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Comparative Analysis of Conventional PID Controller and Fuzzy Controller for Load Frequency and Voltage Control

Sahansil Adhikari[1*], Rohan Khatiwada[1*], Vision Parajuli[1], Suraj Shrestha[1], Afroz Alam[2]
[1] *Department of Electrical Engineering, IOE, Pashchimanchal Campus, Tribhuvan University, Nepal*
[2] *Assistant Professor, Department of Electrical Engineering, HBTU, Kanpur, India*
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Abstract

Power system stability has been identified as a major issue in recent years. It is well known that the demand for electrical power and the load on the system are not constant but alter. Load variations cannot be foreseen or prevented. A sudden change in load can cause variations in the system's frequency and voltage. As a result, for the system to run smoothly, the generation of the system must match the demand for the system. Load frequency control (LFC) and Automatic voltage regulator (AVR) are two essential control systems that contribute in frequency and voltage fluctuation reduction, respectively. The LFC loop controls actual power and frequency, whereas the AVR loop controls reactive power and magnitude of voltage. These controller's primary function is to maintain the voltage and frequency within acceptable limits. In this paper, at initial stage scheme without any controller in MATLAB SIMULINK was implemented and compared it with the scheme using Proportional-Integral-Derivative (PID) controller. Moreover, it provides good transient response, less steady state error, little overshoot and less settling time. Output response for different change in load was observed. Later, LFC scheme of two area interconnected power system using Fuzzy logic was modeled and compared it with response of PID controller in same scheme. Outcome of Fuzzy logic controller (FLC) scheme was observed and found that response was slightly better than PID scheme having short settling time, less overshoot and oscillation.

Keywords— Area Control Error, Automatic Voltage Regulator, Fuzzy Logic Controller, Load Frequency Control, Proportional-Integral-Derivative Controller

Introduction

Power system stability has been identified as a major issue in recent years. It is generally understood that the demand and load on the electrical power system are not constant and constantly changing. The power generated should vary in response of load change for the power system to function properly. Because of faults and sudden changes in system load, a power system is prone to instability. Imbalance in load, on the other hand, cannot be predicted or avoided. Unexpected variations in load might have a negative impact that causes fluctuation in the system's voltage and frequency. As a result, for the system to be stable, the demand plus losses must be equal to the system's generation. LFC and AVR are used as two important control mechanisms for reducing frequency and voltage variations. In particular, within set limits, each subsystem in an interconnected system must adjust the output power of its generators in response to fluctuations in system frequency and/or produce interchange with other areas. This is referred to as LFC. It is also essential to keep a synchronous generator's terminal voltage at a specific level. This is accomplished by employing an AVR. As a result, the LFC regulates frequency an d actual power, while the AVR adjusts voltage magnitude and reactive power. The major purpose of these controllers is to keep the voltage and frequency in acceptable values.

Kavita Goswami and Lata Mishra [2] explored a two-area interconnected power system model using PID controller and concluded that the use of PID controller results in relatively smaller peak overshoot and lesser settling time with zero steady state error. In [4] application of Artificial Intelligence in LFC of interconnected power system is discussed. Authors used ANN approach and drew conclusion that use of AI provide better result than PID controller. Suranjana Bharadwaj used FLC approach for controlling mechanism [5]. LFC control mechanism of multi-area power system using Fuzzy Logic PI controller [8] was proposed by Emre Ozkop et al. The system dynamic performance was observed for three different controller structures, PI, Fuzzy PI and Fuzzy controller and performance was observed and compared. In the IEEE Power India conference, H.D. Mathur and S. Ghosh suggested a Fuzzy method for selecting the best settings for the Proportional-Integral (PI) controller parameters of a LFC and AVR system where Fuzzy Gain Scheduled Proportional-Integral Controller approaches are used for a single area power system.

*Corresponding author.
E-mail: sahansil.adhikari@gmail.com
rohankhatiwada839@gmail.com

2. Model of power systems

2.1 Load Frequency Control

The purpose of Load Frequency Control is to keep the system frequency and inter-area power as close to the specified values as possible. When there is a variation in load demand on the unit, there is an unbalance between the system's power input and output. The LFC's primary goals are as follows:

a) To keep frequency constant
b) To divide the load among the generators
c) To control tie-line interchange schedules

2.2 Automatic Voltage Regulator

The AVR loop is responsible for controlling the magnitude of the generator's terminal voltage. This, in turn keeps the bus voltage stable by adjusting the reactive power output. The technique includes continuous terminal voltage detection, rectification, smoothening, and comparison with a specified dc reference. After amplification and shaping, the compared result "error voltage" is used to control the alternator field excitation.

2.3 Fuzzy Logic Controller

Fuzzy logic is a superset of Boolean algebra. It is better method in solving real world problems.

a) Fuzzifier: The fuzzifier's function is to convert the crisp input values to fuzzy values.

b) Fuzzy Knowledge Base**:** It keeps track of all of the input-output fuzzy relationships. It also has a membership function that describes the input variables of the fuzzy rule base and also the output variables to the unit under control.

c) Fuzzy Rule Base**:** It maintains information about the domain's process activity. In this project, we assign various rules. The fuzzy rule base is made up of a collection of forms that are based on the fuzzy base rule. The IF-THEN rule.

d) Defuzzifier: The defuzzifier's function is to turn fuzzy values from the fuzzy inference engine into crisp values. We employed the centroid approach of defuzzification in this case.

2.4 *Modeling of LFC including AVR in two area interconnected power system*

Modern power systems are classified into several categories. Each of these geographic areas is often linked to the places around it. Tie-lines are transmission lines that connect one location to a neighboring area.

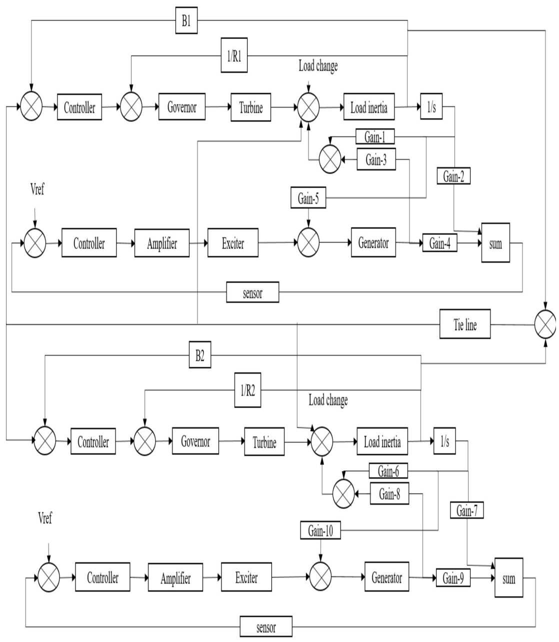

Figure 1. Two area interconnection using tie-line

These tie-lines allow power to be shared between two areas. Load frequency and Voltage regulation management, as the name implies, regulates the flow of power between different areas while maintaining a steady frequency and voltage level.

2.5 Modeling of Load frequency and voltage control of two area interconnected system without controller

Figure 2 shows a block diagram of a LFC and AVR coupled of a two-area linked power system without any controller.

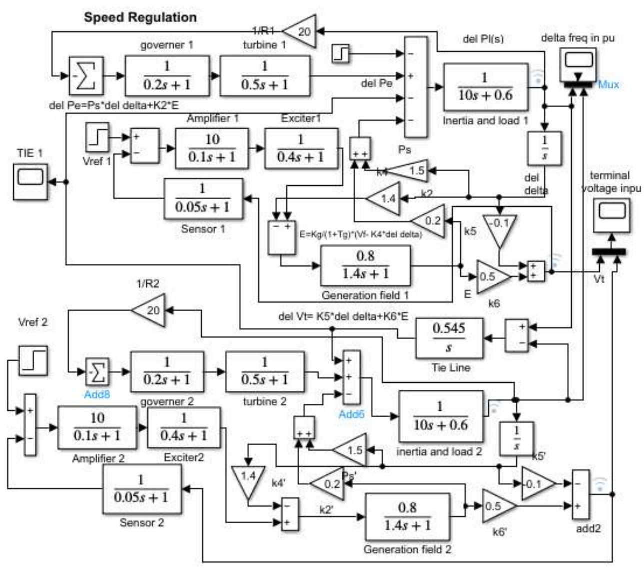

Figure 2. Modeling of Load frequency and voltage control of two area interconnected system without controller

2.6 *Modeling of Load frequency and voltage control of two area interconnected system with PID controller*

Figure 3 shows block diagram of LFC and AVR coupled multi area linked power system with PID controller. PID was used to generate the reset action for controlling the variation in frequency, terminal voltage and tie line power. The tuning of PID was done using hit and trial method and MATLAB PID auto-tuner.

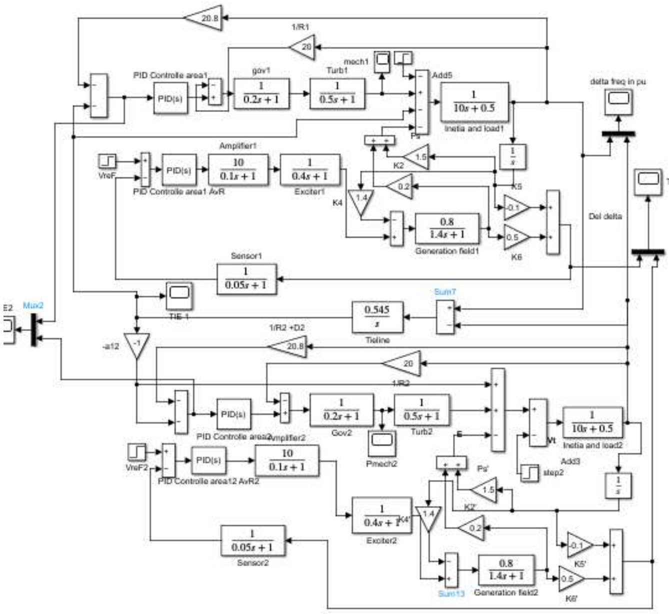

Figure 3. Modeling of Load frequency and voltage control of two area interconnected system with PID controller

2.7 *Modeling of Load Frequency Control of two area interconnected system with PID and FLC*

FLC have been frequently used in industrial processes in recent years due to their predictive nature associated with simplicity and effectiveness for both non-linear and linear system. Knowledge-based rules are developed and the fuzzy rule set is formed based

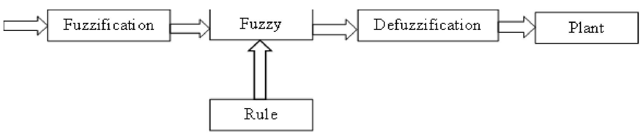

Figure 4. Block diagram of FLC

on that, as shown in table 1. Figure 5, 6 and 7 show membership function of input Area control error (ACE), change in ACE and output which consists of 7 triangular membership functions, respectively.

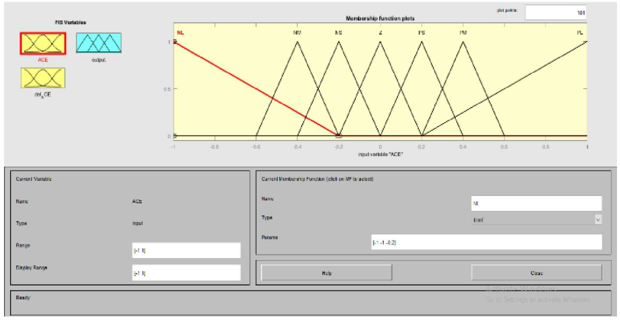

Figure 5. Membership function of input variable ACE

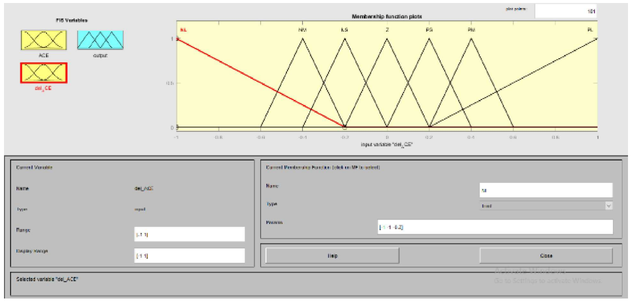

Figure 6. Membership function of input variable del ACE

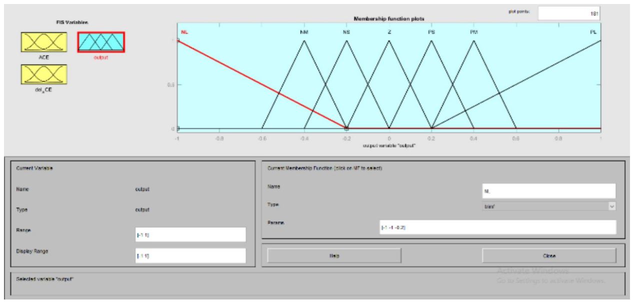

Figure 7. Output membership function

Table 1. Rules for Fuzzy logic controller

ACE ∆ ACE	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NL	NM	NM	NS	Z	PS
NS	NL	NM	NS	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PS	PM	PL
PM	NS	Z	PS	PM	PL	PL	PL
PL	Z	PS	PM	PL	PL	PL	PL

Where, NL: Negative Low, NM: Negative Medium, NS: Negative Small, Z: Zero, PS: Positive Small, PM: Positive Medium, PL: Positive Low

The following linguistic variables are used: NL, NM, NS, Z, PS, PM, and PL. A fuzzy membership function exists for each linguistic variable. Knowledge-based rules are developed and the fuzzy rule set is formed based on that, as shown in table 1.

Figure 8 shows the modelling of the load frequency control of a two-area linked system using FLC and PID. In figure, uppermost part is controlled by using PID controller which is interconnected to another area by using tie line. Similarly, lowermost part is controlled by using FLC controller which is interconnected to another area using tie line.

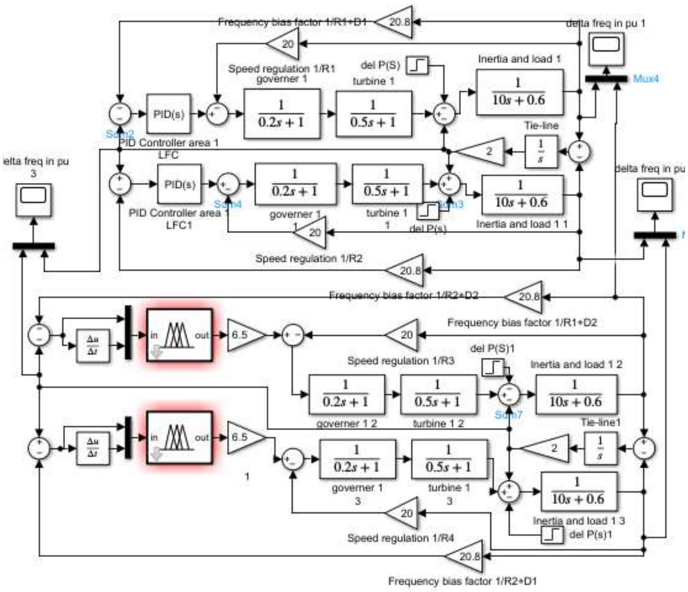

Figure 8. Modeling of Load frequency control of two area inter-connected system with PID and FLC

Here we used same parameter for both PID and FLC controller. We observed the system for 0.1875 pu step load disturbance increases and decreases for area 1 and area 2 while setting the simulation time to 50 seconds and 100 seconds in one case. We consider each area has similar parameters [2]. The parameters for running the system are given in table 2, table 3 and table 4.

Table 2. Simulation parameter of LFC

Quantity	Area-1	Area-2
Change in load in MW	$\triangle P_{L1}$=187.5MW	
Base power	1000 MW	1000 MW
Time constant of governor	τ_{g1}=0.2 sec	τ_{g2}=0.2 sec
Time constant of turbine	τ_{t1}=0.5 sec	τ_{t2}=0.5 sec
Damping constant of load	D_1=0.6	D_2=0.6
Load change	$\triangle P_{L1}$=0.1875 pu and -0.1875 pu	
Inertia constant of generator	H_1=5 MW/MVA	H_2=5 MW/MVA
Speed regulation of governor	R_1=0.05 Hz/pu	R_2=0.05 Hz/pu
Frequency bias factor	B_1=20.8 pu MW/Hz	B_2=20.8 pu MW/Hz
Tie line constant	a_{12}=1	
Synchronizing coefficient of tie line	T_{12}=0.0867 pu	

Table 3. Simulation parameter of AVR

Quantity	Area-1	Area-2
Gain of amplifier	K_{A1}=10	K_{A2}=10
Time constant of the amplifier	τ_{A1}=0.1 sec	τ_{A2}=0.1 sec
Gain of exciter	K_{E1}=1	K_{E2}=1
Time constant of exciter	τ_{E1}=0.4 sec	τ_{E2}=0.4 sec
Generator gain	K_{G1}=0.6	K_{G2}=0.6
time constant of generator	τ_{G1}=1.4 sec	τ_{G2}=1.4 sec
Gain of sensor	K_{R1}=1	K_{R2}=1
Time constant of sensor	τ_{R1}=0.05 sec	τ_{R2}=0.05 sec

Table 4. PID parameters

PID parameters	Area-1	Area-2
PID parameters used for LFC loop	K_p=1	K_p=1
	K_I=0.25	K_I=0.25
	K_D=0.3	K_D=0.3
PID parameters used for AVR loop	K_p=1	K_p=1
	K_I=0.25	K_I=0.25
	K_D=0.3	K_D=0.3

3. Results and discussion

3.1 Without controller

Figure 9 shows frequency response of area 1 and area 2 for 0.1875 pu load variation in area 1. From the graph it is quite evident that without any controller it results high undershoot, long settling time and high steady state error.

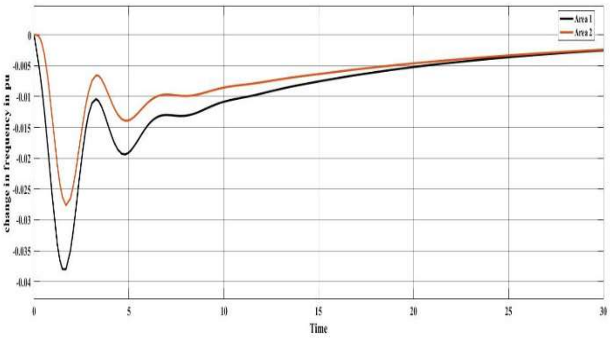

Figure 9. Frequency response without controller

Figure 10 shows terminal voltage response of area 1 and area 2 for 0.1875 pu load variation in area 1. From the graph it is quite evident that without any controller it results high overshoot and high steady state error of about 0.2 pu.

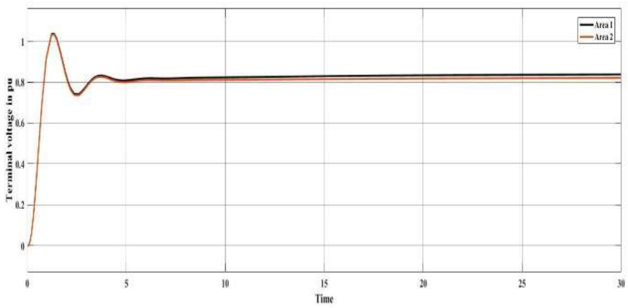

Figure 10. Terminal voltage response without controller

Figure 11 shows change in tie line power for 0.1875 pu load variation in area 1. From the graph it is quite evident that without any controller it results deviation in tie line power from its scheduled values.

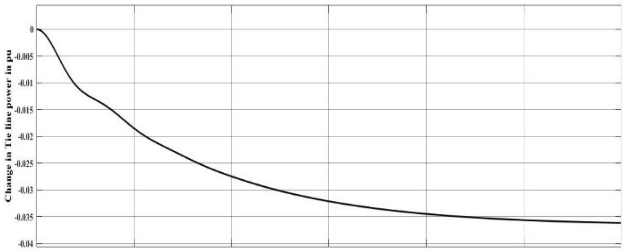

Figure 11. Change in tie line power without controller

3.2 With PID controller

Figure 12 shows frequency response of area 1 and area 2 for 0.1875 pu load variation in area 1. From the graph it is quite evident that with PID controller it results less undershoot, less settling time and nearly zero steady state frequency deviation.

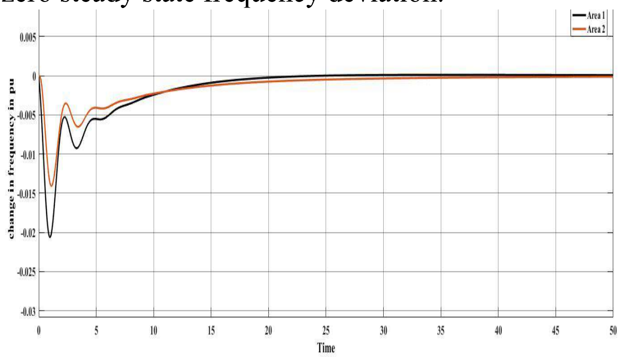

Figure 12. Frequency response with PID controller

Figure 13 shows terminal voltage response of area 1 and area 2 for 0.1875 pu load variation in area 1. From the graph it is quite evident that with implementation of PID controller it results less transient error, less settling time and zero steady state error.

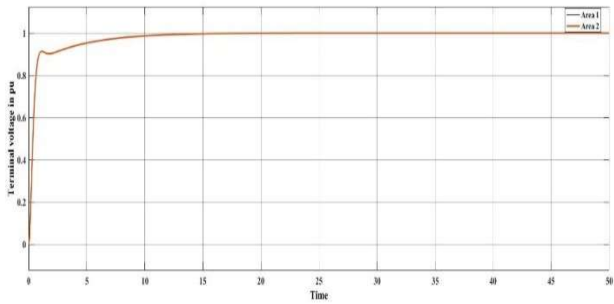

Figure 13. Change in terminal voltage with PID controller

Figure 14 shows change in tie line power for 0.1875 pu load variation in area 1. From the graph it is quite evident that with implementation of PID controller, change in tie line power becomes nearly zero as compared with the scheme without controller.

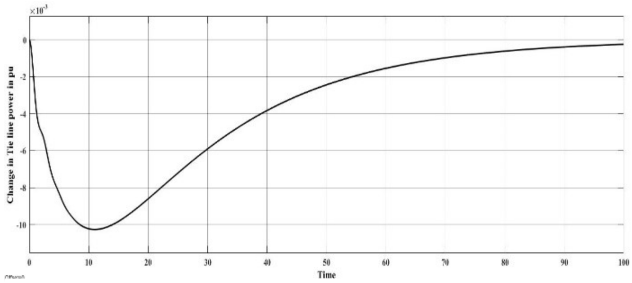

Figure 14. Change in tie line power with PID controller

Figure 15 shows variation in ACE for area 1 and area 2 for 0.1875 pu load variation in area 1. From the graph it is quite evident that as the ACE of the first area increases, this causes the tie line power to flow from area 2 into area 1 to balance the change in the load demand that happened in area 1 and causes the ACE to increase and PID controller comes into action and ACE starts to drop until zero.

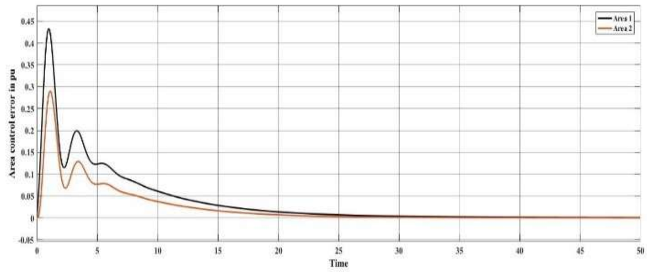

Figure 15. Area control error with PID controller

3.3 PID vs FLC

Figure 16 and 17 shows frequency response of area 1 for 0.1875 pu and -0.1875 pu load change, respectively in same area. The frequency deviation response in figures 16 and 17 demonstrates the system's response. Within a few seconds of using a fuzzy logic controller, the response became noticeably faster. In addition, the frequency deviation overshoot was significantly reduced. Fuzzy controller is simply concerned with the signal that has to be managed and the range of possible values for this signal; no information about the entire system's block is required.

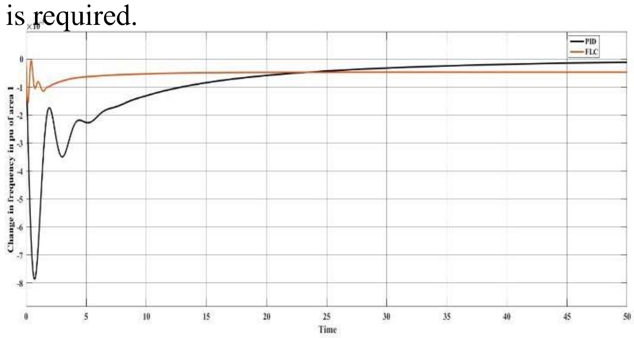

Figure 16. Comparison of frequency response of area 1 for +0.1875 load change

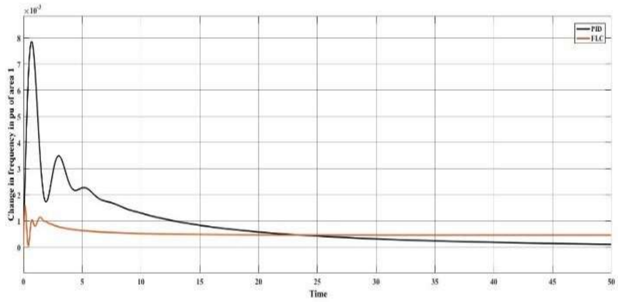

Figure 17. Comparison of frequency response of area 1 for -0.1875 pu load change

The frequency variation of the system approaches a steady state of almost 0.0005 pu, a settling time of about 6 second. Comparison between responses of LFC of two area interconnected power system using PID and FLC is as shown in table 5. Here, we consider +0.1875 pu load change in area 1 and -0.1875 pu load change in area 2. Results considering steady state error, oscillation and settling time is discussed in table 5 given below:

Table 5. PID vs FLC response comparison

	+0.1875 pu load change in area 1	**-0.1875 pu load change in area 1**
PID	The frequency variation of the system reaches a steady state of nearly -0.0002pu, with a settling time of 35 seconds and an undershoot of nearly -0.008pu.	The frequency variation of the system reaches a steady state of nearly +0.0002pu, with a settling time of 35 seconds and an undershoot of nearly +0.008pu.
FLC	The frequency variation of the system reaches a steady state of nearly -0.0005pu, with a settling time of about 6 seconds and an undershoot of nearly -0.0015pu.	The frequency variation of the system reaches a steady state of nearly +0.0005pu, with a settling time of about 7 seconds and an overshoot of nearly +0.0016pu.

4. Conclusion

The model is designed to keep the power system's frequency and voltage consistent (within a specified range of deviation at least). In a two-area interconnected power system's AGC, the ACE is the control signal that activates the system when the tie line power changes. Different controllers are used to control the reference signal ACE in order to control both the transient and steady state responses.

Without any controller, there is huge deviation in tie line power, frequency change and terminal voltage. When a conventional PID controller is used, for a few seconds, the frequency deviation response shows a fall in the frequency of both systems before the ACE changes the set point and over a time period of 20 seconds, returns the variance to exactly to zero error.

To reduce the response time of the system more, a controller has been designed using the modern approach of the fuzzy logic. The fuzzy controller response gave the fastest response of about 5 seconds, and the oscillations were better. We observed outcome of Fuzzy logic controller scheme was better than PID scheme having short settling time, less overshoot and oscillation.

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