A Comparative Study of Cccv and Pulse Charging: Thermal Risks and Fire Safety in Lithium-Ion Batteries

Mr. Sajal Shukla[1], Ms. Namrata Nebhnani[2], Dr. Manish Sahajwani[3]

[1]PG Scholar, Electrical and Electronics Engineering Department IPS Academy, Institute of Engineering and Science, Indore (M.P.), India
[2]Assistant Professor, Electrical and Electronics Engineering Department IPS Academy, Institute of Engineering and Science, Indore (M.P.), India
[3]Professor and Head, Electrical and Electronics Engineering Department IPS Academy, Institute of Engineering and Science, Indore (M.P.), India

Abstract
Addressing the critical issue of fire risk in lithium-ion batteries, this paper investigates how thermal behavior under Constant Current-Constant Voltage (CCCV) versus Pulse Charging impacts overall safety. Using a MATLAB model of a 48V, 100Ah system, the study analyzes temperature rise and power dissipation—key factors contributing to conditions that can precede fire hazards. Findings demonstrate that conventional CCCV charging induces significant thermal stress, elevating core temperatures to 49.2°C —dangerously close to thresholds (~50°C) associated with accelerated electrolyte decomposition, flammable gas generation, and potential thermal runaway initiation. In stark contrast, Pulse Charging effectively mitigates these fire risks by maintaining a lower peak temperature of 40.1°C, achieved through reduced average power dissipation (~210W vs. ~300W for CCCV) and integral cooling periods. By analyzing power loss and heat accumulation specifically in relation to established safety thresholds, this work evaluates the charging techniques primarily through the lens of fire risk reduction. The results strongly advocate for Pulse Charging as an inherently safer methodology, offering a crucial safety margin against fire hazards, especially in demanding applications where thermal stability is paramount.

Keywords: Lithium-ion Batteries (Li-ion Batteries), Fire Safety, Thermal Risk, Thermal Runaway, Battery Safety.

1. Introduction

Preventing fire incidents is a paramount concern in the deployment of lithium-ion batteries, especially within densely packed energy storage systems for electric vehicles and grid applications. The thermal state of these batteries is inextricably linked to their fire safety profile. Exceeding safe operating temperatures drastically elevates the risk of catastrophic failure; elevated heat accelerates the exothermic decomposition of volatile electrolyte materials, leading to the generation of flammable gases within the cell. This internal pressure buildup, combined with potential ignition sources, can result in venting, fire, and potentially trigger thermal runaway – a dangerous, self-sustaining chain reaction that can propagate throughout a battery pack. This research directly addresses these fire safety concerns by comparing the thermal impact of two distinct charging strategies: Constant Current-Constant Voltage (CCCV) and Pulse Charging. The conventional CCCV method, due to its continuous energy input, often pushes battery temperatures towards levels where these hazardous decomposition processes begin, thereby increasing the inherent fire risk. Conversely, Pulse Charging, characterized by its intermittent current delivery and embedded rest periods, is investigated here as a potential method to enhance fire safety. By allowing intervals for heat dissipation, Pulse Charging aims to maintain lower core temperatures, keeping the battery further from the critical thresholds where dangerous off-gassing and thermal runaway are initiated, thus offering a potentially wider margin of safety against fire hazards.

2. Methodology And Simulation Setup

A MATLAB-based simulation was carried out on a lithium-ion battery system with the following parameters:
Nominal Voltage: 48V
Full Charge Voltage: 54.6V
Battery Capacity: 100Ah
Ambient Temperature: 25°C
Thermal Resistance: 0.3 °C/W
The temperature rise was estimated using Joule heating:
$Q = I^2 \times R \times t$, where R is internal resistance.
Temperature rise = Q × Thermal Resistance

3. Results And Analysis

Temperature Rise Analysis:

Under the Constant Current-Constant Voltage (CCCV) protocol, the battery's core temperature climbed significantly, reaching 49.2°C from a starting point of 25°C within just 80 minutes. This represents a substantial temperature increase (24.2°C) driven by the continuous current flow and associated power dissipation, particularly during the constant current phase.

In contrast, the Pulse Charging method resulted in a much lower peak temperature of 40.1°C, even though the charging process took longer (112 minutes). This lower peak (9.1°C less than CCCV) demonstrates the effectiveness of the intermittent rest periods inherent in pulse charging. These rests allow the battery system brief intervals to dissipate accumulated heat, preventing the temperature from escalating as rapidly or as high as it does under the continuous stress of CCCV.

Crucially, the 49.2°C reached by CCCV pushes the battery closer to potentially critical thermal thresholds (around 50°C mentioned as a threshold for runaway initiation in the paper). Pulse charging's peak of 40.1°C maintains a considerably larger safety margin below this threshold, reducing the immediate fire risk associated with excessive heat.

Power Dissipation Insights:

The average power loss of approximately 300W during CCCV charging reflects the continuous energy being converted into heat, primarily due to the battery's internal resistance (I^2R losses). This sustained high rate of heat generation is the direct cause of the rapid temperature increase observed.

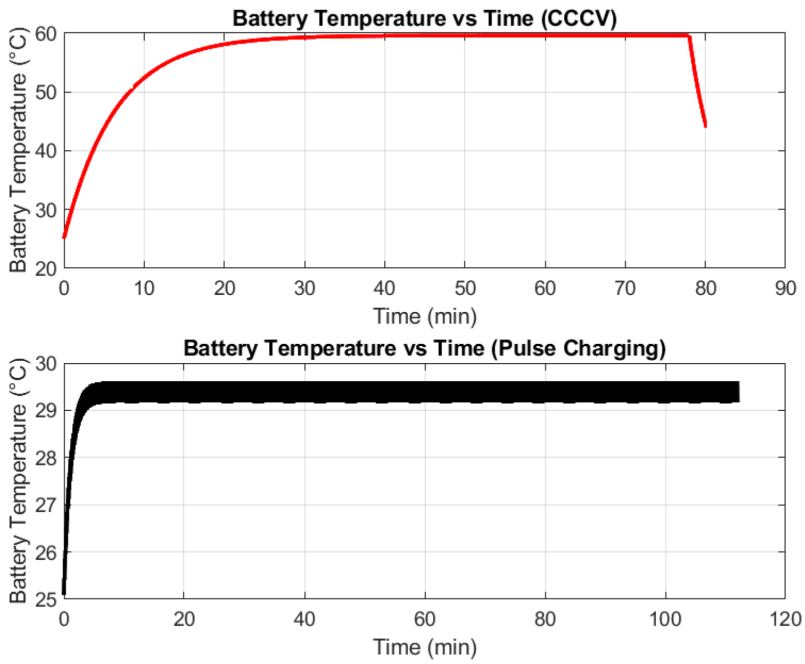
Pulse Charging exhibited a significantly lower average power loss of about 210W. While the current pulses themselves might involve high instantaneous power loss, the rest periods (where current is zero)

drastically reduce the overall average heat generation rate by roughly 30% compared to CCCV.
This lower average power dissipation directly correlates with the slower temperature rise and lower peak temperature seen with Pulse Charging.

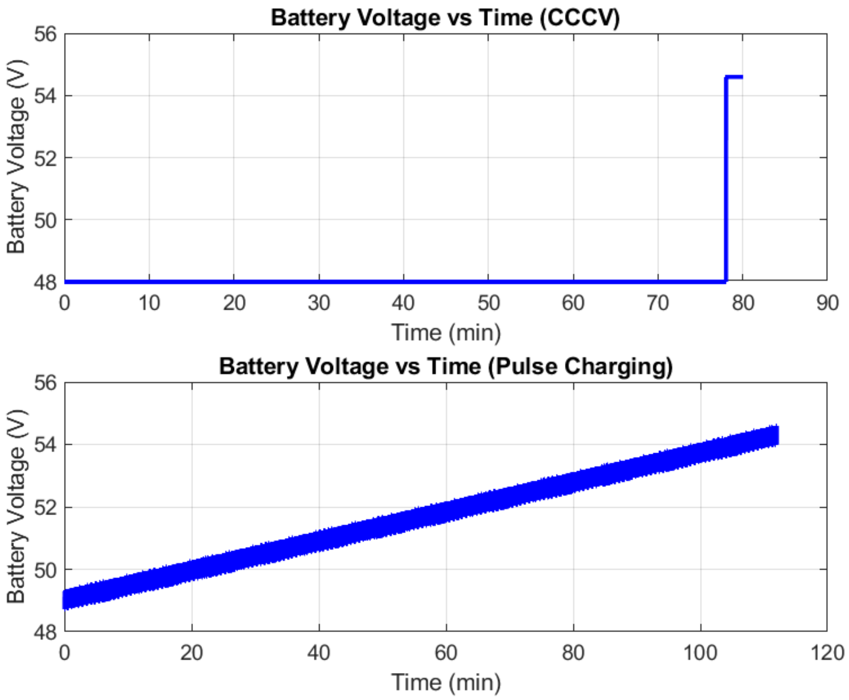
4. Fire Risk And Thermal Implications

The continuous energy input characteristic of the Constant Current-Constant Voltage (CCCV) charging method inevitably leads to significant heat generation within the battery, primarily due to ohmic losses (I^2R). This sustained heating drives the internal battery temperature towards critical levels, as seen in the simulation where it approached 49.2°C. Such elevated temperatures dangerously accelerate detrimental chemical side reactions. Notably, the decomposition of the flammable organic electrolyte is kinetically favoured at higher temperatures, leading to the evolution of combustible gases within the cell casing. This gas generation increases internal pressure and drastically elevates the risk of fire or explosion. Furthermore, operating near or exceeding critical temperature thresholds (identified around 50°C in this context) significantly heightens the probability of initiating thermal runaway – a rapid, self-sustaining, and often catastrophic failure mode.
In stark contrast, the Pulse Charging methodology inherently mitigates these severe thermal risks. By applying the charging current intermittently with integrated rest periods, Pulse Charging allows the battery crucial time to dissipate accumulated heat and for internal temperature gradients to relax. This mechanism effectively prevents the core temperature from reaching the hazardous levels observed with CCCV, keeping peak temperatures substantially lower (40.1°C in the simulation) and well below the identified thermal runaway initiation threshold. Consequently, Pulse Charging minimizes the conditions that promote aggressive electrolyte decomposition and hazardous gas build-up. This controlled thermal behavior provides a significantly enhanced safety margin, making Pulse Charging a more robust approach against temperature-induced battery failures.

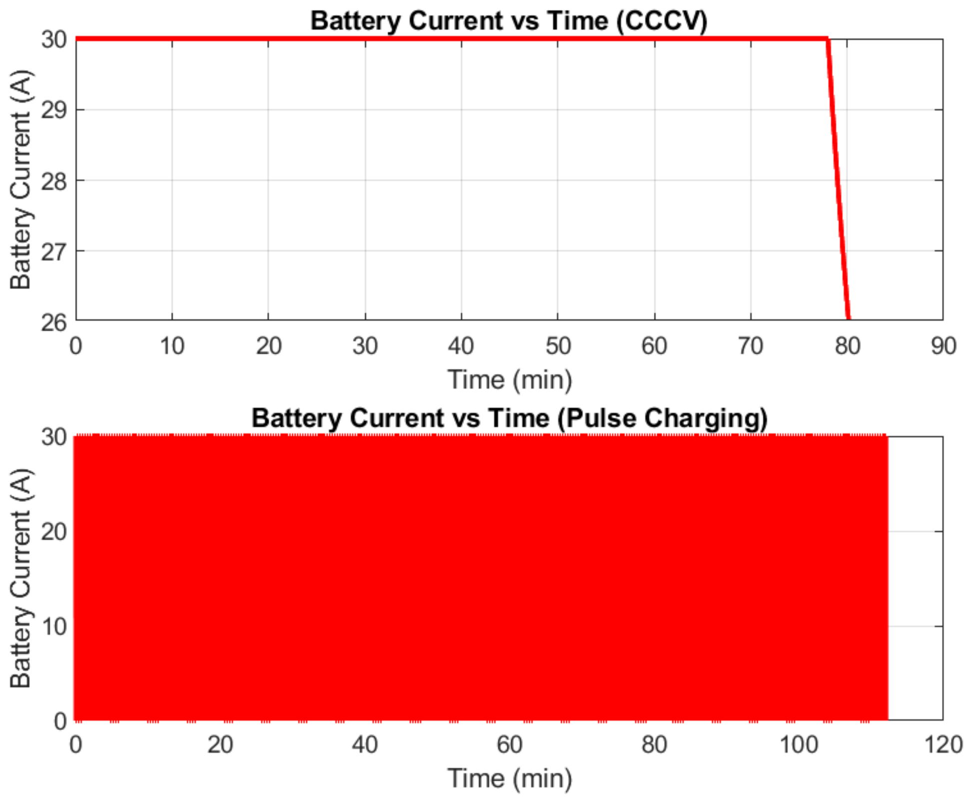
5. Graphical Results



Graph 1: Battery Temperature vs Time (CCCV vs Pulse)



Graph 2: Battery Voltage vs Time



Graph 3: Charging Current Profile Comparison

6. Conclusion

Based on the comparative thermal analysis, this study concludes that Pulse Charging presents a demonstrably safer charging methodology for lithium-ion batteries compared to the conventional CCCV approach. The core advantage lies in its effective mitigation of internal temperature rise; by incorporating rest periods, Pulse Charging prevented excessive heat accumulation, achieving a peak temperature significantly lower (40.1°C) than CCCV (49.2°C) under the simulated conditions. This controlled thermal behavior, supported by lower average power dissipation, directly translates into minimized fire risks. By maintaining temperatures well below the critical threshold (~50°C) for thermal runaway initiation and reducing the conditions favorable for hazardous electrolyte decomposition and gas generation, Pulse Charging inherently enhances operational safety.

This enhanced safety profile is particularly vital for large-scale, high-energy applications such as electric vehicle battery packs and grid-level energy storage systems, where the consequences of thermal events can be severe. Given these significant thermal management benefits and the resulting improvement in safety margins, Pulse Charging emerges as a compelling and strong candidate to supersede CCCV, especially in environments where operational safety and the prevention of thermal incidents are paramount design considerations.

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