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Effects of Realistic Driving Profiles on the Degradation of Lithium-Ion Batteries

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SAEINDIA Society of Automotive Engineers INDIA

ETI Elektrotechnisches Institut

IEEE IAS IEEE Industry Applications Society

Motivation

- LIBs dominant energy storage in EVs
- Capacity and power degradation
- Reliable SOH Estimation
  - SOC Estimation
  - Maintenance planning
  - Cost-efficiency
  - Aging-friendly operating strategies
- Complexity of degradation mechanisms

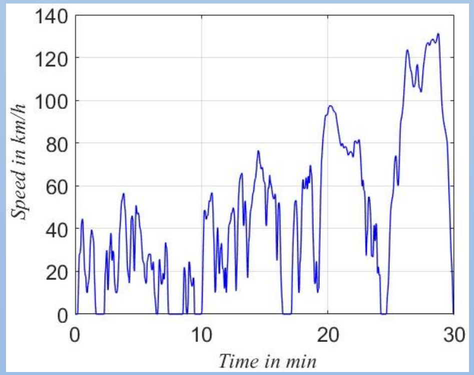
Aging Test Profiles

Conventional Test

1. **Cycling Test:** Charging with CC-CV & discharging with constant C-Rate
2. **Storage Test**

(++) cost effective
(+) easy to implement
(- -) representability

Standardized Driving Profiles



(++) cost effective
(+) representability
(-) speed profiles

Simulated Realistic Driving Profiles

Realistic Driving Profile Generator

(++) cost effective
(++) load oriented
(++) representability
(-) modeling inaccuracies

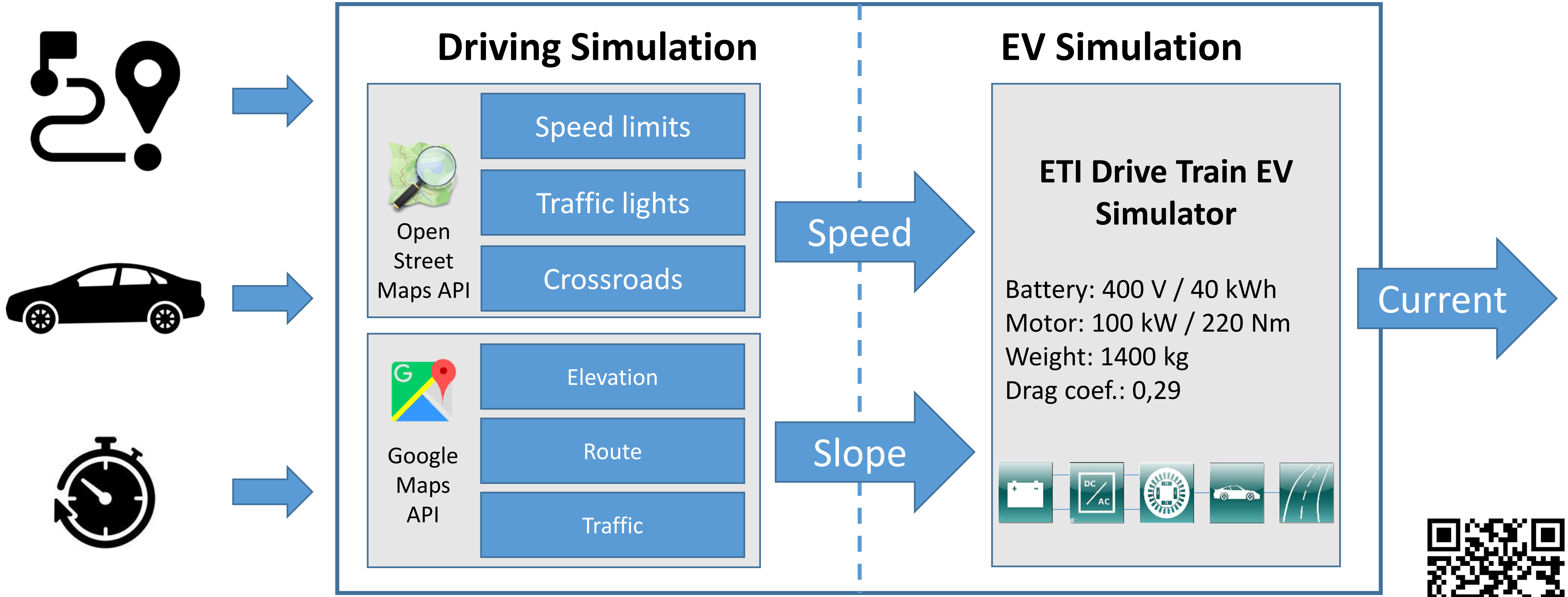
Real Driving Experiments

Image Source: S. Panchal, J. Mcgrory et al., "Cycling degradation testing and analysis of a lifepo4 battery at actual conditions," Int. J. of Energy Research

(+++) real-word condition
(+++) representability
(- - -) time consuming
(- - -) expensive

cost & representativeness

Realistic Driving Profile Generator



Source: Kalk et al., Generating realistic data for developing artificial neural network based SOC estimators for electric vehicles, doi.org/10.5445/IR/1000159884

Overview of Proposed Method

Test Profiles

Realistic Driving Profile Generator

Conventional Test Profiles

Normal Use

High Use

Zyk1

Zyk2

Cell Testing

Cell Cycling

Cell Storage

(25°C 100% SOC
25°C 30%SOC)

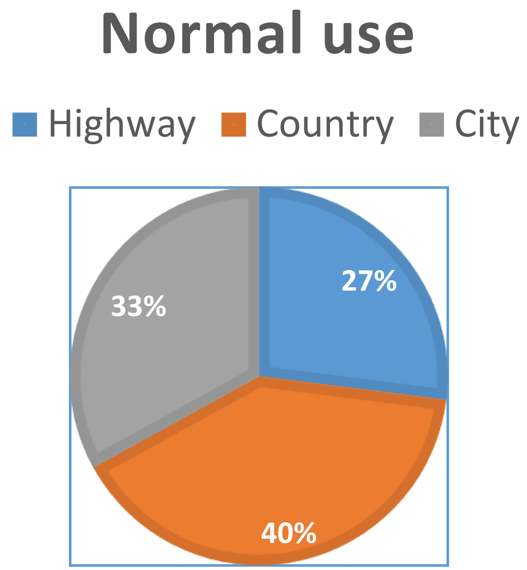
Analysis

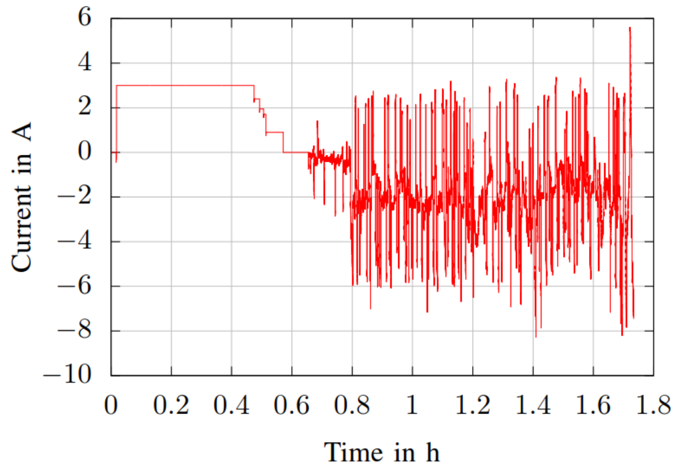
Capacity Test

Electrochemical Impedance Spectroscopy (EIS)

Generated Realistic Driving Profiles

- **"Normal use"** → average usage of passenger cars
  - 96 Road trips in Germany
  - 2376 km total distance
  - Highway, city and country roads
  - Standard charging with CC-CV
- **"High use"** → commercial EV
  - Karlsruhe-Leipzig, Germany
  - 527 km Highway
  - Fast Charging with MSCC





Test Profiles and Cell Cycling

	Realistic tests		Conventional tests	
Profile Name	„Normal Use“	„High Use“	„Zyk1“	„Zyk2“
Discharging	Normal Use	High Use	1C Discharging	2C Discharging
Charging	CC-CV (1/3 C)	MSCC (fast charging)	CC-CV (1/3 C)	CC-CV (1/3 C)
DOD	80 %	80 %	100 %	100 %
Temperature	20°C			
Equipment	Cycling: BaSyTec XCST + Environmental Chamber			
	Capacity Test and EIS Measurement: Biologic BCS 815-128			
Cell type	21700 Round Cell LFP – 3 Ah			

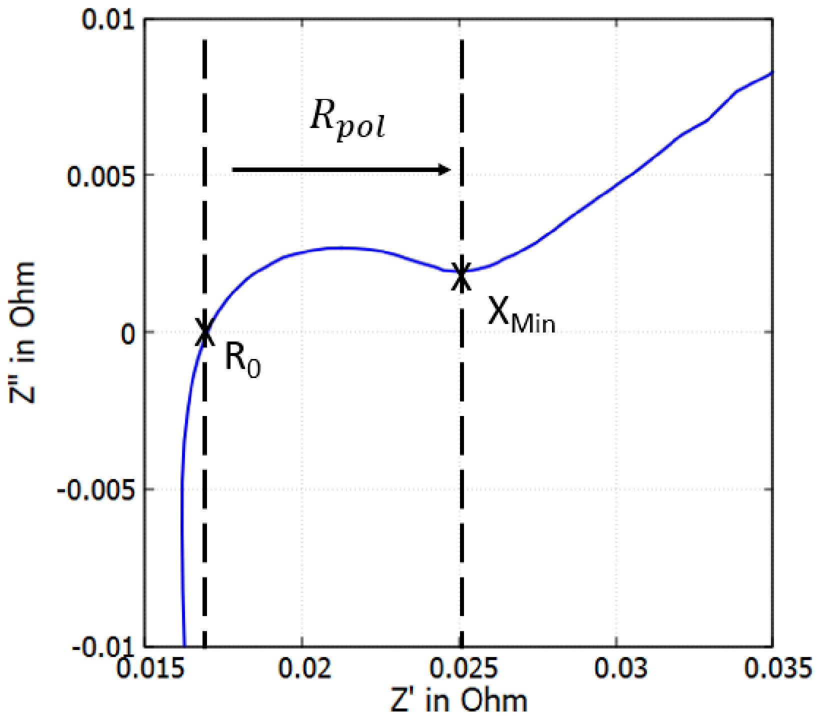
Analysis Methods

Capacity Test:

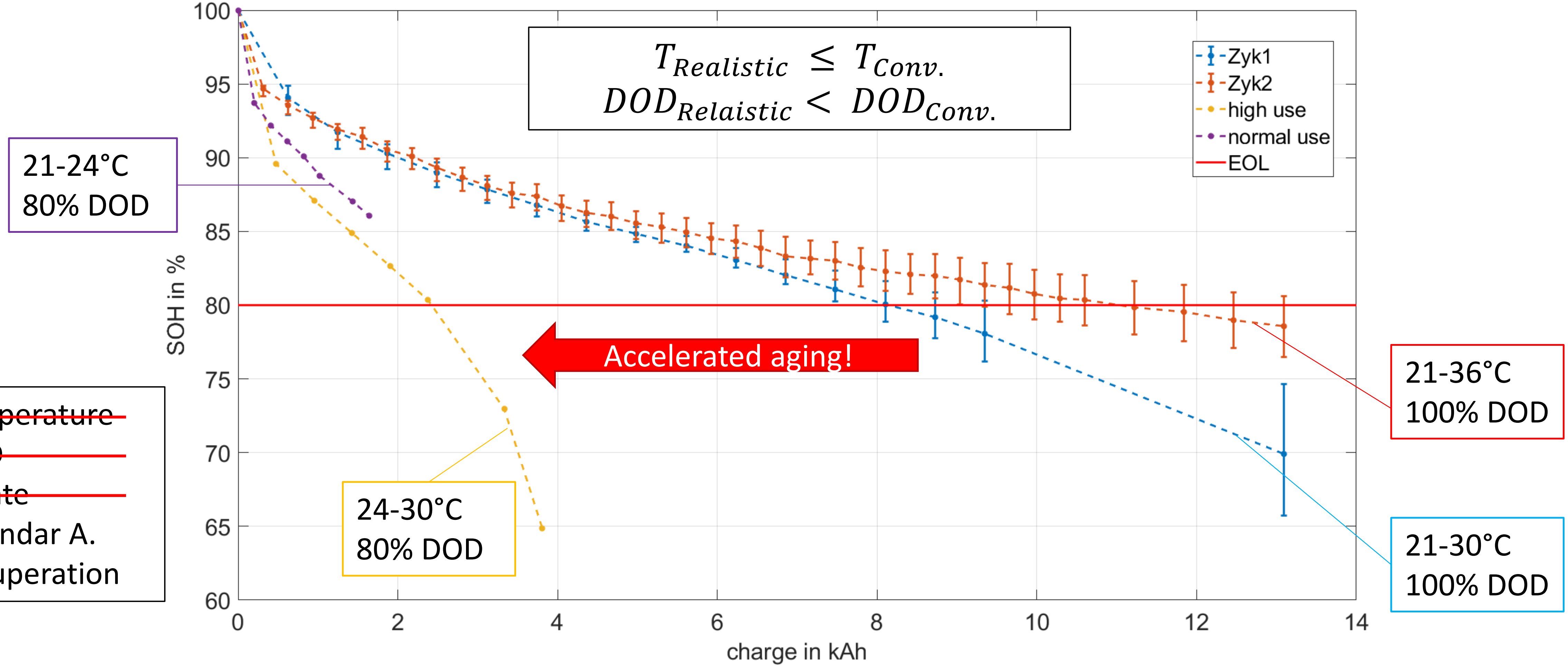
- CC-CV Charging with 1/3 C
- Discharging with 1/3 C

Electrochemical Impedance Spectroscopy (EIS):

- Ohmic (R_0) and polarization resistance (R_{pol}) with points-of-interest method
- R_0 : ohmic losses caused by surface contacts and the conductivity of materials
- R_{pol}: charge transfer losses in interphase transitions and inside the active material of the electrodes

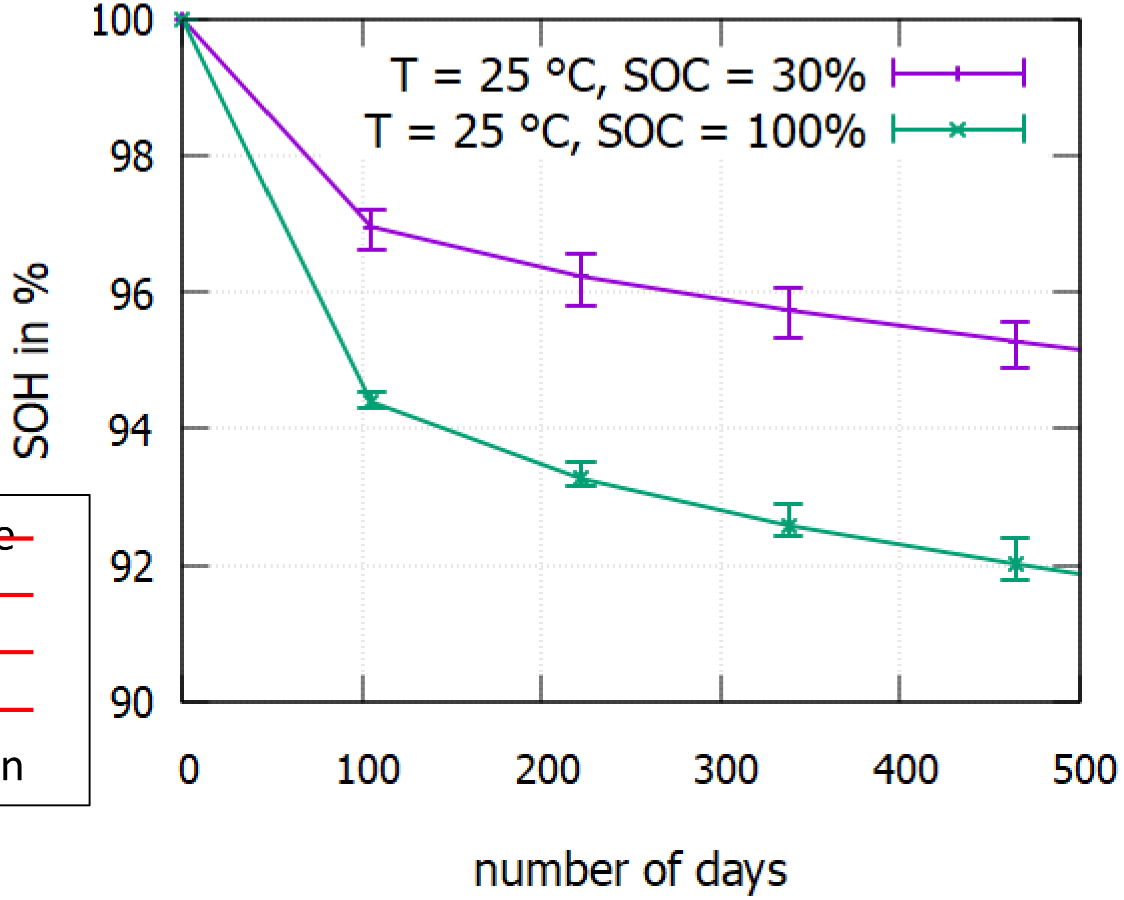


Results: Capacity A. – Cycling Test



- ~~Temperature~~
- ~~DOD~~
- ~~C-Rate~~
- Calendar A.
- Recuperation

Results: Capacity A. – Storage Test

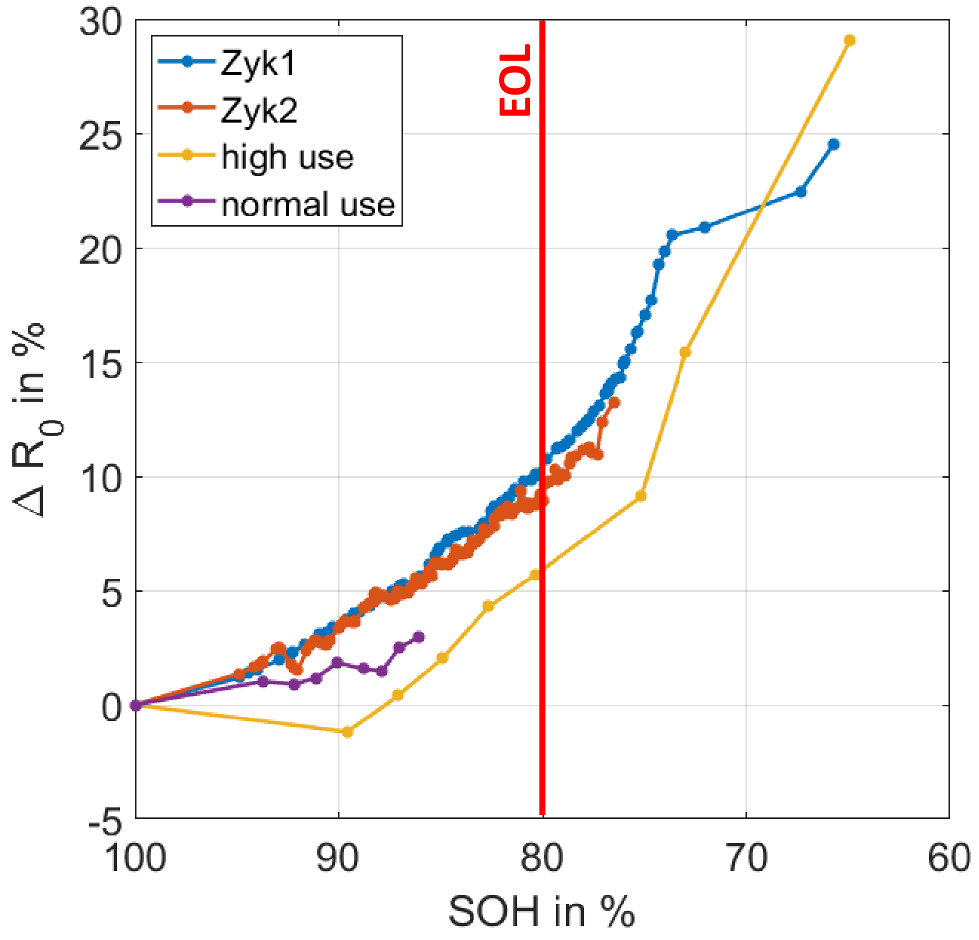


~~Temperature~~
~~DOD~~
~~C-Rate~~
~~Calendar A.~~
- Recuperation

	Cyclic Test Duration
Normal Use	210 days
High Use	98 days
Zyk1	525 days
Zyk2	490 days

Realistic tests < Conventional tests

Results: EIS A.– Ohmic Resistance



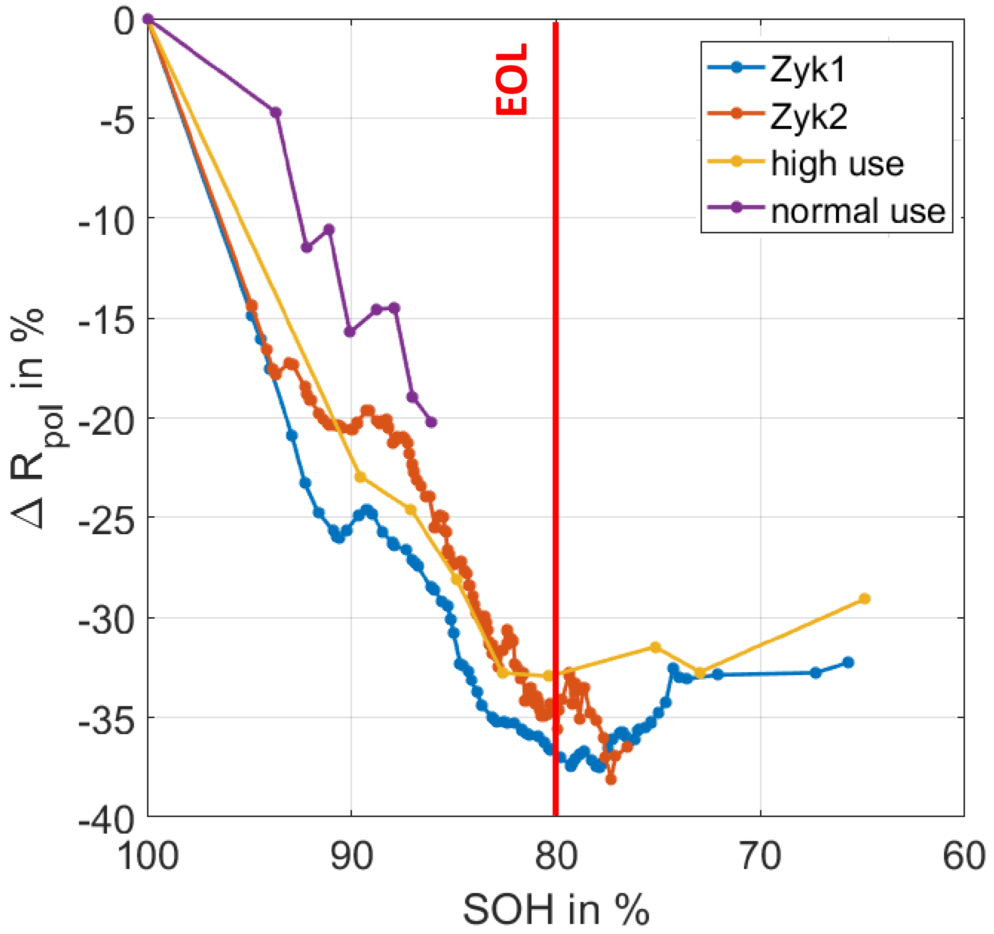
- Increasing R_0
- Realistic Tests < Conventional tests

→ Lower DOD Level at Realistic Tests

$$U_{Cutoff,Conv.} < U_{Cutoff,Realistic}$$

→ Lower voltage limits amplify lithium plating

Results: EIS A.– Polarization Resistance



- Decreasing R_{pol}
- Similar trends across all profiles

→ Dominating degradation mechanisms causing the loss of lithium inventory (LLI) remain unchanged with realistic profiles

Summary & Outlook

- Realistic driving profiles lead to accelerated aging compared to conventional tests.
- Temperature, DOD and calendar aging cannot be the reason for the observed accelerated aging.
- Inclusion of recuperation phases in realistic profiles may be the reason of accelerated aging.
- Employing realistic profiles in testing can enhance the precision of battery lifetime predictions and SOH estimations.
- Further research is essential to fully understand the impacts of real-world conditions and to formulate strategies that prolong the life of EV batteries.

Thank you for your kind attention!

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