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Optimizing Frequency Regulation in Interconnected Thermal and Renewable Power Systems

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***Abstract*— This study investigates load frequency management in multi-area interconnected power systems incorporating photovoltaic power. A comparative analysis is performed between conventional thermal-based systems and those with solar photovoltaic integration. The optimal proportional-integral-derivative (PID) controller parameters are determined using the firefly algorithm, with the Integral Time multiplied by Absolute Error (ITAE) as the optimization criterion. The PID controller is evaluated against Integral Proportional-Integral (PI) controllers, showcasing its superior performance. Furthermore, the effectiveness of the PID controller is demonstrated through simulations involving step load disturbances in area two, under various Step Load Perturbations (SLPs). Results indicate the superiority of the proposed firefly algorithm-based PID controller.**

Keywords*— *Load frequency control; Renewable energy sources, proportional-integral-derivative (PID) controller.

I. INTRODUCTION

The frequency regulation challenge in power systems becomes more pronounced with the integration of multiple energy sources. Load frequency control (LFC) is a widely adopted approach to address this issue, especially in two-area interconnected non-reheated thermal-thermal power systems. Controller tuning methods, such as the firefly algorithm optimization, are employed to enhance the performance of LFC systems. Notably, both Proportional-Integral (PI) and Proportional-Integral-Derivative (PID) controllers are implemented, with the integral of time multiplied absolute error (ITAE) serving as the cost function for desired dynamic response.

Several algorithms and control strategies have been investigated to solve the LFC problem in two-area and multi-source power systems. For instance, a GWO (Grey Wolf Optimization)-based PID controller was proposed in [1], showcasing superior performance compared to Particle Swarm Optimization (PSO) and Artificial Bee Colony (ABC) algorithm-based controllers. Another study [2] focused on non-reheat thermal power plants, optimizing PI and PID controllers through the GWO algorithm and comparing them with Comprehensive Learning Particle Swarm Optimization (CLPSO) and other ITAE-based metaheuristic techniques. The literature also features LFC systems [3] [4] in single- and two-area configurations with various controllers.

Research outcomes [5] indicate that PSO-based controllers offer more efficient control for two-area interconnected power systems than traditional controllers. Additionally, optimization studies [6] have been conducted on three interconnected power systems. Another investigation [7] simultaneously optimized a two-area system using PID controllers with PSO and compared the results with various metaheuristic techniques.

For accommodating changes in tie-line power flow and frequency adjustment with nominal constraints, a Genetic Algorithm (GA)-based LFC approach was recommended in [8] for a two-area system with fluctuating demand. Minimal steady-state errors and faster controller response are crucial for achieving the objectives of LFC. GA has been applied in single, two, and multi-source area systems alongside standard PI and PID controllers to address LFC challenges [9-11]. Moreover, the firefly algorithm has been utilized in [12] to determine optimal gain values for PID controllers in single, two, or multi-area power systems. Another approach employed a fuzzy PID controller for LFC operations [13].

In this research, we employ firefly optimization techniques to determine the best PI and PID controllers based on the ITAE objective function. We focus specifically on two-area interconnected non-reheated thermal-thermal power systems and provide a comparative analysis of their performance.

II. SYSTEM UNDER STUDY

Consideration is given to a two-area power system with thermal units in each control area for the load frequency control problem. The analysis assumes that the area capacity ratio is 1:1, which indicates that each region has the same capacity of 1000MW. Equations (1) and (2) are the governor and turbine transfer function equations, respectively.System undergoes through step load as well as random load disruptions.

A. Model of overall system

The overall system model consists of two area system. The block diagram of system under study is shown in Fig. 1. Area 1 contains gas power plant model along with the aggregate EV model. Area 2 contains thermal power plant. The effect of EV is also included in Area 2.

$$TF_{Gov} = \frac{1}{T_g.s+1} \qquad (1)$$

$$TF_{Tur} = \frac{1}{T_t.s+1} \qquad (2)$$

B. Controller Design

The PI and PID controllers have been extensively recognised and utilised for several years. Fig.2. and Fig.3. demonstrates the block diagram, whereas equations (2) and (3) define the PI and PID controllers, respectively. The performance of the kth area is enhanced by optimising the proportional gain K_P, integral gain K_I, and derivative gain K_D control variables. The K_{PK} regulates overshoots, rising time, and steady-state error with minimal influence on settling. The K_{IK} influences overshoots and rise time, but its influence on settling time is insignificant. The K_{DK} is used to regulate both settling time and overshoot. Utilizing optimization approaches, the controller settings are determined.

For the cost function J, the ITAE approach with simulation time T(s) is applied. Equation (4) cost function yields the optimal value for the controller.

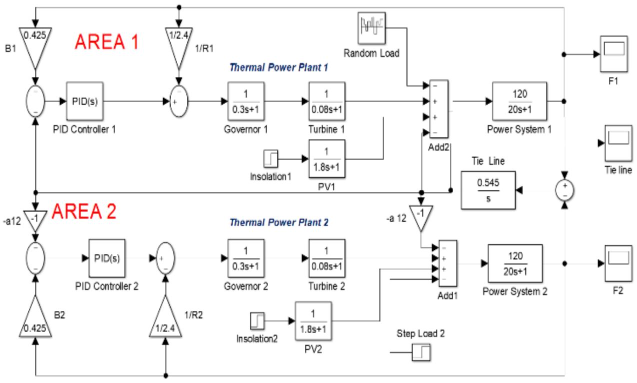

Fig.1. Overall system under study.

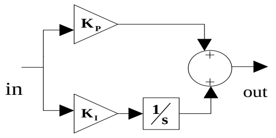

Fig.2. PI controller

$$G(s)_{PI} = K_{Pk} + \frac{K_{Ik}}{s} \qquad (2)$$

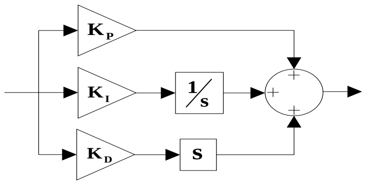

Fig.3.PIDcontroller.

$$G(s)_{PID} = K_{Pk} + \frac{K_{Ik}}{s} + K_{Dk} \cdot s \qquad (3)$$

$$J = \int_0^T \left| \left(\Delta f_{area-1} + \Delta f_{area-2} + \Delta P_{tie} \right) \right| * t dt \qquad (4)$$

III. FIREFLY ALGORITHM

Firefly algorithm is a population-based algorithm that analyses the flashing patterns and behaviour of tropical fireflies (FF-A). This is an effective optimization method. In 2008, Yang presented FF-A at the University of Cambridge. Yang XS further refined this technique for multimodal optimization in 2009 [14]. The FF-A algorithm is depicted in Figure 4. The objective function is defined by the intensity of a firefly's light. The brightness of firefly I at position x is provided by I(x)/f(x) when the objective function is minimized. The equation for the luminosity of light is given by equation (5)

$$I = I_o e^{-\gamma r} \qquad (5)$$

Where, I_0= original intensity of light,

γ = coefficient of light absorption which varies with distance *r*

For Firefly optimization used in this study, tuned values are: number of fireflies = 20, Maximum iterations = 100.

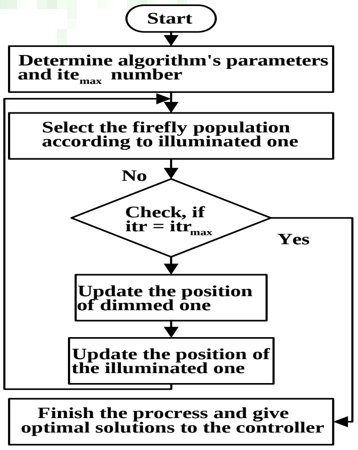

Fig.4. Flowchart of firefly algorithm

IV. SIMULATION PERFORMANCE

The studied system is for a two-area power system with a thermal power plant in each area. This study's primary objective is to consider the importance of the secondary controller for load frequency management. Two classical controllers, PI and PID, have been employed for this purpose. For these controllers' gains, the well-known firefly method has been implemented. The following describes the results' analysis:

Case-1: Step load perturbation (SLP)

In this case, it is considered that 1% SLP is applied in area-1 only i.e., first area demands a power of 0.01 PU and no power demand by the area-2. Figure 5 (a-c) represents the system dynamics for this case and TABLE 1 contain the gains of the PI and PID controllers and cost function value while, TABLE 2 shows the comparison of the dynamics in terms of peak overshoot, peak undershoot and settling time. It is observed from TABLE 2 and Figure 5 that, PID is outperforms in all the comparing parameters. From the cost function curves (Fig. 6) it can be commenting that PID is converging fast which shows its superiority.

Case-2: Random load perturbation (RLP)

In this case, instead of 1 % SLP random load pattern is applied in area-1 only. This study also shows the robustness of the controller. Figure 7 shows the pattern of the random load and Figure 8 (a to c) represents the system dynamics with this load patter. In such loading conditions also PID reveals its superiority compared to PI controller. The obtained gains during this case are showed in TABLE 3.

TABLE 1. Optimized controller gain and Cost value

Parameter	**PI**		**PID**	
	Area-1	**Area-2**	**Area-1**	**Area-2**
K_P	0.3784	0.5328	0.7951	0.281
K_I	0.9815	0.3558	0.9988	1
K_D			0.7420	0.1099

TABLE 2. Comparison of the dynamics

Parameters		**Peak Overshoot (Hz) x10^-3**	**Peak Undershoot (-Hz) x10^-3**	**Settling time (s)**
Δf1	PI	6.08	18.92	36.03
	PID	2.13	16.07	8.91
Δf2	PI	1.5	4.99	48.23
	PID	-	3.7	12.89
ΔP_{tie}	PI	6.92	15.12	47.21
	PID	0.6	11.11	8.12

TABLE 3. Optimized controller gain.

Parameter	**PI**		**PID**	
	Area-1	**Area-2**	**Area-1**	**Area-2**
K_P	0.4212	0.3091	0.5999	0.1909
K_I	0.8911	0.8309	0.9935	0.9885
K_D			0.2039	0.3081

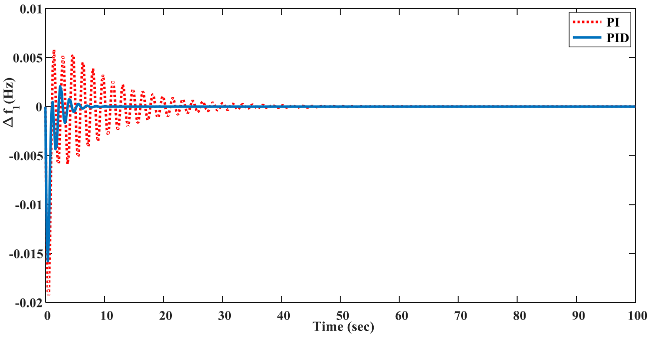

Fig. 5(a)

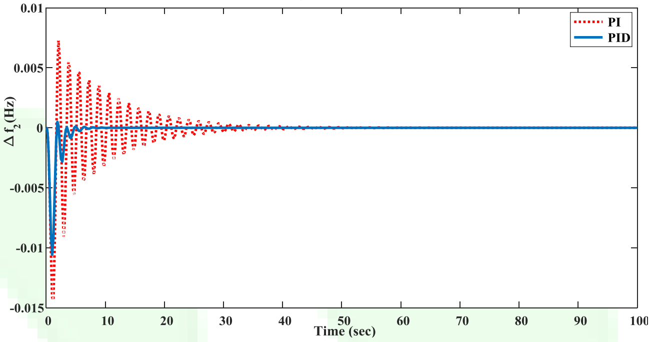

Fig. 5(b)

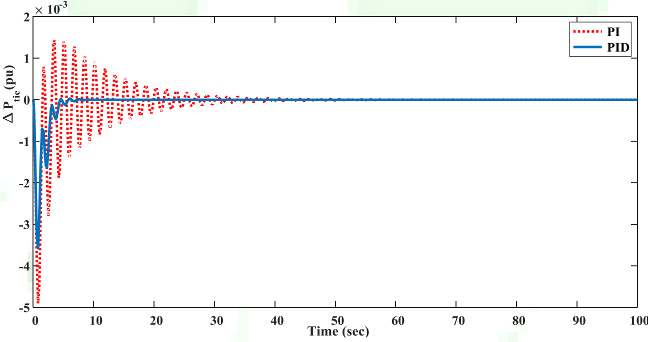

Fig. 5(C)

Fig. 5. Comparison of dynamic responses with PI and PID controller.

(a), (b) , (c) Deviations in area-1&2 frequency and tie-line power.

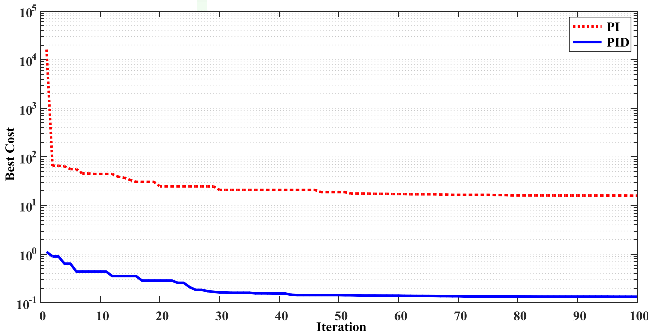

Fig. 6 Comparison of convergence curves of PI and PID

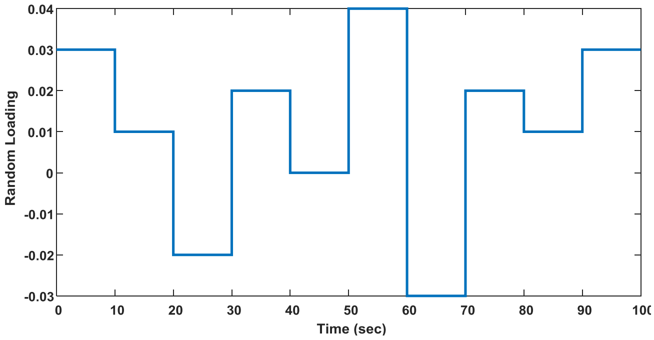

Fig. 7 Random load pattern

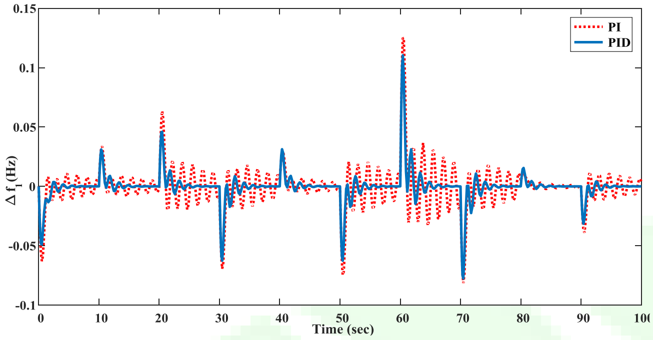

Fig. 8(a)

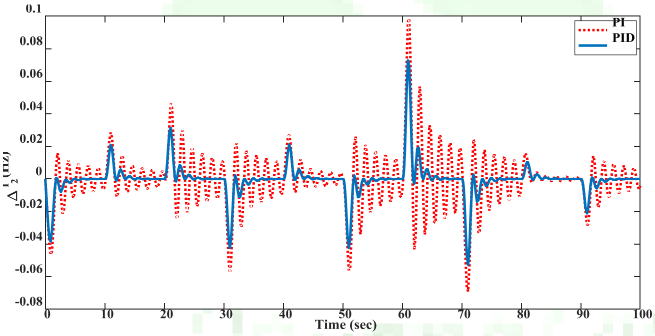

Fig. 8(b)

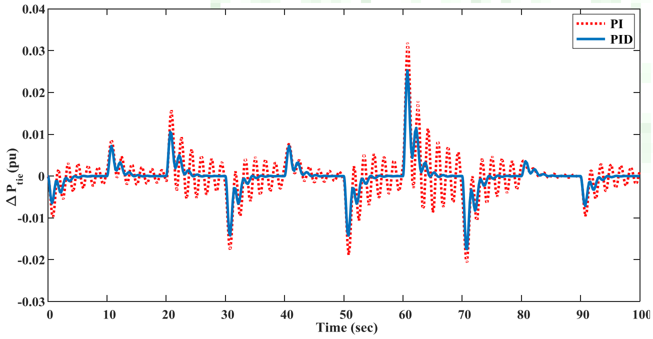

Fig. 8(c)

Fig. 8. Comparison of dynamic responses with PI and PID Controllers for random load.

(a), (b), (c) Deviation in area-1&2 frequency and tie-line power.

V. CONCLUSION AND DISCUSSION

The firefly algorithm optimized PI and PID controllers are successfully utilized for the load frequency control of the two area power system problem. Investigation shows that system dynamic behaviors in all the two cases i.e. SLP and RLP, the dynamics due to PID controllers shows the better response compared with PI in terms of peak overshoot, peak undershoot and settling times. And it is also observed that cost value (J) is found to be minimum for the PID controllers which means lesser the cost value better the controller and better the dynamics. In the future this system can be study with the fractional order controllers.

VI. APPENDIX

System Parameters

T_g is equal to 0.08s,

R_1 and R_2 are equal to 2.4 PU MW/Hz,

T_t is equal to 0.3s,

K_{ps1} and K_{ps2} are equal to 120 Hz/pu Mw,

B_1 and B_2 are equal to 0.425 pu Mw/Hz,

a_{12} is taken as 1 and ,

T_{12} is 0.086 pu Mw/rad.

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