Stability and Performance Analysis of Load Frequency Control of Two Area Power System

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Abstract -- **To preserve the stability and dependability of multi-area power networks, Load frequency control (LFC) maintains equilibrium between generated power and load demand during system-operation. In an interconnected electrical power grid, LFC aims to sustain a consistent frequency within each and every region and ensure steady power flow through the Tie-line. This research paper develops and simulates a two-area hydro-power system using MATLAB/Simulink software, with and without a controller. Initially, a PID controller is utilized, followed by the introduction of PID with Particle Swarm Optimization (PSO-PID) for improved responses. The paper outlines the framework of the PSO-PID controller, illustrating its superior efficacy in reducing settling time, overshoot, and rise time while enhancing system stability.**

Keywords: Load Frequency Control , Proportional Integral Derivative Controller , Particle Swarm Optimization

I. INTRODUCTION

POWER systems generate electricity from renewable or natural energy sources. Load frequency control (LFC) constitutes a vital aspect of power systems, ensuring consumers receive optimal and reliable electricity. Nevertheless, to sustain power balance and address the challenge of power generation control, adjustments in generation are necessary due to the unpredictable and frequent fluctuations in consumer power demands [1]. A control system is imperative to uphold frequency and voltage within predetermined limits and mitigate the impacts of irregular load variations. Voltage is directly correlated with reactive power, whereas frequency is directly linked to real power balance. To maintain stability in systems facing load fluctuations, load frequency control, or LFC, precisely regulates real power and frequency, thus stabilizing bus voltages and frequency. As its name implies, LFC alters the power flow between different regions while ensuring a constant frequency. In essence, LFC constitutes a loop governing the generator's output within the megawatt and frequency spectrum [2]. This loop consists of two components—the primary loop and the secondary loop. In comparison to single-area systems, the challenges associated with frequency control in interconnected areas are more pronounced [3]. Breaking down a large power network, like a national grid, into smaller sections, such as State Electricity Boards, where the generators are interconnected to create a coherent unit, is practical. Within this framework, all generators react simultaneously to changes in load or speed changer setups. This coordinated region is referred to as a control area, where the frequency is expected to remain consistent both statically and dynamically. Simplifying a control area to include only one speed governor, turbine, and load system facilitates the development of an effective control strategy.

Currently, power systems are interconnected with neighboring regions. However, linking power systems results in a significant increase in system complexity, facilitated by tie-lines. The power flow through various tie-lines is coordinated. For instance, area-i might be designated to export a specific quantity of power to area-j while simultaneously importing a predetermined amount of power from area-k. Nonetheless, it is expected that in meeting this commitment, area-i accommodates its personal load fluctuations. This entails increasing generation to meet additional demand within the area or decreasing generation when demand decreases. Despite this, area-i must uphold its commitments to areas j and k regarding power import and export obligations

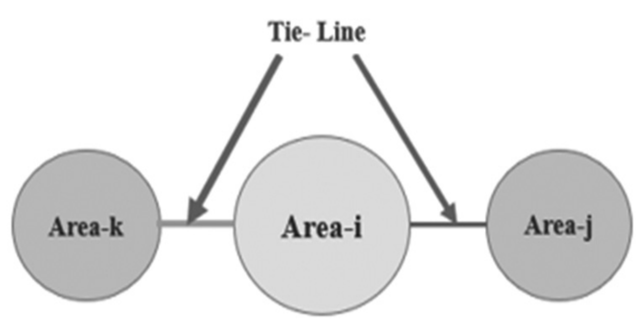

Figure 1. Inter-connected areas in a power system.

Numerous academic sources have investigated LFC in transmission lines using traditional methods meant to stabilise the frequency of the power system. Particle Swarm Optimisation (PSO) based methods automatically tune membership functions, minimising design effort and improving fuzzy control of systems. The PSO approach that this study suggests is simple to use and doesn't require any extra processing complexity. Results from the experimental application of this approach are fairly promising. It shows how to avoid local optima and significantly improve convergence speed and accuracy, resulting in increased accuracy and efficiency. However, there are problems with overshoot and settling time that impair the controller's functionality.The primary advantage of the PSO-PID controller in LFC lies in its ability to dynamically adjust PID parameters in real-time, ensuring that tie-line power flow and system frequency remain within reasonable bounds.

The present objective in control is to control the each area's frequency while simultaneously modifying tie-line power to carry out agreements of inter area power. Turbine control is used to modify generator operation in order to control frequency deviations and bring them back to the desired level. In this paper PID controller is used for LFC and further the response of the PID controller is enhanced by using tuning app in MATLAB and by using PSO Algorithm.

II. MATHEMATICAL MODELLING OF THE POWER SYSTEM

The essential objective of the LFC strategy is to deliver dependable, superior electricity to customers within a single, integrated system. Active power fluctuations cause frequency changes in the system, so control strategies to stabilize load frequency via control loops have to be developed. State variable and transfer function are the two main techniques used, under the right conditions, to convert the power system model into a mathematical representation.

Generator Model: Equation (1) illustrates how the generator equation was obtained using the swing equation.

$$\Delta\omega(s) = \frac{1}{2Hs}\left[\Delta P_m(s) + \Delta P_g(s) - \Delta P_e(s)\right] \tag{1}$$

where

$\Delta P\ m$ = mechanical power deviation

$\Delta P\ g$ = power from generating station

$\Delta P\ e$ =electrical load demand net change

Load Model: Inductive and assistive loads that are either frequency-dependent or independent make up the power system. Thus, the total variation in load power can be expressed as the sum of variations that are frequency-sensitive and frequency-insensitive. A number of variables affect the electric load, including Meteorological factors like weather, climate, humidity, temperature and solar radiation. This is presented in Eqn (2).

$$\Delta P_e(s) = \Delta P_L + D\Delta\omega \tag{2}$$

Where DΔω is to indicate how sensitive the load is to frequency changes, ΔP_L to show the load change independent of frequency. Equation (3) shows how load fluctuation and frequency variation interact.

$$\Delta P_L(freq) = D\Delta\omega = \frac{\Delta P_L(freq)}{\Delta\omega} \tag{3}$$

Turbine Model: The turbine is the source of mechanical energy; it gets its energy from burning gas, coal, or nuclear fission. Equation (4), which shows the relationship between the change in mechanical output power ΔP_m (s) and the change in steam valve position ΔP_v (s), defines its transfer function.

$$G_T(s) = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1 + sT_t} \tag{4}$$

Governor Model: The speed governor functions as a comparator, as shown below:

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta\omega(s) \tag{5}$$

where R is the speed regulation, ΔPref is the reference set power, and ΔPg is the governor's power output.The relationship between valve opening and governor input is expressed as:

$$\Delta P_v(s) = \frac{1}{1 + sT_g}\Delta P_g(s) \tag{6}$$

III. TWO-AREA POWER SYSTEM

Tie-lines make it easier to establish connections between power systems. Electric power can be transferred between different areas through tie-lines. A particular area will use tie-lines to pull energy from other areas when its load changes. Tie-line power exchange disparities must therefore be managed by LFC. The integration of frequency differences between two areas is what essentially constitutes tie-line power errors [9].

Mathematically, representation of Tie-Line power is

$$P_{12} = \frac{|V_1^0||V_2^0|}{X_{12}}\sin\left(\delta_1^0 - \delta_2^0\right) \tag{7}$$

where,

$\delta_1^0\delta_2^0$= power angles of comparable systems in two areas When angles are slightly off, the tie-line power shifts to

$$\Delta P_{12} = T_{12}(\Delta\delta_1 - \Delta\delta_2) \tag{8}$$

Where,

$$T_{12} = \frac{|V_1^0||V_2^0|}{P_{r1}X_{12}}\cos\left(\delta_1^0 - \delta_2^0\right) \tag{9}$$

T_{12} is the coefficient of synchronization.

Reference angle and frequency deviation Δf is related by

$$\Delta f = \frac{1}{2\pi}\frac{d}{dt}(\delta^0 + \Delta\delta) = \frac{1}{2\pi}\frac{d}{dt}(\Delta\delta) \quad (10)$$

$$\Delta\delta = 2\pi \int \Delta f dt \quad (11)$$

$$\Delta P_{tie,1} = 2\pi T_{12}(\int \Delta f_1 dt - \int \Delta f_2 dt) \quad (12)$$

where, Δf_1 *and* Δf_2 are incremental frequency changes of

area 1 and 2, respectively. By taking Laplace transformation of Eqn. (12):-

$$\Delta P_{tie,1}(s) = \frac{2\pi T_{12}}{s}(\Delta f_1(s) - \Delta f_2(s)) \quad (13)$$

In the same manner, area 2's incremental tie line power is determined by

$$\Delta P_{tie,2} = 2\pi T_{21}(\int \Delta f_1 dt - \int \Delta f_2 dt) \quad (14)$$

where,

$$T_{21} = \frac{|V_1^0||V_2^0|}{P_{r2}X_{21}}\cos(\delta_2^0 - \delta_1^0)$$

$$=\left(\frac{P_{r1}}{P_{r2}}\right)T_{12} = a_{12}T_{12}$$

By taking Laplace transformof Eq. (14)

$$\Delta P_{tie,2}(s) = -\frac{2\pi a_{12}T_{12}}{s}(\Delta f_1(s) - \Delta f_2(s)) \quad (15)$$

The schematic of two-area power system tie up by a tie-line is displayed in Fig. 2.

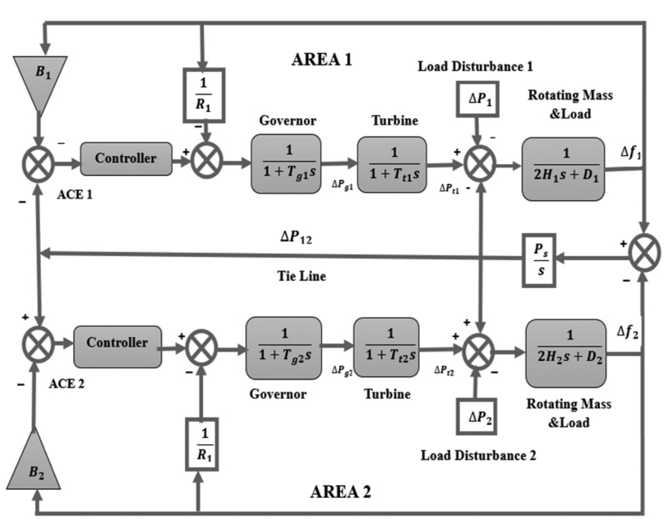

Figure 2. Schematic Diagram of Two Area Interconnected Power System.

Control error of each area is made up of the linear arrangement of tie-line flows and frequency. The disparity between area generation and load (AGC) is denoted by Area Control Error [10].

$$ACE = \sum_{j=1}^{n} \Delta P_{tie,ij} + B_i \Delta f_i \quad (16)$$

where,

Δ_{fi} = Frequency deviation of i^{th} area

$\Delta P_{(tie,ij)}$ = Power flow error in the tie line between i^{th} *and* j^{th} *area.*

B_i = Frequency bias Coefficient of i^{th} area

IV. SYSTEM IMPLEMENTATION AND SIMULINK MODEL

In this paper we considered a two area power system. A 2 GW control area 1 is interconnected with 10 GW area 2 has the parameters with 2 GW base and Area 2has the parameters with 10GW base parameters are depicted in Table I.

TABLE 1 -- PARAMETERS OF TWO-AREA INTERCONNECTED POWER SYSTEM

Area	**1**	**2**
Rated Capacity	2000 MW	10000 MW
Normal Operating Load	1000 MW	5000 MW
Frequency	50	50
Inertia Constant	5	5
Speed Regulation	4%	4%
Governor Time Constant	0.08	0.08
Turbine Time Constant	0.3	0.3
Damping Constant	1%	1%

We utilized these parameters to derive the transfer function model for the governor, turbine, and rotating mass & load. Subsequently, simulation work was carried out for a two-area interconnected power system, based on the schematic diagram depicted in Figure 2, considering the transfer function of each block throughout the simulation procedure.Fig. 3 shows the simulation model of the two-area power system without controller.

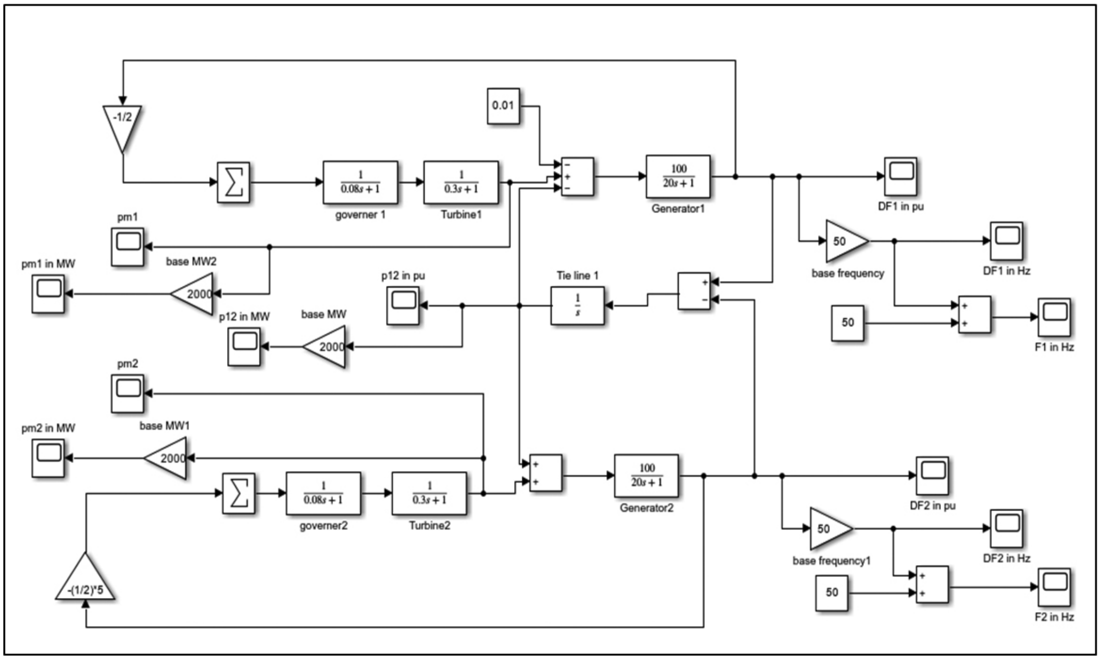

Figure 3*a*. Simulink model of two-area interconnected power system without controller.

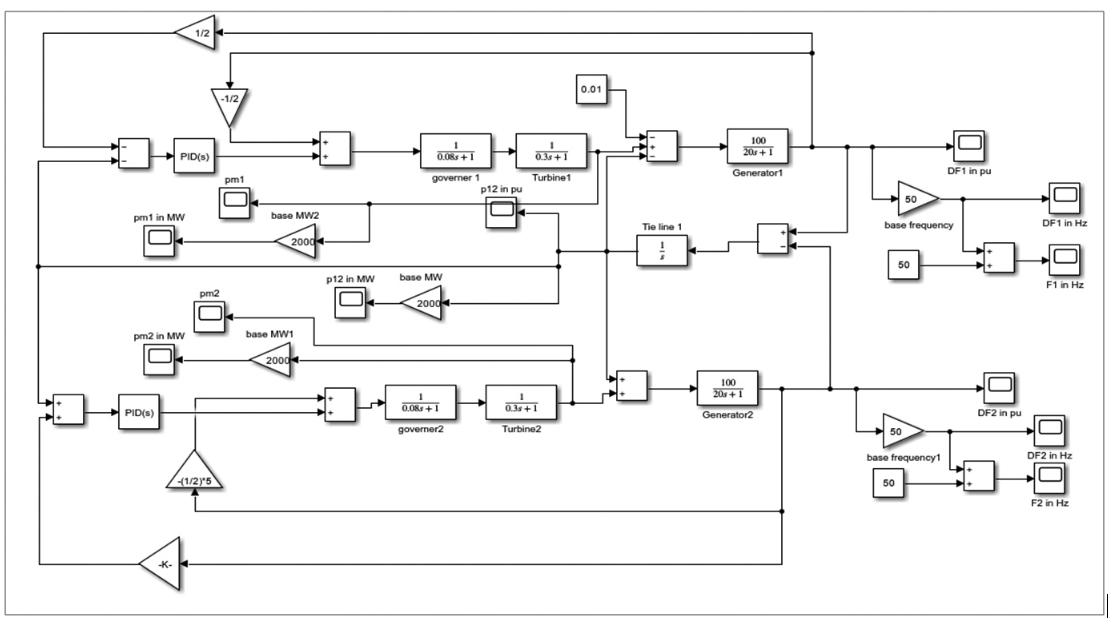

Figure 3*b*. Simulink model of two-area interconnected power system with PID controller.

The simulation results yielded graphs illustrating frequency deviations, mechanical power deviations, and tie-line power flow between area 1 and area 2.

Case 1: Without Controller (20 MW load change in Area1)

Figures 4 &5 show the frequency deviation in both the areas when 20 MW load change in Area 1. The frequency drop is calculated as follows:

Power base is considered as 2 GW then the change in load demand and frequency bias constant is

$\Delta P_{d1}=0.01$ *pu and* $\beta_1=0.51$

Now $\Delta P_{d2} = 0$ since load change is in area 1 alone.

$\beta_2=5\times\beta_1=2.55$ (Since β_1 is calculated with base value 2 GW)

$$\Delta f = \frac{-(\Delta P_{d1} + \Delta P_{d2})}{\beta_1 + \beta_2} = \frac{-(0.01 + 0)}{(0.51 + 2.55)} = -0.00326pu$$

Δf in Hz = -0.00326×50=-0.163Hz

Now the Frequency is 50-0.169=49.831 Hz

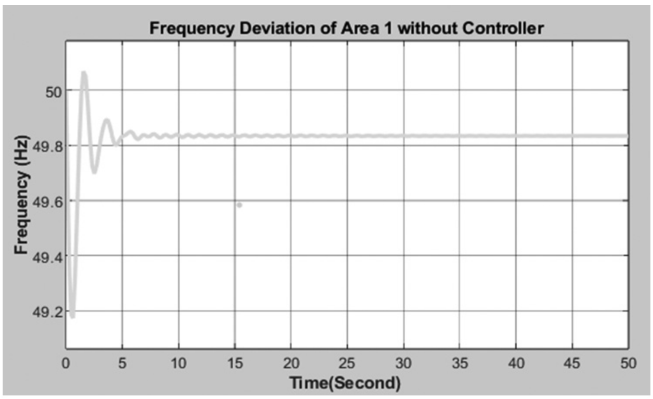

Figure 4. Area 1's Frequency deviation without controller.

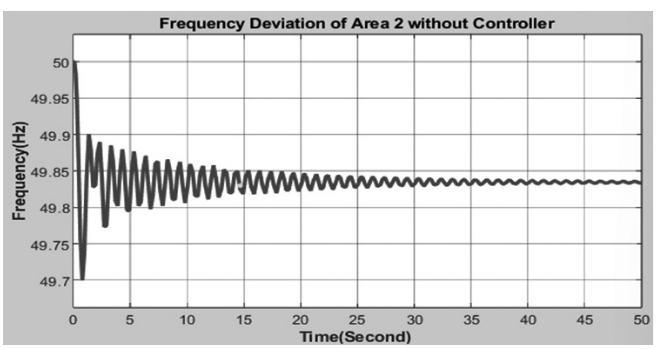

Figure 5. Area 2's frequency deviation without controller.

Figure 7 depicts the mechanical power deviation of area 1 without controller. Mechanical power deviation can be calculated as

$$\Delta P_{m1} = \frac{-\Delta f}{R_1} = \frac{-(-0.00326)}{2} = 0.00163\ pu$$
$$= 3.26\ \text{MW}$$

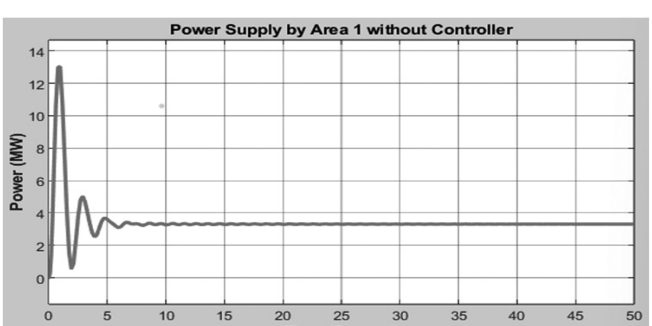

Figure 6. Power supply by area 1 without controller.

Figure 8 depicts the mechanical power deviation of area 2 without controller which is calculated as

$$\Delta P_{m1} = \frac{-\Delta f}{R_2} = \frac{-(-0.00326)}{0.4} = 0.00815\ pu$$
$$= 16.3\text{MW}$$

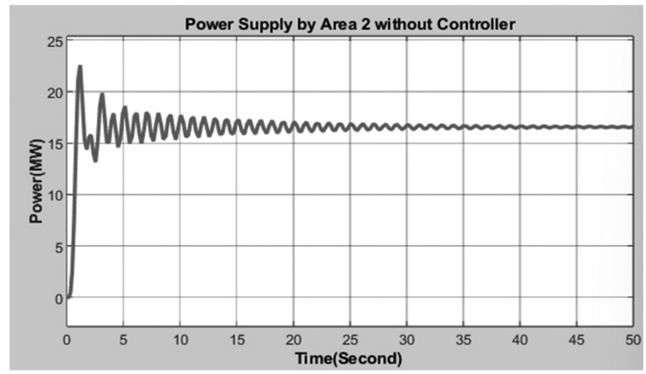

Figure 7. Power supply by area 2 without controller.

Tie line power flow between both the areas is depicted in Fig.9. Change in tie-line power flow can be calculated as

$$\Delta P_{12} = \frac{\beta_1 \Delta P_{d1} - \beta_2 \Delta P_{d2})}{\beta_1 + \beta_2} = \frac{-2.55 \times 0.01}{0.51 + 2.55}$$
$$= 0.008333pu = -16.7\ \text{MW}$$

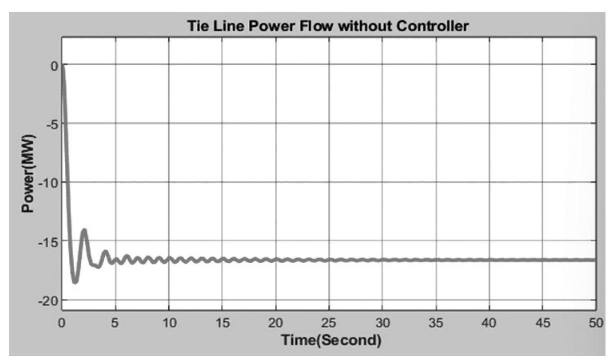

Figure 8. Tie-line power flow.

Case 2: With PID Controller (20 MW load change in Area1)

The frequency returns to its nominal value of 50 Hz by using PID controller. Fig 10 and Fig 11 shows the frequency deviation of both the Area 1 and Area 2 respectively.

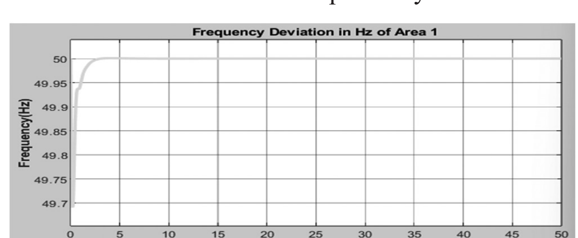

Figure 9. Area 1's frequency deviation with PID controller.

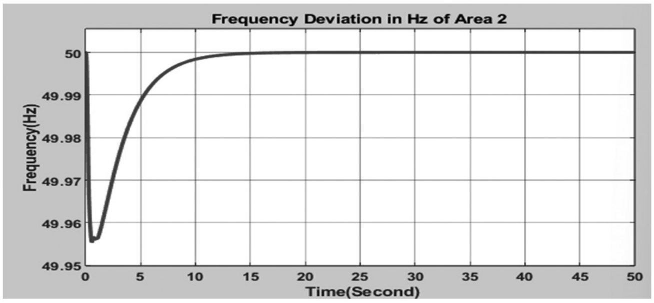

Figure 10. Area 2's frequency deviation with PID controller.

Now, with the load change of 20 MW in Area 1,Area 1 is able to fully meet the increased demand of 20 MW on its own as depicted in Fig 12.

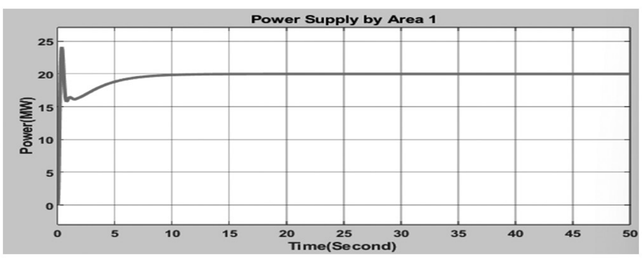

Figure 11. Power supply by Area 1 with PID controller.

Since the load is change in area 1 only there is no change in load at area 2 therefore power supply by area 2 is now became zero by using a PID controller as dipicted in Fig 13.

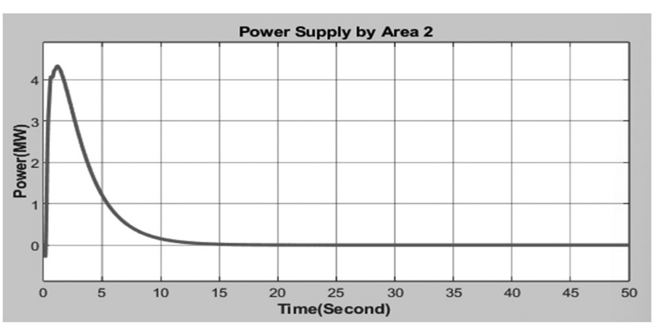

Figure 12. Power supply by Area 2 with PID controller.

As the frequency returns to its par value of 50 Hz and Area 1 meets 20 MW and Area 2 meets 0 MW of its own load demands, there is no alteration in the power flow across the tie line and hence power flow of tie line becomes zero as shown in Fig 14.

TABLE -- II. VALUES OF CONTROLLER PARAMETERS

Gain	PID Controller	PID Tunned with PSO
K_p	2	0.1000
K_i	1	0.1000
K_d	1	0.7044102

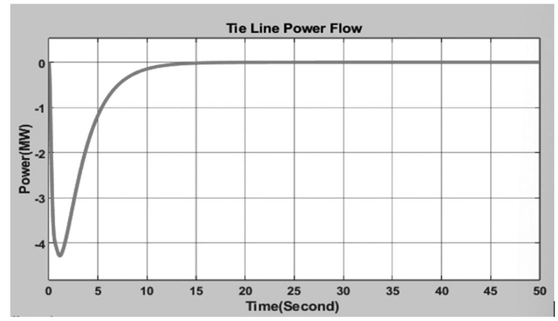

Figure 13. Tie line power flow.

Further the response of the PID controller is enhanced by PSO Algorithm. The primary advantage of the PSO-PID controller in LFC lies in its ability to dynamically adjust PID parameters in real-time, ensuring that tie-line power flow and system frequency remain within resonable bounds. The controller gain values for Ki, Kp, and Kd are computed by the proposed algorithm by means of the PSO algorithm. These values are found by running MATLAB simulations with the goals of reducing rise times, mitigating overshoot and settling times, and getting rid of steady-state errors.Fig 15 shows the frequency deviation in per unit by using PSO algorithm.

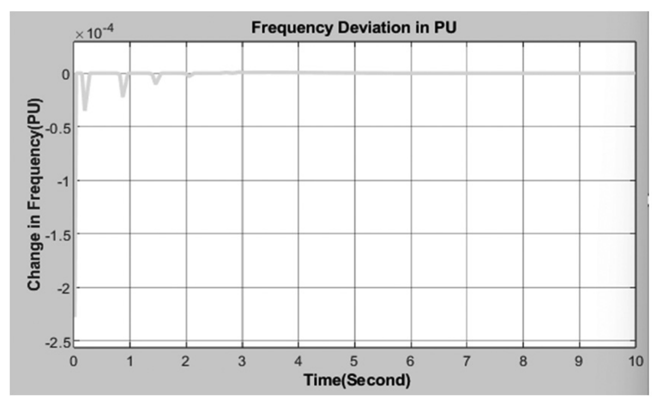

Figure 14. Frequency deviation in PU with PSO-PID controller.

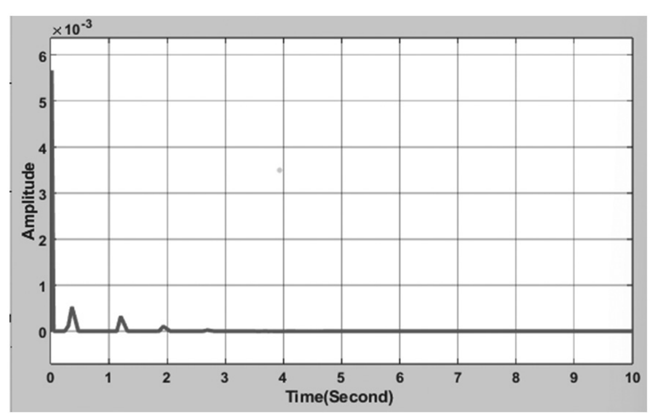

Figure 15. Area control error of Area 1 by using PSO.

TABLE -- III. ROBUSTNESS AND PERFORMANCE PARAMETERS OF CONTROLLER

Parameters	PID Controller	PID Tunned with PSO
Rise Time	0.169 seconds	0 sec
Settling Time	7.6 seconds	0 sec
Overshoot	6.96 %	0 %
Peak	1.07	1
Gain Margin	21.9 dB @ 34.2 rad/s	-27.5deg@
23.9rad/s		
Phase Margin	46.2 deg @ 8.3 rad/s	-41.9deg@
100rad/sec		
Closed Loop Stability	Stable	Stable

Table III presents the robustness and performance parameters for the PID, and PSO-PID controllers. It's apparent from these parameters that the PID controller tuned with the PSO algorithm exhibits superior effectiveness compared to both the PID controller which is tuned by PID controller tunner app. It demonstrates that the performance of the suggested algorithm surpasses others, notably evidenced by achieving zero fault clearing time and settling time utilizing the PSO algorithm.

VI. CONCLUSION

This paper utilizes a PID controller to regulate load frequency control within a Two-Area interconnected power system. Initially, a mathematical model is employed to derive system parameters, and the network is simulated without a controller. Subsequently, PID with Particle Swarm Optimization (PSO) algorithm is utilized for parameter adjustment, generating an m-file containing the Kp, Ki, and Kd parameters through MATLAB. This approach enhances the system's sensitivity, facilitating more adaptive tuning mechanisms for the PID controller settings. The efficacy of the proposed control algorithm is validated, demonstrating significant improvements in overall system performance. Consequently, the suggested PSO-PID controller assumes a critical role in ensuring reliable and high-quality electricity provision. The PSO-PID algorithm yields impressive outcomes, confirming its effectiveness and efficiency in LFC within power systems. It offers superior control performance, stability, adaptability, quick convergence, and user-friendly simplicity.

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