Design And Development of a Low-Cost Portable Solar Power Generator for Rural and Off-Grid Applications

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Abstract

Reliable access to electricity remains a major challenge in rural and semi-urban regions, where frequent power outages and weak grid infrastructure disrupt daily life, education, healthcare services, and small-scale economic activities. Conventional backup solutions such as kerosene lamps and diesel generators are commonly used; however, they are associated with high operating costs, safety hazards, noise pollution, and harmful emissions. In recent years, decentralized renewable energy systems, particularly solar photovoltaic solutions, have emerged as a promising alternative to address these challenges.

This paper presents the design, development, and experimental evaluation of a low-cost portable solar power generator intended to provide basic electrical energy for essential low-power applications. The proposed system utilizes a 10–20 W polycrystalline solar panel as the primary energy source, a 20 A PWM solar charge controller for battery management, and a 12 V, 8 Ah VRLA battery for energy storage. Regulated 12 V DC output ports and 5 V USB ports are provided to power LED lamps, small DC fans, and mobile phones, with provision for connecting a small inverter to demonstrate limited AC load operation.

The design emphasizes affordability, portability, safety, and ease of maintenance using commonly available components. Electrical protection mechanisms such as over-charge, over-discharge, reverse-polarity, and short-circuit protection are integrated to enhance system reliability and battery life. A structured methodology involving component selection, system integration, and step-wise testing was followed. Experimental results demonstrate stable voltage regulation and backup durations of 4–5 hours for LED lighting and 2–3 hours for combined loads. The findings confirm that the proposed system is a practical, eco-friendly, and economical backup power solution suitable for rural households, students, small vendors, and emergency applications.

Keywords: Portable Solar Power Generator, Renewable Energy, Off-Grid Power System, PWM Charge Controller, VRLA Battery, Rural Electrification.

INTRODUCTION

Electricity plays a vital role in modern society by enabling lighting, communication, education, healthcare delivery, and economic activities. Despite continuous investments in power generation and grid expansion, many rural and semi-urban regions still face frequent power outages, voltage fluctuations, and unreliable electricity supply. These challenges are particularly severe in developing countries, where infrastructure limitations and increasing demand place constant stress on centralized power systems.

In the absence of reliable electricity, households often depend on candles, kerosene lamps, and small diesel generators. Although these methods provide temporary relief, they introduce several serious drawbacks. Kerosene lamps are inefficient and contribute to indoor air pollution, posing health risks such as respiratory illnesses. Diesel generators are noisy, require continuous fuel expenditure, and emit harmful greenhouse gases, making them unsuitable for long-term sustainable use. Additionally, the operational cost of fuel-based systems places a significant financial burden on low-income households.

Solar energy has emerged as one of the most promising renewable energy sources due to its abundance, scalability, and decreasing cost of photovoltaic components. Decentralized solar systems offer an effective solution in regions where grid extension is economically or technically infeasible. Portable solar power generators further enhance flexibility by allowing users to transport power sources according to their needs, making them ideal for households, students, small businesses, outdoor activities, and emergency situations.

This paper focuses on the development of a portable solar power generator designed specifically for low-power applications. Rather than aiming to replace high-capacity grid systems, the proposed design provides a reliable and affordable source of electricity for essential needs such as lighting and mobile charging. The system also serves as an educational platform for understanding solar energy conversion, battery management, and protection mechanisms.

I. MATERIALS AND METHODS

This section describes the overall system architecture, hardware components, working methodology, and operational principles of the proposed portable solar power generator.

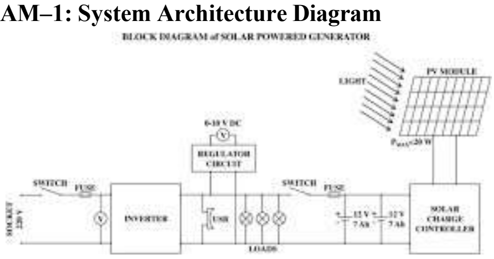
A. System Overview

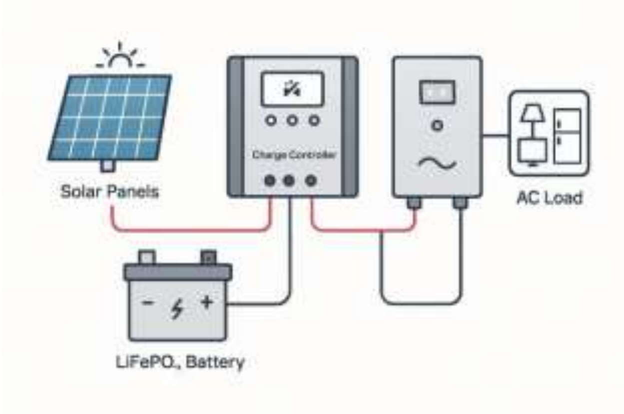
The proposed system is designed as a standalone, portable DC power unit based on a 12 V architecture. The system consists of

four major functional blocks: solar energy capture, charge regulation, energy storage, and load supply. Solar energy is converted into electrical energy using a polycrystalline solar panel and regulated by a PWM charge controller before being stored in a VRLA battery. The stored energy is then supplied to connected loads through regulated DC and USB output ports.
The system supports simultaneous charging and discharging, allowing loads to operate while the battery is being charged, provided that the total connected load does not exceed the rated capacity. Safety components such as fuses, switches, and status indicators are integrated to protect both the system and the user.

B. Hardware Components
The major hardware components used in the system are described below.
Solar Panel:
A 10–20 W polycrystalline solar panel with a nominal output voltage of 12 V is used as the primary energy source.
Polycrystalline panels are selected due to their robustness, wide availability, and cost-effectiveness for small-scale applications.
Solar Charge Controller:
A 20 A PWM solar charge controller is employed to regulate the charging and discharging of the battery. The controller provides built-in protection against over-charging, over-discharging, short-circuit conditions, and reverse-polarity connections.
Battery:
A 12 V, 8 Ah VRLA battery is used for energy storage. VRLA batteries are maintenance-free, reliable, and suitable for portable and low-power renewable energy systems.
DC Output Ports:
Multiple 12 V DC output ports are provided to power LED lamps and small DC appliances such as DC fans.
USB Output Ports:
Two 5 V USB output ports are included for charging mobile phones and other small electronic devices.
Protection Devices:
Inline fuses, insulated copper wiring, and clear polarity markings are used to ensure electrical safety and prevent damage due to faults.
Mechanical Enclosure:
A compact and ventilated enclosure houses all components and provides mechanical protection as well as portability.

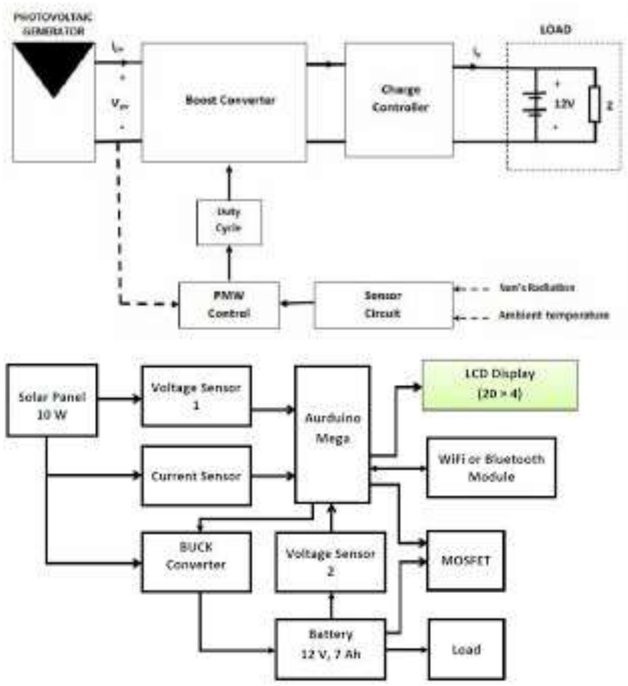
IAGRAM–1: System Architecture Diagram





Caption (copy exactly):
Fig. 1. System architecture of the proposed portable solar power generator
In-text reference
As shown in Fig. 1, the proposed portable solar power generator consists of a solar panel, PWM charge controller, battery storage unit, and regulated DC and USB load outputs.

DIAGRAM–2: Block Diagram of the System



Caption:
Fig. 2. Block diagram showing solar panel, charge controller, battery, and load section
In-text reference:
Fig. 2 illustrates the functional block diagram of the system, where solar energy is converted into electrical energy, regulated through a charge controller, stored in a battery, and supplied to connected loads.

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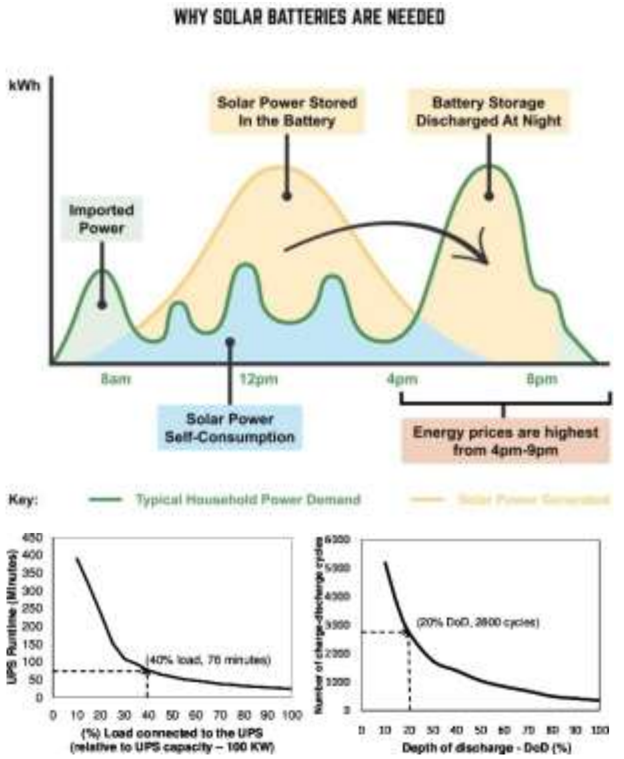
GRAPH: Load Power vs Backup Time



Caption:

Fig. 3. Variation of backup time with respect to connected load power

Graph explanation (Results section me likho):

Fig. 3 shows the relationship between connected load power and battery backup time. As the load power increases, the backup duration decreases due to higher discharge current from the battery. The results indicate that low-power loads such as LED lamps can be supported for longer durations compared to combined loads including DC fans and mobile charging.

C. Control Logic and Power Flow

The PWM charge controller continuously monitors the battery voltage and regulates the charging current from the solar panel. During daylight conditions, the controller charges the battery in bulk and float modes to maintain safe voltage levels. When the battery voltage drops below a predefined threshold, the controller automatically disconnects the load to prevent deep discharge. Once the battery voltage recovers, the load is reconnected automatically.

D. System Operation

The operational sequence of the system is as follows:

1. The solar panel converts sunlight into DC electrical energy.
2. The charge controller regulates voltage and current supplied to the battery.
3. The battery stores energy and supplies power during low or no sunlight conditions.
4. DC and USB outputs deliver regulated power to connected loads.
5. Protection mechanisms ensure safe operation during fault conditions.

II.

RESULTS

Experimental testing was conducted to evaluate the electrical performance, backup duration, and reliability of the proposed system. Voltage and current measurements confirmed stable operation under different load conditions. Backup time tests showed that a single 12 V LED lamp could be powered for approximately 4–5 hours, while combined loads such as an LED lamp and DC fan could operate for 2–3 hours after a full battery charge.

The output voltage remained within acceptable limits during operation, confirming effective regulation by the charge controller. Protection features such as low-voltage cut-off and short-circuit protection operated as expected, preventing damage to the battery and connected devices.

III. DISCUSSION AND SUMMARY

The experimental results demonstrate that the proposed portable solar power generator effectively meets the requirements of basic off-grid power supply. The system provides clean, silent, and reliable energy for essential applications while eliminating fuel costs and emissions associated with conventional backup solutions. The modular design allows easy maintenance and future upgrades.

Limitations of the system include dependence on sunlight availability and restricted power capacity due to the small panel and battery size. However, these limitations are acceptable for the intended low-power applications.

CONCLUSION

This paper presented the design and implementation of a low-cost portable solar power generator suitable for rural and off-grid applications. By integrating a polycrystalline solar panel, PWM charge controller, and VRLA battery, the system delivers reliable DC and USB power for essential loads. The results confirm that the system is affordable, portable, safe, and environmentally friendly. The proposed design can be replicated by educational institutions, NGOs, and small entrepreneurs to improve energy access in underserved communities.

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