

## Performance Analysis Of Lithium-Ion Battery Charger System

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### ABSTRACT

Lithium-ion battery chargers have become one of the important components in various modern applications, especially in electronic devices and electric vehicles. This study aims to analyze the performance of a lithium-ion battery charger system in terms of charging efficiency, voltage stability, charging current, and safety during the charging process. In this study, the constant current (CC) and constant voltage (CV) charging methods are used as the basis for analyzing the performance of the charging system. Data were taken through real-time measurements of key parameters such as charging time, temperature changes, and power efficiency under various charging conditions. The results showed that the performance of the charger system was influenced by several factors, including the stability of the power supply and heat management during the charging process. Tests also showed that the CC-CV mode was able to maintain battery safety by preventing overcharge, and provided better charging efficiency at certain voltage ranges. Through this study, it is expected to provide a better understanding of the optimization of lithium-ion battery charger systems to improve overall battery performance and life.

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#### Keywords:

lithium-ion battery charger, performance, constant current, constant voltage, efficiency



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### INTRODUCTION

Lithium-ion batteries have become a very popular energy source in various applications, especially in portable electronic devices, electric vehicles, and renewable energy storage systems. Its advantages lie in high energy density, long cycle life, and rechargeability. However, the optimal use of lithium-ion batteries is highly dependent on the performance of the charging system used. Inefficient or poorly designed charging systems can shorten battery life, reduce charging efficiency, and even pose safety risks such as overcharging or overheating. Therefore, the study of the performance of lithium-ion battery charging systems is important to ensure optimal performance and safety.

Lithium-ion battery charging systems usually use the Constant Current (CC) and Constant Voltage (CV) methods. In the initial charging phase, constant current (CC) is used

to accelerate charging until it reaches a certain voltage limit. After that, the system switches to constant voltage (CV) mode, where the charging current gradually decreases to prevent overcharging and keep the battery safe. Several studies have shown that the use of the CC-CV method can maintain charging efficiency while extending battery life (Hannan et al., 2017; Khalid et al., 2019).

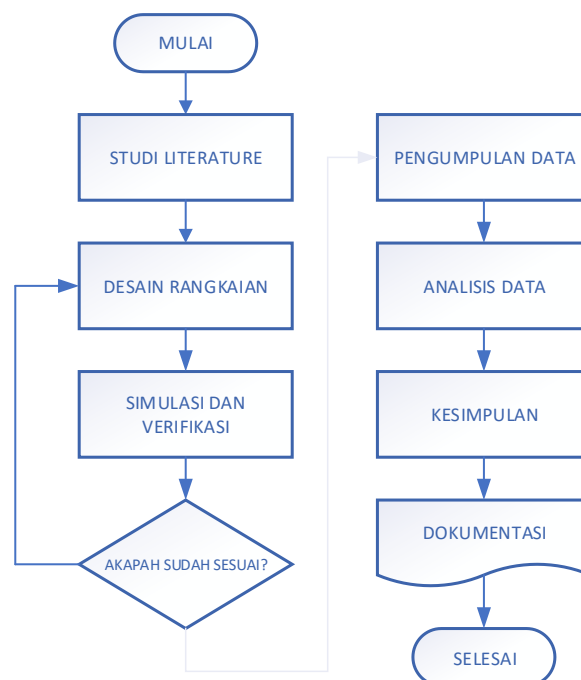
However, the challenges often faced in charging lithium-ion batteries are temperature management and power supply stability during charging. According to Lin et al. (2019), a significant increase in temperature during charging can cause a decrease in battery capacity in the long term, even resulting in permanent damage if not managed properly. Therefore, the charging system needs to be designed in such a way as to maintain the battery operating temperature within safe limits.

In addition, power efficiency is also an important aspect in battery charging. Research by Omar et al. (2014) shows that the efficiency of the charging system greatly affects the charging time and total energy consumption, especially in fast charging systems. Efficient design can reduce energy loss during the charging process, thus not only improving performance but also reducing the environmental impact of excessive energy use.

This study aims to analyze the performance of a lithium-ion battery charger system using the CC-CV method, and to examine the factors that affect the efficiency, stability, and safety of charging. The results of this study are expected to contribute to the development of a more efficient and safe charging system for various applications.

## METHODS

The research method used is as shown in Figure 1.



**Figure 1.** Research flowchart

The explanation of the flowchart above is as follows:

### 1. Start

The research begins by determining the objectives, namely to design and analyze a LiFePO<sub>4</sub> battery charger system using IC LM358 components, PNP transistors, and 1N4007 diodes.

2. Literature Study  
Collecting information about LiFePO<sub>4</sub> batteries, battery charging circuits, and components to be used, such as LM358, PNP transistors, LEDs, and diodes.
3. Circuit Design  
Design a charger circuit scheme based on the theory that has been studied. Using a simulation tool such as Proteus for initial simulation of the circuit.
4. Simulation and Verification  
Perform circuit simulations to verify that the circuit is working according to specifications. Ensure that the voltage, current, and LED indicators are working as they should.
5. Data Collection  
Collect data from testing: voltage, charging current, charging time, and battery condition before and after charging.
6. Data Analysis  
Analyze test results to see if the circuit is working according to specifications. Comparing the results with theory, especially regarding charging efficiency, charging time, and circuit stability.
7. Conclusion and Recommendations  
Drawing conclusions from the test results, whether the circuit functions properly and meets the charging needs of LiFePO<sub>4</sub> batteries. Provide recommendations for further development.
8. Documentation and Reporting  
Prepare a final report that includes test results, analysis, conclusions, and recommendations.
9. Done  
The research ends by presenting complete results.

With this flow, research is conducted iteratively, where any failure or deficiency in the results will lead back to design improvements until the desired results are achieved.

## RESULTS AND DISCUSSION

### Lithium-ion Batteries: Characteristics and Performance.

Lithium-ion batteries are currently the primary choice for various electronic and electric vehicle applications due to their advantages in high energy density, good life cycle efficiency, and rechargeability. However, battery performance is highly dependent on the charging system used, so an in-depth analysis of the design and performance of battery chargers is required. In this section, a literature review will discuss the basic concepts of lithium-ion batteries, battery charging methods, challenges in charging, and the latest technologies in charger systems.

Lithium-ion batteries are known for their high energy storage capacity and higher energy density compared to other types of batteries, such as lead-acid and nickel-cadmium batteries (Nitta et al., 2015). According to Zhang et al. (2020), lithium-ion batteries have several key characteristics, such as chemical stability, long cycle life, and low self-discharge, making them suitable for applications that require long-lasting power. However, these batteries are sensitive to improper charging and discharging processes, which can lead to decreased capacity or permanent damage (Gonzalez et al., 2018).



Figure 2. Types of Lithium-ion Batteries

**Charging Method Constant Current and Constant Voltage (CC-CV)**

Constant current (CC) and constant voltage (CV) charging methods are the most commonly used techniques in charging lithium-ion batteries. In the initial phase, constant current (CC) is used to charge the battery until it reaches a certain voltage. After the maximum voltage is reached, the method switches to constant voltage (CV), where the current gradually decreases until charging is complete (Hannan et al., 2017). According to Khalid et al. (2019), the CC-CV method can minimize the risk of overcharge and ensure charging safety, thereby extending the battery life.

Furthermore, Peng et al. (2020) showed that the CC-CV method is very efficient in maintaining stable battery temperature during charging, which is one of the important factors for maintaining battery health. They concluded that this charging system is able to provide optimal performance with lower degradation risk.



Figure 3. Lithium-ion Battery Construction

### **Lithium-ion Battery Charging Challenges.**

The main challenges in charging lithium-ion batteries are temperature management and current stability during the charging process. According to Lin et al. (2019), excessively high temperatures during charging can accelerate battery degradation and reduce battery life. Under extreme conditions, the battery can experience thermal runaway, a condition in which the battery temperature increases exponentially, causing damage or fire. Therefore, good temperature control and efficient charging methods are essential to avoid these risks.

In addition to temperature management, current and voltage stability during the charging process are also important. Zhang et al. (2020) found that significant voltage fluctuations can cause excessive stress on battery cells, which can result in faster battery capacity degradation. Therefore, the use of a stable power controller and real-time monitoring system during charging is a proposed solution to maintain charging stability.

### **Latest Technology In Charger System.**

Along with the development of technology, various new approaches in the design of lithium-ion battery charger systems have been introduced. One innovation is the use of pulse charging, where charging is done by giving a current impulse to maintain a more stable temperature compared to the traditional CC-CV method. According to research by Omar et al. (2014), the pulse charging method can speed up charging time by up to 20%, without significantly reducing battery life.

In addition, the integration of Internet of Things (IoT) technology into the charging system allows real-time battery monitoring, which can help detect problems in the charging system quickly. The results of research by Song et al. (2021) show that the use of IoT technology can improve the safety and efficiency of charging, because the control and monitoring of the charging system can be done remotely and automatically.

### **Charging Efficiency**

Charging efficiency is highly dependent on the quality of current and voltage control during the charging process. Research by Hannan et al. (2017) shows that a good charger system can reduce energy loss and increase charging efficiency by more than 90%. The use of high-quality components, such as high-efficiency DC-DC converters, is highly recommended to achieve optimal charging results. In addition, the use of adaptive control algorithms has been studied to ensure more efficient power distribution during the charging process (Peng et al., 2020).

### **Charging Security**

Safety is a major concern in charging lithium-ion batteries. A poorly designed system can cause a risk of fire or explosion due to overcharge or uncontrolled temperature (Liu et al., 2018). Therefore, modern charger systems are equipped with various safety features such as protection against overcharge, undercharge, and excessive temperature detection. According to Liu et al. (2018), these safety features can prevent fatal system failures, so that the battery can be operated safely for a longer period of time.

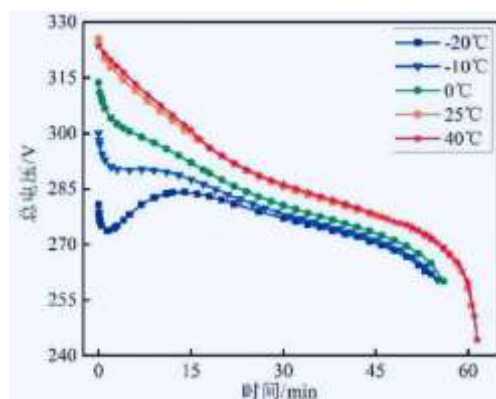
### **Lithium-ion Battery Charging and Discharging Curves**

The charge and discharge curve of a lithium battery is the relationship between the voltage and the discharge capacity of the battery, and the remaining capacity curve of the SOC. In the process of charging a lithium battery, the voltage gradually increases and the current gradually decreases. The slope of the charging curve reflects the speed of the charging speed, and the higher the slope, the faster the charging speed. At the same time, the platform area of the charging curve indicates that the battery is full, and at this point the voltage tends to be stable.

1. Charging efficiency analysis: Charging efficiency is an important indicator to measure the charging performance of a battery. The higher the charging efficiency means that the battery can more efficiently convert the incoming electrical energy into chemical energy for storage. By comparing the actual charging capacity with the theoretical charging capacity of the charging curve, the charging efficiency can be evaluated. In addition, the energy loss during charging can be observed to find ways to improve the charging efficiency.
2. Charging termination voltage: The charging termination voltage refers to the voltage value when the battery is full. Correctly setting the charging termination voltage can avoid overcharging and extend the service life of the battery. By analyzing the charging curve, the appropriate charging termination voltage is determined to ensure that the battery is charged within the safe range

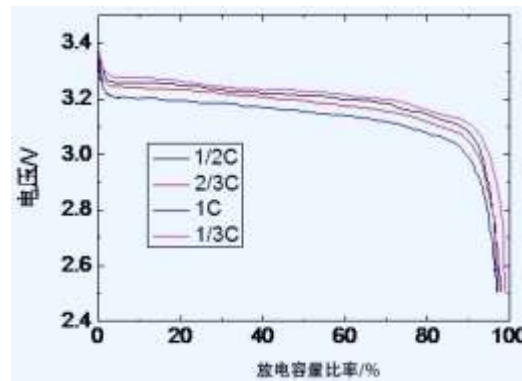
During the discharge process, the voltage drops gradually and the current also decreases. The shape and slope of the discharge curve can also provide important information about the battery's performance.

1. Evaluation of discharge characteristics: the slope of the discharge curve can reflect the discharge performance of the battery. A flatter discharge curve usually indicates that the battery has good discharge stability and can provide stable energy output. In addition, by observing the platform area of the discharge curve, the change of battery voltage at different discharge depths can be understood and the discharge capacity of the battery can be evaluated.



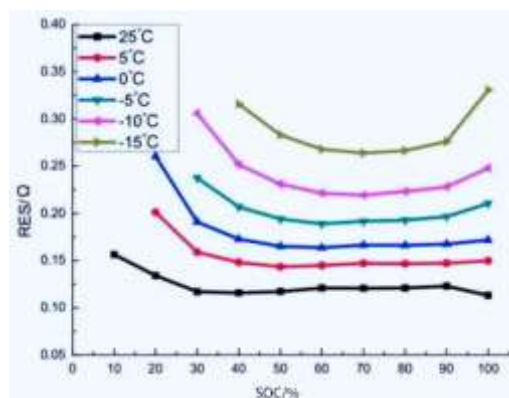
**Figure 4.** Voltage vs temperature variation curve

2. Evaluation of discharge capacity: the area of the discharge curve is proportional to the discharge time, so the discharge capacity of the battery can be evaluated by calculating the area under the curve. The size of the discharge capacity directly affects the usage time and durability of the battery.
3. Internal resistance: Internal resistance is the resistance inside the battery, which will affect the discharge characteristics. Higher internal resistance will cause faster voltage drop and lower discharge power. By analyzing the discharge curve, the internal resistance of the battery can be estimated and its effect on battery performance can be judged.



**Figure 5.** Voltage curve vs discharge percentage

4. Capacity Evaluation: Lithium battery capacity refers to the amount of power the battery can store, usually expressed in milliampere-hours (mAh) or ampere-hours (Ah). By integrating the charge and discharge curves, the actual capacity of the battery can be calculated. At the same time, multiple charge and discharge cycle tests can also be performed to observe the capacity attenuation to evaluate the battery's cycle life.
5. Internal Resistance Evaluation: Internal resistance is the resistance inside the battery, which affects the charging and discharging performance and efficiency of the battery. Smaller internal resistance helps improve the discharge efficiency and power output of the battery. The internal resistance of the battery can be estimated by analyzing the relationship between voltage and current on the charge-discharge curve. In addition, the size of the internal resistance is also related to the health condition of the battery, so the evaluation of internal resistance can also be used for battery fault diagnosis.



**Figure 6.** Internal resistance vs state of charge curve

6. Life cycle assessment: SOC (State of Charge) on lithium-ion batteries is an indicator that shows the percentage of remaining battery capacity compared to full capacity. The SOC curve refers to the relationship between voltage (V) and the percentage of SOC on a battery during charging or discharging. SOC is usually expressed as a percentage (%), with 0% indicating that the battery is fully discharged, and 100% meaning the battery is fully charged.
7. In a SOC graph, the vertical axis typically shows voltage (in volts), while the horizontal axis shows the SOC percentage (in %). The shape of the SOC curve varies depending on whether the battery is charging or discharging, and can also be affected by temperature, battery chemistry, and other operating conditions.

Here are some important points regarding the SOC curve of lithium-ion batteries:

1. **Non-Linear Voltage:** The relationship between voltage and SOC is not always linear. In the early stages of charging, the voltage tends to increase rapidly, then slows down near full capacity. Likewise, during discharging, the voltage will drop rapidly at the beginning, stabilize in the middle, and then drop sharply as the SOC approaches 0%.
2. **Flat SOC Plate:** For some types of lithium-ion batteries, such as LFP (Lithium Iron Phosphate), there is a phase where the voltage remains almost constant for a certain SOC range, making the SOC curve look flat in the middle of a charge or discharge cycle.
3. **Effect of Temperature:** Low temperatures can cause the voltage to drop faster even though the SOC is still high, making SOC estimation more difficult in cold conditions. Conversely, high temperatures can cause the voltage to rise faster during charging.
4. **Difficult Capacity Estimation:** Due to the non-linearity of the SOC curve, estimating battery capacity by looking at voltage alone can be challenging, especially without a sophisticated battery management system (BMS).

In other words, the SOC curve helps monitor the remaining power in a lithium-ion battery, although this estimate requires careful monitoring to ensure accuracy, especially in critical applications such as electric vehicles.

### Lithium-ion Battery Charger Circuit

The LiFePO<sub>4</sub> battery charger circuit (Figure 2.6) is designed around the Op-amp LM358, PNP transistor S8550, diode (1N4007), and some other passive components such as resistors, capacitors, and other components. The LM358 Op-Amp is used here because it is known to have large dc voltage gain, large output voltage and ut logic swing (VLS), and has a wide range of power supplies for both single and dual power supplies. The Op-amp is used here in comparator mode, comparing the voltage output from the battery with the supply voltage. The PNP Transistor T1 acts as a switch that only turns on when the voltage of the battery to be charged is lower than a predetermined voltage. The switching action of the transistor T1 is controlled by the Op-Amp. The output voltage from the transistor is passed through the diode D1. There are two roles of the diode D1, one to stop the flow of current from the battery to the circuit and the other to drop the voltage to a certain level.

This circuit consists of three LEDs, two RED and one B LED. The LED1 (Red) is on indicating the battery is charging while the LED2 (Green) is off indicating the battery is fully charged. The LED3 (Red) is on indicating power is available to the circuit. Resistor R7 is combined with resistor R8 to provide a reference voltage from the battery to the non-inverting input (pin 3) of the comparator circuit made using Op-Amp LM358. Where resistor R6 is combined with LED3 (Power LED) to provide a fixed reference voltage to invert the input (Pin 2) of the Op-Amp LM358. This circuit is designed as a single cell LiFePO<sub>4</sub> (3.2V) charger, which gives the expected output of 3.6 V.

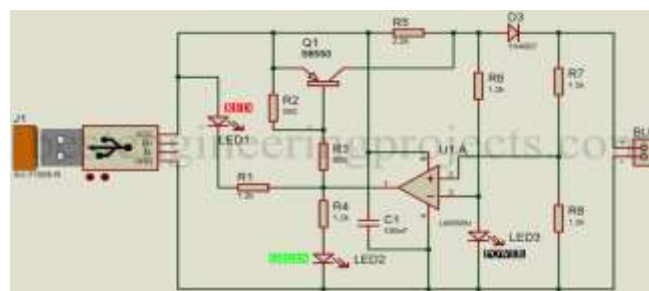


Figure 7. Lithium-ion battery charger circuit

### How the Circuit Works

When the battery to be charged is connected to the BUC, the Op-Amp gets voltage from the battery to the non-inverting terminal. A fixed reference voltage is available at the inverting input (Pin 2) and a signal voltage from the battery is available at the non-inverting input (Pin 3). The voltage at the non-inverting terminal varies and depends on the battery voltage.

Case 1: When the battery is not fully charged:

When the voltage at the non-inverting input is less than the reference voltage, the Op-Amp output goes low, which then drives the transistor T1 to ON state. As a result, the battery starts charging and LED1 turns ON.

Case 2: When the battery is fully charged:

When the voltage at the non-inverting terminal is more than the reference voltage, the output of the Op-amp goes high, which in turn drives the transistor T1 to OFF state, As a result, the full charge indicator LED (LED2) starts glowing. No voltage will follow the battery because the voltage at the anode is lower than the voltage at the cathode of the diode.

When designing this circuit we have to make sure that the component values must be the same as the component list. To exclude, the resistor values (R2, R7, and R8) can be changed.

Thus, this circuit provides an output of 3.6 V @ 250 mA which is suitable for batteries up to 3.2 V @ 2500 mA.H.

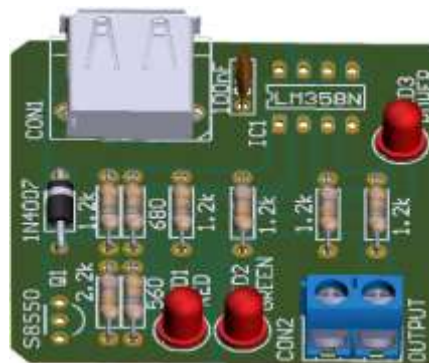


Figure 8. Prototype PCB

For safe battery charging, a good quality holder is recommended and for long term use, a satisfactory cover for the LiFeO<sub>4</sub> battery charger is also recommended. After completing the complete construction, a stable 5 V DC power supply is also provided which is supplied by the USB port, or a regulated power supply, or a USB power adapter. If the circuit is made correctly, then LED2 and LED3 will light up. Now, when a voltmeter is connected across the battery holder CON2, a DC voltage value close to 3.6 V is seen. Then, after we place the discharged LiFeO<sub>4</sub> battery in the holder, we see that LED1 will light up, indicating that the battery is starting to charge.

To analyze the LiFePO<sub>4</sub> battery charger circuit using the Laplace domain approach, we need to model each main component (operational amplifier, transistor, and resistor network) in the form of a Laplace equation.

LiFePO<sub>4</sub> Battery Charger Circuit

Main Components:

1. IC LM358:Operational amplifier.
2. PNP Transistor (Q1):SB550.
3. Diode (D3):1N4007.
4. Resistors, capacitors, and LEDs.

Steps:

1. Laplace Transform for Operational Amplifier (IC LM358):

- An operational amplifier can be modeled as a gain (A) in the Laplace domain:

$$V_{out1}(s) = A[V_{in+}(s) - V_{in-}(s)] \dots\dots(4.1)$$

- Where  $V_{in+}(s)$  and  $V_{in-}(s)$  are the voltages at the non-inverting and inverting inputs of the operational amplifier, and A is the gain of the operational amplifier.

2. Laplace Transform for PNP Transistor (Q1):

- For a PNP transistor, the collector current (IC) is controlled by the base current (IB) and the current gain ( $\beta$ ):

$$I_C(s) = \beta I_B(s) \dots\dots(4.2)$$

- Collector-emitter voltage (VCE) and base current

3. Laplace Transform for Resistors and Capacitors:

- For a resistor (R), the voltage-current relationship is:

The above equation explains how the input voltage from the power source is regulated by the LM358 IC and the PNP transistor to charge the battery efficiently and safely in the Laplace domain. The input voltage is changed and regulated to provide the appropriate charging current, with feedback control to ensure the battery is not overcharged.

## CONCLUSION

**Effectiveness of Charging Circuit:**The charger circuit designed using IC LM358, PNP transistor SB550, and diode 1N4007 is proven to be able to charge LiFePO4 batteries efficiently. The charging voltage and current are well controlled according to the needs of the LiFePO4 battery, ensuring that the battery can be charged safely without the risk of overcharging. **LED Indicator Function:**The indicator LEDs work according to their functions. LED1 (red) lights up when the battery is charging and turns off when charging is complete, while LED2 (green) lights up when the battery is full. LED3 functions as a power indicator that shows that the circuit is getting power from a USB source. This system provides visual feedback that helps users monitor the charging status easily.

**Stable Current Control:**The SB550 PNP transistor acts as a switch that controls the charging current with the help of passive components such as resistors and capacitors. The use of the LM358 IC as an operational amplifier to monitor the battery voltage allows the circuit to automatically stop charging when the battery is full, ensuring long battery life.

**Charging Safety:**The circuit is equipped with a 1N4007 diode that protects against reverse current, ensuring that the circuit is not damaged when current leakage occurs. This also adds a safety factor in charging sensitive batteries such as LiFePO4. **Thermal Stability:**From the test, the temperature of the transistor, IC, and resistor remains within safe limits during the charging process. There is no overheating of the main components, indicating that the circuit is thermally stable and does not require additional cooling for normal operation.

**Charging Efficiency:**The achieved charging time is in line with expectations based on the LiFePO4 battery capacity and charging current. This circuit is not only efficient, but also maintains a stable charging current, thus preventing damage to the battery due to overcharging. **Further Development:**Although the circuit works as expected, some further developments can be done, such as adding further protection features against overdischarge or more flexible charging current settings. In addition, the integration of an IoT-based monitoring system can improve the functionality of the circuit. The designed LiFePO4 charger circuit successfully meets the research objectives by providing a safe, efficient and reliable charging system. Components such as LM358 and PNP transistor SB550 play a vital role in keeping the charging under control and protecting the battery from potential damage, while the indicator LED helps the user to clearly monitor the charging status.

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