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LOAD FREQUENCY CONTROL OF AC MULTI-ISLANDED MICRO GRID SYSTEM USING PIDF CONTROLLER WITH PSO TECHNIQUE

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Abstract:

This paper proposes a method for improving load frequency control (LFC) in AC multi-islanded microgrid systems using a PIDF controller optimized with PSO. The approach considers the system's dynamic characteristics and uncertainties. The PIDF controller is designed to regulate frequency deviation and tie-line power fluctuations in each island. PSO optimizes the controller parameters for optimal performance. Simulation studies demonstrate that the proposed method outperforms traditional PID controllers in terms of frequency regulation, tie-line power control, and system stability, offering a promising solution for enhancing LFC in AC multi-islanded microgrid systems.

Key words: Microgrid, PI, PID and PIDF controllers, PSO optimization techniques

INTRODUCTION:

Load frequency control (LFC) is a critical aspect of power system operation, ensuring the balance between generation and demand to maintain system stability and reliability. In recent years, there has been a growing interest in enhancing LFC performance, especially in AC multi-islanded microgrid systems, which are characterized by dynamic complexities and uncertainties. This paper presents a novel approach for LFC in AC multi-islanded microgrid systems using a Proportional-Integral-Derivative-Filter (PIDF) controller optimized with the Particle Swarm Optimization (PSO) technique. The PIDF controller is designed to regulate frequency deviation and tie-line power fluctuations in each island of the microgrid. The PSO optimization method tunes the PIDF controller parameters to achieve optimal control performance.

Simulation studies on a multi-islanded microgrid system under various operating conditions and disturbances demonstrate that the proposed PIDF controller with PSO optimization outperforms traditional PID controllers in terms of frequency regulation, tie-line power control, and system stability. This paper contributes to the advancement of LFC in AC multi-islanded microgrid systems, offering a promising solution for improving the overall reliability and stability of such systems.

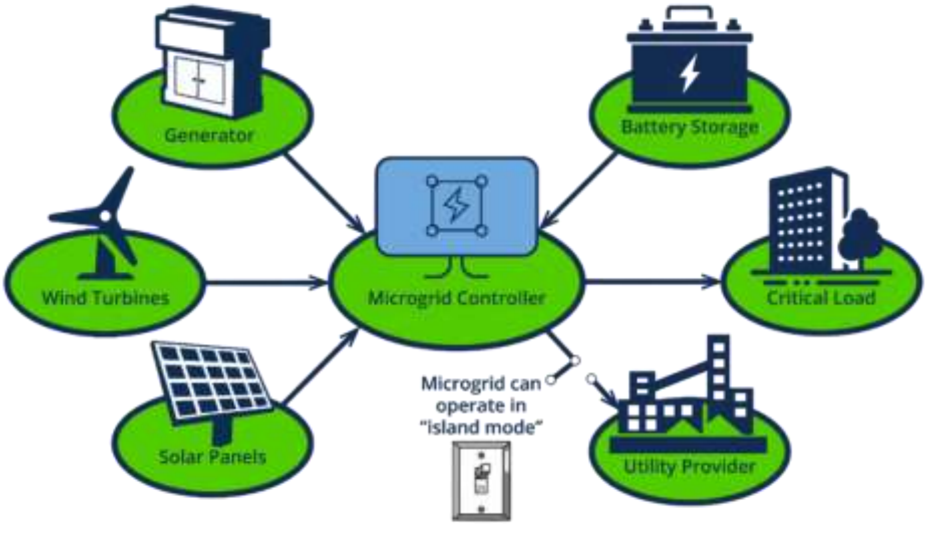

Fig-1 Schematic diagram of Microgrid

CONTRIBUTION

This article discusses analysing load frequency control in a two-area interconnected microgrid system through several steps:

- The microgrid consists of a mix of traditional thermal power units and renewable energy sources like solar photovoltaic arrays, wind farms, diesel engine generators, and energy storage systems.
- An energy storage system (ESS) is integrated into the microgrid to regulate generation and load demand.
- Various controllers including Proportional-Integral (PI), Proportional-Integral-Derivative (PID), and Proportional-Integral-Derivative-Feedforward (PIDF) are applied using the Particle Swarm Optimization (PSO) technique for frequency control.
- The performance of the PIDF controller is evaluated against PI and PID controllers to demonstrate its effectiveness.

DESIGN OF MICROGRID

The design of microgrids include Synchronous Generator, Wind Source, Solar PV arrays and Energy Storage System. The above listed sources are represented by their transfer function model.

1. Solar Photovoltaic system

A solar photovoltaic (PV) system is a renewable energy technology that converts sunlight into electricity using solar panels. These systems consist of solar panels, inverters, mounting structures, and other electrical components. Solar panels are made up of photovoltaic cells, which generate direct current (DC) electricity when exposed to sunlight.

The output of this source can be calculated by the equation given below

$$P_{pv} = S\varphi[1 - 0.005(T_a + 25)]$$

Where,
$\beta =$ Conversion efficiency
S = Area of photovoltaic array (m^2)
$\varphi =$ solar irradiation (km/m^2)
T_a = Ambient temperature (C^0)

Transfer function of the above system can be written as first order lag [4,5].

$$G_{pv}(sys) = \frac{\Delta P_{pv}}{\Delta\varphi} = \frac{K_{pv}}{1 + sT_{pv}}$$

Where,
K_{pv} = Gain constant
T_{pv} = Time constant, reciprocally.

2.Wind Power system

The wind subsystem refers to a component within a larger system, typically within the context of renewable energy generation. It encompasses the turbines, blades, tower, and associated infrastructure used to capture and convert wind energy into electricity. This subsystem plays a vital role in harnessing wind power, a sustainable and increasingly popular source of renewable energy worldwide.

The normal deviation of output power of wind system is given by

$$\delta_w = 0.8\sqrt{P_w}$$

Output fluctuation on the given wind model is founded by the random output fluctuation is multiplied by deviation [6,7].

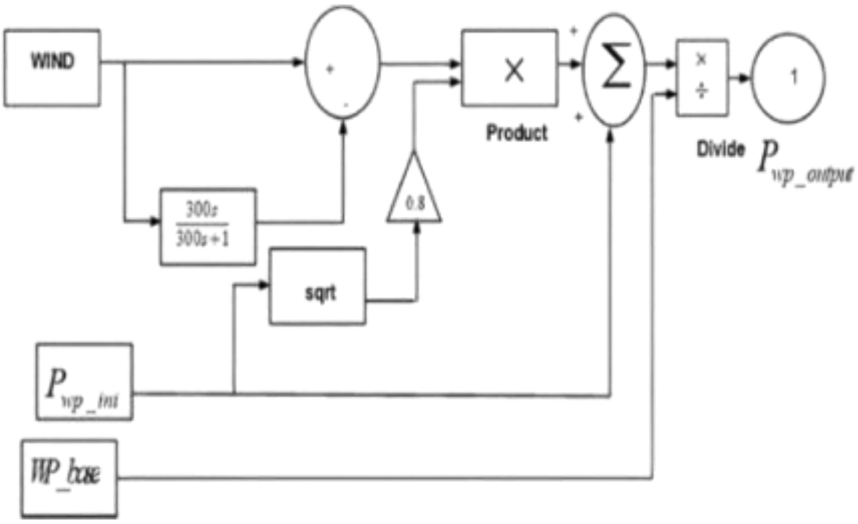

Fig-2 Model of Wind Power System

3.Synchronous Generator

In islanded mode, synchronous generators can be the main source of power generation, providing electricity to local loads independent of the main grid. In this mode, they need to be controlled to maintain the balance between generation and load to ensure stable and reliable power supply. Synchronous generator systems play a crucial role in microgrids by providing stable and reliable power generation, supporting grid stability, and enabling the integration of renewable energy sources.

The Transfer function of this generator system is written as

$$G_g(sys) = \frac{\Delta P_v(sys)}{\Delta P_v(sys)} = \frac{K_t}{1 + sT_g}$$

Where,
T_t = Time constant of the governor
K_t = Turbine time constant
Whose value is set as 1[2,3].

4 Energy Storage System [ESS]

An energy storage system, as simulated in MATLAB, is a critical component in modern power systems aimed at enhancing grid stability, reliability, and efficiency. It encompasses various technologies such as batteries, supercapacitors, and flywheels, integrated with control algorithms to manage energy flow in and out of the system. MATLAB provides a comprehensive platform for modelling, simulating, and optimizing energy storage systems, allowing engineers and researchers to analyse performance, assess different control strategies, and design efficient storage solutions. By leveraging MATLAB's capabilities, practitioners can explore the dynamic behaviour, sizing, and integration of energy storage systems within complex power networks, contributing to the advancement of renewable energy integration, grid modernization, and sustainable energy management practices. The transfer function of this system is written as below

$$G_{ess}(sys) = \frac{\Delta P_{ess}}{\Delta \omega} = \frac{K_{ess}}{1 + sT_{ess}}$$

Where,
K_{ess} = Gain Constant
T_{ess} = Time constant

Power deviation and system frequency variation

The total power generation (P_t) of the microgrid system can be written as
$P_t = P_{sg} + P_{pv} + P_w + P_{ess}$

The difference between the overall power generation and power demand reference is determined by ΔP_e, and it is determined as below

$\Delta P_e = P_t - P_d$

By changing the net power frequency can be changed and is determined by

$$\Delta\omega = \frac{\Delta P_e}{K_s}$$

Where,

K_s= System frequency characteristic constant

The Transfer function for the system frequency variation to per unit power deviation can be determined as

$$G_s(sys) = \frac{\Delta\omega}{\Delta P_e} = \frac{1}{K_s(1+sT_s)} = \frac{1}{d+ms}$$

Where,

m = equivalent inertia constant of the microgrid.

SIMULATION MODEL

The parameter values for the Island Multi-Micro-Grid system are sourced from references and detailed in Table-1. Wind power averages 0.4pu for Microgrid 1 and 0.3pu for Microgrid 2, while solar power averages 0.2pu for both Microgrid 1 and Microgrid 2. The synchronizing power coefficient is set at 1.5pu.

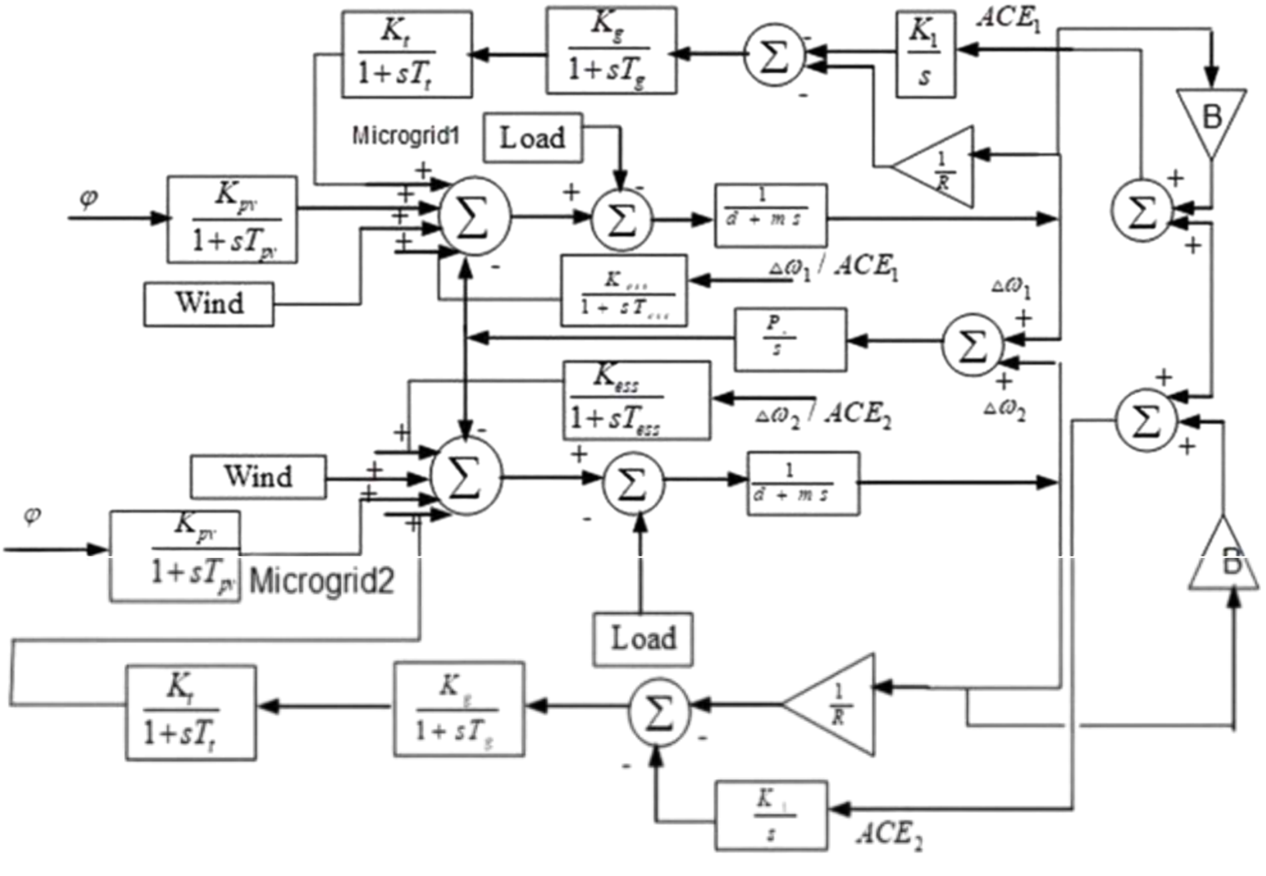

Fig.1.2 Proposed System Block diagram.

Parameter Values

The parameter values of this Island Multi-Micro-Grid system are brought from [2-5, 8-9] and given in the Table-1. The average value of wind power for Micro grid-1 and Micro grid-2 is kept 0.4pu and 0.3 pu respectively. The average value of solar power for Micro grid1and Micro grid2 is kept 0.2 pu for both. The synchronizing power co-efficient p_s is fixed as 1.5pu.

Table-1: Parameter values of studied Microgrid System

SL.No	PARAMETER	DEFINITION	Micrigrid1	Microgrid2
1.	R(PU)	Speed Regulation	0.05	0.04
2.	T_g(s)	Governor time constant	0.1	0.1
3.	T_t(s)	Turbine time constant	0.4	0.4
4.	T_{pv}(S)	Solar pv time constant	1.5	1.4
5.	T_{ess}(S)	ESS time constant	0.1	0.1
6.	K_{ess}	Ess gain constant	-10	-8
7.	K_i	Internal gain	5	7
8.	B(pu)	Frequency biasing factor	10	12.5
9.	M(pu)	Inertia constant	0.8	0.7
10.	D(pu)	Damping constant	0.02	0.03

PSO Optimized Parameters

The time domain simulated results of different responses are acquired in the MATLAB 2016 Simulink environment. The present model of the Multi-Micro-Grid system is expanded in the Simulink environment, and the necessary programming of the PSO technique is written in a .m file.

Table-2: PSO Optimized parameters for minimum fitness values

Controller parameters	PI	PID	PIDF
KP1	0.8754	9.5673	7.7019
KI1	4.6160	9.0491	9.9079
KD1	-	3.3180	2.1649
KP2	0.8629	7.9888	3.4949
KI2	0.9315	9.5791	6.0739
KD2	-	1.5922	7.8452
N1	-	-	138.7219
N2	-	-	145.1919

The superiority of the proposed PIDF controller with the PSO technique is presented by comparing it with conventional PI and PID controllers. The gains of the above controllers are optimized by the PSO algorithm

Output Waveforms

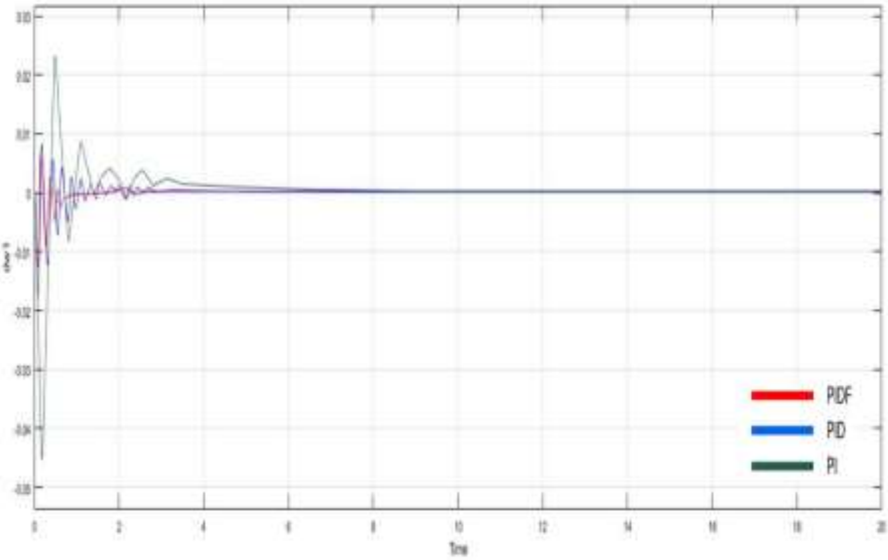

Fig-4.1 The simulation results of deviated power of microgrid-1 with PI, PID and PIDF Controllers using PSO optimization technique

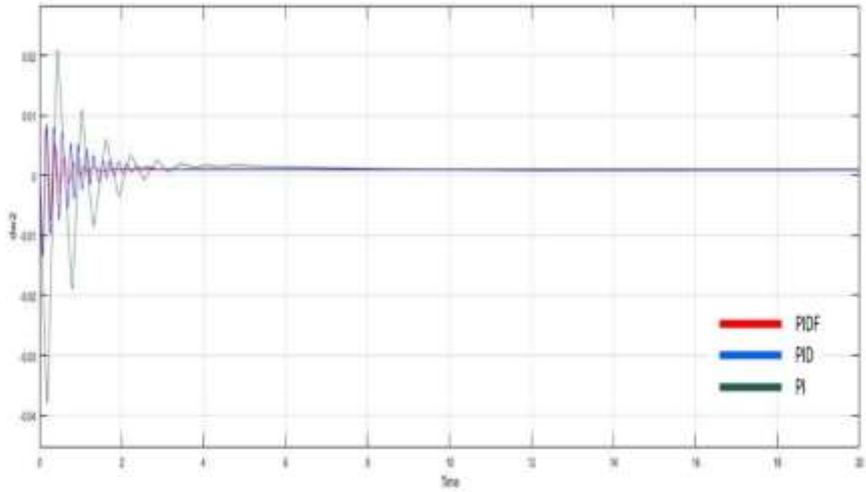

Fig-4.2 The simulation results of deviated power of microgrid-2 with PI, PID and PIDF Controllers using PSO optimization technique

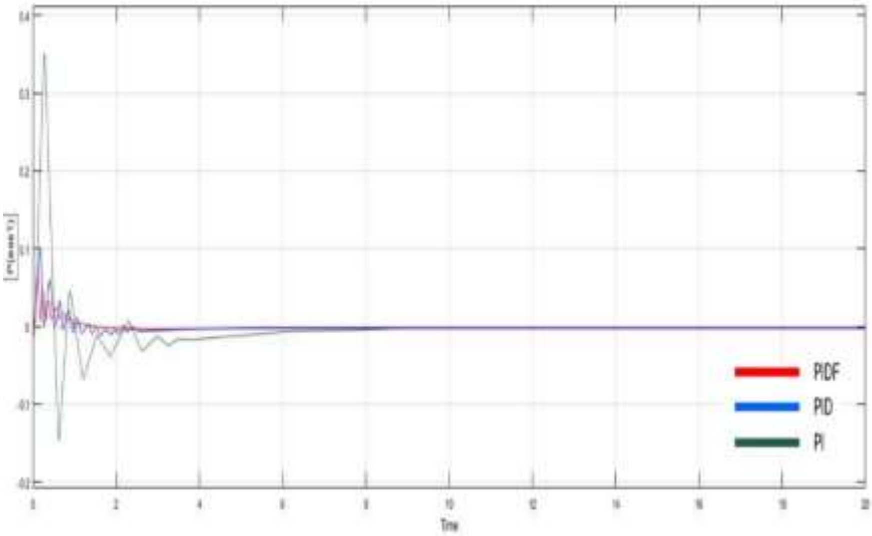

Fig-4.3 The simulation results of energy storage system of microgrid-1 with PI, PID and PIDF Controllers using PSO optimization technique

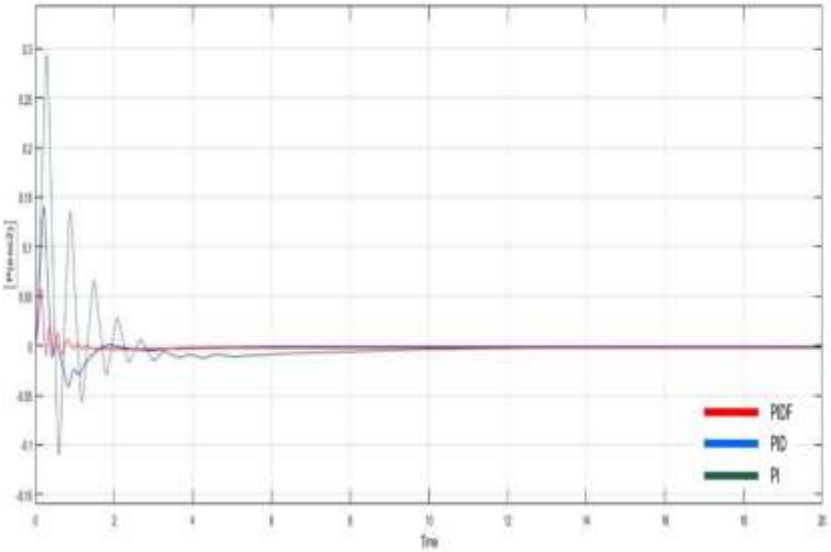

Fig-4.4 The simulation results of energy storage system of microgrid-2 with PI, PID and PIDF Controllers using PSO optimization technique

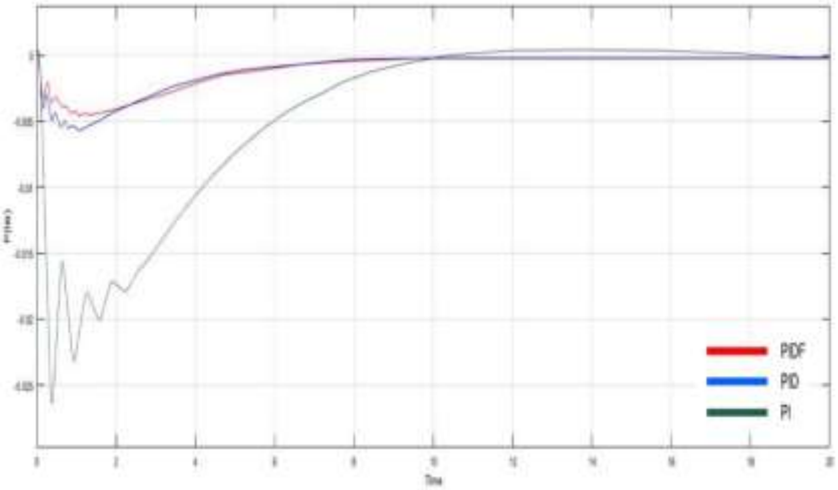

Fig-4.5 The simulation results tie line power between two microgrids with PI, PID and PIDF Controllers using PSO optimization technique

Table-3: The performance indices of the various responses resulting from the different controllers can be tabulated as follows:

Controller	**PI CONTROLLER**			**PID CONTROLLER**			**PIDF CONTROLLER**		
Performance	Over shoot in pu	Under shoot in pu	Settling time in Sec	Over shoot in pu	Under shoot in pu	Settling time in Sec	Over shoot in pu	Under shoot in pu	Settling time in Sec
$\Delta\omega_1$	0.0244	-0.0482	5.0602	0.0105	-0.0213	3.8239	0.0087	-0.0159	3.1874
$\Delta\omega_2$	0.0224	-0.0423	6.3782	0.0104	-0.0164	3.6148	0.0103	-0.0162	2.1535
P_{ess1}	0.3653	-0.1575	6.3755	0.1043	-0.0079	5.8915	0.0672	-0.0036	5.0211
P_{ess2}	0.2535	-0.1038	7.7380	0.0584	-0.0138	5.2162	0.0619	-0.0127	5.1578
ΔP_{tie}	0.0005	-0.0277	13.1031	0	-0.0057	10.4668	0	-0.0046	8.8919

Based on the tabulated results and analysis, the PIDF controller exhibited superior performance in terms of settling time, undershoot, and overshoot when compared to the traditional PI and PID controllers.

CONCLUSION

The application of PIDF controllers with PSO optimization in AC multi-islanded microgrids for load frequency control offers significant advantages. This study has shown that the PIDF controller, optimized using the PSO algorithm, provides superior dynamic response compared to traditional PID and PI controllers as shown in Table-3. By effectively stabilizing frequency, energy storage system dynamics, and tie-line power interactions in a two-area interconnected system, the PIDF controller enhances the overall performance and stability of the microgrid. Additionally, the PSO algorithm's interactive behaviour-based nature makes it a suitable optimization technique for tuning controller parameters. Overall, the combination of PIDF controllers and PSO optimization presents a promising approach for improving load frequency control in AC multi-islanded microgrids.

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