Structure of PID Controller and Its Performance in Multi-Area Power System Network

Arun Kumar Maurya[1] and **Hera Khan**[2]
Department of Electrical and Electronics Engineering, Ajay Kumar Garg Engineering College,
27 Km Stone, Delhi-Meerut Expressway, Adhyatmik Nagar, Ghaziabad 201009 UP India
(Dr. A. P. J. Abdul Kalam Technical University)
[1]arun2021006m@akgec.ac.in, [2]hera2021005m@akgec.ac.in,

Abstract -- **To ensure the readiness, legitimacy and dependability of connected power systems for active power transitions, 'Automatic Generation Control Performance' plays a crucial part. In an interconnected electrical power system, the main motive of 'Load Frequency Control' is to maintain a steady frequency in each area and also ensure power constant of the transmission line (Tie-line). In this study, a two-area hydro-hydro power system is conceptualized and modeled using MATLAB/Simulink software by using three controllers—Integrator, PI, and PID. This paper outlines structure of the PID controller, which is shown to be the most efficient controller in terms of reduction of settling time, overshoot and system stability.**

Keywords: *Load Frequency Control, Optimal PID control, Two-area interconnected system, Voltage profilecontrol*

I. INTRODUCTION

THE load frequency control and voltage profile control are the two controls that are most important for ensuring the consistency and dependability of connected power systems. There may be one or more producing units linked to the same tie line in a single-power system area. Automatic generation control, or load frequency control uses inlet valve openings to boost a generating unit's mechanical output through servo mechanism activation in order to reduce frequency deviations in the event of abrupt load perturbations [1, 2].

In case of hydro and steam power plants, response time of the servo-mechanism is critical. Three types of controllers have been used, namely Proportional (P), Proportional-integral (PI), and proportional-integral-differential (PID). These controllers tuned on a hit-and-miss basis, take time, yet produce encouraging results. During last few decades, researchers used a variety of artificial intelligence techniques to tackle the problem, which alters frequency deviations as well as the power of the tie line of the control areas [3].

Particle swarm intelligence-based PID controller optimization strategy has been used in a connected power system and contrasted with the Ziegler-Nichols approach [4]. To maximize PID benefits, a unique Bacterial Foraging Optimization Algorithm (BFOA)-based approach has been used, and its performance has been evaluated in comparison to that of the traditional Ziegler Nichols (ZN) and Genetic Algorithm (GA) [5].

Using Firefly algorithm, controller gains are optimized, and the R parameter is chosen [6]. Fuzzy's rule-based approach for LFC has been compared with a particle swarm optimization technique [7]. For a multi-area power system, a model predictive control technique is used [8]. Through simulation experiments, a hybrid firefly algorithm based on pattern search was devised and verified for the AGC of multi area systems [9]. Hanwate *et al.* developed a combination of BFOA and PSO optimal PI control approach for multi-objective and multi-area LFC. [10]. The solutions based on artificial intelligence, however, are showing more encouraging outcomes, but it is still difficult to put them into practice because a more complex structure is needed, which raises the system's cost. Therefore, the traditional hit-and-trial strategy is used in this study to find the best gains for the three types of controllers.

II. SYSTEM IMPLEMENTATION

Load frequency control strategy for two-area interconnected power system is investigated in this paper. Figure 1 shows a single-area steam-power plant [1]. Table 1 lists parameters pertinent to the two-area automatic generation control given by Hadi Saadat [2], where a two-area electrical power system is connected through tie line whose common base value is 1000 MVA. An example of 187.5MW rise in load demand in any one area is considered. It is found that both areas increase generation to supply the load demand.

Table 1 -- PARAMETERS OF TWO-AREA SYSTEM MODEL

PARAMETERS	AREA - 1	AREA - 2
Speed Regulation (R)	R_1 =0.05	R_2=0.0625
Frequency sensitive load coefficient (D)	D_1=0.6	D_2=0.9
Inertia constant (H)	H_1=5	H_2=4
Base power	1000 MVA	1000 MVA
Governor time constant (T_g)	T_{g1}=0.2 (in second)	T_{g2} =0.3 (in second)
Turbine time constant (T_t)	T_{t1}=0.5 (in second)	T_{t2}=0.6 (in second)

III. SINGLE-AREA LOAD FREQUENCY MODEL

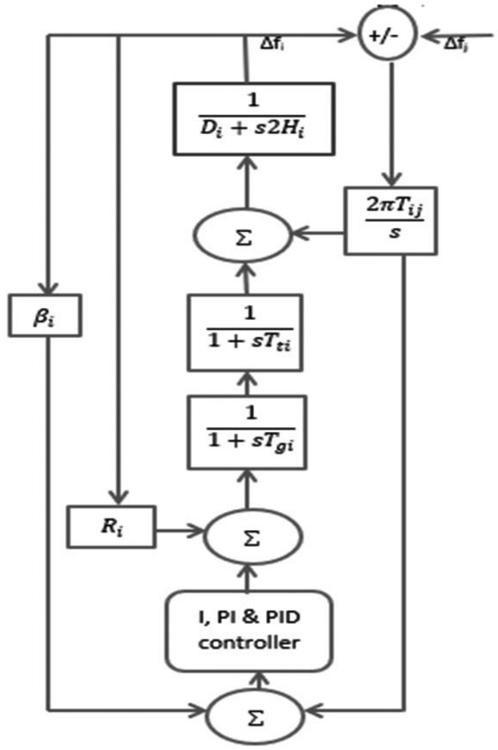

Figure 1. Block diagram of basic single *i*th area electrical power system.

The block diagram of single area load frequency model interconnected with *N* areas having primary governor control & secondary supplementary feedback loop is shown in Fig.1.

IV. ANALYSIS OF TWO-AREA ELECTRICAL POWER SYSTEM WITHOUT CONTROLLER

Here we observe the response of the power system when sudden change in the load side demand of 187.5MW in Area$_1$ occurs in the two-area interconnected electrical system network given in Fig.2.

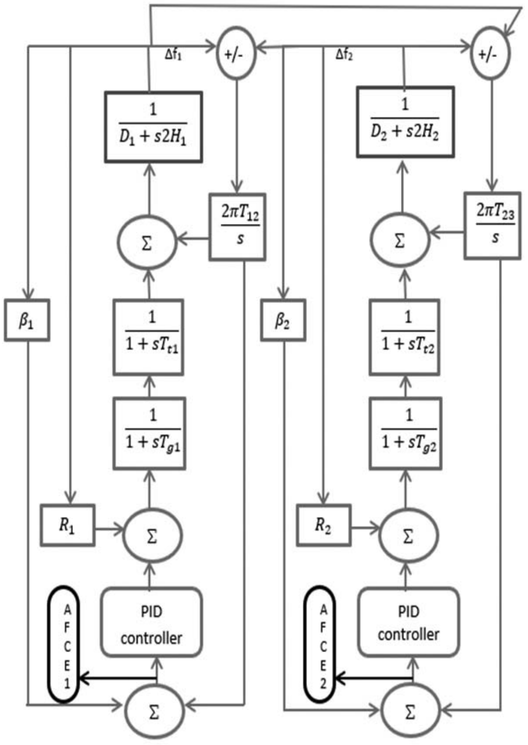

Figure 2. Model of two area electrical power system.

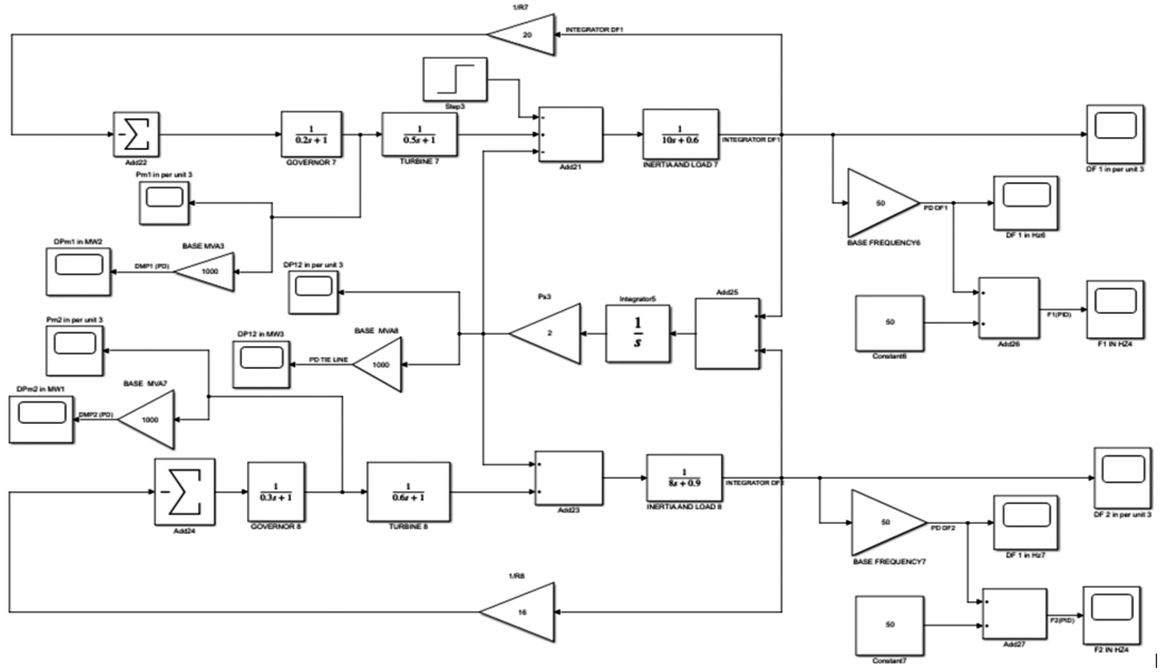

Figure 3. Model of two-area electrical power system without controller.

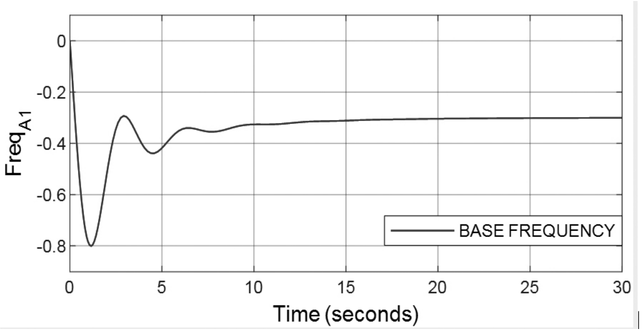

Figure 4. Graph of area 1 frequency deviations without controller.

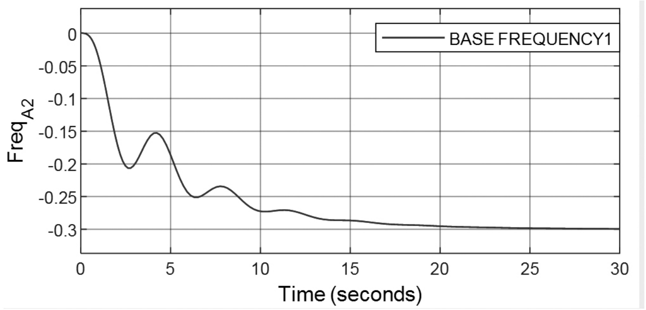

Figure 5. Graph of area 2 frequency deviations without controller.

We observe in Fig. 4 and Fig. 5 that frequency of both Area$_1$ and Area$_2$ deviates from nominal value of 50 Hz. Therefore, the system becomes unbalanced.

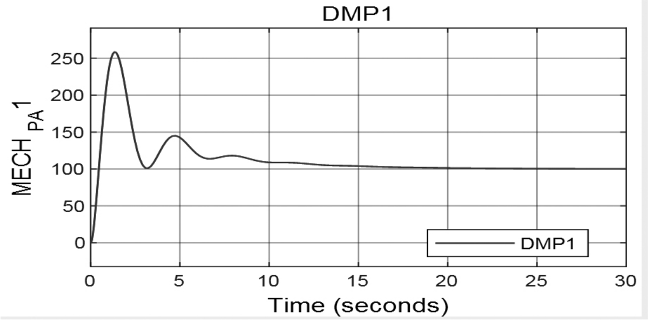

Figure 6. Graph of area 1 mechanical power deviations without controller.

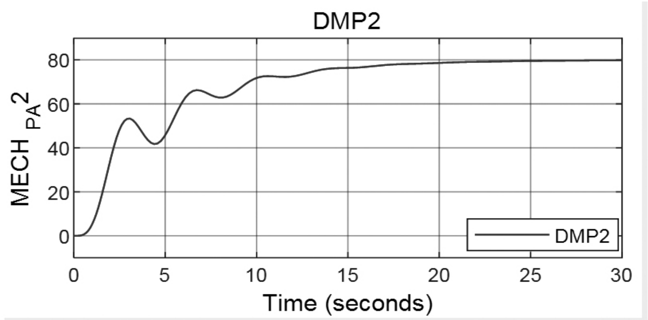

Figure 7. Graph of area 2 mechanical power deviations without controller.

We observe in Fig.6 and 7 that Area$_1$ does not supply the entire load-demand of 187.5 MW. Here, Area$_1$ is supplying 100 MW whereas Area$_2$ is supplying 80 MW.

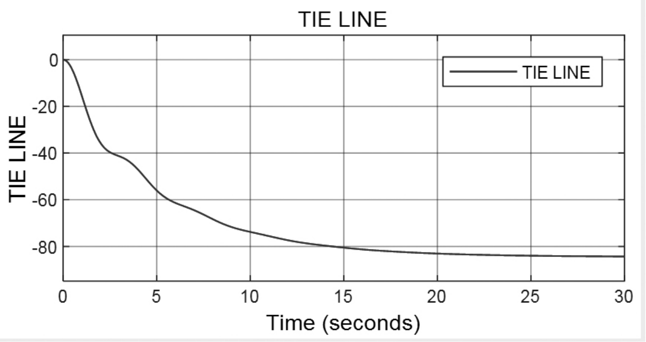

Figure 8. Graph of power of tie line without controller.

Figure 3 shows MATLAB/Simulink modelling of two area electrical power system without using any controller and the parameters of given model are shown in Table 1.

Steady state deviation & variation in power of Transmission line

1. The speed regulation of Area$_1$ and Area$_2$ is given by:

$$\frac{1}{R1} = \frac{1}{0.05} = 20$$
$$\frac{1}{R2} = \frac{1}{0.0625} = 16$$

2. The inertia and load for Area$_1$ and Area$_2$ is given by:

$$\frac{1}{2H_1 s + D_1} = \frac{1}{2 \times 5s + 0.6} = \frac{1}{10s + 0.6}$$
$$\frac{1}{2H_2 s + D_2} = \frac{1}{2 \times 4s + 0.9} = \frac{1}{8s + 0.9}$$

3. The per unit load changes in Area$_1$ given by

$$\Delta P_{L_1} = \frac{187.5}{1000} = 0.1875 \quad p.u$$

4. The per unit steady state frequency deviation is

$$\Delta\omega = \frac{-\Delta P_{L_1}}{D_1 + \frac{1}{R_1} + D_2 + \frac{1}{R_2}}$$
$$= \frac{-0.1875}{0.6 + \frac{1}{0.05} + 0.9 + \frac{1}{0.0625}}$$
$$= \frac{-0.1875}{(0.6+20)+(0.9+16)}$$
$$= -0.005\ p.\ u$$
$$\Delta\omega = -0.005\ p.u$$

5. The change in mechanical power in each phase is:

$$\Delta P_{m_1} = \frac{-\Delta\omega}{R_1}$$
$$= \frac{-(-0.005)}{0.005}$$
$$= 0.1\ p.\ u$$

$$\Delta P_{m_1} = 0.1\ p.\ u$$
$$\Delta P_{m_1} = 0.1 \times 1000 = 100\ MW$$
$$\Delta P_{m_1} = 100\ MW$$

$$\Delta P_{m_2} = \frac{-\Delta\omega}{R_2}$$
$$= \frac{-(-0.005)}{0.0625}$$
$$= 0.08\ p.\ u$$
$$\Delta P_{m_2} = 0.08\ p.\ u$$
$$\Delta P_{m_2} = 0.08 \times 1000 = 80\ MW$$
$$\Delta P_{m_2} = 80\ MW$$

6. Thus, the frequency variation in Hz at steady state is:

$$\Delta F_{actual} = \Delta F_{p.u} \times \Delta F_{base}$$
$$\Delta F_{actual} = -0.005 \times 60 = -0.3\ Hz$$
$$\Delta F_{actual} = -0.3\ Hz$$

7. Here is the steady-state frequency in Hertz:

$$F_{actual} = F_{original+} \Delta F_{actual}$$
$$F_{actual} = 60 - 0.3 = 59.7\ Hz$$
$$F_{actual} = 59.7\ Hz$$

8. The power flow tie line is:

$$\Delta P_{12} = \Delta\omega \times [\frac{1}{R1} + D_2]$$
$$\Delta P_{12} = -0.005 \times [16 + 0.9] = -0.0845\ p.\ u$$
$$\Delta P_{12} = -0.0845 \times 1000 = -84.5\ MW$$
$$\Delta P_{12} = -84.5\ MW$$

We observe that $Area_1$ does not supply whole load demand of 187.5 MW. $Area_1$ is supplying 100 MW and $Area_2$ is supplying 80 MW to the change in load side demand of 187.5MW in $Area_1$. When both the generators of $Area_1$ & $Area_2$ supply power to the change in load side demand of $Area_1$ then there is change in the power of Transmission line. Hence, it is clear that the system is not working in normal mode and is not stable. When there is change in load demand of 187.5 MW in $Area_1$ both generators increase their supply to achieve the rise in demand of load.

CASE STUDIES: SIMULATION AND DISCUSSION

We need to incorporate changes in the model in order that load changes in $Area_1$ should be supplied by generator of $Area_1$ only; and change in load demand in $Area_2$ should be supplied by $Area_2$ only.

Solution:
Each area of every case tends to minimize the area control error (ACE) of the system to zero, with AREA 1 supplying the entire 187.5 MW of load in case 1. Conventional LFC is based on Tie line bias control. Consequently, the control error for each area is as follows

$$ACE_i = \sum_{j=1}^{n} \Delta Pij + Ki \times \Delta\omega$$

where

ΔPij = change in flow of power in tie line and $\Delta\omega$ = steady-state frequency deviation.

In case of a disturbance in neighboring areas, the amount of interaction that occurs is determined by area bias. Therefore if value of Ki is taken equal to the frequency bias factor of that particular area, performance of the whole system is found to be satisfactory.

Frequency bias factor is given as

$$B_i = \frac{1}{R_i} + D_i$$

The value of B_1 and B_2 are calculated from the data as:

$$B_1 = \frac{1}{R_1} + D_1$$
$$= \frac{1}{0.005} + 0.6 = 20.6$$
$$B_1 = 20.6$$
$$B_2 = \frac{1}{R_2} + D_2$$
$$= \frac{1}{0.0625} + 0.9 = 16.9$$
$$B_2 = 16.9$$

Thus, the ACE for two area system is

$$ACE_1 = \Delta P_{12} + B_1 \times \Delta\omega_1$$
$$ACE_2 = \Delta P_{21} + B_2 \times \Delta\omega_2$$

After doing these changes in the model whole load of $Area_1$ may be supplied by $Area_1$ only as well as whole load change of $Area_2$ is supplied by $Area_2$ respectively. In this paper there are two cases of different load in $Area_1$ & $Area_2$ to analyses the Governors' substantial response, different cases are shown in the Table 2 while Table 3 shows the hit and trial values of three different controllers.

TABLE 2 -- NUMBER OF CASE STUDIES OF MODEL IN MATLAB\SIMULINK

CASE STUDEIS	DESCRIPTION
CASE NUMBER: 01	When load is suddenly enhanced by 250 MW in Area$_1$
CASE NUMBER: 02	When load is suddenly enhanced by 100 MW & 50 MW in Area $_{(1 \& 2)}$

TABLE 3 -- VALUE OF CONTAINERS

I	I	PI Controller			PID Controller	
	I	P	I	P	I	D
Case 1	0.3	0.3	0.3	0.3	0.8	2
Case 2	0.3	0.3	0.3	0.3	0.8	2

CASE 1: When load is enhanced by 250 MW in Area 1

In this scenario, Area$_1$'s load demand increases abruptly by 250 MW, and both areas' generators are running at their capability at a base load of 1000 MW. Due to the fact that frequency and load are inversely related, frequency will decrease as load demand increases. Here, gains K_1 and K_2 are added with an integrator with both regions while B_1 and B_2 are added in the feedback loops of both areas. The hit-and-trial approach is used to determine K_1 and K_2's values. Values of K_1 and K_2 are repeatedly modified the to obtain a good answer.

Here K_1 and K_2 is 0.3.
ACE1= Area control error (AREA$_1$)
ACE2= Area control error (AREA$_2$)

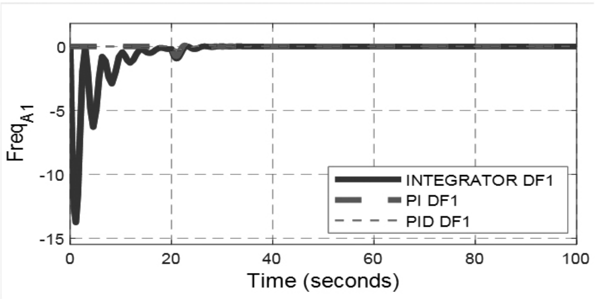

Figure 9. Frequency deviation of area$_1$ in Hz.

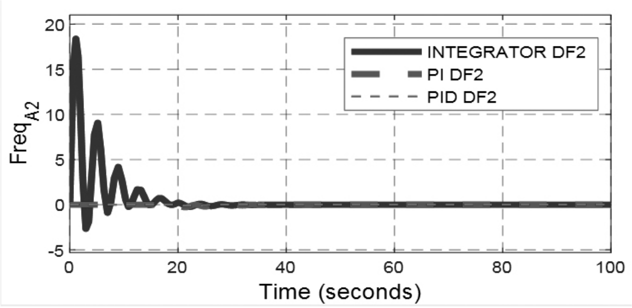

Figure 10. Frequency deviation of area$_2$ in Hz.

The comparison between all three controllers is depicted in the graph, and by making the appropriate model adjustments, we see that the frequency in both areas recovered from 49 Hz to 50 Hz (Area 1 & Area 2).

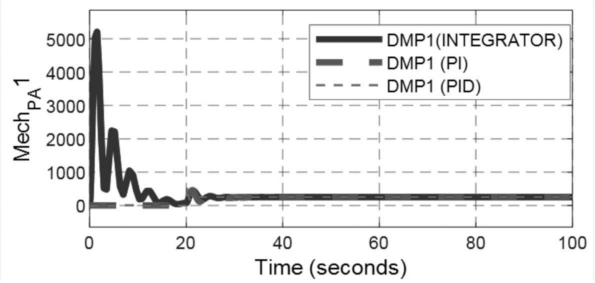

Figure 11: Power supplied by area$_1$.

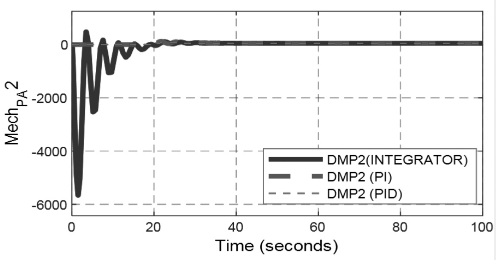

Figure 12. Power supplied by area$_2$.

The graph demonstrates that the PID controller has greater stability than the other two controllers. Area$_2$ has not supplied any power, when Area$_1$ is supplying the entire load.

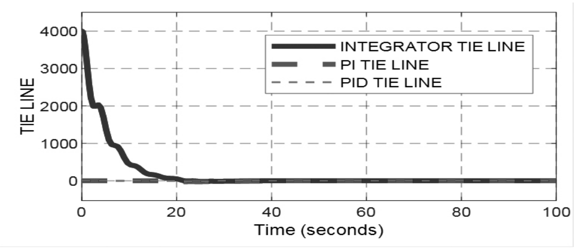

Figure 13. Power of tie line.

As frequency recovers to nominal value of 50 Hz, and Area$_1$ supplies 250 MW of its own load demand, no change occurs in the power of tie line..

Case. 2: When load is suddenly enhanced by 100MW & 50MW in Area (1 & 2)

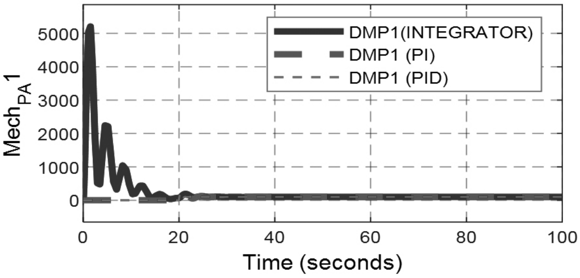

Figure 14. Power supplied by Area$_1$.

Thus load change of 100MW in Area$_1$, the whole load of 100 MW is successfully supplied by Area$_1$ itself.

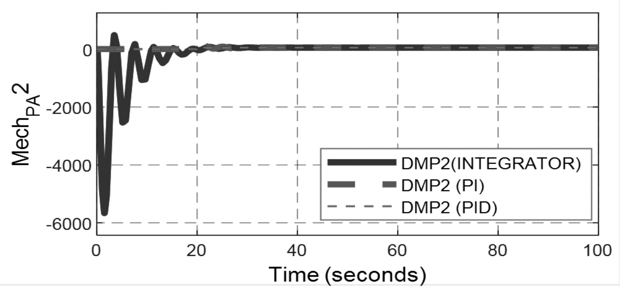

Figure 15. Power supplied by area$_2$.

From Fig.14 & 15, it is clear that with change in load demand occurring in both areas, the power is also supplied by both areas to their respective loads.

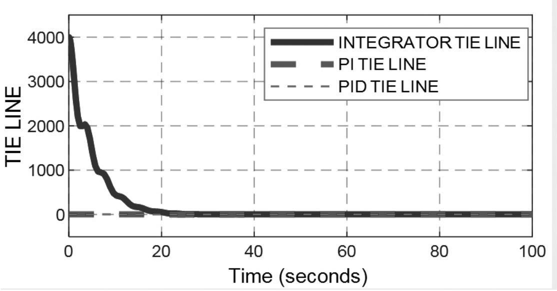

Figure 16. Power of tie line using I, PI and PID controller.

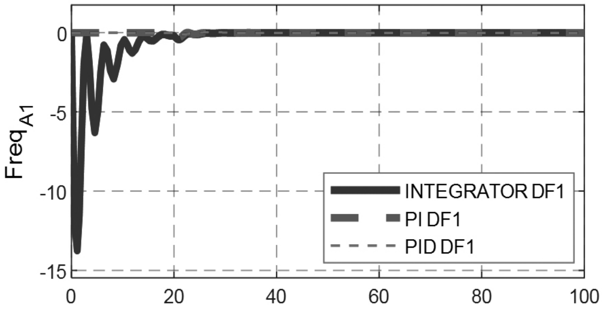

Figure 17. Frequency deviation by area 1.

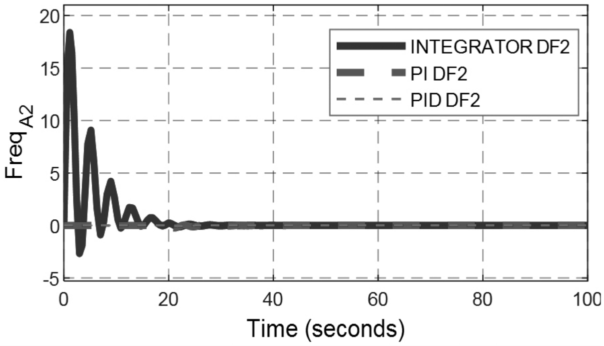

Figure 18. Frequency deviation by area 2.

When area supplies its own load then change in power of tie line should be zero which is clear from the above graph. Adjusting load frequency makes the system more stable than the other two.

TABLE 4 -- OVERSHOOT VALUES FOR FREQUENCY OF BOTH AREAS USING PID CONTROLLER

Proportional-Integral-Differential Controller (PID)

Performance parameters	Max. overshoot	Max undershoot	T_s (seconds)
Freq_A1(p.u.)	0.14	0.2	15
Freq_A2(p.u.)	0	0.055	40
Tie Line (MW)	0	10	30
Mech_1(MW)	5	2	18
Mech_2(MW)	10	0	18

The performance parameters observed from simulation results are depicted in Table 4 for frequency, tie-line, mechanical and settling time of both the areas.

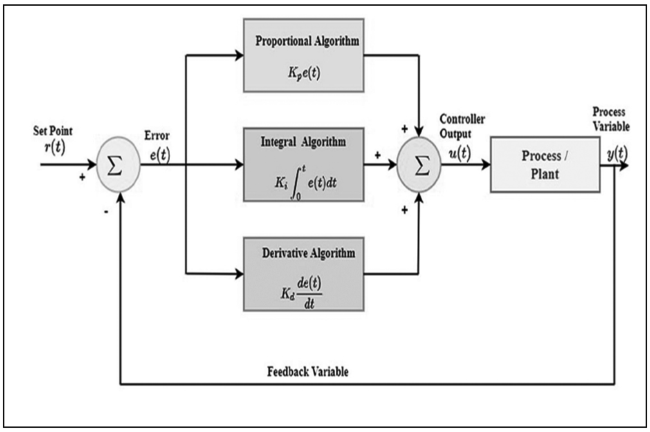

Figure 19. Process control block diagram using PID.

V. STRUCTURE OF PID CONTROLLER

PID controllers use parallel and series structures.

Parallel Type: When P, I, or D act on different solution elements, the sum of their specific effects is the total. Here, each variable is separate from the rest.

Series Type: The properties of pneumatic and analogue electronic circuits are the main sources of series or interactive equation.

If a loop is over-aggressive or vibrates frequently, the gain must be decreased. Resultantly, the answer will be delayed and the loop will gain robustness. This line of reasoning is only valid for the series algorithm. Depending on the overall tune, the parallel algorithm's increased controller phase and decreased gain may result in additional oscillations and instability. As a result, the series algorithm makes it simpler to understand the PID behavior intuitively than the ideal algorithm, which is far more difficult. In contrast, increasing the gain in series algorithms frequently leads to higher stability for self-regulating systems. Thereafter, either increasing or reducing the gains may make system unstable.

VI. CONCLUSION

When values are set suitably, a PID controller based on AGC provides efficient power sharing and superior frequency management for a two-area electrical power system. Simulation results show that the conventional PID algorithm outperforms its competitors with little overshoot and undershoot as well as settling time.

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Mr. Arun Kumar Maurya (b. 12 Dec 1998) is Assistant Professor in Department of Electrical and Electronics Engineering, Ajay Kumar Garg Engineering College, Ghaziabad. He obtained M.Tech degree (2020-22) with H.E. Gov Gold Medal &B.Tech degree (2016-20) with H.E. Gov Silver Medal & AKGEC Gold Medal from Dr. A.P. J. Abdul Kalam Technical University, Lucknow UP. Has abiding passion for research and innovative approach to teaching and learning. He is involved in many projects like Smart India Hackathon, KPIT Sparkle, University Innovation and R&D projects etc. Additionally he actively participated in various technical and non-technical events at Zonal, University, National and International levels. He was recently honored as Young Researcher Award 2021 by INSC Bangalore for the number of achievements, rewards and publications at various national and international bodies.

Published research papers. His key interest areas include Renewable Energy, Power Systems and Control & Instrumentation Systems etc.

Ms. Hera Khan is an Intern in AKGEC-AIA Center for Integrated Automation, AKGEC Skill Foundation in Ajay Kumar Garg Engineering College, Ghaziabad. She had completed her M.Tech (2020-2022) from Ajay Kumar Garg engineering college, Ghaziabad and B.Tech (2016-2020) from Rameshwaram Institute of Management and Technology, Lucknow.

She belongs to Lucknow. She was involved in technical & non-technical activities since her graduation. She has abiding interest in research and published research papers. Her key interest areas include Power Systems and Control & Instrumentation Networks Systems, Automation (PLC, SCADA), Renewable Energy etc.