Experimental approach and BMS implementation of protective sets

Matija Matijašić
Rimac Technology d.o.o.
matija.matijasic@rimac-technology.com

SCIENTIFIC CONFERENCE ON NEW METHODS AND TECHNOLOGIES OF BATTERY SYSTEMS FOR ELECTRIC VEHICLES

28.03.2025.

Funded by the European Union
NextGenerationEU

Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Table of contents

Funded by
the European Union
NextGenerationEU

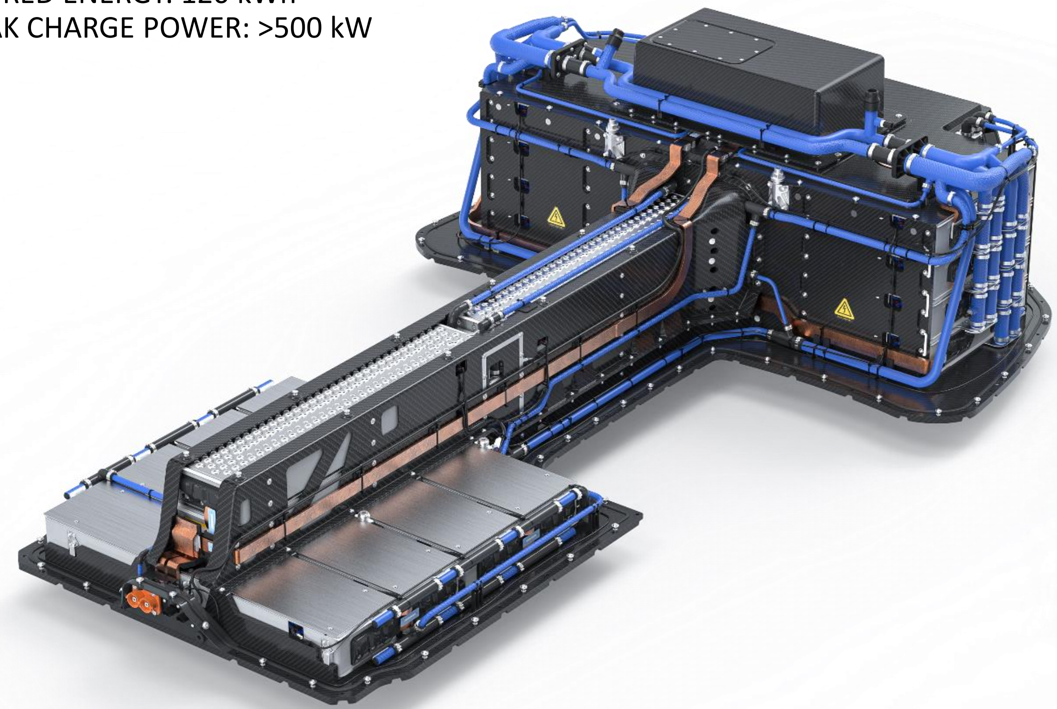
Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Nevera Battery system

BATTERY SYSTEM SPECIFICATION

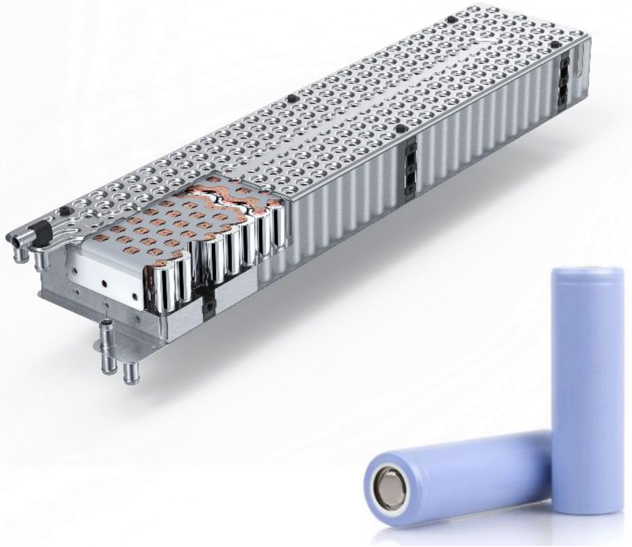
CONFIGURATION: 174S 40P
PEAK DISCHARGE POWER: >1400 KW

STORED ENERGY: 120 kWh
PEAK CHARGE POWER: >500 kW



Battery algorithms:

- State of Charge
- State of Health
- State of Power
- State of Energy
- State of Safety
- State of ….



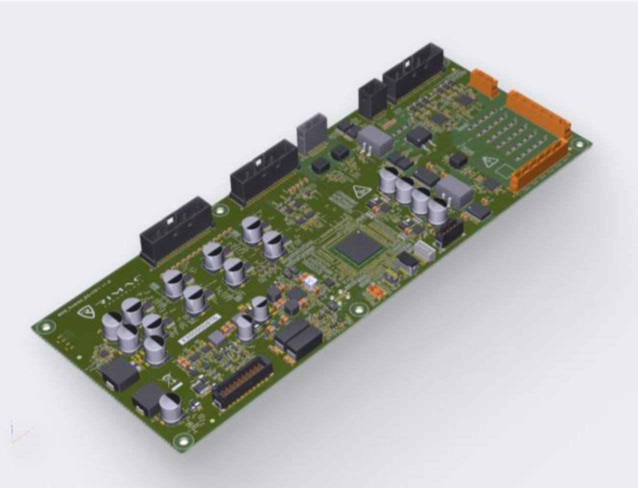
https://www.esdtronix.com/wp-content/uploads/2021/05/21700_li-ion_batteries-500x441.jpg

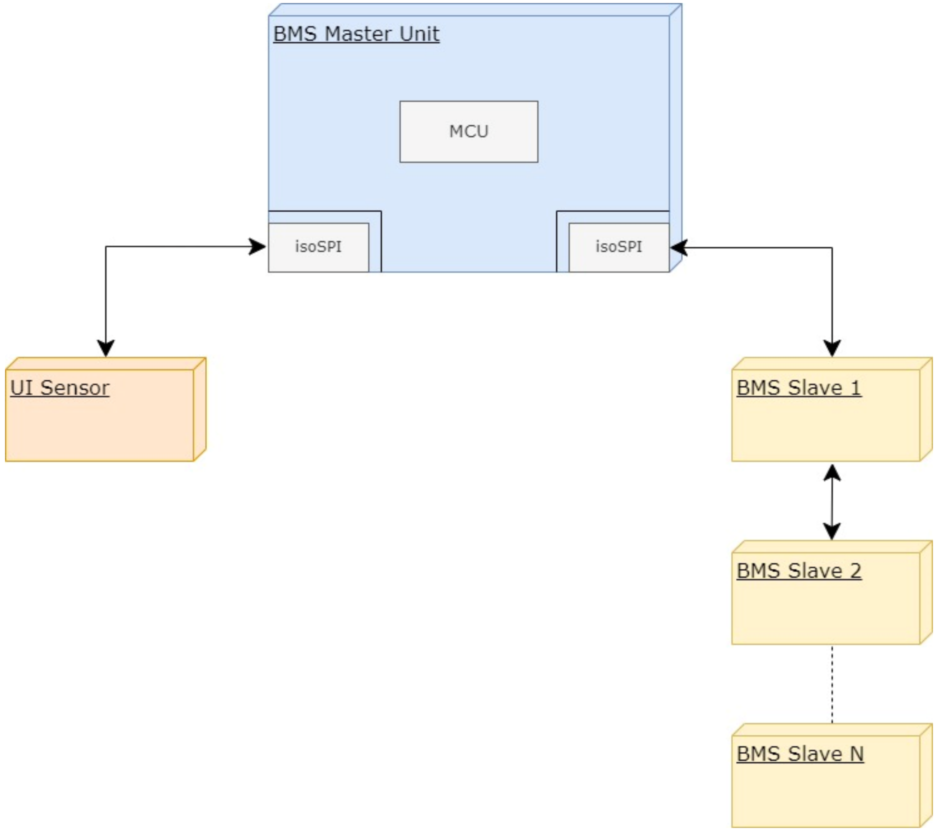
Funded by the European Union
NextGenerationEU

Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

BMS (Battery Management System)

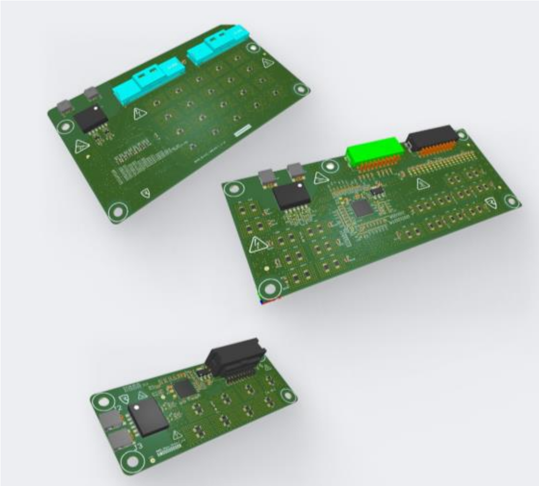
BMS master





- **Specification of BMS Master Unit**
  - Communication towards vehicle
  - CAN-FD support
  - Handling of contactors
  - Activation of pyrofuse
  - Crash detection input
  - HVIL control
  - Battery thermal runaway detection

BMS slave



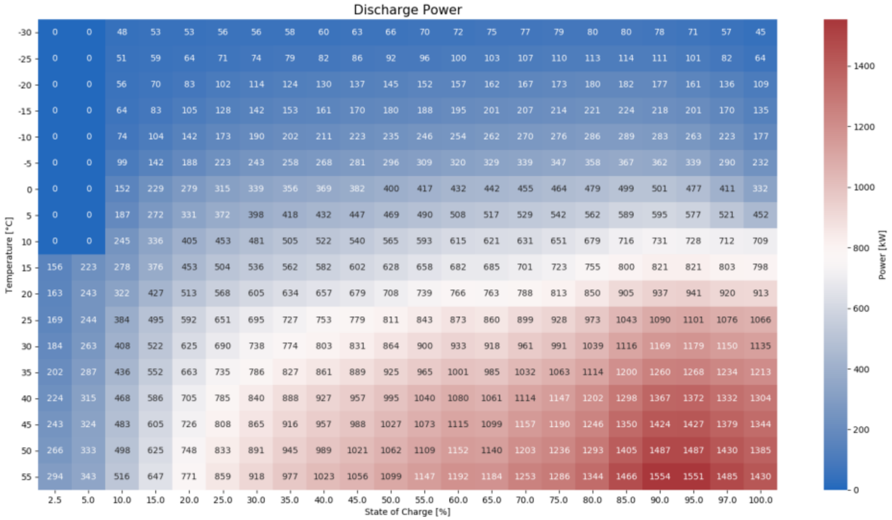
- **Specification of BMS Slave Unit**
  - Up to 238 series connected cells (1000V in total)
  - flexible number of temperature sensors
  - flexible sampling rate
  - flexible balancing current
  - ASIL-D compliant

Funded by the European Union
NextGenerationEU

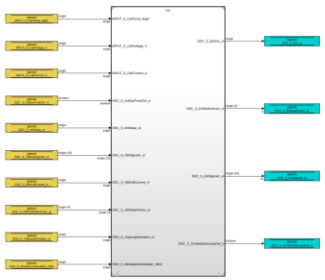
Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

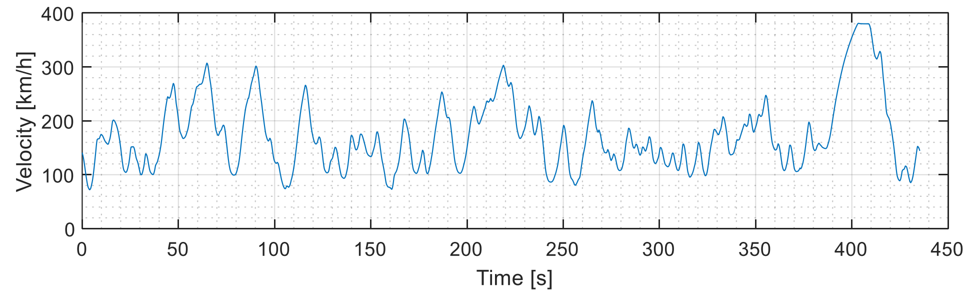
PAST/PRESENT TOWARDS THE FUTURE

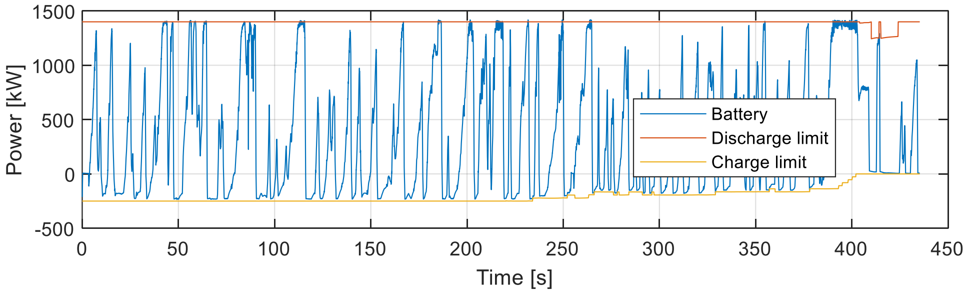
PAST

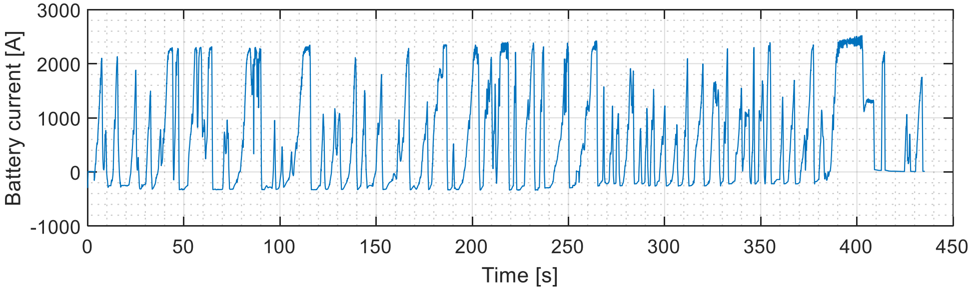


PRESENT







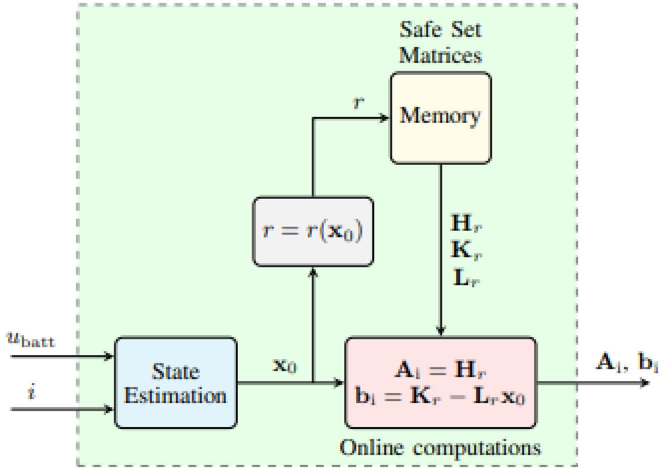


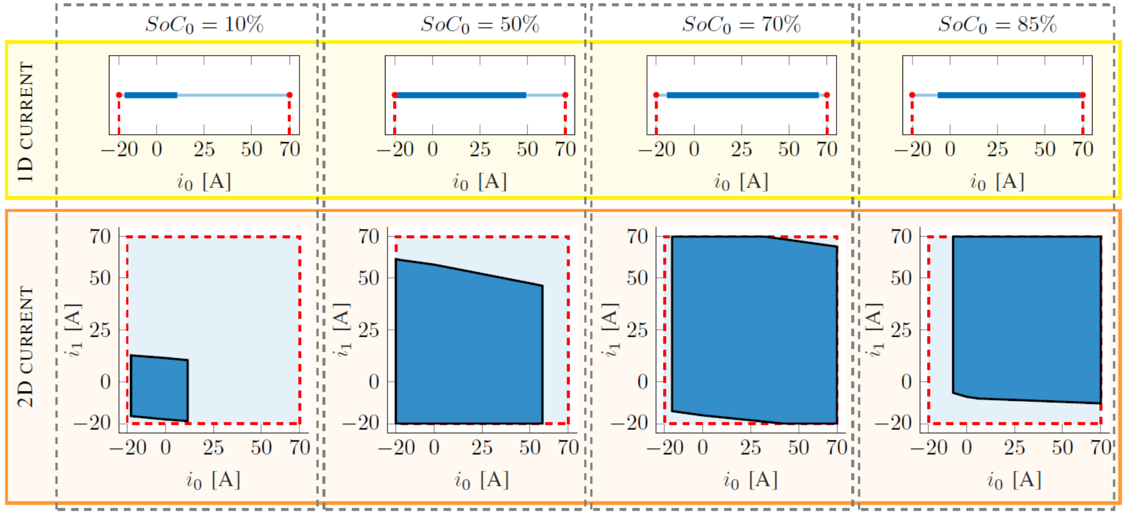
Funded by the European Union
NextGenerationEU

Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

EVBattPredtect

Dynamic predictive protection of the battery integrity of the electric vehicle





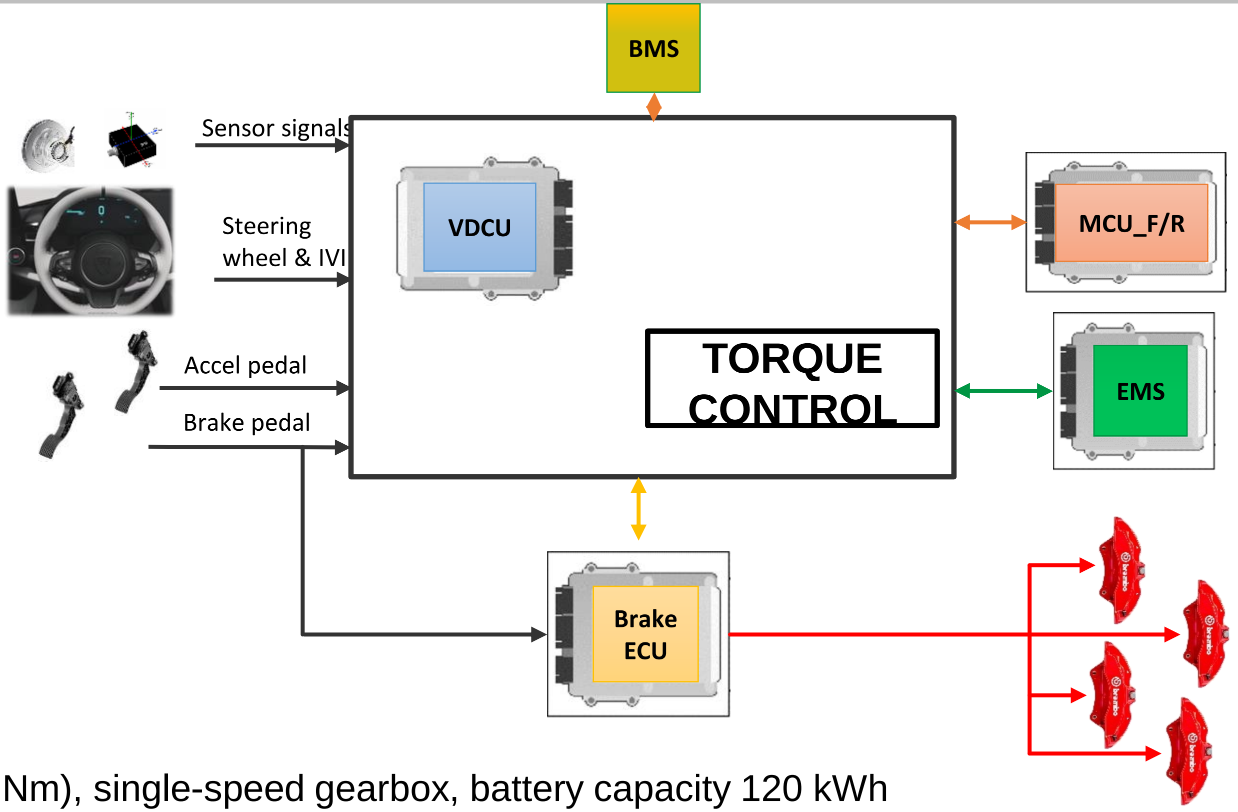
- Prediction horizon 10 seconds (calculating each 20 ms)
- Calculating 1D,2D and 5D currents (current changes).
  - Higher dimension (D) allows higher currents .

D. Leko, F. Rukavina, M. Matijašić, I. Bralić and M. Vašak, "Computationally Efficient Protective Methodology for Lithium-Ion Battery Cells Based on Safe Sets," 2023 IEEE 11th International Conference on Systems and Control (ICSC), Sousse, Tunisia, 2023

Funded by
the European Union
NextGenerationEU

Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Test platform - Rimac Nevera

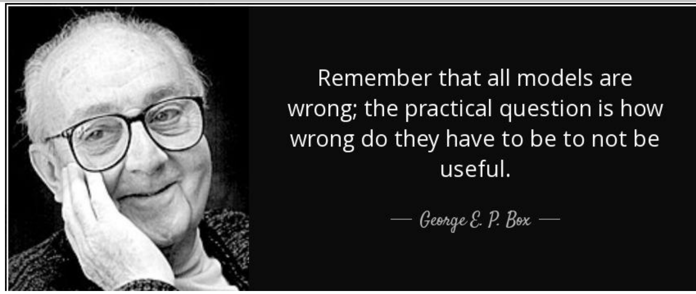


- 4 independent EMs (total power 1400 kW, total max torque 2360 Nm), single-speed gearbox, battery capacity 120 kWh
- Control software lives on the ECUs – the brain of the car -> controls all major vehicle components and vehicle dynamic behaviour, thus defining the vehicle's character and „moods"
- Battery is being protected by the BMS, which communicates with VDCU, providing battery safe power limits and other relevant battery states such as SOC, SOH and cell temperatures and voltages

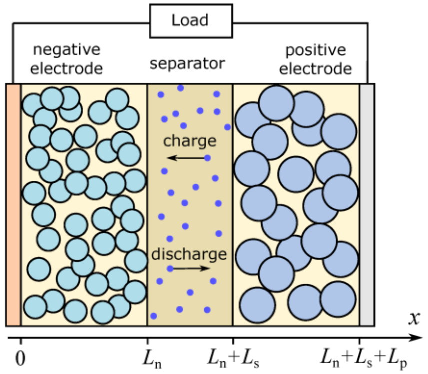
Funded by the European Union NextGenerationEU

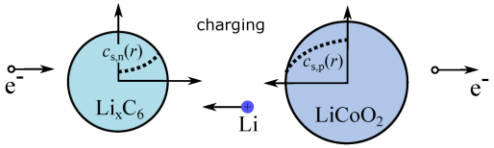
Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Battery cell models



Physics – based models

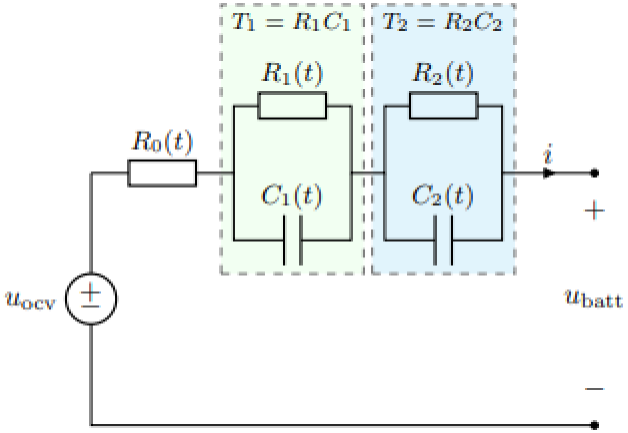




$$\nabla \cdot \left(-\sigma_l \nabla \phi_l + \frac{2\sigma_l RT}{F}\left(1 + \frac{\partial \ln f}{\partial \ln c_l}\right)(1 - t_+)\nabla \ln c_l\right) = i_{tot}$$

$$\varepsilon_l \frac{\partial c_l}{\partial t} + \nabla \cdot (-D_l \nabla c_l) = R_l - \left(\frac{i_{tot} + Q_l}{F}\right) t_+$$

Empirical models



$$\frac{\mathrm{d}}{\mathrm{d}t}u_1(t) = -\frac{1}{R_1C_1}u_1(t) + \frac{1}{C_1}i(t)$$

$$\frac{\mathrm{d}}{\mathrm{d}t}u_2(t) = -\frac{1}{R_2C_2}u_2(t) + \frac{1}{C_2}i(t)$$

ZOH

$$u_1(k+1) = e^{-\frac{1}{T_1}T_s}u_1(k) + R_1\left(1 - e^{-\frac{1}{T_1}T_s}\right)i(k)$$

$$u_2(k+1) = e^{-\frac{1}{T_2}T_s}u_2(k) + R_2\left(1 - e^{-\frac{1}{T_2}T_s}\right)i(k)$$

$$\hat{u}(k) = u_{OCV} - u_1(k) - u_2(k) - R_0 i(k)$$

$$SoC(k+1) = SoC(k) - \frac{T_s}{C}i(k)$$

Sibatov, R.T.; Svetukhin, V.V.; Kitsyuk, E.P.; Pavlov, A.A. Fractional Differential Generalization of the Single Particle Model of a Lithium-Ion Cell. *Electronics* **2019**, *8*, 650
D. Leko, F. Rukavina, M. Matijašić, I. Bralić and M. Vašak, "Computationally Efficient Protective Methodology for Lithium-Ion Battery Cells Based on Safe Sets," 2023 IEEE 11th International Conference on Systems and Control (ICSC), Sousse, Tunisia, 2023

Funded by the European Union
NextGenerationEU

Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

RT Battery Cell testing

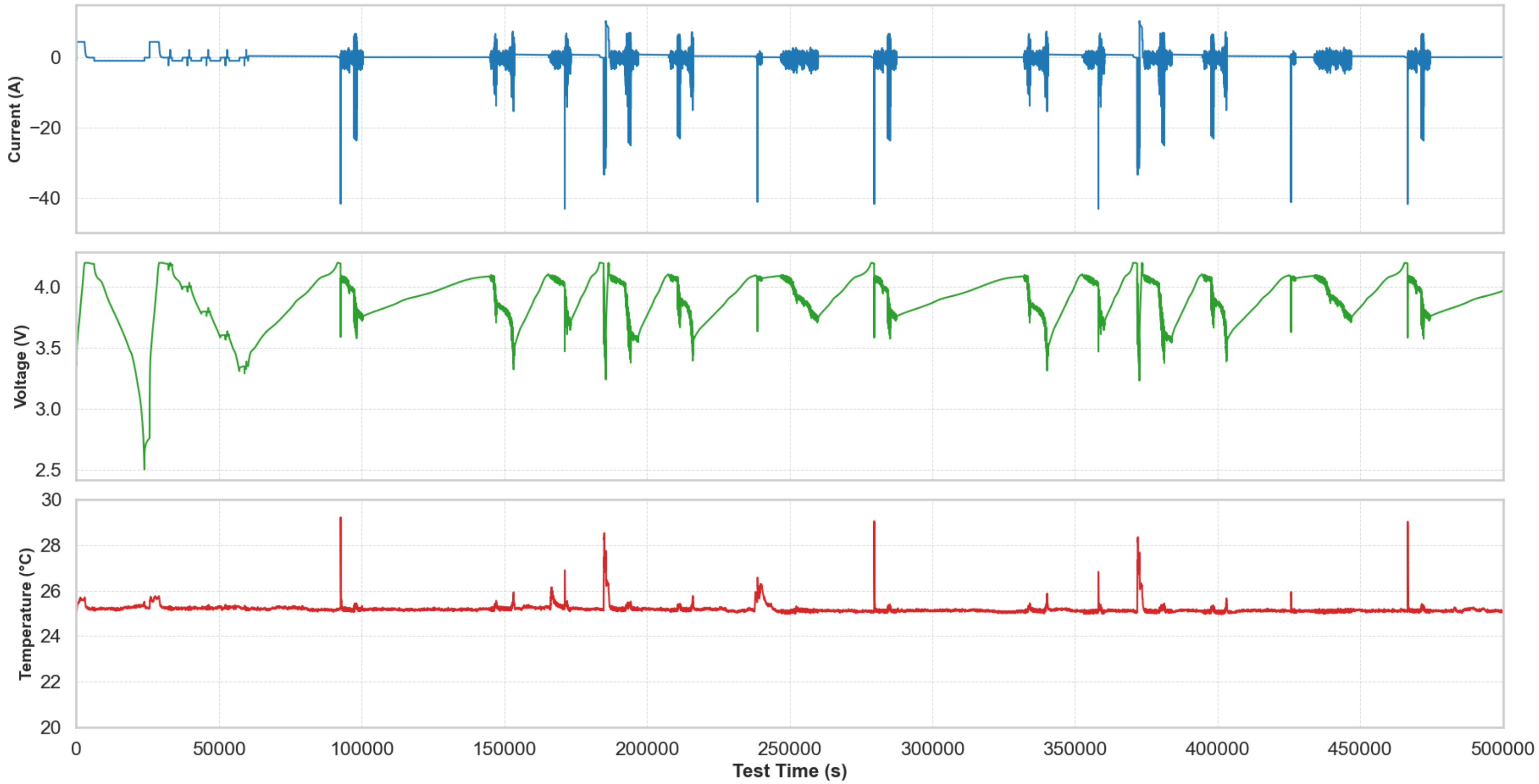
BATTERY CELL TESTING

- **168 testing channels**
- **14 Temperature Chambers**
- **5 Oil baths – calendar ageing**

Funded by the European Union
NextGenerationEU

Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

RT Battery Cell testing

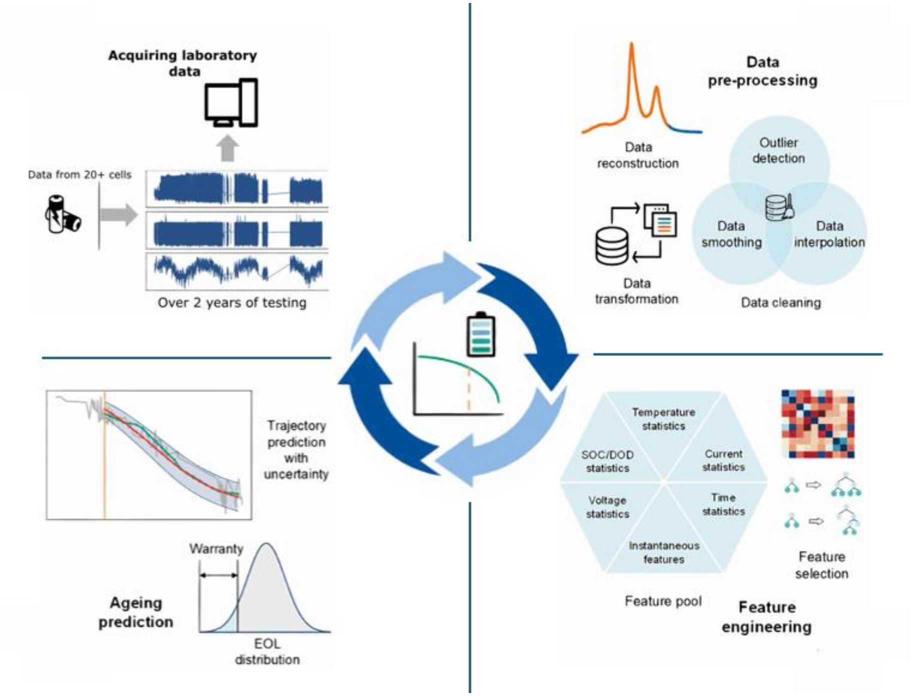


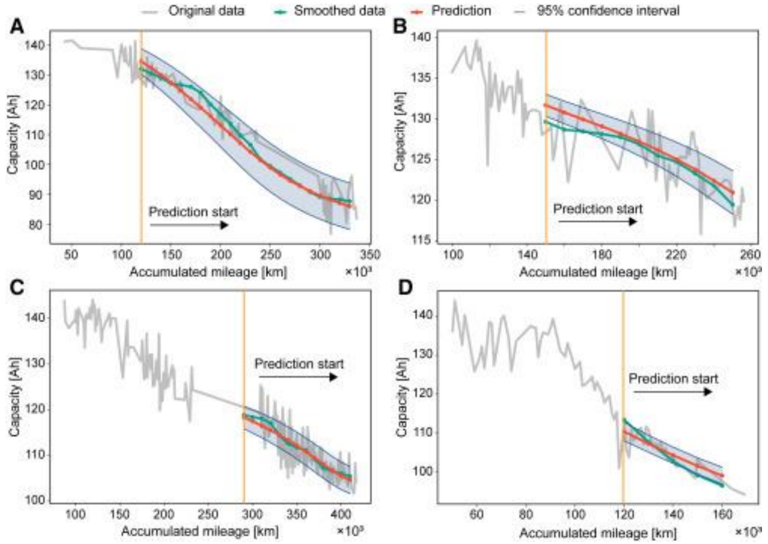
Funded by
the European Union
NextGenerationEU

Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

MLBattProt

Machine learning based model of battery aging used in computational geometry for on-line battery pack health protection





Qiushi Wang, Zhenpo Wang, Peng Liu, Lei Zhang, Dirk Uwe Sauer, Weihan Li,
Large-scale field data-based battery aging prediction driven by statistical features and machine learning, Cell Reports Physical Science, 2023

https://xkcd.com

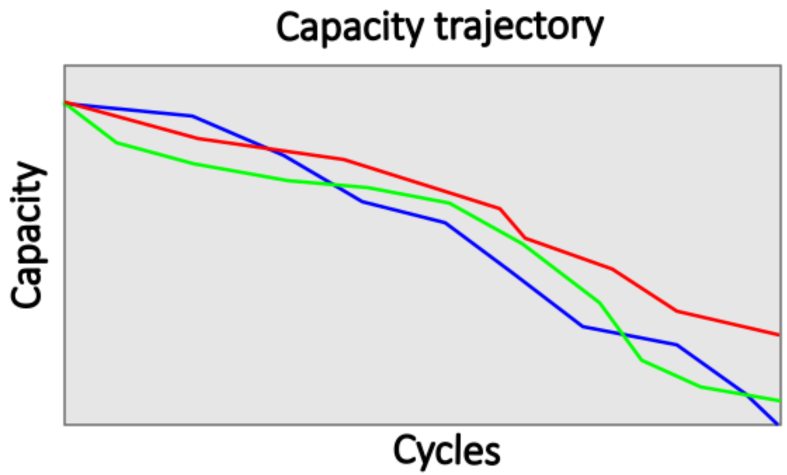
Funded by the European Union
NextGenerationEU

Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

MLBattProt

Target

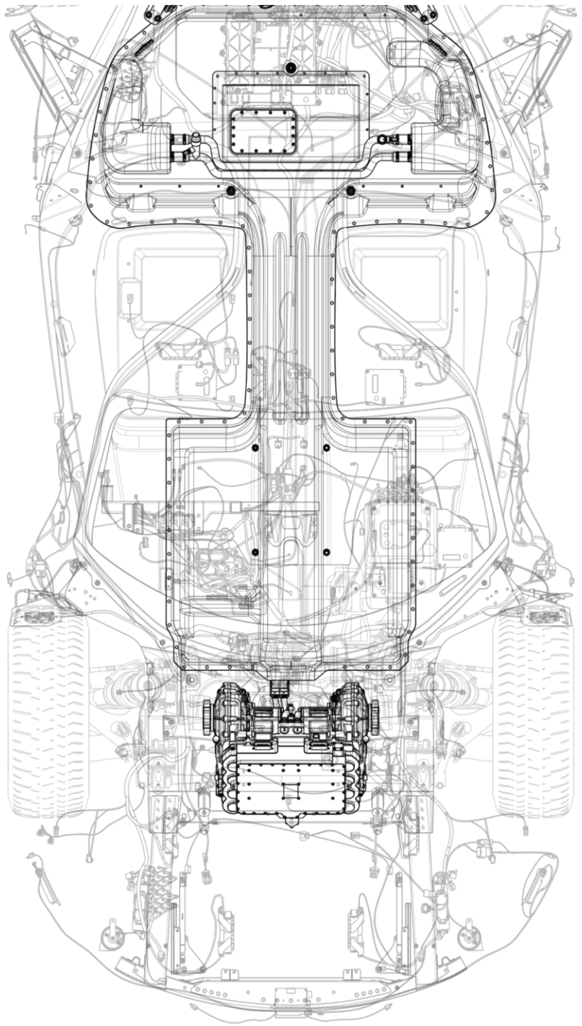
- For each battery state (SoC, T, SoH), maximize performance (charging, regenerative braking, discharging) while ensuring compliance with safety thresholds and absolute operational and degradation limits.



Funded by
the European Union
NextGenerationEU

Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Q&A



Funded by
the European Union
NextGenerationEU

Funded by the European Union – NextGenerationEU. The views and opinions expressed are solely those of the author and do not necessarily reflect the official position of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.