Journal of Electronics and Informatics (ISSN: 2582-3825)
www.irojournals.com/iroei/

BMS Control of UPS for Hybrid Energy System using IoT

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Abstract

This study explores the integration of renewable energy sources, namely wind and solar power, into a home power backup system. In the event of a main power outage, an uninterruptible power supply (UPS) automatically activates to provide electricity to the household. As the UPS operates, its battery gradually depletes. When the battery reaches a low charge threshold, the system initiates charging through renewable energy sources. Once the battery is fully recharged, any surplus energy is redirected to the electrical grid. The system incorporates IoT (Internet of Things) technology using an ESP32 microcontroller to monitor and display real-time data on the battery's State of Charge (SOC) and State of Health (SOH), enabling users to track system performance and anticipate maintenance requirements.

Keywords: ESP32, Renewable Energy Source, Battery, Blynk

1. Introduction

The integration of renewable energy sources such as photovoltaic (PV) panels and wind turbines into microgrids has led to the advancement of smart homes equipped with wind energy systems, rechargeable batteries, external power supplies, and electrical loads [1]-[5]. In this setup, when the UPS battery reaches a low charge level, it seamlessly transitions to renewable energy sources for recharging. Once the battery is fully charged, any excess energy is directed back to the microgrid, enhancing overall efficiency and promoting environmental sustainability [6]-[9]. The system also incorporates Internet of Things (IoT) technology, utilizing real-time

DOI: https://doi.org/10.36548/jei.2025.1.006
Received: 02.03.2025, received in revised form: 30.03.2025, accepted: 13.04.2025, published: 24.04.2025

monitoring of the battery's State of Charge (SOC) and State of Health (SOH), thereby supporting timely maintenance and performance optimization [10]. This research integrates renewable energy, smart automation, and intelligent energy management to provide a sustainable and dependable power solution for modern homes.

2. Flow Chart of Work

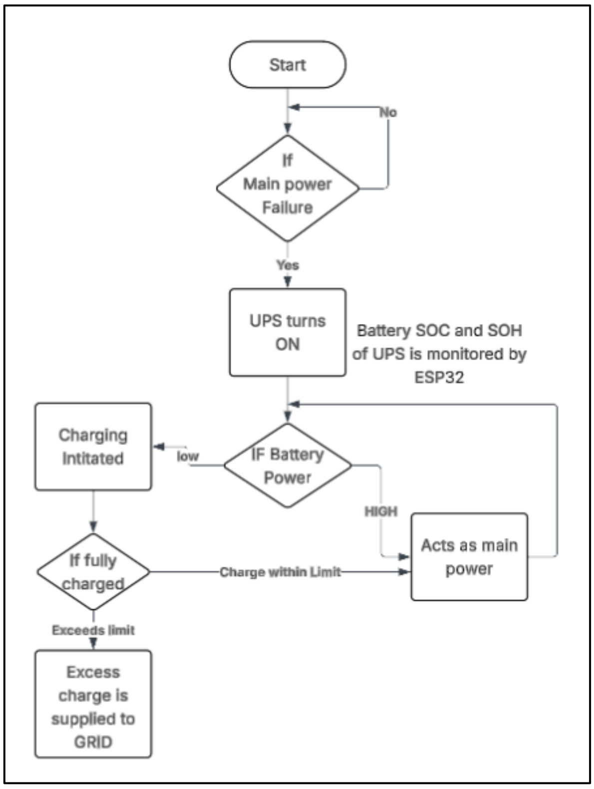

Figure 1. Flow Chart

2.1 Key Functional Flow Chart

The flowchart in Figure 1 shows how a smart home energy backup system works using renewable energy sources and is controlled by an IoT-enabled microcontroller. The step-wise description for the flowchart is as follows.

- **System Start**

  The process begins when the system is powered on.

- **ESP-32 Microcontroller**

  At the heart of the system is the ESP-32, manages all operations—from monitoring power levels to controlling energy flow and sending real-time updates.

- **Solar and Wind Energy Input**

  Solar panels and wind turbines supply renewable energy to the system. This energy is used for charging the battery and powering the home when needed.

- **Data Display on IoT Platform**

  The ESP-32 collects important data like battery charge and health and sends it to a IoT platform.

- **Power Outage Detection**

  The system continuously checks if the main grid power is available. If there's no power, it automatically shifts to backup mode.

- **UPS Powers the Home**

  During a power cut, the UPS (connected to the battery) starts supplying electricity to the home to ensure an uninterrupted power supply.

- **Battery Level Check**

  While the system is running on backup, it keeps checking the battery's charge level. If it drops too low, the system begins charging it using solar and wind energy.

- **Battery Monitoring (SOC & SOH)**
  - **State of Charge (SOC):** Shows how much energy is left in the battery.
  - **State of Health (SOH):** Indicates the overall condition and lifespan of the battery.

- **Battery Charging**

  The system charges the battery using renewable energy sources when the charge is low.

- **Battery Full Check**

  Once the battery reaches full charge, the system checks whether any excess energy is available.

- **Excess Energy Sent to Grid**

  If there's more power than needed, the system transfers it to the main grid, making the setup efficient and eco-friendly.

- **System Loop/End**

  The process keeps running in a loop to maintain continuous monitoring and smart energy management.

3. Proposed Work

The proposed system (Figure 2) combines a Battery Management System (BMS) with an Uninterruptible Power Supply (UPS) in a hybrid energy configuration supported using IoT technology. It improves energy efficiency by utilizing solar and wind power to recharge the UPS battery when its charge falls below a predefined level. Upon reaching this threshold, renewable energy sources are automatically activated to replenish the battery. An ESP32 microcontroller is used to monitor and transmit real-time battery data over the Internet of Things. Key battery parameters such as State of Charge (SOC) and State of Health (SOH) are continuously tracked to maintain system reliability. Furthermore, users can remotely access system information through a user-friendly interface, allowing for timely maintenance and effective energy management. This design promotes sustainable energy use while ensuring a consistent power supply.

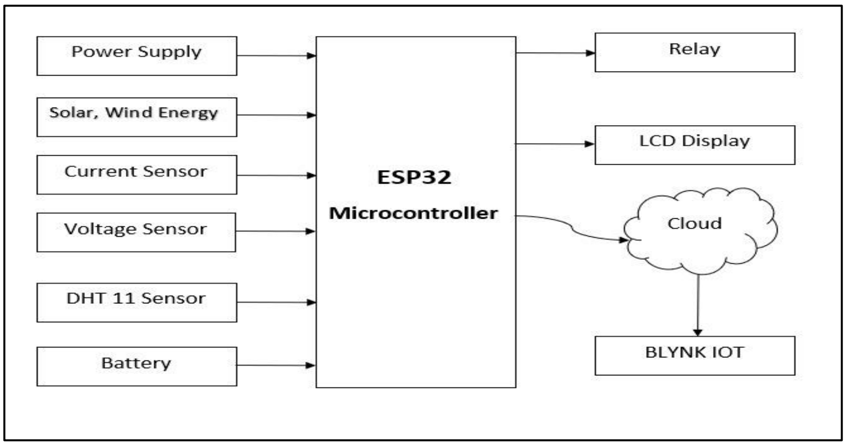

Figure 2. Block Diagram

3.1 ESP32 Microcontroller

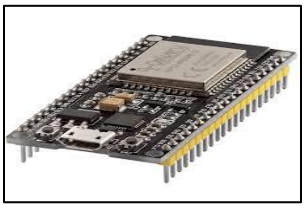

Figure 3. ESP32 Microcontroller

The ESP32 (Figure 3) is a powerful and flexible microcontroller designed by Espressif Systems, featuring integrated Wi-Fi and Bluetooth capabilities. As a System-on-a-Chip (SoC), it combines several functionalities on a single chip, making it ideal for applications in IoT, wireless communication, and embedded system.

3.2 Current Sensor

A current sensor (ACS712) in Figure 4 is used to detect and measure the amount of electric current flowing through a circuit, playing a key role in improving safety, efficiency, and overall system performance.

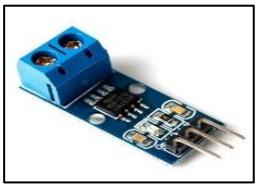

Figure 4. Current Sensor

3.3 Voltage Sensor

A voltage sensor is an electronic device used to monitor and measure voltage within a circuit, contributing significantly to the stability, safety, and efficiency of electrical systems. It works by sensing the voltage and converting it into an analog or digital signal that can be processed or analysed. A 25v voltage detection sensor module is used in the present study to monitor the voltage within the circuit (Figure 5).

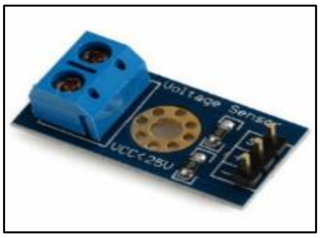

Figure 5. Voltage Sensor

3.4 DHT11 Sensor

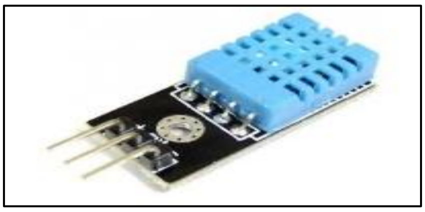

Figure 6. DHT11 Sensor

The DHT11 (Figure 6) is a sensor designed to measure both temperature and humidity, delivering digital output through a single-wire interface. It operates within a temperature range of 0°C to 50°C and can detect humidity levels from 20% to 90% relative humidity (RH). Due to its simplicity and ease of use, it is commonly implemented in applications such as weather stations, smart home systems, agricultural monitoring, and various IoT-based projects requiring environmental data.

3.5 LCD Display with I2C

An LCD (Figure 7) paired with an I2C (Inter-Integrated Circuit) interface simplifies data display by reducing the number of required GPIO pins. It communicates using only two lines—SDA (data) and SCL (clock)—which streamlines connections and makes it ideal for use in ESP32. This setup is widely used in embedded and IoT devices to efficiently present information without occupying multiple I/O pins.

Figure 7. LCD Display with I2C

3.6 Lead-Acid Battery

Figure 8. Lead-Acid Battery

A 6V, 4.5Ah lead-acid battery (Figure 8) is typically charged using the Constant Current/Constant Voltage (CC/CV) technique. In this method, the battery is first charged with a consistent current, which causes the voltage to rise. Once the voltage reaches a predefined level, the charging process switches to maintaining that voltage while the current gradually decreases. Standard charging times range from 12 to 16 hours, though more efficient methods can reduce this to approximately 8 to 10 hours.

3.7 Relay Module

A Single Channel Relay Module (Figure 9) is a small and efficient board used for controlling high-voltage and high-current devices, such as motors, lamps, solenoid valves, and AC appliances. It is paired with ESP32 for automation and switching tasks.

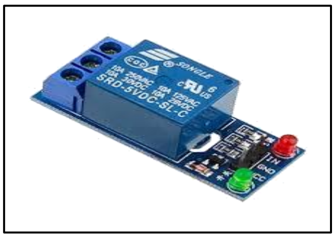

Figure 9. Relay Module

4. Circuit Diagram

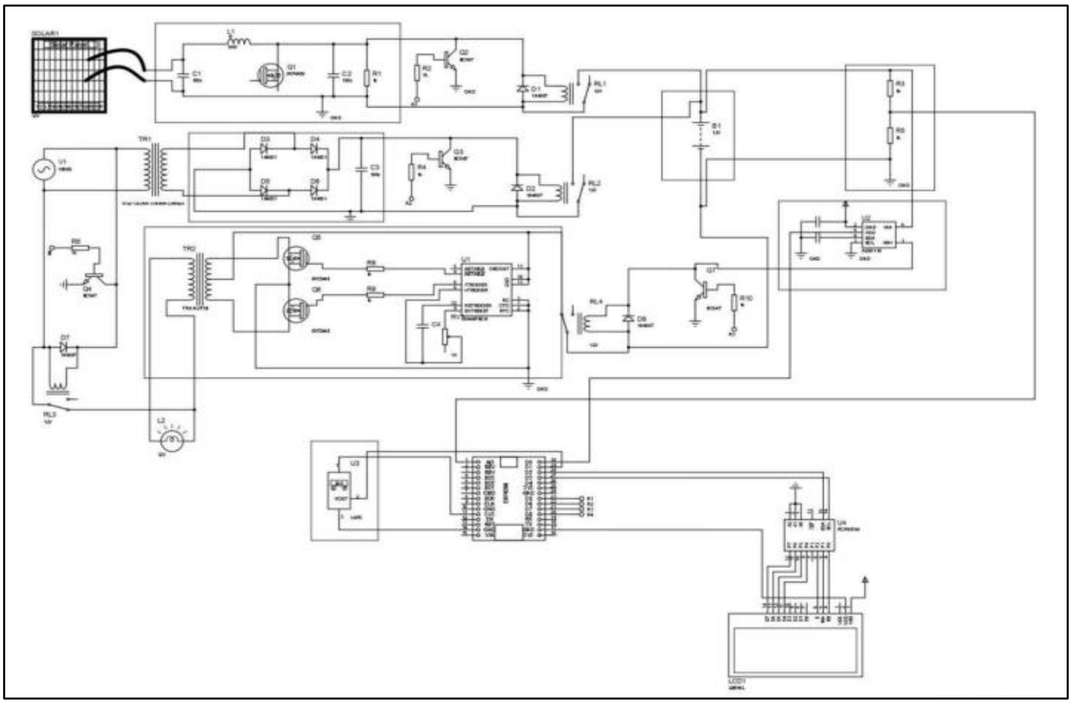

Figure 10. Circuit Diagram

The study aims to develop a smart home power backup system as shown in Figure 10 using renewable energy sources. The system uses a UPS to keep the home powered during a main power outage, charging the battery when it drops too low. An ESP32 microcontroller monitors the battery's condition, sending real-time data to the user through an IoT interface. All of this was designed and tested virtually using MATLAB Simulink. The simulation helped to fine-tune the system manage power flows and component interactions, before building the actual circuit. This approach saved time and made sure the system works correctly before moving to real-world implementation.

5. Working Methodology

The AC distribution network is connected to the load, with voltage and current levels being continuously monitored through a microcontroller. An ESP32 microcontroller is utilized for system control, as shown in the block diagram in Figure 1. The photovoltaic panel consists of multiple solar cells arranged to generate electrical energy. To maximize energy output, a Maximum Power Point Tracking (MPPT) circuit adjusts the panel's orientation for optimal performance. The generated energy is then fed into an inverter, which converts it into AC power. A separate microcontroller is employed for generating the Pulse Width Modulation (PWM) signal for the inverter and managing the four relays, AC loads, and grid interaction, facilitating efficient power distribution. The block diagram of the hybrid UPS system demonstrates how the microcontroller controls relay switching to ensure an uninterrupted power supply.

Case 1: SOC is lower than 80%

- If both Vsp and Vac are not available, R3 relay alone is turned on.
- If Vsp is not available but there is an AC source, then relay R2 and relay R4 is turned on.
- If Vsp is available but there is no AC source, then relay R1 and relay R3 is turned on.
- If Vsp and AC source are available, then relay R1 and relay R4 is turned on.

Case 2: SOC is greater than 80%

- If both Vsp and Vac are not available, the R3 relay alone is turn on.
- If Vsp is not available but there is an AC source, then relay R4 is turned oп.
- If Vsp is available but there is no AC source, then relay R3 is turned on.
- If Vsp and AC source are available, then relay R4 is turned on.

6. Hardware Outcome

The hardware setup of the BMS Control of UPS for Hybrid Energy System using IoT, SOC and SOH estimation is shown below in Figure 11.

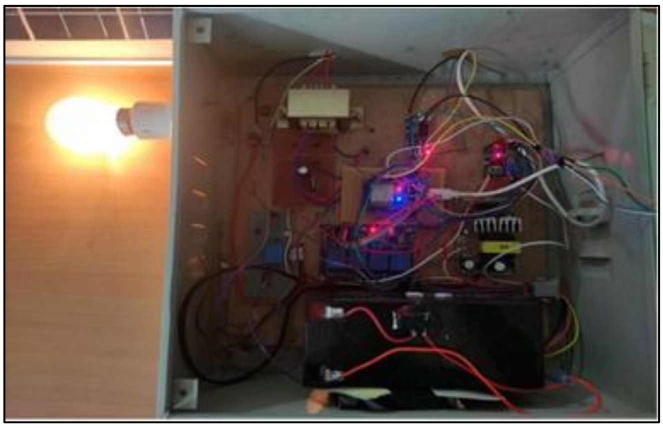

Figure 11. Prototype Hardware Implementation

This study demonstrates the effective integration of renewable energy sources, such as solar panels and wind turbines, within a smart home power management system. The hardware setup includes key components like renewable energy sources, uninterrupted power supply (UPS), external power sources, and essential electrical loads. One of the highlights of the system is its ability to automatically switch to renewable energy when the UPS battery level drops. Once fully charged, any surplus energy is intelligently redirected back to the microgrid, maximizing energy utilization and supporting a greener environment. The system is enhanced with IoT technology, enabling real-time tracking of the battery's State of Charge (SOC) and State of Health (SOH).

This helps in ensuring timely maintenance and improving battery life and overall performance. By combining clean energy, smart automation, and real-time data monitoring, the research delivers a practical, efficient, and eco-friendly power solution customized for the needs of modern homes.

7. Results

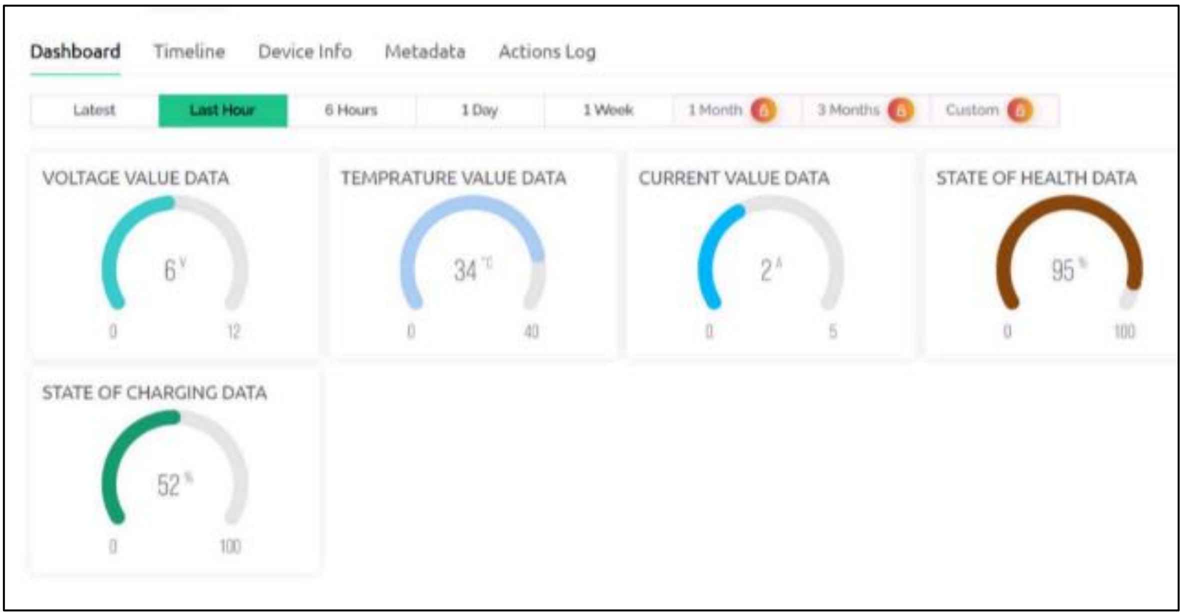

Figure 12. Output in IoT Blynk

Figure 13. LCD Display

The Internet of Things (IoT) plays a key role in the study to make the energy monitoring more efficient and accessible. The system employs sensors to track the battery parameters such as voltage, current, temperature, State of Charge (SOC), and State of Health (SOH). These readings are displayed on an LCD (Figure 13) and are also transmitted to the Blynk mobile app (Figure 12) through Wi-Fi for remote monitoring. When the system is activated, it immediately begins collecting and displaying live data. During testing, the system operated smoothly; the SOC increased as the battery charged, and the temperature and voltage were updated in real time. In the event of battery overheating, a relay was activated to regulate the temperature. Furthermore, the system automatically switches to an alternative power source if solar input decreases. This setup provides clear and reliable remote monitoring,

8. Conclusion

This research successfully demonstrates the development of a smart home power backup system that effectively integrates renewable energy sources with a UPS and IoT technology. The system achieves automated switching to renewable energy for recharging the UPS battery, optimizing energy use, and providing a continuous power supply. Real-time monitoring of key battery parameters (SOC and SOH) through IoT enhances system reliability and enables proactive maintenance. The implementation of this system enables a sustainable and practical solution for smart homes seeking efficient energy management and reliable power backup.

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