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Automatic 12-Volt Battery Charge Controller for Telecommunication Systems

Sylvester Tirones, Raj Kumar

Abstract*: *Everyday electronic applications rely on electric energy to perform work. The growing use of electrical appliances has significantly increased electricity demand. In remote areas where electronic systems are deployed, DC power is essential, making batteries vital for energy storage. Rechargeable batteries are widely used as backup power sources in applications requiring continuous operation, but without appropriate chargers, they become ineffective. Telecommunication systems, crucial for transmitting and receiving information, depend on reliable power. A battery charger matched to the battery's charging and discharging specifications ensures uninterrupted operation. The proposed charger design is simple and cost-effective, using terminal voltage to monitor the state of charge (SoC) of a 12-volt lead-acid battery. This is achieved with a voltage divider circuit calibrated to switch the charger on or off at set voltage levels. The design includes detailed experimental work and component-level implementation, supported by software-based simulation to validate that the charger maintains control within the required charging and discharging limits. Results confirm that the charger operates safely within the specified SoC range, protecting battery health. Thus, this automatic 12-volt battery charge controller is vital for telecommunication systems, especially during main power disruptions. It ensures continued operation and enhances reliability in remote setups such as telecommunication stations, weather monitoring systems, data acquisition units, and other electronics-based remote monitoring applications.

Keywords*: *Battery Charge Controller, 12-Volt Lead Acid Battery, State of Charge (SoC) Monitoring, Automatic Battery Charging, Voltage Divider Circuit, Relay-Based Control, Telecommunication Systems.

Abbreviations:
NBBs: Nickel-Based Batteries
LABs: Lead-Acid Batteries
Ni-Cd: Nickel-Cadmium
Ni-MH: Nickel-Metal Hydride
LIBs: Lithium-Ion Batteries
SoH: State of Health
SoC: State of Charge
OCV: Open-Circuit Voltage
DC: Direct Current

I. INTRODUCTION

Nearly all modern electronic devices, including mobile phones, laptops, vehicles, motorcycles, energy storage systems, and backup systems, operate using direct current (DC) supplied by batteries. Batteries are generally classified into two categories: primary disposable batteries and secondary rechargeable batteries, with the latter seeing increased adoption across various applications. Battery chargers introduce electric energy into the secondary cells by forcing an electric current, with the specific charging protocol — including voltage level, current magnitude, charging duration, and charge-discharge conditions — depending on the type, capacity, and size of the battery being charged [1]. The most widely used rechargeable batteries are lead-acid batteries (LABs), nickel-based batteries (NBBs) such as nickel-cadmium (Ni-Cd) and nickel-metal hydride (Ni-MH), and lithium-ion batteries (LIBs) [3].

Different types of rechargeable batteries exhibit varying tolerances to overcharging. Some can endure minor overcharging without significant degradation, while others are highly sensitive and require strict monitoring [2]. Recharging typically involves applying either a constant voltage or constant current, depending on the battery type. In cases where batteries are susceptible to overcharging, chargers may need to be manually disconnected at the end of the charging cycle [10]. Alternatively, some chargers incorporate timers that terminate the charging process after a predetermined period. Consequently, an effective charge controller is necessary to ensure proper monitoring of both the state of charge (SoC) and, where applicable, the state of health (SoH) of the battery [11]. Several direct estimation methods are commonly used to assess the SoC, including open-circuit voltage, terminal voltage, impedance measurement, and impedance spectroscopy techniques [4].

Although a variety of 12-volt battery chargers are available in the market, many require manual intervention during the charging process. Monitoring the SoC is particularly critical for 12-volt lead-acid batteries, which must adhere to specific charging and discharging rates to ensure optimal performance and longevity [12]. In this paper, a charge controller is proposed that integrates a terminal voltage-based sensing method to monitor the SoC of a 12-volt lead-acid battery. The design features a simple control mechanism comprising a mechanical relay as a switching device and a voltage divider circuit as the sensing element [13]. The relay is configured to automatically switch off the charger once the battery reaches its full state of charge and to reconnect the charger when the SoC falls below 75% of its rated capacity [14].

The remainder of this paper is structured as follows: Section II presents the methodology, Section III discusses the results, and Section IV concludes the work.

II. METHODOLOGY

In this section, we present the three main approaches that are used for qualitative

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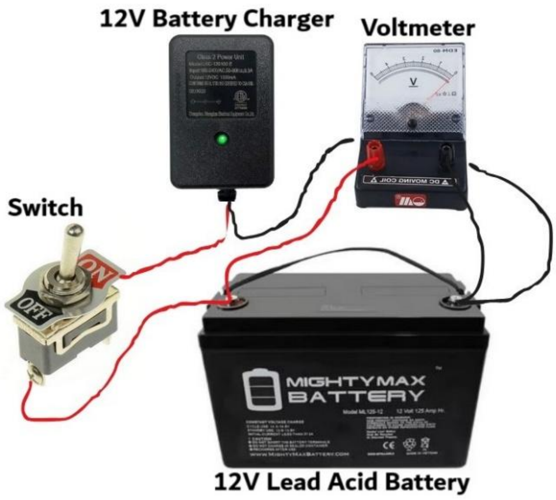
assessment of the working principle of the proposed design of the charge controller. The proposed controller is mainly composed of the battery charging circuit and the battery voltage measurement circuit. Conventional battery charging system composed of a battery charging circuit and an open/closed switch that manually regulate the flow of electric current to the battery; therefore, most are manually controlled. Figure 1 is a typical 12-volt Lead-acid battery charger.



[Fig.1: Typical 12 Volts Battery Charger Connection]

The operation of the battery charger is an exception to the design; however, the specification of the 12 volts lead-acid battery imposed a huge challenge. The specification of the battery is therefore paramount in the design and selection of the charge controller. To enable smooth performance, the specification of the 12 volts lead-acid battery in Table I is observed.

Table-I: 12 Volts Lead Acid Battery Specifications

No	Battery	Specification
1	Capacity	12.0V (5 – 125Ah)
2	Max. Charging Voltage	12.6V
3	Min. Discharge Voltage	8.4V
4	Life - Span	3 – 5 years
5	Max. Charger Voltage	14.4V

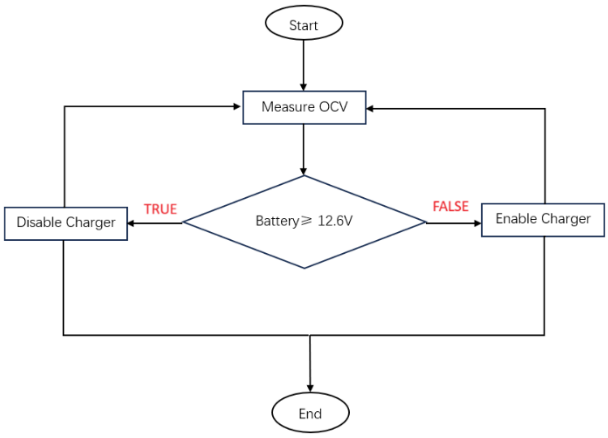
The state of health (SoH) of the battery is suggested that the battery should not charge beyond the maximum capacity of 12.6V terminal voltage. On the other hand, it should not discharge below 70 percent (%) of its terminal voltage. The charging time for the lead-acid battery is computed as

$$Time_{Charging} = \frac{Battery_{Capacity}}{Currrent_{Charging}} \quad \dots \quad (1)$$

where,

- $Time_{charging}$ = measured in hours
- $Battery_{capacity}$ = measured in amp-hours (Ah)
- $Current_{charging}$ = measured in ampere (A)

In this paper, we proposed a charge controller to monitor the charge voltage of the 12-volts battery by monitoring the SoC at its terminal using the open-circuit voltage (OCV) method. The flow chart in Figure 2 describes the continuous measurement performed on the battery.

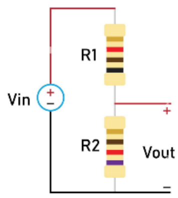


[Fig.2: Flow Chart of Terminal Voltage Measurement and Charger Operation]

The following sections describe the terminal voltage sensing theory using the voltage divider – transistor switching, simulation approach, experimentation approach and the prototyping design.

A. Voltage Divider – Transistor Switching

The OCV measurement of the terminal voltage of the battery plays an important role in the switching behavior of the circuit. The precision voltage divider in Figure 3 provides a fractional voltage corresponding to the terminal voltage of the 12-volts Lead acid battery. The measurement is carefully analyze and obtained by the transistor base terminal for switching purposes.



[Fig.3: Precision Voltage Divider Configuration]

The terminal voltage measurement is achieved by voltage divider circuit, which is the OCV method applied to the 12-volts Lead-acid battery. The structure of resistive voltage divider for DC voltage measurement enables precise calibration [5]. The resistor R_1 and R_2 provides precision resistance to compute the transistor base switching current.

$$V_{transistor} = \left[\frac{R_2}{R_1+R_2}\right] V_{battery} \quad \dots \quad (2)$$

The silicon transistor requires 0.7V to switch ON. Choosing the precision resistor aid in the computation of the $V_{trasistor}$. The following low-level design section provides in-depth system configurations and analysis of the entire proposed charge controller. The schematic of the simple 12 volts battery charger, the control sensing mechanism of the controller, and the clarification of the overall function of the intended charge controller system.

B. Simulation Approach

The simulation design of the battery charge controller provides the first insight to the proposed design scheme of

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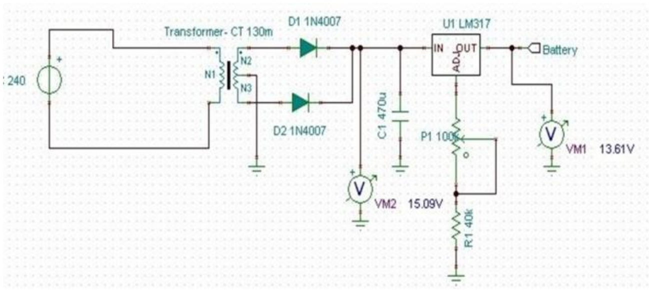
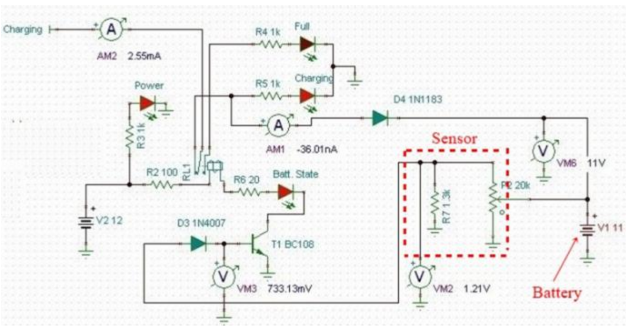
the charge controller. The simulation of the circuit is performed using TINA software. Figure 4 and Figure 5 is the charging circuit and the control circuit respectively. The charging circuit schematic is a traditional battery charger circuit. The battery charger using LM317 voltage regulator in [6] has a limited current of 1.5A and is capable of charging rechargeable batteries of 9V to 12V. This type of charging circuit is seen in Figure 1.



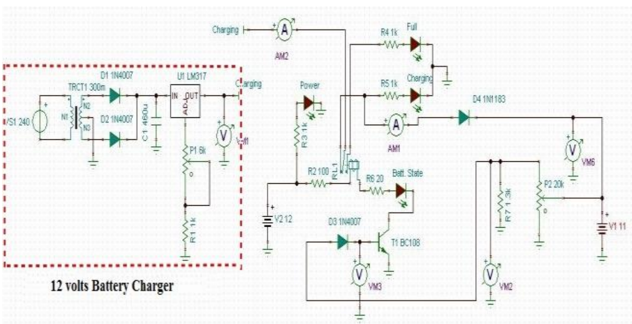
[Fig.4: Schematic of 12 Volts Battery Charger Using LM317]

The schematic of the control circuit inclusive of the battery and the sensor is shown in Figure 5. The battery is connected to the charger and the terminal voltage sensor is connected to the terminal of the battery.



[Fig.5: Schematic of 12 Volts Control Circuit with Voltage Divider, Transistor and Relay]

The cascaded schematic of the proposed circuit of the 12-volts battery charge controller is shown in Figure 6.



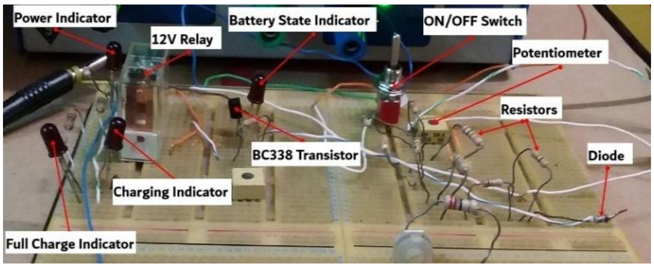
[Fig.6: Schematic of Proposed Cascaded 12 Volts Lead Acid Battery Charge Controller]

The TINA simulation results are presented Table III and Figure 14 in result section III.

C. Experimentation Approach

This section is the realization and implementation of the hardware. The laboratory testing is conducted using physical electrical components. Experimental methods [7] aided in developing the critical understanding of the concept, and provide existing relationship between the theory and application of science and technology; and to think communicate scientifically.

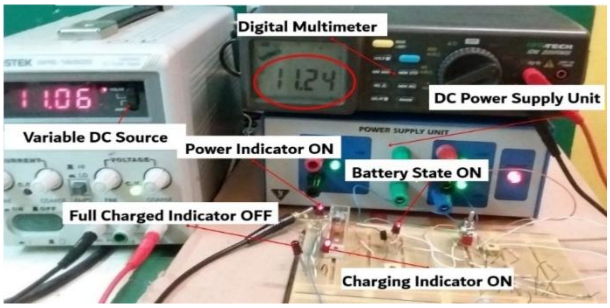
The further approach is the prototyping. Prototyping has the intention of a working product. The laboratory approach design and testing are the initial stage of verifying the reliability and the robustness of the system concerning its specifications. The approach was carried out using components and equipment available at the Department of Electrical and Communication Engineering Laboratory at Papua New Guinea University of Technology.



[Fig.7: Experimental Setup of the Proposed Charge Controller]

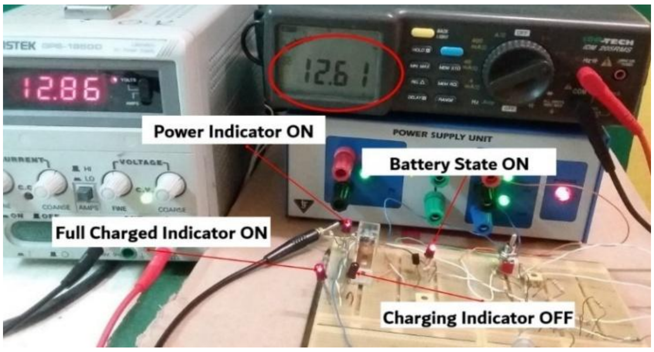
In the design, the breadboard connections of the control circuit are obtained from the schematic in Figure 5. The main component in the design is labelled as shown in Figure 7. The objective of experiment is to see how the common terminal of the relay will automatically switch between the terminal of normally closed (charging) and normally open (cut-off charging).

The 12-volt DC power supply unit functions both as the input for the control circuit and as the battery charger. A variable DC voltage source is employed to simulate the battery, offering adjustable voltage outputs. The positive terminal of the relay coil is connected to the 12V supply, while the negative terminal is linked to the common pin of the transistor. Additionally, the relay's common contact is connected to the positive terminal of the DC supply, with the normally closed terminal connected to the charging indicator and the normally open terminal to the full-charge indicator. When the variable DC voltage source in Figure 8 is adjusted from 0V to 11.24V and up to 12.5V, the voltage at the transistor's base remains below 0.7V, preventing the transistor from conducting. Consequently, the relay remains in its default normally closed position, and the charging indicator remains illuminated.



[Fig.8: Validation of Switch OFF Charging Performance]

When the variable DC voltage source in Figure 9 is adjusted to 12.6 volts, the voltage at the transistor base reaches approximately 0.7 volts, sufficient to activate the transistor. Upon activation, the transistor conducts, allowing current to flow from the collector terminal to the emitter. As a result, the relay closes the circuit, switching from the normally closed contact to the normally open contact, thereby illuminating the battery full indicator.



[Fig.9: Validation of Switch ON Charging Performance]

When decreasing the variable DC voltage source, the relay remains normally open until the voltage drops to 11.2 volts, a point where the transistor switches off and the relay returns to its normally closed position, turning on the charging process. When increasing the voltage, the relay stays normally closed until it reaches 12.6 volts, the transistor switches on and enable the relay to the normally open position, illuminating the full indicator while disabling the charging process. This cycle repeats with voltage adjustments. The experimental results are presented Table III and Figure 14 in the result section III.

D. Prototyping Design

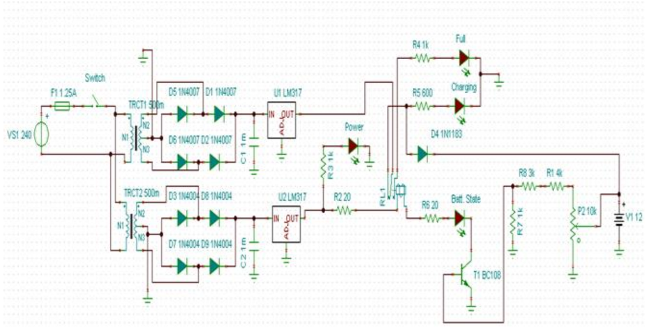
The prototype design is based on the experimental approach through which the implementation was realized on a PCB board. Prototyping is a crucial step in product and venture development, supporting idea generation, design exploration, evaluation, and system integration, while also guiding resource allocation and significantly impacting project success [8].

The main component of the prototype of the 12 volts battery charge controller is listed in Table II.

Table-II: Main Component in Prototype Design

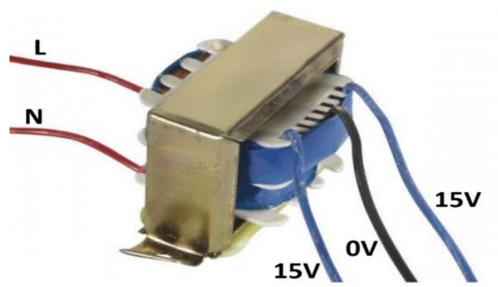
No	Component	Quantity	Function
1	240V/15V 3A centre-tap step down transformer	1	Purpose for stepping down 240VAC to 15VAC voltage
2	1N4007 Full bridge rectifier	1	Rectified 15VAC to 14.4VDC for charging and 12VDC for relay operation
3	LM317 voltage regulator	2	Regulate voltage of 14.4VDC and 12VDC with 3A max. current
4	12V Relay	1	Responsible for switching ON/OFF the charging cycle
5	Voltage divider	1	Precision battery sensor using terminal voltage measurement
6	BC338 NPN Transistor	1	Used for switching electromagnetic relay ON/OFF
7	Light emitting diode	4	Status indicator for charger ON/OFF, power on, and relay operation
8	12V 7Ah lead-acid battery	1	The battery is used for the computation of the charging time

Due to the availability of components and materials required for prototype implementation, the schematic is realized in such a way that it will meet the required objective of the design, and performs the exact functionality as designed using TINA and laboratory approach.



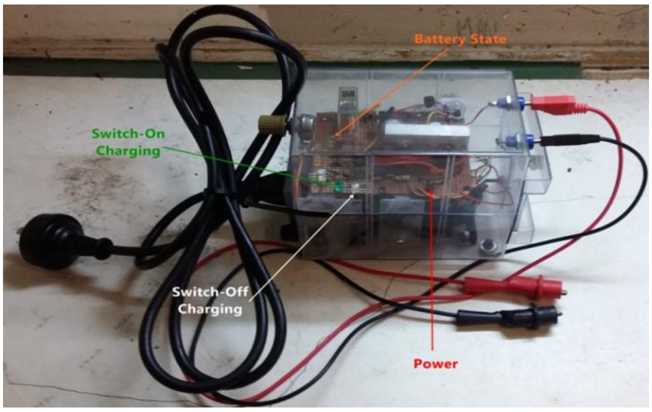
[Fig.10: Schematic of the Prototype of Automatic 12-Volt Battery Charge Controller]

The design was implemented based on the prototype schematic, resulting in the construction of an automatic 12-volt battery charge controller for real-time operation. Figure 12 shows the prototype which has been built to accomplish the objectives of this project. The prototype is built using the schematic provided in Figure 10.



[Fig.11: 240V/15V 3A Step-Down Transformer]

The step-down transformer in Figure 11 is inclusive in the prototype design and its specification and function is highlighted in Table II. The two output of the step-down are shared for the purpose of charging the battery and powering the controller circuit.



[Fig.12: Prototype of Proposed 12-Volt Automatic Battery Charge Controller]

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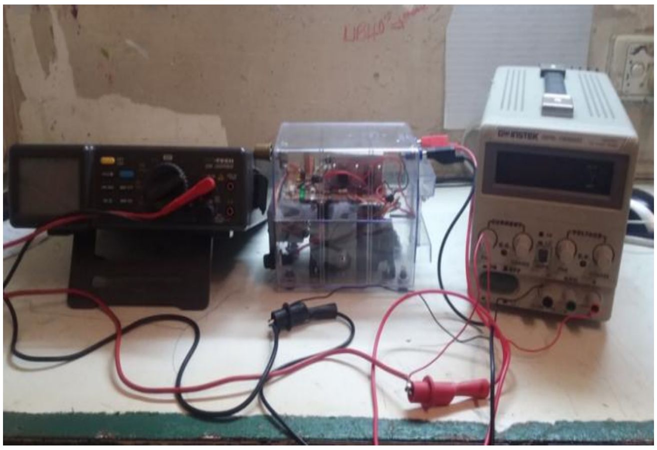
The response of the prototype test is given in the result section III, along with results obtained from the simulation and experimental design. The prototype test is accomplished using the variable DC voltage source as the battery and a multi-meter for collecting the resulting parameters under observation.



[Fig.13: Equipment Used in Determining the Performance of the Proposed Prototype]

Figure 13 depicts the phase of testing and verifying the prototype performance. The DC variable voltage source vary the voltage level which corresponds to the terminal voltage of the battery. The prototype results are presented Table III and Figure 14 in next section III.

III. RESULTS AND DISCUSSION

In this section, the results are presented. There are three comparison tests made to seek validation of the charge controller performance. The main performance includes how the charge controller can accurately monitor and compute the terminal voltage reading and switch the relay ON/OFF depending on the charges accumulated in the 12 volts lead-acid battery. The results are presented in the sequence of control switching, and the overall charger and battery charging performance.

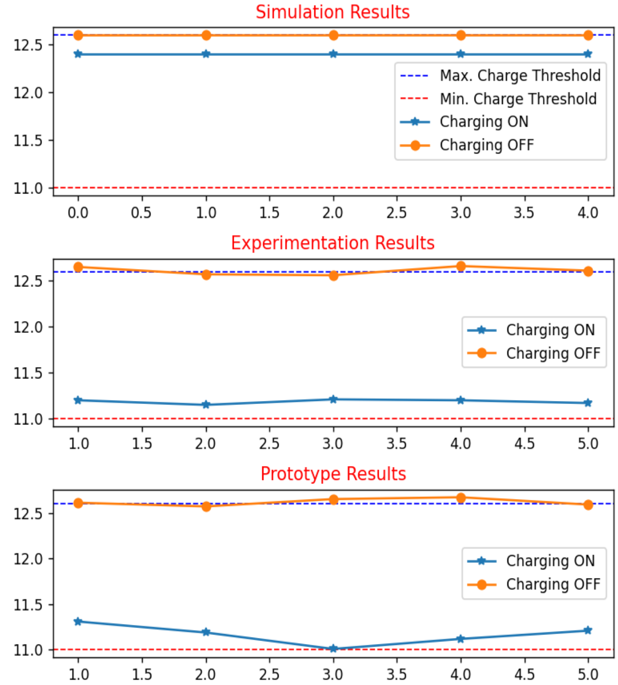
A. Control Switching

The sample collected for each terminal voltage measurement and charger state in methodology section II, sub-section B, C and D is presented in Table III. The stability of the switching mechanism is best computed against the sample observed.

Table-III: Comparison of Validation Results of the Proposed 12-volt Battery Charge Controller

Sample	Simulation		Experimentation		Prototype	
	ON	OFF	ON	OFF	ON	OFF
1	12.4	12.6	11.20	12.65	11.31	12.61
2	12.4	12.6	11.15	12.57	11.19	12.57
3	12.4	12.6	11.21	12.56	11.01	12.65
4	12.4	12.6	11.20	12.64	11.12	12.67
5	12.4	12.6	11.17	12.61	11.21	12.59

Figure 14 shows the data sample for each of tests bounded for upper and lower limit. It can be highlighted periodically that the charge controller performance is within the control limit. It mainly protects the battery from over-discharge.

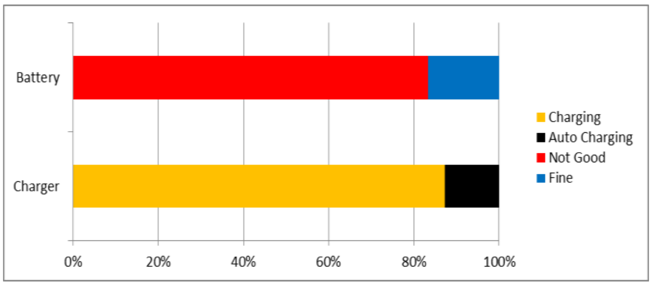


[Fig.14: Comparison of Validation Results Against the Max. and min. Threshold of the Battery]

The results prove that proposed 12 volts charge controller is operating within the control limit of maximum and minimum charge threshold of the battery.

B. Overall Performance

To fully understand the performance of the prototype, we compare the battery against the performance of the automatic charger. From the specifications, battery state performance versus charger performance is indicated using the bar chart shown in Figure 15.

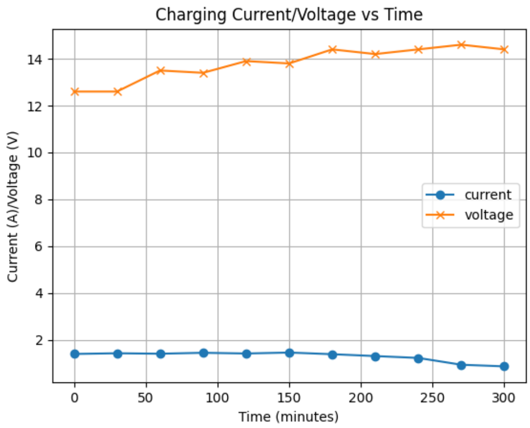


[Fig.15: Performance Comparison Between the Battery and the Charge Controller]

The overall performance of the charger is operating within the fine state of the battery. That is, the charger is capable of monitoring the battery SoC and perform charging by switching ON/OFF the charger respective to the specification of the 12 volts lead-acid battery.

C. Battery Charging Performance

In this section, we present the charging current and voltage of the proposed charge controller. The charging performance of one charging cycle is calculated based on equation 1 given in section II. The resulting voltage, current and time taken of the prototype to fully charged a 12-volts lead-acid battery of capacity 7Ah is given in Figure 16.



[Fig.16: Charging Current and Voltage for one Charging Cycle]

Lead-acid batteries are used across various application modes, each requiring different optimal states of charge (SoC) and specific charging regimens tailored to the particular usage, yet the common goal of all charging strategies remains to restore the battery to an optimal charged state suited to its application, thereby maintaining full functionality and extending its service life [9].

IV. CONCLUSION

The automatic 12-volt battery charge controller plays a crucial role in protecting 12V lead-acid batteries by ensuring proper monitoring of the state of charge (SoC) and maintaining overall battery health. This simple and cost-effective design effectively manages the charging process, automatically supplying current to the battery when the voltage drops below 11.2 volts and disconnecting the charger once the battery reaches its maximum voltage of 12.6 volts. Experimental validation confirmed that the controller maintains the battery within its optimal operational range, thereby enhancing battery lifespan and ensuring reliable support for connected electronic devices. Proper battery management reduces internal chemical degradation, ultimately improving energy storage performance over time. To verify the design, three different approaches were employed, and the results demonstrate that the charge controller operates safely within the defined voltage limits. The system provides a reliable and low-cost solution for protecting batteries during charging and discharging cycles. Future work could extend the design to other applications requiring battery protection and management, offering a convenient and scalable model for energy storage systems.

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DECLARATION STATEMENT

After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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- **Ethical Approval and Consent to Participate:** The content of this article does not necessitate ethical approval or consent to participate with supporting documentation.
- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Authors Contributions:** The authorship of this article is contributed equally to all participating individuals.

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