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Optimal Load Frequency Control of an Interconnected Two-Area Reheat Thermal Power Plant Including Renewable Energy Sources and Energy Storage Device

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***Abstract*— This research focuses on problems of managing the load frequency in multi-area power systems that are interconnected and use photovoltaic power and energy storage devices (ESS). The standard load frequency management approach is used to create a model of a reheat thermal power-based system along with model of a solar, and then energy storage system is added. The firefly algorithm (FA) is used to find the best control variables of proportional-integral-derivative (PID) controller for a two-area power system. The goal function is the sum of Integral Time times Absolute Error (ITAE). In addition, the effect of reheat turbine is analysed with PID controller. In the next stage, the superiority ESS devise over without ESS is proved by the comparison of system dynamics. The load frequency deviation changes less when the energy storage system and controller work together to regulate frequency. This makes the system work better. The simulations have shown that the FA-based PID controller is better than what was mentioned**

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

I. INTRODUCTION

In recent years, as the severity of global warming, energy security worries, and environmental degradation anxieties have increased, it has become universally accepted to maximise the usage of renewable energy. For new power systems, grid-connected power generation from large-scale renewable energy sources, such as solar and wind, has become an inexorable trend. Among them, solar energy is the most frequently employed due to its enormous storage capacity, wide dispersion, and positive peaking [1] characteristics. Nonetheless, as the proportion of renewable energy generation in power systems rises, the frequency modulation capability of conventional generators no longer meets requirements. In the meantime, the ongoing development of grid technology has increased grid connections between different regions, resulting in the formation of multi-regional interconnected power networks [2]. The needs for load frequency control (LFC) in interconnected power systems have continuously increased as power circumstances have become increasingly complex. It has been determined that the installation of energy storage systems (ESS) in power systems is an effective way for mitigating the effects of equipment failures and load demand changes on system functioning. ESS is capable of responding rapidly to load frequency changes in power systems.

Several algorithms and control strategies are utilised to solve the LFC problem. Comparing GWO to PSO and the ABC (Artificial Bee Colony) algorithm, the paper [3] suggested a GWO-based optimization PID controller for the LFC of two-area and multi-source power systems. The research [4] initially addresses a widely used non-reheat type of thermal power plant that includes and omits generation rate restrictions (GRC) of the steam turbine. This system optimises PI and PID controller settings via the GWO algorithm, which is compared to Comprehensive Learning Particle Swarm Optimization (CLPSO) and other ITAE-based meta heuristic techniques.

The results of [5] indicate that PSO-based controllers for two-area linked power systems provide more efficient control than conventional controllers. Three interconnected power systems were optimised in [6].

Simultaneously with PI controller, [7] two-area system is optimised using PID controller utilising PSO, and the results are compared to those of various meta-heuristic techniques.

In paper [8], GA is recommended as LFC for accommodating an anticipated change in tie-line power flow and frequency adjustment with nominal constraints for a two-area system with fluctuating demand. To reach the goal of the LFC, a power system with minimal steady-state errors must incorporate a quicker controller. GA is employed in single, two, and multi-source area systems in addition to standard PI and PID controllers to handle LFC difficulties [9-11]. In [12], a firefly algorithm is utilised to determine the optimal gain value of the PID controller in a single, two, or multi-area power system. In [13], a fuzzy PID controller is employed for the LFC operation.

In this research, firefly algorithm technique are utilised to determine the best PID controller based on ITAE objective functions. Two area interconnected thermal-thermal reheat power systems are compared with and without 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.

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.

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

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

$$TF_{Reheater} = \frac{sK_rT_{tr}+1}{sT_{tr}+1} \qquad (3)$$

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.

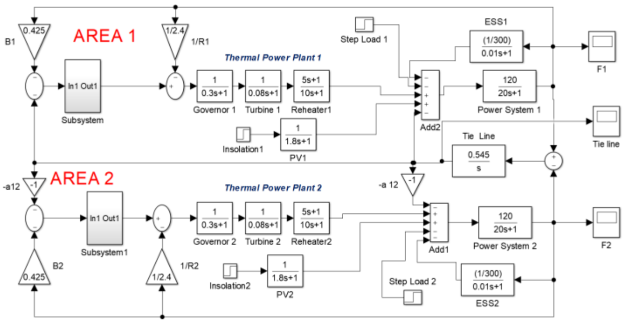

Fig.1. Overall system under study.

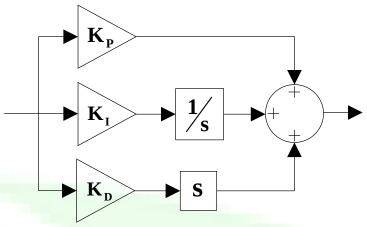

Fig.3. PID controller.

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

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

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 (6)

$$I = I_o e^{-\gamma r} \qquad (6)$$

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.

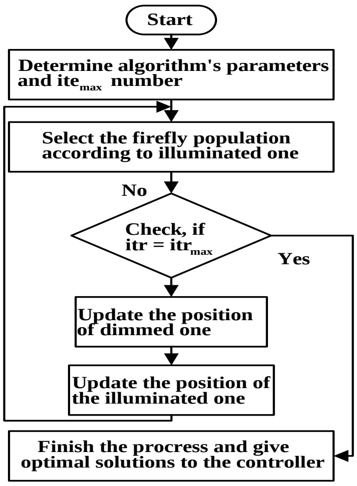

Fig.4. Flowchart of firefly algorithm

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 terns 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)**
Δf_1	PID with reheat	4.8	20.2	18.3
	PID without reheat	2.1	19.7	8.7
Δf_2	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

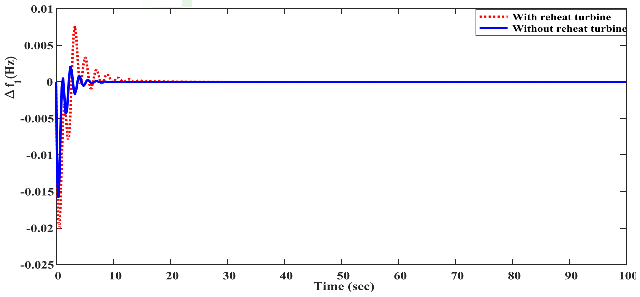

Fig. 3(a)

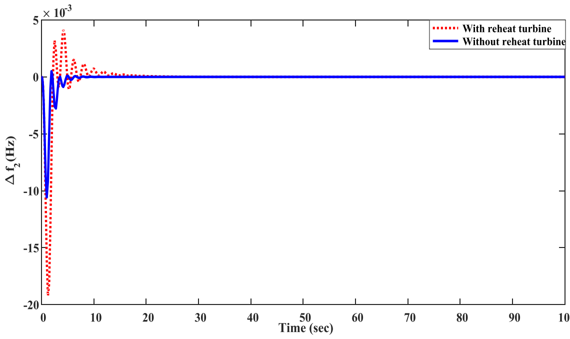

Fig. 3(b)

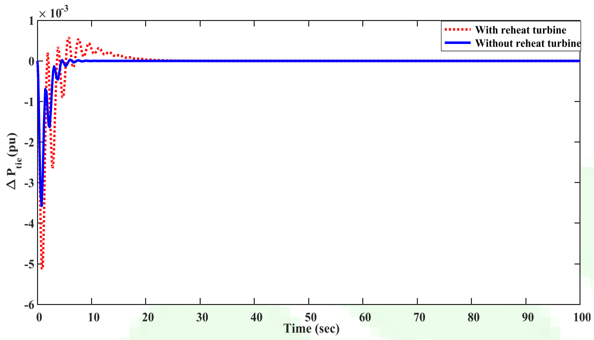

Fig. 3(C)

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

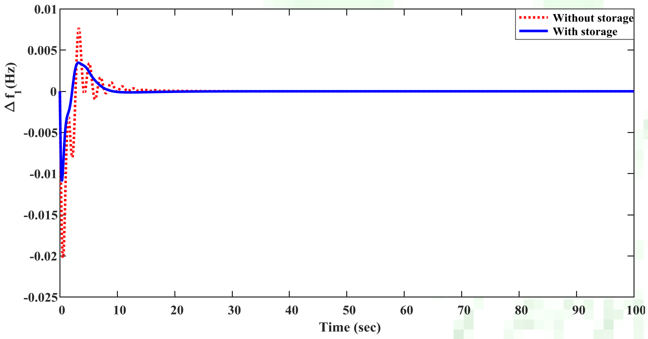

Fig. 4(a)

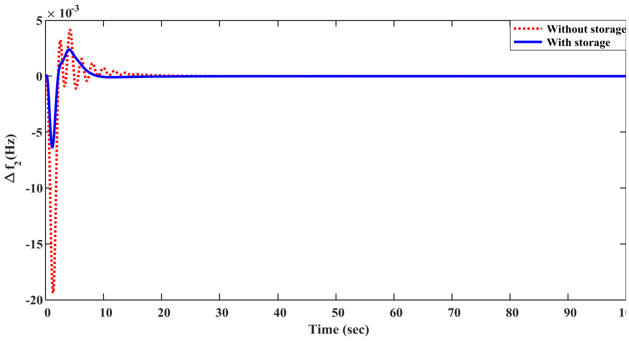

Fig. 4(b)

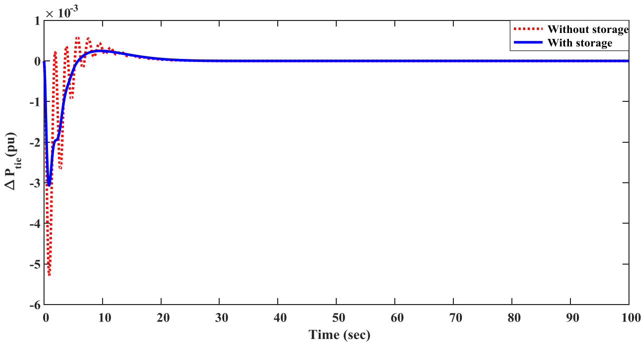

Fig. 4(c)

Fig. 5. 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.

IV. CONCLUSION AND DISCUSSION

The firefly optimized PID controllers are successfully utilized for the load frequency control of the two area power system problem. Investigation done in the two cases i.e., with reheat turbine and with energy storage system (ESS). The system dynamic behaviors, show that due to reheat turbine the dynamics getting distorted, while addition of the ESS supports the frequency regulation. The dynamics due to PID controllers shows the better response compared while using ESS, in terms of peak overshoot, peak undershoot and settling times. In the future this system can be study with the fractional order controllers.

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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