ISSN 1533-9211

DOI: 10.5281/zenodo.10548795

DESIGN AND IMPLEMENTATION OF A PORTABLE LOW-COST SOLAR-POWERED MOBILE PHONE CHARGER FOR OFF-GRID ENVIRONMENTS

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Abstract

This research paper presents the design and implementation of a cost-effective, portable solar-powered mobile phone charger tailored for off-grid environments. The charger's design was meticulously crafted using Proteus software, allowing for detailed simulation and analysis before physical implementation. The implemented model was compared with the simulation output to validate its performance. The charger incorporates a buck converter with an output voltage of 5.05 V, a current rating of 1.51 A, and an output power of 7.61 W. These specifications were achieved through careful component selection and circuit optimization to ensure optimal charging efficiency while utilizing solar energy. The study also evaluates the charger's ability to harness and store solar energy efficiently, making it an environmentally friendly and sustainable solution for off-grid regions. The results showcase the successful realization of a low-cost, solar-powered mobile phone charger with promising implications for providing accessible energy solutions in areas lacking reliable power infrastructure.

Keywords: Solar-Powered Charger, Off-Grid Environments, Proteus Software, Buck Converter, Sustainable Energy, Low-Cost Solution.

1. INTRODUCTION

In recent years, the exponential growth in the usage of mobile devices, particularly mobile phones, has revolutionized the way society's function, communicate, and conduct business [1]–[3]. Yet, as these devices become nearly indispensable in our daily lives, access to reliable power sources for charging remains a considerable challenge for many, especially in off-grid environments [4]. These areas, which are typically isolated from the main power grid, require alternative and sustainable energy solutions that not only cater to their needs but are also eco-friendly [5]. Solar energy, being a renewable and abundant energy source, has emerged as a compelling solution to this challenge [6]–[8]. The potential of harnessing solar energy for mobile phone charging, particularly in off-grid regions, is significant. However, the primary deterrent for its widespread adoption has been the associated cost and the technical challenges related to efficient energy conversion and storage [9]. An ideal solar charger for such environments should not only be effective but also cost-efficient, portable, and durable to withstand the varying conditions of these areas [10]–[16].

The study in [17] focuses on wireless power transfer using solar energy and explores magnetic resonance coupling for efficient charging. However, the limitation is wireless power transfer is

The Seybold REPORT
ISSN 1533-9211
DOI: 10.5281/zenodo.10548795

only 11% efficient, with electricity being wasted during the process. The paper [18] presents a solar-powered mobile phone charger designed for outdoor workers like farmers, featuring small solar panels attached to their caps with 30 polycrystalline silicon solar cells to harness sunlight and charge a mobile phone, demonstrating its effectiveness by increasing a phone's battery from 7% to 67% in 105 minutes during daylight hours. Wireless charging uses electromagnetic induction to transfer power between a transmitter and a receiver, typically from solar-generated AC input to recharge devices, though the current efficiency is only 11%, but ongoing innovation promises improved efficiency and expanded applications, including electric cars and reduced wire usage was studied in [19]. The paper [20] discusses the challenges of rural electrification in Nigeria, proposes an off-grid solar-powered mobile phone charging system as a sustainable solution, and demonstrates its economic advantages with a shorter payback period and higher net present value compared to a gasoline generator investment. The paper [21] suggests a solar-powered system for charging mobile phones as a solution to the increasing importance of renewable energy sources due to the depletion of non-renewable ones, featuring a rechargeable battery for energy storage, overcurrent protection, and low voltage prevention mechanisms, and it can charge various low-voltage devices while displaying battery status through an LCD and micro-controller. The use of solar energy to wirelessly charge mobile phones and presents a prototype system tested for three days, highlighting the significance of light intensity in the charging time was studied in [22]. The paper [23] describes the design, construction, and testing of a solar-powered phone charger, initially using a hydrogen fuel cell that was later replaced by NiMH batteries to power an Arduino Uno, and a 50 W solar panel with a tracking mount, controlled by an Arduino program, to maximize solar efficiency, with plans for potential improvements. The research [24] aims to develop an integrated solar mobile charger, which doubles as a protective case for mobile phones, capturing solar energy and storing it in a rechargeable battery to address the enduring concern of battery backup in a rapidly advancing technology landscape. The research in solar-powered mobile phone chargers faces a notable gap in the development of efficient, compact, and cost-effective integrated solutions, which seamlessly blend with the aesthetic and functionality of modern smartphones, while the main challenges include optimizing energy conversion efficiency, enhancing portability, and overcoming variability in solar power generation due to environmental conditions[21], [25]–[29].

This research paper aims to bridge this gap by introducing the design and practical implementation of a portable, low-cost solar-powered mobile phone charger specifically tailored for off-grid settings. Using the state-of-the-art Proteus software for circuit simulation, a comprehensive approach was undertaken to ensure optimal design and subsequent physical implementation. Emphasis was placed on achieving the desired output specifications, ensuring the charger's efficiency, and guaranteeing the sustainability of the energy solution [30]–[34]. As global efforts intensify towards the adoption of sustainable energy solutions and reducing carbon footprints, the development of such a device becomes not only technologically significant but also socially and environmentally imperative [35]–[37]. The findings of this study provide a promising stepping stone for further innovations in this realm, offering a tangible solution to the pressing energy needs of off-grid regions [38]–[40].

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DOI: 10.5281/zenodo.10548795

2. MATERIALS AND METHOD

Figure 1 illustrates a block diagram featuring a 10 W solar panel, a 10 V to 5 V DC-DC converter, and a USB port. A solar photovoltaic (PV) module rated at 10 watts, aimed at capturing sunlight and transforming it into usable electricity. Connected directly afterward comes a DC-DC converter, designed specifically to down-convert voltage from 10V to a neat 5V.

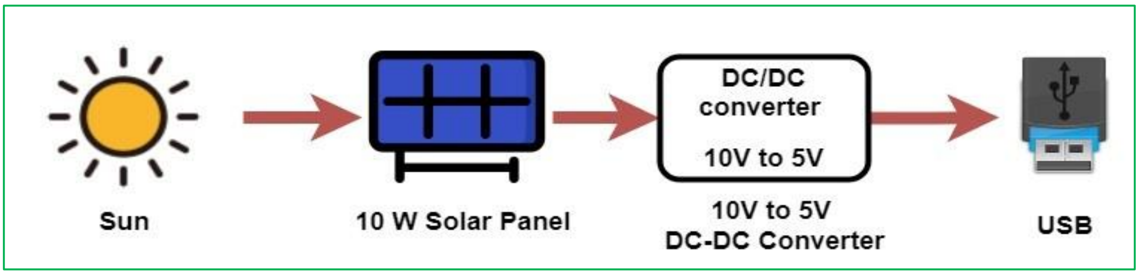

Figure 1: Block Diagram

Finally, this 5V output channelizes through a USB port, employed for the prime objective of charging up a mobile phone. The diagram intends to demonstrate a seamless, eco-friendly method for mobile device charging, leveraging sunlit energy.

2.1 proteus PV panel model

The analogous circuit for the most popular solar cell model includes a series resistor R_s and a shunt resistor R_{sh}, as well as a diode and a current source connected in parallel, as shown in Figure 1. This circuit diagram allows us to determine the output current [41], [42], which is expressed as follows:

$$I = I_{ph} - I_{s,0}\left(\exp\left(\frac{V+IR_S}{aV_t}\right) - 1\right) - \frac{V+IR_S}{R_{sh}} \qquad (1)$$

Where, I_{ph} denotes the solar cell's photocurrent in amperes (A); I_s,0 stands for the solar cell's reverse saturation current in amperes (A); V signifies the solar cell's output voltage in volts (V); a indicates the diode's ideality factor for the solar cell; and V_t refers to the solar cell's thermal voltage. Figure 2 shows the circuit equivalent for a solar cell with a single diode.

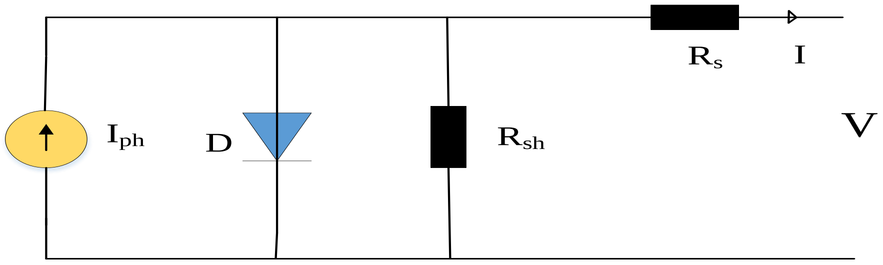

Figure 2: Circuit equivalent for a solar cell with a single diode.

ISSN 1533-9211
DOI: 10.5281/zenodo.10548795

2.2 Description of the Entire PV System

In the context of this research, a SOLARLAND photovoltaic (PV) module serves as the focal point, and the specifics of its design and capabilities are meticulously detailed in Table 1, which provides a comprehensive overview of the module's specifications and technical characteristics.

Table 1: Specifications for PV module (All rating at STC 1000 W/m^2, AM 1.5 spectrum, 25°C)

SOLARLAND Model Number: SLP010-12 Electrical Performance	
Parameters	**Values**
Max Power, P_{max}	10 W
Operating Voltage, V_{mp}	17.0 V
Operating Current, I_{mp}	0.58 A
Open Circuit Voltage, V_{oc}	21.6 V
Short Circuit Current, I_{sc}	0.68 A

2.3 DC-DC Buck Converter

A DC-DC buck converter is an electronic device commonly used in solar PV systems to efficiently reduce the voltage of the solar panel's output to match the voltage requirements of the load or battery, maximizing energy conversion and utilization. It works by switching and regulating the input voltage to produce a lower, stable output voltage, making it an essential component for optimizing power transfer in solar energy applications [43]–[45]. In the context of this simulation, the following table 2 presents the parameters that have been employed, serving as a comprehensive reference for the meticulous examination and understanding of the experimental setup**.**

Table 2: Parameters used for simulation

Parameters	Values
Resistor 1	220 Ω
Resistor 2	680 Ω
Variable resistor	1 kΩ
Capacitor	0.1 µF
DC-DC Step down Buck converter (IC)	LM2596

2.4 DC-DC Buck Converter Output Voltage and Current Equations Analysis

Output Voltage (V_{out}): The output voltage of a buck converter is directly proportional to the input voltage (V_{in}) and the duty cycle (D). The duty cycle is the ratio of the time the switch is on to the total switching period. The equation is:

$$V_{\text{out}} = D \times V_{\text{in}} \quad (2)$$

Where, V_{out} is the output voltage,

D is the duty cycle ($0 < \mathrm{D} < 1$),

V_{in} is the input voltage.

ISSN 1533-9211
DOI: 10.5281/zenodo.10548795

Output Current (I_{out}): The output current depends on the load resistance (R) and the output voltage. It can be described by Ohm's Law:

$$I_{\text{out}} = \frac{V_{\text{out}}}{R} \tag{3}$$

Alternatively, considering the power efficiency (η) of the converter and the input current (I_{in}), the output current can be estimated as:

$$I_{\text{out}} = \eta \times I_{\text{in}} \times \frac{V_{\text{in}}}{V_{\text{out}}} \tag{4}$$

Efficiency Equation: The efficiency (η) of the buck converter is the ratio of the output power (P_{out}) to the input power (P_{in}). This takes into account losses like switching losses, conduction losses, and other parasitic losses.

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{out} \times I_{out}}{V_{in} \times I_{in}} \tag{5}$$

2.5 Simulation Diagram

Solar irradiance will incident on PV array. PV array will convert solar irradiance to electricity. Output of PV array will supply to input of dc-dc buck converter. This system has been shown in figure 3. We will get constant output voltage through buck converter. A led has been connected to the output of buck converter and it will glow.

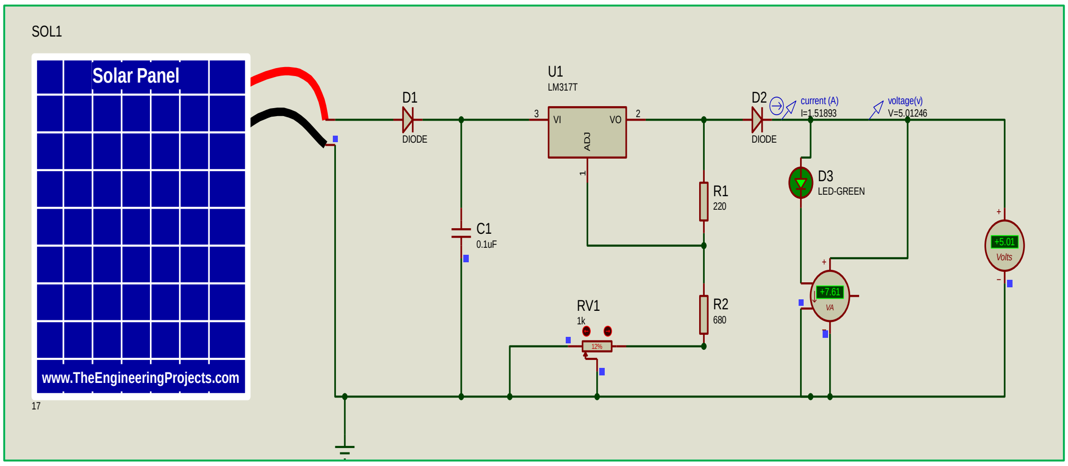

Figure 3: Proteus Simulation circuit with LED

The identical circuit configuration has been successfully implemented, as depicted in Figure 4; however, in this iteration, the LED component has been intentionally omitted. This omission is highlighted to emphasize the comparative analysis and distinctive outcomes arising from the absence of the LED in the experimental setup.

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ISSN 1533-9211
DOI: 10.5281/zenodo.10548795

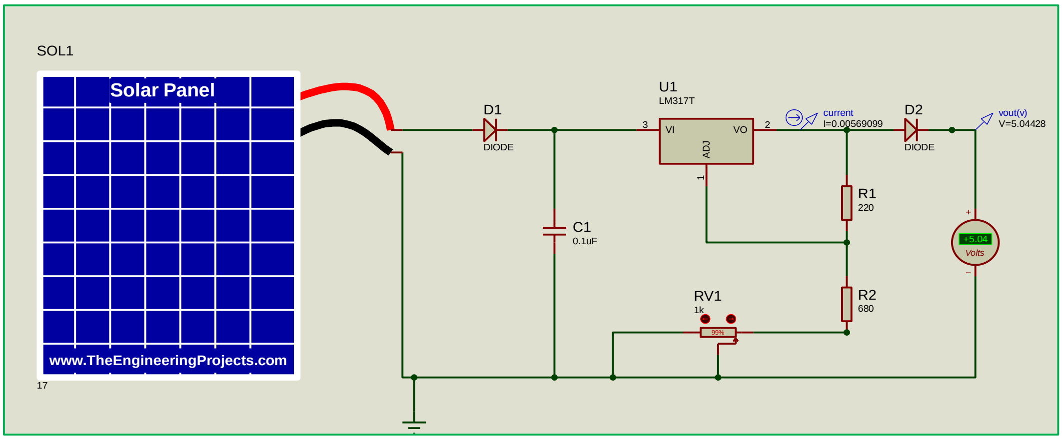

Figure 4: Proteus Simulation circuit without LED

2.6 Circuit Implementation

We have implemented the circuit in practically under sunlight and under no sunlight that has been shown in Fig. 5. In Figure 5(a), a pivotal scenario is depicted where the circuit operates in the absence of incident sunlight, resulting in a state where no output power is generated. This serves as a crucial reference point, illustrating the circuit's behaviour under conditions of minimal or no illumination. The absence of output power in this context underscores the circuit's dependency on solar irradiance for functionality.

In Figure 5(b), a pivotal demonstration unfolds, illustrating the circuit's response to incident sunlight and its consequential generation of output power, effectively facilitating the charging process for a connected phone. This provides a tangible manifestation of the circuit's functionality under optimal conditions, where the input of solar energy translates into a tangible output charging the connected device. The observed correlation between incident sunlight and the active charging state substantiates the circuit's efficacy in harnessing solar power for practical applications, notably phone charging.

(a) Without Sunlight **(b) With Sunlight**

Figure 5: Implemented Circuit Module

ISSN 1533-9211
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3. RESULT AND DISCUSSION

In Fig. 6, the output voltage obtained from the Proteus simulation is meticulously illustrated. The depicted results unequivocally indicate that the output voltage of the designed circuit attains a stable and regulated output voltage of 5.05 volts.

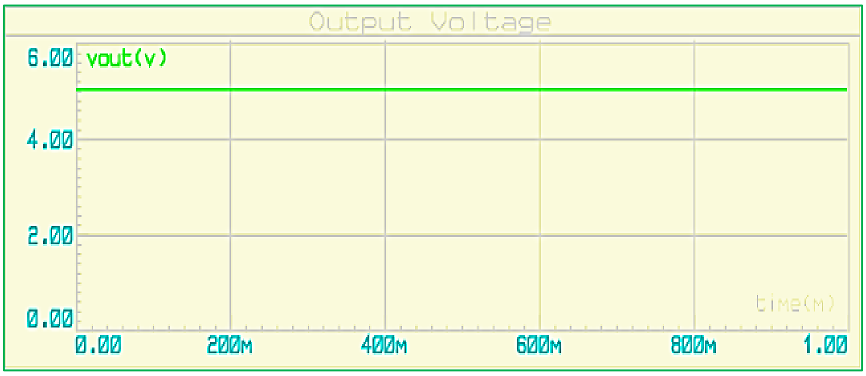

Figure 6: Proteus Simulation Output Voltage

This empirical evidence, derived from the simulation output, serves as a crucial validation of the circuit's functionality and adherence to the specified voltage target. The observed voltage stability and accuracy underscore the robust performance of the proposed circuit, affirming its suitability for practical applications. Fig. 7 presents a comprehensive visualization of the Proteus simulation output, specifically focusing on the dynamic output current characteristics. The discerning examination of these figures distinctly reveals that the output current of the implemented circuit precisely registers at 1.51 amperes.

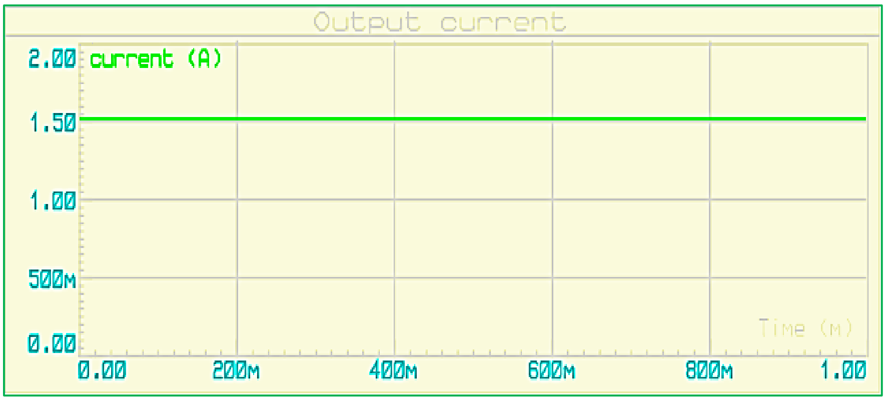

Figure 7: Proteus Simulation Output Current

This empirical demonstration not only underscores the accuracy and stability of the designed circuit but also substantiates its capability to consistently deliver the intended current output. The Proteus simulation results, meticulously illustrated in Fig. 8, provide a detailed portrayal of the output power characteristics of the investigated circuit. Noteworthy among these findings is the unequivocal revelation that the circuit consistently yields an output power of precisely 7.61 Watts.

ISSN 1533-9211
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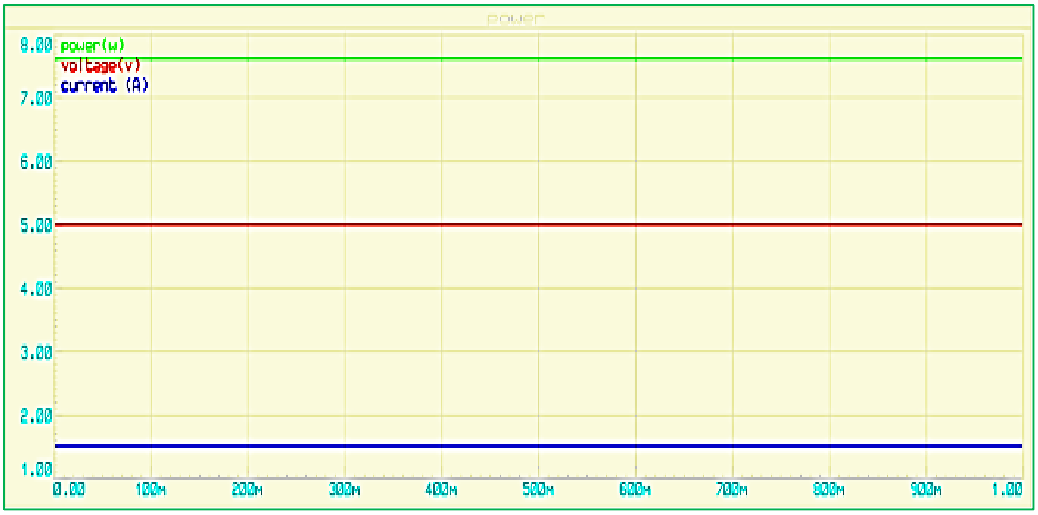

Figure 8: Proteus Simulation Output Power

This empirical evidence serves as a pivotal validation, offering a comprehensive understanding of the circuit's power delivery performance under simulated conditions. The observed stability and accuracy in the output power signify the circuit's robustness in efficiently converting input energy to the desired output, establishing its suitability for practical applications.

4. CONCLUSION AND FUTURE WORK

In conclusion, this research paper has demonstrated the successful design and implementation of an affordable, portable solar-powered mobile phone charger tailored for off-grid environments. The meticulous design process and rigorous simulation in Proteus software ensured precise performance characteristics. The charger's ability to efficiently harness and store solar energy highlights its environmental friendliness and sustainability. The achieved specifications, with an output power of 7.61 W, make it a promising solution for areas lacking reliable power infrastructure. Future work should focus on scalability, incorporating energy storage solutions for extended device use during nighttime or adverse weather conditions, and exploring potential applications in other low-power electronic devices to further enhance accessibility to sustainable energy sources in underserved regions.

Acknowledgments

Authors would like to thanks to Pabna University of Science and Technology (PUST) for using Renewable Energy lab.

Author Contributions: M.F.A., M.S.H.: Conceptualization, methodology, formal analysis, writing—original draft, M.F.A.; supervision, resources, project administration, M.F.A., M.S.H., A.H.S., S.I.S.S., M.A.Y, R.A.; writing—review and editing, project administration, validation. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: Authors declare no conflict of interest.

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ISSN 1533-9211
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