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Modeling of Automatic Generation Control and Automatic Voltage Regulator of Interconnected Thermal Power System

نمذجة متحكم التوليد ومنظم الجهد التلقائي لمحطات التوليد الحرارية المترابطة

A Thesis submitted in partial fulfillment for the requirements of the degree of M.Sc. in Electrical Engineering (Power)

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September 2017

الآيـــــة

﴿ أَلَمْ تَرَوْا أَنَّ اللَّهَ سَخَّرَ لَكُمْ مَا فِي السَّمَاوَاتِ وَمَا فِي الْأَرْضِ وَأَسْبَغَ عَلَيْكُمْ نِعَمَهُ ظَاهِرَةً وَبَاطِنَةً وَمِنَ النَّاسِ مَنْ يُجَادِلُ فِي اللَّهِ بِغَيْرِ عِلْمٍ وَلَا هُدًى وَلَا كِتَابٍ مُنِيرٍ * وَإِذَا قِيلَ لَهُمُ اتَّبِعُوا مَا أَنْزَلَ اللَّهُ قَالُوا بَلْ نَتَّبِعُ مَا وَجَدْنَا عَلَيْهِ آبَاءَنَا أَوَلَوْ كَانَ الشَّيْطَانُ يَدْعُوهُمْ إِلَى عَذَابِ السَّعِيرِ * وَمَنْ يُسْلِمْ وَجْهَهُ إِلَى اللَّهِ وَهُوَ مُحْسِنٌ فَقَدِ اسْتَمْسَكَ بِالْعُرْوَةِ الْوُثْقَى وَإِلَى اللَّهِ عَاقِبَةُ الْأُمُورِ * وَمَنْ كَفَرَ فَلَا يَحْزُنْكَ كُفْرُهُ إِلَيْنَا مَرْجِعُهُمْ فَنُنَبِّئُهُمْ بِمَا عَمِلُوا إِنَّ اللَّهَ عَلِيمٌ بِذَاتِ الصُّدُورِ*﴾

لقمان (20 - 23)

DEDICATION

To the utmost knowledge lighthouse, to our greatest and most honored prophet Mohamed - May peace and grace from Allah be upon him

To whom I miss in the face of difficulties

And did not slow the world to saturate of his affection. My father

And to those who race words to come out and express themselves

Who taught me and suffered difficulties to get to what I am in it

And when you take care of the worries I swim in the sea of tenderness to ease my pain.. My mother.

To whose love flows in my veins and my heart always remembers them, to my brothers.

To those who taught us letters of gold and words of jewel of the utmost and sweetest sentences in the whole knowledge. Who reworded to us their knowledge simply and from their thoughts made a lighthouse guides us through the knowledge and success path, to our honored teachers and professors.

ACKNOWLEDGEMENT

First of all, thanks Allah for guiding me to perform this thesis, otherwise all works will not be completed except with his blessing. I would like to express my profound gratitude to my advisor **Dr. Elfadil Zakaria Yahia Abdalla.** For his invaluable advice and continuous encouragement throughout this work. His suggestions provide me the opportunity to instruct and solve the faced problems.

I would like to thank all my colleagues in the electrical maintenance department at Khartoum North power station, and especially thank the **Eng. Mohammed Mirghani Hassan** who is encouraging me by his strength and intelligence to work hard and complete this thesis. I am also thankful to **Eng.Abdel Rahman Saifedin Alawad** for his valuable suggestions and discussions.

It is impossible to find the right words to thank my mother **Fathia Abdul Malik**, grandmother **Fatima Al Zaki** and my brothers **Fakhri elddin**, **Alaa elddin**, **Mohi elddin** and **Osman** for their love and encouragement. .Without it, this thesis would not be completed.

ABSTRACT

As the interconnected power system, transmits the power from one area to another, frequency will be inevitable deviate from scheduled frequency, in addition to both the active and reactive power demands are continually changes with rising and falling trend, any mismatch between system generation and demand results in change in system frequency that is highly undesired excitation of generator must be regulated in order to match the reactive power demand, otherwise bus voltage falls beyond the permitted limit.

This thesis presents new model for each component of Automatic generation control (AGC) and automatic voltage regulator (AVR) loops considering generator rate constraints (GRC) of one and two areas interconnected thermal power system.

The response with GRC is compared with the analysis done without the Generation Rate Constraint. Although the frequency deviation was found to be less with suitable controllers when the GRC is not considered, it is not the actual frequency deviation. When GRC is considered the actual frequency deviation can be found and then accordingly the controller is tuned. So that the desired frequency and power interchange with neighboring systems are maintained in order to minimize the transient deviations and to provide zero steady state error in appropriate short time. Further the role of automatic voltage control is to maintain the terminal voltage of synchronous generator in order to maintain the bus bar voltage, results are obtained using MATLAB *SIMULINK* software.

المستخلص

نظم القدرة المترابطة يتم فيها نقل القدرة من منطقة الي أخرى وأثنا ذلك تتغير القدرة الحقيقية والتخيلية بالزيادة والنقصان نتيجة للتغير المستمر في الطلب مما يؤدي الي انحراف التردد عن التردد الطبيعي، إن أي اختلاف بين التوليد والطلب يظهر جليا في التردد والجهد مما يتطلب اتخاذ قرار لحظي وإلا فإنهما يخرجان خارج حدود الدقة المحددة.

في هذا البحث تم تطوير نموذج محاكاة لكل من متحكم التوليد ومنظم الجهد التلقائي باعتبار قيود التوليد وتم تطبيق ذلك في محطات التوليد الحرارية.

تمت مقارنة الاستجابة في حالة عدم اعتبار قيود التوليد علي الرغم من أن الإنحراف في التردد كان اقل إلا انه ليس الانحراف الفعلي في التردد وعند إعتبار قيود التوليد تم الحصول علي التردد الفعلي ومن ثم تم ضبط وحدة التحكم ، بحيث يتم الحفاظ على التردد المطلوب وتبادل الطاقة مع النظم المجاورة من أجل تقليل الإنحرافات العابرة وأن يرجع خطأ الحالة الي الصفر في وقت قصير. وعلاوة على ذلك دور المنظم التلقائي للجهد في الحفاظ علي الجهد الطرفي للمولد التزامني بحيث يكون مساويا لجهد الشبكة، تم الحصول علي النتائج ومقارنها باستخدام برنامج المحاكاة في الماتلاب .

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ABBREVIATIONS

AC	Alternating current.
DC	Direct current
AGC	Automatic generation control
AVR	Automatic voltage regulator
ALFC	Automatic load frequency control
GRC	Generation rate constraint
ACE	Area control error
SCADA	Supervisory control and data acquisition
AFRC	Area frequency response characteristic
PID	Proportional integral derivative
Q	Reactive power
KE	kinetic energy
H	Inertia constant of the generator
$\mathrm{y}_{\mathrm{E}}^{0}$	Steam valve setting
$\mathrm{P}_{\mathrm{G}}^{0}$	Generator output
k_{sg}	Gain of speed governor
T_{sg}	Time constant of speed governor
ΔP_D	changes in load demand
$\Delta \mathrm{P}_{\mathrm{C}}$	speed-changer
V_{ref}	reference voltage
V_t	Terminal voltage
$T.F_a$	Transfer function

ΔV_R	Amplifier output
ΔE	Change in generated emf
TR	Time constant of sensor

CHAPTER ONE

INTRODUCTION

1.1 Preface:

Load frequency control (LFC) is an important function in frequency regulation of modem power systems. In order to get a precise realization and accurate insight of the LFC issue, it is essential to take into account the important constraints and main inherent requirements such as physical constraints which affect the power system dynamics. Generation rate constraint (GRC) is a physical constraint that means practical limit on the rate of the change in the generating power due to physical limitations of turbine. GRC has major influence on realistic power system performance due to its non-linearity characteristic. In practice, the rate of active power change that can be attainable by thermal units has a maximum limit [1]. So, the designed LFC for the unconstrained generation rate situation may not be suitable and realistic.

After a load disturbance in a power system, area control error (ACE) signals and control signals deviate from zero. The required power to compensate frequency deviations is provided through a specific ramp rate. The required power to maintain the system in normal condition is prepared by limit rate due to the GRC. The effect of the GRC will be more noticeable when the system encounters with greater step load perturbation. In this way, the system attempts to provide greater power in a fast time horizon to ensure integrity of the interconnected system, but the GRC limits the response of the generating units by reducing the rate of increasing required power to reject the disturbances [2]. The controllers so designed regulate the area control error to zero. For each area, a bias constant determines the relative importance attached to the frequency error feedback with respect to the tie-line power error feedback.

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

The generator excitation system maintains generator voltage and hence, controls the reactive power flow in the power system. A change in the real power demand affects essentially the system frequency, whereas a change in the reactive power affects mainly the voltage magnitude in the power system. The sources of reactive power are generators, capacitors, and reactors. The reactive power of generator is controlled by field excitation [3]. Other methods for improving the voltage profile in the electric transmission systems are static VAR control equipment, switched capacitors, transformer load tap changers, step voltage regulators. The important means of generator reactive power control is the generator excitation control using automatic voltage regulator AVR. The role of an AVR is to maintain the terminal voltage magnitude of synchronous generator at a specified level [4].

1.2 Background:

A literature review shows that in the simultaneous presence of important system constraints and nonlinearities like governor dead band many investigations in the field of automatic generation control have been reported over the past few decades. These deals with how to select a frequency bias, selection of controller parameters and selection of speed regulator parameter of speed governor. Investigations in the area of AGC problem in interconnected power systems have been reported in the past six decades (Ibraheem and Kothari; Shayeghi). A number of control schemes have been employed in the design of AGC controllers in order to achieve better dynamic performance. Among the various types of AGC controllers, the most widely used are classical proportional-integral and proportional integral derivative PID controller.

Nanda dealt with AGC of a single area hydro-thermal system including generation rate constraints. Optimization of integral controller and electric governor parameters had been carried out using ISE criterion. Investigations had been made for the selection of suitable value for governor speed regulation parameter and to explore the effect of tie line strength on the dynamic response. However, the recent advancement in optimal control theory and availability of fast digital computers coupled with enormous capability of handling large amount of data with different type of interconnections motivated the power system engineers to devise recent AGC strategies. There have been a vast variety of research articles relating to AGC controller designs which had made classical controllers structure as the basis for the development of more advanced and even intelligent technique based controllers for AGC applications in power systems [5].

Kumar [6] discusses in “Modeling and simulation of AGC for SCADA based interconnected power system operation” about the new structure for AGC based on SCADA. The effect of governor dead band and stability analysis of AGC [7] is explained in the contest of recent developments in industry.

A literature review shows that in the simultaneous presence of important system constraints and nonlinearities like GDB and the most of the earlier work in the area of automatic generation control in deregulated environment pertains to interconnected thermal system in this research I have been devoted AGC with generating rate constraint.

1.3 Statement of Problem:

As the interconnected power system, transmits the power from one area to another, frequency will be inevitable deviate from scheduled frequency, in addition to both the active and reactive power demands are continually changes with rising and falling trend. A control system is essential to correct the deviation in the presence of external disturbances and structural uncertainties to ensure a safe and smooth operation of power system, to investigate this by using the AGC and AVR to balance operation between the total system generations against load demand.

1.4 Thesis Objectives:

The objective of this thesis are generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the voltage and frequency within permissible limits, developing simulation model for each component of AGC and AVR loops considering generator rate constraints and developing model for the coupling between the automatic generation and voltage control.

1.5 Methodology:

Load frequency and voltage control problems are studied with Automatic Generation Control AGC and Automatic Voltage Regulator AVR with generation rate constraint GRC using proportional integral derivative (PID) controller for two Area Power Systems, AGC problem is solved by applying Area Control Error (ACE) as input to Integrator [9]. Similarly AVR is achieved using PID controller. PID controller is a very popular industrial controller. There are many methods available for tuning of PID controllers [10]. If properly tuned it gives superior performance. These days simulation software tools are widely popular. MATLAB *SIMULINK* is one of them. It can be used to simulate the system and obtain the results.

1.6 Thesis Outlines:

This thesis consists of five chapters, Chapter two gives literature review. Chapter three presents brief description for component of automatic generator control and automatic voltage regulation, and then represents a design, its model, and operating principles. Chapter four gives simulation and results in terminal voltage, change in frequency and change in tie line power and compared between results. Chapter five contains the conclusion and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction:

The basic task of power system is to maintain the balance between power demand and power generation, to provide users with reliable, high-quality electric power. Changes in the power demand affect the frequency of the power system as well as the tie-line power flow between control areas. Therefore, the main objectives of the Load Frequency Control (LFC) are to keep the system frequency at the scheduled value, and regulate the generator units based primarily on area control error (ACE), making the area control error tends to zero under the continuous adjustment of active power, so that the generation of entire system and load power well match.

A frequency avalanche drop aggravated by a voltage avalanche drop causes grave breakdown in the power system and complete stoppage of the paralleled station or division of power system in to separately operating sections with interruptions to power supply of many consumers. The function of automatic frequency control to prevent the power system frequency from approaching a critical value, when loss of active power occurs, by disconnecting part of the loads thereby keeping power stations and there auxiliaries operative. In this case the power system supplies to majority of consumers suffer no interruption and system to disconnected load can be restored within a fairly short period of time.

A power system is a proper system to transmit power economically efficiently and reliable manner. As we know everyone desired the uninterrupted supply. But it is always not possible for a system remains in normal state. For more than 99% of the time a typical system found in its normal state. In this state the frequency and the bus voltages are kept at prescribed value. As these two are responsible for active and reactive power balance [11] the match “Equality” between generation and demand is a fundamental prerequisite for system “Normalcy. Different state of a system is described in figure 2.1.

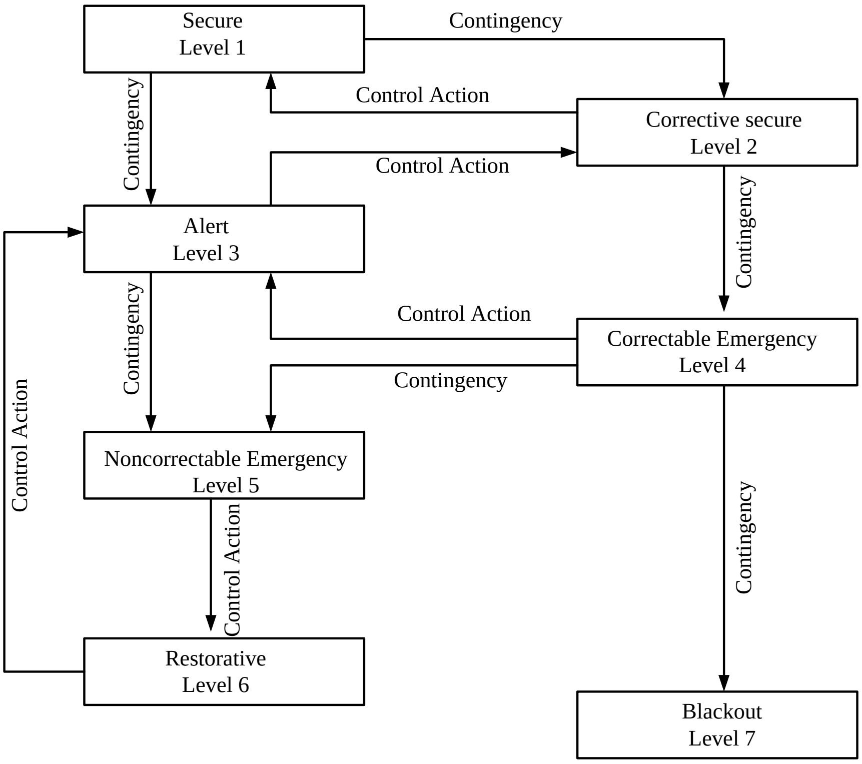

Figure 2.1 power system status

In figure 2.1 if everything fails means control action fails to maintain system stability. Then the system goes in none correctable emergency. Where need of load shedding. So that the following problems need to be studied for a power system operations in normal state.

1. Megawatt -Frequency interaction (active power).
2. Megavar -Voltage interaction (reactive power).
3. Power flow problem.
4. Optimum dispatch.
5. The control problem.

2.2 Megawatt -Frequency (P-f) Interaction:

Constant frequency is identified as the primary mark of a normal operating system. There are at least four reasons why the system frequency must not be allowed to deviate from a chosen constant value.

1. Most type of A.C. motors run at speeds that are directly related to the frequency.
2. The generator turbines, particularly steam driven are designed to operate at very precise speed.
3. The overall operation of power system can be much better controlled if frequency error is kept within strict limit.
4. The large number of electrical clocks are used are driven by synchronous motor. Accuracy of these clocks not only depends on frequency but integral of frequency.

2.2.1 Load Frequency Mechanism:

The frequency is closely related to real power balance in network. Under normal operating generators runs synchronously and generator power tougher that each moment is being drawn by all load plus real transmission losses. Electrical energy cannot be stored. Generation rate must be equal to consumption rate.

Difference would enter into kinetic energy storage. As kinetic energy storage depends on generator speed, a power imbalance will thus translate in to speed (frequency) deviation.

2.3 Megavar Voltage Interactions (Q-V):

Practically all equipment used in or operating of a power system is designed for certain voltage level if it deviates its performance deviates and life expectancy drops. For example torque of induction motor proportional to square of terminal voltage. For voltage control:

1. Excitation control of generator.

2. Switched shunt capacitor or reactor for controlling reactive power.
3. Synchronous capacitor.
4. Tap changing of transformer.

2.4 Cross Coupling between Controls Loops:

A surplus of active power tends to increase system frequency. A surplus of reactive power tends to increase system voltage.

If the active power increases is felt to uniformly when reactive power increased greatest.

As we change active power of one of several generator resulting change in voltage. If we change active power inputs also change in real power.

2.5 Power Flow Problem:

The important aspect of power flow analysis:

1. The total amount of real power in network emanates from generator stations, the location and size of which are fixed. The generation must be equal to demand at each moment and since this power must be divided between generators in unique ratio, in order to achieve the economic operation. We conclude that individual generator output must be closely maintained at predetermined set point. It is important to remember that demand undergo slow but wide changes throughout the 24 hour of the day. We must therefore slowly, either continuously or in the discrete steps, change these set point as the hour wears on. This means that a load flow configuration that fits the demand of a certain hour of day may lock quite different the next hour.
2. Transmission link can carry only certain amount of power and we must make sure that we don’t these links too close to their stability or thermal limit.

3. It is necessary to keep the voltage levels of certain buses within close tolerances. This can be achieved by proper scheduling of reactive power.
4. If power system is a part of a larger pool. It must fulfill certain contractual power scheduling commitment via its tie lines to neighboring system.
5. The disturbance following a massive network fault can cause system outages, the effect of which can be minimized by proper pre fault power flow strategies.
6. Power flow analysis is very important in planning stages of new network or addition to existing one

2.6 Optimal Dispatch:

The energy cost is expressed in Rs/MW will vary greatly between the above types of units. Peaking units are more expensive because on average they are greatly under used. If a utility can save its peak demand by load management, it may possible for years the need acquisition of such units. Maintain proper generation mix is most important requirement for a power company of any size. The problem is not only due to hourly shifting the power demand. The entire generating unit must be regularly maintained. The operating success of a utility Company depends to a great extent upon ability optimally to match the generation to the load not only 24 hour daily time span but over seasons and years.

2.7 Control Action:

Control actions are:

1. Torque and excitation control.
2. Switching in or out of series or shunt capacitors.
3. Regulating transformer tap control.

4. Relay protection control.
5. Stability enhancement using some extra methods.
6. Load shedding.

2.8 Interconnected Power System Network:

During early years small local generating stations supplied power to respective local loads. Each generating stations needed enough installed capacity to feed local loads. Merits of interconnected ac power system:

1. Lesser spinning reserve
2. Economic generation.
3. Lesser installed capacity.
4. Minimized operational cost, maximize efficiency.
5. Better use of energy reserve.
6. Better service to consumer.

Modern power system network is formed by interconnecting several individual controlled ac networks. Each individual controlled ac network has its own generating, transmission, distribution and loads and load control centers. The regional control centre controls generation and in its geographical region to maintain system frequency within limits (+-0.5%) The exchange of power (import/export) between neighboring ac network is dictated by National Load Control Centre. Thus ac network in an interconnected network called national grid. Even neighboring national grids are interconnected to form super grids.(eg. USA, Canada; European grid; UK-France).Interconnection between India Pakistan, India Sri Lanka, India Nepal etc. in initial planning stage(1997).Main task of interconnection is to transfer power.

Interconnection has significant influence on load – frequency control, short circuit level, power system security and stability, power system protection and control, energy management financial accounting.

2.8.1 Configuration and Principal of Interconnection:

The system A and B are interconnected by tie line. Each area has its individual load frequency control which controls the total generation of area to match load losses and interchange. The total control is done by SCADA.

2.8.2 Individual System (Region or Area):

Each individual system generates enough power equal to Regional load, plus net interchange with adjacent system via the tie lines.

Total generation = Total area load + Total net interchange by area

By maintain balance between right hand sides. And left hand side, the frequency of area A is maintained within targeted limits. This condition is fulfilling by AGC, performed Regional load centre.

2.8.3 Total Generation in Interconnected system:

Total generation of group of interconnected system = total load plus losses Algebraic sum of net interchange equal to zero.

- If total generation is less than total load on the grid. The frequency of the entire grid starts falling. Fall of frequency cause increase power inflow from neighboring region.
- If total generation is more than total load, frequency starts rising. Load frequency control is automatic.

This is achieved by:

1. Primary load frequency control.
2. Secondary control: By enough interchange of power between regional grids as per instruction of load control centre.

2.9 Supervisory control and data acquisition system (SCADA):

Today is need of SCADA system because of following reasons:

- Present day power systems have large interconnected networks.

- Maintaining system security, reliability, quality, stability and ensuring economic operation are the major operating concerns.
- The success of the recently evolving electricity market structure will heavily depend on modern information systems and on line decision tools.
- On line monitoring, operation and control of the modern day power systems have become impossible without computer aided monitoring and dispatching systems.

CHAPTER THREE

BASIC CONTROL LOOP DESIGN

3.1 Introduction:

The quality of power means balancing the total system generation against the system load and losses so that the system can remain in steady state. However, both active and reactive power demands are never steady and they continually change with load demand. Steam input to generators, must be regulated to match the active power demand, failing which the speed and thus consequent change in frequency which is highly undesirable. In modern large interconnected system, manual regulation is not feasible and therefore automatic generation and voltage regulation equipment is installed on each generator [12]. Figure 3.1 gives the schematic diagram of load frequency and excitation voltage regulators of a turbo-generator. The controllers are set for particular operating conditions and they take care of small changes in load demand without frequency and voltage exceeding the prescribed limits. With the passage of time, as the change in load demand becomes large, the controllers must be reset either manually or automatically. It has been shown in previous chapters that for small changes active power is dependent on machine angle δ and is independent of bus voltage; while bus voltage is dependent on machine excitation (therefore on reactive generation Q) and is independent of machine angle δ. Change in angle δ is caused by momentary change in generator speed. Therefore, load frequency and excitation voltage control are non-interactive for small changes and can be modeled and analyzed independently. Furthermore, excitation voltage control is fast acting in which the major time constant encountered is that of the generator field;

while the power frequency control is slow acting with major time constant contributed by the turbine and generator moment of inertia-this time constant is much larger than that of the generator field. Thus, the transients in excitation voltage control vanish much faster and do not affect the dynamics of power frequency control. Change in load demand can be identified as: (1) slow varying changes in mean demand, and (2) fast random variations around the mean. The regulators must be designed to be insensitive to fast random changes, otherwise the system will be prone to hunting resulting in excessive wear and tear of rotating machines and control equipment [13].

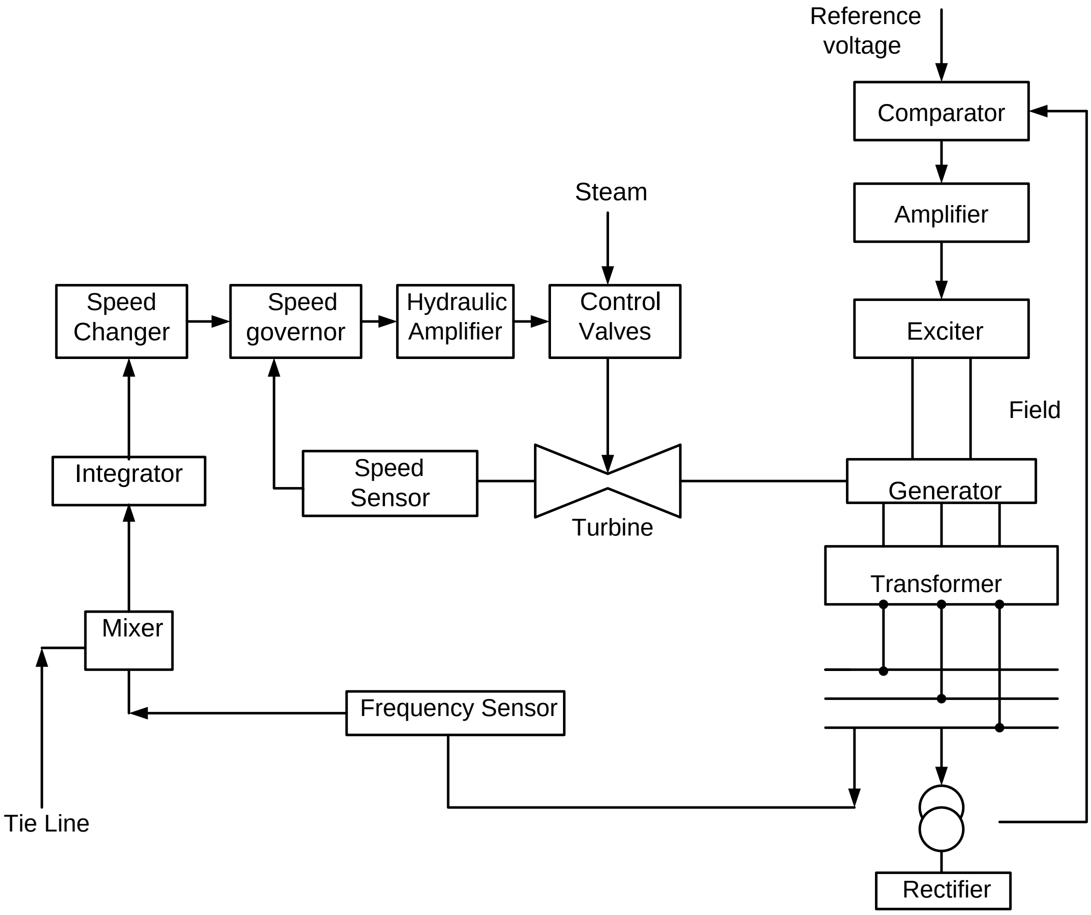

Figure 3.1 Basic Control Loops

3.2 Automatic generation control design:

The first step in the analysis and design of a control system is mathematical modeling of the system. The two most common methods, transfer function method and state variable approach. The stare variable approach can be applied to portray linear as well as nonlinear systems. In order to use the transfer function and linear state equations, the system must first be linearized proper assumptions and approximations are made to linearized the mathematical equations describing the system. And a transfer function model is obtained for following components.

3.3 Generator Load Model:

The increment in power input to the generator-load system (ΔP_G - ΔP_D)

Where $\Delta P_G = \Delta P_T$ incremental turbine power output (assuming generator incremental loss to be negligible, and (ΔP_D) is the load increment.

This increment in power input to the system is accounted for in two ways:

Rate of increase of stored kinetic energy in the generator rotor. At Scheduled frequency (f^0), the stored energy is

$$W_{KE}^{o} = HP_r \tag{3.1}$$

Where P_r is the kW rating of the turbo-generator and H is defined as its inertia constant The kinetic energy being proportional to square of speed (frequency), the kinetic energy at a frequency of (f^0+Δ f) is given by

$$\frac{W_{KE}}{W_{KE}^{o}} = \left(\frac{f^{o}+\Delta f}{f^{o}}\right)^{2} \tag{3.2}$$

$$w_{KE} = HP_r\left(\frac{f^{0}+\Delta f}{f^{0}}\right)^{2} \tag{3.3}$$

$$w_{KE} = HP_r\left(1+\frac{2\Delta f}{f^{0}}+(\frac{2\Delta f}{f^{0}})^{2}\right) \tag{3.4}$$

$$w_{KE} = HP_r\left(1+\frac{2\Delta f}{f^{0}}\right) \tag{3.5}$$

Differential above equation

$$\frac{dW_{KE}}{dt} = \frac{2HP_r}{f^0}\frac{d}{dt}(\Delta f) \tag{3.6}$$

Its assume that the change in motor load is sensitive to speed (frequency), variation for small change in system frequency Δf the rate of change of load with respect to frequency that is $\frac{\partial P_D}{\partial f}$ can be regarded as constant for small changes in frequency Δf and can be expressed as

$$\left(\frac{\partial P_D}{\partial f}\right)\Delta f = B\,\Delta f \tag{3.7}$$

$$B = \frac{\partial P_D}{\partial f} \qquad \text{frequency bias factor} \tag{3.8}$$

$$\Delta P_G - \Delta P_D = \frac{2HP_r}{f^0}\frac{d}{dt}(\Delta f) + B\,\Delta f \tag{3.9}$$

Divide by P_r and rearranging, we get

$$\frac{\Delta P_G}{P_r} - \frac{\Delta P_D}{P_r} = \frac{2H}{f^0}\frac{d}{dt}(\Delta f) + \frac{B\,\Delta f}{P_r} \tag{3.10}$$

$$\Delta P_G(p.u) - \Delta P_D(p.u) = \frac{2H}{f^0}\frac{d}{dt}(\Delta f) + B(p.u)\,\Delta f \tag{3.11}$$

Taking Laplace transform of equation (3.11)

$$\Delta P_G(s) - \Delta P_D(s) = \frac{2H}{f^0}\,s\Delta F(s) + B\,\Delta F(s) \tag{3.12}$$

$$\Delta F(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{\frac{2H}{f^0}s + B} = \frac{1}{B}\left[\frac{\Delta P_G(s) - \Delta P_D(s)}{\frac{2H}{Bf^0}s + 1}\right] \tag{3.13}$$

$$\Delta F(s) = [\Delta P_G(s) - \Delta P_D(s)]\left[\frac{K_{PS}}{1 + s\,T_{PS}}\right] \tag{3.14}$$

Equation (3.14) represent the block diagram of Generator Load Model

$$T_{PS} = (2H / Bf^0) \tag{3.15}$$

T_{PS} ≡ power system time constant

$$K_{PS} = 1/B \tag{3.16}$$

K_{PS} ≡ power system gain

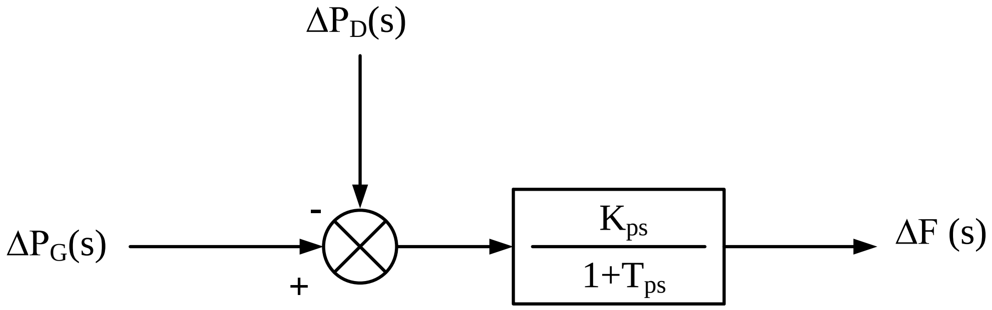

Figure 3.2 Block diagram representation of a Generator load model

3.4 Prime Mover Model:

The source of mechanical power commonly known as the prime mover may be hydraulic turbines at waterfalls, steam turbines whose energy comes from the burning of coal, gas, nuclear fuel, and gas turbines. The model for the turbine relates changes in mechanical power output $\Delta P_t(s)$ to changes in steam valve position different types of turbines vary widely in characteristics. The simplest prime mover model for the non-reheat steam turbine can be approximated with a single time constant (T_t), resulting in the following transfer function:

$$\frac{\Delta P_t(s)}{\Delta y_E(S)} = \frac{K_t}{1+s\,T_t} \qquad (3.17)$$

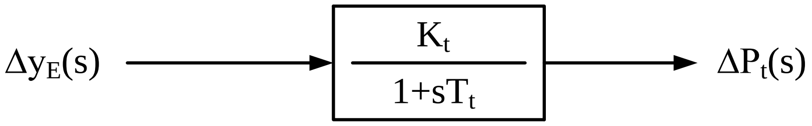

Figure 3.3 Block diagram representation of turbine model

3.5 Speed Governor Model:

When the generator electrical load is suddenly increased, the electrical power exceeds the mechanical power input. This power deficiency is supplied by the kinetic energy stored in the rotating system.

The reduction in kinetic energy causes the turbine speed and, consequently, the generator frequency to fall. The change in speed is sensed by the turbine governor which acts to adjust the turbine input valve to change the mechanical power output to bring the speed to a new steady-state. The earliest governors were the Watt governors which sense the speed by means of rotating fly balls and provide mechanical motion in response to speed changes. However, most modem governors use electronic means to sense speed changes. Figure 3.4 shows schematically the essential elements of a conventional Watt governor, which consists of the following major parts.

(1) **Fly ball speed governor** this is the heart of the system which senses the change in speed (frequency). As the speed increases the fly balls move outwards and the point B on linkage mechanism moves downwards. The reverse happens when the speed decreases.

(2) **Hydraulic amplifier** it comprises a pilot valve movement is converted into high power level piston valve movement. This is necessary in order to open or close the steam valve against high pressure steam.

(3) **Linkage mechanism** ABC is a rigid link pivoted at B and CDE is another rigid link pivoted at D. this link mechanism provides a movement to the control valve in proportion to change in speed. It also provides a feedback from the steam valve movement (link 4).

(4) **Speed changer:** it provides a steady state power output setting for the turbine. Its downward movement opens the upper pilot valve so that more steam is admitted to the turbine under steady conditions (hence more steady power output). The reverse happens for upward movement of speed changer.

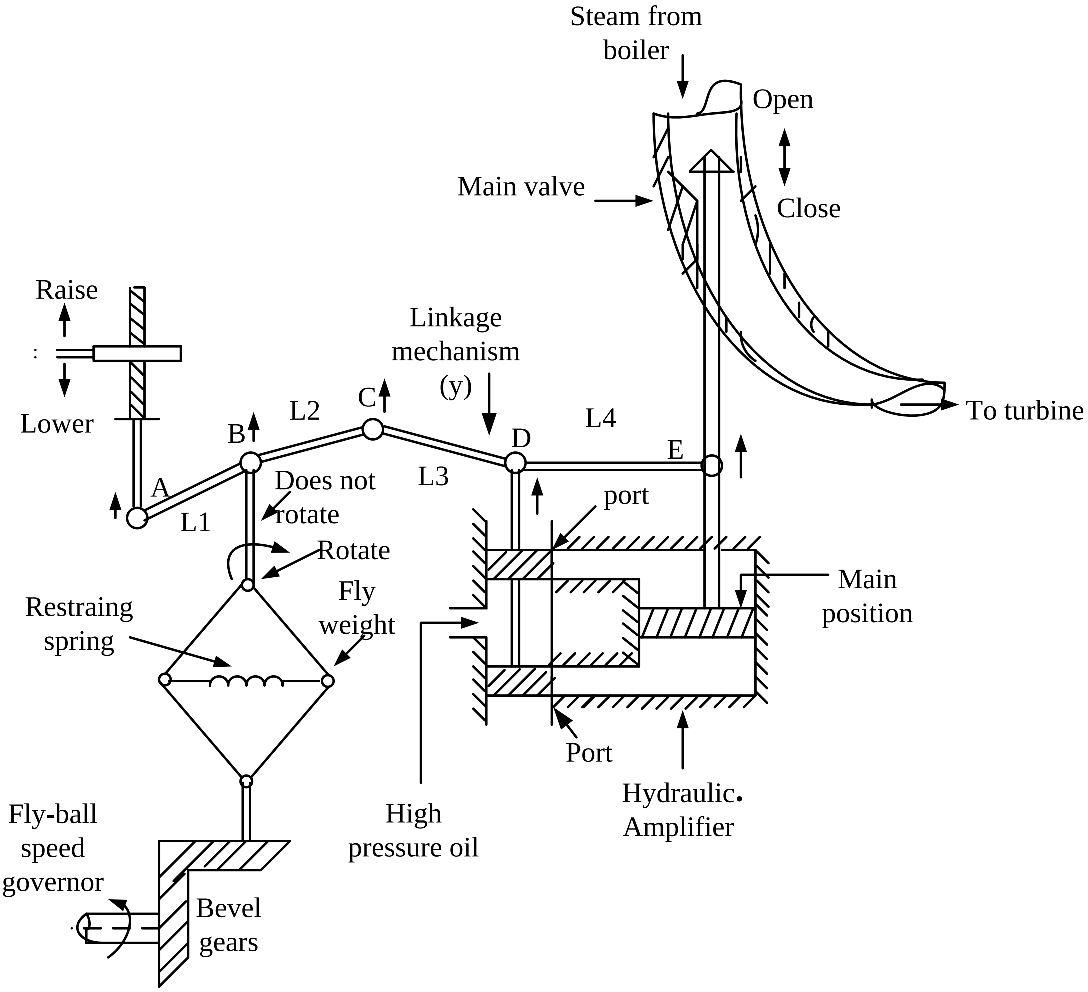

Figure 3.4 Speed governor systems

3.5.1 Model Speed Governor System:

Assume that the system is initially operating under steady conditions-the linkage mechanism stationary and pilot valve closed, steam valve opened by a definite magnitude, turbine running at constant speed with turbine power output balancing the generator load. Let the operating conditions be characterized by

f^0 ≡ System frequency (speed).

P_G^0 ≡ Generator output = turbine output (neglecting generator loss).

y_E^0 ≡ Steam valve setting.

We shall obtain a linear incremental model around these operating conditions. Let the point A on the linkage mechanism be moved downwards by a small amount Δy_A . Is a command which causes the turbine power output to change and can therefore be written as

$$\Delta y_A = k_c \Delta P_c \qquad (3.18)$$

Where ΔP_c is the commanded increase in power.

Two factors contribute to the movement of C:

(i) Δy_Acontribute $-\left[\frac{L_2}{L_1}\right]\Delta y_A$ or $-k_1\ \Delta y_A$

(ii) Increase in frequency Δf causesthe fly balls to move outwards so that (B) moves downwards by a proportional a mount $k_2'\Delta f$. The consequent movement of (C) with (A) remaining fixed at $\Delta y_A$is

$$\left[\frac{L_1+L_2}{L_1}\right]k_2'\Delta f = k_2\Delta f \qquad (3.19)$$

He net movement of C is therefore

$$\Delta y_C = -k_1 k_C \Delta P_C + k_2 \Delta f \qquad (3.20)$$

The movement of D Δy_D, is the amount by which the pilot valve opens It is contributed by Δy_C and Δy_E and can be written as:

$$\Delta y_D = \left[\frac{L_4}{L_3+L_4}\right]\Delta y_C + \left[\frac{L_3}{L_3+L_4}\right]\Delta y_E \qquad (3.21)$$

$$\Delta y_D = k_3 \Delta y_C + k_4 \Delta y_E \qquad (3.22)$$

The movement Δy_Ddepending upon its sign high opens one of the ports of the pilot valve admitting high pressure oil into the cylinder thereby moving the main piston and opening the steam valve by Δy_Ecertain justifiable simplifying assumption which can be made at this stage:

1- Inertial reaction forces of main piston and steam valve are negligible compared to the forces exerted on the piston by high pressure oil.

2- Because of (1) above, the rate of oil admitted to the cylinder is proportional to port opening Δy_D.

The volume of oil admitted to the cylinder is thus proportional to the time integral of $\Delta y_D$the movement Δy_E is obtained by dividing the oil volume by the area of the cross section of the piston. Thus:

$$\Delta y_E = k_5 \int_0^t -(\Delta y_D)\, dt \tag{3.23}$$

It can be verified from the schematic diagram that a positive movement Δy_D, causes negative (upward) movement Δy_E accounting for the negative sign used in Equation (3.23). Taking the Laplace transform of equations (3.20) and (3.22) we get:

$$\Delta y_C(s) = -k_1 k_C \Delta P_C(s) + k_2 \Delta f(s) \tag{3.24}$$

$$\Delta y_D(s) = k_3 \Delta y_C(s) + k_4 \Delta y_E(s) \tag{3.25}$$

$$\Delta y_E(s) = k_5 \frac{1}{s} \Delta y_D(s) \tag{3.26}$$

Eliminating $\Delta y_C(s)$ and $\Delta y_D(s)$ we can write:

$$\Delta y_E(s) = \frac{k_1 k_3 k_C \Delta P_C(s) - k_2 k_3 \Delta f(s)}{k_4 + \frac{s}{k_5}} \tag{3.27}$$

$$\Delta y_E(s) = \left[\Delta P_C(s) - \frac{1}{R}\Delta f(s)\right] \times \left(\frac{k_{sg}}{1 + T_{sg} s}\right) \tag{3.28}$$

$$R = \frac{k_1 k_C}{k_2} \tag{3.29}$$

$R \equiv$ Speed regulation of the governor.

$$k_{sg} = \frac{k_1 k_3 k_C}{k_4} \tag{3.30}$$

$k_{sg} \equiv$ Gain of speed governor.

$$T_{sg} = \frac{1}{k_4 k_5} \tag{3.31}$$

$T_{sg} \equiv$ Time constant of speed governor.

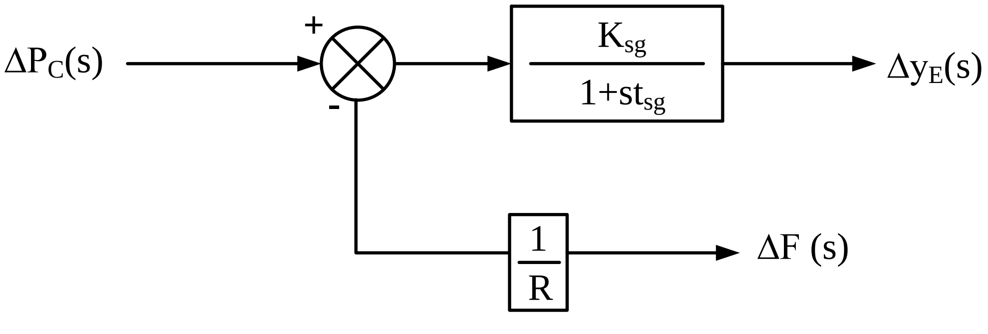

Figure 3.5 Block diagram model of speed governor system

3.6 Complete block diagram representation of load frequency control of an isolated power system:

Figure 3.6 represent the overall block diagram of automatic generator control of isolated area:

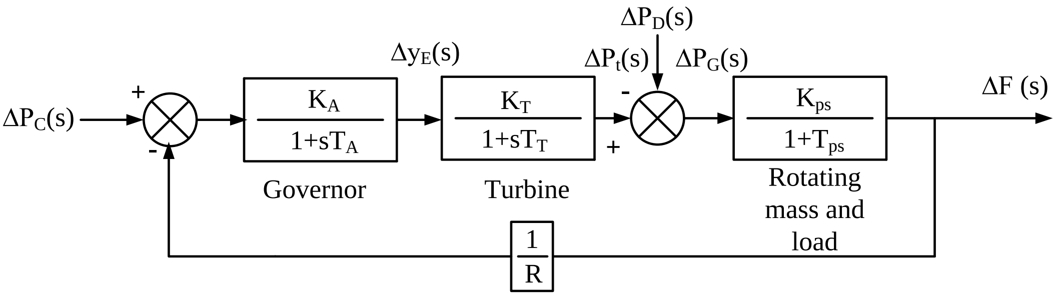

Figure 3.6 Block diagram of LFC

This representation being a 3rd - order system, the characteristic equation for the system will be of the 3rd order.

3.7 Steady-state analysis:

The model of Figure 3.6 shows that there are two important incremental inputs to the load frequency control system ΔP_C the change in speed changer setting and ΔP_D, the change in load demand.

3.7.1 Uncontrolled case:

Let us consider a simple situation in which the speed changer has a fixed setting ($\Delta P_C = 0$), and load demand changes. And free governor operation. For sudden step change in load demand.

$$\Delta P_D(s) = \frac{\Delta P_D}{s} \tag{3.32}$$

$$\Delta F(s)|_{\Delta P_C(s)} = -\left[\frac{K_{Ps}}{(1+ST_{Ps})+\frac{K_A K_T K_{Ps}/R}{(1+ST_A)(1+ST_T)}}\right]\frac{\Delta P_D}{s} \tag{3.33}$$

Applying the final value theorem

$$\Delta F \left| \text{Steady state}_{\Delta P_C=0} = \lim_{s\to 0}[s\Delta F(s)] \right|_{\Delta P_C=0} \tag{3.34}$$

$$\Delta F(s = -\left[\frac{K_{Ps}}{1+\frac{K_{Ps}K_AK_T}{R}}\right]\Delta P_D \tag{3.35}$$

While the gain K_T is the fixed for turbine and K_{Ps} fixed for the power system

$$K_A\ K_T = 1 \tag{3.36}$$

$$\Delta F = -\left[\frac{K_{Ps}}{1+\frac{K_{Ps}}{R}}\right]\Delta P_D \tag{3.37}$$

It's also recognized that

$K_{PS} = 1/B$ and where that $B = \partial P_D/\partial f = (\partial P_D/\partial f)/ P_r$

$$\Delta F = -\left[\frac{{}^{1}/_{B}}{1+\frac{1}{BR}}\right]\Delta P_D \tag{3.38}$$

$$\Delta F = -\left[\frac{1}{B+\frac{1}{R}}\right]\Delta P_D = -\frac{1}{\beta}\Delta P_D \tag{3.39}$$

$$\beta = B + \frac{1}{R} \tag{3.40}$$

The above equation gives the steady state changes in frequency caused by changes in load demand. Speed regulation R is-naturally so adjusted that changes in frequency are small (of the order from no load to full load).

3.7.2 Load demand is constant (controlled case):

It's also observed from the above that increase in load demand ΔP_D is met under steady condition partly by increased generation ΔP_C due to opening of steam valve and partly by decreased the load demand due to drop in frequency.

$$\Delta F(s)|_{\Delta P_D(s)} = \left[\frac{K_AK_TK_{Ps}}{(1+ST_A)(1+ST_T)(1+ST_{Ps})}\Big/\left(1+\frac{K_AK_TK_{Ps}}{(1+ST_A)(1+ST_T)(1+ST_{Ps})}\right)\times\frac{1}{R}\right]\times\frac{\Delta P_C}{s} \tag{3.41}$$

$$\Delta F(s) = \left[\frac{K_AK_TK_{Ps}}{(1+ST_A)(1+ST_T)(1+ST_{Ps})+K_AK_TK_{Ps}\times\frac{1}{R}}\right]\times\frac{\Delta P_C}{s} \tag{3.42}$$

To steady-state value-Applying the final value theorem to equation(3.42)

$$\Delta F \left| \text{Steady state}_{\Delta P_D=0} = \lim_{s\to 0}[s\Delta F(s)]\right|_{\Delta P_D=0} \tag{3.43}$$

$$\Delta F(s) = \left[\frac{K_A K_T K_{Ps}}{1+\frac{K_A K_T K_{Ps}}{R}}\right]\Delta P_C = \left[\frac{K_{Ps}}{1+\frac{K_{Ps}}{R}}\right]\Delta P_C \tag{3.44}$$

$$\Delta F(s) = \left[\frac{1/_{BR}}{1+1/_{BR}}\right]\Delta P_C \tag{3.45}$$

$$\Delta F = \left[\frac{1}{B+\frac{1}{R}}\right]\Delta P_C \tag{3.46}$$

3.7.3 Speed changer and load demand are variables

If the speed changer setting is changed by ΔP_C, while the load demand Changes by ΔP_D, the steady frequency change is obtained by superposition:

$$\Delta F = \left[\frac{1}{B+\frac{1}{R}}\right](\Delta P_C - \Delta P_D) = -\left[\frac{1}{B+\frac{1}{R}}\right]\Delta P_D + \left[\frac{1}{B+\frac{1}{R}}\right]\Delta P_C \tag{3.47}$$

According to equation (3.47) the frequency change causes by load demand can be compensated by changing the setting of speed changer.

$\Delta P_C = \Delta P_D$, for $\Delta f = 0$

3.8 Proportional plus integral control:

It is seen from the above discussion that with the speed governing system installed on each machine, the steady load frequency characteristic for given speed changer setting has considerable droop for the system being used for the illustration above, the steady state droop in frequency will be 2.9 Hz from no load to full load. System frequency specifications are rather stringent and, therefore, so much change in frequency cannot be tolerated. In fact, it is expected that the steady change in frequency cannot be tolerated. In fact, it is expected that the steady change in frequency will be zero. While steady state frequency can be brought can back to the scheduled value by adjusting speed changer setting, the system could undergo intolerable dynamic frequency changes with changes in load. It leads to the natural suggestion that the speed changer setting be adjusted automatically by monitoring the frequency changes. For this purpose, a signal from ΔF is fed through an integrator to the speed changer resulting in the block diagram configuration shown in figure 3.10. The system now modifies to a proportional plus integral controller, which, as is well known from control theory, gives zero steady state error, i.e. ΔF (steady state) = 0 The signal $\Delta P_C(s)$ generated by the integral control must be of opposite sign to $\Delta F\,(s)$ which accounts for negative sign in block for integral controller. Now

$$\Delta F\ (s) = -\left[K_{Ps}/\left[(1+ST_{Ps}) + (1/R+K_i/S)\times K_{Ps}/\left(1+ST_{sg}\right)(1+ST_{ts})\right]\right]\times \Delta PD/S \tag{3.48}$$

$$= -\left(\frac{RSK_{Ps}(1+ST_{Ps})(1+ST_{ts})}{S\left(1+ST_{sg}\right)(1+ST_{ts})(1+ST_{Ps})R+K_{Ps}(K_i R+S)}\right)\Delta PD/S \tag{3.49}$$

$$\Delta F(\text{steady state}) = S\Delta F$$

In contrast to equation (3.38) we find that the steady state change in frequency has been reduced to zero by the addition of the integral controller. This can be argued out physically as well ΔF reaches steady state (a constant value) only when $\Delta P_C = \Delta P_D$ constant. Because of the integrating action of the controller, this is only possible

$$\text{If } \Delta F = 0 \tag{3.50}$$

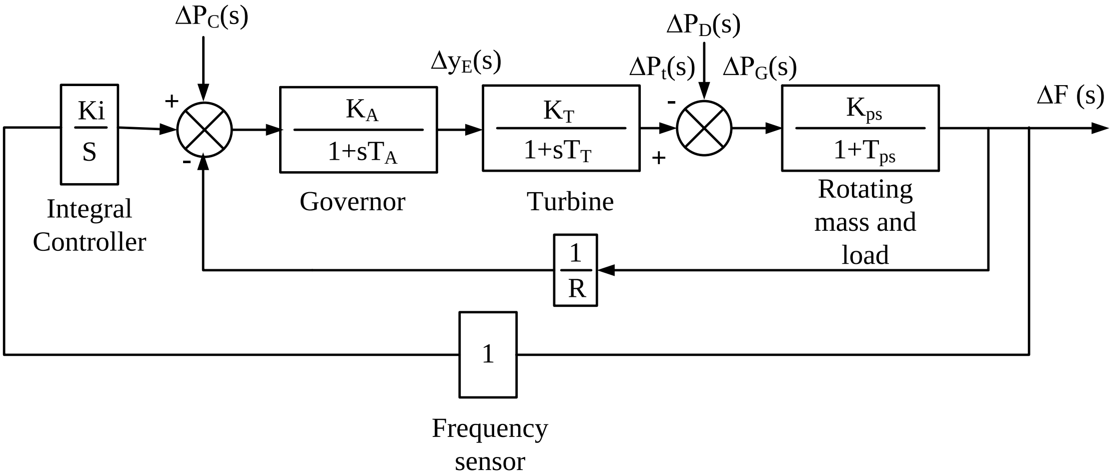

Figure 3.7 Block diagram model of proportional plus integral control

In central load frequency control of a given control area, the change (error) in frequency is known as area control error (ACE). The additional signal fed back in the modified control scheme presented above is the integral of ACE. In the above scheme ACE being zero under steady conditions, a logical design criterion is minimization of $\int \text{ACE}\,dt$ for a step disturbance. This integral is indeed the time error of a synchronous electric clock run from the power supply. In fact, modern power systems keep track of integrated time error all the time. A corrective action (manual adjustment ΔP_C, the speed changer setting) is taken by a large (pre assigned) station in area as soon as the time error exceeds a prescribed value.

3.9 Two-area Load Control:

An extended power system can be divided into a number of load frequency control areas interconnected by means of tie lines. Without loss of generality we shall consider a two-area case connected by a single line as illustrated in Figure 3.8.

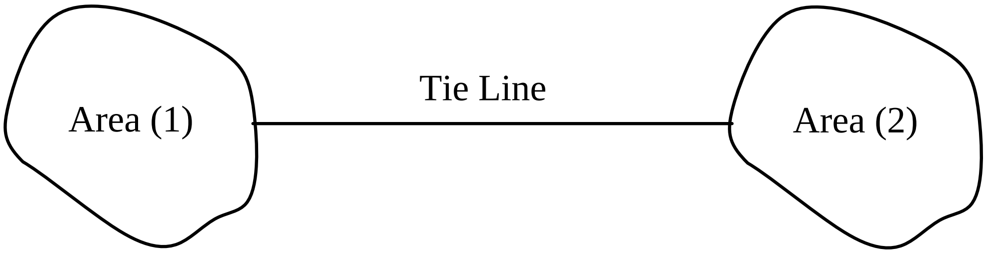

Figure 3.8 Two interconnected control areas (single tie line)

The control objective now is to regulate the frequency of each area and to simultaneously regulate the tie line power as per inter-area power contracts. As in the case of frequency, proportional; plus integral controller will be installed so as to give zero steady state error in tie line power flow as compared to the contracted power.

It is conveniently assumed that each control area can be represented by an equivalent turbine, generator and governor system. Symbols used with suffix one refer to area two and those with suffix two refer to area two.

In an isolated control area case the incremental power (PC - PD) was accounted for by the rate of increase of stored kinetic energy and increase in area load caused by increase in frequency. Since a tie line transports power in or out of an area load caused by increase in frequency. Since a tie line transports power in or out of an area, this fact must be accounted for in the incremental power balance equation of each area.

Power transported out of area one is given by:

$$P_{TL1} = \frac{|E_1||E_2|}{X_{TL}}\sin(\delta_1 - \delta_2) \quad (3.51)$$

δ_1 and δ_2 is the power angles of equivalent machines of the two areas

$|E_1|$ and $|E_2|$ Are voltage magnitude of area one and area two.

X_{TL} is the tie line reactance

If there is the change in load demand of two areas there will be incremental change in power angle$(\Delta\delta_1 - \Delta\delta_2)$. Then the change in the tie line power is :

$$P_{TL1} + \Delta P_{TL1} = \frac{|E_1||E_2|}{X_{TL}}\sin[(\delta_1 - \delta_2) - (\Delta\delta_1 - \Delta\delta_2)] \quad (3.52)$$

$$\Delta P_{TL1} = \frac{|E_1||E_2|}{X_{TL}}\sin(\delta_1 - \delta_2) + \frac{|E_1||E_2|}{X_{TL}}\cos[(\delta_1 - \delta_2)(\Delta\delta_1 - \Delta\delta_2)] \quad (3.53)$$

$$\Delta P_{TL1} = \frac{|E_1||E_2|}{X_{TL}}\cos[(\delta_1 - \delta_2)(\Delta\delta_1 - \Delta\delta_2)] \quad (3.54)$$

For incremental changes in δ_1 and δ_2, the incremental tie line power can be expressed.

$$\Delta P_{TL1_{(pu)}} = T_{12}(\Delta\delta_1 - \Delta\delta_2) \quad (3.55)$$

Where (3.56)

$$T_{12} = \frac{|E_1||E_2|}{X_{TL}}\cos(\delta_1 - \delta_2) \quad (3.57)$$

$T_{12} \equiv$ Synchronizing coefficient of the tie-line

$$T_{12} = \frac{P_{max_{12}}}{P_1}\cos(\delta_1 - \delta_2) \quad (3.58)$$

$$P_{max_{12}} = \frac{|E_1||E_2|}{X_{TL}} \quad (3.59)$$

Static transmission capacity of the tie line

Consider the change in frequency as

$$\Delta\omega = \frac{d}{dt}(\Delta\delta) \quad (3.60)$$

$$2\pi\Delta f = \frac{d}{dt}(\Delta\delta) \quad (3.61)$$

$$\Delta f = \frac{1}{2\pi}\frac{d}{dt}(\Delta\delta) \quad (3.62)$$

In other words

$$\frac{d}{dt}(\Delta\delta) = 2\pi\Delta f \tag{3.63}$$

$$\int \frac{d}{dt}(\Delta\delta) = \int 2\pi\Delta f \tag{3.64}$$

$$\Delta\delta = 2\pi \int \Delta f\, dt \quad \text{rad} \tag{3.65}$$

The change in power angles from area one to area two

$$\Delta\delta_1 = 2\pi \int \Delta f_1\, dt \tag{3.66}$$

$$\Delta\delta_2 = 2\pi \int \Delta f_2\, dt \tag{3.67}$$

Since incremental power angles are relate in term of integrals incremental of frequencies, we can write

$$\Delta P_{TL_1} = 2\pi T_{12}\left(\int \Delta f_1\, dt - \int \Delta f_2\, dt\right) \tag{3.68}$$

where Δf_1 and Δf_2 are incremental frequency changes of areas 1 respectively

Similarly the incremental tie line power out of area 2 is given by

$$\Delta P_{TL_2} = 2\pi T_{21}\left(\int \Delta f_2\, dt - \int \Delta f_1\, dt\right) \tag{3.69}$$

Where

$$T_{21} = \frac{|E_1||E_2|}{X_{TL} P_2}\cos(\delta_2 - \delta_1) \tag{3.70}$$

Divide (3.70) by (3.57) we get

$$\frac{T_{21}}{T_{12}} = \frac{P_1}{P_2} a_{12} \tag{3.71}$$

$$\text{there fore } T_{21} = a_{12}\, T_{12} \tag{3.72}$$

$$\Delta P_{TL_2} = a_{12} \Delta P_{TL_1} \tag{3.73}$$

(LFC-1)- surplus power in p.u. is

$$\Delta P_C - \Delta P_D = \frac{2H}{f^0}\frac{d}{dt}(\Delta f) + B\Delta f \quad \text{for single area} \tag{3.74}$$

For two area case the surplus power can be expressed in pu is

$$\Delta P_{C_1} - \Delta P_{D_1} = \frac{2H_1}{f^0}\frac{d}{dt}(\Delta f_1) + (B_1 \Delta f_1) + \Delta P_{TL_1} \tag{3.75}$$

Taking Laplace Transform on both side of Equation (3.75)

$$\Delta P_{C_1}(s) - \Delta P_{D_1}(s) = \frac{2H_1}{f^0}\frac{d}{dt}S(\Delta f_1(s)) + (B_1 \Delta f_1(s)) + \Delta P_{TL_1}(s) \quad (3.76)$$

Rearranging the above equation as follow, we get

$$\Delta P_{C_i}(s) - \Delta P_{D_i}(s) = \left(\Delta f_1(s)\right)\left[\frac{2H_1}{f^0}S + B_1\right] + \Delta P_{TL_1}(s) \quad (3.77)$$

$$\Delta f_1(s) = \left[\Delta P_{C_i}(s) - \Delta P_{D_i}(s) - \Delta P_{TL_1}(s)\right]\left[\frac{1/B_1}{1+(2H_1/B_1 f^0)S}\right] \quad (3.78)$$

$$\Delta f_1(s) = \left[\Delta P_{C_1}(s) - \Delta P_{D_1}(s) - \Delta P_{TL_1}(s)\right]\left[\frac{K_{Ps}}{1+ST_{Ps}}\right] \quad (3.79)$$

Taking Laplace Trans. Equation (3.55)

$$\Delta P_{TL_1}(s) = 2\pi T_{12}\left(\frac{\Delta f_1(s)}{s} - \frac{\Delta f_2(s)}{s}\right) \quad (3.80)$$

$$\Delta P_{TL_1}(s) = \frac{2\pi T_{12}}{s}(\Delta f_1(s) - \Delta f_2(s)) \quad (3.81)$$

Area two:

$$\Delta P_{TL_2}(s) = \frac{2\pi T_{12}}{s}(\Delta f_1 - \Delta f_2) \quad (3.82)$$

$$\Delta P_{TL_2}(s) = -2\pi a_{12} T_{12}\left(\frac{\Delta f_1}{s} - \frac{\Delta f_2}{s}\right) \quad (3.83)$$

$$\Delta P_{TL_2}(s) = -\frac{2\pi a_{12} T_{12}}{s}(\Delta f_1(s) - \Delta f_2(s)) \quad (3.84)$$

Equations (3.79) and. (3.84) can be represented by a block diagrams as shown below:

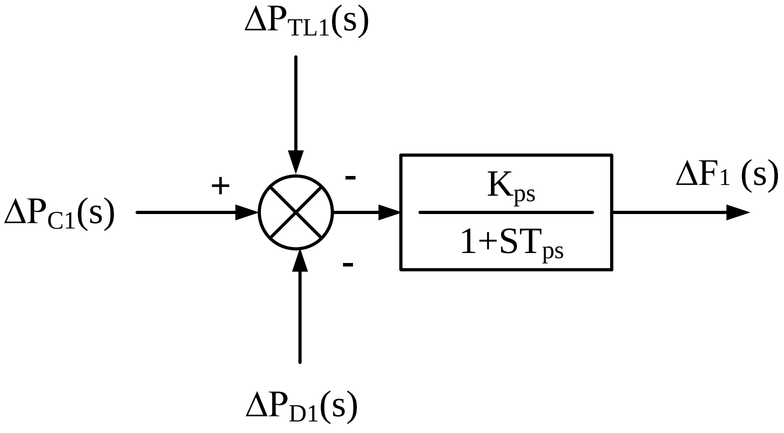

Figure 3.9 Block diagram representation of equation 3.79

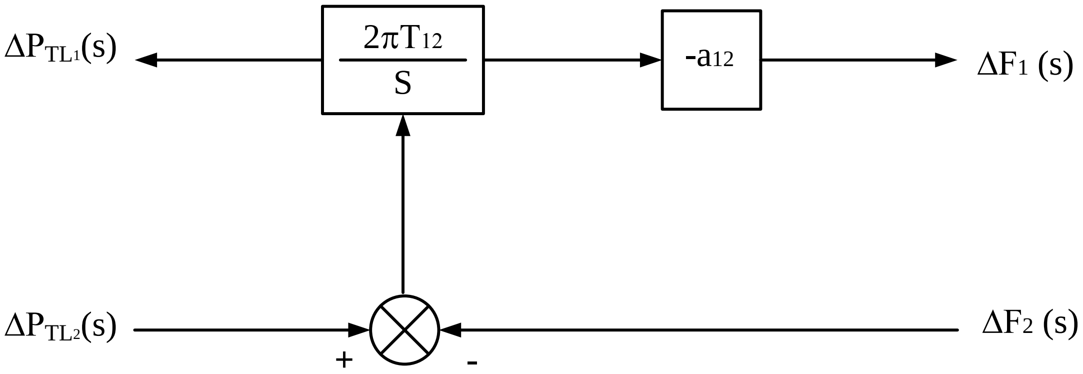

Figure 3.10 Block diagram representation of equation (3.81) and (3.84)

The composite block diagram of a two-area system can be modeled as shown below:

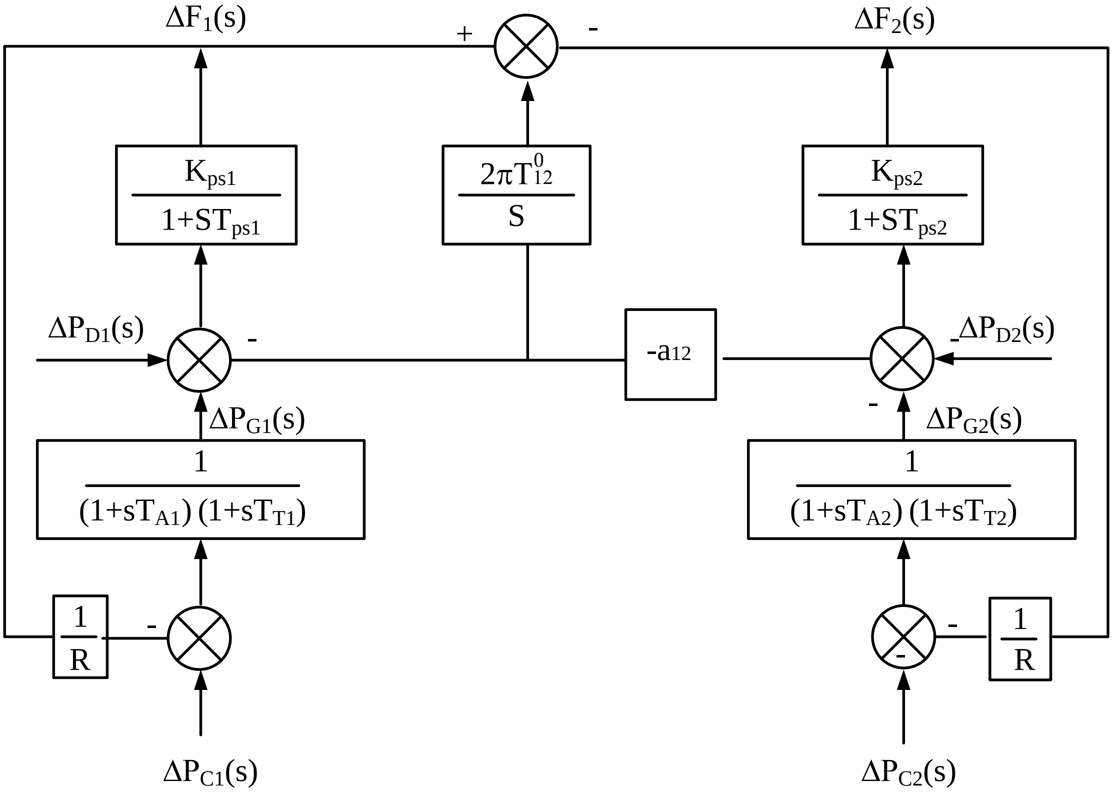

Figure 3.11 Two area system with and load frequency control

3.10 Response of a two-area system:

Also the analysis it's two state

3.10.1 Uncontrolled case:

$$\Delta P_G - \Delta P_D = \frac{2HP_r}{f^0}\frac{d}{dt}(\Delta f) + B\Delta f \tag{3.85}$$

Speed changer positions are fixed

- Static response:

$$\Delta P_{G_1} = \frac{\Delta f}{R_1} \tag{3.86}$$

$$\Delta P_2 = \frac{\Delta f}{R_2} \tag{3.87}$$

The dynamics of 2-area system can be described by.

$$(\Delta P_{G_1} - \Delta P_{D_1}) = \frac{2H_1}{f^0}\frac{d}{dt}(\Delta f_1) + (B_1\Delta f_1) + \Delta P_{TL_1} \tag{3.88}$$

$$(\Delta P_{G_2} - \Delta P_{D_2}) = \frac{22}{f^0}\frac{d}{dt}(\Delta f_2) + (B_2\Delta f_2) + \Delta P_{TL_2} \tag{3.89}$$

$$\frac{d}{dt}(\Delta f) = 0 \;\; \text{Under steady-state condition} \tag{3.90}$$

Sub. Equations (3.86),(3.87) and (3.90) in (3.88) and (3.89)

$$-\frac{\Delta f}{R_1} - \Delta P_{D_1} = B_1\Delta f + \Delta P_{TL_1} \tag{3.91}$$

$$-\frac{\Delta f}{R_2} - \Delta P_{D_2} = B_2\Delta f - a_{12}\Delta P_{TL_1} \tag{3.92}$$

$$\text{Since } \Delta P_{TL_2} = -a_{12}\Delta P_{TL_1} \text{ and } \Delta f_1 = \Delta f_2 = \Delta f \tag{3.93}$$

$$\Delta P_{TL_1} = -\left(\frac{1}{R_1} + B_1\right)\Delta f - \Delta P_{D_1} \tag{3.94}$$

Substituting ΔP_{TL_1} from equation (3.94) in equation (3.92)

$$-\frac{\Delta f}{R_2} - \Delta P_{D_2} = B_2\Delta f - a_{12}\left[-\left(\frac{1}{R_1} + B_1\right)\Delta f - \Delta P_{D_1}\right] \tag{3.95}$$

$$-\frac{\Delta f}{R_2} - B_2\Delta f = \Delta P_{D_2} + a_{12}\left[-\left(\frac{1}{R_1} + B_1\right)\Delta f + \Delta P_{D_1}\right] \tag{3.96}$$

$$-\left(\frac{1}{R_2} + B_2\right)\Delta f - a_{12}\left(\frac{1}{R_1} + B_1\right)\Delta f = \Delta P_{D_2} + a_{12}\Delta P_{D_1} \tag{3.97}$$

$$-\left[\left(\frac{1}{R_2}+B_2\right)+a_{12}\left(\frac{1}{R_1}+B_1\right)\right]\Delta f=\Delta P_{D_2}+a_{12}\Delta P_{D_1} \tag{3.98}$$

$$\Delta f=\frac{\Delta P_{D_2}+a_{12}\Delta P_{D_1}}{\left[\left(\frac{1}{R_2}+B_2\right)+a_{12}\left(\frac{1}{R_1}+B_1\right)\right]} \tag{3.99}$$

Substituting Δf from equation (3.99) in equation (3.94)

$$\Delta P_{TL_1}=\frac{\left(\frac{1}{R_1}+B_1\right)\Delta P_{D_2}-\left(\frac{1}{R_2}+B_2\right)\Delta P_{D_1}}{\left(\frac{1}{R_2}+B_2\right)+a_{12}\left(\frac{1}{R_1}+B_1\right)} \tag{3.100}$$

Equation (3.99) and (3.100) are modified as

Tie line frequency $\Delta f=\frac{\Delta P_{D_1}+a_{12}\Delta P_{D_2}}{[\beta_2+a_{12}\beta_1]}$ (3.101)

$$\Delta P_{TL_1}=\frac{\beta_1\Delta P_{D_2}-\beta_2\Delta P_{D_1}}{\beta_2+a_{12}\beta_1} \tag{3.102}$$

Where

$$\beta_1=\left(\frac{1}{R_1}+B_1\right) \tag{3.103}$$

$$\beta_2=\left(\frac{1}{R_2}+B_2\right) \tag{3.104}$$

Equation (3.101) and (3.102) give the value of the static change in frequency and tie line power respectively as result of sudden step-load change in the two areas. It can be observed that the frequency and tie line power deviations do not reduce to in zero uncontrolled case.

3.10.2 Control case:

By combination of basic block diagram of control area -1 and area -2 and use of figure 3.9 And 3.10, the composite block diagram of two area system can be modeled as shown in figure 3.11 .Figure 3.12 can be obtain by the addition of integral of ACE_1 and ACE_2 to the block diagram shown in figure 3.11 it represent the composite block diagram of two area system with integral control loop here the control signals ΔP_{C_1} and ΔP_{C_2} are generated by the integral of ACE_1 and ACE_2. These control error are obtained through the signal representing the change in the tie line power and local frequency bias.

3.11 Area control error of two areas:

Let us now turn our attention to ACE (area control error) in the presence of a tie line. In the case of an isolated control area, ACE is the change in area frequency which when used in integral control loop forced the steady state frequency error to zero. In order that the steady state tie line power error in a two-area control be made zero another control loop (one for each area) must be introduced to integrate the incremental tie line power signal and feed it back to speed changer. This is accomplished by a single line-integrating block by redefining ACE as linear combination of incremental frequency and tie line power.

Thus, for control area one.

$$\mathrm{ACE}_1 = \Delta \mathrm{P}_{\mathrm{TL}_1} + \mathrm{B}_1 \Delta \mathrm{f}_1 \qquad (3.105)$$

Where the constant b1 is called area frequency bias

Above Equation can be expressed in the Laplace transform as

$$\mathrm{ACE}_1(\mathrm{s}) = \Delta \mathrm{P}_{\mathrm{TL}_1}(\mathrm{s}) + \mathrm{B}_1 \Delta \mathrm{f}_1(\mathrm{s}) \qquad (3.106)$$

Similarly, for the control area 2, ACE2 is expressed as (3.107)

$$\mathrm{ACE}_2(\mathrm{s}) = \Delta \mathrm{P}_{\mathrm{TL}_2}(\mathrm{s}) + \mathrm{B}_2 \Delta \mathrm{f}_2(\mathrm{s}) \qquad (3.108)$$

3.12 Tie Line Bias Control:

From Figure (3.11), speed changer signals can obtained as

$$\Delta \mathrm{P}_{\mathrm{C}_1}(\mathrm{s}) = -\mathrm{K}_{\mathrm{I}_1} \int (\Delta \mathrm{P}_{\mathrm{TL}_1} + \mathrm{B}_1 \Delta \mathrm{f}_1) \mathrm{dt} \qquad (3.109)$$

$$\Delta \mathrm{P}_{\mathrm{C}_2}(\mathrm{s}) = -\mathrm{K}_{\mathrm{I}_2} \int (\Delta \mathrm{P}_{\mathrm{TL}_2} + \mathrm{B}_2 \Delta \mathrm{f}_2) \mathrm{dt} \qquad (3.110)$$

Where

$\mathrm{K}_{\mathrm{I}_1}$ and $\mathrm{K}_{\mathrm{I}_2}$ are the gains of the integrators

The first terms on right-hand side of Equations (3.109) and (3.110) are known as tie-line bias controls

Note that for decreases in both frequency and tie-line power, the speed-changer position decreases and hence the power generation should decrease, i.e. if the ACE is –ve, then the area should increase its generation.

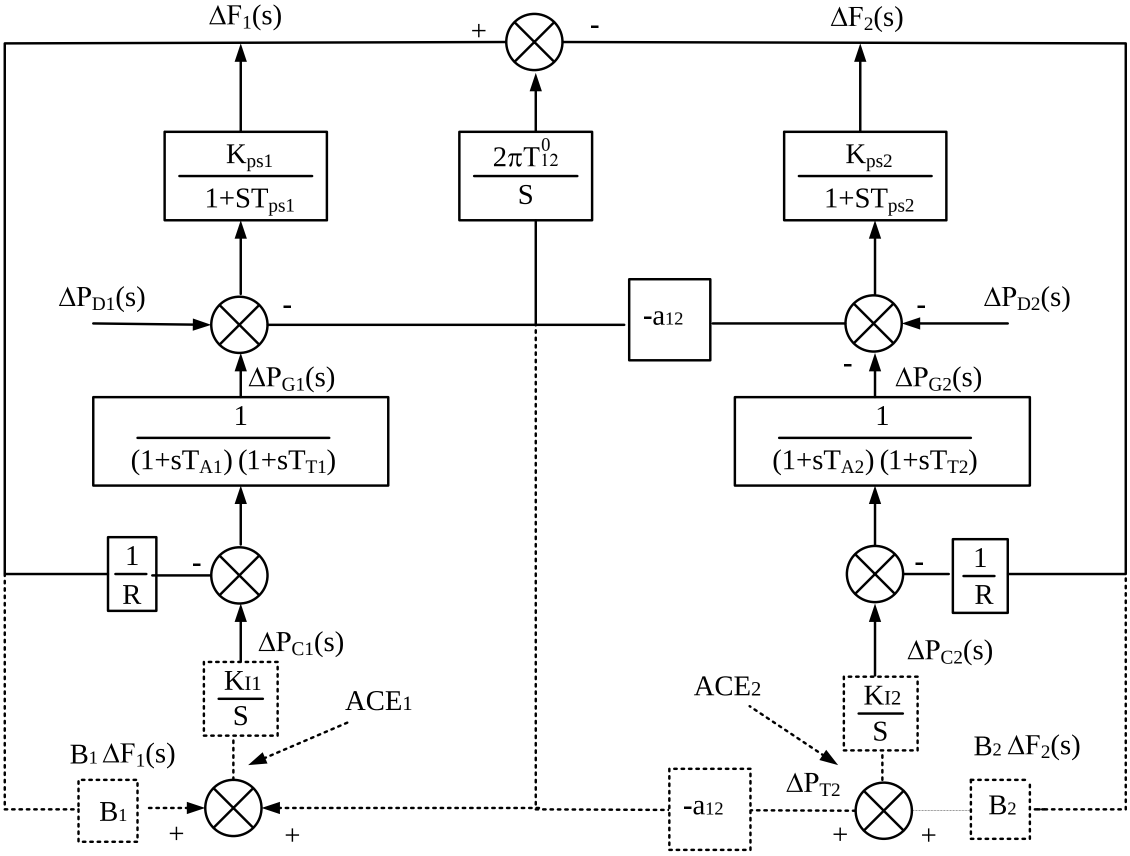

Figure 3.12 Two area system with integral control

3.13 Load Frequency Control with Generation Rate Constraints (GRCs):

Load frequency control problem discussed so far does not consider the effect of the restrictions on the rate of change of power generation. In power systems having steam plants, power generation can change only at a specified maximum rate. The generation rate (from safety considerations of the equipment) for reheat units is quite low. Most of the reheat units have a generation rate around 3%/min. some have a generation rate between 5 to 10%/min. if these constraints are not considered, system is likely to chase large momentary constraints are not considered, system is likely to chase large momentary disturbances. This results in under wear and tear of the controller. Several methods have been proposed to consider the effect of GRC is considered, the system dynamic model becomes non-linear and linear control techniques cannot be applied for the optimization of the controller setting.

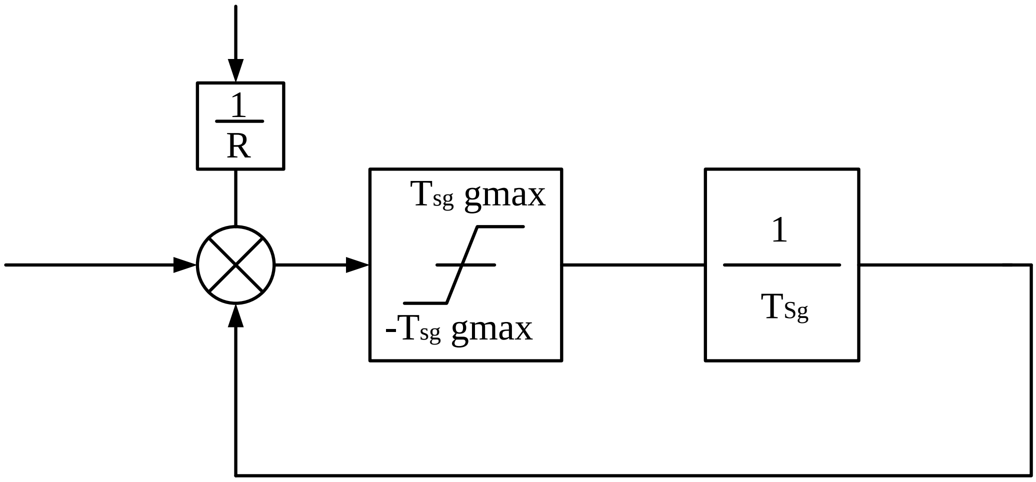

Figure 3.13 Governors with generation rate constraint

If the generation rates denoted by P_{Gi} are included in the state vector, the system order will be altered. Instead of augmenting them, while solving the state equations, it may be verified at each step if GRCs are violated. Another way of considering GRCs for both areas is to add limiters to the governors as shown in figure 3.13, i.e. the maximum rate of valve opening or closing speed is restricted by the limiters. Here T_{sg} Gmax is power rate limit imposed by valve or gate control. In this model $|\Delta Y_E|$<Gmax the banded values imposed by the limiters are selected to restrict the generation rate by 10% per minute.

The GRC result in larger deviations in ACEs as the rate at which generation can change in the area is constrained by limits imposed. Therefore, the duration for which the power needs to be imported increased considerably as compared to the case where generation rate is not constrained. With GRCs, R should be selected with care so as to give the best dynamic response. In hydrothermal system, the generation rate in the hydro area normally remains below the safe limit and therefore GRCs for all the hydro plants can be ignored.

The GRC of thermal units can be modeled in either closed loop or open loop method. Here, the value of GRC for thermal units is considered as 3%/min,

$$|\Delta P_{th}| = 0.03\frac{\mathrm{pu}}{\mathrm{min}} = 0.0005\ (\mathrm{pu/sec})$$

Hence, The GRC for the units can be taken into account by adding two limiters bounded by ±0.0005 within the turbines in the closed loop2 to restrict the generation ramp rate for the thermal plants

3.14 Automatic voltage regulator design:

The generator excitation system maintains generator voltage and controls the reactive power flow. The generator excitation of older system may be provided through slip rings and brushes by mean of DC generator mounted on the same shaft as the rotor of the synchronous motor. As we have seen, a change in the real power demand affects essentially the frequency, whereas a change in the reactive power affects mainly the voltage magnitude. The interaction between voltage and frequency controls in generally weak enough to justify their analysis separately. The sources of reactive power are generators, capacitors, and reactors. The generator reactive powers are controlled by field excitation. other supplementary method of improving the voltage profile in the electric transmission are transformer load tap changers, switched capacitors, step voltage regulators and static vars control equipment. The primary means of generator reactive power control is the generator excitation control using automatic voltage regulator (AVR). The role of an AVR is to hold the terminal voltage magnitude of synchronous generator at the specified level. The schematic diagram of AVR is shown in figure 3.14 as increase in the reactive power load of the generator is accompanied by the drop in the terminal voltage magnitude. The voltage magnitude is sensed through the potential transformer on one phase. This voltage is rectified and compared to DC set point signal. The amplified error signal controls the exciter field and increases the exciter terminal voltage. Thus, the generator field current is increased, which result in an increase in Generated emf. The reactive power generation is increased to a new equilibrium, raising the terminal voltage to desired value.

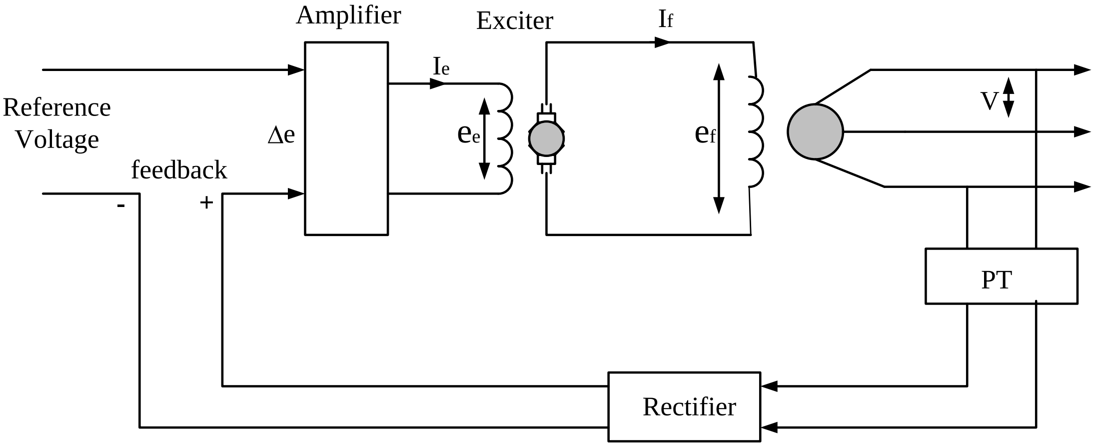

Figure 3.14 Excitation system

3.15 Amplifier Model:

The comparator continuously compares the reference voltage V_{ref} and actual output voltage V_t and generates a voltage error signal, which is fed to the amplifier. The amplifier can be magnetic, rotational or electronic type. Due to the delay in the response of amplifier, its transfer function$(T.F_A)$ is given by:

$$T.F_A = \frac{K_A}{1+ST_A} = \frac{\Delta V_R(s)}{\Delta V_t(s)} \tag{3.111}$$

Where ΔV_R is the amplifier output and ΔV_t is the error voltage and is given by:

$$\Delta V_t = V_{ref} - V_t \tag{3.112}$$

Typical value of amplifier gain (KA) is in the range of 10 to 400.the amplifier time constant is very small, in the range of 0.02 to 0.1 sec, and often is neglected. The output of the amplifier is fed to the exciter.

3.16 Exciter Model:

There is variety of different excitation types. However, modern excitation system uses ac power source through solid state rectifier such as SCR. The output voltage of the exciter is non-linear function of the field voltage because saturation affects the magnetic circuit, thus there is no simple relationship between the terminal voltage and the field voltage of the exciter. Many models with various degree of sophistication have been developed and available on IEEE recommendation publications. A reasonable model of reasonable exciter is a lineralized model which takes into account the major time constant and ignores the saturation and other nonlinearities. In the simplest form, the transfer function of the modern exciter may be represented by the single time constant T_E and a gain K_E.

$$T.F_A = \frac{K_E}{1+ST_E} = \frac{\Delta V_F(s)}{\Delta\, V_R(s)} \tag{3.113}$$

Where ΔV_F is the field voltage of synchronous generator, the time constant of the modern exciter are very small.

3.17 Generator Field Model:

The synchronous machine generated emf is a function of magnetization curve, and its terminal voltage is dependent on generator load. K_G May vary between 0.7 to 1 and T_G between 1 to 2 seconds from full load to no load. The output of the exciter is fed to the generator field winding whose transfer function $(T.F_G)$ is given by

$$T.F_G = \frac{K_G}{1+ST_G} = \frac{\Delta V_t(s)}{\Delta\, V_F(s)} \tag{3.114}$$

Where ΔE is the change in generated emf.

3.18 Sensor Model:

Sensor sensed voltage through a potential transformer the TR time constant of sensor is assuming a range from 0.01 to 0.06.

$$T.F_S = \frac{K_R}{1+ST_R} = \frac{\Delta V_S(s)}{\Delta\, V_t(s)} \tag{3.115}$$

3.19 Complete AVR Block diagram:

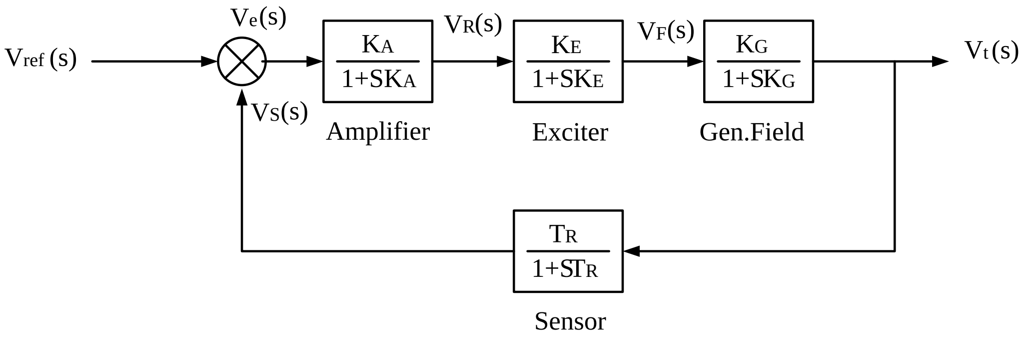

Figure 3.15 Automatic voltage regulator models.

From the above block diagram we can write open loop transfer function which is given as:

$$K_G(s)H(s) = \frac{K_A K_E K_G K_R}{(1+ST_A)(1+ST_E)(1+ST_G)(1+ST_R)} \tag{3.116}$$

And the closed loop transfer function relating the generator terminal voltage V_t (s) to the reference voltage V_{ref} (s) is.

$$\frac{V_t(s)}{V_{ref}(s)} = \frac{K_A K_E K_G K_R(1+ST_R)}{(1+ST_A)(1+ST_E)(1+ST_G)(1+ST_R)+K_A K_E K_G K_R} \tag{3.117}$$

3.20 Proportional Integral Derivative (PID) Controller:

One of the most common controllers available is Proportional integral derivative (PID) controller The PID controller is used to improve the dynamic response as well as to reduce or eliminate the steady-state error. The derivative controller adds a finite zero to the open-loop plant transfer function and improves the transient response. The integral controller adds a pole at origin and increases the system type by one and reduces the steady state error due to a step function to zero. The PID controller transfer function is

$$G_e(s) = K_P + \frac{K_I}{S} + SK_D \tag{3.118}$$

PID controller tuning can be achieved in three steps using MATLAB *SIMULINK*. In Step 1 we select K_P that results in a highly oscillatory stable response with $K_D = K_I = 0$. In Step 2 we fix the parameter K_D, for K_P selected in Step 1, taking care of transient performance. In Step 3 we fix the parameter K_I, for K_P and K_D selected in Steps 1 and 2, taking care of steady state performance. This completes the tuning of PID controller. Following this tuning method the resulting parameters of PID controller are given in Tables 4.2 and 4.3.

The block diagram of AVR with PID is shown in figure 4.3

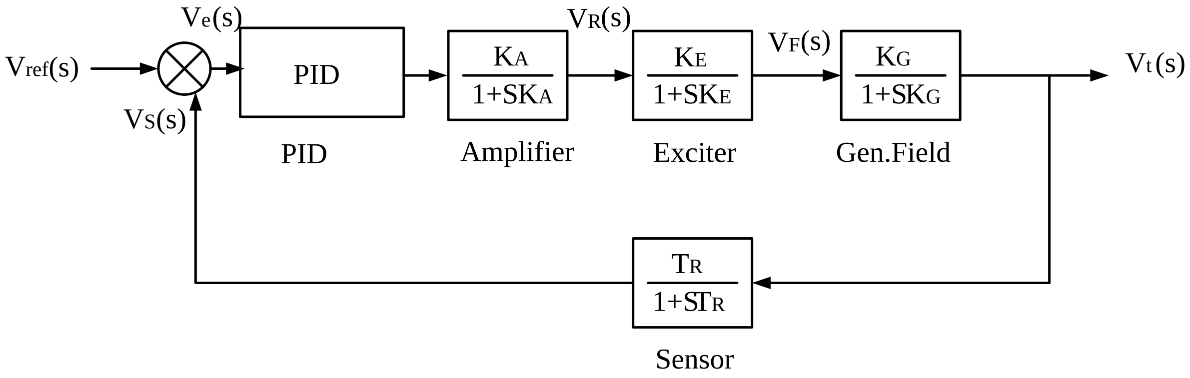

Figure 3.16 Automatic voltage regulator models with PID controller.

CHAPTER FOUR

SIMULATION AND RESULTS

4.1 Introduction

The design and simulation of the system is analyzing using MATLAB *SIMULINK* environment. And it's use it to testing the individual blocks of automatic voltage control and automatic voltage regulator system of single and two areas with generation rate constraint, and used area control error to improve the dynamic response and to reduce the steady state error to zero.

In this study there are many assumption, the model of thermal generation plant, also the system with two control areas that had one tie line between them and the basic block diagram for a single and two areas AGC, the system is in a normal operating mode and the loss of a generating unit will not be considered.

4.2 Simulation data:

Table 4.1 Parameter of AGC model

Quantity	**Area–I**	**Area–II**
Governor Speed regulation	R1=0.051	R2=0.062
Frequency bias factors	D1= 0.62	D2= 0.91
Base power	1000MVA	1000MVA
Governor time constant	t_{g1}=0.2 sec	t_{g2}=0.3 sec
Turbine time constant	t_{T1}=0.5 sec	t_{T2}=0.6 sec
Constant	K=1/2π	K=1/2π
Inertia constant	H_1=5	H_2=4
Nominal frequency	F_1=60Hz	F_2=60Hz
Load change	ΔPL_1=180MW	ΔPL_2=0MW

Table 4.2 parameter of PID Controller

Device	**Gain**
PID Controller	KP=1
	K1=0.25
	KD=0.28

Table 4.3 Parameter of AVR model

Devices	**Gain**	**Time constant**
Amplifier	10	0.1
Exciter	1	0.4
Generator	1	1
Sensor	1	0.05

4.3 Load Frequency Control of Single Area:

4.3.1First order Approximate:

Figure 4.1 represented the block diagram of first order approximate of load frequency control of an isolated area.

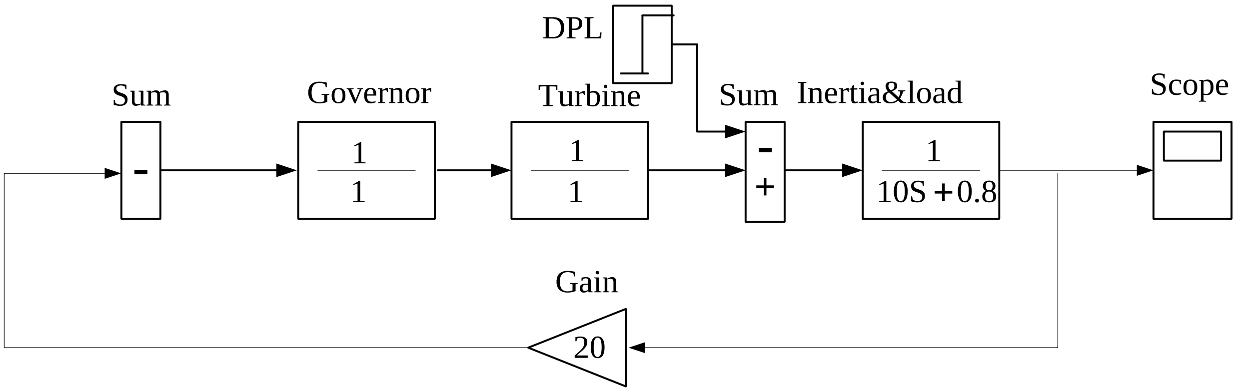

Figure 4.1 First orders approximate of LFC of an isolated area.

In this model the time constant of governor and turbine is negligible, and speed changer has fixed ($\Delta P_C = 0$) for uncontrolled case, and free governor operation, the result of LFC in figure 4.2

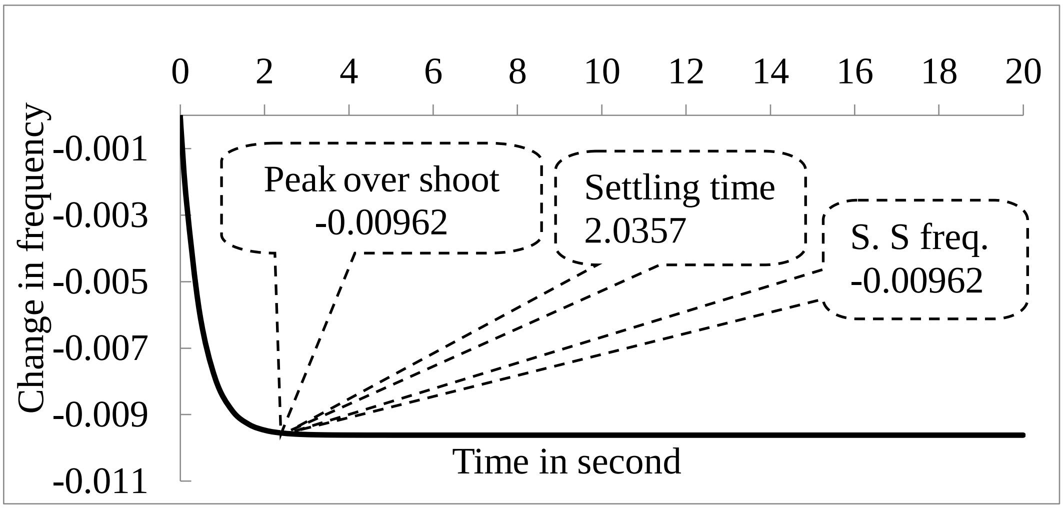

Figure 4.2 first order approximation.

4.3.2 Load Frequency Control Speed Governor System:

We use speed governor for exact response characteristic of uncontrolled case the model and curve of change in frequency vs. time in figures below.

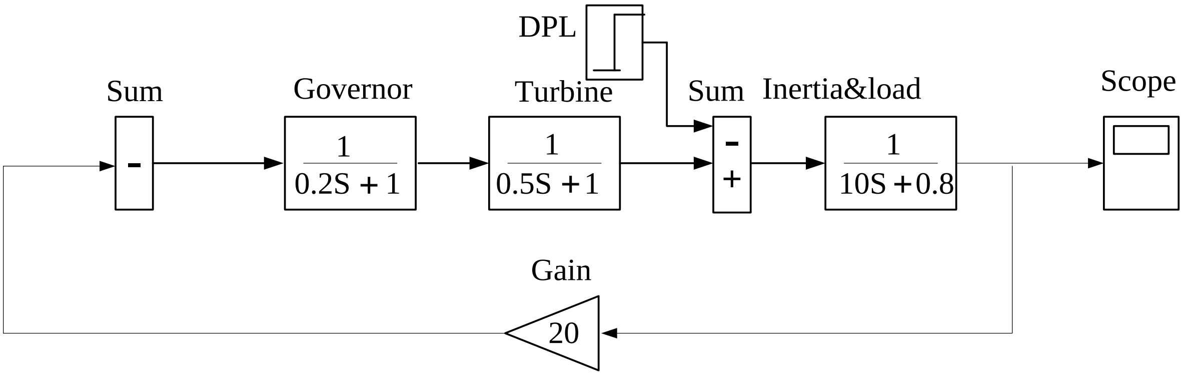

Figure 4.3 Block diagram of single area with a speed governor system.

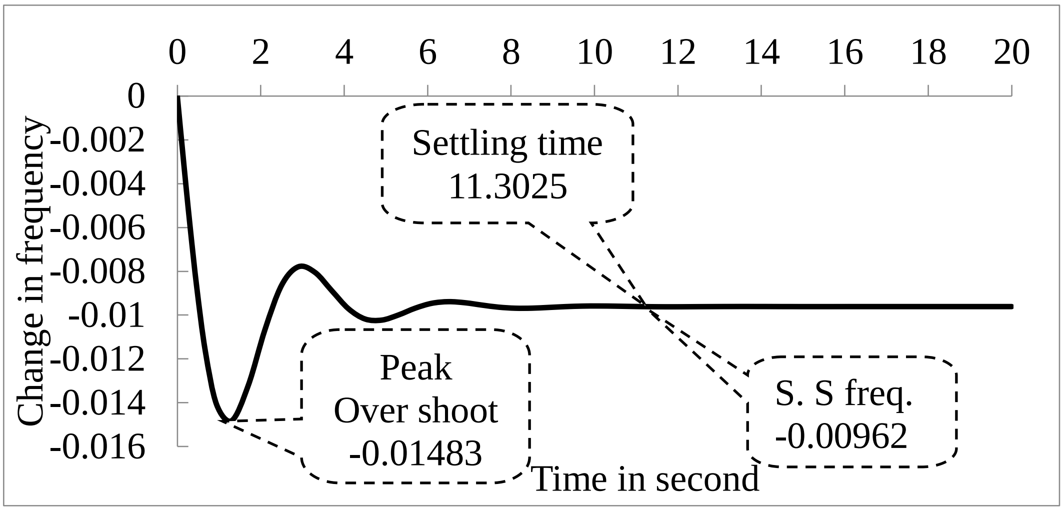

Figure 4.4 Response of the change in frequency

The models discussed in the previous sections are simulated in *SIMULINK*. As seen from the figure 4.4, the change in load brings about the change in speed which causes the variation in the frequency .The unsettled oscillations can be seen from the graph. From the above plot students will be able to understand that the frequency drift will settle down to a finite value and that the new operating frequency will be lower than the nominal value.

The steady state frequency error will not be reduce to zero from figure 4.5 can be achieve that by using area control error.

4.3.3 Load Frequency Control with Area Control Error:

The area control error is the change in area frequency, which when used in an integral-control loop, forces the steady-state frequency error to zero.

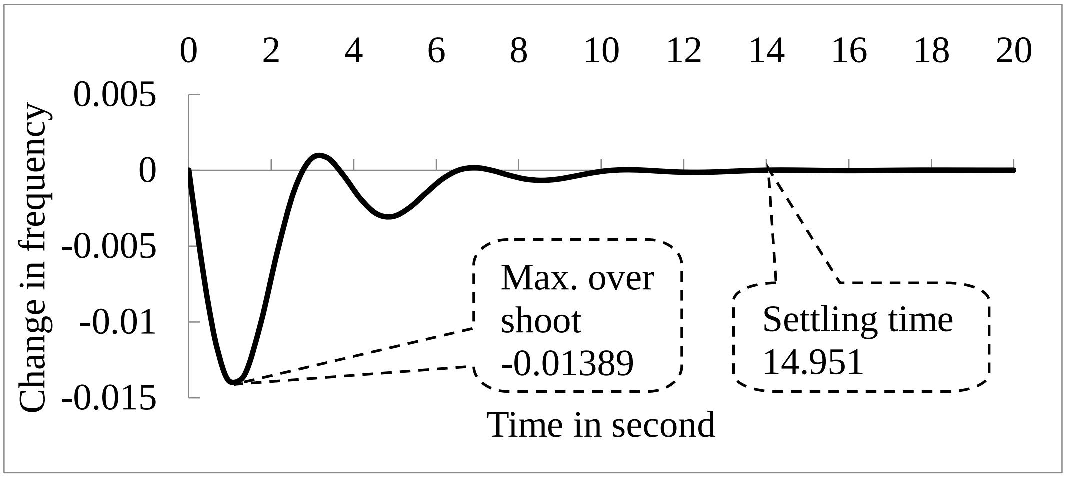

Figure 4.5 Response of load frequency control with area control error.

Now we want to apparent the different between three cases in figure 4.6 and table 4.4, the best response when using the area control error because the steady state error reduced to zero.

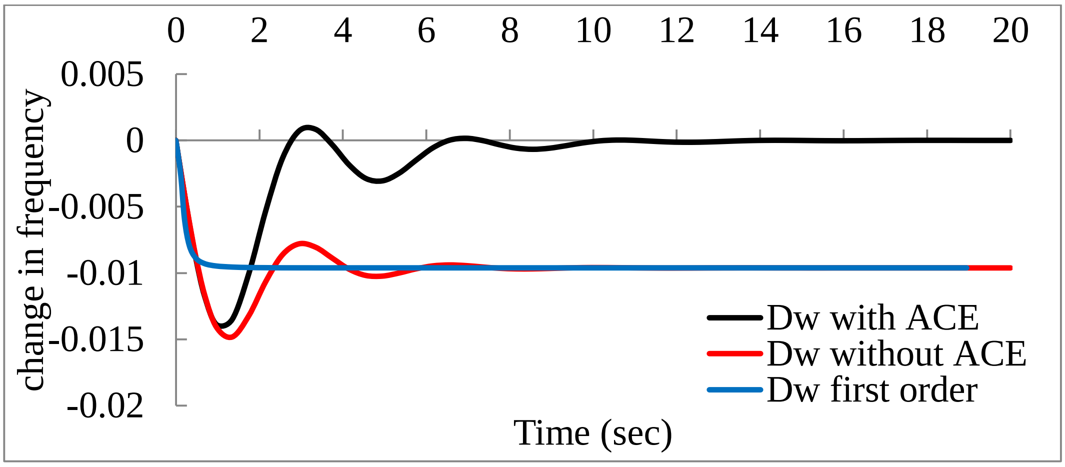

Figure 4.6 Comparisons between three cases.

Table 4.4 Represent summary of figure 4.8

	Peak over shoot	S.S.Freq.	Settling time
First order	-0.00962	-0.00962	02.0235
Without ACE	-0.01483	-0.00962	11.3025
With ACE	-0.01389	0.0	14.951

4.4 Two areas load frequency control:

Figure 4.7 represented the simulation of block diagram of two areas

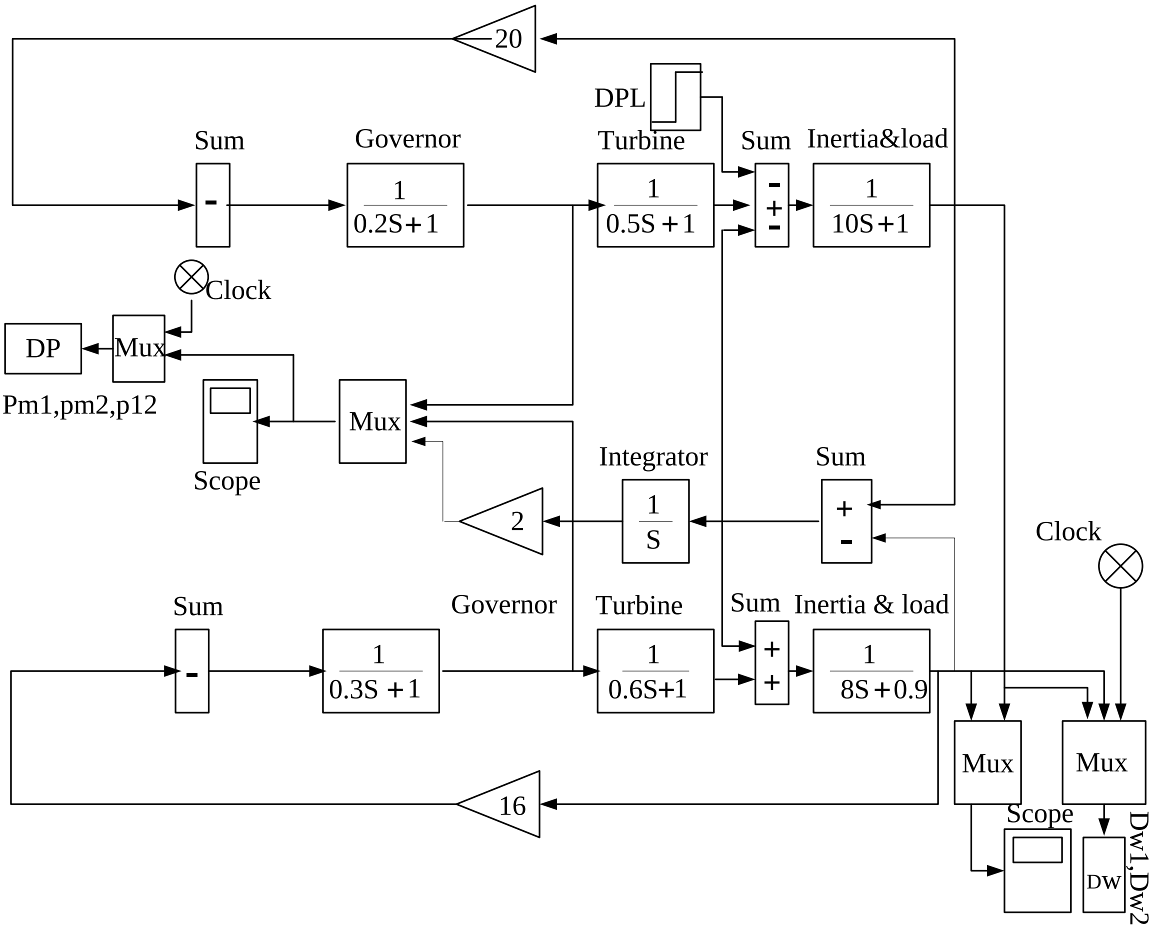

Figure 4.7 Model of two areas load frequency control.

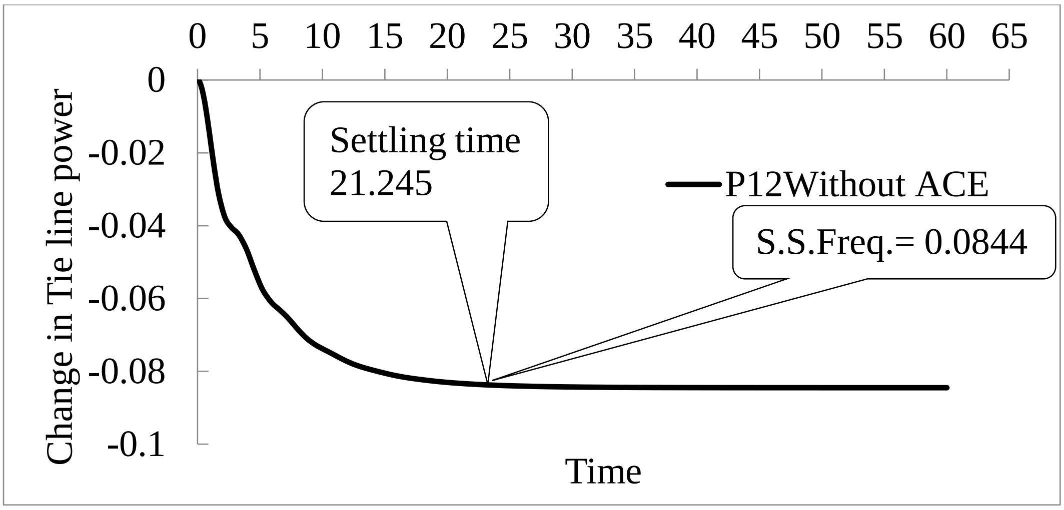

Figure 4.8 Change in tie line power.

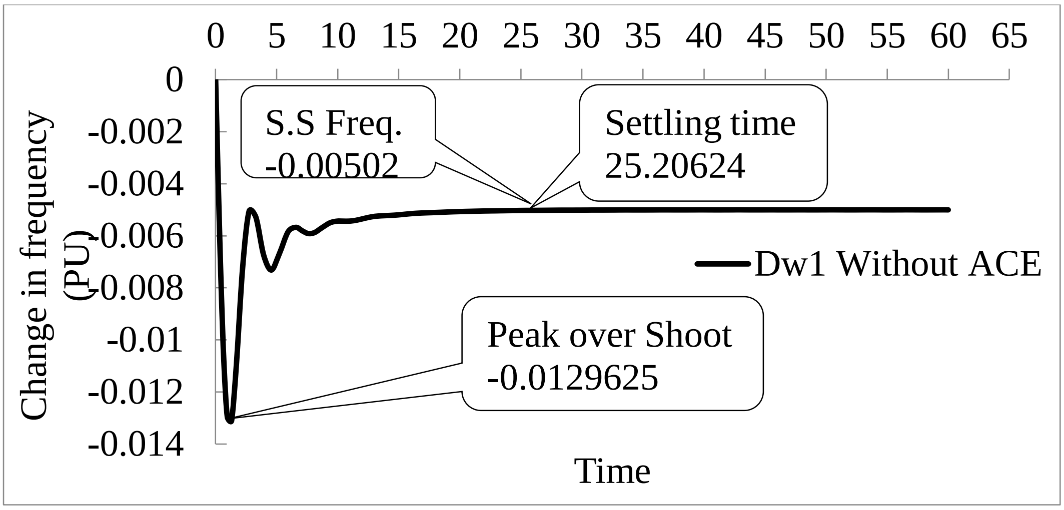

Figure 4.9 Change in frequency of area one without ACE .

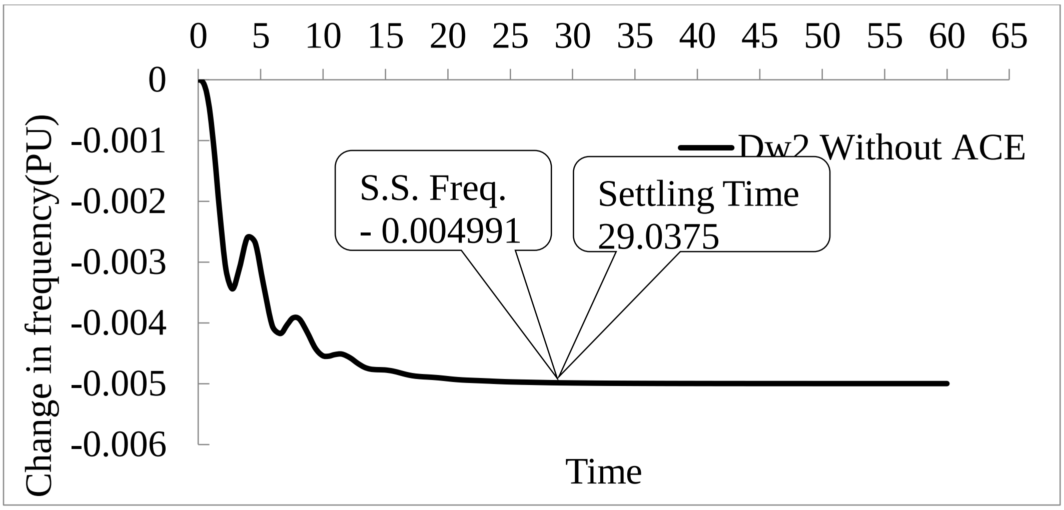

Figure 4.10 Change in frequency of area two without ACE.

Figure 4.10 shows the schematic of LFC of 2-area system without the secondary loop while figure 4.8,9,10 shows the simulation results. As the two systems are interconnected, the frequency drifts of the two will settle down to equal value after some oscillations. The mechanical inputs of the two vary to reduce the mismatch power between the electrical load in area 1 and the mechanical inputs. It can also be observed that area 2 will generate excess power to share the load change in area 1. It can observe the tie-line power flow following a load disturbance in area 1. Compared to the same result with system, appreciated the stability improvement with interconnection.

5.5 Two areas load frequency control with area control error:

The tie line deviation reflects the contribution of regulation characteristic of one area to another. The basic objective of supplementary control is to restore balance between each area load generation. This objective is met when the control action maintains frequency at the scheduled value. The supplementary control should ideally correct only for changes in that area. In other words, if there is a load change in Area1, there should be supplementary control only in Area1 and not in Area 2. For this purpose the area control error (ACE) is used.

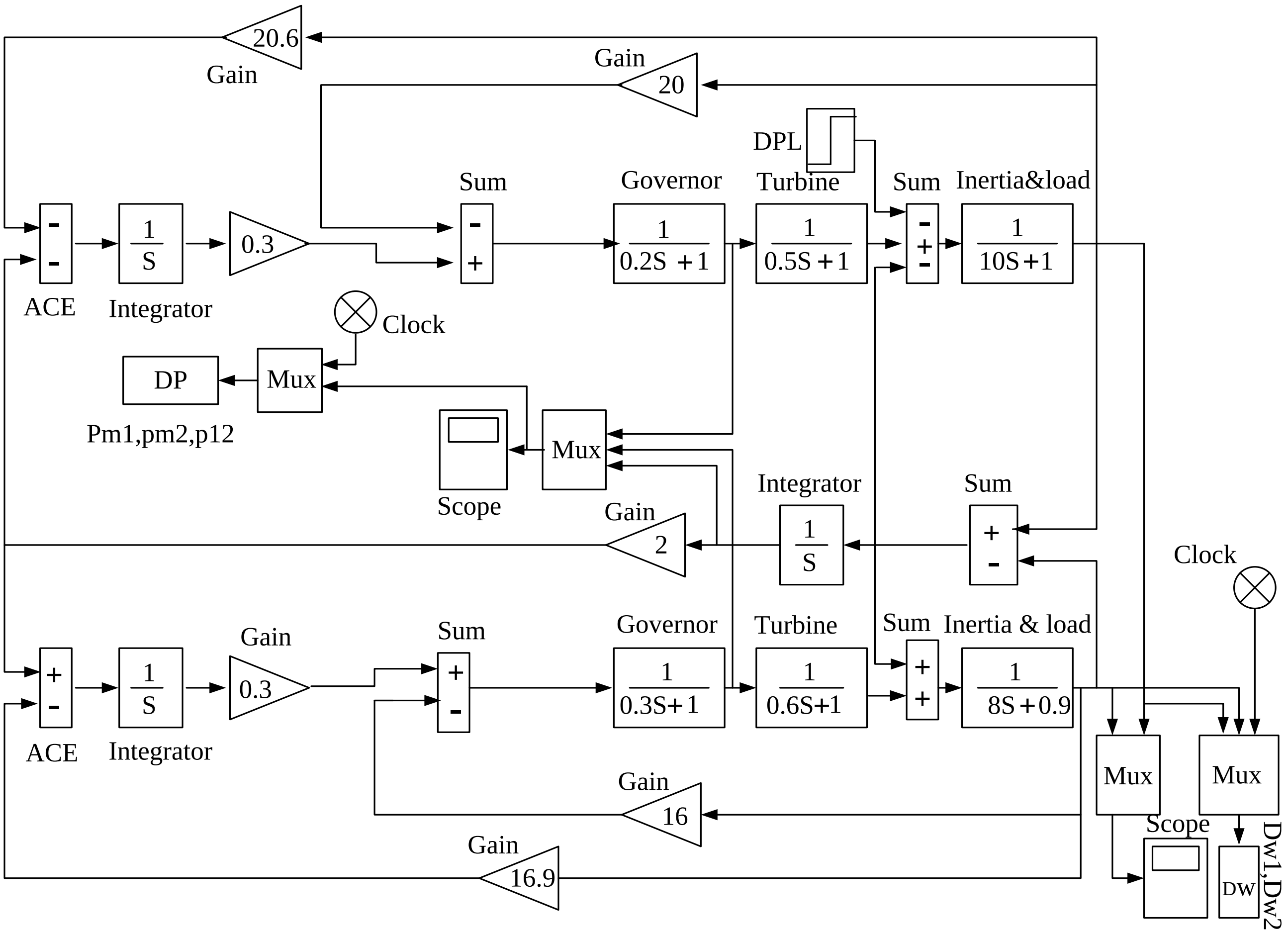

Figure 4.11 Model of two areas loads frequency control with area control error.

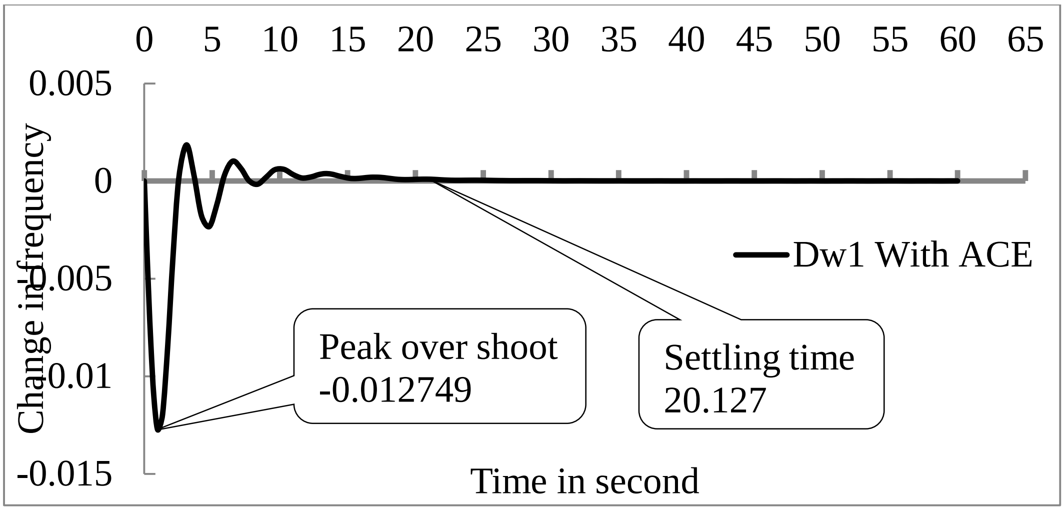

Figure 4.12 Change in frequency of area one with ACE.

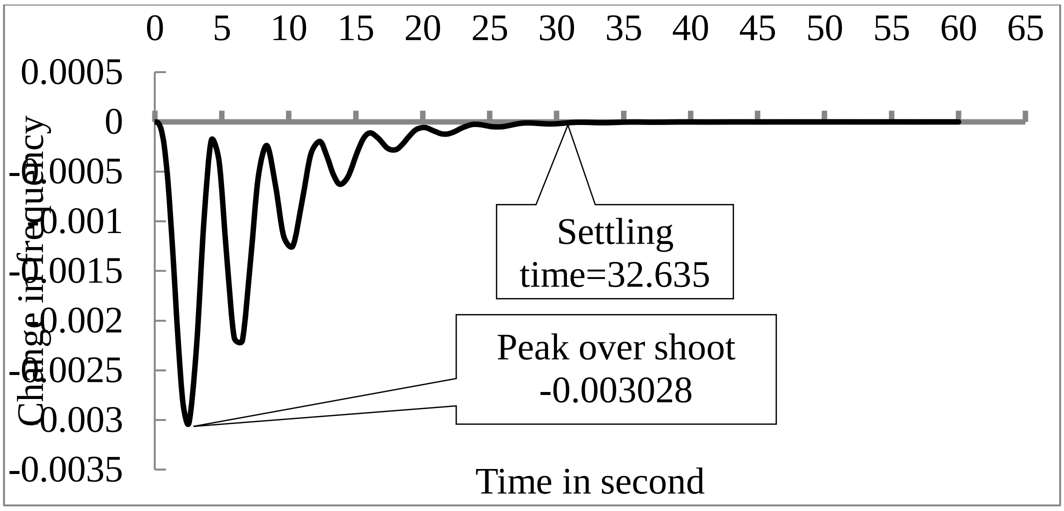

Figure 4.13 Change in frequency of area two with ACE.

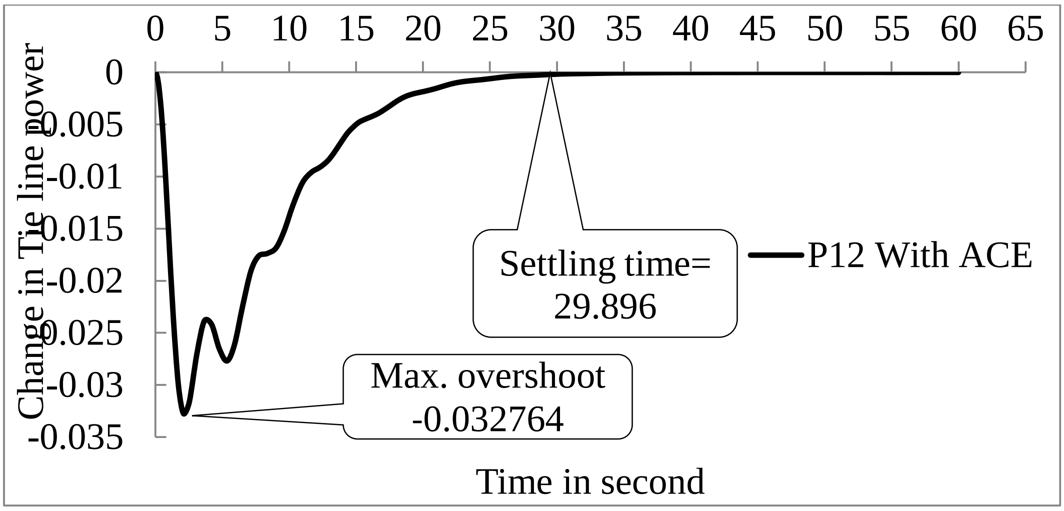

Figure 4.14 Tie line of two areas with ACE.

As seen from the figures the secondary loop causes the return of frequency drifts to zero.

From the above simulation plots it can be observed that the system experiences frequency drift following a load disturbance and it is mainly due to the mismatch between the electrical load and the mechanical input to the turbine. The system oscillation is serious in single area system compared to two area system because all the load change in load is to be met by only one area. Also, using the secondary loop in both the single area as well as the two area system the change in frequency is brought to zero.

4.6 Two areas load frequency control with generation rate constraint:

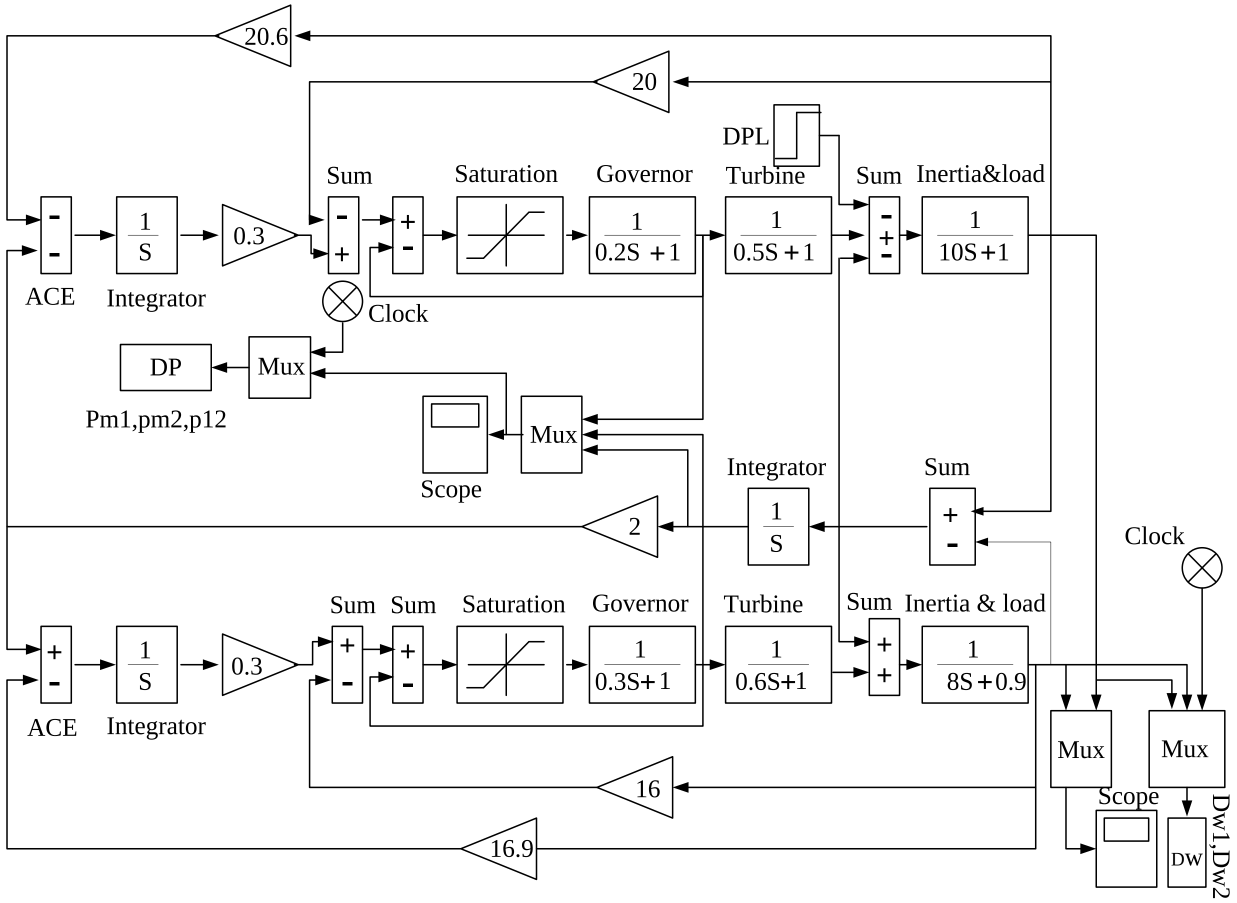

Figure 4.15 Models of two areas with generation rate constraint.

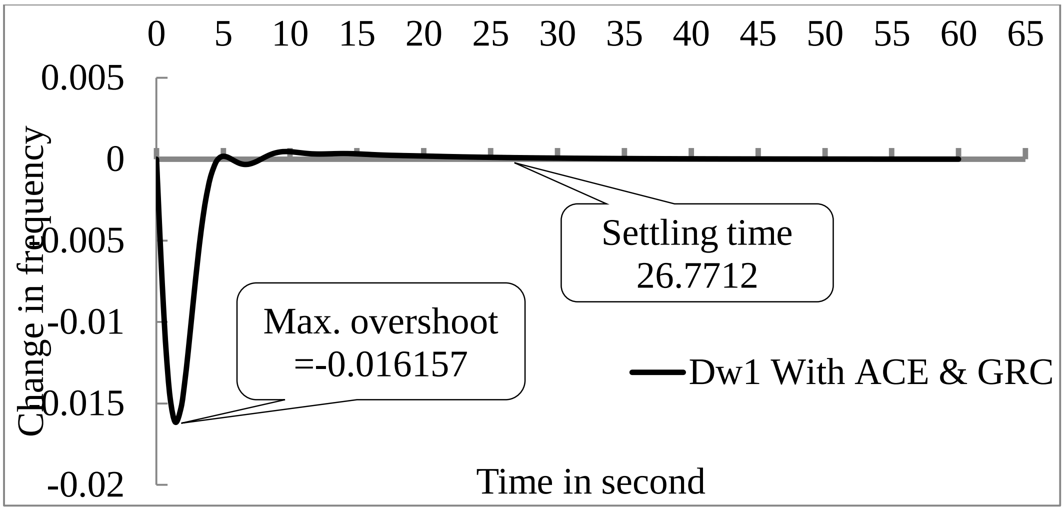

Figure 4.16 Change in frequency of area one with ACE and GRC.

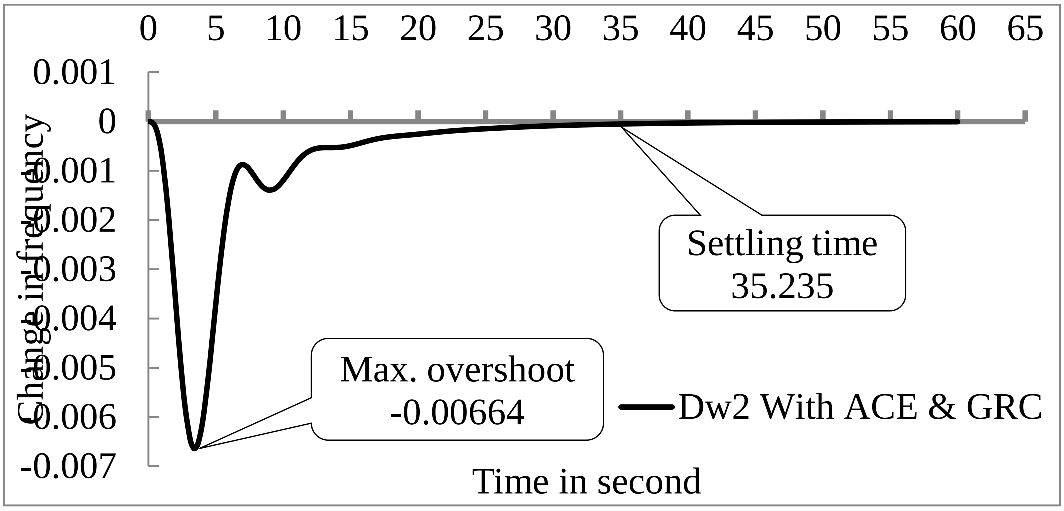

Figure 4.17 Change in frequency of two areas with ACE and GRC.

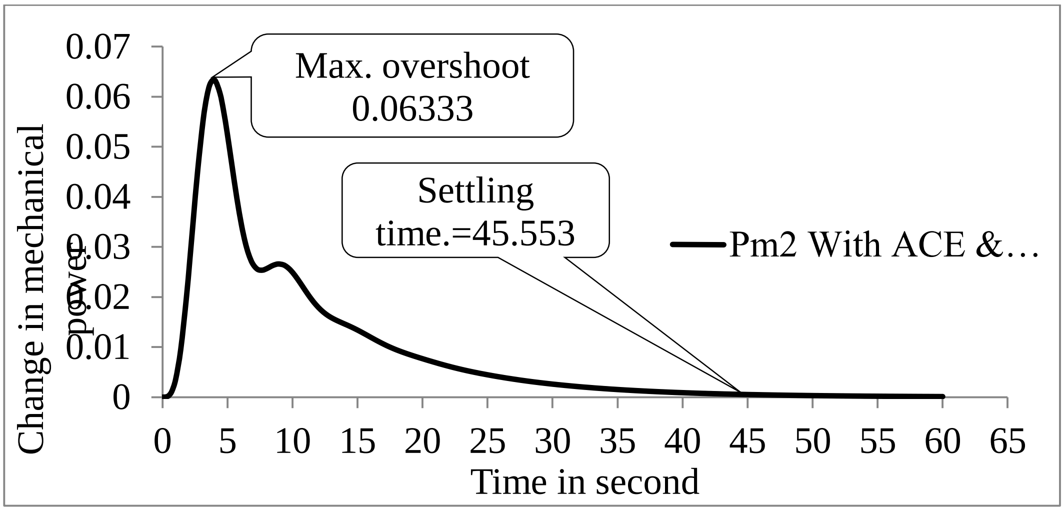

Figure 4.18 Change in mechanical power of area two with ACE and GRC.

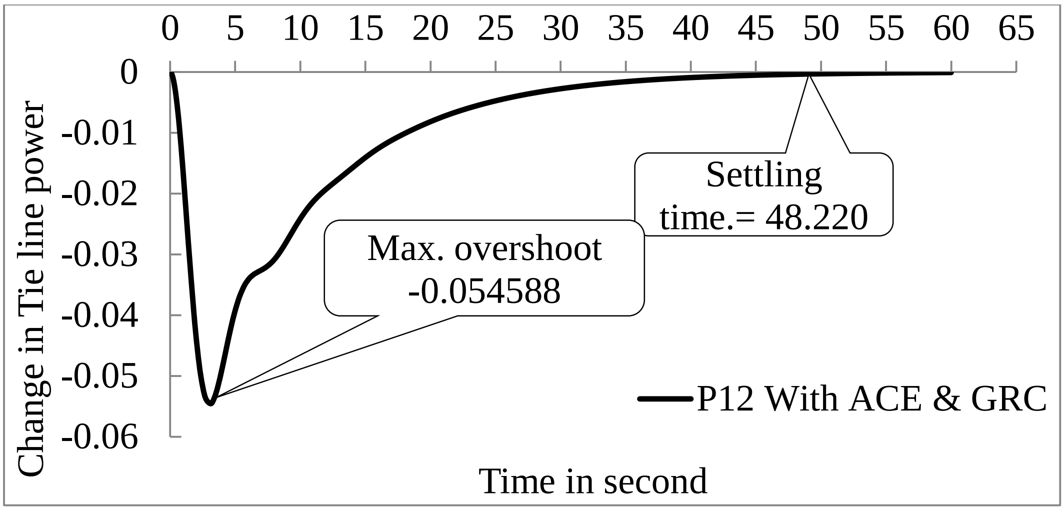

Figure 4.19 Change in tie line power of two areas with ACE and GRC.

4.7 Comparison between three cases:

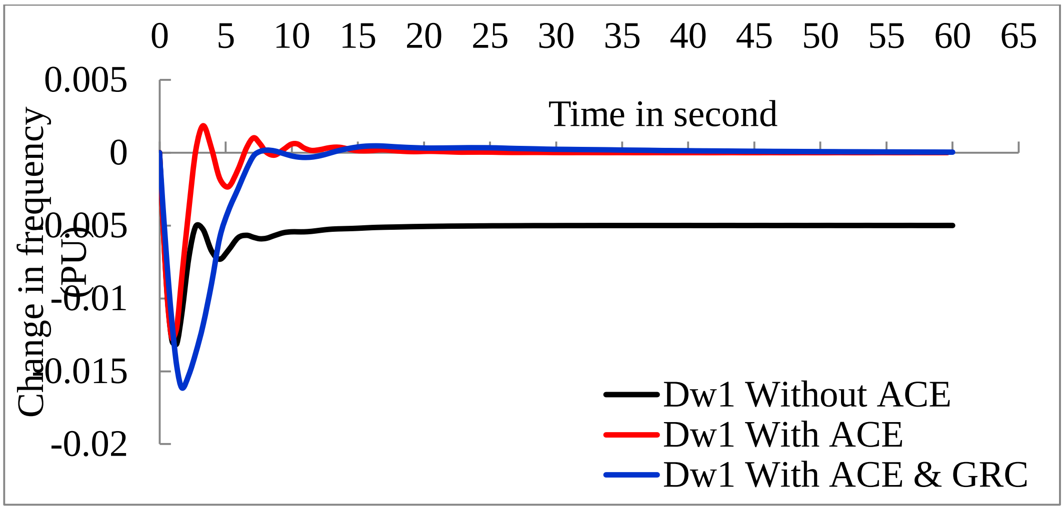

Figure 4.20 Comparisons between Dw1 with and without ACE &GRC.

Table 4.5 Represents the summary of figure 4.20

	Peak over shoot	S.S.Freq.	Settling time
Without ACE	-0.01296	-0.00502	25.20624
With ACE	-0.012749	0.0	20.1273
With GRC	-0.016157	0.0	26.7712

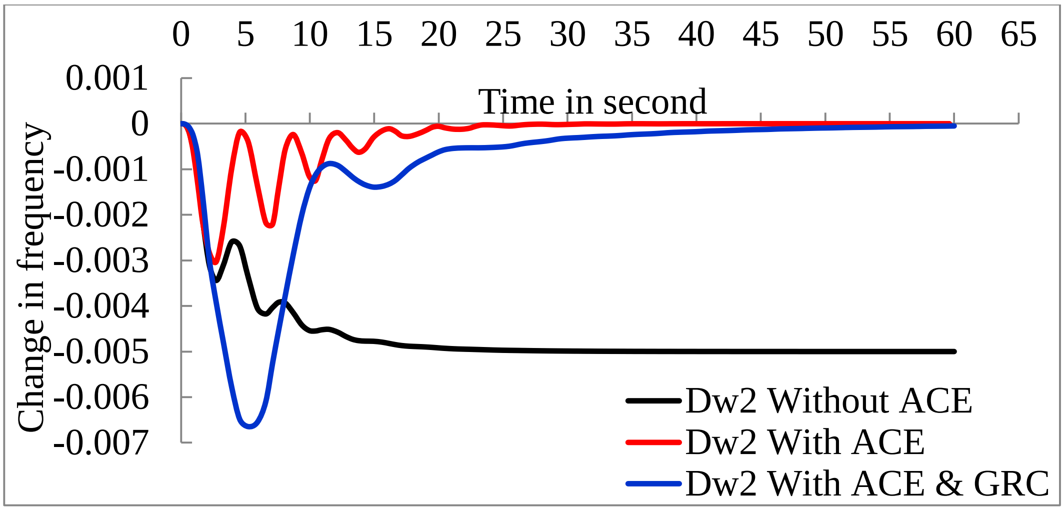

Figure 4.21 Comparisons between Dw2 with and without ACE &GRC.

Table 4.6 Represent the summary of figure 4.21

	Peak over shoot	S.S.Freq.	Settling time
Without ACE	-0.004991	-0.004991	29.037
With ACE	-0.003028	0.0	32.635
With GRC	-0.00664	0.0	35.235

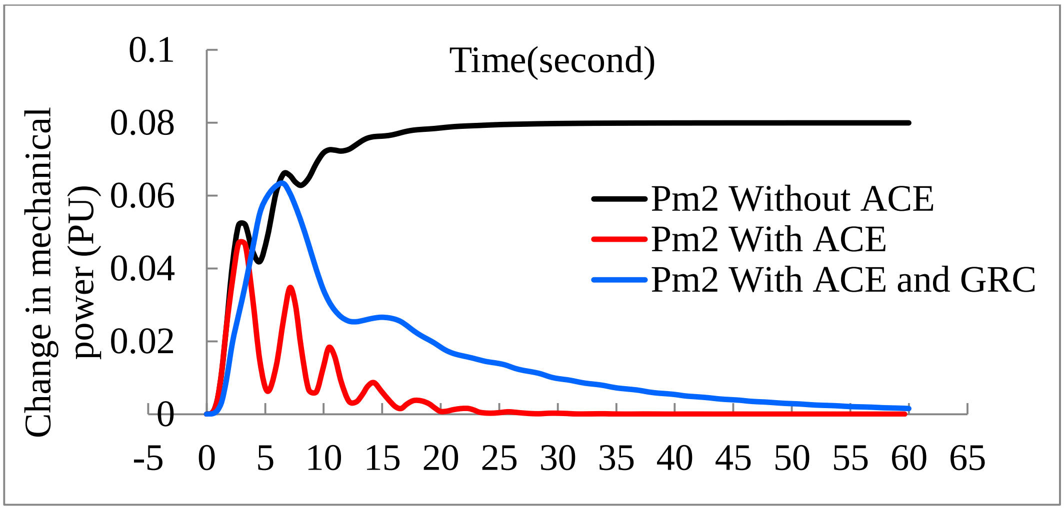

Figure 4.22 Comparisons between Pm2 with and without ACE &GRC.

Table 4.7 Represents the summary of figure 4.22

	Peak over shoot	S.S.Freq.	Settling time
Without ACE	0.07996	0.07996	25.206
With ACE	0.04721	0.0	32.452
With GRC	0.06333	0.0	45.553

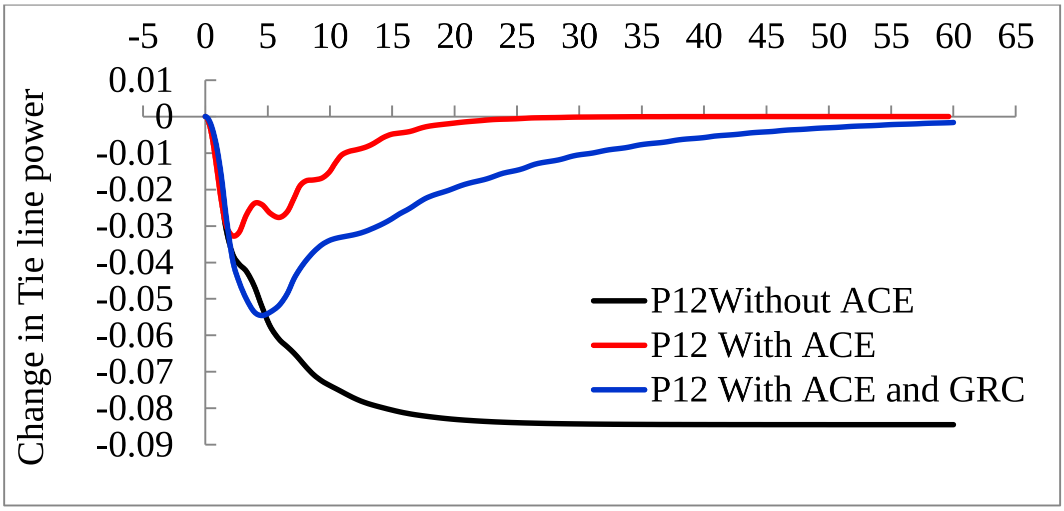

Figure 4.23 Comparisons between P12 with and without ACE &GRC.

Table 4.8 Represents the summary of figure 4.23

	Peak over shoot	S.S.Freq.	Settling time
Without ACE	-0.0844	-0.0844	21.245
With ACE	-0.0327	0.0	29.896
With GRC	-0.0546	0.0	48.220

Automatic Generation Control was implemented in system under studying in the deregulated environment. Effect of GRC is clearly distinct with large oscillations the system overshoots increase and more settling time.

The main reason to consider GRC is that the rapid power increase would draw out excessive steam from the boiler system to cause steam condensation due to adiabatic expansion. Since the temperature and pressure in the HP turbine are normally very high with some margin, it is expected that the steam condensation would not occur with about 20% steam flow change unless the boiler steam pressure itself does not drop below a certain level. Thus it is possible to increase generation power up to about 1.2 pu of normal power during the first tens of seconds. After the generation power has reached this marginal upper bound, the power increase of the turbine should be restricted by the GRC [9,10]. GRC affecting large turbogenerator is generally bounded by 0.1/min. As the constraint of generator and that of control effort calculated in LFC are in direct proportions, GRC will be transformed into system control constraints.

4.8 Automatic voltage regulators:

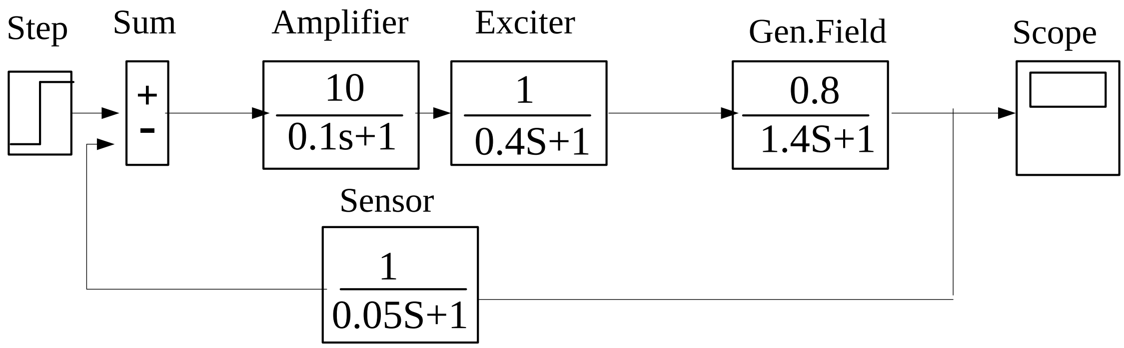

Figure 4.24 Model of automatic voltage regulators without PID controller.

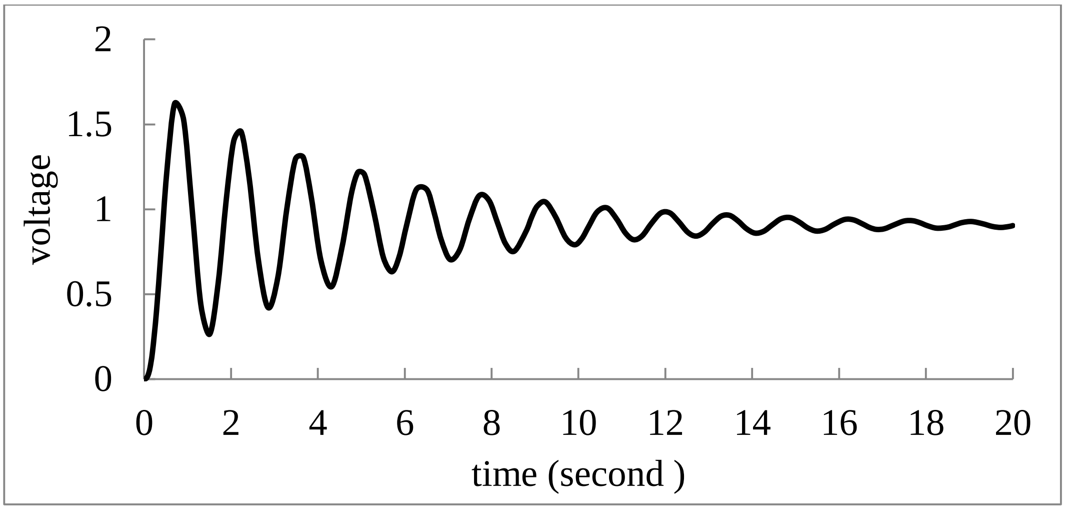

Figure 4.25 Terminal voltage without PID controller.

Since it is found that there are large number of oscillation occurs.

4.8.1 AVR with PID Controller:

Figure 4.26 represent the simulation block diagram of automatic voltage regulator with PID controller

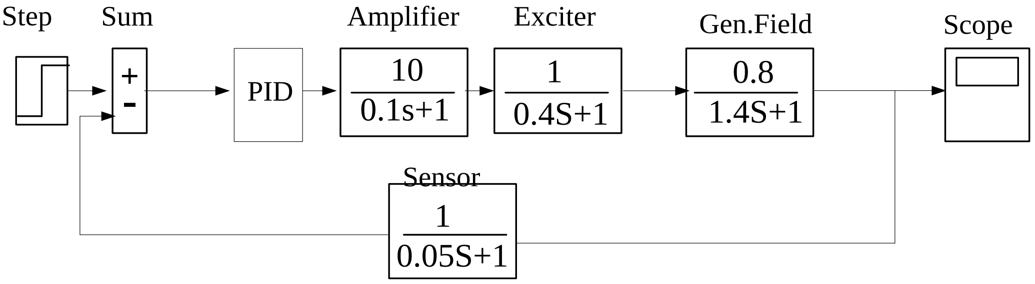

Figure 4.26 Model of automatic voltage regulators with PID controller

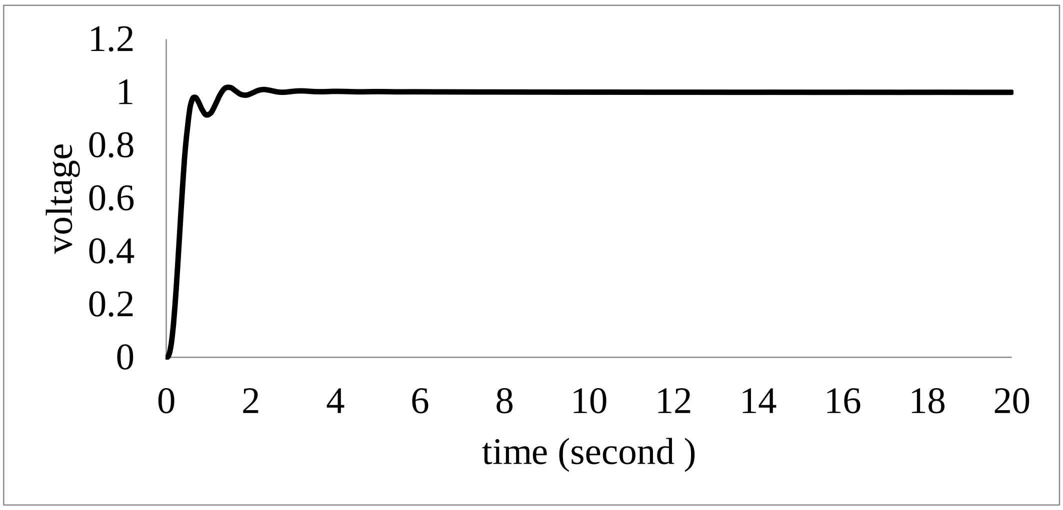

Figure 4.27 Terminal voltage with PID controller

From figure above improve the dynamic response and to reduce the steady state error and number of oscillation is less.

4.9 Coupling between automatic generation control and automatic voltage regulator of single area:

The combined model consisting of AVR loop and ALFC loop for single area power system is shown in Figure 4.28.

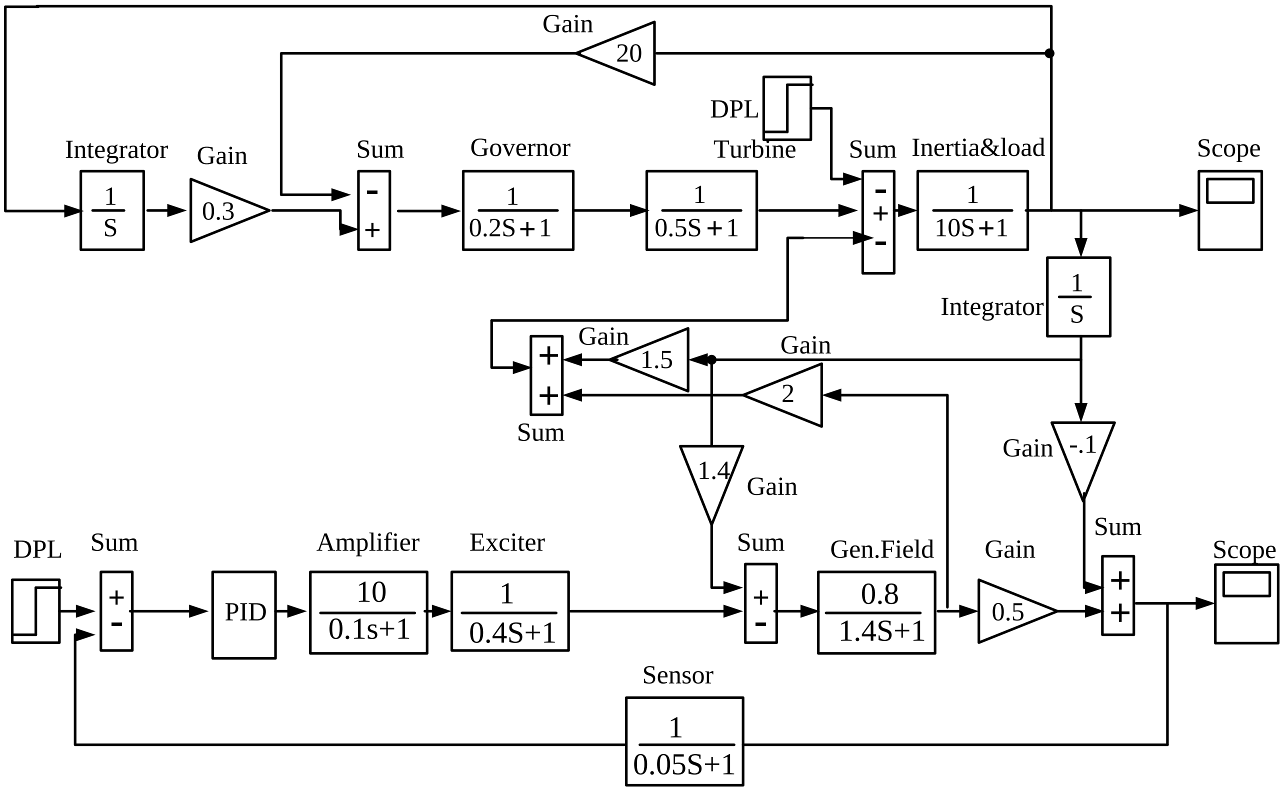

Figure 4.28 Modeling of AGC and AVR of single area.

The two major loops that are AVR loop and ALFC loop has been studied for single area power system. The frequency of the system is dependent on real power output and is taken care of by ALFC. Terminal voltage of the system is dependent on the reactive power of the system and is taken care of by AVR loop. The cross coupling effects between the two loops are studied that are associated with low-frequency oscillations.

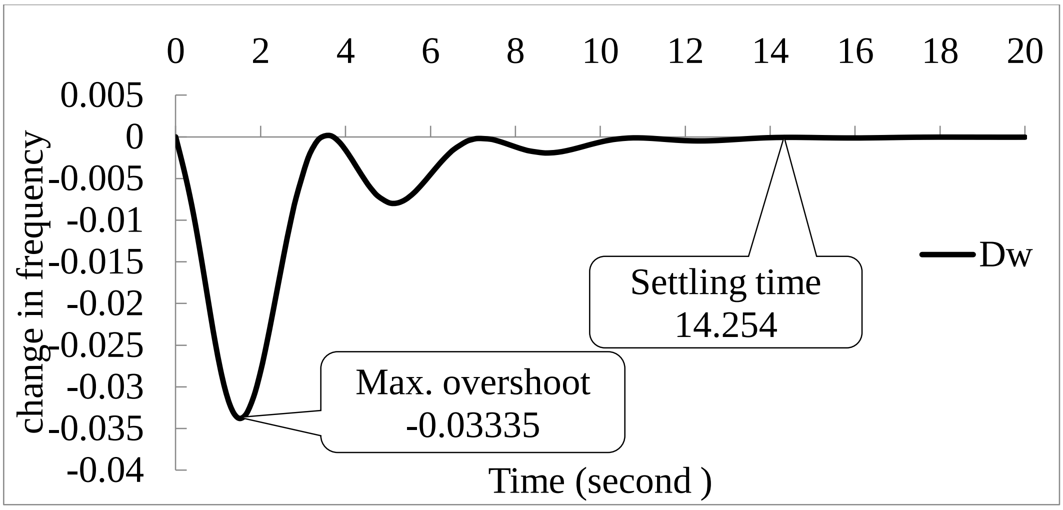

Figure 4.29 Change in frequency of single area AGC and AVR.

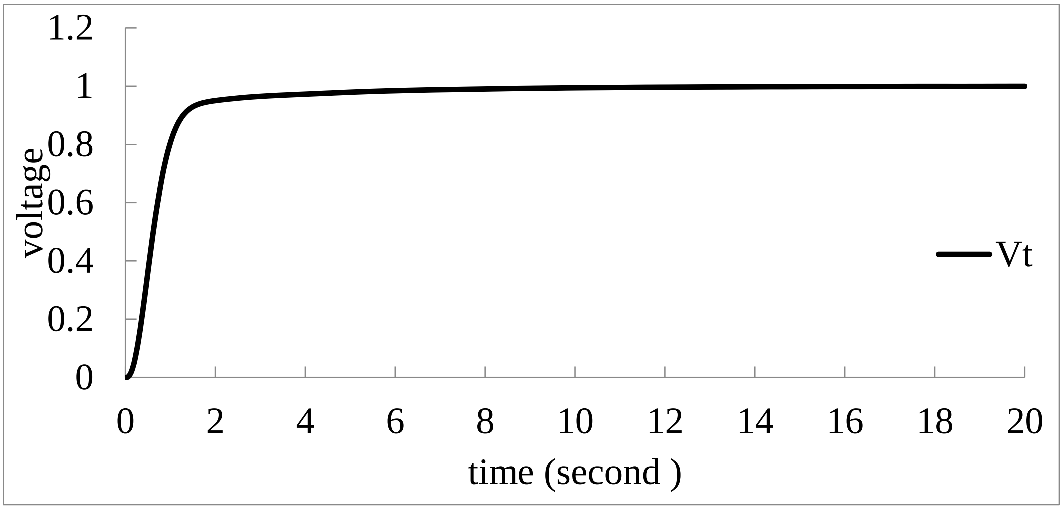

Figure 4.30 Terminal voltage of single area AGC and AVR.

Figures 4.29, 30 shows the deviations in frequency and deviations in terminal voltage after Applying AVR system the AVR loop is able to maintain a regulated terminal voltage under changing load conditions which makes the power system robust. Further, the dynamic responses become better in terms of peak deviations and settling time.

4.10 Coupling between automatic generation control and automatic voltage regulator of two areas:

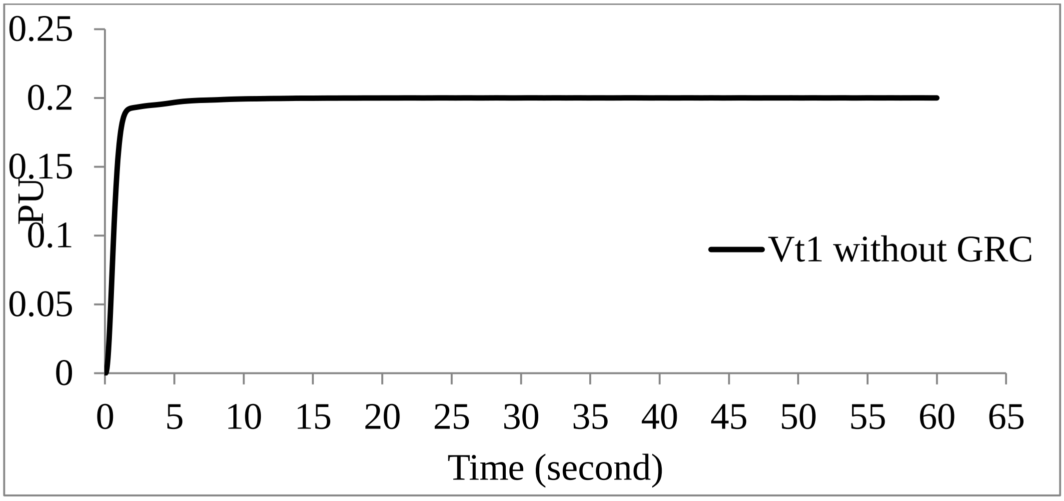

Figure 4.31 Terminal voltage of area one without AGC and AVR.

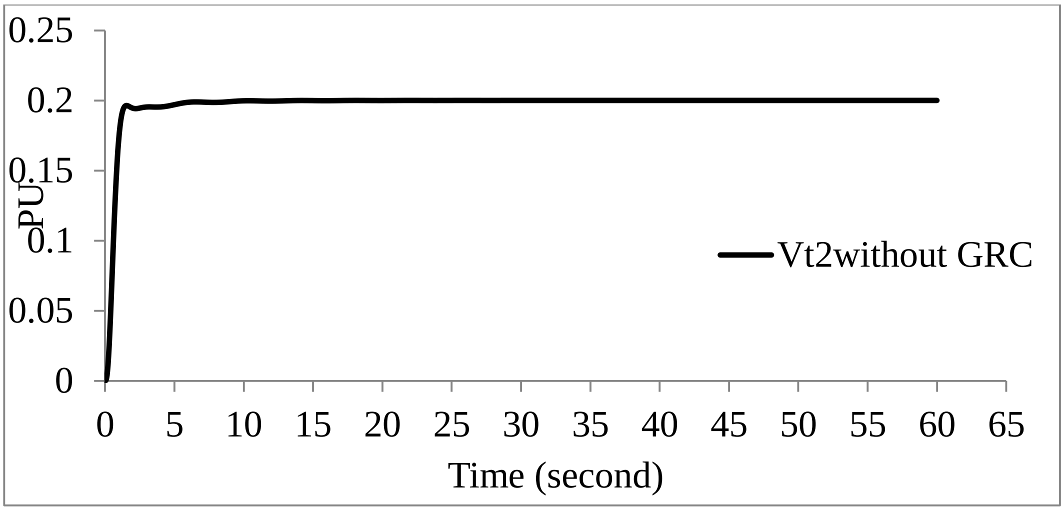

Figure 4.32 Terminal voltage of area two without AGC and AVR.

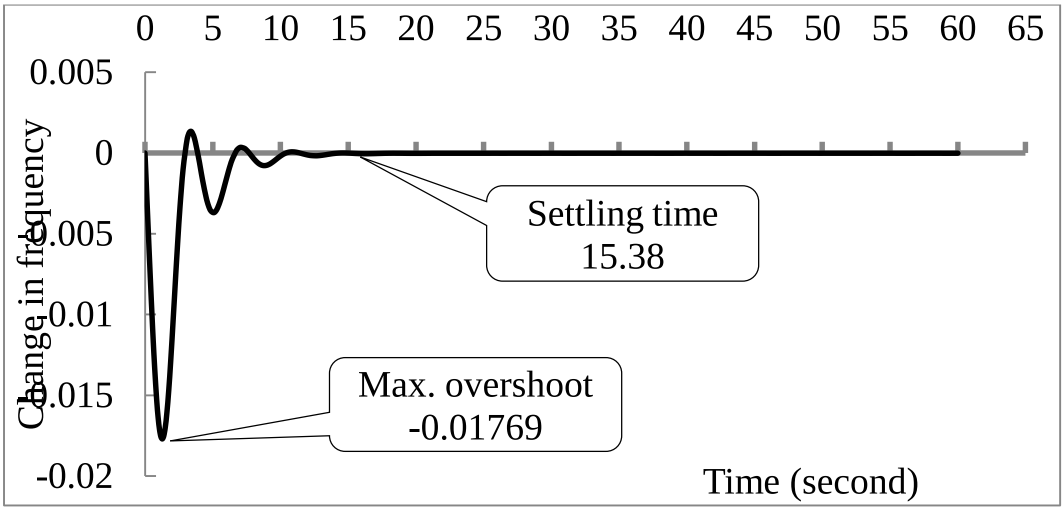

Figure 4.33 Change in frequency of area one without AGC and AVR.

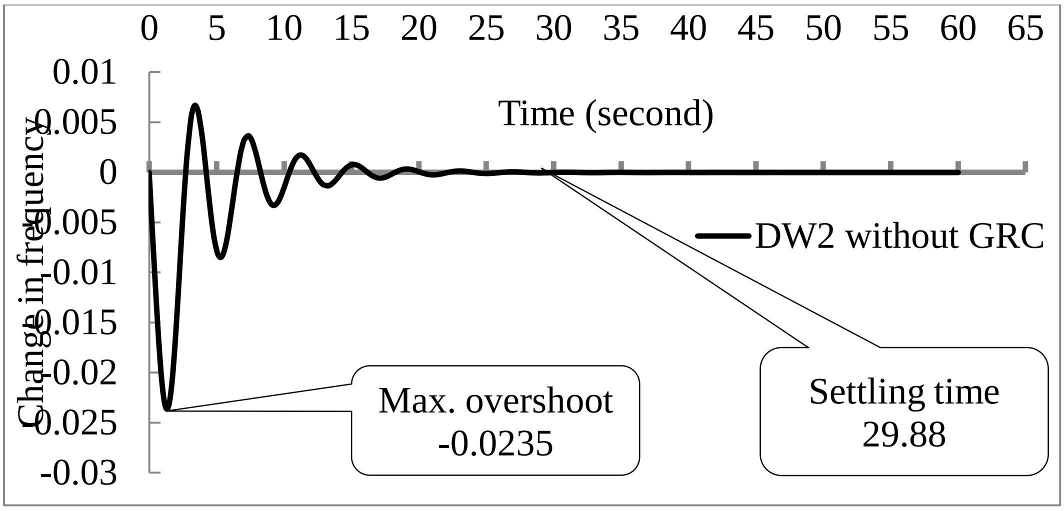

Figure 4.34 Change in frequency of area two without AGC and AVR.

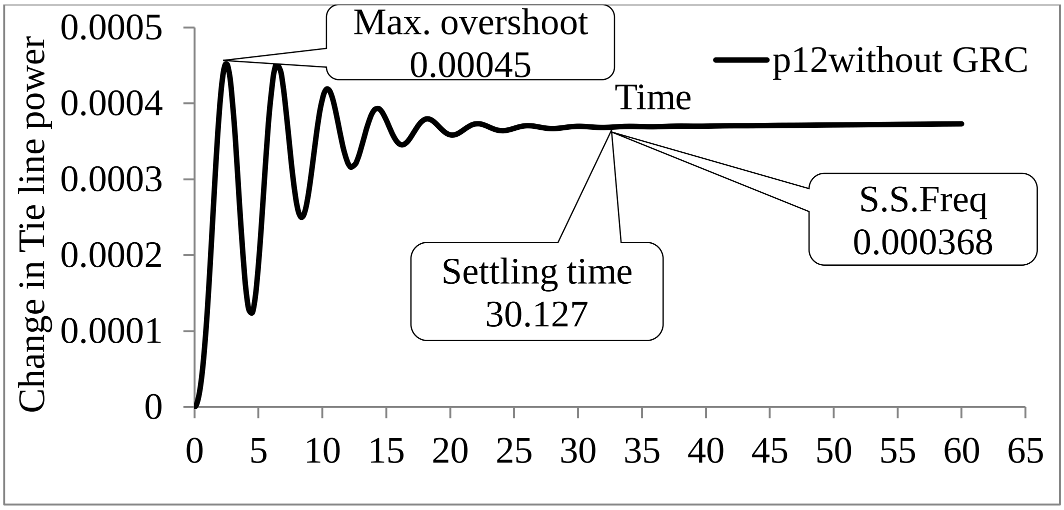

Figure 4.35 Tie line powers of two areas without GRC

Figures 4.31-35 represent the coupling between the two loops AGC and AVR we can see the change in frequency and terminal voltage of two areas. The coupling mainly effects on the response of frequency, the response with coupling is the best than the response without coupling

4.11 Coupling between automatic generation control and automatic voltage regulator while considering generation rate constraint of two areas:

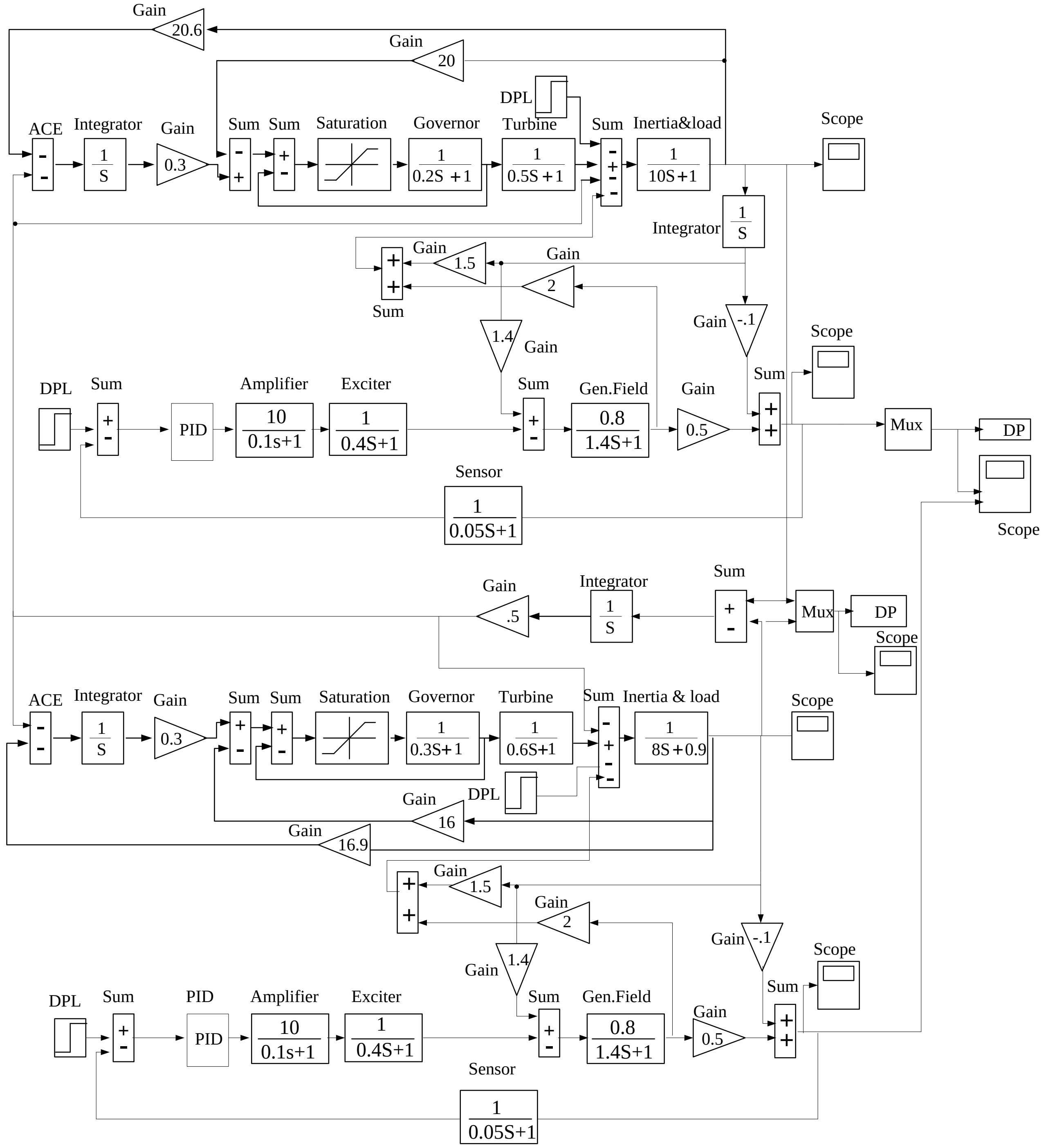

Figure 4.36 Two areas AGC and AVR considering GRC

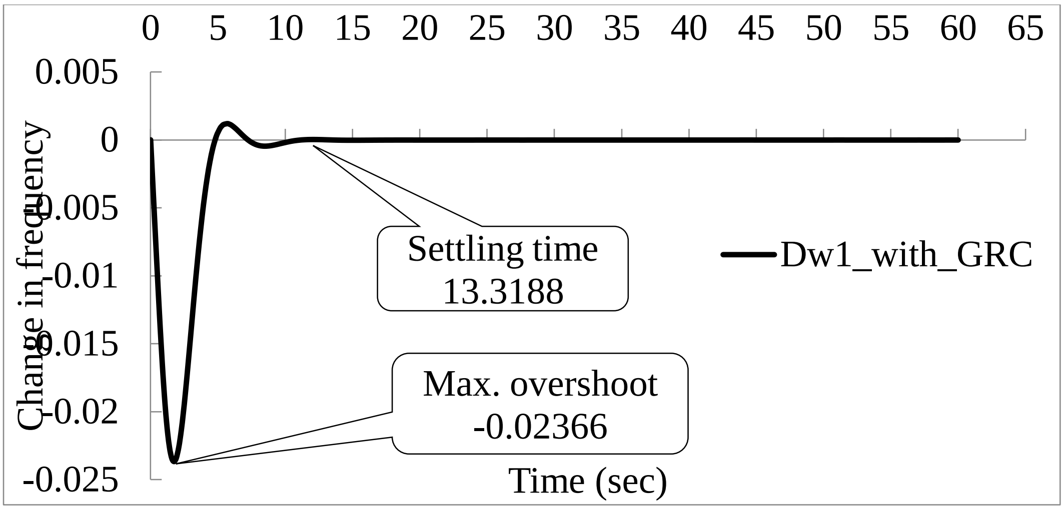

Figure 4.37 Change frequency of area one with AGC, AVR and GRC

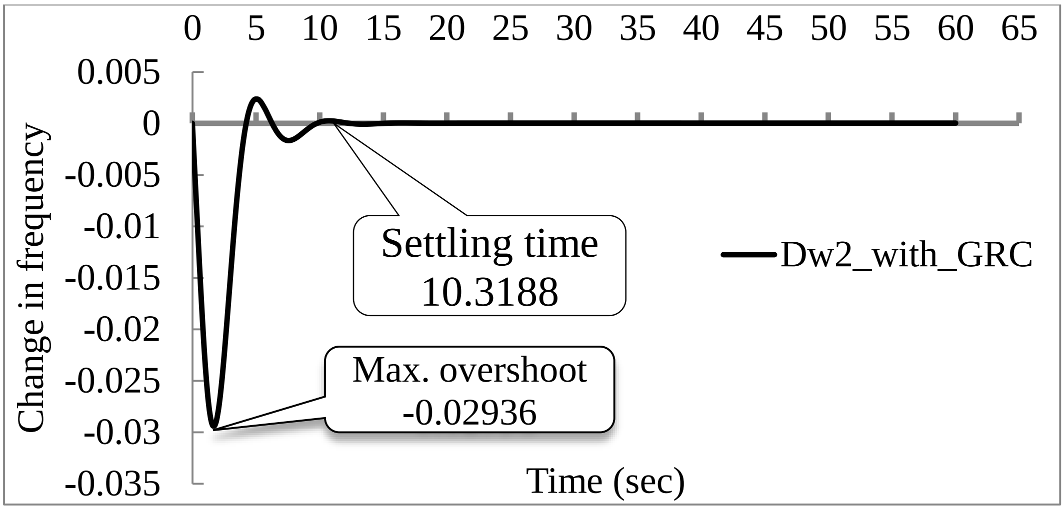

Figure 4.38 Change frequency of area two with AGC, AVR and GRC

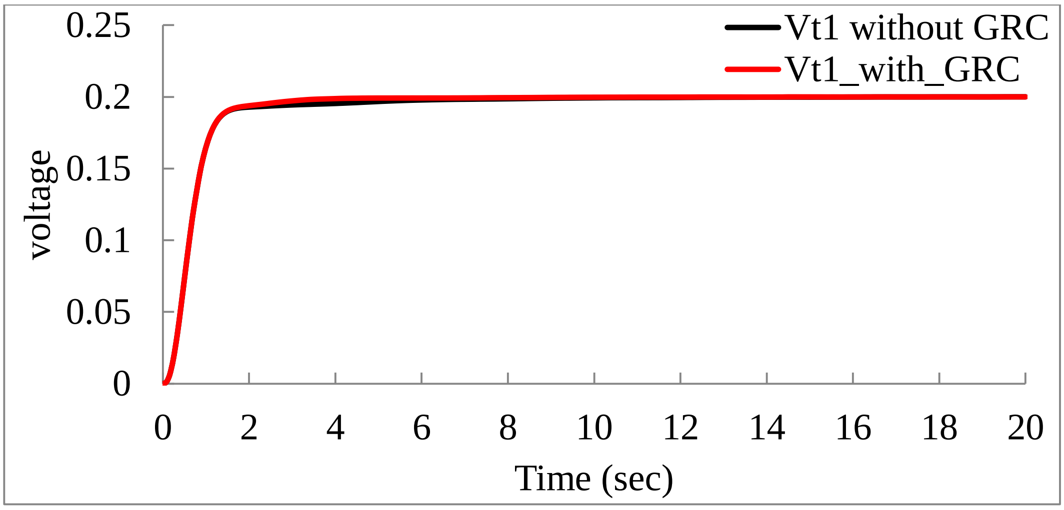

Figure 4.39 Comparison of terminal voltage of area one

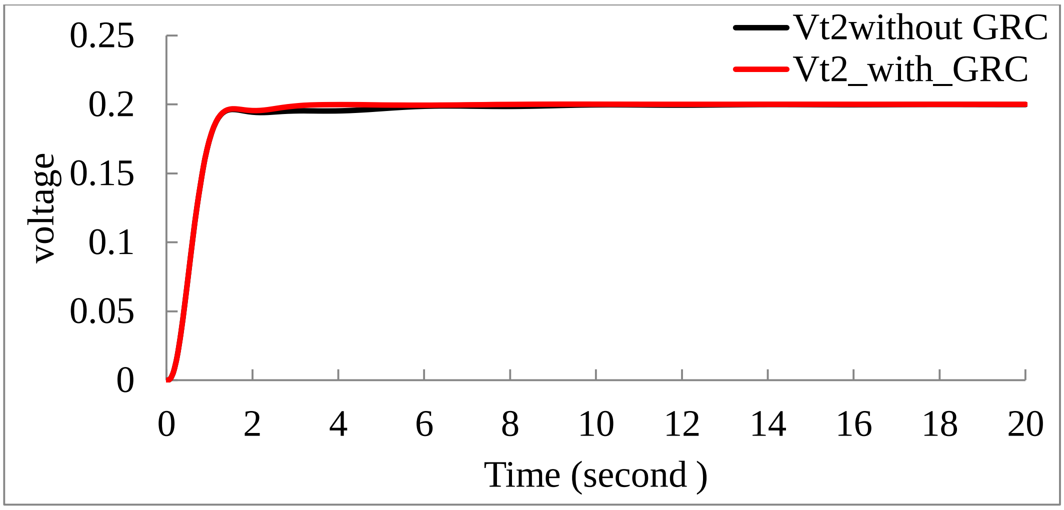

Figure 4.40 Comparison of terminal voltage of area two

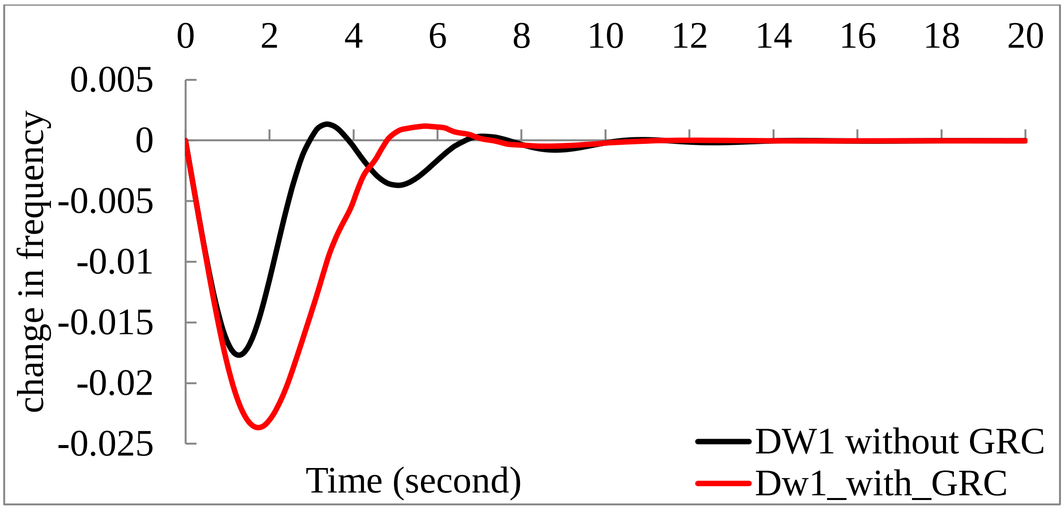

Figure 4.41 Comparison of change in frequency of area one

Table 4.9 Represent summary of figure 4.41

	Peak over shoot	S.S.Freq.	Settling time
With ACE&AVR	-0.01639	0.0	14.1272
With GRC	-0.02366	0.0	10.3188

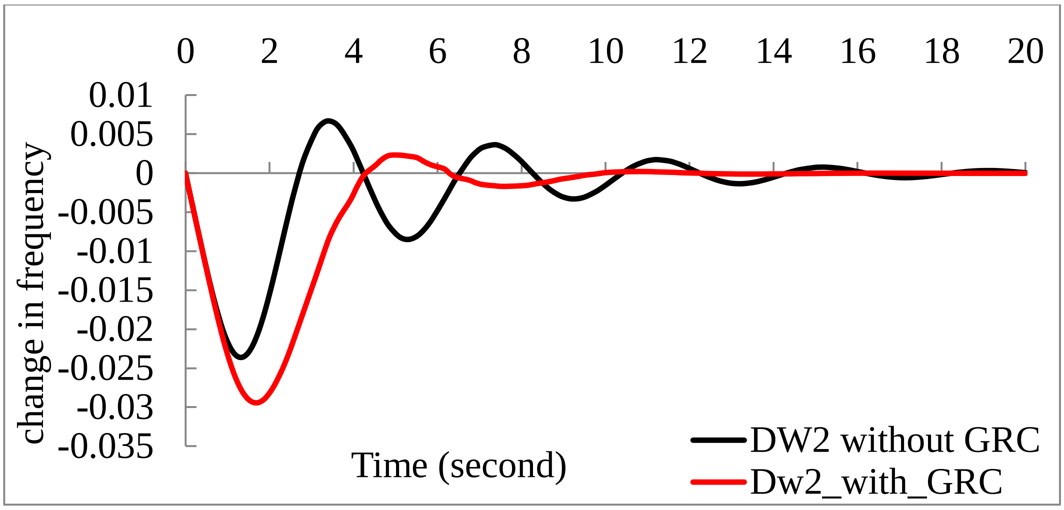

Figure 4.42 Comparison of change in frequency of area two

Table 4.10 Represent summary of figure 4.42

	Peak over shoot	S.S.Freq.	Settling time
With ACE&AVR	-0.02601	0.0	27.3459
With GRC	-0.02936	0.0	10.3188

In this section develop AGC scheme is employed with AVR and considering generation rate constraint. Here coupling between AGC and AVR scheme is employed. The interaction between frequency and voltage exists and cross coupling does exist and can some time troublesome. AVR loop affect the magnitude of generated emf. The internal emf determines the magnitude of real power. It is concluded that changes in AVR loop is felt in AGC loop.

GRC is not effect on the terminal voltage because the GRC is applied only from the speed governor system.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion:

A simulation study of single and two area systems with automatic generation control is carried out with models developed in SIMULINK. The simulation of these systems has been carried out and results analyzed. The operation of single area and two area systems with and without automatic voltage regulator are very well depicted through simulation models. The advantage of interconnection is best understood by comparing the results of single and two area systems. It can be seen that the oscillations due to change in load in any area is damped down quickly because of tie line power flow. It can also be observed that the dynamic response is mainly governed by the secondary loop and hence design criteria of which is extremely vital for efficient implementation.

The frequency of the system is dependent on real power output and is taken care of by ALFC. Terminal voltage of the system is dependent on the reactive power of the system and is taken care of by AVR loop. The cross coupling effects between the two loops are studied which is associated with low-frequency oscillations. It is clear from the results that AVR loop is able to maintain the voltage and frequency deviations in the specified limits and the power system thus becomes more robust. The dynamic responses are further improved in terms of peak deviations and settling time.

6.2 Recommendations:

- Study of automatic generation control and automatic voltage regulator using fuzzy logic controller.
- Study of automatic generation control and automatic voltage regulator using practical swarm’s optimization.
- Study of automatic generation control and automatic voltage regulator with economic dispatch.

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