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RESEARCH ARTICLE OPEN ACCESS

IMPLEMENTATION OF ENHANCED MICROGRID USING MAYFLY ALGORITHM BASED PID CONTROLLER

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ABSTRACT

Micro grids, comprised of distributed generation units, are designed to function independently of the main grid. To ensure stable operation in isolated mode, precise control of system is essential. Common challenges faced by standalone microgrids include maintaining stability of the system with balancing the load and generation from renewable energy sources and preventing fluctuations. Primary objective of paper to develop and execute an auxiliary controller capable of regulating system within a networked microgrid environment. Intermittent nature of renewable energy sources can lead to fluctuations in system frequency and power flow variations in tie line. To mitigate these challenges and balance the nonlinear output from renewable sources, Mayfly Algorithm (MA)-optimized Proportional-Integral-Derivative (PID) controller is proposed and implemented. Validation results demonstrate that the proposed MA-PID controller effectively regulates system in response to varying load demands and renewable energy sources.

I. INTRODUCTION

Generation of renewable energy through distributed energy resources (DERs) of solar panels (PV) and wind turbines (WT) is crucial for environmental sustainability. Micro grids (MGs), powered by these alternative energy sources, have emerged as efficient, controllable, and easily integrable energy systems. Small community networks, or MGs, have gained a lot of interest recently because of their benefits, which include lowering transmission line power losses, optimizing RES utilization, and giving customers dependable electricity.

PV arrays, WTs, DC/AC inverters, in power systems may function in independent or grid-connected modes are examples of typical MGs. Energy Storage Systems (ESSs) are crucial for addressing fluctuations in wind energy and solar power, maintaining power and energy balance, and enhancing power quality. To handle rapid power variations and provide micro grid autonomy, ESSs require high power and energy density. Therefore, combining multiple storage technologies into Hybrid Energy Storage Systems is essential.

The ideal dimensions of the ESS for a specific application are crucial for ensuring the dependable, effective, and cost-efficient functioning of a microgrid. After determining the battery size, it is crucial to manage its energy levels effectively to guarantee the stable and safe functioning of the microgrid. [1] introduces an innovative expert fuzzy system that utilizes grey wolf optimization (GWO) to develop an effective meta-heuristic approach for battery pack design and control of energy. The operation and control of energy under consideration is executed using GWO, which assists in establishing membership functions and generating the rules for expert system.

The smooth and efficient operation of the current network, frequency and voltage regulation, and the management of the energy sources currently in use all depend on MGs. Depending on the weather and surrounding circumstances, MGs—which may function both independently of the grid and in connection with the main grid-have shown effective in mitigating the negative consequences of intermittent energy generation [2].

A comprehensive overview of the literature on control features in AC, DC and hybrid micro grids is included [3]. Numerous studies have been conducted on different micro grids. Using a coefficient diagram technique (CDM) for proportional integral derivative acceleration (PIDA)controller design built for load frequency control (LFC) of an isolated microgrid (IMG) system's frequency stability was investigated [4]. Accelerator PID controller was used, and its achievement was correlated with 2DoF-PID controllers.

Micro grids are tiny power networks that combine dispersed generation with local loads. These devices are often linked to the global network but can be disconnected during major disruptions. They may feed delicate loads. Uncertainties in real power systems include changes in load Micro-grid inverters are being developed to ensure steady voltage and frequency even when there are drastically fluctuating demands. Stability and power quality are maintained by microgrid's freestanding operation, which guarantees steady functioning even during network outages.

Research is being done on how distributed generators (DGs) that are connected to distribution networks behave [5], flaws in system modelling and changes in the structure. The Load Frequency Control problem cannot be resolved using classical controllers with continuous interest. The dependability and frequency stability of the electric power system of the future depend heavily on demand response (DR). To maximize the coefficients proposed cascade fractional order two-degree-of-freedom controller, a quasi-oppositional Harris Hawks Optimization is developed [6].

To overcome these limitations, a versatile controller is necessary. PID controllers have been widely adopted, for first time, a proportional-integral-derivative-filter controller based on colliding bodies optimization algorithm is designed for load frequency control (LFC) of hybrid power systems [7]. The controller's performance is evaluated at its nominal operating points. Traditional methods are used to determine these operating points. While numerous studies have explored various micro grid configurations with hybrid energy sources, the integration of DFIG's within microgrids has received less attention.

This paper introduces a novel micro grid topology powered by wind turbines using doubly fed induction generators and photovoltaic (PV) sources. The key advantage of this design simplified connection to both alternating current (AC) and direct current (DC) grids, eliminating the need for AC/DC and DC/DC converters. This configuration optimizes power control, enhances power quality of both AC and DC grids, regulates voltage and frequency, ensures uninterrupted power supply, and provides local reactive power compensation.

Moreover, a multi-source microgrid offers greater flexibility in power management between the microgrid and the main grid. The paper presents simulation results demonstrating effectiveness of proposed control algorithm under various challenging scenarios, including changes in power demand, random fluctuations, and sudden weather events. This article is structured as follows. Section 2 Micro grid Modelling. Methodology of design of PID controller and May fly algorithm are explained in Section 3. Description of proposed system is section 4 and simulation results is given in 5 Section and finally conclusion is provided.

II. MICRO GRID MODELLING

Although expanding transmission and distribution networks can enhance grid reliability and stability, it can also have drawbacks. These include inefficient electricity transmission to remote and inaccessible locations, higher energy losses during transmission and distribution and increased complexity in safeguarding network due to its wider reach. In response to these issues, distributed generation (DG) has become increasingly popular. DG involves generating electricity at the point of consumption, reducing the need for long-distance transmission. Microgrids are self-contained power systems that incorporate distributed generation (DG) and local loads [8]. These grids can function autonomously or be connected to the larger electrical grid. Figure 1 depicts the overall configuration of a micro grid.

Micro grids can incorporate a variety of renewable and conventional energy sources, including photovoltaic generators, wind turbine generators and battery energy storage systems. These micro resources are interconnected with main grid at point of common coupling (PCC) and communicate using electronic devices. Microgrids often utilize both AC and DC components for power conversion and control [9].

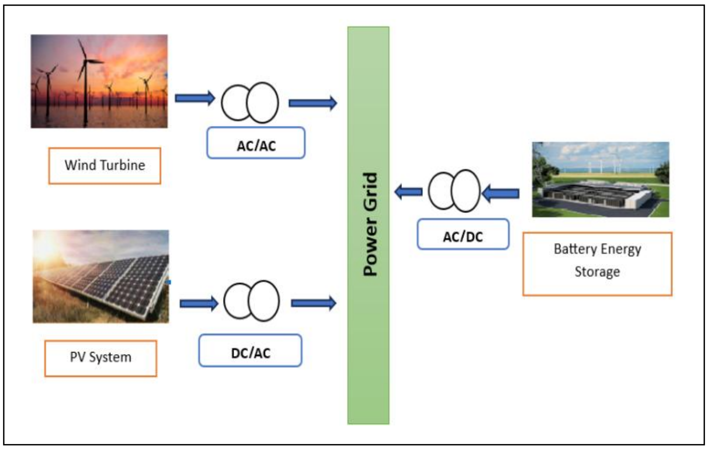

Figure 1: Micro grid structure.
Source: Authors, (2025).

III. METHODOLOGY

III. 1. PID CONTROLLER DESIGN

Effectiveness of proportional integral derivative (PID) controller is determined with its proportional gain (K_p), integral gain (K_i) and derivative gain (K_d). These gains affect controller's response to errors. Figure 2 illustrates a closed-loop control system for regulating DC microgrid voltage using a PID controller. The error signal, which is difference between voltage measured (V_o) and desired voltage (V_d), is amplified by controller. Controller then generates a PWM signal that adjusts power sharing among AC-DC converters in DC micro grid to minimize error [10]. Magnitude and direction of error signal directly correlate discrepancy between V_o and V_d.

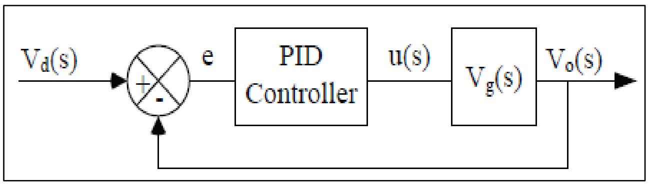

Figure 2: PID Controller.
Source: Authors, (2025).

Output of PID controller is expressed as

$$u(s) = k_p e(s) + k_i \frac{1}{s} e(s) + k_d s e(s) \tag{1}$$

and transfer function is expressed as:

$$G(s) = \frac{u(s)}{e(s)} = k_p + k_i \frac{1}{s} + k_d s \tag{2}$$

Where

$$e(s) = |v_d - v_g| \quad \text{or } e(s) = |v_d - v_o| \tag{3}$$

Increasing K_p can lower rising time but will not remove steady-state inaccuracy. While raising K_i can minimise steady-state error, it may degrade transient responsiveness. On other hand, boosting K_d can increase system stability, minimise overshoot, while improving transient responsiveness.

III. 2. MAYFLY ALGORITHM

Mayflies, an ancient insect group dating back to the Ephemeroptera order, are especially prominent in the UK during May, hence their name. Mayfly algorithm was inspired by behaviors of adult mayflies, including crossover, swarming,mutation, mating rituals and random movement. Initially, randomly generated populations of male and female mayflies are established. In second phase, male flies' velocities are updated, and they are ranked based on their speed. The highest-ranking males then mate with female flies [11]. This algorithm is also used to adjust gain values. Figure 3 depicts MA's functional flow chart.

Male Mayfly Movement

Male mayflies' movements are influenced by the positions of themselves and their neighboring males. location change is computed by adding velocity v^{t+1}, is expressed in Equ (4) and (5)

$$x_i^{t+1}=x_i^t + v_i^{t+1} \tag{4}$$

Speed of male mayfly

$$v_{ij}^{t+1} = v_{ij}^t + a_1 e_p^{\beta r^2}(P\, best_{ij} - x_{ij}^t) + a_1 e_p^{\beta r^2}(g\, best - x_{ij}^t) \tag{5}$$

Where

v_i^{t+1}= Velocity of Mayfly (ith at time t).
ij = Search space dimension.
x_i^t =Fly position at time t.
$a1$, $a2$ = Coefficients of collective effects.
$P\ best_{ij}$ = best local value.
$g\ best_i$ = Mayfly best location.

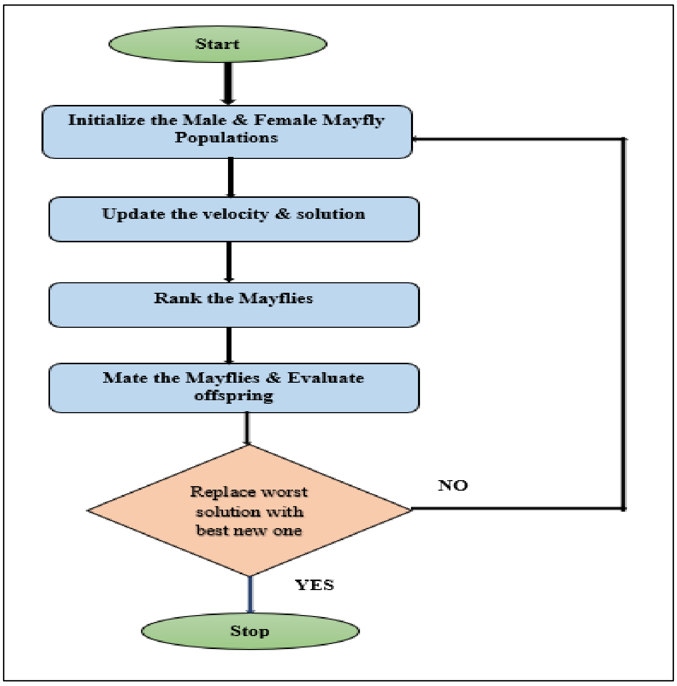

Figure 3: Flowchart of MA.
Source: Authors, (2025).

Leading mayflies in team continuously modify their speed to enhance overall performance. Equation (6) presents updated velocity formula. Dance coefficients 'd' and 'r' are random numbers within range of -1 to 1.

$$v_{ij}^{t+1}=v_{ij}^t + d + r \tag{6}$$

Female Mayfly Movement

Female mayflies increase their speed to update their positions, and y_{t+1} represents the position of i^{th} mayfly at time t.

$$y_i^{t+1} = y_i^t + v_i^{t+1} \tag{7}$$

Attraction occurs randomly, beginning with first-ranked female being drawn to best male. leftover flies are enticed based on their aptness. For depreciation problems, velocity is calculated using following formula, where r_{mf} represents the distance between male and female flies.

$$v_{ij}^{t+1}=\left\{v_{ij}^t + a_2 e^{-\beta r_{mf}^2}(x_{ij}^t - y_{ij}^t)\right\} \quad \text{if } f(y_i) > f(x_i) \tag{8}$$

Many common optimization methods focus on locating points where the derivative is zero. To tackle nonlinear problems, additional variables are often introduced, widening the search area. Numerical techniques can become trapped in suboptimal solutions, hindering their ability to discover the optimal global solution. To overcome these challenges, metaheuristic algorithms are gaining popularity for complex optimization tasks. The Mayfly algorithm is adaptable, suitable for both persistent and distinct problems, and less prone to becoming stuck in local optima [12].

The research proposes using the Mayfly Algorithm (MA) to enhance secondary controller criterion, including K_p, K_i, and K_d. The primary benefits of Mayfly Algorithm are:
Quick convergence with a high convergence rate.
Mating rituals and erratic flight facilitate an equilibrium between exploitation and exploration.

IV. EXPLANATION OF PROPOSED MICRO-GRID

Suggested hybrid energy system incorporates variable-speed wind turbine with a doubly fed induction generator, photovoltaic array, battery, fuel cell, and an additional battery. Wind and solar energy sources are supervised using maximum power point tracking (MPPT) algorithms and connected to a shared DC bus. For wind turbines,

MPPT is implemented at speeds below the nominal value. Above nominal speed, pitch angle control is used to maximize power output. The battery functions as storage device and is connected to DC bus through a bidirectional DC/DC Buck-Boost converter. Wind and solar power generation are subject to weather conditions, and solar power is absent during nighttime.

Photovoltaic Cell

To achieve maximum power output from a photovoltaic (PV) array, it must be operated at optimal power point. An MPPT device, which is high-frequency boost DC-DC converter, is positioned within PV array and DC bus. This device adjusts DC input from PV array, modifying voltage and current to ensure array is properly aligned with DC bus.

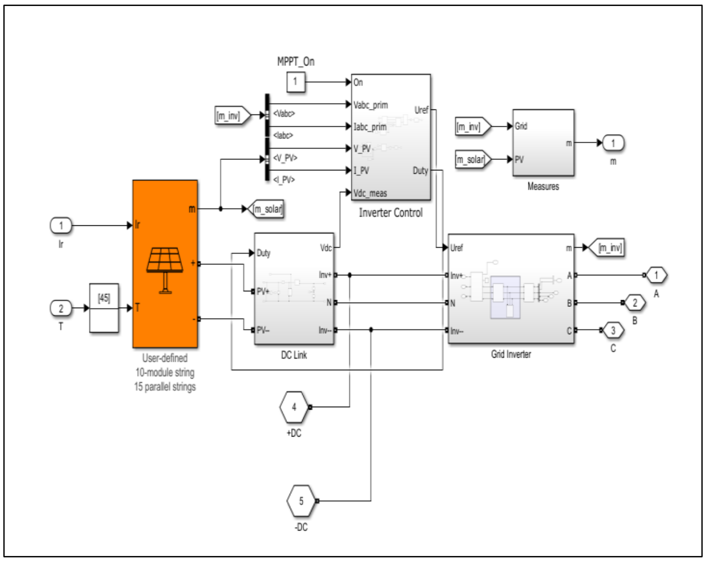

Figure 4: Modeling of PV with irradiance and temperature.
Source: Authors, (2025).

A. Wind Energy Conversion

Figure 4 demonstrates a direct relationship between output power and irradiance from a PV module. Lower irradiance levels govern to reduced power output. However, output current is primarily affected by irradiance, as it may be proportional to photon flux. The MPPT results indicate that has 15 parallel strings, each comprising 10 modules connected in parallel.

In Figure 5 modelling of wind turbine with converters is shown which has wound rotor induction generator, wind turbine control and drive train. The following formula provides the aerodynamic power at the turbine's rotor for wind energy conversion systems:

$$P_{wind} = \frac{1}{2} \rho A V^3 c_p(\lambda, \theta) \quad (9)$$

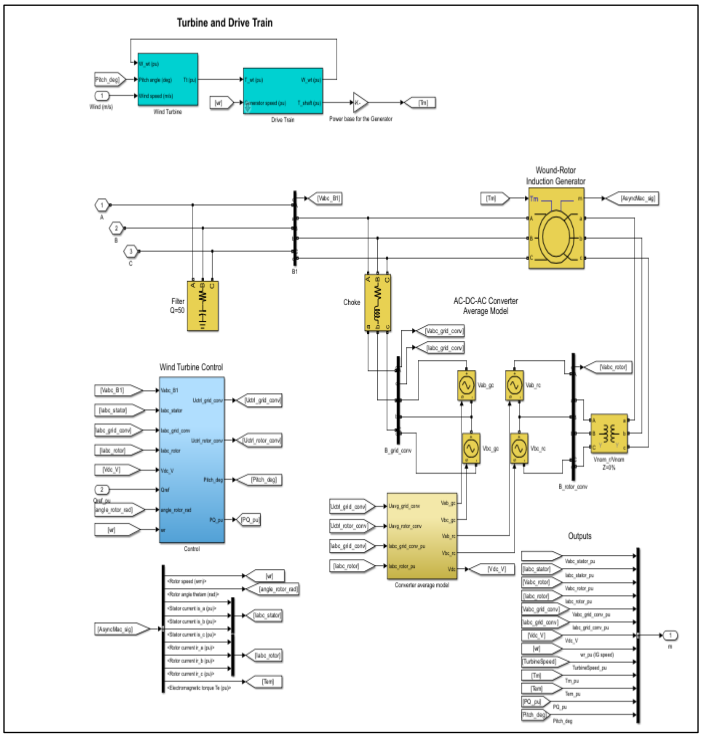

Figure 5: Modeling of PV with irradiance and temperature.
Source: Authors, (2025).

The pertinent variables are represented by the variables p (air density in kilogrammes per cubic metre), A (area swept by the rotor blades in square meters), and v (wind velocity in meters per second). The power coefficient (sometimes called rotor efficiency or Cp) is based on the tip speed ratio (Α) and pitch angle (θ).

B. Battery

The voltage-current (V-I) characteristics of battery model in this study indicate that higher operating temperatures govern to lower terminal voltages for a given current. Initially, excess energy is stored in battery until it reaches full charge.

Afterward, additional power is managed by a buck DC/DC converter. Control actions are triggered by comparing the battery's maximum state of charge (SOC) with its current SOC. When the SOC surpasses 80%, the controller adjusts by increasing the duty cycle to manage the elevated DC bus voltage.

V. SIMULATION RESULT AND DISCUSSION

A simulation test for suggested WT-DFIGs/PV/Battery energy system has been constructed in MATLAB/Simulink utilising component models, with parameters for WT-DFIGs and PV described in the preceding section.

To analyze system performance under various situations, simulations were done utilizing changing load data and variations in weather inputs, such as wind speed, solar irradiation and temperature. Figure 6 below presents the proposed system model, and its performance has been verified.

From the above Figure 7 graph it indicates a stable battery voltage throughout the simulation. The current fluctuations, suggesting that the battery is actively charging and discharging. The power supplied to or drawn from the battery is directly related to the current flow. The SOC graph shows a gradual decrease, indicating that the battery is being discharged.

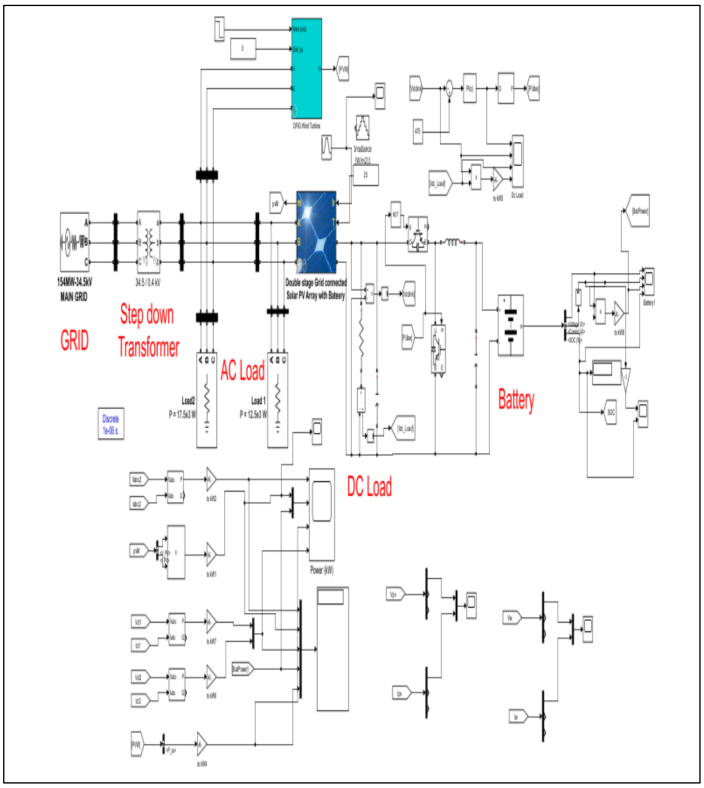

Figure 6: Simulink model of the proposed system.
Source: Authors, (2025).

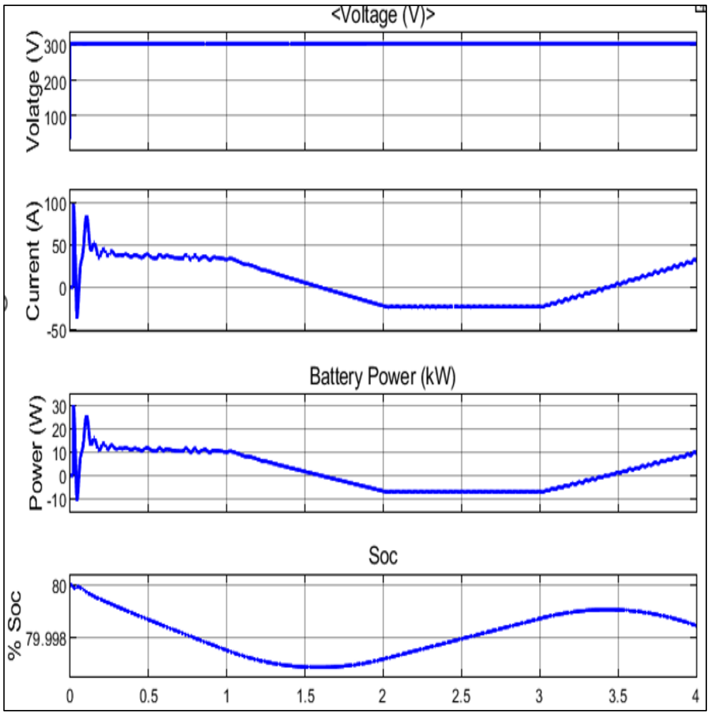

Figure 7: SOC, Current and Voltage of Battery.
Source: Authors, (2025).

From the Figure 8 it shows the DC load characteristics as it appears that the power converter is successfully supplying power to the DC load. The stable duty cycle and DC link voltage indicate that the converter's control system is functioning correctly. The increasing load current and power suggest that the load demand is growing.

From the Figure 9 graphs of power shows that the micro grid is operating effectively, with multiple sources contributing to the power supply. The initial grid power surge might be due to a sudden increase in load or a transient event. The rapid response of the solar PV, battery, and DFIG indicates that micro grid is well-equipped to handle dynamic load changes.

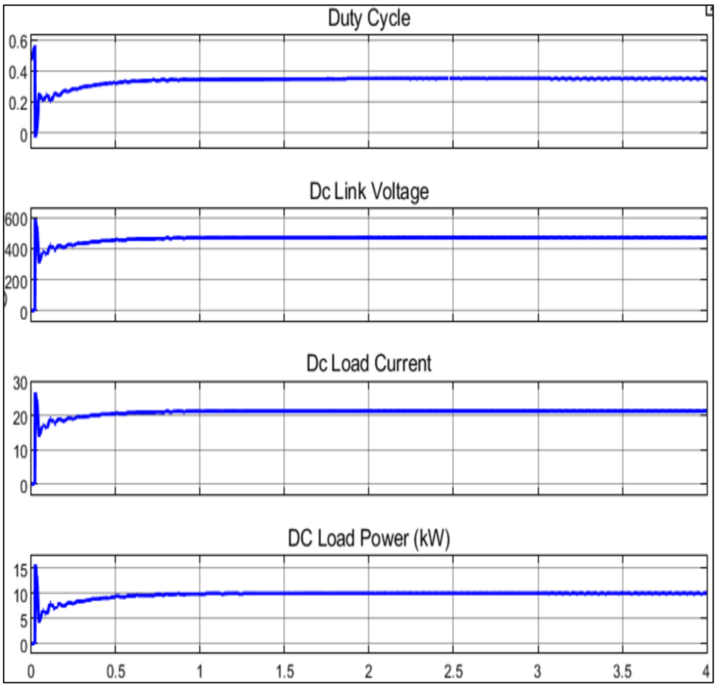

Figure 8: DC load characteristics.
Source: Authors, (2025).

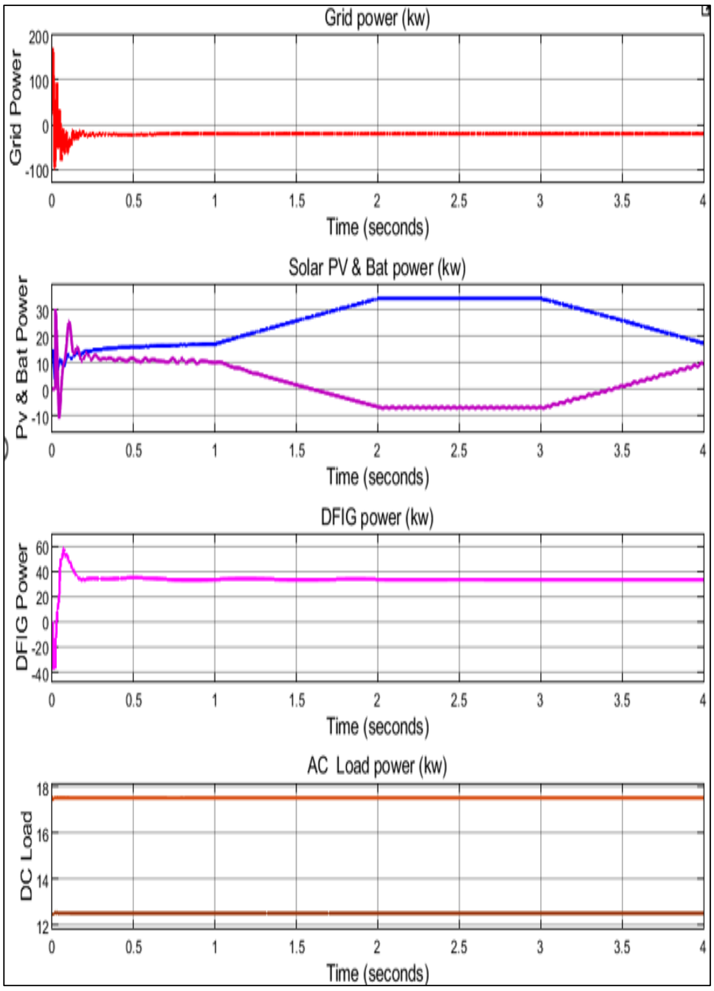

Figure 9: Power Characteristics.
Source: Authors, (2025).

From Figure 10 that the battery is initially subjected to a sudden charging demand. It then charges at a relatively constant rate until it reaches a certain SOC level. After that, the battery starts discharging, potentially due to a change in system conditions or a controlled discharge process

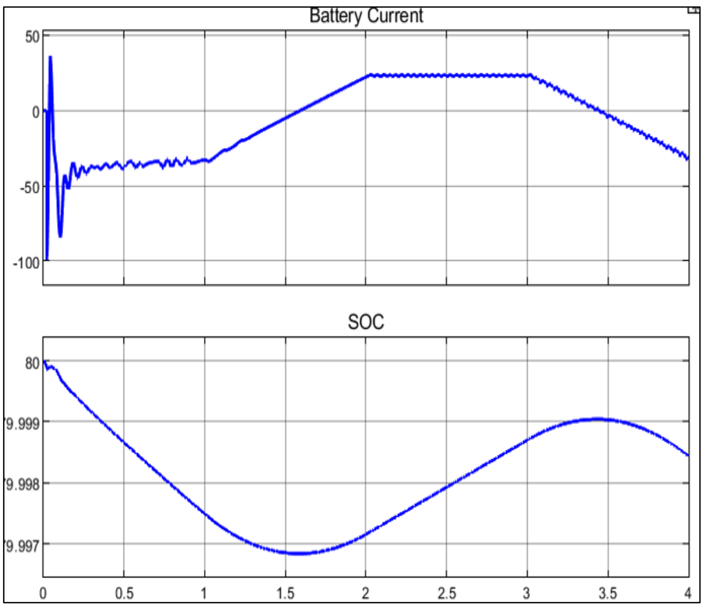

Figure 10: Battery current and SOC.
Source: Authors, (2025).

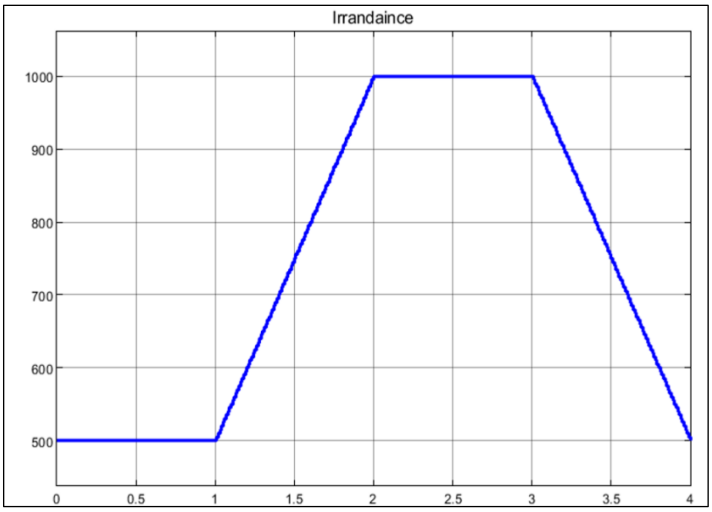

Figure 11: Solar irradaince
Source: Authors, (2025).

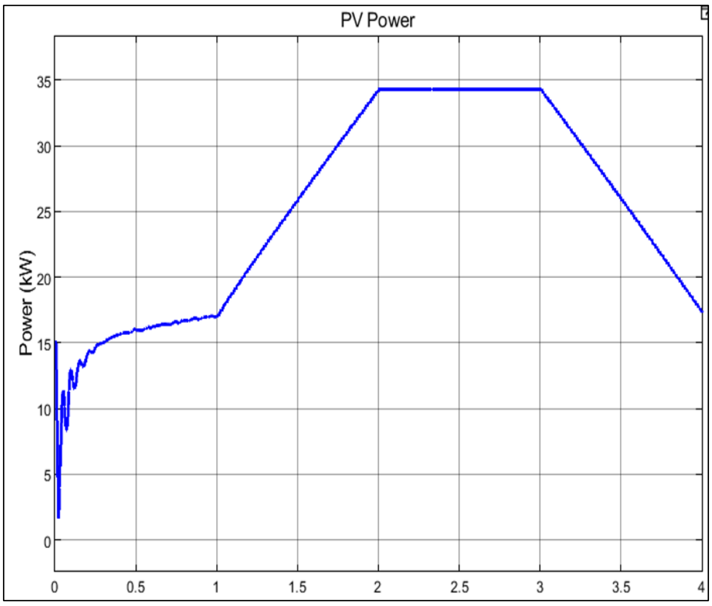

Figure 12: PV power
Source: Authors, (2025).

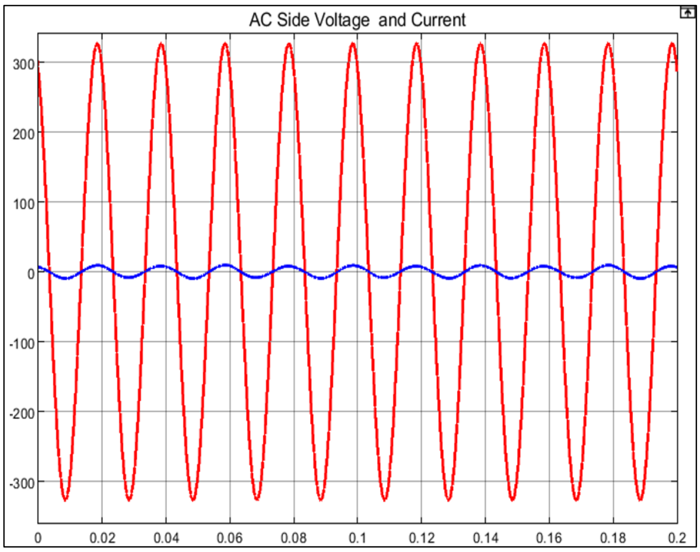

Figure 13: PV side AC voltage and current
Source: Authors, (2025).

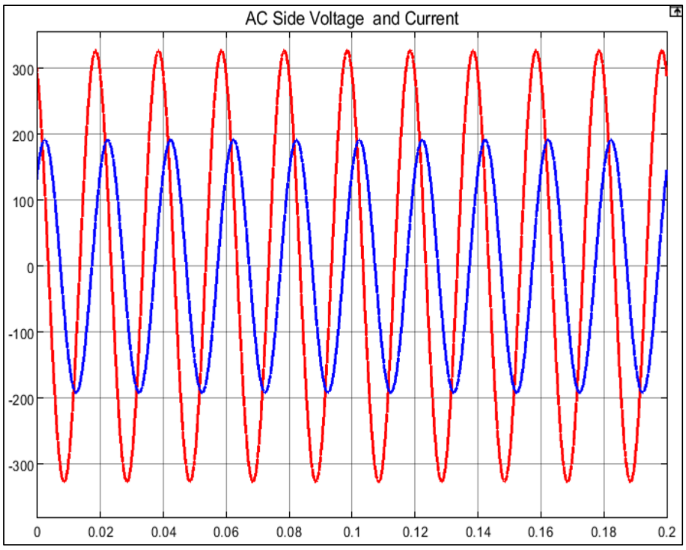

Figure 14: Wind side AC voltage and current
Source: Authors, (2025).

MA-PID controller demonstrated exceptional performance in all vital system scenarios, as illustrated in Figures 7-14. Based on this comprehensive performance analysis, proposed MA-PID controller is appropriate choice for micro grid power system.

The battery parameters used for the simulation are : the type of battery is lead acid battery with nominal voltage of 300 V and rated capacity of 400 Ah. The initial state of charge of battery is 80%. The output of solar array is 0.336x100 KW. The output of wind turbine is 1.5 MW at wind speed of 11 m/s. Two AC type loads and one DC load are used for the simulation. The power demand of one of the AC load is 17.5 KW and the other is of 12.5 KW. The power demand of DC load is 10 KW. The PID controller is fine tuned by using Mayfly Algorithm. The optimal P value is 0.001 and I value is 0.01.

VI. CONCLUSIONS

This research introduces a hybrid microgrid system enhanced by a Mayfly Algorithm-based PID controller to address the pressing challenges associated with renewable energy integration. The microgrid system, comprising wind turbines (WT), photovoltaic (PV) arrays, and hybrid energy storage systems (ESS), demonstrates an effective synergy for maintaining power balance and stability under fluctuating conditions. By leveraging the advantages of a hybrid configuration and advanced control algorithms, the study underscores the potential of microgrids in achieving sustainable and reliable energy systems. The implementation of the MA-PID controller addresses critical concerns such as frequency instability, power fluctuations, and the nonlinear nature of renewable energy output. The controller optimizes the proportional, integral, and derivative gains, ensuring rapid adaptation to changing system dynamics. Simulation results validate the proposed system's capability to maintain stable frequency, regulate voltage, and manage energy efficiently across various scenarios, including load variations and unpredictable weather conditions.

The MA-PID controller significantly improves system stability, minimizing overshoots and steady-state errors. Efficient power sharing among distributed energy resources (DERs) ensures maximum utilization of renewable sources. The modular design of the hybrid microgrid and adaptive control strategy make it applicable for standalone and grid-connected operations. The system effectively adapts to real-time changes, such as varying load demands and abrupt environmental shifts, while maintaining performance.

Despite the promising results, the study recognizes several areas for further research. Real-world implementation of the MA-PID controller would provide deeper insights into its operational reliability and scalability. Additionally, integrating more advanced energy management systems (EMS) and exploring other metaheuristic optimization techniques could enhance the microgrid's performance further. The proposed hybrid microgrid system not only addresses the current challenges of renewable energy integration but also provides a scalable blueprint for future energy systems. By focusing on efficient control mechanisms and robust system design, this study contributes to advancing the deployment of microgrids, thereby supporting global efforts toward a sustainable and resilient energy future.

VII. AUTHOR'S CONTRIBUTION

Conceptualization: M Murali and Dr A Hema Sekhar.
Methodology: M Murali and Dr A Hema Sekhar.
Investigation: M Murali and Dr A Hema Sekhar.
Discussion of results: M Murali and Dr A Hema Sekhar.
Writing – Original Draft: M Murali.
Writing – Review and Editing: M Murali.
Resources: Dr A Hema Sekhar.
Supervision: Dr A Hema Sekhar.
Approval of the final text: M Murali and Dr A Hema Sekhar

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