International Journal on Advanced Science Engineering Information Technology

Vol.13 (2023) No. 1
ISSN: 2088-5334

Development of a 12-V Hybrid Powered Rechargeable Lighting System with Intruder Detection and Mobile Phone Charging Units

Oluwaseun Ibrahim Adebisi [a,*], Isaiah Adediji Adejumobi [a], Simeon Mathew [a], Olawale Olabamidele Thompson [a]

[a] *Department of Electrical and Electronics Engineering, Federal University of Agriculture, Abeokuta, Ogun State, 110121, Nigeria*
Corresponding author: [*]adebisioluwaseun@funaab.edu.ng

***Abstract*—The availability of stable, reliable, and low-cost electricity is one of the key indices for measuring the socioeconomic growth of any nation globally. However, in a developing economy such as Nigeria, marred by insufficient electricity generation, load shedding, and frequent power outage are common occurrences hindering some basic domestic functions, including lighting and charging, among others, to be performed. Therefore, an alternative solution that can serve as a backup for the conventional electricity supply system becomes imperative. This work developed a 12-V hybrid-powered rechargeable lighting system with intruder detection and USB ports for mobile phone charging. The basic components used in the system development are Arduino Nano (ATMega328) microcontroller, GSM (SIM900D) module, Passive Infra-Red (PIR) sensors, light bulbs, mini 12 V lead-acid battery, and 12 V, 20 W solar panel. Using relevant design equations, circuit designs and data processing were implemented around the ATMega328 microcontroller. The developed system was tested, and the output voltages of the lighting and charging units and the functionality of the intruder detection unit were determined. The developed hybrid-powered rechargeable lighting system operated satisfactorily during testing. The lighting and charging units were functional, giving 12 and 5 V output voltages, respectively. The intruder detection unit was active, producing a buzzing sound and sending an SMS alert to the registered phone number on the detection of an intrusion. The developed system is useful for domestic and other similar applications.**

***Keywords*— Intruder detection; lighting; mobile phone charging; Nigeria; power outage.**

Manuscript received 24 Dec. 2021; revised 23 Apr. 2022; accepted 6 Jun. 2022. Date of publication 28 Feb. 2023.

I. INTRODUCTION

Globally, illumination plays a crucial role in every man's life, essentially for carrying out day-to-day activities [1], [2], [3], [4]. Over the years, in most developing countries, including Nigeria, research efforts have been geared towards developing alternative lighting means due to insufficient electricity supply [5], [6]. One of the outcomes of these efforts is the rechargeable lighting system commonly referred to as a rechargeable lamp or lantern. It is a widely used lighting device in homes, schools, camps, hospitals, shops, markets, and other places. A rechargeable lantern's battery can be fully charged within a few hours and be put to use during the night-long period or other important occasions requiring lighting, depending on its capacity. Hence, this device can suitably complement the status of electricity supply in a developing country such as Nigeria, which is characteristically insufficient, epileptic, and unreliable.

Despite the abundant energy resources-coal, oil, gas, hydro, and renewables which could be harnessed for electricity production in Nigeria, the vast majority of the general populace still suffers inadequate access to regular and reliable electricity supply [7], [8], [9], [10], [11], [12], [13]. The Nigerian electricity market has traditionally been a vertically integrated and monopolistic market, where electricity production is anchored by public monopoly suppliers subject to government regulation of prices and investment [14], [15]. A series of challenges characterize this market, the most obvious being the mismatch between electricity supply and demand caused by insufficient generation, which has resulted in massive loading shedding and power outages [16], [17]. The country currently has a 12,522 MW installed capacity of grid electricity, but due to maintenance, gas, water, and transmission constraints, an average of about 4,000 MW is available [8], [18]. The government has taken various measures to address the lingering crises causing a wide gap between the installed and available capacity of grid electricity but to no avail [19], [20], [21]. This has constrained the country's growth and development [22], [23] and also hindered some basic functions in homes and other places that require constant electricity supply, such as lighting and charging to be carried out. Therefore, the need to develop an efficient system that can provide a constant electricity supply for performing these activities and equally provide security of properties in the form of burglar detection is essential.

According to the literature, various rechargeable lighting systems have been designed and implemented for various applications using different techniques. Faritha *et al.* [24] developed and implemented a self-optimizable smart lighting system for classroom applications. Rajani *et al.* [25] designed a solar cell-based telescopic lamp. Ashok and Srikanth [26] designed and implemented a smart solar Light Emitting Diode (LED) light bulb with remote control. Olaitan and Aladenika [27] designed and constructed a portable rechargeable lamp with an automatic mechanical manual timer control switch. Dawson *et al.* [28] developed a solar-rechargeable LED lantern and cell phone charger.

However, in literature, other functions, such as burglar detection, have not been incorporated into the rechargeable lighting system. Thus, in this work, a 12 V hybrid-powered rechargeable lighting system that incorporates multi–Universal Serial Board (USB) charging ports and a burglar alarm unit was developed for domestic application. The need for integration of burglar alarm units was premised on the fact that in recent times in Nigeria, there has been a high rising demand for the protection of properties against theft or unauthorized persons, bringing the use of burglar detection to the fore. The burglar alarm detects intrusion into an area where the lighting system is placed, thereby providing protection against theft or property damage and personal protection against intruders.

A rechargeable lighting system is a portable lighting device or mounted light fixture that converts the electrical energy from a battery into visible light. This lighting system can serve as an alternative means of illumination in any location when there is a power outage [18]. It is particularly useful in remote or rural areas where there is a lack of electricity [19], [31] [32]. It may be used for signaling, as torches, or as outdoor light source [27]. A rechargeable lighting system is typically available in varieties of shapes and sizes in the market [33] and can either be AC mains powered, solar-powered, or hybrid-powered, comprising both ac mains and solar energy sources. Hybrid-powered rechargeable lantern is an improvement over ac mains-powered or solar-powered types. In the event of AC mains failure, the availability of solar energy in the form of sunlight provides the electrical energy to charge the lantern's battery. Also, during the cool day, when the sunshine level drops considerably, the availability of AC mains will provide the electrical energy to charge the device battery for usage. Generally, a rechargeable lighting system for domestic applications is lightweight, user-friendly, safe, and convenient.

II. Materials and Method

A. System Overview

The basic building blocks of the 12 V hybrid-powered rechargeable lighting system implemented in this work are presented in Fig. 1.

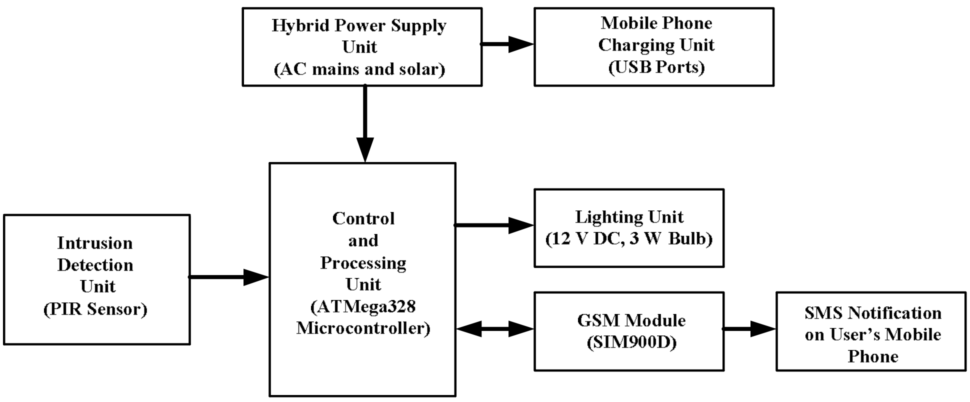

Fig. 1 Block diagram of the hybrid rechargeable lighting system with intrusion detection and charging unit for mobile phone

The system's brain is an Arduino Nano ATMega328 microcontroller that acts as the control and processing unit. It is hybrid-powered, utilizing both AC mains and solar as supply sources. The microcontroller controls the lighting, intrusion detection, and the GSM module. It powers the 3 W lighting bulb by delivering the required 12 V DC for its operation. It utilizes input from the Passive Infra-Red (PIR) sensor in the form of intrusion detection from unauthorized persons to trigger the GSM module (SIM900D), which sends an instant SMS notification to a pre-programmed phone number whenever there is an intrusion. The mobile phone charging unit, which comprises USB ports, is also driven by the hybrid power supply unit.

B. Hybrid Power Supply Unit

The circuit diagram of the hybrid power supply unit implemented is shown in Fig. 2. The main sections of the unit are the solar and AC mains circuits. Solar energy is the primary source of supply for the system. The solar panel employed was rated 12 V, 20 W, and contains 36 cells wired in series to produce about 18 V peak output. The solar panel's output is supplied to the 12 V battery, which powers the overall circuit.

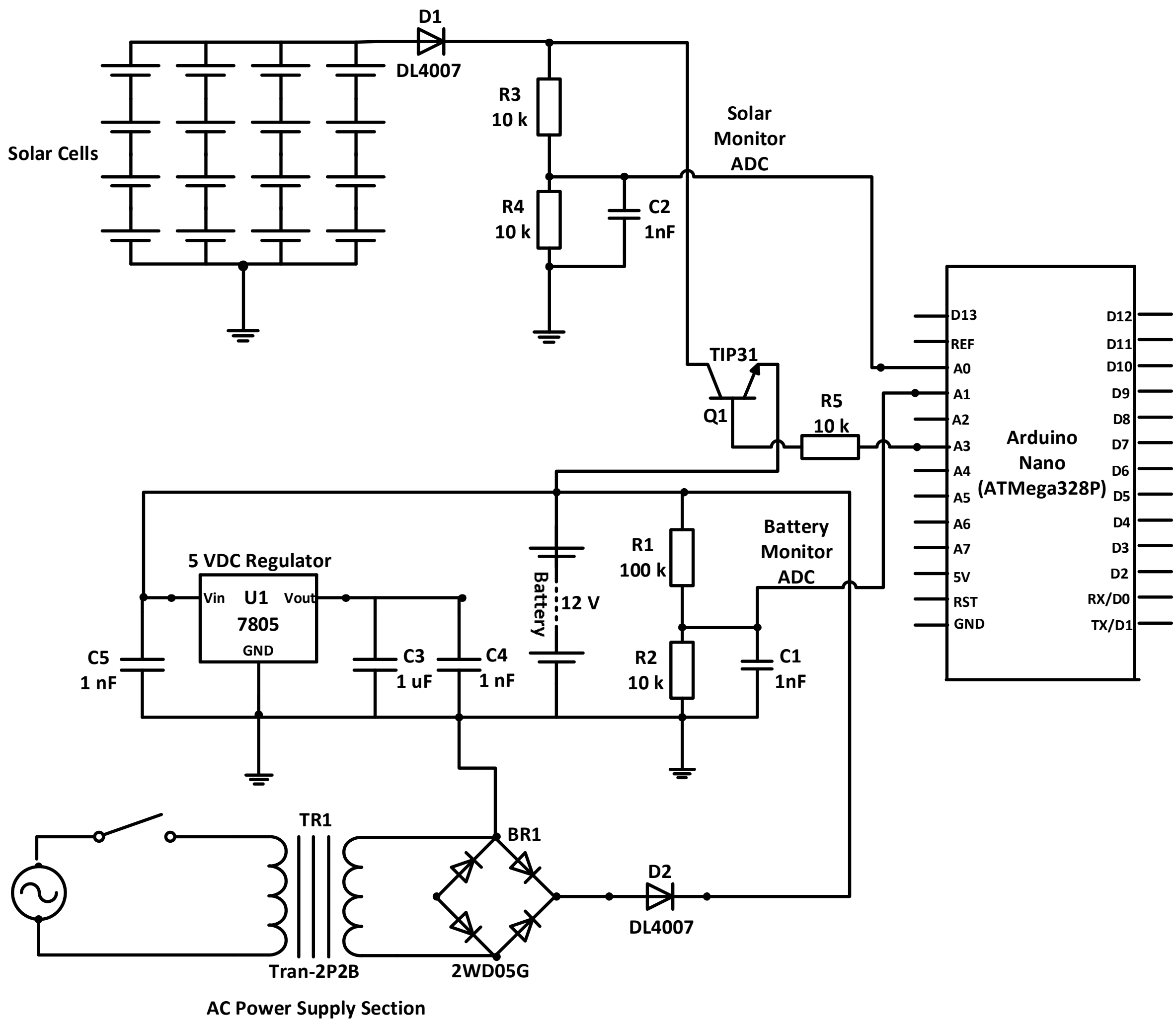

Fig. 2 Hybrid power supply unit

To keep the output voltage from the solar panel at a steady value in case of any fluctuation, a capacitor C_2 was placed across the resistor R_4 for damping. It also helps to eliminate ripples from the output voltage, making it an ideal direct current signal that can be used reliably to measure the supply level. The value of C_1 was randomly chosen as 1 nF since the voltage rating from the solar circuit is the same as that of the entire circuit, which is 12 V.

The output voltage, V_o, from the solar panel was determined using a potential divider formula given by Eq. 1 [34]:

$$V_o = V_i\left(\frac{R_3}{R_3+R_4}\right) \tag{1}$$

The resistance values of R_3 and R_4 were chosen as 10 and 100 kΩ, respectively. The maximum voltage that can be obtained from the solar panel ranges between 17 to 20 V depending on the sun's intensity. However, a 50 V operating condition is envisaged in case of overvoltage. Hence, substituting the values of V_i, R_3 and R_4 as 50 V, 10 kΩ and 100 kΩ respectively in eq. 1, V_o was determined as 4.5 V. At normal working, V_i assumes a value of 18 volts. Using V_i as 18 V in eq. 1 gave V_o as 1.63 V. The output of the solar monitor is fed into an analog input of the Arduino Nano ATMega328 microcontroller. With these calculated output voltage values under overvoltage and normal working conditions, the Arduino program was written such that voltage values between 0 and 1.65 V were calibrated as normal and values above 1.65 V up to 4.5 V as abnormal. In this case, the resistor R_4 of 100 kΩ value serves as protection against overvoltage surges.

The time, t, taken by the capacitor C_2 to charge was calculated using Eq. 2 [34]:

$$t = R_3C_2 \tag{2}$$

With R_3 as 10 kΩ and C_2 as 1 nF, t was estimated as 1 μs. The AC mains supply was used in this work as a secondary means of charging the battery powering the overall system. The conversion of the 220 V AC mains to 5 V DC suitable for the operation of the microcontroller involves transformation from 220 V AC to 12 V AC using a step-down transformer, the rectification of 12 V AC from the transformer using a bridge rectifier, and voltage regulation to the required 5 V DC by the LM7805 IC. Two capacitors, C_4 and C_5 of 1 nF each, were connected across the input and output terminals of the LM7805 IC to eliminate all transient components. These capacitor values were specified in the datasheet of the IC.

The battery chosen for this work was a mini 12 V lead-acid battery with an amperage rating of 12 Ah. The current required to charge the battery from the solar panel was evaluated using the expression of Eq. 3 [34]:

$$I = \frac{\rho P}{V} \quad (3)$$

Assuming a ρ value of 85% with P as 20 W and V as 20 V, current I from the solar panel required to charge the battery was calculated as 1.416 A.

Using I against the amperage rating of the battery, it was estimated that an average of 8.5 hours would be required to charge the battery. The battery monitor circuit was a replica of the solar monitor circuit, and the microcontroller was programmed to monitor the voltage level of the battery. Once the analog read of the microcontroller has risen to 1.63 V, it sends a signal to the base of the transistor Q_1, which serves as a switch, and cuts it off from the solar charging circuit to prevent overcharging.

C. *Design of the Lighting Unit*

The circuit diagram of the lighting unit is presented in Fig. 3. The lighting unit consists of Light Dependent Resistor (LDR) and two 12 V, 3W DC bulbs. The power source for the lighting circuit was tapped directly from the terminals of the 12 V lead-acid battery. The LDR functions as a darkness sensor, sending a signal to the Arduino processor upon sensing darkness.

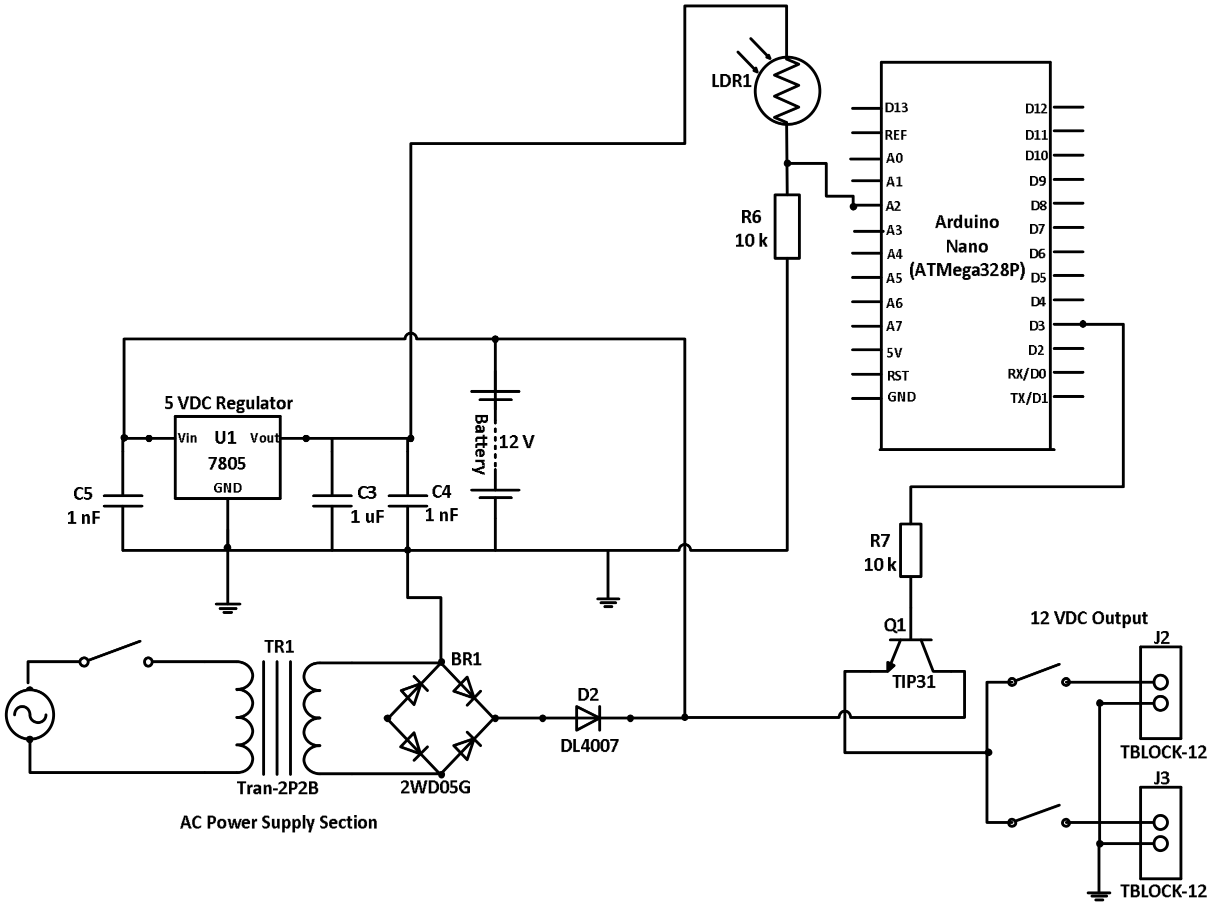

Fig. 3 Lighting circuit

The Arduino processor that has been pre-programmed turns on the lamp's switch through the NPN transistor Q_2. The bulbs on the outside have a manual control that can turn them on or off. The value of resistance R_7 placed in series with the base of the transistor was calculated using Eq. 4 [34]:

$$V_{in} - V_{BE} = I_{in} R_7 \quad (4)$$

With V_{in}, I_{in} and V_{BE} taken as 5 V, 0.5 mA, and 0.7 V, respectively, R_7 was evaluated 8.6 kΩ. However, a 10 kΩ resistor was chosen due to the real-time non-availability of 8.6 kΩ resistor.

D. *Design of the Intrusion Detection Unit*

The schematic of the intrusion detection unit is presented in Fig. 4. The PIR sensor is the major component of this unit. Once a push-button pre-sets it, information on any movement detected within its area of coverage which ranges from 2 to 5 m, will be sent to the digital read of the microcontroller. The sensor was powered by a 5 V output of the LM7805 IC. When the Arduino Nano ATMega328 microcontroller receives the signal from the PIR sensor, it initiates the GSM SIM900D module into action, which sends an SMS stating "Intruder Alert" to the pre-programmed mobile phone number. The value of the pull-down resistor R_8 which connects the PIR sensor to the ground of the battery through the microcontroller, was determined by Eq. 5:

$$V_{in} - V_{og} = I_{in} R_8 \quad (5)$$

Using V_{in}, I_{in} and V_{og} as 5 V, 0.5 mA, and 0 V, respectively, R_8 was calculated as 10 kΩ.

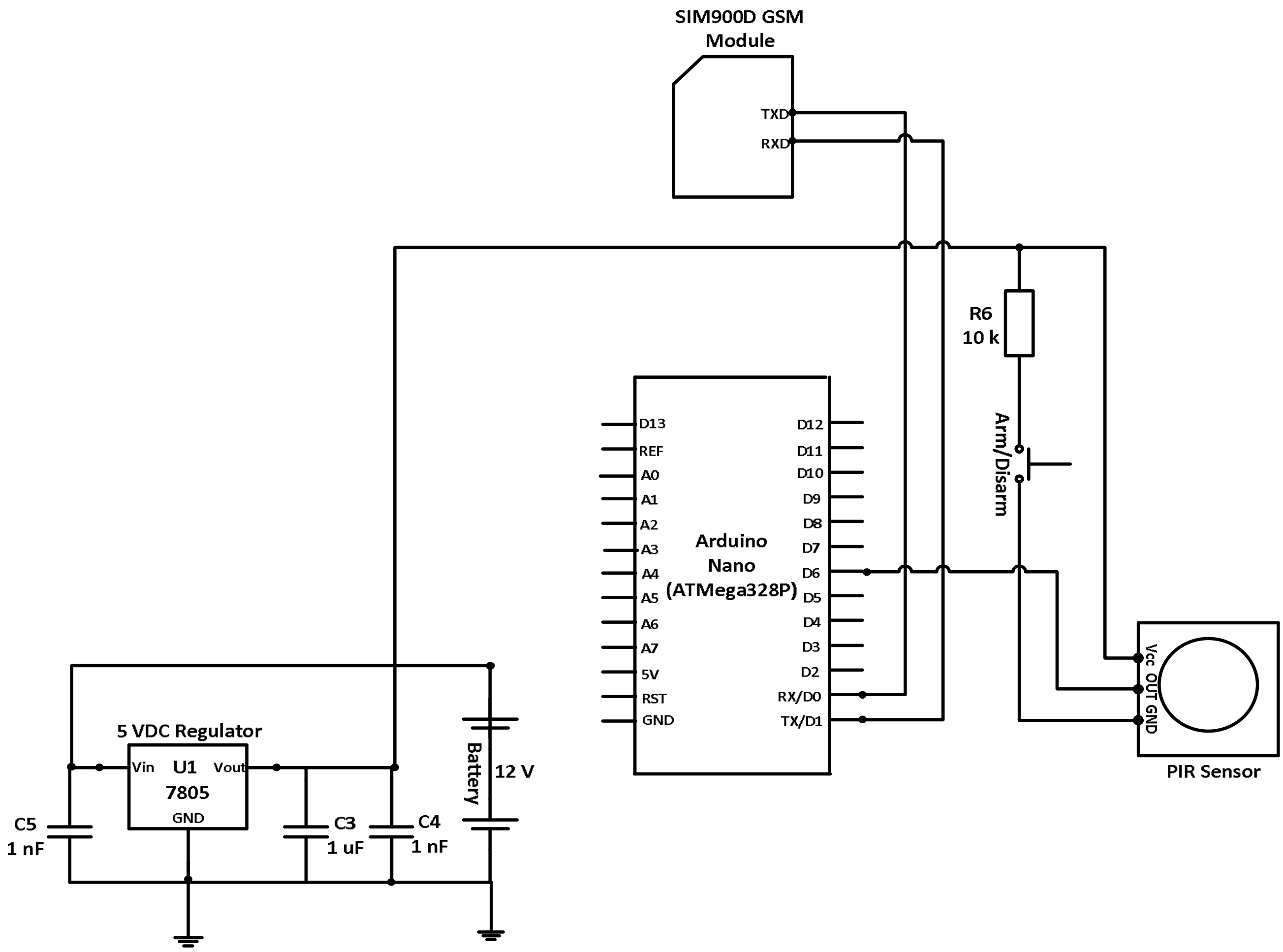

Fig. 4 Schematic of the intrusion detection unit

E. Design of the USB Charging Unit

The USB connectors provided in the charging unit of the rechargeable lighting system were also powered with 5 V output from the LM7805 voltage regulator. The design of this unit ensures that the power supply is always available at the ports at all times to charge mobile phones. The schematic of the charging unit is shown in Fig. 5.

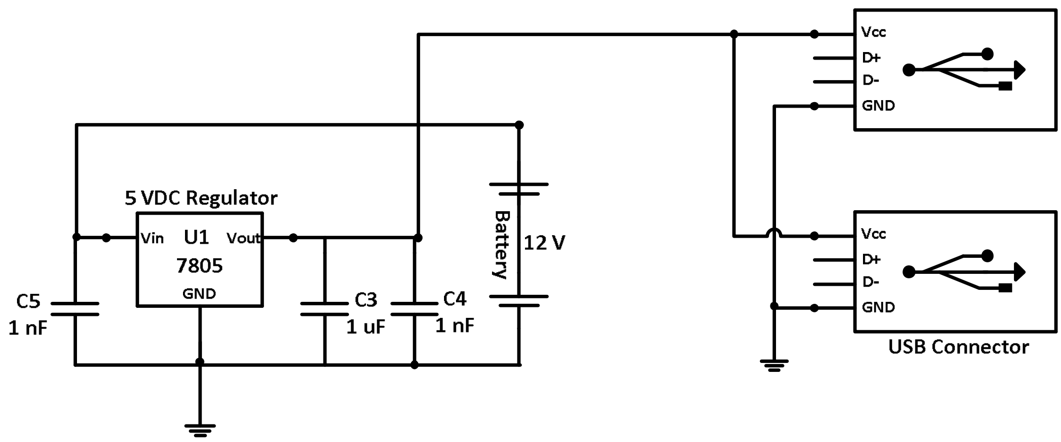

Fig. 5 USB charging unit

F. Overall System Design

The overall circuit diagram of the 12 V hybrid-powered rechargeable lighting system with intrusion detection and mobile phone charging units developed in this work is presented in Fig. 6. The circuit integrates various sub-units, including the hybrid power supply unit, the lighting unit, the intrusion detection unit, and the USB charging unit.

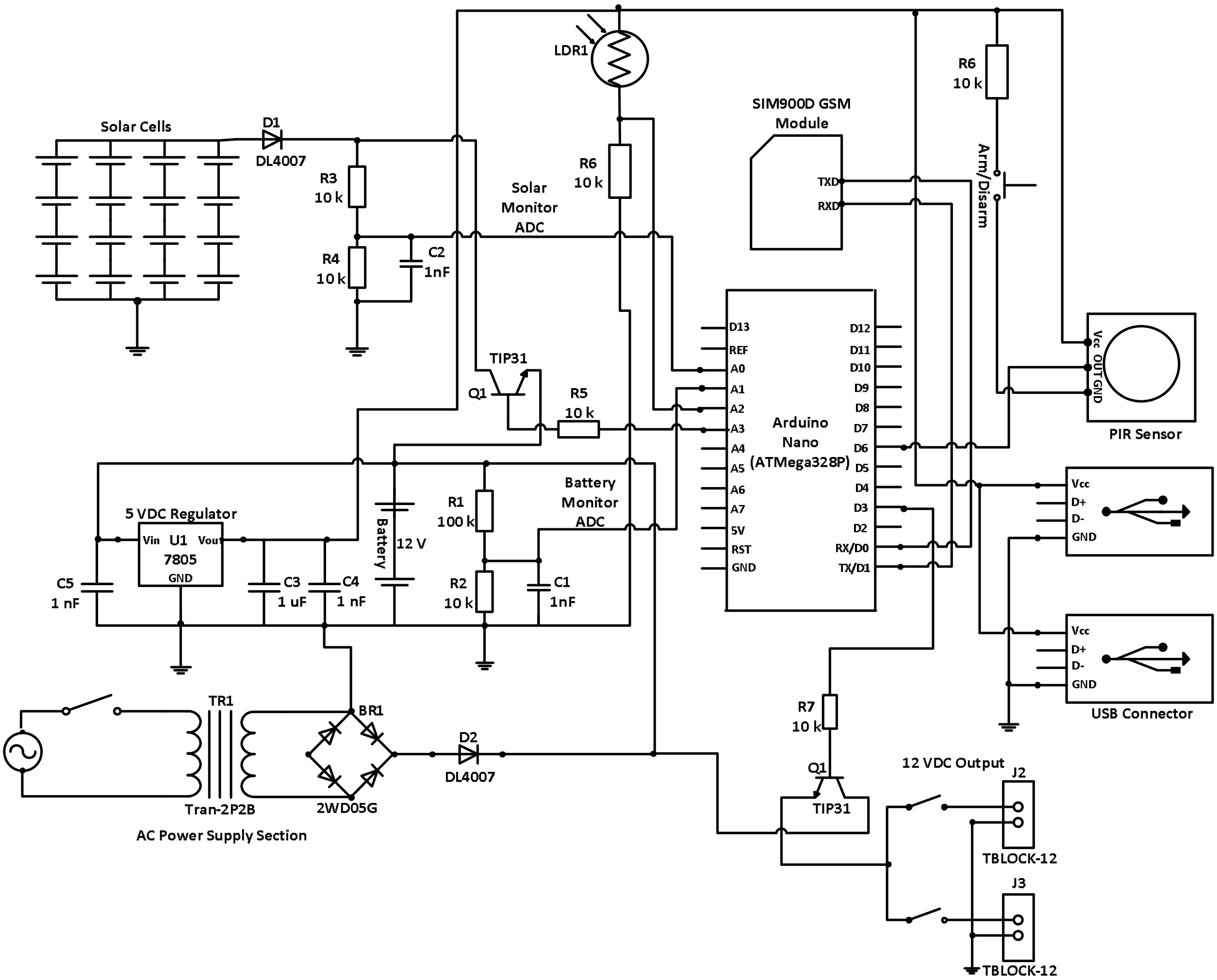

Fig. 6 Overall circuit diagram of the 12 V hybrid-powered rechargeable lighting system with intrusion detection and charging units

G. Testing of the Developed System

A performance test was carried out on the developed 12 V hybrid-powered rechargeable lighting system. The tests performed include the following:

1) Battery Charging Voltage Test: This test was carried out on the system's two input sources (solar and ac mains). The output voltage of the solar panel to charge the battery, which drives the entire system, was measured using a multimeter and compared with the 20.6 V required from the panel for optimum charging of the battery. For the ac mains, the output voltage from the voltage regulator was also measured using a multimeter and compared with the required 12 V DC to charge the battery.

2) Lighting Test: This test was performed to ensure the lighting bulbs have the required voltage to power them. Therefore, the terminal voltage supplied to the bulbs was measured using a multimeter and compared with the 12 V DC required to power the bulbs.

3) Intrusion Detection Test: This test was carried out on the intrusion detection unit of the system when it was enabled and disenabled. The PIR sensor detects motion from over a meter corresponding to the sensitivity level pre-set. Once the sensor senses a movement, a buzzing sound that indicates the buzzer would produce intrusion, and an SMS would be sent to a pre-programmed phone number on the system.

4) Mobile Phone Charging Voltage Test: This test was done with a multimeter to measure the required voltage and current reaching the USB ports to charge the mobile phone.

III. Results and Discussion

A. The Developed System

Figs. 7 and 8 show the fully packaged hybrid-powered rechargeable lighting system and its internal circuitry.

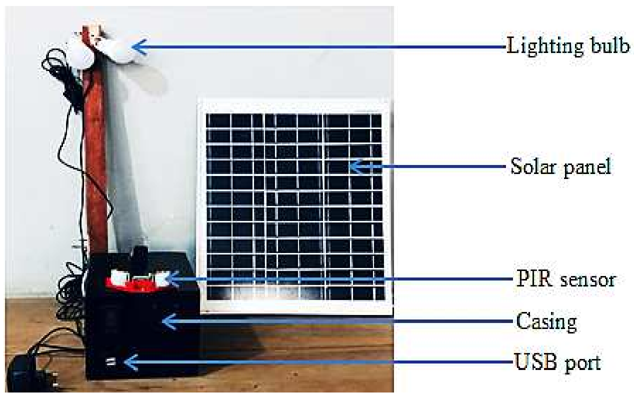

Fig. 7 The developed hybrid-powered rechargeable lighting system

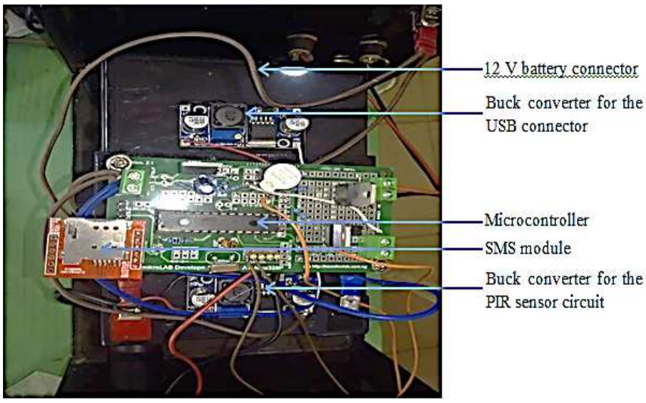

Fig. 8 Internal circuitry of the control unit of the developed system

Fig. 7 shows different external features of the system, including the lighting bulbs, solar panel, PIR sensors, USB ports, among others. Fig. 8 shows component connections on the printed circuit board and the cable connections.

B. *Performance Test Results*

The results of tests conducted on the developed system are presented in Figs. 9 to 11, respectively. Fig. 9 showed that a voltage of 20.6 V was obtained from the solar panel charging the battery powering the system.

Fig. 9 Measured output voltage from solar panel

The main source was used as a backup for the system in case of cool weather or at night when the solar panel is inactive. Also, the solar panel supplied a voltage of 12 V through the charging unit to the battery when the solar panel plug was pulled out. More so, as observed in Figure 10, the lighting bulbs gave a bright illumination during the testing of the system. The terminal voltage supplied to the bulbs was measured as 11.88 V, sufficient to power them. Fig. 11, on the other hand, indicates the charging of a mobile phone connected to the USB port of the system.

Fig. 10 Illuminated lighting bulbs with the developed system under operation

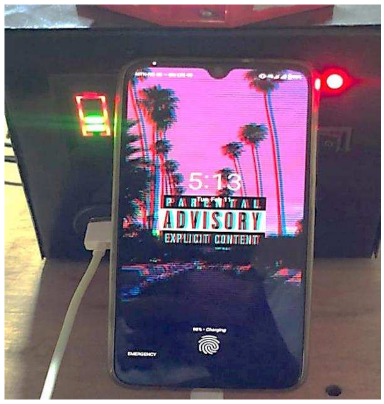

Fig. 11 Charging mobile phone

The charging voltage and current for the phone at the USB ports were measured as 5 V and 2 A, respectively. Equally, the pre-configured mobile phone number received a series of SMS notifications from the system each time an intrusion was detected during testing. Hence, the overall test results revealed that the developed hybrid-powered rechargeable lighting system operated satisfactorily and is suitable for domestic use and other related applications.

IV. Conclusion

Today in a developing nation like Nigeria, where power outages and insecurity are prevalent, the availability of an embedded system that can efficiently assist the citizens in performing some basic domestic functions such as lighting, charging, and home monitoring is still a major challenge. This work developed a 12 V hybrid-powered rechargeable lighting system with intruder detection and USB ports for mobile phone charging.

The developed system is simple, robust, and economical for domestic and other related applications. It is useful for lighting up a room during blackouts. It can charge mobile phones for continuous use and serve as a primary security alert when an unauthorized entry into an apartment is detected. To ensure that the system operates correctly all round the clock, it is recommended that it is armed when the user is leaving the house and disarmed on returning to prevent unnecessary SMS alerts. The master switch of the system should also be turned off if it is not in use to prevent constant draining of the battery and eventual damage.

Nomenclature

V_i	solar panel input voltage	V
R_1, R_2, R_3, R_4	potential divider circuit resistances	Ω
T	time	s
I	solar panel current	A,
P	solar panel power rating	W
V	battery charging voltage	V
V_{in}	arduino analog input voltage	V
I_{in}	arduino analog input current	A
V_{BE}	base-emitter voltage	V
V_{og}	ground potential	V
Greek letter		
ρ	solar panel charging efficiency	
Subscripts		
i, *in*		input

ACKNOWLEDGMENT

The authors are grateful to the immense support of the HIC Mikrolab, Asero, Abeokuta, Ogun State Nigeria during the implementation stage of the developed system.

REFERENCES

[1] A. Silvast and M. J. Virtanen, "An assemblage of framings and tamings: multi-sited analysis of infrastructures as a methodology," *J. Cult. Econ.*, vol. 12, no. 6, pp. 461–477, 2019, doi: 10.1080/17530350.2019.1646156.

[2] M. Füchtenhans and E. H. Grosse, "Smart lighting systems : State-of-the-art and potential applications in warehouse order picking Smart lighting systems : state-of-the-art and potential applications in warehouse order picking," *Int. J. Prod. Res.*, vol. 0, no. 0, pp. 1–23, 2021, doi: 10.1080/00207543.2021.1897177.

[3] D. Ferreira *et al.*, "Efficiency , quality , and environmental impacts : A comparative study of residential artificial lighting," *Energy Reports*, vol. 5, pp. 409–424, 2019, doi: 10.1016/j.egyr.2019.03.009.

[4] J. Falcón *et al.*, "Exposure to Artificial Light at Night and the Consequences for Flora , Fauna , and Ecosystems," *Front. Neurosci.*, vol. 14, pp. 1–39, 2020, doi: 10.3389/fnins.2020.602796.

[5] Sujono *et al.*, "Sharing light and knowledge to underdeveloped village with portable house lighting system," *IEEE Reg. 10 Humanit. Technol. Conf. R10-HTC*, vol. 2019-Novem, pp. 234–237, 2019, doi: 10.1109/R10-HTC47129.2019.9042474.

[6] Y. Hu *et al.*, "A Portable and Efficient Solar-Rechargeable Battery with Ultrafast Photo-Charge/Discharge Rate," *Adv. Energy Mater.*, vol. 9, no. 28, pp. 1–9, 2019, doi: 10.1002/aenm.201900872.

[7] I. D. Ibrahim *et al.*, "A review on Africa energy supply through renewable energy production: Nigeria, Cameroon, Ghana and South Africa as a case study," *Energy Strateg. Rev.*, vol. 38, no. August 2019, p. 100740, 2021, doi: 10.1016/j.esr.2021.100740.

[8] E. Nduka, "How to get rural households out of energy poverty in Nigeria: A contingent valuation," *Energy Policy*, vol. 149, no. November 2020, p. 112072, 2021, doi: 10.1016/j.enpol.2020.112072.

[9] O. B. Adewuyi, M. K. Kiptoo, A. F. Afolayan, T. Amara, O. I. Alawode, and T. Senjyu, "Challenges and prospects of Nigeria's sustainable energy transition with lessons from other countries' experiences," *Energy Reports*, vol. 6, pp. 993–1009, 2020, doi: 10.1016/j.egyr.2020.04.022.

[10] W. Arowolo, P. Blechinger, C. Cader, and Y. Perez, "Seeking workable solutions to the electrification challenge in Nigeria : Minigrid , reverse auctions and institutional adaptation," *Energy Strateg. Rev.*, vol. 23, no. December 2018, pp. 114–141, 2019, doi: 10.1016/j.esr.2018.12.007.

[11] O. Eseyin and J. O. Ogunjobi, "Sustainable Electricity Supply and Poverty Reduction in Nigeria," vol. 12, no. 1, pp. 54–61, 2022.

[12] H. B. Adedayo, S. A. Adio, and B. O. Oboirien, "Energy research in Nigeria : A bibliometric analysis," *Energy Strateg. Rev.*, vol. 34, no. February, p. 100629, 2021, doi: 10.1016/j.esr.2021.100629.

[13] O. Ogunmodimu and E. C. Okoroigwe, "Solar thermal electricity in Nigeria: Prospects and challenges," *Energy Policy*, vol. 128, pp. 440–448, 2019, doi: 10.1016/j.enpol.2019.01.013.

[14] O. I. Adebisi and I. Adediji Adejumobi, "Development of a Web Service Based Information Exchange Platform for the Nigerian Deregulated Electricity Market," in *IEEE PES/IAS PowerAfrica Conference: Power Economics and Energy Innovation in Africa, PowerAfrica 2019*, 2019, pp. 176–181, doi: 10.1109/PowerAfrica.2019.8928847.

[15] O. I. Adebisi and I. A. Adejumobi, "Development of a Load Management Scheme for the Nigerian Deregulated Electricity Market Using Regression Model," in *IEEE PES/IAS PowerAfrica Conference: Power Economics and Energy Innovation in Africa, PowerAfrica 2019*, 2019, pp. 682–687, doi: 10.1109/PowerAfrica.2019.8928928.

[16] A. Gungah, N. V. Emodi, and M. O. Dioha, "Improving Nigeria's renewable energy policy design: A case study approach," *Energy Policy*, vol. 130, no. April, pp. 89–100, 2019, doi: 10.1016/j.enpol.2019.03.059.

[17] O. J. Ayamolowo, E. Buraimoh, A. O. Salau, and J. O. Dada, "Nigeria Electricity Power Supply System: The Past, Present and the Future," *IEEE PES/IAS PowerAfrica Conf. Power Econ. Energy Innov. Africa, PowerAfrica 2019*, no. August, pp. 64–69, 2019, doi: 10.1109/PowerAfrica.2019.8928767.

[18] A. Nwozor, S. Oshewolo, and O. Ogundele, "Energy poverty and environmental sustainability in Nigeria: An exploratory assessment," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 331, no. 2019, pp. 1–14, 2019, doi: 10.1088/1755-1315/331/1/012033.

[19] O. B. Fakehinde, O. S. Fayomi, U. K. Efemwenkieki, K. O. Babaremu, D. O. Kolawole, and S. O. Oyedepo, "Viability of hydroelectricity in Nigeria and the future prospect," *Energy Procedia*, vol. 157, no. 2018, pp. 871–878, 2019, doi: 10.1016/j.egypro.2018.11.253.

[20] H. S. Ali, S. P. Nathaniel, G. Uzuner, F. V. Bekun, and S. A. Sarkodie, "Trivariate modelling of the nexus between electricity consumption, urbanization and economic growth in Nigeria: fresh insights from Maki Cointegration and causality tests," *Heliyon*, vol. 6, no. 2, p. e03400, 2020, doi: 10.1016/j.heliyon.2020.e03400.

[21] O. M. Babatunde, C. O. Ayegbusi, D. E. Babatunde, P. O. Oluseyi, and T. E. Somefun, "Electricity supply in Nigeria: Cost comparison between grid power tariff and fossil-powered generator," *Int. J. Energy Econ. Policy*, vol. 10, no. 2, pp. 160–164, 2020, doi: 10.32479/ijeep.8590.

[22] M. W. Ssali, J. Du, I. A. Mensah, and D. O. Hongo, "Investigating the nexus among environmental pollution, economic growth, energy use, and foreign direct investment in 6 selected sub-Saharan African countries," *Environ. Sci. Pollut. Res.*, vol. 26, no. 11, pp. 11245–11260, 2019, doi: 10.1007/s11356-019-04455-0.

[23] M. Irfan, Z.-Y. Zhao, M. Ahmad, and M. Mukeshimana, "Solar Energy Development in Pakistan: Barriers and Policy Recommendations," *Sustainability*, vol. 11, no. 4, p. 1206, 2019, doi: 10.3390/su11041206.

[24] J. Faritha Banu, R. Revathi, M. Suganya, and N. R. Gladiss Merlin, "IoT based Cloud integrated smart classroom for smart and a sustainable campus," *Procedia Comput. Sci.*, vol. 172, no. 2019, pp. 77–81, 2020, doi: 10.1016/j.procs.2020.05.012.

[25] A. Rajani, H. M. Saputra, R. Arief Subekti, D. G. Subagio, and A. Nurhakim, "Design and Performance of Solar-powered Telescopic Lamp," *Proceeding - 2019 Int. Conf. Sustain. Energy Eng. Appl. Innov. Technol. Towar. Energy Resilience, ICSEEA 2019*, pp. 155–158, 2019, doi: 10.1109/ICSEEA47812.2019.8938646.

[26] S. Ashok and B. Srikanth, "Design and Construction of Smart Solar LED Light Bulb with Remote Control," *Int. J. Res. Eng. Technol.*, vol. 06, pp. 90–92, 2017.

[27] S. K. Olaitan and A. K. Aladenika, "the Design and Construction of a Potable Rechargeable Lamp With Automatic Mechanical Manual Timer Control Switch .," vol. 1, no. 7, pp. 1–3, 2015.

[28] S. C. Dawson, M. E. Deagen, F. N. Dye, B. S. Mircheff, and R. O. Ramelb, "Solar-Rechargeable LED Lantern and Cell Phone Charger," California Polytechnic State University, 2011.

[29] A. Mahajan, S. P. Harish, and J. Urpelainen, "The behavioral impact of basic energy access: A randomized controlled trial with solar lanterns in rural India," *Energy Sustain. Dev.*, vol. 57, pp. 214–225, 2020, doi: 10.1016/j.esd.2020.04.005.

[30] M. Hasan and K. A. Khan, "Dynamic model of Bryophyllum pinnatum leaf fueled BPL cell: a possible alternate source of electricity at the off-grid region in Bangladesh," *Microsyst. Technol.*, vol. 25, no. 6, pp. 2481–2492, 2019, doi: 10.1007/s00542-018-4149-y.

[31] A. H. Danlami, S. D. Applanaidu, and R. Islam, "Movement towards the adoption of non-traditional household lighting fuel energy in developing areas," *Biofuels*, vol. 10, no. 5, pp. 623–633, 2017, doi: 10.1080/17597269.2017.1338125.

[32] R. Bhukya, P. K. Nalli, K. S. Kadali, and M. C. Bade, "Designing of Lithium - Ion Battery Pack Rechargeable on a Hybrid System with Battery Management System (BMS) for DC Loads of Low Power Applications – A Prototype Model," *J. Phys. Conf. Ser.*, vol. 2089, no. 1, p. 012017, 2021, doi: 10.1088/1742-6596/2089/1/012017.

[33] E. van Hove and N. G. Johnson, "Refugee settlements in transition: Energy access and development challenges in Northern Uganda," *Energy Res. Soc. Sci.*, vol. 78, p. 102103, 2021, doi: https://doi.org/10.1016/j.erss.2021.102103.

[34] B. L. Theraja and A. K. Theraja, *A Textbook of Electrical Technology*, 5th ed. New Delhi, India: S. Chand, 2002.