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Enhanced Load Frequency Control in Multi-Area Power Systems Using Fuzzy Logic Techniques

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Abstract : Power systems is the backbone of electrical distribution. Power systems is interconnected in nature. Various single areas are connected together to make a bigger system called the multi-area system. There are various disturbances in Power System like change of load, short circuit, open circuit occurring time to time in the system. Any type of these disturbances in this system causes deviation in system frequency. The electrical equipment that are used in daily life are highly dependent on system frequency. If there is any frequency change the equipment gets affected and will cause mal-operation of the whole system. So it is highly important to maintain the deviations within limits as soon as possible after the disturbances.

Keywords: Load Frequency Control (LFC), Multi-area Power System, Fuzzy Logic Controller (FLC), PID Controller, Control System Design, System Modeling, Simulation and Analysis.

I. INTRODUCTION

1.1. GENERAL INTRODUCTION TO LFC

Power Systems is the interconnection of many different control areas. They are connected to each other with the help of tie-lines. Disturbance in any of these controlarea can cause the frequency to from its normal value. It is important to maintain the frequency constant for the proper working of Power Systems. This is maintained with the help of Load Frequency Control. Load Frequency Control is the process of controlling the real power output of the generating unit with the change in the frequency of the system in the event of a disturbance. Disturbance can be in any side. It can be in the generating part or the load part. Disturbance can also be due to the disturbance in any other area of the power systems. This maintains the frequency at 50Hz in India, in USA it is 60Hz.

1.2. Literature Survey

The single and multi-area systems contain the problems of LFC in PS. In early times frequency of PS was controlled with the help of flywheel governor. It was found to be unsatisfactory. So conventional controllers like PID controllers were used to keep frequency in limits. It was required to correct the frequency deviation by the use of LFC of the system. Effects of non-linearities was also realized in LFC. LFC was carried out in single area system. LFC is extended to multi-area systems. LFC using PID controllers is performed on various single and multi-area systems. PID controllers and Fuzzy controllers are used for LFC in multi-area systems. Intelligent methods like Fuzzy controllers were helpful in LFC of multi- area systems Fuzzy logic controllers give better results as compared to conventional controllers.

1.3. Objective of work

Frequency of the power system is the important parameter. All equipment depends on frequency of the system. So this should be maintained within limits.

The main objective of this work is:
1. To build a two and four area system consisting of different power system areas in MATLAB/Simulink platform.
2. To use PID controller to stabilize the frequency deviations occurring during disturbances.
3. After using PID controller, fuzzy controller and with prolonged disturbance is studied. It is compared with above obtained results.

II. LOAD FREQUENCY CONTROL IN MULTI-AREA SYSTEM

2.1. Introduction

Load frequency control is an important part of the Power Systems. To understand it properly, it is required to study about the basic components of Power Systems. This chapter gives information about various parts of Power Systems. This chapter describes this by using the block diagram of each part with their related equations. After this the study of Load Frequency Control will be performed. Finally, this chapter includes the details about the types of turbines used in the project and their transfer functions.

2.2. Power Systems: Overview

The objective in electrical power systems is to transform the available natural forms of energy into electrical energy by the use of electric generators and then transferring it to the end consumers located far away from the generating unit. Generating unit may be a thermal, a hydro plant, a nuclear plant, etc. after generation this is transferred to the consumers via transmission lines. An electrical power system is an interconnected and a complex structure which is divided into many different subsystems that are called the Generation subsystem, the Transmission subsystem and the Distribution subsystem.

2.3. Working System Description

The real power system network comprises of many elements such as the generators, the lines, the loads, the controllers and the protection devices. The dynamics of a system is the function of its constituent elements. So, if we want to study any system, it is very important to have the information about its various elements involved in it. In this section, introduction to the elements of the power system model to be used in the thesis in single area and multi-area systems is given with their respective transfer function models. First one is the generator model.

2.3.1. Generator model

In this model, turbine's mechanical power is transformed to electrical power by the generator set unit. In the study of our topic of LFC, the target is to obtain the output speed of rotor as the frequency in the power systems depends on it. So rotor speed is used in LFC instead of the energy transformation.

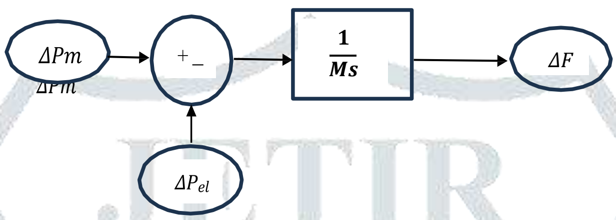

Fig.2.1 Generator's Block Diagram

2.3.2. Load model

The loads in our study are categorized as:

1. resistive loads (1P), they remains unchanged when the rotor speed changes.
2. motor loads which vary with the load speed.

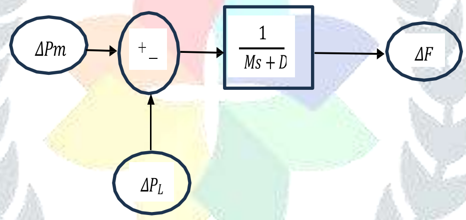

Fig.2.2 Load's Block Diagram

2.3.3. Prime mover model

The model of the prime mover keeps track of the input steam supply to the generator and keeps track of the boiler's control system in a steam turbine in the case of a hydro-generator turbine.

The model of the prime mover system is shown below.

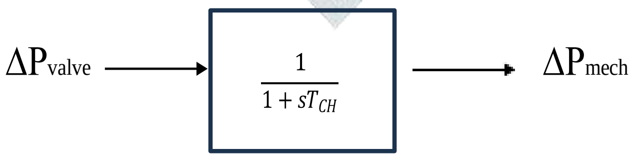

Fig. 2.3 Prime mover's model

2.3.4. The Governor model

Governor is that part of the system which is connected in the system to sense the frequency deviations that are due to the variations in the load and it regulates it by controlling the inputs to the turbines. The block diagram of the governing unit is given in Fig. 2.4.

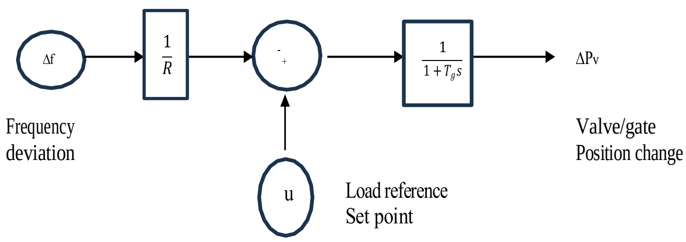

Fig 2.4 the governor model

2.4. Load frequency control in single area systems

Constant frequency is maintained in a single area network by using an integrator which acts as a reference for the governor units. Block diagram for load frequency control in single area system is given below.

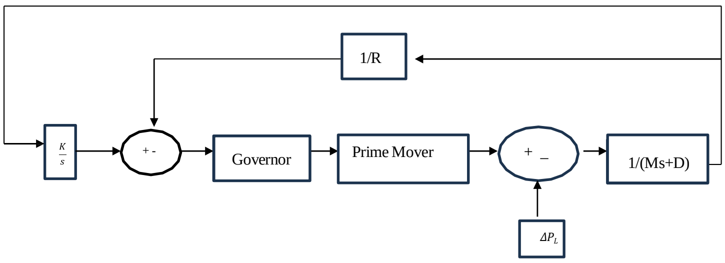

Fig 2.5 Load frequency control in single area system.

2.5. Load Frequency control in multi-area systems

In single area network, there are two quantities on which the focus remains. One is the change in frequency, and other one is the change in the tie-line power exchanges. These two quantities are clubbed together to form a new term called the ACE. ACE is defined by the equation given below.

$$ACEi = \Delta P12 + bi\Delta fi \qquad (1)$$

Here,
ACE = Area Control Error of ith area.
ΔP12 = changed in tie-line power between area 1 and area 2
bi = frequency bias constant of ith area
Δfi = frequency deviation of ith area
Tie-line arrangement in any two area system is modelled as shown below.

$$\Delta P_{tie,ij} = \frac{1}{s} T_{ij} [\Delta F_i(s) - \Delta F_j(s) \qquad (2)$$

Where,
ΔPtie,ij = tie-line power exchange between area 1 and area 2
Tij = tie-line synchronization torque co-efficient

Multi-area systems is the interconnection of two or more areas with the help of tie-lines. Generalized block diagram of a two area network is given in the below figure.

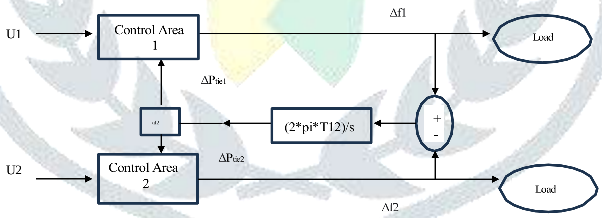

Fig 2.6 Block diagram of generalized two area system.

This equation can be shown in a model as shown below.

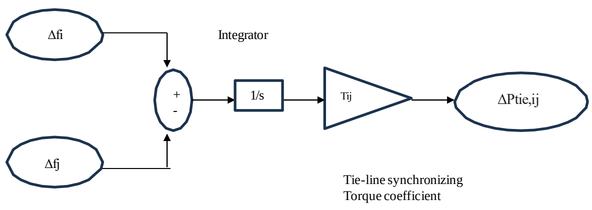

Fig 2.7 Two area tie-line model

III. LOAD FREQUENCY CONTROL WITHOUT ANY CONTROLLER

3.1. Single Area System

It is an electrical area independent from any other area in the power system network, in which there is one or more than one generating units, which distributes the electricity in the same area. In this single area it is the responsibility of the single generating unit in the area to maintain the normal frequency in case of any disturbance to the system. These single area systems are the building blocks of the larger multi-area power systems. The characteristics of a single area network is very simple and easy to determine. This helps us to study the more complex multi-area networks. Now we describe various single area networks in the coming sections.

3.2. Thermal Systems

Modelling of a single area thermal system is performed in MATLAB/Simulink as shown in Fig. 3.1 below.

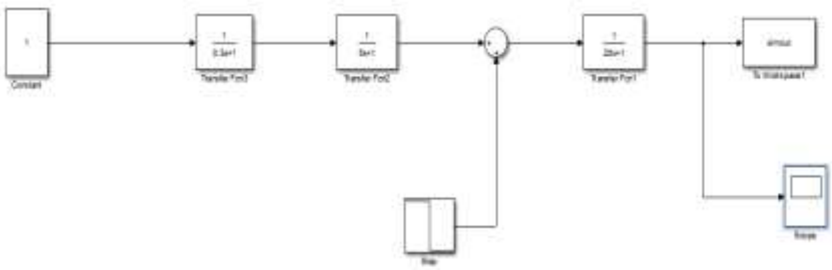

Fig 3.1 Single Area Thermal System

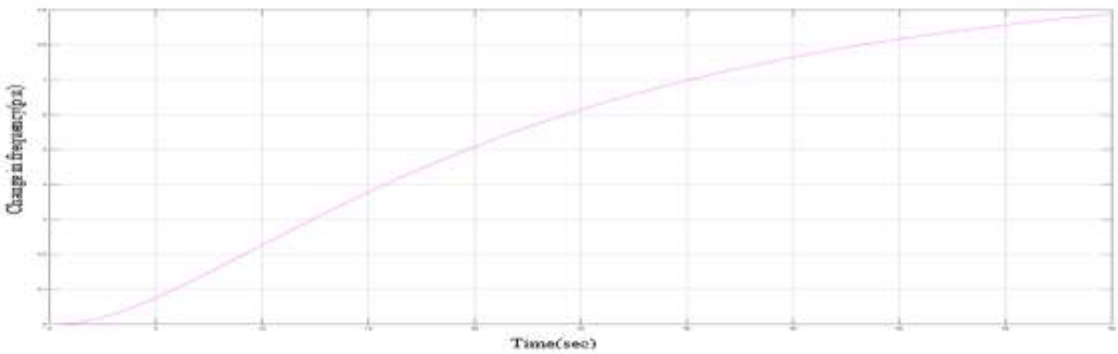

Fig 3.2 shows the step disturbance response in a single area thermal system without governor

3.3. Hydro Systems

Modelling of a single area hydro system is performed in MATLAB/Simulink as shown in Fig. 3.3 below.

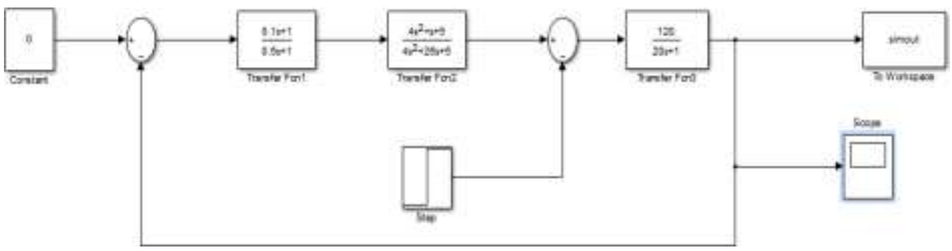

Fig 3.3 Single area hydro system with governor

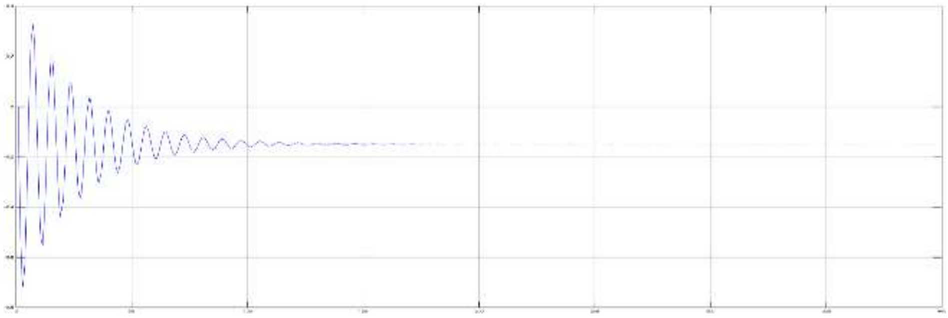

Fig 3.4 Response of a single area hydro system with generator

3.4. Multi-area systems

In real the power system is made up of many single areas connected together to form a larger multi- area system. They are connected with each other through tie-lines

Fig 3.5 two area system

In two area system any variations should be met by the generators in both the areas. Moreover the tie-line power change should also be made to be zero. This is made possible by using an integrator which integrates the power from the tie-line and feedbacks it to the governors.

ACE is defined as

$$ACEi = Pi + bi\Delta fi \qquad (3)$$

Where,

Bi = biasing factor

Δfi = change in frequency of areal

In two area system there are two areas dependent on each other. Thus the ACE for a two area system can be defined as given below.

ACE for area 1 is given by,

$$ACE_1(s) = P_1(s) + b_1\Delta f_1(s) \qquad (4)$$

IV. LOAD FREQUENCY CONTROL USING PID CONTROLLER

4.1. PID controllers

PID controllers are the commonly used controllers for many control actions. In this chapter we are using them for the load frequency control in single and multi-area systems. PID controllers are made up of three controllers called the Proportional (P), Integral (I), and the Derivative (D) controllers. The PID controller is discussed in the section below.

4.2. PID controller

PID controller is the combination of proportional, integral and derivative controllers in either series or parallel configuration. Equation of a normally used PID controller is

$$Uc(s) = [Kp + \frac{KI}{S} + KDs]\ E(s) \qquad (5)$$

Structure of the PID controller used in the thesis is given in the Fig 4.4 below.

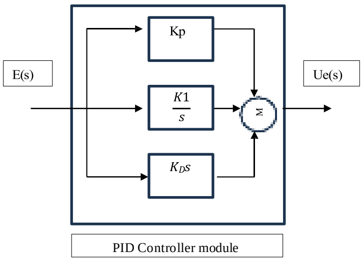

Fig 4.1 PID controller block diagram

4.3. PID controller in two area system

Performance of single area system was analyzed in the previous chapter. It was concluded that the governor is necessary for stabilization of frequency. In this chapter we will use PID controller to stabilize frequency in two, three and four area systems. Figure below shows the effect of PID controllers in a two area system.

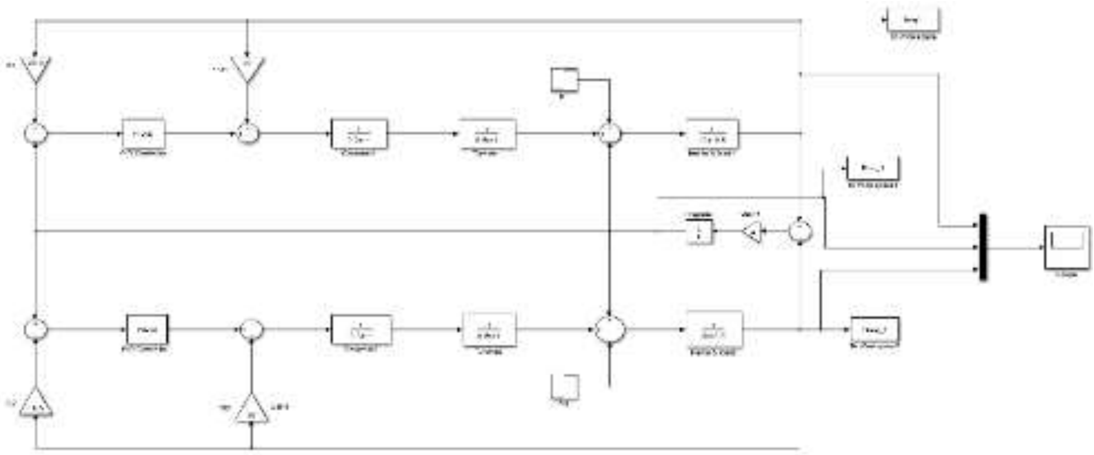

Fig. 4.2 PID controller in two area system

In the Fig 4.3 we are only using the PID controller in two area system. For all the below responses, the controller we are using we have to keep the controller as 1 and remaining as zero for all the P, I, PI, PD and PID controllers.

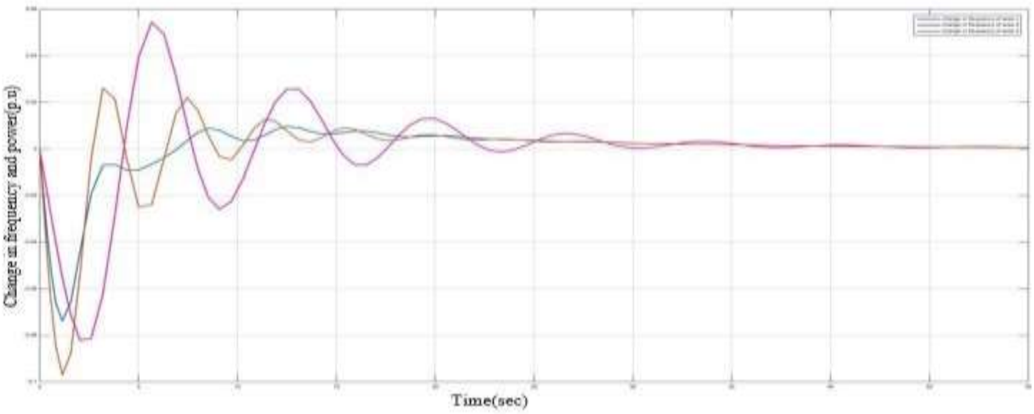

Fig 4.3 Response of two area system with PID controller

Controller	Settling time (in seconds)		Overshoot (in p.u)		Undershoot (in p.u)		Tieline power (in p.u)
	Area1	Area2	Area1	Area2	Area1	Area2	On steady state
P	55	60	0.079	0.092	0.048	0.08	65
I	18	17	0.09	0.106	0.028	0.05	21
PI	50	65	0.079	0.092	0.048	0.08	70
PD	10	10	0.058	0.072	0.001	0.008	25
PID	8	8	0.058	0.071	0.012	0.025	25

Table 4.1 Comparision responses for PID controller

The PID controller exhibits the best performance with the shortest settling times, minimal overshoot, and reduced tie-line power deviations, ensuring optimal stability for the two area system.

4.4. PID controller in four-area system

In this section we will study LFC in four area system. In the figure given below the MATLAB model of a four area system is presented. Response of four area system with PID controller is shown below the figure

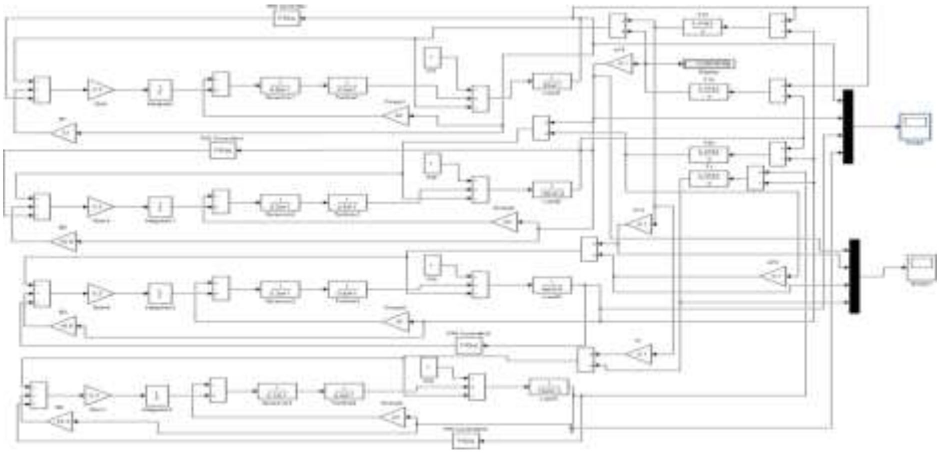

Fig 4.4 MATLAB model of the four area system

In the Fig 4.5 we are only using the PID controller in four area system. For all the below responses, the controller we are using we have to keep the controller as 1 and remaining as zero for all the P, PI and PID controllers.

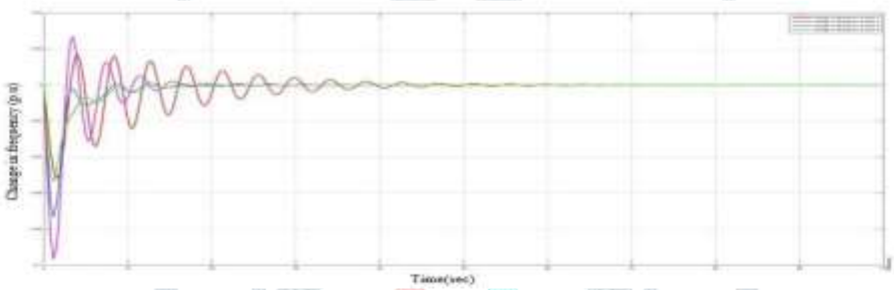

Fig 4.5 Response of four area system with PID Controller

Con troll er	Settling time (in seconds)				Overshoot (in p.u)				Undershoot (in p.u)			
	Are a1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4	Area 1	Area 2	Area 3	Area 4
P	70	25	35	17	0.018	0.001	0.026	0	0.05	0.072	0.098	0.052
PI	60	20	35	17	0.018	0.001	0.028	0	0.051	0.072	0.098	0.052
PID	60	55	55	55	0.021	0.008	0.03	0.006	0.051	0.072	0.098	0.052

Table 4.2 Area-wise response of four area system

From the above table results it is shown that PID controller is better than the P and PI controller in multi area system. The results indicate that the PID controller outperforms P and PI controllers in a four-area system, achieving shorter settling times and lower overshoot and undershoot values, thereby enhancing overall system stability.

V. LOAD FREQUENCY CONTROL USING FUZZY LOGIC

5.1. Fuzzy Logic Controller

With the in technology, fuzzy logic has played a significant role. Fuzzy logic was proposed by A. Zedah in 1965. This logic was similar to human thinking and logical reasoning. Since it is being used in many parts of the world. Fuzzy logic controller works on the principle of Fuzzy set. It is a set of values between [0,1] as compared to conventional logic where only two values (0 and 1) are considered. Fuzzy logic controller has also proved to be useful in Power Systems. Conventional methods are not able to give satisfactory results as compared to fuzzy logic. In this chapter, fuzzy logic controller is designed to minimize the variations in frequency in the output. In this study first two area system is considered and after that four area system is considered. Fuzzy logic is used to design the controller for load frequency control.

5.2. Structure of Fuzzy Logic Controller

The FLC works on the basis of four parts. They are: -

1. Fuzzification
2. Membership functions
3. Rules
4. Defuzzification

Thus ,a fuzzy set based controller is used to design a controller for L.FC in multi-area systems. This fuzzy logic developed is used in single and multi-area systems. Performance of this controller will be compared with the conventional controllers.

5.3. FLC in two area system

Here we are considering the thermal system for LFC.

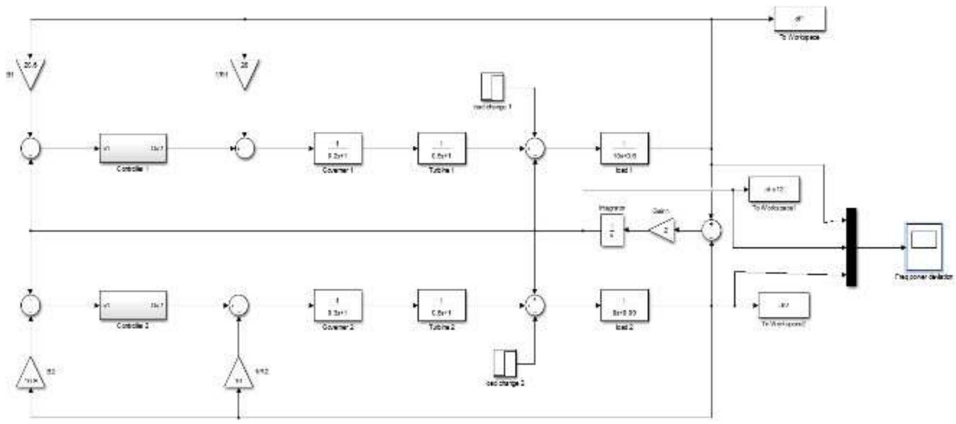

Fig 5.1 Two area system with LFC

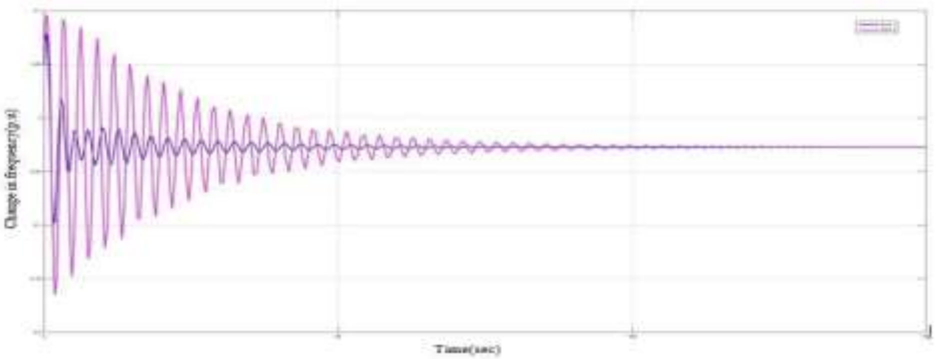

Fig 5.2 Response of two area system with FLC

Settling time (in seconds)		Overshoot (in p.u.)		Undershoot (in p.u.)	
Area1	**Area2**	**Area1**	**Area2**	**Area1**	**Area2**
80	120	0.08	0.09	0.09	0.17

Table 5.1 Response of two area system with FLC

From the above results it is concluded that the Fuzzy Logic controller performs better than the conventional PID controller.

5.4. FLC in four-area system

The MATLAB/Simulink model of a four area system is shown in the figure given below. FLC is used in the model. A disturbance of 0.05 P.U is given to the area 1 and the change in frequency and tie-line power is noticed in the figures given below.

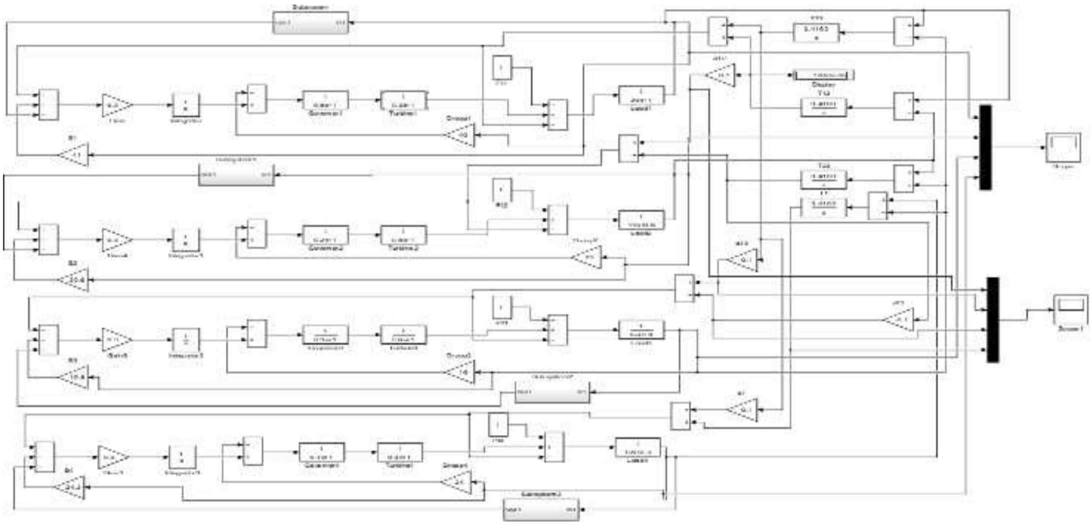

Fig 5.3 Four-area system MATLAB/SIMULINK model with FLC

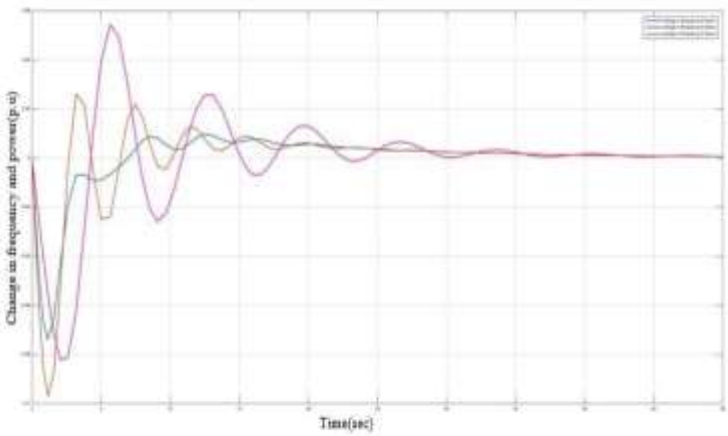

Fig 5.4 Response of four-area system with FLC

Controller	Settling time (in seconds)				Overshoot (in p.u)				Undershoot (in p.u)			
	Area1	**Area2**	**Area3**	**Area4**	**Area1**	**Area2**	**Area3**	**Area4**	**Area1**	**Area2**	**Area3**	**Area4**
P	70	25	35	17	0.018	0.001	0.026	0	0.05	0.072	0.098	0.052
PI	60	20	35	17	0.018	0.001	0.028	0	0.051	0.072	0.098	0.052
PID	60	55	55	55	0.021	0.008	0.03	0.006	0.051	0.072	0.098	0.052

Table 5.2 Response of four-area system with FLC

From the above results it is concluded that the Fuzzy Logic controller performs better than the conventional PID controller.

VI. CONCLUSIONS

6.1. Conclusion

This Project contributes to the Load Frequency Control (LFC) in multi-area power systems using conventional and intelligent controllers. The focus was on PID controllers and Fuzzy Logic controllers.

PID controllers were tested with different configurations (I, PI, PID) in controlling load frequency disturbances in a multi-area system comprising thermal and hydro systems. Among these, the PID controller configuration provided the best performance in terms of frequency stabilization.

Fuzzy Logic control was also employed to manage frequency deviations. The performance of the Fuzzy controller depends heavily on the accuracy and number of fuzzy rules. While increasing the number of fuzzy rules enhances system response, it also leads to higher computational time and effort. Comparatively, the Fuzzy controller outperformed the PID controllers in improving the system response.

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