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Research Article

Experimental design and performance characterization of a foldable solar-charging 10,000mah mobile phone power bank

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Abstract

The rapid growth of mobile device use has increased the demand for reliable portable power solutions. With over 7.4 billion mobile phone users in 2024 and an average battery life of less than ten hours, the need for sustainable charging options is clear. This work presents the design and performance analysis of a 10,000 mAh foldable solar-powered power bank. The system combines a solar panel array, lithium-ion battery storage, a TP4056 charging circuit, and an LCD interface within a collapsible pouch for easy transport and use. It supports both solar and AC charging and features four USB output ports for charging multiple devices simultaneously. Test results indicate a solar charging output of 6 W, an average charging current of 1.2 A, and a practical efficiency of 83.7% with a theoretical efficiency of 85.5%. The compact foldable design improves portability, making the device suitable for outdoor activities, travel, power outages, and emergencies.

Nomenclature and units

P	$Watt(W)$
G	Solar irradiance
Eb	Battery efficiency
mAh	Milliampere-hour
A	Surface area of solar panel

1.0 Introduction

The surge in global mobile device usage necessitates sustainable, portable energy solutions. In many regions of sub-Saharan Africa, access to grid power remains unreliable. This work introduces a cost-effective, foldable solar power bank designed to bridge the energy access gap while aligning with global sustainability goals (Adewuyi & Olalekan, 2019). This study introduces an affordable, foldable solar power bank designed to address energy access gaps while aligning with international sustainability goals (Kumar, 2020). We now live in an era dominated by renewable energy and portable power solutions. As dependence on electronic devices grows, finding sustainable and efficient ways to charge them on the go is crucial. That's where the concept of a solar-powered power bank comes in. This device combines the convenience of a portable charger with the environmental benefits of solar energy. It provides a reliable, eco-friendly power source that enables device charging anytime, anywhere, while lowering your carbon footprint (Adarsha et al., 2018). Unlike traditional power banks that rely solely on electrical outlets or batteries, solar power banks use photovoltaic cells to convert sunlight into electricity. These cells are integrated into the device, capturing solar energy and storing it in the internal battery for later use. Additionally, solar power banks promote sustainability by reducing dependence on conventional energy sources and lessening the environmental impact of fossil fuel power generation. By harnessing renewable solar energy, we support the global shift toward cleaner, more sustainable energy options. One key advantage of a solar-powered power bank is its versatility. Whether hiking in the wild, camping under the stars, or enjoying outdoor activities, you can use solar energy to charge phones, tablets, cameras, and other USB-compatible devices. It provides a mobile, off-grid energy solution that operates independently of traditional power sources.

2.0 Materials and Methods

The methodology comprises the major components used and are described which are specifically described in the Block diagram as follows in Figure 2.7:

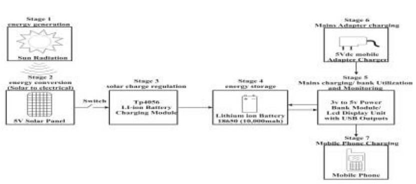

Figure 2.7: Foldable Solar Power Bank Block

2.1: Block Diagram Overview

The solar charger system includes:

i. Photovoltaic (PV) panels
ii. TP4056 Charge controller
iii. Li-ion Battery (3.7V nominal)
iv. LED Display
v. 5V Boost Converter
vi. USB Output ports.

The PVC cells generate DC electricity, which the TP4056 regulates to charge the battery. Store energy is later boosted to 5V for USB output.

2.2: Photovoltaic Cell

A solar panel comprises a collection of solar photovoltaic (PV) modules that are electrically interconnected and affixed to a supporting framework. Each photovoltaic module consists of an array of interconnected solar cells, typically made from crystalline silicon, that convert sunlight into direct current (DC) electricity through the photovoltaic effect (Green et al., 2015). These panels are widely used in both commercial and residential applications to generate and supply clean energy (IEA, 2021 and Kumar,2020). Solar panels form integral components of larger PV systems, which include inverters, interface wiring, batteries, and optional solar trackers for efficiency improvement (Fraunhofer, 2023). Although solar cells are only one method of electricity generation, they are among the most convenient for small- to medium-scale decentralized applications due to their modularity and scalability (Razykov et al., 2011). Photovoltaic (PV) cells are fabricated from two layers of specially treated silicon that create an electric field when exposed to sunlight, allowing electricity to flow through an external circuit (Luque & Hegedus, 2011). These individual cells are assembled into modules, which are then enclosed in durable glass and framed with aluminum for protection and installation. Depending on the configuration, modules may be designed to produce specific output voltages; for instance, a nominal 5V panel may generate up to 7V under optimal sunlight conditions to ensure sufficient charging voltage (Smets et al., 2016). We utilized Energia-brand solar panels, which are constructed from high-efficiency monocrystalline silicon solar cells. These cells are encapsulated between UV-stable ethylene vinyl acetate (EVA) layers and toughened low-iron glass for maximum light transmission. The module is protected by a high-durability back sheet and housed in an anodized aluminum frame fitted with a junction box to withstand harsh environmental conditions (Energia, 2023).

Figure 2.2 A foldable solar panel pouch

2.3: Battery

The type of battery used in a power bank is a matter of choice. Lithium-ion 18650 batteries and Lithium-polymer batteries are the predominant forms of rechargeable batteries utilized in contemporary power banks. Lithium-ion power banks are the more prevalent of the two. However, of the two, lithium-ion power banks are the most common on the market (Caldera,2024).

Figure 2.3 Li-ion 18650 battery

According to Battery University, lithium-ion (Li-ion) batteries were developed in the early 1990s as a safer alternative to rechargeable metallic lithium batteries, which suffered from dendrite-induced short circuits and thermal runaway hazards. Sony commercialized the first Li-ion battery in 1991, marking the beginning of its dominance in consumer electronics. These batteries have since become the most widely used chemistry due to their high energy density, relatively low cost, low self-discharge, and absence of memory effect. There are four main components of Li-ion batteries:

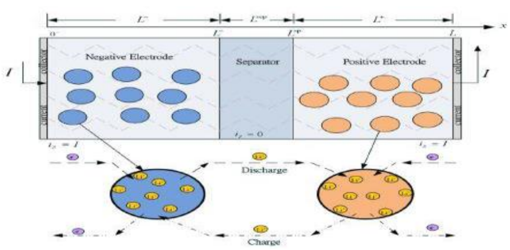

Figure 2.4 Structure of a Li-ion battery cell

i. Voltage regulation and Protection Features of the TP4056 Li-Ion charge controller:

The TP4056 module used in this project integrates both a TP4056 Li-Ion charge controller IC and a DW01A battery protection IC. Some commercially available TP4056 boards do not include protection circuitry; however, the module used in this research includes full protection features. Together with the FS8205A dual MOSFET, the module provides:

- **Constant-current/constant-voltage (CC/CV) charging:** The controller maintains a stable current until the battery approaches 4.2 V, then switches to voltage regulation.

- **Over-discharge protection:** When the lithium-ion cell voltage drops below **2.4 V**, output to the load is automatically cut off. Once the battery is recharged above **3.0 V**, discharge resumes.

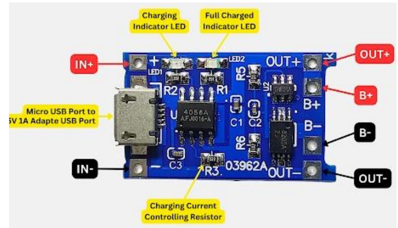

Figure 2.5: TP4056

The device controls lithium battery charging from a stable current to voltage. Over-discharge pro manages the constant current to steady voltage charging of a linked lithium battery. When a connected battery is discharged below 2.4V, the module will cut output power until the battery voltage is recharged above 3.0V (the over-discharge release voltage), at which point it will again allow power discharge to a connected load. The discharge control MOSFET (FS8205A Dual MOSFET) allows the battery to charge through a tiny pathway even if the module blocks power from leaving when over-discharged.

- **Overcharge protection**: The module will safely charge your battery to 4.2V. Over current and short-circuit protection - the module will cut the output from the battery if the discharge rate exceeds 3A or if a short-circuit condition occurs. Soft-start protection limits inrush current
- **Trickle charge (battery reconditioning)**: if the battery voltage is less than 2.9V, the module will utilize 130mA of trickle charge current until it reaches 2.9V, at which t you can charge the battery using either micro-USB or +/- connectors, as illustrated in the image. The battery can be charged via micro-USB or +/- connections, as depicted in the Power Supply Options Diagram. The power source must provide a minimum of 1A for the charger to effectively charge a battery. Most contemporary phone and USB chargers can deliver 1A or greater; verify the specifications on the packaging. Utilize a 1A USB cable for micro-USB connections.

2.4: The System Description:

A portable energy supply with cutting-edge features, the 5V 2.4A Dual USB Micro/Type-C Power Bank Module is compact and versatile. With its two USB connections, which encompass a Micro USB and a Type-C port, you can charge several gadgets right now. You can follow the song of strength degrees using the built-in LED display, which gives real-time information on the amount of battery potential left. Its modest size (6.5 x 2.5 cm) makes it incredibly transportable and excellent for editing or building your personal DIY electrical banks. This module gives reliable and effective charging, making it a tremendous choice for cellular strength requirements.

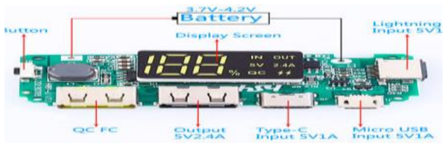

Figure 2.6: A 5V 2.4A Dual USB Micro/Type-C Power Bank Module with LED Display

We have 4 solar panels, each rated at 1.5 watts and operating at 5V DC, Calculate the approximate charging time for a 10000mAh (10Ah) battery, as follows: PV output depends on panel area, irradiance, and panel efficiency (Green et al., 2020).

Solar Panel Output and Charging Calculations
Four panels each rated at 1.5W,5VDC
Total Power Output

$$P_{total} = 1.5W \times 4 = 6W \qquad i$$

3.0: System Design

3.1: Charging Current:

Solar charging experiments were conducted under measured environmental conditions rather than relying on time-of-day estimations: Solar radiance: Measured using a TES-1333R solar power meter with accuracy ±10W/m^{2,} and the typical irradiance values during testing ranged between 780 – 910W/m^2., while the ambient temperature was measured using a UNI-T UT33S digital Thermo-Hygrometer, with accuracy of ±0.5C and temperature range: 29 – 33^{0}C.

Solar panels provide current based on their output power and the sunlight conditions. The current

$$\left(current\ (I) = \frac{Total\ power}{Panel\ voltage}\right) \qquad ii$$

Since each panel operates at 5V DC, the current

$$\left(current\ (I) = \frac{6watts}{5v} = 1.2A\right)$$

3.2: Charging Current:
Charging time can be estimated using the formula:

$$I = \frac{P_{total}}{V} = \frac{6W}{5V} = 1.2\text{A} \qquad iii$$

Charging Time

$$\text{Time} = \frac{10000\text{mAh}}{1200\text{mA}} = 8.33\text{hrs} \qquad iv$$

For comparison, using a 2A USB charger at 85% efficiency:

$$Time = \frac{10000}{2000\ x\ 0.85} = 5.88\text{hrs} \qquad v$$

The portable solar-powered phone charger is designed to provide reliable charging for mobile devices using energy from the sun. The heart of the system is a photovoltaic (PV) panel that captures sunlight and converts it into electricity. These solar panels are composed of multiple solar cells wired together to achieve the desired voltage and power output. However, since sunlight isn't constant throughout the day, the electrical output from the panels tends to fluctuate. To ensure that the connected battery is safely and efficiently charged, a TP4056 lithium-ion charge controller is used. This compact module regulates the voltage output from the solar panel and safeguards the battery against overcharging, which is essential for maintaining battery health and ensuring stable energy transmission over time. The energy is stored in a lithium-ion battery, typically rated. The system's portability and 24/7 usability come from this stored power, portable and usable at any time, not just when the sun is out. A small display is included in the setup to show the battery level, so users can know when it's time to recharge. Before the power is sent to a phone or other device, a boost converter increases the battery voltage from 3.7V to the standard 5V required for USB charging. This final stage includes USB ports where mobile devices can be plugged in. Altogether, this system provides a compact and reliable way to keep phones charged, especially in areas without consistent electricity or for people on the move.

3.3: Circuit Diagram

The system circuit consists of two major component modules: the TP4056 charging control module circuit and the power bank boost module circuit. In Figures 3.2 and 3.3 below, the circuit diagrams of the Tp4056 module and the power bank module are captured, respectively. Their circuits are further integrated into the larger circuit diagram, which consists of solar panels, batteries, switches, output ports, and other components, to achieve the desired solar power backup bank.

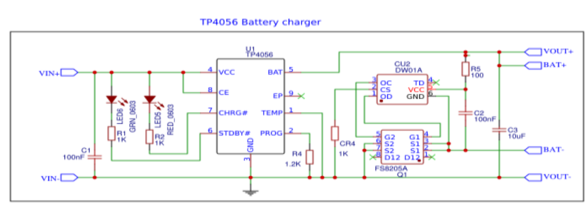

Figure 2.8: TP4056 Charger Circuit

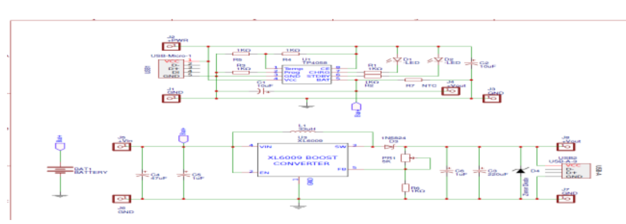

Figure 2.9: Complete System Circuit Diagram

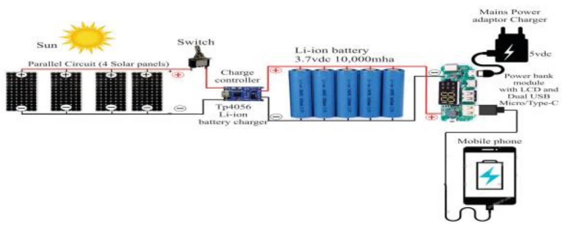

Figure 3.0: Complete System Circuit

4.0: Working Principle

A solar-powered power bank works by converting sunlight into electricity and storing that energy for later use. The system initiates with a solar panel composed of photovoltaic (PV) cells that capture sunlight and transform it into direct current (DC) electricity. These cells comprise specialized semiconductor materials that produce an electric field upon exposure to light. The raw DC power from the panel isn't directly suitable for charging the battery, so a charge controller is used. This circuit modulates the voltage and current to securely charge the internal battery without overloading or compromising its integrity. The controller continuously assesses the battery's condition, modulating the energy supply accordingly. The battery, usually a lithium-ion or lithium polymer type—stores the energy until it's needed to charge a phone or other device. When a device is plugged into the power bank, the stored energy is delivered in a controlled and safe way. The system continues to collect solar energy as long as there's sunlight, keeping the battery topped up. Overall efficiency depends on the quality of the solar panel, the effectiveness of the charging circuit, and the battery's capacity.

5.0 Results and Discussions

This section presents what we observed when the foldable solar power bank was tested in real outdoor conditions and during controlled indoor measurements. Instead of relying only on theory or simulations, we focused on how the system performed under normal sunlight levels, how long it took to charge, and how efficiently the battery stored the harvested solar energy. The results give a clear picture of the system's strengths, such as stable charging during peak sunshine, and its limitations, especially when sunlight drops or becomes inconsistent. By comparing the measured values with the expected theoretical performance, we can better understand how the solar panels, TP4056 charge controller, and battery work together in real life. These findings help show how practical the power bank is for everyday off grid use and highlight areas where future versions can be improved.

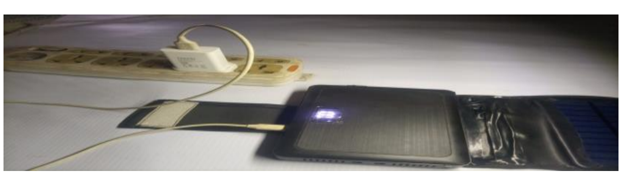

Figure 5.1: Charging using an AC 5VDC adapter

Figure 5.2: Charging test on a mobile phone

Table 5.1: Solar panel output data

Time	Voltage (v)	Current (I)
8 am to 10 am	4.9	0.8
10 am to 12 pm	5.1	1.0
12 pm. to 2 pm	5.3	1.1
2 pm to 4 pm	5.3	1.1
4 pm to 6 pm	5.0	0.9

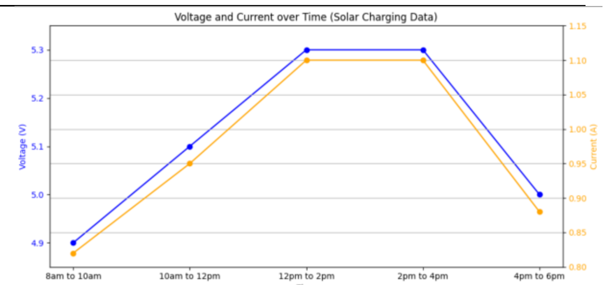

Figure 5.4: Solar Panel Output (Voltage and Current Versus Time)

5.1: Solar Charging Performance

The maximum observed power was 5.83W (12pm – 4pm), which is below the theoretical 6W from four 1.5W panels. This difference is expected because real panels rarely operate at nameplate rating due to:

i. Sun angle
ii. Temperature losses
iii. Internal panel inefficiencies
iv. Dust and shading
v. Charge controller conversion losses.

The time required for full charging is a critical parameter in fulfilling the system's requirements. The test for the full charging time required is performed with a 1A current, and the results are presented in Table 4.1 and the voltage and current graph that depicts the performance analysis of the charging rate performance in Figure 4.2 above.

5.2: Charging Performance

When using the Ac mobile adapter to charge the power bank battery, the following information was obtained: To get a full charge time for the power bank battery using 2A and 1A chargers, the results are presented in the tables below.

Table 5.2: AC adapter charging Time

Ac adaptor charger (specification)	Time taken for full charge (hours)
5vdc, 1A	11.76 hrs.
5vdc, 2A	5.88 hrs.

Charging time using a 2A adapter aligns with theoretical value (approximately = 5.88hrs), validating the internal boost converter and TP4056 CC-CV charging characteristics.

5.3: Battery Efficiency

To obtain battery efficiency, the discharge time was observed. The discharge time of the backup battery depends solely on the number of loads connected; in the case where this device only feeds a single load, this means longer discharge time. The battery capacity at 10,000mAh in an ideal situation should be able to deliver 2 full charges to any average smartphone. After some testing using different smart phones with different battery capacities the following results were obtained.

Table 3.3: Battery Efficiency

Smart Phone Battery Capacity	Number of Full Circles of charge delivered by the bank	Total phone percentage of charge delivered by the bank	Total charge delivered by the bank
4,000 mAh	2	200%	8,000 mAh
4,500 mAh	1.9	190%	8,550 mAh
5,000 mAh	1.71	171%	8,550 mAh

The battery efficiency is obtained using this formula.

Efficiency formula

$$\eta = \frac{Energy\ Out}{Energy\ in} x100\% \qquad vi$$

Where

$$Energy = V\ x\ I\ x\ t \qquad vii$$

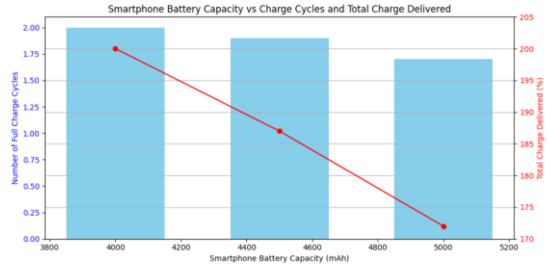

Figure: 5.5: Smartphone Battery Capacity with Charge Cycle and Total Charge Delivered

Average delivered capacity =

$$\frac{8000 + 8550 + 8550}{3} = 8367\ \text{mAh}$$

Assuming nominal battery voltage = 3.7 V

$$E_{\text{out}} = 8.367\text{Ah} \times 3.7\text{V} = 30.96\text{Wh}$$

Input Energy During Charging, Lithium-ion cells typically follow CC–CV charging behavior (Zhang et al., 2019).

$$E_{\text{in}} = 10\text{Ah} \times 3.7\text{V} = 37\text{Wh}$$

True Battery + System Efficiency

$$\eta = \frac{30.96}{37} \times 100 = 83.7\%$$

6.0 Conclusions

In conclusion, solar-powered power banks provide a portable and eco-friendly solution for charging electronic gadgets. Power banks utilize solar energy to reduce our dependence on grid electricity. Solar-powered power banks turn sunshine into stored electrical energy through efficient solar panels with 78 – 97% power delivered of the rated power, depending on the time of day, dependable batteries with 83.7% energy efficiency, and meticulously designed charging and power management circuits. Modern solar powered power banks offer convenient charging, yet their future potential is significant. The efficiency of solar panels, energy storage capabilities, and intelligent features can enhance the performance and utility of these devices. Potential advancements encompass adaptable and transparent solar panels, multi-source charging systems, and integration of the Internet of Things (IoT).

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Declaration of conflict of interest

The author has contributed to the conceptualization, design and execution of this journal article. He has worked on drafting and critically revising the article to include significant intellectual content. This manuscript has not been previously submitted or reviewed by any other journal or publishing platform. Additionally, the author do not have any organization that has direct or indirect financial stake in the subject matter discussed in this manuscript.

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