Design and Simulation of Integral Controller Based LFC

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Abstract: *The main objectives of Load Frequency Control (LFC) are to hold the frequency constant (Δf = 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. In LFC there are two major loops. Automatic Voltage Regulator (AVR) and Automatic Load Frequency Control (ALFC) Loops. AVR Loop controls the magnitude of the terminal voltage V. The ALFC Loop regulates the megawatt output and frequency (speed) of Generator via the speed governor and the control valves that the steam flow is regulated to match the megawatt output. There are many controllers used in LFC such as Integral Controller based LFC, Fuzzy Controller based LFC, ANN based LFC, Genetic Algorithm based LFC and Power System Optimization (PSO) based LFC. In this paper the integral controller based LFC is used to hold the frequency constant. Here the SIMULINK Model of single area and two area power systems are simulated using SIMULINK.*
Keywords: *LFC, AGC, Integral controller, AVR, ALFC, ACE.*

I. Introduction

Power systems are very large and complex electrical networks consisting of generation networks, transmission networks and distribution networks along with loads which are being distributed throughout the network over a large geographical area. In the power system, the system load keeps changing from time to time according to the needs of the consumers. So properly designed controllers are required for the regulation of the system variations in order to maintain the stability of the power system as well as guarantee its reliable operation. For large scale power systems which consists of inter-connected control areas, load frequency then it is important to keep the frequency and inter area tie 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. A well designed power system should be able to provide the acceptable levels of power quality by keeping the frequency and voltage magnitude within tolerable limits. Changes in the power system load affects mainly the system frequency, while the reactive power is less sensitive to changes in frequency and is mainly dependent on fluctuations of voltage magnitude. So the control of the real and reactive power in the power system is dealt separately. The load frequency control mainly deals with the control of the system frequency and real power whereas the automatic Voltage regulator loop regulates the changes in the reactive power and voltage magnitude. Load frequency control is the basis of many advanced concepts of the large scale control of the power system**.**

II. Reasons for the need of maintaining constant frequency

(1) The speed of a.c. motors are directely related to the frequency.
(2) If the normal operating frequency is 50 Hz and the turbines run at speeds corresponding to frequencies less than 47.5 Hz or above 52.5 Hz, then the blades of the turbines may get damaged.
(3) The under frequency operation of the power transformer is not desirable. For constant system voltage if the frequency is below the desired level then the normal flux in the core increases. This sustained under frequency operation of the power transformer results in low efficiency and over-heating of the transformer windings.
(4) With reduced frequency the blast by ID fans and FD fans decrease, and so the generation decreases and thus it becomes a multiplying effect and may result in shut down of the plant.
(5) The electric clocks are driven by the synchronous motors. The accuracy of the clocks are not only dependent on the frequency but also is an integral of the this frequency error. The speed of a.c. motors are directely related to the frequency.

III. Load Frequency Control

Electric power is generated by converting mechanical energy into electrical energy. The rotor mass, which contains turbine and generator units, stores kinetic energy due to its rotation. This stored kinetic energy accounts for sudden increase in the load. Let us denote the mechanical torque input by T_m and the output electrical torque by T_e. Neglecting the rotational losses, a generator unit is said to be operating in the steady state

at a constant speed when the difference between these two elements of torque is zero. In this case we say that the accelerating torque is zero.

$$Ta = Tm - Te \qquad (3.1)$$

When the electric power demand increases suddenly, the electric torque increases. However, without any feedback mechanism to alter the mechanical torque, T_m remains constant. Therefore the accelerating torque given by becomes negative causing a deceleration of the rotor mass. As the rotor decelerates, kinetic energy is released to supply the increase in the load. Also note that during this time, the system frequency, which is proportional to the rotor speed, also decreases. We can thus infer that any deviation in the frequency for its nominal value of 50 or 60 Hz is indicative of the imbalance between T_m and T_e. The frequency drops when $T_m < T_e$ and rises when $T_m > T_e$. The steady state power-frequency relation is shown in Fig.1.1. In this figure the slope of the ΔP_{ref} line is negative and is given by

$$-R = \frac{\Delta f}{\Delta P_m} \qquad (3.2)$$

Where R is called the **regulating constant.** From this figure we can write the steady state power frequency relation as
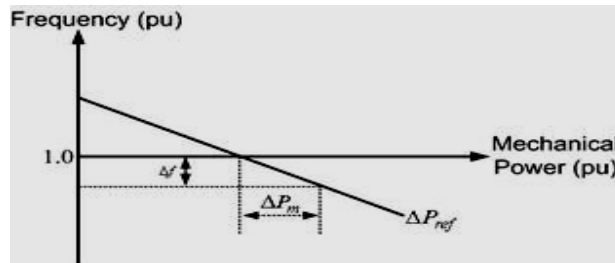

Fig. 3.1 A typical steady-state power-frequency curves.

$$\Delta P_m = \Delta P_{ref} - \frac{1}{R}\Delta f \qquad (3.3)$$

Suppose an interconnected power system contains N turbine-generator units. Then the steady-state power-frequency relation is given by the summation of (3.3) for each of these units as

$$\Delta P_m = \Delta P_{m1} + \Delta P_{m2} + \cdots \ldots \ldots + \Delta P_{mN}$$

$$= \left(\Delta P_{ref1} + \Delta P_{ref2} + \cdots \ldots \ldots \Delta P_{refN}\right) - \left(\frac{1}{R_1} + \frac{1}{R_2} + \cdots \ldots \ldots + \frac{1}{R_N}\right)\Delta f$$

$$(3.4)$$

In the above equation, ΔP_m is the total change in turbine-generator mechanical power and ΔP_{ref} is the total change in the reference power settings in the power system. Also note that since all the generators are supposed to work in synchronism, the change is frequency of each of the units is the same and is denoted by Δf. Then the **frequency response characteristics** is defined as

$$\beta = \left(\frac{1}{R_1} + \frac{1}{R_2} + \cdots \ldots \ldots + \frac{1}{R_N}\right) \qquad (3.5)$$

We can therefore modify (1.4) as

$$\Delta P_m = \Delta P_{ref} - \beta \Delta f \qquad (3.6)$$

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. As we have seen 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 Fig. 3.2.
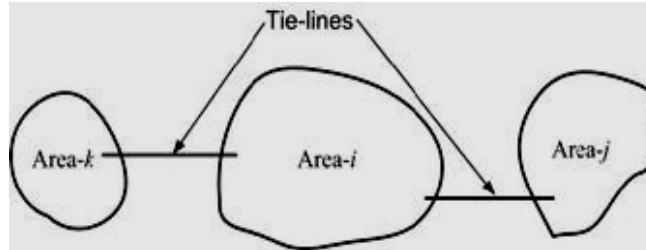

Fig 3.2. Interconnected areas in a power system.

We can therefore state that the load frequency control (LFC) has the following two objectives:
- Hold the frequency constant (Δ 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

$$ACE = (P_{tie} - P_{sch}) + B_f \Delta f = \Delta P_{tie} + B_f \Delta f \qquad (3.7)$$

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

$$\Delta P_{ref,i} = -K_i \int ACE \ dt \qquad (3.8)$$

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 $\Delta P_{ref, i}$ from (3.8), commands are given to various turbine-generator controls to adjust their reference power settings.

IV. Design and Simulations

4.1 SIMULINK model

A SIMULINK model is constructed for isolated uncontrolled power system as shown in Fig
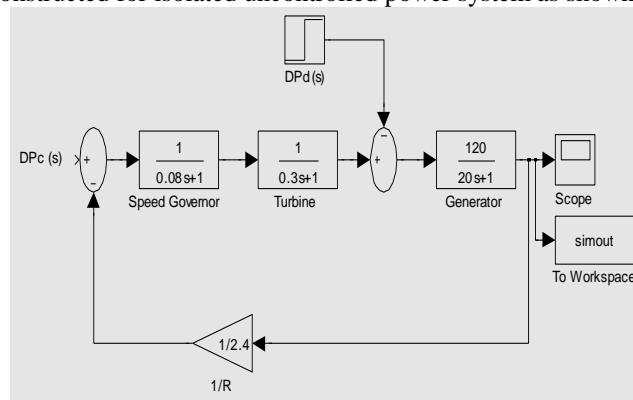

Fig.4.1 SIMULINK model for uncontrolled isolated area.

4.2 SIMULINK model results

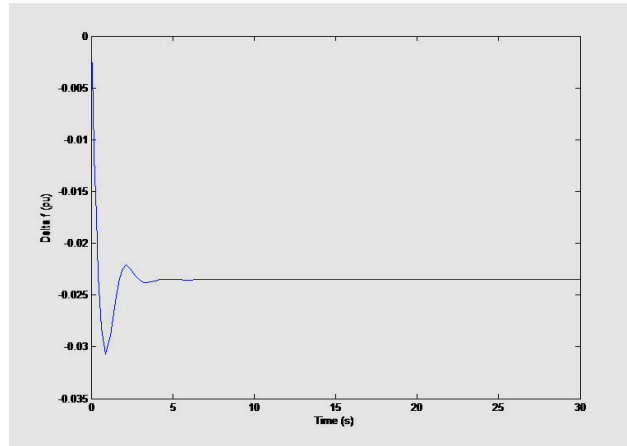The results of the SIMULINK model constructed for isolated uncontrolled power system are shown in Fig

Fig.4.2 SIMULINK dynamic response of change in frequency without controller

4.3 MATLAB program results
The MATLAB program written above for uncontrolled case is run and the results obtained are given in Fig.
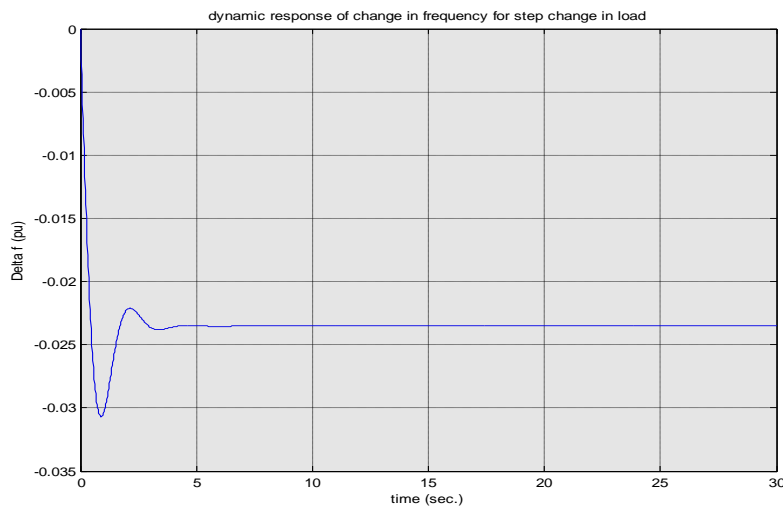

Fig. 4.3 MATLAB command results for uncontrolled single-area

We observe that both the responses match with each other, also the steady-state frequency deviation Δf (steady state) is -0.0235 Hz and frequency returns to its steady value in approximately 6 seconds.

4.4 SIMULINK model with integral controller (single-area case)
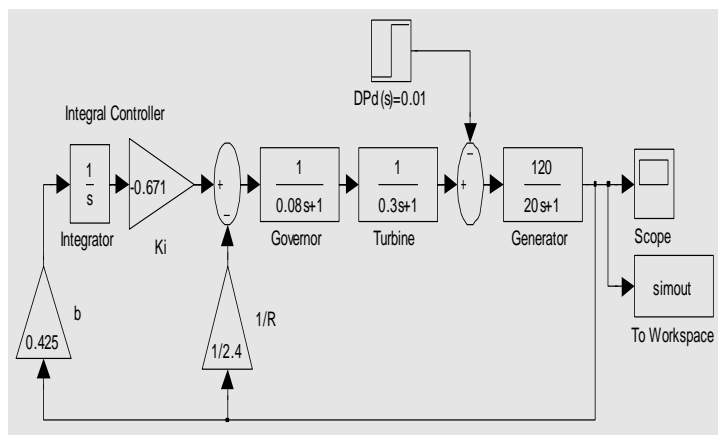A SIMULINK model named is constructed as shown in Fig.

FIG 4.4 SIMULINK model with integral controller (single-area case)

4.5 SIMULINK model results
The results of the SIMULINK model constructed for isolated controlled power system are shown in Fig.
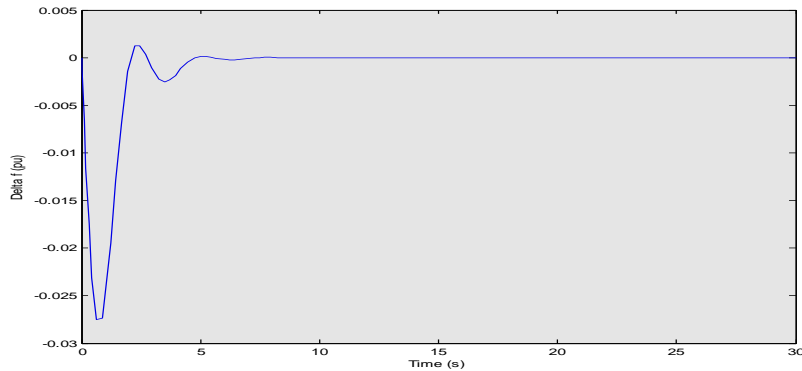

FIG 4.5 SIMULINK dynamic response of change in frequency with integral control action

4.6 MATLAB program results
The MATLAB program for controlled case is run and the results obtained are given in Fig.
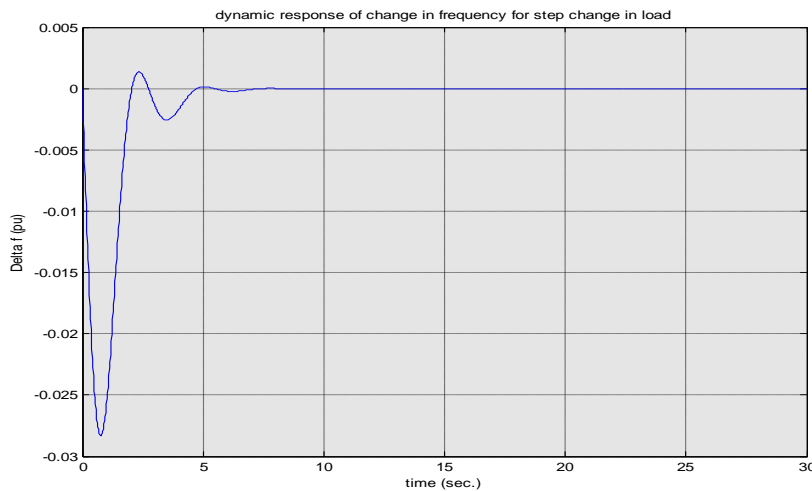

FIG.4.6 Frequency deviation step response with MATLAB program
        We observe that both the responses match with each other, also the steady-state frequency deviation Δf (steady state) is zero as derived in Eq. (3.20) and frequency returns to its steady value in approximately 6 seconds.
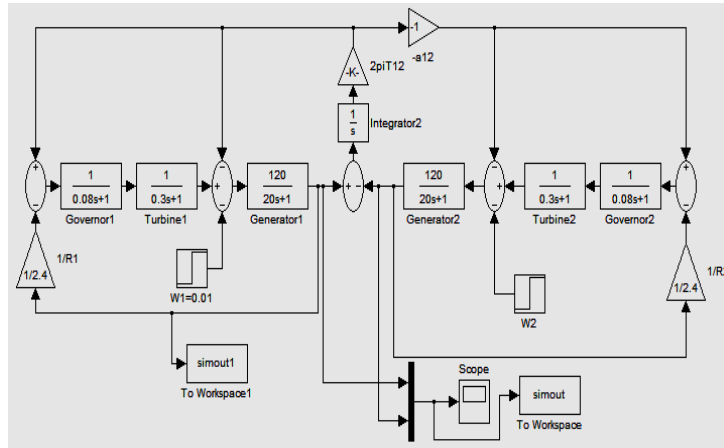
4.7 SIMULINK model of two area system is shown as

FIG 4.7 SIMULINK models of two areas

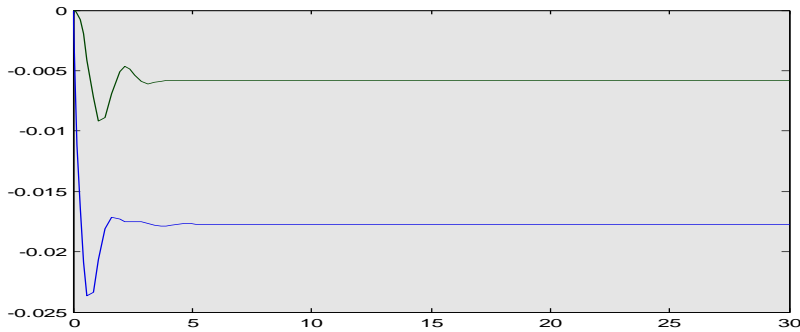**4.7.1 Result of the SIMULINK model is shown:**

Fig. 4.8 Result of SIMULINK model of two area

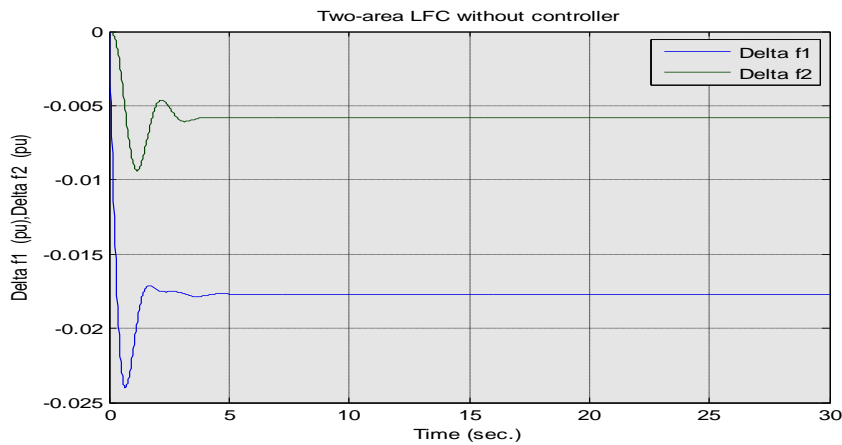**4.7.2 Programming is done in MATLAB and result is obtained as:**

Fig. 4.9 Result of two area LFC without integral controller
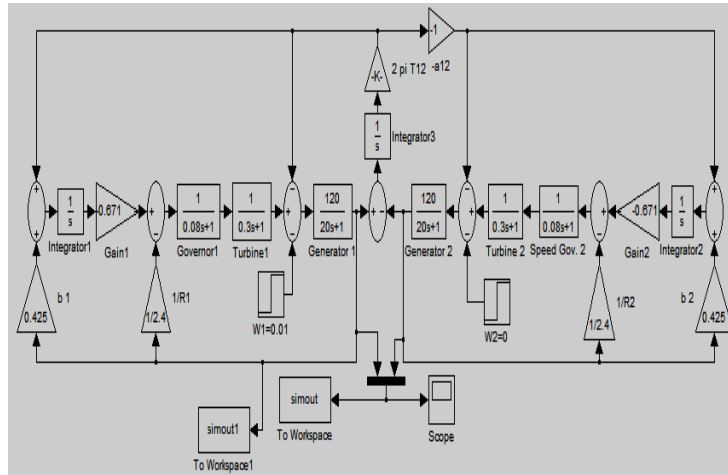
4.8 SIMULINK model of two areas with integral controller:

Fig. 4.10 SIMULINK model of two area with integral controller

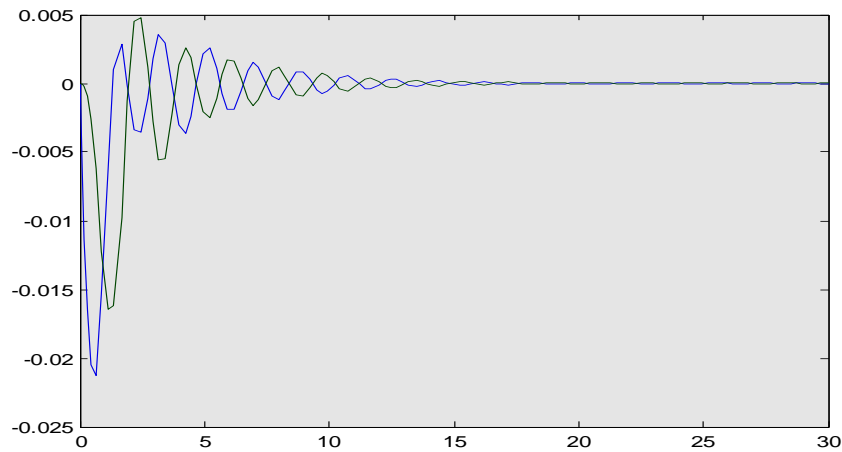**4.8.1 Result of SIMULINK model is obtained as:**

Fig 4.11 Result of SIMULINK model of two area with integral controller

4.8.2 MATLAB Programming is done in workspace and results are obtained as:
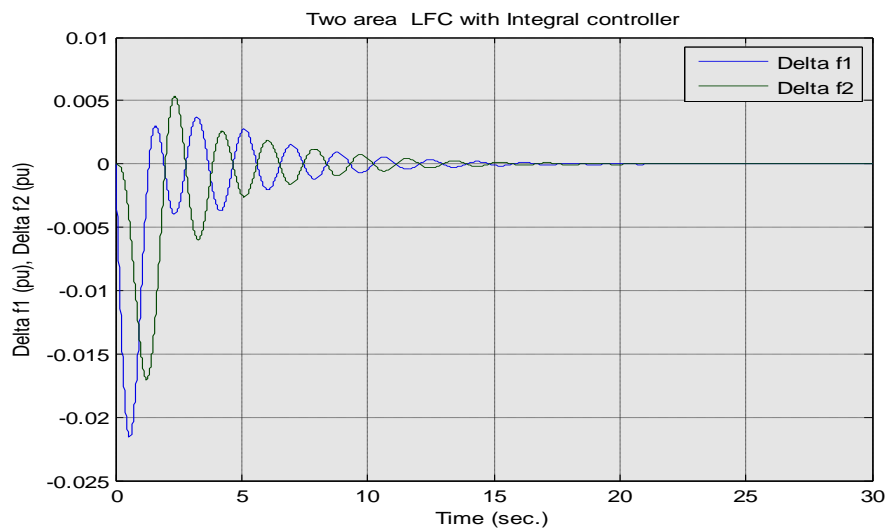

Fig 4.12 Result of two area LFC with integral controller in MATLAB

V. Conclusion

In this work frequency deviation problem associated with load frequency control is evaluated. It is seen that Integral Controller is required to stable the frequency. By properly selecting the control parameters of the dual mode controller, frequency deviations and the tie line power can be effectively controlled. Due to disturbances in the power system, the frequency is deviates. So Integral Controller is used to over this problem. By using the Integral Controller frequency can be stable. Load-frequency control in a deregulated environment may result in free choice by units to participator not in this operation. It is shown that if the percentage of the units participating in this control action is very small, system performance deteriorates to a point that is unacceptable. It is therefore recommended that minimum requirements be established. The minimum requirements are system-dependent. The whole structures of power system have non- linear dynamic and their operation points may change. Therefore Integral Controller should be used. From the simulations we have seen that the proposed control approach achieves better control results than other controllers. Simulations results show that the proposed Integral Controller approach can be effectively suppress exogenous disturbance in steady state.

VI. Future Work

Various controllers may be used to manage the frequency deviations and changes in tie line power.

It may be implemented to system with three and four areas and also the performance of the system may be studied.

The LFC of power system can be designed by PID controller via different optimization technique.

The parameters in this work has been taken constant throughout the whole operation.But there may be parameter uncertainty due to wear and tear, temperature variation, imperfection of component, aging effect, environment changes etc. So during controller design the variation of parameter may be taken in to consideration.

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