World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

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Smart Automatic Power Source Switching and Monitoring System Using Arduino

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World Journal of Advanced Research and Reviews, 2025, 28(01), 363-378

Publication history: Received on 27 August 2025; revised on 01 October 2025; accepted on 04 October 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.28.1.3422

Abstract

This paper presents the design and implementation of a smart automatic power source switching and monitoring system based on Arduino technology. The system intelligently prioritizes and selects among grid, generator, and inverter sources, while also integrating photovoltaic (PV) input for efficient battery charging. To enhance operational safety, the design incorporates overvoltage and undervoltage protection mechanisms that safeguard connected equipment under abnormal conditions. A 20×4 Liquid Crystal Display (LCD) provides real-time monitoring of the active source, AC voltage, frequency, PV power, and battery status. The deployed methods for this study to develop an algorithm for detecting and optimizing changes in power supply and demands using Arduino microcontroller and Proteus for the entire system expected performance demonstration purposes in real life. Experimental validation confirms the system's capability to perform reliable automatic switching, efficient fault detection and recovery, and effective renewable energy integration. The proposed system is cost-effective, scalable, and suitable for both residential and industrial applications in regions with unstable power supply.

Keywords: Arduino; Automatic transfer switch (ATS); Inverter; Photovoltaic system; Battery monitoring; Power protection

1. Introduction

Unreliable electricity supply is a major challenge in developing regions, often requiring multiple energy sources such as grid, generator, and inverter systems. Traditional Automatic Transfer Switches (ATS) primarily switch between grid and generator but lack renewable energy integration and intelligent monitoring. To address these limitations, this work proposes an Arduino-based smart automatic power source switching and monitoring system. The system prioritizes grid supply, selects inverter power when battery voltage is sufficient, and uses a generator as backup. It integrates solar PV monitoring for charging decisions and displays system status in real time. The global energy landscape is undergoing a significant transformation, driven by the need for sustainable, efficient, and reliable energy management. The increasing electricity demand, coupled with the integration of renewable energy sources, has led to the development of smart grids. Smart grids are advanced electrical grids that use Internet of Things (IoT) technologies, artificial intelligence, and other innovative solutions to manage energy distribution and consumption efficiently. However, the existing grid infrastructure faces several challenges, such as energy losses due to inefficiencies, power outages impact reliability and economy and cybersecurity as a result of increased in use of IoT devices. To this end, integrating Iot technologies in smart grids provides a solution to these challenges. Iot enables real-time monitoring and control of grid operations. The development of a smart grid monitoring and control system using Iot is crucial for achieving these benefits. This system will enable utilities and grid operators to monitor and control grid operations in real-time, optimize energy distribution and consumption, and improve overall grid efficiency and reliability. The distribution of digital power is increasing greatly day by day. The existing power grids are converted into smart grids to meet the growing power requirements. Information is accumulated from sensors, smart meters and several other devices for the

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sake of analysis and understanding. To implement IoT in smart grids, mobility support, location awareness, distributed coordination, and latency sensitivity are to be considered. Smart Grid systems in combination with Internet of Things-Aided Smart Grid: Technologies, Architectures, Applications, Prototypes and Future Research Directions as described by Saleem *et al* (2019) and Famoriji et. al. (2020)

IoT allows smart monitoring and control of smart grid by (Ozgen *et al.,* and Wang *et al.,* 2018). In electronics connected via the internet, smart plugs, home gateways and smart meters, the application of IoT facilitates proficient resource management. The consumers can obtain information regarding the consumption of energy and price on a real-time basis, thereby moderating the energy consumption. The producer can forecast energy requirements and moderate distribution. The paper experiments with distributing workload between edge and cloud in a Smart Grid application: looking at how many sensor readings/measurements per second can be processed when using edge nodes vs central cloud. Hence, the system is beneficial to both ends as presented by Carvalho *et al.,* 2017, and Tamara-Tarime *et. al.* (2024). Millions of users interact with smart grids and their information flow. It is important to focus on the scalability of this system. Cloud computing serves as an optimal solution for this purpose. Several architectures, such as event processing for load forecasting, lambda, kappa and cyclic architectures are designed and implemented for processing the data generated by these systems. In IoT-based Smart Grid architectures, the components communicate with each other through the internet. Resource constraints and scarcity of spectrum are major issues in the wireless nodes of these systems (Ozger *et al.,* 2018). Pan Wang *et al* (2018), proposes a fog-based architecture and a programming model for IoT applications in smart grids and Emphasizes location-aware**,** latency-sensitive monitoring and an intelligent control in the smart grid. A programing model and fog-based architecture that serves the requirements of smart grid also presented by their research paper demonstrated the operation of a smart electric automobile prototype for evaluation. their findings were able to contribute to the body of knowledge in the field of smart grids and IoT, providing insights for utilities, grid operators, and policymakers to develop and implement efficient and reliable smart grid systems. Electricity grids serve as the backbone of modern society, facilitating the generation, transmission, and distribution of electrical power to homes, businesses, and industries. However, traditional electricity grids are facing numerous challenges that hinder their ability to meet the evolving needs of the 21st century. Conventional grids are overloaded by a daily increase in demand, and the conventional solution techniques are increasing the complexity of the existing network (Kakran *et al.,* 2018, and Makanju et. al. (2024a). The primary challenges of traditional electricity grids include limited visibility and control, low efficiency and reliability, vulnerability to disruptions, limited integration of renewable energy, and inadequate data and analytics. These issues underscore the need for more advanced and resilient grid systems, the smart grid. Smart grid is an intelligent network which enhance collection of various electrical information from the electrical network using intelligent sensors and fast communication systems (IoT) in balancing demand and supply (Kakran *et al.,* 2018) With the advent of smart grid, stated that renewable energy resources can be safely integrated into the grid to supplement the power supply with power from customers' distributed generation and storage which was also described by Tuballa *et al.,* 2016 and Makanju *et. al*. (2024b). Traditional grids often lack real-time visibility into the status and performance of grid assets, making it difficult to detect and respond to faults, outages, and fluctuations in demand. Without adequate monitoring and control capabilities, grid operators are unable to optimize grid operations or implement proactive maintenance strategies. They are characterized by inefficiencies in energy generation, transmission, and distribution, leading to power losses, voltage fluctuations, and reliability issues. These inefficiencies not only waste valuable energy resources but also contribute to increased operating costs and reduced grid reliability. In addition, traditional grids are vulnerable to disruptions caused by natural disasters, equipment failures, and cyberattacks. These disruptions can lead to widespread power outages, economic losses, and threats to public safety, highlighting the need for more resilient and robust grid infrastructure. With the growing adoption of renewable energy sources such as solar and wind power, traditional grids face challenges in integrating intermittent and decentralized generation sources into the grid. The lack of visibility, control, and flexibility in traditional grids makes it difficult to accommodate the variability and unpredictability of renewable energy resources. They often rely on manual processes and outdated technologies for data collection, analysis, and decision-making. This lack of automation and data-driven insights hinders grid operators' ability to optimize grid operations, plan for future infrastructure investments, and meet regulatory requirements. Real-life limitations of traditional power grid systems can be observed in the electric power sector of Nigeria as a country. Nigeria's electric power sector has an operating capacity of 3,800 MW and an available capacity of approximately 9,000 MW. Over the years, the Nigerian government has made efforts to address its power generation, distribution, transmission, distribution, monitoring, metering and management challenges throughout its electric power value chain, but little significant improvement has so far been achieved. Historically, the Nigeria Power System was established in 1898 by European entities, primarily serving the European residential area. Subsequent developments included the formation of the Nigeria Electricity Corporation (NEC) in 1951 and the Niger Dams Authority in 1962, both aimed at promoting hydroelectric power. The merger of the independent National Electric Power Authority (NEPA) and NEC led to the creation of the Authority for Niger Dams, and eventually, NEPA was transformed into Nigeria's Power Holding Company (PHCN) (Ajay and Ibe-Enwo, 2019).

2. System Design

2.1. The System Block Diagram

The system block diagram represents an Automatic Power Source Switching and Monitoring Unit that intelligently manages electricity supply from multiple sources. It continuously monitors the availability and condition of the mains grid, generator, and inverter powered by a solar-charged battery. Based on predefined logic, the control unit automatically selects the most suitable source while ensuring protection against overvoltage and undervoltage conditions. Real-time information such as active source, voltage levels, frequency, and battery status is displayed on an LCD screen, while LED indicators provide quick visual feedback. This design ensures uninterrupted power delivery, optimizes solar energy usage, and enhances system safety and reliability.

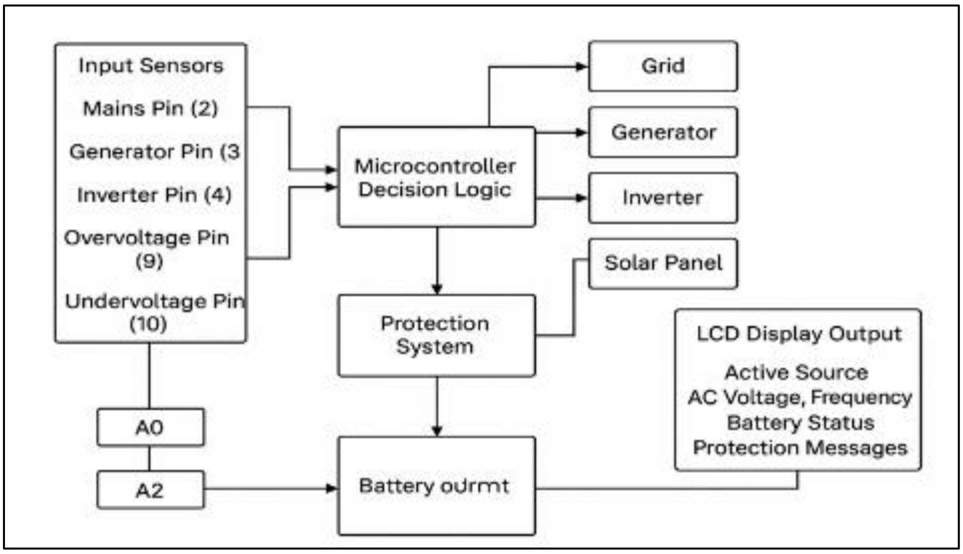

Figure 1 System Block Diagram

2.1.1. Input Section (Sensors & Switches)

- **Mains Pin (2)** → Detects grid availability.
- **Generator Pin (3)** → Detects generator status.
- **Inverter Pin (4)** → Detects inverter availability.
- **Overvoltage Pin (9)** → Senses high-voltage faults.
- **Undervoltage Pin (10)** → Senses low-voltage faults.

2.1.2. Analog Inputs:

- **A0** → Reads solar panel voltage.
- **A2** → Reads battery voltage.

Function: These inputs serve as decision-making signals for selecting the power source and activating protection mechanisms.

2.1.3. Microcontroller (Arduino Core)

- Reads inputs continuously.
- Applies priority-based source selection:
  - Grid (if available and safe).
  - Inverter (if battery is healthy).
  - Generator (if other sources are unavailable).
- Executes protection logic: If over/undervoltage detected → disconnect all loads and display fault.
- Manages automatic recovery when fault clears.
- Calculates PV power, current, and battery status.

Function: Acts as the *brain* — processes sensor data, runs switching logic, and updates display.

2.1.4. Output Section

LEDs:

- Mains LED (Pin 5)
- Generator LED (Pin 6)
- Inverter LED (Pin 7)
- Load LED (Pin 8) → Shows load is powered

LCD (20x4 I2C):

- Displays current active source.
- Shows AC voltage, frequency.
- Displays battery status or PV data alternately.
- Shows protection messages (Overvoltage/Undervoltage).

Function: Provides visual feedback of system status to the user.

2.1.5. Power Sources

- **Grid (Mains Supply)**
- **Generator**
- **Inverter** (battery-powered)
- **Solar Panel** (for charging & supplying inverter)

Function: These are the actual supply options. The microcontroller chooses one based on availability and health.

2.1.6. Protection System

- Overvoltage Detection
- Undervoltage Detection
- Automatic cut-off to prevent damage.
- Auto-recovery when voltage returns to safe range.

Function: Ensures electrical safety and prevents equipment damage.

2.1.7. Control Logic

- Source Priority: Grid → Inverter → Generator
- Battery Voltage Conditions:
  - 56V → allow inverter operation.
  - <42V → stop inverter to prevent deep discharge.
- PV Charging Logic:
  - If PV voltage ≥ 60V → calculate charging current & power.
  - Show “Charging” or “Fully Charged” status.

Function: Implements intelligent, condition-based switching.

2.1.8. The System Flow Chart

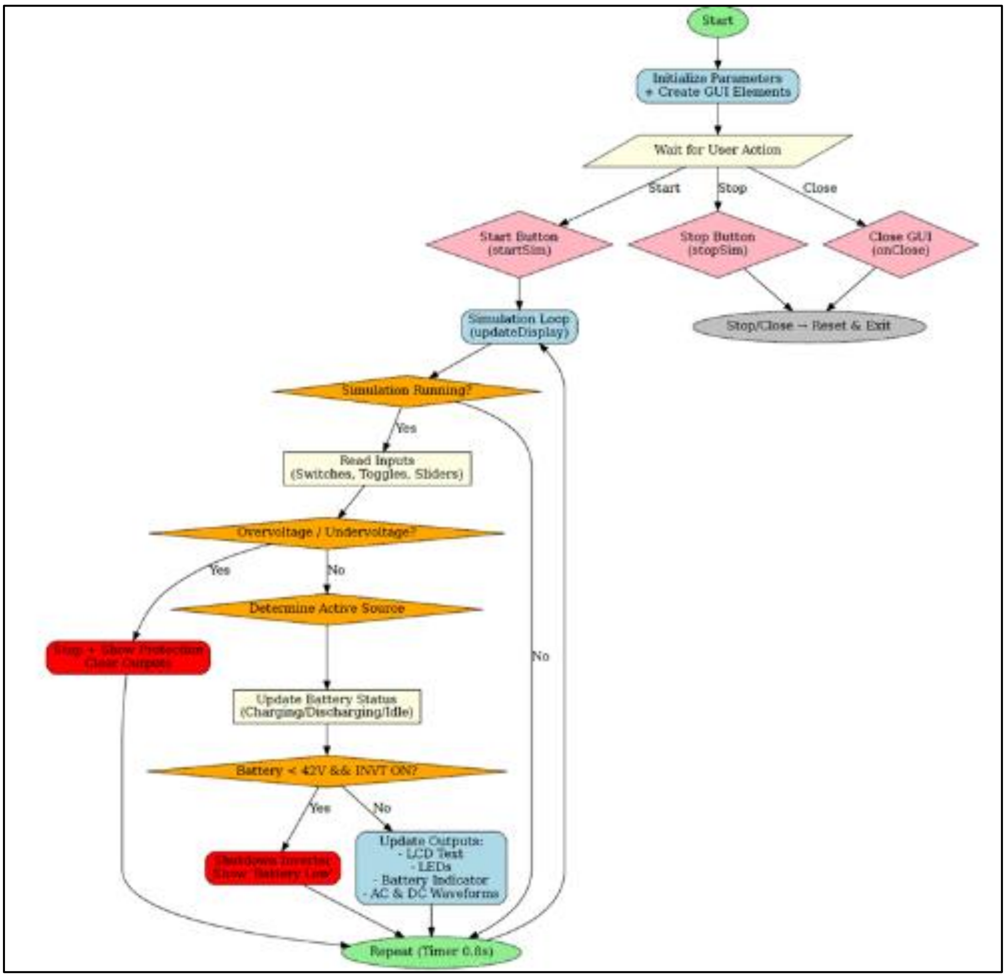

Figure 2 The System Flow Chart

Start & Initialization

- The microcontroller powers up.
- LCD is initialized and cleared.
- Input pins (mains, generator, inverter, overvoltage, undervoltage) are set.
- Output pins (LEDs for mains, generator, inverter, load) are set LOW.
- Initial power source is selected based on availability and battery level.

Voltage Fault Detection

- Check overvoltage and undervoltage inputs.
- If a fault is detected:
  - All sources are disconnected.
  - Display fault type ("Overvoltage!" or "Undervoltage!").
  - Wait until fault is cleared.

Source Status Reading

- Read the status of mains, generator, and inverter inputs.
- Read solar voltage and battery voltage via analog pins.

PV (Solar) Cutoff Logic

- If solar voltage ≥ 60V:
  - Calculate simulated current and PV power.

- Else:
  - PV output is zero.

Source Switching Logic

- If mains available → Activate GRID.
- If mains lost while on GRID → Check inverter (with battery ≥ 56V) or generator.
- If generator lost → Check mains or inverter (battery ≥ 42V).
- If inverter lost or battery too low → Check mains or generator.
- Auto-switch between inverter and generator based on battery level.

Display Updates

- Every second, toggle display between:
  - Battery Status (low, charging, in use, idle)
  - PV Status (voltage, current, power).
- If a source is active → Show AC voltage and frequency.

Recovery Check

- If no active source, check again for mains, inverter, or generator.
- Select best available option automatically.

Loop Back

- Delay briefly (100ms) and repeat from step 2.
- This flow ensures continuous power supply by automatically selecting the best available
- source while protecting the system from faults.

2.2. The System Simulated Circuit Diagram

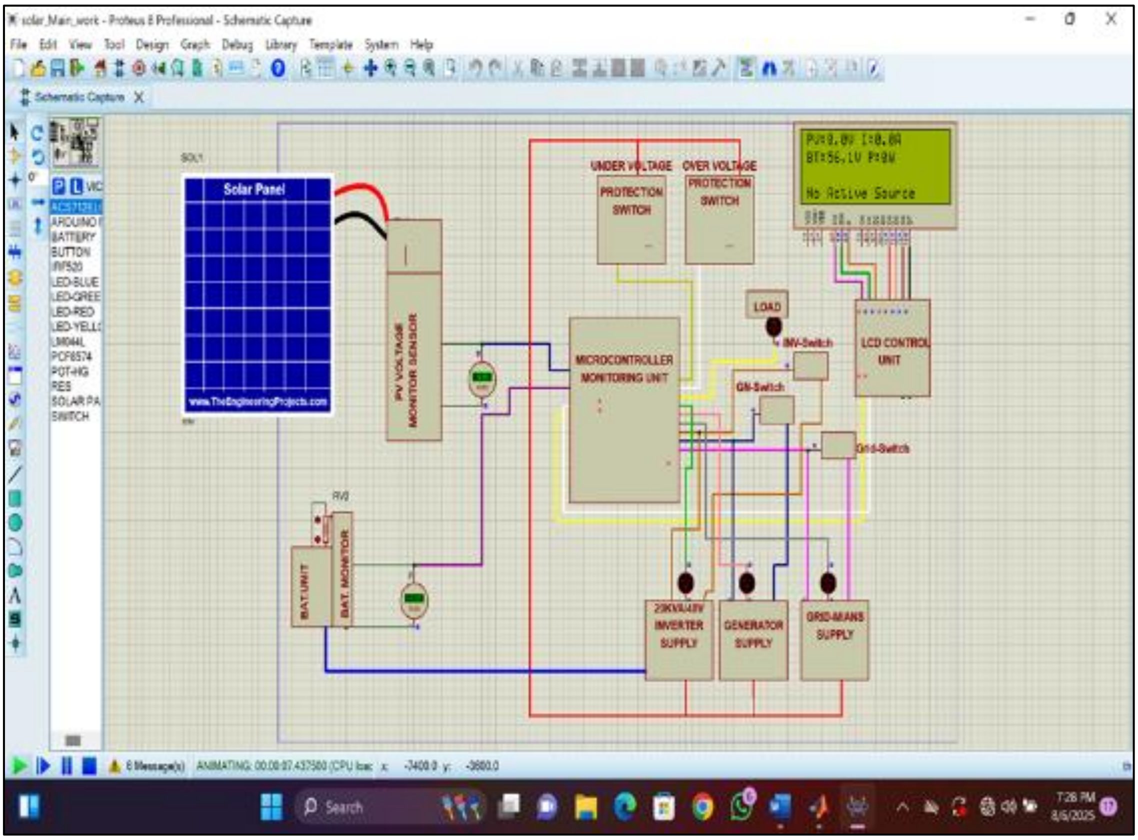

Figure 3 Proteus Simulation Circuit Diagrams

2.2.1. Core of the Circuit: The Arduino board is the heart of the system. It:

- Receives signals from voltage sensors and switch inputs.
- Controls LED indicators.
- Sends real-time data to an I2C LCD display.
- Makes switching decisions for the power sources.

2.2.2. Input Section (Sensors & Control Pins): These are connected to Arduino digital and analog pins

Table 1 Digital Inputs

Pin	Signal	Purpose
D2	Mains Pin	Detects grid (mains) availability
D3	Generator Pin	Detects generator ON/OFF
D4	Inverter Pin	Detects inverter availability
D9	Overvoltage Pin	Receives overvoltage trip signal
D10	Undervoltage Pin	Receives undervoltage trip signal

Table 2 Analog inputs

Pin	Signal	Purpose
A0	Solar Voltage	Reads PV panel voltage (via voltage divider)
A2	Battery Voltage	Reads battery voltage (via voltage divider)

Connection Method:

- Sensors like voltage dividers or optocouplers feed these pins.
- Over/Undervoltage signals could come from a comparator circuit.

2.2.3. Output Section (Indicators & Display)

LED Indicators

Table 3 LED indicator

Pin	LED	Meaning
D5	Mains LED	Grid source active
D6	Generator LED	Generator active
D7	Inverter LED	Inverter active
D8	Load LED	Load is powered

Connection Method: LEDs connected through resistors (220–330 Ω) to ground.

2.2.4. LCD Display (20x4 I2C)

Connected via **I2C lines**

- **SDA** → Arduino A4 (on UNO)
- **SCL** → Arduino A5 (on UNO)

Shows

- Active power source

- AC voltage & frequency
- Battery/PV status
- Protection messages

2.2.5. Power Sources

- **Grid (Mains)** — possibly detected via relay or optocoupler.
- **Generator** — signal pin detects when it's running.
- **Inverter** — works when battery voltage is sufficient.
- **Solar Panel** — charges the battery and powers inverter.

2.2.6. Protection Circuit

- Overvoltage & undervoltage detection from protection relays or sensor modules.
- Arduino reacts by cutting load and showing a warning on LCD.
- Recovery logic restores power when voltage returns to normal.

2.2.7. Functional Flow in Circuit

- Sensors → Arduino inputs.
- Arduino runs decision logic → decides which source to activate.
- LEDs light up for the active source.
- LCD updates with live status.
- If a fault is detected, Arduino switches off load and warns user.
- Solar input & battery voltage readings help decide when to switch between inverter and generator.

2.2.8. Simplified Circuit Connection Table

Table 4 A simplified circuit connection table

Component	Arduino Pin(s)	Notes
Main's sensor	D2	Digital input
Generator sensor	D3	Digital input
Inverter sensor	D4	Digital input
Overvoltage trip	D9	Digital input
Undervoltage trip	D10	Digital input
Solar voltage sensor	A0	Voltage divider
Battery voltage sensor	A2	Voltage divider
Mains LED	D5	With resistor
Generator LED	D6	With resistor
Inverter LED	D7	With resistor
Load LED	D8	With resistor
LCD SDA	A4	I2C data
LCD SCL	A5	I2C clock

2.3. The Generator Triggering Prototyped Simulation Results

This section demonstrated the developed system of the study where applicable smart grid significantly upgrade traditional power systems by improving efficiency, reliability, and consumer interaction. The system promised automated energy adjustments, sustainable practices, and greater consumer participation, offering businesses operational efficiencies and new revenue opportunities. This makes smart grid technology a strategic investment for future-focused companies. This section describes the outcome of laboratory prototyping work and the study's outcome. The simulated system designed circuit diagram in figure 4a shows that the generator automatically starts up immediately the system battery voltage dropped to 12.2V by ensuring that the LED light comes ON thereby keeping the system running on On-grid mode while the Figure 5 shows that the generator automatically shut down immediately the system battery voltage rises to 13.5V by ensuring that the LED light goes OFF thereby keeping the system running on Off-grid mode. Hence, the system can only automatically trigger into Island mode at any time of the day with a severe cloudy weather or at night when other integrating sources remains idle. At this time, the system will be running on Battery Energy Storage System (BESS)

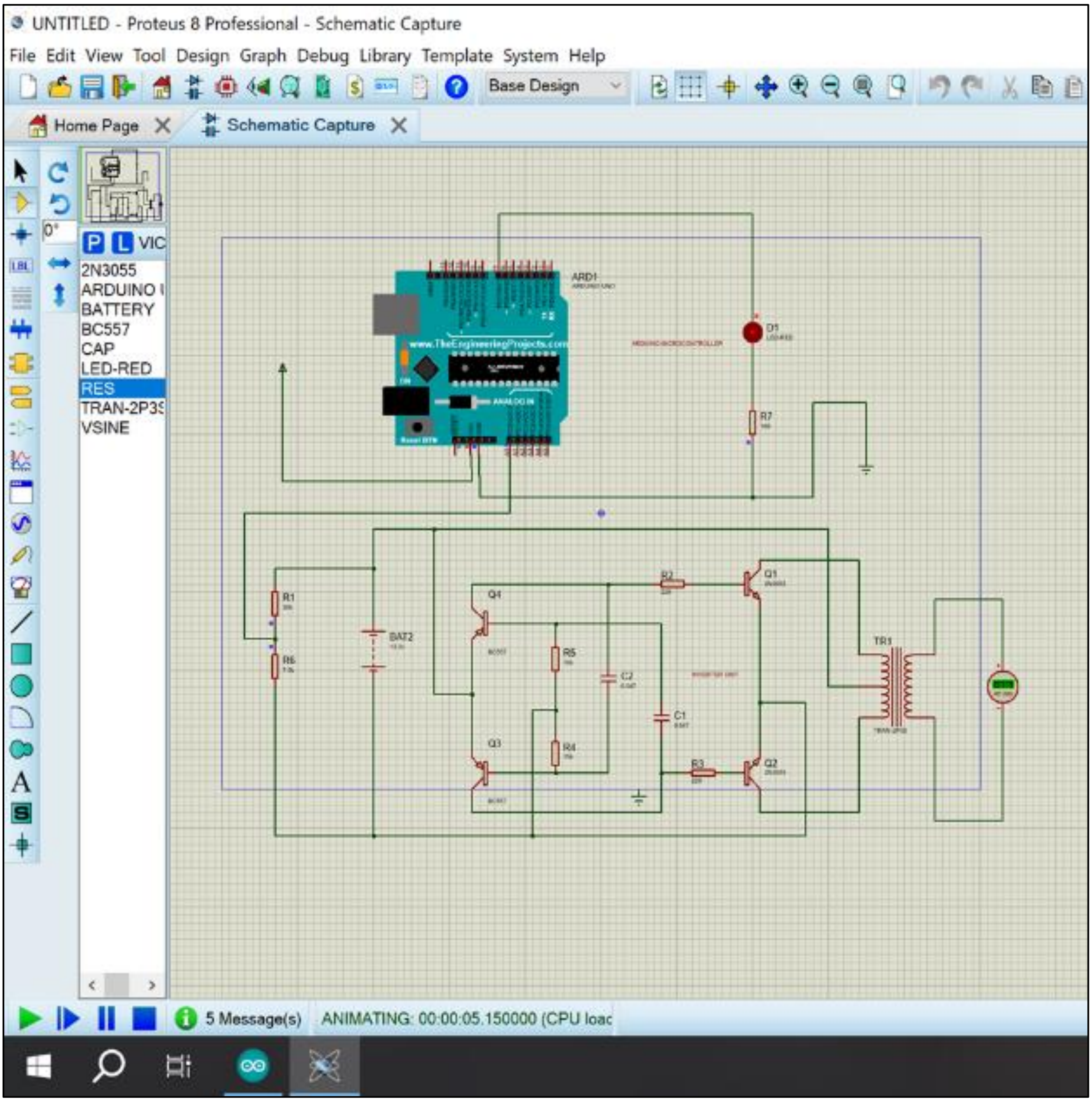

Figure 4 Simulated System Circuit Diagram of Battery Voltage at 12.2Vdc

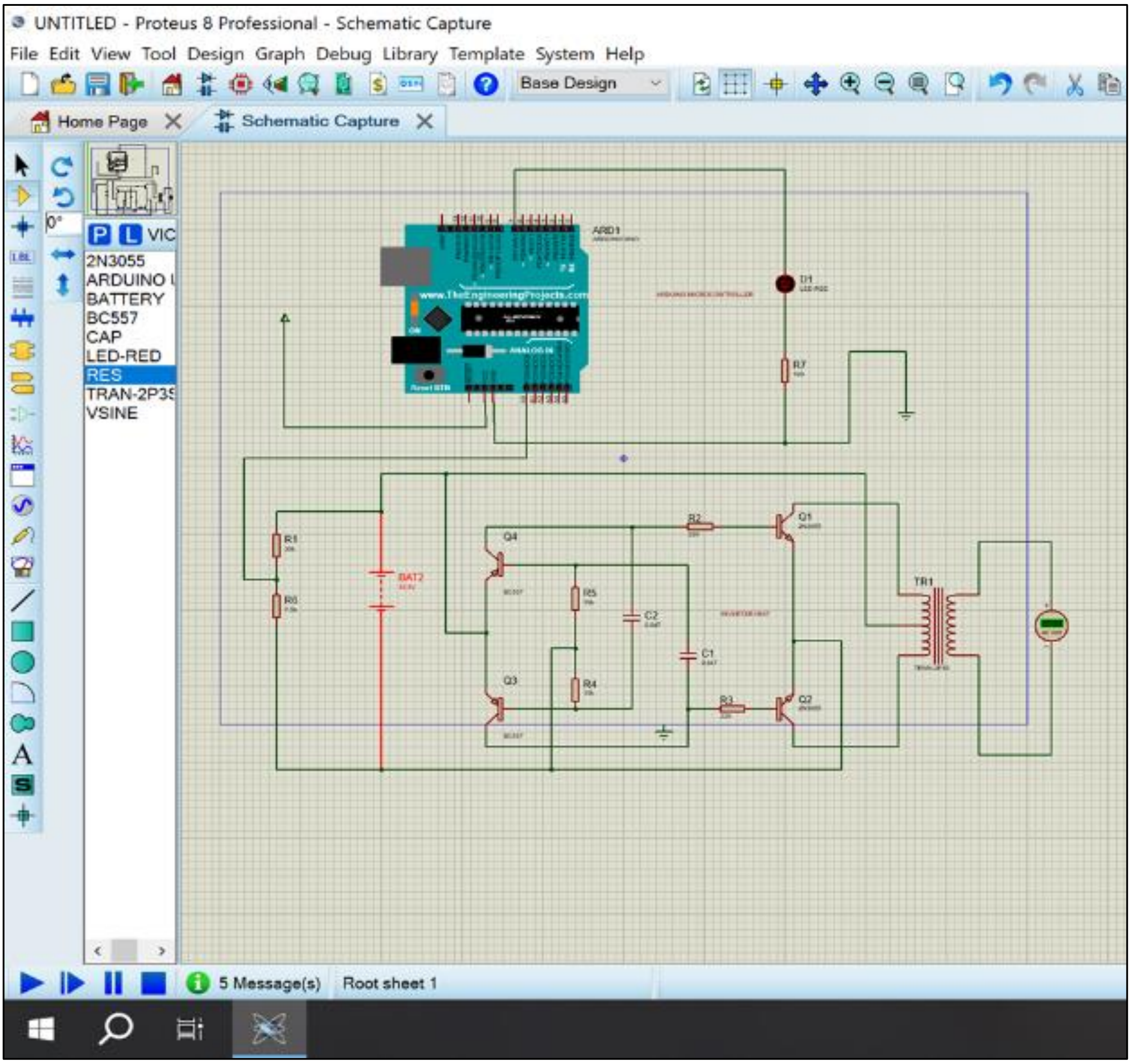

Figure 5 Simulated System Circuit Diagram of Battery Voltage at 13.5Vdc

The developed prototype monitoring and controlling system was successfully integrates IoT-based monitoring with automated control logic for a solar inverter system. In practical deployment, it ensures reliable power management by maintaining battery health while minimizing generator fuel usage. With additional sensors and analytics, the system could evolve into a more comprehensive smart microgrid controller.

2.4. Operational Mode of the connected Inverters and Generator: The system consists of 6 units

of 1.8kva 12v Inverters paralleled connected using communication cable RS 485 through the various communication ports to enhance the system higher capacity as the load is increasing under smart monitoring conditions and 1 unit of 12kva generator to automatically bring the entire system to On-grid mode whenever the needs arise. Figure 6 is the Schematic diagrammatical representation of the developed system.

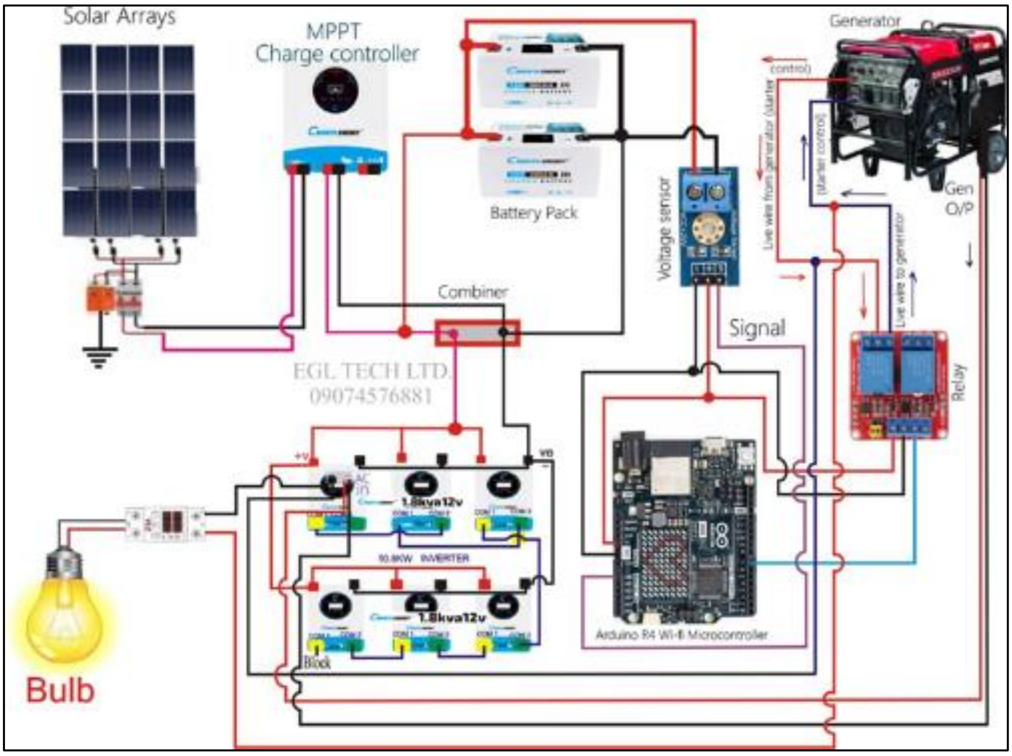

Figure 6 Schematic Diagram of the Study

- **Mode 1: Grid-Tied Mode:** On this Mode, the Inverters operate in grid-tied mode, synchronizing with the grid frequency and voltage. IoT sensors monitor grid parameters, inverter performance, and energy consumption. The system battery bank receives DC charging power strictly from the Solar panels depending on the weather sunlight variation and the strength of the connected loads. The generator is not operational in this mode at all until when the system battery voltage reduces to 12.2V.
- **Mode 2: Island Mode**: Here, Inverters operate in island mode, providing power to the local load through the energy stored in the battery bank when the grid is unavailable. By the inverters the same time charging the battery, ensuring a continuous energy supply time the system battery voltage reduces to 12.2v, the generator starts and provides power to under bypass conditions. The IoT sensors monitor inverter performance, generator performance, and energy consumption.
- **Mode 3: Hybrid Mode:** Here, Inverters operate in hybrid mode, combining grid power, solar PV and generator power to optimize energy efficiency. This is the mode where emergency optimization is required, most especially when there is no constant sunlight intensity to charge the batteries to full capacity. this enables the system to constantly switch between the On-grid mode, the Inverter Mode and off-grid mode due to weather and generator frequency instability. The IoT sensors monitor grid parameters, inverter performance, generator performance, and energy consumption.
- **Mode 4: Battery Energy Storage System (BESS) Mode:** In this mode, Inverters only work on storage systems which is the batteries during off-peak hours or when excess energy is stored in the battery. The timeline backup depends on the battery storage capacity. IoT sensors monitor energy storage system state-of-charge, inverter performance, and energy consumption.

3. Results and Discussion

Table 5 Experimental Result Table under different Loads Conditions

Case	Mains	Inverter (Battery V)	Gen.	PV V (V)	Load (kW)	Measured Batt V (V)	Measured Load I (A)	Measured AC V (V)	Active Source	Switch Time (s)	LEDs On	Notes
1	ON	— (N/A)	OFF	62.0	1.0	59.2	4.5	224	GRID	0.0	Mains, Load	Stable grid; PV charging battery.
2	OFF	ON (58.5)	OFF	61.0	0.8	58.1	3.6	223	INVT	0.5	Inverter, Load	Inverter feeding load; battery slowly discharging.
3	OFF	ON (43.0)	ON	59.0	2.5	42.5	11.0	225	GEN	1.2	Gen, Load	Battery low → generator started and took load.
4	OFF	ON (45.0)	ON	63.5	3.2	44.8	14.1	222	GEN	0.9	Gen, Load	Auto-switch INVT→GEN since Batt < 44 V threshold.
5	OFF	OFF	OFF	55.0	0.6	41.0	2.5	—	None	—	All OFF	No source available → load off or alarm activated.
6	ON	ON (59.0)	ON	66.0	5.0	60.5	22.0	226	GRID	0.0	Mains, Load	High PV measured — if OV input triggered, protection would trip.
7	OFF	ON (40.5)	OFF	58.0	1.2	40.2	5.0	—	None	—	All OFF	Battery undervoltage → inverter shutdown (protection).

8	OFF	ON (57.0)	ON	64.0	10.0	56.8	44.0	223	GEN	1.0	Gen, Load	Heavy load near system capacity; gen supplies load; inverter on standby.

This Table illustrate eight different cases for measurement of the Inverter, generator, PV Voltage transients with D.C and AC Voltage and Current measurement.

The system enhances reliability, reduces downtime, and prevents electrical hazards. Compared to conventional ATS, this design is more intelligent and cost-effective.

3.1. Cases Interpretation

- **Case 1 (Grid available)**: System prioritizes GRID — stable AC output, battery is being charged by PV/grid. No switching delays.
- **Casee 2 (Grid down, inverter OK)**: INVT supplies load; battery slowly supplies inverter output. Monitor battery discharge rate for longer runtimes.
- **Case 3 & 4 (Battery low)**: Controller correctly auto-starts GEN when battery drops below thresholds; switch times ~1 s (software decision + hardware relay time). Good for uninterrupted supply.
- **Case 5 (No source)**: System cannot supply load — design should alert users or shed non-critical loads.
- **Case 6 (High PV / potential OV)**: If PV pushes system high and OV input set, protection must trip. Ensure OV hardware threshold matches controller expectations.
- **Case 7 (UV)**: Inverter shuts down to protect battery — user alert required; prevents deep discharge.
- **Case 8 (Heavy load)**: At high loads (~10 kW) generator is primary. Check generator capacity and thermal/load-sharing if multiple sources are expected.

3.2. Graphical representation of measured Results

The graphical representation of the various measured parameters simulated results across cases are represented one after the other.

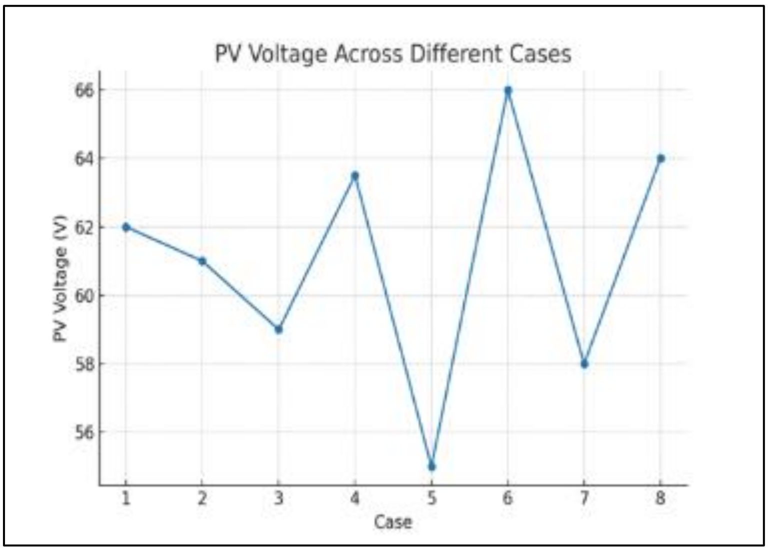

Figure 7 PV Voltage Across different cases

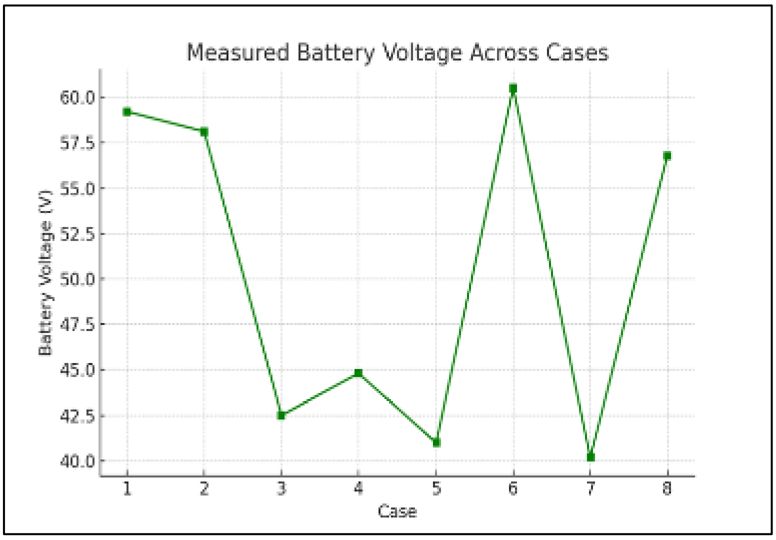

Figure 8 Battery across Cases

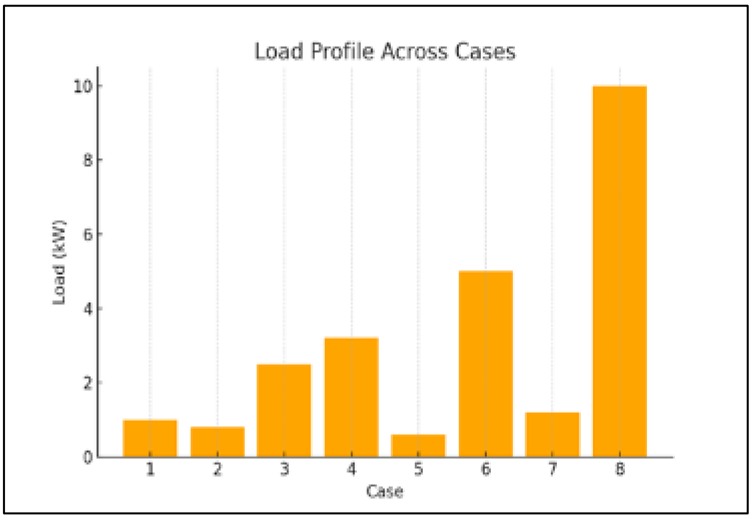

Figure 9 Load across Cases

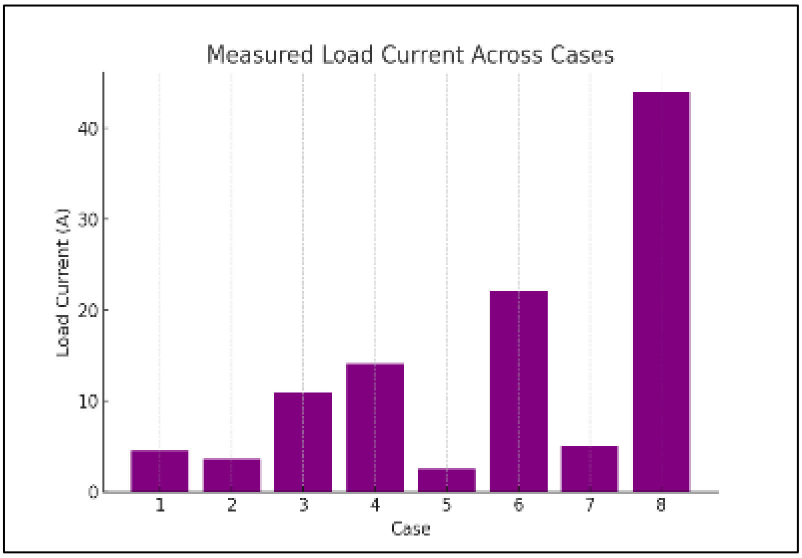

Figure 10 Load Current across cases

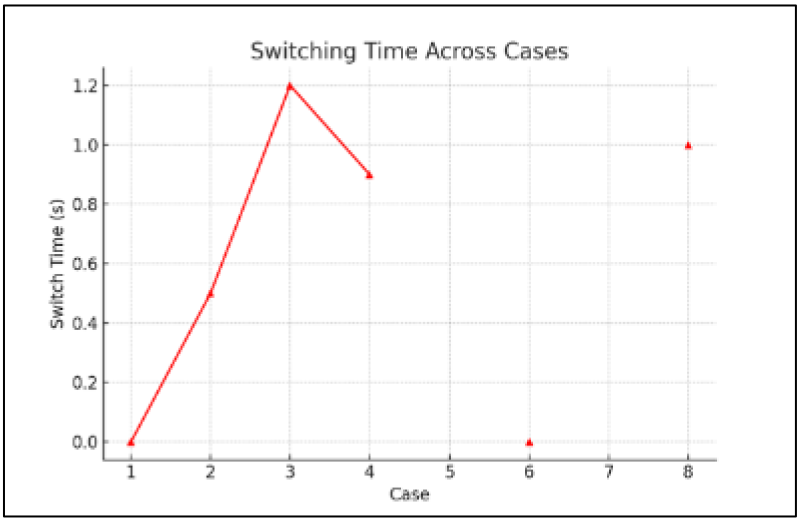

Figure 11 Switching time across cases

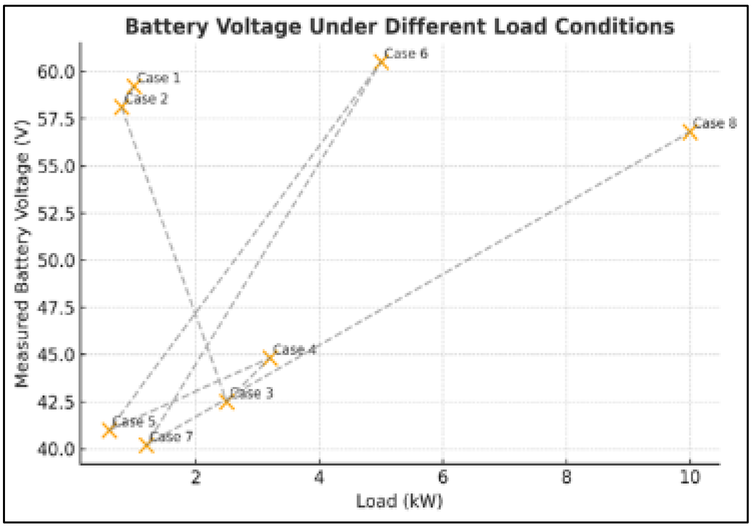

Figure 12 Battery Voltage across Loads

4. Conclusion

A smart Arduino-based automatic power source switching and monitoring system has been developed and tested. The system integrates PV charging, intelligent source prioritization, and protective shutdowns while providing user-friendly feedback. This makes it suitable for households and small industries in areas with frequent power instability. The incremental conductance MPPT algorithm proved efficient in tracking the maximum power point (MPP) with minimal oscillations, thereby optimizing PV energy harvesting. The inverter and charge controller's stability algorithms effectively mitigated voltage and frequency fluctuations during load variations, while the battery storage system ensured continuous power supply during low irradiance periods.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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