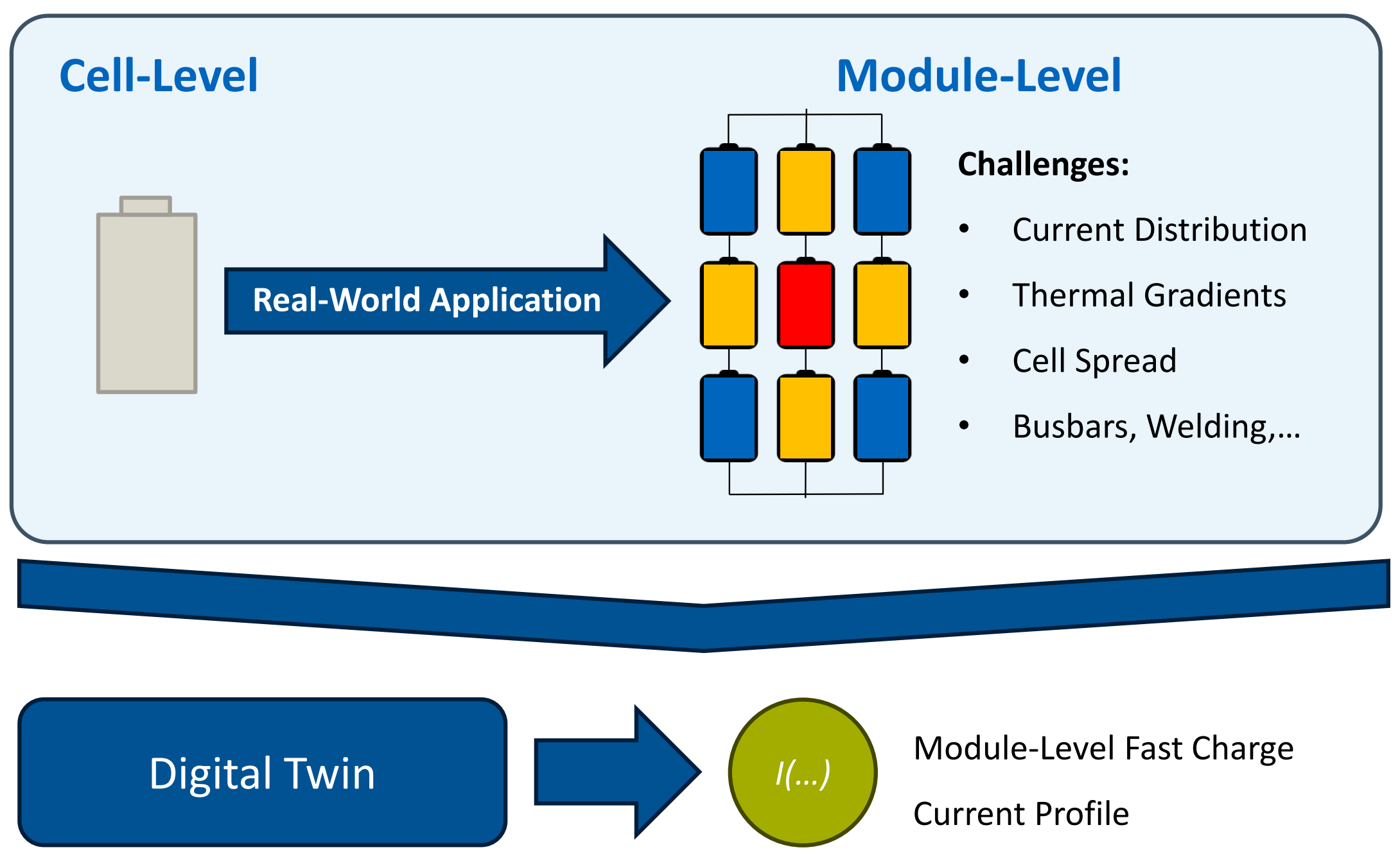
Technical University of Munich

Anode Potential Control for Electric Vehicle Fast Charging on Cell and Module Level

Kareem Abo Gamra, Raphael Urban, Christian Allgäuer, Markus Lienkamp

Background

Ultra-fast charging in 15 minutes or less is increasingly demanded for electric vehicles to offer a similar experience to internal combustion engine vehicle refueling [1]. To achieve this, several past studies have proposed model-based fast charging to prevent lithium plating by maintaining positive anode potentials [2]. Only few of these studies however examine pack-level degradation behavior, although past research has indicated, that pack-level behavior cannot be extrapolated from cell-level analysis [3, 4]. In the context of model-based charging strategies, interconnected cells pose a challenge due to electrical and thermal coupling effects, as well as unknown current distributions between the cells [5]. This necessitates examinations of both individual cells and battery modules, to allow direct comparison and evaluate the applicability of model-based fast charging for different use-cases.



Cell-Level

Module-Level

Real-World Application

Challenges:
- Current Distribution
- Thermal Gradients
- Cell Spread
- Busbars, Welding,…

Digital Twin

I(…)

Module-Level Fast Charge Current Profile

Methodology

To analyze the scalability of model-based fast charging to module-level, a commercially available **electrochemical cell model** is deployed to implement **anode-potential control** using a PID-Controller in MATLAB/Simulink and generating charge profile tables for use on a commercially available 18650 battery cell. Three cells are aged at a charge rate of **4C (10A)** using anode potential control at temperatures of **0°C, 25°C and 40°C.**

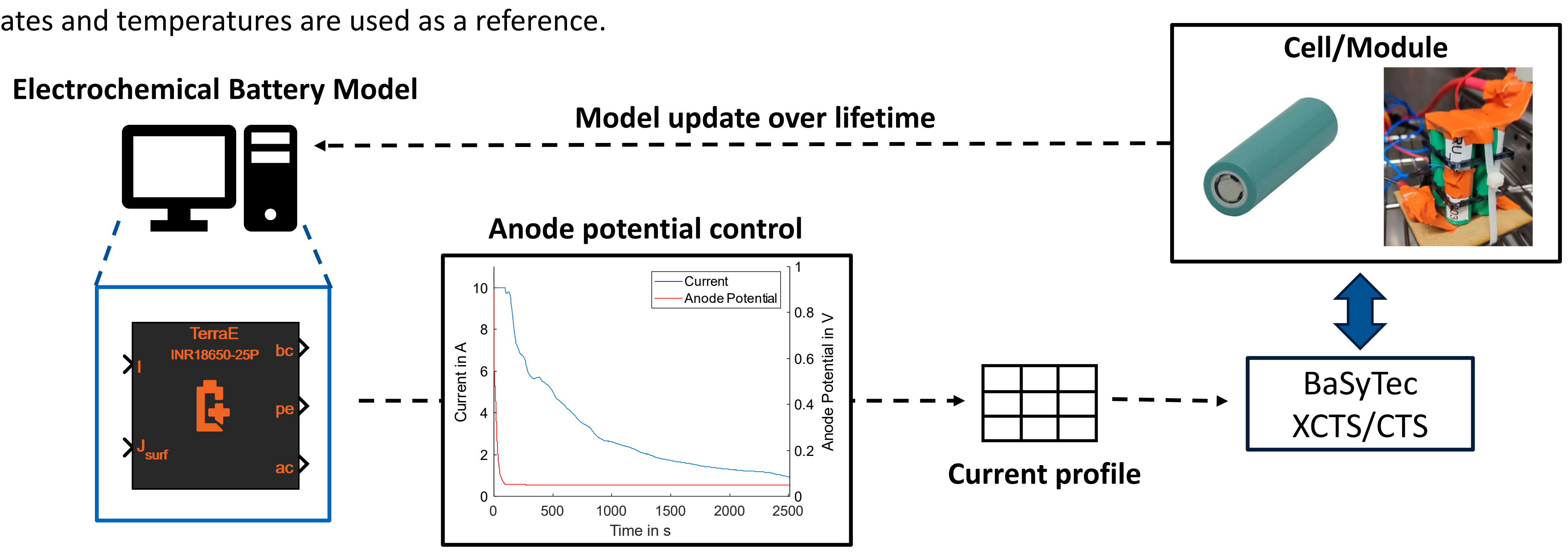
Additionally, two modules consisting of **4 cells in parallel** are constructed and laser-welded for **4C** aging at **0°C and 25°C.** The electrical coupling is modelled using PID-controllers to adjust the current to achieve identical voltages across the individual cells. Checkups are performed every 25 or 50 cycles at **25°C** and consist of the following:

- **C/3** constant-current constant-voltage **(CCCV)** charge and discharge for capacity determination
- **C/25** pseudo-open-circuit-voltage **(pOCV)** measurement
- Hybrid-pulse-power-characterization **(HPPC)** at **25%, 50% and 75% state-of-charge (SOC)** using charge and discharge pulses of **C/3, 1C, 2C, 3C and 4C.**

The cell models are updated using the measured capacity and resistance to generate new charge profiles, thus achieving derating over lifetime. CCCV aging measurements at different C-rates and temperatures are used as a reference.

Cell under study

Property	Value
Manufacturer	TerraE
Type	INR18650-25P
Format	18650
Cathode	NMC
Anode	Graphite
Rated capacity	2.5 Ah
Voltage bounds	2.5 - 4.2 V
Max. charge	4 A
Max. discharge	20 A



Electrochemical Battery Model

Model update over lifetime

Cell/Module

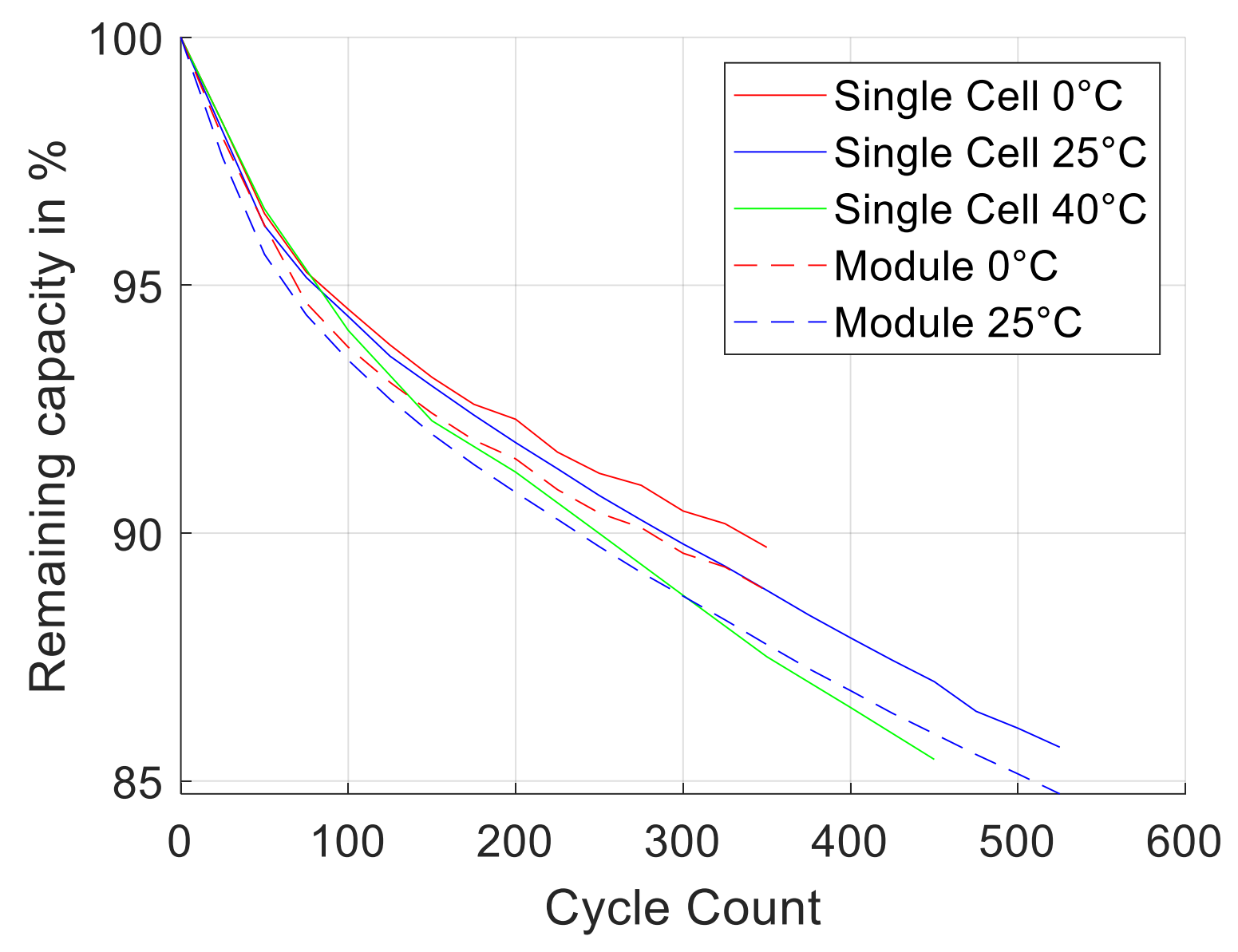
Anode potential control

Current profile

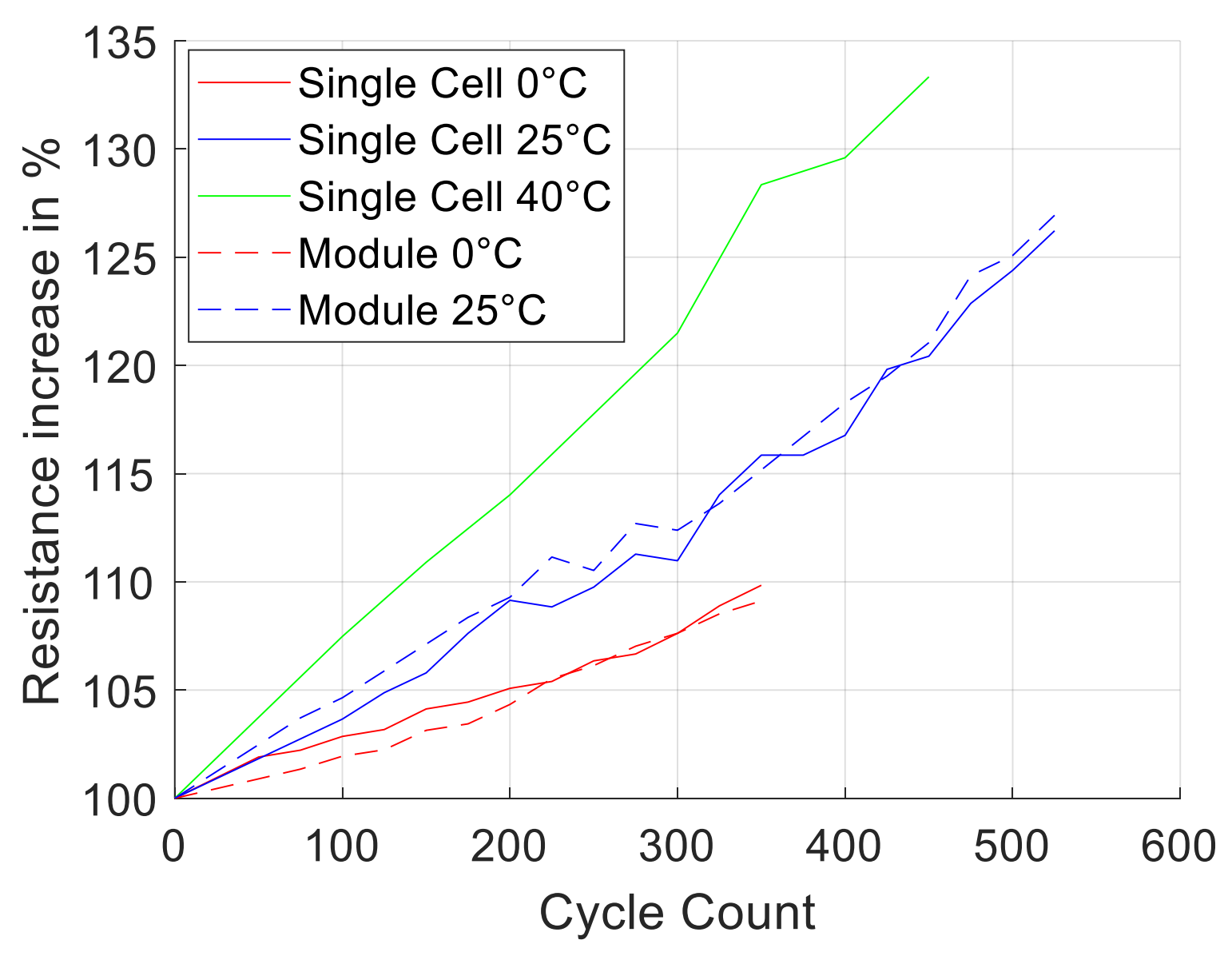
BaSyTec XCTS/CTS

Results

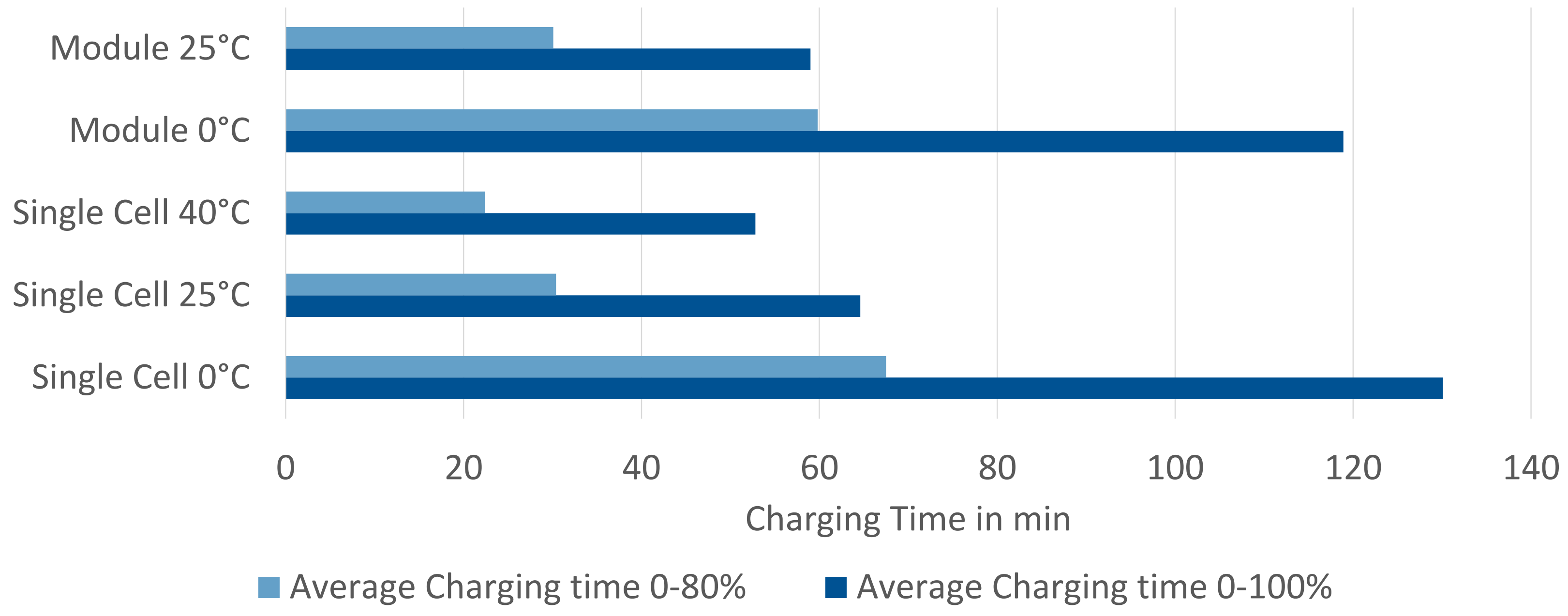
Capacity loss



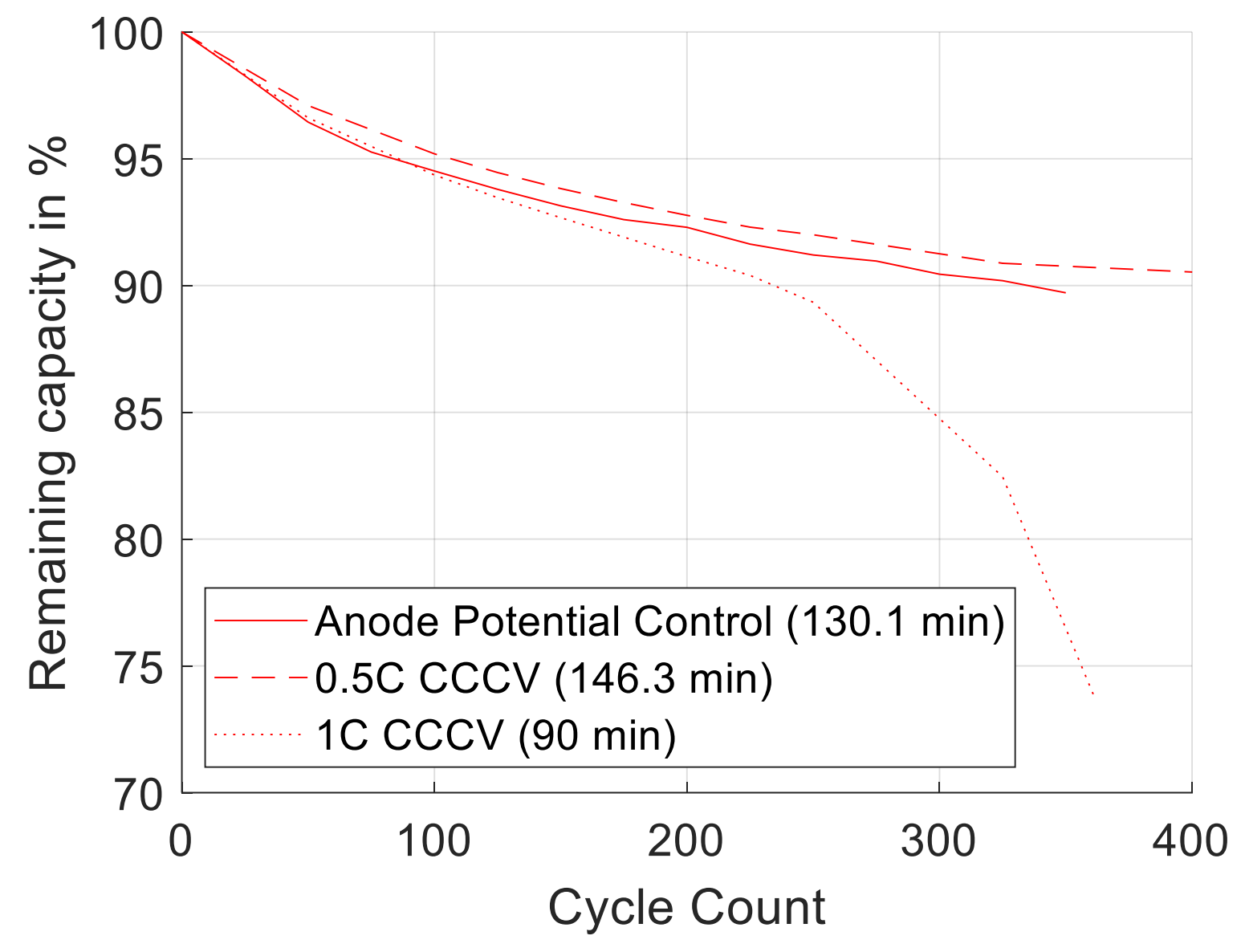
Resistance increase



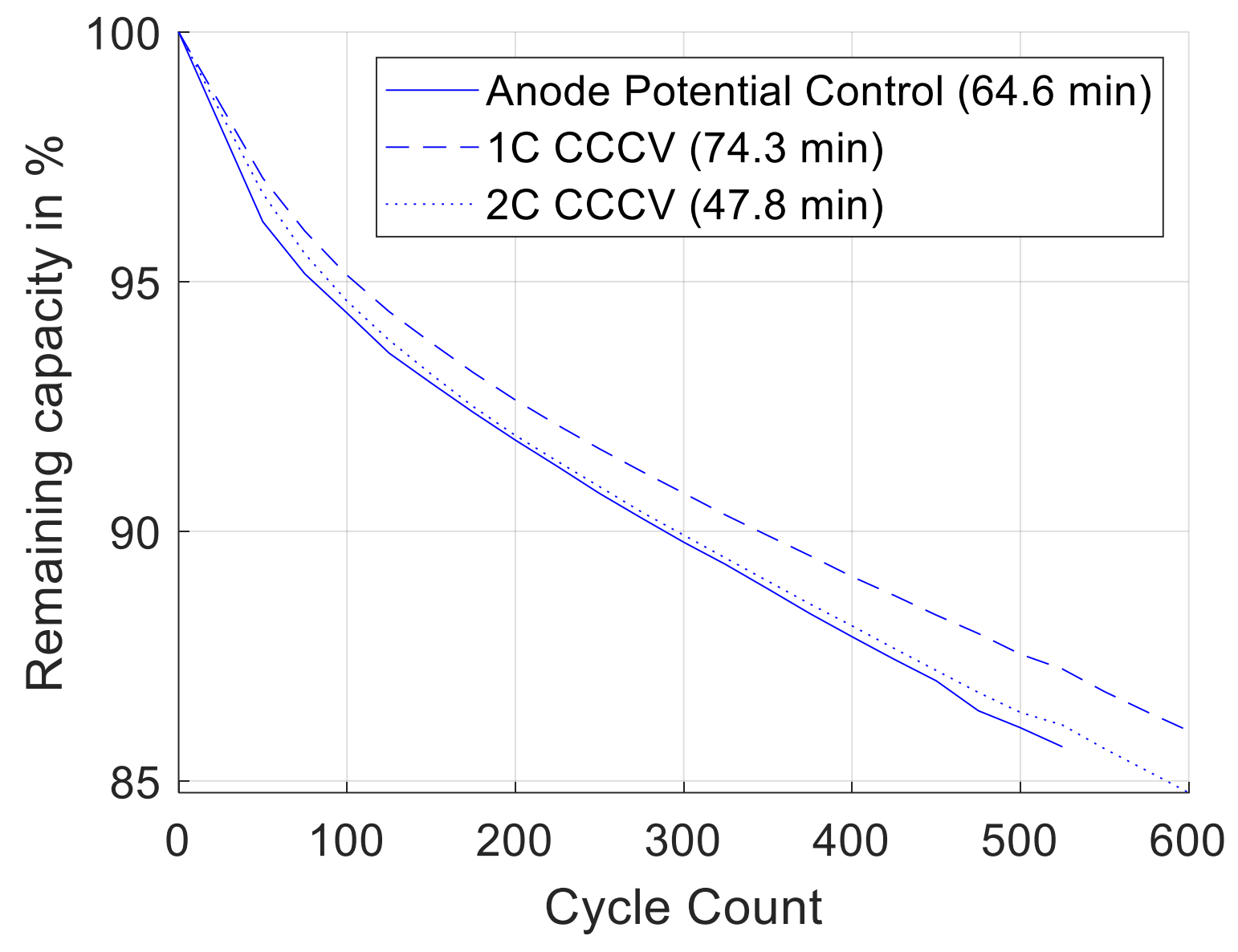
Average charging times using anode potential control



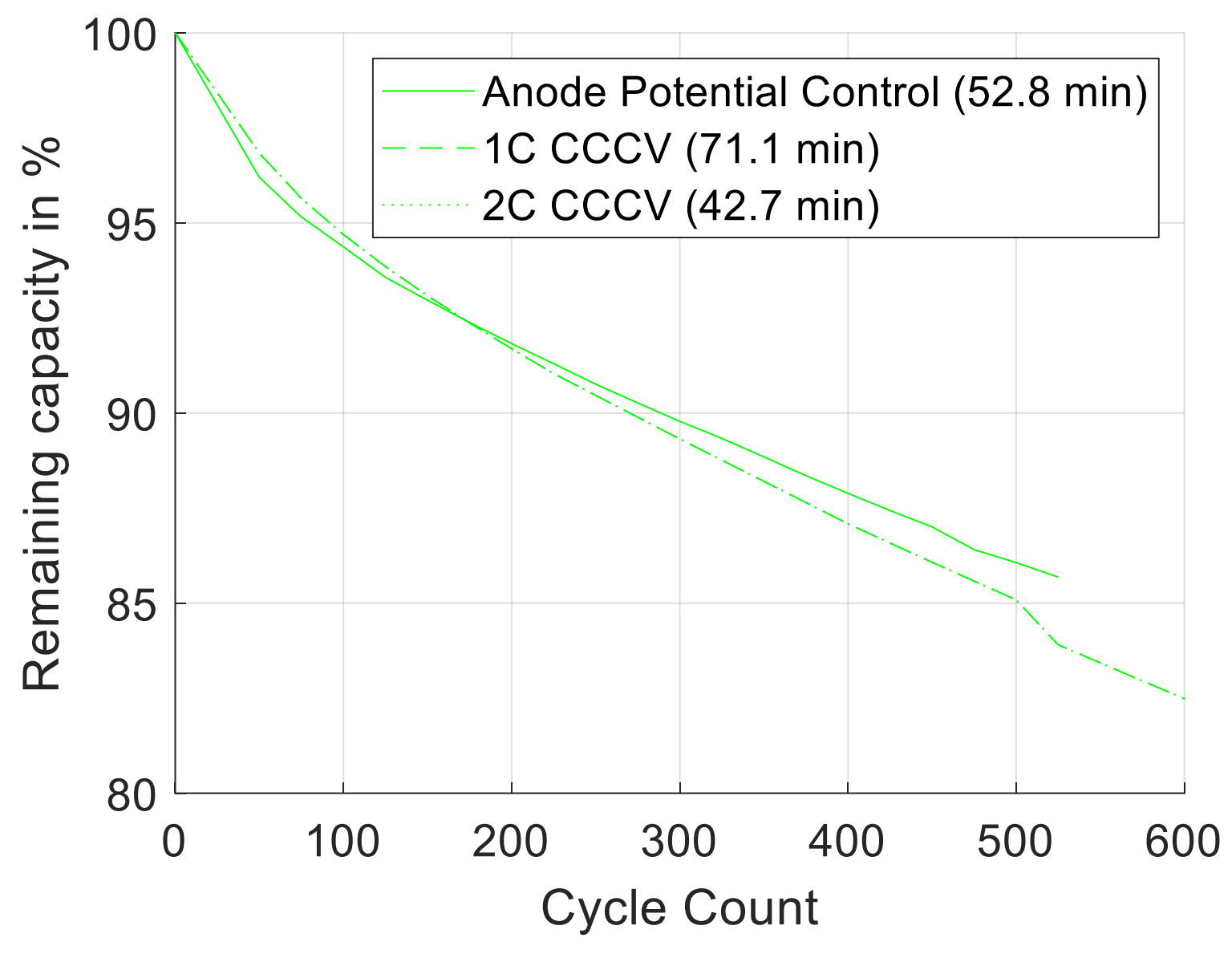
Anode Potential Control vs. CCCV (0°C)



Anode Potential Control vs. CCCV (25°C)



Anode Potential Control vs. CCCV (40°C)



- Capacity retention remains similar over all tested anode potential control cells/modules. Increased temperatures allow higher charging speeds, which leads to an increase in capacity loss and resistance growth.
- The examined modules degrade slightly faster than the single cells for both temperatures. This may be due to the increased charging speeds, which may indicate growing model inaccuracies due to unknown individual cell states within the modules.
- Anode potential control offers similar or reduced aging compared to time-equivalent CCCV charging regarding longevity.

Key Takeaways

- Anode potential control poses a viable charging strategy to increase charging speeds without risking significantly accelerated degradation on single cell and module level.
- Application of model-based fast charging on module level requires precise knowledge of electrical and thermal interactions between cells to maintain cycle life performance. Unknown aging trajectories of individual cells may pose a challenge.

Future Research

- Advanced aging diagnostics and post-mortem analysis to evaluate charging strategy and ambient temperature influence on occurring aging mechanisms.
- Development of electro-thermal modelling methodology to predict individual cell behavior within battery packs and derive module-adjusted charging strategies.

Technische Universität München
TUM School of Engineering & Design
Institute of Automotive Technology

Acknowledgment
Financial support was provided by the
German Federal Ministry of Economic Affairs and Climate Action (BMWK)
within the research projects “ultraBatt” and under grant number 01MV21015D.
The authors also thank Michael Kick, Christian Geiger and Dekun Ren for their support of this study,
as well as Batemo for providing the cell model.

Federal Ministry
for Economic Affairs
and Climate Action

DLR Projektträger

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