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Development of a Cost-Effective Rechargeable 5V Solar Lamp

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ABSTRACT---- ***Millions of people living in rural areas around the world lack access to reliable and affordable lighting. Their reliance on traditional lighting sources poses health risk, environmental concerns and economic burdens. Energy poverty persists, highlighting the need for sustainable energy and affordable lighting solution. This study presents the design and construction of a cost-effective rechargeable 5V solar lamp, tailored to meet the lighting needs of rural households. The construction of the lamp began with the assembly of all the components such as battery, solar cell, light emitting diode (LED) and connecting wires, all coupled and soldered to a TP4056 module and then enclosed in a P-box to provide a secure and safe housing of the internal components. With its durable construction, efficient energy conversion, reliable performance and low maintenance requirements, this solar lamp offers a viable, attractive and sustainable lighting solution for off-grid communities. This study contributes to environmental conservation and improved energy access for rural households and provides valuable insights for the development of cost-effective and sustainable solar-powered lighting solutions by reducing reliance on traditional lighting sources.***

Keywords--- Renewable energy, Cost-Effective, solar lamp, Rechargeable

1. INTRODUCTION

The quest for sustainable and renewable energy sources has become a global priority, driven by the need to mitigate climate change and ensure energy access for all [1-2]. The emission of greenhouse gases from fossil fuels such as coal, oil, and natural gas negatively affects both the environment and human health. As long as the world depends on a fuel-powered economy, achieving a cleaner environment will remain out of reach. Eventually, alternative energy sources will become necessary, as current fuels are unsustainable. [3-4]. Solar energy has emerged as a viable alternative to traditional energy especially for off-grid communities [5]. However, the backdrop of energy poverty in Nigeria where millions of people lack access to reliable and affordable lighting, the reliance on kerosene lamps, candles, and flashlights poses significant health risks, environmental concerns, and economic burdens on households. Despite the growing adoption of solar-powered lighting solutions, existing products are often expensive, inefficient, or unreliable, thereby limiting their widespread adoption. Therefore, this research focuses on design and constructs a cost-effective rechargeable 5V solar lamp, tailored to meet the lighting needs of rural households and to address the knowledge gap in the design and development of cost-effective, efficient, and sustainable solar-powered lighting solutions for off-grid communities, to evaluate its technical performance and economic viability, and assess its potential for replication and scalability. By bridging this research gap, this findings seeks to contribute to the global efforts to achieve Sustainable Development Goal 7 (SDG 7) by ensuring access to affordable, reliable, sustainable, and modern energy for all [6, 7].

Solar energy is one of the most abundant and promising renewable energy sources available today, with the potential to meet a significant portion of global energy demands [8]. The current renewable energy research is concentrated on harnessing energy from the sun; this includes solar thermal panels, which convert solar energy into thermal energy, and photovoltaics, which convert solar energy into electricity. [9]. Solar energy plays a crucial role in transitioning away from fossil fuels, combating climate change, and achieving energy security globally, as emphasized by the United Nations' Sustainable Development Goals(SDG-7) [10].

2. THE SCIENCE OF SOLAR ENERGY

Solar energy is harnessed using two primary technologies:

2.1 Photovoltaic (PV) Systems: PV cells convert sunlight directly into electricity through the photovoltaic effect, where sunlight excites electrons in semiconductor materials like silicon, generating an electric current [11].

2.2 Concentrated Solar Power (CSP): CSP uses optical fibers that channel concentrated sunlight from mirrors or lenses to a central receiver, efficiently converting light into thermal energy with reduced losses. This thermal energy is then utilized to generate steam, driving turbines to produce electricity, thereby enhancing overall system efficiency [12]. Both systems allow for scalable energy production, from small residential applications to large utility-scale solar farms.

3. SOLAR AS A RENEWABLE ENERGY SOURCE

Solar energy can also be used for thermal applications, such as heating water, air, and spaces [13]. The adoption of solar energy technologies yields numerous benefits, including job creation, economic growth, electrification for urban and rural communities, skill development, poverty reduction, environmental protection, and climate change mitigation. Furthermore, it will stimulate local industries by promoting the domestic manufacturing of components for solar and wind power stations [14]. Solar energy systems also require minimal maintenance and have no fuel costs, resulting in low operating costs [15]. Overall, solar energy is a clean, sustainable, and cost-effective source of energy [16].

3.1 Global Impact of Solar Energy

3.1.1 Climate Change Mitigation: Solar energy is a cornerstone of global efforts to reduce carbon emissions, with many countries adopting ambitious renewable energy targets under the Paris Agreement [17].

3.1.2 Energy Access: In regions with limited electricity infrastructure, solar power provides a reliable and cost-effective energy solution, improving living standards and supporting economic activities.

3.1.3 Economic Benefits: The solar industries contributes to economic growth through job creation and reduced energy costs. For example, solar energy systems have become the cheapest source of electricity in many regions [18].

4. MATERIALS

Components of the Solar Lamp are, P-box, Solar cell, Battery, Jumper Wires, TP 4056 Module, Lead and Tapes.

4.1 P-box

The P-box is a protective enclosure that houses and shields the electronic components from environmental factors, ensuring their safety and longevity.

4.2 Solar Cell

The Polycrystalline solar cell generates electricity by converting sunlight into electrical energy, producing 2 watts of power at 5V.

Figure 1. Photovoltaic (PV) Module

4.2.1 Photovoltaic Cells: The Key to Solar Energy

Photovoltaic cells are the building blocks of solar energy systems. These cells convert sunlight into electricity through the photovoltaic effect, generating DC power from semiconductor materials [19].

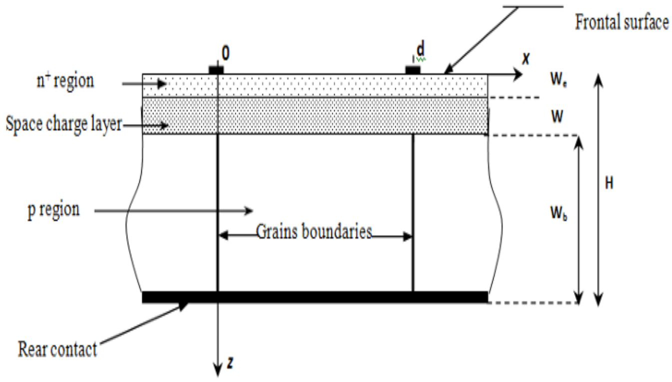

Figure 2. Schematic Model of Poly Silicon Solar Cell

4.3 Battery

The Li-ion battery stores excess energy generated by the solar cell, enabling the lamp to function continuously, even in the absence of direct sunlight.

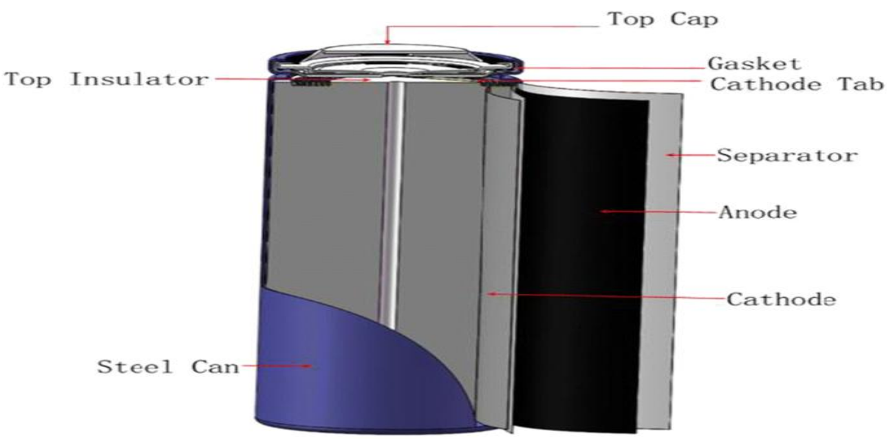

Figure 3. Composition of a Li-ion battery

4.3.1 Lithium-ion (Li-ion) battery

Lithium-ion (Li-ion) batteries are recognized for their exceptional durability and prolonged lifespan, capable of withstanding 300 to 500 charges and discharge cycles before degradation [20]. This durability translates to several years of reliable service, even with frequent use [21]. Li-ion batteries are less susceptible to memory effects, which can reduce their overall lifespan [22]. Factors such as storage conditions, operating temperature, and charging habits also impact Li-ion battery durability [23]. Proper storage and maintenance can significantly extend the lifespan of Li-ion batteries, with studies showing up to 80% capacity retention after 300 cycles and up to 10 years of lifespan with proper maintenance and storage. Furthermore, research highlights the importance of avoiding deep discharges and storing Li-ion batteries in cool, dry places to minimize degradation [24-25].

4.4 Light Emitting Diode (LED) Light

The 4x7 LED light produces visible light by converting electrical energy from the solar cell or battery, providing a bright and reliable source of illumination.

4.5 Jumper Wires

Jumper wires connect the electronic components together, enabling the flow of electrical energy and communication between different parts of the circuit.

4.6 TP4056 Module

The TP4056 module is a 3.7V single-cell Li-ion battery charging module, which can charge not only 18650 batteries, but also 3.7V Li-ion batteries of various sizes and types. The module's core component is the TP4056 IC, a powerful IC designed for charging lithium batteries. This IC is designed and built with programs to charge Li-ion batteries, extend battery backup time, and enhance service life. Additionally, the IC features a temperature sensor pin, allowing connection to an NTC type thermometer to monitor battery temperature during charging. The IC is programmed to stop charging when the battery temperature exceeds a predetermined limit. Furthermore, the module includes a LED indicator, which displays a red light during charging and automatically switches to blue once charging is complete. The maximum output current is 1A, but can be adjusted using resistors [26].

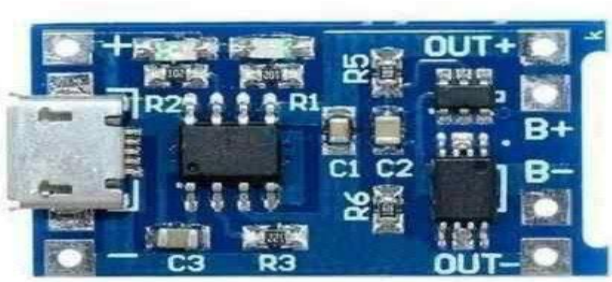

Figure 4. TP4056 Module

4.7 Lead and Tapes

The lead and tapes secure wires and components in place, providing stable and reliable connections and preventing damage to components.

5. WORKING PRINCIPLE OF THE 5V SOLAR LAMP

The 2W solar cell operates by converting sunlight into electricity, which serves as the core component [27]. When exposed to sunlight, the solar cell generates 5 volts of electricity, sufficient to power the lamp [28]. The electricity produced is then stored in a Li-ion battery, acting as a reservoir for excess energy generated during the day [29]. This stored energy is utilized to power the lamp at night or on cloudy days [30]. The lamp's voltage regulator ensures a stable and consistent voltage supply, regulating the output from the solar cell and battery to maintain a constant 5 volts [31]. A resistor is employed to limit the current flowing to the 4x7 LED light, preventing damage from excessive current [32]. The LED light is the final component, producing illumination when electricity from the solar cell or battery flows through it. The lamp also features an external USB charging port and an indicator light displaying the charging status, providing additional functionality and convenience [33-34].

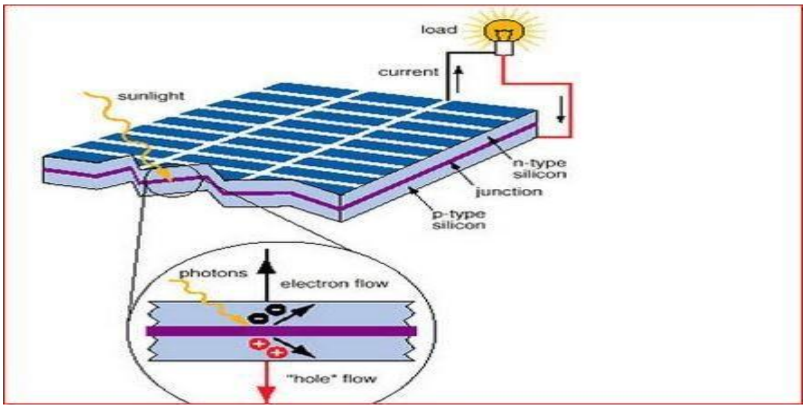

Figure 5. Diagram of a Photovoltaic System

(b)

Figure 6(a). The Front view of the 5v Solar Lamp Showing the LED light and the control switch

(b). The Rear View of the Solar Lamp Showing the 2 watt Solar Panel

5.1 Performance Test

The 5V solar lamp underwent a series of tests to evaluate its performance. The LED light was initially tested in a small room, demonstrating sufficient illumination capabilities. Further testing involved charging the battery using the solar panel, which took 5 hours to reach 100% capacity and provided 8 hours of efficient lighting.

5.2 Circuit Diagram of the 5 Volts Solar Lamp

The 6V solar panel circuit is designed to charge a battery and power an LED lamp using solar energy. The circuit consists of a solar panel, battery, charge controller, and LED lamp, utilizing transistors (Q1-Q3) for amplification and switching. Resistors (R1-R7) provide voltage division, current limiting, and biasing, while capacitors (C1-C3) filter out noise, regulate voltage, and provide timing functions. This configuration enables the circuit to efficiently harness solar energy and provide a reliable and sustainable source of light.

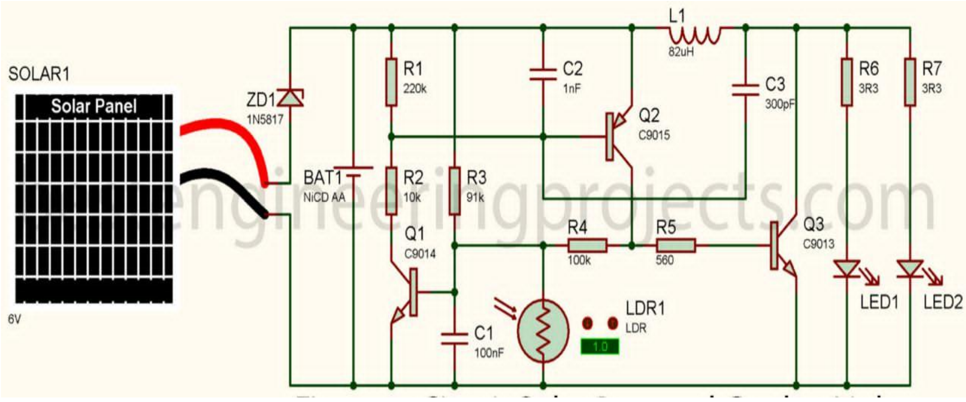

Figure 7. Circuit diagram of the 5V Solar Lamp

5.3 Cost-Effective

Although lighting accounts for only 4-10% of energy consumption in residential and commercial buildings [35], there is growing interest in researching low-energy efficient lamps. By harnessing solar energy, this project provides a clean and affordable alternative for off-grid communities, cutting fossil fuel costs. Furthermore, ongoing efforts by organizations aim to enhance low-energy efficient lamps from both technological and customer perspectives, focusing on cost reduction [36-37].

6. CONCLUSION AND RECOMMENDATIONS

The development and implementation of the 5V solar lamp demonstrate the capacity of renewable energy technologies to mitigate energy deficiencies in underprivileged areas. Its high-efficiency energy conversion, consistent operational reliability, and robust structural design position it as a sustainable and long-lasting illumination solution. Moreover, by minimizing dependence on fossil fuels, the project plays a significant role in promoting environmental sustainability and advancing equitable energy access.

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