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Load Frequency Control of Multi-Area Power System with PI Controller

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Abstract: The main objective of load frequency control (LFC) is to regulate the electrical power supply of multi-area power system network and change the system frequency and tie-line load. The load variation on a power system being unpredictable drifts in frequency and voltage from their nominal values resulting in loss of generation due to tripping of lines and even blackouts. Fluctuation is more in the single area system than two area systems because of variations in the load are handled by one area only. Variation in the frequency is made to be zero by using a secondary loop in both single areas in addition to two area systems. Three area systems also operate in a similar manner like that of two a rea system. Frequency and voltage drifts can be minimized and kept within tolerable limits by automatic generation control (AGC). LFC is utilized to minimize the transient deviations in these variables like area, frequency and tie-line power interchange) and to ensure their steady state errors to be zeros. Automatic generation control of a system consists of two parts; LFC and automatic voltage regulator (AVR). In this paper, a simulation study is carried out to understand the operation of load frequency controller by developing model in SIMULINK MATLAB.

Keywords: AGC; Tie line power; PI controller; One area; Two area; Three area power system; Load frequency control

I. INTRODUCTION

Power system is very complicated electric network, in which the distributed load is transferred over a large area [1]. In power system network the frequency variation due to load disturbances and causes the power quality problems with voltage and frequency [2]. In power system the load varies with respect to time, control these variations and maintain the stability the power system controllers are designed. Complexity has been increased in power system due to rapid development in the industries. To solve the complexity the control problem mainly has two divisions- one is based on the active power controlling the frequency; whereas other is based on reactive power regulating the voltage [3]. Active and the reactive power exist due to continuous variation in the loads. The main intention is keep the variation in frequency and voltage constant. Frequency is dependent on active power and voltage varies as

reactive power. Controlling of frequency and active power is commonly known as Automatic Load Frequency Control. ALFC deals with controlling generator real power output and its frequency. Other problem like parameters and model uncertainties are the major problem for a controller designer. For the stability of power system there should be a proper balance between the active power and the reactive power. A three phase AC current is used for the distribution of the electricity.

In case of imbalance, frequency and voltage adopt a finite value leading to instability in power system. So an enhanced controlling system is necessary to avoid all these variations and possession the voltage and frequency at their standard values. Since variation in the frequency and voltage is due to the combined effect of active and the reactive power [4]. Control issue is decoupled into two independent issues-one of active power and other is reactive power control. In order to achieve interconnected operation of a power system, electrical energy system must be maintained at a desired operating level characterized by nominal frequency, voltage profile and load flow configuration. This is achieved by close control of real and reactive powers generated through the controllable source of the system.

For efficient transmission and distribution proper balance of active and reactive power is essential otherwise the power system may enter into instability mode. As a result of the imbalance, the frequency and voltage levels will oscillate around the steady state values and settle down to a finite value after a long delay which is undesirable for stability. Thus a control system is essential to cancel the effects of the random load changes and to keep the frequency and voltage at the standard values. Although the active power and reactive power have combined effects on the frequency and voltage, the control problem of the frequency and voltage can be decoupled; the frequency is dependent on the active power while the voltage is highly dependent on the reactive power. Thus the control issue in power systems can be decoupled into two independent problems; one is about the active power and frequency control while the other is about the reactive power and voltage control. In power system, load is not at constant then automatic frequency and voltage regulators are required at the generating stations to sustain a load. If any problems arise between generation and demand, causes the system frequency to deviate from scheduled value. Thus high frequency deviation may lead to system collapse. This necessitates an accurate and fast acting controller to maintain constant nominal frequency [5]. The limitations of the conventional controls- Integral, PI, and PID are slow and lack of efficiency in handling system nonlinearities.

II. BASIC STRUCTURE OF AUTOMATIC GENERATION CONTROL (AGC)

2.1. Governors

Governors are employed in power system for sensing the predisposition in frequency which is the result of the modification in load and eliminate by changing the turbine inputs such as the characteristic for speed regulation (R) and the governor time constant (T_g). If the varying in load occurs without the load reference then some part of the alteration can be compensated by adjusting the valve/gate and the remaining portion of the alteration can be depicted in the form of deviation in frequency. Governors are setup in the power system for detecting the partiality in

frequency which is the outcome of the alteration in load and then remove it by transmitting the turbine such as feature of the governor time constant and speed regulation. Governors are utilizing in the power system network to controls the velocity of turbine, controller, and increases frequency directive. The load is not constant; it changes according the demand. In case power is not consistent, it results in poor power quality. The supervision framework gives important conformity by monitoring the steam to the turbine [6] (Figure 1).

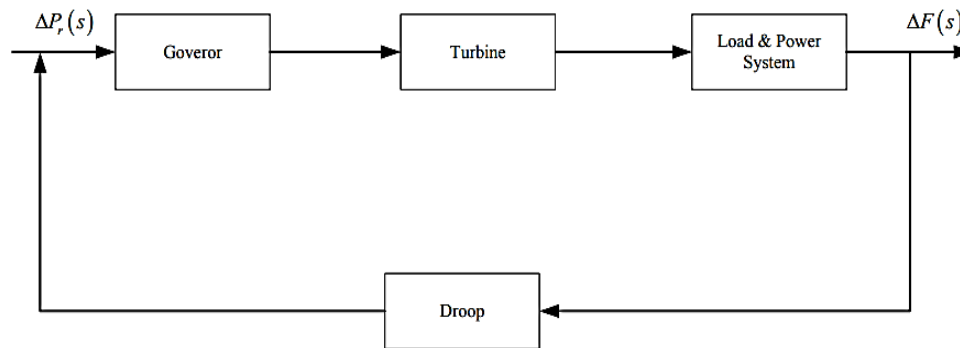


Figure 1: Basic structure of AGC.

2.2. Turbine

Natural energy is transformed with the help of turbines in the power system. A turbine is a rotational automated machine that expands steam and changes in to mechanical force ΔP_m which is suitably given to the generator. Three types of turbines are usually operated such as reheat, hydraulic and non-reheat turbines, which could be demonstrated and maintained by transfer function model [7]. Non-reheat turbines are presented in the form of first order-units where time delay occurs between the torque production and switching of the valve. The project of reheat turbine is finished by utilizing double-order elements as there change in then phase due to rise and fall in the density of the condensation. To stabilize, the hydraulic turbine needs temporary droop compensation in the governor.

2.3. Load

The power systems load establishes diversity of electrical devices. The loads that are resistive, for example lighting and also heating loads are not dependent on frequency, but the motor loads are responsive to frequency depending on the speed-load characteristics [8-10].

III. LOAD FREQUENCY CONTROL

Imbalances between load and generation must be corrected within seconds to avoid frequency deviations that might threaten the stability and security of the power system. The problem of controlling the frequency in large power systems by adjusting the production of generating units in response to changes in the load is called load frequency control (LFC) [11,12]. The Objectives of LFC are to provide zero steady-state errors of frequency and tie-line exchange variations, high damping of frequency oscillations and decreasing overshoot of the disturbance. The load frequency control of a multi area power system generally incorporates proper control system, by which the area

frequencies can be bring back to its predefined value or very nearer to its predefined value as the tie line power, when the sudden variation occurs in load.

IV. PI CONTROLLER

Most common utilized controllers are the proportional integral (PI) and proportional integral derivative (PID) controller [13]. The PI controllers are used to improve the dynamic response as well as to reduce or eliminate the steady state error [14]. The derivative controller adds a finite zero to the open loop plant transfer the function and improves the transient response. PI is made up of two main components i.e. proportional and integral. However the foremost standard controller are Proportional-Integral (PI) and Proportional Integral-derivative (PID) controller. PI controller are used in industries, quantitatively around 95%. In case of proportional controller, it has a head start output gain also the output response and desired response lies in between offset value.

The increasing proportional gain, offset can be reduced. PI controller offers the identical advantages of accelerated response due to P-action and the zero regular position error due to I action. The error signals are amplified, mixed and converted to a real power signal that controls the valve for generating a bulky signal [15]. PI-controller controller provides the doubly compensations of highest towards P-action and non-stable state error because of I-action. Through PI-control, improvement in the transient response can be observed and simultaneously steady state error can be taken to zero value.

V. MODELLING OF AUTOMATIC GAIN CONTROL (AGC)

AGC plays a significant role in the power system by maintaining scheduled system frequency and tie line flow during normal operating condition and also during small perturbations. Power system is a combination of generation, transmission and distribution networks and loads. The active and reactive power demands from different loads vary continuously. The change in real power demand affects the frequency while the change in the reactive power affects the voltage. The main constraint on a system is to keep the deviations of the frequency and the voltage constant. In an interconnected power system, as a power load demand varies randomly, both area frequency and tie-line power interchange also vary. Load frequency control has a control feature in the speed governing linkage mechanism. AGC , which have a speed governing linkage mechanism. In this mechanism if the generator speed is suddenly falls or exceeds to its nominal pre- specified value then the speed governor sense the speed of generator and it will adjust the steam water which is given to the turbine. Because ultimately the electromagnetic torque which produced by the turbine is regulated then the generator speed and output power become regulate to its normal value. The main aim of load frequency control is to minimize the transient variations in these variables and also to make sure that their steady state errors is zero.

The objectives LFC are to minimize the transient deviations in these variables (area frequency and tie-line power interchange) and to ensure their steady state errors to be zeros. When dealing with the LFC problem of power systems, unexpected external disturbances, parameter uncertainties and the model uncertainties of the power system pose big challenges for controller designer.

A. Single Area System with Primary Loop

Figure 2 shows the Automatic Load Frequency Control (ALFC) loop. Frequency is change with the load and discriminated with reference speed setting. The frequency can be set to the desired value by making generation and demand equal with the help of steam valve controller which regulate steam valve and increases power output from generators. It serves the primary purpose for balancing the real power through regulating turbine output (ΔP_m) according the variation in load demand (ΔP_o).

In Figure 2, ΔP_{ref} is the changing velocity reference placing and ΔP_o is the disturbance. ALFC is known as the primary ALFC feedback. It address the adjusting number one intention of actual energy stability by means of the rotary engine output ΔP_m to suit the change in load demand ΔP_o .

The transfer functions of the model of the single area system as shown in Figure 2. Is as below:

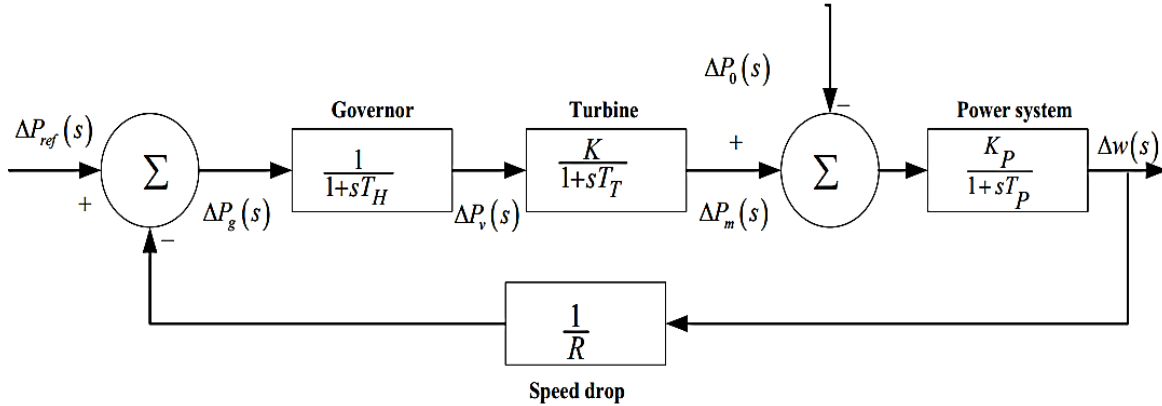


Figure 2: Transfer function diagram of one area ALFC with primary loop.

$$KG(s)H(s) = \frac{1}{R} \frac{1}{(2Hs + D)(1 + \tau_T s)(1 + \tau_g s)} \quad (1)$$

$$\frac{\Delta w(s)}{-\Delta P_L(s)} = \frac{1}{(2Hs + D) + \frac{1}{R}} \quad (2)$$

$$\Delta w(s) = -\Delta w(s)T(s) \quad (3)$$

In status no frequency-deviation load ($D=0$)

$$\Delta w_{ss} = (-\Delta P_o)R \quad (4)$$

From the above equations the steady state value of new system frequency which is less than the initial value. It make the frequency drift Δw to zero or to an acceptable value with the help of secondary loop for stable operation.

B. Single Area with Secondary Loop

Due to change in load there is change in the steady state frequency (Δw) so we need another loop apart from (Δw) primary loop to convey the frequency to the initial value, before the load disturbance occurs. The integral controller Which is responsible in making the frequency deviation zero is put in the secondary loop as shown in Figure 3.

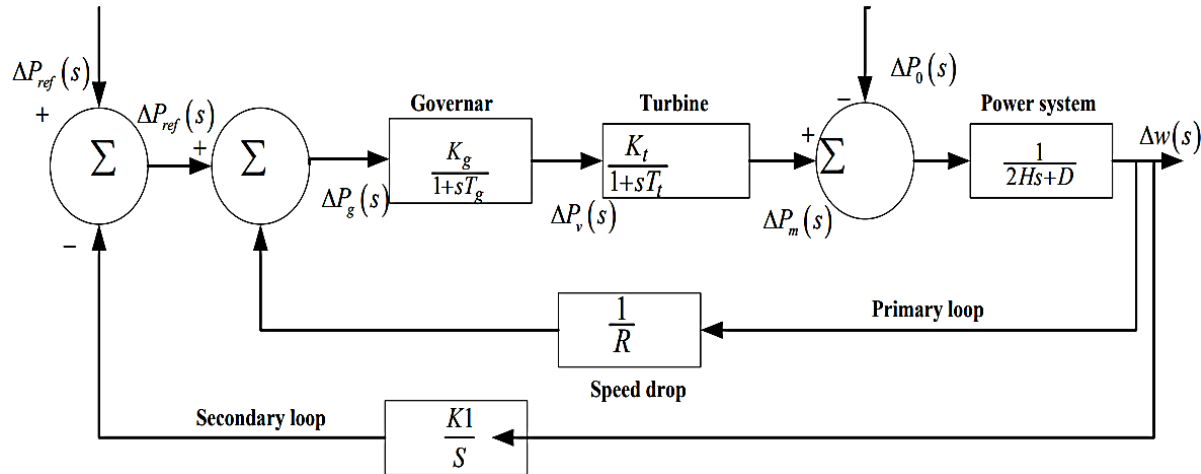


Figure 3: Transfer function diagram of one area with secondary loop.

In Figure 2 ALFC loop, the first part of initial energy insure to maintean the change in load demand to ΔP_o relate the turbine product ΔP_m . But a change in load results the frequency deviation Δw there is steady state, the frequency changed. In this future is met by basic contr0ller that form for frequency diversity reduced. AGC mutually the analytical feedback is commonly known as ALFC.

The integral group transfer function:

$$w = \frac{1}{D + \frac{1}{R}} (\Delta P_{ref} - \Delta P_o) \quad (5)$$

C. Double Area System with Primary Loop

This block is equal t0 the one area but the adding in ΔP_{12} . Consider that's difference in load ΔP_o area one, area two frequencies of adjust to steady state value shown in Figure 4. $\Delta w = \Delta w1 = \Delta w2$

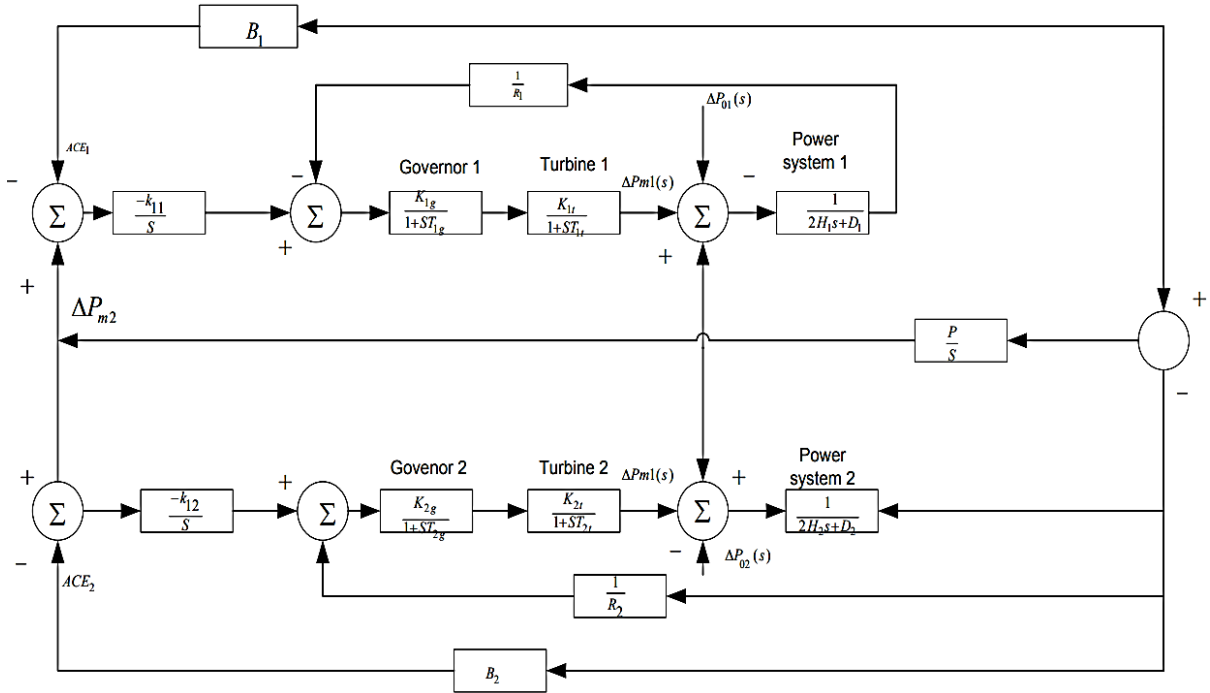


Figure 4: Two area system with primary loop.

Suppose in load change ΔP_o in area one. The frequency changing is the steady state equals all the areas. That is $\Delta w = \Delta w1 = \Delta w2$

$$\Delta P_{12} = \frac{-\Delta P_{o1} \beta_1}{\beta_1 + \beta_2} \quad (6)$$

When load increase in system, minimize the area frequency every system and dominant to charging of intrconnected line energy. If ΔP_{12} sign change then energy goes from system two to system one.

$$\Delta w = \frac{-\Delta P_{o2}}{\beta_1 + \beta_2} \quad (7)$$

$$\Delta P_{12} = \Delta P_{21} = \frac{-\Delta P_{o2} \beta_1}{\beta_1 + \beta_2} \quad (8)$$

D. Double Area with Secondry Loop

The secondary control basically restores balance linking all area load generation which is possible by maintaining the frequency at scheduled value. This is shown in Figure 5. Suppose there is a variation in load in area 1 then the secondary control is in area 1 and not in area 2 so area control error (ACE) is being brought to use when steady-state is reached and reference power set points, it will be zero. The secondary loop system initaly restores the value interconnected every system load generation and maintain the possible frequency at a right time. The area compromise for every system lead to consist of tie-line error and frequency will be linear combination.

In case of area1: $ACE_1 = \Delta p_{12} + \beta \Delta W$ (9)

In case of area2: $ACE_2 = \Delta p_{21} + \beta \Delta W$ (10)

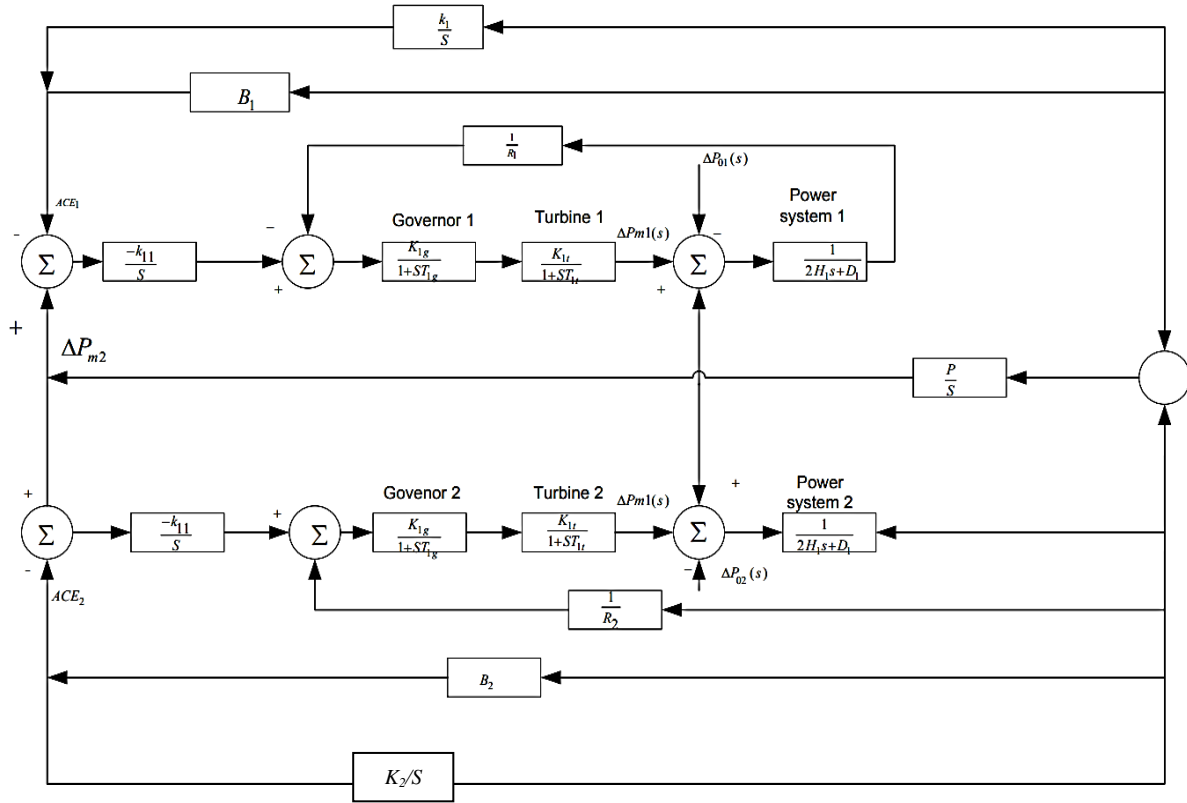


Figure 5: Two area system with secondary loop.

E. Three Area systems with Primary Loop

There is variation in steady state when vary in the load frequency (Δw) so that next feedback away from initial feedback to generate the frequency to the primary value. The system in 3 area system as to the 2 area system and shown in Figure 6. This proportion integral system that is lie in the multi area system. They tie-line power the interconnection make between the control system frequency change in the three areas is as follows:

$$\Delta F_1(s) = - \frac{R_1 K_p m_1}{\frac{K_p (s + K_i R_1)}{(sT_g + 1)(sT_p + 1)} + R_1 s (sT_t + 1)} \quad (13)$$

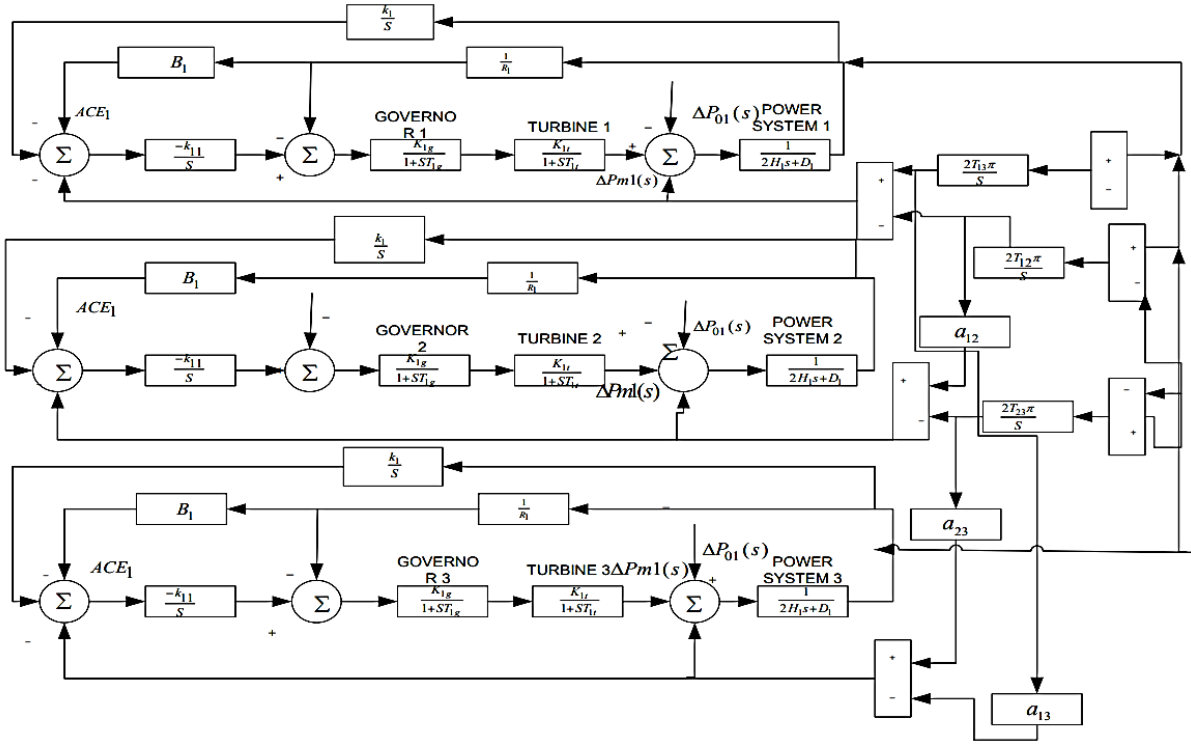


Figure 6: Three area system with primary loop.

The integral controller which is responsible in making the frequency deviation zero is put in the secondary loop. Three area interconnected system consists of three interconnected control areas. There is flow of tie line power as per the changes in the load demand due to the interconnection made between the control areas. Thus the overall stability of the system is maintained at a balanced condition in spite of the constant variations in the load and load changes.

$$\Delta F_2(s) = -\frac{R_2 K_p m_2}{K_p (K_{i1} R_2 + s) + R_2 s (s T_g + 1)(1 + s T t)(1 + s T p)} \quad (14)$$

$$\Delta F_3(s) = -\frac{R_3 m_3 K_p}{K_p (K_{i3} R_3 + s) + s R_3 (1 + T_g s)(1 + T t s)(1 + T p s)} \quad (15)$$

The tie-line power flow in between 3 areas system is as below:

$$\Delta p_{12}(s) = \frac{2\pi T^0}{s} [\Delta f_1(s) - \Delta f_2(s)] \quad (16)$$

$$\Delta p_{13}(s) = \frac{2\pi T^0}{s} [\Delta f_1(s) - \Delta f_3(s)] \quad (17)$$

$$\Delta p_{23}(s) = \frac{2\pi T^0}{s} [\Delta f_2(s) - \Delta f_3(s)] \quad (18)$$

F. Three Area System with Secondary Loop

The control in three area system is like the two area system and is shown in Figure 7. The integral control loop which is used in the single area system and two area system can also be related to the three area systems. Due to change in load there is change in the steady state frequency so we need another loop apart from primary loop to make the frequency to the initial value, before the load disturbance occurs.

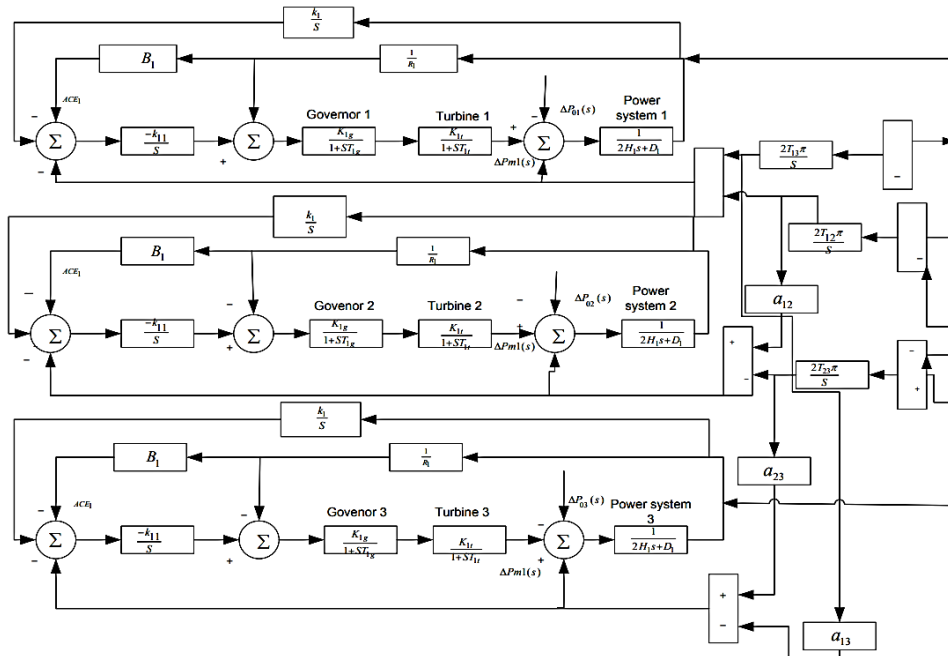


Figure 7: Three area system with secondary loop.

Three different areas are assumed to be equal. In case of interlinked system of different power, the quantities

$$p_{12} = -\frac{a_{r1}}{a_{r2}}, p_{23} = -\frac{a_{r2}}{a_{r3}} \text{ and } p_{23} = -\frac{a_{r1}}{a_{r3}}$$

VI. SIMULATION RESULT OF MULTIAREA SYSTEM

6.1. One Area with Primary Loop

Figure 8 shows that the change in load causes alteration in speed and that causes deviation in frequency.

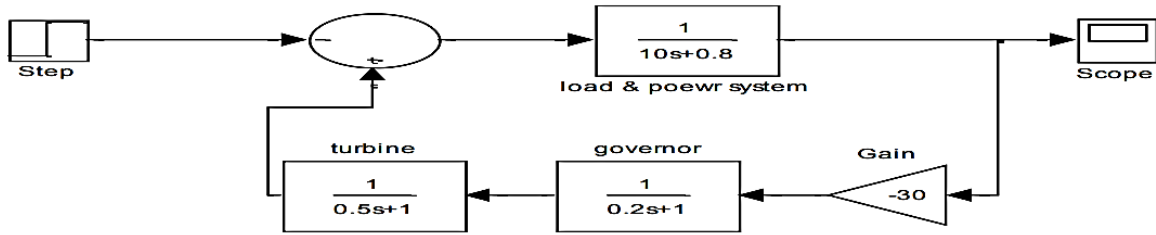


Figure 8: Single area with primary loop.

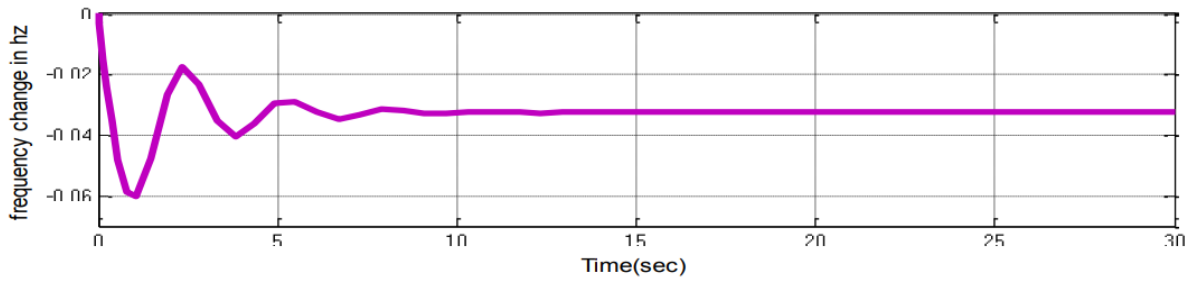


Figure 9: Frequency change ($\Delta\omega$) vs. time for one area with primary loop.

Figure 9 shows the deviation in load, leads to change in velocity which results in change in frequency. The frequency oscillation will slowly come down to limited value. The different parameters for selected frequencies is directed towards smaller parameters.

B. One Area with Secondary Loop

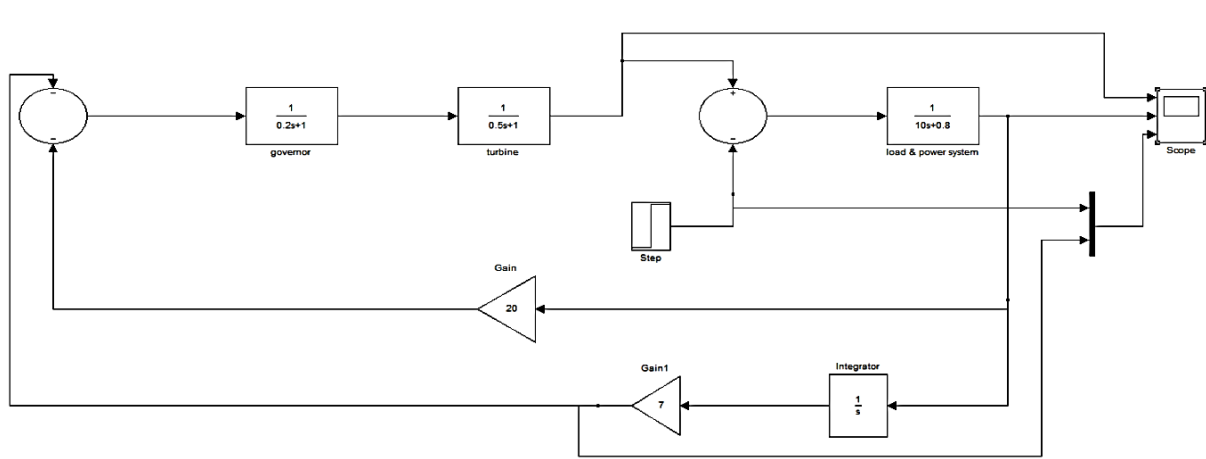


Figure 10: Simulink model of one area with secondary loop

The secondary loop which a single area system with an controller used gain to balance reference signal to adopted the signal to ΔP_{ref} turn around Δw to 0 (Figure 10). The simulation output of one space within the controller loop and therefore frequency is changes that are created 0 because of the controller loop (Figure 11).

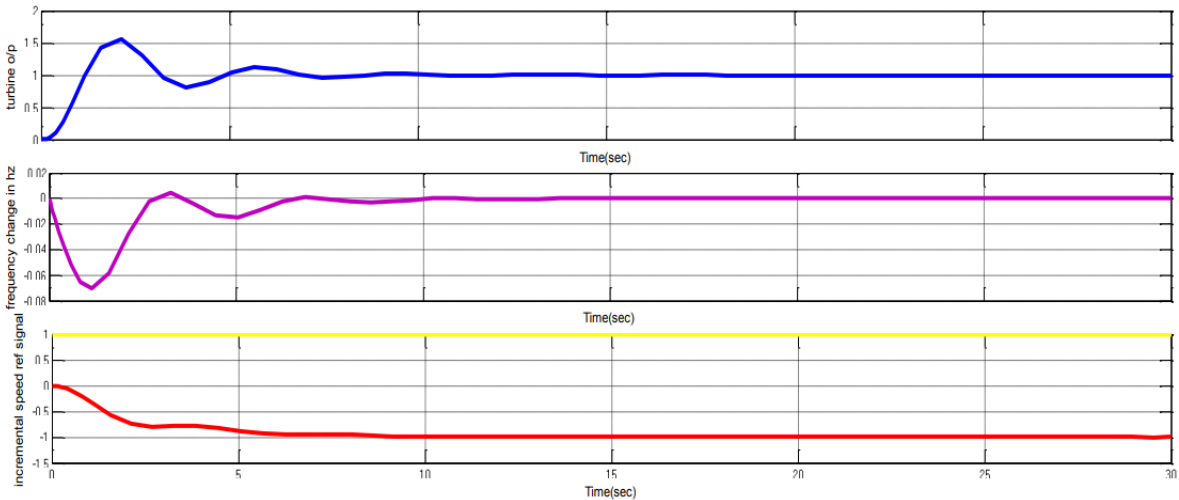


Figure 11: Simulation output of one area with secondary loop.

B. Double Area with Primary Loop

Figure 12 presents that the two systems are being interrelated so the drifts in the frequency of the two are liable to settle down to similar value soon after a few oscillations. The two mechanical inputs changes to minimize the inequality power connecting electrical load in area 1 as well as the mechanical inputs. Area 2 is capable to generate excessive power to distribute the variation in load in area 1.

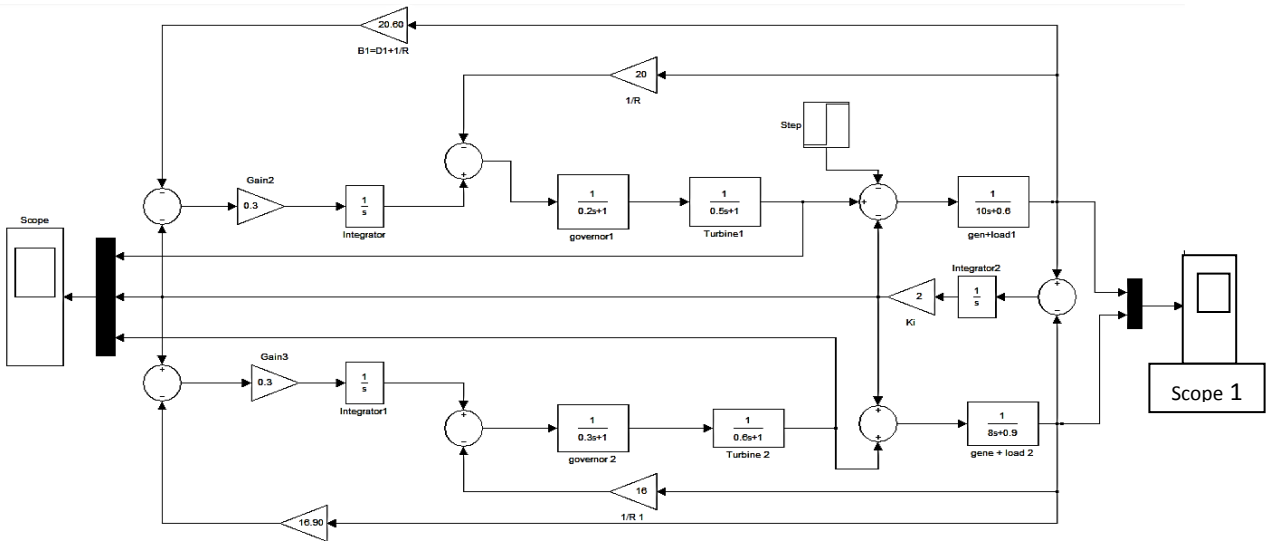


Figure 12: Simulation daigram of double area with primary feedback.

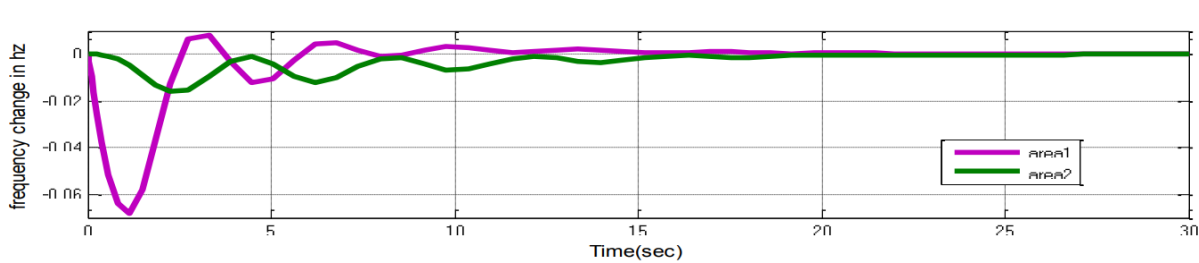


Figure 13: Frequency change vs. time.

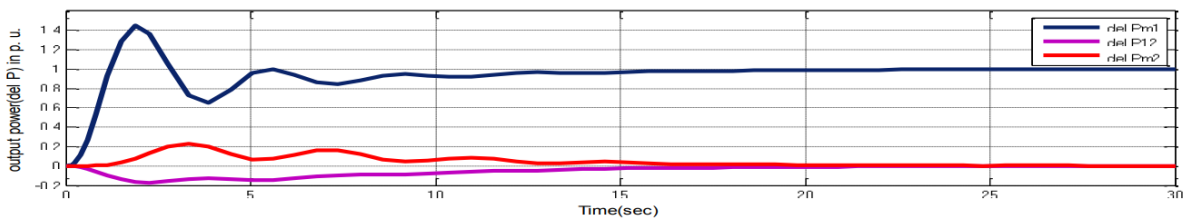


Figure 14: Output power deviation vs. time.

Figure 12 represent the ALFC of double-area with the primary loop Figure 13 as the both the part are interlinked, Figure 14 presents the frequency oscillations of the two area system, after small oscillation the frequency achieve steady state position. The mechanical inputs of double systems are minimizing the different energy in mechanical inputs and the electrical load in area1. Although we get same results as area 1 but stability is improved with interconnection.

D. Two Area System with Secondary Loop

Two area systems by using secondary loop are shown in Figure 15. The secondary loop is responsible for the minimization of drifts in frequency to zero as shown in Figure 16. By changing the secondary loop gain we can see the variation in the system dynamic response characteristics through tie line power as given away in Figure 17. We have taken the values of the different parameters for modeling the Simulink model and its successful operation to obtain the desired results.

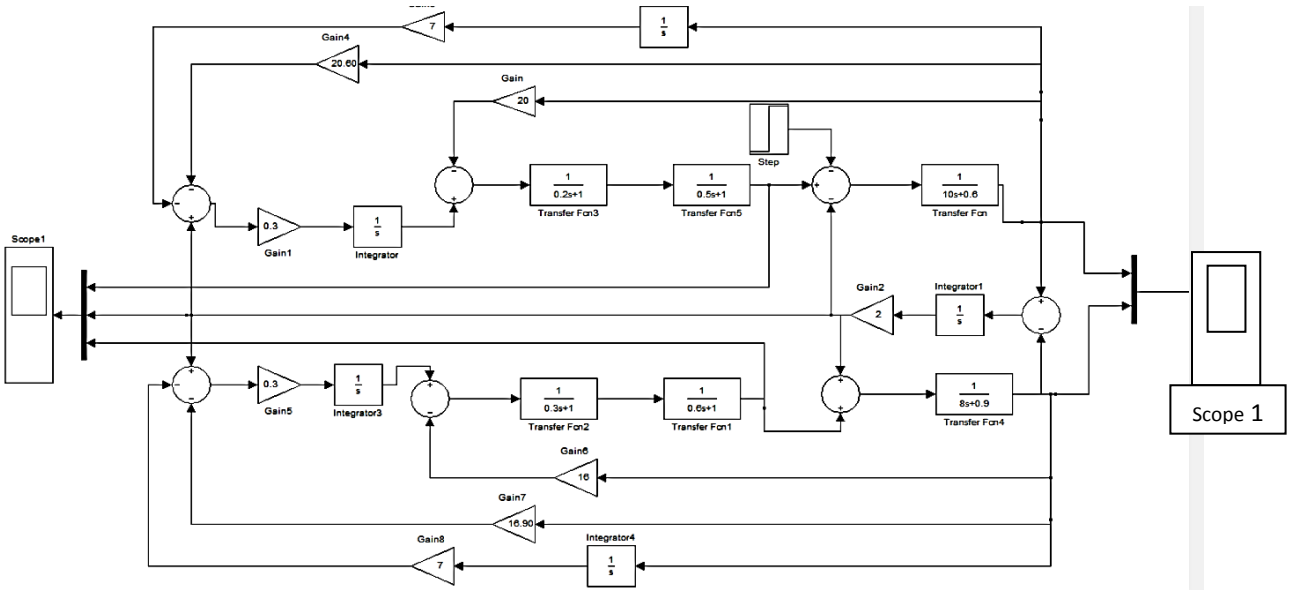


Figure 15: Simulation diagram for double area.

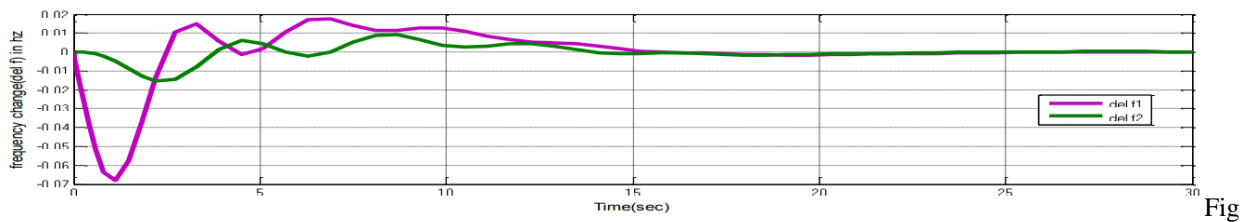


Figure 16: Frequency change vs. time.

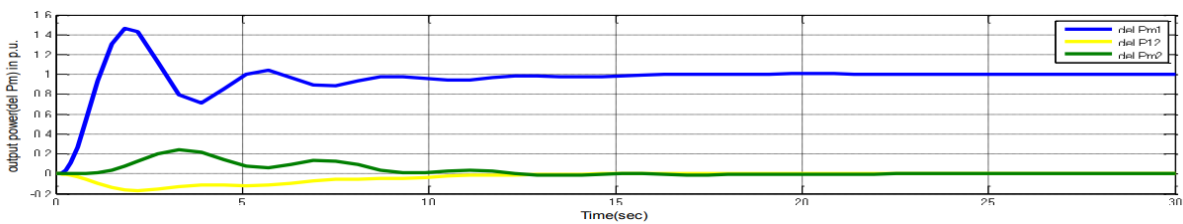


Figure 17: Simulation results in output power deviation vs. time.

C. Simulation Diagram of Three Areas with Primary Loop

Three area interconnected systems without using secondary loop is given in Figure 18. Figure 19 presents the settling down of frequency to a finite value which is less than the actual frequency. Figure 20 shows the power change due to tie-line on account of the deviation in the load.

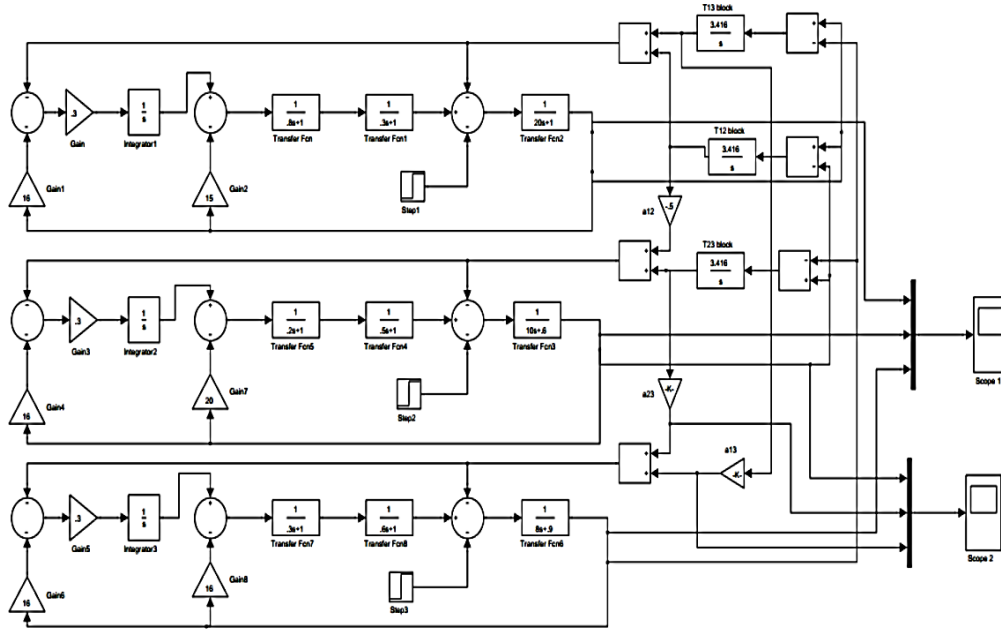


Figure 18: Three areas without secondary loop.

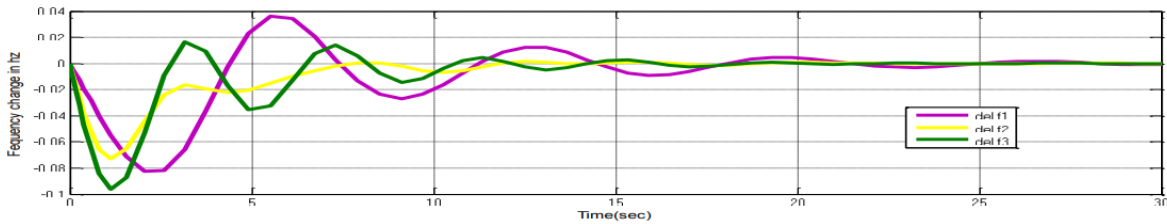


Figure 19: Frequency deviation vs. time.

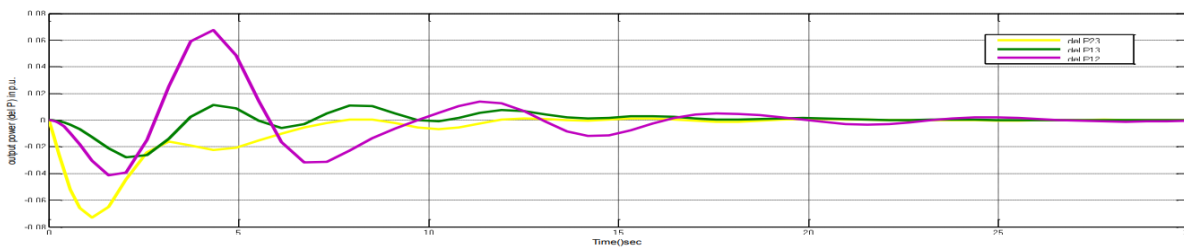


Figure 20: Simulation results output power deviation vs. time in three area system.

Three area systems with primary loop are given in Figures 19 and 20 and presents the stability is gain of the inter-connection of power system.

D. Simulink Model of Three Areas with Secondary Loop

The model for the three area system including the secondary control is given below in Figure 21. The results of the variation in frequency as well as tie line power output with respect to time are being shown in Figures 22 and 23. The system operates in a similar way to that of the two area system, taking into consideration the changes in the load.

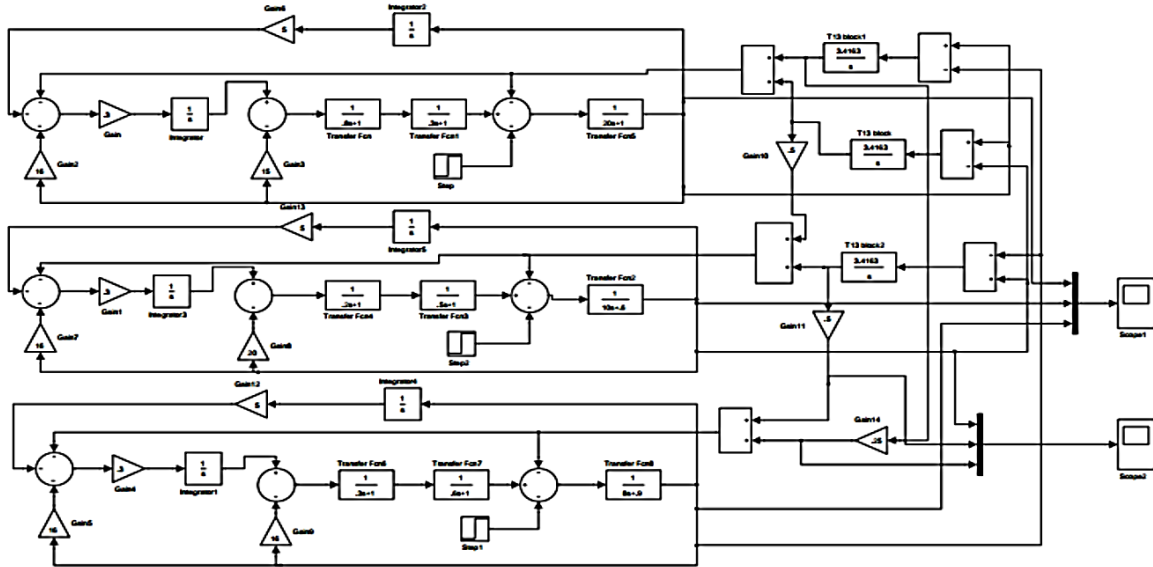


Figure 21: Three areas by using secondary loop.

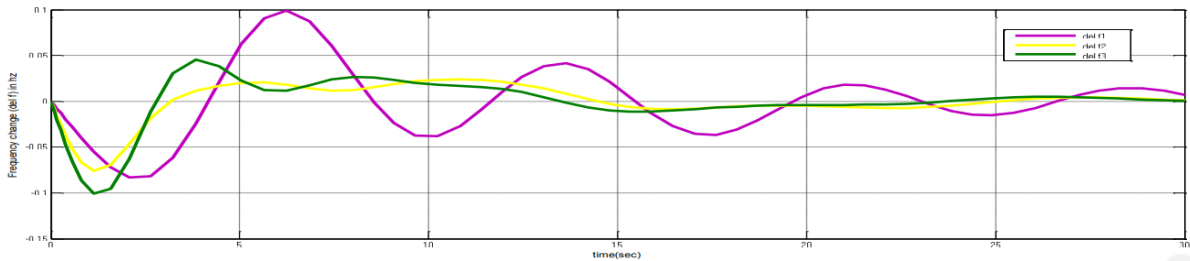


Figure 22: Frequency changes vs. time.

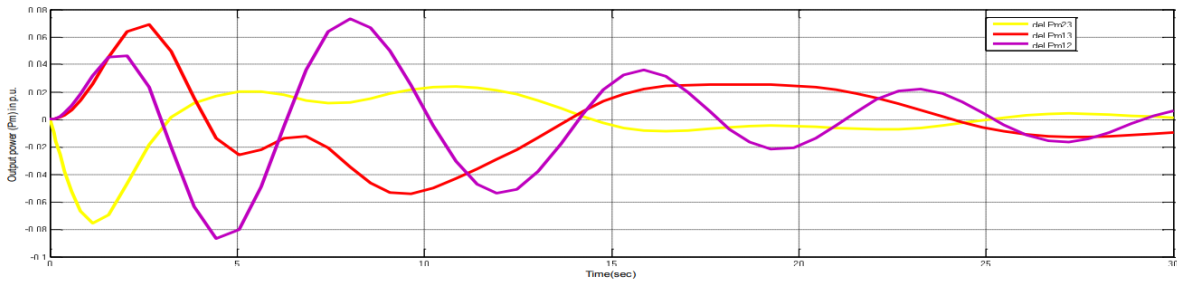


Figure 23: Power deviation vs. time.

VIII. CONCLUSION

A simulation study of single area, two areas and three areas as a multi system with automatic generation and control is carried out with models developed in SIMULINK MATLAB. The system experiences frequency drift following a load disturbance and it is mainly due to the mismatch between the electrical load and the mechanical input to the turbine. All these aforesaid systems are controlled with conventional PI controller. The performance of PI controller has been compared frequency deviation of three different area systems. PI controller shows the best performance of settling time less frequency deviation and minimum oscillations. The system encounters drifts in the frequency succeeding a disturbance in the load and it is primarily because of the mismatch involving the electrical load as well as the mechanical input which is given to the prime mover/turbine. The system oscillation is serious in single area system compared to two area and three area system because all the load change in load is to be met by only one area. Also, using the secondary loop in single area as well as the two areas and three area systems the change in frequency is brought to zero. The simulation of these systems has been carried out and results analyzed. The operation of single area and two area systems with and without secondary loops are very well depicted through simulation models. The advantage of interconnection is best understood by comparing the results of single area, two area and three area systems. It can be seen that the oscillations due to change in load in any area is damped down quickly because of tie line power flow. It can also be observed that the dynamic response is mainly governed by the secondary loop and hence design criteria of which is extremely vital for efficient implementation.

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