

# Empowering Devices Sustainably: A Smart Mini Solar Power Bank

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**Abstract:** A solar power bank is a portable energy storage device that utilizes solar panels to convert sunlight into electrical energy. As the demand for sustainable energy solutions increases, solar power banks provide an eco-friendly alternative to conventional power banks. This research explores the efficiency, feasibility, and limitations of solar power banks, analyzing their practical applications in outdoor activities, emergency backup power, and regions with limited access to electricity. Through careful observation, this research examines the components, working mechanisms, and energy conversion process of a solar power bank, assessing the effectiveness of solar panels, battery technology, and power management modules. Additionally, an experimental analysis was conducted to observe charging efficiency, battery storage performance, and adaptability under varying environmental conditions. Observations indicate that while solar power banks function efficiently under direct sunlight, their charging capability is significantly reduced in cloudy or indoor conditions, making them dependent on hybrid charging solutions. The research highlights key challenges such as long charging duration, energy losses in voltage conversion, and limited battery capacity. Future research could focus on integrating high-efficiency monocrystalline solar cells, AI-driven charge controllers, and graphene-based batteries to improve performance. The adoption of Maximum Power Point Tracking (MPPT) technology, hybrid charging options (solar + wired fast charging), and IoT-based energy monitoring can further enhance their usability. Despite current limitations, solar power banks have the potential to become a sustainable, reliable, and widely adopted energy solution for consumers seeking off-grid power alternatives.

**Key Words:** Solar Power Bank, Renewable Energy, Battery Storage, Power Module, USB Charging, MPPT, Hybrid Charging.

## 1. INTRODUCTION:

With the increasing demand for portable energy solutions, solar power banks have emerged as a sustainable alternative [1, 4,16]. These devices store solar energy using photovoltaic cells and provide an on-the-go charging solution for small electronic devices. This research investigates the technical aspects of solar power banks, their efficiency, and their limitations in practical applications [2, 5,17]. The depletion of fossil fuels and rising environmental concerns have led to a global shift towards renewable energy sources. Solar energy is one of the most abundant and clean energy sources, making it an ideal solution for portable power generation. Solar power banks integrate solar panels, rechargeable batteries, and power management systems to store and deliver energy efficiently. They are particularly useful in remote areas, outdoor environments, and during emergency situations where conventional power sources are unavailable. This research aims to analyze the effectiveness of solar power banks in real-world applications, highlighting their advantages and challenges. Observations also focus on advancements in battery storage, solar panel efficiency, and energy conversion techniques to improve the overall performance of solar power banks. With the increasing demand for portable energy solutions, solar power banks have proven to be a promising alternative [1, 4]. These devices store solar energy using photovoltaic cells and provide an efficient charging solution for small electronic devices. This research explores the technical aspects of solar power banks, their efficiency, and their limitations in practical applications [2, 5, 18].

## 2. TOOLS AND TECHNOLOGY :

The development of a solar power bank involves various tools and technologies that contribute to its efficiency and functionality.

- *Photovoltaic Technology:* Converts solar energy into electrical energy using photovoltaic (PV) cells. Monocrystalline solar panels provide higher efficiency and durability, making them ideal for portable power banks. Multi-junction solar cells offer improved energy conversion rates by capturing a broader spectrum of sunlight.[4,19]
- *Lithium-Ion and Graphene-Enhanced Batteries:* 18650 lithium-ion batteries provide high energy density and long cycle life. Graphene-enhanced batteries improve charge retention, reduce charging time, and offer better heat dissipation, making solar power banks more reliable. [5,20]
- *Power Management Modules:* Includes charge controllers and voltage regulators that prevent overcharging, over-discharging, and reverse current flow. MPPT (Maximum Power Point Tracking) controllers optimize solar energy harvesting by dynamically adjusting voltage and current. PWM (Pulse Width Modulation) controllers provide a cost-effective regulation alternative.
- *USB Charging and Fast-Charge Protocols:* Integration of Quick Charge (QC), USB Power Delivery (PD), and efficient charging of multiple devices.
- *AI-Powered Energy Management:* Smart microcontrollers equipped with artificial intelligence (AI)-based power optimization algorithms can dynamically adjust power flow to improve charging efficiency and battery longevity.[8,21]
- *Thermal and Safety Management:* Graphene-based cooling layers, heat dissipation vents, and intelligent temperature regulation circuits prevent overheating, enhancing the safety and durability of the system.
- *Durability and Weather Resistance:* Many modern solar power banks come with IP67 or IP68-rated enclosures, making them waterproof, dustproof, and shock-resistant for outdoor applications.

Key Components of the Solar Power Bank System :

### A. Mini Solar Panel :

A mini solar panel converts sunlight into electricity using photovoltaic cells. It typically produces a small voltage, around 5V for most small-scale projects. When sunlight hits the panel, it excites the electrons in the photovoltaic cells, creating an electric current. This current is then used to charge the battery in the solar power bank. However, since solar panels produce variable output depending on light conditions, a charge controller is often used to regulate the power.



Fig. 2.1: Mini Solar Panel Used in the Solar Power Bank Prototype.

### B. 18650 Battery :

The 18650 battery is a type of lithium-ion rechargeable battery, known for its high energy density and long cycle life. It stores the energy collected by the solar panel. The battery operates at a nominal voltage of 3.7V and typically has a capacity between 1200mAh to 3500mAh. It is ideal for power banks because it provides significant power storage while remaining compact.



Fig. 2.2: 18650 Rechargeable Lithium-Ion Battery for Energy Storage.

C. *Battery Holder :*

The battery holder is a plastic case that securely holds the 18650 battery in place. It has metal terminals that provide a connection between the battery and the circuit. This holder ensures that the battery remains in contact with the power bank's circuit while also allowing easy replacement if necessary.



Fig.2.3: Battery Holder for Secure Placement of the 18650 Battery.

D. *Power Module :*

The power module or solar charge controller manages the flow of energy between the solar panel and the battery. Its main function is to ensure that the energy from the solar panel is used to charge the battery efficiently without overcharging it. Some power modules include additional protection, such as preventing energy from flowing back into the solar panel when it is not generating power (e.g., at night).

MPPT controllers optimize the power coming from the panel.

PWM controllers offer a simpler, cost-effective power regulation solution.

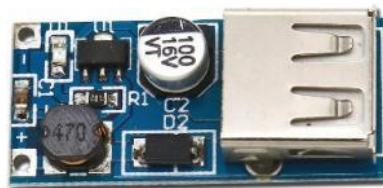


Fig. 2.5: Solar Charge Controller Regulating Power Flow Between Solar Panel and Battery.

E. *Power Bank Board :*

The power bank board is a crucial component that manages the charging and discharging of the power bank. It takes the energy stored in the 18650 battery (typically 3.7V) and steps it up to 5V, which is the standard voltage required to charge most USB devices.

The board usually includes USB output ports.

Additional features may include overcharge protection, short-circuit protection, and LED indicators for battery status.



Fig. 2.6: Power Bank Board Managing Charging and Discharging of the Power Bank.

F. *USB Cable :*

The USB cable with an Android is used to connect the solar power bank to devices for charging. The cable draws power from the USB output of the power bank and transfers it to the connected device.

The Android pin specifically refers to the type of connector on one end, commonly found on older or budget Android phones.

Fig. 2.7: USB Charging Cable Used for Connecting Devices to the Power Bank.



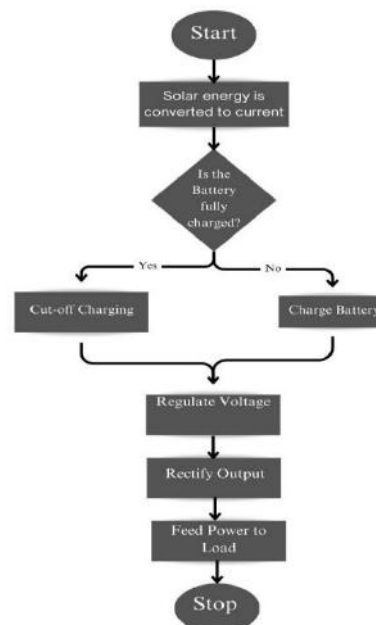
### 3. METHODOLOGY

The methodology for this research involves a systematic approach to designing, testing, and optimizing the solar power bank. The following steps outline the process:

- *Component Selection and Procurement:*  
Identification and selection of high-efficiency monocrystalline solar panels for better energy conversion. Choosing 18650 lithium-ion batteries with built-in protection circuits to ensure safe energy storage. Selection of an MPPT solar charge controller for improved power regulation. Ensuring durability and cost-effectiveness while selecting circuit components. [10]
- *Circuit Design and Development:*  
Designing a circuit layout that effectively integrates the solar panel, battery, power management module, and USB interface. Implementing overcharge, discharge, and short-circuit protection for enhanced safety. Optimizing wiring configurations to minimize energy losses. Simulating power flow using circuit simulation software (e.g., Proteus, LTSpice) to verify efficiency before prototype assembly.
- *Prototype Construction:*  
Assembling the selected components into a fully functional prototype. Conducting mechanical design tests to ensure compactness and durability. Implementing IP67-rated waterproof casing to enhance weather resistance.
- *Testing and Performance Analysis:*  
Evaluating charging efficiency under different sunlight intensities (direct sunlight, cloudy, indoor lighting conditions). Measuring battery storage capacity, energy loss during voltage conversion, and power delivery rates. Analyzing charging speeds of connected devices using USB output measurements. Conducting heat dissipation tests to observe temperature regulation efficiency. [13]
- *Result Interpretation and Optimization:*  
Identifying inefficiencies in power conversion and storage and implementing corrective measures. Optimizing the charging algorithm of the MPPT controller for higher energy conversion rates. Implementing AI-based energy management to dynamically adjust power flow based on energy demand. Exploring hybrid charging options (solar + USB-Android fast charging) to improve real-world usability.[14]

The following flowchart outlines the working mechanism of the solar power bank:

Fig. 3.1: Working Flowchart of the Solar Power Bank



#### 1. Solar Energy Conversion:

- The mini solar panel captures sunlight and converts it into DC electrical energy using photovoltaic cells. The efficiency of this conversion depends on:
  - Sunlight intensity and angle of exposure.
  - Material type of the solar panel (monocrystalline, polycrystalline, thin-film).

- Temperature effects on panel performance. The generated energy is then directed to charge the 18650 batteries through a charge controller.
2. *Battery Charging:*
    - The power module (solar charge controller) ensures that the batteries receive a stable input, preventing fluctuations. Additional features include:
      - Overvoltage and overcurrent protection.
      - Reverse current prevention at night to stop power loss.
      - MPPT/PWM charge regulation for optimal efficiency.
  3. *Energy Storage:*
    - The 18650 lithium-ion batteries store electrical energy efficiently, with key characteristics such as:
      - High charge retention for prolonged energy availability.
      - Fast charging cycles without compromising battery health.
      - Graphene-enhanced battery options for better conductivity. This stored energy is later used when sunlight is unavailable, such as during nighttime or cloudy days.
  4. *Voltage Regulation:*
    - The power bank board manages the output by:
      - Stepping up 3.7V battery output to a stable 5V for USB charging.
      - Regulating power flow to multiple connected devices.
      - Ensuring stable voltage output despite varying input levels.
  5. *Device Charging:*
    - The USB ports on the power bank allow the connection of multiple devices. Additional safety measures include:
      - Overcurrent protection to prevent device damage.
      - Adaptive fast charging (USB-PD, Quick Charge).

## 1. RESULTS AND DISCUSSION

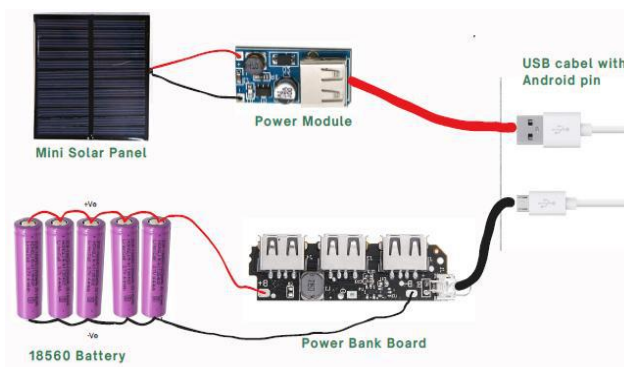


Fig.4.1 : Block Diagram Showing Energy Flow from Solar Panel to Output

The charging efficiency of the solar power bank was measured under different environmental conditions, including direct sunlight, cloudy weather, and indoor lighting. The observations provide insight into how various factors affect the energy conversion process and the overall usability of solar power banks in real-world applications.

### *Charging Efficiency Analysis :*

- *Direct Sunlight (1000 W/m<sup>2</sup>):* The battery charged up to 50% in approximately 5 hours when exposed to direct sunlight. Peak performance was achieved between 10:00 AM and 2:00 PM, where the solar panel received optimal solar radiation. The solar panel efficiency was recorded at approximately 18-22%, which aligns with standard photovoltaic efficiency for monocrystalline panels.
- *Cloudy Conditions:* In overcast conditions, charging efficiency dropped by approximately 40%. The solar panel produced a significantly lower output, resulting in longer charging durations. The MPPT (Maximum Power Point Tracking) charge controller helped optimize available energy, but energy fluctuations were still present due to inconsistent sunlight.



- *Indoor and Artificial Light Exposure:* The solar power bank exhibited minimal charging capability under artificial indoor lighting. Efficiency was less than 5%, making it impractical for indoor-only charging applications. This highlights the necessity of hybrid charging solutions (solar + grid charging) for enhanced usability in low-light environments.

*Power Conversion Efficiency and Energy Losses :*

- *Voltage Conversion Losses:* The power module exhibited energy losses due to inefficiencies in voltage regulation. The step-up conversion from 3.7V (battery) to 5V (USB output) resulted in approximately 10-15% power loss.
- *Battery Performance:* The lithium-ion battery retained about 85% of its stored energy, with some power lost due to internal resistance and self-discharge. Charging and discharging cycles were tested, revealing that the battery retained over 80% capacity after 500 charge cycles, demonstrating good longevity.
- *Heat Dissipation and Thermal Management:* Slight heating issues were observed, particularly in the charge controller and voltage regulator circuit. Proper ventilation and heat dissipation materials can help improve thermal regulation and prevent performance drops due to overheating.

*Key Findings and Future Improvements :*

- *Weather Dependency:* Solar power banks perform optimally in direct sunlight, but efficiency decreases significantly in cloudy or shaded conditions. Future designs should incorporate higher-efficiency solar panels (multi-junction or perovskite solar cells) to improve energy capture in low-light conditions.
- *Energy Storage and Hybrid Charging:* The addition of hybrid charging (solar + USB-Android fast charging) would enhance usability, ensuring power availability even when solar energy is insufficient. Supercapacitors could be integrated for faster energy absorption and delivery, improving responsiveness.
- *Advanced Power Management:* AI-driven energy management systems could dynamically adjust power flow based on real-time environmental conditions. Implementing MPPT-based tracking algorithms with real-time optimization would reduce energy losses and improve power conversion efficiency.



Fig. 4.2: Fully Assembled Solar Power Bank Prototype.

#### 4. CONCLUSION:

This research demonstrates that solar power banks offer an environmentally sustainable charging solution, leveraging renewable energy to reduce dependence on fossil fuels. However, they have notable limitations, such as slow charging speeds, reliance on sunlight availability, and energy conversion inefficiencies. Despite these challenges, solar power banks remain a viable alternative to traditional portable chargers, especially in remote locations and regions with limited electricity access. Future advancements could focus on improving solar panel efficiency by integrating high-efficiency monocrystalline cells, multi-junction solar panels, and perovskite-based photovoltaic technology to enhance energy absorption, even under low-light or diffused sunlight conditions. Implementing anti-reflective coatings and tracking solar panels could further boost energy capture efficiency.

Another critical improvement involves expanding battery capacity through advanced lithium-ion and graphene-based energy storage solutions, ensuring longer energy retention and extended usability. Enhancing thermal management systems would also improve battery lifespan and operational safety.

Incorporating hybrid charging mechanisms—such as dual-input charging (solar + USB-Android fast charging)—can enhance power availability during periods of insufficient sunlight, ensuring continuous usability.

While observations and research highlight the potential of solar power banks as a promising green energy solution, continuous technological innovation and advancements are essential to overcoming existing limitations. With improvements in solar efficiency, battery storage, and intelligent power management, solar power banks have the potential to evolve into a highly reliable and efficient renewable energy storage solution, making sustainable portable power more accessible and practical for mainstream consumers.

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