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Microcontroller-Based Variable DC Battery Charger with Auto Cutoff and Deep Discharge Protection for Enhanced Battery Management

Sudipto Pramanik[1], Moytri Ghosal[2],
Sandipa Chowdhury[3], and Md. Mehedi Hasan[4]
[1,2,3]Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology
Dhaka,1000,Bangladesh
[1,4]Department of Electrical and Electronic Engineering , Daffodil International University
Dhaka,1216,Bangladesh
Email: [1]sudipto.eee0247.c@diu.edu.bd, 0424062538@eee.buet.ac.bd, [2]moytrighosal@gmail.com,
[3]csandipa556@gmail.com, [4]mehedi33-1403@diu.edu.bd

***Abstract*—With the growing emphasis on adaptable and efficient energy storage systems, there is an increasing need for battery chargers capable of delivering variable DC output while ensuring battery safety. Although recent work has explored power converter designs, such as resonant LLC and SEPIC topologies for conversion and protection, most implementations rely on either hardwired analog circuits or complex, high-overhead microcontroller setups. In this work, we present a variable output battery charger that uses a simple microcontroller to safely manage both the charging and discharging processes. The charger automatically stops charging when the battery reaches 90% of its rated voltage and stops discharging when the voltage drops to 20%, thus helping to prevent degradation and extend battery life. These features were difficult to integrate solely through analog circuit logic. The system is built around a buck converter for output voltage regulation, while the microcontroller enables real-time monitoring and seamless adaptation to various batteries. This design maintains hardware simplicity, eliminates the need for advanced software control, and offers a low-cost, flexible, and reliable solution for modern battery-powered applications.**

***Index Terms*—Variable DC Output, Microcontroller-based Control, Output Voltage Regulation, Buck Converter, Automatic Cutoff, Deep Discharge Protection.**

I. INTRODUCTION

Rechargeable batteries are at the heart of modern technology, powering everything from everyday gadgets like smartphones and laptops to large-scale systems such as electric vehicles and renewable energy storage solutions. Battery types like lithium-ion, lead-acid, and nickel-cadmium are especially popular due to their high energy density and ability to be recharged again and again. But with this widespread use comes a major challenge: different batteries require different rated voltages to charge on. Most chargers on the market are designed for just one type of battery, meaning users often need separate chargers for each device or system. This not only drives up costs but also adds unnecessary complexity. It's clear there's a growing need for a flexible, all-in-one charging solution.

On top of that, safety is just as important as flexibility. First, overcharging can lead to overheating, shorten its lifespan, and in extreme cases, even cause fires or explosions. On the other hand, letting a battery discharge too deeply can damage it permanently, reducing its ability to hold a charge. To avoid these risks, modern battery chargers are expected to incorporate automatic protection mechanisms i.e. *auto cutoff* and *deep discharge protection*, to prevent overcharging and ensure that the battery is not drained to dangerously low levels.

In response to these needs, this paper presents a battery charger that's both versatile and safe. It uses a buck converter to efficiently produce a variable DC output, making it compatible with multiple battery types including lithium-ion, lead-acid, and NiCd. What sets this design apart is how it manages safety features. Instead of relying solely on analog circuitry—which can become complicated when trying to add multiple protections—we've used a microcontroller-based system. This approach gives us more control and makes it easier to monitor battery voltage in real time.

The proposed charger integrates two essential safety features. First, it includes an auto cutoff mechanism that automatically terminates the charging process when the battery reaches 90% of its rated voltage. This prevents overcharging and contributes to longer battery life. Second, it incorporates a deep discharge protection system, which disconnects the battery from the load once the voltage drops below a preset safe threshold. This feature ensures that the battery does not undergo irreversible damage due to excessive discharge.

This system, therefore, uniquely combines microcontroller-based control with a buck converter for variable DC output and integrates auto cutoff and deep discharge protection in a single, cost-effective design. Unlike traditional microcontroller-based chargers, which often rely on complex software or analog circuits, our approach simplifies the design while ensuring enhanced safety and battery longevity across various battery

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chemistries.

In summary, this paper underscores the importance of integrating safety features with charging flexibility and presents a simple yet effective hardware-software hybrid solution that meets the needs of modern battery-operated systems. By addressing the shortcomings of traditional fixed-output chargers, the proposed system lays the foundation for a more adaptable and sustainable approach to battery charging, suited for the evolving requirements of various technological fields.

II. Literature Review

Rechargeable battery systems have inspired a wide range of research in recent years, particularly around power conversion efficiency, safety mechanisms, and intelligent control. This section explores key contributions and highlights the existing gaps that motivate our proposed solution.

Initial studies have primarily focused on efficient power conversion. Shafiei et al. [1] presented high-order resonant power converters using modified LLC and L3C2 topologies capable of wide voltage regulation and efficiencies up to 96%. However, these designs did not incorporate charge termination or deep discharge features. Guo et al. [2] developed a solar-based SEPIC converter for Li-ion batteries capable of handling variable voltage conditions. Despite flexibility, their system lacked intelligent cutoff or discharge control. Jha and Singh et al. [3] introduced a compact charger for electric vehicles operating in both bulk and float charge modes with deep discharge cut-off. However, their implementation remained domain-specific and was not generalized for multiple battery types.

As battery safety emerged as a growing concern, several researchers turned to the development of protection circuits. Zhou and Zhang et al. [4] implemented a voltage comparator-based circuit to disconnect batteries at low voltage. Similar configurations were seen in et al. [5]–[7], focusing on the logical cutoff when threshold levels are breached. Zhang et al. [8] analyzed Li/S batteries, emphasizing irreversible capacity loss below 1.8 V, underlining the necessity of discharge thresholds. Similarly, Yanbo et al. [9] empirically determined the optimal charge cutoff voltage to minimize capacity loss and enhance safety. However, these implementations largely relied on analog components and lacked real-time monitoring or dynamic control capabilities.

Recognizing the limitations of static analog systems, more recent efforts have investigated the integration of intelligent control mechanisms. Su and Yang et al. [10] proposed computer-controlled circuits that switch between charge/discharge states using voltage and temperature thresholds. Choifin and Lestariningsih et al. [11] applied an ARM Cortex M0 microcontroller to control wind-powered battery charging, incorporating 50% depth-of-discharge (DoD) auto cut-off. Shen et al. [12] offered a mathematical model for estimating battery available capacity under variable loads using real-time identification, enabling more dynamic control. However, this was limited to data estimation without direct circuit control.

Efforts to create fully integrated, safety-aware systems have also been notable. Barchi et al. [13] proposed an all-in-one DC UPS integrating battery care, charging, and overload protection. While it supports variable DC outputs, it is proprietary and not open-source or adaptive. Kurokawa et al. [14] proposed a protection circuit that disables charging in deep discharge states but lacks real-time adaptability. Liu and Wang et al. [15] introduced a circuit that dynamically disconnects any series cell in a battery pack if over-discharge is detected. While practical, it lacked microcontroller feedback integration. Similarly, systems developed by Diallo et al. [16] and Song-Rong et al. [17] offered analog-based protection circuits for overcharge and deep discharge, yet failed to support programmable variability across different battery chemistries. Furthermore, Shen et al. [18] and Song et al. [19] highlighted the detrimental effects of over-discharge on battery lifespan and advocated for effective cutoff control; however, their work did not include practical implementations.

Despite the significant advancements highlighted above, several limitations remain unaddressed in existing research. Many proposed systems either lack the ability to provide a variable DC output adaptable to diverse battery chemistries or fail to integrate both auto cutoff and deep discharge protection within a unified, microcontroller-based architecture. Additionally, a large portion of prior work is either purely analog, lacks real-time monitoring, or is constrained to specific applications such as electric vehicles or wind-powered systems.

Our proposed system addresses these critical gaps by introducing a microcontroller-controlled battery charging system that employs a buck converter to generate an adjustable DC output suitable for various battery types. The system automatically terminates charging when the battery voltage reaches 90% of its rated capacity. It also halts discharging at 20%, ensuring deep discharge protection and thereby enhancing the overall battery life. Real-time monitoring is achieved through an Arduino microcontroller that manages the switching for both charging and discharging, while status LEDs provide visual feedback on system operation.

III. Methodology

The approach to creating a battery charger with adjustable DC output, automatic cut-off, and deep discharge protection focuses on providing a system that is flexible, efficient, and safe. The design process is systematic, ensuring reliability and practicality. At the core of the system lies an Arduino microcontroller, integrated with other components to precisely manage voltage levels, oversee charging, and protect the battery during discharging.

A. Design Strategy and System Overview

The design adopts a hybrid strategy, combining the control capabilities of an Arduino microcontroller with the respon-

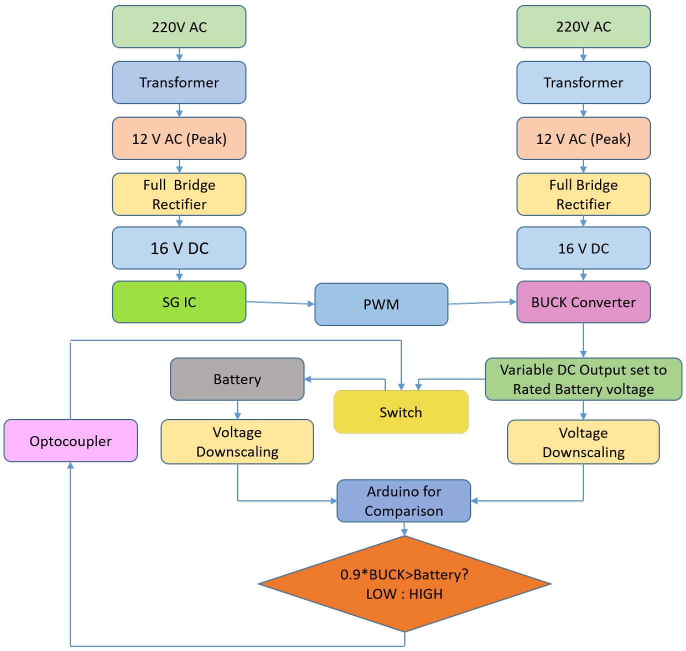


Fig. 1: Schematic of the Charging Mechanism, featuring Variable DC Output and Automatic Cutoff.

siveness of analog circuits for real-time voltage monitoring and regulation. The system is composed of two primary functional blocks: the charging module and the discharging module. These operate independently but are synchronized through centralized control and feedback logic.

A block-level overview of the charging system is presented in Fig. 1, which illustrates the step-by-step operation from AC input conversion to the triggering of auto cutoff logic. Similarly, the discharging system flow, shown in Fig. 2, details how real-time voltage monitoring ensures load disconnection once the battery voltage falls below the defined threshold.

B. Charging Mechanism

As outlined in Fig. 1, charging begins with a 220V AC input that is stepped down and rectified to 16V DC using transformers and bridge rectifiers. This DC voltage is then regulated by a buck converter[1] to provide a stable, variable DC output suitable for battery charging. The SG IC and PWM control block ensure smooth pulse-based voltage adjustment.

The Arduino microcontroller continuously senses both the current battery voltage and the rated battery voltage set in the output of the buck converter. Now, to protect the Arduino, which operates at a lower voltage level, from potential damage due to high voltage, voltage dividers are used to reduce the voltages to a safe level (20%) before it is read by the Arduino. Once the battery reaches 90% of its rated voltage, the Arduino triggers the automatic cutoff mechanism by deactivating the switch, thereby terminating charging. This logic ensures that the battery is not overcharged, which improves both operational safety and battery lifespan.

C. Discharging Mechanism

The discharging process is equally safeguarded. As shown in Fig. 2, once the battery is supplying power to a load, the Arduino continuously compares the real-time battery voltage with a predefined lower limit (20% of its nominal voltage). This 20% threshold is achieved by scaling down buck converter's output voltage which has already been set to the battery's rated voltage. If the battery voltage drops below this threshold, the Arduino is triggered to cut off the discharge path by switching off the connected load. Here again, to protect the Arduino from potential high voltage, the voltages are scaled down by a factor. This mechanism is essential to prevent deep discharge, which could permanently damage the battery or reduce its useful life.

D. Rationale for the Design Choices

The Arduino platform was selected due to its flexibility, low cost, and simplicity for custom logic implementation. It handles threshold checking, switching control, and interaction with analog components efficiently. By incorporating analog circuitry, the system achieves a fast response to voltage changes without introducing significant software overhead, striking a balance between precision and speed. This hybrid approach not only simplifies the design but also enhances reliability by reducing system complexity.

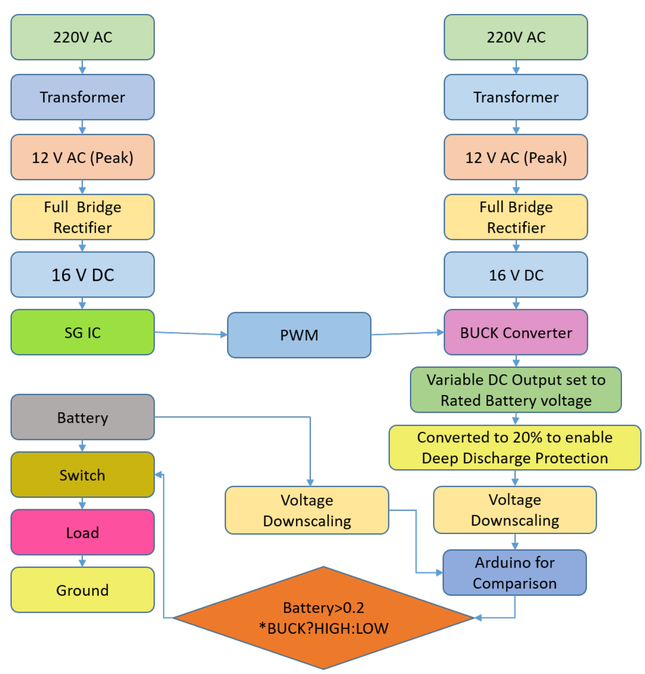


Fig. 2: Schematic of Discharging Mechanism, attributing Deep Discharge Protection.

[1]A buck converter is a DC-DC step down converter that reduces input voltage to a lower DC output using a transistor, inductor, and capacitor block. The transistor switches on and off, while the inductor and capacitor smooth the output to provide stable voltage.

E. Testing and Validation

To verify that the system meets its design targets, several tests has been conducted across key functional aspects. The first set of tests focus on ensuring that the charger halts charging once the battery reaches 90% of its rated capacity. Similarly, the discharging system has been tested to confirm that it reliably triggers the cutoff mechanism when the battery voltage drops to the predefined 20% threshold, preventing deep discharge. In addition to these, the system's variable DC output has been evaluated by testing its adaptability to different battery types. The tests ensure that the system can provide the appropriate output voltage for various battery chemistries, confirming its flexibility and compatibility.

IV. Results and Findings

This section dives into the experimental outcomes of the battery charger system, which boasts a variable DC output, auto cutoff, and deep discharge protection. The findings are broken down into the charging and discharging phases, shining a light on how the system performs and behaves under different conditions.

A. Charging Process with Auto Cutoff

The charging process is enabled when the battery's initial voltage is below 90% of its rated value. A green LED lights up, giving a clear signal that the charging has begun. The buck converter sets its output to align with the battery's rated voltage, and as the process continues, the battery voltage climbs steadily, tracked through real-time monitoring.

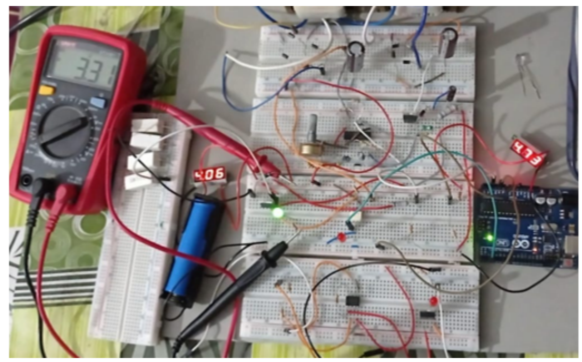
Once the battery hits 90% of its rated voltage, the auto cutoff feature springs into action, with a red LED glowing to show the system has stepped in to prevent overcharging. This keeps the battery safe and sound. During tests, the battery, with a rated voltage of 4.5 V, increased in voltage from 3.31 V to 4.05 V, and the charging halted as the cutoff point was reached.

The efficiency of the buck converter was measured to be 91% at full load and 87% at partial load. In addition, the system's inaccuracy of voltage sensing was found to be ±0.15 V, providing precise control over the charging and discharging processes. The response time for cutoff was recorded at approximately 1 second, ensuring prompt intervention to avoid overcharging.

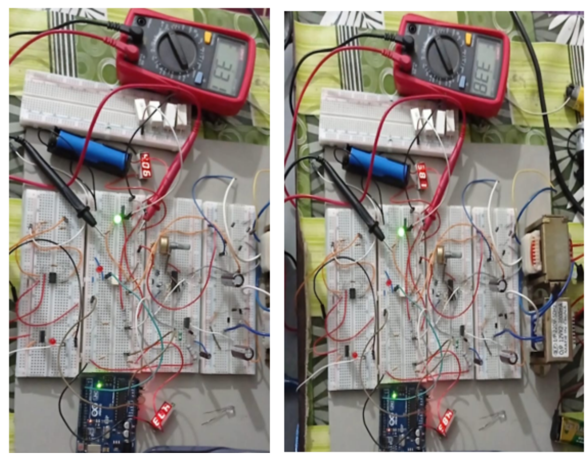
The system's ability to handle this process seamlessly is a big win, ensuring the battery gets just the right amount of charge without any risk of damage. It's a smooth, hands-off operation that makes the system stand out.

The charging process is laid out in Fig. 3, which describes how the battery voltage evolves during charging. Panel (a) shows the initialization of the charging process for a battery with present voltage value significantly below its rated value. Panel (b) captures the voltage rising up from 3.31 V to 3.38 V as the system continues to provide power. Finally, panel (c) highlights the switch to cutoff mode, with the red LED flashing on to mark the end of the charging cycle.

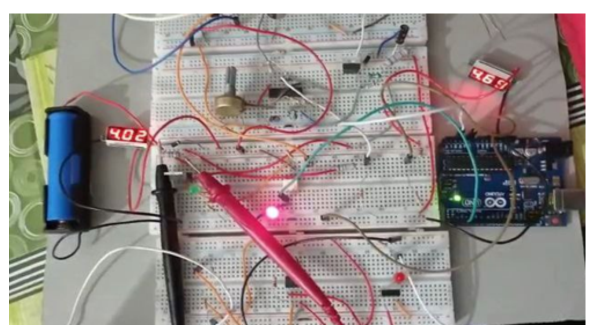
Further illustrating the charging behavior, Fig. 4 presents the voltage profile of the 4.5V battery during the charging cycle. The plot clearly shows the battery voltage increasing over time until it reaches the 90% cutoff threshold, at which point charging is terminated. This visual representation confirms the effectiveness of the automatic cutoff mechanism in preventing overcharging.



(a) Initialization of the Charging Process



(b) Rise of Voltage during the Charging State



(c) Auto Cutoff Activated (Red LED ON)

Fig. 3: Sequential Illustration of the Charging process.

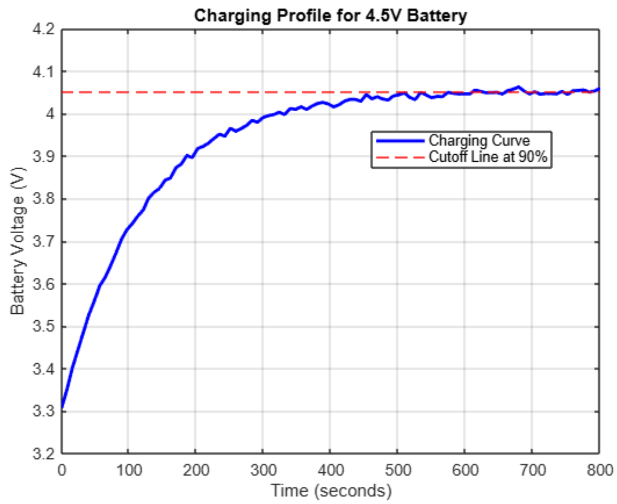


Fig. 4: Charging Profile for a 4.5V Battery, illustrating the voltage increase and the 90% cutoff line.

B. Deep Discharge Control

The discharging process gets rolling when the battery's voltage is above 20% of its rated value. The battery powers the load, with the process sparked by the comparator's output. If the voltage drops below the 20% safety threshold, the system steps in and cuts the battery off from the load, shielding it from deep discharge damage.

The discharging process is illustrated in Fig. 5, which outlines the stages of battery discharge. Panel (a) shows the battery in full discharge mode, with the blue LED glowing to indicate that the process is active. Panel (b) demonstrates the activation of deep discharge protection when the voltage drops below the 20% threshold, with the blue LED turning off as the battery is disconnected. The red LED then lights up, signaling that the discharge has been safely halted.

This feature is a game-changer for battery longevity, ensuring it's never pushed beyond its limits. The system's quick response to low voltage levels adds an extra layer of reliability.

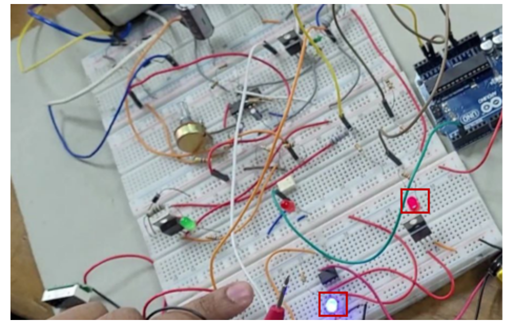
Complementing the sequential illustrations, Fig. 6 shows the discharging profile for a 20V battery. The plot clearly depicts the battery voltage decreasing over time under load until it reaches the deep discharge protection line (20% of the rated voltage), at which point the load is disconnected, safeguarding the battery from irreversible damage.

C. Charging-Discharging Cycle

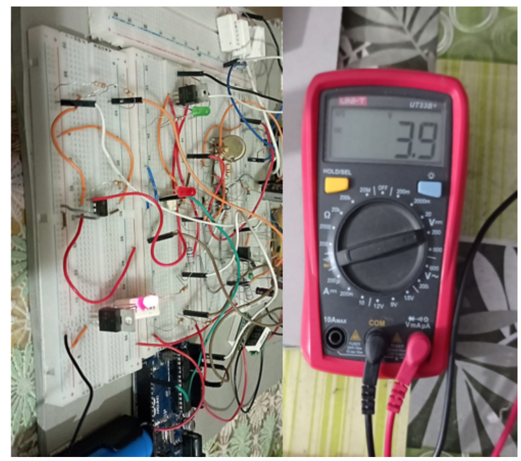
To provide a comprehensive overview of the system's operation, this subsection illustrates the complete charge and discharge cycle under different conditions.

Fig. 7 presents the overall charging and discharging behavior where the load was not connected during the charging phase and was only connected after the charging process completes and some time passes. This conceptual diagram demonstrates how the battery voltage is managed throughout different phases, from charging and maintaining the 90% cutoff to discharging and activating deep discharge protection at 20%, thereby illustrating the system's core functionality.

Furthermore, Fig. 8 provides an alternative visualization of the complete cycle, where the load was connected from the



(a) Battery in Active Discharge mode



(b) Deep Discharge Protection Activated (Red LED On)

Fig. 5: Sequential Illustration of the Discharging process.

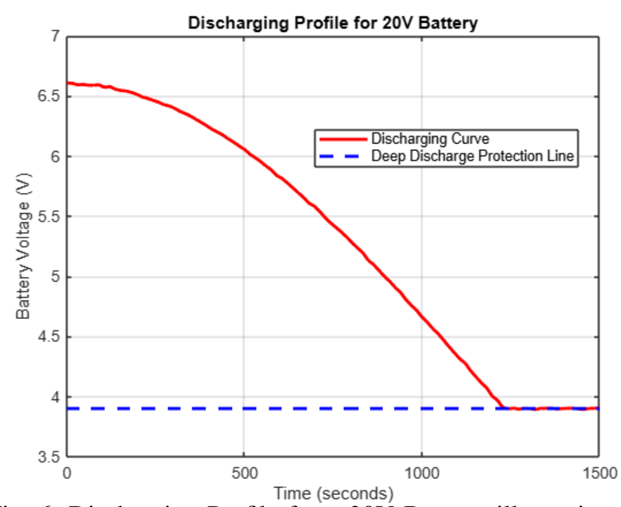


Fig. 6: Discharging Profile for a 20V Battery, illustrating the voltage decrease and the deep discharge protection line.

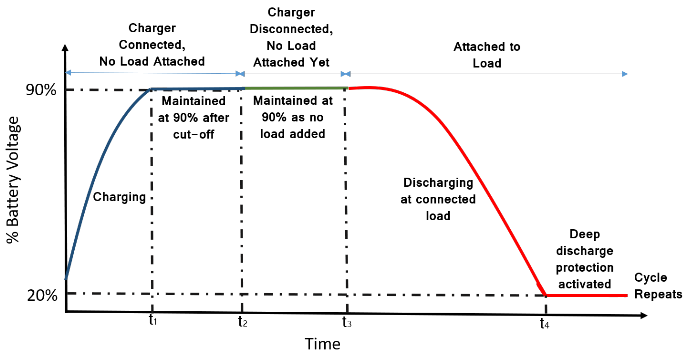


Fig. 7: Conceptual Illustration of the complete Charging and Discharging Cycle (Load Connected After Charging).

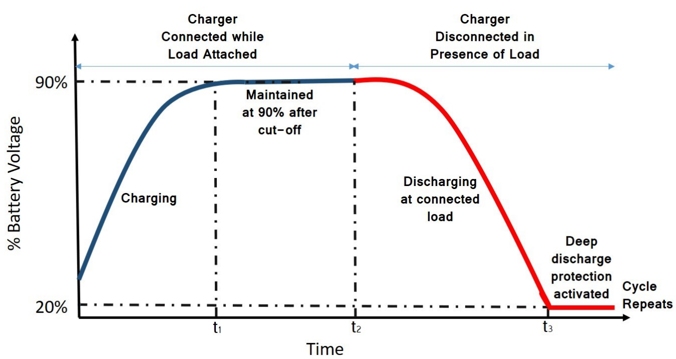


Fig. 8: Conceptual Illustration of the complete Charging and Discharging Cycle (Load Connected from Beginning).

very beginning of the process. This reinforces the system's adaptability and comprehensive battery protection across different operational scenarios, showcasing its performance under continuous load.

D. System Performance and Reliability

The system operates reliably, with auto cutoff and deep discharge protection features functioning seamlessly. It switches between charging and discharging based on the battery's voltage, halting charging at 90% and preventing discharge below 20%, ensuring the battery remains safe and operational throughout each cycle.

The integration of analog control and microcontroller monitoring enables quick adaptation to voltage changes without manual adjustments, providing precise regulation and protection. This ensures smooth operation and makes the system ideal for real-world applications, offering confidence in the battery's safety.

V. Conclusion

This paper presents the design and implementation of an Arduino-based smart battery charger with automatic cutoff and deep discharge protection. Utilizing a buck converter, the charger offers a variable DC output, ensuring compatibility with batteries of distinct ratings. Automatic cutoff and deep discharge protection are achieved with the control of Arduino.

Experimental results confirm that the system operates as intended. The auto cutoff feature halts charging at 90% of the rated voltage, preventing overcharging, while deep discharge protection disconnects the load when the voltage drops below 20%, avoiding permanent damage. Real-time monitoring through the Arduino ensures precise voltage control, safeguarding the battery from both overcharging and deep discharge.

The system demonstrated reliable performance in both charging and discharging phases, with clear visual indicators (LEDs) providing intuitive feedback. These safety features validate the design's effectiveness, making it suitable for applications in consumer electronics, electric vehicles, and renewable energy systems.

This work presents a cost-effective, intelligent charging solution that integrates real-time monitoring with advanced battery management. It establishes a foundation for future research into adaptive charging algorithms, enhancing battery longevity and safety. The proposed system provides a robust approach and opens new avenues for improving battery performance and safety across various sectors.

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