Volume 12. No 2, May 2025
e-ISSN 2527-9572 / p-ISSN 2354-8924

Battery Cell Charging Behavior Analysis Using Constant Current and Constant Voltage Methods

Anna Cyntia PDY
Electrical Engineering Department, Andalas University,
Limau Manis, Pauh, Padang City,
West Sumatra 25175 Indonesia
annacyntia99@gmail.com

***Muhammad Imran Hamid**
Electrical Engineering Department, Andalas University,
Limau Manis, Pauh, Padang City,
West Sumatra 25175 Indonesia
imran@eng.unand.ac.id

Ayu Elsa Afriyanti
Electrical Engineering Deparment, Andalas University,
Limau Manis, Pauh, Padang City,
West Sumatra 25175 Indonesia
ayuelsa240494@gmail.com

Abstract – This study presents a detailed simulation of lithium-ion battery charging using the Constant Current/Constant Voltage (CC/CV) method. MATLAB is used in conjunction with certain mathematical algorithms, such as numerical integration and curve fitting, to simulate the charging process, utilizing parameters including a constant current of 1C and a voltage threshold of 4.2V. The simulation analyzes the charging efficiency, usable capacity, and internal impedance variation under various current levels and voltage thresholds. The CC/CV method is compared with findings from other studies that also used the CC/CV charging technique, highlighting similarities and differences in the results. This analysis reveals that while CC/CV is effective in balancing charging speed and safety, minimizing the risk of overcharging, some studies note challenges related to temperature variations and their impact on battery performance. While CC/CV offers optimal management for lithium-ion battery charging, future research can focus on investigating the long-term effects of CC/CV on battery life under various environmental conditions, considering the findings and methodologies of similar studies.

Keywords: Battery charging, Constant Current/Constant Voltage, Efficiency, Overcharging, Lithium-Ion Battery

I. Introduction

In the modern era with rapid technological developments, the need for efficient and environmentally friendly energy sources is increasingly pressing. Lithium-ion batteries have become a key component in energy storage, widely used in everything from electronic devices to electric vehicles[1][2]. One of the main challenges in battery utilization is understanding the charging and discharging behavior, which greatly affects the longevity and performance of the battery[3][4]. Optimizing the charging process is key to maintaining battery life, especially considering the increasing dependence on battery-powered devices in everyday life.

The battery charging process is greatly influenced by various factors, such as the type of battery, its capacity, ambient temperature, and the charging method used[5]. Ambient temperature, for example, affects how quickly the battery charges and how efficiently the power can be held[6][7]. Therefore, understanding these factors is essential to maximize the life and performance of battery cells. Various studies have been conducted previously in charging strategies. In [8] this study conducted optimal charging based on the limit charging current curve. The curve is obtained through analysis of temperature variations and polarization voltage during the charging process. With the application carried out, charging time can be shortened and charging capacity can be increased. In [9] a constant polarization-based fuzzy control method is used to improve charging efficiency by adjusting the charging current based on the state of charge (SOC) of the battery. This method speeds up the charging time without any obvious increase in temperature. Previous studies have shown that these studies tend to focus on one or two parameters, thus not providing a complete picture of the impact of the charging process on battery performance.

Therefore, this study monitors various parameters such as SOC, terminal voltage, current, and power during the charging process. The method used is the Constant Current/Constant Voltage (CC/CV) method using an electrochemical model and an equivalent circuit model. This method is one of the most widely used methods for charging lithium-ion batteries[10][11]. This method consists of two phases: a constant current phase, where the battery is charged with a fixed current until it reaches its maximum voltage, and a constant voltage phase, where the voltage remains stable and the current decreases until the battery is full. The advantages of this method lie in controlling the internal resistance of the battery and preventing overheating, which makes it popular in a variety of applications, from small devices to electric vehicles.

This study aims to conduct a comprehensive simulation using MATLAB software to analyze the charging behavior of lithium-ion batteries using the CC/CV method. The simulation will monitor and analyze the changes in SOC, terminal voltage, current, and power during charging, to provide a better understanding of how the interaction between these parameters affects battery performance and lifetime. Therefore, this study develops a comprehensive simulation model, which is expected to provide practical guidance in optimizing the battery charging process, especially in electric vehicles and renewable energy storage applications.

II. RESEARCH METHOD

A. Battery Simulation Model

This study simulates the charging of a lithium-ion battery using an equivalent circuit model (ECM)[12] to analyze the electrochemical behavior of the battery in Figure 1. ECM represents a Lithium-ion battery as a combination of ideal electrical components, such as resistors, capacitors, and voltage sources [13]. This model allows for in-depth analysis of the behavior of a Lithium-ion battery under various operating conditions. The model includes three main components: (1) internal ohmic resistance (Rs), (2) a parallel resistor-capacitor (RC) network consisting of a polarization resistance (Rp) and a polarization capacitance (Cp) to simulate the transient response, and (3) an open-circuit voltage (VOC) that depends on the state of charge (SoC). The model parameters are obtained from experimental data on NMC 18650-type battery cells.

In the equivalent circuit, Rs, Rp, and Cp in this model are functions of temperature and SoC. The model assumes that Rs, Rp, and Cp are quasi-stationary over short periods of time, since the changes in SoC and temperature over time are minimal, making them constant during identification for real-time applications. The mathematical basis of this model is based on Kirchhoff's laws, which allow terminal voltage (v_b) and other variables such as current (i_b) to be expressed through differential equations. These equations describe the voltage drop across the RC network and other internal parameters of the battery during charging and discharging.

Using Kirchhoff's laws, the dynamics of this circuit can be expressed as follows:

$$v_b(t) = v_{oc}\big(h(t)\big) - R_s i_b(t) - v_c(t) \qquad (1)$$

$$\frac{dv_c(t)}{dt} = -\frac{1}{C_p R_p} v_c(t) + \frac{1}{C_p} i_b(t) \qquad (2)$$

Where $v_b(t)$ and $i_b(t)$ are the terminal voltage and current, respectively, and $v_b(t)$ is the voltage across the RC network, which cannot be measured directly[14].

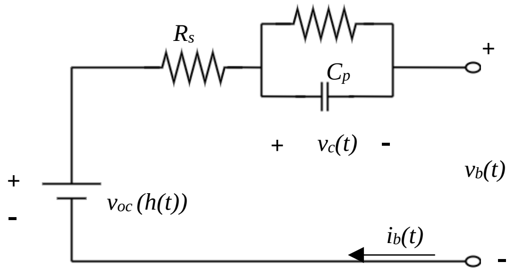

Figure 1. Equivalent circuit model of a lithium-ion battery[14]

B. Constant Current-Constant Voltage (CC-CV) Charging Method

This study used the CC-CV charging method, one of the most reliable techniques to ensure safe and efficient battery charging. In the first stage, a constant current (CC) is applied until a maximum voltage of 4.2V is reached. After that, a constant voltage (CV) mode is initiated while the current decreases. The voltage is maintained at the maximum condition, while the current decreases, preventing overcharging and ensuring the battery reaches its full capacity safely. The effectiveness of the CC-CV method is evaluated through a charging graph, which plots the voltage and current against time, showing how the current decreases as the SoC approaches full capacity in Figure 2.

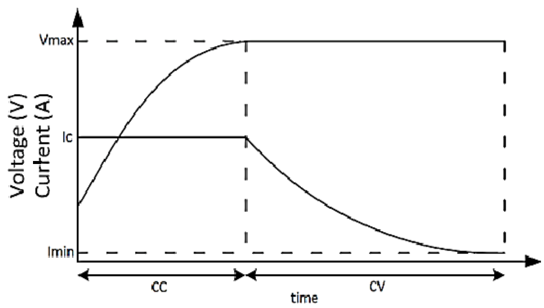

Figure 2. CC-CV method filling curve[15]

The figure 2 above shows a charging graph that illustrates the safe and efficient transition from constant current to constant voltage charging, designed to prevent overcharging and ensure the battery reaches its maximum capacity without damage.

C. Simulation Setup

The simulations were performed using MATLAB to model the battery charging process. Numerical algorithms solve the system of differential equations governing the electrochemical phenomena of the battery. Simulations were run on an NMC 18650 lithium-ion battery cell, with parameters such as nominal capacity, internal resistance, and open-circuit voltage obtained from experimental data. The main simulation parameters included a charging current of 1C during the CC phase, followed by a voltage of 4.2V during the CV phase. The maximum operating temperature was limited to 45°C to examine its effect on performance. The simulations spanned a total time of 10,001 seconds, starting with an initial SoC of 50%, a maximum voltage of 4.15V, and a CC charging current set at 9A.

D. Data Processing and Visualization

Lithium-ion battery charging simulation adopts a loop-based approach to repeat the charging process. At each iteration, key parameters such as State of Charge (SoC), terminal voltage, and current are updated based on the current state of the battery. These updates are done systematically to ensure that each step accurately reflects the battery state.

During the simulation, several state variables are also updated and stored. These include the current from the RC resistor, which is used to account for the impact of internal resistance on charging, as well as the hysteresis voltage, which affects the charging and discharging characteristics of the battery. Updating these variables allows for a deeper analysis of how the battery conditions function during the charging cycle.

After the charging process is complete, the simulation results are presented through several subplots. These subplots depict the relationship between SoC, terminal voltage, current, and power over time, providing a clear picture of the battery charging dynamics. By displaying these data simultaneously, researchers can easily identify patterns and trends that emerge during the charging cycle.

Additionally, additional graphs show the changes in current and power simultaneously. These visualizations provide further insight into the dynamic behavior of lithium-ion batteries during the Constant Current (CC) and Constant Voltage (CV) phases of the charging process. By understanding the interactions between current, power, and SoC, researchers can optimize charging strategies to improve battery efficiency and longevity.

This clear and systematic visualization not only helps in data analysis but also supports decision-making in designing and implementing better battery charging methods.

III. RESULTS AND DISCUSSION

The following are the results and analysis of a lithium-ion battery charging simulation using the Constant Current/Constant Voltage (CC/CV) method that illustrates how the battery's State of Charge (SOC) changes over time during the charging process. The simulation results contain the dynamics of battery charging in two main phases of constant current and constant voltage and show how the battery reaches its total capacity safely and efficiently. Further analysis of these results will help understand the influence of the parameters used in the model on battery charging performance.

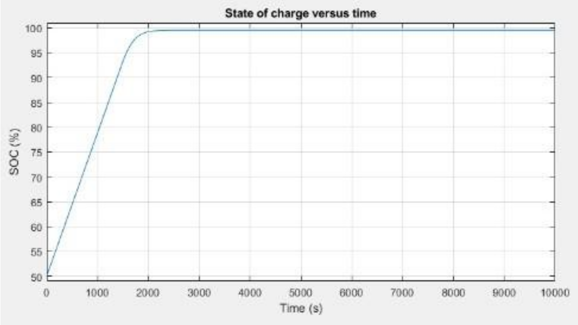

Figure 3. SoC versus time graph

In the initial charging phase, the battery's State of Charge (SOC) increases rapidly from 50% to nearly 100%, as shown in Figure 3, which shows that the battery is charged with a constant current (CC) of 9 A. Since the charging current remains constant in this phase, the SOC increases almost linearly with time. After about 2000 seconds, the rate of increase in SOC begins to slow down, indicating a transition to the constant voltage (CV) charging phase, where the battery terminal voltage has reached the maximum set voltage of 4.15 V, and the charging current begins to decrease to keep the voltage constant. For the remaining simulation time of up to 10000 seconds, the SOC remains stable at nearly 100%, indicating that the battery is fully charged and charging continues in constant voltage mode with a tiny current. This graph illustrates the typical CC/CV charging characteristics for lithium-ion batteries, where the constant current phase increases the SOC rapidly, followed by the constant voltage phase that charges the battery safely to total capacity without exceeding the specified voltage limit. Based on the results of the State of Charge (SOC) analysis against time, it can be seen that the SOC increases significantly in the early stages of charging with constant current (CC) before reaching a constant voltage condition (CV), next for the "Terminal voltage versus time" graph where the battery terminal voltage changes during the charging process.

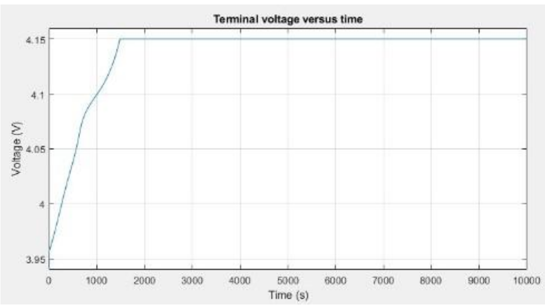

Figure 4. Terminal voltage versus time graph

In Figure 4, the Terminal voltage versus time graph shows that at the beginning of charging, the battery terminal voltage increases rapidly from about 3.95 V. This increase occurs during the constant current (CC) phase, where the current remains at 9 A. The terminal voltage increases as the battery absorbs energy and as it approaches 4.15 V (the maximum allowable voltage), the rate of voltage increase begins to slow down. This indicates the transition from the constant current (CC) charging phase to the constant voltage (CV) phase.

After about 1500 seconds, the terminal voltage reaches 4.15 V, the upper voltage limit for charging. At this point, the program decreases the charging current to keep the terminal voltage constant at 4.15 V. The graph shows that after this transition, the voltage remains stable at 4.15 V for the remainder of the charging duration, while the current decreases slowly until the charge is nearly complete.

This analysis shows typical CC/CV charging characteristics, where the battery terminal voltage increases rapidly during constant current charging until it reaches the maximum voltage limit. After that, the charging system switches to constant voltage mode, where the current is gradually reduced to maintain the voltage at a safe level, avoid overcharging, and protect the battery. These results are essential for understanding how battery voltage should be managed during charging to maintain the performance and safety of lithium-ion batteries.

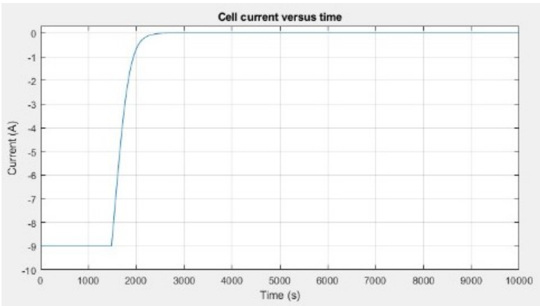

Figure 5. Cell current versus time graph

Next, in Figure 5, the Cell current versus time graph shows how the battery charging current changes during the CC/CV charging process. At the beginning of charging, the current is around -9 A, indicating the constant current (CC) phase, where the current is kept at a constant value to charge the battery quickly. The negative sign on the current indicates the direction of current flow into the battery during the charging process. The charging current remains constant at -9 A until around 1500 seconds, reflecting that the battery is being charged consistently at this stage.

When the terminal voltage reaches the maximum limit of 4.15 V (as analyzed in the voltage graph), the current graph shows that the current begins to decrease exponentially. This decrease marks the transition to the constant voltage (CV) phase, where the charging current is gradually reduced to maintain the voltage at a safe maximum level. The current decreases toward zero over time, indicating that the battery is almost fully charged and only requires a small current to maintain a constant voltage without the risk of overcharging.

This graph illustrates the CC/CV charging strategy, where a constant current is used to charge the battery quickly until the maximum voltage is reached. This is followed by a decrease in current to maintain a constant voltage and ensure safe and efficient charging. This analysis is essential to understand how the charging current is regulated during the lithium-ion battery charging process to maximize efficiency and extend the battery cycle life.

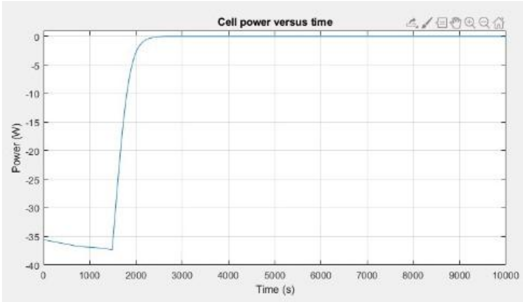

Figure 6. Cell power versus time graph

The last parameter is power, where the Cell Power versus Time graph shown in Figure 6 shows the battery charging behavior. At the beginning of charging, the power absorbed by the battery cell is negative, around -35 W, reflecting that energy is accumulated in the battery. During this stage, the terminal voltage increases as the State of Charge (SOC) increases, but the power remains negative because the charging current is still relatively large. Over time, around 1000 to 3000 seconds, the graph shows a rapid increase in power to near zero. This indicates that the terminal voltage is almost reaching the maximum allowable limit, so the charging current is reduced to keep the voltage within safe limits, which causes the power absorbed by the battery to decrease drastically. At the final stage of charging, after 3000 seconds, the power absorbed by the battery cell is almost zero, indicating that the battery is almost complete and the charging current is getting smaller to maintain the maximum voltage. At this point, the charge is in the Constant Voltage (CV) phase, where very little energy enters the battery, indicating that the battery is almost fully charged.

Based on the battery charging process test using the Constant Current/Constant Voltage (CC/CV) method depicted in the four States of Charge, Terminal Voltage, Current, and Power graphs shows typical charging dynamics for lithium-ion batteries. The SOC increases rapidly in the early charging stages, reflecting the constant current (CC) phase where the battery is charged with a stable current of 9 A. The terminal voltage at the same time increases from around 3.95 V to a maximum of 4.15 V. When this maximum voltage is reached, the charge switches to the constant voltage (CV) phase, where the voltage is maintained at 4.15 V, while the charging current gradually decreases. This decrease in current occurs because the battery is approaching total capacity, which is also reflected in the power absorbed by the battery. In the final stages of charging, the power absorbed by the battery approaches zero, indicating that the battery is almost complete and only requires a small current to maintain a constant voltage. Overall, this CC/CV method enables fast and efficient battery charging in the initial stage, followed by safer and more controlled charging in the final stage, to avoid the risk of overcharging and ensure long battery life.

The results of this study indicate that the voltage versus time graph reaches a stable condition within 1500 seconds, while in the study referred to in the journal [16], a stable condition is reached after 3600 seconds. In addition, the current versus time graph in this study also reaches stability within 1500 seconds, while in the study [16], the current takes the same time as the voltage, which is 3600 seconds. Based on this comparison, it can be concluded that this study is able to achieve stability in each parameter in a shorter time than previous studies.

IV. Conclusion

In conclusion, the battery charging method using the Constant Current/Constant Voltage (CCCV) approach has proven effective in safely and efficiently charging lithium-ion batteries. The charging process begins with a constant current (CC), allowing for rapid charging until the terminal voltage reaches a predetermined maximum limit. Once this maximum voltage is achieved, the charging switches to a constant voltage (CV) mode, during which the current is gradually reduced to maintain a stable voltage. This method not only maximizes charging efficiency but also protects the battery from the risks of overcharging and overheating, ultimately extending battery life. Analysis from the simulation indicates that the CCCV method can optimally manage battery charging by balancing charging speed with operational safety, making it an ideal choice for various applications. The CCCV method holds significant potential for areas such as electric vehicles and renewable energy storage systems, where efficient and safe battery management is critical. Future research could explore advancements in charging techniques, particularly through the integration of battery management systems (BMS) to monitor and optimize real-time battery conditions, enhancing the effectiveness of the CCCV method even further.

V. Acknowledgments

The authors, thanks to Electrical Engineering Department, Andalas University in most cases, sponsor and facilitations support.

References

[1] X. D. X. Dqj, E. D. Q. G. Lzhq, Q. Ri, Z. Lpsolhv, W. Lw, and L. V Kljko, "A Timely Review of Lithium-ion Batteries in Electic Vehicles: Progress, FutureOpportunities, and Challenges," vol. 01015, 2021.

[2] D. N. T. How, M. A. Hannan, M. S. H. Lipu, K. S. M. Sahari, P. J. Ker, and K. M. Muttaqi, "State-of-Charge Estimation of Li-Ion Battery in Electric Vehicles: A Deep Neural Network Approach," *IEEE Trans. Ind. Appl.*, vol. 56, no. 5, pp. 5565–5574, 2020, doi: 10.1109/TIA.2020.3004294.

[3] R. He *et al.*, "Towards interactional management for power batteries of electric vehicles," *RSC Adv.*, vol. 13, no. 3, pp. 2036–2056, 2023, doi: 10.1039/d2ra06004c.

[4] D. Selvabharathi and N. Muruganantham, "Battery health and performance monitoring system: A closer look at state of health (SoH) assessment methods of a lead-acid battery," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 18, no. 1, pp. 261–267, 2019, doi: 10.11591/ijeecs.v18.i1.pp261-267.

[5] J. K. Thomas, H. R. Crasta, K. Kausthubha, C. Gowda, and A. Rao, "Battery monitoring system using machine learning," *J. Energy Storage*, vol. 40, no. December 2020, p. 102741, 2021, doi: 10.1016/j.est.2021.102741.

[6] S. Wang *et al.*, "Effects of Current and Ambient Temperature on Thermal Response of Lithium Ion Battery," *Batteries*, vol. 8, no. 11, 2022, doi: 10.3390/batteries8110203.

[7] Y. Cao, K. Wang, Z. Wang, J. Wang, Y. Yang, and X. Xu, "Utilization of liquid nitrogen as efficient inhibitor upon thermal runaway of 18650 lithium ion battery in open space," *Renew. Energy*, vol. 206, pp. 1097–1105, 2023, doi: https://doi.org/10.1016/j.renene.2023.02.117.

[8] Y. Gao, C. Zhang, Q. Liu, Y. Jiang, W. Ma, and Y. Mu, "An optimal charging strategy of lithium-ion batteries based on polarization and temperature rise," *IEEE Transp. Electrif. Conf. Expo, ITEC Asia-Pacific 2014 - Conf. Proc.*, no. 1, pp. 1–6, 2014, doi: 10.1109/ITEC-AP.2014.6941149.

[9] J. Jiang, C. Zhang, J. Wen, W. Zhang, and S. M. Sharkh, "An optimal charging method for li-ion batteries using a fuzzy-control approach based on polarization properties," *IEEE Trans. Veh. Technol.*, vol. 62, no. 7, pp. 3000–3009, 2013, doi: 10.1109/TVT.2013.2252214.

[10] A. Tomaszewska *et al.*, "Lithium-ion battery fast charging: A review," *eTransportation*, vol. 1, p. 100011, 2019, doi: 10.1016/j.etran.2019.100011.

[11] S. J. Thomson, P. Thomas, R. Anjali, and E. Rajan, "Design and Prototype Modelling of a CC/CV Electric Vehicle Battery Charging Circuit," *2018 Int. Conf. Circuits Syst. Digit. Enterp. Technol. ICCSDET 2018*, no. September, pp. 1–5, 2018, doi: 10.1109/ICCSDET.2018.8821071.

[12] T. Feng, L. Yang, X. Zhao, H. Zhang, and J. Qiang, "Online identification of lithium-ion battery parameters based on an improved equivalent-circuit model and its implementation on battery state-of-power prediction," *J. Power Sources*, vol. 281, pp. 192–203, 2015, doi: 10.1016/j.jpowsour.2015.01.154.

[13] M. Auch, T. Kuthada, S. Giese, and A. Wagner, "Influence of Lithium-Ion-Battery Equivalent Circuit Model Parameter Dependencies and Architectures on the Predicted Heat Generation in Real-Life Drive Cycles," *Batteries*, vol. 9, no. 5, 2023, doi: 10.3390/batteries9050274.

[14] D. Mu, J. Jiang, and C. Zhang, "Online semiparametric identification of lithium-ion batteries using the wavelet-based partially linear battery model," *Energies*, vol. 6, no. 5, pp. 2583–2604, 2013, doi:

10.3390/en6052583.
[15] M. I. Akbar, M. Z. Efendi, and S. D. Nugraha, "SEPIC Converter for Lead Acid Battery Charger Using Fuzzy Logic type-2 Controller," *JAREE (Journal Adv. Res. Electr. Eng.*, vol. 6, no. 1, pp. 36–41, 2022, doi: 10.12962/jaree.v6i1.240.
[16] B. Charging, "Wide-Load-Range Double-T Resonant Converter for CC / CV," 2024.