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Advanced optimization load frequency control for multi-islanded micro grid system with tie-line loading by using PSO

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ABSTRACT

This manuscript presents the design of a microgrid featuring solar and wind as uncontrollable energy sources, alongside controllable sources like batteries and a diesel generator, aiming to address power supply variations resulting from load fluctuations. Controllers are imperative to mitigate these challenges, and the manuscript emphasizes the need for precise tuning of gain values for optimal electrical energy utilization. In lieu of the trial-and-error approach, particle swarm optimization (PSO) is employed for enhanced steady-state response in the Microgrid. The study also introduces the application of proportional-integral (PI), proportional-integral-derivative (PID), and PID with feed forward (PIDF) controllers to effectively address and resolve identified issues ensuring improved system performance and consistent power supply stability in the microgrid system.

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1. INTRODUCTION

The electric power system encounters challenge due to the unpredictable nature of load, emphasizing the critical need for a delicate balance between generated power and demand. Transmission losses are factored into consumer considerations, and load forecasting techniques play a pivotal role in predicting power demand, aiming to maintain equilibrium with generated power for system stability. The load frequency control (LFC) [1]-[5] mechanism assumes significance in ensuring the system frequency remains within permissible limits, particularly following load shifts, with a primary goal of minimizing steady-state frequency error between control centers. As the demand for power rises and conventional fuel sources diminish, there is a notable shift towards sustainable alternatives, exemplified by the emergence of Microgrids. Historically reliant on non-renewable fuels, power generation is undergoing a transformation with the increasing adoption of renewable resources such as solar energy, wind energy, and biomass [6]-[10]. This evolution not only addresses escalating power needs but also aligns with environmental goals by curbing greenhouse emissions and reducing air pollution. Microgrids, confined to specific geographic areas, comprise small-scale power plants that encompass generators and renewable sources like wind and solar. Integrating energy-saving measures without the inclusion of energy storage systems (ESS), Microgrids function as backup during peak demand, interconnected through tie lines. Components like wind power, solar PV, synchronous generators, and loads characterize each microgrid. Operating in grid-connected or islanded modes, the latter presents frequency control challenges. Studies emphasize the heightened unpredictability in systems with wind and solar models. The comparison between traditional power systems and evolving Microgrids encapsulates the dynamic interplay between established practices and emerging sustainable technologies.

2. MODELS OF SYSTEM

Figure 1 depicts the Modeling-Method for the Microgrid. This self-sufficient microgrid includes a solar power source (12 kW), wind source (9 kW), diesel generator (22 kVA), and a battery (5 Ahr), as highlighted in the context of this paper. With a combined generation capacity of 1.8 kW from renewable and manageable sources, the battery primarily serves to supply power during short outages [11]-[15]. To optimize resource utilization and minimize power oscillations in response to varying loads, the article employs the PSO optimization technique along with the Xo Operator as a control approach.

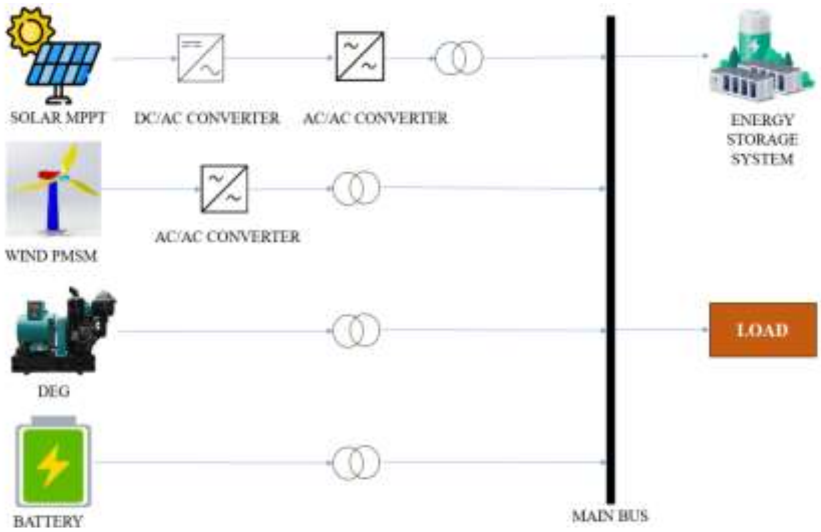

Figure 1. Block diagram of micro grid

2.1. Solar MPPT

This module optimizes the power output from the solar source (in kilowatts) based on real-time solar irradiance and temperature conditions. The solar photo voltaic system comprises multiple cells, which can be interconnected either in series or parallel to achieve the desired output voltage and current. The relationship between voltage and current exhibits a nonlinear nature. The maximal power output of the photo voltaic array is influenced by variations in solar radiation. To optimize the solar PV model's performance and attain maximum power output, an effective control strategy is essential for harnessing solar radiation efficiently [16]-[20].

$$GPV = KPV/1 + sTPV \tag{1}$$

2.2. Wind PMSM

The wind turbine generator system harnesses wind energy (in kilowatts) and adjusts its output based on real-time wind speed and other meteorological factors. A wind permanent magnet synchronous motor (PMSM) is an electric motor used in wind turbine systems. This type of motor utilizes permanent magnets to generate a magnetic field, offering high efficiency and reliability. In the context of wind energy, PMSM's play a key role in converting wind power into electrical energy, making them a vital component in modern wind turbine technology.

$$ə W = 0.8 * \sqrt{PW} \tag{2}$$

2.3. Diesel generator

The diesel generator (in kilovolt-amperes) provides additional power to the microgrid, and its operation is influenced by real-time fuel availability, load demand, and other operational parameters. The role of a Diesel Engine generator within a Microgrid is to supplement any power deficit, ensuring a balance between the supply and load requirements. Typically, a diesel generator is the preferred choice for smaller microgrids. However, for larger microgrids, a turbine-driven generator is often favored. In addition to addressing power shortfalls, these standby generators contribute to maintaining a stable and reliable power supply, enhancing the overall resilience of the Microgrid. The choice between diesel and turbine-driven generators is influenced by the size and specific needs of the microgrid, with each offering distinct advantages in different scenarios [20]-[30].

$$Gg = Kg/1 + sTg \tag{3}$$

2.4. Battery

Batteries are electrochemical galvanic cells that convert chemical energy into electrical energy, making them a prevalent power source in diverse applications. Their widespread adoption is attributed to their cost-effectiveness and straightforward design. These portable energy storage devices find extensive use in domestic, commercial, and economic settings, showcasing their versatility in providing reliable and accessible power [31]-[33].

2.5. Particle swarm optimization

Figure 2 depicts particle swarm optimization (PSO) is an optimization algorithm inspired by collective behavior observed in nature, such as bird flocks or fish schools. Introduced by Eberhart and Kennedy in the 1990s, PSO involves a population of particles exploring a solution space iteratively. Each particle adjusts its position based on its own experience and the collective knowledge of the swarm. Velocity and position updates guide the particles dynamically, leading them towards optimal solutions over successive iterations. PSO's strength lies in its ability to efficiently explore solution spaces through collaborative, swarm-based optimization.

Steps To Analyze PSO Algorithm

Step 1 - Initialization: Set the population size, maximum number of iterations, inertia weight, acceleration constants, and initialize particles' positions and velocities randomly within the solution space.

Step 2 - Objective Function Evaluation: Evaluate the fitness (objective function value) for each particle based on its current position. Update the personal best positions and values for each particle.

Step 3 - Global Best Update: Identify the particle with the best fitness value among the entire population.

Step 4 - Particle Movement Update: For each iteration, update each particle's velocity and position. Perform iterations for all particles.

Step 5 - Objective Function Re-evaluation: Evaluate the fitness for each particle based on its updated position. Updates the personal best positions and values for each particle if a better solution is found.

Step 6- Global Best Update: Update the global best if any particle has a better fitness than the current gbest.

Step 7 - Termination Criteria: Repeat the Particle Movement Update and Objective Function Re-evaluation steps until reaching the maximum number of iterations or a convergence criterion is met.

(e.g., a predefined fitness threshold).

3. SIMULATION ANALYSIS AND RESULTS

A microgrid system comprises diverse power sources, including a diesel generator, a battery, wind, and solar power. To address an augmented load demand, met jointly by the battery and diesel generator, the objective is to optimize the microgrid system's controller parameters. This optimization aims to achieve specific performance goals, such as reducing operating costs, enhancing energy efficiency, or ensuring a consistent power supply. The analysis involved the application of both the traditional Trial and Error method and the PSO method. The system operated for a duration of 60 seconds, with the analysis conducted through 10 rounds of PSO optimization, each with varying probabilities.

Case 1: Comparison of PI controller

The tie line load power analysis conducted on the islanded microgrid system using the PI controller reveals a comprehensive depiction of performance metrics. The results showcase the maximum peak overshoots and undershoots, offering insights into the controller's ability to manage transient conditions. Additionally, the settling time is examined, providing valuable information on the system's stability and responsiveness. These parameters collectively contribute to a thorough understanding of the PI controller's effectiveness in regulating tie line load power within the islanded microgrid, crucial for ensuring the system's reliability and efficiency during dynamic operational scenarios.

Table 1 and Figure 3 presents the performance metrics of a proportional-integral (PI) controller in managing the tie-line power in a multi-islanded microgrid system. Specifically, it lists the overshoot, undershoot, and settling time values for a given scenario. The overshoot, recorded at 0.1, indicates the extent to which the tie-line power exceeded its target value initially. The undershoot, measured at -0.026, shows how much the power dipped below the target before stabilizing. The settling time, recorded at 16.9 seconds, represents the time taken for the tie-line power to return and stay within a specified range around the target value after a disturbance. These metrics are critical for assessing the performance and stability of the PI controller in maintaining the balance of power in the system.

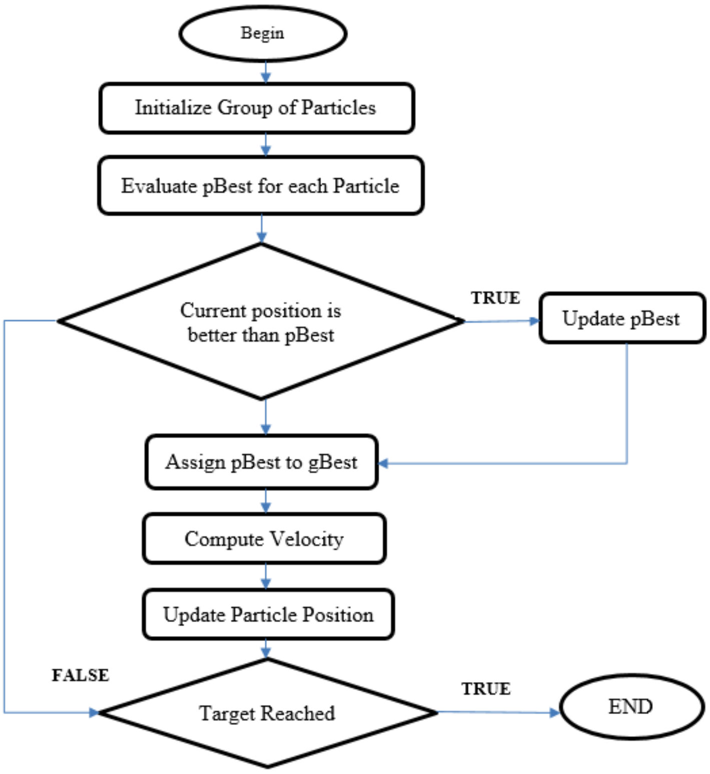

Figure 2. Particle swarm optimization

Table 1. Values of tie line power obtained through PI controller

S.No	Overshoot	Undershoot	Settling time
1.	0.1	-0.026	16.9

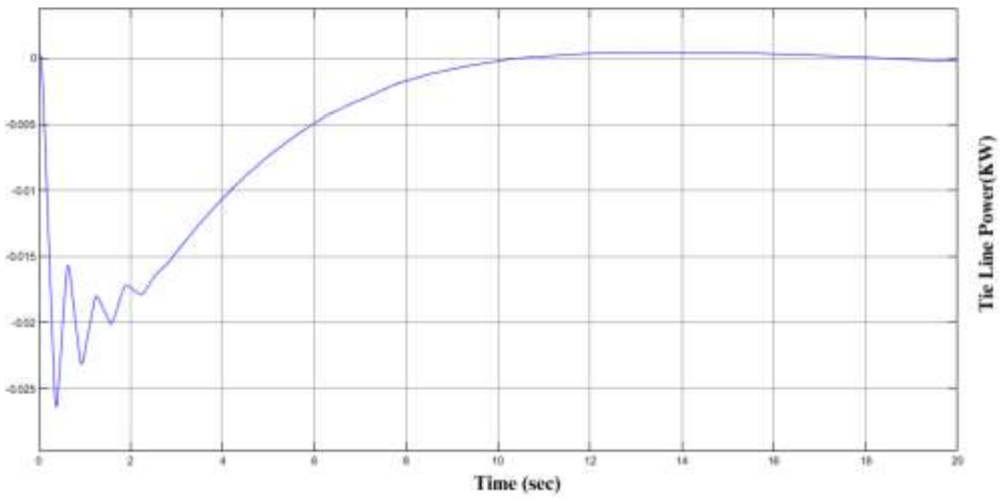

Figure 3. Results from PI controller

Case 2: Comparison of PID controller

The evaluation of tie line load power in the islanded microgrid system, employing the PID controller, presents a nuanced perspective on performance metrics. In comparison to the PI controller, the PID variant exhibits notable variations, showcasing improved handling of transient conditions. The analysis includes insights into maximum peak overshoots, undershoots, and settling time, emphasizing the PID controller's enhanced ability to fine-tune and optimize system response. These findings underscore the PID controller's efficacy in maintaining stability and responsiveness, suggesting potential advancements over the performance observed with the PI controller in the dynamic operational scenarios of the islanded microgrid.

Table 2 and Figure 4 provides performance metrics for the tie-line power control using a proportional-integral-derivative (PID) controller in a multi-islanded microgrid system. The recorded overshoot is 0.1, indicating the maximum extent to which the tie-line power initially exceeded its target value. The undershoot is -0.0039, reflecting a minor deviation below the target before stabilization. The settling time is 9.7 seconds, which is the duration required for the tie-line power to stabilize within a specified range around the target after a disturbance. These metrics demonstrate that the PID controller offers a more precise and quicker response compared to a PI controller, with significantly reduced undershoot and faster settling time.

Table 2. Values of tie line power obtained through PID controller

S.No	Overshoot	Undershoot	settling time
1.	0.1	-0.0039	9.7

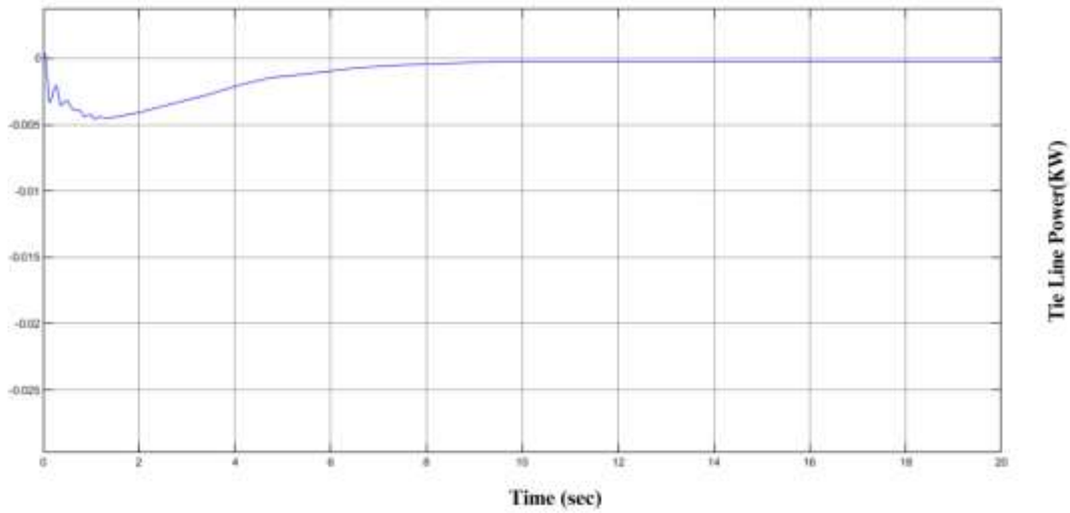

Figure 4. Results of PID controller

Case 3: Result analysedwith PIDF controller

Table 3 and Figure 5 Significant improvements in results have been achieved through the implementation of PID with feed-forward gain (PIDF) in the islanded microgrid system. The utilization of feed-forward gain introduces an additional layer of control, contributing to enhanced system performance. The positive outcomes are visually represented in the accompanying figure, illustrating the effectiveness of PIDF in regulating tie line load power. This advanced control configuration, integrating both PID elements and feed-forward gain, demonstrates superior capabilities in addressing transient conditions and optimizing overall system response within the dynamic operational context of the islanded microgrid.

Table 3 presents the performance metrics for tie-line power control using a PIDF controller in a multi-islanded microgrid system. The data shows an overshoot of 0, indicating that the PIDF controller effectively prevents any initial power surge above the target value. The undershoot is recorded at -0.0045, a minimal deviation below the target before stabilization. The settling time is 8.001 seconds, marking the time required for the tie-line power to stabilize within an acceptable range around the target after a disturbance. These results highlight the PIDF controller's superior performance in achieving precise and rapid stabilization without overshooting, compared to both PI and PID controllers.

Table 3. Values of tie line power obtained through PIDF controller

S.No	Overshoot	Undershoot	Settling time
1.	0	-0.0045	8.001

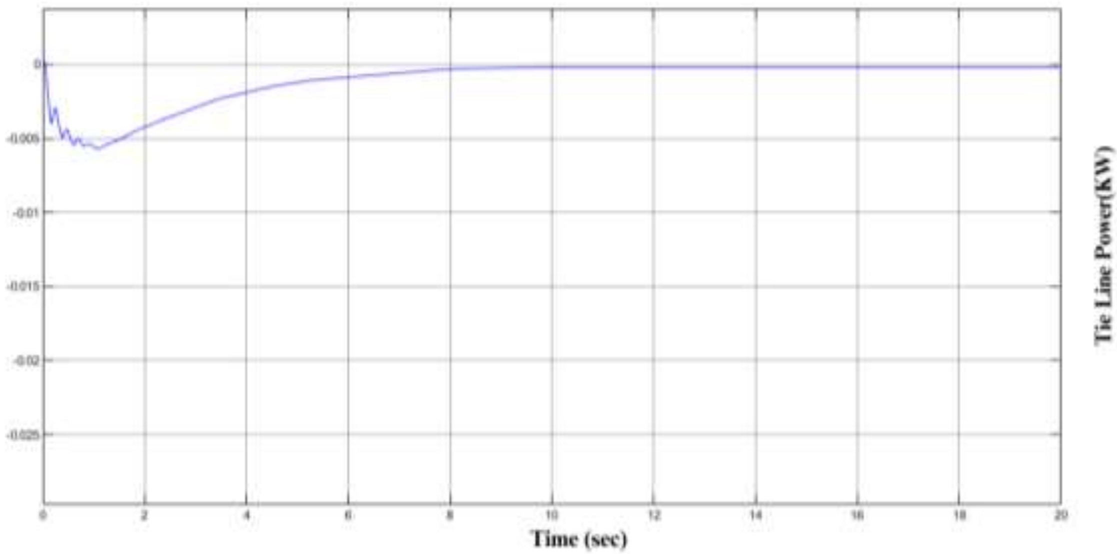

Figure 5. Results of PIDF controller

4. CONCLUSION

In conclusion, the study addressed the optimization of a hybrid system with solar, wind, batteries, and a diesel generator. Utilizing MPPT trackers and PI/PID controllers, gain levels were tuned to enhance system performance. Comparisons between PID and PIDF controllers were made for Tie Line Loading Power regulation. The results indicated that the PIDF controller outperformed, demonstrating superior stability and response compared to PID. The implementation of PSO algorithm for gain tuning proved effective, emphasizing its efficacy in optimizing the hybrid system

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