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ANALYSIS OF PERFORMANCE CHARACTERISTICS AND EFFICIENCY OF ELECTRIC CAR BATTERY CHARGING USING THE METHOD (CC-CV)

Muhammad Hanafi Sahar Lubis[1]
Arnawan Hasibuan[1*]
Dedi Fariadi[1]
Dahlan Abdullah[2]
Fakhruddin Ahmad Nasution[1]
Misbahul Jannah[1]
Abdullah A. Z[3]

[1]Program Studi Teknik Elektro, Fakultas Teknik, Universitas Malikussaleh
[2]Program Studi Sistem Informasi, Fakultas Teknik, Universitas Malikussaleh
Jl. Kampus Unimal Bukit Indah, Muara Satu, Kota Lhokseumawe 24355, INDONESIA

[3]Faculty of Electrical Engineering Technology, Universiti Malaysia Perlis
Kampus Alam UniMAP, Pauh Putra, Arau, Perlis 02600, MALAYSIA

Abstract

The growth of electric vehicles (EVs) continues to increase in line with the global awareness of the importance of using environmentally friendly energy. One of the main components in an EV system is the battery, which requires an efficient and safe charging system. The Constant Current–Constant Voltage (CC-CV) charging method is one of the most commonly used approaches, as it maintains stable current and voltage during the charging process. This study aims to design a battery charging system simulation for electric vehicles using the CC-CV method, analyze the charging performance characteristics, and evaluate its efficiency. The research method used is simulation with MATLAB/Simulink software. The research stages include literature review, problem identification, circuit simulation design, simulation implementation, and result analysis. A PI Controller is employed to precisely regulate current and voltage, along with State of Charge (SoC) and voltage sensors to monitor the battery condition in real-time. Simulation results show that the system is capable of automatically transitioning between Constant Current (CC) and Constant Voltage (CV) modes responsively and stably. In CC mode, charging occurs rapidly with constant current, while in CV mode, voltage is kept stable and current gradually decreases. The achieved charging indicating that the CC-CV method enables a fast, safe, and efficient charging process while minimizing the risks of overcharging and overvoltage.

Keywords:
Electric vehicle; battery charging; CC-CV; MATLAB/simulink; charging efficiency.

Abstrak

Pertumbuhan kendaraan listrik (*electric vehicle*/EV) terus meningkat seiring dengan kesadaran global terhadap pentingnya penggunaan energi ramah lingkungan. Salah satu komponen utama dalam sistem kendaraan listrik adalah baterai, yang memerlukan sistem pengisian daya yang efisien dan aman. Metode pengisian *Constant Current–Constant Voltage* (CC-CV) merupakan salah satu pendekatan yang paling umum digunakan karena mampu menjaga kestabilan arus dan tegangan selama proses pengisian. Penelitian ini bertujuan untuk merancang simulasi sistem pengisian daya baterai kendaraan listrik menggunakan metode CC CV, menganalisis karakteristik performa pengisian, serta mengevaluasi efisiensinya. Metode penelitian yang digunakan adalah simulasi menggunakan perangkat lunak MATLAB/*Simulink*. Tahapan penelitian meliputi studi literatur, identifikasi masalah, perancangan rangkaian simulasi, pelaksanaan simulasi, serta analisis hasil simulasi. Dalam perancangannya, digunakan PI *Controller* untuk mengatur arus dan tegangan secara presisi, serta sensor *State of Charge* (SoC) dan sensor tegangan untuk memantau kondisi baterai secara real-time. Hasil simulasi menunjukkan bahwa sistem mampu melakukan transisi otomatis antara mode *Constant Current* (CC) dan *Constant Voltage* (CV) secara responsif dan stabil. Pada mode CC, pengisian berjalan cepat dengan arus konstan, sedangkan pada mode CV, tegangan dijaga tetap dan arus menurun secara bertahap. Efisiensi

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pengisian daya yang dicapai menunjukkan bahwa metode CC-CV mampu memberikan proses pengisian yang cepat, aman, dan efisien, serta meminimalkan risiko *overcharge* dan *overvoltage*). `

Kata Kunci:
Kendaraan listrik; pengisian baterai; CC-CV; MATLAB/simulink; seisiensi pengisian.

***Corresponding author:**
Arnawan Hasibuan, Program Studi Teknik Elektro, Fakultas Teknik, Universitas Malikussaleh.
Jl. Kampus Unimal Bukit Indah, Muara Satu, Kota Lhokseumawe 24355, INDONESIA
Email: arnawan@unimal.ac.id

1. INTRODUCTION

In recent years, the transportation sector has undergone significant changes in an effort to reduce pollution and address limited fuel availability by shifting to battery-powered vehicles) (A. et al., 2024). One mode of transportation that has begun to adopt battery technology is the electric car (Abdul Aziz et al., 2021). From the 19th to the early 20th century, to reduce pollution levels in metropolitan areas, restrictions on the use of gasoline-powered vehicles were implemented, leading to the introduction of electric vehicles as a smarter alternative (Devi Anjani et al., 2024). These restrictive policies have driven the growth of the electric vehicle market, with many countries providing incentives to encourage the purchase of hybrid and battery-powered vehicles (Hasibuan et al., 2022).

The process of charging electric vehicles is generally carried out in two stages, namely constant current charging (Constant Current/CC) and constant voltage charging (Constant Voltage/CV) (Hasibuan et al., 2022). In the initial stage, the charger operates in CC mode, where the battery is charged with a fixed current so that the battery voltage gradually increases. Once the battery voltage reaches a predetermined maximum limit, the system switches to CV mode, which maintains a fixed voltage while the charging current gradually decreases (Hasibuan et al., 2021). Charging is declared complete when the battery current reaches a certain threshold value (Hasibuan & Sartika Tambunan, 2021).

Previous research explains that charging using the constant current (CC) method can indeed speed up charging time, but has the risk of causing excessive temperature increases andovercharge, which can damage the battery (Tanjung et al., 2022). On the other hand, the constant voltage (CV) method offers safer charging because the voltage is controlled stably, but the process is slower. Therefore, the CC-CV method is the most optimal choice because it combines speed and safety in the battery charging process (Rika Widianita, 2023).

In this method, the charging process begins by applying a constant current (CC) to accelerate charging until the battery voltage reaches a predetermined maximum limit (Syururi et al., 2022). Afterward, charging continues while maintaining a constant voltage (CV) until the charging current decreases to the specified limit.cut-offThe combination of these two stages allows for a fast charging process while minimizing the risk of overcharging and overheating, which can damage the battery (Ramadhan et al., 2022).

During the battery charging process, the charging voltage must be controlled to maintain a stable value at a predetermined value. In this study, a battery charging system was designed using a DC converter.buck converteras a voltage regulator (Mardatillah & Prayudha.S, 2024). To ensure the converter's output voltage remains constant and responsive to changes in load and transient conditions, a Proportional-Integral (PI) control method is applied, optimized according to system parameters (Mauriraya, 2022). This PI control functions as a feedback system that maintains current and voltage stability during the charging process. Previous research also explains that to maintain current and voltage stability at optimal points during the charging process, the application of PI control is necessary.Proportional–Integral–Derivative(PID) has been proven to provide effective performance (Károlyi et al., 2022).

Considering these various research findings, the application of the CC-CV method to electric vehicle battery charging systems is highly relevant, not only in terms of time efficiency but also in terms of its contribution to extending battery life and improving charging safety (Nasution et al., 2021).

2. LITERATURE REVIEW

2.1. Characteristics of Electric Car Batteries

The battery is a crucial component in an electric motor system, with various typeslithium ionwhich have unique characteristics. Optimal electric motor performance depends heavily on proper battery selection and management (Andriansyah, 2024).

To ensure optimal battery performance, several key parameters must be closely monitored, including voltage, current, temperature, specific gravity, and resistivity. These parameters form the basis for accurately analyzing battery capacity and condition (Pamungkas et al., 2021).

The implementation of a precise control and monitoring system is a fundamental requirement in battery management. This system must be able to monitor and regulate these parameters in real time to ensure the operational efficiency of electric motorcycles. Effective battery management not only improves vehicle performance but also extends battery life and optimizes energy consumption. The integration of a sophisticated battery management system enables electric motorcycles to become a more efficient and sustainable transportation solution (Nugraha et al., 2025).

The equation used in the characteristics of lithium-ion batteries is as follows:

1. Charging Efficiency (η)

$$\eta = \frac{Eoutput}{Einput} x100\% \quad (2.1)$$

Where,
η = efficiency (%)
Eoutput=the energy released from the battery during usage
Einput = the energy supplied to the battery during charging

2. Input Energy (E)

$$E = V\ x\ I\ x\ t \quad (2.2)$$

Where,
E = energy(Joule or Watt-sekon)
V = voltage (Volt)
I = current (Ampere)
t = time (Second)

3. Increase Rate(SoC)

$$\Delta SoC\ per\ second = \frac{SoC\ final - SoC\ initial}{\Delta(second)} \quad (2.3)$$

Where,
ΔSoC per second= change in State of Charge per second during the observation period, expressed in %/second
SoC_{final} = state of Charge at the end of the observation period (%).
$SoC_{initial}$ = State of Charge at the beginning of the observation period (%).
Δt (second) = the observation time interval, expressed in seconds.

4. Battery Charge

$$Q = I \times t \quad (2.4)$$

Dimana,
Q = electric charge (*Coulomb*)
I = current (*Ampere*)
T = time (detik)

5. Percentage of Full Capacity

$$SoC = \frac{Qstored}{Qmax} \times 100\% \quad (2.5)$$

Where,
Percentage/SoC = valued in percentage (%)
Q_{stored} = stored charged at present (Ah)
Q_{max} = full battery capacity (Ah)

2.2. *DC-DC Converter*

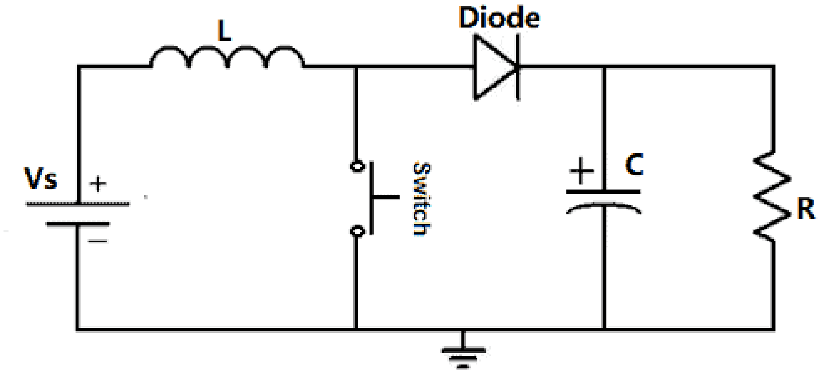

Figure1. SLD *DC-DC Buck Converter*

DC-DC converter, also known as a DC chopper, is an electronic circuit or electromechanical device that uses electronic switching (such as MOSFET, IGBT, andThyristor, among others) to convert a DC voltage source from one voltage level to a higher voltage level. A DC-DC converter is a high-frequency power conversion circuit that uses inductors and high-frequency switching. On the other hand, capacitors and transformers help smooth out switching noise from the regulated DC voltage (Singh et al., 2025).

DC-DC converters can be classified into two main categories based on their electrical isolation: isolated and non-isolated. In isolated converters, there is galvanic separation between the input and output sides through a transformer, allowing the grounding systems on both sides to operate independently. This feature is critical for equipment safety and protection, especially in applications requiring electrical isolation (Sukmasae & Akbar, 2024).

In contrast, non-isolated DC-DC converters have a grounding system directly connected between the input and output. While simpler in design and generally more economical, this type may be less suitable for applications requiring high levels of safety or strict electrical isolation. The choice of converter type must be tailored to the specific needs of the application (Sutikno & Satrian Purnama, 2020).

Table1. Specification*DC-DC Converter*

Specification	*DC-DC Converter*
Topology	*Isolated Full-bridge converter*
Maximum Power	50 kW
Frequency*switching*	50 -100 kHz
Duty cycle range	0.1 - 0.9

Table 1shows the value of each component in the system to produce output voltage.

2.3. *PID Controller*

The PI controller is used to maintain current and voltage stability during the charging process, reducing steady-state errors and accelerating system response. This block plays a crucial role in maintaining voltage stability in the CV phase and regulating current in the CC phase, ensuring efficient and safe charging (Zeng et al., 2023).

This controller functions to maintain the stability of current and voltage during the charging process, especially in maintaining the voltage during the charging phase.Constant Voltage and control the current in the phaseConstant Current. Adjusting these parameters ensures the charging system runs optimally, safely, and in accordance with the battery's characteristics (Ramadhan et al., 2022).

Simulations were conducted to analyze the performance of electric vehicle battery charging using the methodConstant Current - Constant Voltage (CC-CV)The model used consists of a MOSFET-based switching buck converter, two separate PI controllers (for current and voltage), and a logic block for selecting the charging mode based on the valueState of Charge (SoC)battery. The system sampling time value is set at 20 µs (2e-5 s), according to control requirementsswitching (Ramakrishnan et al., 2024).

3. RESEARCH METHOD

This study aims to analyze the efficiency of electric vehicle battery charging using the methodConstant Current–Constant Voltage(CC–CV) through simulation in MATLAB/Simulink. The research approach is experimental and simulation-based with systematic stages including literature study, model design, simulation implementation, and result analysis. The model design stage includes the development of a battery charging system consisting of two main modes: constant current (CC) and constant voltage (CV) charging. To support system performance, a PI controller (Proportional-Integral) to maintain current and voltage stability during the process. The system is designed using various Simulink blocks, such asDC Voltage Source, Battery, PWM Generator, and logic control using switches and PID Controller.

Primary data is obtained directly from simulation results in the form of graphs of voltage, current, andState of Charge(SoC) battery, while secondary data was collected from technical literature and scientific journals as a basis for modeling and parameterizing the system. Simulations were performed with discrete configurations to capture the transient response andsteady-stateduring the charging process. System performance evaluation is performed through analysis of current and voltage dynamics, transitions between CC and CV modes, and charging efficiency based on a comparison of input and output energy. This analysis method allows for a comprehensive assessment of the charging characteristics and effectiveness of the CC–CV method in the context of electric vehicles.

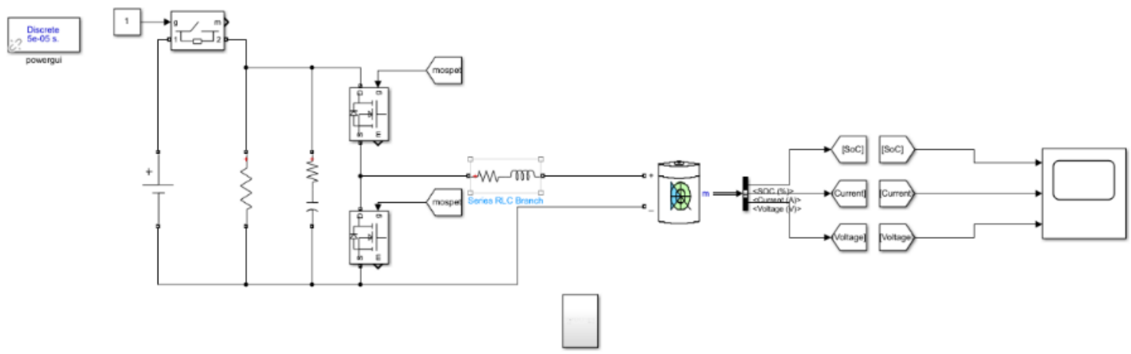

Figure2. Battery Charging Simulation CC CV Approach Without Controller

Simulations were conducted to analyze the performance of electric vehicle battery charging using the methodConstant Current - Constant Voltage (CC-CV) without operators and see the difference when using operators like PI. The model used consists of buck converterMOSFET-based switching, without using a control controller, as well as a logic block for selecting the charging mode based on the valueState of Charge(SoC) battery. The system sampling time value is set at 20 µs (2e-5 s), according to the switching control requirements

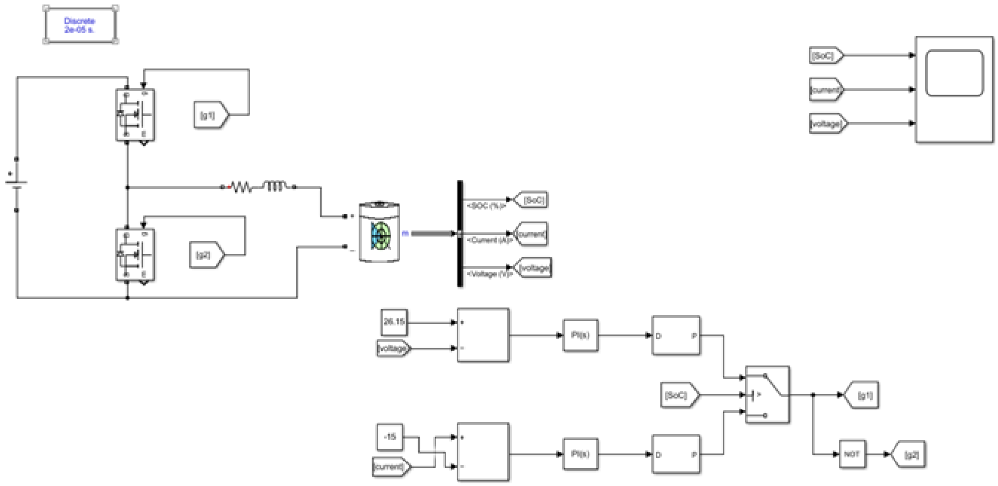

Figure 3. Battery Charging Simulation CC CV Approach with Controller

Simulations were conducted to analyze the performance of electric vehicle battery charging using the methodConstant Current - Constant Voltage (CC-CV)The model used consists of a MOSFET-based switching buck converter, two separate PI controllers (for current and voltage), and a logic block for selecting the charging mode based on the valueState of Charge (SoC)battery. The system sampling time value is set at 20 µs (2e-5 s), according to control requirements.switching.

4. RESULTS AND DISCUSSION

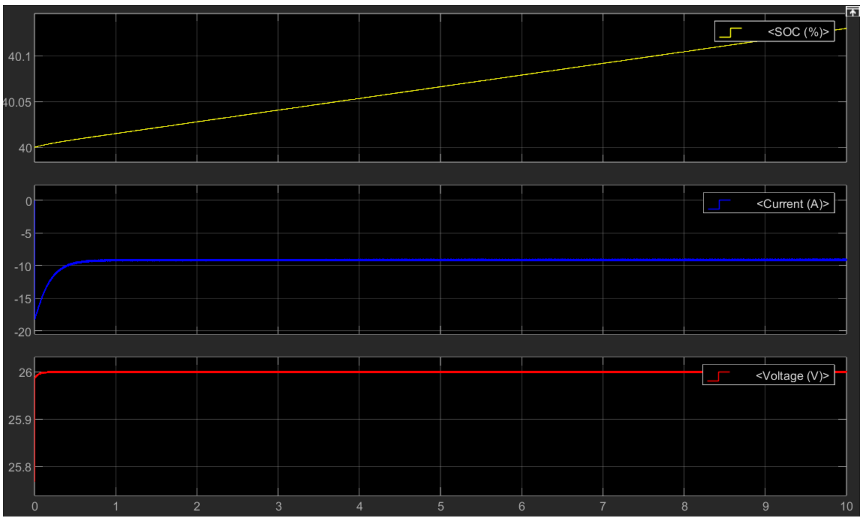

Figure 4. Voltage, Current, SoC Response of CC Charging

Based on the simulation results using the approachConstant Current(CC) indicates the ability to maintain a stable charging current at a reference value of −15A. This stability is achieved through the application of a controller Proportional-Integral (PI) with parameters P=0.01 and I=2 that has been type by Ziegler–Nichols calculation's, which effectively minimizes the difference between the reference current and the actual current. During the charging process, the battery voltage increases gradually from 25.85 V to nearly 26 V, according to the characteristics of the CC stage which acts as the initial phase of fast charging.

Changing State of Charge(SoC) from 40% to approximately 40.20% in a short simulation duration demonstrates the effectiveness of this method in rapidly increasing the charging capacity. The main advantage of the CC approach lies in its ability to provide fast charging at low SoC, making it ideal for use in initial charging conditions. However, this method has limitations in the form of potentialovervoltage when the transition leads to the level Constant Voltage(CV) is not properly controlled. Therefore, although the CC method proves to be efficient in the initial stages of filling

Table 2. Battery Charging Performance Characteristics Using the CC ApproachCC

Parameter	Mark	Unit	Information
Early SoC	40,00	%	Battery condition before charging
Final SoC	40,20	%	Battery condition after charging
ΔSoC	0,20	%	SoC changes during charging
Simulation time (t)	10	Second	Duration of thecharging process
SoC Increase rate per second	0,02	%/second	(40,20−40,00)/10
Charging current (I)	15	A	Constant current during charging
Input charge (Q)	0,04167	Ah	15x 10/3600
Battery full capacity (Qmaks)	20	Ah	Nominal battery capacity
Percentage of full capacity	0,20835	%	0,04167/20 x100

Based on the calculation results shown in Table 2, the initial State of Charge (SoC) of the battery before charging was at 40.00%, while after the 10-second charging process the SoC increased to 40.20%. This 0.20% increase indicates an increase in capacity during the charging process. The SoC increase rate per second is calculated from the difference between the final and initial SoC divided by the charging duration, resulting in a value of 0.02% per second. The charging process was carried out using a constant current of 15 A, which resulted in an input charge of 0.04167 Ah, according to the calculation results. The full capacity of the battery used in this simulation is 20 Ah, so the input charge is equivalent to 0.20835% of the full capacity. These results indicate that in a short charging time, the increase in SoC is relatively small, but in accordance with the theory that the magnitude of the SoC increase is influenced by the magnitude of the charging current, battery capacity, and charging duration

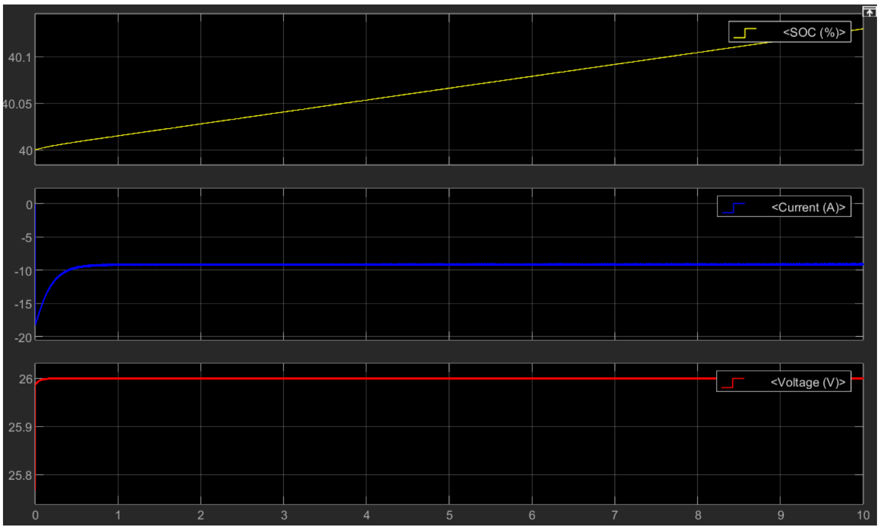

Figure 5. Voltage, Current, SoC Response of CV Charging

The Constant Voltage (CV) approach maintains a constant charging voltage at a predetermined reference value, in this case 26 V, throughout the charging process. In the simulation, a Proportional-Integral (PI) controller with parameters P=10 and I=200 is used to maintain a stable output voltage according to the setpoint. The simulation results show that the battery voltage immediately reaches 26 V at the beginning of the process and remains stable until the end of the charging stage, while the charging current experiences a gradual decrease from −20 A to −10 A. This characteristic is in accordance with the theory of the CV method, where in the initial stage of charging (low to medium SoC), the current is relatively large because the potential difference between the battery and the source is still high. As the SoC increases, the internal resistance of the battery increases so that the charging current naturally decreases, even though the voltage is maintained constant. The change in State of Charge (SoC) in the simulation only increases by about 0.02% due to the short simulation time. If the charging process is continued until the 20 Ah battery is fully charged, the total energy stored in the battery will reach ±1,872 kJ with a supply energy of approximately 2,000 kJ, resulting in a charging efficiency of approximately 93.6%. This efficiency is lower than the CC or CC–CV methods because the significant current drop in the final stage makes the energy supply last longer, resulting in increased energy losses. However, the CV method has the advantage of safety in the final stage of charging, because the voltage is maintained within the safe limits of the battery, so the risk of overvoltage and cell degradation can be minimized. This makes the CV method suitable for use as the final stage of charging or in systems that prioritize safety and battery longevity over charging speed.

Table 3. Battery Charging Performance Characteristics Using the CV Approach

Parameter	**Calculation Result Value**	**Unit**	**Information**
Initial voltage (V_{early})	26,00	V	Battery voltage at the start of the CV stage
Final voltage (V_{early})	26,00	V	Battery voltage at the end of the CV stage
Average voltage (V_{flat})	26,00	V	The voltage is kept constant during charging.
Initial current (I_{early})	20	A	The charging current at the beginning of the CV level
Final current (I_{final})	10	A	Charging current at the end of the CV stage
Average current (I_{flat})	15	A	Average current during CV stage
Charging time (t)	60	s	CV stage simulation duration
Energy total (E_{total})	23,40	kJ	Energy supplied to the battery during the simulation
SoC upgrade rate	0,0208	%/s	Average SoC increase per second
Input charge (Q)	0,25	Ah	Electrical charge that enters during the simulation
Parameter	Nilai Hasil Perhitungan	Satuan	Information

Table 3 presents the results of the calculation of battery charging performance characteristics using the Constant Voltage (CV) method. In this method, the charging voltage is maintained at a constant value of 26.00 V from the beginning to the end of the process, according to the setpoint set by the PI controller. At the beginning of charging, the current is 20 A and gradually decreases to 10 A at the end of the simulation duration. This current decrease is a typical characteristic of the CV method, where the current value decreases as the battery State of Charge (SoC) increases. During the simulation process, the average current flowing is 15 A with a charging duration of 60 seconds.

Based on the calculation results, the total energy supplied during the simulation was 23.40 kJ, with the electric charge stored in the battery being 0.25 Ah or equivalent to 1.25% of the full capacity of a 20 Ah battery. The SoC increase rate during the simulation was recorded at 0.0208% per second. Under ideal simulation conditions that do not consider energy losses, the charging efficiency reaches 100%. However, under real-life operational conditions until the battery is fully charged, the efficiency of the CV method can decrease due to a significant reduction in current in the final stage, which prolongs the charging time and increases energy losses.

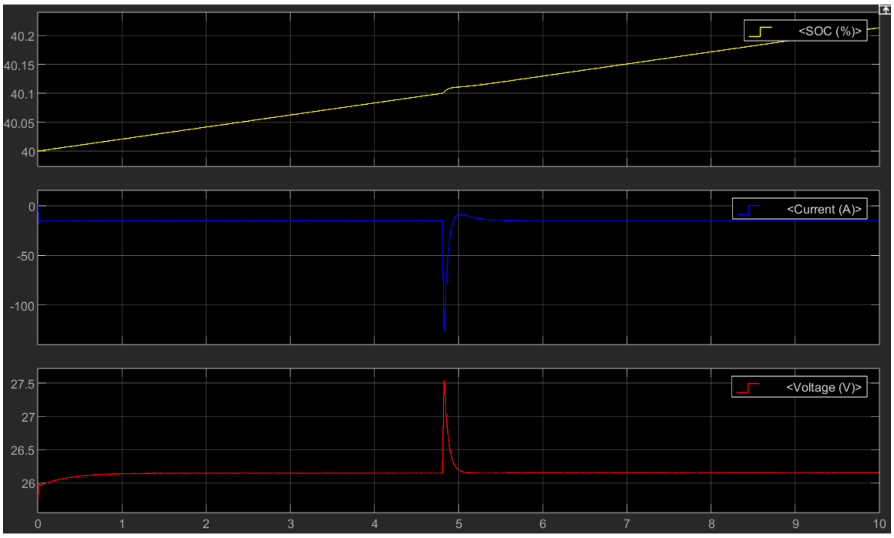

Figure 6. Voltage, Current, SoC Response of CC-CV Charging

Based on the simulation results, the methodConstant Current–Constant Voltage(CC–CV) shows optimal charging performance. During a 120-second charging duration, the total energy supplied reaches 38.88 kJ with an input charge of 0.50 Ah or equivalent to 2.5% of the full capacity of a 20 Ah battery. The rate of increaseState of Charge(SoC) average recorded at 0.0208% per second.

The charging process begins in the CC phase with a constant current of 15 A until the battery voltage reaches 26 V. After that, the CV phase is executed to maintain the voltage at that value, accompanied by a gradual decrease in current to maintain battery safety. The combination of these two methods provides higher efficiency than using the CC or CV method alone, and is able to minimize the risk ofovervoltageand battery cell degradation..

Table 4. Battery Charging Performance Characteristics Using the CC-CV Approach

Parameter	Calculation Result Value	Unit	Information
Initial voltage (V_{early})	25,85	V	Battery voltage at the start of the CC stage
Final voltage (V_{early})	26,00	V	Battery voltage at the end of the CV stage
Average voltage (V_{flat})	25,925 (CC) / 26,00 (CV)	V	Average voltage of each stage
Initial current (I_{early})	15 (CC) / 15 (CV)	A	Initial charging current for each stage
Final current (I_{final})	15 (CC) / 10 (CV)	A	Final charging current of each stage
Average current (I_{flat})	15 (CC) / 12,5 (CV)	A	Average current per stage
Charging time (t)	60 (CC) / 60 (CV)	s	Duration of filling each stage
CC level energy	23,33	kJ	Energy supplied at the CC stage
CV level energy	19,50	kJ	Energy supplied at the CV stage
Total energy (E_{total})	42,83	kJ	Energy supplied during the CC–CV process
SoC upgrade rate	0,0191	%/s	Average SoC increase per second

Table 4 presents the results of calculating the battery charging performance characteristics using the methodConstant Current–Constant Voltage(CC–CV). In the CC stage, the initial battery voltage was recorded at 25.85 V and increased to 26.00 V at the end of the stage before switching to CV mode. The average voltage in the CC stage was 25.925 V, while in the CV stage the voltage was kept constant at 26.00

V according to the predetermined setpoint. The charging current at the beginning of the CC and CV stages was both 15 A, but at the end of the CV stage the current decreased to 10 A, according to the characteristics of the CV method. The average current during the CC stage was 15 A, while in the CV stage it was recorded at 12.5 A.

Each charging stage lasts for 60 seconds, so the total duration of the CC–CV process is 120 seconds. The energy supplied in the CC stage is 23.33 kJ, while in the CV stage it is 19.50 kJ, so the total energy entering the battery during the charging process reaches 42.83 kJ. The average SoC (SoC) was recorded at 0.0191% per second, reflecting the stability of the SoC increase during the transition from the CC stage to the CV stage. This characteristic indicates that the CC–CV method is capable of providing fast charging in the initial stage while maintaining safety in the final stage, thereby increasing charging efficiency and minimizing the risk of overvoltage in the battery.

5. CONCLUSION

Simulation of charging lithium-ion batteries, which is the most common type of battery used in electric vehicles, has been carried out by applying three charging methods, namely*Constant Current* (CC), *Constant Voltage* (CV), and *Constant Current–Constant Voltage*(CC-CV). The simulation results provide an overview of the characteristics and response of the battery during the charging process. Among the three methods tested, the CC CV method showed the most optimal performance and is recommended as the main method, because it is able to charge the battery relatively quickly while maintaining the temperature within safe limits. In the test with a charging current of 15 A, the battery was successfully fully charged in 3900 seconds with a maximum temperature not exceeding 45°C. Although the CC method showed a shorter charging time, temperature control during charging was more effectively achieved in the CC-CV method, so this method is superior in terms of thermal safety and system reliability.

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