Safety- and Aging-aware Fast Charging of Lithium-Ion Batteries with Model Predictive Control

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Abstract

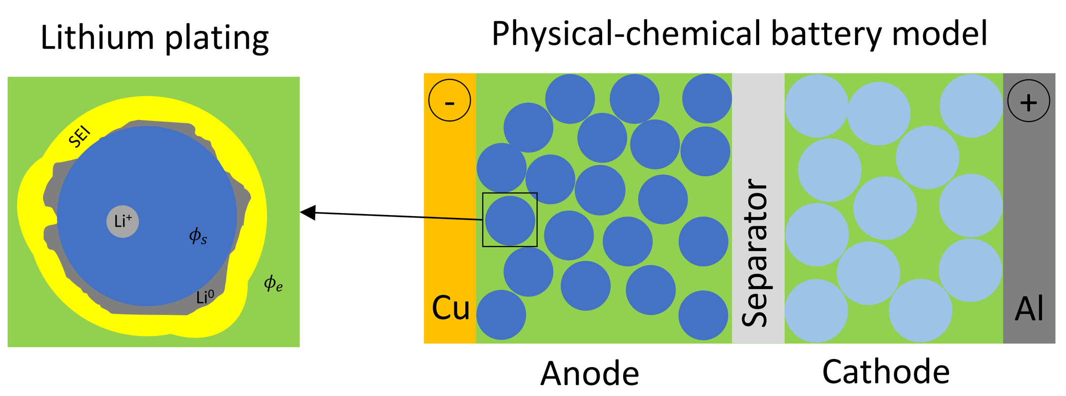
During fast charging of lithium-ion batteries, a phenomenon known as lithium plating may occur, wherein lithium metal is deposited onto the anode surface more quickly than intercalation takes place. In this poster, a fast charging framework is presented by combining a reduced order electrochemical battery model, extended Kalman filter and model predictive controller to reduce lithium plating.

Conclusion

The proposed fast charging framework can increase the charging time of lithium-ion batteries significantly while mitigating lithium plating, reducing aging and increasing safety. The presented model-based implementation of the fast charging algorithm enables rapid adaptation to new battery types, which is of great interest to battery research and industry.

Introduction

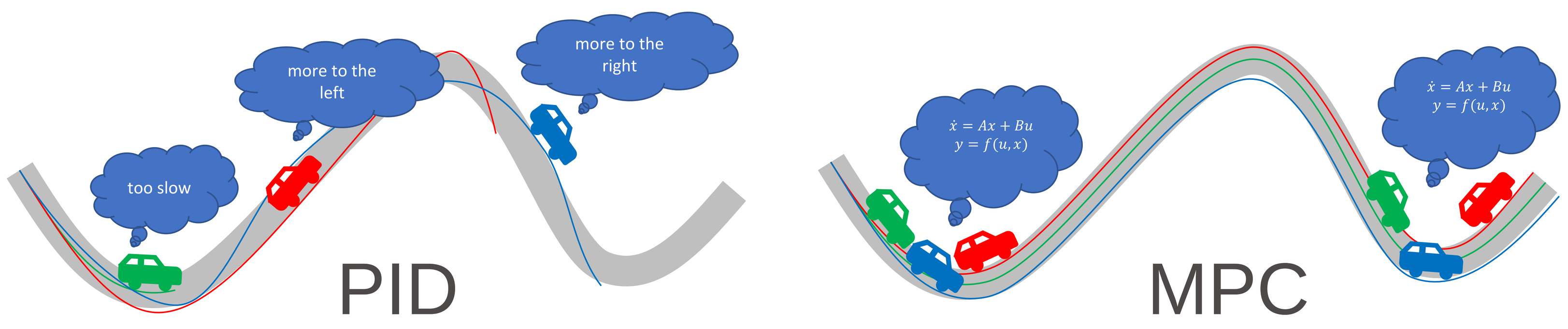
- Lithium plating can occur, if at low temperature the anode potential vs. Li/Li^+ drops below 0V
- Physical-chemical battery model can simulate the necessary battery internal states
- Model order reduction in state-space notation for implementation on the battery management system



Model Predictive Control (MPC)

Is an optimal control technique in which the computed control actions minimize a cost function for a constrained dynamic system over a finite, time horizon.

- Can be applied to control multiple constraints
- Can handle multiple input multiple output systems
- No parameter tuning and no cascading necessary



Methodology

- Define optimization problem with a cost function and constraints
- Use extended Kalman filter for state estimation
- Apply two optimization algorithms
  - Quadratic Programming (QP)
  - Nonlinear solver
- Apply model in the loop validation to verify functionality
- Perform processor and hardware in the loop (HIL) to verify closed loop control capability

Cost function

$$\min_{i_{app}} J_k = \sum_{i=1}^{m} ||SOC_r - SOC_{k+i|k}||^2$$

Constraints

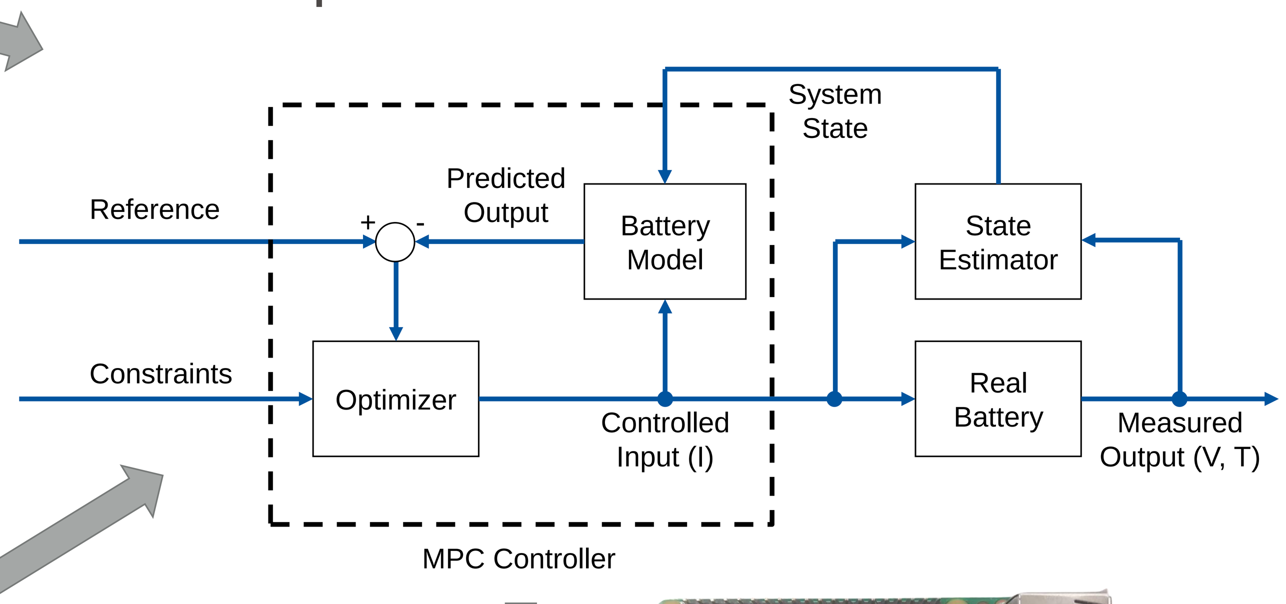
subj. to $-10A \leq i_{app,k} \leq 10A$

$$2.5V \leq V_{cell,k} \leq 4.2V$$
$$0 \leq SOC_k \leq 0.8$$
$$T \leq 40°C$$
$$\text{Anode pot. vs. Li/Li}^+ \geq 5mV$$

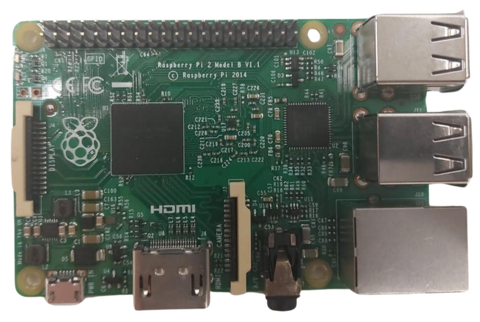
Reduced order battery model

$$\dot{x} = Ax + Bu$$
$$y = f(u, x)$$

Model predictive control architecture



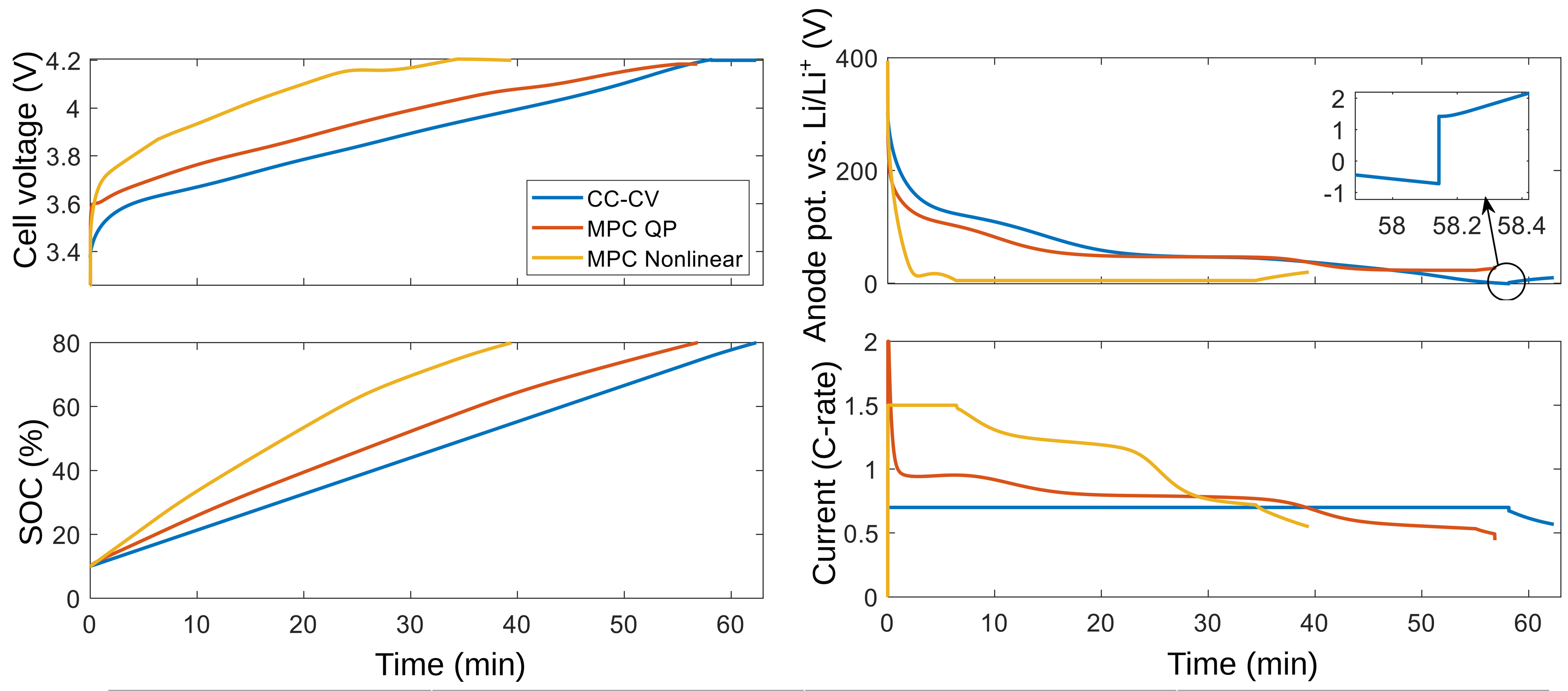
Deployed on a Raspberry Pi 3 B+



Results

- Applied to a commercial NMC811/SiC battery, charge from 10% to 80% SOC at 0°C environment temperature
- MPC charging time is 35% faster compared to CC-CV proposed by the manufacturer's data sheet
- Maintain anode potential vs Li/Li^+ above 0V during the entire charging process
- HIL execution time validation with a Raspberry Pi 3 B+

	EKF	MPC QP	MPC Nonlinear
Mean time	0.069 ms	0.997 ms	24.96 ms
Max time	0.88 ms	26.74 ms	116.73 ms



	CC-CV	MPC QP	MPC Nonlinear
Charging time	62min 21s	56min 12s	39min 25s

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