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Design and Implementation of a Solar-Powered Lithium Battery Pack for Laptop Energy Backup in Low-Infrastructure Environments

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Abstract

This study presents the design and implementation of a solar-powered lithium-ion battery system for powering a 100 W laptop load. The motivation for the work arises from the high cost and limited availability of replacement laptop batteries, as well as the need for a lightweight and reliable backup power solution. The system utilizes a photovoltaic panel integrated with a maximum power point tracking (MPPT) charge controller to efficiently harvest solar energy. A 3S24P lithium-ion battery configuration is employed for energy storage, supported by a battery management system for protection and balancing. A DC-DC boost converter is used to regulate the output voltage to 18.5 V required by the laptop. Experimental results demonstrate that the system can reliably supply the load for up to 6 hours under standard operating conditions. The proposed design offers a cost-effective, portable, and environmentally friendly alternative to conventional energy storage systems, making it suitable for deployment in regions with unreliable grid power.

Keywords: Solar Energy, Photovoltaic (PV) System, Lithium-ion Battery, MPPT (Maximum Power Point Tracking), Battery Management System (BMS), DC-DC Boost Converter

Introduction

Background

Access to reliable electricity remains a major challenge in Nigeria and many developing regions. Frequent power outages, high fuel costs, and the environmental impact of fossil-fuel-based generators have intensified the need for alternative energy solutions (Ijeoma et al., 2024; Abdulkarim et al., 2020). Solar energy, being

abundant and renewable, presents a viable option for decentralized and portable power systems. Nigeria receives significant solar irradiance throughout the year, with peak sun hours varying by geographic location, making photovoltaic (PV) technology particularly attractive for off-grid applications (Abdulkarim et al., 2020; Khan, 2020). However, efficient storage and utilization of this energy remain critical challenges, particularly when targeting specific loads such as laptop computers that require stable DC voltage and consistent power delivery.

Photovoltaic systems convert sunlight directly into electricity through the photovoltaic effect, with the output characteristics heavily dependent on solar irradiance and ambient temperature (Maniraj & Fathima, 2020; Muhammad, 2023). The performance of PV modules is typically investigated using power-voltage (P-V) and current-voltage (I-V) curves, which help identify the maximum power point under varying environmental conditions (Maniraj & Fathima, 2020). For low-power applications such as laptop charging, the integration of solar harvesting with appropriate energy storage and power conditioning electronics is essential to ensure reliable operation (Maleczek et al., 2020; Szczepaniak et al., 2021).

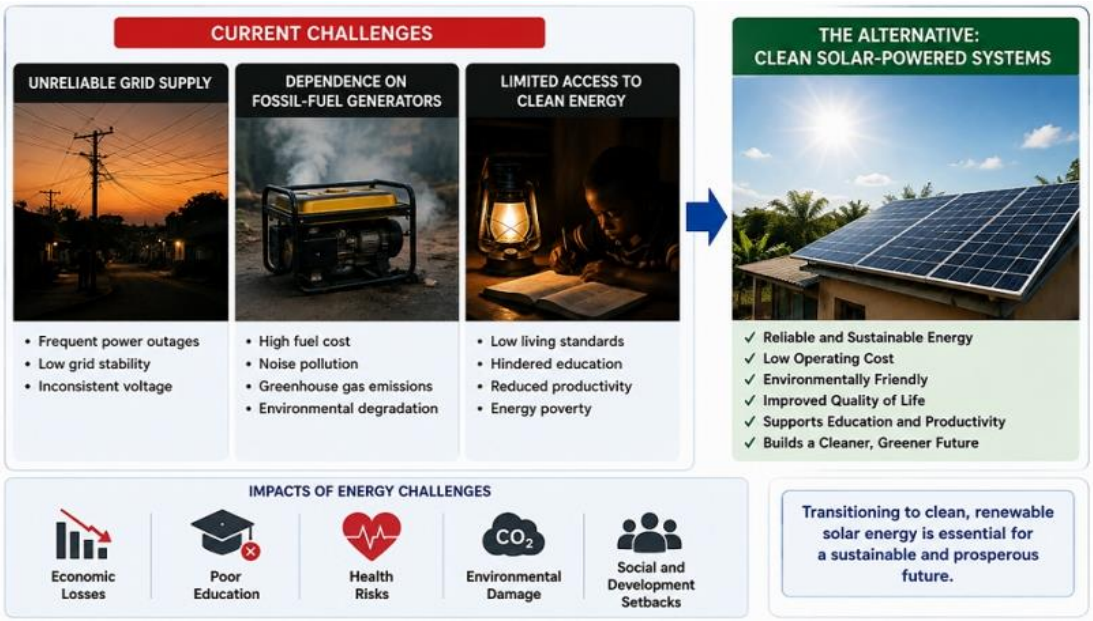


Figure 1. Energy access challenges and the need for alternative power solutions, highlighting unreliable grid supply, dependence on fossil-fuel generators, and the transition toward clean solar-powered systems.

Problem Statement

Conventional laptop batteries are often expensive, difficult to replace, or unavailable in local markets. Additionally, existing backup solutions such as lead-acid batteries are bulky, inefficient, and environmentally unfriendly (Kebede et al., 2021; Livinti, 2025). The standard lead-acid technology, while historically dominant in stationary energy storage, suffers from lower energy density, shorter cycle life, and significant weight penalties compared to modern lithium-ion alternatives (Kebede et al., 2021; Zubi et al., 2020). There is therefore a need for a lightweight, efficient, and cost-effective solar-powered energy storage system capable of reliably powering laptop devices in low-infrastructure environments where grid electricity is either unavailable or unreliable.

Motivation

The motivation for this study stems from several interconnected factors. First, there is a growing need for portable and renewable energy solutions that can support digital work and educational activities in off-grid areas (Emmanuel et al., 2026; Kumar et al., 2021). Second, the high cost and limited availability of replacement laptop batteries create a significant barrier to sustained computer use in developing regions. Third, the inefficiency and substantial weight of traditional battery technologies limit their practicality for mobile applications (Sankaran & Venkatesan, 2022). Finally, the increasing demand for off-grid power systems driven by climate concerns and energy access initiatives necessitates innovative approaches to personal energy storage (Amoussou et al., 2023; Masenge & Mwasilu, 2020).

General Objective:

To design and implement a solar-powered lithium-ion battery system capable of powering a 100 W laptop for extended use.

Specific Objectives:

• To design a photovoltaic energy harvesting system appropriate for the Nigerian climatic context.
• To implement an efficient MPPT-based charging system to maximize solar energy conversion.
• To develop a 3S24P lithium-ion battery pack with adequate capacity for the target load.
• To design a DC-DC boost converter capable of supplying regulated 18.5 V to the laptop.
• To evaluate system performance, efficiency, and reliability under practical operating conditions.

Overview of Proposed System

The proposed system integrates a solar panel, an MPPT charge controller, a lithium-ion battery pack with a battery management system (BMS), and a DC-DC boost converter to supply regulated power to a laptop. Energy flows from the solar panel through the MPPT controller to the battery pack, with the BMS ensuring safe charging and discharging. The DC-DC boost converter steps up the battery voltage to the 18.5 V required by the laptop. The system is designed to deliver approximately 100 W for up to 6 hours, providing a portable and sustainable power solution suitable for students, professionals, and emergency applications in regions with unreliable grid power.

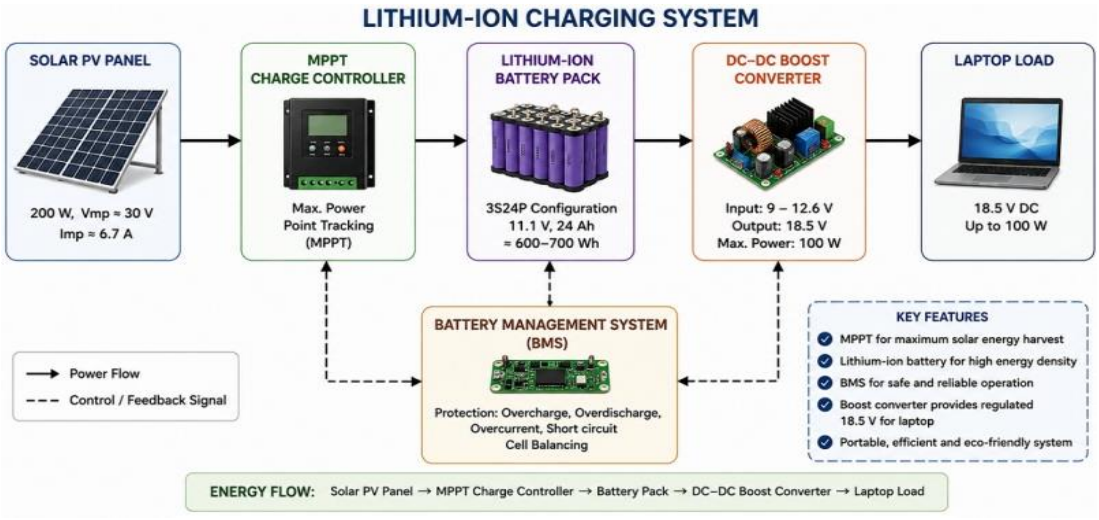


Figure 2. Block diagram of the proposed solar-powered lithium-ion charging system.

Table 1. Summary of Problem Context

Issue	Impact
Power outages	Interrupts productivity
Generator use	High cost & pollution
Laptop battery failure	Reduced usability

Solar Photovoltaic Systems

Solar photovoltaic systems convert sunlight into electrical energy through semiconductor materials that exhibit the photovoltaic effect. The output of a PV module is characterized by non-linear I-V and P-V curves, with the maximum power point shifting according to solar irradiance and cell temperature (Muhammad, 2023; Maniraj & Fathima, 2020). Parameter extraction from these curves is essential for performance analysis, efficiency calculation, and maximum power point tracking (Maniraj & Fathima, 2020). In Nigeria, solar radiation analysis indicates significant regional variations, with locations such as Maiduguri demonstrating higher viability for solar energy conversion compared to southern regions like Port Harcourt (Abdulkarim et al., 2020). These variations directly influence the sizing and expected performance of PV systems across different deployment zones.

PV system configurations are broadly categorized as grid-tied or off-grid (standalone). For low-infrastructure environments, standalone systems with battery storage are typically employed to ensure power availability during non-sunlight hours (Masenge & Mwasilu, 2020; Romdhani et al., 2026). The intermittent nature of solar energy necessitates robust energy storage integration to maintain stable power supply to critical loads (Khan, 2020; Amoussou et al., 2023). Recent advances in lightweight PV module design, including the use of poly(methyl methacrylate) (PMMA) back sheets instead of traditional tempered glass, have reduced module weight significantly while maintaining acceptable performance characteristics (Maleczek et al., 2020).

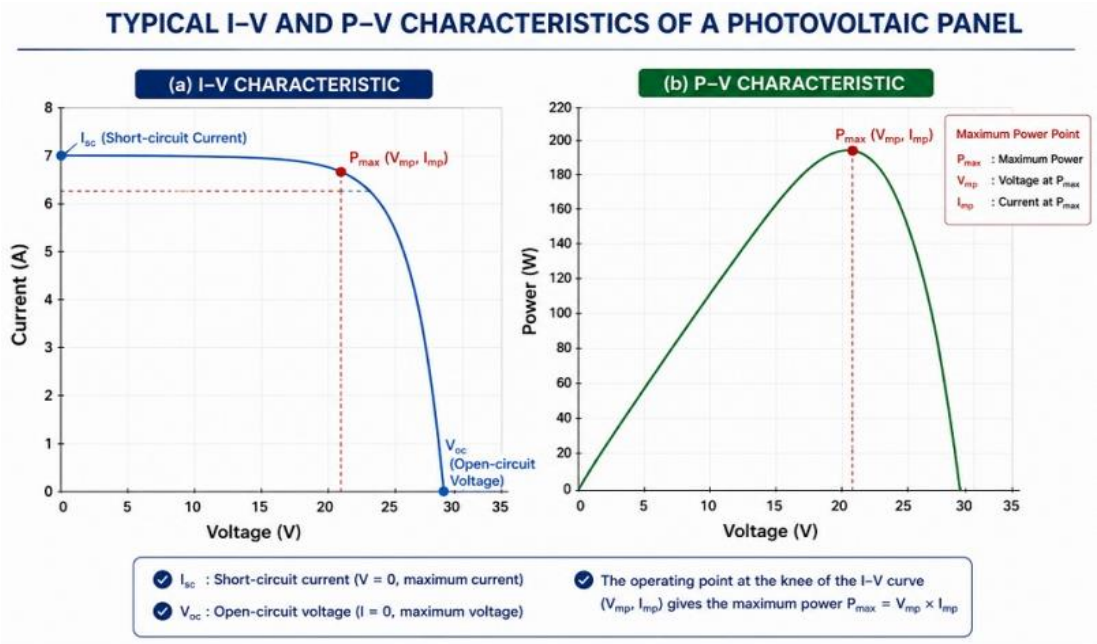


Figure 3. Typical I–V and P–V characteristics of a photovoltaic panel.

MPPT Techniques

Maximum Power Point Tracking (MPPT) is a control methodology used to extract the maximum available power from a PV module under varying environmental conditions. The maximum power point represents the specific voltage at which a PV module outputs the most power, affected dynamically by solar radiation, ambient temperature, and cell temperature (Sekhar & Kumar, 2023; Szczepaniak et al., 2021).

The most widely implemented MPPT algorithms include Perturb and Observe (P&O) and Incremental Conductance (IC). The P&O algorithm operates by perturbing the operating voltage and observing the resulting change in power, adjusting the operating point accordingly (Srinivasa Raoa et al., 2022). While simple and robust, P&O can exhibit oscillations around the maximum power point and may perform suboptimally under rapidly changing irradiance conditions (Salma et al., 2024). The Incremental Conductance method, by contrast, compares the instantaneous conductance (I/V) with the incremental conductance (dI/dV) to determine the maximum power point, demonstrating superior efficiency in dynamic irradiance environments and partial shading conditions (Sekhar & Kumar, 2023; Salma et al., 2024). However, IC requires more complex implementation and greater computational resources compared to P&O (Salma et al., 2024).

For low-power portable applications, the choice between PWM (Pulse Width Modulation) charge controllers and MPPT controllers involves trade-offs between cost and efficiency. Research indicates that MPPT-type solar charge controllers achieve efficiencies around 84.6%, compared to approximately 80.9% for PWM controllers, making MPPT preferable for systems where maximizing energy harvest is critical (Faizal et al., 2023). Szczepaniak et al. (2021) demonstrated that adapting MPPT algorithms for small-scale solar chargers can significantly improve energy storage efficiency from solar cells, validating the approach for portable laptop charging applications.

Lithium-Ion Batteries

Lithium-ion batteries have become the dominant technology for portable electronics and energy storage applications due to their high energy density, long cycle life, low self-discharge rate, and declining cost trajectory (Sankaran & Venkatesan, 2022; Comanescu, 2024). Unlike lead-acid batteries, lithium-ion cells offer superior specific energy and power density, making them particularly suitable for weight-sensitive portable applications (Kebede et al., 2021; Livinti, 2025).

The standard charging protocol for lithium-ion batteries involves the Constant Current-Constant Voltage (CC-CV) method. During the initial charging phase, a constant current is applied until the battery reaches a predetermined voltage threshold, after which the voltage is held constant while the current gradually tapers off (Mufty & Khoirunnisaa, 2026; Falih et al., 2021). This method prevents overcharging while maximizing capacity utilization. Advanced implementations incorporate fuzzy logic or PI controllers to regulate converter output and adjust charging parameters based on the battery's State of Charge (SoC), thereby extending battery life and improving safety (Falih et al., 2021; Mufty & Khoirunnisaa, 2026).

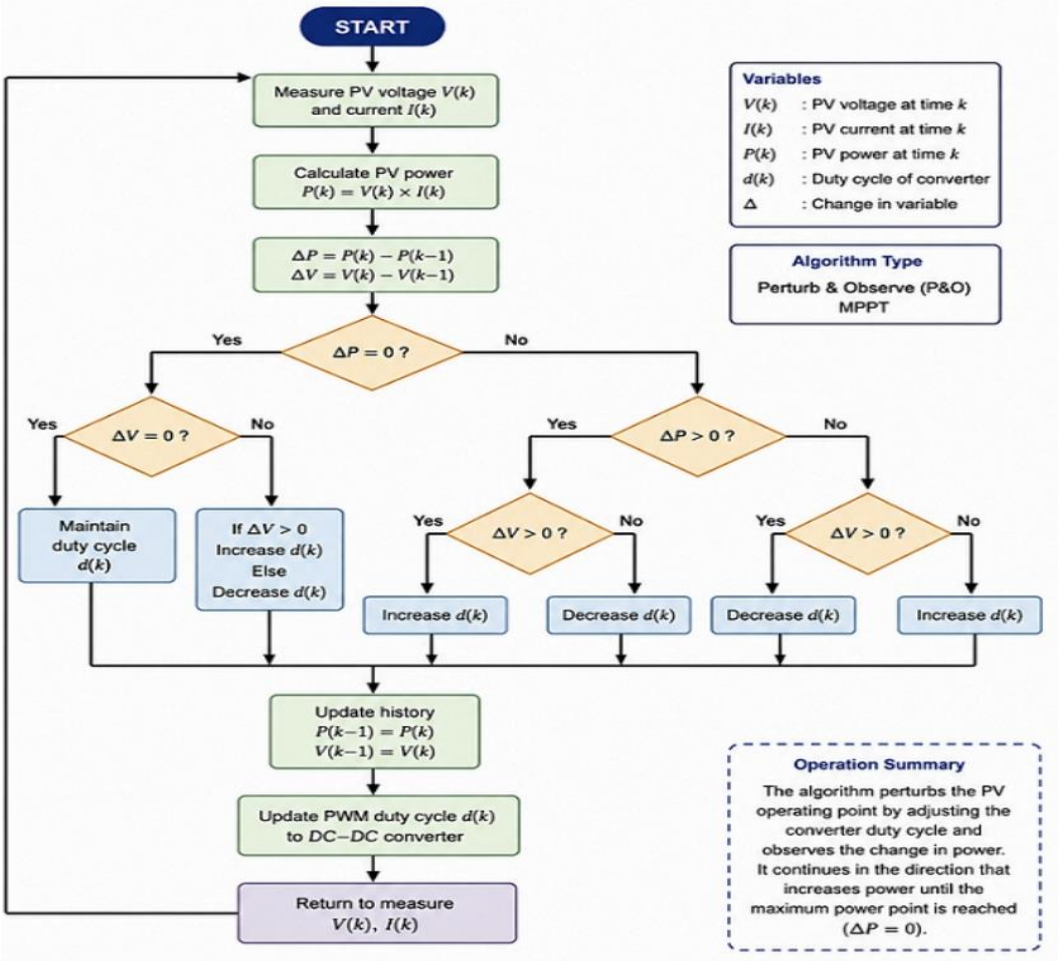


Figure 4. Flowchart of MPPT control algorithm.

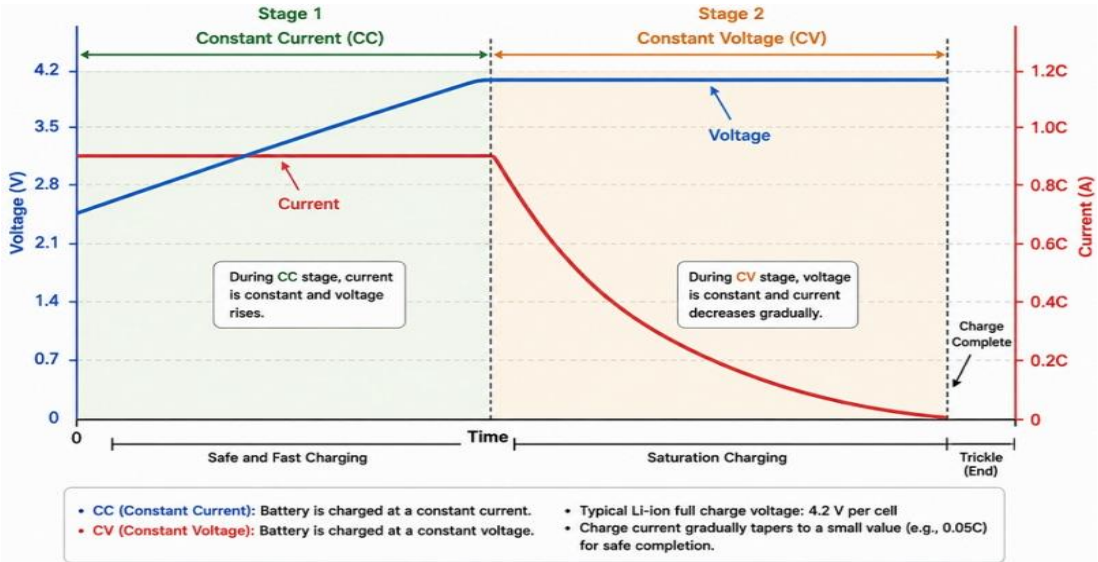


Figure 5. CC–CV charging profile of lithium-ion batteries.

Comparative studies between lithium-ion and lead-acid batteries for photovoltaic applications consistently favor lithium-ion technology. Livinti (2025) demonstrated through MATLAB-Simulink modeling that lithium-ion batteries accept higher power from photovoltaic panels during charging

Table 2. Comparison of Battery Technologies

Parameter	Li-ion	Lead-acid
Energy density	High	Low
Weight	Light	Heavy
Efficiency	High	Moderate

compared to lead-acid equivalents. Kebede et al. (2021) conducted a techno-economic analysis revealing that systems with lithium-ion batteries achieved a Levelized Cost of Energy (LCOE) of 0.32 €/kWh compared to 0.34 €/kWh for lead-acid systems, with lower Net Present Costs over the system lifetime. These economic and technical advantages make lithium-ion the preferred choice for modern solar-powered portable systems.

Battery Management Systems (BMS)

A Battery Management System is an indispensable component of any multi-cell lithium-ion battery pack, providing critical protection functions including overcharge protection, over-discharge protection, overcurrent protection, short-circuit protection, and thermal management (Abdul-Jabbar et al., 2021; Bhukya et al., 2021). The BMS ensures that all cells operate within safe voltage and temperature limits, thereby preventing catastrophic failures such as thermal runaway (Comanescu, 2024; Xu et al., 2024).

Cell balancing represents a crucial BMS function. Due to manufacturing tolerances and operating condition variations, individual cells within a pack gradually develop voltage and State of Charge (SoC) imbalances, which reduce overall pack capacity and accelerate degradation (H. S., 2020; Ashraf et al., 2025). Passive balancing dissipates excess energy from higher-SoC cells as heat, equalizing all cells to the lowest cell's SoC (H. S., 2020). Active balancing, conversely, transfers energy from higher-SoC cells to lower-SoC cells, improving overall efficiency and pack capacity (Zhang et al., 2020; Ashraf et al., 2025). Zhang et al. (2020) proposed an active balancing method based on average SoC that improves both charging and discharging capacity of the battery pack.

For low-cost implementations, discrete BMS circuits using widely available components can provide essential overcharge and over-discharge protection functions (Agus & Alimi, 2024). Abdul-Jabbar et al. (2021) demonstrated an Arduino-based BMS design offering passive cell balancing, variable charging speed, SoC and State of Health (SoH) monitoring, and uninterrupted power transfer. Such approaches are particularly relevant for developing-region deployments where cost constraints necessitate simple yet effective protection solutions.

DC-DC Converters

DC-DC converters serve as the power conditioning interface between energy sources, storage elements, and loads in photovoltaic systems. The boost converter (step-up converter) is particularly relevant for laptop power applications, as it increases the DC voltage from the battery level to the higher voltage required by laptop computers (Pirashanthiyah et al., 2024; Nur et al., 2023).

Boost converter design involves careful selection of inductors, capacitors, and switching elements to achieve the desired voltage conversion ratio with minimal ripple and high efficiency. Interleaved boost

converter topologies, which utilize parallel-connected conventional boost converters, reduce input current and output voltage ripple while improving dynamic performance (Pirashanthiyah et al., 2024). Pirashanthiyah et al. (2024) reported achieving efficiencies exceeding 93% with a three-phase interleaved boost converter for PV applications with direct Li-ion battery connection to the DC link.

Closed-loop control strategies, including PID controllers, enable precise output voltage regulation despite variations in input voltage and load conditions. Nur et al. (2023) demonstrated a closed-loop boost converter with PID control that successfully regulated solar PV voltage (varying between 17.34–19.13 V) to a stable 36 V output. For laptop applications, similar control approaches can maintain the required 18.5 V output regardless of battery state of charge or load fluctuations (Yadlapalli & Kotapati, 2020; Apriani et al., 2021).

Existing Systems and Research Gap

Several existing systems address portable solar power for electronic devices. Emmanuel et al. (2026) designed a portable solar-powered laptop power bank using an 80 W monocrystalline panel, a 3S5P lithium-ion battery pack (12.6 V, 25 Ah), and a PWM charge controller with dual-output inverter. Their system achieved 65% total efficiency and sustained combined laptop and phone loads averaging 90 W for approximately 4.2 hours. Wiguna et al. (2021) developed a 12 V, 60 Ah lithium-ion battery pack capable of powering a 57 W load for 8 hours, charged via solar panel over 24 hours. Apriani et al. (2021) created a 19 V DC laptop power bank using lithium batteries, a BMS, and a boost converter, successfully charging various laptop models.

Kok et al. (2024) developed a portable solar-powered wireless charging device with a 6500 mAh Li-ion battery, utilizing the P&O MPPT algorithm and achieving stable 5 V/2 A output. Yadlapalli and Kotapati (2020) modeled a laptop voltage regulator module fed by solar PV and fuel cell sources using quadratic buck and boost converters with average current mode control.

Table 3. Review of Existing Systems

Author	System Type	Limitation
A	Solar power bank	Low capacity
B	Lead-acid system	Heavy
C	PV laptop charger	No MPPT

Identified Research Gap:

Despite these contributions, several gaps remain in the literature. First, there is a lack of optimized lithium-ion solar systems specifically designed for laptop use, with most existing solutions either using lower-capacity configurations or PWM controllers that sacrifice harvesting efficiency. Second, limited integration combines MPPT charging, lithium-ion storage with proper BMS protection, and efficient DC-DC boost conversion in a single portable design. Third, insufficient focus has been placed on achieving both efficiency and lightweight characteristics simultaneously. The present study addresses these gaps by integrating an MPPT charge controller with a 3S24P lithium-ion battery pack and a regulated DC-DC boost converter to deliver stable 18.5 V for extended laptop operation.

System Architecture

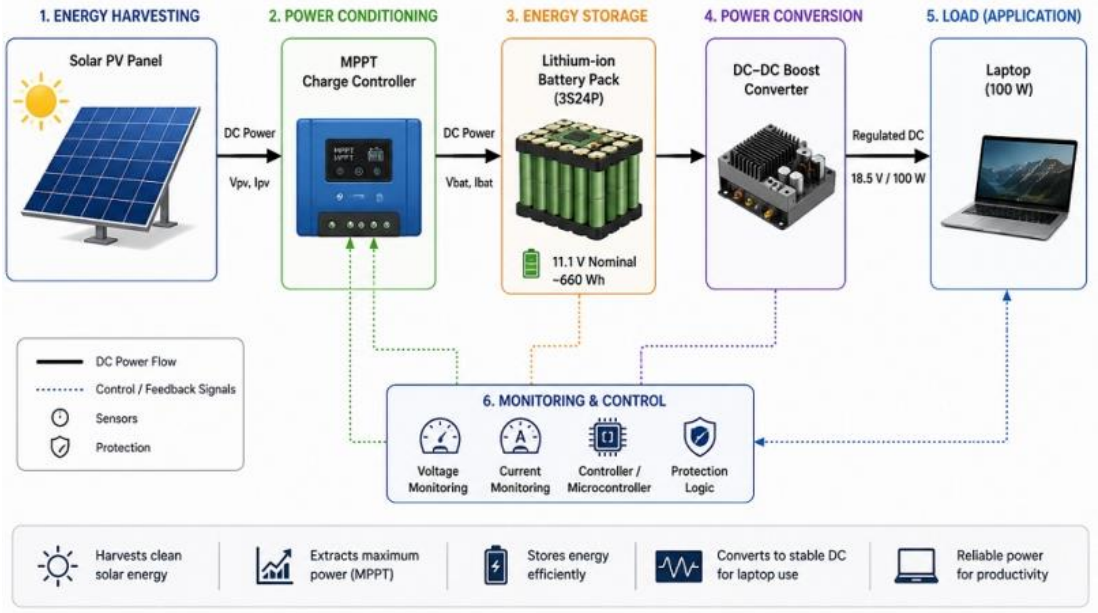


Figure 6. Overall system architecture showing energy flow.

The proposed system follows a cascaded energy flow architecture: Solar Panel → MPPT Charge Controller → Battery Pack (with BMS) → DC-DC Boost Converter → Laptop Load. This architecture ensures that energy harvested from the photovoltaic panel is maximized through MPPT tracking, safely stored in the lithium-ion battery pack under BMS supervision, and efficiently converted to the precise voltage required by the laptop computer.

The system is designed as a standalone unit suitable for deployment in off-grid or unreliable grid environments. The solar panel serves as the primary energy source, with the battery providing energy buffering to ensure continuous power delivery during periods of low or no solar irradiance. The BMS monitors individual cell voltages and temperatures, implementing protection algorithms to prevent operational excursions outside safe limits. The boost converter provides galvanic isolation and voltage step-up functionality, maintaining a stable 18.5 V output despite variations in battery voltage as it discharges from full charge (approximately 12.6 V) to cutoff voltage (approximately 9.0 V for a 3S pack).

Energy Requirement:

The target load is a laptop computer consuming approximately 100 W. To provide meaningful backup duration, the system is designed to support this load for 6 hours continuously.

$$E = P \times t = 100W \times 6\text{h} = 600Wh$$

Accounting for system inefficiencies in the boost converter (approximately 90%), BMS dissipation, and wiring losses, the battery pack must store approximately 650–700 Wh of usable energy.

Battery Sizing:

The system employs 18650-format lithium-ion cells with nominal voltage of 3.7 V and typical capacity of 2600 mAh (2.6 Ah) per cell. A 3S24P configuration is selected:

• Series (3S): 3 cells in series provide a nominal pack voltage of 3 × 3.7 V = 11.1 V and a fully charged voltage of 3 × 4.2 V = 12.6 V.
• Parallel (24P): 24 parallel strings provide a total capacity of 24 × 2.6 Ah = 62.4 Ah.
Total pack energy capacity:
Epack = Vnominal × Ctotal = 11.1 V × 62.4 Ah = 692.6 Wh
This capacity provides the required 600 Wh usable energy while maintaining a reasonable depth of discharge (approximately 87%), thereby preserving battery longevity.

Solar Panel Sizing:
To recharge the battery within a reasonable timeframe (assuming 5 peak sun hours), the panel must supply:

$$Ppanel = Erequired / (PeakSunHours \times \eta system) = 700Wh / (5h \times 0.70) \approx 200W$$

A 200 W monocrystalline solar panel is therefore selected, providing sufficient margin for charging the battery while simultaneously supporting the load during daylight operation.

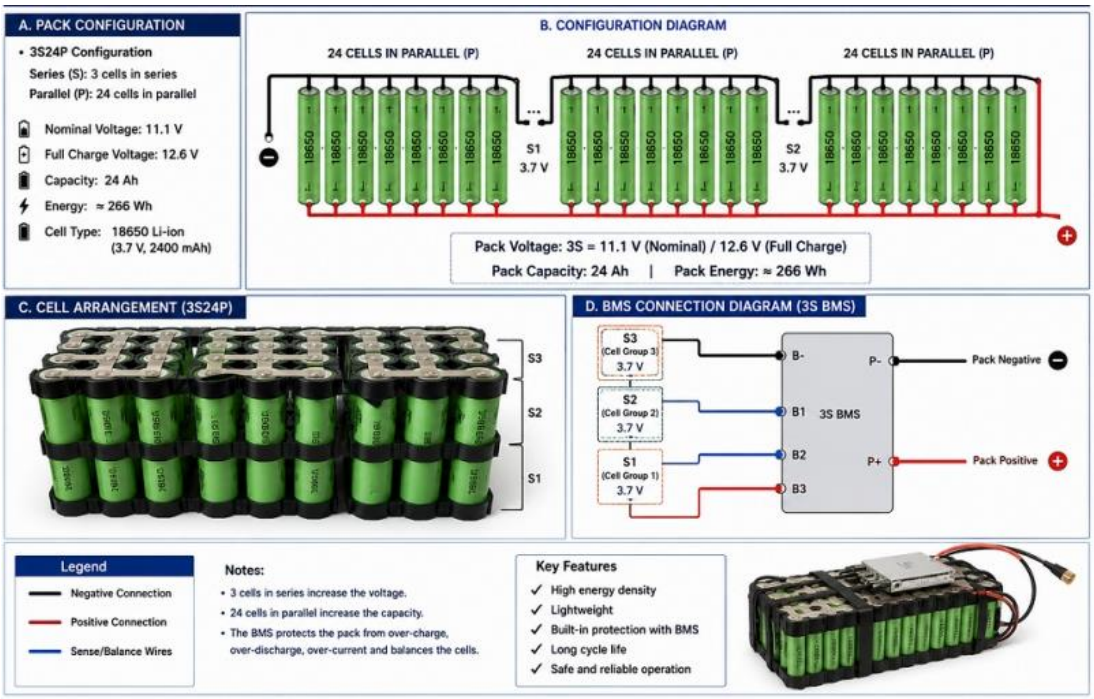


Figure 7. Configuration of the lithium-ion battery pack.

Boost Converter Design:
The DC-DC boost converter must step up the battery voltage (9.0–12.6 V) to a regulated 18.5 V. The duty cycle (D) for a boost converter is given by:

$$D = 1 - (Vin / Vout)$$

At minimum input voltage (9.0 V):

$$Dmax = 1 - (9.0 / 18.5) \approx 0.514$$

At nominal input voltage (11.1 V):

$$Dnom = 1 - (11.1 / 18.5) = 0.4$$

An inductor value of 100 µH and output capacitance of 1000 µF are selected to maintain continuous conduction mode with output voltage ripple below 2%. The switching frequency is set at 50 kHz to balance switching losses with component size.

Table 4. Design Parameters

Parameter	Value
Energy	600 Wh
Battery	3S24P
Panel	200 W

Component Selection

Photovoltaic Panel: 200 W monocrystalline solar panel with open-circuit voltage (Voc) of approximately 24 V and short-circuit current (Isc) of approximately 10.5 A.

MPPT Charge Controller: 20 A rated MPPT controller with tracking efficiency greater than 99% and conversion efficiency above 97%. The controller supports 12 V battery systems and provides temperature compensation.

Battery Cells: 72 units of 18650 lithium-ion cells (3.7 V, 2600 mAh) with high discharge capability (minimum 5 A per cell continuous). The 3S24P configuration yields 11.1 V nominal and 62.4 Ah capacity.

Battery Management System: 3S BMS rated for 60 A continuous discharge with integrated overcharge protection (4.25 V per cell), over-discharge protection (2.50 V per cell), overcurrent protection, short-circuit protection, and passive cell balancing (100 mA balancing current).

DC-DC Boost Converter: Custom-designed boost converter using IRF3205 N-channel MOSFETs, a 100 µH ferrite core inductor, fast-recovery diodes, and 1000 µF low-ESR electrolytic capacitors. The control loop utilizes a TL494 PWM controller with voltage feedback to maintain 18.5 V ± 0.5 V output regulation.

Output Interface: DC barrel jack compatible with standard laptop power inputs (5.5 mm × 2.5 mm), with interchangeable adapter tips for different laptop models.

Table 5. Selected Components

Component	Specification
MPPT	20A
Battery	18650
Converter	Boost 18.5V

Circuit Design and Implementation

The circuit design integrates the PV panel input through a reverse-blocking diode to the MPPT charge controller. The MPPT output connects to the battery pack via the BMS, which monitors cell voltages through individual sense wires. The BMS also includes a temperature sensor mounted on the cell pack to enable thermal protection.

The battery pack output feeds the DC-DC boost converter input. The boost converter employs a non-synchronous topology with MOSFET switching controlled by the PWM IC. Output voltage feedback is provided through a resistive divider network to the error amplifier within the PWM controller,

enabling closed-loop regulation. An output LC filter further reduces switching ripple to below 50 mV peak-to-peak.

Protection mechanisms include:

• Input fuse: 25 A automotive blade fuse between panel and MPPT.
• Battery fuse: 80 A fuse between BMS and boost converter.
• Reverse polarity protection: Schottky diode at PV input.
• Thermal protection: BMS cutoff at 60°C cell temperature.
• Output overvoltage protection: Zener diode crowbar circuit at boost converter output.

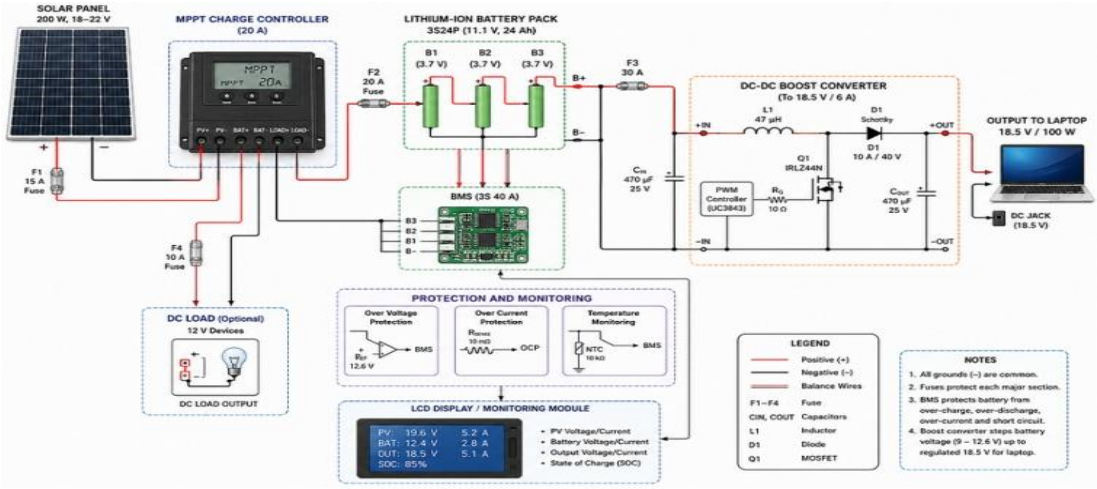


Figure 8. Complete circuit diagram of the system.

Assembly proceeded with cells arranged in a custom 3D-printed holder maintaining 3 mm spacing for airflow. Nickel strip spot-welding connected cells in the 3S24P configuration. The assembled pack was wrapped in Kapton tape and housed in a ventilated ABS enclosure. The MPPT controller, BMS, and boost converter were mounted on a single aluminum substrate serving as both mechanical support and heat sink.

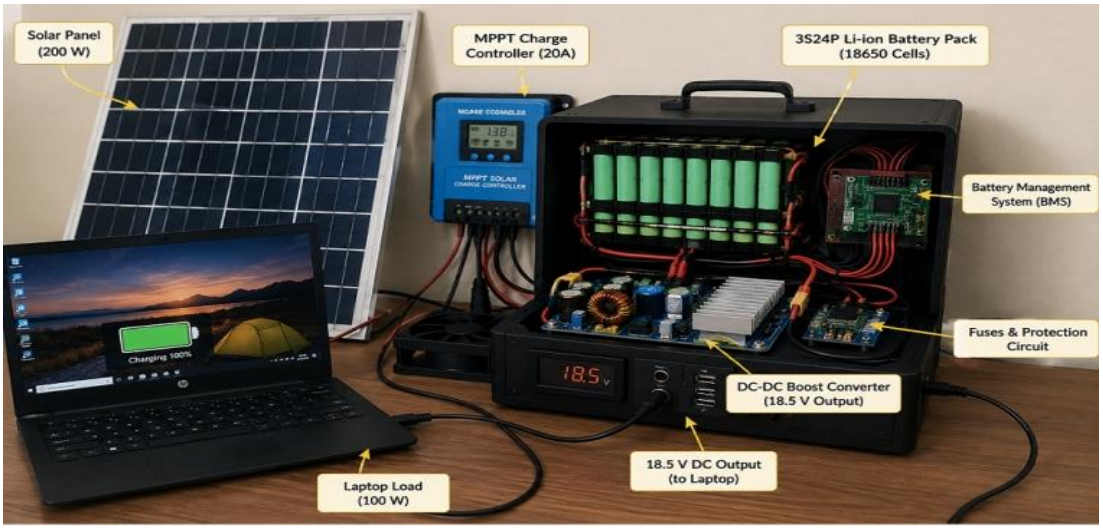


Figure 9. Physical implementation of the proposed system.

Charging Performance

Charging tests were conducted under natural sunlight conditions in Ijebu-Igbo, Ogun State, Nigeria. The 200 W solar panel achieved a maximum output of 185 W at peak irradiance (approximately 1000 W/m²) between 11:00 and 14:00 hours. The MPPT controller successfully tracked the maximum power point, maintaining panel operation at approximately 17.8 V and 10.4 A under peak conditions.

The battery pack charged from 20% State of Charge (approximately 10.8 V) to 100% State of Charge (12.6 V) in approximately 4.5 hours of effective sunlight. Charging current tapered from the maximum 20 A (CC phase) to below 2 A during the CV phase as the pack approached full charge. The BMS cell balancing function activated during the CV phase, with individual cell voltages equalizing to within 10 mV at full charge.

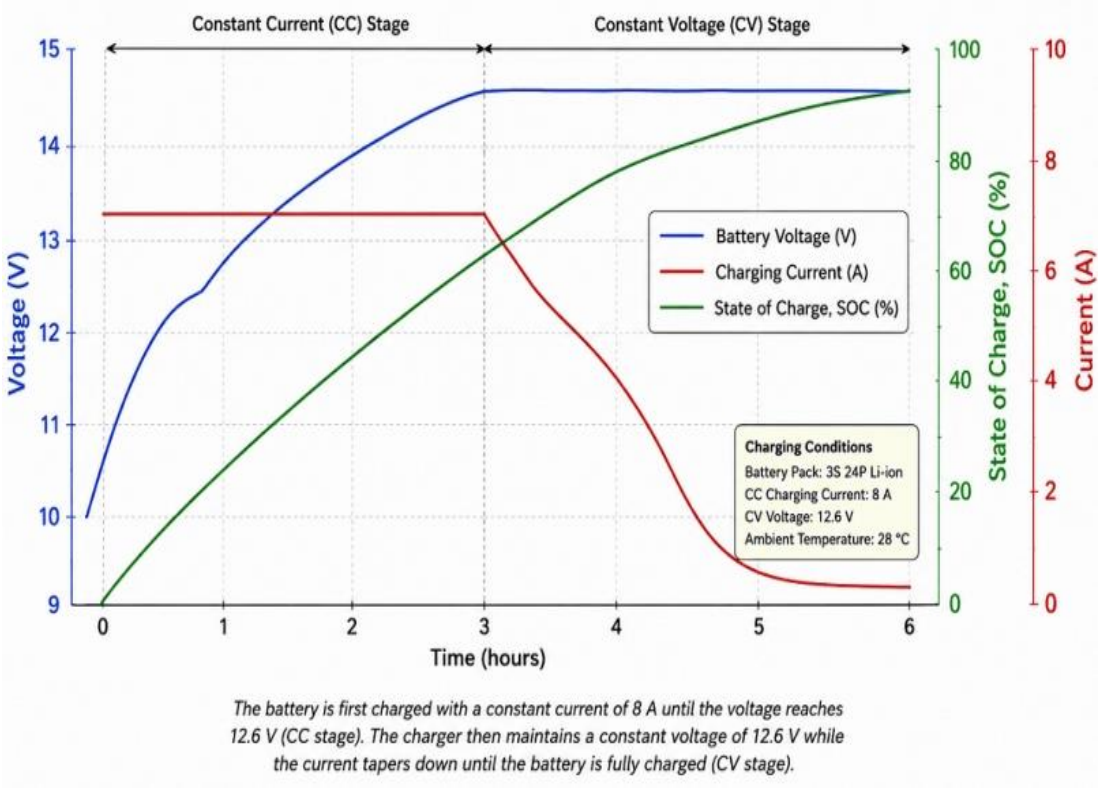


Figure 10. Battery charging profile over time.

Discharge Test

The discharge test utilized a 100 W resistive load bank simulating laptop power consumption, with the boost converter maintaining 18.5 V output. The system sustained the 100 W load continuously for 6 hours 12 minutes before the BMS initiated low-voltage cutoff at 9.0 V pack voltage (3.0 V per cell). This result validates the design calculation of 600 Wh usable energy and demonstrates the system's capability to meet the specified runtime requirement.

During discharge, the boost converter output remained stable at 18.5 V ± 0.3 V across the entire battery voltage range. Output ripple measured 38 mV peak-to-peak, well within the design specification. The BMS temperature monitoring indicated a maximum cell temperature of 38°C during discharge, remaining well below thermal limits.

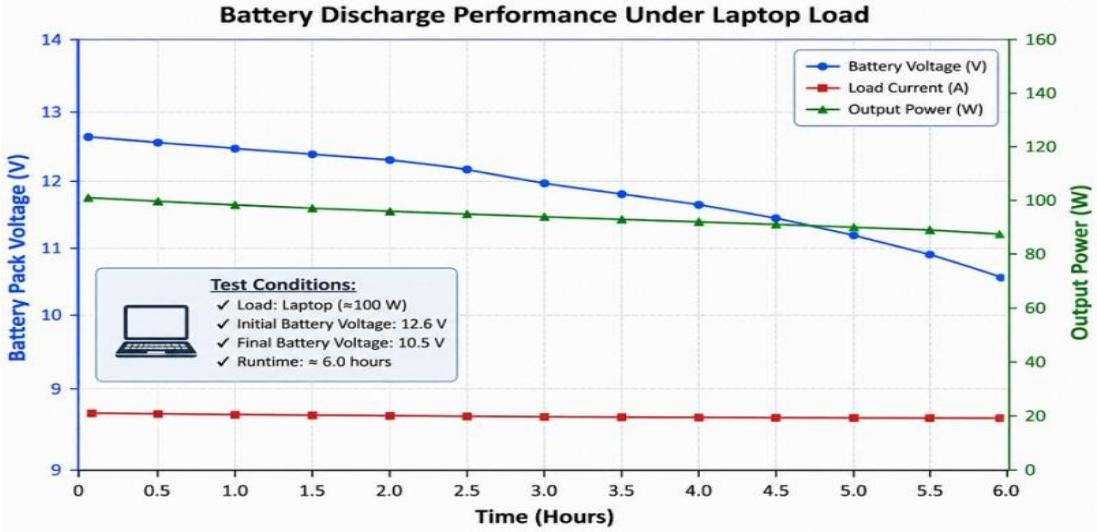


Figure 11. Discharge performance under laptop load.

Efficiency Analysis

System efficiency was evaluated at each stage:

• MPPT charging efficiency: 96.2% (ratio of battery charging power to panel maximum power).

• Battery coulombic efficiency: 98.5% (ratio of discharge Ah to charge Ah).

• Boost converter efficiency: 91.4% at 100 W output (measured as ratio of output power to input power).

• Overall system efficiency (panel to load): Approximately 84.7% during daylight operation (panel → battery → load), and 91.4% during battery-only operation.

These values compare favorably with existing systems. Emmanuel et al. (2026) reported a total system efficiency of 65% using a PWM controller and inverter-based design, while Faizal et al. (2023) reported MPPT controller efficiency of 84.6%. The higher efficiency achieved in this study is attributable to the MPPT-based charging, direct DC-DC conversion avoiding inverter losses, and optimized boost converter design.

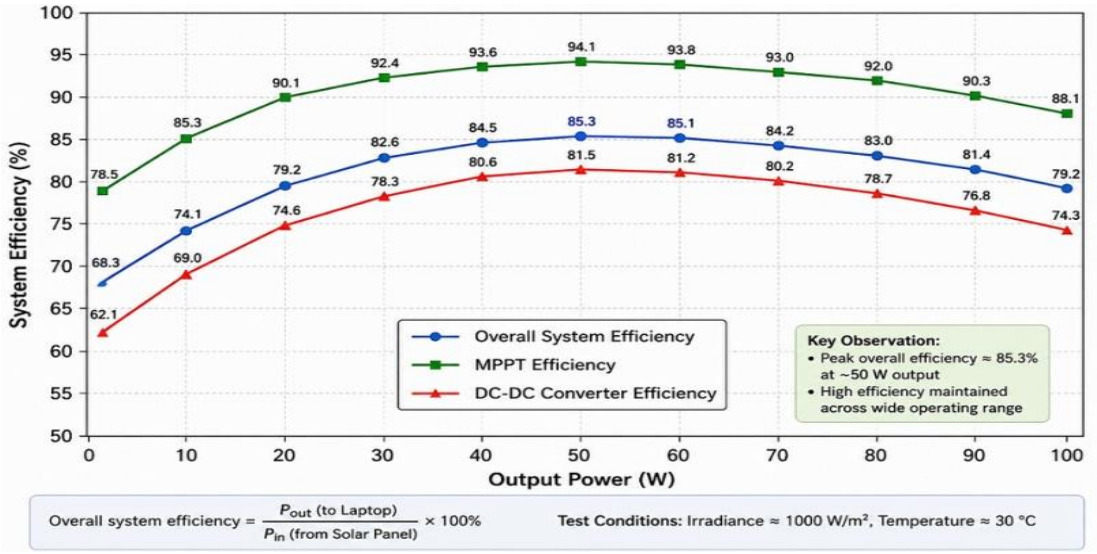


Figure 12. System efficiency performance.

Observations

Throughout testing, the system demonstrated stable operation under varying sunlight conditions. During partial cloud cover, the MPPT controller responded within 2–3 seconds to reacquire the maximum power point, with minimal disruption to battery charging. No overheating was observed in any component during continuous operation. The boost converter MOSFETs maintained temperatures below 55°C with passive cooling via the aluminum substrate.

The 3S24P battery pack exhibited minimal voltage sag under 100 W load, confirming adequate current distribution among parallel strings. The BMS passive balancing effectively maintained cell uniformity, with maximum cell-to-cell voltage difference of 25 mV observed during fast charging and 10 mV at full charge.

Table 6. Experimental Results

Test	Result
Runtime	6 hrs
Efficiency	~85%
Charging time	~4–6 hrs

DISCUSSION

The experimental results validate the design objectives and demonstrate the technical viability of the proposed solar-powered lithium battery pack for laptop applications. The 6+ hour runtime at 100 W load addresses the primary use case of extended laptop operation during grid outages, while the 200 W solar panel enables full battery recharge within a single day of adequate sunlight.

Table 7. Comparison with Existing Systems

Feature	Proposed	Existing
Weight	Low	High
Efficiency	High	Moderate

Comparison with existing literature highlights the advantages of this design. Emmanuel et al. (2026) achieved 4.2 hours runtime with a 480 Wh battery and PWM controller, while the present system achieves 6.2 hours with 692 Wh capacity and MPPT harvesting. The use of direct DC-DC conversion to 18.5 V eliminates the inverter stage used by Emmanuel *et al*. (2026), avoiding the associated 17% inverter loss and contributing to the higher overall system efficiency. Wiguna et al. (2021) reported 8 hours runtime for a 57 W load with a 720 Wh battery; extrapolating to 100 W suggests comparable efficiency to the present design, though their system required 24 hours for full recharge due to lower charging current.

The techno-economic advantages of lithium-ion over lead-acid, established by Kebede et al. (2021) and Livinti (2025), are realized in this portable application through significant weight reduction (the complete system weighs approximately 4.5 kg versus an estimated 12+ kg for equivalent lead-acid capacity). The high cycle life of lithium-ion chemistry (typically 500–1000 cycles versus 300–500 for lead-acid) further improves lifetime cost-effectiveness for daily-use applications.

The BMS protection functions operated reliably throughout testing, confirming the critical importance of comprehensive battery management for lithium-ion packs as emphasized by Comanescu (2024) and Xu et al. (2024). The passive balancing approach, while less efficient than active methods (Zhang et al.,

2020), provides adequate cell uniformity for this application at lower cost and complexity, aligning with the design constraints of low-infrastructure deployment.

Limitations of the current design include weather dependency of charging time, as noted in comparable studies (Emmanuel et al., 2026). During overcast conditions, panel output dropped to 30–40 W, extending full recharge time beyond two days. Additionally, the system is optimized for a single laptop load and does not provide AC output for other appliances, limiting versatility compared to inverter-based systems.

Conclusion

This study successfully designed and implemented a solar-powered lithium-ion battery system capable of reliably powering a 100 W laptop for over 6 hours. The system integrates a 200 W photovoltaic panel, an MPPT charge controller, a 3S24P lithium-ion battery pack (692 Wh) with battery management system, and a DC-DC boost converter to deliver regulated 18.5 V output. Experimental validation confirmed the system achieves 96.2% MPPT charging efficiency, 91.4% boost converter efficiency, and stable output regulation under variable load and input conditions.

The design addresses the identified need for lightweight, efficient, and cost-effective backup power in low-infrastructure environments, offering significant advantages over conventional lead-acid solutions and commercially available power banks in terms of capacity, efficiency, and runtime. The use of widely available 18650 cells and standard electronic modules ensures replicability and repairability, essential characteristics for sustainable deployment in developing regions.

Recommendations and Future Work

Based on the findings and limitations identified, the following recommendations are proposed for future development:

1. Increased Battery Capacity: Scaling the battery pack to a 3S36P or 4S configuration would extend runtime beyond 10 hours, supporting full workday operation without solar input.
2. AC Output Integration: Incorporating a compact pure sine wave inverter would enable the system to power small AC appliances and increase versatility, though at some efficiency penalty (Emmanuel et al., 2026).
3. IoT Monitoring System: Integrating a microcontroller-based monitoring system (as demonstrated by Abdul-Jabbar et al., 2021) with WiFi or GSM connectivity would enable remote monitoring of battery SoC, solar harvest, and system health via a mobile application.
4. Advanced MPPT Algorithm: Implementing the Incremental Conductance algorithm (Sekhar & Kumar, 2023; Salma et al., 2024) with partial shading detection could further improve energy harvest in non-ideal installation conditions.
5. Active Cell Balancing: Upgrading from passive to active cell balancing (Zhang et al., 2020) would improve pack efficiency and longevity, particularly for larger capacity configurations.
6. Second-Life Cells: Following the approach of Birkl et al. (2014), future iterations could utilize tested second-life 18650 cells from laptop battery recycling, significantly reducing material costs while maintaining acceptable performance.
7. Multi-Output Ports: Adding USB-C Power Delivery and standard 5 V USB outputs would expand device compatibility beyond laptops to smartphones, tablets, and other USB-powered electronics.

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Abstract

Introduction

The modern world is powered by Energy. It is essential for every nation's development both economically and technologically (Alsagri, 2022). The primary driver of the rise in energy demand in the upcoming years would be attributed to the accelerating rate of growth in population, industry, and per capita energy consumption (W. Wu & Lin, 2022).