State-of-Health Estimation of Lithium-ion Batteries for Enhanced Electric Vehicle Safety

Pinki Saini (Roll no.: 22110194), Department of Electrical Engineering, IIT Gandhinagar
Advisor: Dr. Pallavi Bharadwaj, Smart Power Electronics Laboratory (SPEL), Department of Electrical Engineering, IIT Gandhinagar

Abstract

- Lithium-ion batteries degrade with usage, reducing Electric Vehicle (EV) safety and performance.
- A less experimentally extensive empirical technique is proposed for State-of-Health (SOH) estimation using voltage-time data during constant current charging.

Objectives

- To develop a simplified and efficient SOH estimation technique.
- Ensure real-time compatibility with Battery Management System (BMS).
- To bypass the need of internal battery parameters for SOH prediction.

Motivation and Introduction

Lithium-ion batteries degrade over time, reducing EV safety and performance

⇩

Accurate SOH estimation is vital to monitor battery condition and safety

⇩

Several SOH estimation techniques were studied — physics-based, model-based, and empirical approaches

⇩

Existing methods in literature are often complex, need more data, or unsuitable for real-time use

⇩

This project develops a simple, lightweight, and BMS-compatible SOH estimation technique

⇩

The goal is to enable real-time battery health monitoring to prevent battery abuse and enhance EV safety

Methodology

1. Model Development:

- Adopted a **2RC Equivalent-Circuit Model (ECM)** to study the behaviour of a lithium-ion battery, shown in Fig. 1.
- Development of state of charge-open circuit voltage relation with **low charging (C/20-rate)** cycling data.

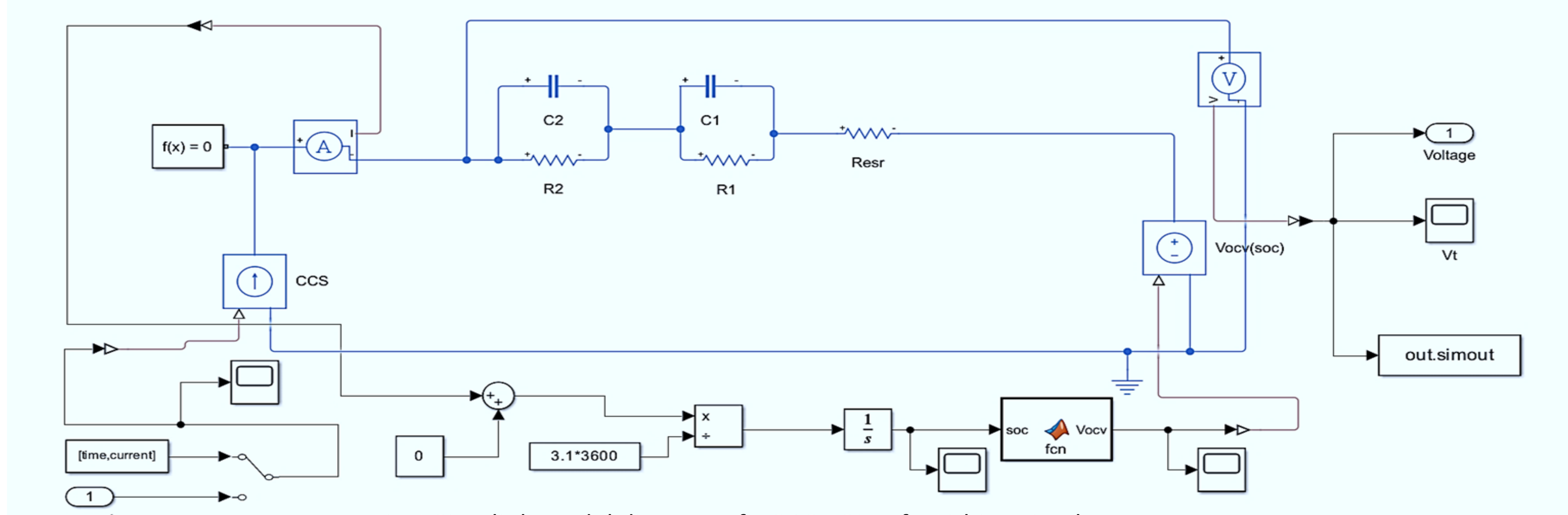

Fig:1 Simulink model diagram of a 2RC ECM of a Lithium-ion battery

2. Parameter Estimation:

- Parameters Resr=0.0414 Ω, R1=0.0292 Ω, R2=0.0154 Ω, C1=1.0984e+03 F, and C2=3.8849e+04 F were estimated using **pulse cycling method,** shown in Fig. 2.
- A C/2 constant current charging is then performed, as shown in Fig. 3.

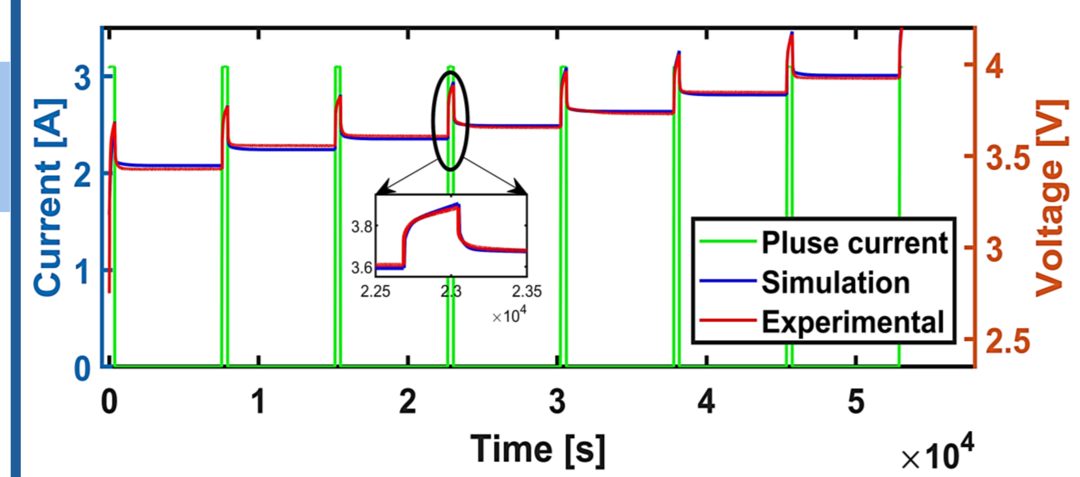

Fig:2 Pulse current (1C) and voltage simulation profiles

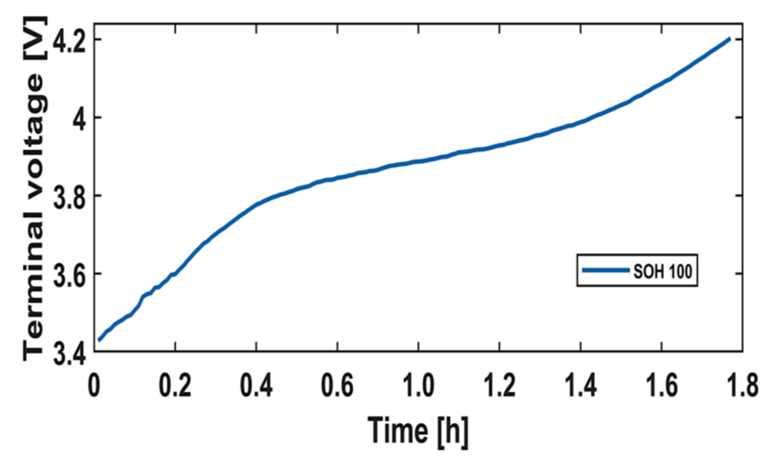

Fig: 3 Voltage-time profile at SOH 100%

- From [2], we observed that as SOH decreases, the voltage-time curve shifts upward and reaches the upper cutoff voltage in shorter time, shown below.

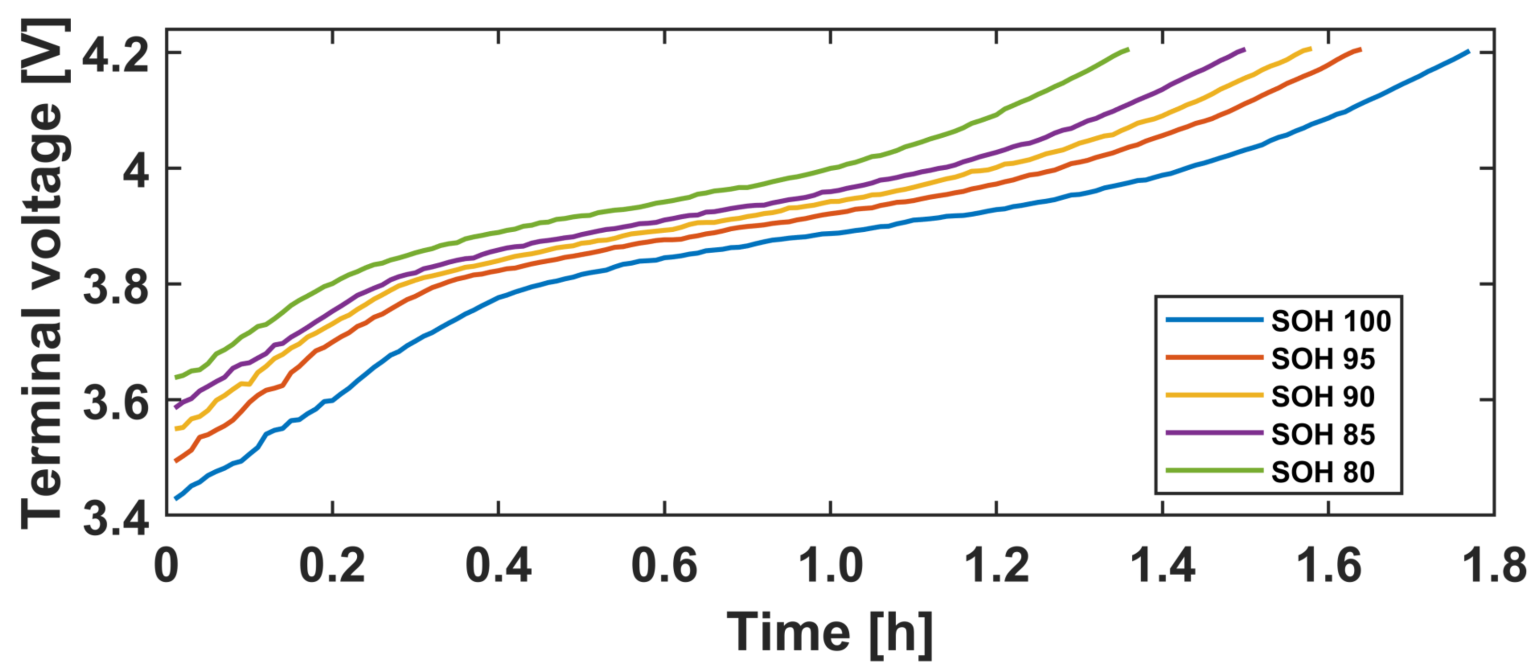

Fig: 4 Voltage-time profiles at different SOH levels [2]

Hypothesis

- The changes in the voltage vs time profiles (shown in Fig. 4) can be utilized to reliably predict the SOH of a new battery with unknown voltage vs time plot.

Feature Extraction

- Extracted two key features from each voltage vs time curve of lithium-ion battery at different SOH levels (100, 95, 90, 85, and 80), shown in Fig. 5.

1. **Slope**: Change in voltage per unit time in 3.8V–4.0V region.
2. **T_4V**: Total time taken to reach 4.0V.

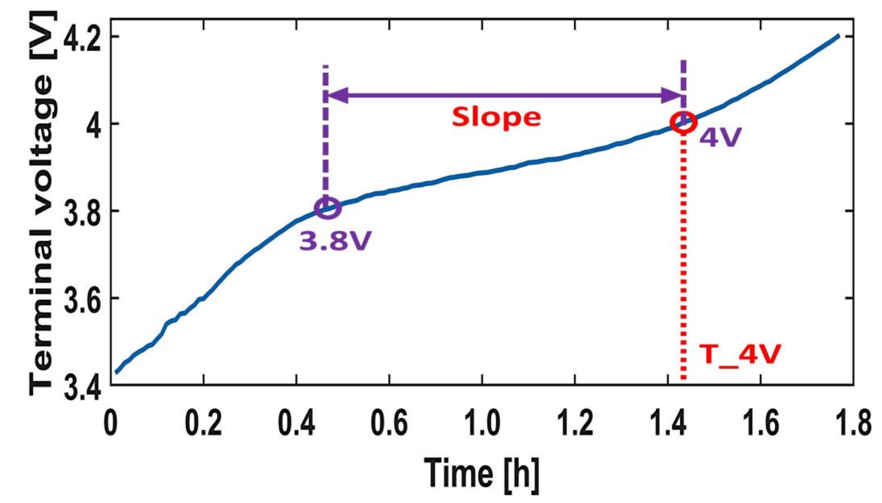

Fig: 5 Representation of feature extraction

➢ Flow Diagram of SOH estimation algorithm from unknown voltage-time profile is presented below:

Known Voltage-Time Profiles ⇨ Feature Extraction ⇨ MATLAB Regression Fit Function ⇩ Unknown Voltage-Time Profile ⇦ Feature Extract and Mapping ⇦ SOH Prediction

Results

Different Cases	Actual SOH	Slope (V/sec)	T_4V (hrs)	Predicted SOH	Absolute Percentage error
CASE 1	[87-89]%	0.002919	1.14	88.06%	[1.22, 1.06]%
CASE 2	[98-100]%	0.002654	1.36	99.10%	[1.12, 0.90]%

Conclusion

- Proposed method is simple, accurate, and real-time implementable.
- Requires only voltage-time data, no need of internal battery parameters.
- Compatible with embedded BMS in EVs.

Future Scope

- Test with real experimental charging data at different SOH levels.
- Extend to study the effect of temperature variation for SOH estimation.
- Deploy in STM32-based plug-and-play IoT system.

Acknowledgment

- Extremely thankful to Mr. Shiv Shankar Sinha for all the guidance.

References

1. Lin, Cheng, Aihua Tang, and Wenwei Wang. "A review of SOH estimation methods in Lithium-ion batteries for electric vehicle applications." *Energy Procedia* 75 (2025): 1920-1925.
2. Guo, Zhen, et al. "State of health estimation for lithium ion batteries based on charging curves." *Journal of Power Sources* 249 (2024): 457-462.