

Smart Solar Lighting: FPGA-Driven Control for Sustainable and Adaptive Illumination

Anuar Jaafar^{1*}, Chan Yan Yi², Nik Mohd Zarif Hashim³, Haziezol Helmi Mohd Yusof⁴, Sharifah Fatmadiana Wan Muhammad Hatta⁵, Abd Majid Darsono⁶

^{1,2,3,4,6}Centre for Telecommunication Research and Innovation (CeTRI), Fakulti Teknologi dan Kejuruteraan Elektronik dan Komputer, Universiti Teknikal Malaysia Melaka

⁵Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.

***Corresponding**

DOI: <https://dx.doi.org/10.47772/IJRISS.2025.906000204>

Received: 04 June 2025; Accepted: 05 June 2025; Published: 08 July 2025

ABSTRACT

Nowadays, electricity has become an essential need to carry out people's daily routines. One of the applications of electricity is to provide electrical power to our home lighting system at night. However, most of the electricity is generated by burning fossil fuels. Fossil fuel is a non-renewable and finite resource, which causes pollution to the environment. Instead of burning fossil fuels, the renewable resource solar energy could be a great solution. The solar panel generates electrical power from solar energy stored in the lead-acid battery through the charging and discharging process. The solar-powered lighting system is controlled by the Xilinx Spartan 6 FPGA Development board. Field Programmable Gate Array is an integrated circuit containing programmable logic blocks and interconnection circuits. It is used as a system controller that is programmed by uses Verilog HDL according to different requirements. The output of this project is the lead-acid battery provides power to light on the LED when the Light Dependent Resistor detects darkness and the lead-acid battery in a fully-charged situation. Also, the lead-acid battery will change the state from discharging to the charging stage when low voltage is detected. This project involves developing a solar-powered lighting system via Field Programmable Gate Array and the analysis of the number of battery cycle life based on the different Depth of Discharge (DOD).

Keywords: Solar Powered Lighting System, Lead-Acid Battery, FPGA.

INTRODUCTION

Global energy demand is increasing, the higher energy demand is expected in well-developed and developing countries in the coming decades. Most of the electricity production is generated from combustion fuels, mostly with fossil fuels [1]. However, electricity produced by burning fossil fuels is harmful to the environment, the carbon dioxide CO₂ emissions produced by burning fossil fuels can pollute the air, which contributes to global warming and climate change [2], [3], [4].

The increasing emission of carbon dioxide (CO₂) from the use of fossil fuels contributes significantly to air pollution and global climate change. To address these environmental challenges, it is essential to transition to alternative energy sources for everyday applications. Among these, renewable energy stands out as a sustainable and environmentally friendly solution. Solar energy is a widely used form of renewable energy that directly converts sunlight into electricity through solar cells [5], [6]. Unlike fossil fuels, solar energy systems do not emit air pollutants or greenhouse gases during operation, making them a clean energy option. One of the most practical and common applications of solar energy is solar-powered lighting. A typical solar lighting system consists of a solar panel, a rechargeable lead-acid battery, and LED lights [7]. During the day, the solar panel captures sunlight and charges the battery; at night, the stored energy is used to power the LED lights

through a discharging process [7], [8]. This system not only reduces reliance on non-renewable energy sources but also minimizes environmental impact, making it a viable solution for sustainable lighting.

LED in the lighting system will save energy, minimize CO₂ emissions, and numerous advantages over conventional lamps: the better energy efficiency of lighting systems, longer lifecycle, less maintenance, higher flexibility and control of the light level, and lower power consumption and environment-friendly [9], [10]. Also, the LEDs can have their light emission control known as dimming. Pulse Width Modulation (PWM) controls the luminous flux of the LED, which uses a square wave power supply for these applications, then the light flux is changed by varying the signal's duty cycle.

Besides the Field Programmable Gate Array (FPGA), different embedded systems were implemented before FPGA became popular for the solar-powered lighting system. Priyanka and K. Baskaran using a PIC16F877A microcontroller to control the solar LED street lighting system and aims for power saving [11]. They use the LDR sensor to indicate the light intensity and the photoelectric sensors to detect the movements. Next, S. Sarkar et al. use an Arduino UNO to control the solar street lighting system and design the system by using the Arduino IDE software [12]. The lighting system also uses the LDR sensor to detect the light intensity, and the LED will light up with different levels of brightness based on the changes of the light intensity detected by the LDR sensor. Besides that, the intelligent battery level monitoring unit was proposed, which means the microcontroller keeps monitoring the battery level for battery replacement purposes. However, this study is not focusing on the analysis of the battery service life.

Besides that, a smart street light system using FPGA, Xilinx ISE 9.2i tools, and ModelSim software were developed [13]. However, the purpose of this project is for energy-saving and reduce power consumption. In the proposed system, the switch on and off of the street light depends on the light intensity detected by LDR. Besides that, they also apply the PWM technique in the dimming control of the LED. But the results may vary in real life due to the power consumption of the others component since no hardware or prototype is developed.

For this work, a Xilinx Spartan 6 FPGA development board was used to control the whole solar-powered lighting system and design the system using the Xilinx ISE 14.7 software. As a result, the brightness of LED will vary depending on the LDR sensor's output, and the battery level is always monitored and displayed by the FPGA.

METHODOLOGY

The solar-powered lighting system shown in Figure 1 is made up of a wide variety of individual components. A solar cell, a lead-acid battery, an FPGA, Light Emitting Diodes (LEDs), a buck converter, an analog-to-digital converter, a Light Dependent Resistor (LDR), and a MOSFET are some of these components. This complex arrangement of parts creates the fundamental framework of the system and enables the capture, storage, and controlled illumination of light through a coordinated action of these vital elements. The solar-powered lighting system is complicated and sophisticated, which is highlighted by its multifarious arrangement. As a result, it is a topic of scholarly interest and research in the field of cutting-edge electronics and sustainable energy technologies.

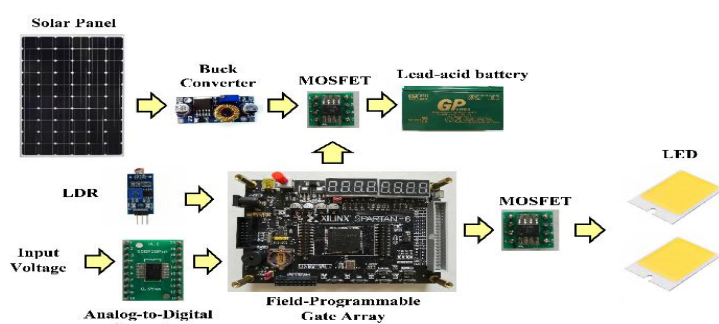


Figure 1. Proposed System

Through the use of a buck converter, which lowers the charging voltage, the solar panel plays a crucial part in this system by recharging a lead-acid battery. A NCE6008AS Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) is modulated as part of the process under the exact direction of an FPGA (Field-Programmable Gate Array). The FPGA then determines the input voltage by interacting with an AD7822 analog-to-digital converter. Two Light Emitting Diodes (LEDs) serve as the system's output devices, and they carry out dimming operations by influencing another MOSFET that is controlled by the FPGA [14], [15]. Importantly, the Light Dependent Resistor (LDR) only activates the LEDs when it detects ambient darkness, which is in line with a careful strategy for energy conservation and functional optimization.

Charging and discharging Algorithm

A carefully designed charging algorithm, as shown in Figure 2, has been implemented to reduce the danger of overcharging. The algorithm starts by determining the system's operating status, namely if it is in the charging mode, and depending on that finding, moves on to the next stage. The switch, which is an essential part of the procedure, regularly toggles, allowing the measurement of battery voltage while it is off. The algorithm repeats this process if the measured battery voltage is below the 12.72V cutoff, keeping watch until this requirement is satisfied. When the battery is fully charged, the system switches over to the draining mode without any noticeable delay. If the system does not start out in the charging mode, on the other hand, the algorithm stops working. This methodical algorithmic approach is essential for managing the charging process effectively, improving operational effectiveness and safety.

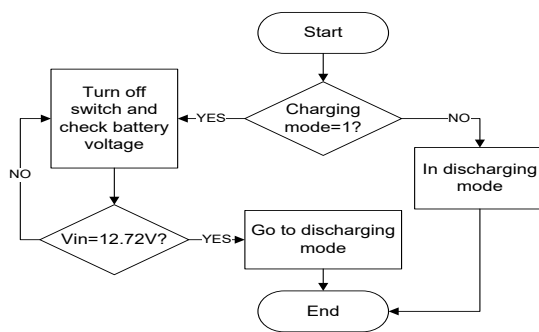


Figure 2. Charging Algorithm

The discharging algorithm is illustrated in Figure 3, which begins its execution by first evaluating the system's operational condition to determine whether it is in the discharging mode. Within the algorithmic framework, the development to succeeding phases is controlled by this crucial decision. Notably, the switch oscillates continually, making it easier to gauge battery voltage when it is in the open position. The algorithm repeats this stage until this condition is satisfied if the observed battery voltage is greater than or equal to the 12.24V threshold. However, the device seamlessly switches into the charging mode if the battery voltage drops below 12.24V. On the other hand, if the system does not initially reside in the discharging mode, it suggests that the system is in the charging mode, which results in the algorithm's termination. This methodical algorithmic design functions as a crucial control mechanism for upholding the integrity and effectiveness of operational processes.

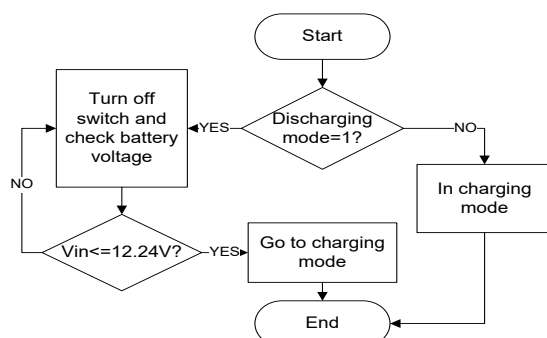


Figure 3. Discharging Algorithm

LED Dimming with Pulse Width Modulation (PWM)

The Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) is effectively controlled by the Pulse Width Modulation (PWM) signal, which is managed via FPGA within the operational framework of this system. Table 1 provides a systematic explanation of the subtle luminosity levels of Light Emitting Diodes (LEDs) in response to different battery voltage levels. The LED brightness reaches full luminance, which denotes a 100% intensity level, when the battery voltage is equal to or greater than 12.48V and the Light Dependent Resistor (LDR) sensor detects the absence of ambient light. In contrast, the LED's brightness drops to 50% when the LDR sensor detects a dark environment and the battery voltage drops below the 12.48V threshold. This calibrated control of LED brightness works as an effective and flexible mechanism to save energy use and improve system performance.

Table 1. LED brightness levels based on different battery voltage levels

Battery Voltage	Brightness (%)
>12.48V	100
<12.48V	50

The number of battery life cycles estimation based on different Depth of Discharge (DOD)

The solar illumination system is operated for analytical purposes under ideal solar irradiance circumstances, which are often characterized by clear and sunny days. The lead-acid battery inside the system is started and then charged to its maximum capacity throughout this operational period. After the battery has reached full charge, the system starts the discharge cycle. During this phase, the battery can release its stored energy up until it reaches a lower threshold level, at which time the discharge cycle is terminated. The performance of the solar-powered lighting system can be thoroughly examined, considering both the charging and discharging phases, thanks to this methodical approach to system analysis. This is made possible by the optimal environmental conditions that are suitable to solar energy harnessing and storage.

$n_{\text{cycle}} = \frac{\text{life expectancy (years)}}{\text{cycle(hours)}} \times 365 \times 24$	(1)
--	-----

Table 2. Specification Provided by Battery Manufacturer

Parameter	Value (%)
Nominal Voltage	12V
Nominal Capacity	7.2Ah
Nominal Temperature	25 °C ± 3 °C
Maximum charge current	2.16A
Cells per unit	6
Lifecycles Expectancy	5 years

In conclusion, it is crucial to stress that the entire testing process was repeated three times, which was a necessary step for enabling a thorough comparison of the battery cycle life across different depths of discharge (DOD). The battery was discharged in the initial iteration until the DOD was properly calibrated to 40%. The battery was then put through a discharge cycle in the second iteration, continuing until the DOD hit the predetermined level of 50%. The third iteration required a discharge operation up until a certain DOD level of

60%. After meticulously recording the total number of operational hours, the enumeration of cycles was obtained using the approach described in Equation (1), which is dependent on the features described in Table 2. The comprehensive assessment of battery performance in relation to various DOD scenarios depends on this tripartite experimental technique.

RESULTS AND DISCUSSION

The thorough analysis, presentation, and evaluation of simulation results and prototype performance assessments for the solar-powered lighting system are covered in this section. The first stage entailed running system simulations using the Xilinx ISE 14.7 software. These simulations were run with the main goal of validating the methodology while closely examining the theoretical foundations and algorithmic elements of the system. Such simulations provide a virtual testing ground to validate the theoretical constructs prior to real-world deployment, which is an essential first step in determining the system's effectiveness. The obtained insights from these simulations are then compared to the empirical prototype results, leading to a comprehensive assessment of the performance of the solar-powered lighting system that considers both theoretical and practical aspects.

Simulation Results of Charging and Discharging Algorithm

At clock cycle 25, the charging mode module takes on the crucial duty of determining the charging status. This determination is based on a precise assessment of both battery voltage and the charging flag's status, known as "gotocharge." This flag, "gotocharge," serves as a key indicator controlling the system's operational mode, indicating whether it will stay in the charging mode or switch to the discharging mode. A major change in the "gotocharge" signal occurs at clock cycle 25, as seen in Figure 4, causing a change from a logical high state to a logical low state. This crucial change denotes that the system swiftly stops charging after successfully reaching a full charge state, in accordance with the operational parameters stored in the control module of the system.

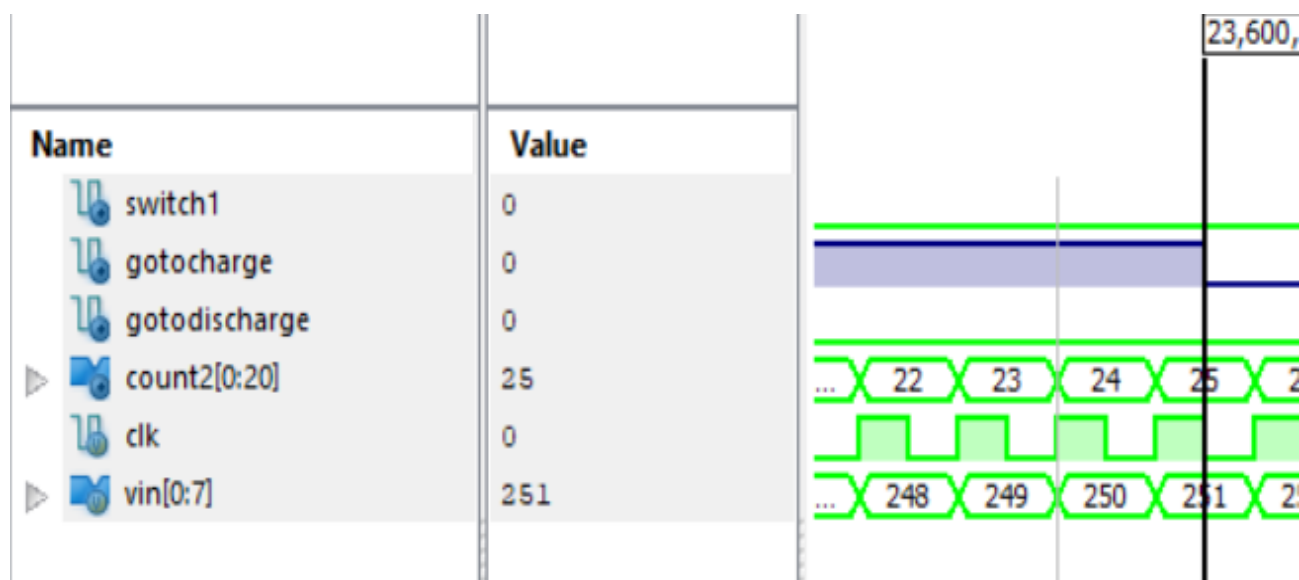


Figure 4. Simulation result of charging algorithm when the FPGA detects the battery is fully charged

The "gotocharge" signal transitions to a logical high state (1) at clock cycle 25, as seen in Figure 5. This crucial shift in the signal's status depends on the ability to identify input voltage levels that are below the 12.24V set threshold. This specific signal state change denotes the beginning of the system's charging procedure. It means that when certain particular circumstances occur, the system starts the necessary processes for recharging the battery. The system's dynamic adaptability and the accuracy of its control mechanism are demonstrated by this real-time response to voltage criteria, which makes sure that the charging mode is selectively activated in response to specified voltage parameters, improving energy management and overall performance of the solar-powered lighting system.

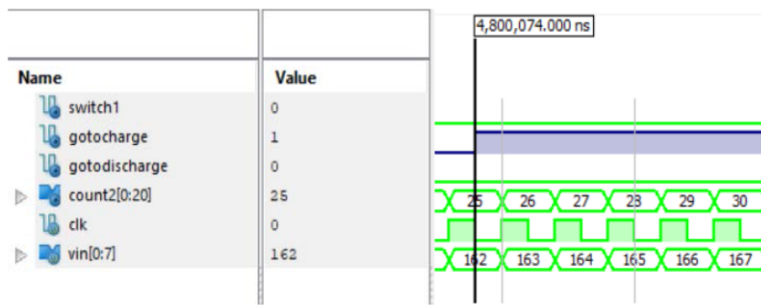


Figure 5. Simulation result of charging algorithm when the system detects the low voltage of the battery

At clock cycle 51 of the discharging mode, the system performs a thorough status evaluation made possible by its capacity to recognize both the battery voltage and the condition of the "gotodischarge" discharging flag as shown in Figure 6. This flag plays a crucial part in determining the system's operational mode, serving as a discernible indicator to decide whether the system should stay in the discharging mode or switch to another mode. The system's decision-making is orchestrated by the synchronicity of these determinants, specifically battery voltage and the "gotodischarge" flag, which makes sure that the mode of operation adheres to the set operational parameters. The system's adaptability and precision in implementing the discharge mode are highlighted by this dynamic assessment, which helps the solar-powered lighting system operate more efficiently and effectively.

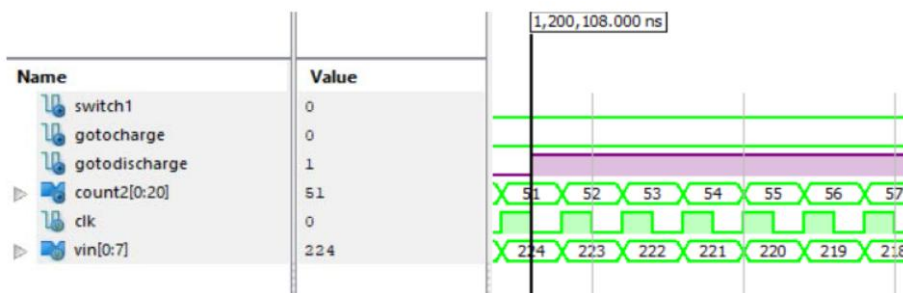


Figure 6. Simulation result of discharging algorithm when the system detects the battery is fully charged

The "gotodischarge" signal pivots to a logical low state (0) at clock cycle 51, as shown in Figure 6, which takes place when the system detects an input voltage below the predetermined threshold of 12.24V. The system ends the discharge mode under these specified voltage settings, as indicated by this transition, which denotes the end of the discharging process. Figure 7 depicts the opposite case, in contrast, where the "gotodischarge" signal enters a logical high state (1) at clock cycle 51. When the system reaches a full charge, the signal status changes to indicate the beginning of the discharging process. These in-the-moment responses, which are painstakingly timed to voltage standards, demonstrate the system's prowess in adapting its operational mode dynamically and optimizing energy usage within the solar-powered lighting system.

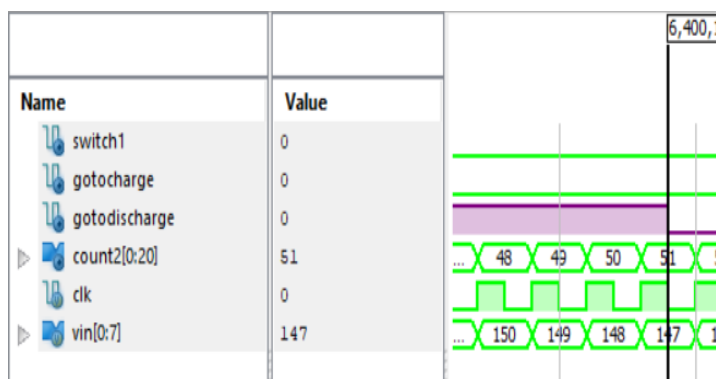


Figure 7. Simulation result of discharging algorithm when the system detects the low battery voltage

Simulation Results of LED Dimming with PWM

A systematic control of LED brightness is planned in this simulation project in direct relation to changes in battery voltage levels. The waveform properties of the LED while it works at maximum luminosity, or 100% brightness level, are beautifully depicted in Figure 8. The answer of Equation (1), which mandates that the input voltage detection must above the threshold of 12.24V, determines whether there will be a perceptible shift to this high-brightness condition. As a result, the LED is dynamically activated to function at a 100% duty cycle in these circumstances. When the voltage level described above is present, the Light Dependent Resistor (LDR) assumes a state known as HIGH, which causes the luminous reaction. The advanced control methods used in the solar-powered lighting system, which guarantee optimum energy efficiency and illumination efficacy, are demonstrated by the dynamic adjustment of LED luminance.

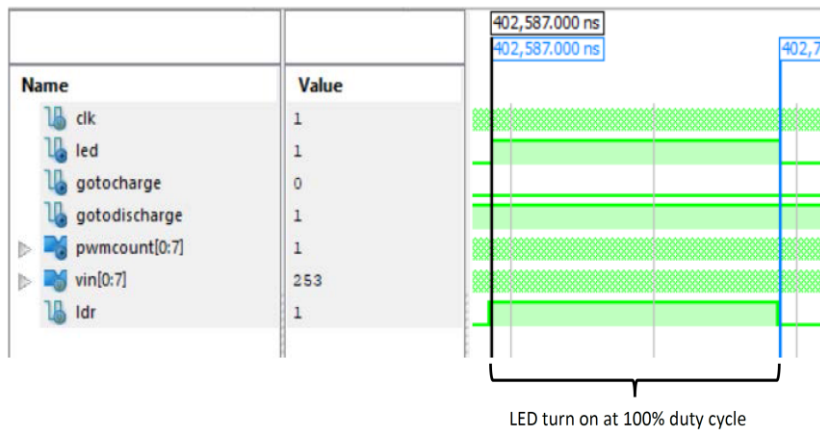


Figure 8. Simulation result of 100% brightness of the LED

In contrast, Figure 9 explains the waveform properties of the LED, particularly when it works at a 50% reduction in luminance. This decrease in brightness is inextricably related to the identification of an input voltage below the preset 12.24V threshold. As a result, the LED is urged to glow at a 50% duty cycle in compliance with the set standards described in the analysis that came before it. This 50% duty cycle modulation of LED brightness happens simultaneously with times when the Light Dependent Resistor (LDR) assumes the HIGH state, which corresponds to the relevant voltage level. The system's ability to manage energy resources and illumination levels within the context of solar-powered lighting with such precise control of LED brightness emphasizes how adaptable and responsive it is.

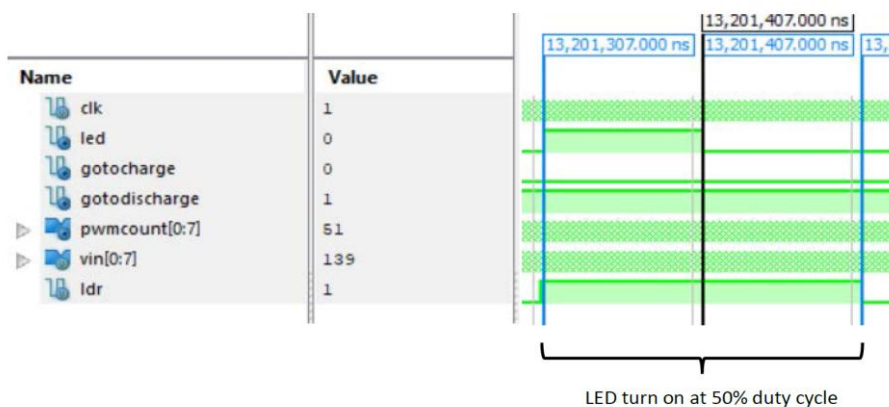


Figure 9. Simulation result of 50% brightness of the LED

PROTOTYPE RESULTS

A later phase involved the practical realization of the system by the implementation of an FPGA-based prototype after the acquisition of simulation data. The physical design of the solar-powered lighting system is

neatly illustrated in Figure 10, which includes vital parts such the FPGA, the MOSFET circuit, an Analog-to-Digital Converter (ADC), a voltage divider circuit, Light Emitting Diodes (LEDs), a lead-acid battery, and a solar panel. This extensive group of hardware components serves as an example of how the system's conceptual design is really implemented in the real world. The FPGA, which serves as the system's central control unit, coordinates how various elements interact with one another, making it easier for the solar lighting system to be integrated and run effectively. This prototype instantiation acts as a crucial step in confirming the viability and functionality of the system under test as the link between simulation and practical implementation.

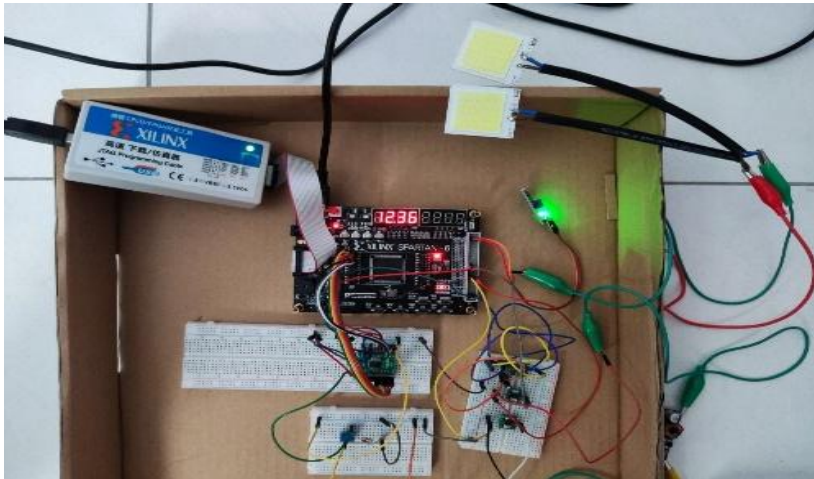


Figure 10. Hardware circuit of the Solar Powered Lighting System

Analysis of the number of battery life cycles based on different Depth of Discharge (DOD)

Three separate tests were carried out, each based on a different Depth of Discharge (DOD) configuration, to produce the required results. Over the course of three consecutive days with comparable weather, these investigations took place. Such an experimental approach, defined by the deliberate alignment of climatic conditions and the rigorous calibration of DOD parameters, was crucial in ensuring the robustness and dependability of the empirical data acquired. This methodological approach seeks to isolate the impact of DOD variations by maintaining consistency in environmental factors throughout the experimental trials, allowing a precise and discerning evaluation of the solar-powered lighting system's performance under various discharge scenarios.

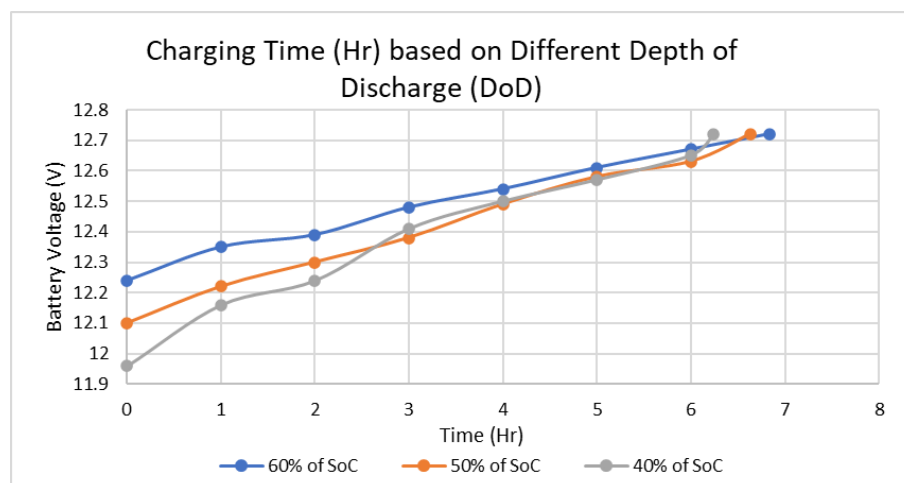


Figure 11. Total charging time based on different Depth of Discharge (DOD)

As depicted in Figure 11, the cumulative charging duration was meticulously documented across three discrete Depth of Discharge (DOD) scenarios. In the initial instance, the system embarked on the charging cycle, commencing from an initial battery voltage of 12.24V and culminating in full charge, necessitating a total

duration of 6.83 hours. Subsequently, a parallel experiment was conducted, wherein the charging operation commenced at a slightly lower initial voltage of 12.1V. This endeavor resulted in a marginally reduced charging time of 6.63 hours. Finally, in the third experimental iteration, the system initiated the charging process with a battery voltage of 11.96V, leading to a total charging duration of 6.24 hours. These careful records of charging times under various DOD circumstances help us fully comprehend the system's performance dynamics.

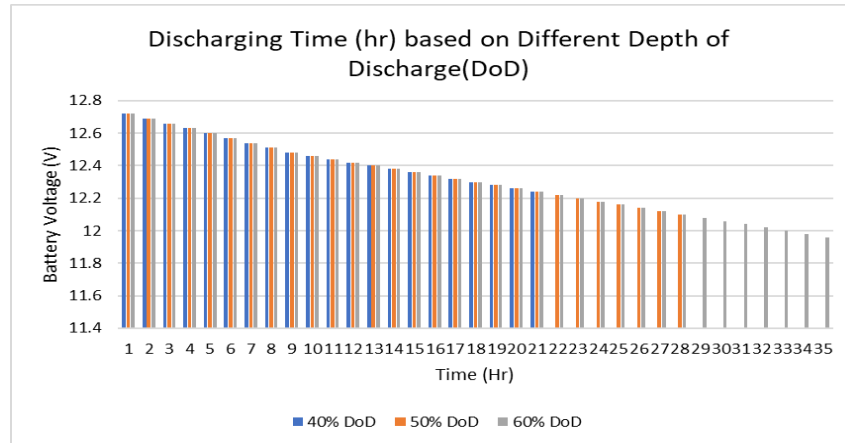


Figure 12. Total discharging time based on different Depth of Discharge (DOD)

According to the conclusions drawn from Figure 12, a thorough examination of the total discharging times under three distinct Depth of Discharge (DOD) configurations has been carried out. First, the battery must be discharged for a total of 21 hours in order to attain a DOD of 40%, or 12.24V. Therefore, when aiming for a DOD of 50% or 12.1V, the discharge operation lasts for 28 hours. Last but not least, a discharging window of 35 hours is required to achieve a DOD of 60% or 11.96V. The cumulative hours, which include both the charging and discharging stages, have been painstakingly recorded to give a comprehensive picture of the operational effectiveness and performance traits of the solar-powered lighting system under various DOD circumstances.

The calculation of battery life cycles based on various Depth of Discharge (DOD) configurations has been thoroughly carried out using Equation (1), as shown in Figure 13. To clarify, the calculations show that the battery can be dependably used for an outstanding 1574 cycles during the course of its operational lifespan when it goes through a discharge cycle to attain a DOD of 40%. The battery's utility is thus increased to 1265 cycles in the context of a 50% DOD discharge cycle before its operational limit is reached. Conversely, the battery's operational longevity shortens and allows for only 1062 cycles before reaching the end of its lifespan when it encounters a discharge to a DOD of 60% or a voltage level of 11.96V each cycle. These empirical findings highlight the complex interactions between DOD and battery life and provide a complex understanding of system performance.

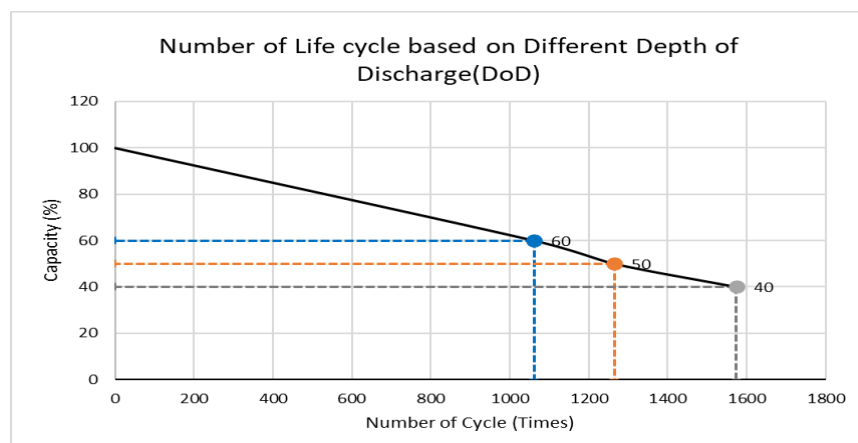


Figure 13. Number of battery life cycles based on different Depth of Discharge (DOD)

CONCLUSION

In conclusion, it is clear that the initiative has accomplished its stated goals admirably. A notable milestone is the creation of a working prototype of the solar-powered lighting system using the Xilinx Spartan 6 FPGA Development Board. The charging and discharging processes have been carried out with excellent operational performance by the system. The prevention of both overcharging and over-discharging of the battery has been greatly aided by the efficient formulation and use of charging and discharging algorithms. Additionally, the AD7822 8-bit ADC converter has allowed the FPGA to demonstrate its capabilities of reading input voltage levels, making it possible to display input voltage in real-time on the seven-segment display. This extensive project's completion highlights the efficient fusion of cutting-edge electronics and renewable energy technology.

Additionally, the research successfully extended the time that lights operate by carefully adjusting LED brightness, which boasts an astonishing spectrum of 61 distinct levels that adjust in accordance with battery charge levels. The combined results highlight the FPGA's ability to execute numerous operations in parallel at the hardware level, which is evidence of its parallel processing skills. In order to build the system, careful execution management of each sub-module was essential to assure exact adherence to the timing requirements of the main control loop. Due to the FPGA's inherent capacity for real parallel execution—a distinguishing feature that has been the focus of this project's benefits and contributions—these various functions have been seamlessly merged into a single controller.

Furthermore, it is a noteworthy accomplishment that the total operating hours' data were successfully acquired. We now have a complete record of the number of operating hours thanks to an iterative procedure that involved repeating the charging and discharging cycles three times, each with a different Depth of Discharge (DOD) setting. The number of battery life cycles has also been estimated concurrently, taking into account various DOD levels. Notably, the results have shown that lead-acid batteries have longer lifespans when they are not subjected to deep discharges, highlighting the critical part that DOD plays in determining battery life cycles. But it is crucial to understand that a variety of elements, including corrosion, temperature, charge level, active material deterioration, and overload circumstances, interact to affect battery life. Several approaches may be used to measure battery life, necessitating a varied approach for accurate estimations of battery life cycle and refined comparisons in upcoming research projects.

ACKNOWLEDGEMENT

The authors would like to express their thanks to Faculty of Electronics and Computer Technology and Engineering (FTKEK) at Universiti Teknikal Malaysia Melaka (UTeM) for their assistance in acquiring the essential information and resources for the successful completion of the research. The authors would also like to extend their gratitude to their collaborators at University of Malaya for the financial and scientific support they provided.

REFERENCES

1. M. D. Leonard, E. E. Michaelides, and D. N. Michaelides, "Energy storage needs for the substitution of fossil fuel power plants with renewables," *Renew Energy*, vol. 145, pp. 951–962, 2020, doi: 10.1016/j.renene.2019.06.066.
2. S. K. Alavipanah, M. Mansourmoghaddam, Z. Gomeh, and E. Hamzeh, "The reciprocal effect of Global warming and climatic change (new perspective)," *Desert*, vol. 27, no. 2, 2022, [Online]. Available: <https://jdesert.ut.ac.ir/>
3. X. Liu, F. Hao, K. Portney, and Y. Liu, "Examining Public Concern about Global Warming and Climate Change in China," *China Quarterly*, vol. 242, pp. 460–486, 2019, doi: 10.1017/S0305741019000845.
4. R. Panda and M. Maity, "Global Warming and Climate Change On Earth: Duties and Challenges of Human Beings," *International Journal of Research in Engineering, Science and Management*, vol. 4, no. 1, pp. 122–125, 2021, [Online]. Available: <http://journals.resaim.com/ijresm/article/view/478>

5. W. H. Cheng et al., "CO₂ Reduction to CO with 19% Efficiency in a Solar-Driven Gas Diffusion Electrode Flow Cell under Outdoor Solar Illumination," *ACS Energy Lett*, pp. 470–476, 2020, doi: 10.1021/acsenergylett.9b02576.
6. R. Li, Y. Shi, M. Wu, S. Hong, and P. Wang, "Photovoltaic panel cooling by atmospheric water sorption–evaporation cycle," *Nat Sustain*, vol. 3, no. 8, pp. 636–643, 2020, doi: 10.1038/s41893-020-0535-4.
7. S. H. M. R. R. J. P. R, "Hybrid Solar-Powered Street Lighting System with Battery Storage and Grid Integration," 2023 International Conference on Circuit Power and Computing Technologies (ICCPCT), 2023.
8. H. Suyanto, Erlina, R. A. Diantari, and H. Al Rasyid, "Study on Optimization of System Management Battery for Lithium Batteries and Lead Acid Batteries at the New and Renewable Energy Research Center IT PLN," *Proceedings - 2021 IEEE 5th International Conference on Information Technology, Information Systems and Electrical Engineering: Applying Data Science and Artificial Intelligence Technologies for Global Challenges During Pandemic Era, ICITISEE 2021*, pp. 213–218, 2021, doi: 10.1109/ICITISEE53823.2021.9655905.
9. N. A. Jasim, H. A. R. Akkar, and N. K. Kasim, "Power Management of LED Street Lighting System Based on FPGA Power Management of LED Street Lighting System Based on إلىء دنتسما عراوشلا قرانا مماظني في عوضلا ثعابلا دويادلا حيباصم لقاطلا قرادا تجمربملا تيقطنملا تاباوبلا تصلاحلا," no. February, 2013.
10. K. Sehairi, C. Benbouchama, K. El Houari, and C. Fatima, "A real-time implementation of moving object action recognition system based on motion analysis," *Indonesian Journal of Electrical Engineering and Informatics*, vol. 5, no. 1, pp. 44–58, 2017, doi: 10.11591/ijeei.v5i1.261.
11. K. B. Priyanka S., "control of solar LED street lighting system based on climatic condition and object movements," *Issn: 0975-6736*, vol. 03, no. 02, pp. 480–486, 2015.
12. S. Sarkar, K. Mohan, and P. Vankhande, "Smart Street-lighting using Green Energy," *IEEE 4th International Conference on Knowledge-Based Engineering and Innovation (KBEI) Dec.22nd,2017*, no. International Conference on Intelligent Computing and Control Systems ICICCS 2017, pp. 157–163, 2017.
13. N. T. Gadawe and S. L. Qaddoori, "Design and implementation of smart traffic light controller using VHDL language," *International Journal of Engineering & Technology*, vol. 8, no. 4, p. 596, 2019, doi: 10.14419/ijet.v8i4.29478.
14. S. M. A. Motakabber, M. I. R. Rokon, A. H. M. Zahirul Alam, M. A. Matin, and M. Mahmud, "Efficient Dual Mode Arbitration Scheme for Multiprocessor Hardware Interface in System-on-Chip," *Indonesian Journal of Electrical Engineering and Informatics*, vol. 11, no. 4, pp. 1097–1110, Dec. 2023, doi: 10.52549/ijeei.v11i4.5032.
15. Alali, H. Elmaaradi, M. Khaldoun, and M. Sadik, "The review of heterogeneous design frameworks/Platforms for digital systems embedded in FPGAs, and SoCs," *Indonesian Journal of Electrical Engineering and Informatics*, vol. 9, no. 4, pp. 811–826, Dec. 2021, doi: 10.52549/ijeei.v9i4.3243.