WOLKITE UNIVERSITY

COLLEGE OF ENGINERRING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND COMPUTER
ENGINEERING (ELECTRICAL POWER ENGINEERING STREAM)

TITLE: AUTOMATIC GENERATION CONTROL (LOAD FREQUENCY CONTROL) IN TWO AREA POWER SYSTEM

FINAL YEAR PROJECT REPORT

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DECLARATION

We, declare that this project, automatic generation control in two area power system using PID controller and the work presented in it are our own work. We confirm that: this work done mainly in candidate for a Bachelor Degree at this University (WOLKITE UNIVERTY). We have seen some other literature review from the work of others. And this is to certify that the project titled “AUTOMATIC GENERATION CONTROL IN TWO AREA POWER SYSTEM” carried out by:

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ABSTRACT

The main aim of this thesis is to reduce the damping an oscillation of frequency and it also deals with the automatic generation control (AGC) of two areas interconnected hydraulic power systems. The major problem arising from large scale electric power system interconnection is the low frequency oscillation of interconnected system. The primary object of the AGC is to balance the total system generation against system load and losses, 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. For a complete system model we have to study the oscillation of AGC loop with PID CONTROLLERS. This model of AGC is tested on two-area power system. The result is shown in simulation; and will be reachable in dynamic and steady state responses. The simulation results of two areas are compared using MATLAB/SIMULINK software by using PID controllers and PID controllers can be tuned by using many methods. In all methods an initial guess is made for PID controller parameter settings. Then these parameter settings are improved by fine tuning of the controller.

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LIST OF ACRONYMS

ALFC	automatic load frequency control
AGC	automatic generation control
ΔPd	load change
ΔPm	mechanical power change
ΔPe	electrical power change
ΔPg	generation change
Tw	water flow starting time constant
TG	Speed governor time constant
Tt	Speed turbine time constant
TR	time constant of transient droop
Tp	Power system (generator) time constant.
ACE	Area control error
SCADA	supervisory control and data acquisition
LQR	linear quadratic regulation
MAPS	multi area power system
Δf	Frequency deviation error.
Δp12 (Δptie1)	Tie line power flow error from area one to area two.
B	Frequency bias factor.
Deq	load damping constant
Rt	transient regulation
TR	reset time constant
T12	Tie line synchronizing torque coefficient
M (2H)	moment of inertia constant
PID	Proportional-Integral-Derivative
KP	proportional gain
Ki	integral gain
Kd	derivative gain
MAT LAB	matrix laboratory

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CHAPTER ONE

INTRODUCTION

1.1 back ground

A power system is a proper system to transmit power economically efficiently and in a reliable manner. It is known that everyone desires uninterrupted supply. But it is always not possible for a system to remain in normal state. This can be achieved by managing the generations and the demands. Generation can be managed better by AGC system which deals with frequency and economic dispatch control. 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. Thus design of Automatic Generation Control (AGC) $^{\text{play}}$ a vital role in the automation of power system. The objective of control strategy is to generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the frequency within permissible limits.

Change in machine angle, δ, is caused by momentary change in generator/rotor speed. So the speed of the generator in hydropower plants is controlled (regulated) using the governor controller, which controls the inlet/gate, in order to increase or decrease the water jet hitting the blades of the turbine. Frequency deviations are due to variations in active power demand. The power system is subjected to local variations of random magnitudes and durations. A control signal made up of tie line flow deviation added to frequency deviation weighted by a bias factor would accomplish the desired objective. This control signal is known as area control error (ACE). ACE serves to indicate when total generation must be raised or lowered in a control area.

1.2 Problem Statement

Active power balance must be maintained between generating and utilizing the AC power. However, the users of the electric power change the loads randomly and momentarily. And unexpected external disturbances, parameter uncertainties and the model uncertainties of the power system pose big challenges in the power system. Thus, it will be impossible to maintain the balances of active powers without control. As a result of the imbalance, the frequency levels will be varying with the change of the loads which ultimately result in deviation of the frequency from the standard values during operation (rated values of different machines, electronic equipment & appliances). The standard rated values of operating frequency is 60Hz and 50Hz which differ from country to country. In Ethiopia, it is 50 Hz. So the target problem considered here is Frequency fluctuation.

1.3 Objective

1.3.1 General Objective

The main aim of the project is to design Automatic Generation control (automatic load frequency control) in two area power system by using PID controller.

1.3.2 Specific Objectives

- Measuring and modeling of frequency variations and to take automatic control measure
- To maintain power balance in the system
- To Design and simulate ALFC by using Mat lab software.
- To assist in controlling the frequency of interconnected systems
- To minimize steady-state errors of frequency and tie-line exchange variations, high damping of frequency oscillations and decreasing overshoot of the disturbance so that the system is not too far from stability.

1.4 Organization of the thesis

The thesis report has five chapters. Chapter one is the introduction part and it includes the background and over view of the project explanation such as objective and scope. Chapter two explains the theoretical background and literature review of the project. Chapter three contains the modeling of the LFC with and without PID controller. In chapter four we simulate the model and discussed the results. In the last chapter five, we put the conclusion, recommendation, limitation and future work of the project.

1.5 Scope of the Project

The scope of this project is to control the load frequency in two area power system. By power system, it is a complex which includes generation, transmission and distribution of electrical power. So when we decide to work on ALFC control in two area power systems, the frequency control of the generating units in hydropower plants. The AGC system is also somewhat complex system, which may include SCADA system and used in very large grid systems, in addition to LFC control mechanisms. In this case we did not explain the detailed function in terms of load dispatch of the AGC system. Rather we biased more on the LFC of the two area power system. It is to focus on the LFC system. The PID controller is used in this project. The proposed controller, PID controller is tuned and implemented in to the LFC system using software MATLAB. The simulation data of the PID controller and without controller is analyzed and compared.

CHAPTER TWO

THEORETICAL BACKGROUND AND LITRATURE REVIEW

2.1 Introduction

Many investigations in the field of automatic generation control of interconnected power system have been reported over the past few decades. These investigations deal with how to select a frequency bias, selection of controller parameters and selection of speed regulator parameter of speed governor. Investigation regarding to the AGC of interconnected system is limited to the selection of controller parameter. There are volumes of research articles which have been appeared in the literature regarding Automatic Generation Control (AGC) of single area or multi area power system considering various control strategies. These are summarized comprehensively in [1]. This section, specifically gives a brief literature review on LFC of power system using intelligent control techniques. A number of investigations have been done in the area of LFC. The successful operation of interconnected power systems requires the matching of total generation with total load demand and associated system losses [2]. With time, the operating point of a power system changes, and hence, these systems may experience deviations in nominal system frequency and scheduled power exchanges to other areas, which may yield undesirable effects [3].

2.2 Control techniques

A lot of control techniques are proposed by the researches in their pioneer work to design LFC controllers. The controllers are based on:

I. Classical control techniques
   - LQR based controlling techniques

II. Soft computing techniques/Artificial intelligence techniques
   - Fuzzy logic based technique

2.2.1 Classical control techniques

The pioneering work by a number of control engineers, namely Bode, NY Quist, and Black, has established links between the frequency response of a control system and its closed-loop transient performance in the time domain [4]. The investigations carried out using classical control approaches reveal that it will result in relatively large overshoots and transient frequency deviation. The AGC regulator design techniques using modern optimal control theory enable the power engineers to design an optimal control system with respect to given performance criterion [5].

Fosha and Elgerd were the first to present their pioneering work on optimal AGC regulator design using this concept. A two area interconnected power system consisting of two identical power plants of non re heat thermal turbines was considered for investigations [6].

In this review flywheel governor is used to maintain the system. Flywheel by itself acts as energy reservoir and has no control quality of working medium and not inter connected to each other due to this reason we want to replace by PID controller. PID controller is simple, have good stability and give response rapidly.

- **LQR based controlling techniques**

Optimal control design for the linear systems with quadratic performance (Linear Quadratic Regulator (LQR) has been established. The purpose of optimal regulator design is to determine the optimal control rule. There are several competing objectives that need to be simultaneously satisfied (system step response, rise time, overshoot, disturbance rejection, or integral absolute error). These objectives are imbedded in system's Eigen values that are measures of system stability and robustness. [9] Proposed a combination of „Matching conditions and Lyapunov stability theory is adopted to implement a robust stabilizing controller. Yang et.al suggested a controller which is based on structured singular values (SSVs) and each local area load-frequency controller can be designed independently [10]. The robust stability condition for the overall system can be easily stated to achieve a sufficient interaction margin and a sufficient gain and phase margin defined in classical feedback theory during each independent design. KO et.al published that LQR problem needs to be reformulated for finding a common Lyapunov function for the set of considered linear systems. This is accomplished by representing the underlying control optimization problem in terms of a system of linear-matrix-inequality (LMI) constraints. The solution of LMI equations involves a form of quadratic Lyapunov function that not only gives the stability property of the controlled system but can also be used for achieving certain performance specifications [10].

2.2.3 Soft computing techniques/Artificial intelligence techniques

The emerging techniques of artificial intelligence have a common feature, i.e. they had the ability to process the complex information. In AI technique all the short circuit analysis in three-phase is carried out offline, and the fault is located online within short time. Different AI tools were successfully applied for all power system purposes such as Expert Systems, Artificial Neural Network, Fuzzy Logic and genetic algorithm realizing distinctive performances over the conventional ones [10]. Among the various AI based techniques, fuzzy logic approach is observed to be applicable and attractive for dealing with complex and ill-defined problems which may be impossible or too expensive with conventional methods.

- **Fuzzy logic based techniques**

A fuzzy logic based intelligent controller is designed to facilitate the smooth operation and less oscillatory when system is subjected to a sudden load change. Fuzzy controller is based on a logical system called fuzzy logic which is much closer in spirit to human thinking and natural language than classical logical systems [11]. Fuzzy set theory and fuzzy logic establish the rules of a nonlinear mapping. The main goal of LFC in interconnected power systems is to protect the balance between production and consumption [11]. Because of the complexity and multi-variable conditions of the power system, conventional control methods may not give satisfactory solutions. On the other hand, their robustness and reliability make fuzzy controllers useful in solving a wide range of control problems. Load frequency control in two area system using fuzzy logic algorithm is found to be suitable. But the fix fuzzy rule expert systems have some drawbacks as [11]:

1. It is difficult to acquire knowledge
2. There is no adaptability and hence for dynamic time varying system, it is unable to perform well due to change in system.

Generally, from the Literature Survey following GAPS has been framed.

1. Classical techniques most of the times are divert from optimal solution and are very time consuming.
2. Classical techniques are suffering from premature convergence..

2.3 Necessity to Maintain Frequency Constant

Frequency is the basic power system quantities which should be always specified and maintained at certain standard values in order to have health and stable functioning of power system elements and loads. To have such standard working values, the problem starts from the generation units.

2.3.1 Reasons to Keep the Frequency at Constant Level:

- Most of the AC motors require constant frequency supply in order to maintain constant speed.
- In industry, frequency affects the continuous operation of the process.
- To maintain a synchronous operation of various units in the power system
- Frequency is also responsible in affecting amount of power transmitted through interconnected lines.
- Electrical clocks may lose or gain time when they are driven by synchronous motors.

- For synchronization purpose, this helps to have stable system.
- If the normal operating frequency is 50 Hz and the turbines run at speeds corresponding to frequencies less permissible limit than (47.5 Hz or above 52.5 Hz),then the blades of the turbines may get damaged.

2.4 Effects of poor Power System Control:

some of the major effects are mal-operation of control devices relays etc, extra losses in capacitors, transformers and rotating machines, fast ageing of equipment, loss of production due to service interruptions, electro-magnetic interference due to transients and power fluctuation not tolerated by power electronic parts.

Major Causes: nonlinear loads, adjustable speed drives, traction drives, start of large motor loads, arc furnaces, intermittent load transients, lightning, switching operations and fault occurrences.

These and other related events are the ultimate agents to bring disturbances in generating plants. As it is not feasible to control manually, the AGC systems have been found necessary through time to tackle unpredictable incidences.

Concepts in Control Area: Control areas in power system are generally classified in to two in terms of number of connected areas:

- Isolated or Single area power system
- Interconnected or Multi-area power system (MAPS); here two or more single areas are interconnected using tie-lines.

2.5 Automatic Generation Control

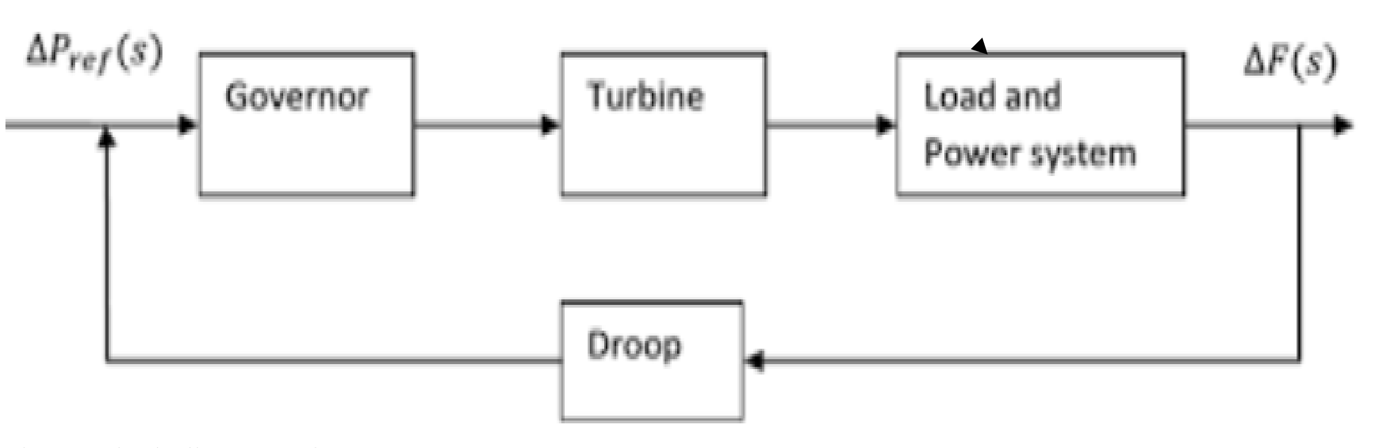


Fig 2.1Block diagram of LFC

Four basic objectives of power system operation during normal operating conditions are associated with automatic generation control (AGC/LFC):

i) Matching total system generation to total system load;
ii) Regulating system electrical frequency error to zero;
iii) Distributing system generation among control areas so that net area ties flows match net area tie flow schedules;
iv) Distributing area generation among area generation sources so that area operating costs are minimized.

Under abnormal conditions, one or more areas may be able to correct for the generation-load
Mismatch due to insufficient generation reserve on AGC. In such an event, other areas assist by permitting the inter areas power transfers to deviate from scheduled values and by allowing system frequency to depart from its pre disturbance value. Each area participates in frequency regulation in proportion to its available regulating capacity relative to that of overall system.

Frequency is an indicator of power balance between the supply and demand in a power system. Feedback control is used to keep frequency in the power system almost constant by regulating the supplied power. Common practices suggest that maintaining a maximum frequency deviation of 1% from the nominal value as an excursion outside the limits in system frequency might cause undesirable effects such as under/over frequency and over-excitation relay tripping which can initiate a cascade failure. If demand or power supplied changes in a power system, the frequency will also change as result of imbalance. Thus, extreme changes in generation or demand will bring about major deviations from the nominal system frequency; perhaps, outside the maximum tolerances. This unbalance is corrected by the speed controllers, also called speed governors, which control the power generated in the prime movers. The prime movers are usually turbines fed by steam, gas, or water. The mechanical to electrical energy conversion for transmission of energy in electrical form is performed in the generator. The low frequency oscillation analysis in hydro-dominant power systems will focus on hydro turbine dynamics. For frequency control, the state for which we are interested to control is the speed, which is equal to the system frequency when given in per unit. Our objective for control under a disturbance is to manipulate the inputs to keep bounded between certain limits in a required time, i.e. $\omega = 1 + 0.01$ p.u. This will determine the performance in the control strategy during disturbances. Currently, to fulfill this objective two control loops are involved in this task, the primary and secondary loop control. Here the automatic load frequency control mechanism/automatic generation control plays great role. For large scale power systems, which consist of inter-connected control areas, it is important to keep the frequency and inter area tie line power near to the scheduled values. The input mechanical power is used to control the frequency of the generators and the change in the frequency and tie-line power are sensed, which is a measure of the change in rotor angle. The functions of the ALFC are to maintain steady state frequency, control tie-line power exchange and divide the load between the generators. The tie-line power deviation is given by $\Delta Ptie$ and the change in frequency Δf is measured by $\Delta\delta s$, the change in the rotor angle δ. The error signals Δf and $\Delta Ptie$ are amplified, mixed and transformed to a useful signal. In a large scale inter connected power system, one of the most significant problems is both active and reactive power demands are never being at steady state and they will continually change with rising and falling trend. Regarding the control target, power generation systems are classified as single area and multi-area control. In a single area system, there is no tie-line schedule to be maintained. Thus the function of the ALFC is only to bring the frequency to the nominal values. The controller gain in this case needs to be adjusted for satisfactory response (in terms of overshoot, settling time, etc.) of the system.

- Although each generator will be having a separate speed governor, all the generators in the control area are replaced by a single equivalent generator and the ALFC for the area correspond to this equivalent generator.

In an interconnected (multi area) system, there will be one ALFC loop for each control area. Several generators connected in parallel (located also at different locations/generating stations) will meet the load demand of such a geographically large area power supply system. Such a coherent area is called a control area in which the frequency is assumed to be the same throughout the static and dynamic conditions.

- All generators are tightly coupled together to form – Coherent Group.
- All generators respond in unison to changes in load or speed changer settings.
- All generators are running coherently - termed as Control Area.

In real practice, the system of a single generator that feeds a large and complex area has rarely occurred. All the generators may have the same response characteristics to the changes in load demand.

If a change in load is taken care by two generating stations running at parallel, then the complexity of the system increases. The possibility of sharing the load by two machines is as follow:

- For two generating stations that are connected to each other by tie line, if the change in load is either at A or at B and the generation of A is alone asked to regulate so as to have constant frequency then this kind of regulation is called Flat Frequency Regulation.
- The other possibility of sharing the load is that both A and B would regulate their generations to maintain the constant frequency. This is called parallel frequency regulation.

- The third possibility is that the change in the frequency of a particular area is taken care of by the generator of that area thereby the tie-line loading remains the same. This method is known as flat tie-line loading control.

Selective Frequency control, each system in a group takes care of the load changes on its own system and does not aid the other systems in the group for changes outside its own limits.

Tie-line Load-bias control, all the power systems in the interconnection aid one another in regulating frequency regardless of where the frequency change originates.

2.5.1 Primary Frequency Control

A turbine prime mover of a conventional generator is typically equipped with an external control loop called governor control. Governor control system regulates the rotation speed of the shaft by changing the supply to the turbine and thus control frequency.

This type of control is designed to keep the stability of the power system in contingency conditions like large generation or load outages. The governor response is started almost instantaneously, although a governed generator generally needs some time to achieve the output level dictated by governor control system.

Primary Control is more commonly known as Frequency Response. It consists of generator, speed governor and turbine. Frequency Response occurs within the first few seconds following a change in system frequency (disturbance) to stabilize the Interconnection.

The governor dead-band, which is a region around normal frequency where the governor is not activated, is also a very important issue in frequency control.

Frequency Response is provided by:

- Governor Action: Governors on generators sense a change in speed and adjust the energy input into the generators prime mover.
- Load: The speed of motors in an Interconnection change in direct proportion to frequency. As frequency drops, motors will turn slower and draw less energy. Rapid reduction of system load may also be effected by automatic operation of under-frequency relays which interrupt pre-defined loads within fractions of seconds or within seconds of frequency reaching a predetermined value. Such reduction of load may be contractually represented as interruptible load or may be provided in the form of resources procured as reliability (or Ancillary) services. As a safety net, percentages of firm load may be dropped by under-frequency load shedding programs to ensure stabilization of the systems under severe disturbance scenarios. These load characteristics assist in stabilizing frequency following a disturbance.

The most common type of disturbance in an Interconnection is associated with the loss of a generator, which causes a decline in frequency. In general, the amount of (frequency-responsive) Spinning Reserve in an Interconnection will determine the amount of available Frequency Response. It is important to remember that Primary Control will not return frequency to normal, but only stabilize it. Other control components are used to restore frequency to normal, which is secondary control.

2.5.2 Secondary Control

Primary frequency control is decentralized and only able to limit and stop frequency excursions but not well suited to bring the frequency back to its target value. Instead, secondary frequency control is a centralized automatic control which is able to restore the frequency to its set point. It typically includes the balancing services deployed in the "minutes" time frame. Some resources however, such as hydroelectric generation, can respond faster in many cases. This control is accomplished using the automatic control mechanisms (LFC/AGC) and the manual actions taken by the dispatcher to provide additional adjustments. In short, Secondary Control maintains the minute-to-minute balance throughout the day and is used to restore frequency to its scheduled value, usually 50/60 Hz, following a disturbance. Secondary Control is provided by both Spinning and Non-Spinning Reserves. Secondary control loop consists of primary loop as well as the combination of PID controllers and others. The most common means of exercising secondary control is through Automatic Generation Control (AGC). AGC operates in conjunction with Supervisory Control and Data Acquisition (SCADA) systems. Using system frequency and net actual interchange, plus knowledge of net scheduled interchange, it is possible to determine the system's energy balance with its interconnection in near-real-time.

2.5.3 AGC Governor Regulating terms in frequency regulation:

Dead-band: It is the general characteristic of governors. This simply means that until frequency error is beyond a threshold, the governor ignores it. When frequency error exceeds the threshold (.036 Hz, or 36 mhz by convention) the governor becomes active. It is worth noting that for older, mechanical-style governors the dead-band may be larger and has associated with it the mechanical lash that exists in mechanically-coupled devices.

Speed Droop: droop is the amount of speed (or frequency) change that is necessary to cause the main prime mover control mechanism to move from fully closed to fully open. In general, the percent movement of the main prime mover control mechanism can be calculated as the speed change (in percent) divided by the per unit droop. A governor tuned with speed droop will open the control valve or gate a specified amount for a given disturbance. This is accomplished by using feedback from the main prime mover control mechanism (valve, gate, servomotor, etc.).

If a 1% change in speed occurs, the main control mechanism must move enough to cause the feedback through the droop element to cancel this speed change. Thus, for a 1% speed change, the percent movement of the main control mechanism will be the reciprocal of the droop (i.e. if the droop is 5% the movement will be 1/.05 = 20).

If the governor is tuned to be "isochronous" (i.e. zero droop), it will keep opening the valve or gate until the frequency is restored to the original value. This type of tuning is used on small, isolated power systems, but would result in excess governor movement on large, interconnected systems.

Speed Regulation: The term speed regulation refers to the amount of speed or frequency change that is necessary to cause the output of the synchronous generator to change from zero output to full output. In contrast with droop, this term focuses on the output of the generator, rather than the position of its valves. In some cases, especially in hydro, the droop setting will be significantly different from the resulting speed regulation. This is due to the nonlinear relationship between valve or gate position and water, gas or steam flow through the turbine.

Speed regulation can be implemented directly in electro hydraulic and digital electro hydraulic governors by using a watt transducer to provide feedback from the generator output to replace the feedback from the prime mover control mechanism.

Governor Droop: Droop is turbines response to Changes in interconnection Frequency (Speed). Droop distributes Frequency regulation to all generators in the interconnection. A recommended droop setting is of 2 to 5% with a maximum dead band of +/- 0.036 Hz.

2.6 Two Area Power System Flow

A two area system consists of two single area systems, connected through a power line called tie-line. It is a special multi-area control system where only two single area systems are connected via tie-line power flow.

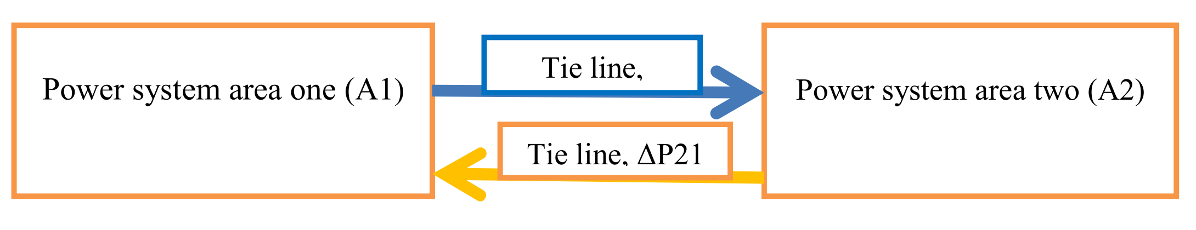


Fig 2.2 Two area power system

- Each power area may have a number of generators which are closely coupled together so as to form a coherent group, i.e. all the generators respond in unison to changes in the load.
- Each area feeds its user pool, and the tie line allows electric power to flow between the areas. Information about the local area is found in the tie line power fluctuations. Therefore, the tie-

line power is sensed, and the result is fed back into both areas. It is conveniently assumed that each control area can be represented by an equivalent turbine, generator, governor and load system.

Considering a practical power system with a number of generating stations and loads, it is possible to divide an extended power or very large power system (such as national grid) into sub-areas in which the generators are tightly coupled together so as to form a coherent group (all the generators respond in unison to changes in load or speed changer settings). This is helpful in order to ease the control mechanism and to have flexibility in the system.

2.6.1 Advantages of Interconnected power system Areas

- Reduces Reserve Capacity – thus reduces installed capacity
- Capital Cost/kW is less for larger Unit
- Effective Use of Generators
- Optimization of Generation – installed capacity is reduced
- Reliability
- Exchange or sale of power
- Disturbed areas taking other area's help
- Long distance sale and transfer of power

2.6.2 Disadvantages of Interconnected power system Areas

- Faults get Propagated – calls for fast switchgear
- Circuit Breaker rating increases
- Proper management required (costly and complex EMS-energy management system) and it must be automated
- If the one area is affected by any disturbance, also the other area affected without any reason.

2.7 Area Control Error (ACE)

The integral control is composed of a frequency sensor and an integrator. The frequency sensor measures the frequency error and this error signal is fed into the integrator. The input to the integrator is called the area control error (ACE). ACEs are used as actuating signals to active changes in the reference power set points and when steady state is reached, $\Delta P12$ and $\Delta\omega$ will be zero. ACE changes the frequency in each area and forces the steady state frequency error to zero. ACE is the combination of deviation in frequency and tie-line power. When all areas have zero ACEs, Δ net interchange and frequency deviation will be zero steady state error but frequency bias factor will work ($\beta \neq 0$). ACE measures area load change and give us good control.

If ACE <0, we must increase generation

ACE >0, we must decrease generation

ACE =0, the system is stable and no steady state error

To maintain a net interchange of power with its area neighbors, an AGC uses real power flow measurements of all tie lines emanating from the area and subtracts the scheduled interchange to calculate an error value. The net power interchanges, together with a gain, B (MW/0.1Hz), called the frequency bias, as a multiplier on the frequency deviation is called the Area Control Error (ACE). The real power summation of ACE loses information as to the flow of individual tie lines but is concerned with area net generation. The tie lines transfer power through the area from one neighbor to the next, called „Wheeling Power". The wheeling power cancels algebraically in the ACE. Thus one area purchases or sells blocks of power (MWh) with non-neighbor utilities

- Power Sale between Areas (from A to C)

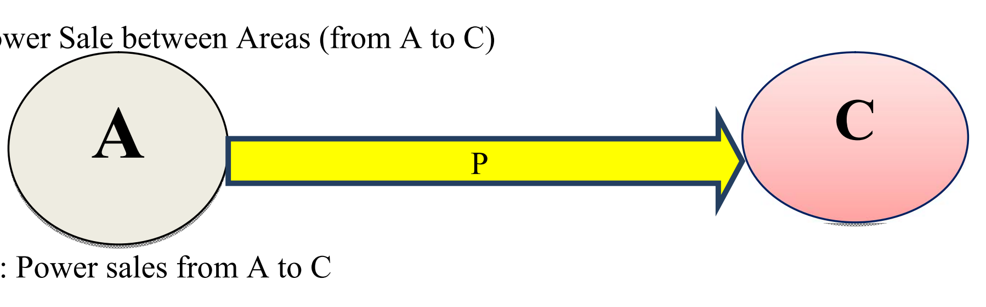


Fig 2.3: Power sales from A to C

- A – selling a power p' to C, then ACE for A = p
- Power export starts until its AGC forces ACE to become zero
- Area C introduces –p' into its ACE
- Power flows in to area C until its ACE becomes zero

It is further assumed that the areas share the disturbance in proportion to their generating capacity and operating characteristics.

2.7 Integral Controller

The frequency sensor measures the error in frequency, Δf, and this error signal is fed in to the integrator. The input to the integrator is known as Area Control Error- ACE = Δf.The ACE is the change in area frequency, which means when used in an integral-control loop, forces the steady state frequency error to zero.

The integrator produces a real power command signal, ΔPC, and is given by;

$\Delta Pc = -K\int \Delta f dt = KI\int (ACE)dt$, then the signal ΔPc is fed in to the speed changer causing it to move. KI is called the integral gain constant, which controls the rate of integration. It is a positive constant and controls the speed response of the control loop. The negative sign in the integral controller is for producing a negative or decrease command for a positive frequency error.

2.8 PID Controller

PID controller is the combination the three modes: proportional mode, integral mode & derivative mode PID controllers are generally functioning to ensure the dynamic response is improved at the same time decrease or get rid of the steady-state error. These controllers are awfully popular because they can regularly supply high-quality closed loop response characteristics. Their simplicity and easy to construct in controller structure using analogue and digital components have lead them to take over industrial applications. Furthermore, applications of PID control have been verified successfully. These are feedback loop mechanism and widely used in industrial control system. In LFC loop these are used in stabilization of the frequency where as in AVR loop to stabilize the terminal voltage. The transient response can be improved by using PID controller as compared to integral controller. So PID controllers are better as compared to integrator. The results obtained with PID controller has less overshoot or undershoot and less settling time as compared to integrator. The block diagram of Proportional Integral Derivative (PID) controller is shown below.

P

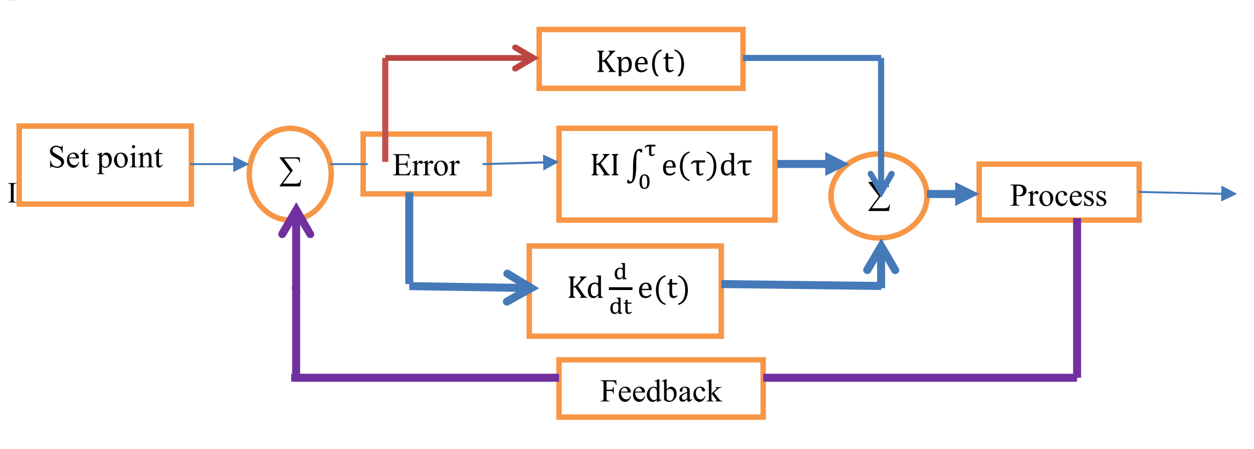


Fig 2.4 block diagram of PID controller

The PID controller improves the transient response so as to reduce error amplitude with each oscillation and then output is eventually settled to a final desired value. Better margin of stability is ensured with PID controllers. The mathematical equation for the PID controller is given as.

$$y(t) = k_p(t) + k_i\int_0^t e(t)d(t) + k_d\frac{d}{dt}e(t) \quad (2.1)$$

Where y (t) is the controller output and e (t) is the error signal. K_P, K_i and K_d are proportional, integral and derivative gains of the controller.

Proportional Gain(Kp): A proportional controller (P) reduces error responses to disturbances, but still allows a steady-state error.

Larger values of Kp typically means faster response since the larger the error, the larger the Proportional term compensation. An excessively large proportional gain will lead to process instability and oscillation.

Integral Gain (K_i): When the controller includes a term proportional to the integral of the error (I), then the steady state error to a constant input is eliminated, although typically at the cost of deterioration in the dynamic response. Larger values of Ki imply steady state errors are eliminated more quickly. The trade-off is larger overshoot; any negative error integrated during transient response must be integrated away by positive error before we reach steady state.

Derivative Gain (K_d): A derivative control typically makes the system better damped and more stable. Larger values of Kd decrease overshoot, but slows down transient response and may lead to instability due to signal noise amplification in the differentiation of the error.

The response characteristics of PID controller with respect to decreasing or increasing for each gain, is summarized in the following table.

Increase of	Rise time	Maximum Overshoot	Settling Time	Steady State error
P	Decrease	Increase	Small change	Decrease
I	Decrease	Increase	Increase	Eliminate
D	Small change	Decrease	Decrease	Small change

Table 2.1 Characteristics of PID Controller Components

2.8.1Advantages of PID Controller:

- The PID algorithm is the most popular feedback controller algorithm used. It is a robust easily understood algorithm that can provide excellent control performance despite the varied dynamic characteristics of processes. For MAPS (multi-area power system) with GRC (generation rate constraint) nonlinearity the system settles quickly with less peak overshoot when PID controller is used. For MAPS without GRC nonlinearity the system settles quickly when PID controller is used, even though the peak overshoot (undershoot) is more.

2.8.2 Disadvantage of PID Controllers:

- They can perform poorly in some applications. PID controllers, when used alone, can give poor performance when the PID loop gains must be reduced so that the control system does not overshoot, oscillate or hunt about the control set point value. A problem with the Derivative term is that small amounts of measurement or process noise can cause large amounts of change in the output. By tuning the three parameters (coefficients) i.e. the proportional coefficient, integral coefficient and differential coefficient, the PID controller can provide individualized control requirements. There are many methods available for tuning of PID controllers. All these methods are used as initial guess for PID controller parameter settings. Later these settings are improved by fine tuning. Nowadays simulation software is widely popular. MATLAB Simulink is one of them.

PID controller tuning can be achieved in three steps:

Step1: Set the gain parameter KP. Here KD and KI are zero. By trial and error select KP that results in a stable oscillatory performance.

Higher KP results in decrease of rise time and steady state error but highly oscillatory response. In a multi input system if KP is high it is observed that it is difficult to damp out these oscillations. Hence selecting KP that results near to critical damping in case of multiple inputs is necessary.

Step 2: Now using derivative control reduce the above oscillations by providing proper damping which results in reasonable overshoot and settling time. This can be achieved by varying KD with KP found in Step 1 and analyzing the resulting response from the corresponding simulation. So we have fixed KP and KD. Still KI = 0.

Step 3: So far we have taken care of transient performance. What remains is steady state performance. Here we concentrate on steady state error. If steady state error is not zero, then for the values of KP and KD fixed in Step 2, vary KI and select the KI that results in zero steady state error in minimum time.

The PID controller will be used for the stabilization of the frequency in the AGC problems. So tuning of PID controller is very important to get optimal performance.

CHAPTER THREE

METHODOLOGY AND MATHEMATICAL MODELLING

3.1 Methodology

All the electrical loads including both commercial and industrial satisfactorily perform when they operate at normal frequency. But in modern power system there is always deviation in frequency due to frequent change in loading pattern. Therefore, the precise control of frequency is the major issues & challenging task for power system engineers. Frequency control can be accomplished through LFC/AGC [1]. .

- **the basic role of LFC/AGC is to**

- Deliver the desired real output power from a generator to meet the variation in load.
- Regulate the system frequency of a large interconnected power system.
- Maintain the tie-line interchange power schedules between control areas.

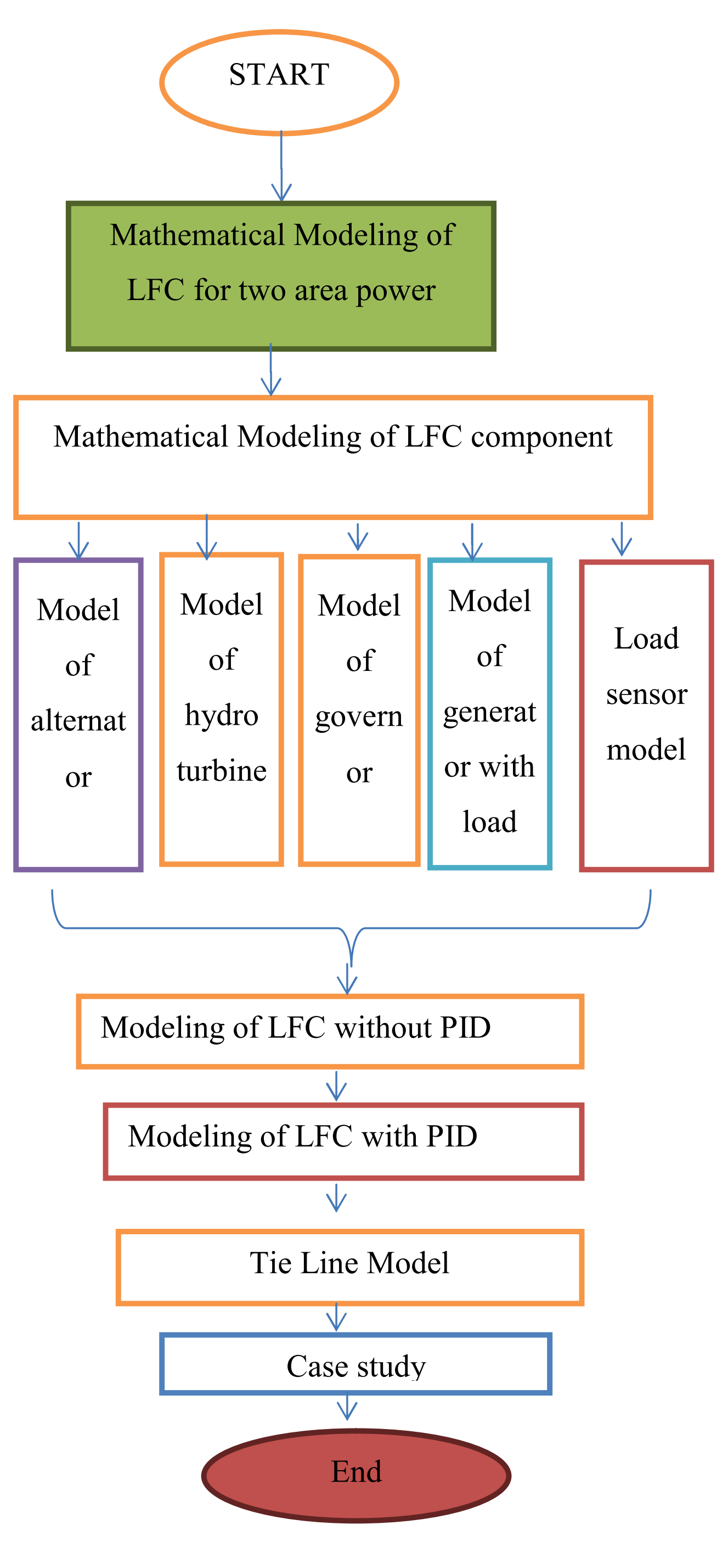


Fig 3.1 flow chart diagram of work flow

3.2 Mathematical modeling of LFC systems

In this section transfer function model of each component of ALFC/AGC in an interconnected power system is presented. The various components of LFC systems used in the power system model are

(a) Alternator
(b) Load
(c) Governor
(d) Prime mover.

3.2.1 Mathematical model of alternator

In power system mathematical model of alternator can be developed using swing equation given by:

$$\frac{2GH}{W_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_M - \Delta P_E \quad \text{...(3.5)}$$

Where ' 'H is the inertia constant in MJ/MVA, ' 'G is the rating of the machine in MVA, sw is the synchronous angular speed in rad/sec, $\Delta\delta$ is change in the rotor angle in rad, Δ MP and Δ PE are the change in mechanical input power and electrical output power in MW respectively

$$\frac{2GH}{W_S}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - P_e$$

Here $\Delta P_m = \frac{\Delta P_M}{G}$ and $\Delta p_e = \frac{\Delta PE}{G}$ are expressed in per unit

$$\Rightarrow \frac{2H}{W_S}\frac{d}{dt}\left(\frac{d\Delta\delta}{dt}\right) = \Delta P_m - P_e$$

$$\Rightarrow \frac{2H}{W_s}\frac{d\Delta w}{dt} = \Delta p_m - \Delta p_e$$

$$\Rightarrow 2H\frac{d\left(\frac{\Delta w}{w_s}\right)}{dt} = \Delta P_m - \Delta P_e$$

$$\Rightarrow \frac{d(\Delta w)}{dt} = \frac{\Delta P_m - \Delta P_e}{2H} \quad \text{.......... ....(3.6)}$$

Here ' Δ W' is the angular speed deviation in per unit. Taking Laplace transform on both sides of equation (3.6), we have

$$S\Delta W(S)=\frac{\Delta p_m(s)-\Delta p_e(s)}{2H}$$

$$\Delta W(s)=\frac{1}{2H_s}(\Delta p_{m(s)}-\Delta p_{e(s)})\text{...}(3.7)$$

3.2.2 Hydro-Turbine Model

A turbine unit in power systems is used to transform the natural energy, such as the Energy from water, into mechanical power (Δ Pm) that is supplied to the generator.

- At the steady state, the water speeds inside the penstock at various point are constant, so are the water pressures at the various points.
- In power system analysis we usually use simplified inelastic (or say stiff) penstock model with water hammer effect included.
- When the water gate suddenly opens, the volume of the water flow will tend to increase which causes the reduction of water pressure and the output power will decrease at first and then turn to increase. This effect is called as WHE (water hammer effect). The WHE of the penstock greatly worsens the dynamic behavior of the hydro-turbines.

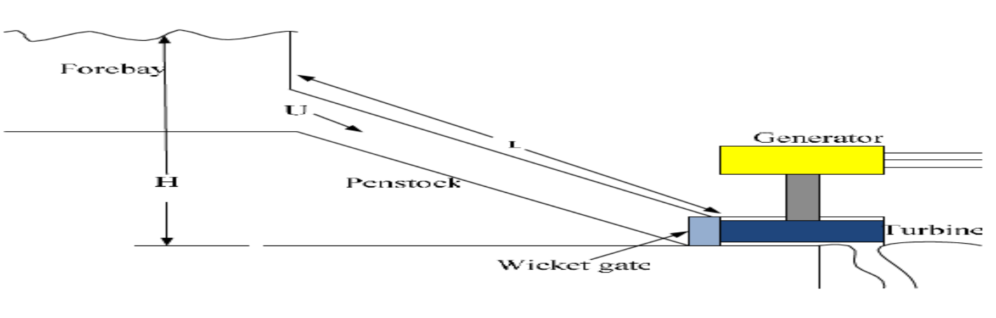


Fig 3.2: Typical hydro-turbine system

1. Upper reservoir 2. Penstock 3.Hydro-turbine 4.lower reservoir

The water hammer effect makes the relation of □ (flow speed) and P_m (mechanical power) like figure below

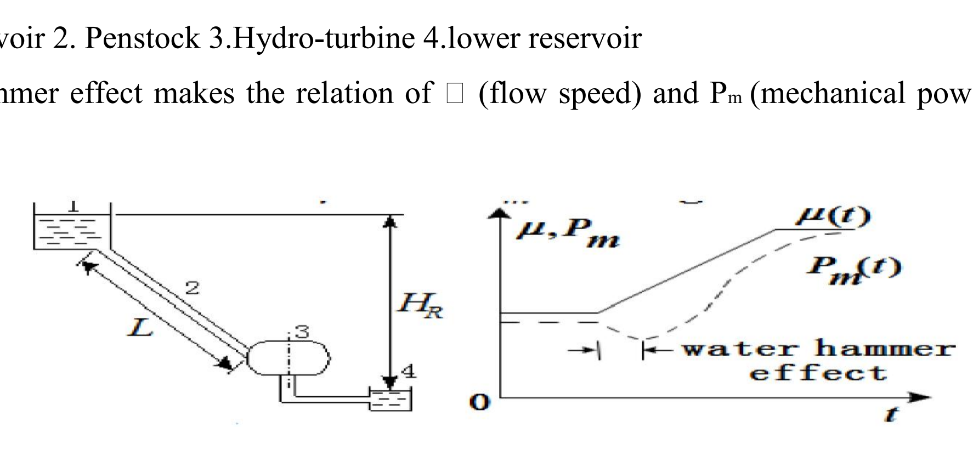


Fig 3.3: Block diagram of hydro turbine and its water hammer effect

The effect can be described as follows.

$h = -Tw\frac{dq}{dt}$……………………………………………………………………………(3.8)

Where h: increment of water head

q: increment of water flow

Tw: water starting time constant, (Tw: the time for water velocity increases in the penstock from zero to the rated value VR under rated water head HR and rated condition.)and water starting time constant is given by:

$T_{W=}\frac{L_{VR}}{gH_r}$ …. . (3.9)

Where L: the length of the penstock,

g: acceleration due to gravity.

V: velocity in m/sec

Hr. head of the reservoir

$\frac{\Delta T}{\Delta X} = \frac{1-T\omega S}{1+0.5T\omega S}$……………………………..……………………………………………(3.12)

3.2.3 Load Model

The power loads can be decomposed into resistive loads (ΔPL), which remain constant when the rotor speed is changing, and motor loads that change with load frequency or speed changes, given by BΔf. Therefore, the load change ΔPL is composed of frequency independent and frequency dependent load types. The frequency dependent load types are very sensitive for small frequency deviations. If the mechanical power remains unchanged, the motor loads will compensate the load change at a rotor speed that is different from a scheduled value, which is shown below, Where *D* is the load damping constant.

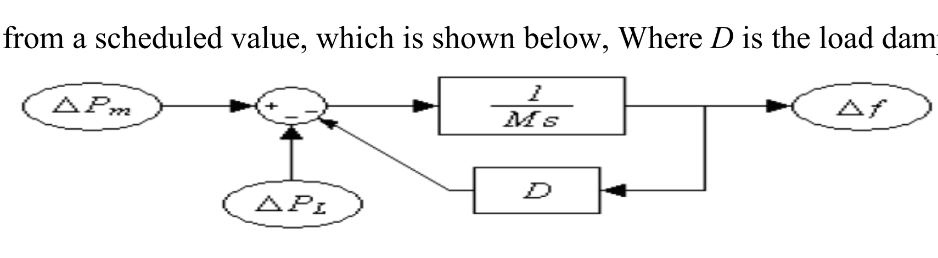


Fig 3.4: Block diagram of the generator with load damping effect

3.2.4 Generator-Load Model:

The reduced form of the above two figure, which is the generator model that we plan to use for the LFC design and the load model together gives the following diagram The Laplace-transform representation of the block is

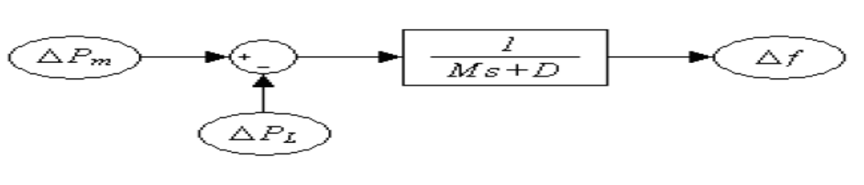


Fig 3.5: Reduced block diagram of the generator with the load damping effect

$$\mathrm{T.F} = \frac{1}{\mathrm{Ms+D}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3.13)$$

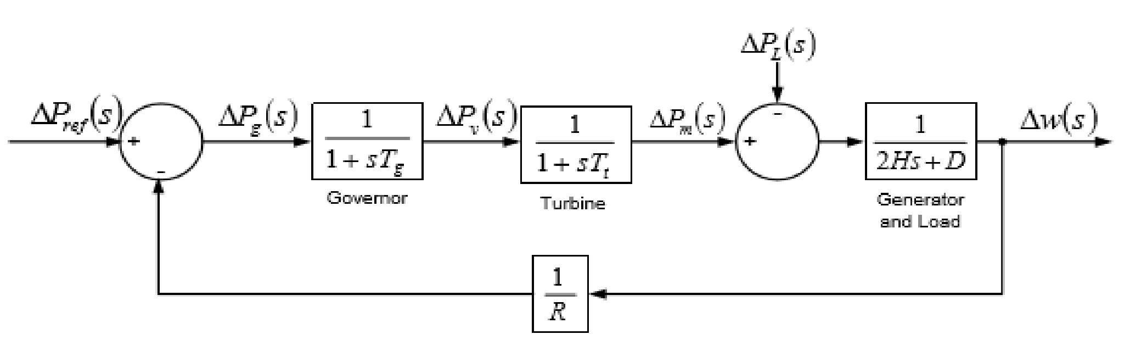


Fig 3.6 transfer function model of LFC of isolated power system

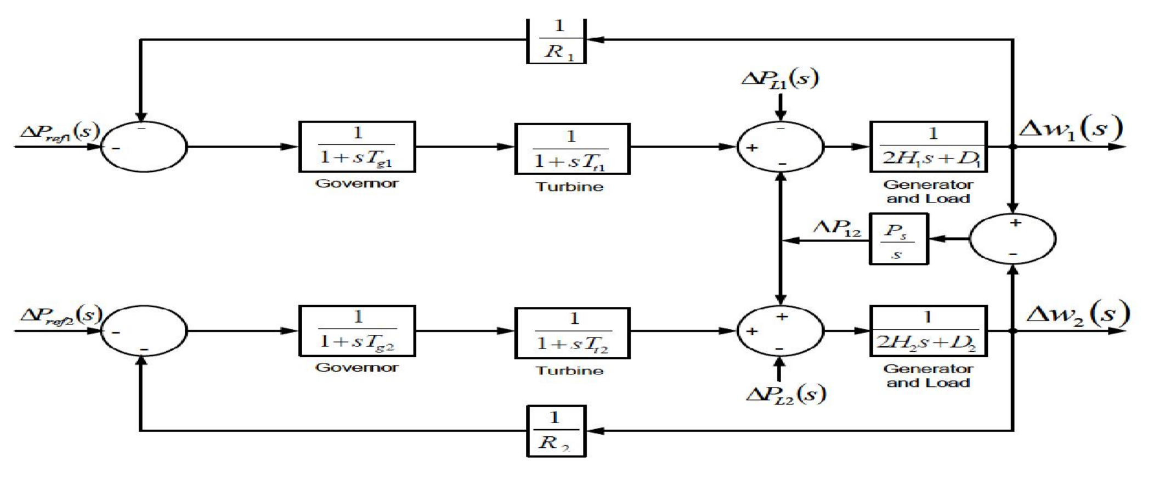


Fig 3.7 Two-area power n systems with primary LFC loop without PID controller.

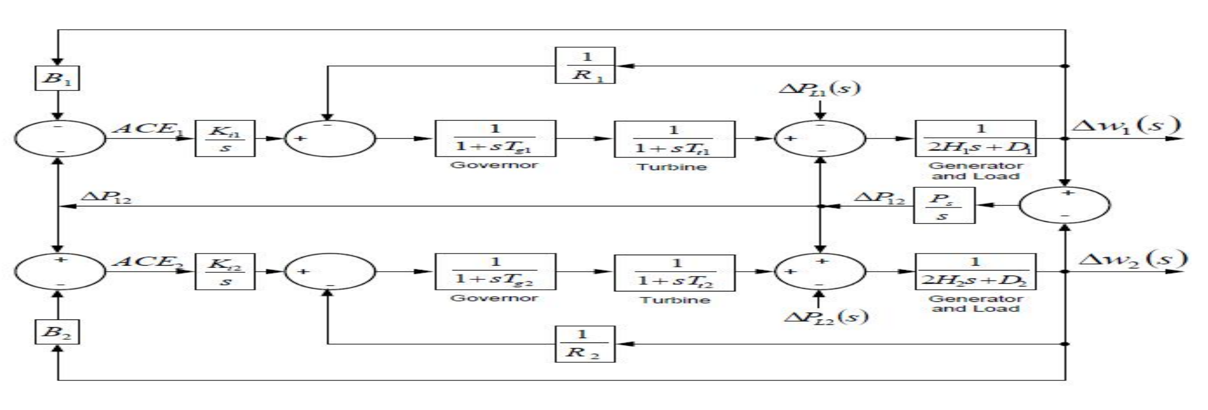


Fig 3.8 Two-area interconnected Power System equipped with integral controller in each area.

Obviously, generators represent the most important targets for power system control. The automatic control of generators involves control loops with which the large generators in the power system are equipped. Automatic Load Frequency Control (ALFC) loop as shown above.

The main purposes of this control loops is to maintain frequency at acceptable values in a power system. The falling water to the turbine must be continuously regulated in LFC loop in order to match the active power demand otherwise the machine speed will be varying consequent for changes in frequency.

The frequency at various systems may goes to beyond/blow the prescribed limit. As rule of thumb, the maximum permissible of changes in frequency is about ± 5% Hz/volt. If the nominal values are not kept, there will be highly undesirable conditions in the power system like frequency fluctuations if frequency is not maintained at constant. The automatic control should act in a closed loop manner, to detect the small changes in the system and initiate actions to eliminate the deviations.

ALFC is has two loop, a fast primary loop responds to the frequency changes and regulates the water flow via the speed governor and control valves/gates to match the active power output with that of the load. The time period here is a few seconds. The frequency is controlled via control of the active power.

A slower secondary loop maintains fine frequency adjustment to maintain proper active power exchange with other interconnected networks via tie-lines. This loop does not respond to fast load changes but instead focuses on changes, which lead to frequency drifting over several minutes.

3.4 Composite Regulating Characteristics of Power Systems

In the analysis of load frequency controls (LFC), the collective performance of all generators in the system is implemented. The inter machine oscillation and transmission system performance are therefore not considered. We assume that coherent response of all generators to exchange in the system load and represent them by an equivalent generator. The equivalent generator has an inertia constant M_{eq} equal to the sum of the inertia constant of all the generating units and is driven by the combined mechanical outputs of the individual turbines .similarly, the effects of the system loads are lumped into a single damping constant D. Generally, the equivalent generator inertia constant (M_{eq}), load damping constant (D_{eq}) and frequency response characteristic (B_{eq}) can be represented as follows.

$$M_{eq=\sum i=1,\ldots nMi}$$

$$\mathbf{D}_{\mathbf{eq=\sum i=1,..nDi}}$$

$$\boldsymbol{R}_{\boldsymbol{eq=\frac{1}{R1}+\frac{1}{R2}+\cdots\frac{.1}{Rn}}}$$

$$\mathbf{B}_{\mathbf{eq=\sum i=1\ldots n\frac{1}{Ri}+\sum i=1\ldots nDi}}$$

The composite power/frequency characteristics of a power system that depends on the combined effect of the total droops of all generator speed governors. It also depends on the frequency characteristics of all loads in the system. For the system with n generators and a composite load damping constant of D. the steady state frequency deviation following a load change ($\Delta \mathbf{PL}$) is given by

$$\Delta f = \frac{-\Delta \mathrm{PL}}{\left(\frac{1}{R1}+\frac{1}{R2}+\cdots\frac{1}{Rn}\right)+D}$$

$$= \frac{-\Delta \mathrm{PL}}{\left(\frac{1}{R_{eq}}\right)+D} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.14)$$

Thus the composite frequency response characteristics of the system is

$$\beta = \frac{-\Delta \mathrm{PL}}{\Delta \mathrm{f}} = \frac{1}{\mathrm{Req}} + \mathbf{D} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.15)$$

It is expressed in MW/Hz

Therefore for single area/ two generator system $\frac{1}{\mathrm{Req}} = \frac{1}{\mathrm{R1}} + \frac{1}{\mathrm{R2}}$

$$\Delta \mathbf{f} = \frac{-\Delta \mathrm{PL}}{\left(\frac{1}{R1}+\frac{1}{R2}\right)+D} = \frac{-\Delta \mathrm{PL}}{\left(\frac{1}{\mathrm{Req}}\right)+D} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.16)$$

An increase of the system load by change in load ($\Delta \mathbf{PL}$) at nominal frequency results in a total generation increase of ΔPG due to governor action and a total system load reduction of ΔPD due to its frequency sensitive characteristic.As we have seen from the block diagram a complete block diagram representation of an isolated power system comprising two turbines, generator, two governor and load and the droop compensator for each generating unit and an equivalent frequency characteristic response(B).

3.5 Governor Model

Speed Governing Mechanism: The speed governing mechanism includes the following parts. Speed Governor: It is an error sensing device in load frequency control. It includes all the elements that are directly responsive to speed and influence other elements of the system to initiate action.

Governor Controlled Valves/gates: They control the input to the turbine and are actuated by the speed control mechanism.

Speed Control Mechanism: It includes all equipment such as levers and linkages, servomotors, amplifying devices and relays that are placed between the speed governor and the governor controlled valves/gates.

Speed Changer: It enables the speed governor system to adjust the speed of the turbo generator unit while in operation.

The main function of the turbine governing system is to regulate the turbine-generator speed and hence the frequency and the active power in response to load variation. Governors are the units that are used in power systems to sense the frequency bias caused by the load change and cancel it by varying the inputs of the turbines.

The speed control mechanism includes equipment such as, servomotors, pressure or power amplifying devices, levers and linkages between the speed governor and governor-controlled gates. The speed governor normally actuates the governor-controlled gates that regulate the water input to the turbine through the speed control mechanism.

Hydro turbine governing systems are strongly influenced by the effects of water inertia and, as a result, two servomotors are used to provide the required force to move the control gate. The first pilot servomotor, low power, operates the distributor or relay valve of the second main gate servomotor, high-power. The pilot servomotor has a pilot valve that is controlled either by a mechanical governor or by an electronic regulator. The output of the speed-sensing devices is the deviation from the reference speed.

The permanent speed droop R_P determines the amount of change in output a unit produces in response to a change in unit speed. The permanent speed droop determines the amount of participation the unit produces when responding to disturbances in system frequency in operation while synchronized to an interconnected power system.

The temporary (transient) droop R_T is used to limit overshoot of the turbine control servomotor during a transient condition

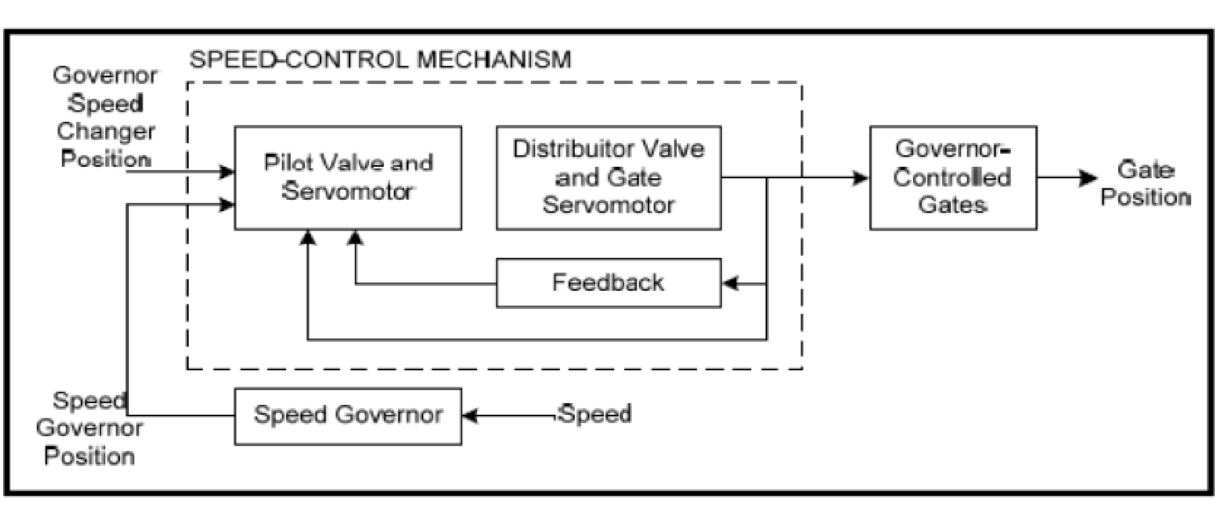


Fig 3.9: Schematic diagram of mechanical hydraulic governor system of hydro turbine

There are two classification of speed governing system.

1. mechanical-hydraulic controlled system
2. electro-hydraulic controlled system

In both these type, hydraulic servomotor is used for positioning the gate, to control the water flow. For now, we focused on the mechanical-hydraulic controlled system of turbine.

Mathematical Modeling: The following Figure shows a simplified mechanical-hydraulic governor. The variables used in the derivation of the transfer functions are per-unit derivatives from the initial steady-state values.

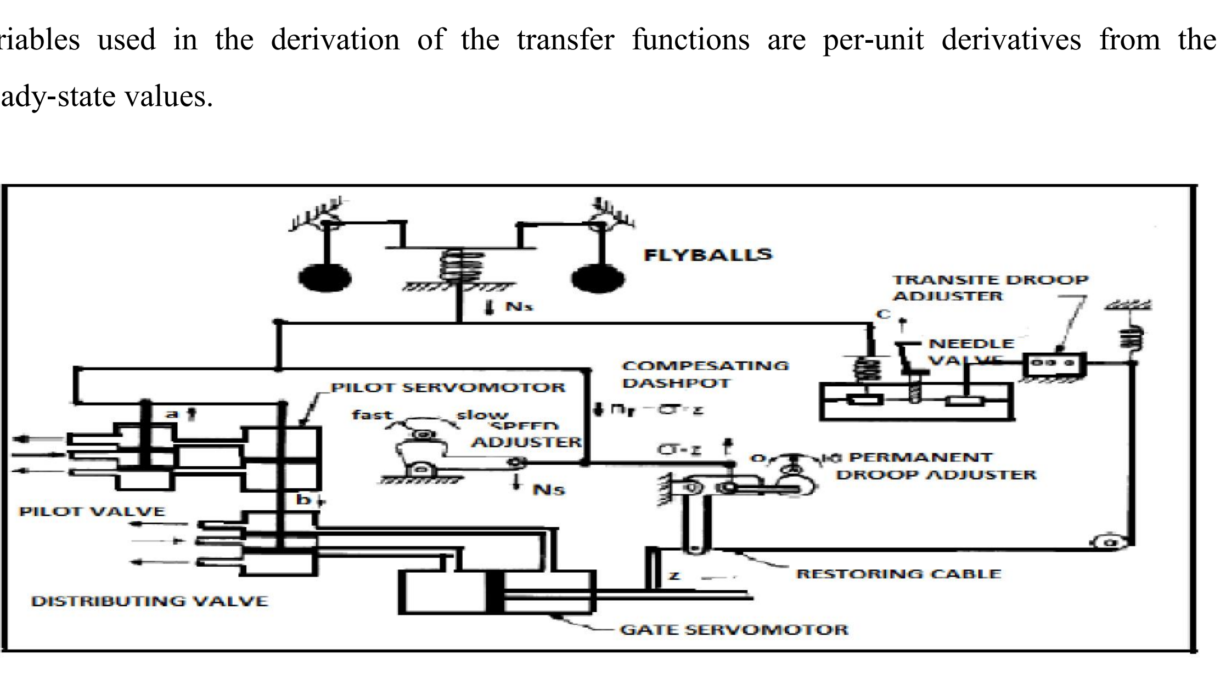


Fig 3.10: Mechanical-Hydraulic Governing System.

The transfer function of the distributing valve and gate servomotor is $\boldsymbol{y/b} = \frac{\mathbf{K1}}{\mathbf{s}}$

The transfer function of the pilot valve and pilot servomotor is $\boldsymbol{b/a} = \frac{\mathbf{K2}}{\mathbf{1+TpS}}$

Where K2 is determined by the feedback lever ratio and Tp by the port areas of the pilot valve & K2, Combining the above Equations $\frac{\mathbf{y}}{\mathbf{b}} * \frac{\mathbf{b}}{\mathbf{a}} = \frac{\mathbf{k1k2}}{\mathbf{s(1+Tps)}} = \frac{\mathbf{ks}}{\mathbf{s(1+Tps)}}$ $\boldsymbol{y/a} = \frac{\mathbf{ks}}{\mathbf{s(1+Tps)}}$

The servomotor gain Ks is determined by the pilot valve feedback lever ratio and the port areas of the distributing valve and gate servomotor.

Assuming that the flow of dashpot fluid through the needle valve is proportional to the dashpot pressure, the dashpot transfer function is

$$\frac{\mathbf{C}}{\mathbf{Y}} = \mathbf{Rt}\frac{\mathbf{Trs}}{\mathbf{1 + Trs}}$$

The temporary droop R_T is determined by the selection of pivot-point for the lever connected to the input piston. The reset time T_R is determined by the needle valve setting.

The pilot valve input signal is produced adding the action of a system of floating levers, the reference speed, shaft speed, permanent droop, and temporary droop signals.

$$a = \omega_{ref} - \omega_s - R_p Y - R_T \frac{Trs}{1 + Trs}$$

A combination of Equations:

$$Y = \frac{ks}{s(1 + Tps)} \times a$$

$$Y = \frac{ks}{s(1 + Tps)} * \left[\omega_{ref} - \omega_s - RpY - \frac{RtTrs}{1 + Trs}\right]$$

$$Y + RpY + \frac{RtTrs}{1 + Trs} Y = \frac{ks}{s(1 + Tps)} * \left[\omega_{ref} - \omega_s\right]$$

$$Y\left[1 + Rp + \frac{RtTrs}{1 + Trs}\right] = \frac{ks}{s(1 + Tps)} * \left[\omega_{ref} - \omega_s\right]$$

$$Y = \frac{\frac{ks}{s(1 + Tps)} * \left[\omega_{ref} - \omega_s\right]}{\left[1 + Rp + \frac{RtTrs}{1 + Trs}\right]}$$

$$\frac{Y}{\omega_{ref} - \omega_s} = \frac{\frac{ks}{s(1 + Tps)}}{1 + Rp + \frac{RtTrs}{1 + Trs}}$$

The block diagram of a typical hydro turbine governing system suitable for stability analysis is shown in Figure below

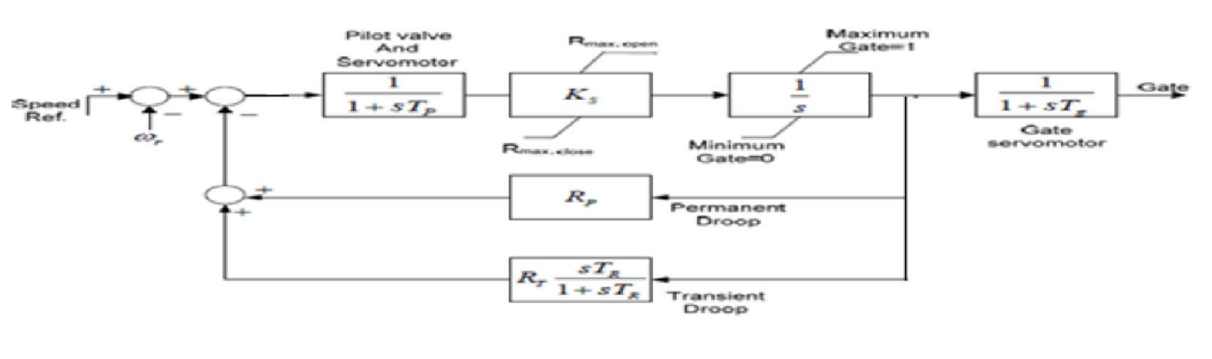


Fig 3.11: Block diagram of a typical hydro governing system for system stability analysis

As the pilot valve and servomotor time constant T_P is several times smaller than the time constants Tg and T_R, it may be neglected. Finally, by rearranging the above transfer function and assuming the gain Ks=1, we will get the following transient droop transfer function

$T.F = \frac{TrS+1}{Tr\left(\frac{Rt}{Rp}\right)S+1}$……………………………………………………………………………(3.37)

and for gate servomotor, the transfer function is given as

$T.F = \frac{1}{1+TgS}$……………………………………………………………………………… (3.38)

T_r=reset time constant, R_P-permanent droop, R_T-transient droop, T_P-time constant for pilot servo motor and Tg-time constant for gate servomotor.

3.6 Tie Line Model

The transmission lines that connect an area to its neighboring area are called tie-lines. Power sharing between two areas occurs through these tie-lines. Load frequency control, as the name signifies, regulates the power flow between different areas while holding the frequency constant. 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 an alteration in frequency and because of which the desired frequency is regained. The two area interconnected system shown below. It consists of tie line reactance Xtie. For load-frequency studies, each area may be represented by an equivalent generating unit exhibiting its overall performance. Such composite models are acceptable since we are not concerned about inter machine oscillations within each area.

Figure 3.12(b) shows the electrical equivalent of the system, with each area represented by a voltage source behind an equivalent reactance as viewed from the tie bus. The power flow on the tie line from area 1 to area 2 is: $\mathbf{P12 = \frac{E1\times E2}{XT} Sin(\delta1 - \delta2)}$ … … … … … … … … … … … … … … .. $\mathbf{(3.17)}$

Linearizing about an initial operating point represented by $\boldsymbol{\delta1 = \delta10\ and \delta2 = \delta20}$, we have

$\mathbf{\Delta P12 = T\Delta\delta12}$ … … … … … . … … … … … … … … … … … … … … … $\mathbf{(3.18)}$

Where $\Delta\boldsymbol{\delta}12=\Delta\boldsymbol{\delta}1-\Delta\boldsymbol{\delta}2$, and T is the synchronizing torque coefficient given by

$\mathbf{T = \frac{E1\times E2}{XT} Cos(\delta1 - \delta2)}$ … … … … … … … … … … … … … … … … … .. $\mathbf{(3.19)}$

A positive ΔP12 represents an increase in power transfer from area 1 to area 2. This in effect is equivalent to increasing the load of area 1 and decreasing the load of area2; therefore, feedback of ΔP12 has a negative sign for area 1 and a positive sign for area 2.

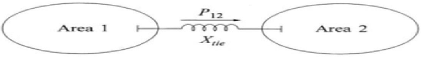
$$\boldsymbol{\Delta P12 = -\Delta P21} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{3.20})$$

By considering the relationship between area power angle and frequency

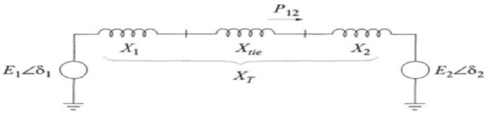
$$\boldsymbol{\Delta P_{tie12} = 2\pi T_{12}\left(\int \Delta f1 - \int \Delta f2\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{3.21})$$

Using the Laplace transform

$$\boldsymbol{\Delta P_{tie12} = \frac{2\pi}{s} T12\big(\Delta f1(s) - \Delta f2(s)\big)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{3.22})$$



(a) Two-area system



(b) Electrical equivalent

Fig 3.12 Two area system and its electrical equivalent

From Figure 4.12, we can see that the tie-line power error is the integral of the frequency difference between the two interconnected areas.

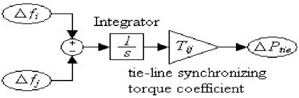


Fig 3.13: Block diagram of the tie-lines

The steady state frequency deviation (f-f$_0$) is the same for two areas, for a total load change of ΔP_L

$$\boldsymbol{\Delta f = \Delta\omega 1 = \Delta\omega 2 = \frac{-\Delta PL}{\left[\frac{1}{Req1}+\frac{1}{Req2}\right]+D1+D2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{3.23})$$

Consider the steady state values following an increase in area one load by ΔP_{L1}

For area 1 we have

$$\boldsymbol{\Delta P_{m1} - \Delta P_{12} - \Delta P_{L1} = \Delta f * D1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (\mathbf{3.24})$$

And area two

$$\Delta P_{m2} + \Delta P_{12} = \Delta f * D2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.25)$$

The change in mechanical power depends on regulation. Hence,

$$\Delta P_{m1} = -\frac{\Delta f}{R1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.26)$$

$$\Delta P_{m2} = -\frac{\Delta f}{R2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.27)$$

By substituting of equations 3.22 and 3.23 on 3.20 and 3.21 respectively, we get

$$\Delta f\left(\frac{1}{R1} + D1\right) = [\Delta P_{12} + \Delta P_{L1}] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.28)$$

And

$$\Delta f\left(\frac{1}{R2} + D2\right) = \Delta P_{12} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \ldots\ldots\ldots\ldots.. (3.29)$$

By solving the equations 3.26 and 3.27 simultaneously:

$$\Delta f = \frac{-\Delta P_{L1}}{\left(\frac{1}{R1}+D1\right)+\left(\frac{1}{R2}+D2\right)} = \frac{-\Delta P_{L1}}{B1+B2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.30)$$

$$\Delta P_{12} = \frac{-\Delta P_{L1}\left(\frac{1}{R1}+D1\right)}{\left[\left(\frac{1}{R1}+D1\right)+\left(\frac{1}{R2}+D2\right)\right]} = \frac{-\Delta P_{L1}(B2)}{B1+B2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \ldots\ldots\ldots (3.31)$$

Where, B1 and B2 are the composite frequency response characteristics of area 1 and 2, respectively. The above relations are depicted in figure below:

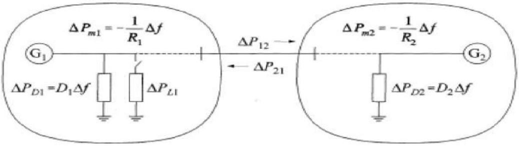


Fig 3.14: Effect of load change in area 1

An increase in area 1 load by [illegible] in both areas and a tie line flow of [illegible]12.a negative [illegible] is indicative of flow from area 2 to area 1.the tie line flow deviation reflects the contribution of the regulation characteristics ($\frac{1}{R}$+D) of one area to another.

Similarly, for a change in area 2 load by $\Delta PL2$

$$\Delta f = \frac{\Delta P_{L1}}{\left(\frac{1}{R1}+D1\right)+\left(\frac{1}{R2}+D2\right)} = \frac{-\Delta P_{L2}}{B1+B2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.32)$$

$$\Delta P_{12} = -\Delta P_{21} = \frac{\Delta P_{L2}(B1)}{B1+B2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.33)$$

The above relationship forms the basis for the load frequency control of interconnected system. Area Control Error: To maintain a net interchange of power with its area neighbors, an AGC uses real power flow measurements of all tie lines emanating from the area and subtracts the scheduled interchange to calculate an error value. The goals of ALFC are not only to cancel frequency error in each area, but also to drive the tie-line power exchange according to schedule. Since the tie-line power error is the integral of the frequency difference between each pair of areas, if we control frequency error back to zero, any steady state errors in the frequency of the system would result in tie-line power errors. Therefore, we need to include the information of the tie-line power deviation into our control input. The net power interchange, together with a gain, B (MW/0.1Hz), called the frequency bias, as a multiplier on the frequency deviation is called the Area Control Error (ACE) given by

$$\mathbf{ACE_i = \sum_{j=1}^{n} \Delta Ptieij + Bi\Delta fMW} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.34)$$

Where: BI is the frequency response characteristic for area I,

$$\mathbf{B = \frac{1}{Req} + D}$$

Area control error for the two interconnected area are given by

For Area One

$$\mathbf{ACE1 = \Delta P_{12} + B1\Delta f} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.35)$$

For Area Two

$$\mathbf{ACE2 = \Delta P_{21} + B2\Delta f} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.36)$$

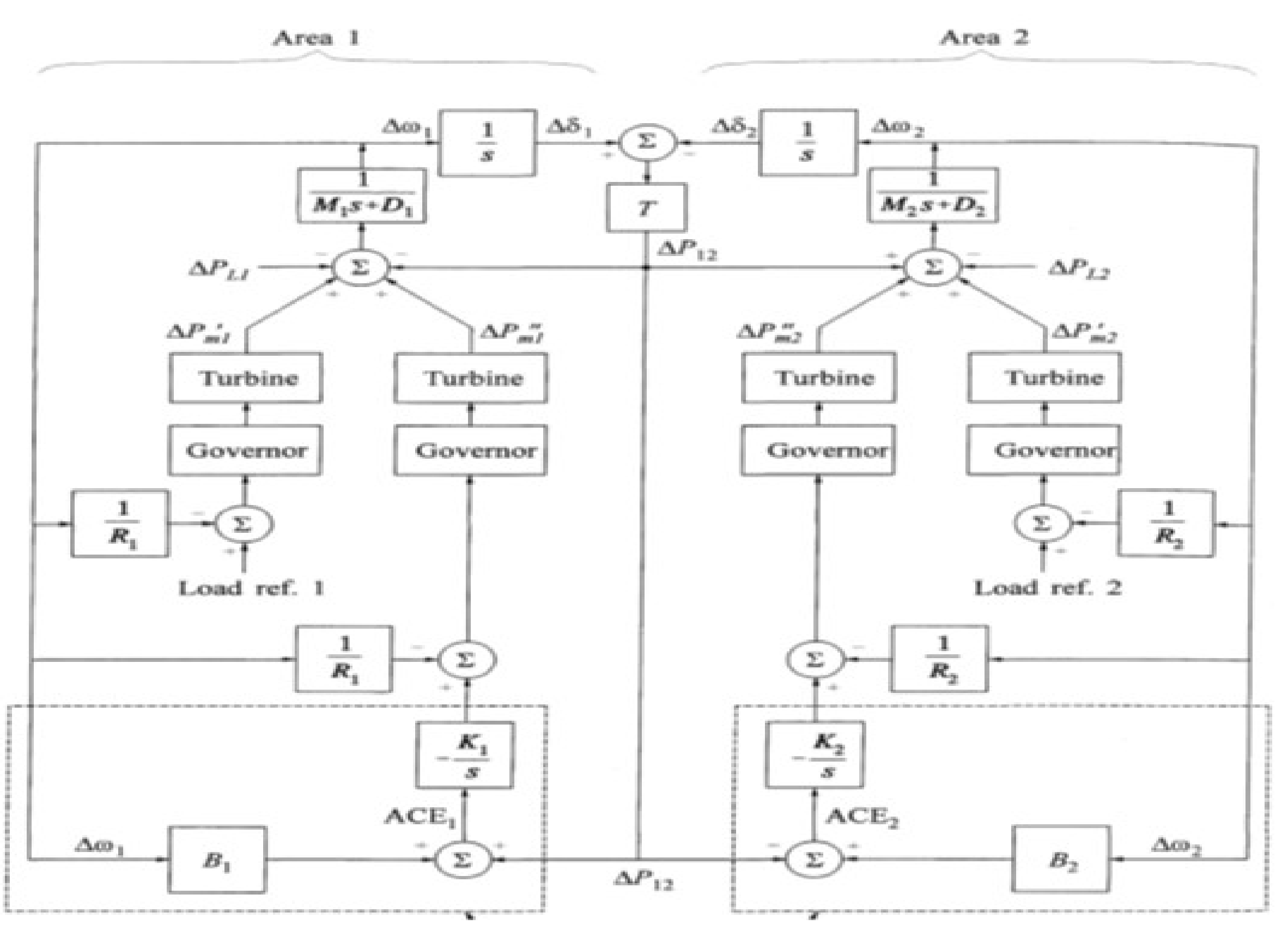


Fig 3.15: Block diagram of two area system with supplementary control;

3.7 Case Study Analysis

In this part we want to analyze a sample case study for two areas interconnected system with primary and supplementary automatic control in which LFC control are applied. The two areas are to have a total generating capacity of 900MW, with spinning reserve capacity of area one 150MW and area two 200MW. The following parameters are considered for each area.

Area One

The Generation capacity of area one is 400MW

The Load connected to area one is 500MW

Load variation of area one is 1% for 1% change in frequency D=1

Nominal frequency=50HZ,

5% change in frequency cause for 100% change in power output

Spinning reserve capacity =150MW spread uniformly over 400MW.

Water time constant, Tw=1sec

Time constant for gate servomotor, TG=0.2sec

Inertia constant, M=6

Area Two

Generation capacity of area two is 500MW

The load connected to this area is 400 MW

Load variation for area one is 1% for 1% change in frequency D=1

Nominal frequency=50HZ,

4% change in frequency cause for 100% change in power output.

Spinning reserve capacity of area two is 200MW spread uniformly over 500MW.

Water time constant, Tw=1sec

Time constant for gate servomotor, Tg =0.3sec

Inertia constant, M=5

For Area One

Droop regulation for area one

R1=Δf/Δp=5%/100%=**0.05**, i.e. both droop regulations has a value of 5% or 0.05

Therefore for one area system with the two units,

1/Req1=1/R1+1/R2=1/0.05+1/0.05=20+20=40,here:R1=R2=5%=0.0.05.

Because of two equivalent parallel machines.

Req1= R1*R2/ (R1+R2) = (0.05*0.05)/0.05+0.05=0.0025/0.1=0.025/1=**0.025**.

Deq1=D11+D12=2, frequency bias factor of area one is given by B1=1/Req1+Deq1=1/0.025+2=**42**

A 2.5 percent total droop of 550MW generating capacity (including spinning reserve of 150 MW) in area one corresponds to 1/Req1 = (1/Reqt1)*(Pgt1/fop) =1/0.025*550/50=**440MW/HZ**

, the equivalent inertia constant Meq=M11+M12=**12**,

The transient regulation is given by Rt=[2.3-(Tw-1)0.15]Tw/Meq=**0.1916** where Tw=1sec, and

The reset time constant is given by TR= [5-(TW-1)0.5] TW=**5**, at Tw=1sec Therefore for our single area system, the transfer function of

Generator and load Tf=1/ (Meqs+Deq1) =1/ (12s+2)

Turbine Tf= 1-Tws/ (1+0.5Tws) = (1-s)/ (1+0.5s)

Transient droop Tf = (TRs+1)/ [TR (Rt/Req1) s+1] = (5s+1)/ [5(0.1916/0.025) s+1] = (1+5s)/ (1+38s)

Governor Tf=1/ (1+Tgs) =1/ (1+0.2s)

For Area Two

Droop regulation for area two is:

$R2=\Delta f/\Delta p=$**0.04**, i.e. both droop regulation has a value of 4% or 0.04

Therefore for our single area system

$1/Req2=1/R1+1/R2 = (R1+R2) / R1*R2$, here $R1=R2=4\%=0.04$

$Req2= R1*R2/ (R1+R2) =0.04*0.04/(0.04+0.04)=$**0.02**

A 2 percent total droop of 700 MW generating capacity (including spinning reserve of 200 MW) in area two corresponds to $1/ Req2= (1/Reqt2)*(Pgt2/fop)=1/0.02*700/50=$700Mw/Hz $Deq2=D21+D22=$**2**

Frequency bias factor of area two is given by $B2= 1/Req+D=1/0.02+2=$**52**

The equivalent inertia constant $Meq2=M21+M22=$**10**

the transient regulation is given by $Rt=[2.3-(Tw-1)0.15]Tw/Meq=$**0.23** and the reset time constant is given by $TR= [5-(Tw-1)0.5]$ $Tw=5sec$.Therefore for our single area system, the transfer function of

Generator and load	$Tf=1/ (Meq+D) =1/ (10s+2)$
Turbine	$Tf=\Delta T/\Delta x= 1-Tws/ (1+0.5Tws) =1-s/ (1+0.5s)$
Transient droop	$Tf=Trs+1/ [Tr (Rt/Req2) s+1] =5s+1/[5(0.23/0.02)s+1]=5s+1/ (57s+1)$
Governor	$Tf=1/ (1+Tgs) =1/ (1+0.3s)$

Total droop regulation due to 1250 MW generating capacity in the two interconnected area is

$1/Rtotal=1/ (1/R1) + (1/R2) = 440+700=$**1140MW/HZ**

Case I. load Loss of 100MW (0.1 p.u) in area one, and 1000MW is taken as base for all cases.

Load damping due to 400MW load (remaining after loss of 100MW load) in area one is

$Deq1=2*400MW/50Hz =$ **16 MW/HZ**

Load damping due to 400MW load (remaining after loss of 100MW load) in area two is

$D\ eq2=2*400MW/50HZ =$**16MW/HZ**

Total effective load damping of the two interconnected area is given by

$Deqt=Deq1+Deq2=16+16=$**32MW/HZ**

Change in system frequency deviation due to loss of 100MW load in area one is equal to

$\Delta f = -\Delta pL/ (1/Req+D\ eq =-\Delta pL/ [(1/Req1t+1/Req2t) +Deqt] = - (-100)/ (1140+32) =$**0.08532HZ**

Load changes in the two areas due to increase in frequency are

$\Delta PL1= Deq1\Delta f = 16MW/HZ*0.08532HZ=$**1.365MW**

$\Delta PL2= Deq2\Delta f = 16MW/HZ*0.08532HZ=$**1.365MW**

Generation changes in the two areas due to speed regulation are

$\Delta PG1 = -1/Req1\ \Delta f = -440*0.08532=$ **-37.54MW**

$\Delta PG2 = -1/Req2\ \Delta f = -700*0.08532=$ **-59.724MW**

The new load and generation power as follow

Area One

Load=500-100+1.365=**401.365MW**

Generation=400-37.54 =**362.46MW**

Area two

Load=400-0+1.365 =**401.365MW**

Generation = 500-59.724=**440.276MW**

The steady state frequency is **50.08532HZ**.this error is controlled by the primary control only since the load increase can be carried out by only the spinning reserve capacity of that area.

Case II: the generation Loss of 200 MW in area one, when the load is not carrying by the spinning reserve.

This is out of spinning reserve and at this limit area one is no longer able to control the error (could not be control). Therefore, supplementary control (secondary control) of area two is now able to control the ACE. Hence, $ACE2=B2\Delta f-\Delta P12=0$ or $\Delta P12= B2\Delta f$

But $B2=1/Req+D\ eq =1/0.02+2=52MW/0.1HZ=$**520MW/HZ**, $\Delta P12=B2\Delta$

There is a net reduction in system frequency. This cause a reduction in loads due to frequency sensitivity, area one load damping is $D1eq=2*500/50$ =**20MW/HZ**

The steady-state frequency deviation (f-fo) is the same for the two areas. The balance of generation loss in area one is made up by a reduction in load and tie power flow from area 2. Hence: $150= \Delta P21-Deq1\Delta f$ or $-150= \Delta P12+Deq1\Delta f$ since $\Delta P21= -\Delta P12$

Hence: $-150=20\Delta f+520\ \Delta f$ and $-150= [20+520]\ \Delta f$, $\Delta f= -150/520+20=$ **-0.277HZ**

The tie line power flow change, $P12= B2\Delta f=520(-0.277) = -144.44MW$ i.e. $P21=144.44$ mw, a negative $\Delta P12$ ($\Delta P21$) is indicative of flow from area 2 to area 1

Change in area one load is: $\Delta PL1= D1\Delta f =20(-0\ .277) =$ **-5.54MW**

Change in area two loads is: $\Delta PL2= D2\Delta f = 16(-0.277) =$ **-4.432MW**

The new load and generation area as follow

Area One

Load =500MW-5.54 MW =**494.46MW**

Generation=400-50MW =**350MW**

Area Two

Load=400MW-4.432MW =**395.568MW**

Generation=500-4.432+144.44MW =**640MW** ,the steady state tie line power flow from area two to area one is 144.44MW and the system frequency is 50HZ-0.277HZ=**49.723HZ**.

CHAPTER FOUR

SIMULATION RESULTS AND DISCUSION

We have tabulated the parameter specifications for the components from the sample case study we calculated under chapter three as following. Some constants such as frequency regulator/droop characteristics, different time constants and other parameters, which have not been calculated under the case study, are taken from IEEE standard nominal values. See in the appendix.

4.1 LFC Simulation and Results

We simulated in two cases, first case load Loss of 100MW in area one without the PID controller and with PID controller and the second case generation loss of 200MW in area one without the PID controller and with PID controller. The results are displayed and the difference of the system response is clear, and it is the expected response in each case.

4.1.1 LFC simulation without PID Controller

The AGC/LFC MATLAB block diagram and the responses without controller are shown below.

The common feature of the results is that the steady state error is very large, or it never comes to steady state rather it oscillates and deviates from the actual value. The system responses to the disturbance after certain time delay and it is impossible to correct the error as there is no way to adjust. The ultimate result for such power system areas is to trip out and load isolation which is unnecessary.

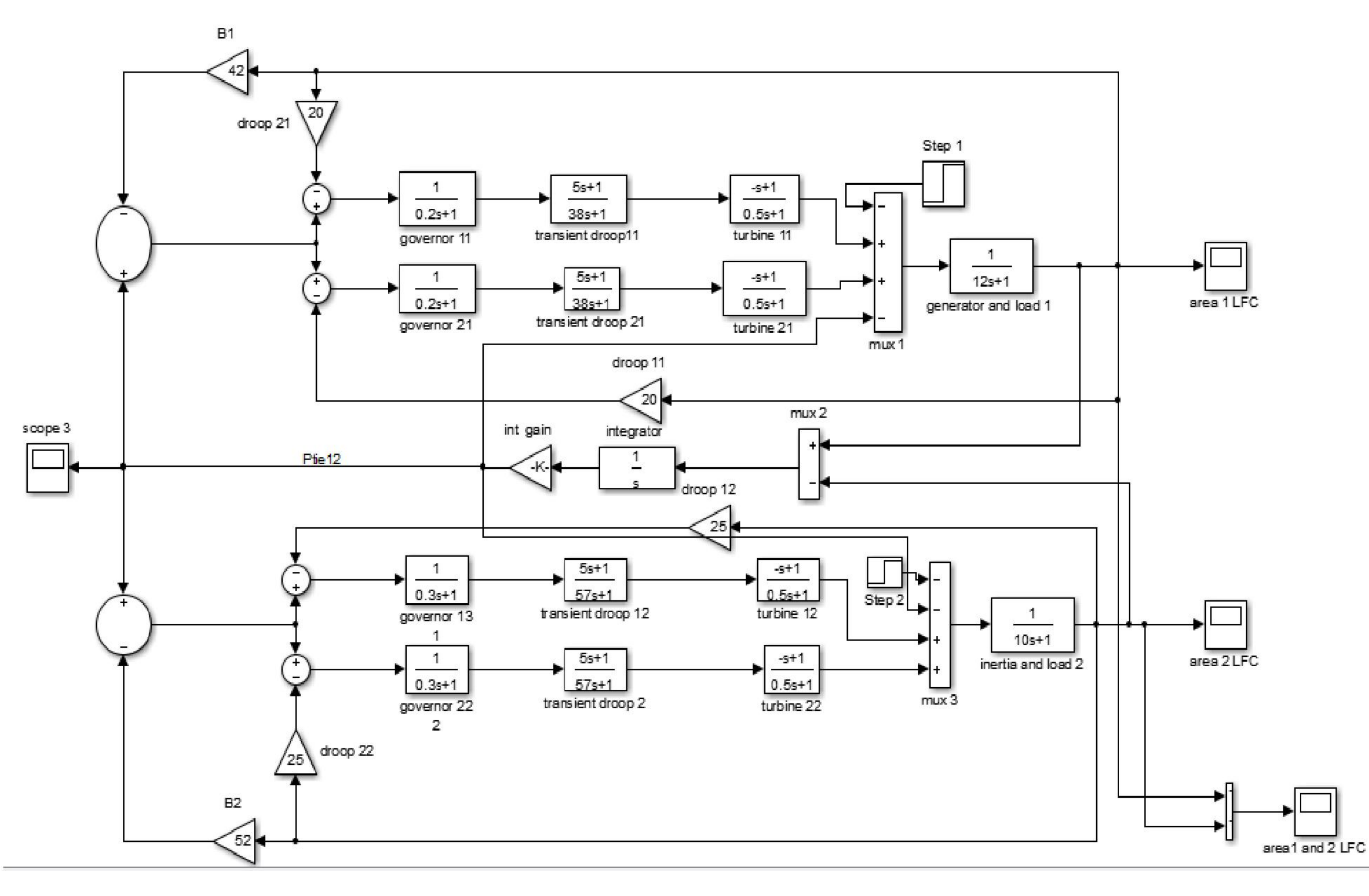


Fig 4.1: LFC simulation block diagram without PID controller.

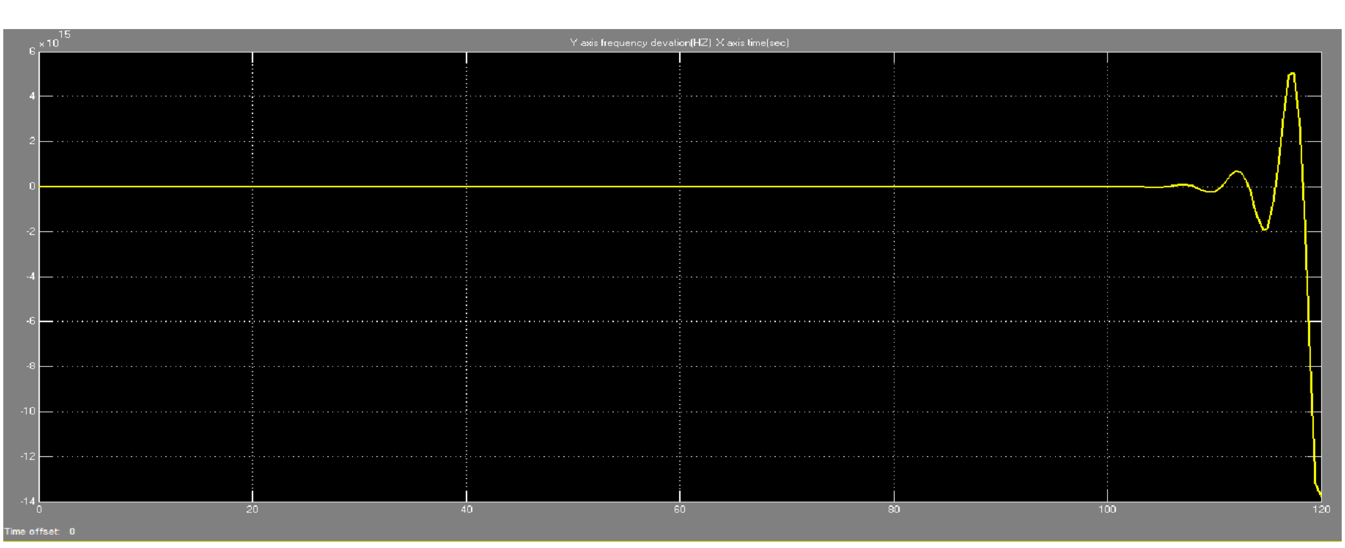


Fig 4.2 :Two area frequency deviations of Load loss 100 MW for Area I without PID controller.

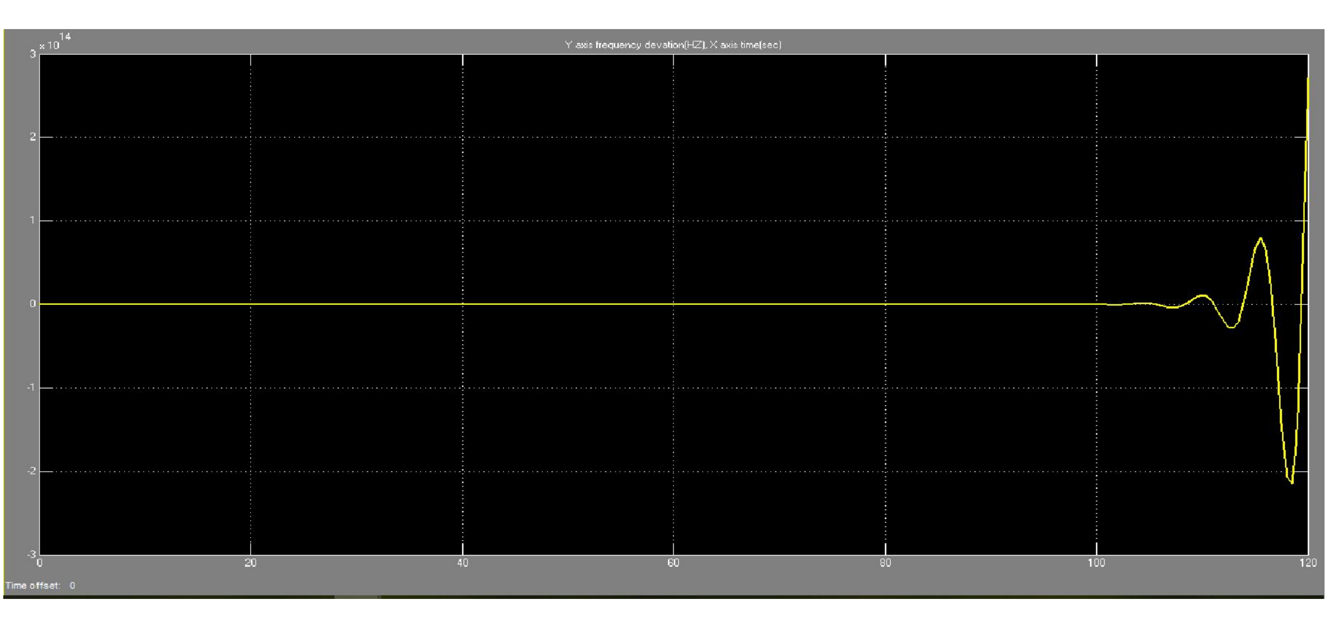


Fig 4.3: Two Area frequency deviations of Load loss 100 MW for Area II without PID controller.

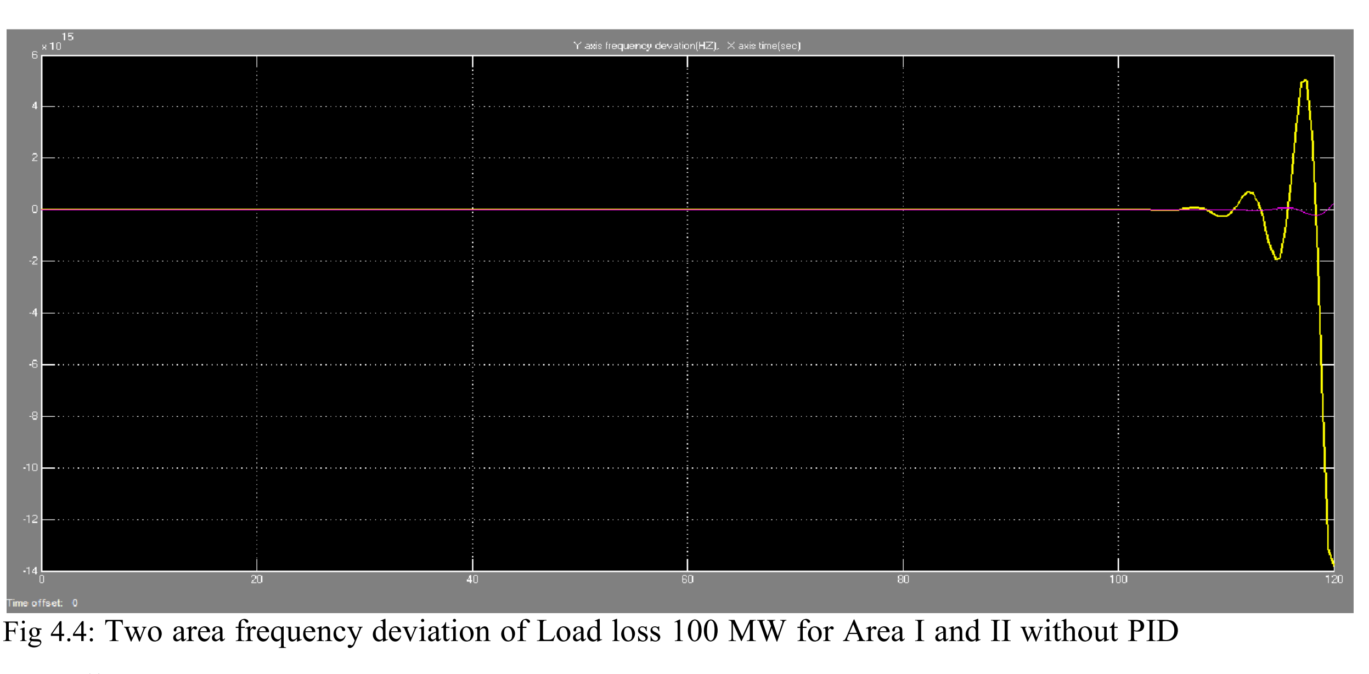


Fig 4.4: Two area frequency deviation of Load loss 100 MW for Area I and II without PID controller.

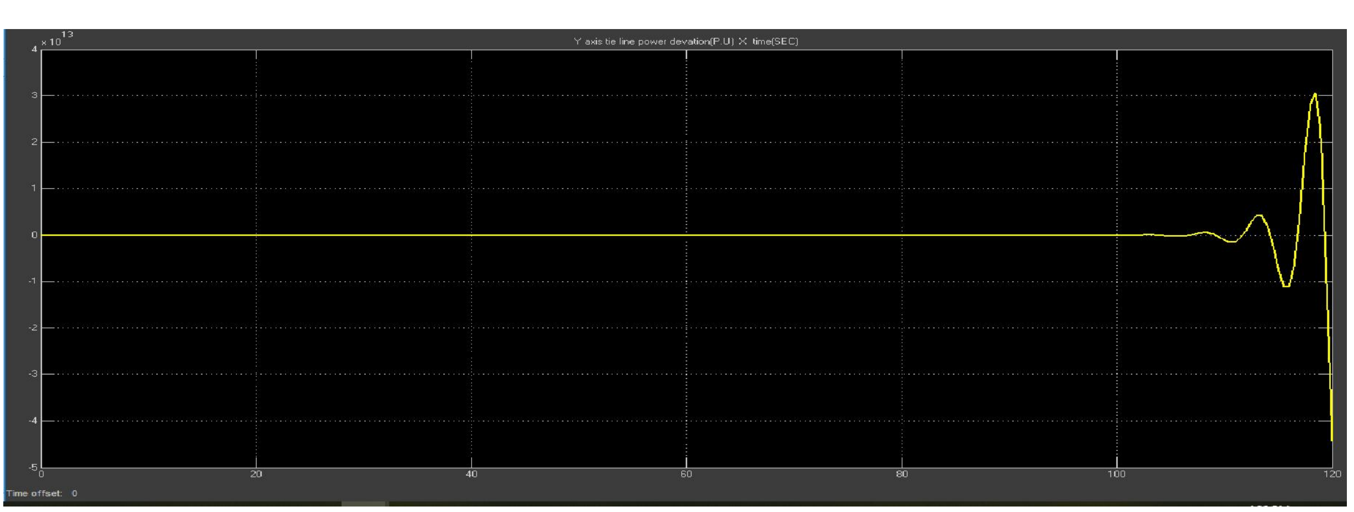


Fig 4.5: Two area tie-line power deviation of Load loss 100 MW for Area II without PID controller.

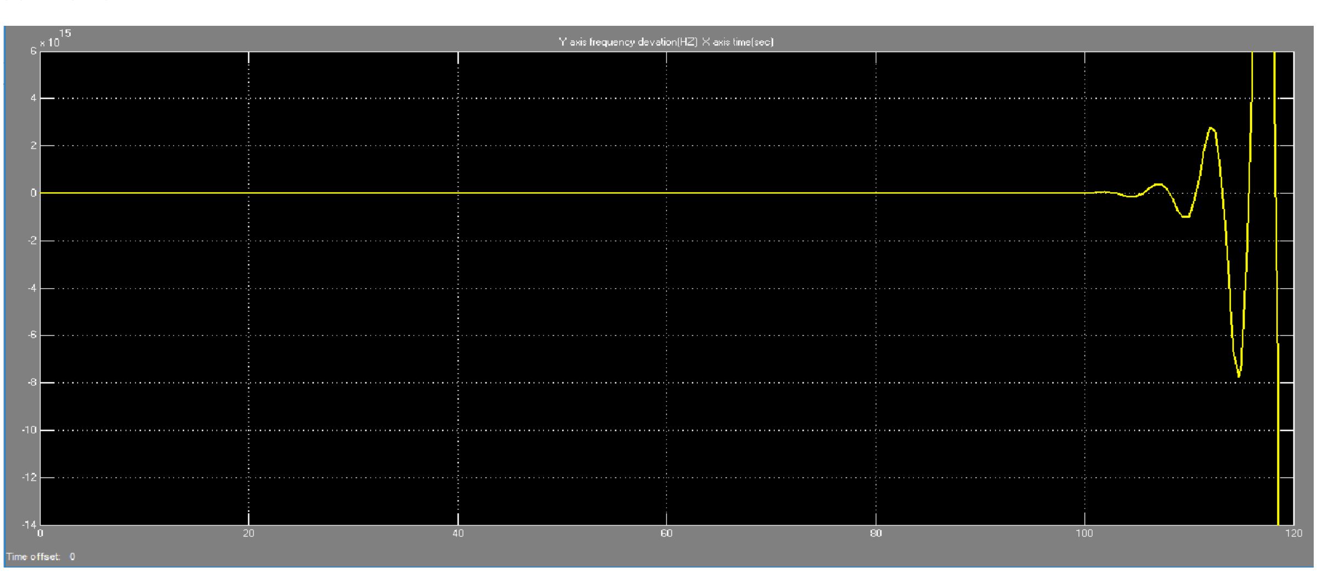


Fig 4.6: Two Area Frequency Deviation of generation loss 200MW for Area I without PID controller.

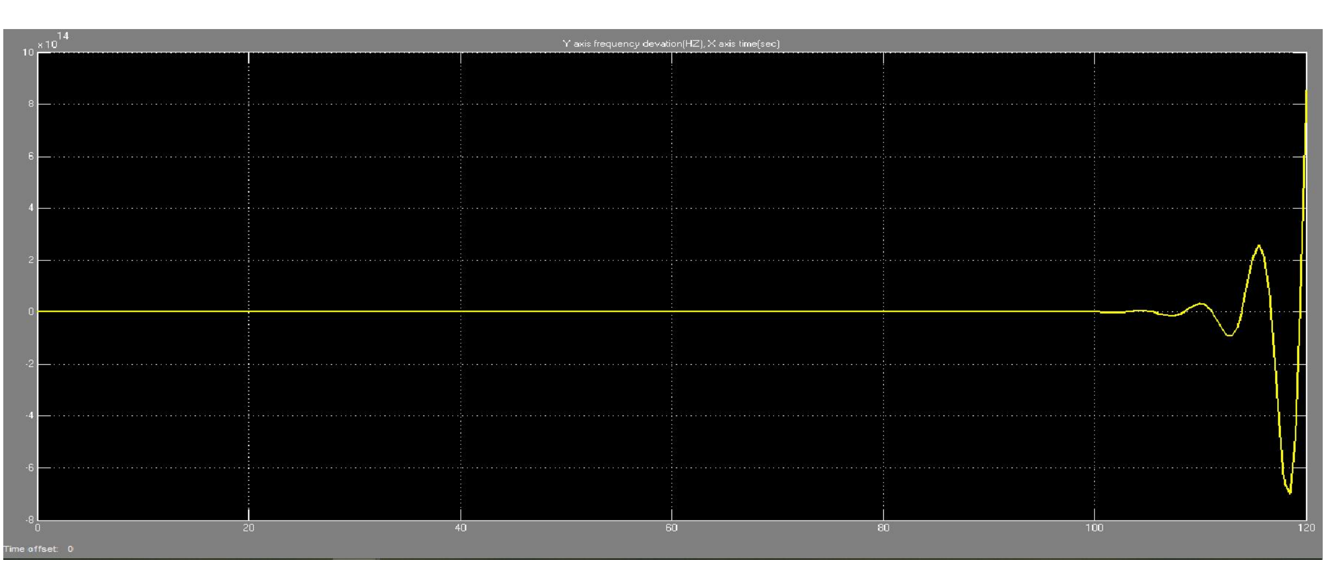


Fig 4.7: Two Area Frequency Deviation of generation loss 200MW for Area II without PID controller.

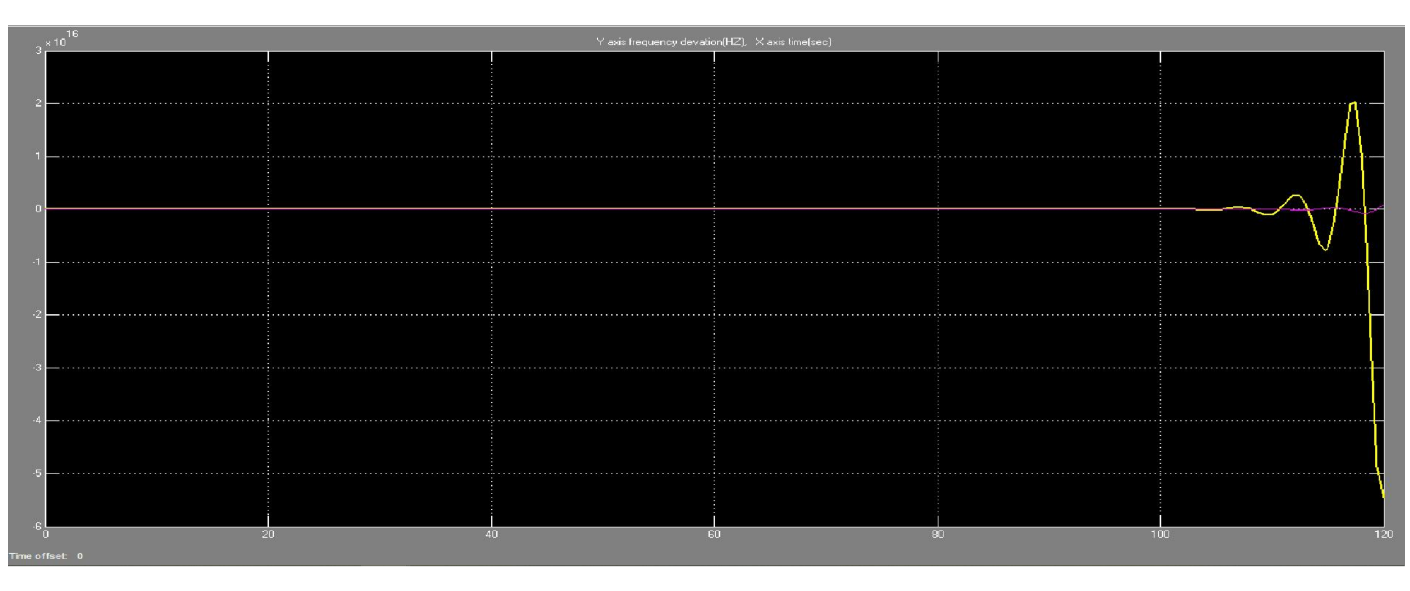


Fig 4.8: Two Area Frequency Deviation of generation loss 200MW for Area I and II without PID controller.

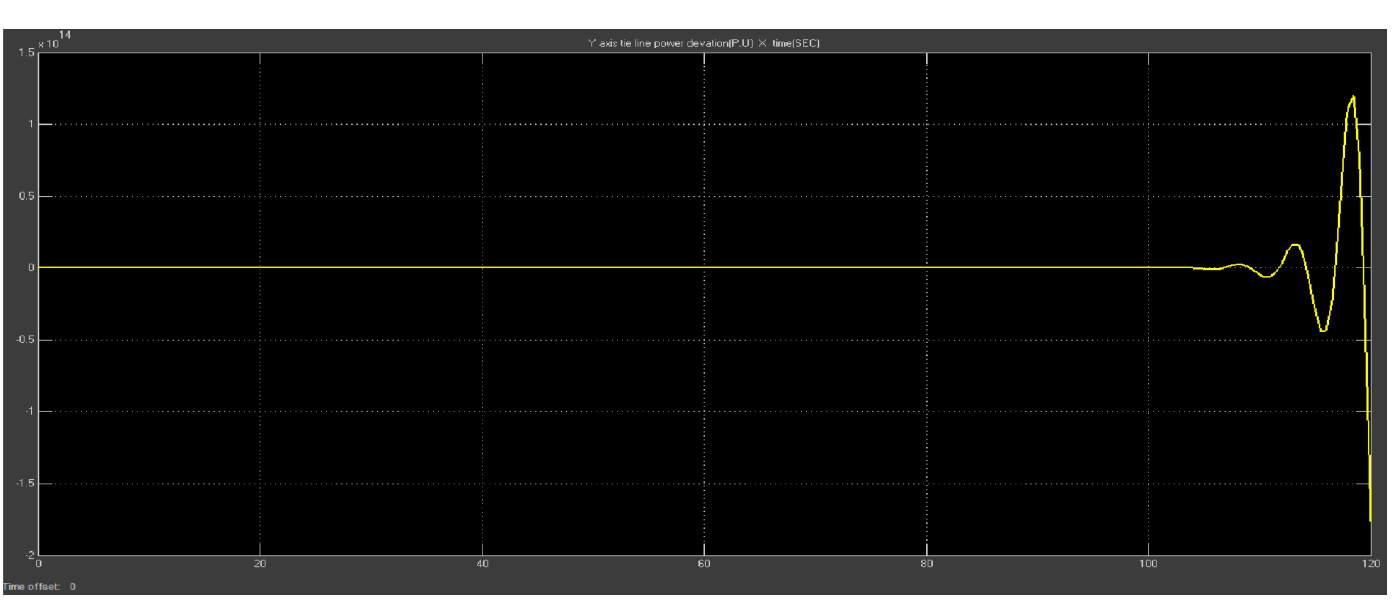


Fig 4.9: Two Area tie-line power deviation of generation loss 200 MW without PID controller.

4.1.2 LFC simulation with PID Controller.

The simulation block diagram for the LFC system with PID controller is given below. As shown in the system response, the controller has a great effect and it brings the system into stable state within satisfactory time response. The tuning mechanism for the controller is stepwise (try and error approach), and the values of the gain parameters of the controller that gave the compromised results in terms of system performance characteristics are given in the following table. PID controller parameter

Parameters	Area 1	Area 2
K P	0.2	0.2
KI	0.2	0.2
KD	0.4	0.5

Table 4.1 PID parameters used for LFC simulation

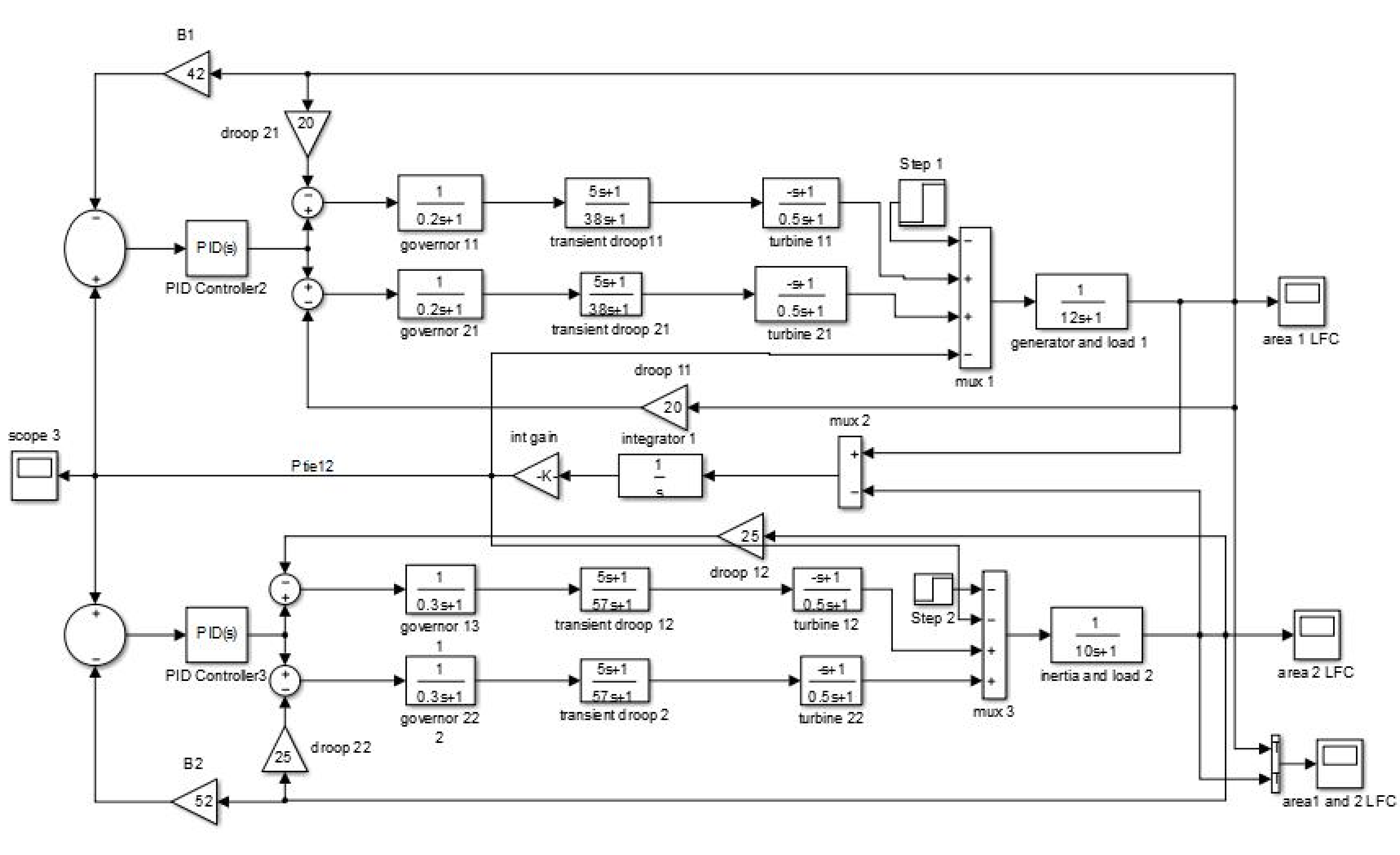


Fig 4.10: LFC simulation block diagram with PID controller

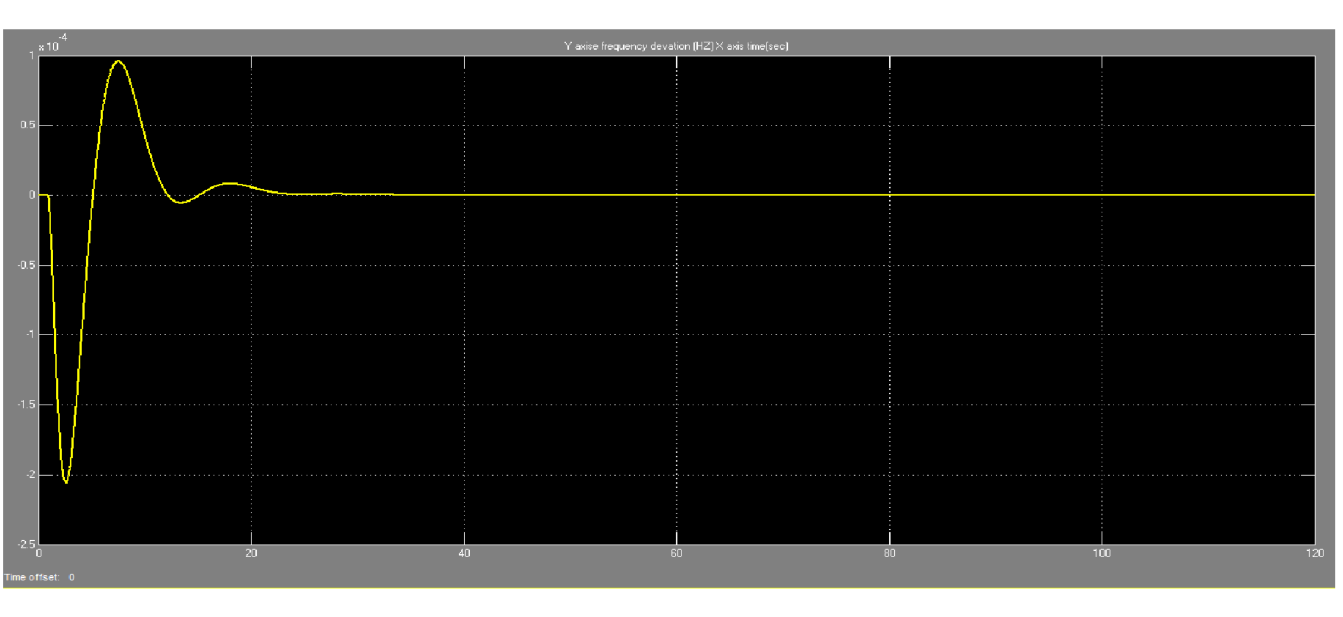


Fig 4.11: Two area frequency deviation of Load loss 100 MW for Area I with PID controller

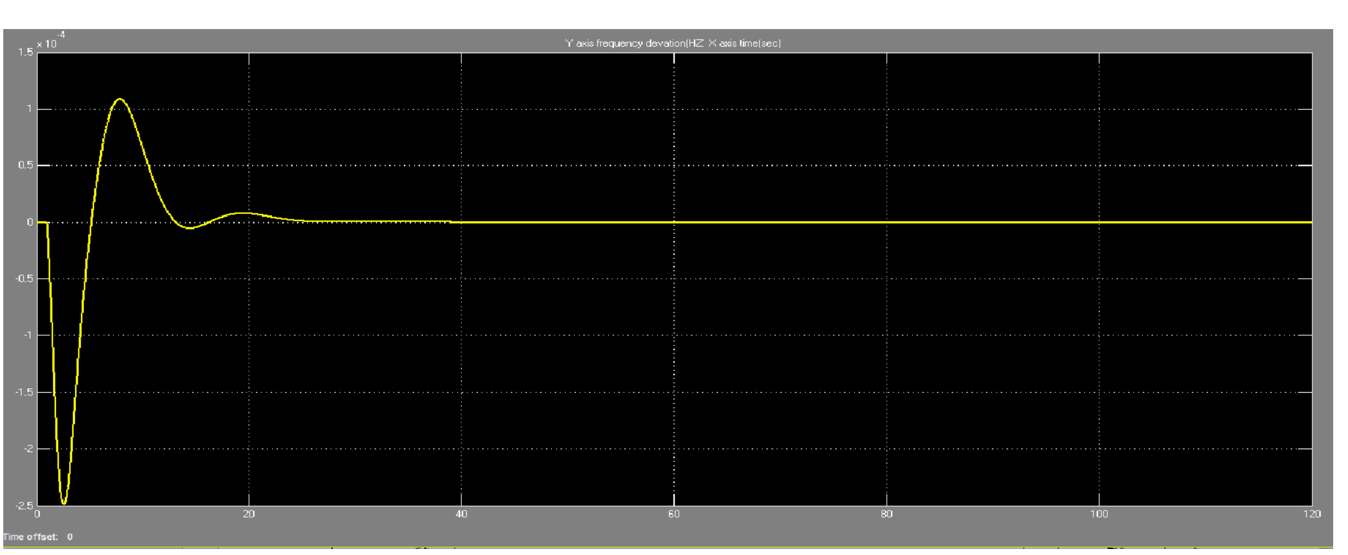


Fig 4.12: Two area frequency deviation of Load loss 100 MW for Area II with PID controller

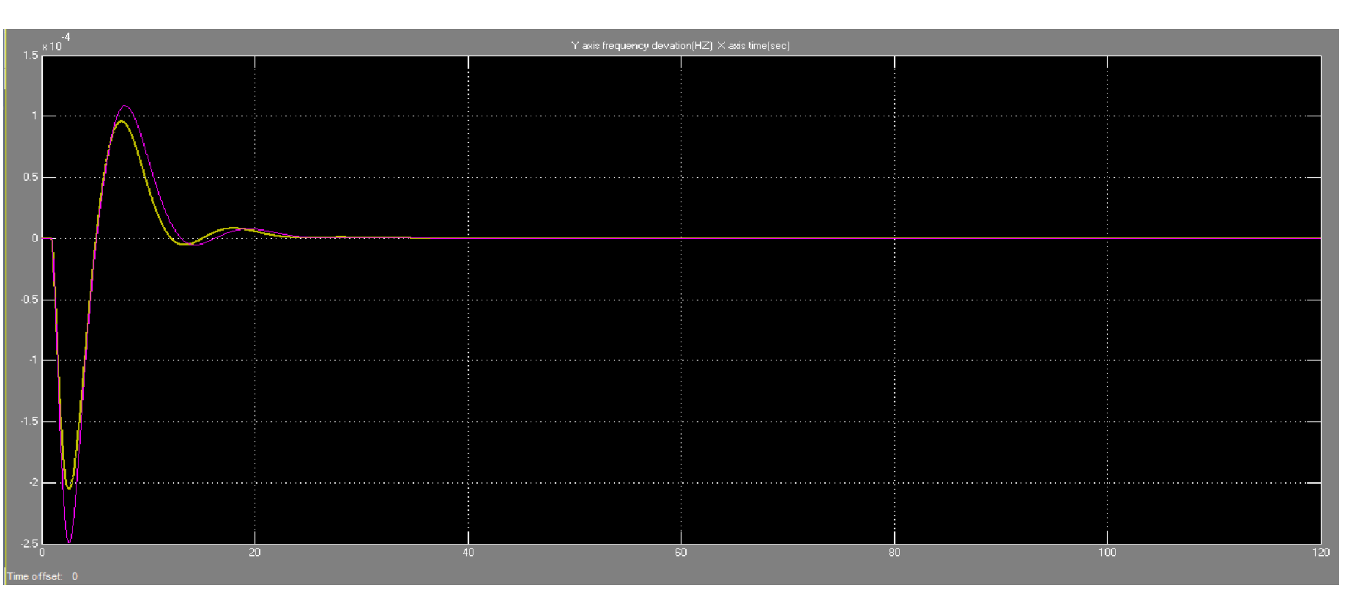


Fig13: Two area frequency deviation of Load loss 100 MW for Area I and II without PID controller.

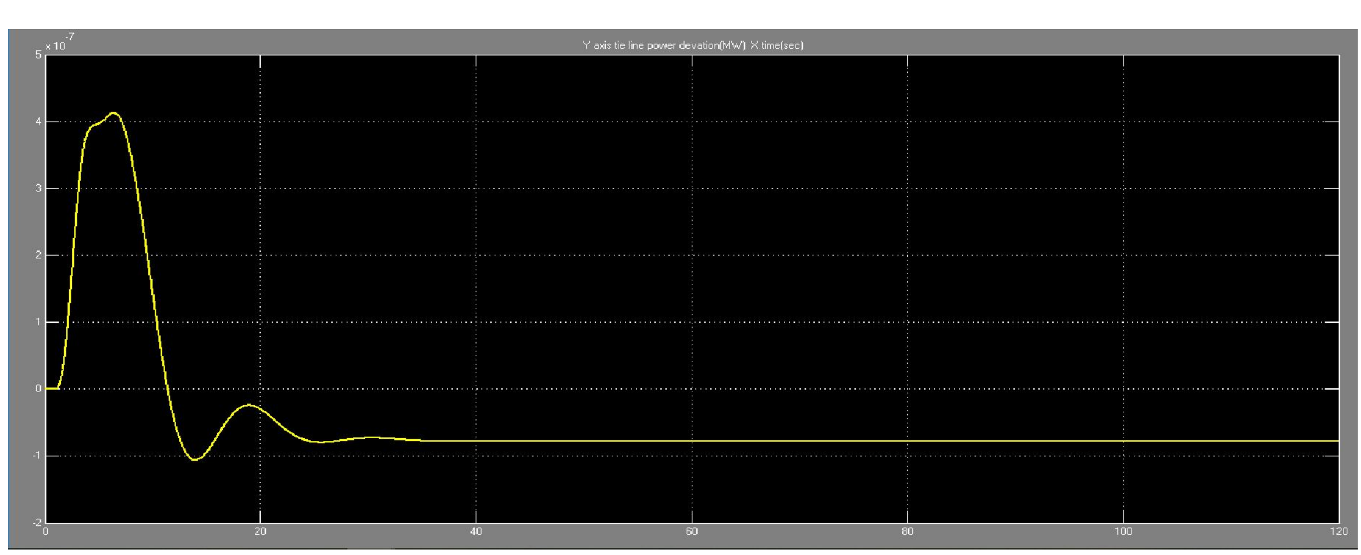


Fig 4.14: Two area tie-line power deviation for load loss of 100 MW with PID controller.

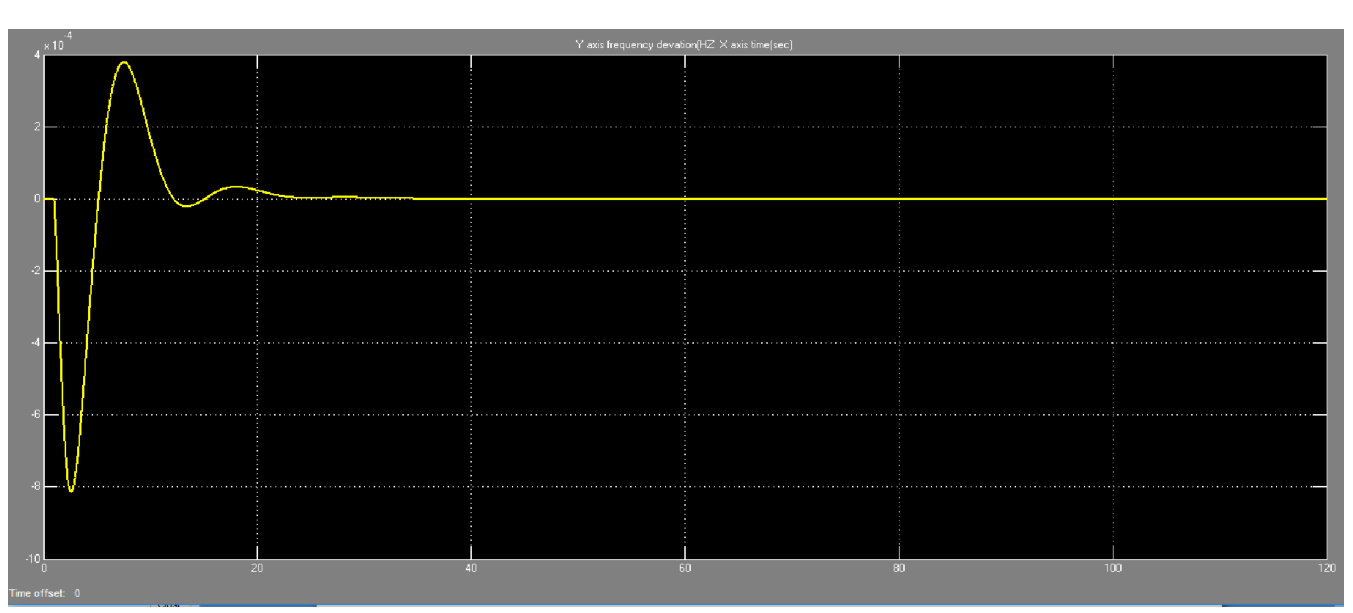


Fig 4.15: Two Area Frequency Deviation of generation loss 200MW for Area I with controller.

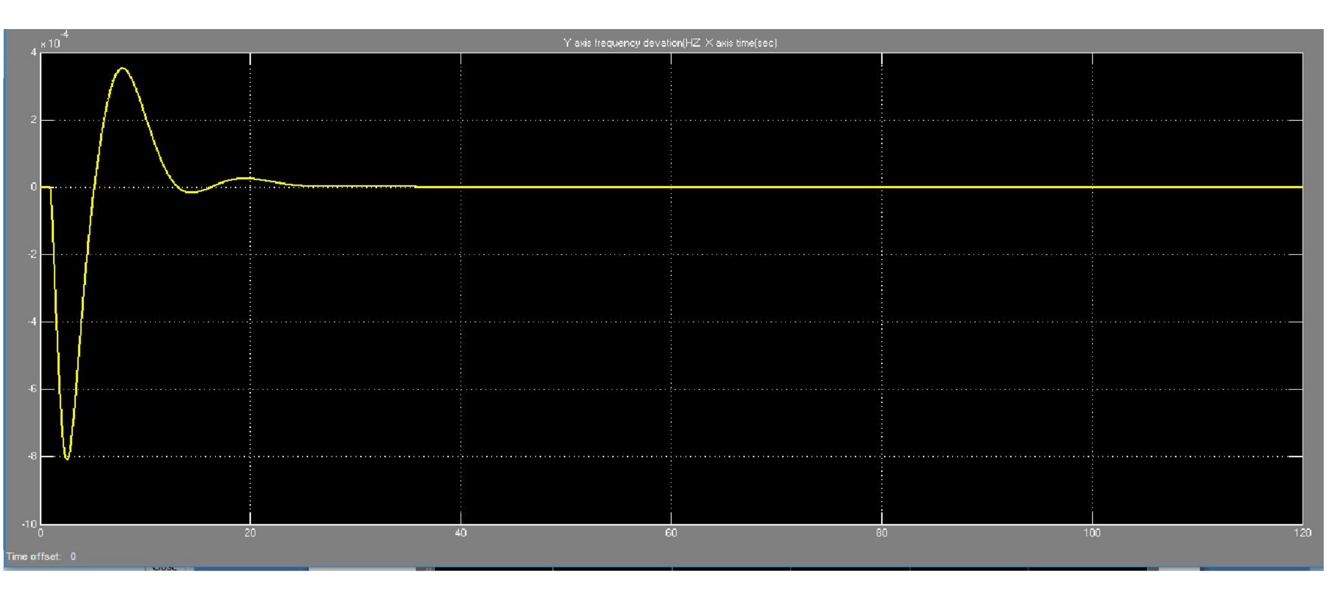


Fig 4.16: Two Area Frequency Deviation of generation loss 200MW for Area II with controller.

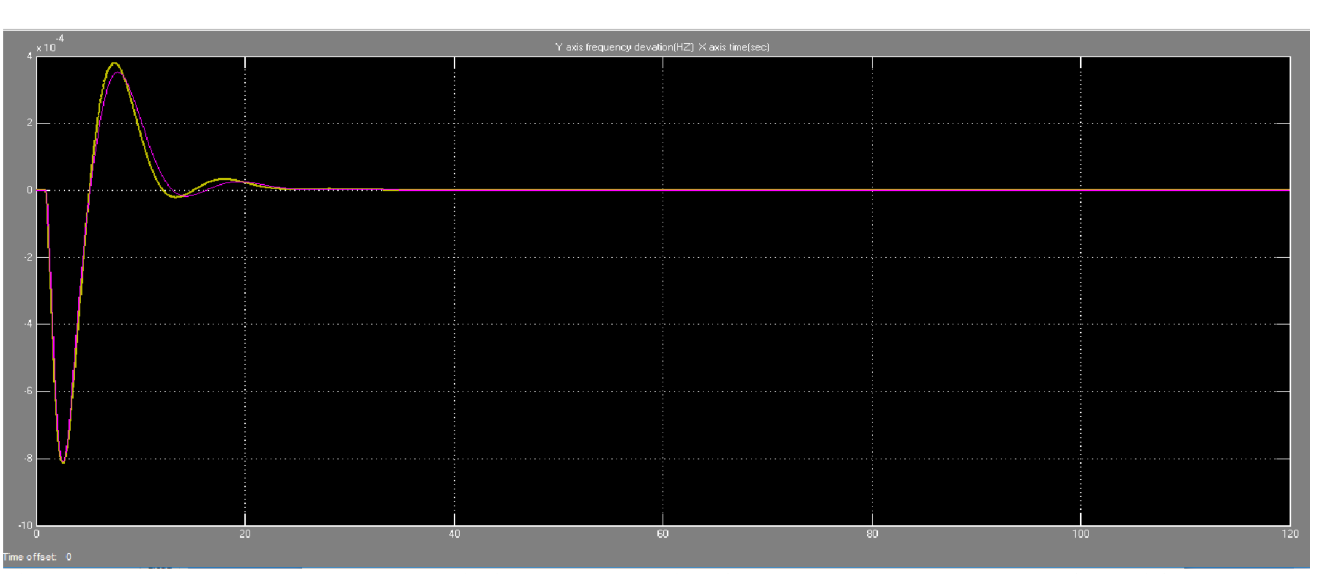


Fig 4.17: Two Area Frequency Deviation of generation loss 200MW for Area I and II with PID controller.

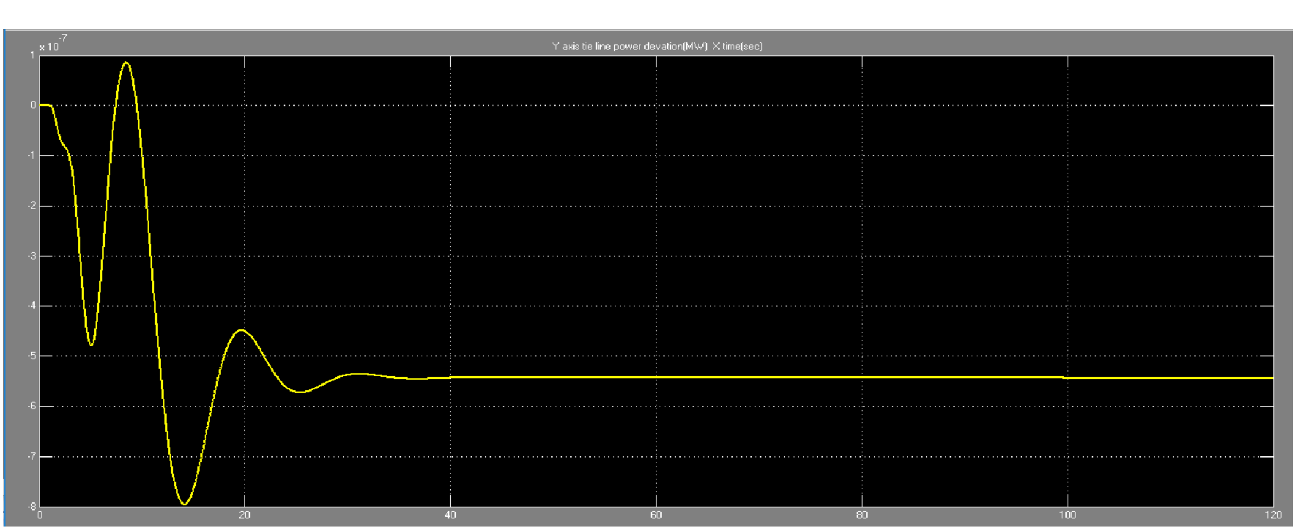


Fig 4.18: Two Area tie-line power deviation of generation loss 200 MW with PID controller.

4.2 Discussion and simulation result

The simulation has been conducted in Mat lab Simulink package for two area power system by using PID controller. Tie-line parameters for two area power system are described in Table (4.1) without controller and Table (4.2) with controller. The simulation models for two area power system without controller and with controller are shown in the above figures. In this paper the simulation performance of frequency deviation and rate of change of tie–line power flow for each areas are described. The results are shown in comparison with and without PID controller. This shows the output waveform of the system which describes the frequency deviation in terms of a sudden load change in each area. The (PID) controller is used to maintain zero steady-state errors for frequency deviation. Without using the (PID) control, the system cannot maintain zero steady–state error for long time. Before the PID controller is used in the system, the response was very poor almost in all performance characteristics, such as steady state error minimization, over or under shoot, delay of response, stability etc. A PID controller which can be adjusted or tuned to obtain desired control, was implemented to overcome such drawbacks in the voltage and frequency response of the system. The derivative action gives the controller the capabilities to improve transient response. The derivative action reduces overshoot and decrease oscillation around the set point. However, the PID controller is suggested for slow process, the purpose is to be free of noise. Fast processes (process with slow time constant) are very easily susceptible to produce noise.

(Fig 4.2, 4.3 and 4.4) and (Fig 4.11, 4.12 and 13) shows the comparison of frequency deviation for load change due to load loss 100MW of area 1 without and with PID controller respectively. When area 1 load loss 100MW without using PID controller the frequency deviations ($f1$= 50.08532HZ) occur in both two area, this frequency deviation $f1$=50.0852≈50HZ) nearly turns to stable. After using PID controller, There is no frequency deviation (f=50Hz) or (Δf=0.08532HZ). PID controller gives smooth performance and reduces steady state error to zero and finally turns to stable the neighboring areas.

(Fig 4.6, 4.7 and 4.8) and (Fig 4.15, 4.16 and 17) shows the comparison of frequency deviation for load change due to generation loss 200MW of area 1 without and with PID controller respectively. When area 1 generation loss 100MW without using PID controller the frequency deviations ($f1$= 49.723HZ) or (Δf2=0.-277HZ) occur in both two area, this frequency deviation $f1$=49.723HZ≈50HZ) nearly turns to stable. After using PID controller, There is no frequency deviation (f=50Hz).

Fig 4.5and fig 4.14 shows the comparison of tie-line power deviation for load loss 100MW in area 1 without and with PID controller respectively. And also Fig 4.9 and fig 4.17 shows the comparison of tie-line power deviation for generation loss 200MW in area 1 without and with PID controller respectively. When without using PID controller, the tie-line power deviation too much steady state error occur in both areas. It takes long time to be stable operation. After using PID controller, there are small power deviations among two area power systems. Short time runs to be stable operation. Tie-line power deviation turns to nearly zero steady state error. PID controller gives smooth performance and reduces tie-line.

And from simulation result we have seen that various time response of the output of the error signal or deviation frequency and power deviations for tie line in per unit i.e.: the range of time response of the output signal for simulation of LFC with PID control is given by: normal operating time is (0-1sec), disturbance time (1sec-aproximatly15.5sec), primary control(15.5sec-around 35sec)and secondary control(35sec-120sec) and for tie line disturbance is occur from 0 to around 40 second and then the power deviations' become constant and tend to zero.

CHAPTER FIVE

CONCLUSION, LIMMITATION, RECOMMENDATION AND FUTURE WORK

5.1 conclusion

In this project we have tried to control the frequency fluctuation in power system due to different disturbances in the system using PID controller. In power supply system, LFC is the basic systems to be concerned on in power system control. To do this we have worked in the MATLAB simulation software and it was very helpful and made the work easy. The results shown that by using this model more accuracy could be reachable in dynamic and in the steady state responses. The speed governor control loops should be considered as interacting loops when a complete study is done. Note that the choice of values for the governor regulation parameter R speed stabilizer gain has a significant effect on the damping of intersystem oscillations as well as area frequencies. The quality of power supply is determined by constant of frequency. The reliable power supply has the characteristics of minimum frequency deviation and response. The frequency response of LFC loop is interact with different proportional gains was analyzed. The LFC is used to maintain a zero steady state error and It can be concluded that PID controllers are used to minimize the frequency over shoot and transient oscillations with in a zero steady state error. But the control capability of such controllers is specified to disturbances that exist for moderate time most of the time. So, even though the PID controller is easy to design and less costly to incorporate in controlling of the LFC there should be devised another mechanism to control if it is believed that there may be such acute disturbance of frequency in the system and that may stay for long time relatively. In this study, the PID controller has been investigated for load frequency control of two area power system. The comparison of two area power system with and without PID controller is developed in MATLAB as shown above figures. The simulation result is shown that the control system gives smooth performance and is convenient in load frequency control. PID controller has been successfully applied to recover the system frequency to its nominal value and to control scheduled reference power of a generating unit in two area system. In this paper, the frequency variations and tie-line power deviation for two areas are described in the comparison of with and without controller. The performances of tie line flow in each area during load change are also presented as simulation result. PID control system is leading to a stable power system with zero steady state error. Modeling and simulation analysis of two area power systems are clearly described in this study.

5.2 Recommendation

In reliable power system, the automatic load frequency is essential. Many result papers are presented in this field for various design configuration, control methods and simulation results. Therefore, to develop the automatic load frequency control system, the conventional controller is essential. The PID controller has some weak points. These weak effects are such as taking long-time to reset the frequency and power deviation to its nominal value and getting too much variation error. To compensate these, other modern control techniques such as fuzzy logic controller, neural networks controller, genetic algorithm method and bee algorithm method are recommended for more reliable and more accurate results. The next better recommendation is to use optimal tuning method for parameter value selection and to study the second order and third order differential equations for the analysis of dynamic response of the interconnected power system.

Finally We have recommended to our department should prepare the appropriate materials for the appropriate work and initiate students to implement in hard ware to the future .And it should create awareness toward the students how they do their project and providing the appropriate information to their advisors how they advise and assists. Finally it should provide electrical materials which used for hard ware implementation.

5.3 limitation

The limitation of our project is time since this project need several time to accomplished effectively, perfectly and efficiently, so four months is not enough, because of the complexity and very broad concept contained specially data collection for acertain two specified and known generation hydro power plants are so difficult to gather their value or data of the plants of what we went is so seldom. Even though there is no obvious data generation hydro power plants near to our campus to shows the design and analysis and the general overview of the generation power plant concept of automatic generation control in two area power system, we were took case study, proper assumption and the remaining are taken from international electrical and electronic engineering (IEEE) nominal standard value.

And the next drawback is there is no adequate internet connection access of this university. Despite we have computer laboratory there is no continuous electric power in the university and surrounding towns.

5.4 Future work

PID controller has proved satisfactory system response due to its simplicity control structure and easy to adjust, but the disadvantage of such approach is the gain settings designed for particular operating conditions, is giving poor performance under different loading conditions.

Nowadays the technology in power system control is upgraded from day to day in an alarming case. The target of such improvements in control of power supply is to have reliable power and secured system at affordable cost. To have such power supply system, controlling of each parameter is in the system is paramount. This needs robotic control mechanism which can solve the drawback of the PID controller used in this project's the PID controller can be incorporated with other control mechanisms in order to have real time gain parameter setting of the PID controller for each momentary change of operating conditions in the system. This may be such as the addition of micro controller based operating system for such problems.

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APPENDICS

Parameter	Area 1	Area 2
Governor Speed regulation	R11 =R21= 0.05	R12 =R22= 0.04
Load damping constant(D)	D11=D21=1	D12=D22=1
Inertia constant(M)	M11=M21=6	M12=M22=5
Base power	1000MVA	1000MVA
Governor time constant	Tg11=Tg21= 0.2 sec	Tg12=Tg22= 0.3 sec
Turbine time constant(TR)	Tt11 =Tt21= 5 sec	Tt11 =Tt21= 5 sec
Transient regulation(RT)	Rt11=Rt21=0.19	Rt12=Rt22=0.23
Nominal frequency	f1 = 50 Hz	f2 = 50 Hz
Load	Δ PL1=5.54MW	Δ PL2 = 4.432MW
Load disturbance in per unit	(Δ PL1)p.u = 0.0054	(Δ PL2)p.u=0.00432

Appendix A: IEEE standard value of the Parameters used for LFC system.

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