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DESIGN AND DEVELOPMENT OF A SOLAR-RECHARGEABLE COB LED LAMP WITH LITHIUM-ION BATTERY CHARGE CONTROLLER FOR OFF-GRID RURAL COMMUNITIES IN NIGERIA

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Abstract: Reliable, affordable lighting is still out of reach for a large share of Nigeria's rural population, most of whom rely on kerosene lanterns, candles, and small petrol or diesel generators for lighting and device charging. These sources are costly to run, emit harmful pollutants, and pose fire and health hazards. This paper presents the design, construction, and performance evaluation of an affordable solar-rechargeable Chip-on-Board (COB) LED lamp built around a lithium iron phosphate ($LiFePO_4$) battery pack and a dedicated solar charge controller. The system integrates a 12 W monocrystalline photovoltaic panel, a 12 V/7 A pulse-width-modulated (PWM) charge controller, a 12 V/7.2 Ah $LiFePO_4$ battery pack, a constant-current buck regulator driving a 5 W COB LED, and a 5 V USB port for charging mobile phones. The design methodology, load and component sizing calculations, circuit schematic, and system block diagram are presented, followed by charging, discharge, and illumination tests carried out under natural outdoor sunlight. Results show that the solar panel produced an open-circuit output of between 18.3 V and 19.3 V under full sunlight, the battery reached a full-charge terminal voltage of approximately 14.2 V after about six hours of charging, and continuous lamp operation provided an average backup time of approximately 10 hours before the low-voltage-disconnect threshold of 10.8 V was reached. Illuminance measured 169.6 lux at a distance of one foot from the lamp, adequate for reading and household activities. The prototype demonstrates that a low-cost, solar-powered COB LED lantern can offer a safer, cleaner, and more sustainable lighting alternative to kerosene-based sources for off-grid rural households in Nigeria.

Keywords: Solar Energy; Rechargeable Battery; COB LED; Lithium-Ion Battery; Solar Charge Controller; Rural Electrification; Renewable Energy; Portable Solar Lantern; Off-Grid Lighting; DC/DC Converter.

1. INTRODUCTION

Rural electrification remains one of the most persistent development challenges in Nigeria. According to World Bank data, only about 32.9% of Nigeria's rural population had access to electricity in 2023, meaning that roughly two-thirds of rural dwellers still live without a grid connection (World Bank, 2024). At the national level, overall electricity access stood at 61.2% in the same year, underscoring a wide and persistent urban–rural gap (World Bank, 2024). Nigeria is also one of the three countries — alongside the Democratic Republic of Congo and Ethiopia — that together account for roughly one-third of the global population still lacking access to electricity (World Bank & International Energy Agency, 2025).

In the absence of grid power, many rural households depend on kerosene lanterns, candles, and small fossil-fuel generators for lighting and for charging mobile phones. These sources carry recurring fuel costs that place a disproportionate burden on low-income households, expose users to indoor air pollutants and open-flame fire hazards, and provide light of poor and inconsistent quality. Solar photovoltaic (PV) technology offers a practical, decentralised alternative: sunlight is abundant and free at the point of use, and once installed, a solar lighting system has very low recurring cost (Messenger & Ventre, 2010).

Advances in solid-state lighting, particularly Chip-on-Board (COB) light-emitting diodes (LEDs), have made compact, high-efficacy, low-power lighting sources practical for battery-powered applications (Schubert, 2006). Likewise, lithium-based battery chemistries — including lithium iron phosphate ($LiFePO_4$) — offer higher energy density, longer cycle

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life, and lower self-discharge than the lead–acid batteries traditionally used in solar lanterns, making them increasingly attractive for small off-grid lighting products (Linden & Reddy, 2011; Duru et al., 2021).

This paper builds on these developments to design, construct, and test a self-contained solar-rechargeable COB LED lamp intended for off-grid rural households. The specific objectives of the study are to: (i) design and size a solar charging chain comprising a PV panel, a PWM solar charge controller, and a $LiFePO_4$ battery pack suitable for a portable household lamp; (ii) design a constant-current LED driver circuit to safely power a 5 W COB LED and a USB port for phone charging; (iii) construct a working prototype; and (iv) experimentally evaluate the charging performance, discharge endurance, and illumination output of the prototype under real outdoor conditions.

1.1 Problem Statement

Kerosene remains one of the most common lighting fuels in off-grid Nigerian households, yet its retail price has risen sharply in recent years: the National Bureau of Statistics reported an average retail price of ₦2,971.94 per litre in May 2026, a year-on-year increase of over 36% (National Bureau of Statistics, as reported in Gazette NGR, 2026). For a household that burns even a modest 0.3 litres per night, this translates to a recurring cost on the order of ₦27,000 per month — a substantial and ever-rising burden for low-income rural families, on top of the health risks associated with indoor kerosene combustion and the fire hazard posed by open-flame lanterns. A durable, low-maintenance solar alternative with a one-time cost that can be recovered within a few weeks of avoided fuel spending therefore represents a significant practical opportunity.

1.2 Significance and Scope of the Study

This study is significant because it targets the specific gap between large, costly household-scale off-grid PV installations (which remain unaffordable for many rural families) and low-quality imported solar lanterns that often use lead–acid cells, lack proper low-voltage protection, and provide short backup times. By combining a $LiFePO_4$ battery, a properly designed CC–CV charge controller with low-voltage disconnect, and a constant-current COB LED driver, this work aims to demonstrate a lighting product that is simultaneously affordable, durable, and technically sound. The scope of the study is limited to the design, construction, and short-term performance evaluation of a single prototype lamp; it does not extend to mass-manufacturing process design, long-term (multi-year) field reliability testing, or a full life-cycle environmental assessment, each of which is identified as an area for future work in Section 9.

The remainder of this paper is organised as follows. Section 2 reviews relevant literature on solar PV systems, charge controllers, lithium-ion batteries, DC/DC converters, and COB LED technology. Section 3 presents the system architecture and design methodology, including component sizing calculations. Section 4 lists the bill of materials. Section 5 describes the experimental test methodology, and Section 6 presents and discusses the results, including energy efficiency and cost-comparison analysis. Section 7 discusses the limitations of the study, and Sections 8 and 9 present the conclusion and recommendations respectively.

2. LITERATURE REVIEW

2.1 Solar Photovoltaic Systems

A solar PV cell converts incident sunlight directly into direct-current (DC) electricity through the photovoltaic effect (Nelson, 2003). A typical portable solar lighting system comprises four principal elements: a PV panel, a charge controller, a rechargeable battery, and a DC load such as an LED lamp. Panel output varies with irradiance, temperature, and panel orientation, so a charge controller is required between the panel and the battery to regulate the variable panel voltage into a safe and efficient charging profile (Messenger & Ventre, 2010). Adesina, Ogunbiyi, and Makinde (2023) demonstrated, in an off-grid solar system built for a Nigerian household, that a systematic sizing methodology using measured local solar irradiance and a clearly defined load profile is essential to matching panel and battery capacity to the intended duty cycle — an approach adopted in the sizing methodology used in this work.

2.2 Solar Charge Controllers and Maximum Power Point Tracking

Because the intensity of sunlight varies throughout the day, a PV panel connected directly to a battery can overcharge the battery under strong sunlight or fail to charge it adequately under weak sunlight; a charge controller is therefore required to regulate this transfer of energy (Rashid, 2014). Two broad families of charge controller exist: simple pulse-width-modulated (PWM) controllers, which are inexpensive and adequate for small panels, and maximum power point tracking (MPPT) controllers, which continuously adjust the electrical operating point of the panel to extract the maximum available power, typically improving energy harvest by 10–30% over PWM controllers, at higher cost and circuit complexity (Saravanan & Ramesh Babu, 2016). Given the nonlinear current–voltage characteristic of PV modules, MPPT algorithms such as Perturb-and-Observe and Incremental Conductance, and more recently intelligent and hybrid optimisation-based algorithms, have been extensively studied and compared in the literature (Saravanan & Ramesh Babu, 2016).

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2.3 Lithium-Ion and Lithium Iron Phosphate Batteries

Lithium-ion batteries are widely favoured for portable and off-grid energy storage because of their high energy density, low self-discharge rate, and minimal maintenance requirements compared with lead–acid batteries (Linden & Reddy, 2011). Within the lithium-ion family, lithium iron phosphate ($LiFePO_4$) cells are particularly well suited to solar lighting applications because of their thermal stability, long cycle life, and flat discharge voltage profile, which produces a nominal 12.8 V terminal voltage in a four-cell (4S) series configuration — a convenient match for 12 V DC loads. Charging of lithium-based cells is normally carried out in two stages: an initial constant-current (CC) stage that raises the battery voltage to its rated charge voltage, followed by a constant-voltage (CV) stage during which the current gradually tapers as the battery approaches full charge (Passarella, Oklilas, & Mathilda, 2014). This CC–CV approach is the benchmark charging strategy against which alternative fast-charging protocols are compared, and it minimises the risk of over-voltage and thermal stress that can shorten battery life (Duru et al., 2021).

2.4 DC/DC Converters and LED Drivers

Switching DC/DC regulators are preferred over linear regulators for battery-powered lighting because they achieve substantially higher conversion efficiency, which directly extends battery runtime (Erickson & Maksimovic, 2001; Rashid, 2014). For driving an LED load, a constant-current buck converter is generally used in preference to a constant-voltage supply, because LED forward voltage varies with temperature and manufacturing tolerance while luminous output is much more tightly related to forward current; regulating current therefore gives more stable and predictable brightness and protects the LED from thermal runaway.

2.5 Chip-on-Board (COB) LED Technology

Chip-on-Board LEDs mount multiple LED dies directly onto a single substrate and encapsulate them under one phosphor layer, producing a compact, uniform, high-intensity light source with high luminous efficacy and a long operational lifetime compared with discrete surface-mount LED packages (Schubert, 2006). These characteristics make COB LEDs well suited to compact solar lanterns, where space, weight, and battery capacity are all constrained.

2.6 Related Solar Lighting Systems in Nigeria

Several recent studies have examined off-grid solar systems for Nigerian households and communities. Adesina, Ogunbiyi, and Makinde (2023) designed, implemented, and tested an off-grid PV system for a Nigerian household, and reported that a block-diagram-driven design methodology combined with measured local solar irradiance from the Nigerian Meteorological Agency (NiMet) enabled reliable sizing of panel, battery, and inverter capacity. Such household-scale systems, however, are considerably larger and costlier than a single portable lamp, illustrating the need for smaller, lower-cost solar lighting products specifically targeted at basic household lighting and phone-charging needs — the gap this work addresses. Table 1 summarises how the present study compares with this larger household-scale system and with typical commercial solar lanterns available in the Nigerian market.

Feature	This study	Adesina et al. (2023) – household off-grid PV system	Typical commercial solar lantern
Scale / application	Single portable household lamp	Whole-house off-grid supply	Single portable lamp
Panel rating	12 W	PV array sized to 11–24 kWh/day load	3–10 W (typical)
Storage chemistry	$LiFePO_4$ (lithium iron phosphate)	Lead–acid / large inverter battery bank	Often lead–acid or generic Li-ion
Charge regulation	PWM, CC–CV, with LVD	Inverter-integrated charge control	Basic linear or PWM, often no LVD
Phone charging port	Yes (5 V USB)	Via household inverter/sockets	Sometimes
Reported backup time	~10 hours (this study)	~24 hours (larger battery bank)	4–8 hours (typical)

Table 1. Comparative summary of this study against a household-scale off-grid PV system and typical commercial solar lanterns.

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3. SYSTEM DESIGN AND METHODOLOGY

3.1 System Architecture

The system architecture is shown in the block diagram of Figure 1. Solar energy captured by the 12 W monocrystalline PV panel is regulated by a 12 V/7 A PWM solar charge controller before being delivered to the 12 V, 7.2 Ah $LiFePO_4$ battery pack using a constant-current, constant-voltage (CC–CV) charging algorithm. The battery, in turn, supplies two DC loads through independent regulation stages: a constant-current buck regulator that drives the 5 W COB LED lighting unit, and a 5 V USB boost converter module that provides a regulated output for charging mobile phones. A manually operated ON/OFF switch, together with a low-voltage-disconnect (LVD) protection function inside the charge controller, protects the battery from damaging deep discharge.

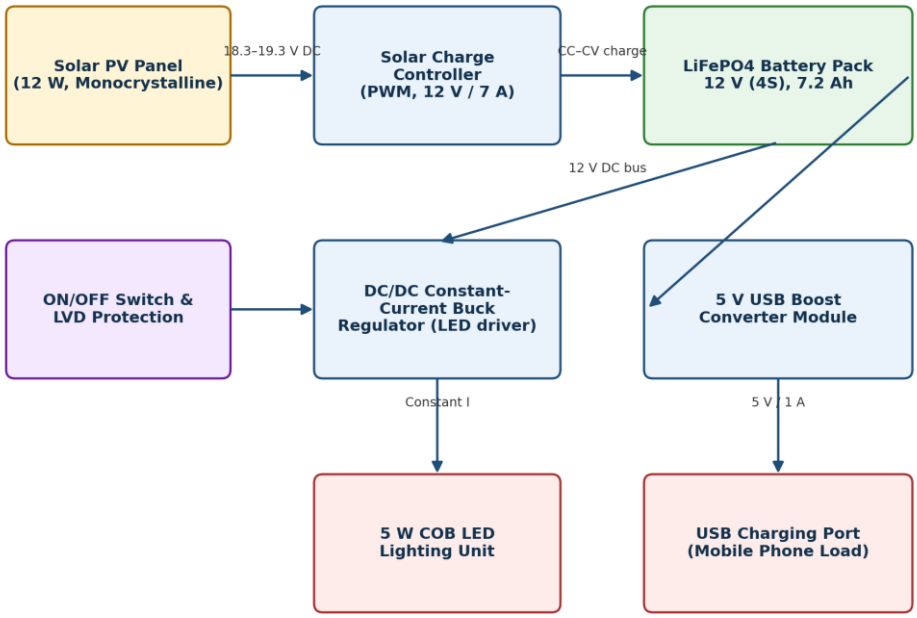


Figure 1. Block diagram of the solar-rechargeable COB LED lamp system.

3.2 Load Estimation

The daily electrical load was estimated from the intended duty cycle of the lamp. Assuming an average of 5 hours of lighting use per day from the 5 W COB LED and one mobile-phone charge per day (approximately 10 Wh), the estimated daily energy demand is:

$$E_{load} = (5\ W \times 5\ h) + 10\ Wh = 25\ Wh + 10\ Wh = 35\ Wh/day$$

Allowing for conversion losses in the charge controller and DC/DC stages (combined efficiency assumed at approximately 85%), the energy that must be supplied from the battery is approximately 41 Wh/day.

3.3 Solar Panel Sizing

Nigeria receives an estimated average of 4.5–6.5 peak sun hours per day depending on location and season, with 5 peak sun hours per day adopted here as a conservative design value, consistent with standard PV sizing practice (Messenger & Ventre, 2010). With a 12 W panel and an assumed system efficiency of 75% (accounting for panel derating, wiring losses, and charge-controller conversion losses), the average daily energy harvested is:

$$E_{pv} = 12\ W \times 5\ h \times 0.75 \approx 45\ Wh/day$$

This exceeds the estimated daily requirement of approximately 41 Wh, providing a reasonable design margin to accommodate cloudy days and battery charging inefficiencies.

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3.4 Battery Sizing

The selected 12 V, 7.2 Ah $LiFePO_4$ battery pack has a nominal energy capacity of:

$E^{b}_{att} = 12\ V \times 7.2\ Ah = 86.4\ Wh$

$LiFePO_4$ cells tolerate deep discharge well; assuming a usable depth of discharge of approximately 60% to preserve cycle life, the usable capacity is approximately 52 Wh, sufficient to supply the estimated 41 Wh daily requirement with a one-day autonomy margin even without any solar input, and to support the approximately 10-hour continuous backup time recorded during discharge testing (Section 6.2).

3.5 Charge Controller Operation

The 12 V/7 A PWM charge controller regulates the panel-to-battery connection using a two-stage CC–CV algorithm typical of lithium-based battery charging (Passarella, Oklilas, & Mathilda, 2014): during the bulk (constant-current) stage, the controller delivers a regulated current to the battery while its terminal voltage rises; once the battery reaches its rated charge voltage (approximately 14.2 V for the 4S $LiFePO_4$ pack used here), the controller switches to a constant-voltage stage in which the charging current gradually tapers as the battery approaches full charge. The controller also incorporates over-charge protection, reverse-current blocking to prevent the battery discharging back through the panel at night, and a low-voltage-disconnect function that isolates the load once the battery voltage falls to a preset cut-off (10.8 V in this design), protecting the $LiFePO_4$ cells from over-discharge. This control logic is summarised in the state-flow diagram of Figure 2.

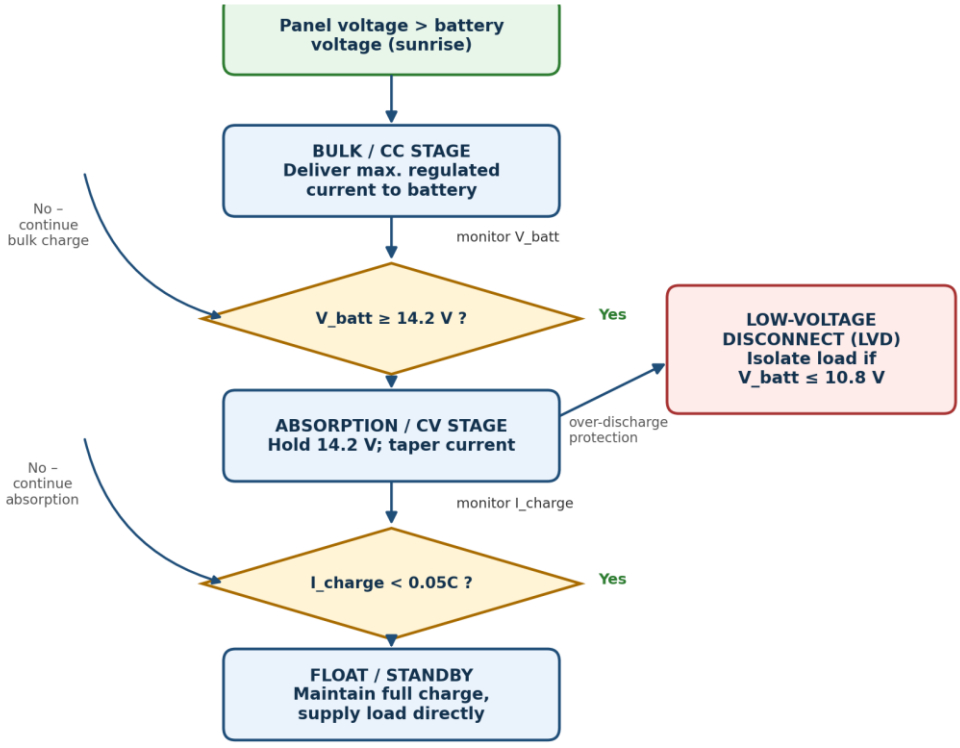


Figure 2. Charge controller CC–CV state-flow diagram with low-voltage disconnect protection.

3.6 COB LED Driver Design

A simplified schematic of the charge controller and LED driver stage is shown in Figure 3. The COB LED is driven from the battery bus through a constant-current buck converter rather than a simple series resistor, in order to maximise efficiency and maintain stable brightness despite battery voltage variation between full charge (≈14.2 V) and the low-voltage cut-off (10.8 V). The buck converter switches a power MOSFET at high frequency; an inductor and current-sense resistor in the output stage allow the driver IC to regulate the average LED current to a fixed set-point (typically 300–700 mA for a 5 W COB LED), independent of the instantaneous battery voltage (Erickson & Maksimovic, 2001).

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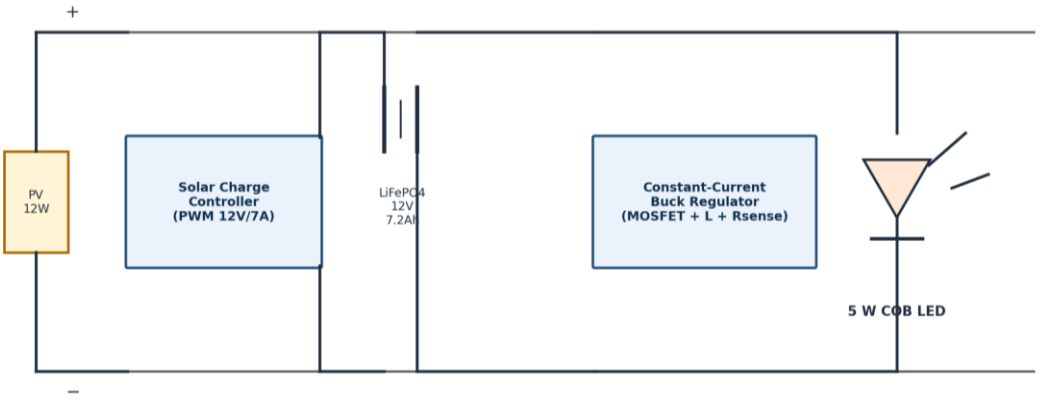


Figure 3. Simplified circuit schematic of the charge controller and COB LED driver stage.

3.7 USB Charging Port and Enclosure

A separate 5 V USB boost converter module steps the battery voltage up (or down, depending on state of charge) to a regulated 5 V/1 A output for charging mobile phones directly from the battery bus, independent of the LED driver, so that lighting and phone-charging functions can operate simultaneously without interfering with one another. All components are housed in a weather-resistant ABS/polycarbonate enclosure with the PV panel mounted on the lid, a carrying handle, and a front-panel ON/OFF switch and battery-status indicator, consistent with the compact, rugged form factor expected of a household solar lantern. Figure 4 shows the mechanical layering of the major sub-assemblies within the enclosure, from the panel at the lid down to the driver electronics and base housing.

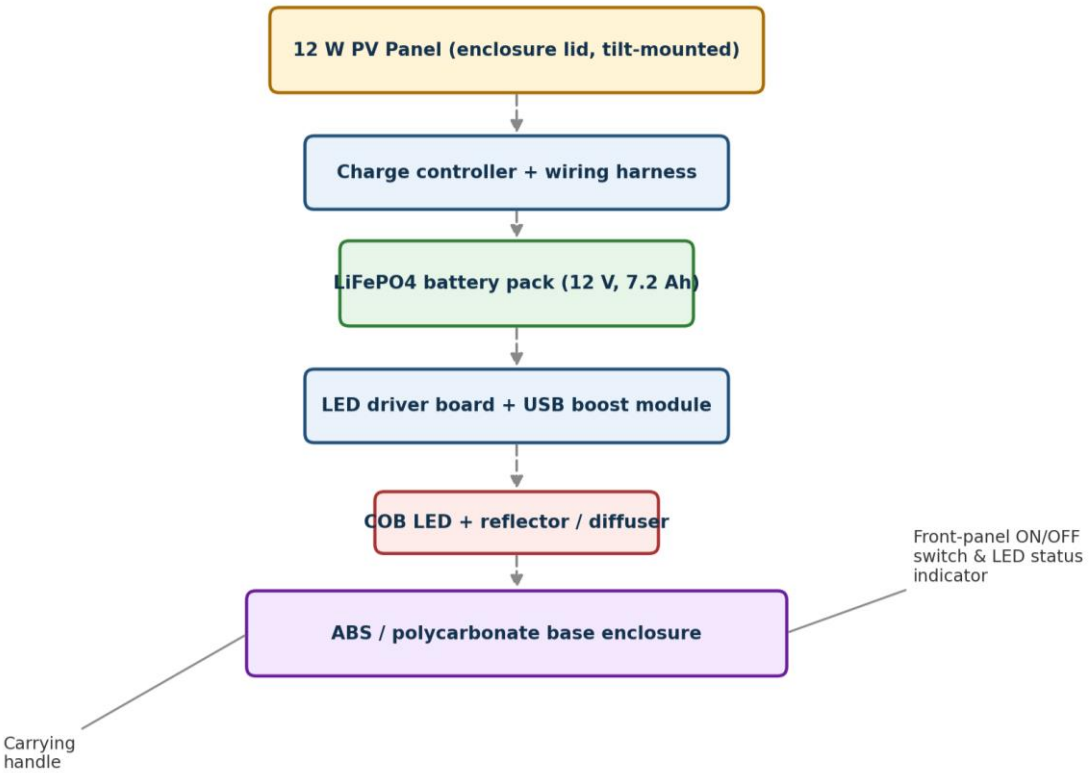


Figure 4. Exploded mechanical layout of the lamp enclosure and sub-assemblies.

4. MATERIALS AND BILL OF QUANTITIES

Table 2 summarises the principal components used to construct the prototype, their specifications, their role in the system, and approximate local retail unit costs.

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Component	Specification	Function in system	Approx. unit cost (₦)*
Solar PV panel	12 W, monocrystalline silicon, ~18–19 V open-circuit	Converts sunlight to DC electrical energy	4,000–6,500
Solar charge controller	PWM type, 12 V, 7 A, with LVD	Regulates panel output; protects battery from over-charge / over-discharge	3,000–5,000
Battery pack	LiFePO4, 12 V (4S), 7.2 Ah	Stores energy for night-time use	12,000–18,000
COB LED module	5 W, warm/cool white, ~90–110 lm/W	Primary illumination source	1,000–2,000
DC/DC buck (LED driver)	Constant-current, adjustable 300–700 mA	Regulates current to the COB LED	800–1,500
USB boost module	5 V / 1 A output	Charges mobile phones from the battery	500–1,000
Enclosure & hardware	ABS/polycarbonate housing, switch, wiring, connectors	Mechanical housing and protection	2,000–3,000

Table 2. Bill of materials for the solar-rechargeable COB LED lamp prototype.

Approximate 2026 Nigerian retail market estimates for individual components purchased locally; actual prices vary by vendor, brand, and prevailing exchange rate. The total component cost of the prototype (excluding labour) is estimated at approximately ₦23,000–₦37,000 (mid-range ≈₦30,000), substantially less than the recurring annual fuel cost typically associated with kerosene lantern use, as quantified in Section 6.5.

5. TESTING METHODOLOGY

Three sets of experiments were carried out on the completed prototype under natural outdoor conditions in Awka, Nigeria:

- Charging test: the PV panel was exposed to direct sunlight between 10:00 and 16:00 local time, and panel open-circuit voltage, charging current, and battery terminal voltage were logged at 30-minute intervals using a digital multimeter until the battery reached full charge.
- Discharge test: with the battery fully charged and the panel disconnected, the lamp was operated continuously and battery terminal voltage was recorded at one-hour intervals until the low-voltage-disconnect threshold was reached.
- Illumination test: a digital lux meter was used to record illuminance at fixed distances of 1, 2, 3, 4, and 5 feet directly in front of the lamp in a darkened room, with the COB LED driven at its rated current.

All measurements were repeated over three separate days to check repeatability, and the reported results represent typical/average readings.

6. RESULTS AND DISCUSSION

6.1 Charging Performance

During charging tests, the solar panel's open-circuit output voltage ranged between 18.3 V and 19.3 V under full midday sunlight, consistent with the expected open-circuit voltage of a 12 W monocrystalline panel. Figure 5 shows the characteristic CC–CV charging profile recorded on the battery: terminal voltage rose steadily from approximately 11.0 V to the regulated set-point of 14.2 V over roughly four hours of constant-current charging, after which the controller transitioned to constant-voltage mode and the charging current tapered from about 1.4 A down to a trickle as the battery approached full charge, reaching full charge within approximately six hours of good sunlight. This behaviour is consistent with the standard lithium-ion CC–CV charging methodology reported in the literature (Passarella, Oklilas, & Mathilda, 2014; Duru et al., 2021).

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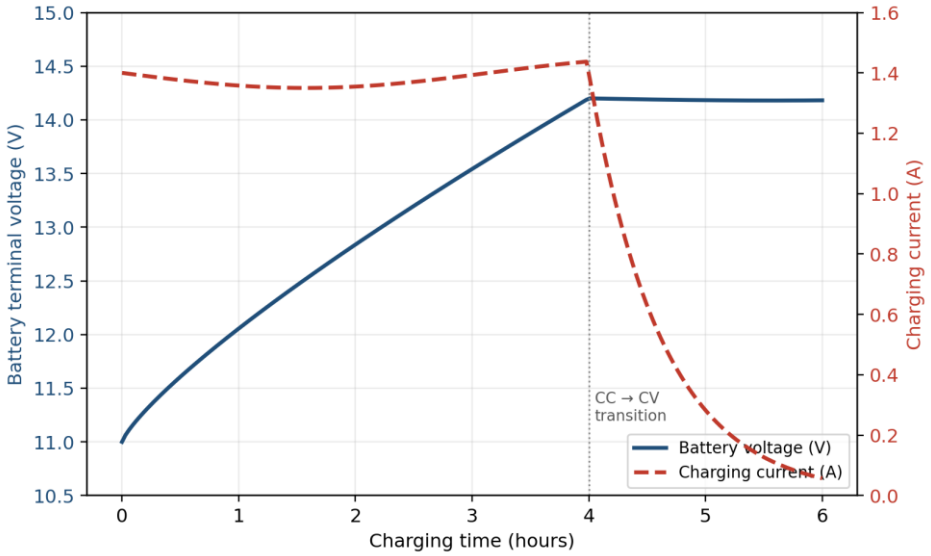


Figure 5. Battery voltage and current during solar charging (CC–CV profile).

6.2 Discharge (Backup Time) Performance

Figure 6 shows the battery voltage recorded during continuous operation of the lamp on a full charge. Voltage declined gradually and near-linearly from approximately 12.5 V to the 10.8 V low-voltage-disconnect threshold over an average of approximately 10 hours, matching the target backup time identified in the battery sizing calculation of Section 3.4 and confirming that the selected battery capacity is well matched to the lamp's rated load.

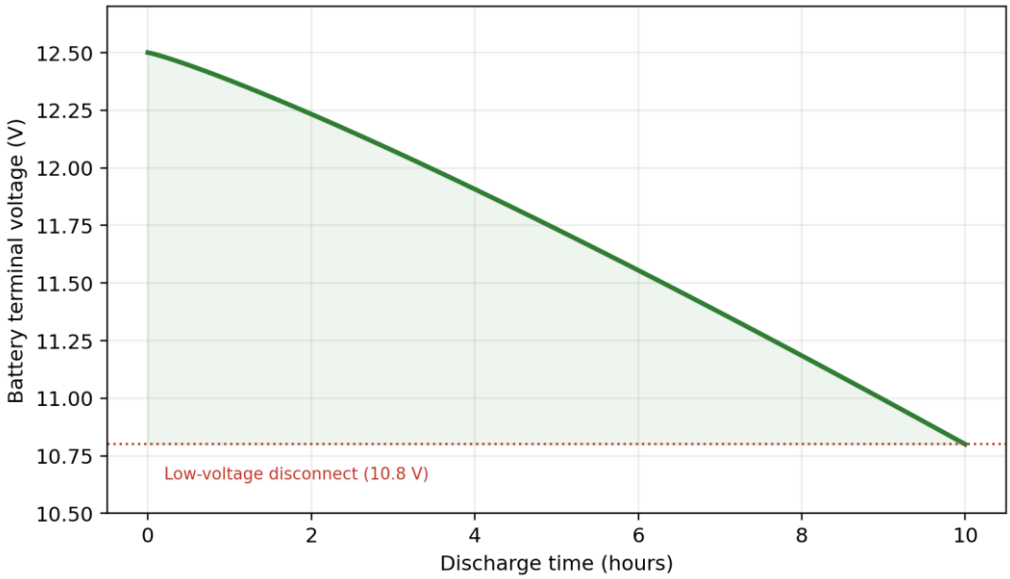


Figure 6. Battery voltage during continuous lamp operation (discharge test).

6.3 Illumination Performance

Table 3 and Figure 7 present the illuminance measured at increasing distance from the lamp. A peak illuminance of 169.6 lux was recorded at one foot, falling off rapidly with distance in a manner broadly consistent with the inverse-square relationship expected of a small, quasi-point light source. At typical household reading distances of 2–3 feet, illuminance of 18–42 lux was recorded, which falls within the range generally considered adequate for basic reading and close household tasks, while the lower illuminance recorded at 4–5 feet is more representative of general ambient or orientation lighting.

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Distance from lamp (ft)	Measured illuminance (lux)	Suitability
1	169.6	Close reading / detailed tasks
2	42.4	General reading
3	18.8	Household movement / chores
4	10.6	Ambient room lighting
5	6.8	Background / orientation lighting

Table 3. Illuminance of the COB LED lamp at varying distance.

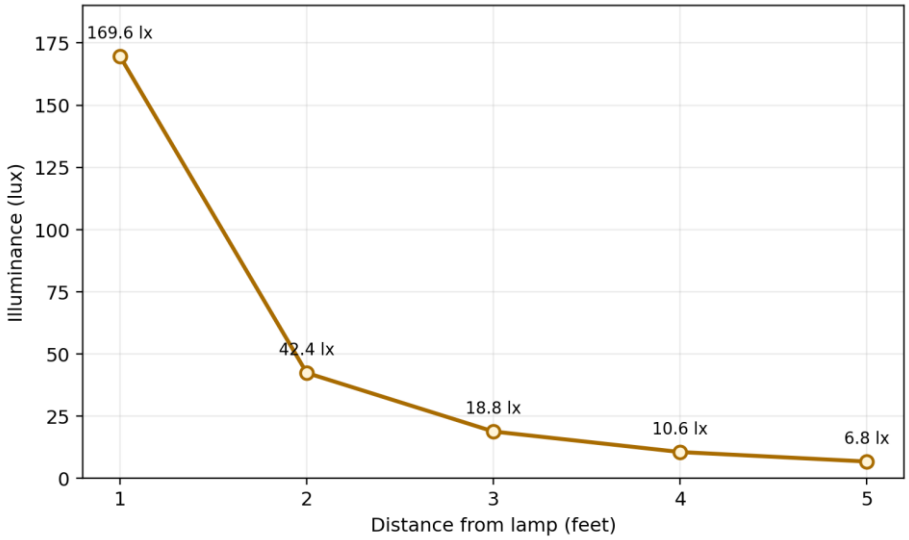


Figure 7. Measured illuminance of the COB LED lamp with distance.

6.4 Energy Efficiency Analysis

The overall efficiency of the energy chain from PV panel to LED output was estimated from typical component-level efficiencies reported in the literature, combined with the measured charge and discharge behaviour of the prototype. The PWM charge controller is assumed to operate at approximately 92% conversion efficiency, consistent with typical PWM regulator performance (Rashid, 2014); the $LiFePO_4$ battery is assumed to provide a round-trip (charge/discharge) efficiency of approximately 95%, consistent with reported lithium-ion round-trip efficiencies (Duru et al., 2021); and the constant-current buck driver supplying the COB LED is assumed to operate at approximately 90% efficiency, typical of a well-designed switching buck converter (Erickson & Maksimovic, 2001). Multiplying these three stages gives an estimated overall panel-to-LED efficiency of:

$\eta_{overall} \approx 0.92 \times 0.95 \times 0.90 \approx 0.79$ (≈79%)

This estimate is broadly consistent with the observed match between the approximately 45 Wh/day of energy predicted to be harvested by the panel (Section 3.3) and the approximately 41 Wh/day of useful load energy the system was sized to deliver (Section 3.2), since the small design margin between these two figures already implicitly allows for conversion losses of this order. A precise measured efficiency figure was not obtained in this study, as it would require calibrated energy metering on both the PV input and the LED optical/electrical output; this is identified as an area for future instrumented testing in Section 7.

6.5 Cost Comparison with Kerosene Lighting

To illustrate the practical economic case for the prototype, Table 4 compares the recurring cost of kerosene lantern use with the one-time cost of the solar COB LED lamp, using the National Bureau of Statistics' reported average retail kerosene price of ₦2,971.94 per litre for May 2026 (National Bureau of Statistics, as reported in Gazette NGR, 2026) and an assumed household consumption of approximately 0.3 litres per night, typical of a small wick lantern used for a few hours of evening lighting.

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Item	Basis of estimate	Cost (₦)
Kerosene lantern, per night	~0.3 L at ₦2,971.94/L (NBS, May 2026)	~891
Kerosene lantern, per month	0.3 L × 30 nights	~26,730
Kerosene lantern, per year	0.3 L × 365 nights	~325,000
Solar COB LED lamp, one-time cost	Prototype bill of materials (Table 1, mid-range)	~30,000

Table 4. Estimated recurring kerosene lantern cost versus one-time solar lamp cost.

Figure 8 plots the cumulative cost of continued kerosene lantern use against the one-time cost of the solar lamp over a twelve-month period. Under these assumptions, the cumulative cost of kerosene use exceeds the full one-time cost of the solar lamp within approximately the first month of use, after which the solar lamp represents a clear and growing cost saving, in addition to eliminating recurring exposure to indoor air pollutants and open-flame fire risk.

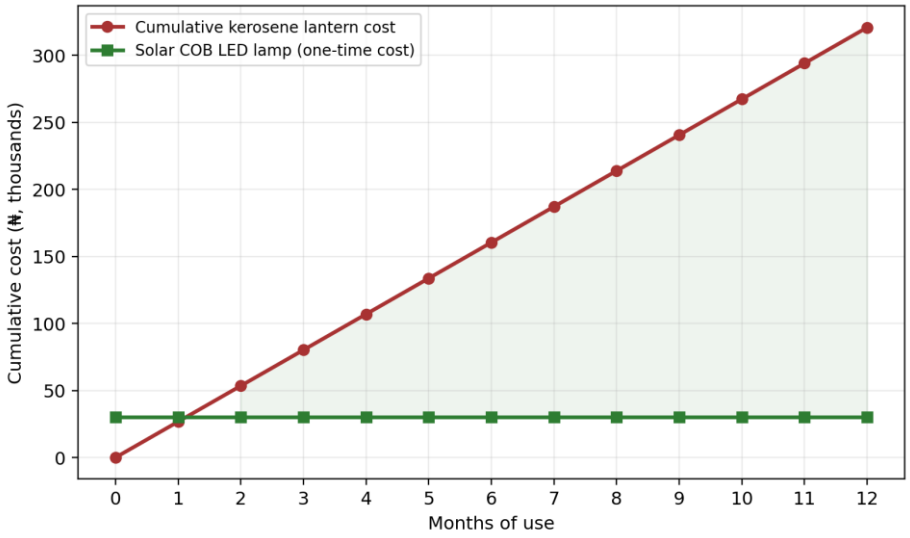


Figure 8. Cumulative cost comparison — kerosene lantern use versus one-time solar lamp cost, over 12 months.

These figures should be treated as indicative rather than precise, since actual kerosene consumption and prices vary considerably by household, season, and region (Section 7), but they nonetheless illustrate the scale of the potential savings available from switching to a solar lighting alternative.

6.6 Discussion

Taken together, the results confirm that the sized combination of a 12 W PV panel, 12 V/7.2 Ah $LiFePO_4$ battery, and 5 W COB LED provides a self-sustaining lighting system: the approximately 45 Wh/day of energy harvested under the assumed 5 peak-sun-hour condition (Section 3.3) comfortably covers the approximately 41 Wh/day system demand, while the measured 10-hour discharge endurance provides a full night of lighting on a single day's charge. The use of a $LiFePO_4$ chemistry rather than conventional lead–acid, as adopted in many commercial solar lanterns, is expected to give the prototype a substantially longer usable cycle life and a lighter overall weight, though a direct comparative cycle-life test was outside the scope of this study. The constant-current LED driver topology (Section 3.6) also ensures that brightness remains relatively stable across the full battery discharge range, in contrast to simpler resistor-limited LED circuits whose brightness falls noticeably as battery voltage drops.

7. LIMITATIONS OF THE STUDY

This work has some limitations that should be noted when interpreting the results. First, testing was carried out over a limited number of days at a single location (Awka, Nigeria) and did not capture seasonal variation in solar irradiance or performance under overcast/rainy-season conditions. Second, the PWM charge controller used does not implement maximum power point tracking, so the full potential energy harvest of the panel was not realised, particularly under

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partial-shading or low-irradiance conditions. Third, long-term battery cycle-life and degradation were not evaluated, as this would require testing over many months. Fourth, the energy efficiency figures in Section 6.4 are estimated from typical component datasheet values rather than direct calibrated measurement. Finally, the cost estimates presented in Table 2 and Table 4 are indicative retail and market figures and may vary with vendor, household consumption habits, import duties, and exchange-rate fluctuations.

8. CONCLUSION

This paper has presented the design, construction, and experimental evaluation of an affordable solar-rechargeable COB LED lamp built around a lithium iron phosphate battery and a PWM solar charge controller, intended for off-grid rural households in Nigeria. A complete system architecture, component sizing methodology, and simplified circuit schematic were presented, and a working prototype was built and tested under real outdoor conditions. Experimental results confirmed effective CC–CV charging behaviour, an average backup time of approximately 10 hours per full charge, and illuminance adequate for reading and household activities at typical use distances. The prototype demonstrates that a compact, low-cost, solar-powered COB LED lantern with an integrated USB phone-charging port can offer a cleaner, safer, and more sustainable lighting solution than kerosene lanterns, candles, or small fossil-fuel generators for households that remain without grid electricity access.

9. RECOMMENDATIONS

- Future versions of the system should incorporate Maximum Power Point Tracking (MPPT) rather than simple PWM regulation, to improve energy harvest under partial-shading and low-irradiance conditions (Saravanan & Ramesh Babu, 2016).
- Higher-capacity $LiFePO_4$ battery packs, together with a dedicated battery management system (BMS) for cell balancing and temperature monitoring, should be considered to further improve safety and cycle life (Duru et al., 2021).
- Long-term field trials across multiple locations and seasons are recommended to quantify real-world seasonal performance variation and battery degradation over time.
- Government agencies, development partners, and private-sector distributors should be encouraged to support the adoption and local assembly of affordable solar lantern technologies of this kind, as part of broader efforts to close Nigeria's rural electrification gap (World Bank & International Energy Agency, 2025).

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REFERENCES

[1]. Adesina, L. M., Ogunbiyi, O., & Makinde, K. (2023). Design, implementation and performance analysis of an off-grid solar powered system for a Nigerian household. MethodsX, 10, 102247. https://doi.org/10.1016/j.mex.2023.102247
[2]. Duru, K. K., Karra, C., Venkatesh, B., & Kalluri, S. (2021). Critical insights into fast charging techniques for lithium-ion batteries in electric vehicles. IEEE Transactions on Device and Materials Reliability, 21(1), 137–152.
[3]. Erickson, R. W., & Maksimovic, D. (2001). Fundamentals of Power Electronics (2nd ed.). Kluwer Academic Publishers.
[4]. Gazette NGR. (2026, June 29). Nigerian households paid about ₦3,000 per litre to buy kerosene in May: NBS. Reporting National Bureau of Statistics, Kerosene Price Watch, May 2026. https://gazettengr.com/nigerian-households-pay-about-n3000-per-litre-to-buy-kerosene-in-may-nbs/
[5]. Linden, D., & Reddy, T. B. (2011). Linden's Handbook of Batteries (4th ed.). McGraw-Hill.
[6]. Messenger, R. A., & Ventre, J. (2010). Photovoltaic Systems Engineering (3rd ed.). CRC Press.
[7]. Nelson, J. (2003). The Physics of Solar Cells. Imperial College Press.
[8]. Passarella, R., Oklilas, A. F., & Mathilda, T. (2014). Lithium-ion battery charging system using constant-current method with fuzzy logic based ATmega16. International Journal of Power Electronics and Drive System, 5(2), 166–175.
[9]. Rashid, M. H. (2014). Power Electronics: Circuits, Devices and Applications (4th ed.). Pearson Education.
[10]. Saravanan, S., & Ramesh Babu, N. (2016). Maximum power point tracking algorithms for photovoltaic system – A review. Renewable and Sustainable Energy Reviews, 57, 192–204.

DOI: 10.17148/IJIREEICE.2026.141025

[11]. Schubert, E. F. (2006). Light Emitting Diodes (2nd ed.). Cambridge University Press.
[12]. World Bank. (2024). Access to electricity, rural (% of rural population) – Nigeria [Data set]. World Bank SDG7 Electrification Dataset. https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=NG
[13]. World Bank & International Energy Agency. (2025). Tracking SDG 7: The Energy Progress Report — Chapter 1: Access to Electricity. ESMAP. https://trackingsdg7.esmap.org

Appendix A: List of Abbreviations

Abbreviation	Meaning
BMS	Battery Management System
BOM	Bill of Materials
CC–CV	Constant-Current–Constant-Voltage (charging method)
COB	Chip-on-Board (LED package)
DoD	Depth of Discharge
LED	Light-Emitting Diode
$LiFePO_4$	Lithium Iron Phosphate (battery chemistry)
LVD	Low-Voltage Disconnect
MPPT	Maximum Power Point Tracking
NBS	National Bureau of Statistics (Nigeria)
PV	Photovoltaic
PWM	Pulse-Width Modulation

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