Renewable Energy-Based Microgrid Power Management System

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***Abstract* -** Renewable energy-based microgrids are emerging as a sustainable solution to meet the growing energy demands while reducing dependence on fossil fuels. This paper presents an advanced energy management system (EMS) for microgrids integrating renewable energy sources such as solar and wind. The proposed EMS optimizes power generation, storage, and consumption using intelligent algorithms to ensure reliability, cost-effectiveness, and grid stability. A hybrid approach combining demand-side management, battery energy storage, and real-time load forecasting is implemented to enhance efficiency. Simulation results demonstrate the effectiveness of the system in minimizing energy wastage, reducing carbon footprint, and ensuring uninterrupted power supply. The study highlights the potential of renewable energy-based microgrids in achieving a sustainable and resilient energy future.

Keywords – MATLAB, Renewable energy sources, Hybrid power system, Photovoltaic, Wind Turbine, Battery, Energy management system .

I. INTRODUCTION

The increasing global emphasis on sustainable living has spurred the demand for innovative energy management solutions that align with environmental and economic goals. Residential energy consumption constitutes a significant portion of global electricity usage, making it a critical area for introducing energy-efficient and renewable energy solutions. In this context, the capstone project titled "Renewable Energy-Based Microgrid Power Management System" seeks to address the pressing need for cost-effective and environmentally conscious energy systems tailored for residential loads.

This project focuses on the design and implementation of a cutting-edge energy management system capable of integrating multiple energy sources—solar photovoltaic (PV) panels, wind turbines, and conventional grid electricity—into a seamless and efficient framework. The primary objective is to reduce electricity costs for residents while promoting the adoption of renewable energy sources, thereby contributing to sustainable energy practices and minimizing the environmental impact of residential energy use.

To achieve these objectives, the project employs a simulation-based methodology using MATLAB/Simulink. The proposed energy management system is modelled and analysed under various operating conditions to assess its performance and effectiveness. The simulations evaluate the individual contributions of solar panels, wind turbines, and grid electricity, as well as their combined operation. By considering real-world variables such as fluctuating energy demand, weather conditions, and grid availability, the study provides a comprehensive analysis of the system’s potential to optimize energy usage and costs.

The simulation results underscore the system’s effectiveness in achieving substantial cost savings while significantly increasing the reliance on renewable energy sources. The integration of solar and wind energy within a residential microgrid demonstrates the feasibility of reducing dependency on conventional fossil fuel-based grid electricity, thereby lowering carbon emissions. This highlights the project’s dual impact: fostering economic feasibility and advancing environmental sustainability.

Through this innovative approach, the *"Renewable Energy-Based Microgrid Power Management System"* project contributes to the evolving field of energy management systems by providing valuable insights into the practical application of hybrid renewable energy systems in residential settings. It highlights the potential for creating economically viable and environmentally sustainable solutions that encourage widespread adoption of renewable energy technologies.

In summary, this project not only showcases the significant benefits of integrating renewable energy sources into residential energy systems but also emphasizes the potential for promoting sustainable living practices. By reducing electricity costs, lowering carbon emissions, and decreasing reliance on fossil fuels, the proposed microgrid system offers a promising and practical solution for addressing the challenges of energy management in residential applications

II. LITERATURE REVIEW

Literature Review: Energy Management System for Renewable Energy-Based Microgrid Using MATLAB/Simulink

The increasing demand for electricity and the depletion of conventional energy resources necessitate the integration of renewable energy sources into power systems. This integration requires robust energy management systems (EMS) to address challenges such as fluctuating power generation, grid stability, and efficient utilization of available resources. The following literature provides insights into the advancements and methodologies in modelling and implementing EMS for hybrid renewable energy-based microgrids using MATLAB/Simulink.

1. Integration of Hybrid Energy Model with Solar PV, Hydro, and Wind Turbine

This study emphasizes the necessity of hybrid energy systems for ensuring a continuous and reliable electricity supply, particularly under variable solar irradiance and wind speed conditions. The research presents a MATLAB/Simulink-based model integrating solar PV cells, wind turbines, and hydro energy systems. The comparative analysis highlights the advantages of hybrid systems over single-source energy systems, particularly in mitigating intermittency issues and ensuring grid stability. This work underscores the importance of combining multiple renewable energy sources to address fluctuations and improve system resilience, laying a foundation for EMS development.

2. Energy Management System for Hybrid Renewable Energy-Based Microgrid

This paper introduces a hybrid microgrid comprising solar, wind, and battery storage systems, managed by a fuzzy logic controller (FLC). The proposed EMS ensures efficient power generation and storage by dynamically responding to load variations. Compared to conventional PI controllers, the FLC demonstrates superior performance in managing active power, reactive power, battery state of charge (SoC), and harmonic mitigation. The simulations in MATLAB/Simulink validate the effectiveness of the FLC in enhancing system performance and reliability. This study provides a strong basis for designing intelligent EMS frameworks for hybrid systems.

3. Simulation of Microgrid with Energy Management System

This work focuses on the implementation of a DC microgrid comprising photovoltaic arrays, wind turbine generators, battery storage, and grid integration. An EMS is developed to schedule generation and load efficiently under variable conditions. The MATLAB/Simulink-based model highlights the role of EMS in ensuring seamless operation under fluctuating generation and load scenarios. By incorporating battery storage, the study addresses energy balance, demonstrating the practical viability of hybrid renewable energy systems in real-world applications. This research supports the development of EMS by providing insights into scheduling and resource allocation.

4. Energy Management System for Grid-Integrated Microgrid Using Fuzzy Logic Controller

This study enhances microgrid operation by integrating an AC/DC hybrid energy system with an EMS utilizing fuzzy logic control. The hybrid system includes PV arrays, wind turbines, and asynchronous generators, with maximum power point tracking (MPPT) implemented via the perturb and observe (P&O) algorithm. The EMS optimizes battery performance, extending its lifecycle by maintaining a desirable SoC. The transient state analysis under varying conditions demonstrates the model's robustness and adaptability. This research highlights the importance of intelligent controllers like FLC in achieving power balance and extending system reliability.

III. SYSTEM DESIGN AND COMPONENTS SPECIFICATION

Block diagram

The block diagram of the "Renewable Energy-Based Microgrid Performance Analysis" system visually represents the integration of key components designed to optimize renewable energy sources for a residential load. This diagram provides a clear understanding of the system's architecture and the interactions between its various elements, ensuring efficient energy utilization and reliability.

- **Solar Panels**: The solar panels capture sunlight and convert it into electrical energy. The energy generated is directed to the energy management system for further distribution.
- **Wind Turbines**: Wind turbines harness wind energy to generate electricity. Similar to solar panels, the energy produced by wind turbines is fed into the energy management system.

- **Conventional Grid Electricity**: This component represents the traditional electrical grid, providing a stable and reliable source of electricity to the residential load.
- **Battery system:** The system also includes a Battery System, which governs the storage and release of energy in the battery storage units. The battery system ensures that excess energy from renewable sources is efficiently stored and made available during periods of low energy production, enhancing the system's reliability and sustainability.

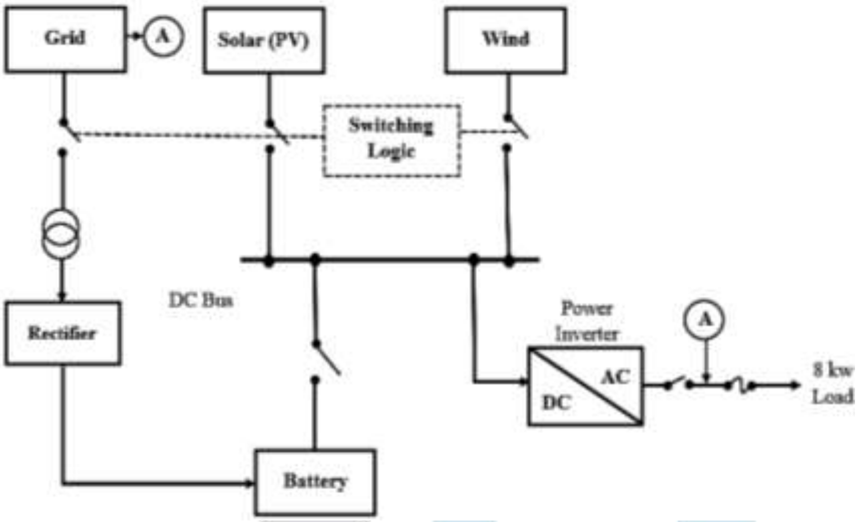


Figure 3.1 Block diagram

Microgrid System Modelling

1. PV panel modelling

The solar panel array captures sunlight, converting it into direct current (DC) electrical energy. Positioned strategically, this array is a fundamental component for harnessing renewable solar energy and contributing to the overall power generation.

Array data

Parallel Strings = 2

Series-connected modules per strings = 20

- Total Load demand for Photo-Voltic panels are = 8 KW
- The maximum power of a single module is = 240.53 W.
- Number of modules connected in series = 20
- Power per string = 240.53×20 = 4810.6 W
- No. of strings = (Total load demand / Power per string)

No. of strings = $\frac{8000}{4810.6}$ = 1.66

- Number of modules connected in parallel string = 2

Total Power = 2×4810.6 = 9621.2W

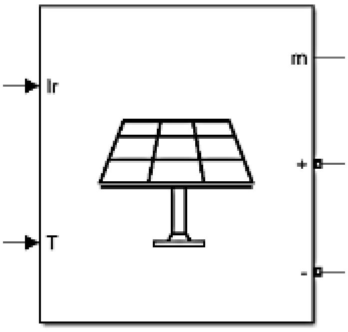


Figure 3.2 PV array

2. Wind Turbine modelling

The wind turbine array captures wind energy, converting it into electrical energy. Positioned strategically, this array complements the solar panel array, contributing renewable energy to the system, particularly during periods of wind activity.

The output power of a Wind turbine is given by:

$$\mathbf{P} = \left(\frac{1}{2}\right) \rho * A * v^3 * C_p * \eta$$

Where:

- P is the output power of the wind turbine (in watts, W).
- ρ is the air density (kg/m^3)
- A is the swept area of the wind turbine blades
- v is the wind speed (in m/s)
- C_p is the power coefficient, which represents the efficiency of the turbine in converting wind energy into mechanical energy.
- η is the overall efficiency of the system.

$$\mathbf{P} = \left(\frac{1}{2}\right) \rho * A * v^3 * C_p * \eta$$

In order to find the power generation from a wind turbine we have to calculate its swept area (A) of the blades. Swept area is the area of the circle created by the blades as they sweep through the air.

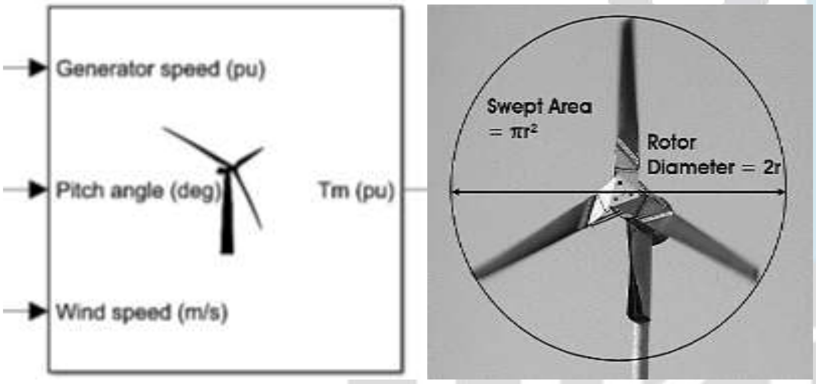


Figure 3.3 Wind turbine

3. Battery

The battery serves as an energy storage device, storing excess direct current (DC) energy generated by the solar panel array. This stored energy acts as a buffer, ensuring a continuous power supply during periods of low renewable energy generation.

Nominal voltage (V) = 700
Rated capacity (Ah) = 100
Initial state-of-charge (%) = 50

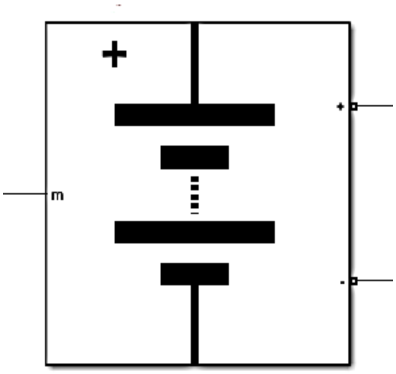


Figure 3.4 Battery

Battery Modelling:

Energy Demand (Wh) = Total Power Demand (W)×Autonomy Period (h)
Total Power Demand = 8 KW
Autonomy Period (h) = 10 h

Energy Demand = 8000W×10h= 80000Wh

Depth of Discharge (DoD):

Usable Energy (Wh) = $\frac{Energy\ Demand\ (Wh)}{Depth\ of\ Discharge\ (DoD)}$

Usable Energy (Wh) = $\frac{80000\text{Wh}}{1.23}$

Usable Energy (Wh) =65000Wh

Battery Capacity:

Battery Capacity (Ah) = $\frac{Useable\ Energy}{Battery\ Voltage}$

Battery Capacity (Ah) = $\frac{65000}{700}$

Battery Capacity (Ah) = 100 Ah

4. Mathematical Operators for Bill Calculation

Mathematical operators are employed for bill calculation, involving algorithms that consider various factors such as energy consumption, rates, and time of use. These operators are crucial for determining electricity costs accurately, providing residents with transparent and detailed billing information based on their energy usage patterns.

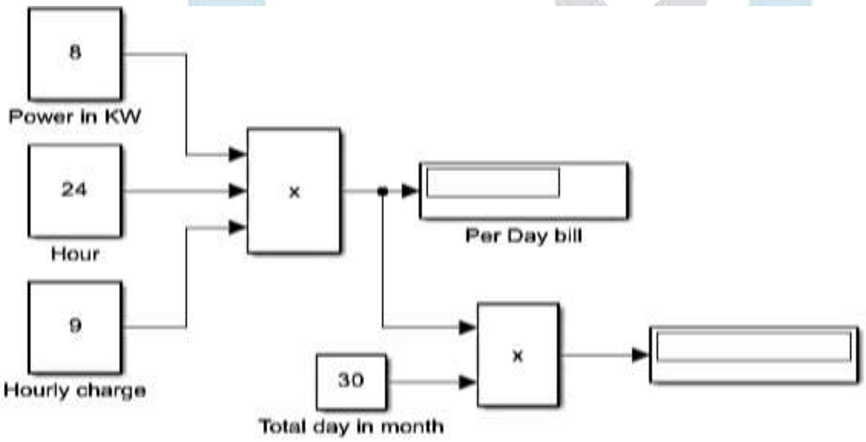


Figure 3.5 Mathematical blocks

Together, these components form a sophisticated and integrated system, enabling efficient energy management, analysis, and control in pursuit of a sustainable and cost-effective living environment.

IV. COMPLETE CIRCUIT DESIGN

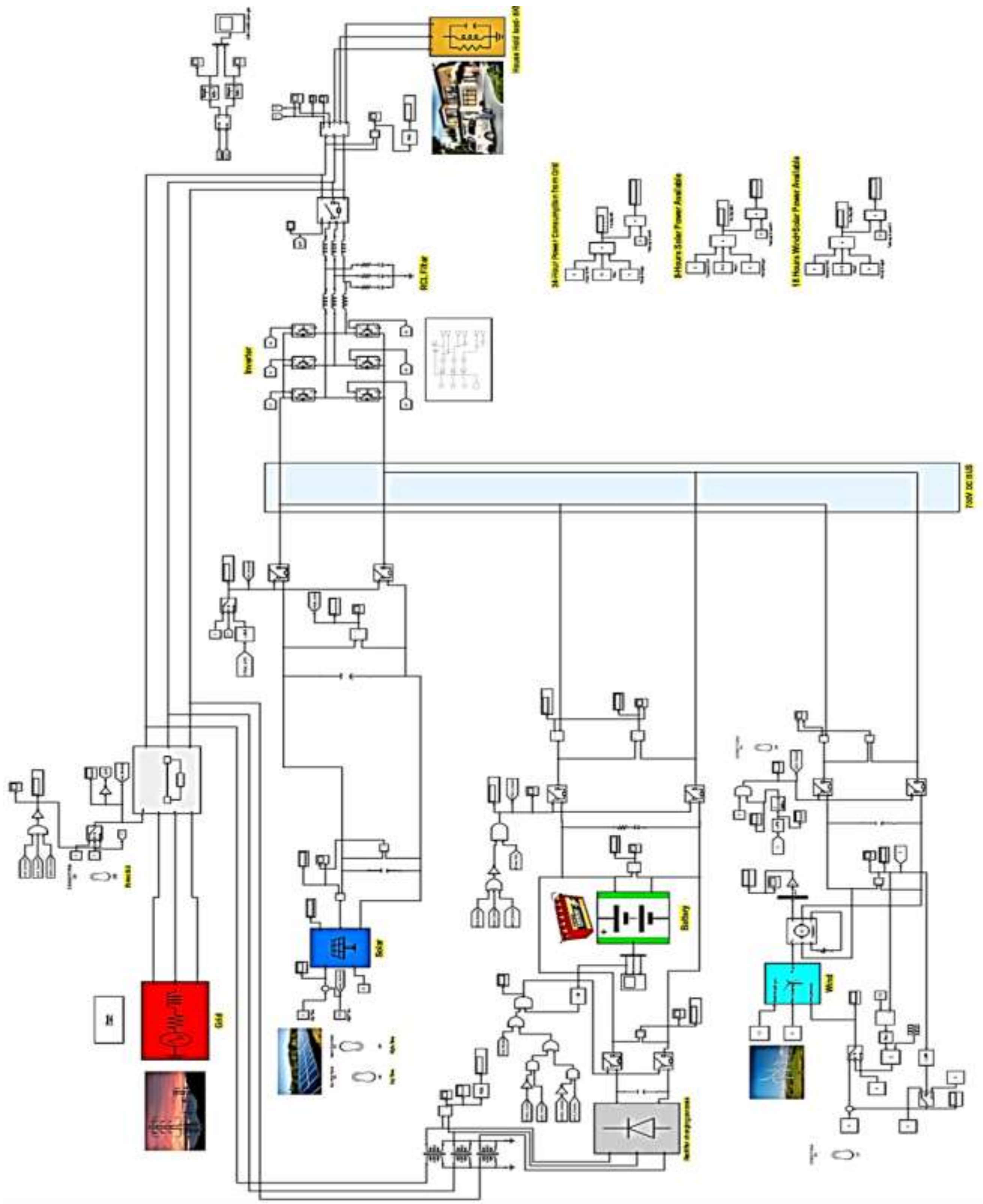


Figure 4 Circuit diagram

V. SIMULATION RESULTS

Different scenario of source

1) **Scenario-1:** Only Grid Power Source available
2) **Scenario-2:** Only Solar Power Source available
3) **Scenario-3:** Only Wind Power Source available
4) **Scenario-4:** Solar + Wind Power Source are available
5) **Scenario-5:** Solar to Wind or Wind to Solar Power changeover on different condition
6) **Scenario-6:** Grid, solar & Wind all fail

The scenarios described above are explained in detail below.

5.1.1 Scenario-1

Only Grid Power Source available: The grid is supplying power to meet the entire load demand as both solar and wind energy sources are unavailable. Simultaneously, the battery is charging using grid power to ensure energy storage for future use.

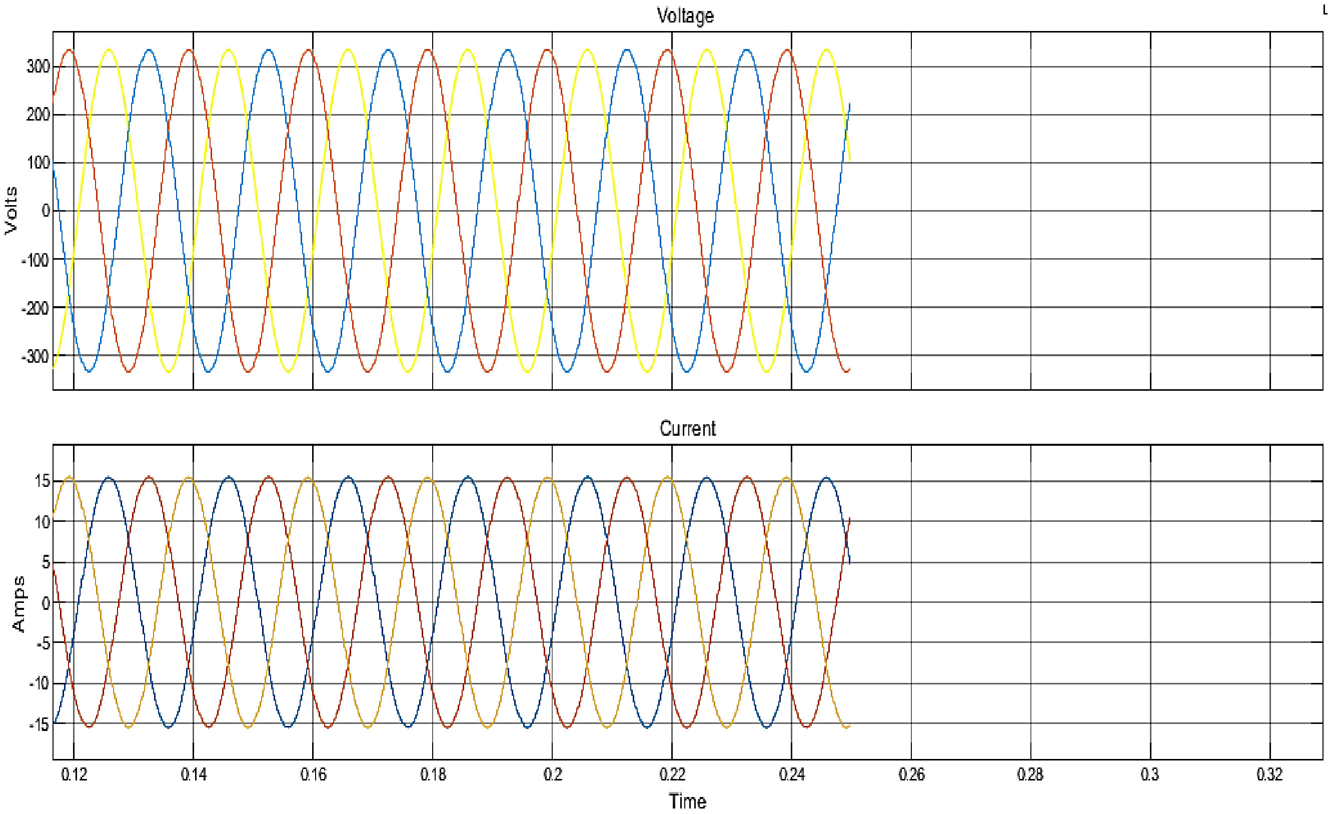


Figure 5.1 Output Voltage and Current of scenario – 1

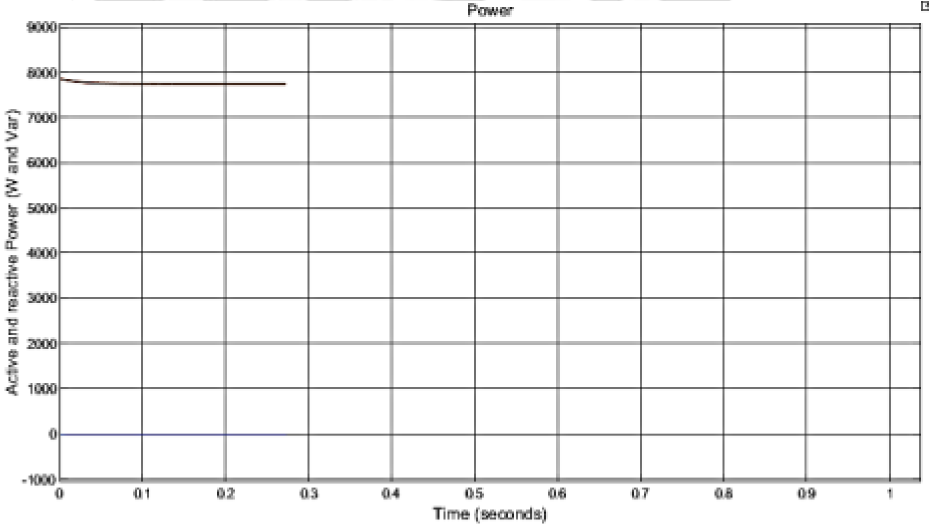


Figure 5.2 Output power of scenario – 1

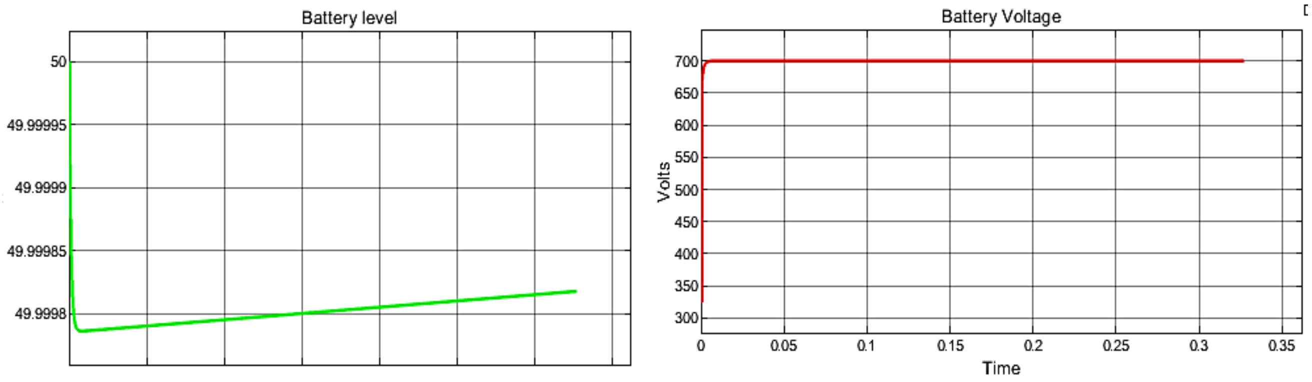


Figure 5.3 Battery level and voltage of the scenario -1

5.1.2 Scenario-2

Only Solar Power Source available: Solar power is available and supplying the total load while both wind and grid power are unavailable or isolated. Additionally, the battery is being charged using the surplus solar power.

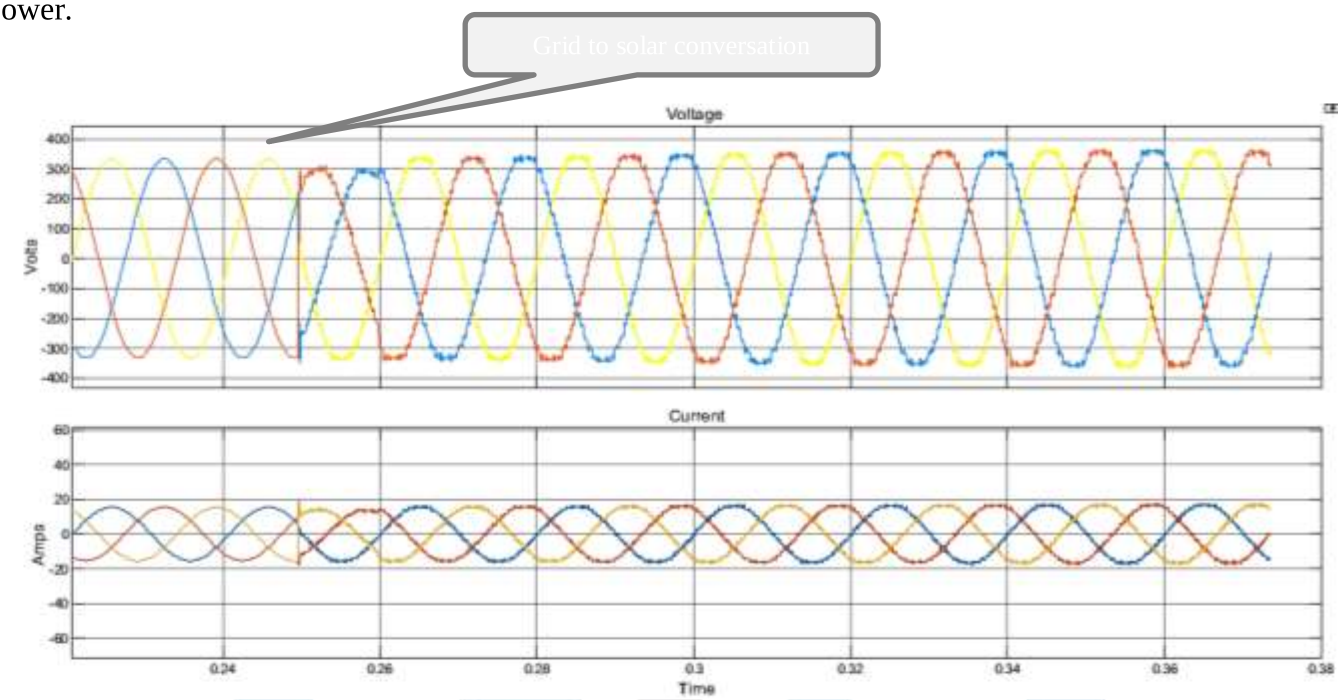


Figure 5.4 Output Voltage and Current of scenario – 2

Conditions:

Solar toggle switch → Day time
Wind toggle switch → All OFF condition
Battery charging → 50%

Whenever satisfactory voltage is generated by solar at instant power source changed from GRID to SOLAR. Initially take some time because of battery charge to satisfactory level (Like here 50%)

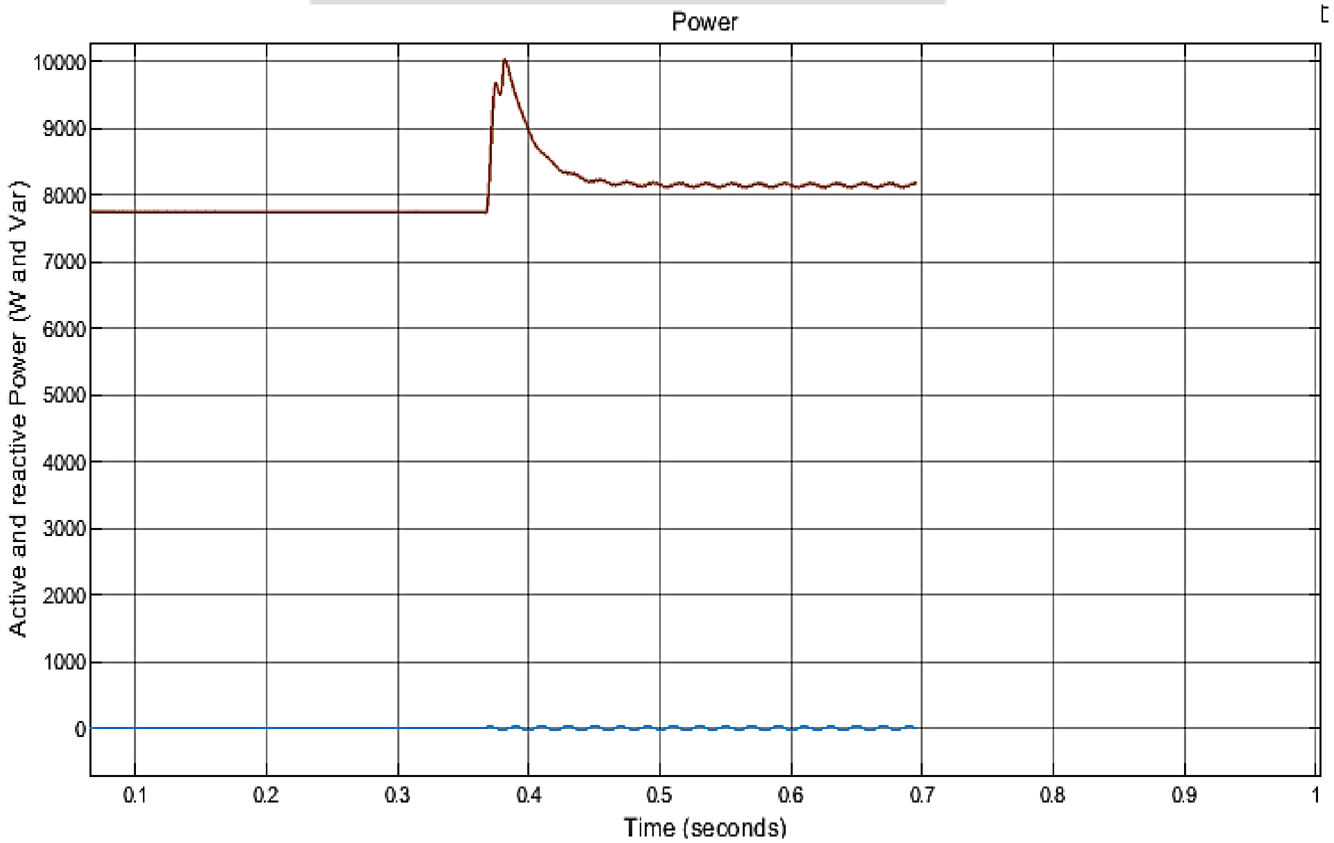


Figure 5.5 Output power of scenario – 2

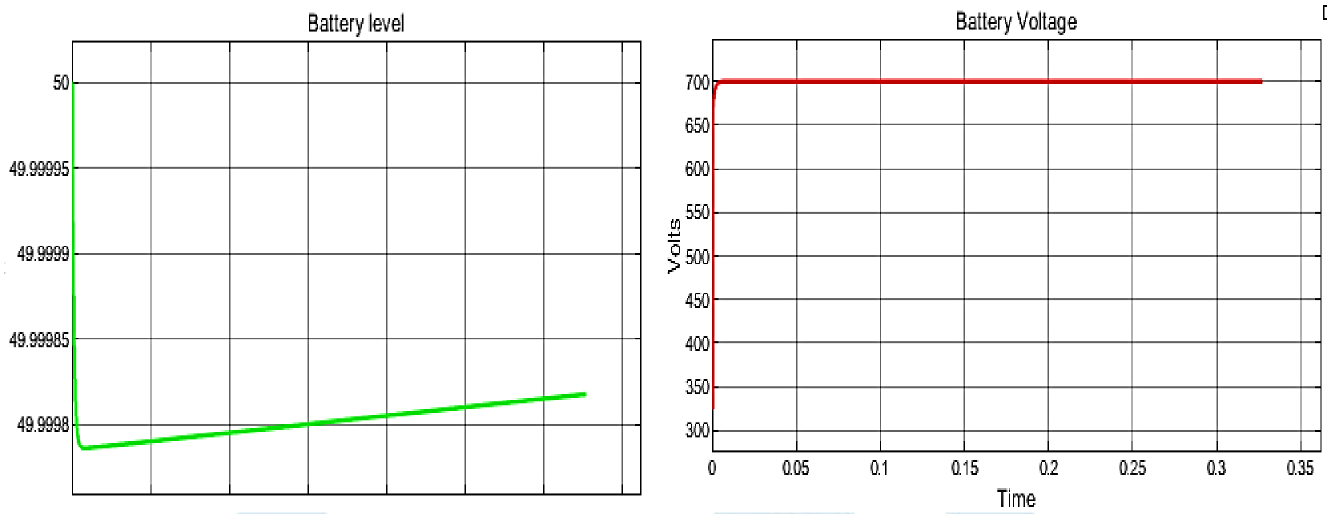


Figure 5.6 Battery level and voltage of the scenario -2

5.1.3 Scenario-3

Only Wind Power Source available: The wind power system is operational and supplies the total load demand. Simultaneously, the surplus wind power is utilized to charge the battery, while solar and grid power remain unavailable or isolated.

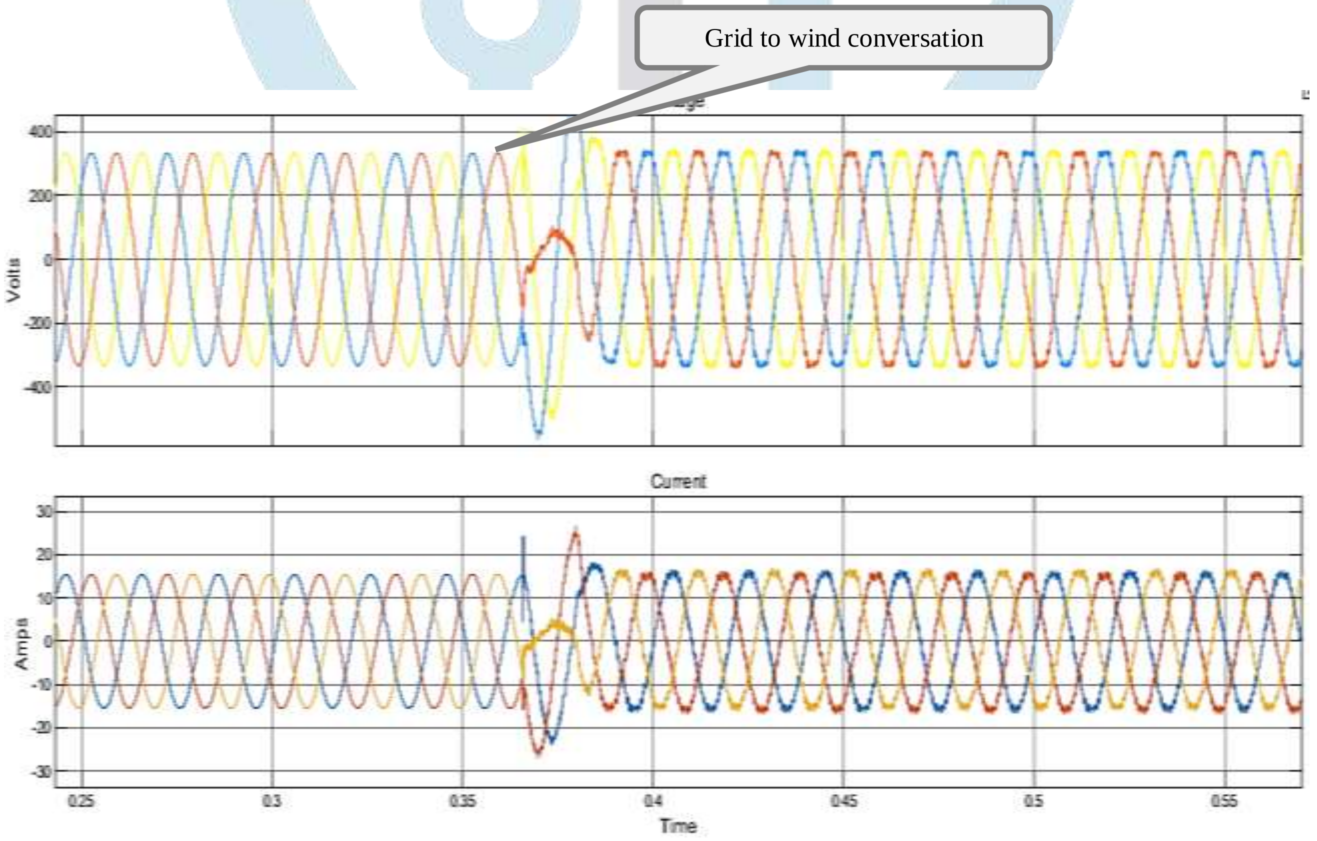


Figure 5.7 Output Voltage and Current of scenario – 3

Conditions:

Solar toggle switches → All OFF condition
Wind toggle switch → Normal wind speed
Battery charging → 50%

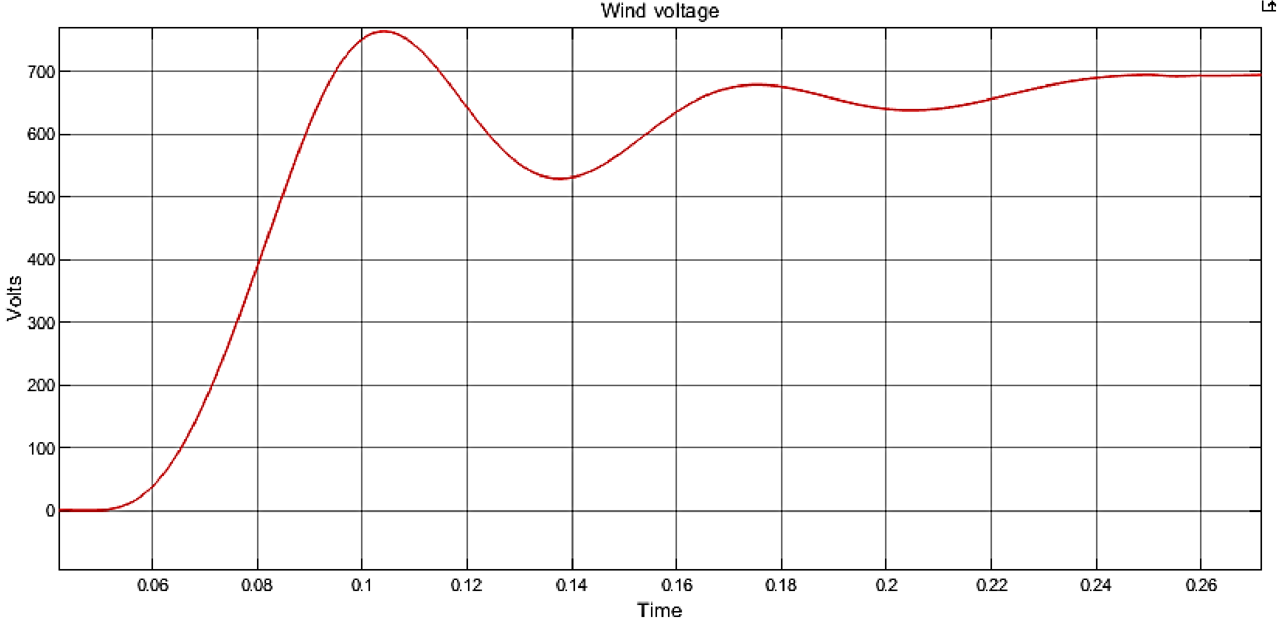


Figure 5.8 Output Voltage variation of wind

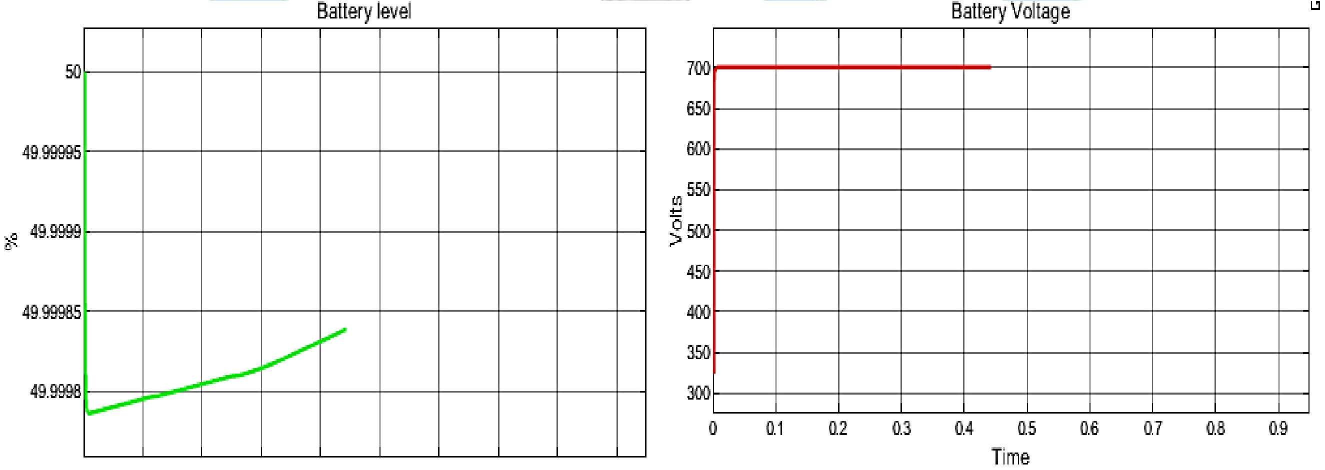
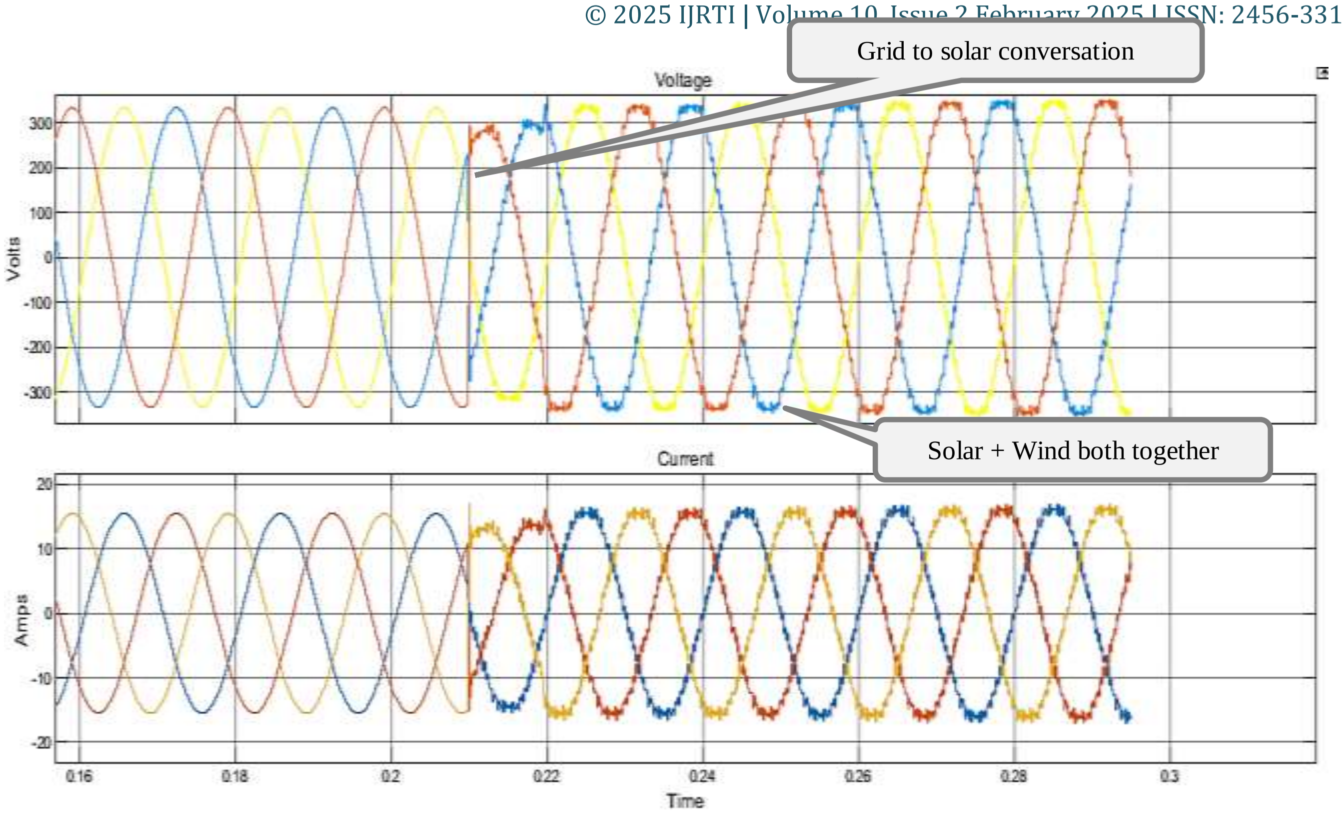


Figure 5.9 Battery level and voltage of the scenario – 3

5.1.4 Scenario-4

Solar + Wind Power Source are available: Solar + Wind Power Source: Solar and wind power supply the total load while the system operates in isolated mode (grid unavailable). Excess energy from solar and wind sources is used to charge the battery.



Grid to solar conversation

Solar + Wind both together

Figure 5.10 Output Voltage and Current of scenario – 4

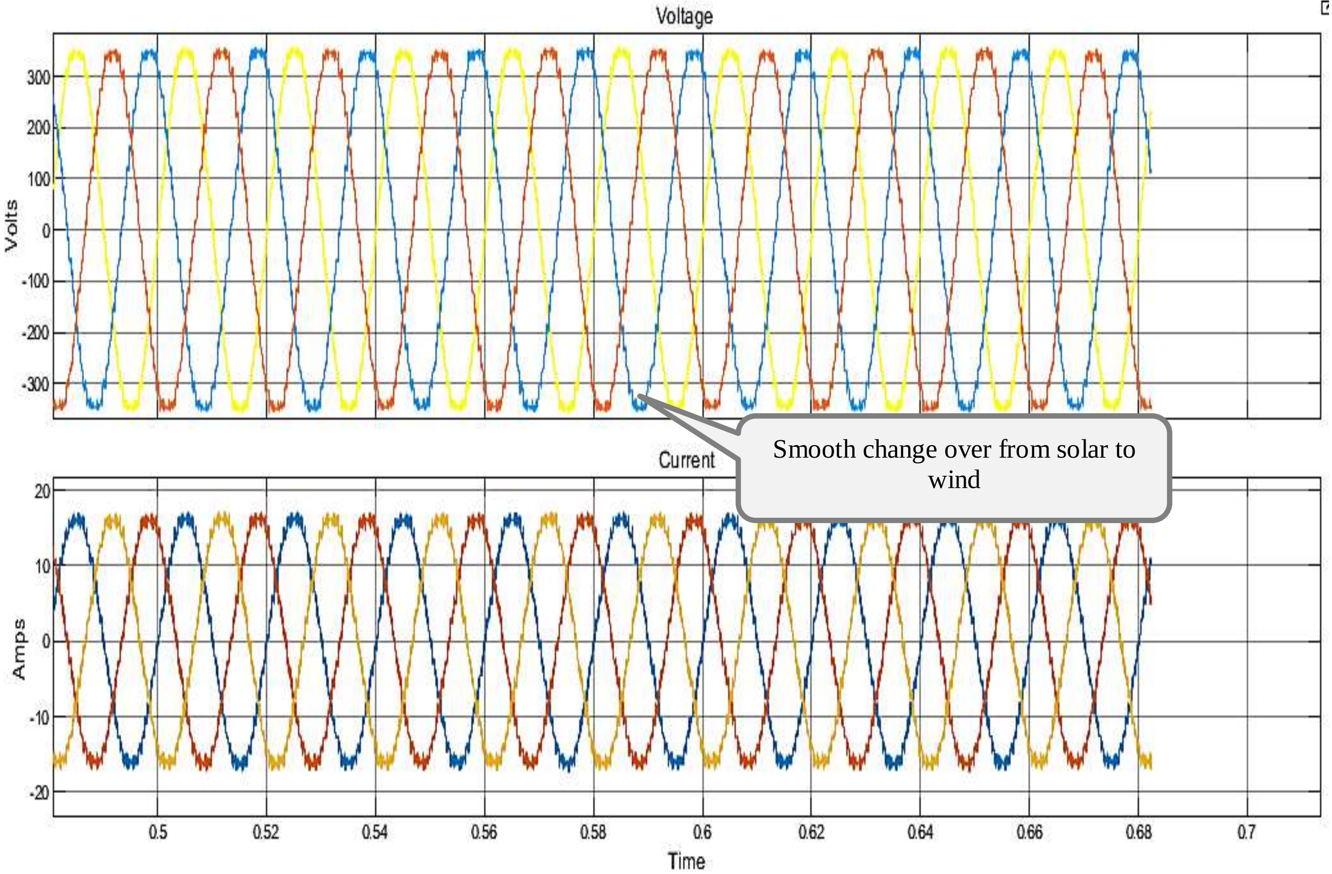
Conditions:
Solar toggle switches → Day time
Wind toggle switch → Normal wind speed
Battery charging → 50%

5.1.5 Scenario-5

Solar to Wind or Wind to Solar Power changeover on different condition: When SOLAR fail to tackle the load WIND will be single handed tackle the load & whenever both fail GRID come to picture & tackle the load or vise-versa.

Conditions:

Before	**After**
Solar toggle switches → Day time	Solar toggle switches → Night time
Wind toggle switch → Normal wind speed	Wind toggle switch → Normal wind speed
Battery charging → 50%	Battery charging → 50%

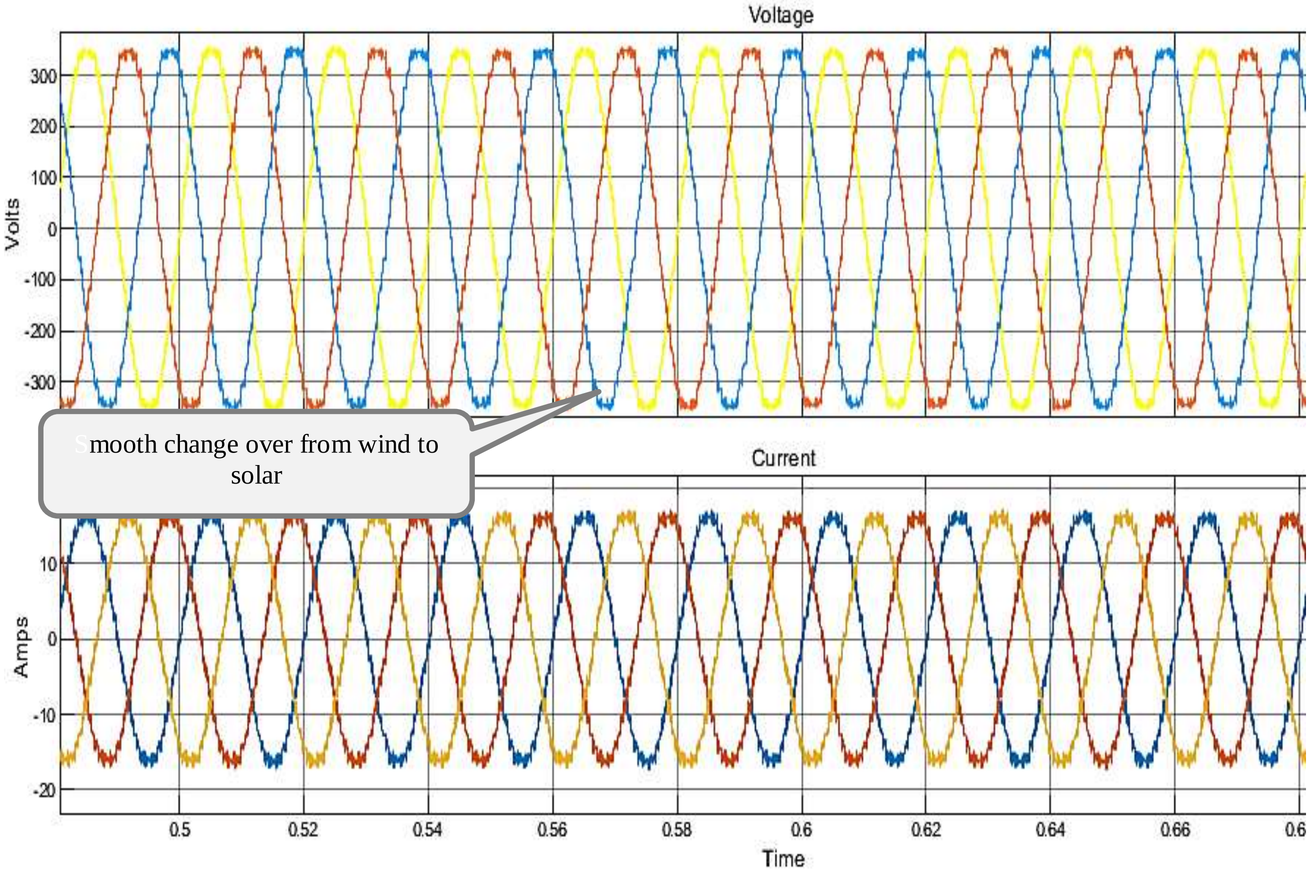


Smooth change over from solar to wind

Figure 5.11 Output Voltage and Current of scenario – 5

Conditions:

Before	**After**
Solar toggle switches → Day time	Solar toggle switches → Day time
Wind toggle switch → Normal wind speed	Wind toggle switch → No wind
Battery charging → 50%	Battery charging → 50%



Smooth change over from wind to solar

Figure 5.12 Output Voltage and Current of scenario – 5

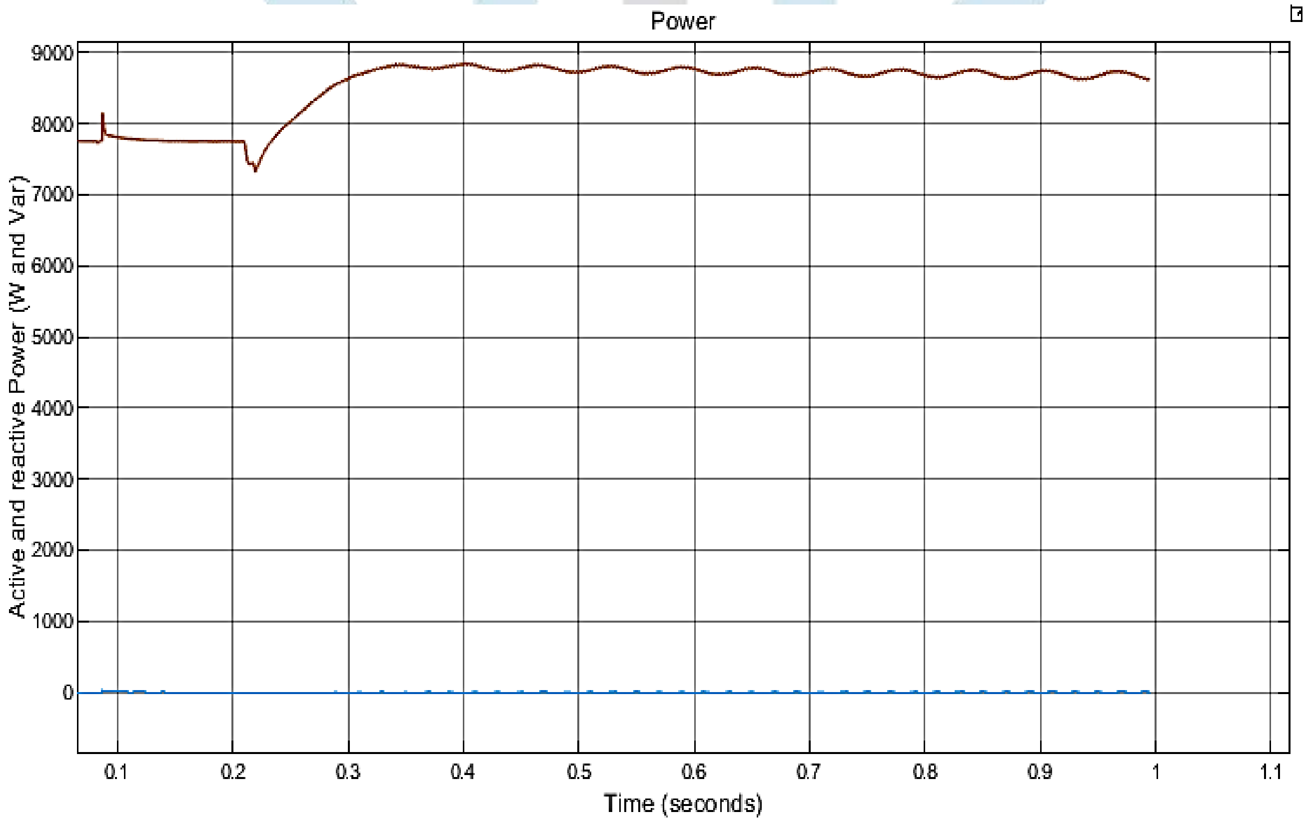


Figure 5.13 Output power of scenario – 5

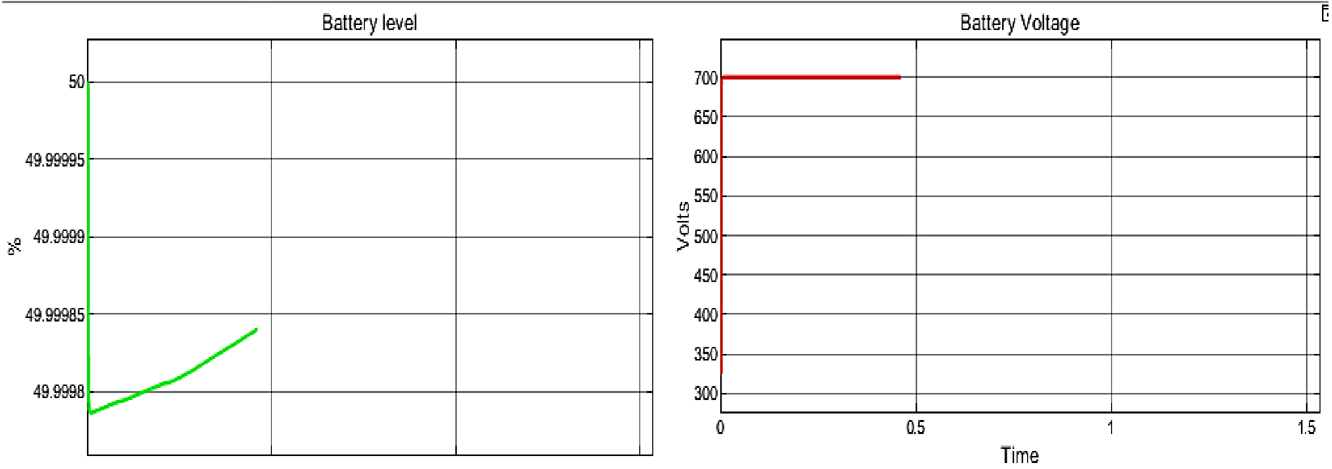
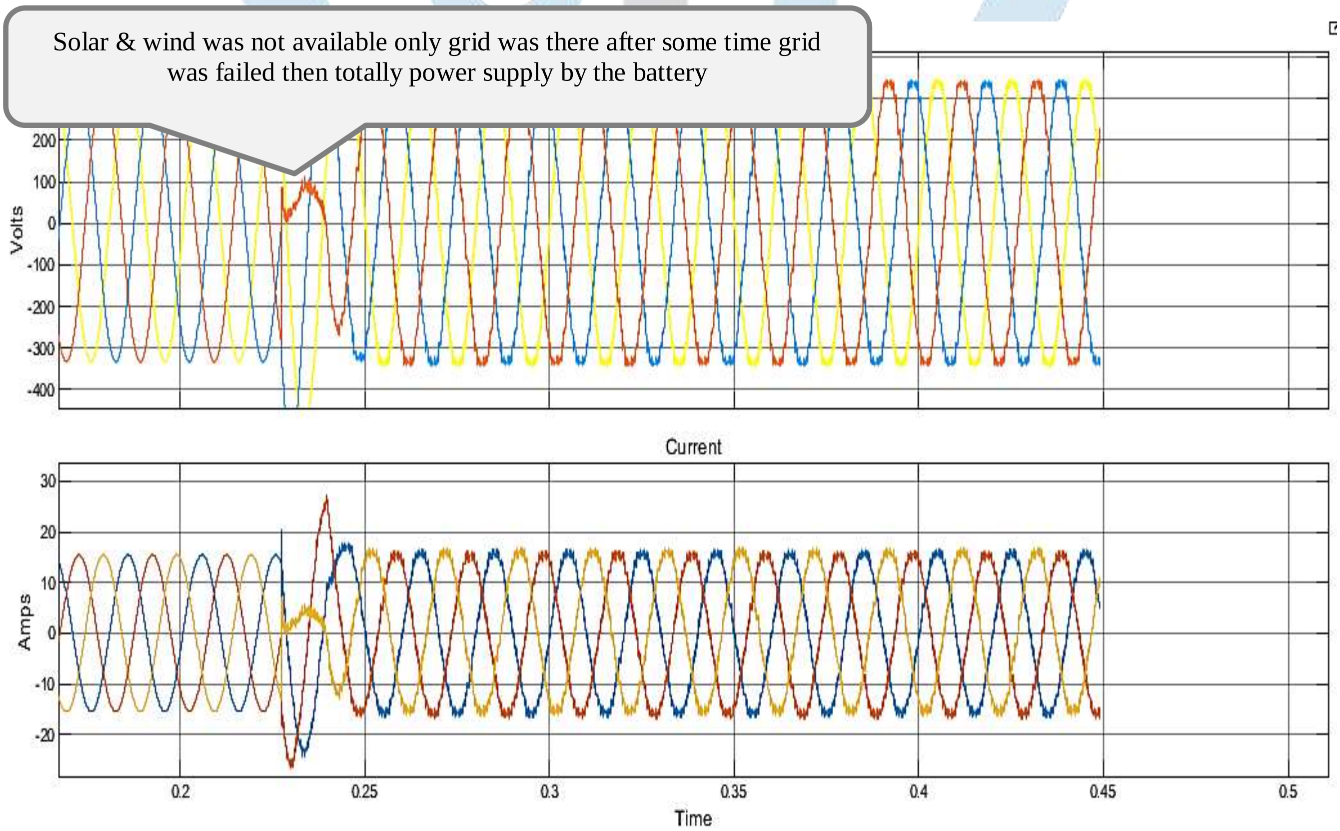


Figure 5.14 Battery level and voltage of the scenario – 5

Battery is continuously charging no matter whether power source is changing from solar to grid or vice versa.

5.1.6 Scenario-6

In the event of a complete failure of all primary power sources, such as solar, wind, and the grid, resulting in a blackout condition, the battery system becomes crucial. It takes over to provide power and support the total load for a limited duration, ensuring continuity of electricity supply until the primary sources are restored or alternative solutions are activated.



Solar & wind was not available only grid was there after some time grid was failed then totally power supply by the battery

Figure 5.15 Output Voltage and Current of scenario – 6

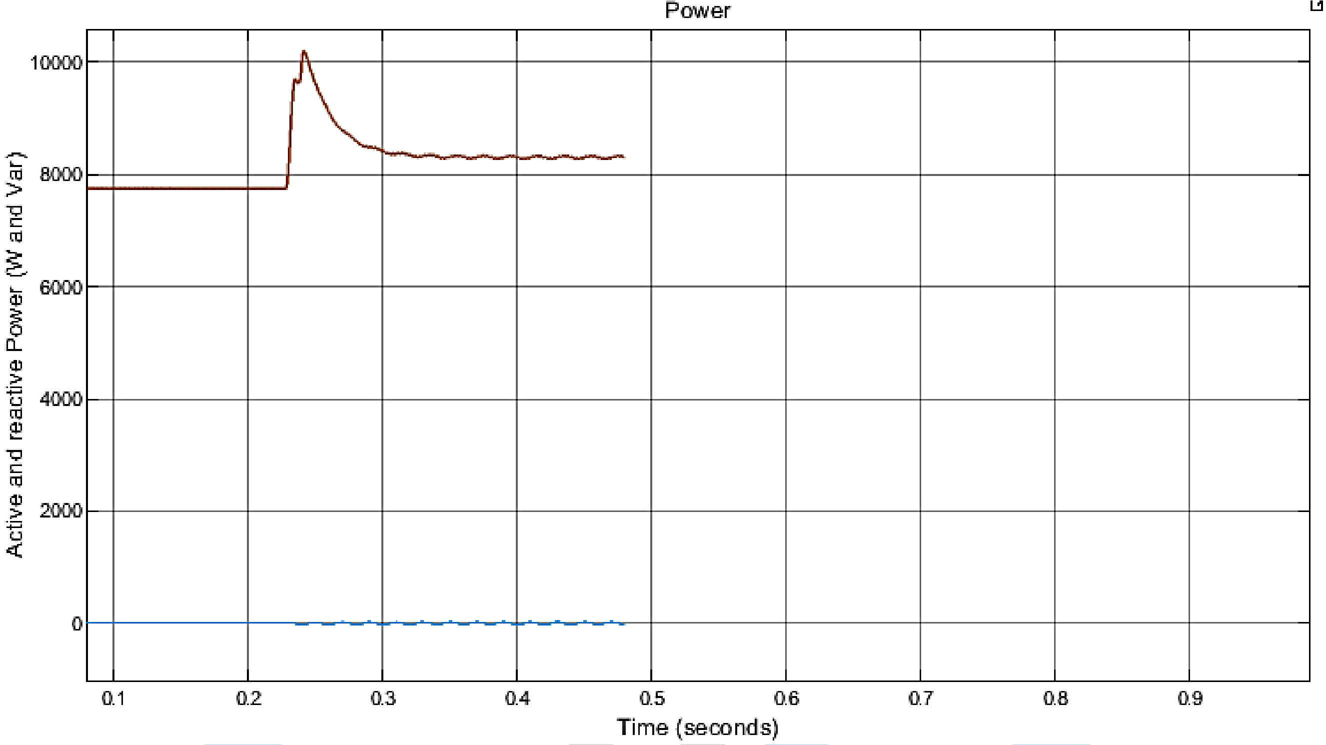


Figure 5.16 Output power of scenario – 6

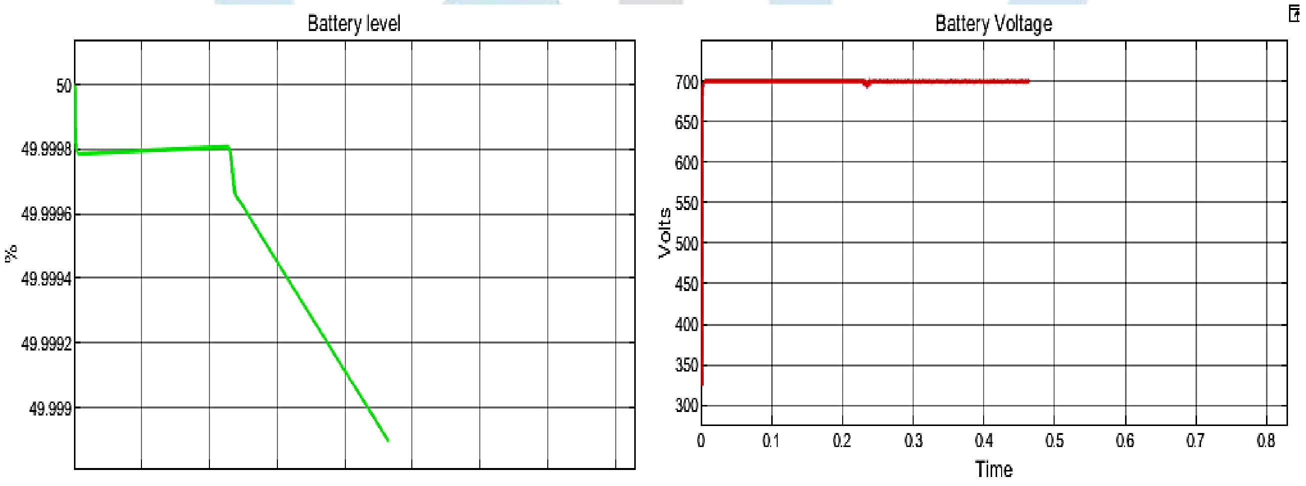


Figure 5.17 Battery level and voltage of the scenario – 6

VI. CONCLUSION

The "Renewable Energy-Based Microgrid Energy Management System" demonstrates the transformative potential of integrating solar, wind, and grid electricity to create a cost-effective and environmentally sustainable energy solution for residential applications. By leveraging advanced simulation techniques in MATLAB/Simulink, the project validates the economic and environmental advantages of adopting renewable energy in a residential microgrid setup. The significant reduction in electricity costs, combined with the increased reliance on renewable sources, underscores the feasibility of implementing such systems on a larger scale.

This project not only provides a blueprint for sustainable energy management in residential settings but also reinforces the importance of innovative energy solutions in addressing global challenges such as climate change and energy scarcity. By promoting the adoption of renewable energy and reducing carbon emissions, the proposed system aligns with the growing demand for sustainable living, paving the way for a greener and more economically viable future.

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