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Optimal Frequency Management in a Thermal Renewable Hybrid Power System with Energy Storage

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Abstract—This study focuses on the difficulties of managing load frequency in interconnected multi-area power networks that include solar electricity and energy storage devices (ESS). A comprehensive model is created by combining a reheat thermal power system, a solar power system, and an energy storage system (ESS). The firefly algorithm (FA) is used to optimise the parameters of the proportional-integral-derivative (PID) controller for a two-area power system. The optimisation process is guided by the objective function, which is based on the product of Integral Time and Absolute Error (ITAE). Additionally, the analysis examines how the reheat turbine affects the operation of the PID controller. The study emphasises the exceptional efficiency of the ESS by examining the behaviour of the system, illustrating a decrease in load frequency deviation and an improvement in system stability when the ESS and controller work together to regulate frequency. The simulation findings confirm the efficacy of the FA-based PID controller, outperforming other approaches.

Keywords: Load frequency control; Renewable energy sources, energy storage device, proportional-integral-derivative (PID) controller.

I. INTRODUCTION

Signal Global warming, energy security, and environmental degradation have led to a growing consensus on the significance of maximizing renewable energy use. Grid-connected power generation from large-scale renewable sources, especially solar and wind, dominates emerging power systems. Solar energy is notable for its large storage capacity, ubiquitous availability, and favorable peaking [1]. As power systems use more renewable energy, conventional generators' frequency regulating capabilities become inadequate. Additionally, grid technology has created multi-regional interconnected power networks [2], increasing the requirement for load frequency control (LFC) in complicated power scenarios. ESS can quickly adapt to load frequency variations, making them a useful way to minimize equipment failures and load demand fluctuations in power systems.

A range of algorithms and control strategies are employed to tackle the LFC problem. For instance, a study [3] compared the Grey Wolf Optimization (GWO) algorithm to Particle Swarm Optimization (PSO) and Artificial Bee Colony (ABC) algorithm, suggesting a GWO-based optimization PID controller for LFC in two-area and multi-source power systems. Another investigation [4] focused on non-reheat thermal power plants, optimizing PI and PID controller settings using the GWO algorithm and comparing them with Comprehensive Learning Particle Swarm Optimization (CLPSO) and other ITAE-based metaheuristic techniques. Furthermore, research findings [5] demonstrated that PSO-based controllers outperformed conventional controllers in two-area interconnected power systems, while [6] optimized three interconnected power systems.

In a similar vein, a study [7] optimized a two-area system using a PID controller with PSO, comparing the results to various metaheuristic techniques. Another research paper [8] recommended the use of Genetic Algorithms (GA) for LFC in a two-area system with fluctuating demand, allowing for accommodating anticipated changes in tie-line power flow and frequency adjustment within specified constraints. To achieve effective LFC, controllers with minimal steady-state errors and faster response times are crucial. GA was implemented in single, two, and multi-source area systems, in addition to standard PI and PID controllers, to address LFC challenges [9-11]. In another study [12], a firefly algorithm was employed to determine the optimal gain values for PID controllers in single, two, or multi-area power systems. Additionally, fuzzy PID controllers were utilized for LFC operations in [13]. In this research, we utilize the firefly algorithm technique to determine the optimal PID controller based on ITAE objective functions. We compare two-area interconnected thermal-thermal reheat power systems with and without the incorporation of ESS.

II. SYSTEM UNDER STUDY

Consideration is given to a two-area power system with thermal units along with photovoltaic source in each control area for the load frequency control problem. The system is also including the energy storage system (ESS). 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 and Equation 3 represents transfer function of the reheater. 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.

$$TF_{Gov} = \frac{1}{T_g.s+1} \tag{1}$$

$$TF_{Tur} = \frac{1}{T_t.s+1} \tag{2}$$

$$TF_{\mathrm{Reheater}} = \frac{sK_rT_{tr}+1}{sT_{tr}+1} \tag{3}$$

B. Controller Design

The PID controllers have been extensively recognised and utilised for several years. Fig.2 demonstrates the block diagram, whereas equation (4) defines the PID controller. The performance of the kth area is enhanced by optimising the proportional gain K_{PK}, integral gain K_{IK}, and derivative gain K_{DK} control variables. For the cost function J, the ITAE approach with simulation time T(s) is applied. Equation (5) cost function yields the optimal value for the controller.

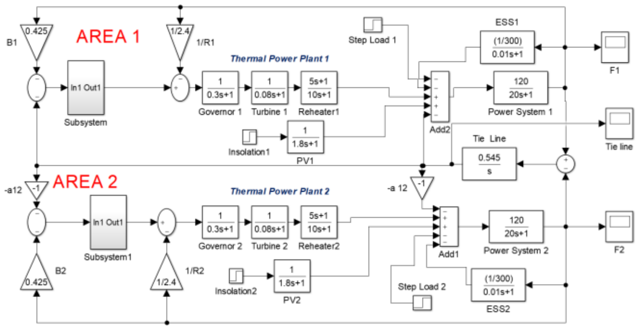

Fig.1. Overall system under study.

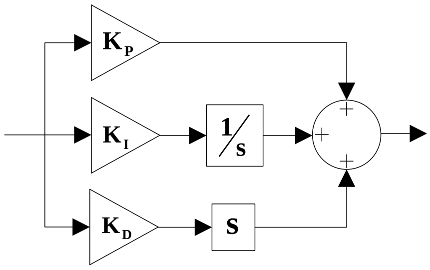

Fig.3. PID controller.

$$G(s)_{PID} = K_{Pk} + \frac{K_{Ik}}{s} + K_{Dk}\cdot s \tag{4}$$

$$J = \int_0^T \left|\left(\Delta f_{area-1} + \Delta f_{area-2} + \Delta P_{tie}\right)\right| * t dt \tag{5}$$

III. FIREFLY ALGORITHM

In Firefly algorithm is a population-based algorithm that analyses the flashing patterns and behavior 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 (6)

$$I = I_o e^{-\gamma r} \tag{6}$$

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.

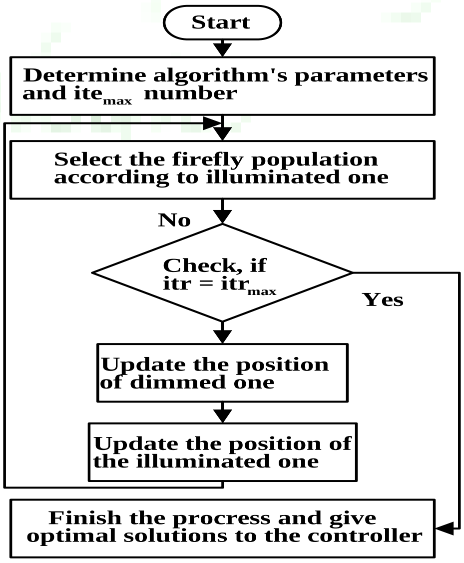

Fig.4. Flowchart of firefly algorithm

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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: Effect of reheat turbine

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 3 (a-c) represents the system dynamics for this case and TABLE 1 contain the gains of the PID controllers for with and without reheat turbine 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 3 that, the dynamics with reheat turbine is deteriorates the system performance in all the comparing parameters.

Case-2: Effect of Energy storage System

In this case, energy storage device is implemented in both the area along with the same sources with reheat turbine.

This study shows the that the ESS supports the frequency regulation. Figure 4 represents the system dynamics with this case. With the inclusion of ESS dynamics found better in terms of peak overshoot, undershoot and settling time. The obtained gains of PID controller during ESS are showed in TABLE 3.

Table 1. Optimized Controller Gain And Cost Value

Parameter	PID (with reheat turbine)		PID (without reheat turbine)	
	Area-1	Area-2	Area-1	Area-2
K_P	0.7076	0.6763	0.5179	0.182
K_I	0.8955	0.8584	1	0.9999
K_D	0.0123	0.4611	0.2074	0.0921

TABLE 2. Comparison of the dynamics

Parameters		Peak Overshoot (Hz) x10^-3	Peak Undershoot (-Hz) x10^-3	Settling time (s)
Δf1	PID with reheat	4.8	20.2	18.3
	PID without reheat	2.1	19.7	8.7
Δf2	PID with reheat	1.4	4.8	27.1
	PID without reheat	-	3.6	10.3
ΔP_{tie}	PID with reheat	7.2	5.2	29.6
	PID without reheat	0.5	3.1	7.2

TABLE 3. Optimized controller gain.

Parameter	PID (with storage)	
	Area-1	Area-2
K_P	0.9981	0.8121
K_I	1	0.9571
K_D	0.9998	0.1822

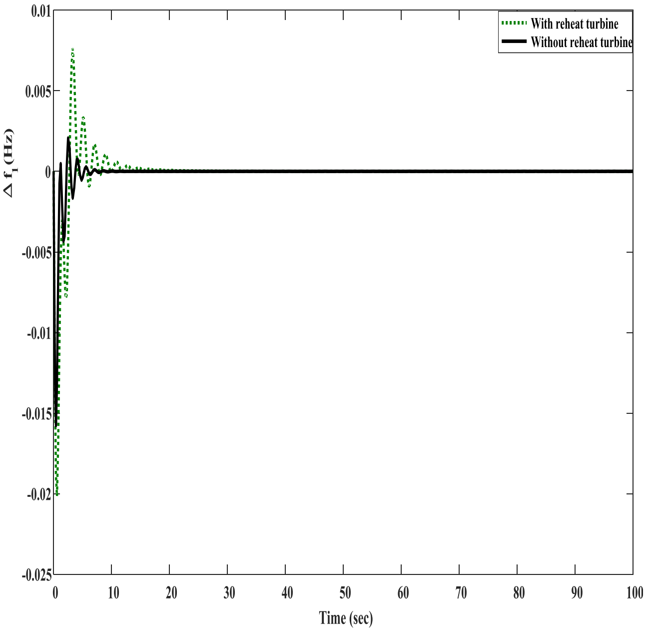

Fig. 3(a)

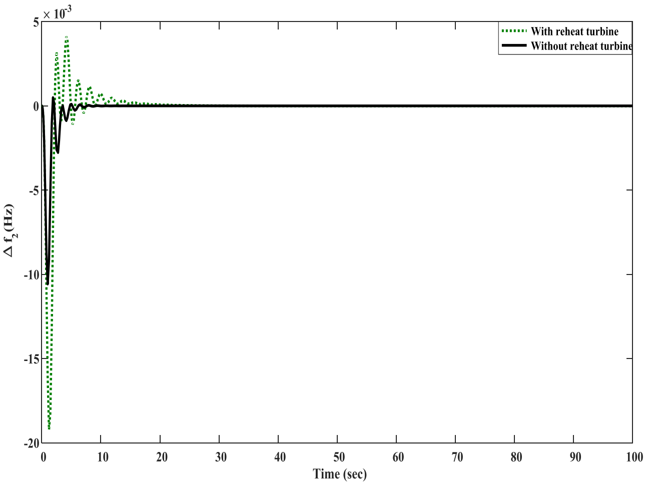

Fig. 3(b)

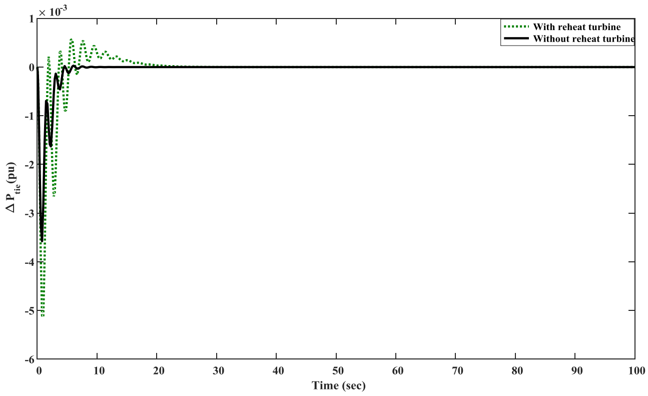

Fig. 3(C)

Fig. 3. Comparison of dynamic responses with and without reheat turbine deviations in: (a) area-1 (b) area-2 frequency and (c) tie-line power.

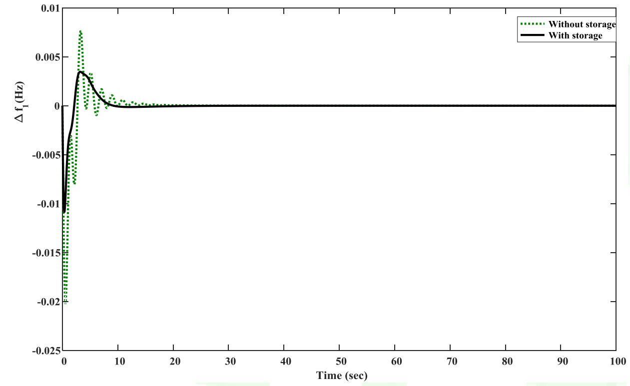

Fig. 4(a)

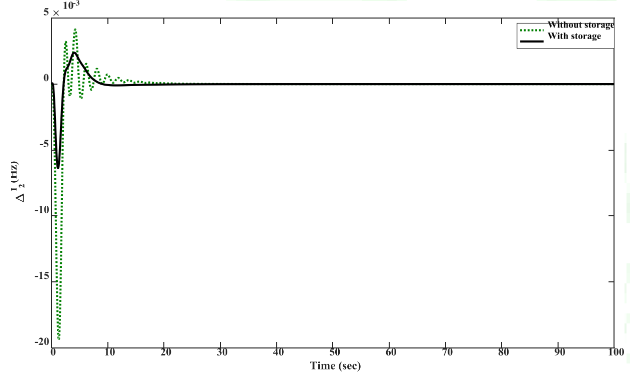

Fig. 4(b)

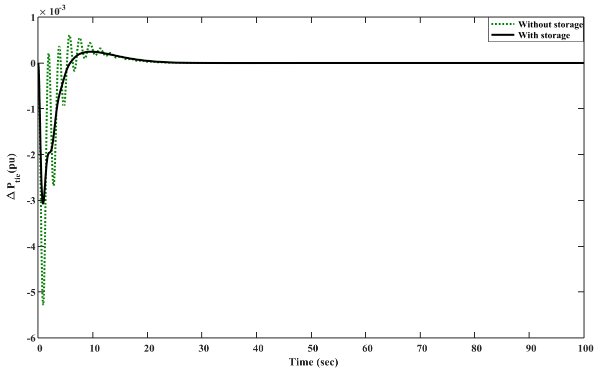

Fig. 4(c)

Fig. 4. Comparison of dynamic responses with and storage deviation in: (a) area-1 (b) area-2 frequency and (c) tie-line power.

V. CONCLUSION AND DISCUSSION

The two-area power system load frequency control is solved with firefly optimized PID controllers. Reheat turbine and energy storage system investigations. System dynamic behaviors reveal that reheat turbine distorts dynamics, while ESS regulates frequency. PID controllers have better peak overshoot, peak undershoot, and settling times than ESS. This system can be studied with fractional order controllers later.

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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