PHEV Energy Storage Systems and Related Electronics: Current Issues and Prospective Practical Solutions

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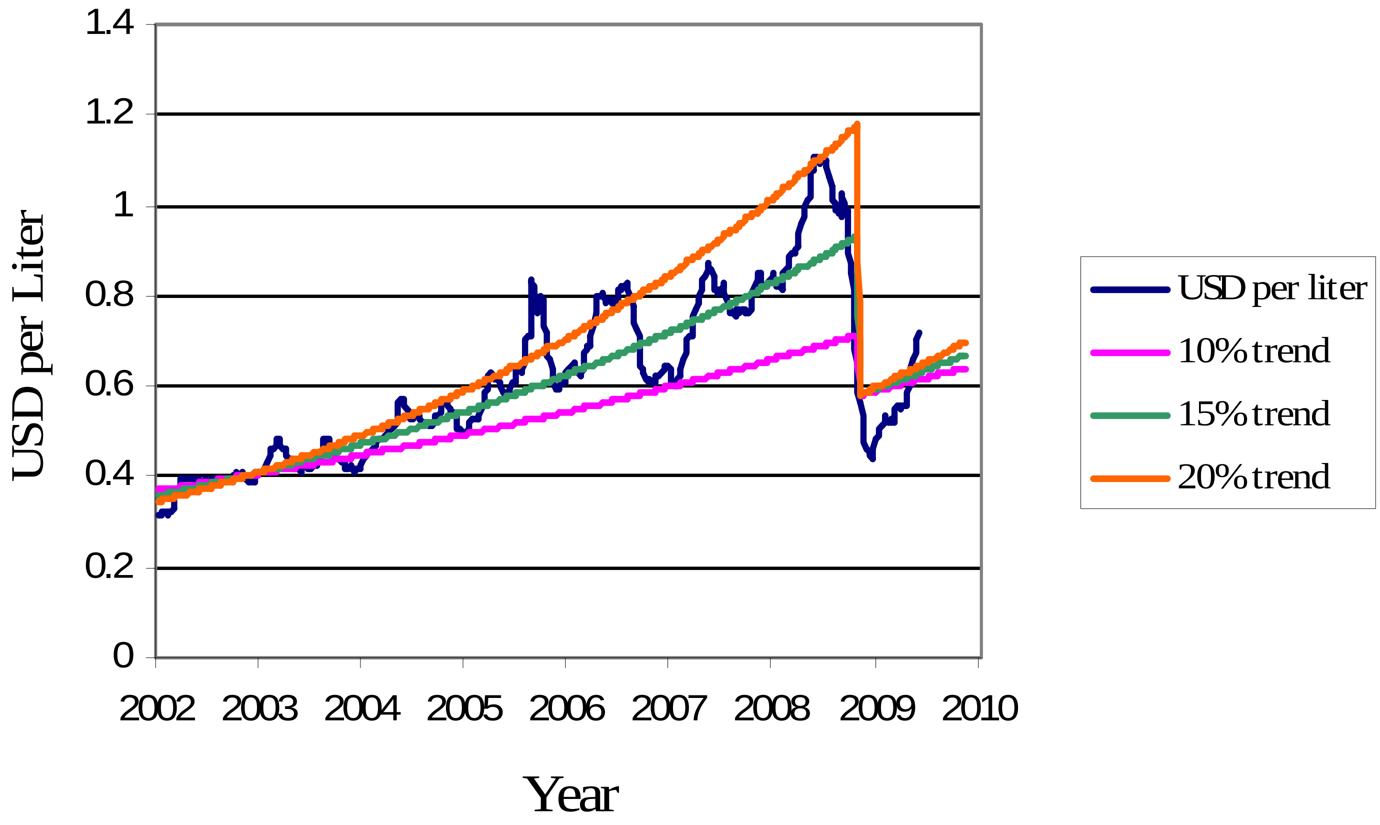
Outline

- Introduction
- Characteristics of Li-Ion Batteries
- Battery Cell Equalization
- Cost and Economic Analysis
- Novel Battery Cell Equalizer
- Prototype Development
- Conclusions

Introduction

Gas Price Trends in North America (at pump)



Data source: www.eia.doe.gov

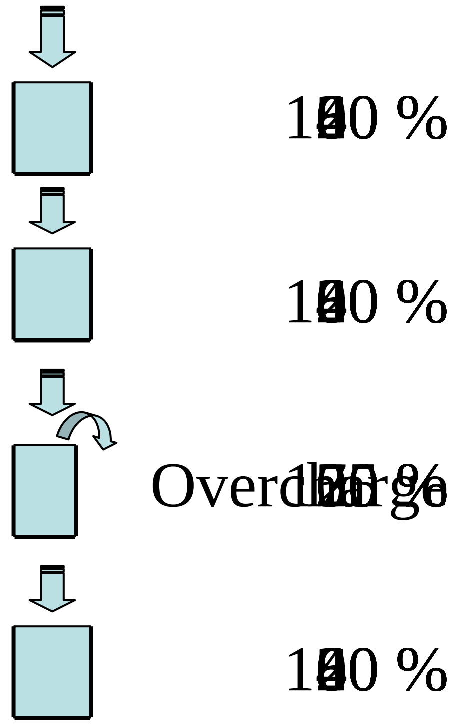
Lithium Batteries for EVs/PHEVs

Characteristics:

- High energy density (80 to 160Wh/kg);
- High power density (300 to 1500W/kg);
- Low internal impedance, low self-discharge;
- High cost and average cycle life;
- Damage or safety hazard, if mishandled.

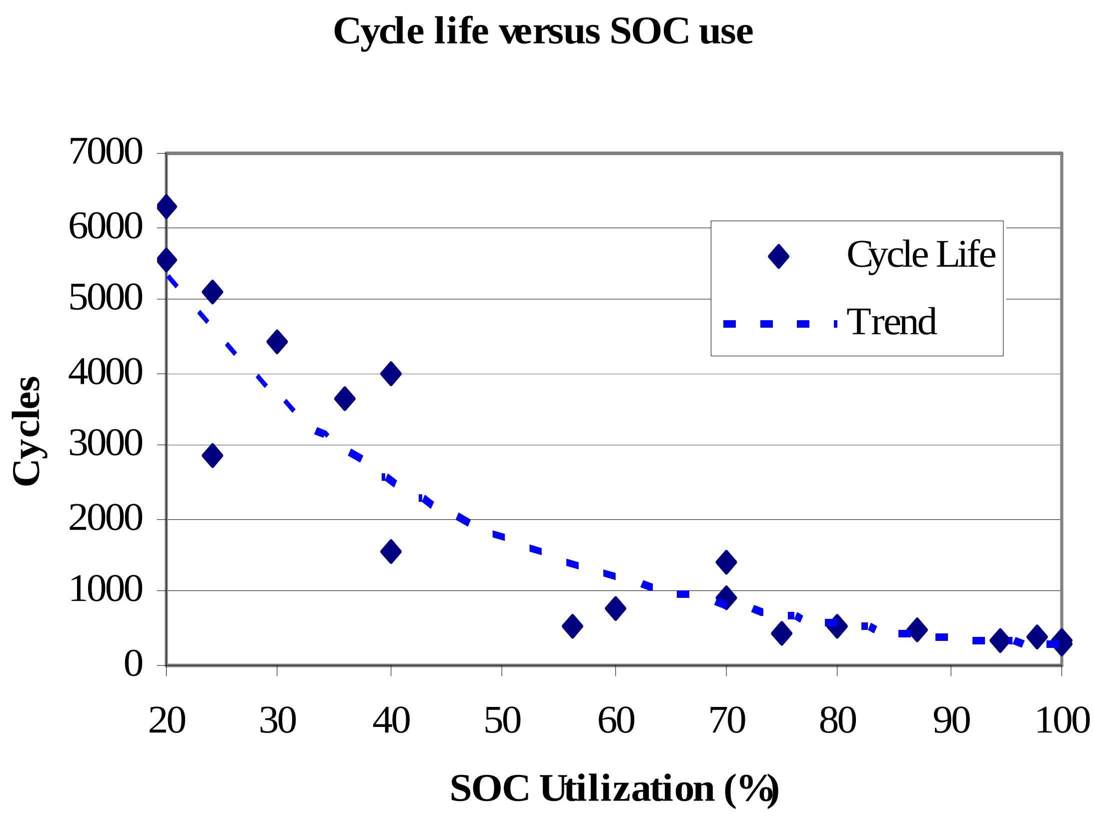
Lithium Batteries for EVs / PHEVs

Charging Cells in Series



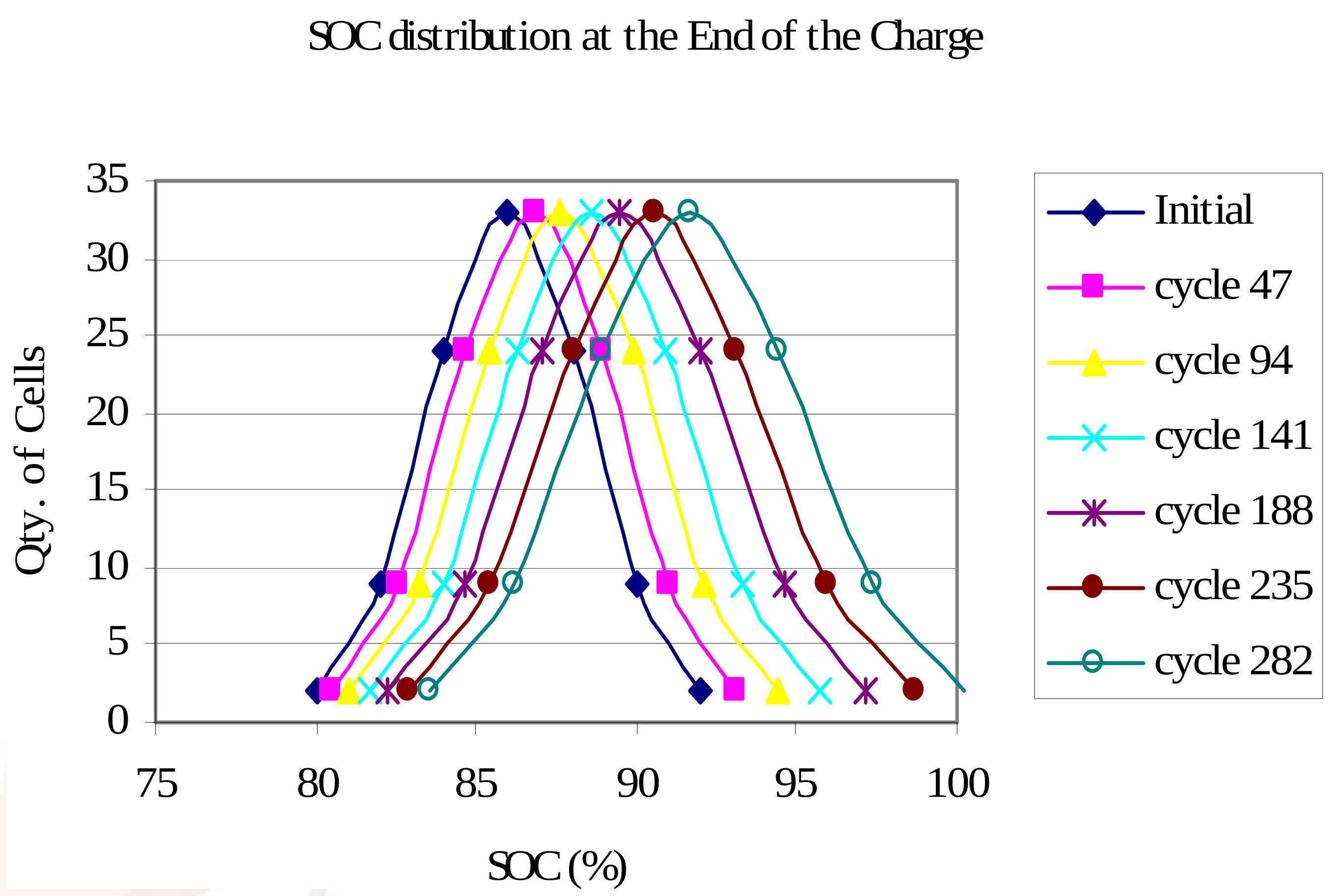
Lithium Batteries for EVs/PHEVs

Cycle Life



Lithium Batteries for EVs / PHEVs

Cycle Life

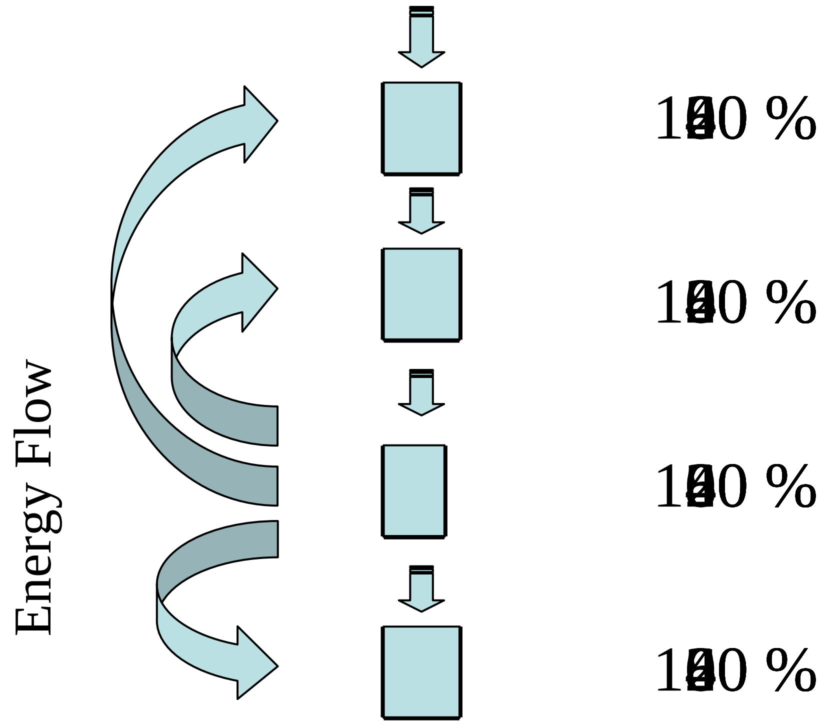


Lithium Batteries for EVs / PHEVs

Risks of Overcharging

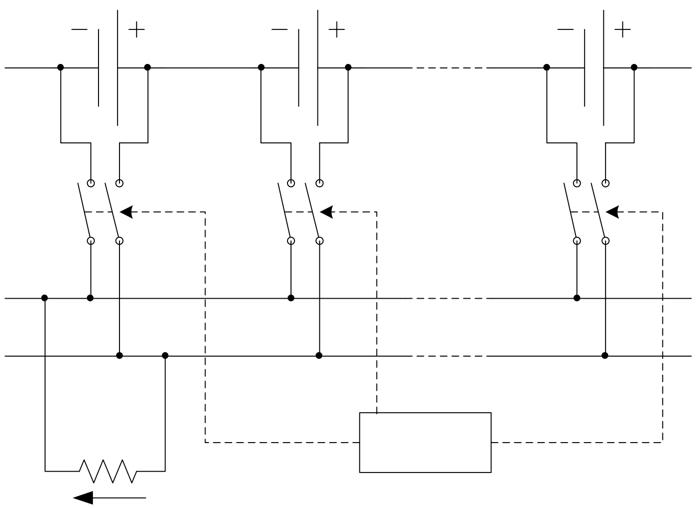
Battery Cell Equalization

Energy Distribution

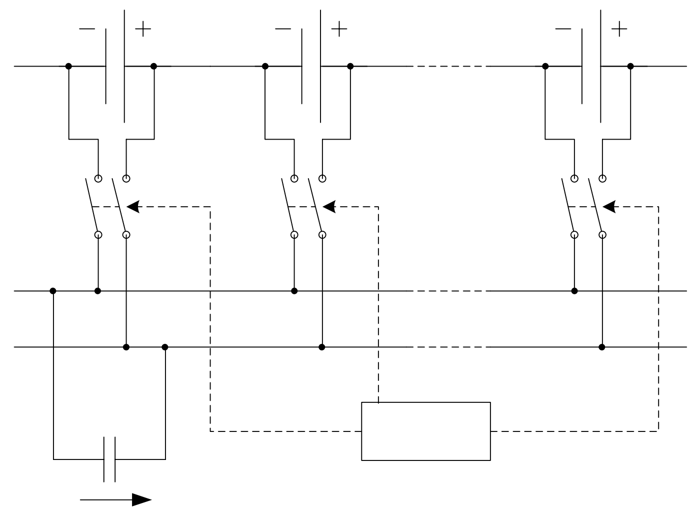


Battery Cell Equalizers

Low-Cost Configurations



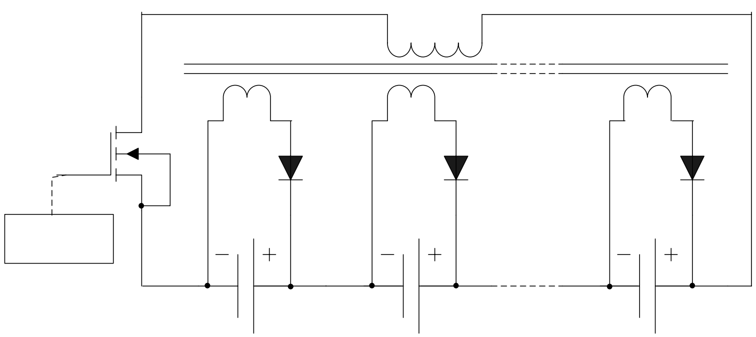
Resistive Equalizer



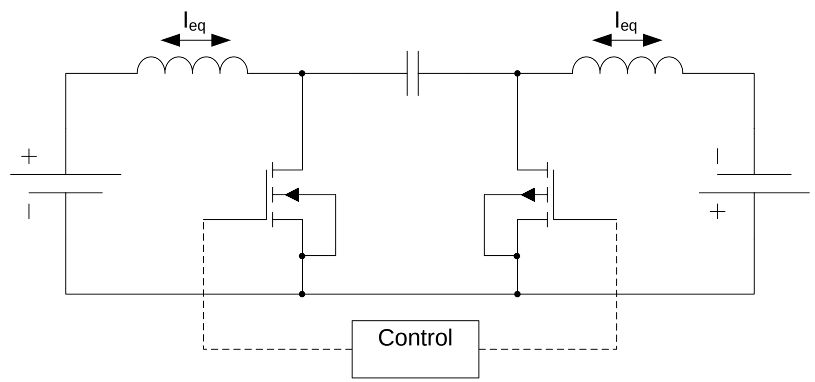
Capacitive Equalizer

Battery Cell Equalizers

Medium Current – Low Loss Configurations



Transformer Equalizer

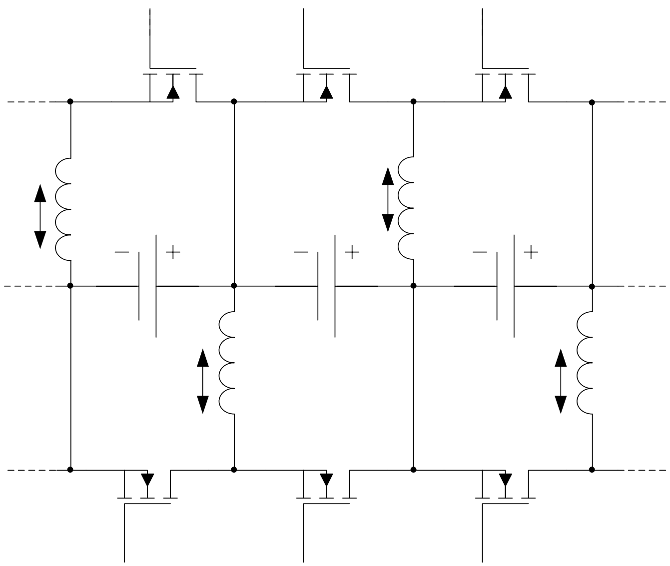


Cuk Equalizer

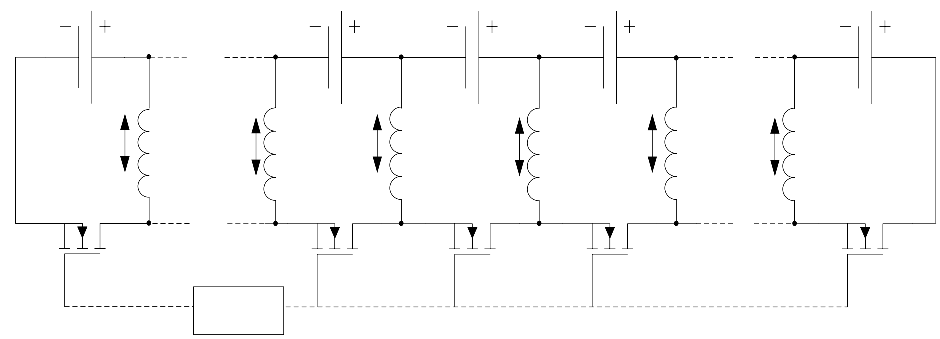
Control

Battery Cell Equalizers

High Current – Low Loss Configurations



Typical Inductive Equalizer



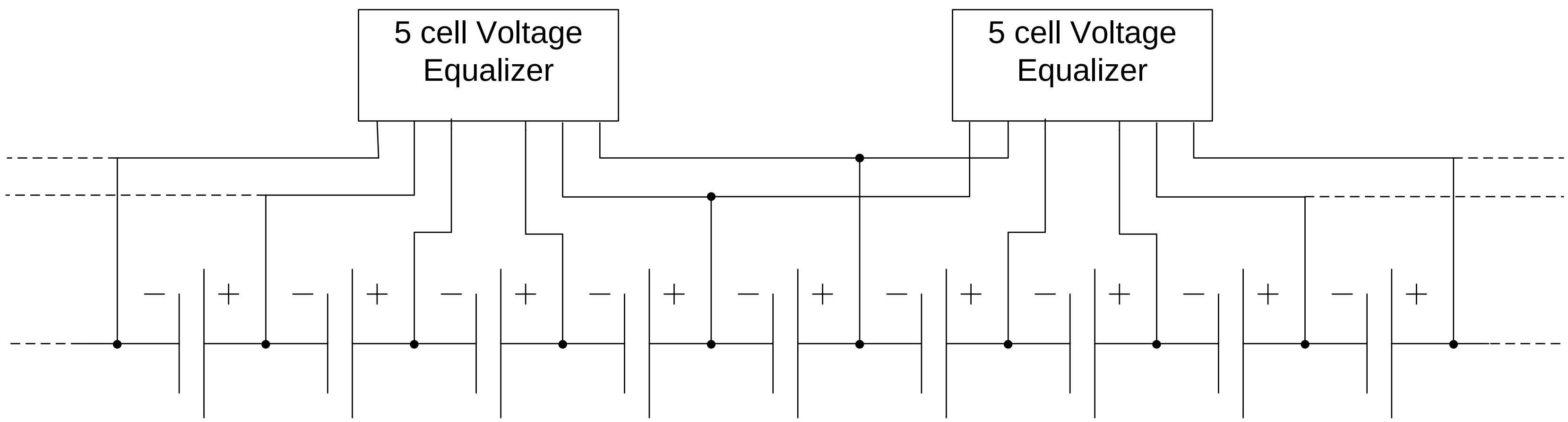
Novel Equalizer

I_{eq}

I_{eq}

Novel Battery Cell Equalizer

Equalizer Chaining Method



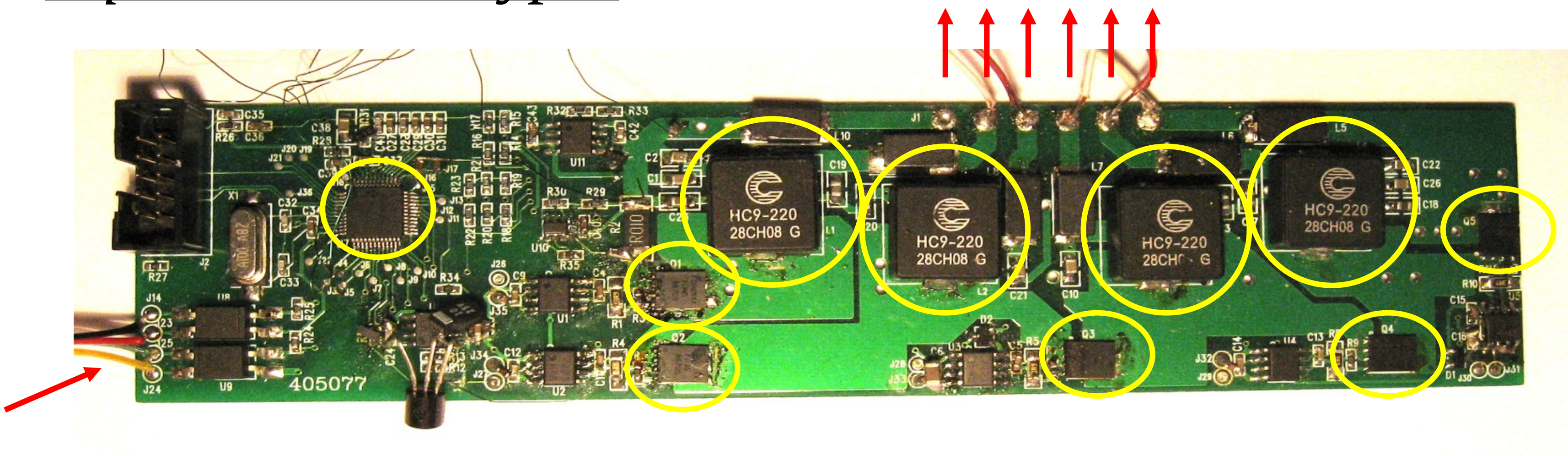
Battery Cell Equalizers

Summary

Equalizer type	Equalizing current	Current distribution	Current control	Current ripple	Manufacture	Cost	Control
Resistive	--	N.A.	+	+++	+++	+++	+++
Capacitive	-	+	--	--	++	++	++
Basic Inductive	++	+	+	++	+	-	-
Cuk	++	+	+	+++	-	--	-
Transformer	+	+++	--	--	--	--	++
Novel equalizer	++	++	++	++	+	+	--

Novel Battery Cell Equalizer

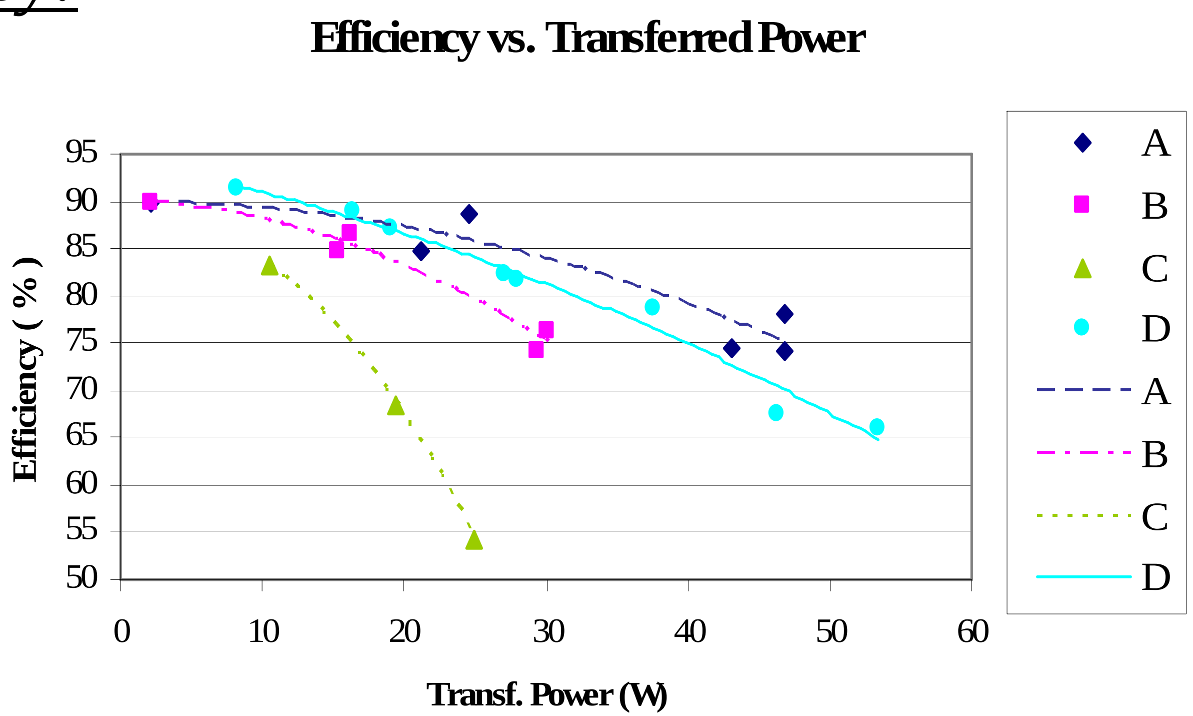
Equalizer Prototype:



- ➢Microcontroller
- ➢MOSFETs
- ➢Inductors
- ➢To 5 battery cells in series
- ➢Communication Bus

Novel Battery Cell Equalizer

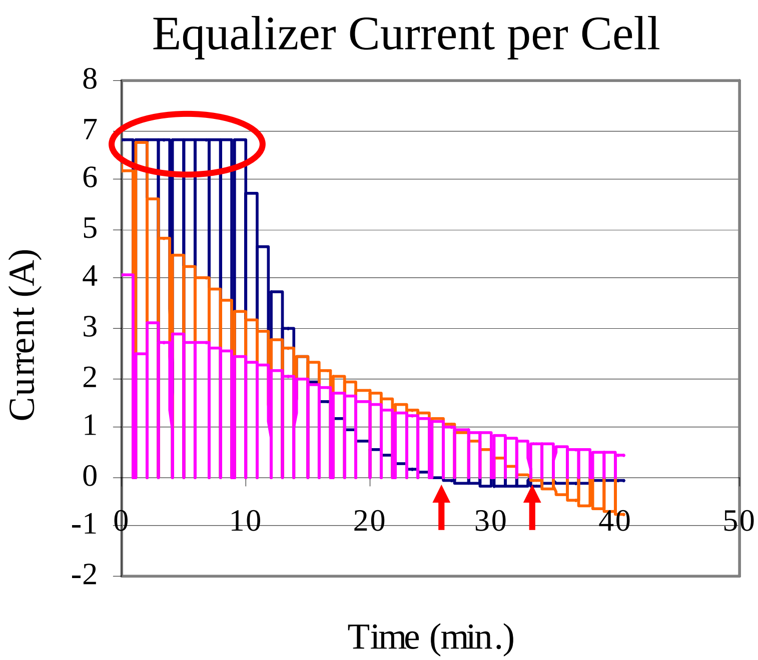
Efficiency:

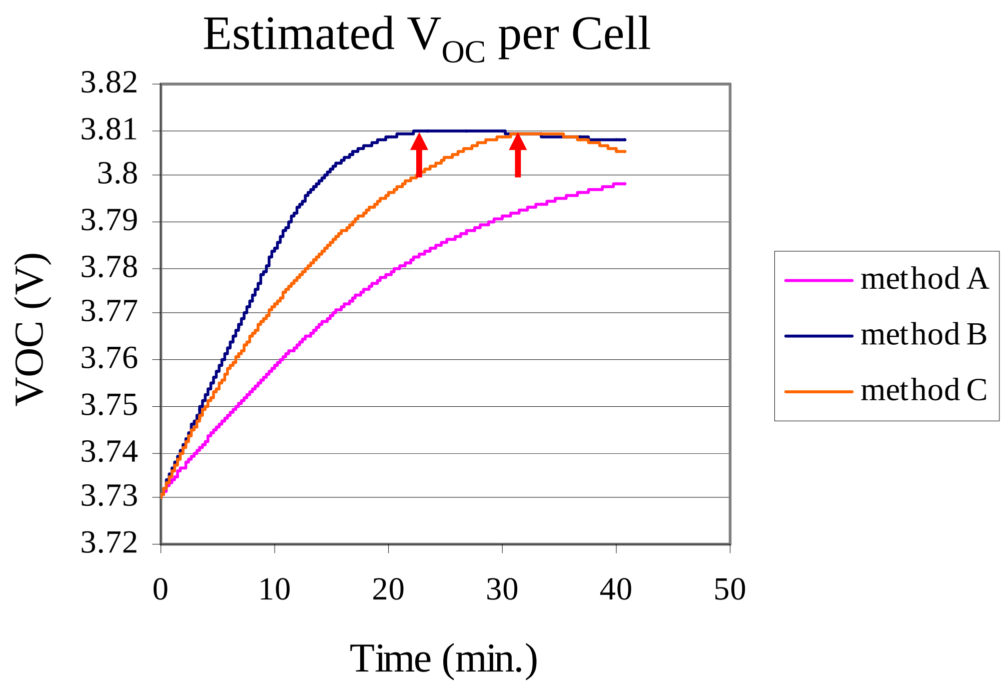


(A) Novel EQ. first Cell, (B) Novel EQ. second Cell, (C) Typ. EQ. First Cell, (D) Typ. EQ. second Cell

Dynamic Response

Modeling and Simulation Results:

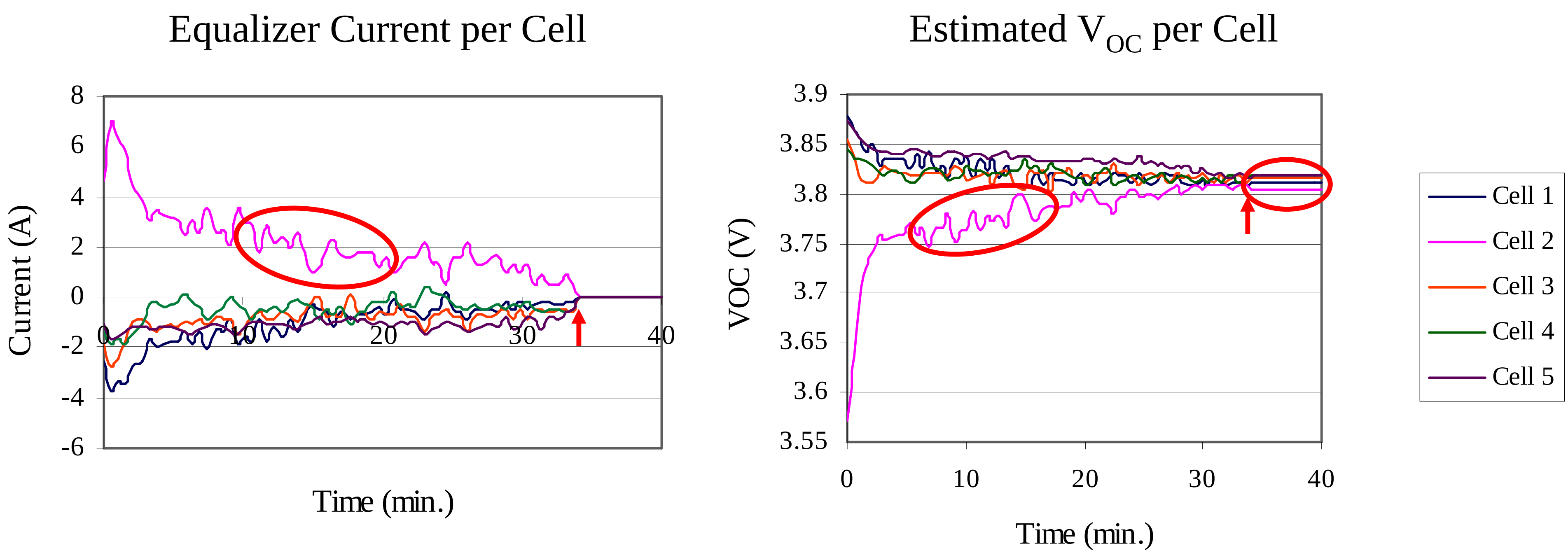




Method A: Direct cell-voltage equalization; no VOC estimation; critically damped.
Method B: Equalization based on V_{OC} estimation; critically damped.
Method C: Equalization based on V_{OC} estimation; over-damped, similar to prototype.

Dynamic Response

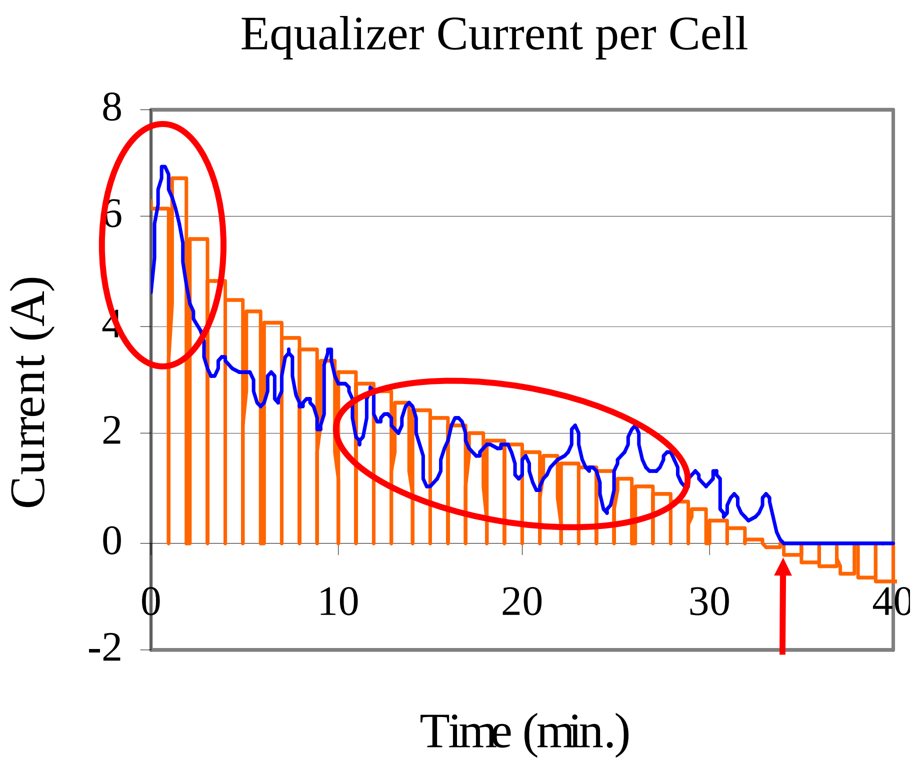
Experimental Results:

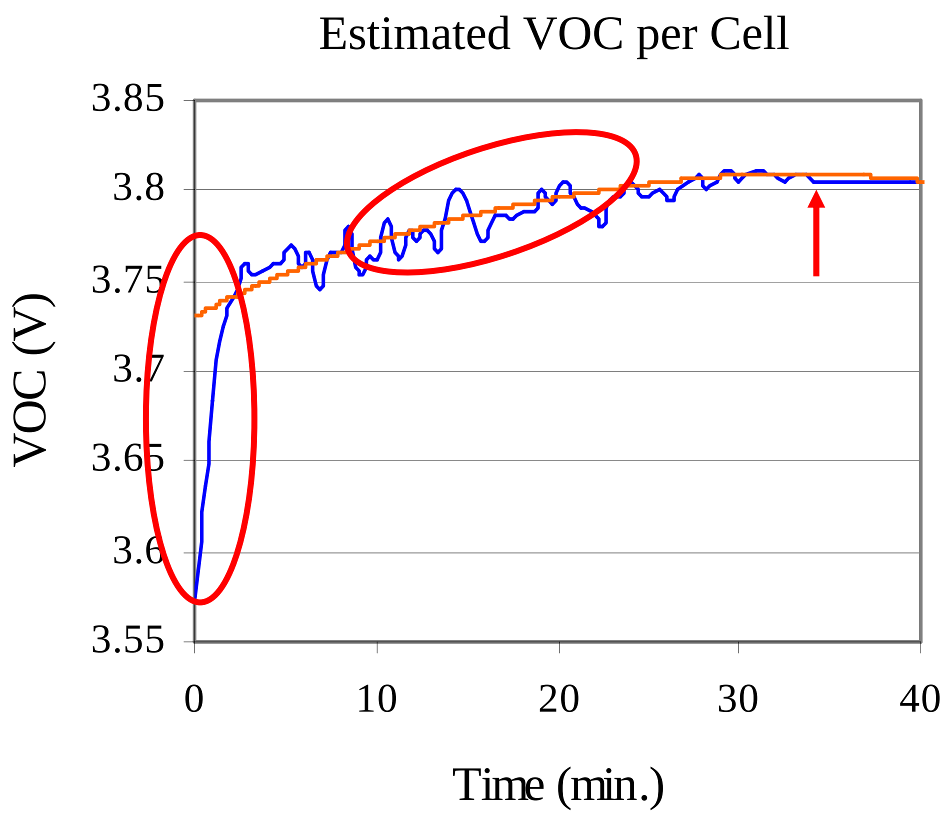


5-cell equalizer, cell #2 previously discharged by 2.5Ah capacity

Dynamic Response

Comparison Between Simulations and Measurements:





Simulation results, using method C.

Measurements, using the 5-cell equalizer, cell #2 previously discharged by 2.5Ah capacity

Economic Analysis

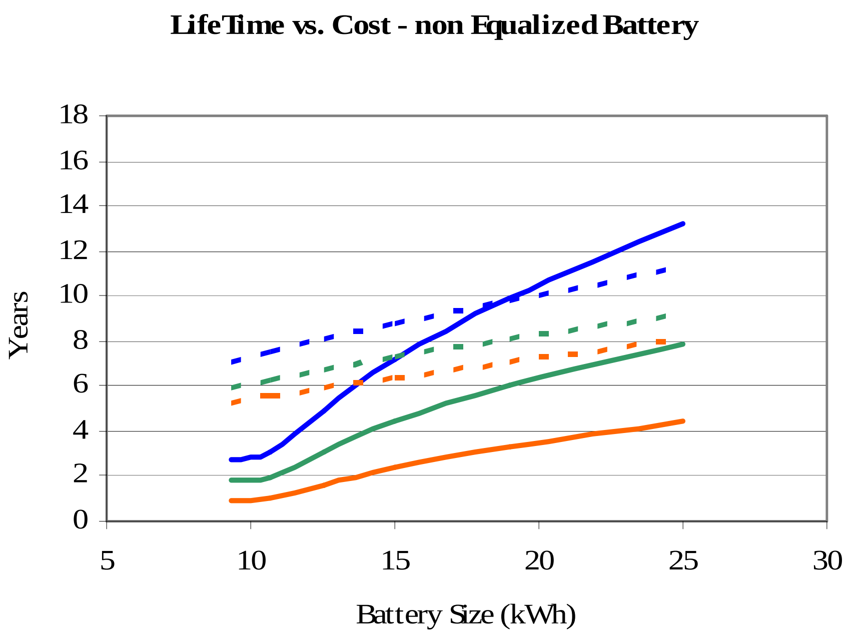
Cost Analysis

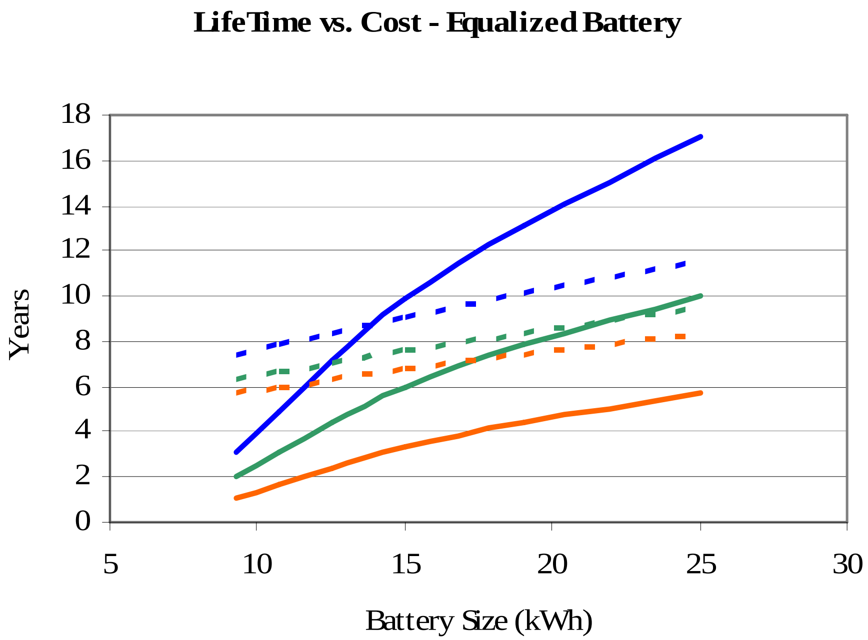
Eq. Type	$/board	Cells/ board	$/Cell	Boards/ Pack	$/Pack
Novel Equalizer	15.84	4	3.96	25	$396.00
Typical Inductive Equalizer	15.81	3	5.27	34	$537.50

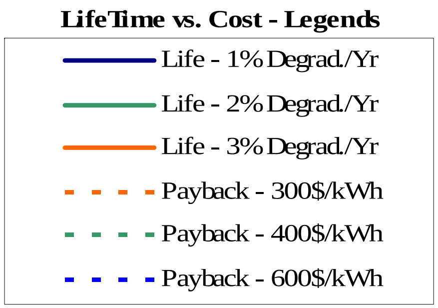
- Only $4.00 equalization per cell, compared to >$60.00 of the battery cell. Less than 10% of the battery cost.
- 37% improvement in cost for the "Novel Configuration."

Economic Analysis

Comparison of Equalized and Non-Equalized Systems







System Payback Time vs. Battery Lifetime, for Non-Equalized and Equalized Systems

Economic Analysis – Inferences

PHEVs are economically feasible with current battery/equalizing technologies, given the following conditions:

- The battery must be oversized, in order to last more than 10 years. This increases customer financial load.
- Battery management, including a power electronic cell equalizer, extends battery life and guarantees overall safety.
- Of course, battery improvements, such us Lithium Iron-Phosphate will help lower economic risks.

Conclusions and Future Work

- For EV/PHEV applications, the proposed novel cell equalizer displayed exceptional performance in most aspects, except control complexity.
- Reduced SOC utilization (50% capacity or less) and use of a high current, high efficiency, low cost cell equalizer makes future EVs economically viable.
- A detailed comparison with the popular inductive equalizer has been performed, demonstrating lower cost (40% lower) and higher efficiency (15-20% higher).
- The control method has been integrated within the proposed equalizer system, and modeled, simulated, and validated against experimental measurements, performed on a commercial grade prototype.
- As future work, the overall energy management system could be performed in one central processor.
- Furthermore, using advanced V_{OC} estimation methods, overall accuracy and stability gains can be achieved.

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