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A Comprehensive Review of Constant Current Constant Voltage Charging Strategies for Electric Vehicle Batteries

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Abstract:

The rapid growth of electric vehicles has intensified the need for efficient, safe, and reliable battery charging strategies. Among various approaches, the constant current constant Voltage (CC–CV) charging method remains the most widely adopted due to its simplicity and robustness. However, conventional CC–CV charging suffers from inherent limitations such as abrupt mode transition, prolonged charging duration, thermal stress, and accelerated battery degradation, particularly under fast-charging conditions. To address these challenges, this paper presents a comprehensive review of modified CC–CV charging strategies with an emphasis on optimized transition control, adaptive regulation, and intelligent charging techniques. Recent advancements including multi-stage charging, temperature-aware and health-aware control, model predictive control, and learning-based methods are systematically analyzed. The review highlights how these approaches enhance charging efficiency, improve thermal stability, and extend battery lifespan while maintaining operational safety. Furthermore, key challenges related to real-time implementation, battery aging, and integration with smart grids are discussed. Finally, future research directions focusing on adaptive, data-driven, and vehicle-to-grid–enabled charging frameworks are outlined to support the development of next-generation electric vehicle charging systems.

Keywords: Electric Vehicles; Lithium-Ion Battery; CC–CV Charging Strategy; Modified CC–CV Control; Fast Charging; Battery Management System.

1. Introduction

The electrification of transportation has emerged as a key solution for reducing greenhouse gas emissions and dependence on fossil fuels. As electric vehicles (EVs) become increasingly prevalent, the performance and reliability of their energy storage systems play a critical role in determining overall vehicle efficiency and user acceptance. Lithium-ion batteries are widely employed in EVs due to their high energy density and long operational life; however, their performance is strongly influenced by the charging strategy employed. Inefficient or poorly controlled charging can lead to excessive heat generation, accelerated aging, and reduced safety margins.

Among the available charging techniques, the Constant Current–Constant Voltage (CC–CV) method is the most commonly implemented because of its simplicity and ease of integration into battery management systems. Nevertheless, conventional CC–CV charging does not fully address the dynamic electrochemical behavior of batteries, particularly under fast-charging and high-power conditions. Issues such as abrupt mode transitions, increased thermal stress, and prolonged charging time limit its effectiveness in modern electric mobility applications. Consequently, researchers have proposed various modified CC–CV strategies that incorporate adaptive control, optimized transition mechanisms, and intelligent decision-making to enhance performance and reliability. This paper aims to review recent advancements in modified CC–CV charging strategies, focusing on their operational principles, control methodologies, and performance improvements. By critically analyzing existing approaches and identifying current limitations, this review seeks to provide insights into the development of efficient, safe, and scalable charging solutions suitable for next-generation electric vehicle systems.

2. Literature Review

The study in [1] introduces a health-aware CC–CV charging strategy where the transition point between constant current and constant voltage is optimized using heuristic optimization. The method focuses on minimizing battery degradation while maintaining fast charging performance. The optimized switching point reduces thermal stress and enhances overall battery lifespan compared to conventional CC–CV schemes. In [2], a multi-stage constant voltage charging approach is proposed to enhance lithium-ion battery health. The method employs multiple voltage levels instead of a single CV stage, resulting in smoother current decay and reduced polarization effects. The results demonstrate improved energy efficiency and prolonged battery lifespan under repeated charge–discharge cycles. The work in [3] presents a real-time learning-assisted charging strategy for electric vehicle batteries. The proposed approach dynamically adapts charging parameters based on operating conditions and battery behavior. This adaptive framework improves robustness against parameter uncertainty and enables efficient charging under varying environmental and load conditions. A constant temperature–constant voltage (CT–CV) charging method is investigated in [4], focusing on minimizing energy loss and thermal stress. By regulating the charging current to maintain a stable temperature, the proposed approach significantly enhances safety and charging efficiency, especially under high-power operating conditions. In [5], a closed-loop CT–CV charging technique is introduced to reduce charging time while maintaining thermal safety. The study demonstrates that temperature-based feedback control allows faster charging without exceeding critical thermal limits, making it suitable for high-energy-density lithium-ion batteries. The analysis in [6] evaluates CT–CV charging performance for lithium-ion and NCM 18650 cells. The results confirm that temperature-regulated charging significantly improves thermal stability and extends battery life compared to conventional CC–CV methods. The work presented in [7] focuses on optimizing constant temperature–constant voltage charging for electric vehicles. The proposed strategy effectively balances charging speed and thermal constraints, demonstrating improved efficiency and reduced battery degradation under high-power charging scenarios. In [8], a multi-step constant current charging profile is developed for fast charging applications. The proposed optimization-based approach reduces charging time while maintaining acceptable temperature rise, making it suitable for high-capacity energy storage systems. The study in [9] proposes a multi-stage constant current charging strategy optimized using a nature-inspired algorithm. The method achieves improved charging efficiency and thermal performance while ensuring safe operating limits throughout the charging process. An optimized multi-stepped CC–CV fast charging controller is presented in [10]. The proposed approach enhances charging speed and reduces battery stress through optimized current segmentation, demonstrating superior performance compared to traditional CC–CV charging. The work in [11] introduces a real-time model predictive control (MPC) framework for lithium-ion battery charging. The approach predicts future battery behavior and optimizes charging inputs while respecting voltage and temperature constraints, resulting in improved efficiency and safety.

In [12], a model predictive control-based fast charging strategy is developed for vehicular batteries. The method effectively balances fast charging requirements with thermal and voltage constraints, demonstrating improved system stability and performance. A multi-objective optimization framework for lithium-ion battery charging is presented in [13]. The approach integrates surrogate modelling and advanced optimization techniques to simultaneously optimize efficiency, thermal behavior, and battery degradation. The study in [14] proposes an improved particle swarm optimization–based charging strategy. By tuning controller parameters adaptively, the method enhances charging efficiency and reduces energy loss under varying operating conditions. Pulse charging behavior and its influence on battery cycling performance are investigated in [15]. The results show that pulse charging can reduce internal resistance and improve cycle life compared to conventional constant current charging. An enhanced pulse charging strategy is introduced in [16], demonstrating improved electrochemical performance and reduced degradation. The study highlights the benefits of pulse-based methods for long-term battery health. In [17], an add-on pulse charging architecture is proposed to enable rapid charging of lithium-ion batteries. The system improves charge acceptance while maintaining safety and compatibility with existing charging infrastructures. The work in [18] investigates charge transfer dynamics within battery electrodes, providing insight into electrochemical behavior under different charging conditions. These findings support the development of optimized charging strategies with reduced degradation. A comparative analysis of constant current and constant voltage operation is presented in [19]. The study highlights the trade-offs between efficiency and stability, emphasizing the importance of selecting appropriate control modes for energy systems. Study in [20] analyses system dynamics under constant voltage operation using transfer function modelling. The findings contribute to a deeper understanding of voltage-regulated systems and support the design of stable and efficient charging controllers.

3. Conventional CC–CV Charging Method

3.1 Principle of CC–CV Charging

The Constant Current–Constant Voltage (CC–CV) charging technique is the most widely adopted charging strategy for lithium-ion batteries due to its simplicity, reliability, and ease of implementation in battery management systems. The fundamental principle of CC–CV charging involves dividing the charging process into two sequential operating stages: the constant current (CC) stage and the constant voltage (CV) stage. In the CC stage, the charger delivers a fixed current to the battery, typically defined as a fraction or multiple of the rated capacity (C-rate). During this phase, the battery voltage gradually increases as lithium ions intercalate into the electrode structure. This stage enables rapid energy transfer and is responsible for charging a significant portion of the battery capacity within a relatively short duration. Once the terminal voltage reaches a predefined upper voltage limit—commonly 4.2 V per cell for lithium-ion batteries—the charging control transitions to the CV stage. In this stage, the charger maintains a constant voltage while allowing the current to naturally decrease as the battery approaches full state of charge. The charging process is terminated when the current drops below a specified cutoff threshold, indicating near-full saturation of the battery. The CC–CV method is favored because it balances charging speed, safety, and simplicity. It can be easily implemented using conventional power electronic converters and does not require complex computational algorithms.

3.2 Mathematical Modelling of Conventional CC–CV Charging

The battery terminal voltage $V_b(t)$ can be represented as:

$$V_b(t) = Voc(SOC) + I(t) \cdot R_{int} \tag{1}$$

V_{oc} is the open-circuit voltage dependent on state of charge (SOC), $I(t)$ is the charging current, R_{int} is the internal resistance of the battery.

3.2.1 Constant Current (CC) Mode

During the CC phase, the charging current is maintained constant:

$$I(t) = I_{CC}, 0 \le t < t_{sw} \tag{2}$$

The SOC evolution is given by:

$$SOC(t) = SOC_0 + \frac{1}{C_n}\int_0^t I_{CC}\,dt \quad (3)$$

C_n is the nominal battery capacity.

The CC phase continues until:

$$V_b(t) = V_{max} \quad (4)$$

3.2.2 Constant Voltage (CV) Mode

Once the voltage reaches the threshold V_{max}, the control switches to CV mode:

$$V_b(t) = V_{max}, \quad t \geq t_{sw} \quad (5)$$

The current naturally decays as:

$$I(t) = \frac{V_{max} - V_{oc}(SOC)}{R_{int}} \quad (6)$$

Figure 2 illustrates the conventional Constant Current–Constant Voltage (CC–CV) charging process, where the battery is initially charged at a constant current until the terminal voltage reaches its rated value, followed by a constant voltage phase in which the charging current gradually decreases.

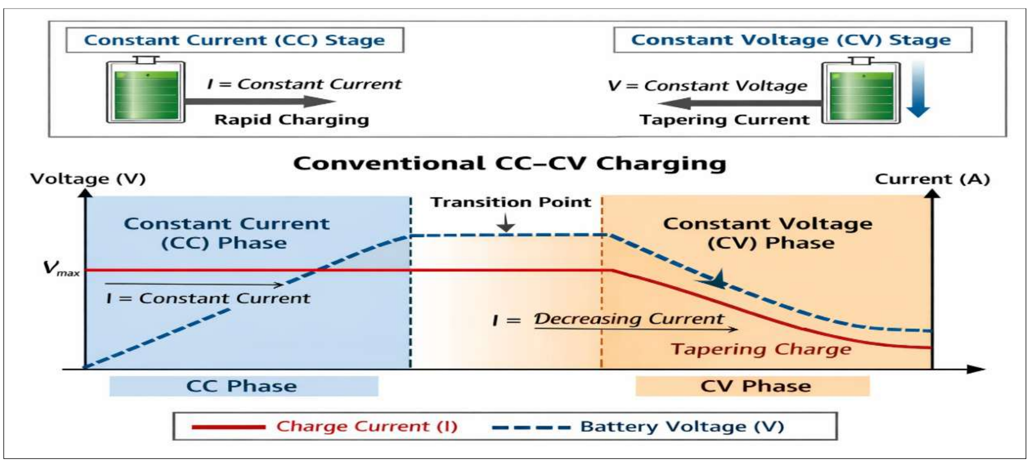

Fig. 1 Conventional CC–CV Charging

3.3 Challenges and Limitations of Conventional CC–CV Charging

Despite its widespread use, the conventional CC–CV charging method exhibits several inherent limitations. One of the primary challenges is the abrupt transition between CC and CV modes, which can introduce current and voltage fluctuations, causing electrical stress and potential instability in the charging system. Another major limitation is the lack of adaptability to varying operating conditions. Fixed voltage and current thresholds do not account for changes in temperature, battery aging, or load conditions. As a result, the same charging profile may lead to suboptimal performance or accelerated degradation under different operating scenarios. Furthermore, the prolonged CV stage significantly increases overall charging time, making conventional CC–CV unsuitable for fast-charging applications. The inability to dynamically adjust charging parameters also limits energy efficiency and increases thermal stress. These limitations highlight the necessity for advanced charging strategies that incorporate adaptive control, optimized transition mechanisms, and real-time feedback to improve charging efficiency, safety, and battery lifespan.

4. Modified CC–CV Control Strategies

Conventional CC–CV charging, although widely adopted, suffers from abrupt mode transitions, thermal stress, and inefficiencies under fast-changing conditions. To overcome these limitations, modified CC–CV charging strategies have been developed by incorporating adaptive control, optimized transition mechanisms, and predictive modelling. This section presents a detailed formulation of modified CC–CV charging strategies along with mathematical modelling of the control process.

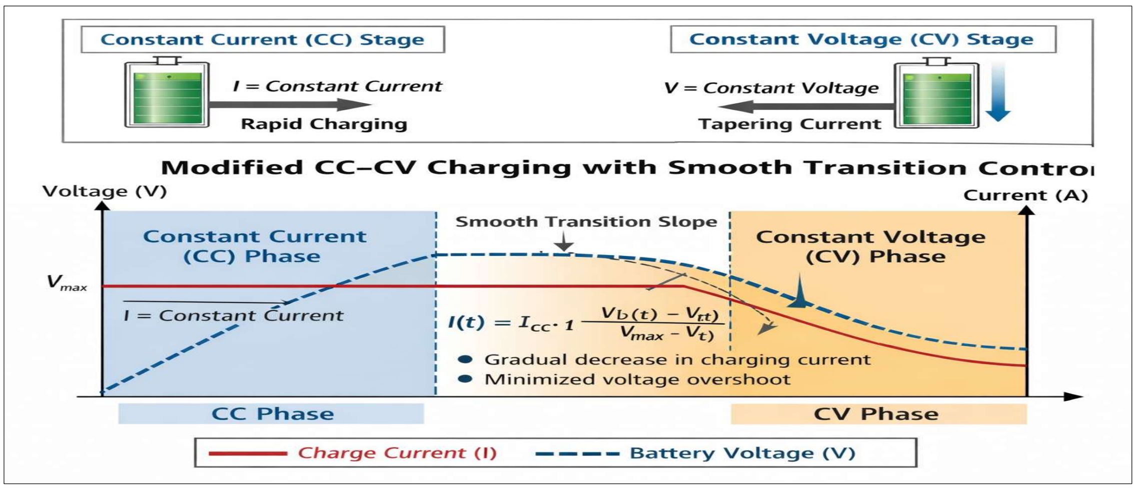

Fig .2 Modified CC-CV Charging with smooth transition control

Figure 2 depicts the modified CC–CV charging strategy incorporating a smooth transition between constant current and constant voltage modes, reducing voltage overshoot, minimizing thermal stress, and improving overall charging efficiency. To reduce transition stress, a smooth transition function is introduced near the CC–CV boundary.
Instead of a hard switch, current is gradually reduced as:

$$I(t) = I_{CC} \cdot \left(1 - \alpha \frac{V_b(t) - V_{th}}{V_{max} - V_{th}} \right) \tag{7}$$

V_{th} is the pre-transition voltage, α is a tuning coefficient controlling slope smoothness.
This approach minimizes voltage overshoot and improves stability.

4.1 Soft Transition-Based CC–CV Control

Soft transition techniques gradually reduce the charging current near the voltage threshold, minimizing volta ge overshoot and thermal stress. This approach improves stability and extends battery life.

4.2 Adaptive CC–CV Control Based on Battery State

To further enhance performance, adaptive control strategies modify charging parameters in real time based on battery state variables such as temperature T, SOC, and internal resistance.

$$I_{ref}(t) = f(SOC, T, R_{int}) \tag{8}$$

A typical formulation is:

$$I_{ref}(t) = I_{max} \cdot e^{-k(T - T_{ref}} \tag{9}$$

k is the thermal sensitivity coefficient, T_{ref} is the reference temperature.

4.3 Model Predictive CC–CV Control

Model Predictive Control (MPC) further enhances CC–CV charging by optimizing control actions over a finite horizon:

$$min\sum_{k=1}^{N}\left[w_1(SOC_{ref}-SOC_k)^2 + w_2(T_k-T_{ref})^2 + w_3 I_k^2 \right] \tag{10}$$

Subject to:

$$V_k \le V_{max},\ \ T_k \le T_{max}, I_k \le I_{max} \tag{11}$$

5. Conclusion

This paper presented a comprehensive review of modified Constant Current Constant Voltage (CC–CV) charging strategies for electric vehicle battery systems, emphasizing their role in improving charging efficiency, thermal safety, and battery longevity. Conventional CC–CV charging, although widely adopted due to its simplicity, suffers from inherent limitations such as abrupt mode transition, excessive thermal stress, and reduced effectiveness under fast-changing conditions. To address these challenges, recent research has focused on enhanced CC–CV methodologies incorporating smooth transition control, adaptive current regulation, and intelligent decision-making mechanisms. The reviewed studies demonstrate that optimized CC–CV strategies such as multi-stage charging, temperature-aware control, and learning-based approaches significantly mitigate voltage overshoot, reduce thermal degradation, and improve overall charging performance. Moreover, the integration of predictive and adaptive control techniques enables better handling of battery aging, operating uncertainties, and varying environmental conditions. These advancements collectively contribute to safer, faster, and more reliable charging systems suitable for next-generation electric vehicles. Despite notable progress, several challenges remain, particularly in achieving real-time implementation, maintaining accuracy under aging effects, and ensuring compatibility with renewable energy sources and smart grid infrastructures. Future research should therefore emphasize AI-assisted adaptive charging, degradation-aware control models, and hardware-in-the-loop validation to bridge the gap between theoretical developments and real-world deployment. Overall, optimized CC–CV charging strategies represent a critical pathway toward achieving efficient, resilient, and sustainable electric mobility systems.

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