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Load Frequency Control in Two Area Interconnected Micro grid system using Hybrid PSO and Firefly Algorithm

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Abstract:

An effective meta-heuristic, population-based Hybrid Firefly Particle Swarm Optimisation (HFPSO) algorithm is employed in this paper to address for tuning classical PID controllers in a two-area interconnected microgrid system with renewable energy sources. HFPSO is a hybridisation of the Firefly algorithm Optimisation (FFO) and the Particle Swarm Optimisation (PSO) technique is employed to speed up the convergence rate and improve the exploration and exploitation strategies. The proposed hybrid PSO-FA algorithm combines the global exploration ability of PSO with the local exploitation strength of FA, ensuring improved convergence and robustness. Simulation studies are carried out on a two-area microgrid model developed in MATLAB/Simulink to analyse frequency deviations in both areas and tie-line power oscillations. The uniqueness of using Hybrid Firefly–PSO in frequency stabilisation is further highlighted by this work. The hybrid metaheuristic framework, in contrast to traditional techniques, successfully strikes a balance between exploration and exploitation, leading to fewer oscillations, better damping properties, and quicker system recovery.

Keywords — **Load Frequency Control (LFC), Hybrid Optimization, Firefly Algorithm (FA), Particle Swarm Optimization (PSO), HFPSO**

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I. INTRODUCTION

Frequency stabilisation has become a crucial issue as renewable energy sources are increasingly included into contemporary power grids, particularly in networked microgrid systems. Frequency robustness is very important, if the system frequency changes from the ideal values, it could lead to major problems or even a complete blackout of the system [1]. System stability is weakened by oscillations brought about by solar and wind power variability. In such systems, frequency management and power balance are guaranteed by load frequency control, or LFC. Additionally, the actual power is directly proportional to the frequency. Consequently, in order to maintain the frequency at its predetermined level, the total demand and loss power must be considered [2]. The power equilibrium, which is the equivalent of the generated power, should be achieved. increases beyond its designated value and conversely decreases when the demand for electricity exceeds the generated power. LFC consistently monitors the frequency and maintains it within the specified limits by balancing generation and requirement authorities [3]. LFC is becoming significant with the expansion of MAIPSs, especially because to the rising integration of wind energy, photovoltaic systems, electric vehicles, and storage devices [4]. Significant study examining the LFC issue considers the AGC regulator, factors influencing control performance, fluctuations in uncertainty, excitation controller, AC/DC gearbox linkages, and load characteristics. As the linked power system grows increasingly complicated, any variation in demand might propagate to many regions, potentially leading to a total blackout. Fuzzy logic control (FLC) [5], artificial neural networks (ANNs) [6], and genetic algorithms (GA) [7] have recently led to improvements. These ideas are an attempt to tackle the problems encountered difficulties when developing LFCs due to a lack of understanding of power systems and nonlinearity. The structure, energy sources, and storage mechanisms of power systems have seen substantial transformations in the past several decades. The introduction of new systems, such as renewable energy sources and superconducting magnetic energy storage (SMES), as well as the increased complexity and nonlinearity of current power systems, are examples of these shifts [8]. Frequency stabilisation has become a crucial issue as renewable energy sources are increasingly included into contemporary power grids, particularly in networked microgrid systems. System stability is weakened by oscillations brought about by solar and wind power variability. In such systems, frequency management and power balance are guaranteed by load frequency control, or LFC. As a result, the control procedures used to solve the LFC problem have been adjusted to take into account the changes in system parameters and their effects on overall stability. The performance of classical PID controllers is limited by its set parameters, despite their widespread use. For PID tuning, metaheuristic optimisation techniques like Harris Hawks Optimisation (HHO) [9], Firefly Algorithm (FA) [10], Genetic Algorithm (GA) [11], and Particle Swarm Optimisation (PSO) [12] have been used. However, single-algorithm methods frequently have problems like delayed exploration or premature convergence. Hybrid algorithms have been suggested as a solution [13]. In order to achieve optimal PID tuning in a two-area linked microgrid system, this paper presents a hybrid PSO+FA technique.

II. PROPOSED MICROGRID SYSTEM

Photovoltaic systems, tiny wind turbines, conventional thermal generators, and other renewable energy sources are all part of the two-area linked microgrid that is being explored in this study. In order to simulate real-world operational conditions, nonlinearity and stochastic disturbances are introduced into the model of tie-line dynamics. A MATLAB/Simulink-built two-area linked microgrid model is the test system under consideration. Renewable energy sources and conventional units are integrated in each location through a tie-line. Reducing tie-line power oscillations and regulating frequency variations in Area-1 and Area-2 are the control objectives. Since the system accounts for both load disruptions and the unpredictability of renewable energy, it serves as an excellent test bed for cutting-edge control solutions.

Ship diesel generators (SDGs) are a common auxiliary power source in maritime microgrids [14,15]. These generators have a reputation for being effective, requiring little upkeep, and minimising unstable oscillations. The current state of electric cars may be described in three ways: regulated, charging, and operating. Controllable EVs' high output and energy capacity restrict their charging and discharging capabilities [16], [17], and [18]. Energy-efficient microgrid systems are the subject of this study. These technologies include small-scale diesel generators [19], fuel cells, and aqua-electrolysers [20, 21]. These systems have the advantages of rapid starting, increased dependability, and improved energy efficiency. An environmentally benign and sustainable energy source, biodiesel-fueled generators, wind turbines, and biogas plants use energy storage [22] technologies such batteries and photovoltaic systems to balance out power fluctuations. A schematic block architecture for the suggested networked microgrid system is shown in Figure 1.

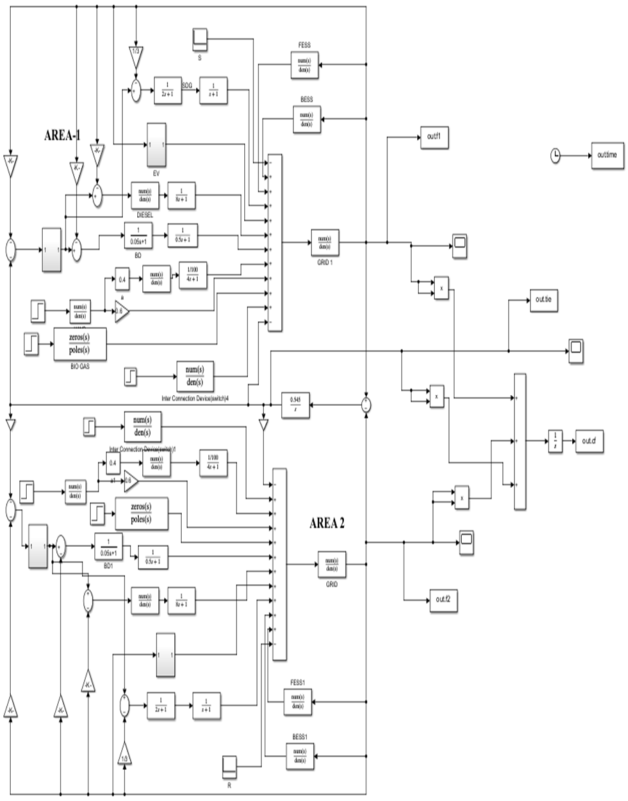

Fig.1.Micro Grid System with Two Interconnected Areas in MATLAB Simulink

III. HYBRID PSO AND FIREFLY ALGORITHM

The hybrid algorithm that has been suggested combines the benefits of FA and PSO. The global search procedure is guided by PSO, which guarantees a diverse exploration of the solution space. FA refines prospective regions by utilising local optima through attractiveness-based movements. Ibrahim Berkan Aydileksit created the hybrid firefly and particle swarm optimisation [23]. To maximise firefly and particle strengths, a balance is maintained between exploration (local optima) and exploitation (global optima) swarm methods [24][25] are present. In the firefly algorithm, there are words for both new velocity (V) and personal best location (pbest). When it comes to exploration, the PSO approach provides quick convergence in a global search. In addition, the firefly method is useful for small region searches since it provides excellent exploitation.

$$f(j,t) = \{\text{true, jfitness-value } (\text{particle}_j^t \leq g\ \text{best}^{t-1}), \{\text{false,jfitness-value}(\text{particle}_j^t \leq \text{gbest}^{t-1}) \ldots\ldots(1)$$

Input parameters are provided, population-based techniques are employed, constant swarm vectors are initialised, global best and individual best swarms are mathematically evaluated and assigned, and new velocity and position are computed.

IV. RESULTS

The The evolution of the optimal cost across iterations for population sizes of 10 and 20 is depicted by the convergence curve (Figure 2). The hybrid method converges quickly in both circumstances, as seen by the cost significantly decreasing in the first 5–10 rounds. Approximately 20 iterations later, the algorithm stabilises near the global optimum. In comparison to a lesser population size (10), a larger population size (20) offers smoother convergence and marginally higher ultimate accuracy. This illustrates how exploration (PSO) and exploitation (FA) are robustly balanced in HFPSO.

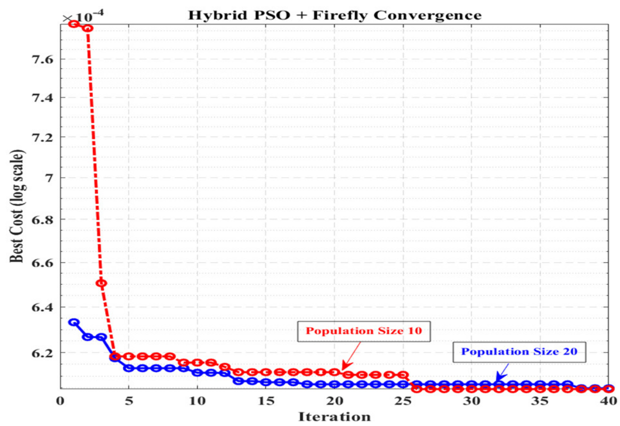

Fig.2. Convergence of Hybrid PSO and Firefly algorithms with different sizes and 40 iterations

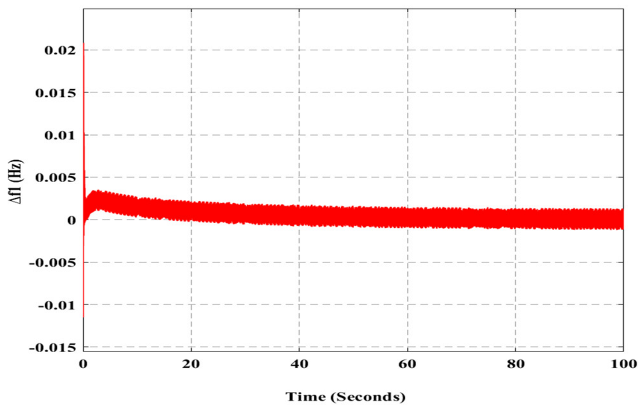

Fig.3. Frequency Deviation in Area 1 for step natured disturbance

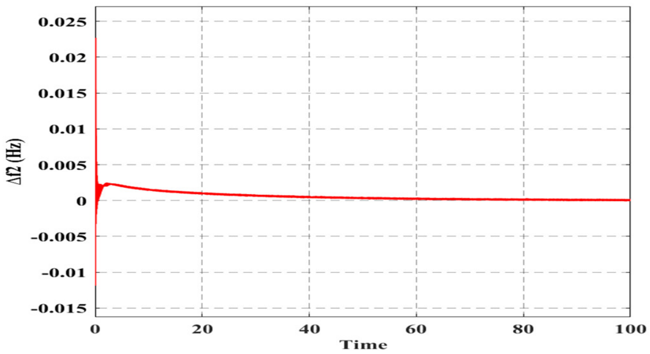

Fig.4. Frequency Deviation in Area 2 for step natured disturbance

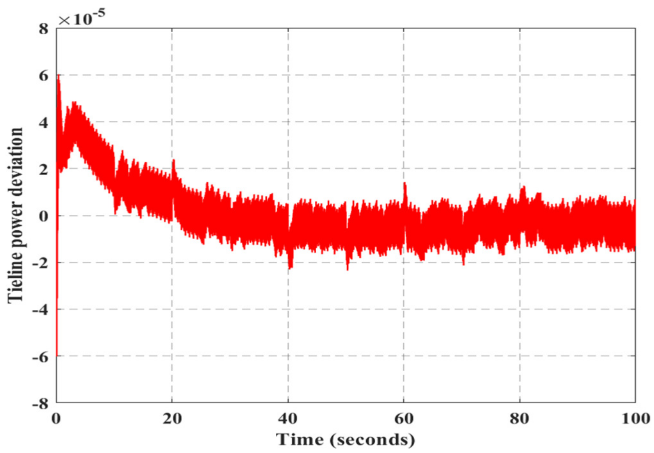

Fig.5. Tie-line Deviation for step natured disturbance

Area-1's frequency response exhibits a slight overshoot (<0.005 Hz), with oscillations settling in around 20 seconds, guaranteeing strong stabilisation. The reaction is significantly smoother in Area-2, with a settling time of around 15 seconds and an overshoot of less than 0.004 Hz, demonstrating the two regions' coordinated management. After peaking at about 6×10^{-5} pu, the tie-line power deviation is adequately damped in 30 seconds, stabilising the inter-area power flow. All of these findings support the idea that the HFPSO-tuned PID controller minimises overshoot, shortens settling time, and offers steady, dependable performance even when renewable energy fluctuates.

V. CONCLUSIONS

In two-area linked microgrids with renewable integration, this research effectively utilises a Hybrid Firefly-PSO (HFPSO) algorithm for PID tuning. The frequency stabilisation and oscillation reduction capabilities of HFPSO are validated by the simulation results. Fast and robust convergence is ensured by the method, which reaches global optimums within 20 iterations. Both regions exhibit short stabilisation periods (<20 s) and very little overshoot (<0.005 Hz) in frequency deviations. Oscillations in tie-line power are significantly dampened and settle into a steady state after thirty seconds. Adding support for demand response, electric vehicle integration, and multi-objective frameworks to HFPSO is a goal of future research.

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