of tie line bias is utilized to get rid of the steady state error because of frequency plus the exchange of the power due to tie-lines. This shows that all of the control areas should put in their share in frequency control, besides dealing with their own particular total interchange of power.

Let,

ACE_1 = area control error of area 1

ACE_2 = area control error of area 2

ACE_3 = area control error of area 3

ACE_1, ACE_2 and ACE_3 are shown as linear arrangement of frequency along with tie-line power error as follows:

$$ACE_1 = \Delta P_{12}(s) + b_1 \Delta f_1 \tag{2.25}$$

$$ACE_2 = \Delta P_{23}(s) + b_2 \Delta f_2 \tag{2.26}$$

$$ACE_1 = \Delta P_{31}(s) + b_3 \Delta f_3 \tag{2.27}$$

Where $b_1, b_2\ and\ b_3$ are known as bias in area frequency of area 1, area 2 and area 3 respectively.

Area control error (ACE) is negative when the net power flow output from an area is very small or else when the frequency has dropped or both. During such situations we need to increase the generation

CHAPTER THREE

MATHEMATICAL MODEL FOR VARIOUS SYSTEM

3.1 Single Area System

Figure (3.1) shows the Automatic Load Frequency Control (ALFC) loop. The frequency which changes with load is contrasted with reference speed setting. The frequency can be set to the desired value by making generation and demand equal with the help of steam valve controller which regulate steam valve and increases power output from generators .It serves the primary basic purpose of balancing the real power by regulating turbine output ($\Delta P\mathrm{m}$) according to the variation in load demand (ΔP_0).

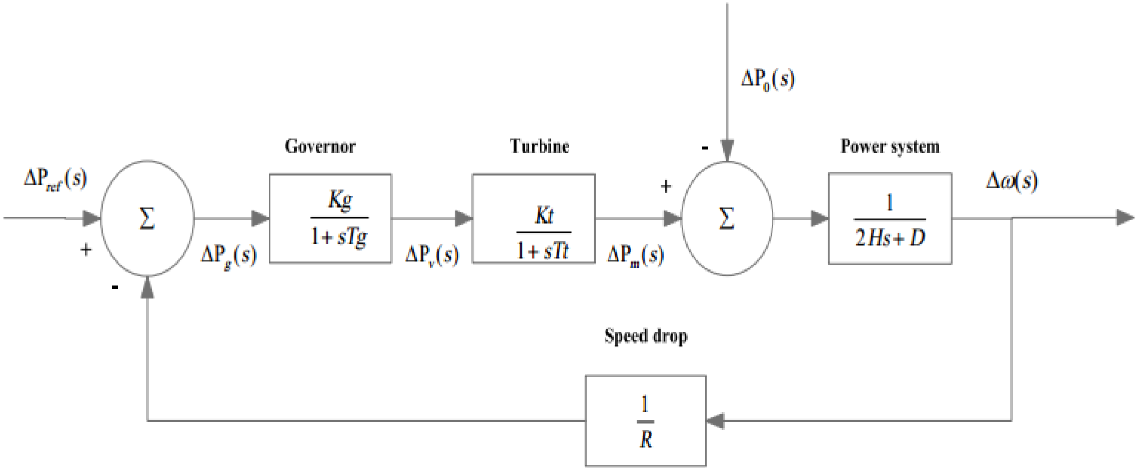

Figure 3.1: Model of single area ALFC without using secondary control

The transfer function of the model of the single area system as shown in Figure (3.1) is as below:

KG(s) H(s) = $\frac{1}{R}\frac{1}{(2H_s+D)\left(1+\tau_g s\right)(1+\tau_T s)}$ (3.1)

$$\frac{\Delta\omega(s)}{-\Delta P_L(s)} = \frac{\left(1+\tau_g s\right)(1+\tau_T s)}{(2H_s+D)\left(1+\tau_g s\right)(1+\tau_T s)+1/R} \tag{3.2}$$

$$\Delta\omega(s) = -\Delta P_0(s)T(s) \tag{3.3}$$

For the case with load which is not sensitive to frequency load (D=0) :

$$\Delta\omega_{ss} = (-\Delta p_0)R \tag{3.4}$$

From the above equations we can get the steady state value of new system frequency which is less than the initial value. But we have to make the frequency drift ($\Delta\omega$) to zero or to an acceptable value with the help of secondary loop for stable operation. This is shown above in Figure (3.1).

Due to change in load there is change in the steady state frequency ($\Delta\omega$) so we need another loop apart from primary loop to convey the frequency to the initial value, before the load disturbance occurs. The integral controller which is responsible in making the frequency deviation zero is put in the secondary loop as shown in Figure (3.2) Therefore the signal from ($\Delta\omega$(s)) is being feedback all the way through an integrator block (1/s) to regulate (ΔP_{ref}) to get the frequency value to steady state. Thus ($\Delta\omega$(s)) = 0. Thus integral action is responsible for automatic adjustment of (ΔP_{ref}) making ($\Delta\,\omega$) =0. So this act is known as Automatic Load Frequency Control transfer function with integral group is shown below by representing it in the form of equations.

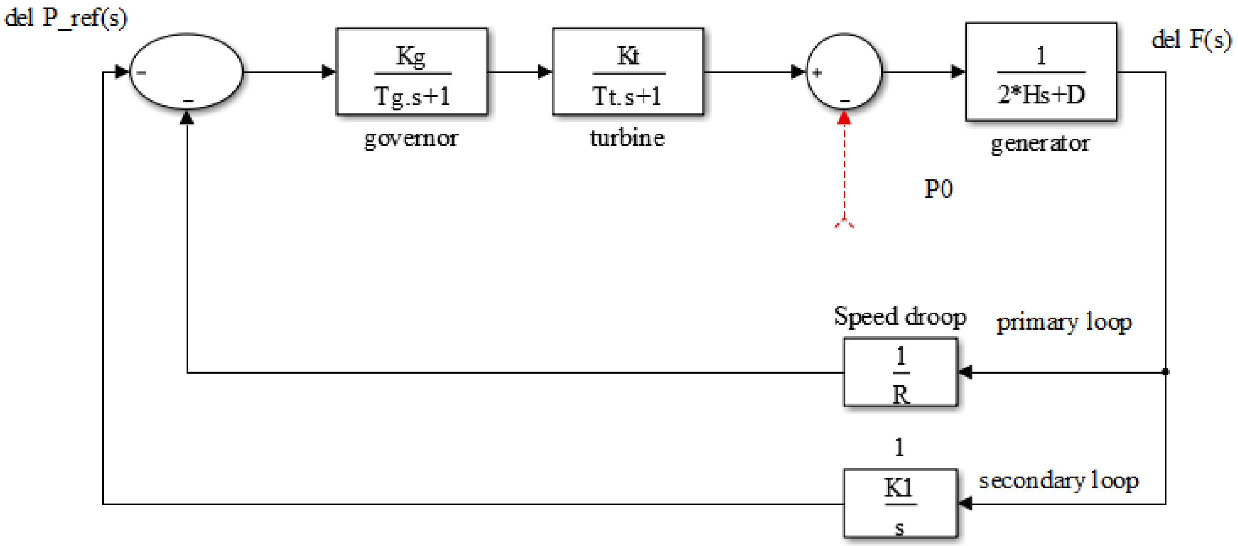

Figure 3.2: Model of single area ALFC by using secondary control

$$\Delta\omega = \frac{1}{D+1/R}\left[\Delta P_{ref} - \Delta P_0\right] \tag{3.5}$$

3.2 Two Area System

Two area interconnected system which is joined by means of tie-lines for the flow of tie-line power is given in Figure (3.3). Let the additional input be ΔP12, ΔP01 be the load change in area1 and the respective frequencies of the two areas be

$$\Delta\omega = \Delta\omega_1 = \Delta\omega_2 \tag{3.6}$$

Let X12 be the reactance of the tie line, then power delivered from area 1 to area 2 is

$$P_{1\,2} = \frac{|V_1|\,|V_2|}{X_{1\,2}} \sin\,(\delta 1\text{-}\delta 2) \tag{3.7}$$

When $X12 = X2 + Xtie + X1$ and $\delta 12 = \delta 1\text{-}\delta 2$

Equation can be linearized as:

$$\Delta P_{12} = \frac{d\,p_{1\,2}}{d\,\delta_{1\,2}}|\delta_{12} \qquad \Delta\delta_{12} = P_s\Delta\delta_{12} \tag{3.8}$$

Let:

$$\Delta\omega = \Delta\omega_1 = \Delta\omega_2$$

For area 1,

$$\Delta P_{m1} - \Delta P_{12} - \Delta P_{01} = \Delta\omega D_1 \tag{3.9}$$

$$\Delta P_{m1} = -\Delta P_{m2} = \Delta P_{12} = \Delta\omega D_2 \tag{3.10}$$

For area2,

$$\Delta P_{m1} = \frac{-\Delta\omega}{R_1} \tag{3.11}$$

$$\Delta P_{m2} = \frac{-\Delta\omega}{R_2} \tag{3.12}$$

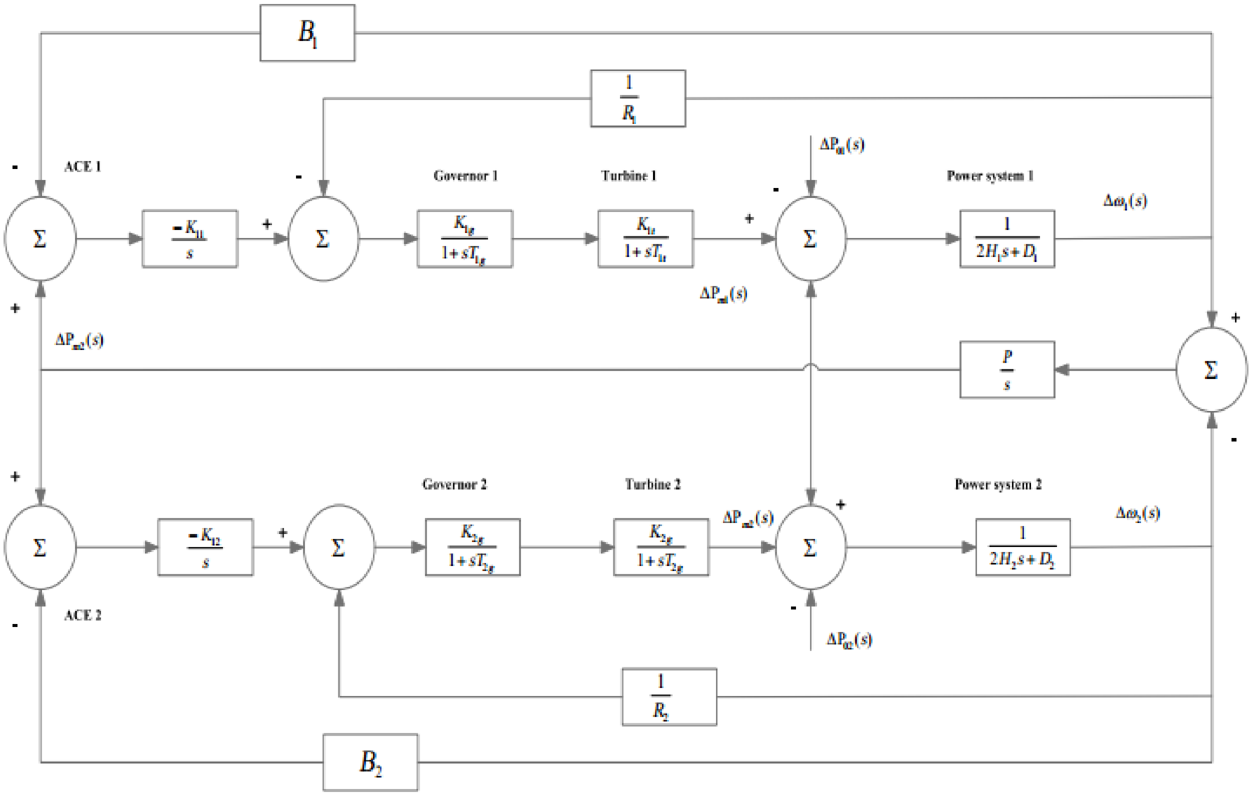

Figure 3.3: Model of two area system without using secondary loop or using only primary loop control

$$\Delta P_{12} = \frac{-\Delta p_{01}\beta_1}{\beta_1 + \beta_2} \tag{3.12}$$

Thus rise in load in area 1 reduces the frequency of both the areas and leads to the flow of tie-line power. If (ΔP_{12}) is negative then power flows from area 2 to area 1. Correspondingly for alteration in load in area 2 (ΔP_{02}),

$$\Delta\omega = \frac{-\Delta P_{01}\beta_1}{\beta_1 + \beta_2} \tag{3.13}$$

$$\Delta P_{12} = -\Delta P_{21} = \frac{-\Delta P_{02}\beta_1}{\beta_1 + \beta_2} \tag{3.14}$$

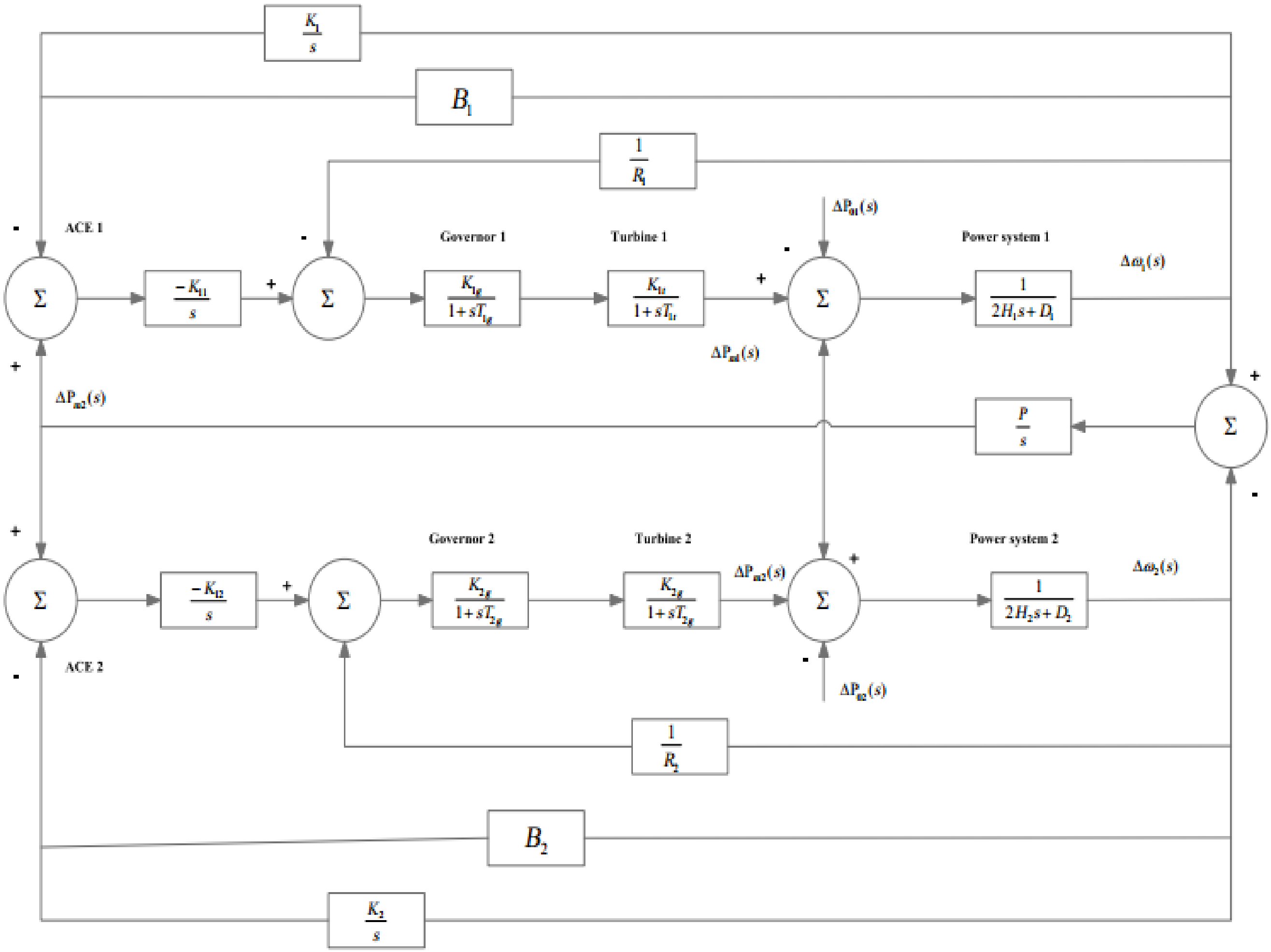

Figure 3.4: Model of two area system by using secondary loop

The secondary control basically restores balance linking all area load generation which is possible by maintaining the frequency at scheduled value .This is shown in Figure (3.4) Suppose there is a variation in load in area1 then these secondary control is in area 1 and not in area 2 so area control error (ACE) is being brought to use .The ACE constituting two areas is represented as follows In case of area 1:

$$ACE_1 = \Delta P_{12} + \beta_1 \Delta\omega \tag{3.15}$$

In case of area 2:

$$ACE_2 = \Delta P_{21} + \beta_2 \Delta\omega \tag{3.16}$$

For an entire load change of (ΔP_D) the steady state frequency deviation in two areas is:

$$\Delta\omega = \frac{-\Delta P_{L1}}{\left(\frac{1}{R_1} + D_1\right) + (\frac{1}{R_2} + D_2)} = \frac{-\Delta P_{L1}}{\beta_1 + \beta_2} \tag{3.17}$$

There can be one (ALFC) for every control area in an interrelated multi area system. (ACEs) are the actuating signals that stimulate modifications in reference power set points such that (ΔP_{12}) and ($\Delta\omega$) becomes zero as soon as steady-state is attained.

Each area ACE is a combination of frequency as well as tie-line error.

$$ACE_1 = \sum nj = \Delta P_{ij} + K_i \Delta\omega \tag{3.18}$$

3.3 Three Area System

The control in three area system is like the two area system and is shown in Figure (3.5) the integral control loop which is used in the single area system and two area system can also be related to the three area systems. Due to change in load there is change in the steady state frequency ($\Delta\omega$) so we need another loop apart from primary loop to make the frequency to the initial value, before the load disturbance occurs.

The integral controller which is responsible in making the frequency deviation zero is put in the secondary loop. Three area interconnected system consists of three interconnected control areas. There is flow of tie line power as per the changes in the load demand due to the interconnection made between the control areas.

Thus the overall stability of the system is maintained at a balanced condition in spite of the constant variations in the load and load changes.

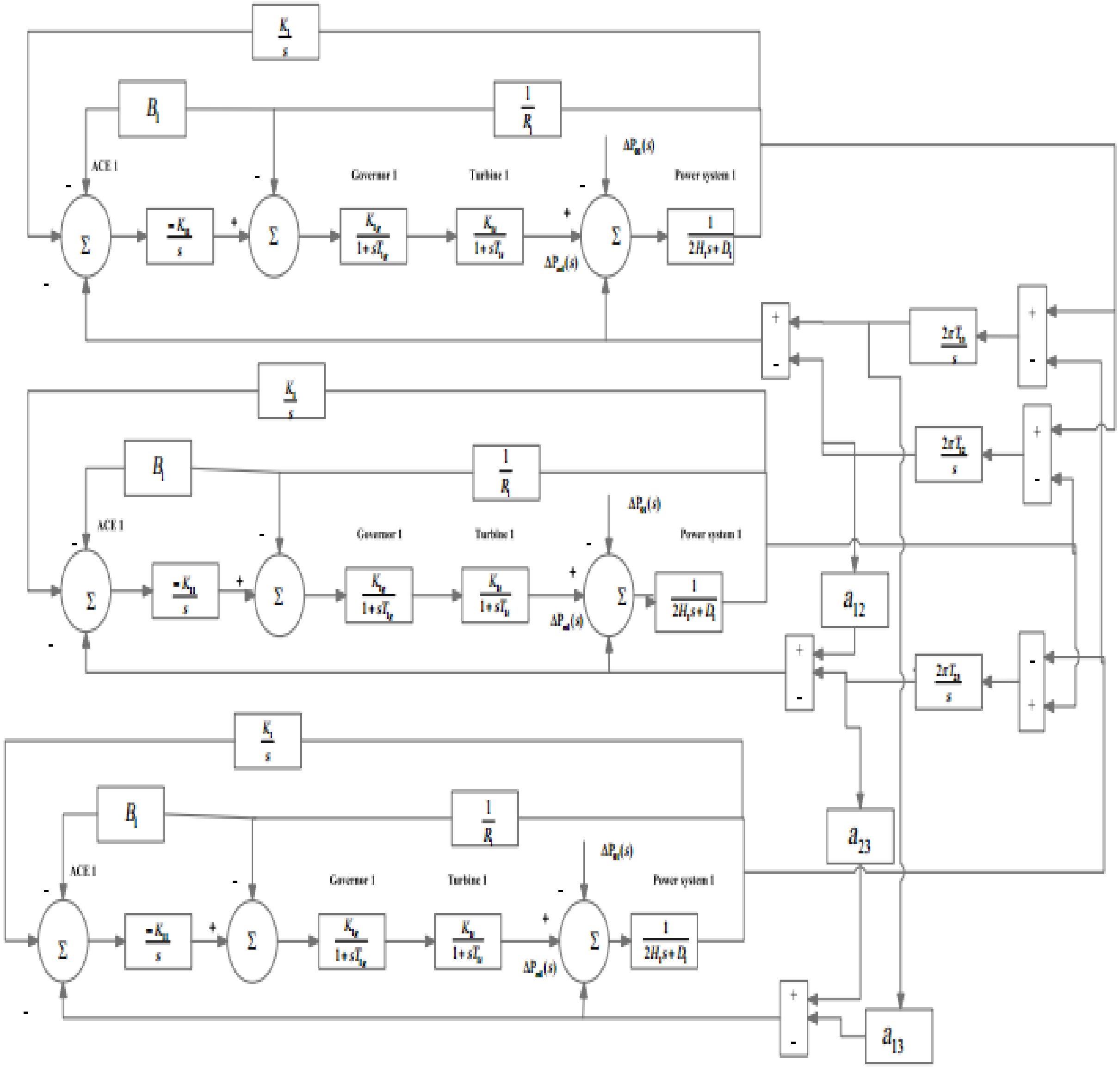

Figure 3.5: Model of three area system by using secondary loop

Change in frequency for the three areas is as follows:

$$\Delta f_1\,(s) = \frac{R_1 K_p\left(sT_g + 1\right)(sT_t + 1)}{K_p(s + Ki_1 R_1) + R_1 s\left(sT_g + 1\right)\left(sT_p + 1\right)(sT_t + 1)} \qquad (3.19)$$

$$\Delta f_2(s) = \frac{R_2 K_p\left(sT_g + \ 1\right)(sT_t + 1)}{K_p(s + Ki_2 R_2) + R_2 s\left(sT_g + \ 1\right)\left(sT_p + 1\right)(sT_t + \ 1)} \quad (3.20)$$

$$\Delta f_3\ (s) = \frac{R_3 K_p\left(sT_g + \ 1\right)(sT_t + 1)}{K_p(s + Ki_3 R_3) + R_3 s\left(sT_g + \ 1\right)\left(sT_p + 1\right)(sT_t + \ 1)} \quad (3.21)$$

The tie-line power flow among three areas is as below:

$$\Delta P_{1\ 2} = \frac{2\Pi T^0}{s}(\Delta f_1(s) - \Delta f_2(s)) \quad (3.21)$$

$$\Delta P_{1\ 3} = \frac{2\Pi T^0}{s}(\Delta f_1(s) - \Delta f_3(s)) \quad (3.22)$$

$$\Delta P_{2\ 3} = \frac{2\Pi T^0}{s}(\Delta f_2(s) - \Delta f_3(s)) \quad (3.2$$

CHAPTER FOUR

SIMULATION RESULTS OF AUTOMATIC LOAD FREQUENCY

By using simulation models we can obtain the performance characteristics of the system very easily and quickly for analysis purposes. Below are the various systems Simulink models with their respective responses plotted against time. Here we considered single area, two area and three area systems

4.1 Single Area System Without Using Secondary Loop

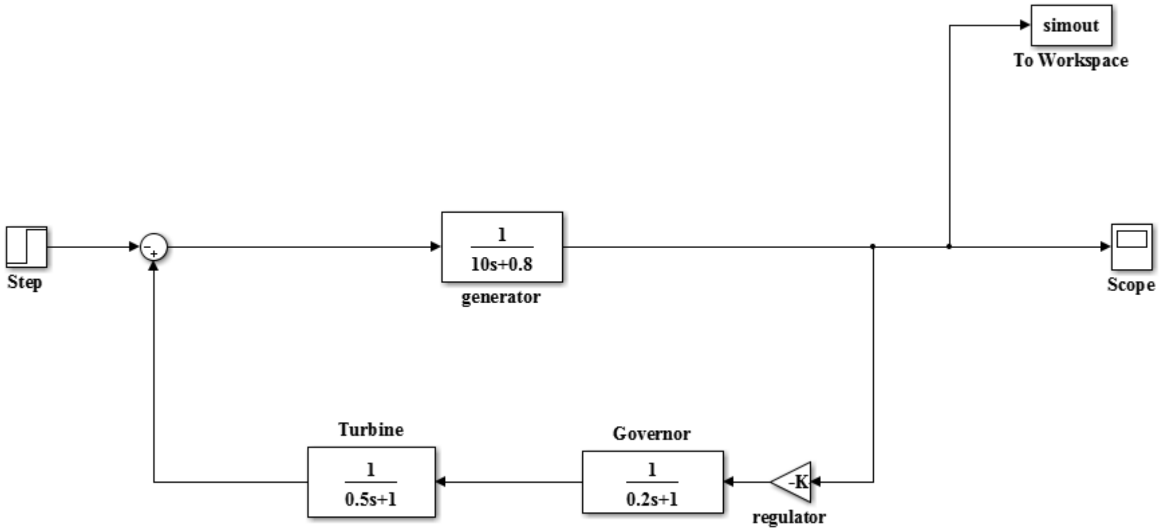

Figure 4.1: Simulink model of single area system without using secondary loop

Table 4.1: System parameters for single area system without using secondary control:

Name	Kg	Tg(s)	Kt	Tt(s)	H(s)	D(puMW/Hz)	1/R
Value	1	0.20	1	0.5	5	0.8	30

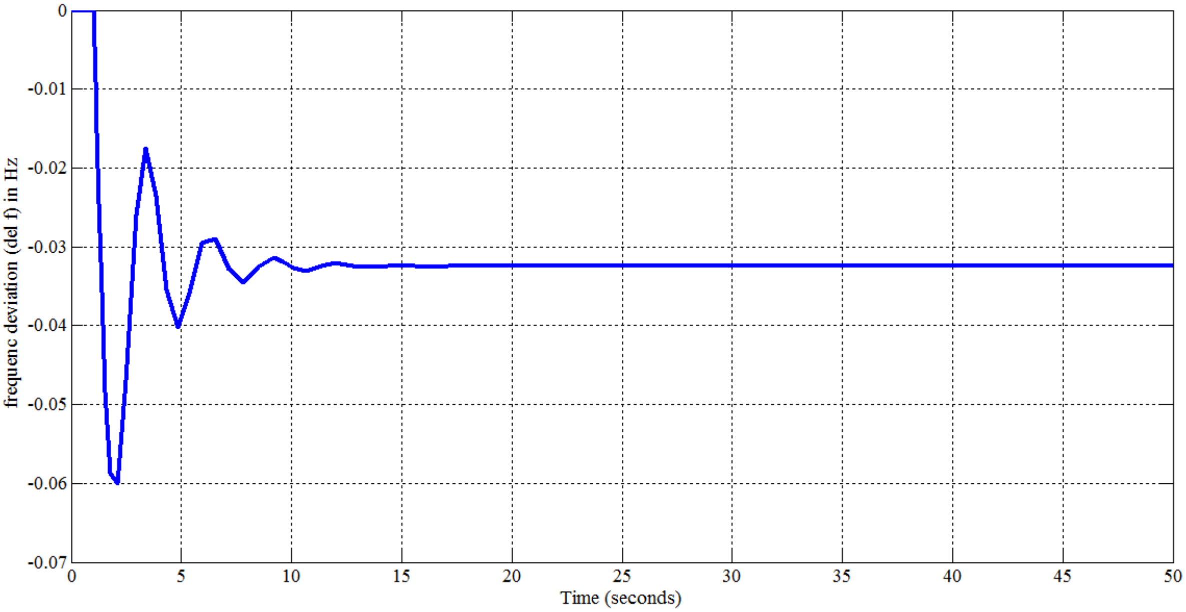

Figure 4.2: Frequency deviation vs. time for single area system without secondary loop

The plot in Figure (4.2): which is obtained by simulating the model as shown in Figure (4.1) shows that the change in load causes alteration in speed and that causes deviation in frequency. From the plot we are able to comprehend that the frequency oscillations will gradually stay down to a limited value.

The operating frequency is supposed to be lesser than the nominal value . We have taken the values of the different parameters as shown in table (4.1) for modeling the Simulink model and its successful operation to obtain the desired results.

4.2 Single Area System by Using Secondary Loop

In Figure (4.3) an integral controller by means of a gain i.e. Ki is used to regulate the signal of speed reference i.e. ΔPref (as given away in Figure (4.6)) so that Δf(s) proceeds to zero (as shown in Figure (4.5)). Figure (4.4) shows the variation in turbine output with time. The drift in frequency has been brought to zero because of the integral loop. We have taken the values of the different parameters as shown in table 2 for modeling the Simulink model and its successful operation to obtain the desired results.

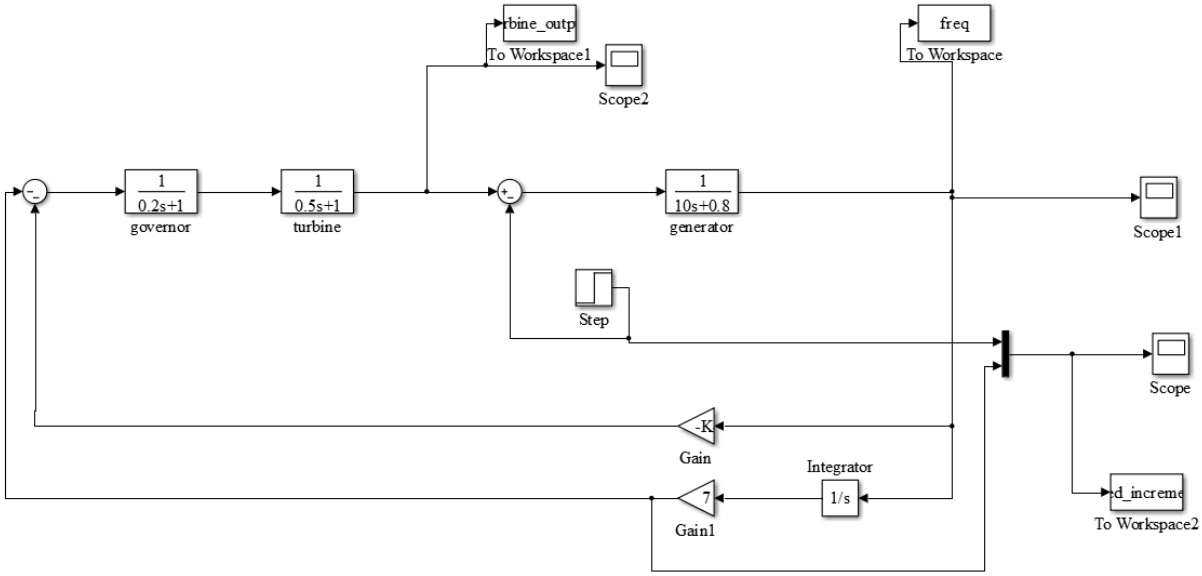

Figure 4.3: Simulink model for single area system by using secondary loop

Table 4.2: System parameters for single area system by using secondary control

Name	Kg	Tg(s)	Kt	Tt(s)	H(s)	D(p.u.MW/Hz)	1/R	K1
Value	1	0.20	1	0.5	5	0.80	20	7

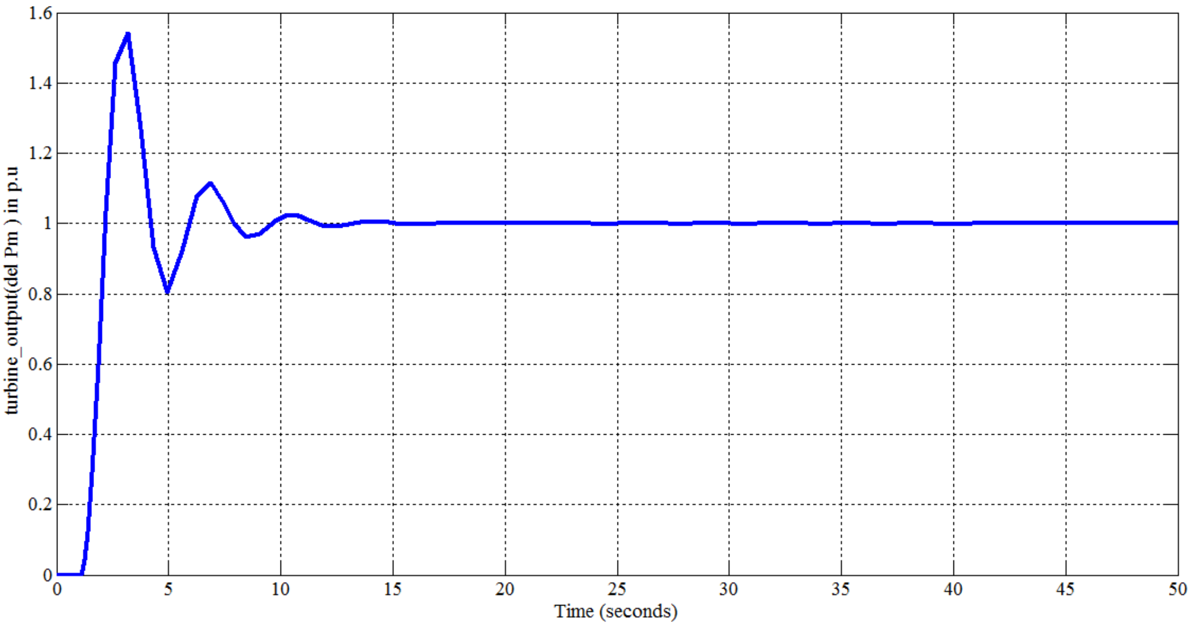

Figure 4.4: Change in turbine output vs. time for single area system by using secondary loop

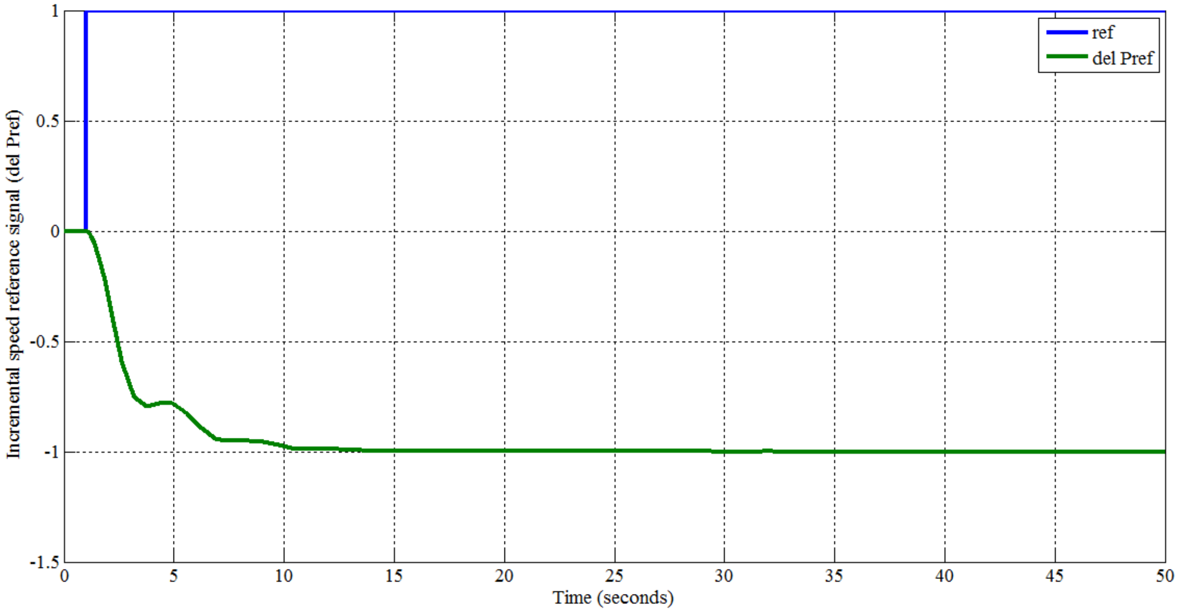

Figure 4.5: Incremental speed reference signal vs. time for single area by using secondary loop

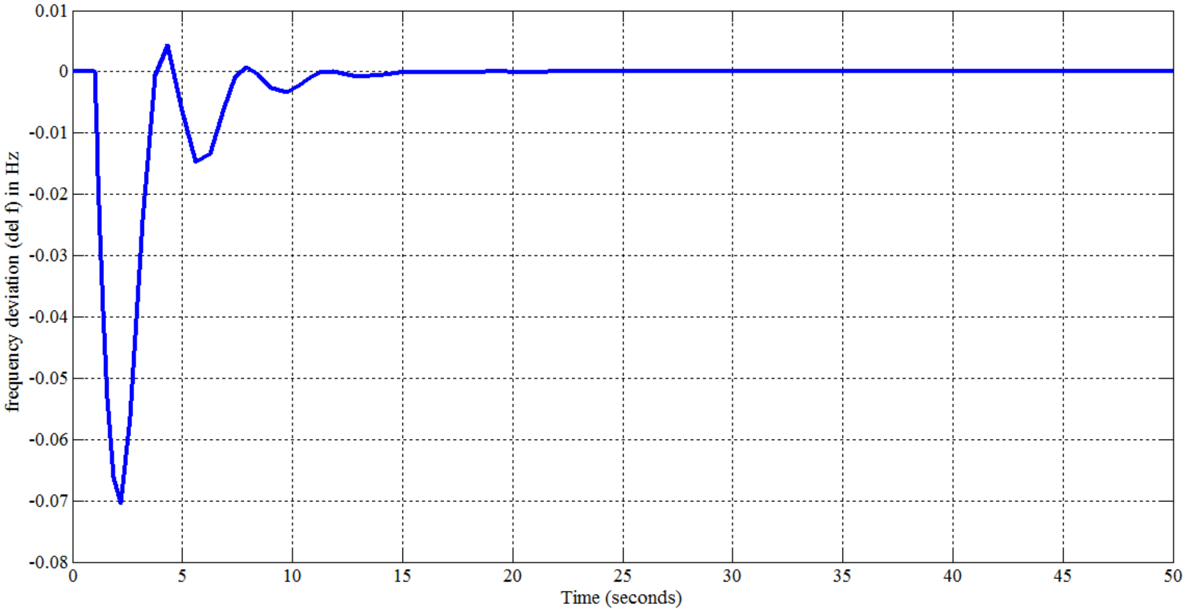

Figure 4.6: Change in frequency vs. time for single area system by using secondary loop

4.3 Two Area System Without Using Secondary Loop

Figure(4.7) presents that the two systems are being interrelated so the drifts in the frequency of the two are liable to settle down to similar value soon after a few oscillations . The two mechanical inputs changes to minimize the inequality power connecting electrical load in area 1 as well as the mechanical inputs. Area 2 is capable to generate excessive power to distribute the variation in load in area 1. We have taken the values of the different parameters as shown in table (4.3) for modeling the Simulink model and its successful operation to obtain the desired results .

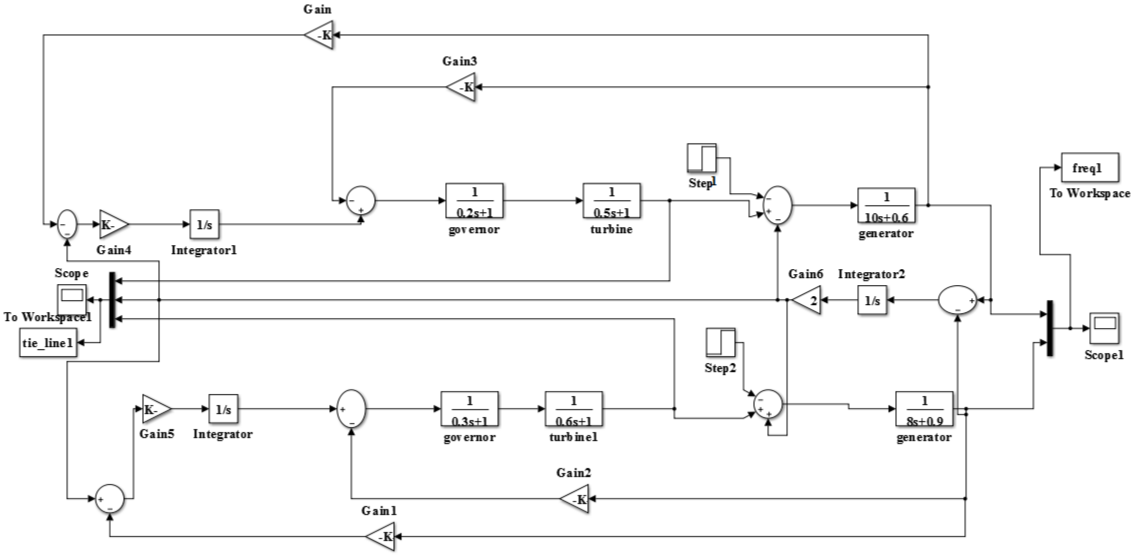

Figure 4.7: Simulink model of two area system without secondary loop

Table 4.3: System parameters for two area system without using secondary control:

Name	Kg	Tg(s)	Kt	Tt(s)	H(s)	D(p.u.MW/Hz)	1/R	ΔPL(p.u)
Area 1	1	0.20	1	0.50	5	0.60	20	0
Area 2	1	0.30	1	0.60	4	0.90	16	1

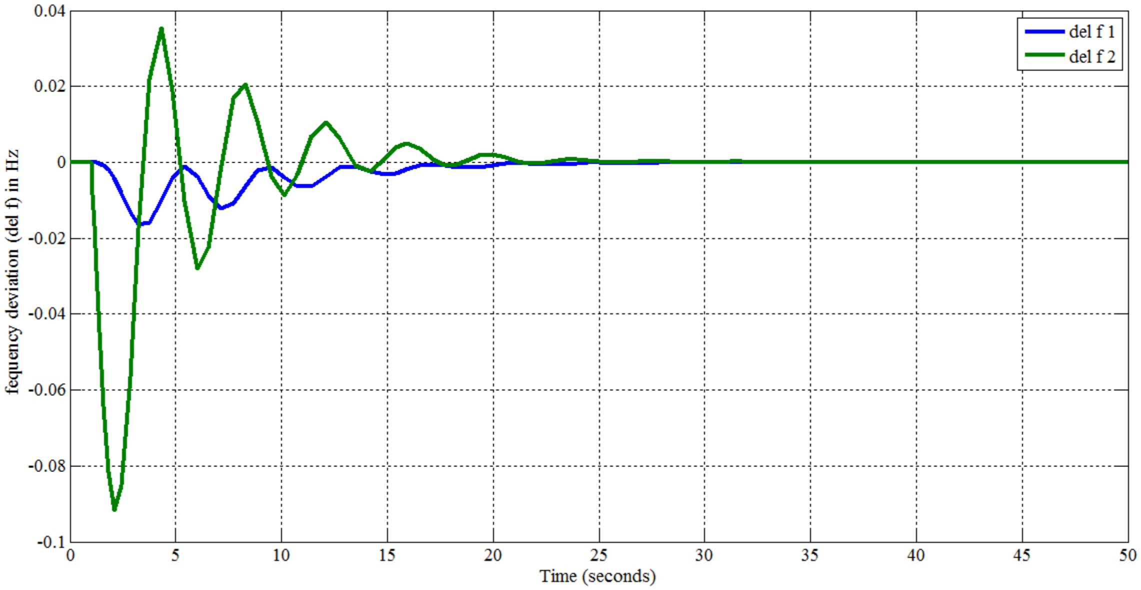

Figure 4.8: Frequency deviation vs. time for two area system without using secondary loop

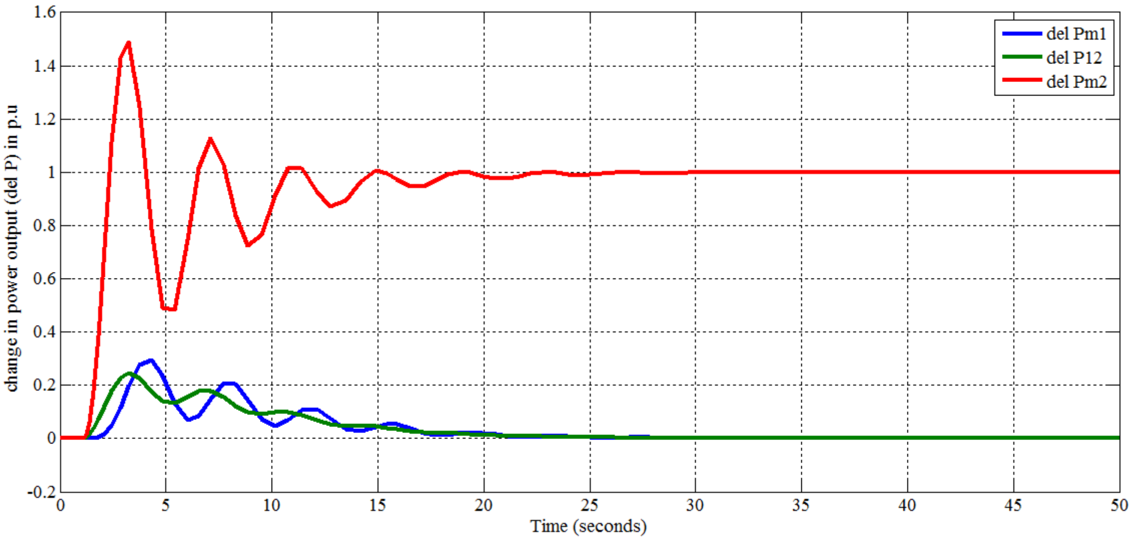

Figure 4.9: Change in power output vs. time for two area without using secondary loop

Changes in flow of tie-line power might be observed with changes in disturbance by load in area 1 as given away in Figure (4.9) and Figure (4.8) proves that the frequency can be resolved to a limited value which is less than the actual frequency. Although we get same results as area 1 but stability is improved with interconnection.

4.4 Two Area System by Using Secondary Loop

Two area systems by using secondary loop are shown in Figure(4.10) The secondary loop is responsible for the minimization of drifts in frequency to zero as shown in Figure(4.11) By changing the secondary loop gain we can see the variation in the system dynamic response characteristics through tie line power as given away in Figure(4.12) We have taken the values of the different parameters as shown in table (4.4) for modeling the Simulink model and its successful operation to obtain the desired results.

Table 4.4: System parameters for two area system by using secondary control

Name	Kg	Tg(s)	Kt	Tt(s)	H(s)	D(p.u.MW/Hz)	1/R	ΔPL(p.u)	k1
Area1	1	0.20	1	0.50	5	0.60	20	0	7
Area 2	1	0.30	1	0.60	4	0.90	16	1	7

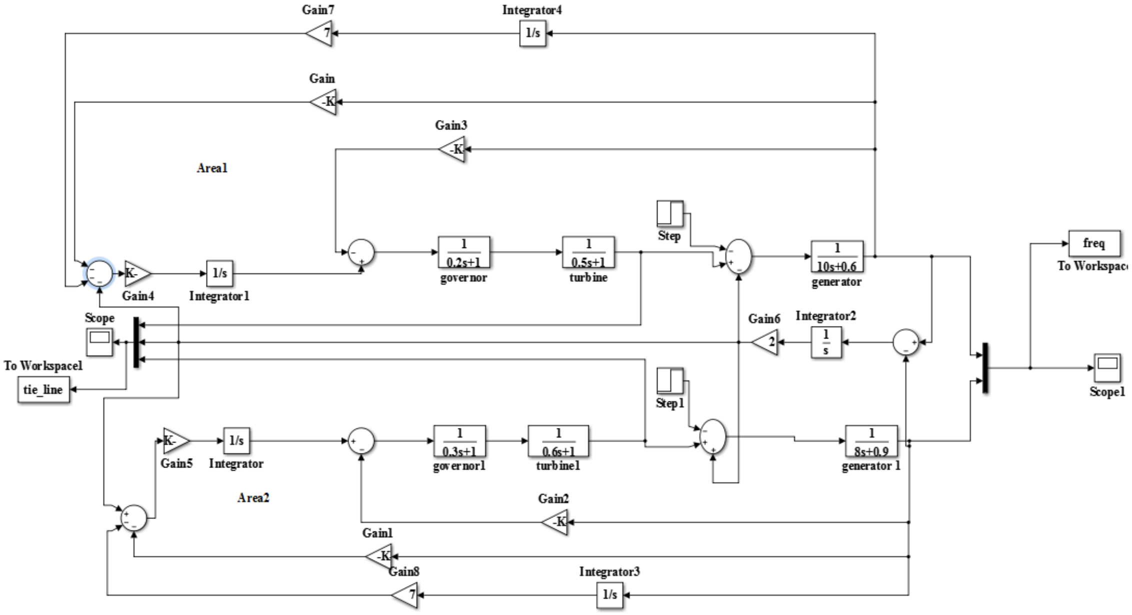

Figure 4.10: Simulink model for two area system by using secondary loop.

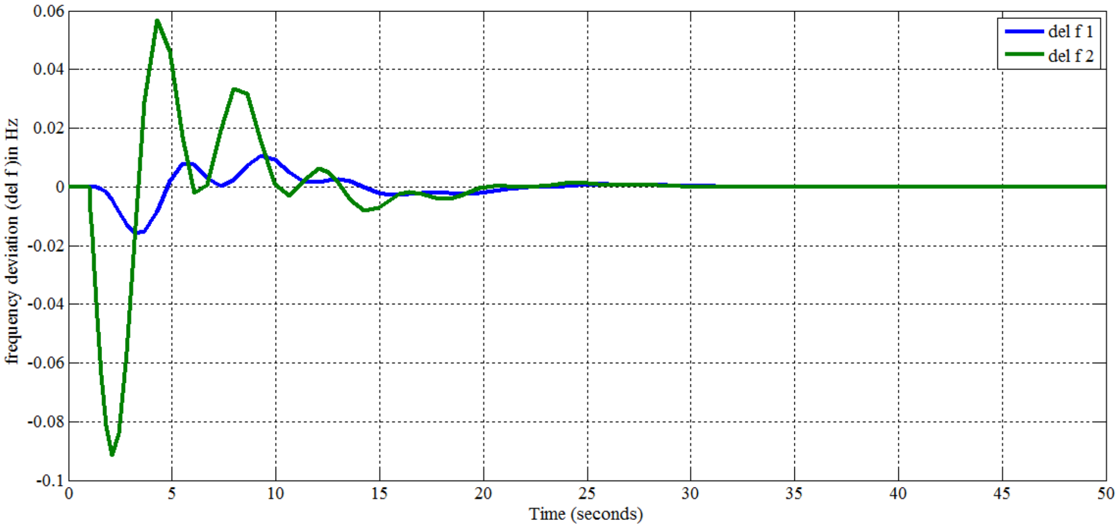

Figure 4.11: Frequency deviation vs. time for two area by using secondary loop

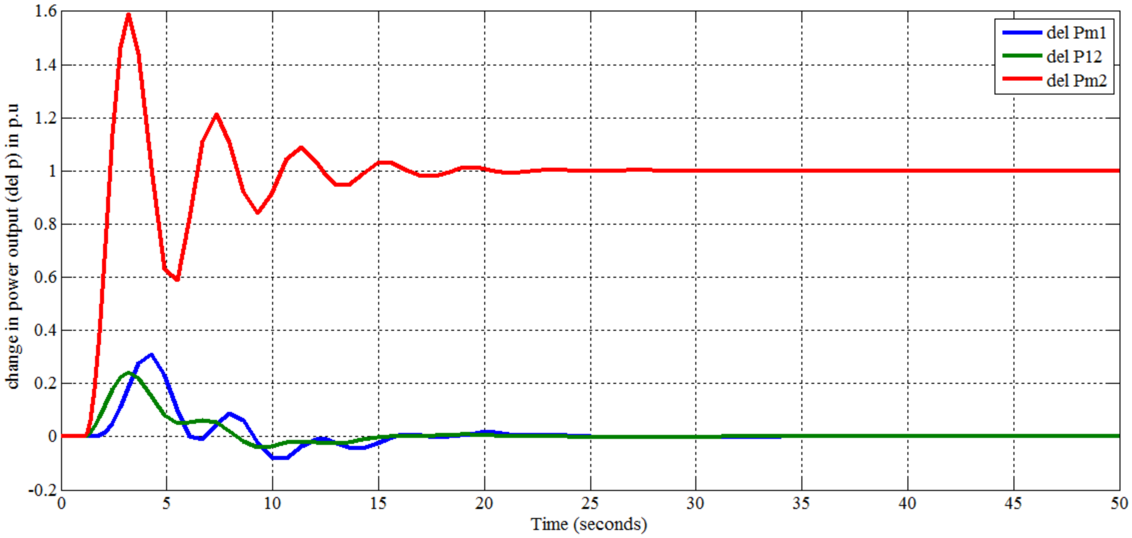

Figure 4.12: Change in power output vs. time for two area by using secondary loop

4.5 Three Area System Without Using Secondary Loop

Three area interconnected systems without using secondary loop is given in Figure (4.13) and Figure (4.14) presents the settling down of frequency to a finite value which is less than the actual frequency. Figure (4.15) shows the power change due to tie -line on account of the deviation in the load. Here stability is improved with interconnection .We have taken the values of the different parameters as shown in table (4.5) for modeling the Simulink model and its successful operation to obtain the desired results.

Table 4.5: System parameters for three area system without using secondary control

Name	Kg	Tg (s)	Kt	Tt (s)	H(s)	D(p.u.MW/Hz)	1/R	ΔPL(p.u)
Area1	1	0.80	1	0.30	10	1.00	15	1
Area2	1	0.20	1	0.50	5	0.60	20	0
Area3	1	0.30	1	0.60	4	0.90	16	0

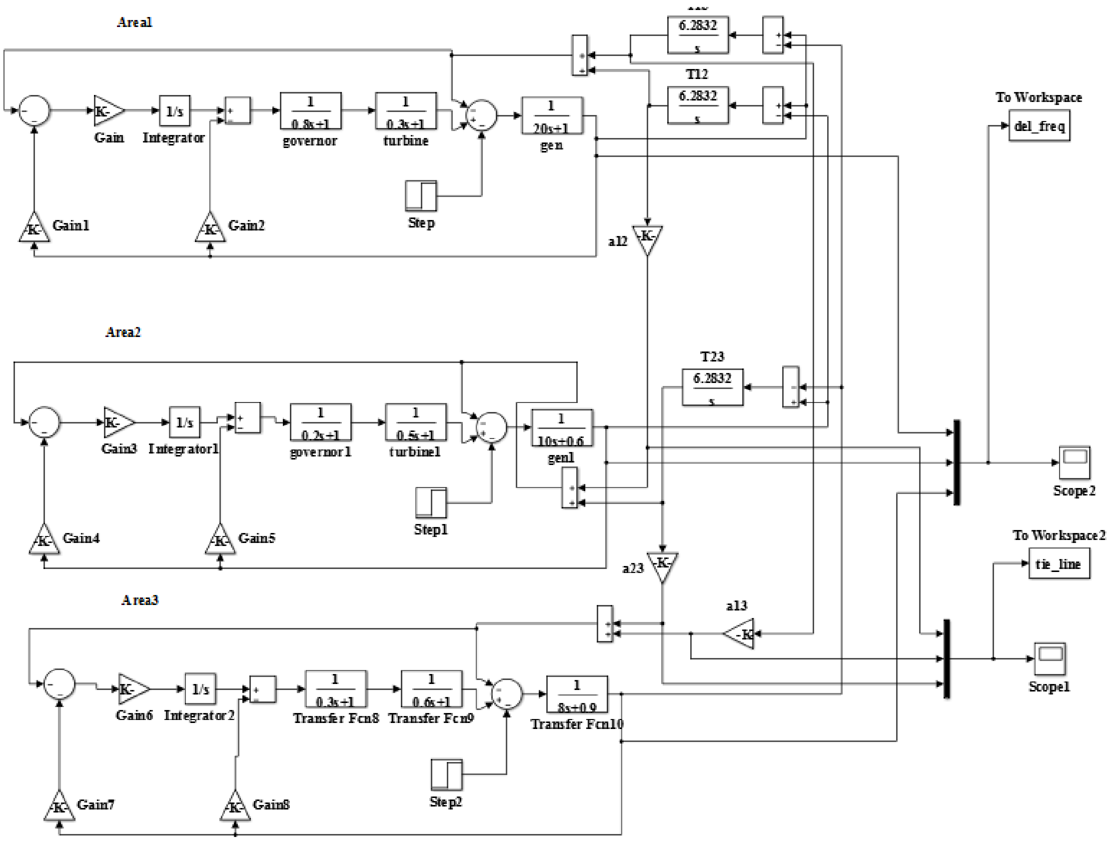

Figure 4.13: Simulink model of three area system without using secondary loop

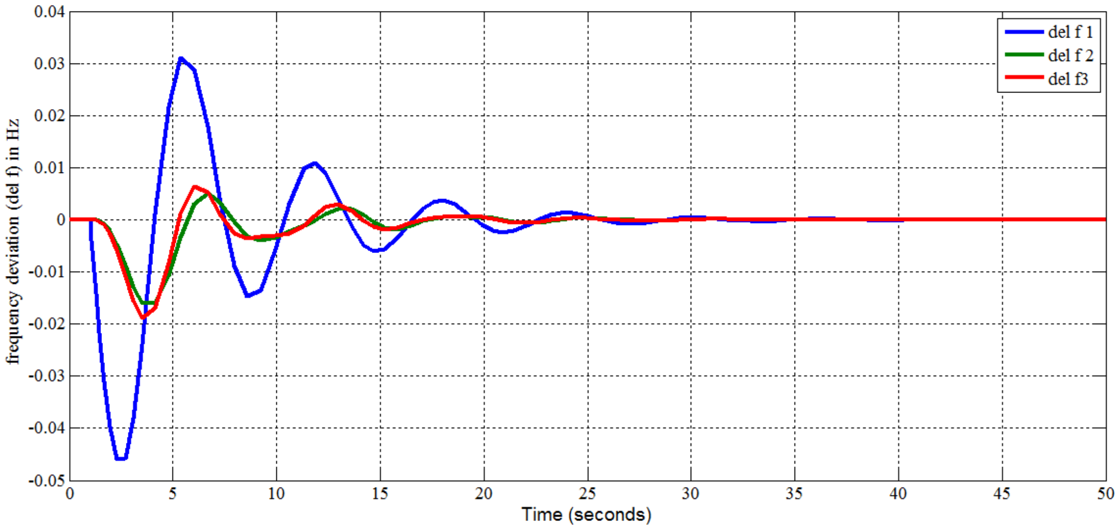

Figure 4.14: Frequency deviation vs. time for three area system without using secondary loop

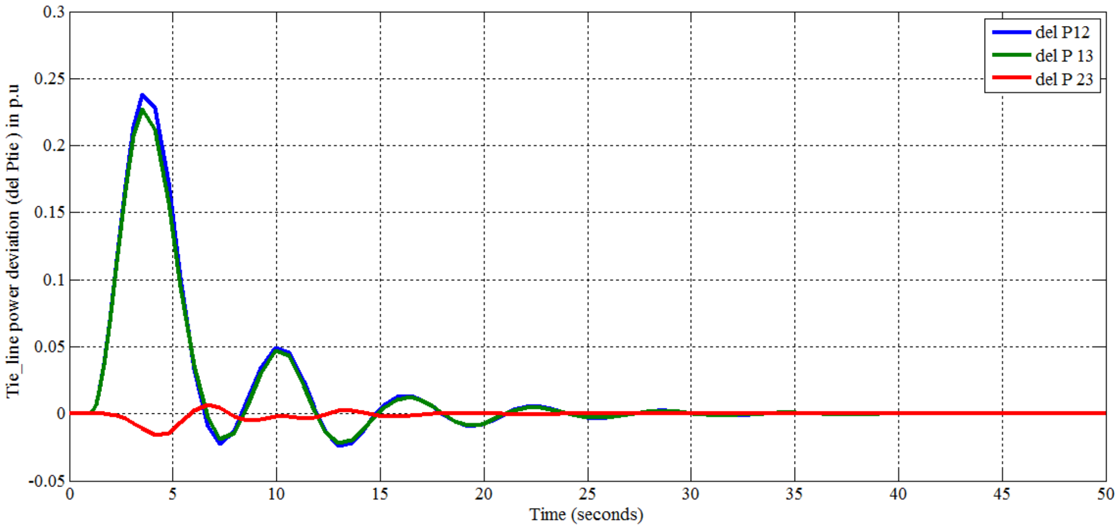

Figure 4.15: Change in Tie line power deviation vs. time for three area system without using secondary loop

4.6 Three Area System By Using Secondary Loop

The model for the three area system including the secondary control is given away in Figure (4.16) The results of the variation in frequency as well as tie line power output with respect to time are being shown in Figure (4.17) and Figure (4.18) the system operates in a similar way to that of the two area system, taking into consideration the changes in the load. We have taken the values of the different parameters as shown in table (4.6) for modeling the Simulink model and its successful operation to obtain the desired results.

Table 4.6: System parameters for three area system by using secondary control

Name	kg	Tg(s)	Kt	Tt(s)	Tp(s)	H(s)	D (p.u.MW/Hz)	Ki	1/R	ΔPL (p.u)
Area 1	1	0.80	1	0.30	20	10	1.00	7	17	1
Area 2	1	0.20	1	0.50	10	5	0.60	7	20	0
Area 3	1	0.30	1	0.60	8	4	0.90	7	16	0

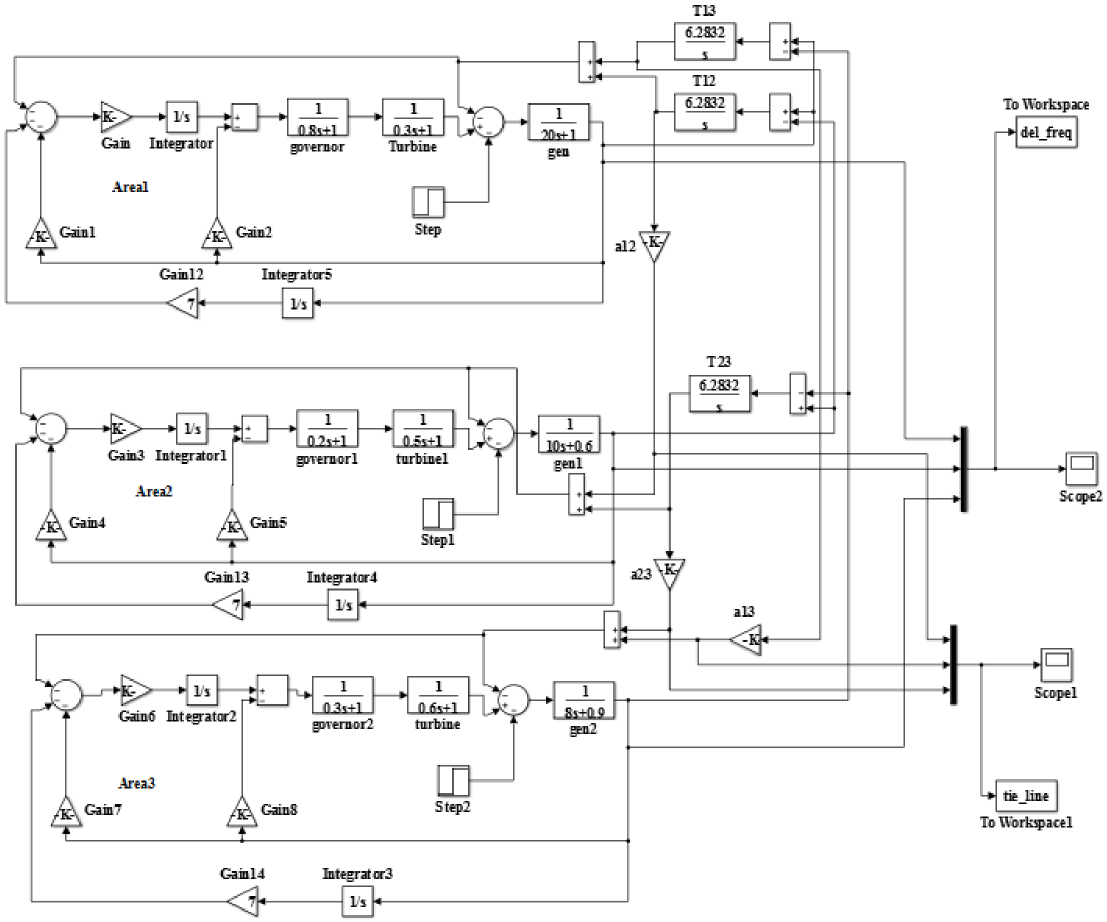

Figure 4.16: Simulink model of three area system by using secondary loop

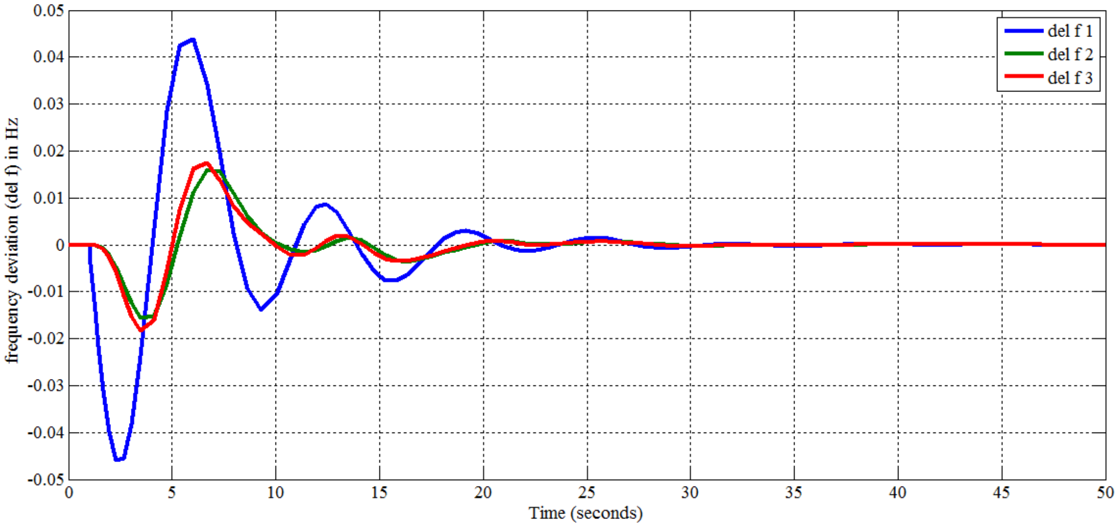

Figure 4.17: Frequency deviation vs. time for three area system by using secondary loop

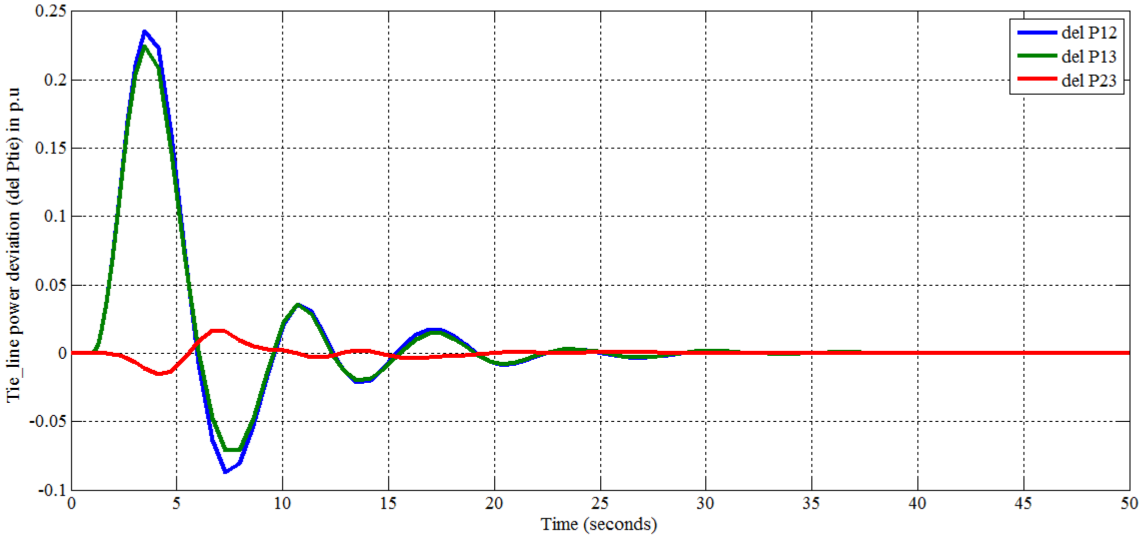

Figure 4.18: Change in Tie line power deviation vs. time for three area system by using secondary loop

4.7 Observation

By considering the above-stated simulation graphs it could be seen that the system encounters drifts in the frequency succeeding a disturbance in the load and it is primarily because of the mismatch involving the electrical load as well as the mechanical input which is given to the prime mover/turbine. Fluctuations in the system is more in the single area system than two area systems for the reason that all the variations in the load are to be handled by one area only. Moreover variation in frequency is made to be zero by using a secondary loop in both single area in addition to two area systems. We also see that the three area system also operates in a similar manner like that of two area system.

4.8 Summary

Thus after developing models in SIMULINK help to understand the principles behind LFC including challenges. In case of single area without secondary loop load changes so speed change and thus drifts in frequency is settled down near to a limited value(-0.033 Hz) and so new working frequency(49.967 Hz) is less as compared to the supposed value(50 Hz). In case of single area with secondary control loop frequency drifts is made zero by integral controller. In case of tow area with primary control loop there is stability improvement with interconnection. In case of tow area with secondary control loop this loop is responsible for making the frequency drifts to zero value and by changing gain dynamic response is observed.

In case of three area the system operates similar to that of case of tow area just it consists of three control areas. Thus the advantage of interconnection is understood and we see that the dynamic response is chiefly administered by means of the secondary loop.

CHAPTER FIVE

CONCLUSION AND RECOMMMENDATIONS

5.1 Conclusion

The thesis has chiefly investigated on the frequency change as well as change in the tie line power due to the change in the load and obtains the response from primary control loop and secondary control loop.

Firstly secondary are being introduced for minimizing the deviations in frequency and tie line power. This is usually effective in case of a single area system or an isolated system as the secondary control loop i.e. an integral controller is generally responsible for reducing the changes in the frequency deviations to zero and maintains the system stability. Therefore without the presence of secondary loop the system losses its stability.

Secondly interconnection of two or more systems is being introduced to regulate the load through tie line power exchange. Interconnecting two or more areas ensures the sharing of the power among the systems during the times of load changes which may occur in any area at any time. Therefore the burden on the controllers to minimize the changes in the frequency is reduced as a result of the rise in the power demand can be fulfilled by drawing power from the neighboring areas and thus maintains the stability of the system.

The simulation results in time-domain verified the effectiveness of secondary control loop through successfully regulating the ACE outputs, frequency errors and tie-line power errors in the presences of load changes.

5.2 Recommendations

- Various controllers may be used to manage the frequency deviations and changes in tie line power.
- It may be implemented to system with four areas and also the performance of the system may be studied.

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