iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: V Month of publication: May 2025

DOI: https://doi.org/10.22214/ijraset.2025.71649

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue V May 2025- Available at www.ijraset.com

Battery Charging Methods: A Comparative Analysis

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Abstract: Efficient battery charging strategies are critical for emerging applications such as electric vehicles (EVs) and portable electronics. This study offers a comprehensive evaluation of five prevalent charging methods—Constant Current–Constant Voltage (CC-CV), Pulse, Trickle, Fast, and Taper charging—through both theoretical analysis and empirical data synthesis. Performance metrics include charging time, energy efficiency, thermal behaviour, and long-term battery health. The findings reveal that while Fast charging provides rapid energy delivery, CC-CV remains optimal for balancing speed and longevity, with potential enhancements from hybrid approaches incorporating pulse modulation.
Keywords: Battery charging, Electric vehicle, Charging methods

I. INTRODUCTION

Battery charging involves a sequence of stages to optimize ion intercalation and minimize side reactions. Parameters such as applied voltage, current profile, and temperature control govern the electrochemical stability of lithium-ion and other rechargeable chemistries. Effective charging must mitigate risks of lithium plating and electrolyte decomposition while maintaining user convenience.

A. Background On Battery Charging

Battery charging involves a sequence of stages to optimize ion intercalation and minimize side reactions. Parameters such as applied voltage, current profile, and temperature control govern the electrochemical stability of lithium-ion and other rechargeable chemistries. Effective charging must mitigate risks of lithium plating and electrolyte decomposition while maintaining user convenience.

1) Voltage (V): Driving potential across cell terminals.
2) Current (A): Charge throughput rate affecting intercalation speed.
3) State of Charge (SOC%): Indicator of available capacity.
4) Charging Power (kW): Energy delivery rate governed by charger electronics.
5) Charging Time (mins): Operational latency for achieving target SOC.
6) Energy Efficiency (%): Ratio of stored versus supplied energy

B. Charging Methods Overview

1) CC-CV Charging

Combines a constant current phase until a voltage threshold, followed by maintaining voltage constant while current tapers. Widely used in industry due to its predictable thermal profile and broad compatibility.

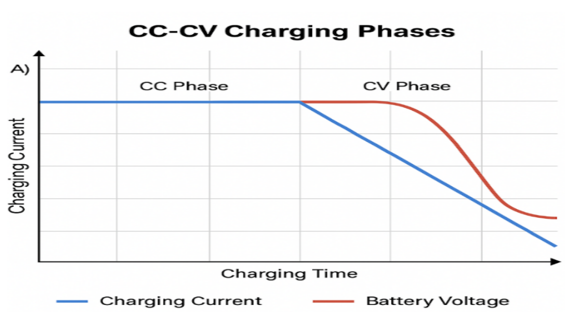


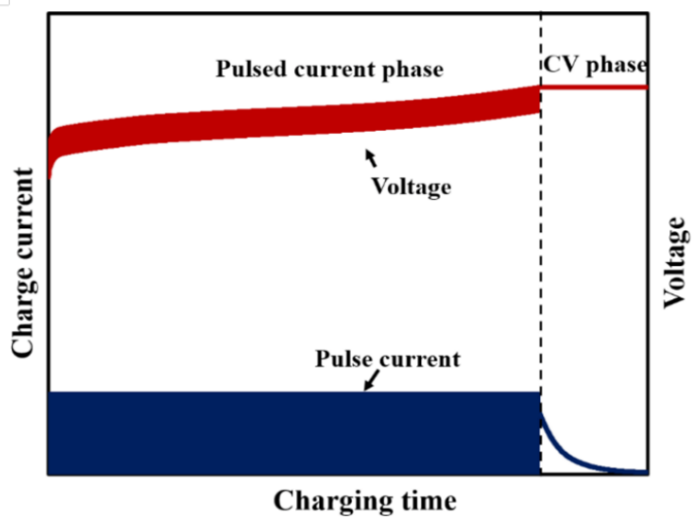
Fig 1: CC-CV charging process

Advantages:
- Uniform energy input
- Simplicity of implementation
- High cycle retention

Disadvantages:
- Extended taper phase
- Persisting thermal stress

2) Pulse Charging

Combines a constant current phase until a voltage threshold, followed by maintaining voltage constant while current tapers. Widely used in industry due to its predictable thermal profile and broad compatibility.



Graph 1: Pulse charging phase current Vs time graph

Advantages:
- Enhanced longevity
- Thermal control

Disadvantages:
- Complex hardware
- Longer total cycle time

3) Trickle Charging

Combines a constant current phase until a voltage threshold, followed by maintaining voltage constant while current tapers. Widely used in industry due to its predictable thermal profile and broad compatibility.

Advantages:
- Maintains SOC
- Minimal stress

Disadvantages:
- Not time-efficient
- Limited applicability

4) Fast Charging

Delivers elevated currents to achieve rapid replenishment. Critical for EV public infrastructure but challenged by accelerated material aging.

Advantages:
- Minimal downtime
- User convenience

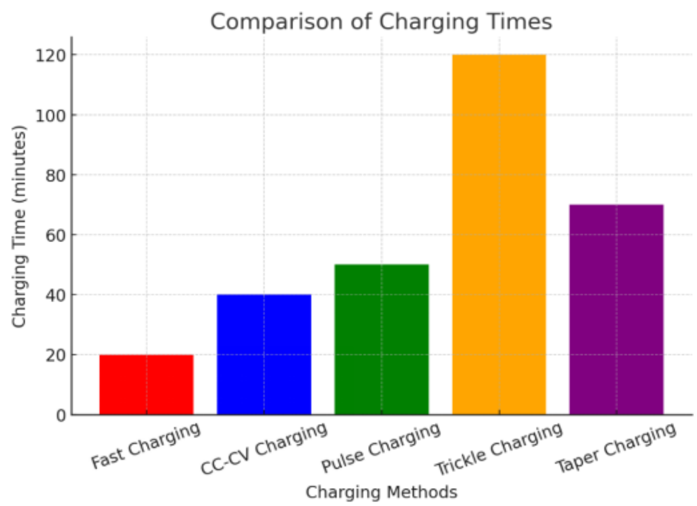
Disadvantages:
- Thermal hotspots
- Accelerated wear

5) Taper Charging

Gradually decreases current as SOC approaches 100%, protecting against overcharge. A refinement of CC-CV technique.

Advantages:
- Prevents overcharge
- Extends calendar life

Disadvantages:
- Longer overall charge duration



Graph 3: Comparison of charging type Vs charging time

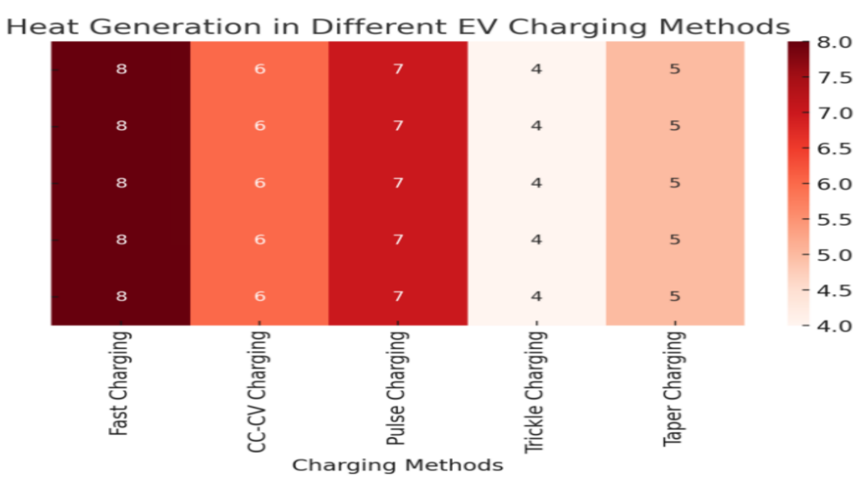


FIG 2: COMPARISON OF CHARGING TYPE VS HEAT LOSS

Table1: The table shows comparative study for charging methods depending on different methods.

Comparison of Charging Methods

Charging Method	Speed	Efficiency	Heat Generation	Best Use Case
Fast Charging	⚡ ⚡ ⚡ ⚡ ⚡	Moderate	High	EVs needing rapid refueling
[illegible]	[illegible]	[illegible]	[illegible]	Standard charging for EVs &
Taper Charging	⚡ ⚡	High	Low	Optimized charge completion
Pulse Charging	⚡ ⚡ ⚡	High	Low	Reducing battery stress
Trickle	⚡	Very High	Very Low	Battery maintenance

II. METHODOLOGY

This comparative analysis was conducted using a simulation-based approach implemented in MATLAB Simulink. The simulation model was developed to evaluate five distinct battery charging methods: Constant Current–Constant Voltage (CC-CV), Pulse, Trickle, Fast, and Taper charging. Each method was simulated under uniform conditions to ensure a fair comparison across performance metrics such as charging time, energy efficiency, thermal behavior, and battery health impact.The output data from these simulations—including voltage, current, temperature profiles, and state of charge (SOC)—was recorded and processed using Microsoft Excel for clarity and structured analysis. The summarized results in the accompanying spreadsheet serve as the empirical basis for the conclusions drawn in this study.

III. CONCLUSIONS

The comparative study demonstrates that CC-CV charging provides the most balanced performance, offering fast charging rates with moderate thermal stress and high energy efficiency, making it ideal for both EVs and consumer electronics. Fast Charging meets urgent energy demands but accelerates degradation, suggesting its use be limited to rapid-refuel scenarios. Pulse and Trickle Charging techniques significantly reduce heat generation and prolong cycle life, positioning them as preferred methods for maintenance and long-term storage. Taper Charging offers precise end-of-charge control, preventing overcharge and further safeguarding battery health, albeit at slower overall rates. Future research should explore hybridized charging schemes that integrate the benefits of multiple methods and leverage AI-driven algorithms to dynamically optimize current and voltage profiles in real time

ACKNOWLEDGMENT

The authors gratefully acknowledge the invaluable guidance of Dr. Falguni Bhavsar throughout this research project. We also thank our colleagues Atharva D. Patil, Devvrat J. Vichare, Shreyas Amte, Ganesh Pujari, and Parth Marotkar for their contributions to data collection and analysis.

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