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A Novel Approach to Multi-Objective Control for Battery-Enabled Hybrid Micro Grid

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Abstract: In this study, we present a new technique for overcoming the operational difficulties faced by Microgrid (MG) systems, which are capable of functioning in both islanding and grid-connected states. As the expenses and requirements of traditional energy sources rise, there's been a growing focus on renewable energy alternatives. A key issue in the operation of MG systems is the efficient management of control to ensure the highest possible power output despite the variability in generation. To tackle this, we suggest a power-sharing strategy that is optimized for the components of Solar Photovoltaic (PV), wind, and Battery Energy Storage Systems (BESS). Our approach is environmentally sustainable, reducing pollution and greenhouse gas emissions, which in turn benefits the natural environment.

We formulate a multi-faceted objective function designed to enhance system efficiency while keeping costs to a minimum. By employing the Genetic Wolf Optimization (GWO) algorithm, we achieve outstanding outcomes in lowering the financial expenses associated with microgrid electricity production, surpassing traditional optimization techniques such as Particle Swarm Optimization (PSO) and Bacteria Foraging Optimization (BFO). Furthermore, we introduce a control framework that organizes the operation of each subsystem to ensure the stability of frequency in the face of unpredictable generation and demand. A comparative study validates the effectiveness of our approach, highlighting the GWO algorithm's advantage in optimizing microgrid performance.

Keywords: Renewable sources, CO2, AI, ML, FS-feature selection, Forecasting, RF, Linear SVM, DT, LR, MSE, MAE, MAPE, R2

I. INTRODUCTION

The surging demand for electricity has accelerated the adoption of alternative energy sources. While traditional power generation systems can operate independently or in conjunction with the main grid, their increasing costs and environmental concerns have driven the exploration of Distributed Generation (DG). Unlike centralized power plants, DG offers localized power production tailored to specific needs. These systems can operate autonomously or be integrated into the grid, facilitating the creation of microgrids (MGs) to reduce grid size.However, Renewable Energy-Based Systems (REBS), the cornerstone of many DG systems, face challenges due to their intermittent nature and the complexities of managing multiple DG units. Recent advancements in power electronics have enabled the seamless integration of various REBS into both standalone and grid-connected configurations. To ensure reliable and stable power supply, microgrids incorporate sophisticated control strategies. Countries with abundant solar resources, such as India, often combine solar and wind power to mitigate the challenges of intermittent generation. The use of droop control in microgrids is particularly recognized for its reliability and [missing information].

Solar power with wind energy systems to ensure a continuous power supply. The use of droop control in Microgrids (MGs) is commended for its reliability and the low need for communication, making it easy to add new units. However, the traditional droop control techniques, which take into account line impedance, voltage, and frequency, still struggle with stability issues. This paper introduces a new hierarchical droop control method aimed at ensuring power delivery and maintaining operational frequency across all Distributed Generation (DG) units, even in the face of changing demand. Each DG unit will use the Penguin Search Algorithm (PSA), a meta-heuristic optimization technique inspired by the cooperative hunting tactics of penguins. The PSA algorithm has shown superior performance compared to other methods like Particle Swarm Optimization (PSO) and Bacteria Foraging Optimization (BFO). The scheme is implemented in MATLAB and tested under various load conditions. The results demonstrate that the proposed hierarchical supervisory control is effective in delivering power, maintaining frequency, and achieving performance standards under different scenarios. This approach also supports economic goals, reduces carbon emissions, and minimizes the use of batteries, thereby extending battery life and reducing the overall cost of the system.

II. MICROGRID MODELING

This study focusses on analyzing a solar and wind battery system

A. Solar PV system

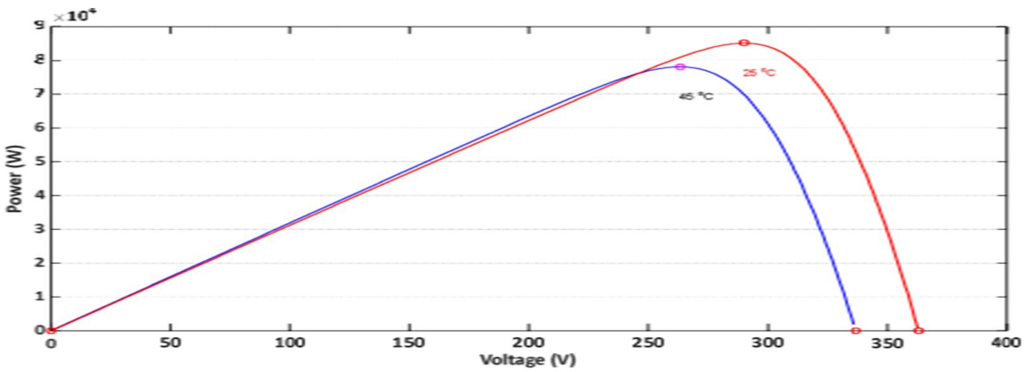

Fig. 1. Power vs. Voltage Characteristics of a Solar PV Module

In order to maximize energy generation, the solar photovoltaic (PV) panel uses the Perturb and Observe (P&O) method of the Maximum Power Point Tracking (MPPT) algorithm. The current model's comprehensive specs are given in

[10].

$$I_{pv} = 5_p I_{ph} - 5_p I_{rs} \left[\exp\left(\frac{q}{k\theta A}\frac{V^{PV}}{n_s}\right) - 1\right] \qquad (1)$$

$$I_{ph} = [I_{src} + k_{\theta}(\theta - \theta_r)] \frac{s}{100} \qquad (2)$$

B. Fuelcell

A Battery Energy Storage System (BESS) is integrated with fuel cells to enhance grid stability. The BESS stores excess energy during periods of high generation and discharges it back into the grid via a bidirectional converter when demand surges. The battery's State of Charge (SOC) is estimated based on its terminal voltage, as detailed in [11].

$$SOC(t) = SOC(t-1) + \frac{1}{3.6}\frac{1}{Size_B}\frac{P_B(t)}{V_{DC}(t)}\Delta(t) \quad (3)$$

PB(t) stands for the electrical power supplied, VDC is the voltage at the DC connection of the battery module, and SizeB represents the total energy stored in the battery in kilowatt-hours.

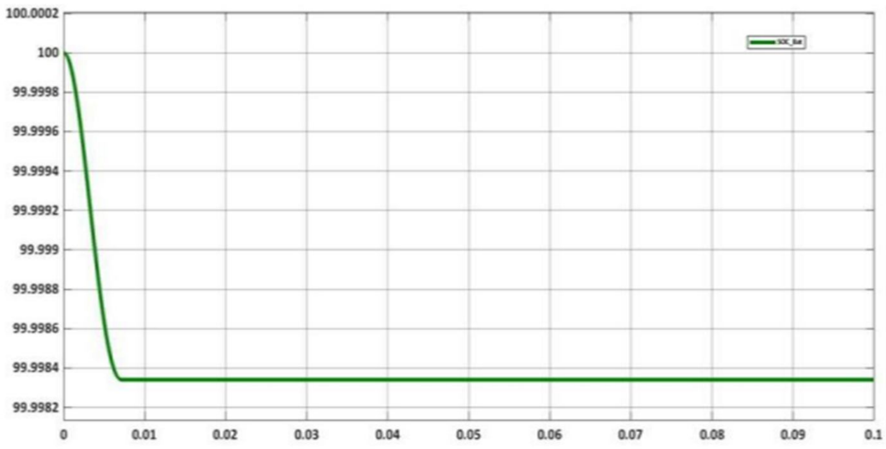

Fig. 2. Battery Charge Status

Within this setup, the wind turbine is linked to a Permanent Magnet Synchronous Generator (PMSG) to produce electrical energy. A Maximum Power Point Tracking (MPPT) algorithm is used to enhance the power yield from the wind by fine-tuning the system to operate at its peak performance. The electrical power collected by the wind turbine is as outlined in [12].

$$P_m = \frac{1}{2}\rho A C_P(\lambda) V^3 \quad (4)$$

Where,

$$\lambda = \frac{r_m \omega_r}{V_w} \quad (5)$$

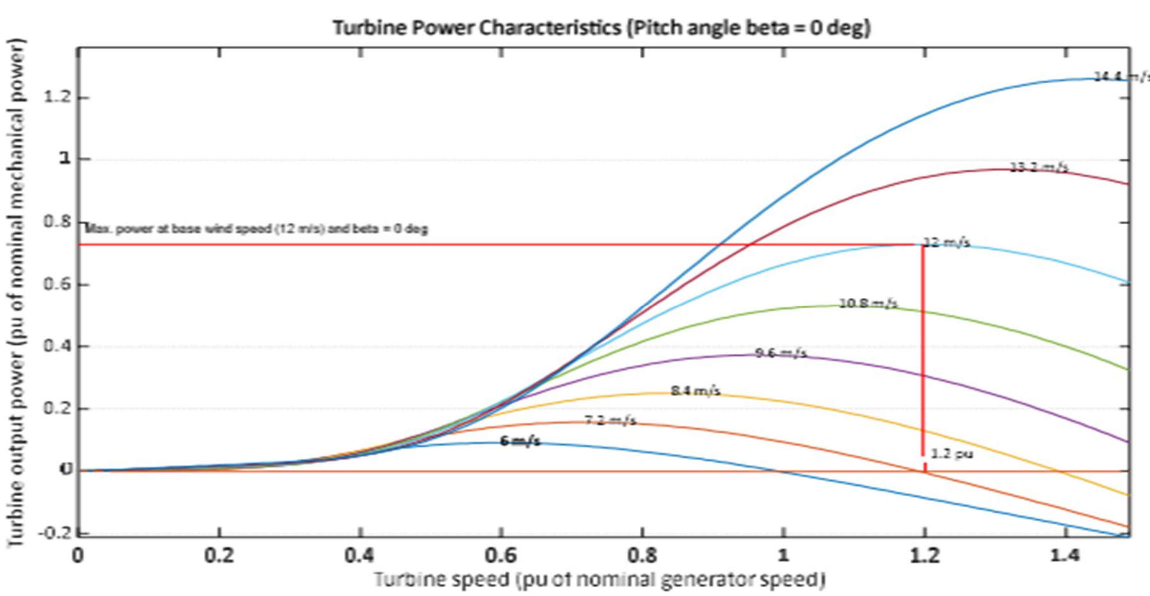

Fig 3. Wind Turbine Power Characteristics

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In a Permanent Magnet Synchronous Generator (PMSG), the voltage equation, following the application of Parks Transformation, is written as:

$$v_{gd} = (R_g + \rho L_d) i_q + \omega_c L_d i_d + \omega_c f_f \qquad (6)$$
$$v_{gq} = (R_g + \rho L_q) i_d - \omega_c L_q i_q \qquad (7)$$

Stator currents along the quadrature and direct axes are represented by the symbols i_q and i_d, respectively, and the stator resistance is indicated by the symbol Rg. L_d and L_q stand for the inductances connected to the generator's d- and q-axes. Mathematically, the resultant torque is expressed as follows:

$$T_e = \frac{3}{2} p (f_f i_q - (L_d - L_q) i_d i_q) \qquad (8)$$

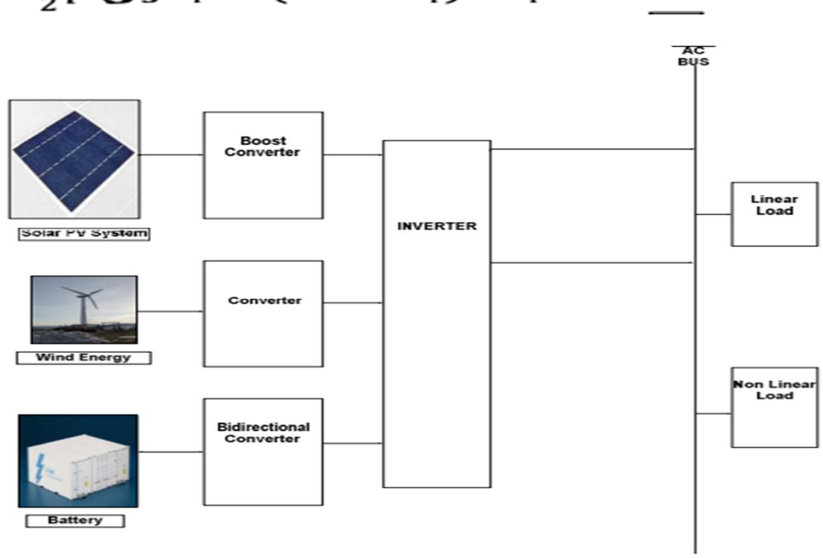

Fig 4. Proposed System Design

III. CONTROL STRUCTURE

We suggest a complex, hierarchical control system to maximize power distribution and reduce harmonics. The bidirectional converter in the battery and the boost converter in the photovoltaic (PV) system will work together under a master-slave control scheme.

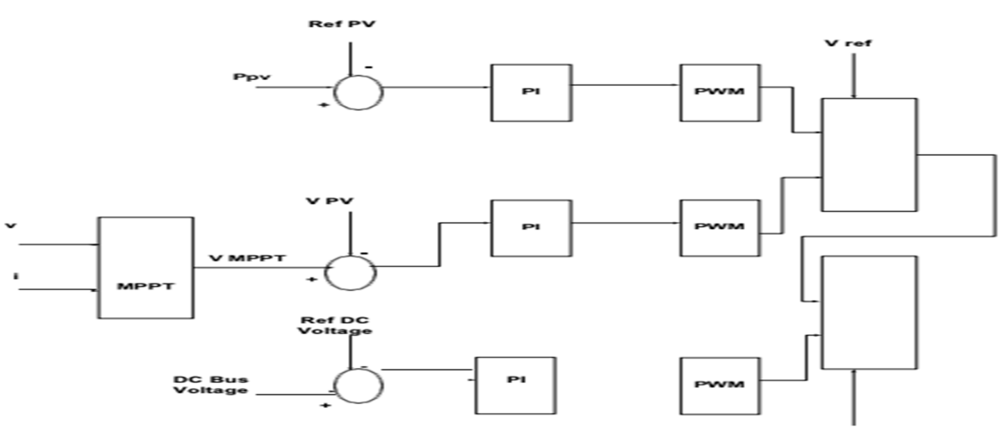

Fig 5. PV Array Controller

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A. Solar PV management

The Maximum Power Point Tracking (MPPT) technique is applied to maximize solar energy production all day long. The solar power system uses droop control to monitor the direct current (DC) level at the connecting point and modifies the voltage and frequency at this intersection. The process is shown in Figure 5.

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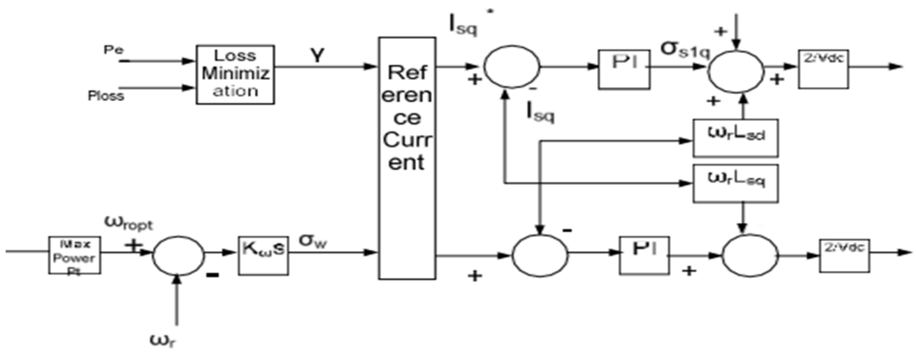
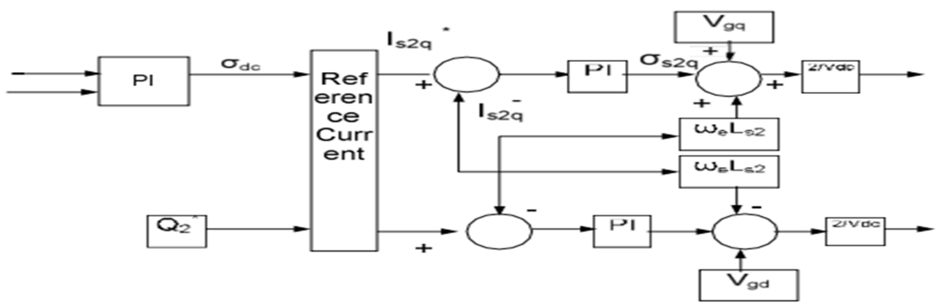
B. Wind energy management

An essential part of energy storage is the battery bank, which stores extra electricity to be released later on in times of high demand. Our goal is to minimize energy utilization in order to increase battery lifespan and hence lower total system expenses. For grid integration, the stored direct current (DC) is changed into alternating current (AC) using a three-phase inverter. A Phase-Locked Loop (PLL) creates a reference phase angle, θ, to guarantee smooth grid synchronization.



MACHINE SIDE CONVERTER CONTROL



GRID SIDE CONVERTER CONTROL

Fig. 6. Control Scheme of the Wind System

The control method for the wind energy system is shown in Figure 6, where two PI controllers are located on the machine-side converter. The machine's stator currents are under the control of each PI controller in the dq-frame; the superscript * denotes the input reference values for the PI controllers. The machine's stator currents in the dq-frame are represented by the stator currents, idsi_{ds}ids and iqsi_{qs}iqs.

$$R_s i_{ds} + L_s \frac{d i_{sd}}{dt} = K_{p1}(i^*_{ds} - i_{ds}) + K_{i1}\emptyset_1 \quad (9)$$

$$R_s i_{qs} + L_s \frac{d i_{qd}}{dt} = K_{p2}(i^*_{qs} - i_{qs}) + K_{i2}\emptyset_2 \quad (10)$$

Kp1, Kp2K_{p2}Kp2, Ki1K_{i1}Ki1, and Ki2K_{i2}Ki2 represent the gain ratios and integral gains of the PI controllers. φ1\varphi_1φ1 and φ2\varphi_2φ2 are the intermediate variables added by the PI controllers. The reference voltage is evaluated against the angle calculated from the Phase-Locked Loop (PLL), which produces the pulses for the Pulse Width Modulation (PWM) gate.

IV. ENERGY MANAGEMENT TECHNIQUE

A. Power Distribution Network Design

This section introduces a new technique to improve power distribution, as shown in Figure 7. The plan is to maximize the efficiency of power transfer from the solar energy system while lowering battery consumption. The system modifies to favor solar energy when sunlight is scarce, which lowers operating costs.

B. Multi-Objective PSA for cost optimization

A Particle Swarm Optimization (PSO) algorithm, inspired by the collective behavior of birds, is used to optimize a simplified model. PSO fits well with our objective of cost minimization because of its capacity to handle complex, nonlinear difficulties. This study is based on the Multi-Goal Penguin Search Algorithm (PSA).The primary objective of the optimization process is to configure Object Constraint Language (OCL) parameters using PSO. Impedances are geographically represented and affect bus numbers based on probabilistic considerations. PSO looks at potential bus locations and makes iterative adjustments to find the optimal impedance values, within predefined bounds, that are advantageous to all parties. The algorithm adjusts the impedance positions based on how well-performing previous solutions were.

$$D_{new} = D_{id} + rand(X_{Best} - X_{id}) \qquad (11)$$

Using the rand() method, a randomized search yields the ideal resistance value. The best local solution (Xbest), the global best solution (Xid), and a newly offered solution (Dnew) are the three solution alternatives that are taken into consideration. Equation (11) is used to iteratively update these values for every location in the space

$$\min(CostP_{Gi}) = \alpha_i P_{Gi}^2 + \beta_i P_{Gi} + \gamma_i \qquad (12)$$

The cost factors of each generator are represented by the variables αi\alpha_iαi, βi\beta_iβi, and γigamma_iγi, while the power generation of the iiith units is represented by PGiP_{G_i}PGi.

V. ALGORITHM

1) Develop a first collection of (I) potential solutions (DG) that are grouped together.
2) Establish the starting likelihood for the presence of each bus.
3) Continue until the total number of iterations equals the number of generations: Implement a random alteration.
4) Increase the power output by applying the given formula.
5) Modify the bus count based on the enhanced power output.
6) Calculate the fitness score for every potential solution.
7) Re-evaluate the power output and note the lowest cost.

8) Reallocate the cost probabilities based on the new data.
9) Revise the optimal solution using the present structure.

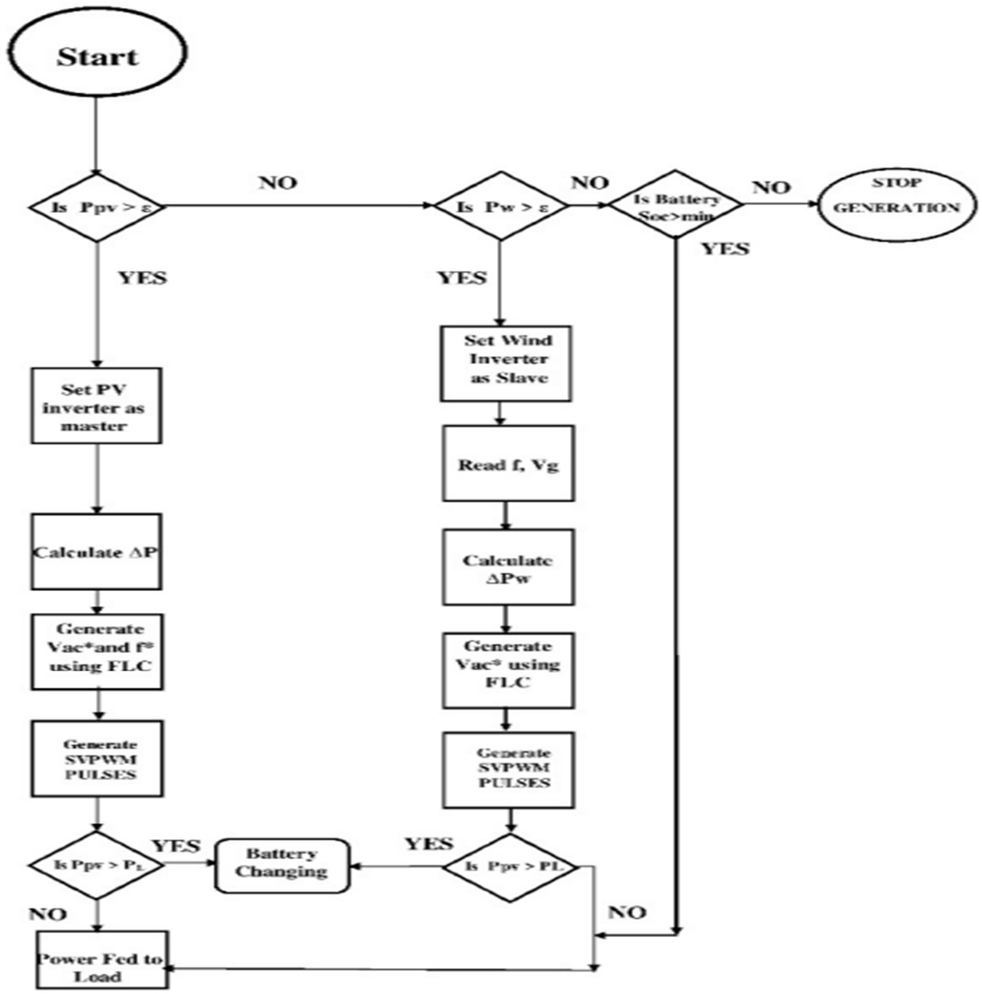


Fig. 7. Flowchart of the Energy Management Strategy

VI. RESULT & DISCUSSION

To generate power, a Permanent Magnet Synchronous Generator (PMSG) is linked right away to the wind turbine. A Maximum Power Point Tracking (MPPT) algorithm is implemented to maximize power extraction from the prevailing wind conditions and optimize system performance. A detailed explanation of the properties of the wind turbine for power production can be found in reference [12].Table I

Table shows comparative analysis of output.

Algorithm	Run Time	Final Cost
Without Optimization	10.45	1120,456
PSO	12.38	1108.84
BFO	14.82	1107.65

PSA	10.38	1106.94
GWO	11.47	1104.82

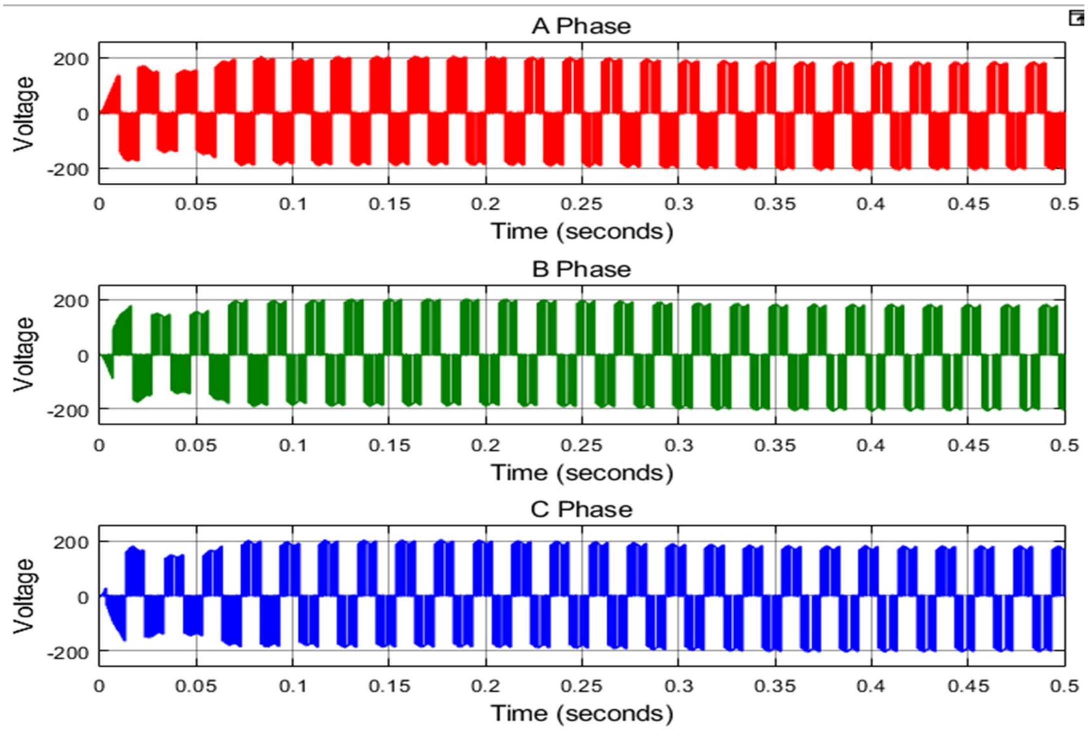


Fig.8 Line voltage of PWM in performance of controllers and inverter outputs

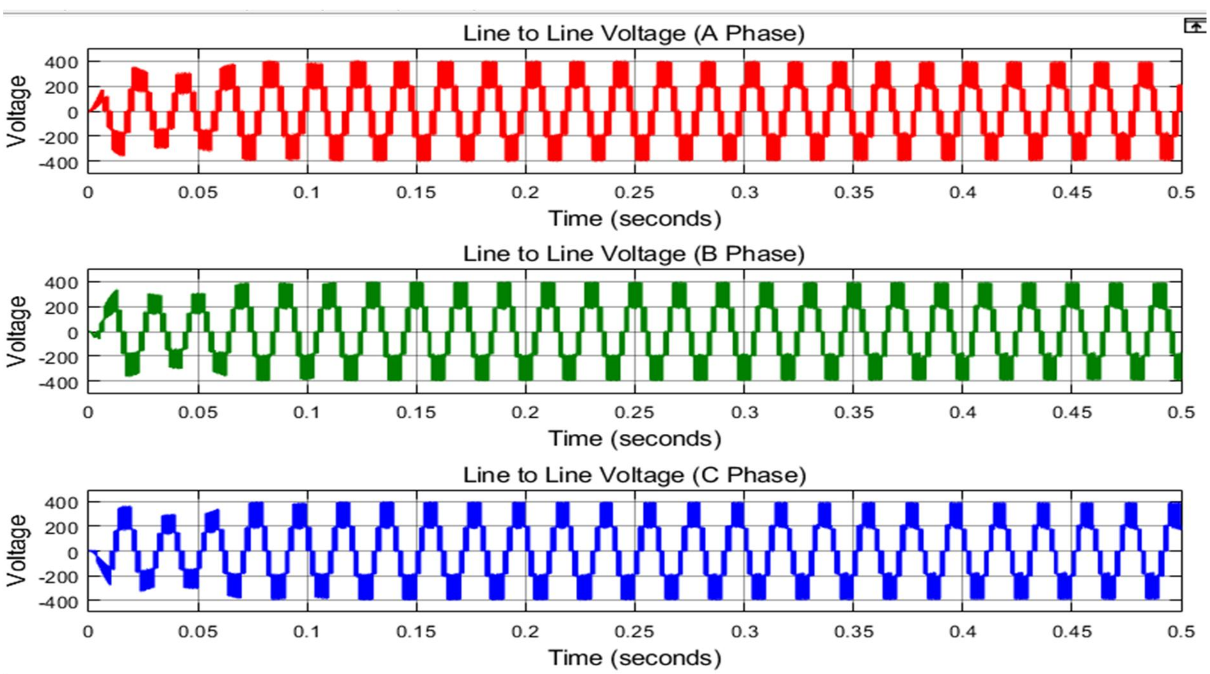
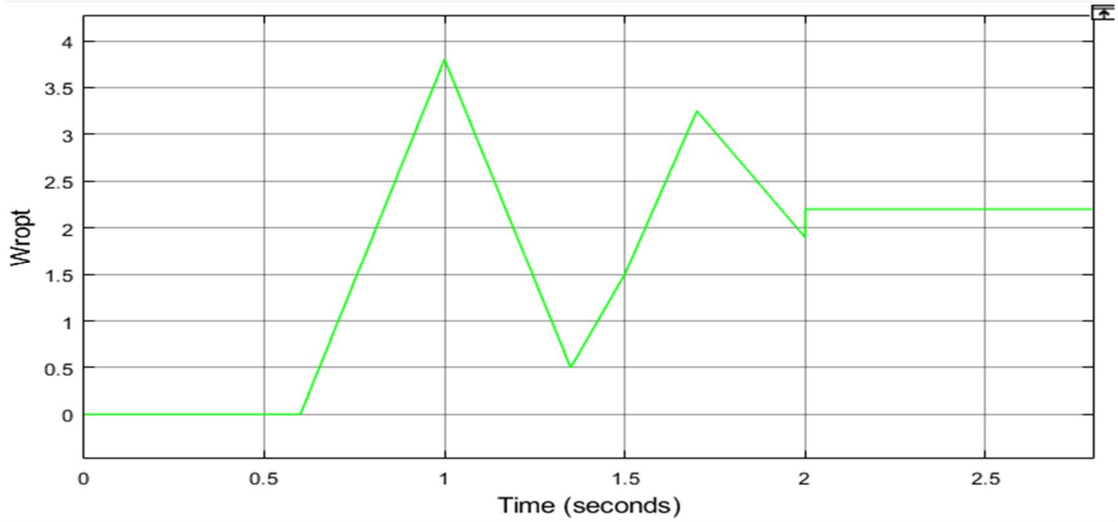
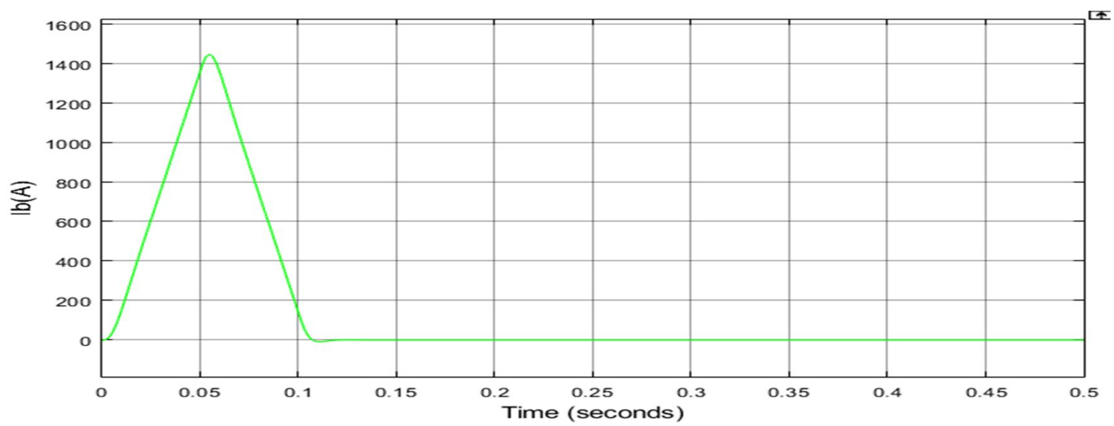
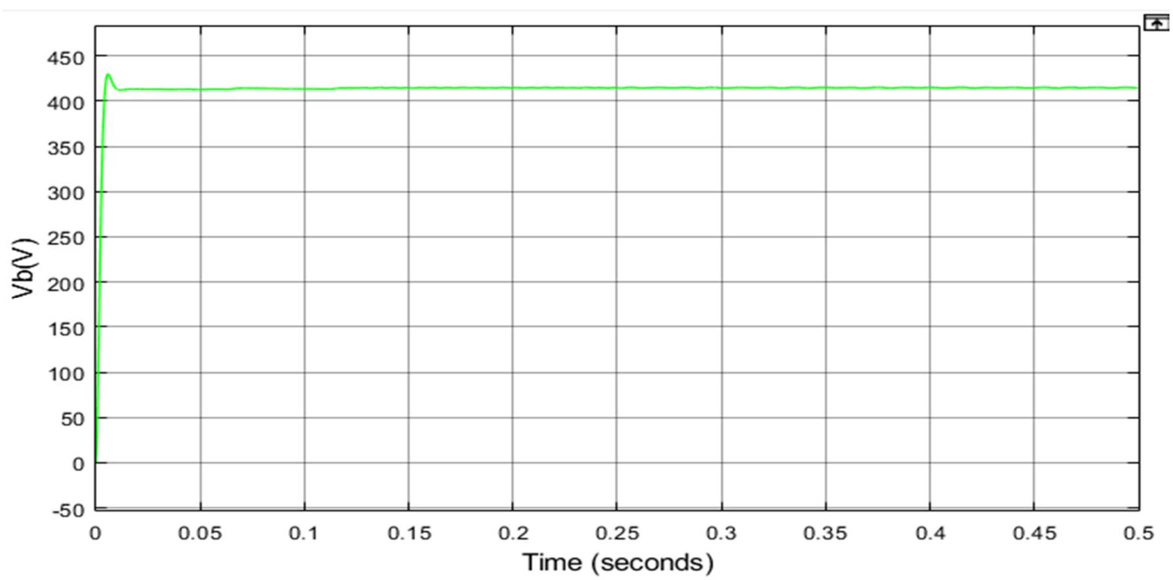


Fig.10 Phase Voltage of Gris Side Converter


Wropt
Time (seconds)


Ib(A)
Time (seconds)


Vb(V)
Time (seconds)

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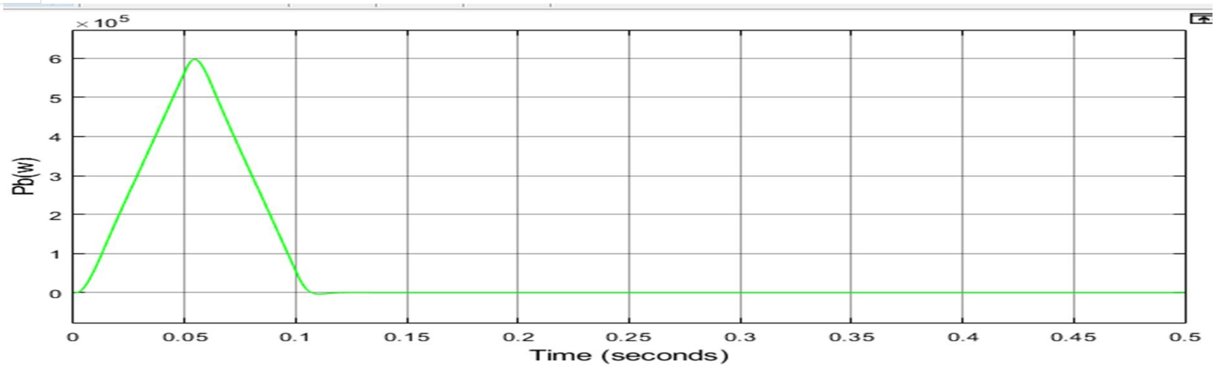
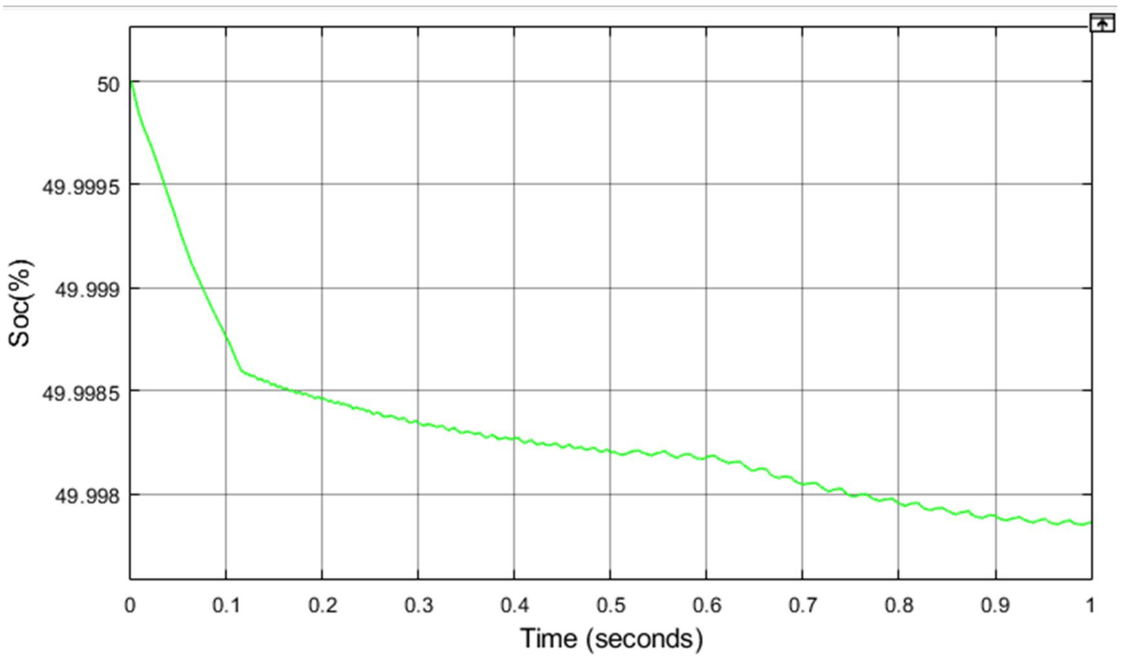
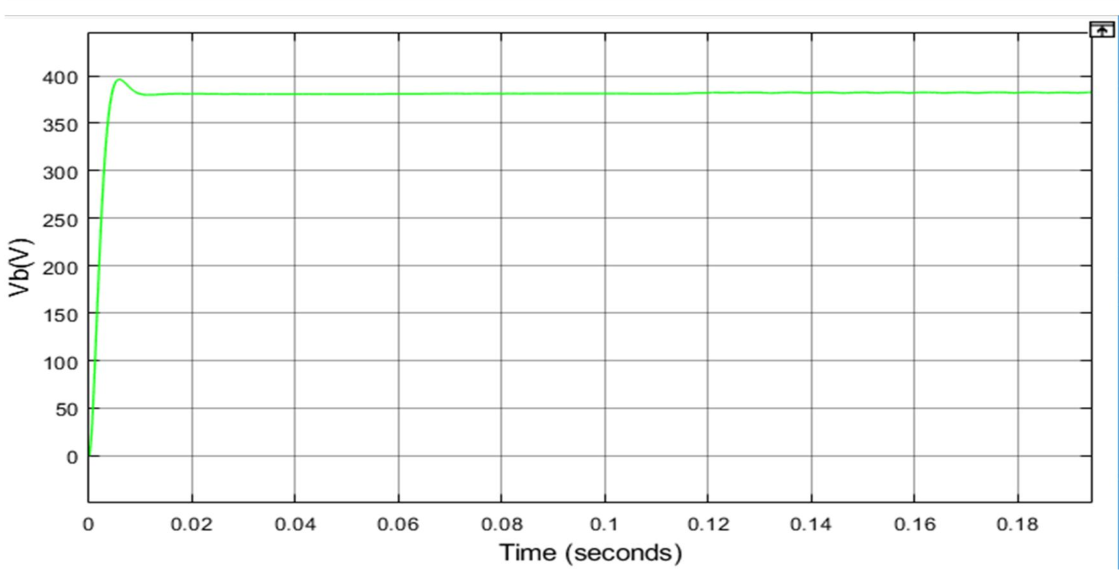


Fig. 3 Results for Battery source voltage, current , state of charge and power respectively





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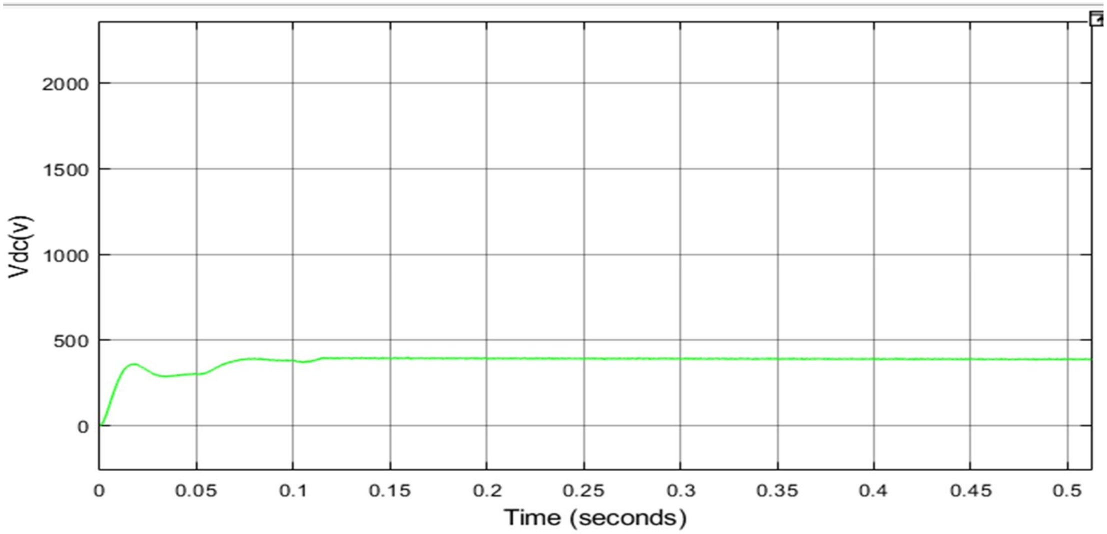


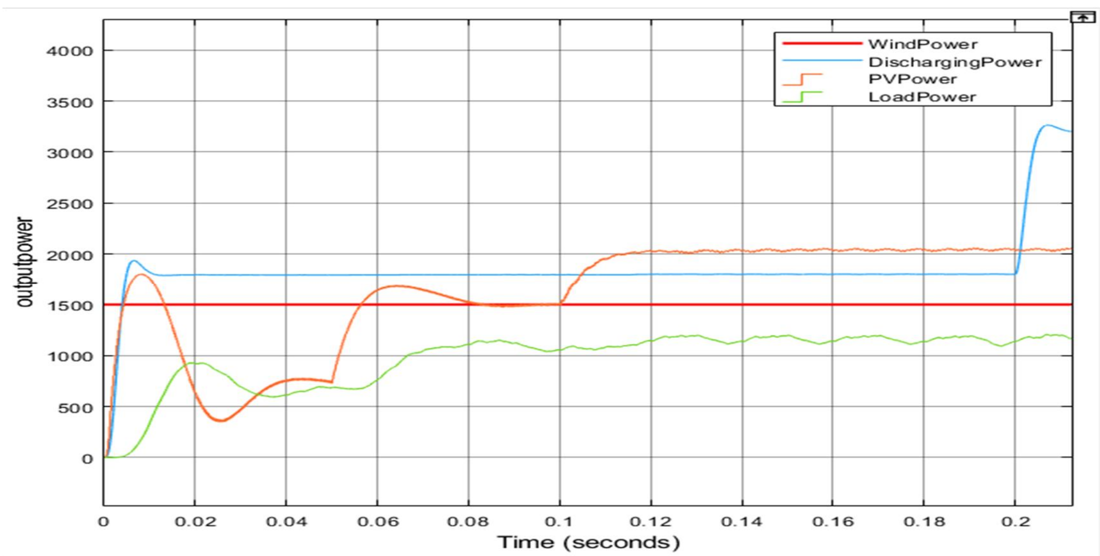
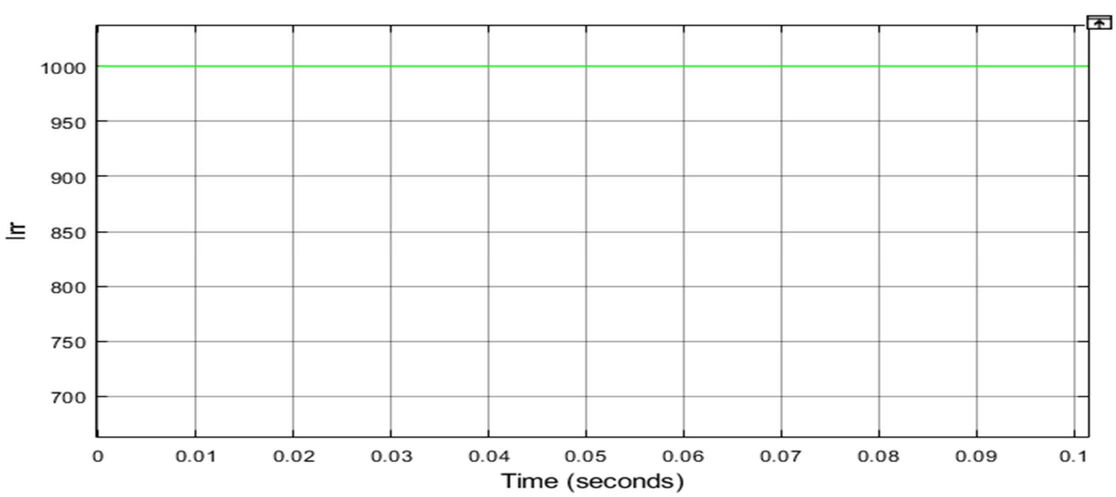
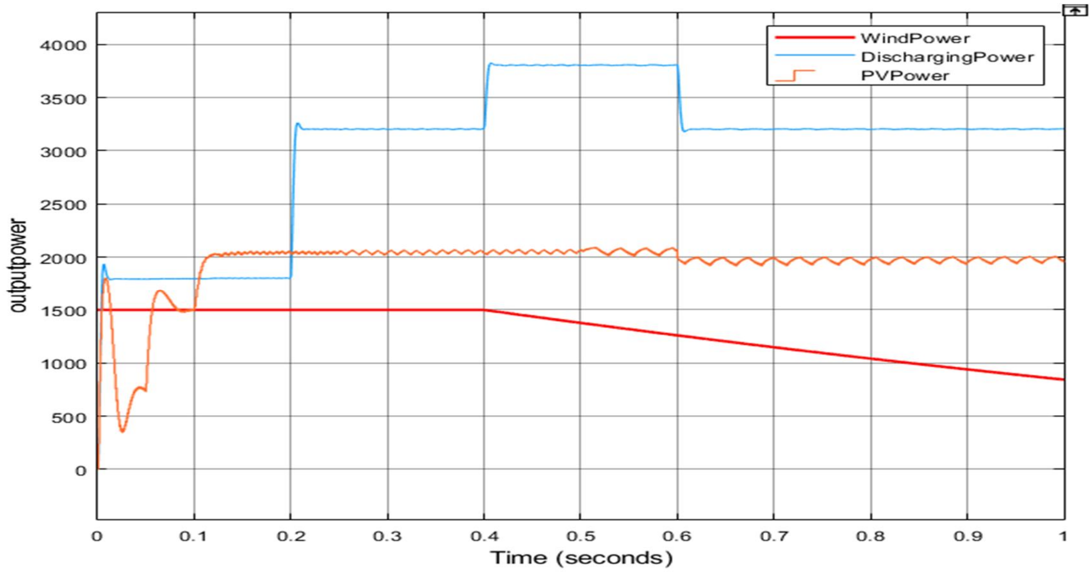
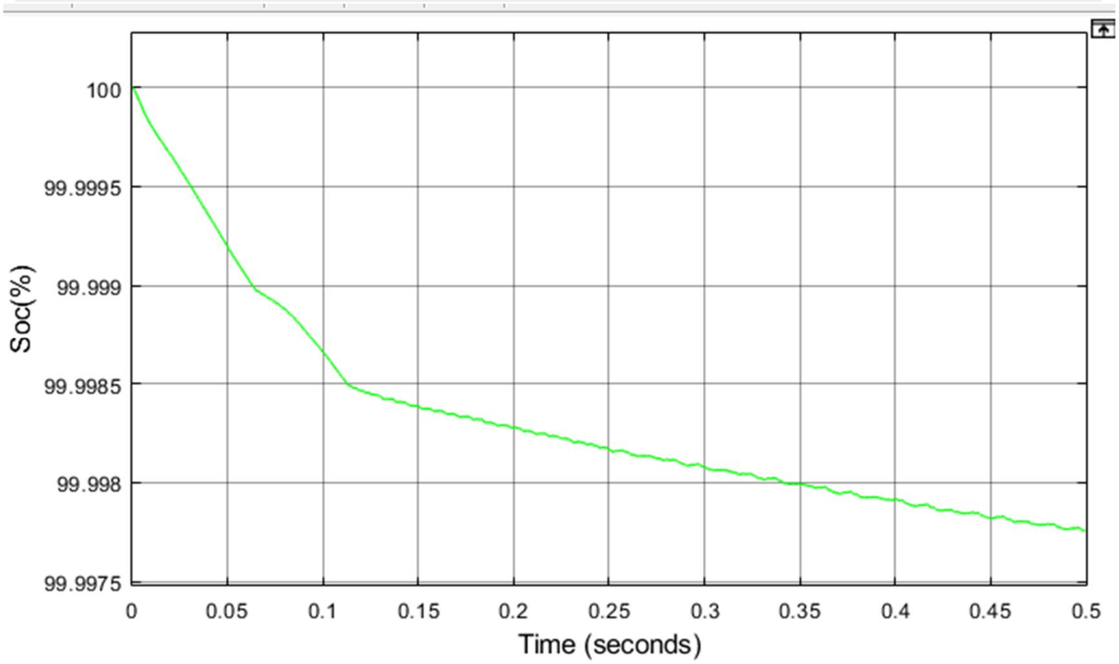


Fig.4 Power Output from Battery for Charging and Discharging, PV and Wind







Simulation Results for load voltage, current and power respectively

VII. CONCLUSION

This research presents a structured control system framework that effectively supplies power to the utility even with fluctuating Distributed Generation (DG) and demand patterns. Moreover, a strategy that balances multiple goals ensures the system operates with the lowest possible maintenance expenses. By setting up charging and discharging schedules for Battery Energy Storage Systems (BESS), the risk of system failures during periods of reduced DG production is reduced. The results underscore the effective functioning of Microgrid Control operations. Future studies could investigate the integration of variable energy sources and non-linear loads to improve the system's resilience and performance.

VIII. ACKNOWLEDGMENT

The authors declare that every piece of information provided is totally our own creation and has not been imitated from any other source

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