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PID Controller Tuning for Load Frequency Control in Interconnected Two-Area Power System Using NSGA-II Algorithm

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Abstract: This paper proposes Load Frequency Control (LFC) for a two-area interconnected power system using Non-dominated Sorting Genetic Algorithm II (NSGA-II). A PID controller is employed, and its parameters are optimally tuned through multi-objective optimization considering ITAE and control effort. Simulation results show that NSGA-II significantly reduces frequency deviations, settling time, and overshoot compared to conventional tuning, ensuring improved system stability.

Keywords: *Load Frequency Control (LFC), Two-Area Non-reheat Power System, NSGA-II, PID Controller, ITAE, Frequency Deviation, Settling Time, Overshoot, Tie-Line Power Flow.*

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I. INTRODUCTION

A contemporary power system is an interactive, integrated network intended to generate, transmit, and distribute electric power economically and reliably. One of the most severe functional aspects is holding system frequency within acceptable limits because frequency is a direct representation of the balance between generation and load demand. Any imbalance in this equilibrium results in system frequency fluctuations, which if not adjusted, might results in instability equipment damage, or even widespread blackouts. In order to solve this problem, load frequency control (LFC) is necessary to adjust generation according to load changes.

For a two-area power system, the whole system is separated into two control areas, each with its own generation units and loads, but with a connecting tie-line which allows for power exchange. A load change in one area not only causes a local frequency change but also a change in power flow on the tie-line between the areas. Therefore, LFC in a two-area system has a dual role: to return each area's frequency to its nominal value and to keep tie-line power flow at the scheduled level. This is carried out by a hierarchical control strategy. The primary control, which is controlled by turbine governors, gives an instant but partial response towards frequency deviations. The secondary control, which is referred to as Automatic Generation Control (AGC), adjusts the generation to return frequency and tie-line power to their desired values. Tertiary control provides for optimal economic operation and effective reserve management in the long term. Load Frequency control for a two-area power system is necessary to ensure stability, reliable operation, and coordinated power sharing between regions that are connected.

In load frequency control (LFC), controllers are responsible for the stability and reliable operation under changing load conditions. With a sudden change in load, there arises an imbalance of generation and demand that causes disturbances in system frequency and tie-line power flow. To offset this, controllers are utilized to control the output of generating units as well as return system variables to their desired values. The main controller, based on the governor mechanism, gives an instantaneous response by varying turbine input to partly stop the frequency deviation. The action is not sufficient in itself to bring back frequency to nominal value. Thus, the secondary controller, commonly known as the Automatic Generation Control (AGC), is utilized for removing steady-state error through the fine-tuning of generator set-points so that frequency comes back to nominal and tie-line power exchange equals scheduled values [1]. In interconnected multi-area systems, secondary controllers also facilitate coordinated power sharing and reduce inter-area oscillations. In addition, sophisticated controllers like PID, Fuzzy, Model Predictive, or AI-based optimization methods are increasingly used to enhance dynamic response, minimize overshoot, and achieve robustness against system uncertainties. Controllers in LFC are therefore crucial in obtaining stability, accuracy, and reliability in contemporary power system operation. Use of various techniques and controllers are found from the literature survey which is explained below. In 2015, Kouba et. al [2] presents load frequency control of two or multi area using fuzzy logic PID

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controller and compared the results with PSO algorithm and Ziegler-Nicholas method and found that FLC-PID has better performance. In 2016, D. Guha et. al. [3] have compared GWO with CLPSO and essemble mutation and crossover strategies and parameters in differential evolution on a two-area non-reheat power system. In 2017, A. Sahu et. al. [4] used PID controller in single,two and multi area and found that PID outperform PI and I controllers. In 2017, A. Pritam et. al. [5] states that a integral controller tuned using genetic algorithm with the effect of generation rate constatnt (GRC) gives better performance. In 2017, Yijun et.al. [6] introduces a two level coordinated LFC for interconnected power system on the basis of a multi-agent system (MAS) and found that MAS based LFC gives improved results. In 2018, Bodepalli et. al. [7] tune PID controller using Firefly Algorithm for two-area reheat system. In 2018, Rahim et. al. [8] use PI controller and fuzzy logic in two-area power system and compared them on the basis of steady state error and other parameters. In 2018, Ruchika Lamba et. al. [9] proposed a Interval Fractional Order PID (INFOPID) controller to deal with non-linearities using Kharitonov's theorem. In 2019, S. Murli et. al. [10] introduced a new technique for LFC by using Inertia Emulation Controlled (INEC) HVDC tie-line. In 2020, D. Mishra et. al. [11] used Particle Swarm Optimization (PSO) algorithm for a PIDF controller to handle frequency in Multi-Micro-Grid System. In 2022, Keya Akter et al. [12] proposed ANN and Fuzzy Logic PID controllers for LFC and found that Fuzzy-PID provide best result for two area power system. In 2023, EI. Schiemy et. al. [13] used the Artificial Rabbits Algorithm (ARA) to tune PID controller. In 2023, H. Shukla et. al. [14] studied LFC for a combined thermal power system and EV model, where PID is tuned using Firefly Algorithm (FA). In 2024, Raghav Garg et. al. [15] studied the application of Linear Quadratic Regulator (LQR) to load frequency control (LFC) in a two-area power system.

II. PROBLEM FORMULATION

➢ *System Description*

A two-area power system has two control areas with each having generation and load, which are tied by a tie-line for power exchange. Any change in one area load results in frequency deviations and impacts the tie-line power flow in both the areas. To counteract this, Load Frequency Control (LFC) is implemented, wherein the governor undertakes primary control and the Automatic Generation Control (AGC) adjusts the frequency and tie-line power back to scheduled values. This coordinated control guarantees stability, dependability, and appropriate power sharing among the two regions.

The block diagram of two area power system is shown in Fig.1.

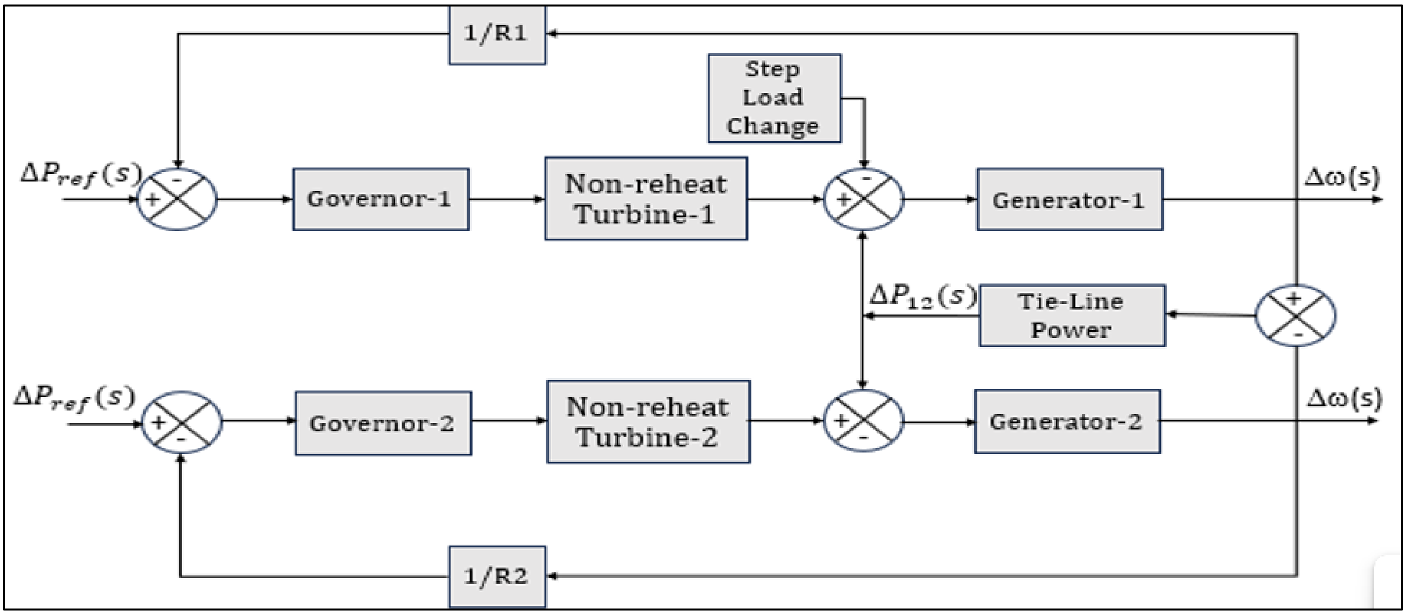

Fig 1 Block Diagram of Two-Area Non-Reheat Power System

The transfer functions used in the model are given below:

- *Governor Model*

$$G\_g(s)=1/(1+\tau\_g(s)) \quad (1)$$

- *Prime Mover Model*

$$Gt(s)=1/(1+\tau\_t((s)) \quad (2)$$

$$0.2 < \tau\_t < 2 \text{ seconds}$$

- *Load And Inertia Model:*

$$\Delta\omega(s)/(\Delta P\_m(s)-\Delta P\_t(s)) =1/(2H+D) \quad (3)$$

- *Frequency Bias Factor (Afrc):*

$$B=D+1/R \quad (4)$$

- *Power Flow Between Two Areas:*

$$\Delta P12=Ps*(\Delta\delta1-\Delta\delta2) \quad (5)$$

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Table 1 Parameters of Two Area Power System

Parameters	Symbol	Area-1	Area-2
Speed Regulation	**R**	0.05	0.0625
Load Frequency Constant	**D**	0.8	0.8
AFRC=D+1/R	**B**	20.8	16.9
Inertia Constant	**H**	5	4
Governor Time Constant	τ_g	0.2	0.3
Turbine Time Constant	τ_T	0.5	0.6

➢ *Objective Function*

Objective function defines the goal of an algorithm such as minimizing error, cost, deviation, minimizing overshoot and fast settling time. It provides performance measures to guide the algorithm to select best solutions. By analyzing literature it is found that settling time, overshoot and integral time absolute error (ITAE) are the mostly used objective functions of load frequency control. In this paper the aim to select these optimization function, is to obtain the performance parameters of PID controller *i.e.* Kp, Ki, Kd to select appropriate solution to fulfil the goals of algorithm.

• *ITAE-Integral Time Absolute Error*

ITAE is a performance index used in two power system to evaluate the response of the system. It considers frequency deviations in both areas and tie line power between the two areas. By multiplying them with time before integration, ITAE penalizes sustained deviations more heavily, encouraging faster error elimination and smoother control action.

ITAE equation for two area is given below:

$$ITAE\_2A=\int_0^{Ts}[|e1(t)|+|e2(t)|+|\Delta P\_tie(t)|] * tdt \qquad (6)$$

Here, Δω Obtained From Two Area Non Reheat Model Is Fed To ITAE Model Is Shown Below In Fig.2.

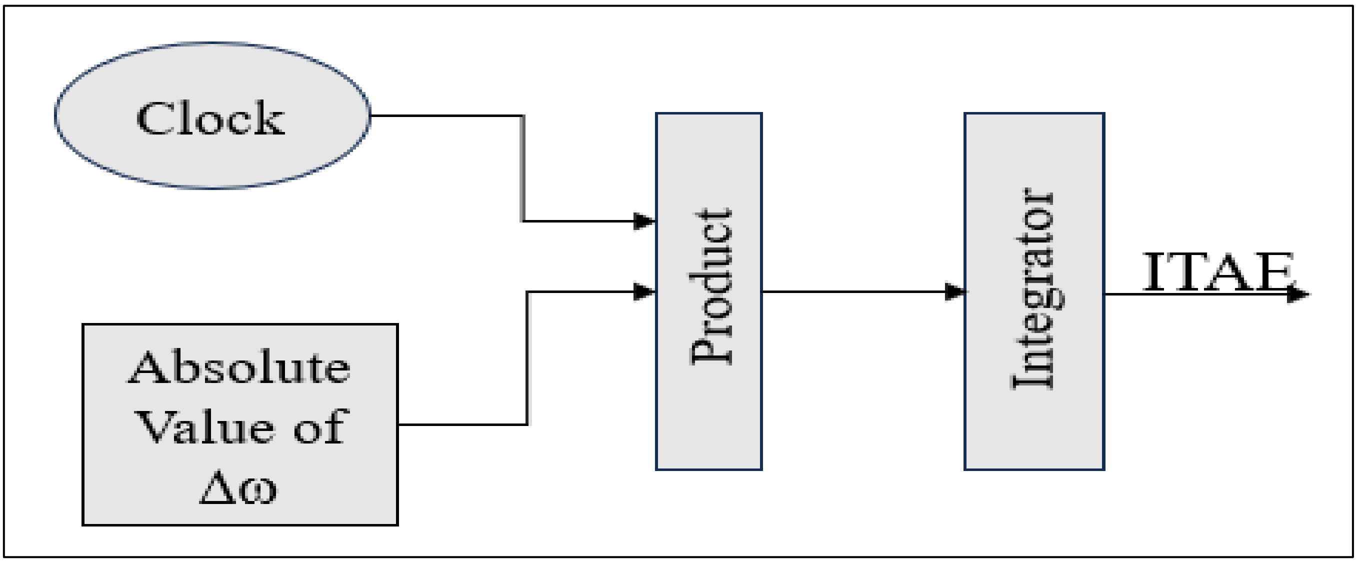

Fig 2 Block Diagram of ITAE

• *Settling Time*

It is the time taken by system to settle response within a specific tolerance band (±2% or ±5%) or to reach its final steady state after encountering a disturbance.

• *Overshoot*

The amount by which systems response exceeds its final steady state value during transient or disturbance and is generally expressed in percentage.

III. NSGA-II-PID-CONTROLLER STRUCTURE/DESIGN

➢ *Conventional PID Controller*

A widely used control strategy to adjust systems output by using proportional, integral and derivative gains where proportional gain is used for error correction, integral gain for eliminating steady-state error and derivative gain for prediction of possible future error. The block diagram of PID controller is shown in Fig.3.

➢ *Non- Dominated Sorting Genetic Algorithm (NSGA-II)*

NSGA-II is an advanced evolutionary algorithm used for multi objective optimization by classifying solutions across non-dominated fronts and preserve diversity by crowd. It works on principle of natural evolution and selection and include specific feature to handle multi objective optimization.

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Here,

- Crowding distance maintain diversity among solutions
- Elitism guarantees best solution across many generations
- Widely use to tune PID controllers for industry applications.
- Parameters of NSGA-II algorithm are shown below in Table II. Pseudo code for NSGA-II algorithm is shown below in Algorithm 1.

➢ *Related Equations*

The equation of PID controller in time domain can be written as:

U(t)=Kp*e(t) + Ki*∫ e(t)dt + Kd*(de(t)/dt) (7)

In frequency domain (s-domain) can be written as:

U(s)=Kp + (Ki/s) +Kd*s (8)

Where, U(t)= variables of PID controller

e(t)= error value
de= change in error
kp=proportional gain constant
ki= Integral gain constant
kd= Derivative gain constant

➢ *Parameters of PID Controller*

The list of PID controllers obtained from applied algorithm and comparison with literature is shown below in *Table III.*

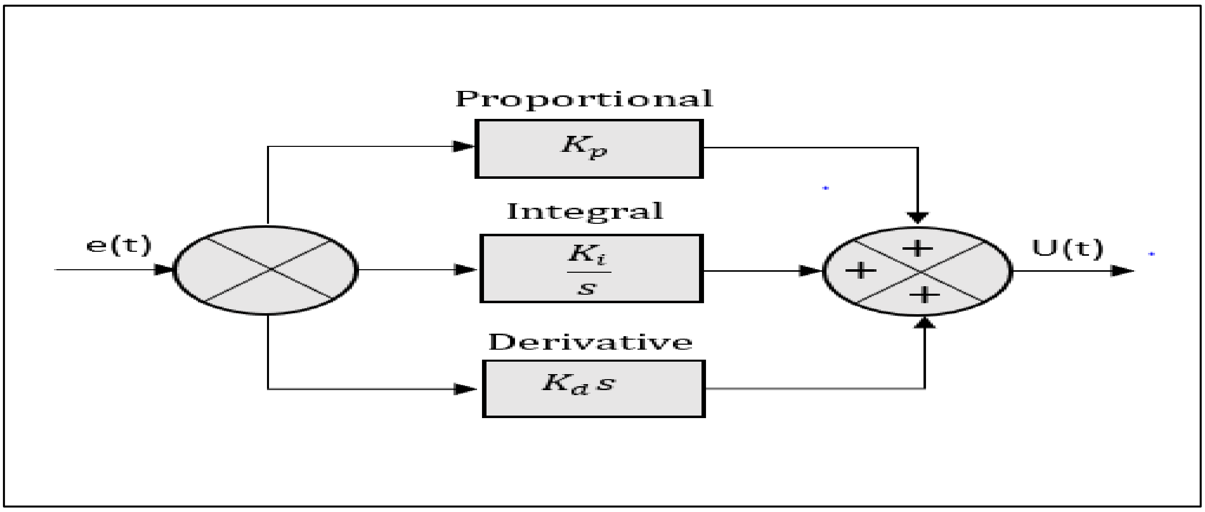

Fig 3 Block Diagram of PID Controller

Table 2 NSGA-II Parameter

Parameters of NSGA-II	Values
Variables	6
Upper Bound	[10 10 10 10 10 10]
Lower Bound	[0 0 0 0 0 0]
Population Size	20
Maximum Generations	30

IV. SIMULATION RESULTS

A step load 0.1875 per unit is applied at t=0 at area-1 for modelling purposes. The simulation is executed using MATLAB R2023a-simulink program. The simulation was executed on a machine equipped with an intel i3 7th generation processor running at 2.30 GHz, 8GB of RAM and operating on Windows 10. A comparison of proposed technique with literature is given below in *Table IV.* Problem and parameters of the two-area non-reheat power system is taken from the book power system analysis by Hadi Saadat.

Table 3 List of Pid Controller Parameters

Authors		Area-1			Area-2	
	K_p	K_i	K_d	K_p	K_i	K_d
S. Murli 2019 [10]	0.7111	0.7865	0.2504	0.1386	0.2585	0.3833
D. Mishra 2020 [11]	7.7021	9.9086	2.1650	3.4955	6.0742	7.8453
EI. Schiemy 2023 [13]	1.8751	2.9974	0.5873	2.9790	0.7296	1.0501
H. Shukla 2023 [14]	0.0126	0.9999	0.9327	0.1253	0.4683	0.4188
Proposed NSGA-II	**9.0423**	**9.9923**	**3.9998**	**0.1320**	**0.0938**	**3.6039**

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Table 4 Comparison of Performance Parameters

Author	Area-1		Area-2	
	Overshoot	**Settling Time**	**Overshoot**	**Settling Time**
S. Murli 2019 [10]	3.7566e+08	10.8708	8.8151e+09	20.4288
D. Mishra 2020 [11]	7.8845e+12	8.0128	2.2642e+03	16.2993
EI. Schiemy 2023 [13]	8.4904e+04	8.2649	1.2769e+04	14.1449
H. Shukla 2023 [14]	1.0082e+04	13.0299	1.0428e+04	16.4111
Proposed NSGA-II	**1.7211e+04**	**4.50329**	**6.1768e+03**	**18.6657**

➢ *Plots of Deviaton in Frequecny Versus Time*

A two area non-reheat power system is designed using the parameters given in *Table 1* with the use of algorithm NSGA-II to tune PID controller and results are compared with literature and hence obtained results are shown below in *fig.4, fig.5, fig.6*. *Fig.4* frequency deviation in area-1 of two area power system where frequency deviation is plot on y-axis with respect to time plotted on x-axis. Fig.5 shows frequency deviation in area-2 of two area power system.

➢ *Plot of Tie-Line Power Flow Deviation*

Fig.6 shows the variation in tie-line power flow due to the different PID parameters with respect to time.

Algorithm 1: NSGA-II

```
function nsga2_lfc()
    %% Parameter bounds
    pop_size = 20;
    gens = 30;
    var_min = [0 0 0];  % Kp, Ki, Kd min
    var_max = [10  10    10];     % Kp, Ki, Kd max
    n_var = 3;

    %% Initialize population
    pop = initialize_population(pop_size, var_min, var_max, n_var);

    %% Evaluate and sort
    for gen = 1:gens
        % Evaluate objectives: [ITAE, MaxDeltaF]
        for i = 1:pop_size
            [f1, f2] = evaluate_objectives(pop(i).Position);
            pop(i).Cost = [f1, f2];
        end

        % Non-dominated Sorting
        [pop, fronts] = non_dominated_sorting(pop);

        % Crowding distance
        pop = calculate_crowding(pop, fronts);

        % Generate offspring using crossover & mutation
        offspring = genetic_operators(pop, var_min, var_max);

        % Combine and select next generation
        pop = environmental_selection([pop, offspring], pop_size);
    end

    %% Final Pareto Front
    plot_pareto(pop);
end
```

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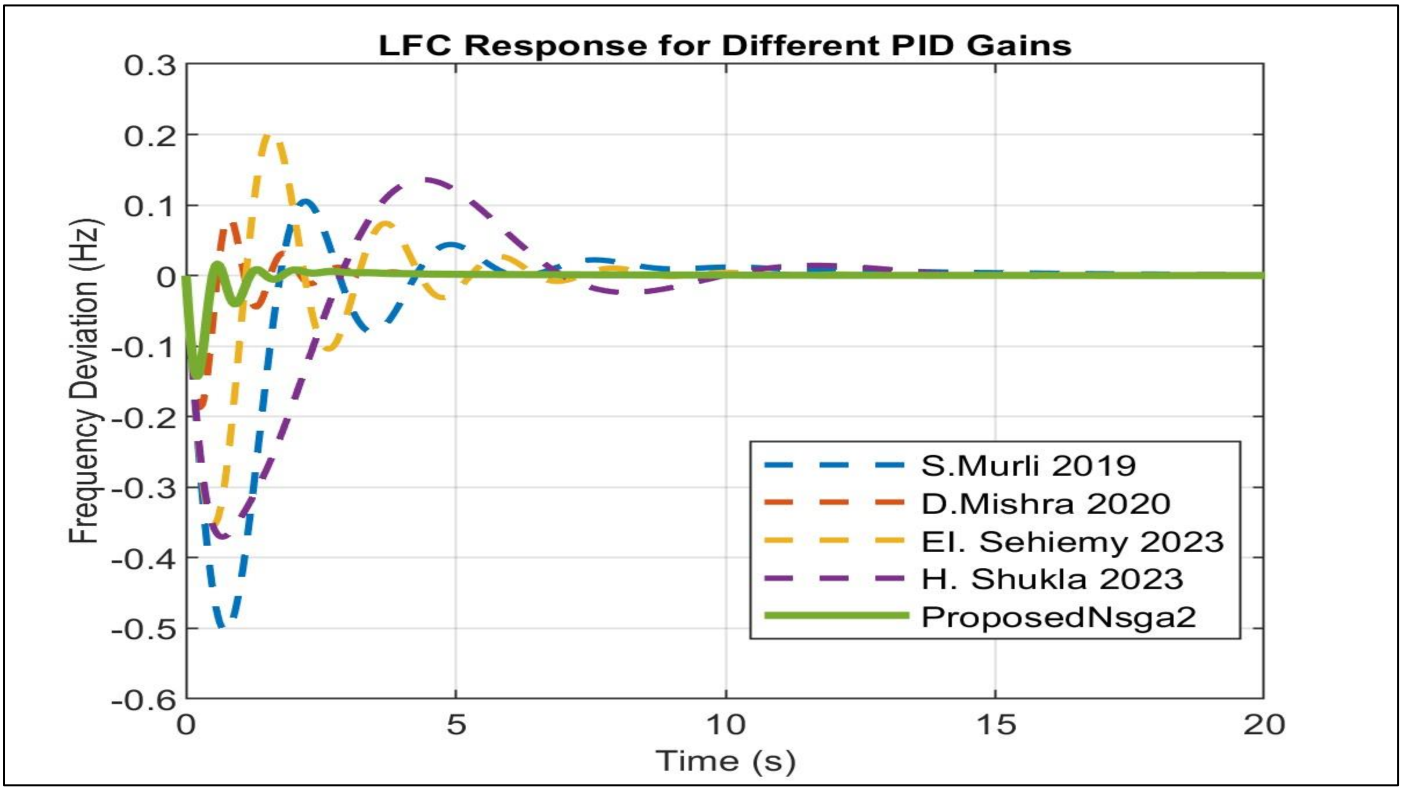

Fig 4 Frequency Deviation in Area-1 of Two Area Power System

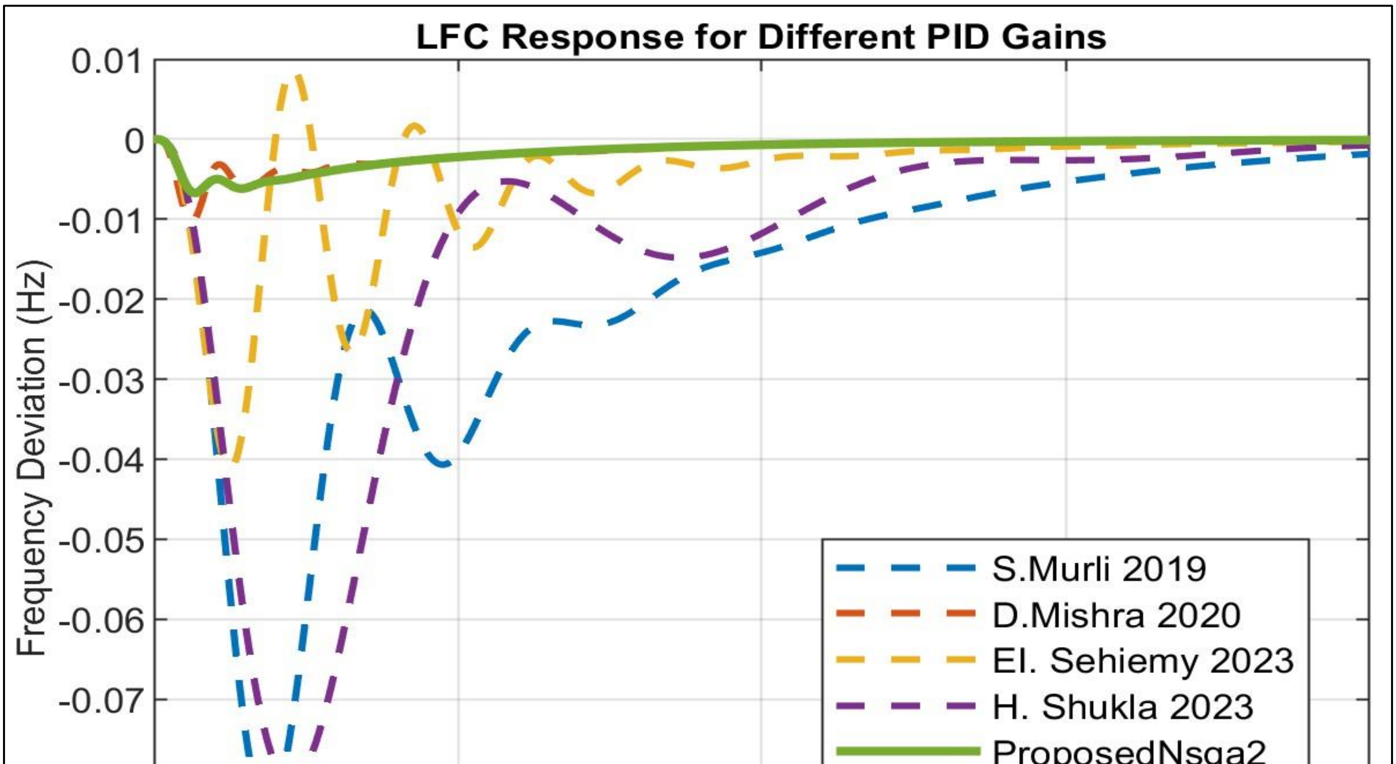

Fig 5 Frequency Deviation in Area-2 of Two Area Power System

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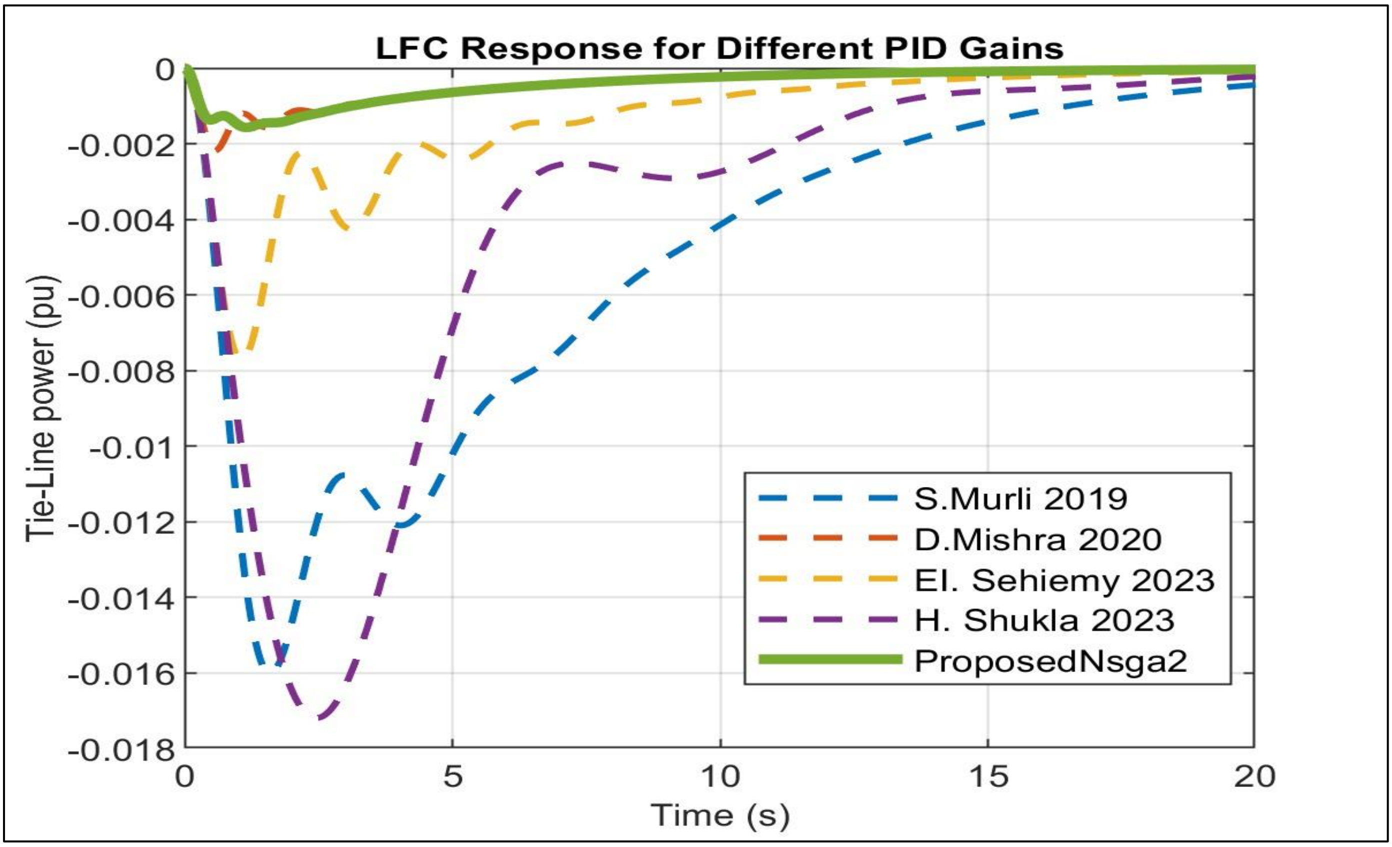

Fig 6 Tie-line Power Flow between Two Areas

V. CONCLUSION

This paper proves that NSGA-II can efficiently optimize PID controller parameters for Load Frequency Control of a two-area power system interconnected. By simultaneously optimizing various objectives like ITAE and control effort, the new method attains quicker settling time, lower frequency deviations, and NSGA-II, and better tie-line power stability than the traditional method. Therefore, NSGA-II offers an effective and strong solution for optimizing dynamic performance of advanced power systems.

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