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Load Frequency Control for Two-Area Deregulated Power System

Jyoti Gupta[1], Manish Kumar Singla[2], Anupma Gupta[3], Rajneesh Talwar[4]*
[1]Department of Computer Science, Shree Guru Gobind Singh Tricentenary University, Gurugram, Haryana, (INDIA).
[2,3,4]Department of Interdisciplinary Courses in Engineering, Chitkara University Institute of Engineering & Technology, Chitkara University, Punjab, India.

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***Corresponding author**
Email:
anupmagupta31@gmail.com
7837494036

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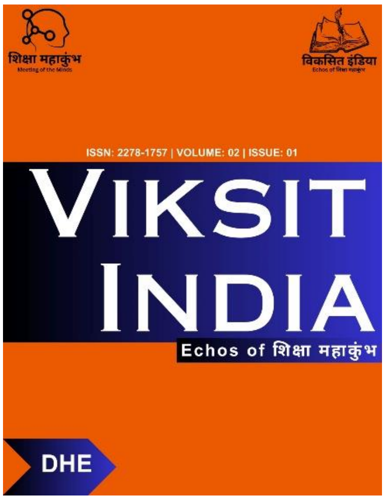

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Abstract

Due to the reduction in resources and increasing load demand, it is of utmost importance to control power generation. The reliable operations of energy system are constantly exposed to serious threats as the demand for generator loads increases. The independent turbine system, generator, and load frequency control (LFC) or automatic generation control (AGC) system are used to perform the job of automatic regulation of frequency. Following parameters are needed to be controlled for the operation of a damaged and undamaged generator: Firstly, the frequency must be kept constant, and secondly, the power of the tie bar that falls within the specified limits. To retain a balance between load demand and power generation for specific energy system is the most important function of power generation. A comparative study of system frequency using Proportional Integral Differential (PID) control is being put forward, and the model is simulated in the MATLAB environment. This paper focuses on analyzing the two-area power system, and proposes the design of the automatic load frequency control system using PID control.

Keywords: Load Frequency Control, Proportional Integral Differential Control, Two-Area System, Disco Participation Matrix, Deregulated Environment.

Introduction

Generation, transmission, and distribution of electric power are done using a combination of non-linear electrical components, called an electric power system. A common control scheme, called the control area (CA), applies to several interconnected subsystems. Time deviations are exhibited by the active energy flow between the control areas and the frequency of the energy system [1].

The difference between generation and consumption in control chain, and instability of the signal source over time are responsible for these deviations. For load changes, the desired constant frequency in each control region is maintained by the load frequency control. Active energy exchange with adjacent control areas is also maintained by load frequency control at scheduled intervals [2].

There are a wide range of uncertainties illustrated in the parameters of two-area electric power system in the method put forward. If the electric utility attempts to be more innovative in decreasing losses and improving reliability and efficiency of the service, then profits can be maximized by minimizing the costs in a deregulated environment. Regardless of increasing competition, the customer base will be maintained by the utility by following the process. Electric power can be exchanged between two systems by using the tie line which is also used to calculate the area control error [3].

The load frequency is also controlled with the help of optimization [4-5].

This optimization is done by controlling the generation and demand. The frequency is maintained by controlling the generation and load to ensure the balance between them. This ensures that the power system is working efficiently and reliably. This process of frequency control is known as automatic generation control (AGC). It is done by using feedback control systems and various algorithms such as proportional-integral-derivative (PID) control. AGC is an important part of power system stability. AGC helps to maintain the desired frequency and power output of the generators and helps to keep them in balance. It also helps to maintain the system stability by responding quickly to disturbances in the system. The main contribution of the manuscript is given below:

1. The paper addresses the significance of controlling power generation due to resource reduction and increasing load demand, emphasizing the critical importance of reliable energy system operations.

2. The study discusses the use of an independent turbine system, generator, and load frequency control (LFC) or automatic generation control (AGC) system for automatic frequency regulation.
3. Two main parameters for the operation of damaged and undamaged generators are highlighted: constant frequency maintenance and power control within specified limits.
4. A comparative study of system frequency using Proportional Integral Differential (PID) control is conducted, and the model is simulated in MATLAB for a two-area power system.
5. The paper proposes the design of an automatic load frequency control system using PID control, focusing on analyzing the effectiveness of this approach for achieving a balance between load demand and power generation in the energy system.

Modelling of Isolated Power System

To behold the case of LFC, a single turbine generator system, capable of providing independent load, is assumed. There are basically three parts of the single generator LFC scheme. Taking into account a single area thermal system [6] as an example, a mathematical transfer function can be found below:

Model of the speed governing system of turbine

The figure 1 shown below depicts the speed control of the steam turbine. Its main components include:

1. **Fly ball speed governor:** It is the core component of the system and its task is to detect the variation in speed frequency. As can be inferred from the figure 1 shows, the ball moves outward if the speed of the system increases, and there is decrease in then point B of the mechanism and vice versa.
2. **Hydraulic amplifier:** This component also serves as an important component in the speed governing system of turbines, which consists of a main piston and a control valve to govern the speed of the turbine. When a steam valve has to be opened and closed in order to prevent high pressure steam from entering, the small movements of the low-level valves are converted into the bigger movements of the high-level piston valves. This allows for more precise control of the steam and helps to regulate the speed of the turbine. This helps to ensure the turbine runs smoothly and efficiently. It also helps to prevent any damage to the turbine and its components.

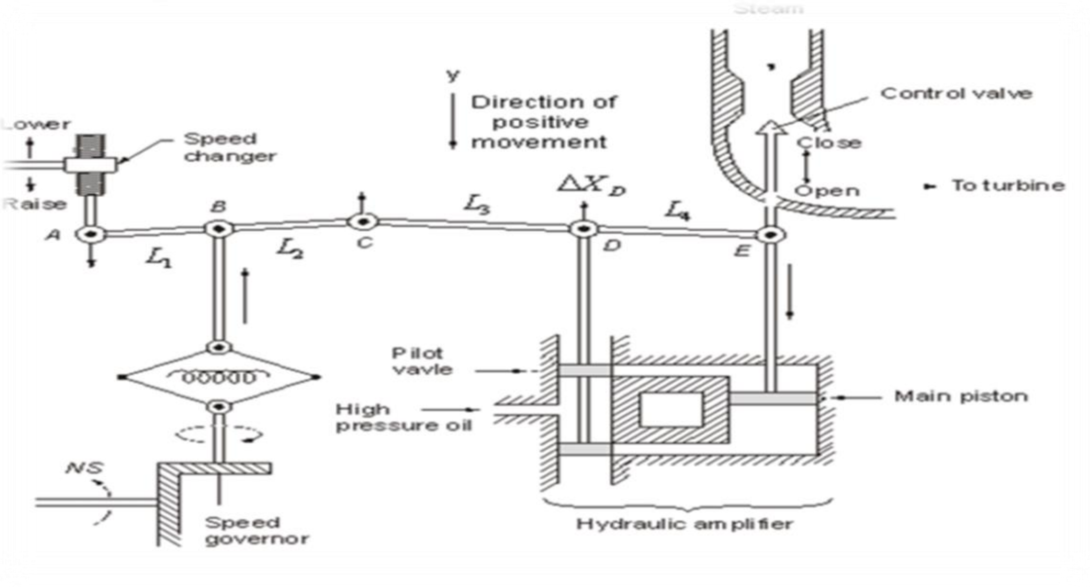

Fig.1 Speed governing system of turbine [7]

3. **Linkage mechanism:** It is a firm linkage connection every individual mechanism with each other in system, as ABC and CDE which is pivoted at B and D, respectively. These connections control the flow of the valve proportional with speed variation. It also enables the feedback of the steam valve.
4. **Speed changer:** In order to attain stability, it is used to regulate the output power of the turbine mechanism. In a stable state, upper control valve is moved downward, and as a result, more steam enters the turbine, and vice versa.

On the linkage mechanism, let point A moves downward by a small amount, Δy_A. Since power of a turbine can be changed using the above command, thus it can be stated as follows:

$$\Delta y_A = K_C \Delta P_C$$

Where, ΔP_C is the command signal to improve power.

A series of mechanisms need to be activated to increase ΔP_C. Due to this, the pilot valve is set in upward motion which allows high-pressure oil to flow to the upper end of the main piston, flowing downward. Due to the relative opening of the steam valve, the speed of the turbine and thus the frequency of the system increases.

The net movement of C is given as: -

$$\Delta y_C = -K_1 K_C \Delta P_C + K_2 \Delta f$$

The amount of opening of the pilot valve is described by Δy_D and can be written as follows: -

$$\Delta y_D = \left(\frac{L_4}{L_{3+L_4}}\right)\Delta y_C + \left(\frac{L_3}{L_4+L_3}\right)\Delta y_E$$
$$= k_3 \Delta y_C + K_4 \Delta y_E$$

It is contributed by Δy_C and Δy_E. In the signal's response by opening one of the pilot valve-ports that fills the cylinder with oil at high-pressure, Δy_D moves by opening the steam valve and moving the piston by Δy_E. There exists a direct relation between the amount of oil that is put into the cylinder and the integration time Δy_D. The Δy_E motion is

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the ratio of the amount of oil volume to the cross-sectional area of the piston. So,

$$\Delta y_E = K_5 \int_0^t -\Delta y_D dt$$

Taking Laplace of all equations:

$$\Delta y_C(s) = -K_1 K_C \Delta P_C(s) + k_2 \Delta F_S$$
$$\Delta y_D(s) = -K_3 \Delta y_C(s) + k_4 \Delta y_E(s)$$
$$\Delta y_E(s) = -K_5 \left(\frac{1}{s}\right) \Delta y_D(s)$$

After eliminating $\Delta y_C(s)$and$\Delta y_D(s)$,the equation becomes: -

$$\Delta y_E(s) = \frac{K_1 K_3 K_C \Delta P_C(s) - K_2 K_3 \Delta F(s)}{K_4 + \frac{S}{K_5}}$$
$$= \Delta P_C(s) - \frac{1}{R}\Delta F(s) \times \frac{K_{sg}}{1 + T_{sg}}$$

Where,
R=$\frac{K_1 K}{K_2}$.
$K_{sg} = \frac{K_1 K_3 K_C}{K_4}$.
$T_{sg} = \frac{1}{K_5 K_4}$.

The following block diagram as shown in figure 2 can be used to represent the above equation:

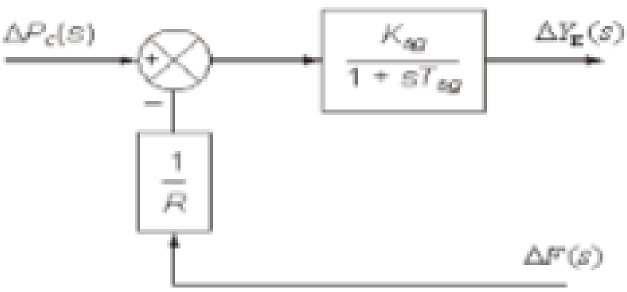

Fig. 2 Block diagram of speed governor

- **Turbine Model**
  Two main factors strongly influence dynamic response. These are: (a) between the steam inlet valve and the first stageof turbine, steam is introduced, and (b) the output is caused by the storage action of super heaters when high pressure phase leads low pressure phase. Therefore, turbine transfer function is characterized by the two main time constants $\Delta Kt, Tt(s)$. By using a unique equivalent time constant as shownin fig 3, the turbine can be modelled for simplifying the analysis [8].

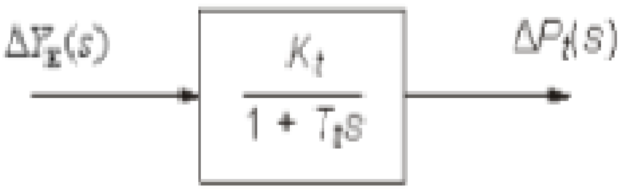

Fig.3 Turbine transfer function model

- **Generator Load Model**
  The incremental change in the input power to the generator-load system is given by:

$$\Delta P_G - \Delta P_D$$

Where,
ΔP_D is the increment in the load
ΔP_G =ΔP_T is the incremental change in turbine power output (generator incremental loss is assumed to be negligible).

$$\Delta F(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{B + \frac{2H}{f^o}S}$$
$$\Delta P_G(s) - \Delta P_D(s) \times \frac{K_{PS}}{1 + T_{PS}S}$$

Where,

$$T_{PS} = \frac{2H}{Bf^O}$$
$$K_{PS} = \frac{1}{B}$$

The block diagram shown in figure 4 represents the given equation:

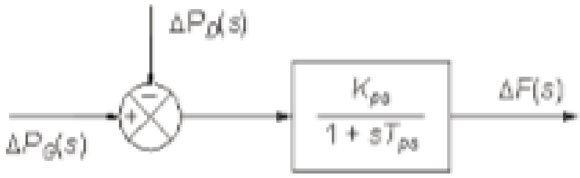

Fig. 4 Block diagram representation of generator load model

Block Diagram of Load Frequency Control of an Isolated Area
The block diagrams of the regulator, turbine and the generator with feedback loop is comprised in the block diagram of an isolated power system as shown in fig 5:

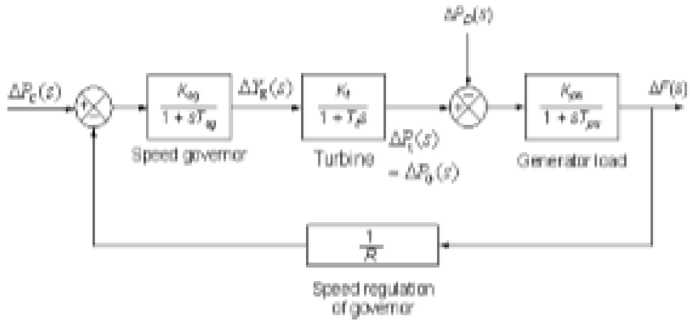

Fig. 5 Controlled isolated area simulink model

Deregulated Two Area System
To elucidate the method put forward, extensive parametric uncertainties are provided with two-area power systems. If you are in an environment which is deregulated in a deregulated system, the company will try to refine the services offered to the customer by discovering something new through their extensive efforts. This will inturn maximize the profits, and minimize costs. In this way, the company tries to ensure that it retains its customers despite competition [9-11]. This method is beneficial for both the customers and the companies. Customers will be able to receive better services at a lower cost, while companies will be able to increase their profits. Moreover, the competition will also help to keep prices low. This will ensure that customers have access to the best services at the most competitive prices. It will also lead to increased customer loyalty, as customers are more likely to stay with a company that offers them quality services at a good price.

Consider a two-area system with two DISCOs (power distribution) and two GENCOs (power generation) in each area. Ensure that GENCO1, GENCO2, DISCO1, and DISCO2 are located within Area 1 and GENCO3, GENCO4, DISCO3, and DISCO4 are located within Area 2, in the same order that is shown in figure 6:

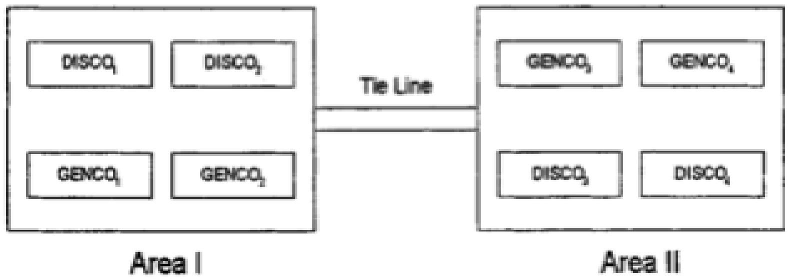

Fig. 6 Block diagram of two area system

The fig. 7 shows a power system interconnected in two areas, where Δf1 and Δf2 indicate the deviation in the frequency (Hz) in area 1 and area 2 respectively, and ΔPd1 and ΔPd2 indicate the increase in load demand. In the earlier researches, dynamic models which include state variables have been derived by the researchers by using dynamic models of power systems.

Deregulation has many implications for the operation and control of electrical system networks. Extensive information exchange, dissemination, integration, and open access between and within utilities has become a neccessity due to deregulation. Participation factor is used to represent Disco participation matrix (DPM) which inturn is based on load distribution. In this case,there is a requirement of an area participation matrix from two areas. This matrix is used to track the flows between two areas and assess the performance of the system. The matrix also helps identify congested lines and areas of instability. It is an essential tool for monitoring and managing the electrical network. It also helps identify the most efficient way to shift the load in order to reduce losses and increase the reliability of the system. The matrix can also be used to identify and eliminate inefficient practices. It can also be used to determine the optimal size and placement of new equipment, as well as to identify potential issues with existing equipment.

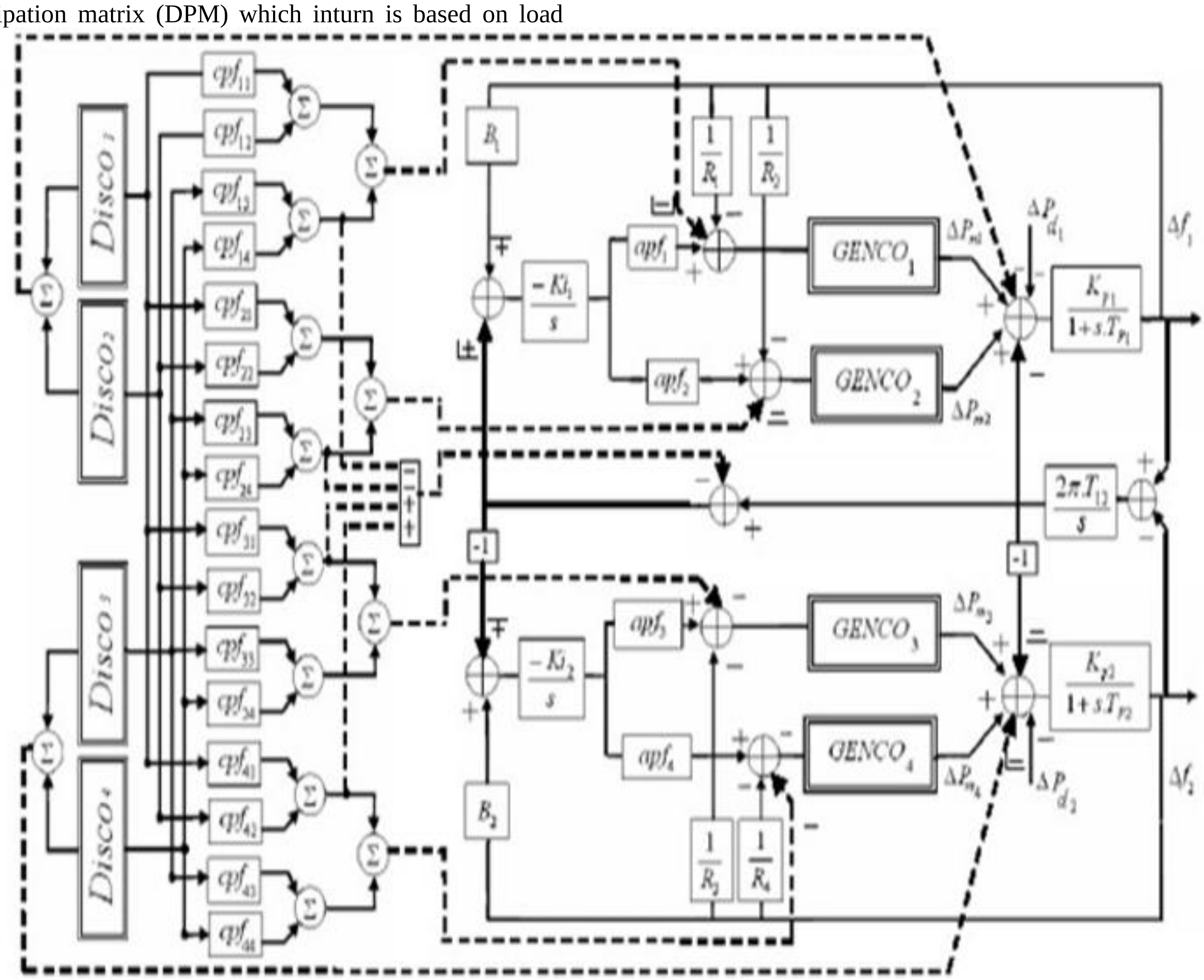

Fig.7 Two area Deregulated system

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Simulation And Results Of The System

In this case, all Discos have a contract with available Gencos, as per the given DPM

$$\begin{vmatrix} 0.5 & 0.25 & 0 & 0.3 \\ 0.2 & 0.25 & 0 & 0 \\ 0 & 0.25 & 1 & 0.7 \\ 0.3 & 0.25 & 0 & 0 \end{vmatrix}$$

Here, 0.1 pu MW of electricity is required for each Disco demands from Gencos. The participation factors as specified in the DPM matrix gives the above requirements. Factors participating in each Genco area control error are given as 11D pf 0.75, 12D pf 0.25, 21D pf 0.5, and 22D pf 0.5. The table 1 represents the comparison of settling time, peak overshoot and frequency error of controller of two area power system and power programmed/arranged into the tie line is: -

$$\Delta \boldsymbol{P}_{\boldsymbol{tie1-2,scheduled}}$$

$$\sum_{i=1}^{2}\sum_{j=3}^{4} \boldsymbol{CPf}_{ij}\,\Delta \boldsymbol{PL}_{j} - \sum_{i=3}^{4}\sum_{j=1}^{2} \boldsymbol{CPf}_{ij}\,\Delta \boldsymbol{PL}_{j}$$

Table 1 Comparisons of settling time, peak overshoot & Frequency error of controller of two area Power System

For $\Delta f1$	With Controller	
	Simulink	Workspace
Settling Time (s)	13.5	13.5
Peak overshoot (pu)	-0.0216	-0.0216
Freq. Error $\Delta f1$ (pu)	0	0

In conjunction with varing the load or changes in speed switch settings, an expanded energy system (eg. National network) can be divided into sub-areas (suppose state electrical commissions). The region which is assumed to operate at same frequency for both, dynamic and static conditions, is known as the control region. The controlling area can be reduced by charging systems, speed regulators and the turbine generators to create a proper controlling strategy. The simulink model of uncontrolled isolated area is shown in fig. 8. The fig. 9 represents the simulink of load frequency control using PID controller for the two area derregulated system and fig. 11, 12 shows the results of frequency deviation of area 1 and area 2:

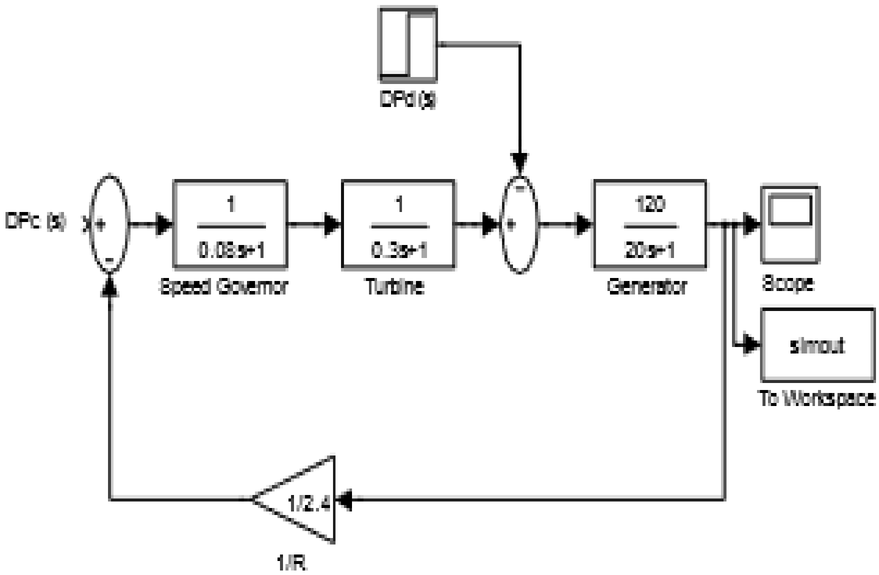

Fig. 8 Uncontrolled isolated area simulink model

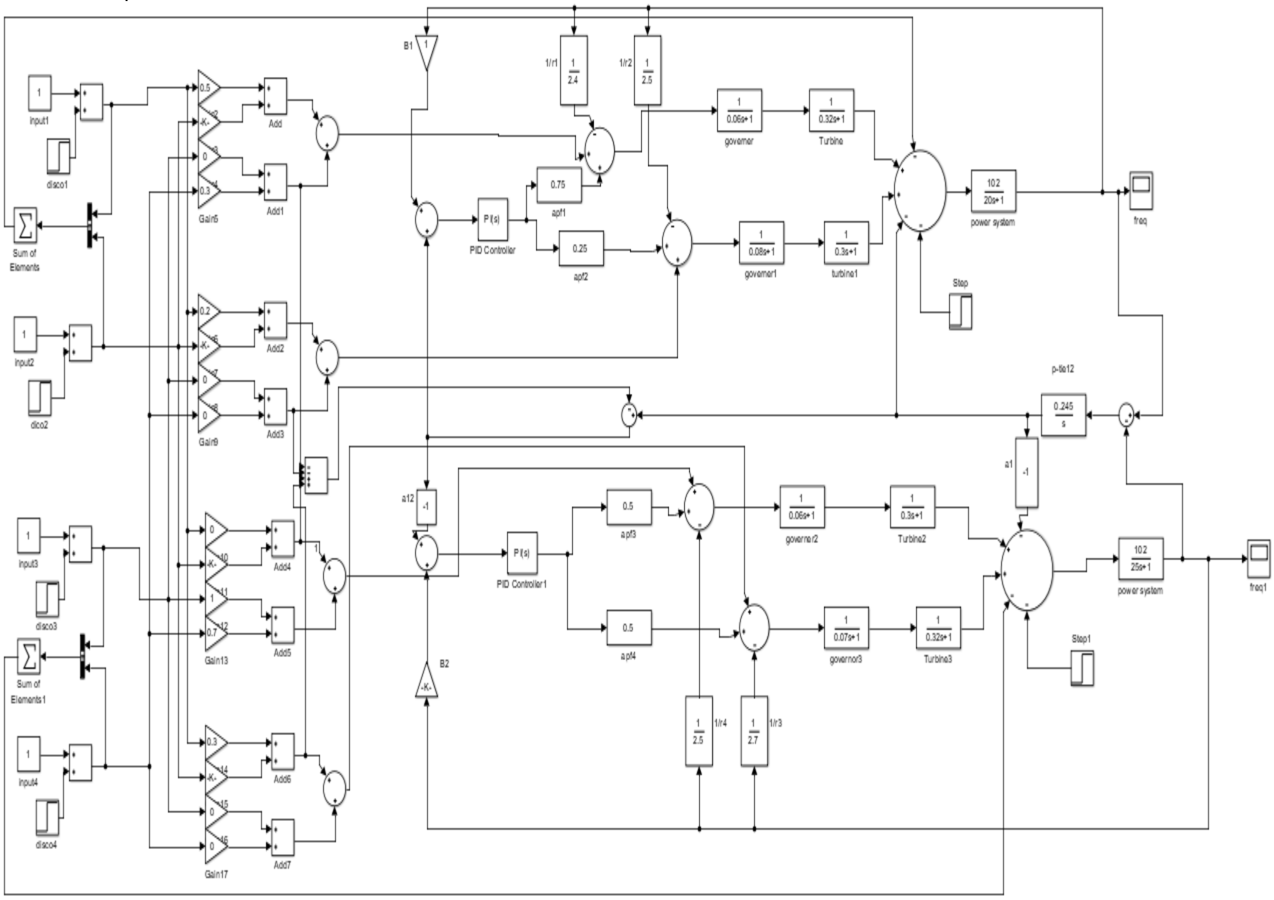

Fig. 9 LFC using PID Control for the two area derregulated system

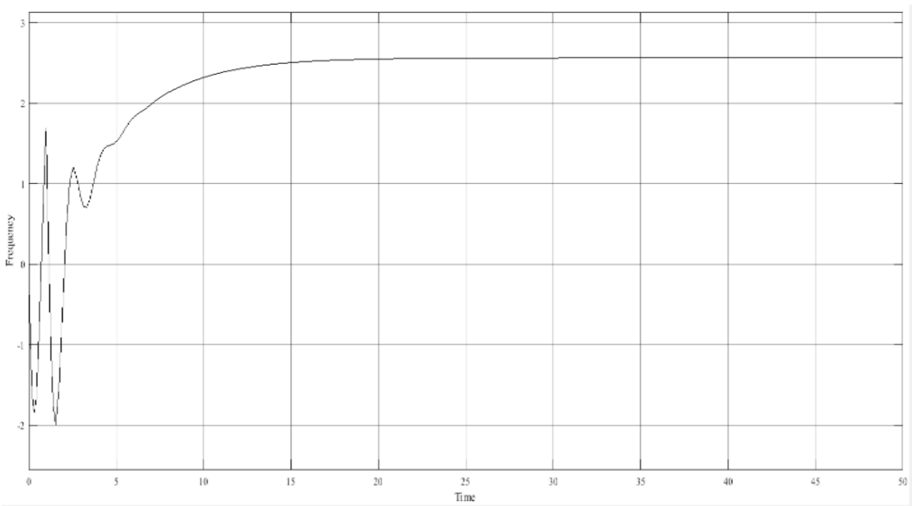

Fig. 10 Deviation of Frequency (Hz) in area1

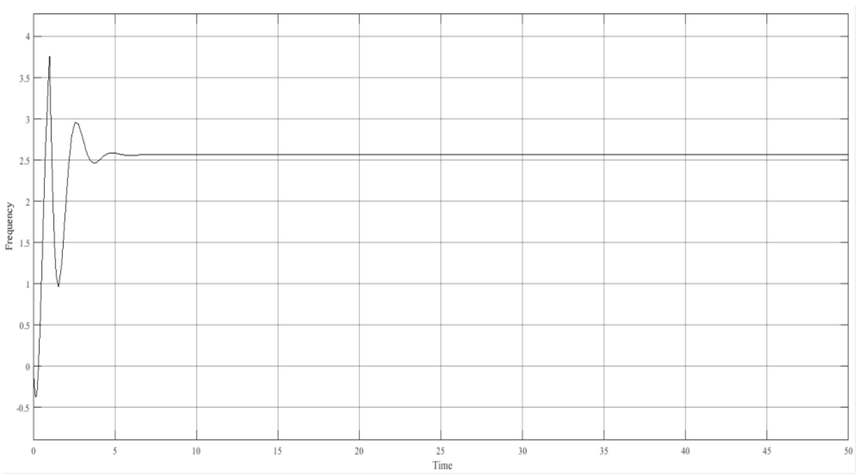

Fig. 11 Deviation of Frequency (Hz) in area2

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Conclusions

In the research of energy systems, one of the most important issues is modified LFC in deregulated environment. In this paper, for problems related to LFC in deregulated power system, a PID (Proportional Integral Differential) based controller is put forward by using the strategy of modified LFC.

In the demand situation, while investigating issues governing Load Frequency Control (LFC), proper care is ensured for the controller capacity requirements and load frequency control through which load changes can be tracked. Actual measurement can not be accessed by the state variable. Hence, to meet all the needs of the situation, practically, PID contoller can be used. The above method was designed for a two-area deregulated system with two contracted areas. The law of continuous time control has been proposed. The verification of the propsed controller is done by simulating the load frequency control in a two-area deregulated power system. The system doesn't have a stable status error in the area control error signal. In the sliding mode, it is more robust as compared to system parameter variation. The system output with the controller proposed, can be compared with that of the traditional controller for better understanding. The method proposed guarantess parameter uncertainty, load change, and strong performance against parameters and thus is very effective.

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