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Comparative Analysis of Charging Methods CC, CV, CC-CV, MSCC in Electric Vehicle Charging System

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Abstract - *Electric vehicles (EVs) offer a sustainable solution to fossil fuel depletion and environmental degradation. With zero emissions, EVs are more efficient than traditional fuel-powered vehicles and play a key role in reducing greenhouse gases and air pollution, supporting climate goals. Despite these benefits, EV adoption is limited by battery-related challenges, particularly in charging efficiency. To address this, it is crucial to explore effective battery charging methods. Lithium-ion batteries, widely used due to their superior performance, require optimized charging techniques for efficiency and longevity. This project explores different methods for charging lithium-ion batteries, including constant voltage charging, constant current charging, a combination of constant current and constant voltage charging, as well as multistep constant current charging. MATLAB/Simulink software is used to simulate and analyze these methods, providing insights into their charging characteristics. Furthermore, electricity may move both ways between the EV battery and the grid thanks to the combination of bi-directional AC-DC and DC-DC converters, which improves grid stability and facilitates effective energy transfer.*

Key Words*: *EVC Systems, CC, CV, CC-CV, MSCC, DC-DC Converter, AC-DC Converter

1.INTRODUCTION

The electrification of transportation is a critical step toward a sustainable future, with electric vehicles (EVs) leading the charge to reduce carbon emissions and dependence on fossil fuels. As environmental initiatives gain global momentum, the importance of EVs continues to grow, spurring advancements in vehicle technology and the infrastructure that supports them. At the core of this infrastructure is the EV charging system, a vital element that delivers energy from the grid to power the EV battery. The efficiency, speed, and reliability of charging systems directly impact the practicality and attractiveness of owning an EV, especially as the number of EVs on the road increases.

Fast and efficient charging systems are essential for multiple reasons. First, minimizing charging times is vital to increasing EV appeal, as long waits can deter adoption when compared to the quick refuelling of internal combustion engine vehicles. A robust, rapid charging system can ease these concerns and make EVs more appealing to a wider market. Second, efficiency during the grid-to-battery power transfer must be maximized to reduce energy loss. Inefficient systems not only waste energy but also produce excess heat, which can reduce battery lifespan and raise safety concerns. Enhancing energy efficiency in charging systems is essential to meet the growing demand for EVs sustainably.

Reliability and safety are equally crucial for EV charging systems. These systems must function consistently across diverse conditions, guarding against electrical hazards, preventing overcharging, and ensuring stable voltage and current delivery. Reliable charging systems also contribute to battery longevity, reducing degradation and enhancing overall vehicle performance. Additionally, as EVs connect with smart grids, charging systems must manage energy flows intelligently, potentially supporting bidirectional energy transfer (vehicle-to-grid technology) to balance grid demand. This capability allows EVs to serve as mobile energy storage units, improving grid stability during peak demand. In response to these needs, various charging strategies have been developed, each addressing key aspects such as battery health, energy efficiency, and charging speed. Manufacturers continue to innovate, aiming to create systems that meet the diverse requirements of EVs, from compact passenger cars to larger commercial vehicles.

The paper is structured as follows: Section II outlines the primary block diagram of the proposed model along with the circuit design. Section III describes the charging methods and control strategies used. Section IV contains the simulation model, whereas section V has the simulation results and discussion. Section VI describes the proposed system's conclusion.

2. DESIGNED CIRCUIT

Figure 1 illustrates the structure of a typical Electric Vehicle Charging System (EVCS). The three-phase AC source that powers the system is first transformed via an AC-DC converter. In order to prepare the AC input for additional processing, this first step converts it to DC. After that, the DC-DC converter modifies the voltage to satisfy the needs of the battery pack in the electric car. This configuration ensures efficient energy transfer from the power grid to the EV battery, facilitating reliable and controlled charging for optimal battery performance.

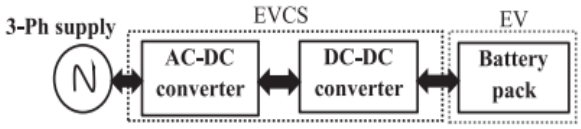

Figure 1. Structure of a typical Electric Vehicle Charging Circuit.

2.1 Design of the Bi-directional AC–DC Converter

Through filter inductance, the bidirectional three-phase AC-DC converter is connected to the distribution grid. The DC output voltage of the converter can be stated as follows.

$$V_{dc} = \frac{2*\sqrt{2}V_{l-l}}{\sqrt{3}m}$$

Here, V_{l-l} represents the voltage of the line three-phase AC sources (in volts), and 'm' denotes the modulation index. The DC-link capacitance is determined based on the following criteria.

$$C = \frac{P_{dc}}{V_{dc}\times 4\pi f\times \Delta V_{dc}}$$

Here ,f represents the source's frequency (in hertz), ΔV_{dc} is the ripple voltage (in volts), and P_{dc} as maximum DC power (in watts).

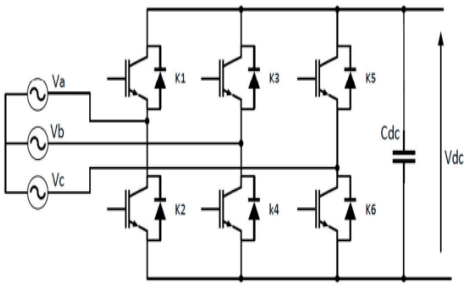

Figure 2. Design of a Bidirectional AC to DC Converter Model

2.2 Design of a Bidirectional DC-DC Converter

The bi-directional DC-DC converter, which is placed between the AC-DC converter and the EV battery pack, operates in buck mode while charging and boost mode when discharging. Because of this, the battery side inductor is intended to operate in both modes.

Both the buck and boost modes inductor values are determined using the following formulas.

$$L_b = \frac{D(V_{dc} - V_b)}{f_s \Delta I_L}$$

$$L_b = \frac{DV_b}{f_s \Delta I_L}$$

Here, V_{dc} is the DC-link voltage (in volts), V_b is the battery voltage (in volts), f_s is the switching frequency (in Hertz) and L_b is the filter inductor on the battery side (in Henrys).

For battery charging, the dc-dc converter's output filter capacitor (C_b)) is computed using

$$C_b = \frac{\Delta I_L}{8f_s \times \Delta V_b}$$

Here ΔV_b represents the ripple voltage at the output (in volts).

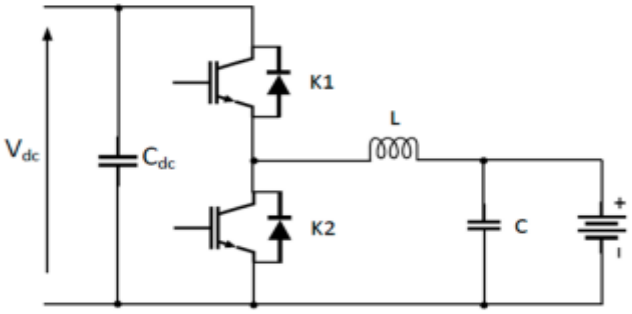

Figure 3. The Bidirectional DC-DC Converter's Design

3. Charging Techniques for Batteries

3.1 Constant Voltage Charge Method

The charging characteristics of this approach are depicted in Fig. 4. As the name implies, the battery voltage remains relatively constant. After reaching the predetermined value during the charging process. It is essential to adjust the charging voltage in line with the recommended charge and temperature parameters. Setting an incorrect voltage can lead to either overcharging or undercharging the battery.

On the other hand, the charging current gradually drops. It reaches its maximum at the start of the charging cycle, when it must be controlled to protect the devices, and then progressively decreases to its lowest point at the end of the charging time. In other words, the current that the battery draws from the power source decreases as its state of charge grows. The charging speed of this method is often slower than that of other charging methods. Basic control techniques, however, make it easy to manage.

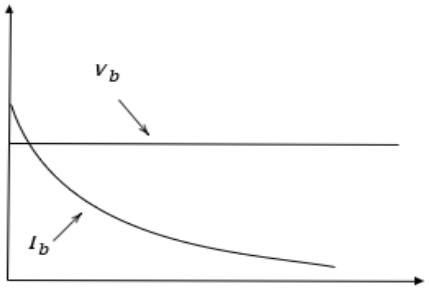

Figure 4. Steady Voltage Charging

3.2 II. Constant Current Charge Method

Fig. 5 shows the charging properties of this technique. Another basic charging method that employs a steady stream is this one. The current in a string of cells connected in series stays consistent during the charging process and is uniform across each individual cell. While a larger charging current may result in dangerously high battery temperatures, a lower charging current will increase the total charging time. Therefore, selecting an appropriate charging current is crucial for battery safety. Overcharging with a constant current method can also reduce the battery's lifespan. As charging progresses, the battery's voltage increases due to the accumulation of charge. Because the current is constant and doesn't drop over time, this approach allows for quicker charging.

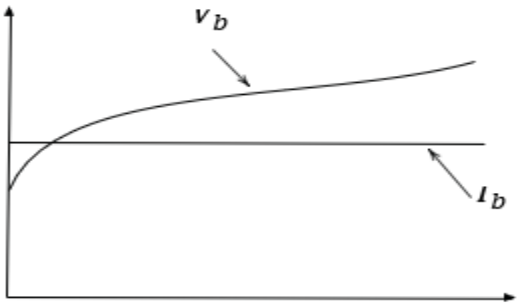

Figure 5. Steady Current charging

3.3 Constant Current-Constant Voltage Charging

Fig. 6 shows the charging characteristics of this approach. This hybrid method raises the voltage gradually after starting with a steady current. The voltage is kept steady while the current drops in accordance with the battery's state of charge (SOC) until it achieves its assigned value, which is usually close to full charge. When the current falls to a minimal value set by the manufacturer, the charging process ends. This popular charging algorithm combines the advantages of constant voltage and constant current techniques.. It is particularly suited for smaller batteries, where voltage is more evenly distributed across the cells. However, in high-voltage batteries, where multiple cells are connected in series, voltage may not be as evenly distributed. In general, this technique is quicker than conventional constant voltage charging and helps avoid overcharging.

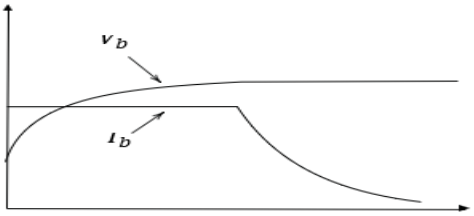

Figure 6. Constant Current- Constant Voltage charging

3.4 Multi-Step Constant Current Charging

Multi-Stage Constant Current (MSCC) charging is an advanced method that breaks the charging process into several stages, each utilizing a specific constant current. This technique is designed to optimize charging efficiency, enhance safety, and increase the lifespan of batteries, particularly lithium-ion batteries, which are frequently used in energy storage and electric car applications.

The MSCC charging technique modifies the charging procedure based on the state of charge (SOC) of the battery. Initially, a higher current is used to quickly raise the SOC, enabling faster charging when the battery is capable of handling increased current without risk. As the SOC rises and the battery approaches its full capacity, the charging current is gradually reduced in stages. This step-down in current helps to limit heat generation, prevent overcharging, and reduce stress on the battery, thus helping to minimize wear and extend its lifespan. This multi-phase approach is especially beneficial in applications where battery health, charging speed, and efficiency are critical considerations. By controlling current flow through each stage, MSCC charging ensures a more balanced and stable charging cycle, making it ideal for

devices and systems that demand reliable, long-lasting battery performance

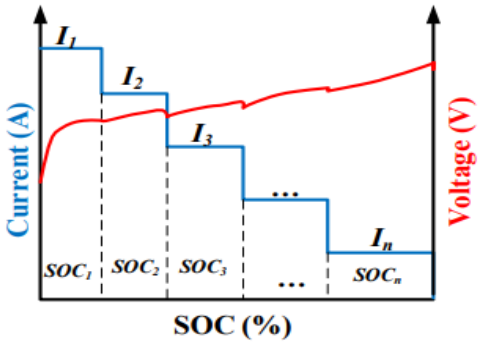

Figure 7. Multi-step Constant Current charging

3.5 Controller Circuit Design

Fig. 8 shows the controller circuit, which is made to satisfy the particular requirements of the charging method. Consistent voltage charging maintains a consistent voltage, whereas Constant Current (CC) charging keeps the current at a constant level. The battery voltage hits a predetermined threshold in the CC-CV charging technique, at which point the current progressively drops while the voltage stays steady. The DC-DC converter adjusts the duty cycle of the IGBT switches using voltage and current feedback to ensure these charging requirements are met. As a result, the duty cycle is not fixed but varies based on the battery's voltage and current needs. The carrier frequency of the Pulse Width Modulation (PWM) signal is 10 kHz. The maximum and lowest duty cycles of the switches are constrained by a saturation limiter. The controller circuit seen in the picture integrates voltage and current control operations and is particularly made for the CC-CV charging technique.

The reference current for the DC-DC converter is produced using a novel MSCC control technique. Fig. 9 displays the block diagram that demonstrates this MSCC control approach. This method uses the charging/discharging (Ch/Dch) mode selection signal and the battery's state of charge (SOC) to calculate the reference current. When the SOC is less than 80% during the charging phase (Ch/Dch = HIGH), the reference current is initially set at 33.5 A. Upon reaching 80% SOC, the reference current is lowered to 23.5 A. The reference current drops to 13.5 A if the SOC hits or is above 90%.Once the SOC hits 100%, the reference current is set to zero. The reference current

is kept at 33.5 A during the discharging phase (Ch/Dch = LOW), while the SOC is between 20% and 100%. Zero reference current is used if the SOC falls below 20%. Faster battery charging, fewer transients during current changes, and improved control over battery voltage by reducing the charging current—particularly during the switch from CC to CV mode—are just a few benefits of the suggested MSCC technique.

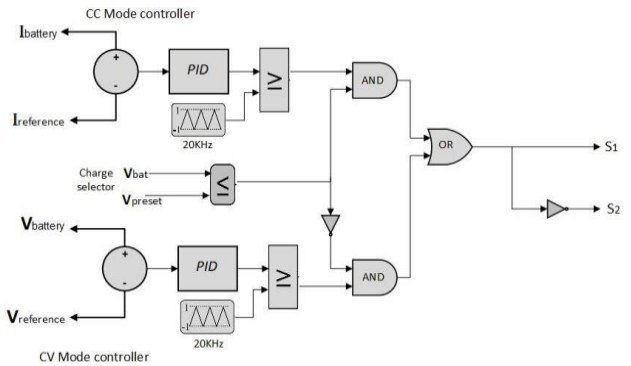

Figure.8 The control system for Constant Voltage (CV), Constant Current (CC), and Constant Current-Constant Voltage (CC-CV) charging.

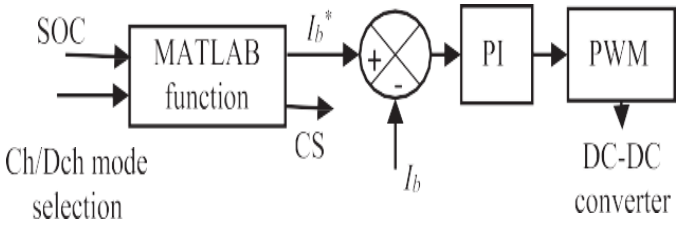

Figure 9 Proposed MSCC control method for the DC-DC converter.

4. SIMULATION OF THE PROPOSED SYSTEM

The Simulink models shown in Figures 10, 11, 12 and 13 were created and run using the MATLAB/Simulink environment. Figure 10 presents the simulation model of the grid-connected Electric Vehicle Charging Station (EVCS) system, which illustrates how the charging infrastructure integrates with the grid to manage energy flow. The bidirectional AC-DC controller simulation model, which is in charge of converting and controlling electricity between the AC grid and the DC side of the EVCS, is shown in Figure 11. This facilitates energy exchanges between vehicles and the grid (V2G and G2V). Figure 12 showcases the DC-DC controller simulation model, which supports various charging methods such as CC, CV, and CC-CV, to assess their effects on battery performance. Finally, Figure 13 illustrates the simulation model of the MSCC (Multi-Stage Constant Current) controller, which is designed to enhance charging efficiency by adjusting current in multiple stages according to the SOC of the battery.

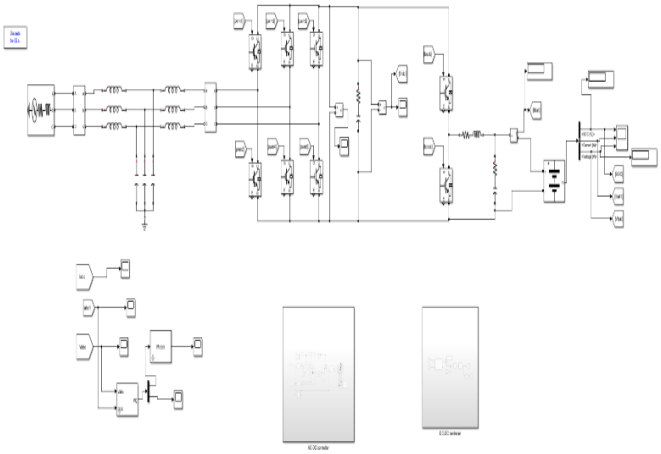

Figure 10. Simulink model of EVCS connected to grid

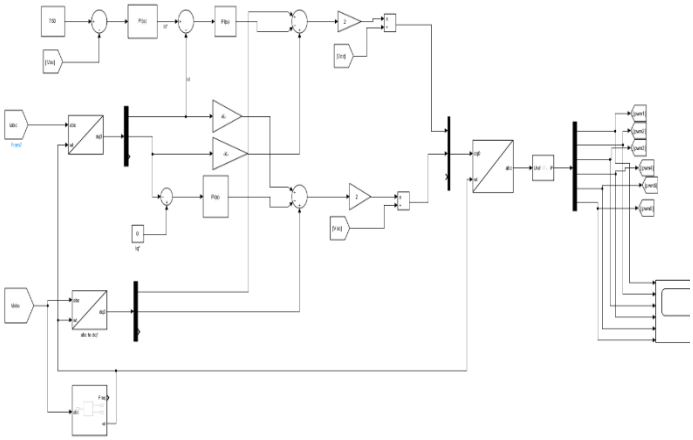

Figure 11. Simulink model of AC-DC controller

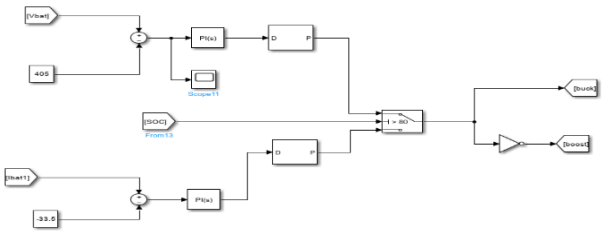

Figure 12. Simulink model for controlling a DC-DC converter in Constant Current (CC), Constant Voltage (CV), and combined CC-CV charging modes.

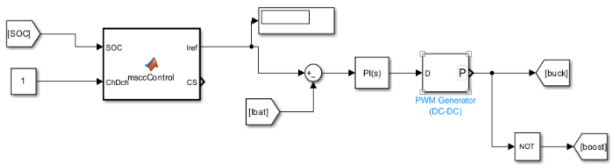

Figure 13. Simulink model for DC-DC controller designed for Multi-Stage Constant Current (MSCC) charging.

SIMULATION PARAMETERS

S.no	Parameter	Value
1	Grid Voltage	415 V
2	Input Frequency	50 Hz
3	Nominal Voltage of the Battery	360 Volts
4	Battery Ampere-Hour (Ah) Capacity	66.2 Ah
5	DC-link Voltage (Vdc)	750 V
6	DC-link capacitor	3300μF
7	Switching frequency	10 kHz

5. SIMULATION RESULTS

This section presents the simulation results of the proposed system employing different charging methods: CC, CV, CC-CV, and MSCC. Figures 14, 15, 16, and 17 illustrate the battery voltage, current, and State of Charge (SOC) for each of these charging approaches.

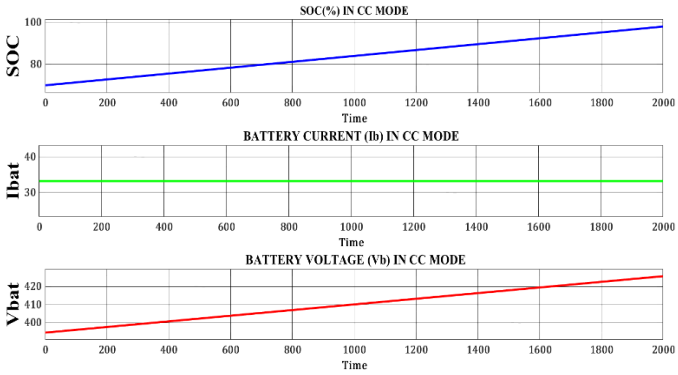

Figure 14. Waveforms for State of Charge (SOC), voltage (Vb), and current (Ib) in CC charging mode

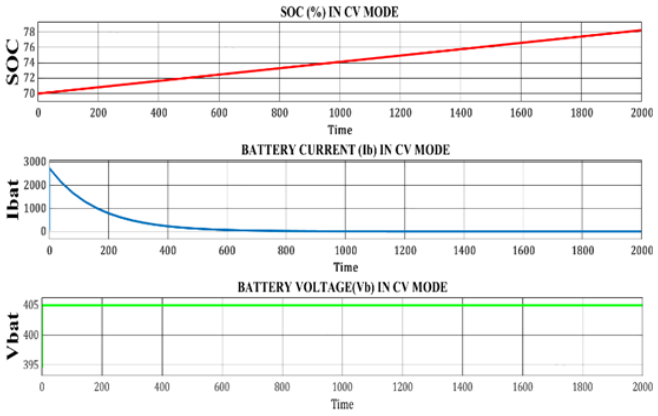

Figure 15. Waveforms for State of Charge (SOC), voltage (Vb), and current (Ib) in CV charging mode.

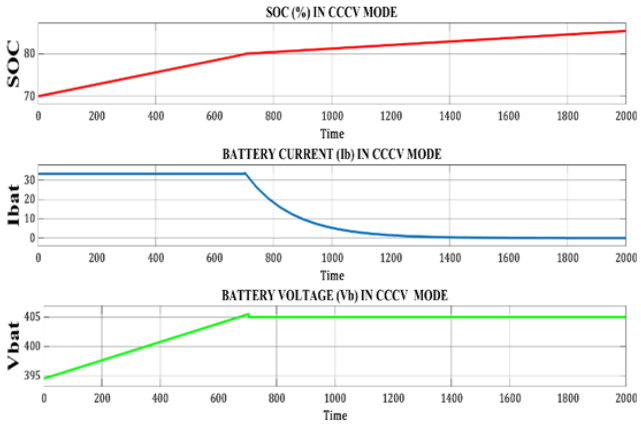

Figure 16 Waveforms for State of Charge (SOC), voltage (Vb), and current (Ib) in CC-CV charging mode

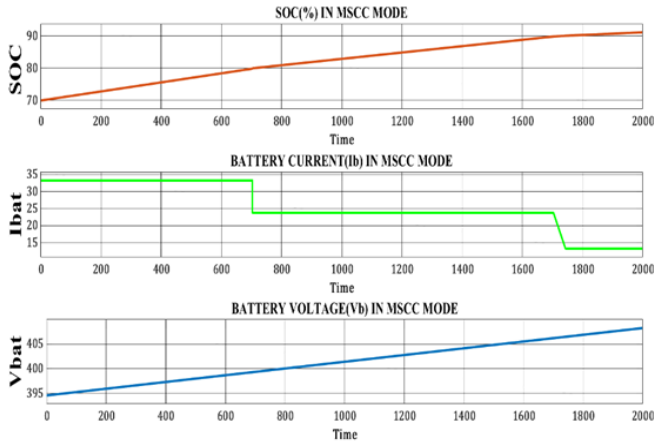

Figure 17. Waveforms for State of Charge (SOC), voltage (Vb), and current (Ib) in MSCC charging mode

The active power on the grid side is measured at 16.49 kW, while the battery side receives 13.22 kW. This indicates a power loss of 3.27 kW during the energy transfer process. These losses account for approximately 19.82% of the total power supplied by the grid. Such losses can be attributed to various factors, including line resistance, switching losses in power converters, and thermal dissipation in system components. Despite these losses, the system demonstrates a reasonable level of efficiency for practical applications, ensuring reliable energy transfer to the battery. Enhancing the efficiency of inverters and reducing resistive losses in power lines could significantly minimize energy dissipation. Additionally, better thermal management strategies within the battery and power electronics could further optimize performance. The negligible reactive power on the battery side emphasizes the effectiveness of the system in transferring energy predominantly through active power, reflecting its suitability for high-performance applications.

A COMPARISON OF CHARGE METHODS

Charging techniques	**duration**	Change in SOC%	**Increase in voltage**	**Temperature increase**
CV charging	2000 s	70-78	404-405 volts	Low
CC charging	2000 s	70-98	395-427 volts	High
CC-CV charging	2000 s	70-85	395-405 volts	Moderate
MSCC charging	2000 s	70-92	395-409 volts	Moderate

The table compares four EV battery charging methods—CV, CC, CC-CV, and MSCC—based on their effects on State of Charge (SOC), voltage rise, and temperature rise over 2000 seconds. CV charging, which shows the smallest SOC increase (70% to 78%) and minimal voltage rise (404.8V to 405.6V), is the safest, though less efficient. CC charging achieves the highest SOC increase (70% to 98%) but also causes significant voltage (395V to 427V) and temperature rises, which may stress the battery. The hybrid CC-CV method balances safety and efficiency with a moderate SOC increase (70% to 85%), a safer voltage range (395V to 405V), and moderate thermal impact. MSCC offers a promising alternative with a high SOC increase (92%), moderate voltage rise (395V to 409V), and balanced thermal management, making it a safer option compared to CC. Each method involves trade-offs, with CC prioritizing speed and the others balancing safety, efficiency, and thermal control.

The variations in temperature across different charging methods result from how energy is delivered to the battery. A set voltage is applied to the battery durithe Constant Voltage (CV) charging procedure. As the battery approaches full charge, its internal resistance increases. To maintain the constant voltage, the charging current automatically decreases. This gradual reduction in current minimizes the rate of energy input, leading to reduced heat generation and a safer charging process.

Conversely, Constant Current (CC) charging involves a steady high current input, which can increase internal resistance within the battery cells. This higher resistance results in more heat dissipation, leading to a significant temperature rise. To mitigate the temperature rise associated with CC charging, CC-CV charging combines the initial rapid charging phase of CC with the controlled finishing phase of CV. This approach balances charging speed and thermal management. Modified Constant Current (MSCC) charging further refines this process by dynamically adjusting the current throughout the charging cycle. By intelligently controlling the current flow, MSCC minimizes heat generation, ensuring faster charging without compromising battery health.

6. CONCLUSION

The comparison of the CV, CC, CC-CV, and MSCC charging techniques emphasizes how important it is to strike a balance between battery safety, charging efficiency, and heat control. Because it causes less thermal and electrical stress, Constant Voltage (CV) charging is the safest choice, even though it results in slower charging. It is characterized by the smallest State of Charge (SOC) increase (70% to 78%) and the least amount of voltage rise (404.8V to 405.6V). Constant Current (CC) charging, on the other hand, increases SOC the fastest (70% to 98%) but at the cost of considerable voltage (395V to 427V) and temperature increases, which could hasten battery deterioration.

In comparison to CC, the CC-CV approach offers a moderate SOC rise (70–85%), preserves an acceptable voltage range (395–405), and lowers thermal stress. With a notable 92% SOC gain, a moderate voltage increase (395V to 409V), and balanced thermal performance, the Modified Constant Current (MSCC) approach is a viable substitute for reaching both effectiveness and security. These results highlight how crucial it is to choose the best charging approach depending on the intended trade-off between battery longevity, charging speed, and temperature control. Improving the charging technique can greatly extend the life, safety, and overall performance of EV batteries.

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