Institute for Power Electronics and Electrical Drives
Electrochemical Energy Conversion and Storage Systems
Prof. Dr. rer. nat. Dirk Uwe Sauer

From Accelerated Aging Tests to a Lifetime Prediction Model: Analyzing Lithium-Ion Batteries

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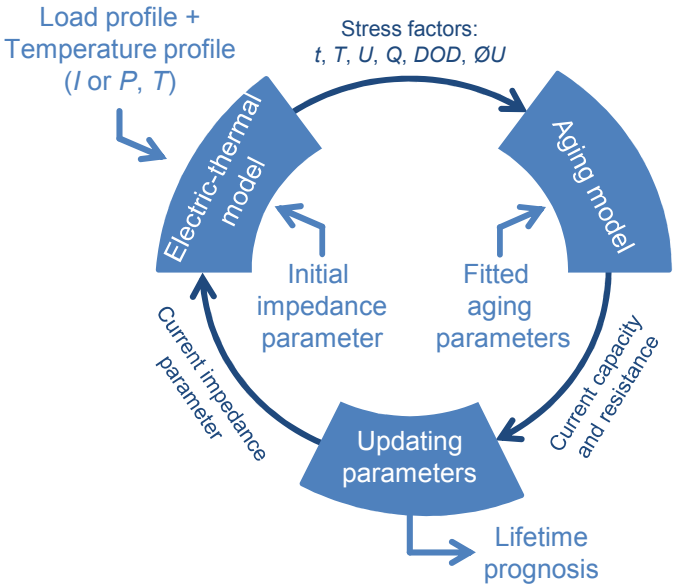


18.11.2013

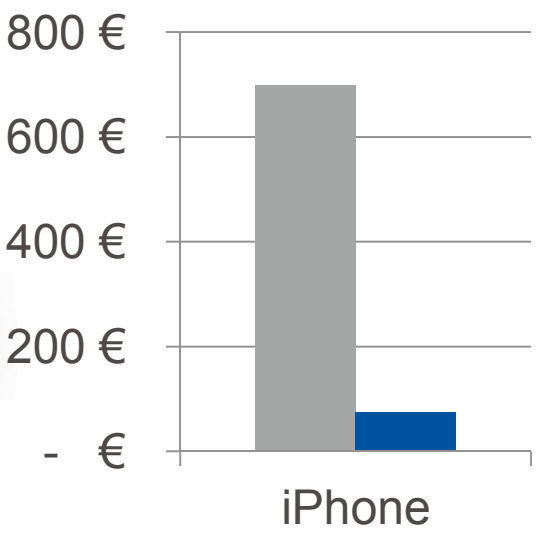
Johannes Schmalstieg[1,3], Stefan Käbitz[1,3], Madeleine Ecker[1,3], Dirk Uwe Sauer[1,2,3]

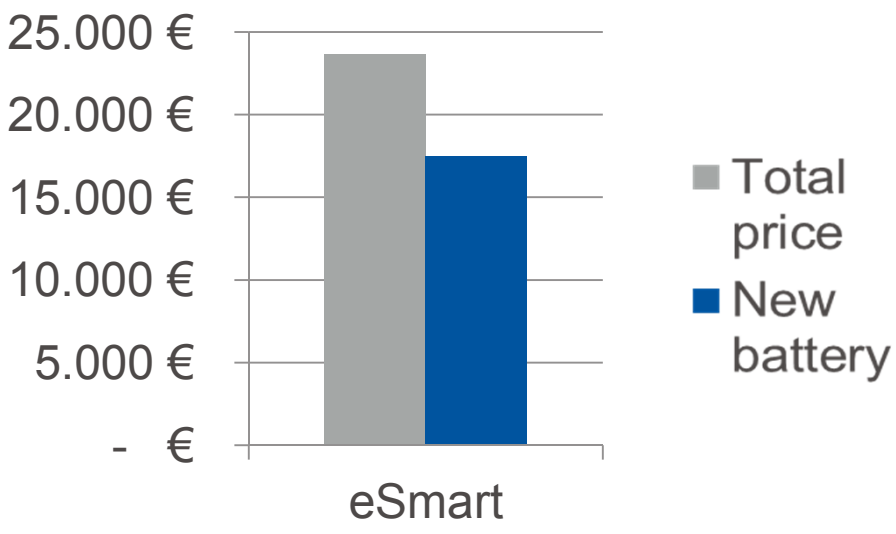
1 Electrochemical Energy Conversion and Storage Group, Institute for Power Electronics and Electrical Drives (ISEA), RWTH Aachen University, Germany
2 Institute for Power Generation and Storage Systems (PGS), E.ON ERC, RWTH Aachen University, Germany
3 Jülich Aachen Research Alliance, JARA-Energy, Germany

Why lifetime estimation?

topoften.com

vehiclemy.com

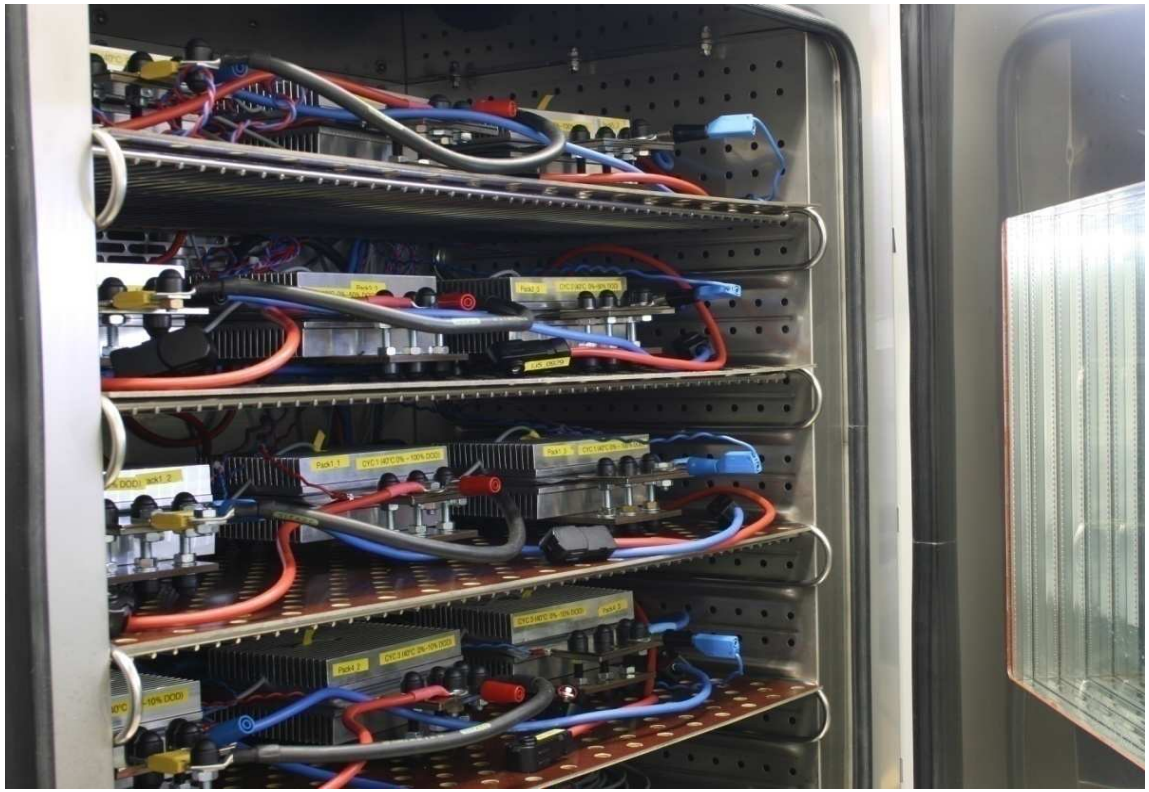




Methods of lifetime estimation

- Real life tests using application specific load profiles
  - Valid only for pre-defined scenario
  - Time consuming

- Aging model
  - Accelerated aging tests at defined conditions
  - Can be used for a wide range of load profiles



Accelerated aging tests

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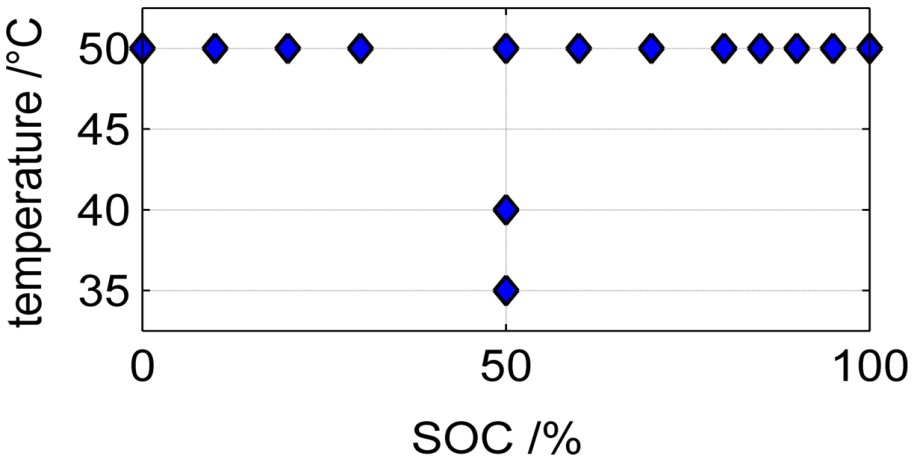
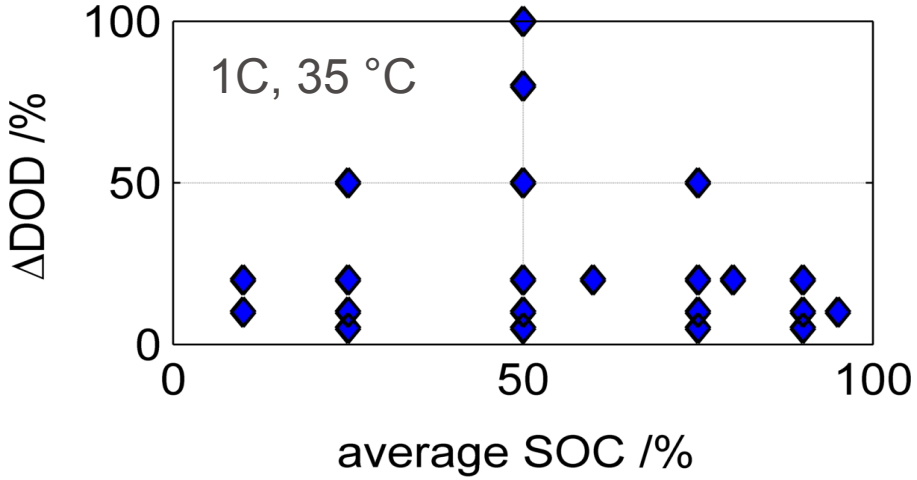
calendar aging | cycle aging





Calendar aging: Time dependency

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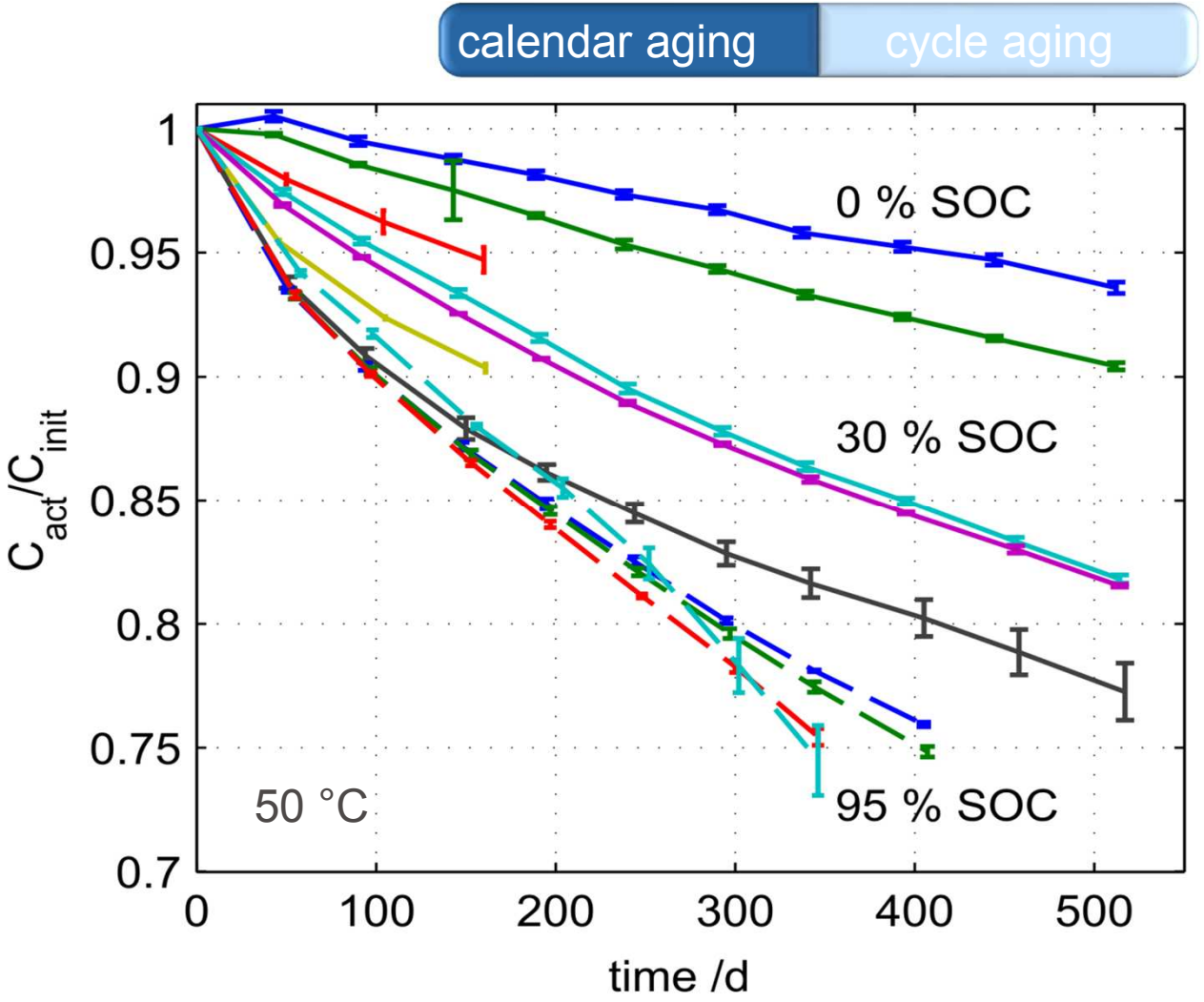
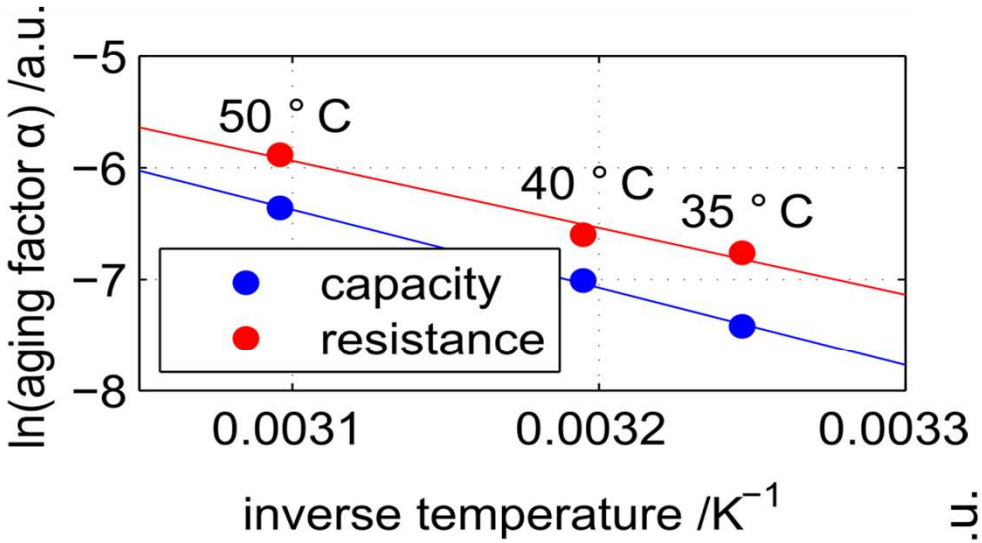
- Uniform capacity aging

- Two step fitting
  1. Fit $m + \alpha \cdot t^{0.75}$ to single tests
  2. Analyze α on voltage and temperature influence

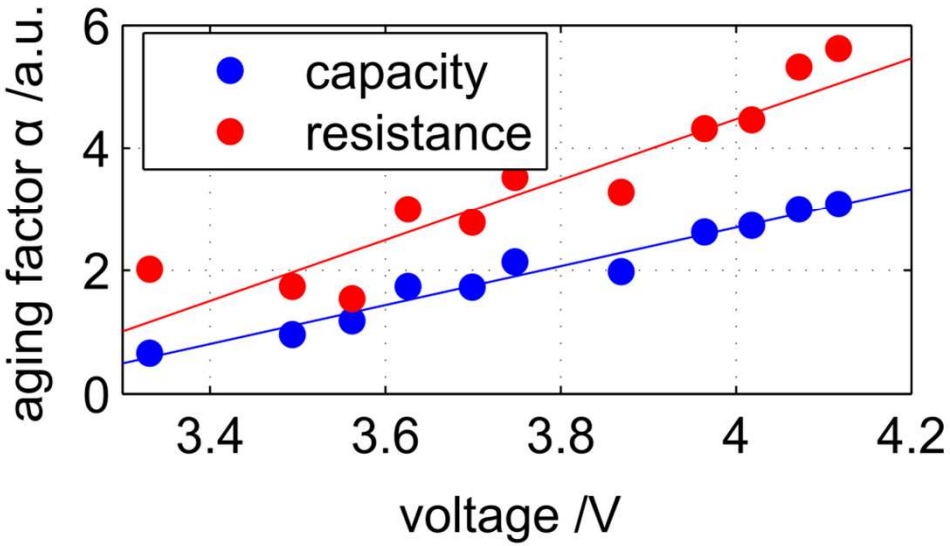


Calendar aging:
Temperature + voltage dependency



- Temperature dependency matches Arrhenius equation

- Analyse fit factor α
  - $m + \alpha \cdot t^{0.75}$



Cycle aging
Charge throughput dependency

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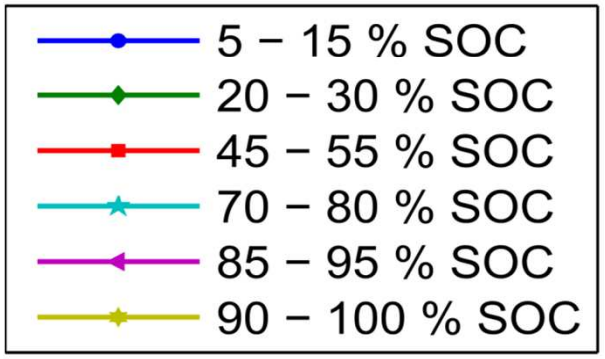
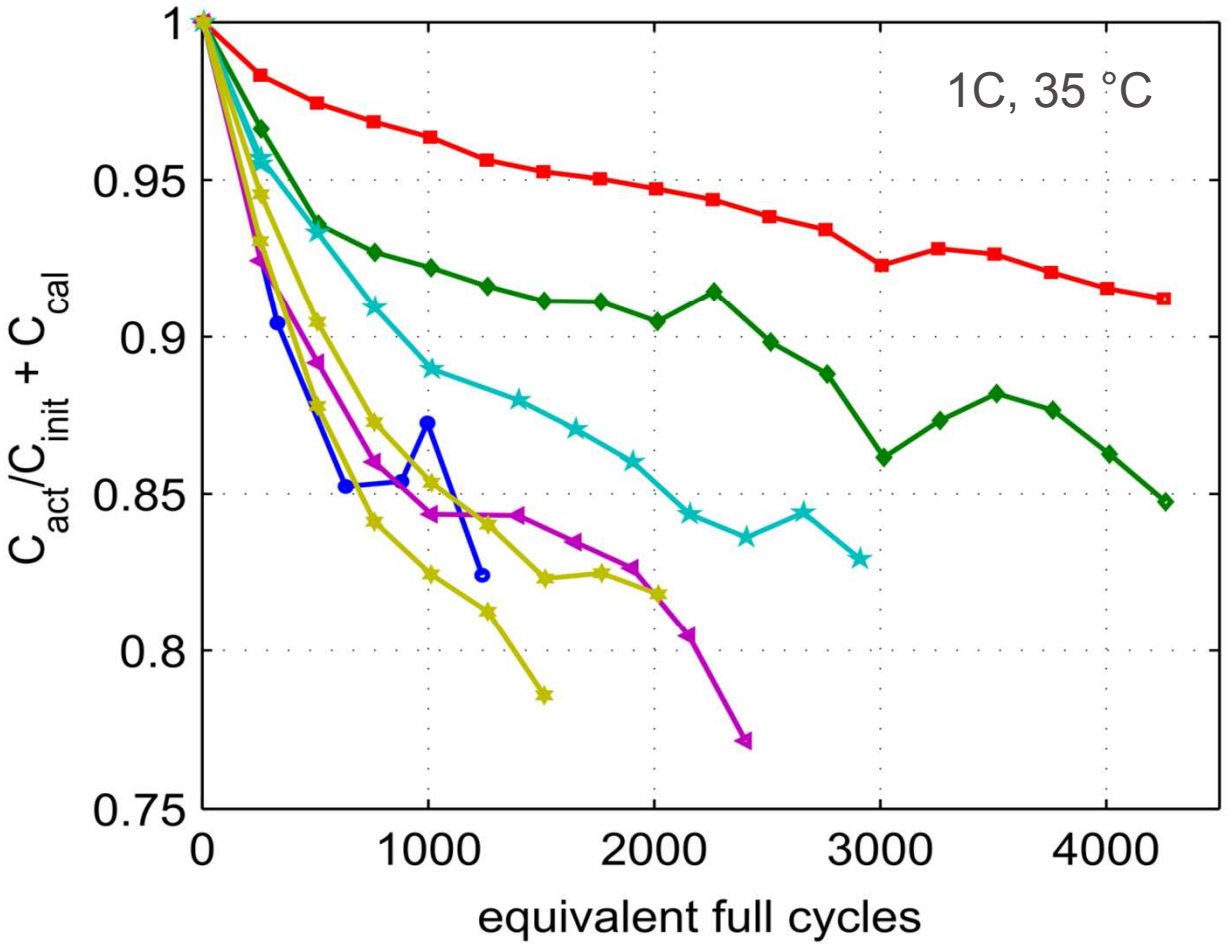
calendar aging | cycle aging

- Cycle aging results corrected by calendar aging
- Fit function
  - $C = m - \beta \cdot \sqrt{Q}$





Cycle aging:
Cycle depth + average voltage dependency

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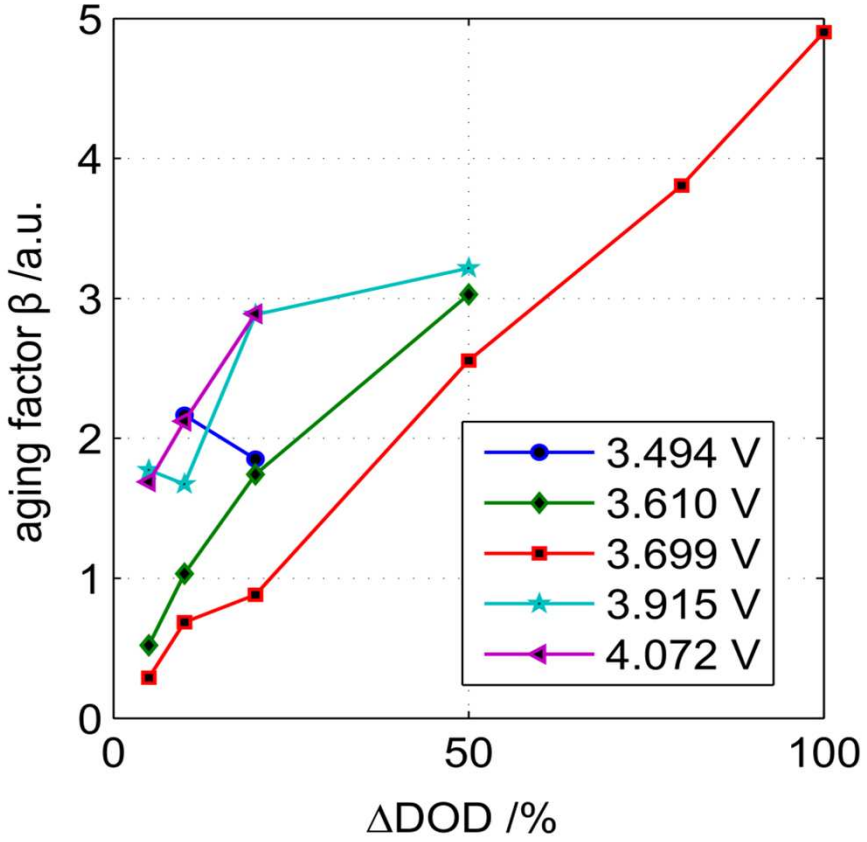
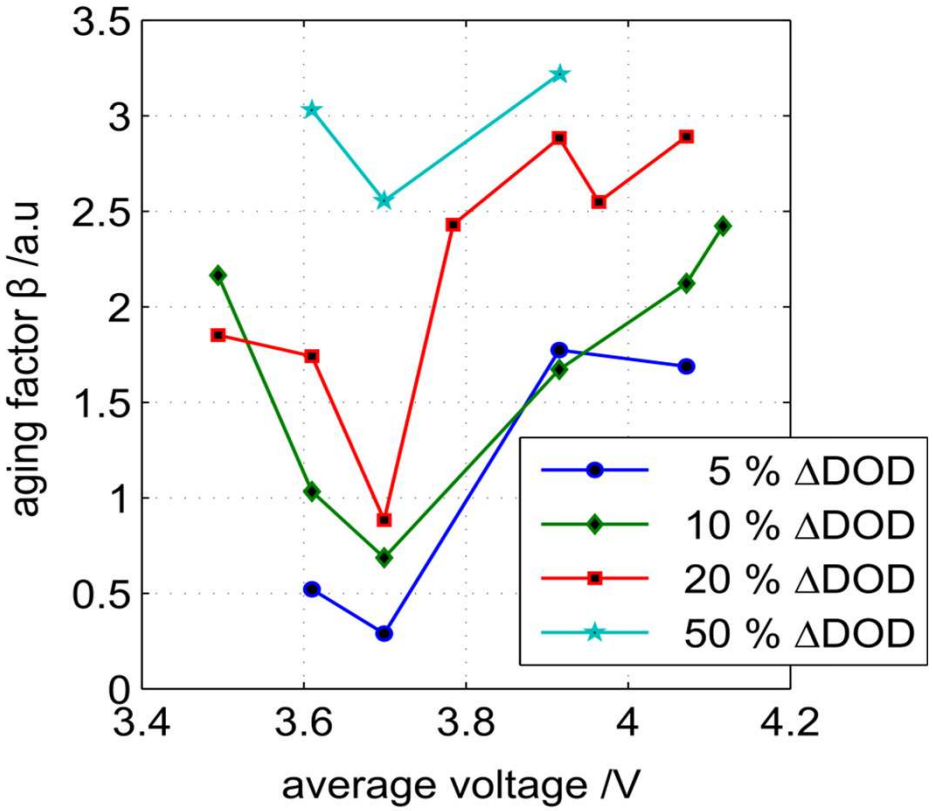
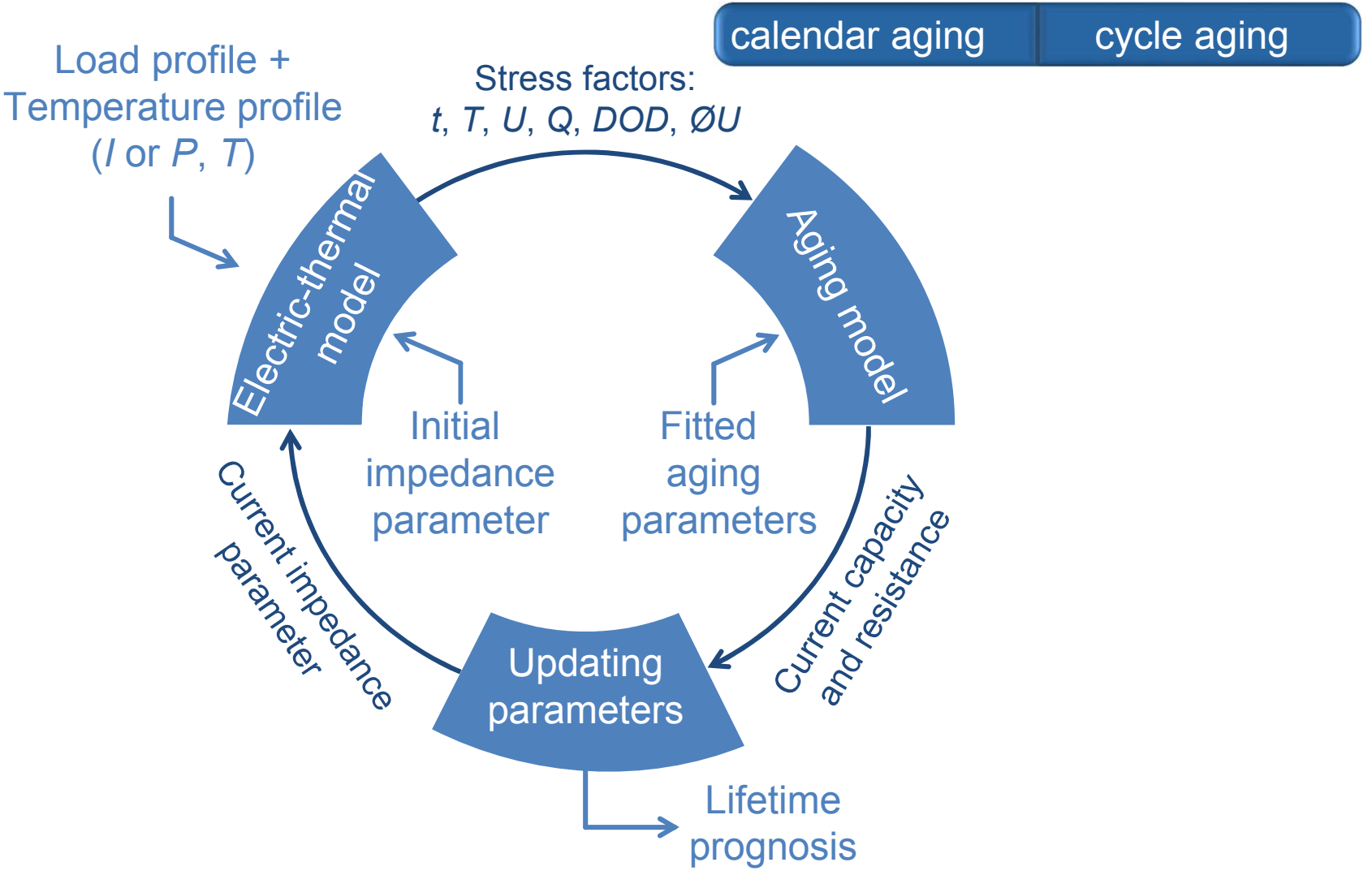
calendar aging | cycle aging



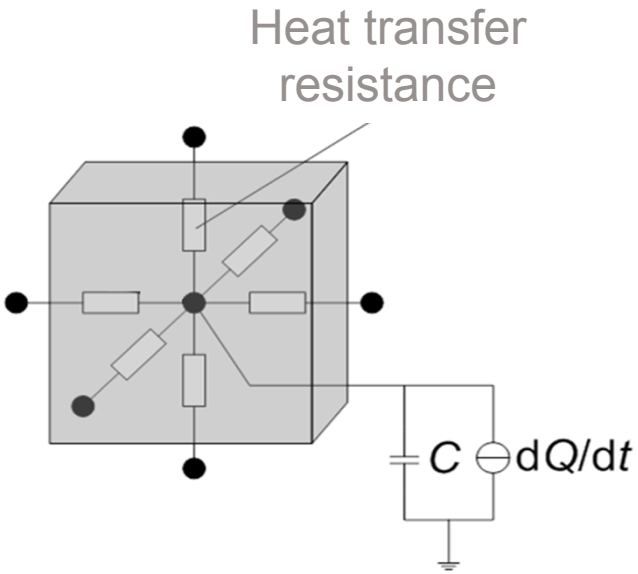


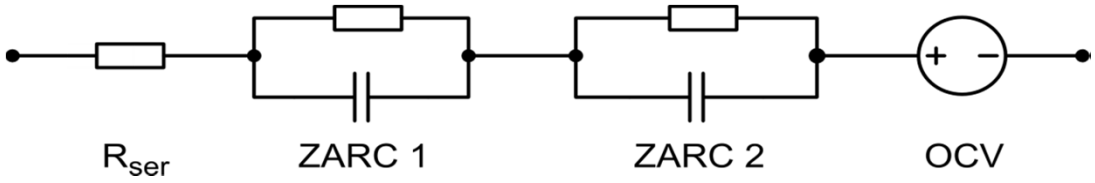
Holistic model

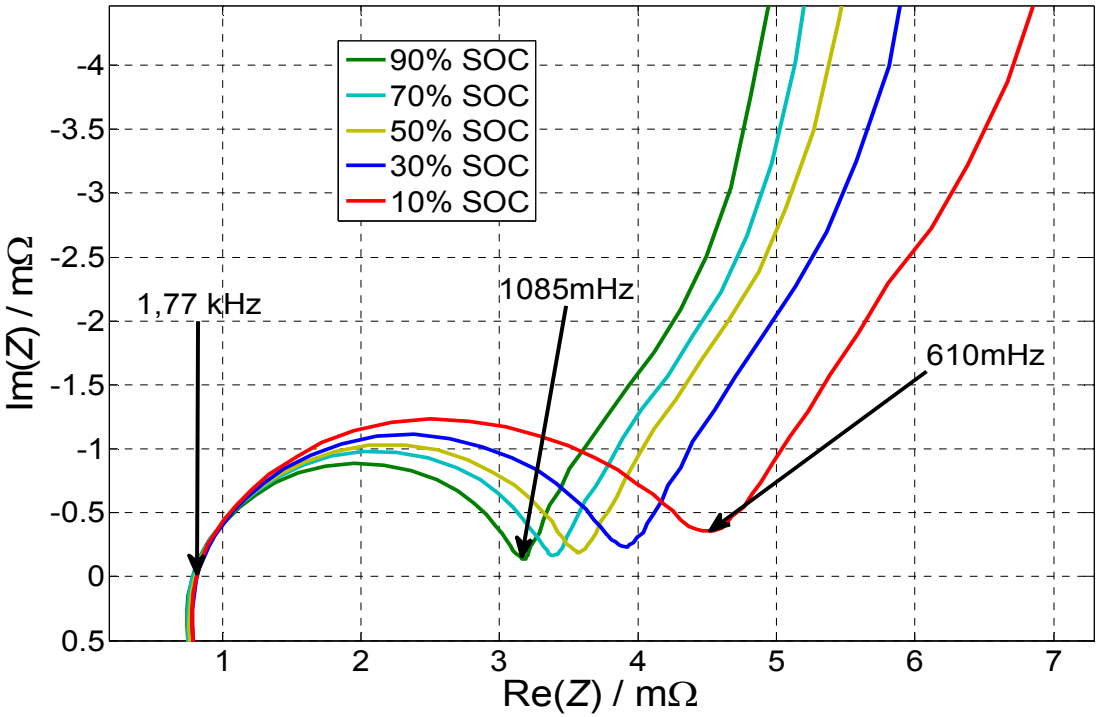


Electric-thermal model

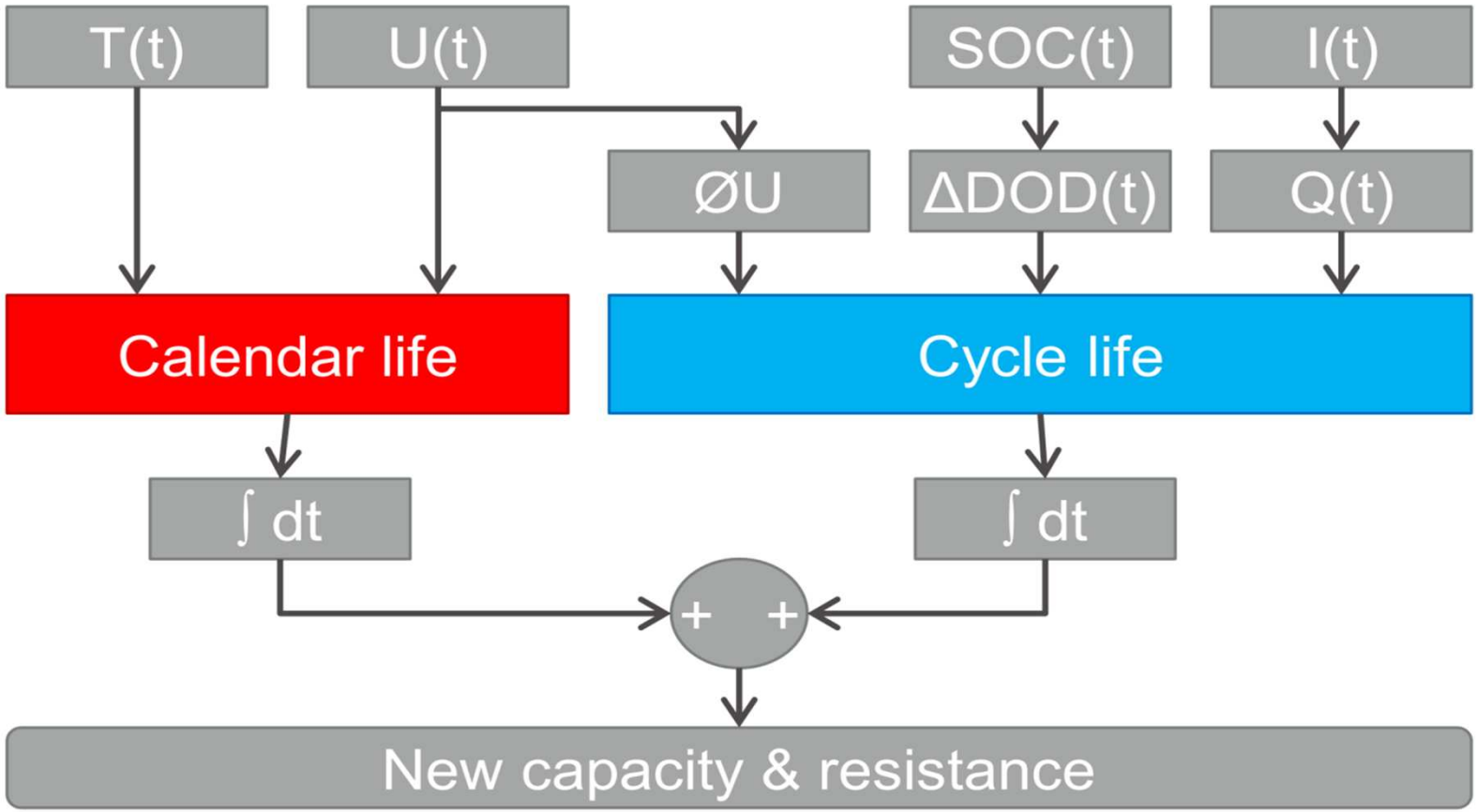
- Impedance based electric model
  - Lookup tables for parameters at different temperatures and SOC
- Simple thermal model



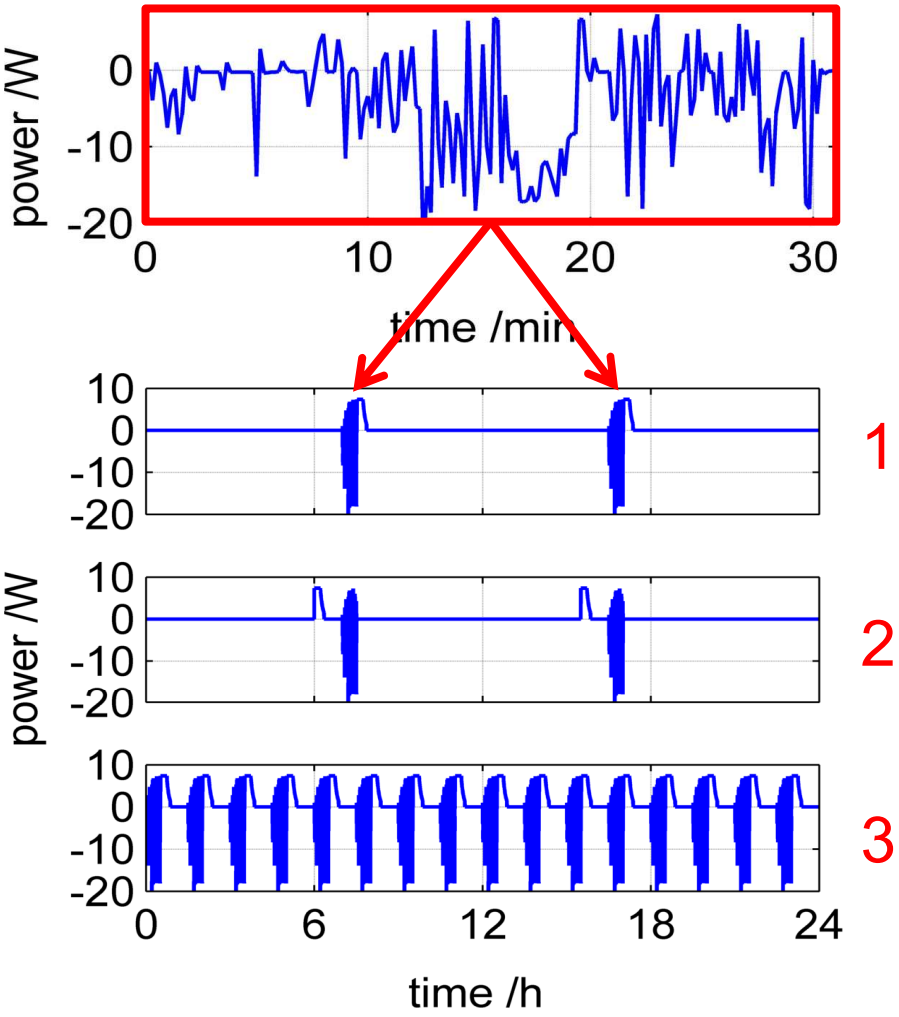


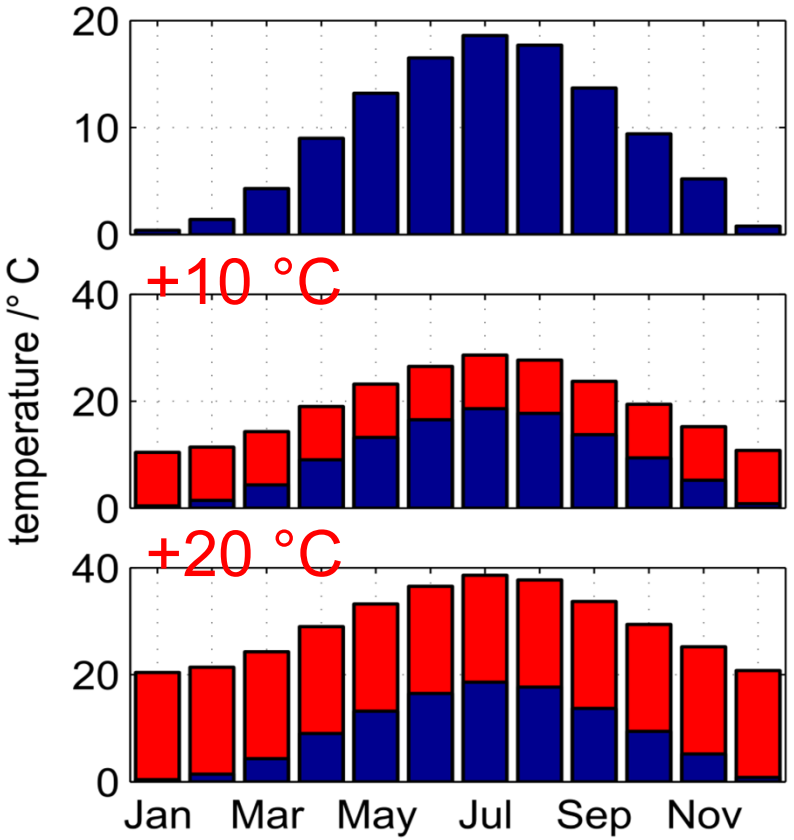


Aging model

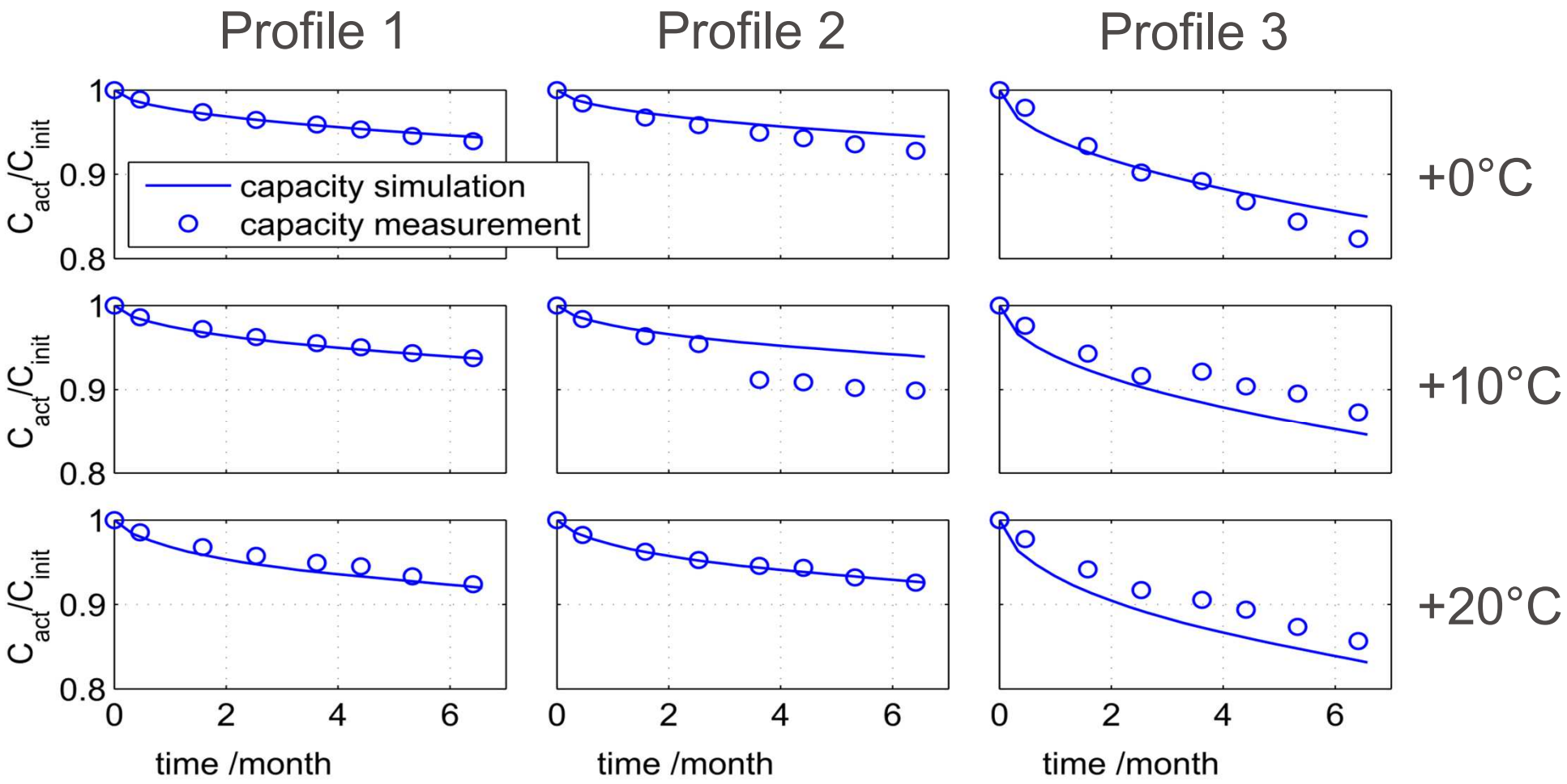

T(t)
U(t)
SOC(t)
I(t)
ØU
ΔDOD(t)
Q(t)
Calendar life
Cycle life
∫ dt
∫ dt
+
+
New capacity & resistance

Verification profile





Verification



Conclusion

- Commercial 18650 cell aged at accelerated conditions
- Describe capacity loss and resistance increase by mathematical functions
- Holistic model simulates calendar and cycle life
  - Current or power profiles can be applied
  - Ambient air temperature profiles are possible
- Verification has a good match
- A powerful tool to optimize BMS strategies and battery lifetime

Thank you for your attention

This work has been developed in the projects “e performance” (13N10656) and “e production” (16N12035), funded by the German Federal Ministry of Education and Research.

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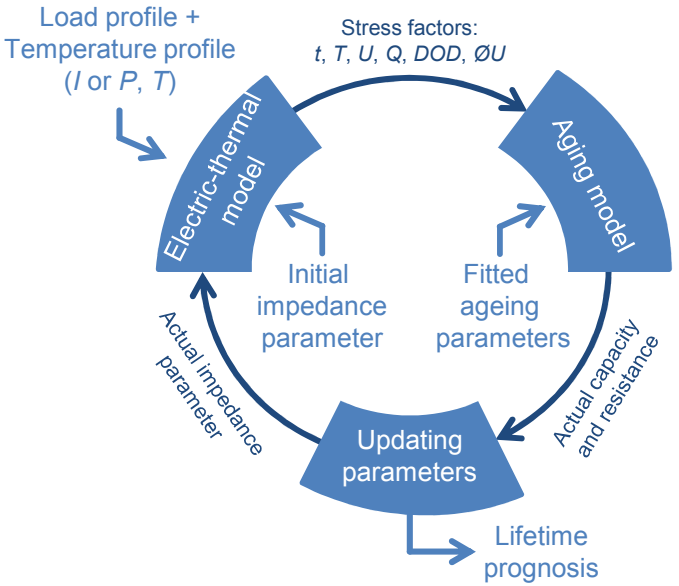

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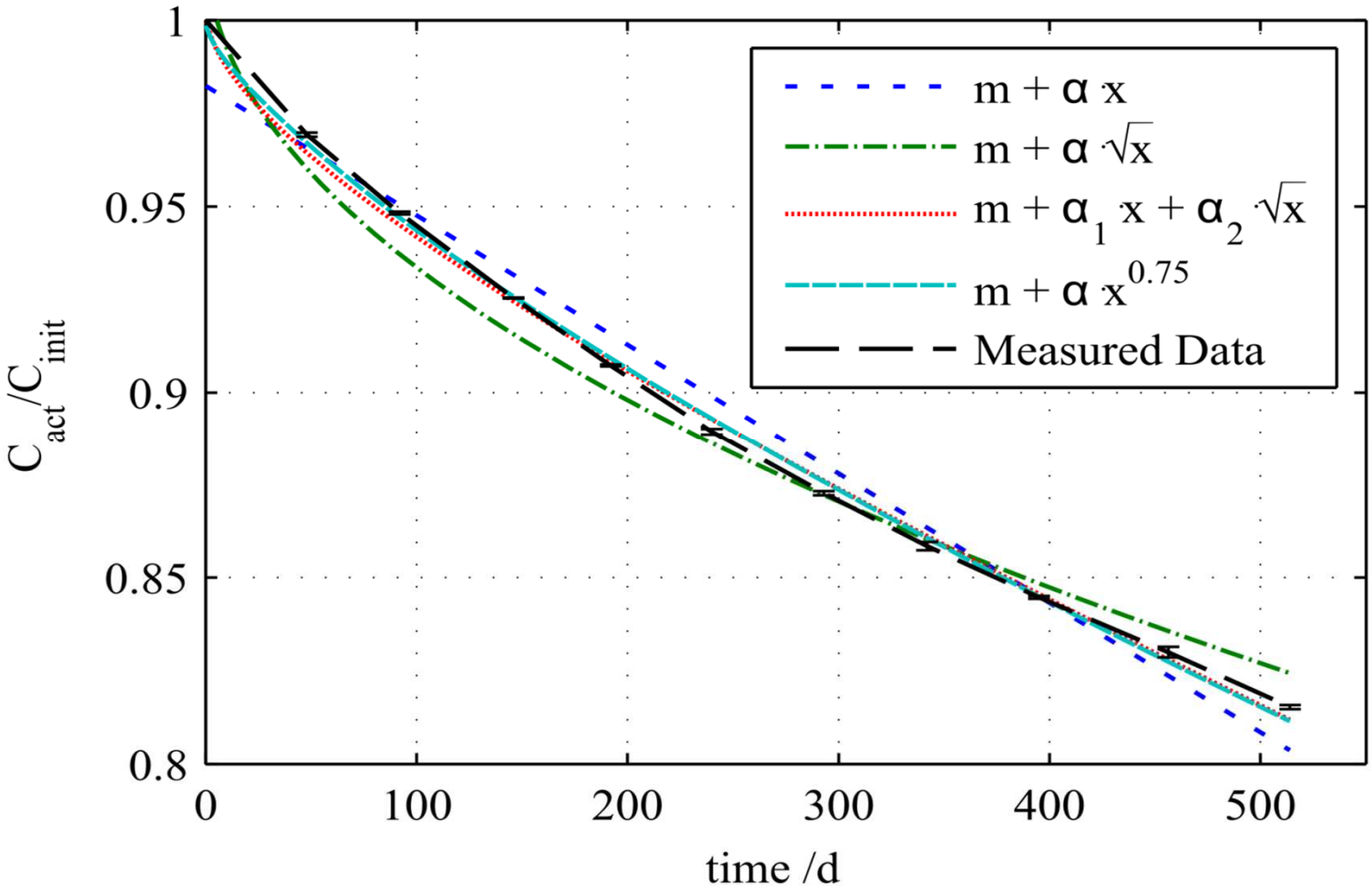
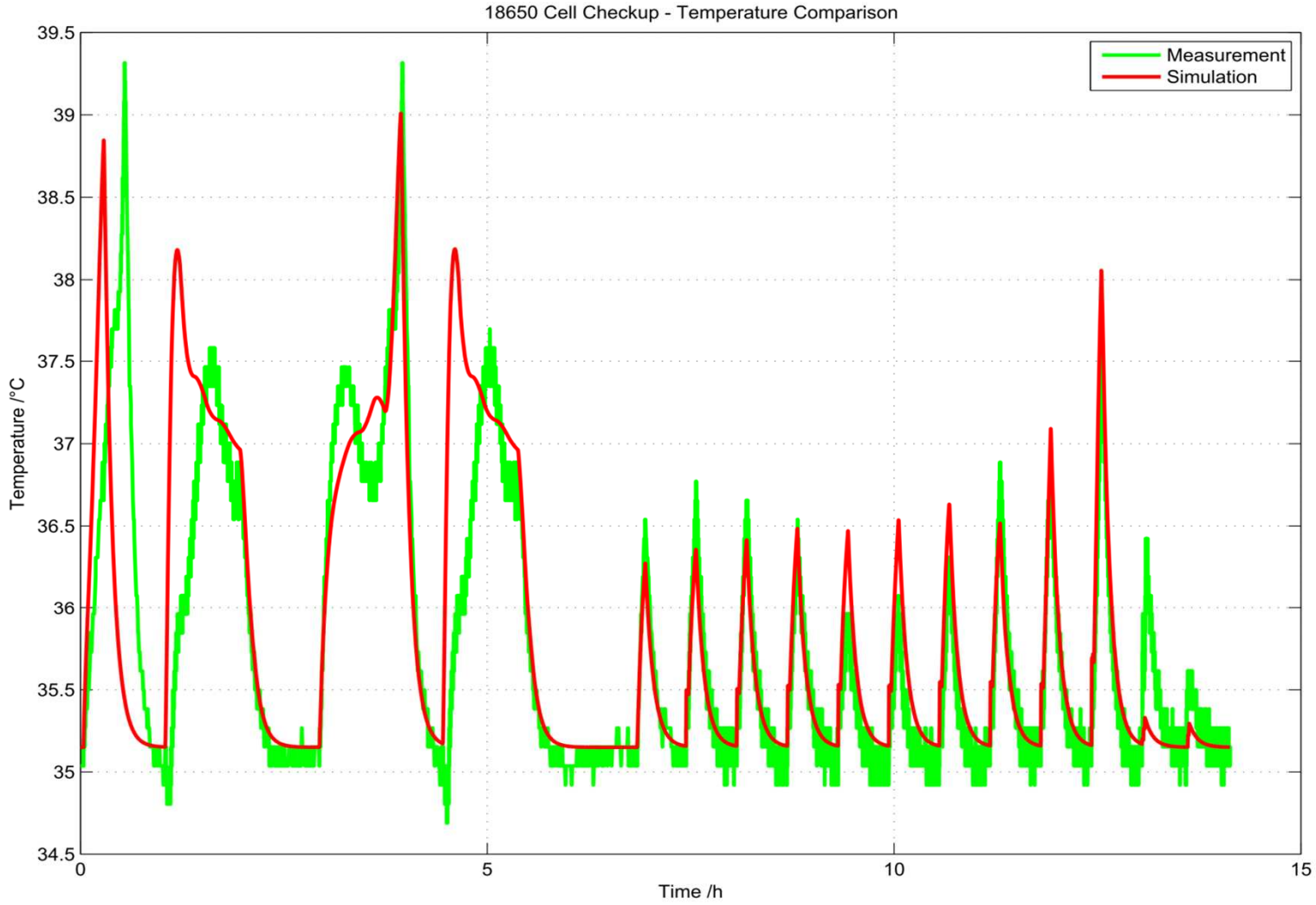
Time fitting




18650 Cell Checkup - Temperature Comparison
Measurement
Simulation
Temperature /°C
Time /h
39.5
39
38.5
38
37.5
37
36.5
36
35.5
35
34.5
0
5
10
15