ISSN 2320-9984
Volume 12 Issue 1 | March 2024
ISSN: 2320-9984 (Online)
International Journal of Modern Engineering & Management Research
Website: www.ijmemr.org

Control of Multi Area Power Systems by Using AFC Technique

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Abstract—*The rapid growth of the industries has further lead to the increased complexity of the power system. Frequency is greatly depends on active power and the voltage greatly depends on the reactive power. So the control difficulty in the power system may be divided into two parts. One is related to the control of the active power along with the frequency whereas the other is related to the reactive power along with the regulation of voltage. The active power control and the frequency control are generally known as the Automatic Load Frequency Control. Maintaining power system frequency at constant value is very important for the reliability of the power generating equipment and the utilization equipment at the customer end. The automatic frequency regulation is achieved by governing systems of individual turbine-generators and Automatic Generation Control (AGC) or Load frequency control (LFC) system of the power system.*

Keywords:— *Load Frequency Control, Frequency Variation in a Single Machine, Area Control Error.*

1. INTRODUCTION

Synchronous generators respond to load -generation imbalances by accelerating or decelerating. When load increases, generation slows down, effectively releasing some of its inertial energy to compensate for the load increase [1]. When load decreases, generation speeds up, absorbing the oversupply as increased inertial energy [2]. Because load is constantly changing, an unregulated synchronous generator has highly variable speed resulting in highly variable system frequency, an unacceptable situation because, penalties for poor-performance (CPS), Load performance can be frequency-dependent Motor speed Steam-turbine blades may lose life or fail under frequencies that vary from design levels. Some relays are frequency-dependent under frequency load shedding relays frequency dip may increase for given loss of generation. The fact that frequency changes with the load-generation imbalance gives a good way to regulate the imbalance by using frequency as a regulation signal. A given power system will have many generators, so we must balance load with total generation by appropriately regulating each generator in response to frequency changes. As a result of how power systems evolved, the load-frequency control problem is even more complex. Initially, there were many isolated interconnections, each one having the problem of balancing its load with its generation. Gradually, in order to enhance reliability, isolated systems interconnected to assist one another in emergency situations.

2. FREQUENCY VARIATION IN A SINGLE MACHINE

To understand the variation of frequency in a power system, consider a single machine connected to an isolated load, as shown in the figure 1.

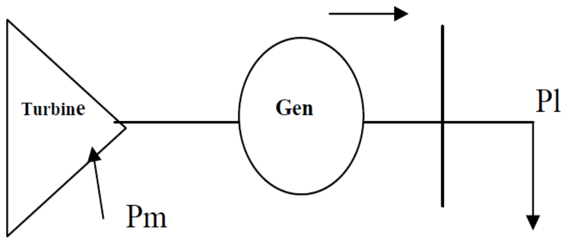


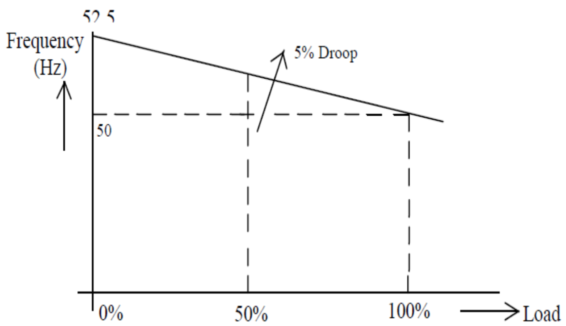
Figure 1: Single Turbine Generator with Load

Normally, the turbine mechanical power (P_m) and the electrical load power (P_l) are equal [3]. Whenever there is a change in load, with mechanical power remaining the same the speed (ω) of the turbine generator changes as decided by the rotating inertia (M) of the rotor system, as given by the following differential equation.

$$P_m - P_l = M\left[\frac{d\omega}{dt}\right]$$

The governing system senses this change in speed and adjusts steam control valve so that mechanical power (P_m) matches with the changed load (P_l). Speed variation stops but at a different steady value. The change in frequency (Δω) at steady state can be described using the following equation in terms of change in load (ΔP_l) and a factor R called 'speed regulation or 'droop'.

$$\boldsymbol{\Delta\omega = -[\Delta P_l]R}$$



3. CONCEPT OF CONTROL AREA

Modern day power systems are divided into various areas. For example in India, there are five regional grids, e.g., Eastern Region, Western Region etc. Each of these areas is generally interconnected to its neighboring areas. 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. For Example that the system frequency rises when the load decreases if ΔP_{ref} is kept at zero. Similarly the frequency may drop if the load increases. However it is desirable to maintain the frequency constant such that $\Delta f=0$. The power flow through different tie-lines are scheduled - for example, area- i may export a pre-specified amount of power to area- j while importing another pre-specified amount of power from area- k . However it is expected that to fulfill this obligation, area- i absorbs its own load change, i.e., increase generation to supply extra load in the area or decrease generation when the load demand in the area has reduced. While doing this area- i must however maintain its obligation to areas j and k as far as importing and exporting power is concerned. A conceptual diagram of the interconnected areas is shown in Figure 2.

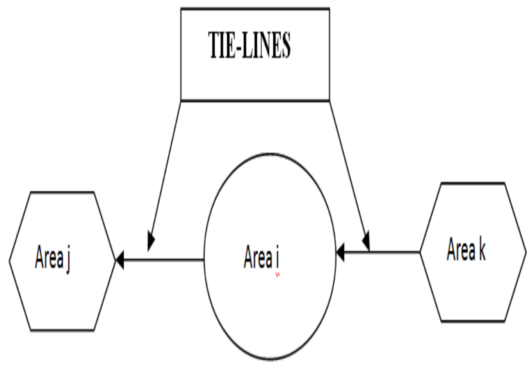


Figure 2: Interconnected areas in a power system.

4. LOAD FREQUENCY CONTROL

The speed/ frequency variation concept can be extended from a single turbine-generator system to a power system comprising several turbine- generators as shown in Figure 3. Now the mismatch between the total power generated and the total electrical load causes the frequency change as dictated by the combined system inertia [4]. The governors of all the automatically to match the combined generation with the new combined load. This action is called primary regulation. But frequency remains at a new value and set points must be adjusted, just as in single machine case for frequency restoration. This is done by the Automatic Load Frequency controller (AFC) as shown in Figure 4. This process of set point adjustment is called secondary regulation. When load change occurs frequency varies and the regulation initially for the first few seconds is due to the action of the governors of all generating units and subsequently the Load frequency control system prevails.

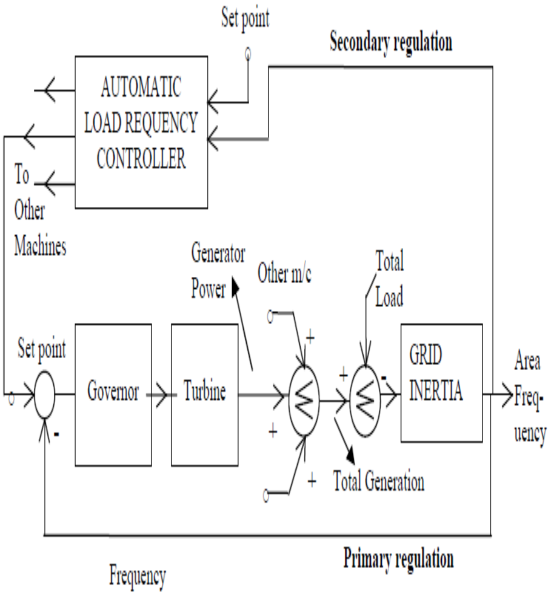


Figure 3: Block Diagram Showing Power System Frequency Variation

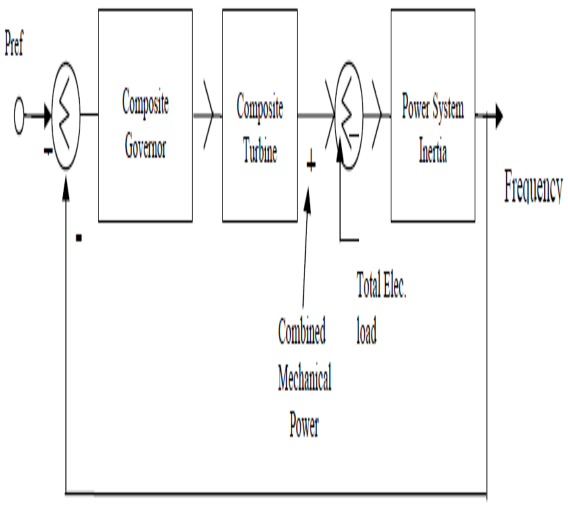


Figure 4: Automatic Load R frequency Control System

5. PARAMETER RELATING TO CONTROL AREAS

The major PARAMETER relating to control areas are as follows:- Hold the frequency constant ($\Delta f = 0$) against any load change. Each area must contribute to absorb any load change such that frequency does not deviate. Each area must maintain the tie-line power flow to its pre-specified value. The first step in the LFC is to form the area control error (ACE) that is defined as

$$ACE = (P_{tie} - P_{sch}) + B_f \Delta f = \Delta P_{tie} + B_f \Delta f$$

where P_{tie} and P_{sch} are tie-line power and scheduled power through tie-line respectively and the constant B_f is called the frequency bias constant .The change in the reference of the power setting $\Delta P_{ref, i}$, of the area- i is then obtained by the feedback of the ACE through an integral controller of the form

$$\Delta P_{ref\ i} = -K_i \int ACE\ dt$$

where K_i is the integral gain. The ACE is negative if the net power flow out of an area is low or if the frequency has dropped or both. In this case the generation must be increased. This can be achieved by increasing $\Delta P_{ref, i}$. This negative sign accounts for this inverse relation between $\Delta P_{ref, i}$ and ACE. The tie-line power flow and frequency of each area are monitored in its control center. Once the ACE is computed and $\Delta P_{ref, i}$ is obtained commands are given to various turbine-generator controls to adjust their reference power settings. Each control area should accomplish its individual load demand in addition to the power transfer all the way through tie lines on the basis of communal agreement [5]. Every control area must have adjustable frequency according to the control.

6. SIMULATION RESULTS AND DISCUSSION

By using simulation models we can obtain the performance characteristics of the system very easily and quickly for analysis purposes. Below are the various systems simulink models with their respective responses plotted against time.

7. SINGLE AREA SYSTEM WITHOUT USING SECONDARY LOOP

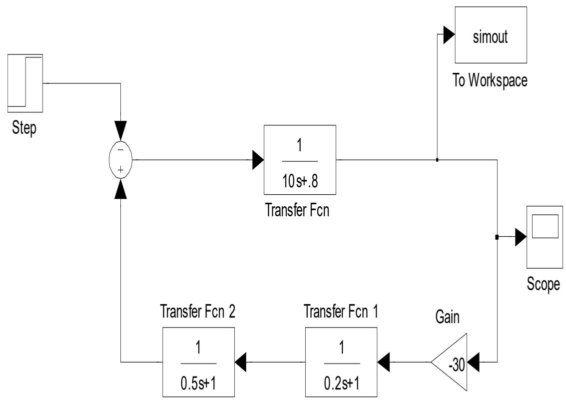


Figure 5: Simulink model of single area system without using secondary loop

Table 1: System parameters for single area system without using secondary control

Name	Kg	Tg(s)	Kt	Tt(s)	H(s)	D (p u M W / Hz)	1/R
Value	1	0.20	1	0.50	5	0.80	30

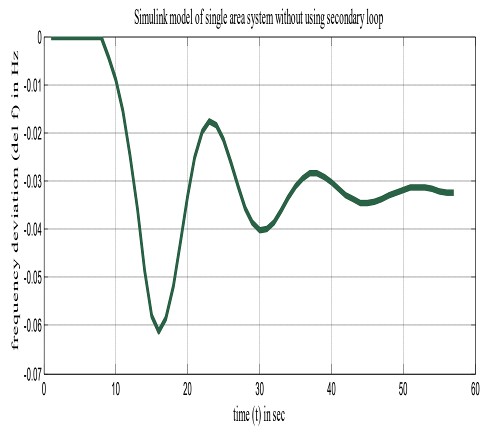


Figure 6: Frequency deviation vs. time for single area system without secondary loop

The plot in Figure 6 which is obtained by simulating the model as shown in Figure 5 shows that the change in load causes alteration in speed and that causes deviation in frequency Δf . From the plot we are able to comprehend that the frequency oscillations will gradually stay down to a limited value. The new-fangled operating frequency is supposed to be lesser than the nominal value. We have taken the values of the different parameters as shown in table1 for modeling the simulink model and its successful operation to obtain the desired results.

8. SINGLE AREA SYSTEM BY USING SECONDARY LOOP

In Figure 7 an integral controller by means of a gain i.e. Ki is used to regulate the signal of speed reference i.e. ΔP_{ref} (as given away in Figure 10) so that Δf_s proceeds to zero (as shown in Figure 9). Figure 8 shows the variation in turbine output with time. The drift in frequency has been brought to zero because of the integral loop. We have taken the values of the different parameters as shown in table 2 for modeling the simulink model and its successful operation to obtain the desired results.

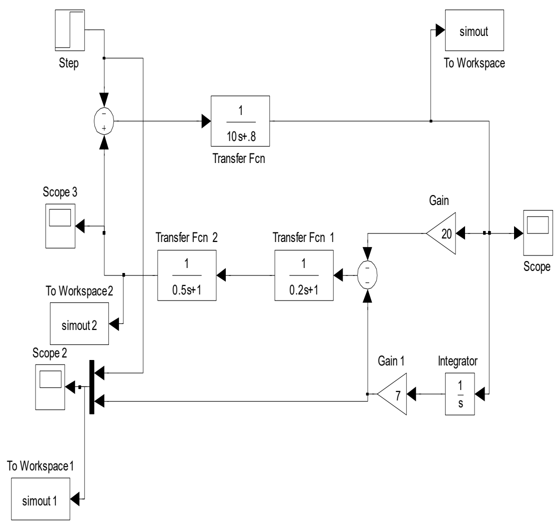


Figure 7: Simulink model for single area system by using secondary loop

Table 2: System parameters for single area system by using secondary control

Name	Kg	Tg(s)	Kt	Tt(s)	H (s)	D (p.u.M W/Hz)	1/R	K1
Value	1	1	0.20	0.50	5	0.8	20	7

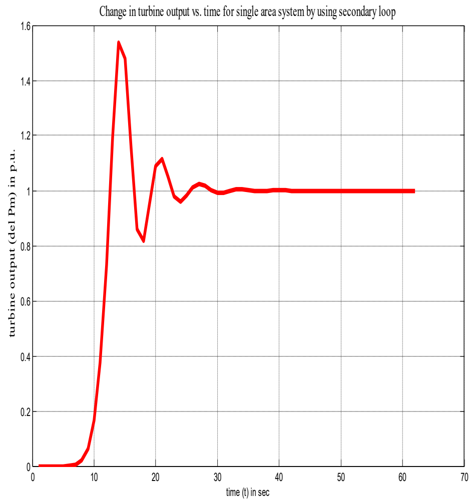


Figure 8: Change in turbine output vs. time for single area system by using secondary loop

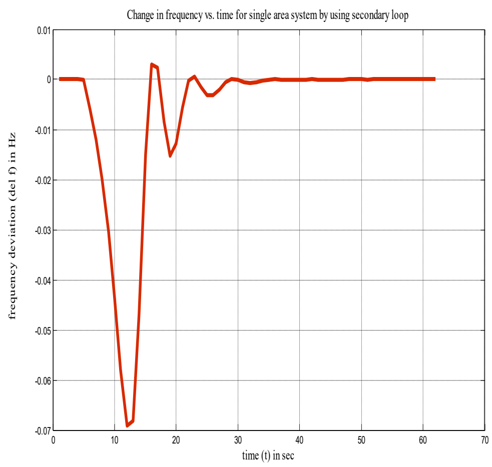


Figure 9: Change in frequency vs. time for single area system by using secondary loop

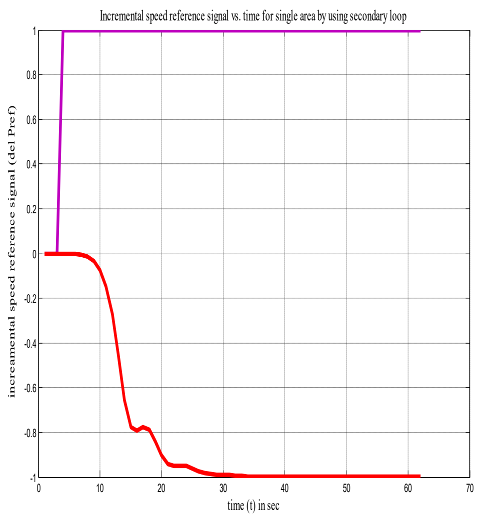


Figure 10: Incremental speed reference signal vs. time for single area by using secondary loop

9. TWO AREA SYSTEMS WITHOUT USING SECONDARY LOOP

Figure 11 presents that the two systems are being interrelated so the drifts in the frequency of the two are liable to settle down to similar value soon after a few oscillations. The two mechanical inputs changes to minimize the inequality power connecting electrical load in area 1 as well as the mechanical inputs. Area 2 is capable to generate excessive power to distribute the variation in load in area 1. We have taken the values of the different parameters as shown in table 3 for modeling the simulink model and its successful operation to obtain the desired results.

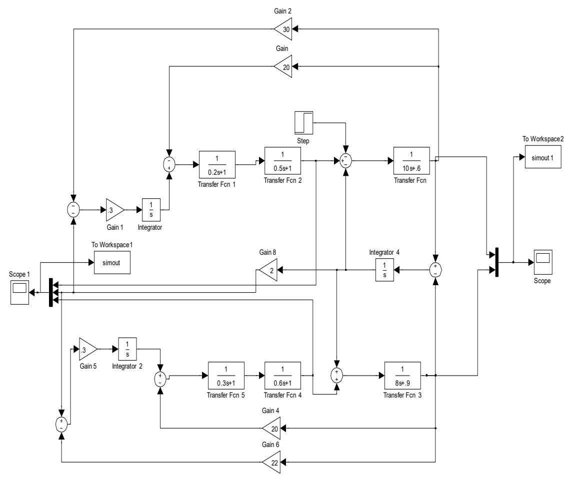


Figure 11: Simulink model of two area system without secondary loop

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

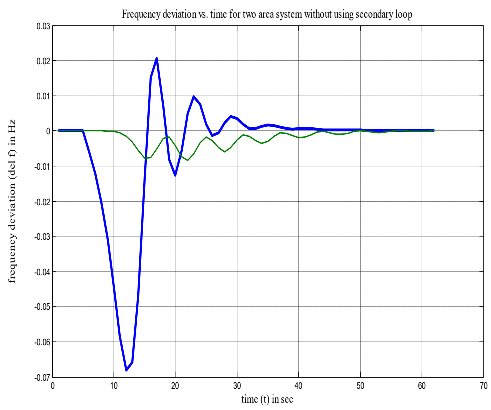


Figure 12: Frequency deviation vs. time for two area system without using secondary loop

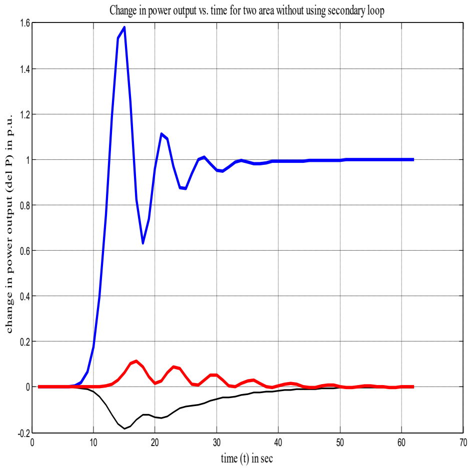


Figure 13: Change in power output vs. time for two area without using secondary loop

10. TWO AREA SYSTEM BY USING SECONDARY LOOP

Two area systems by using secondary loop are shown in Figure 14 The secondary loop is responsible for the minimization of drifts in frequency to zero as shown in Figure 15. 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 16. We have taken the values of the different parameters as shown in table 4 for modeling the simulink model and its successful operation to obtain the desired results.

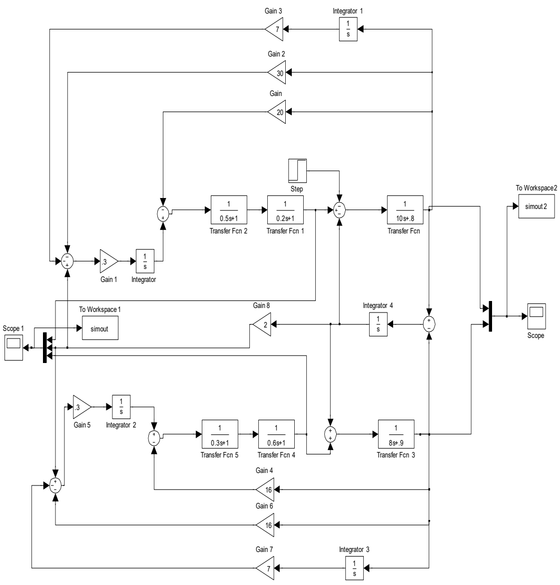


Figure 14: Simulink model for two area system by using secondary loop

Table 4: System parameters for two area system by using secondary control

Name	Kg	Tg(s)	Kt	Tt(s)	H(s)	D(p.u.MW/Hz)	1/R	ΔPL(p.u)	K1
Area 1	1	0.20	1	0.50	5	0.60	20	0	7
Area 2	1	0.30	1	0.60	4	0.90	16	16	7

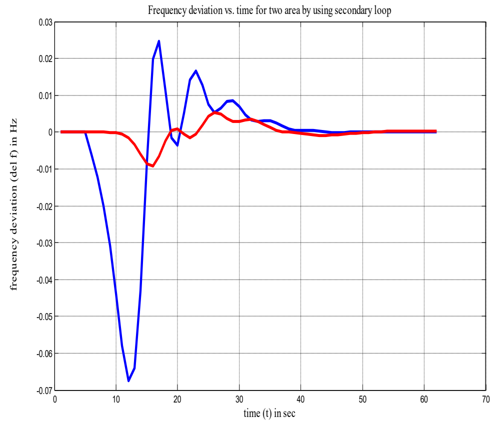


Figure 15: Frequency deviation vs. time for two area by using secondary loop

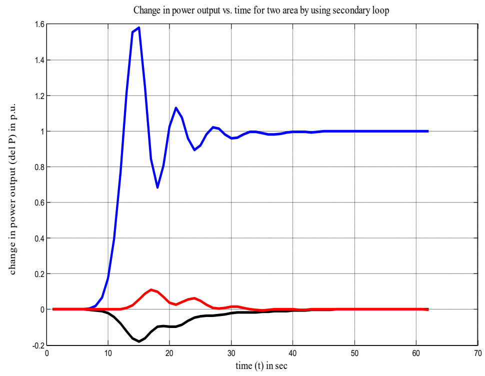


Figure 16: Change in power output vs. time for two area by using secondary loop

11. THREE AREA SYSTEM WITHOUT USING SECONDARY LOOP

Three area interconnected systems without using secondary loop is given in Figure 17. Figure 18 presents the settling down of frequency to a finite value which is less than the actual frequency. Figure 19 shows the power change due to tie-line on account of the deviation in the load. Here stability is improved with interconnection. We have taken the values of the different parameters as shown in table 5 for modeling the simulink model and its successful operation to obtain the desired results.

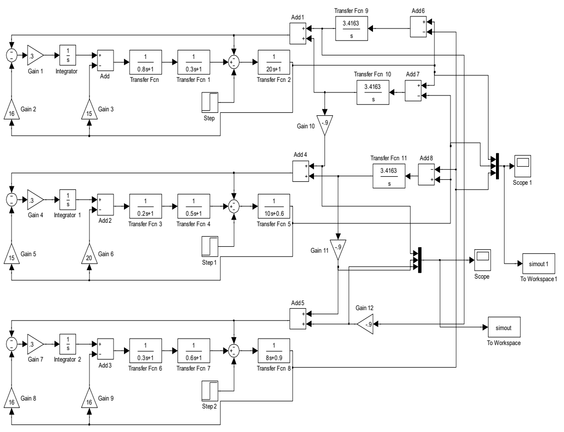


Figure 17: Simulink model of three area system without using secondary loop

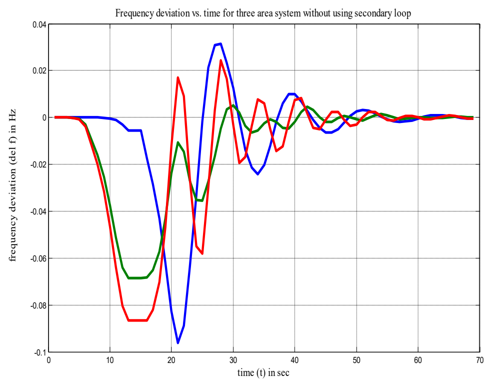


Figure 18: Frequency deviation vs. time for three area system without using secondary loop

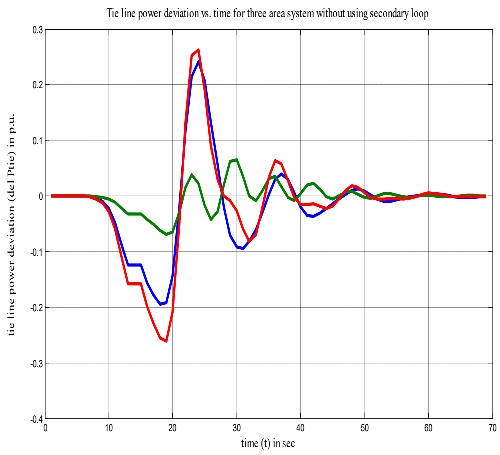


Figure 19: Tie line power deviation vs. time for three area system without using secondary loop

Table 5: System parameters for three area system without using secondary control

Name	Kg	Tg(s)	Kt	Tt(s)	H(s)	D(p.u.MW/Hz)	1/R	ΔPL(p.u)
Area 1	1	0.80	1	0.30	10	1.00	15	1
Area 2	1	0.20	1	0.50	5	0.60	20	0
Area 3	1	0.30	1	0.60	4	0.90	16	0

12. THREE AREA SYSTEM BY USING SECONDARY LOOP

The model for the three area system including the secondary control is given away in Figure 20. The results of the variation in frequency as well as tie line power output with respect to time are being shown in Figure 21 and Figure 22. The system operates in a similar way to that of the two area system, taking into consideration the changes in the load. We have taken the values of the different parameters as shown in table 6 for modeling the simulink model and its successful operation to obtain the desired result

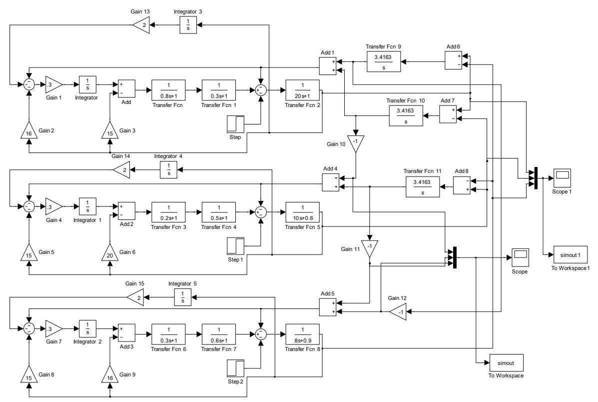


Figure 20: Simulink model of three area system by using secondary loop

Table 6: System parameters for three area system by using secondary control

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

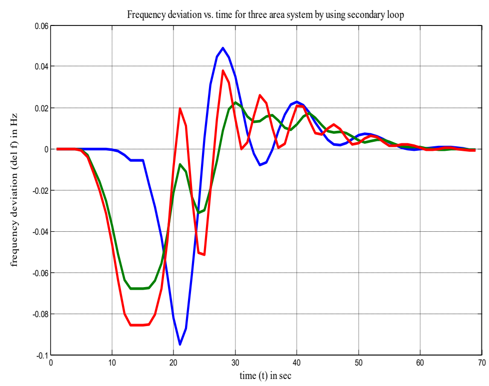


Figure 21: Frequency deviation vs. time for three area system by using secondary loop

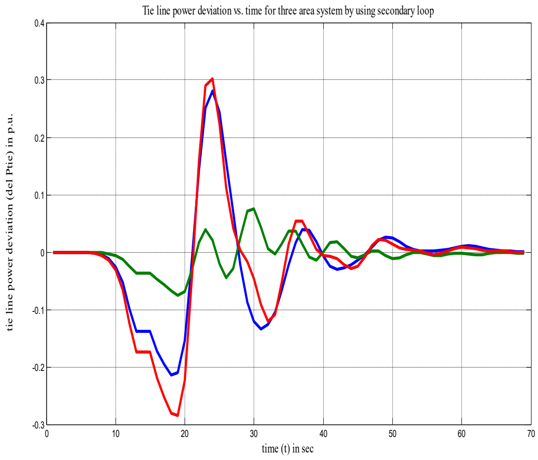


Figure 22: Tie line power deviation vs. time for three area system by using secondary loop

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