STATE OF POWER ESTIMATION FOR MOTORSPORT APPLICATIONS

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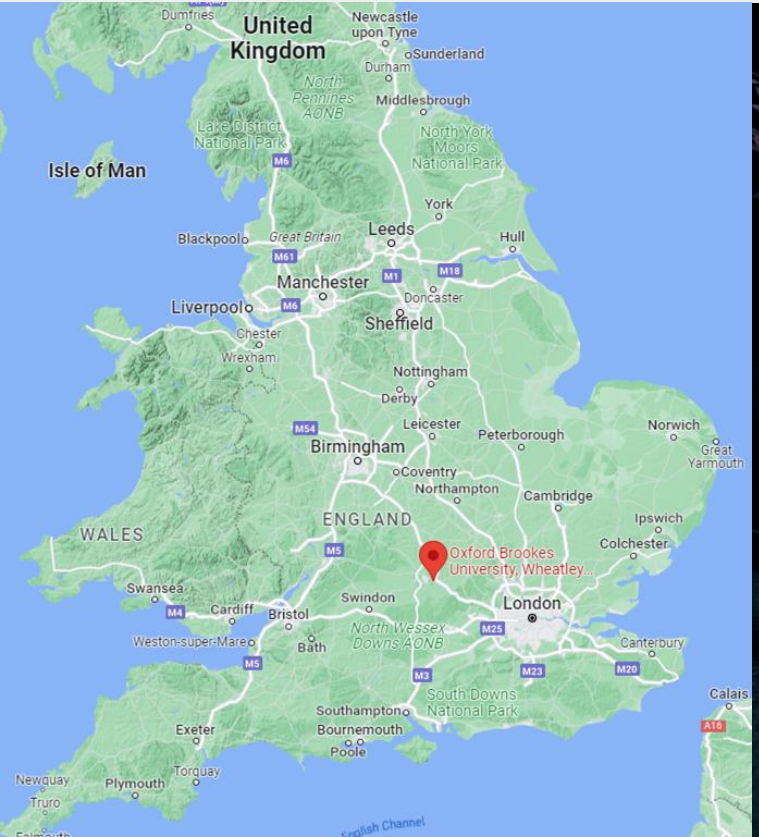
OXFORD BROOKES RACING

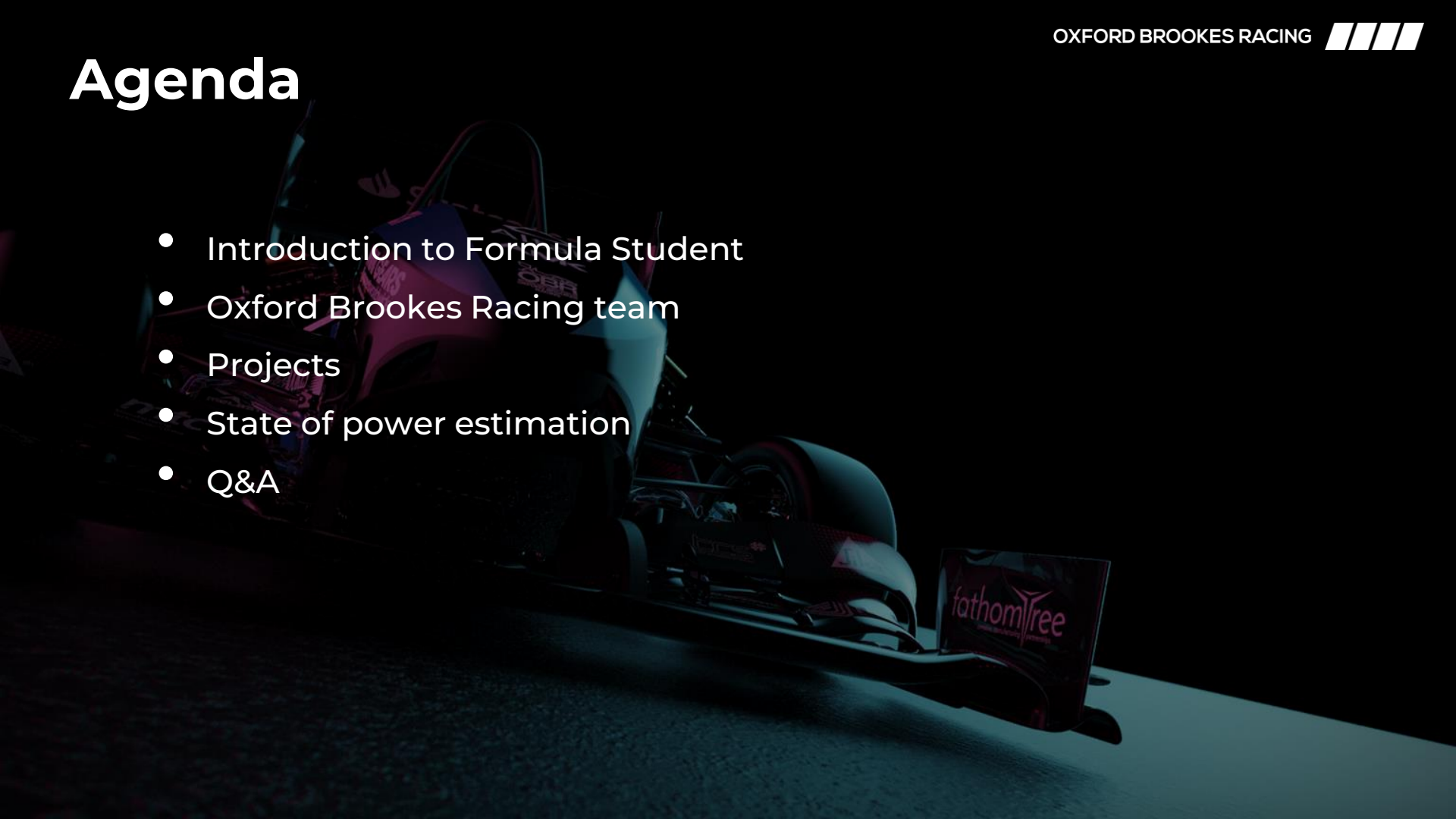
OXFORD BROOKES UNIVERSITY

HVES The High Voltage & Energy Storage Group at Oxford Brookes University



- **Oxford Brookes Racing**
- **High Voltage & Energy Storage Lab**
  - 08 channels cell tester
  - 05 thermal chambers
  - AVL battery pack tester (250kW – 1200V)

Agenda



- Introduction to Formula Student
- Oxford Brookes Racing team
- Projects
- State of power estimation
- Q&A

What is Formula Student?

- +1000 teams from more than 20 countries design and build a formula-style racing car.
- Europe's most established educational engineering competition.

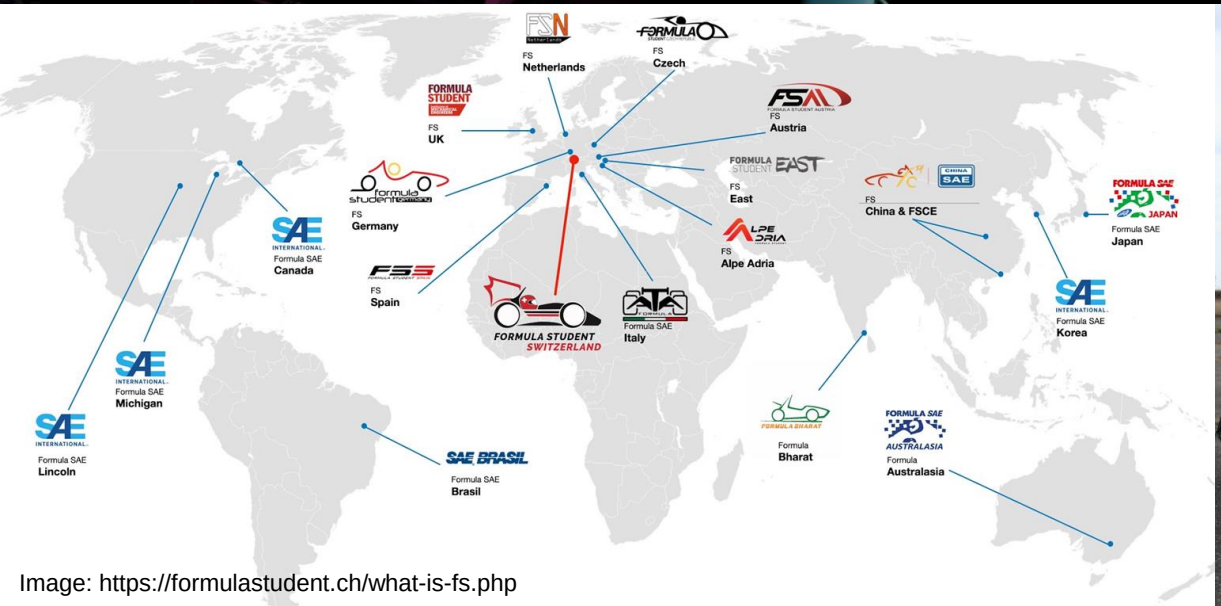


Image: https://formulastudent.ch/what-is-fs.php

DYNAMIC EVENTS

Acceleration (75 points)
75m straight line run

Skidpad (75 points)
Figure of 8 constant radius circles

Autocross (100 points)
One lap time trial

Endurance (250 points)
22km time trial

Efficiency (100 points)
Energy used

STATICS EVENTS

Design (160 points)
Justify your design to industry professionals

Cost (120 points)
How much does your car cost to make
Understanding of cost driven decisions

Business (120 points)
Present a business model based around your car

Lap Time Simulation (20 points)
Evaluate four different FS powertrain types and two aerodynamic configurations.

OBR Legacy

1999

Top UK Team

2003

2009

Hybrid Vehicle Development

2012

Top UK Team

2014

1st Place Design Top UK Team

2016

Fastest Ever UK Car

2018

2019

2nd Place Overall

Top UK Team

OBR Legacy

1999

Top UK Team

2003

2009

Fastest Ever UK Car

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2nd Place Overall

2014 2018 2019

OBRs First Fully Electric Car

2016

Hybrid Vehicle Development

1st Place Design Top UK Team

2021

Top UK Team

2022

1st Place Design
1st Place Laptime

Battery Development

Battery Development

1. Cell selection
2. Testing
3. Modelling
4. Mechanical design

Battery Test Consortium (BTC)

Cell	Chemistry
Samsung 25R	NMC
LG HG2	NMC
Sony VTC6	NMC
Melasta SLPB6542126	LCO
Melasta SLPB8542126	LCO
Melasta SLPB8346143	LCO
Melasta SLPBB142124	LCO
Melasta SLPB8870175	LCO
Melasta SLPB7336128HV	NMC
Melasta SLPB9542124HV	NMC
Melasta SLPBB042126HV	NMC
Melasta SLPB7579207HV	NMC

Free available datasets for FS teams:

- HPPC
- GITT
- EIS
- Pseudo-OCV
- FS Endurance Drive Cycle
- Degradation

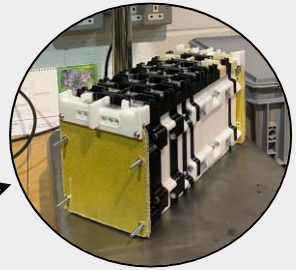
BTC GitHub repository

Battery Modelling | Mechanical Design | Battery Testing | Cell selection

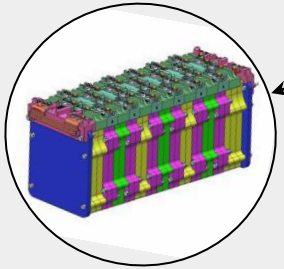
Planden, B., Lukow, K. (2021). Battery Test Consortium. Available at: https://github.com/Oxford-Brookes-HVES/BTC

Cell tab resistance

Development module (2P26S)



Decreasing cell's tab joint resistance

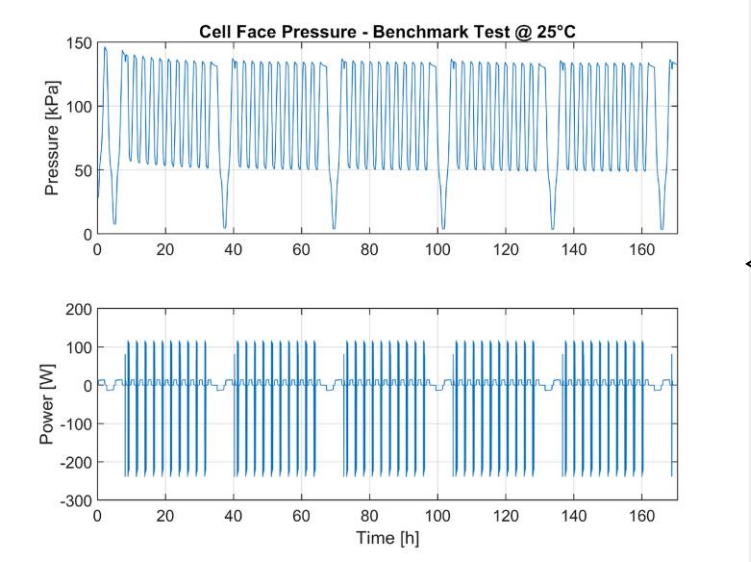


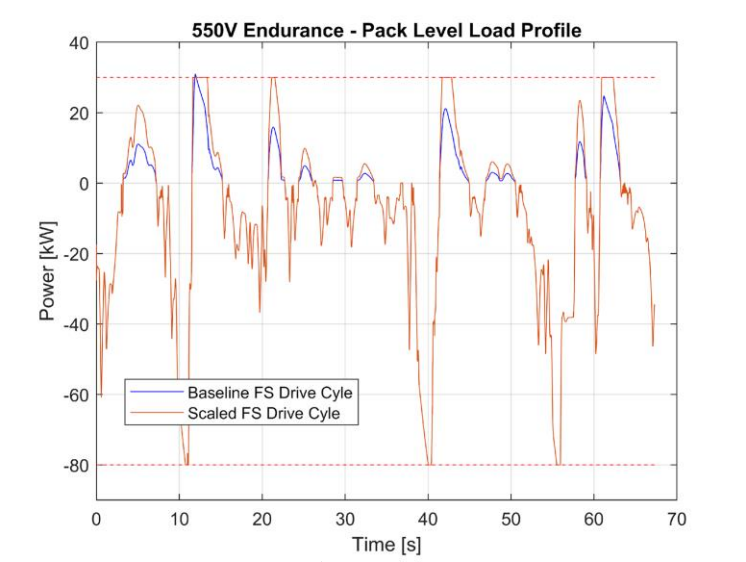
Battery pack specifications:

- LCO Melasta pouch cell
- 550V
- 2P130S

Battery Modelling	Mechanical Design	Battery Testing	Cell selection

Charging C-rates testing

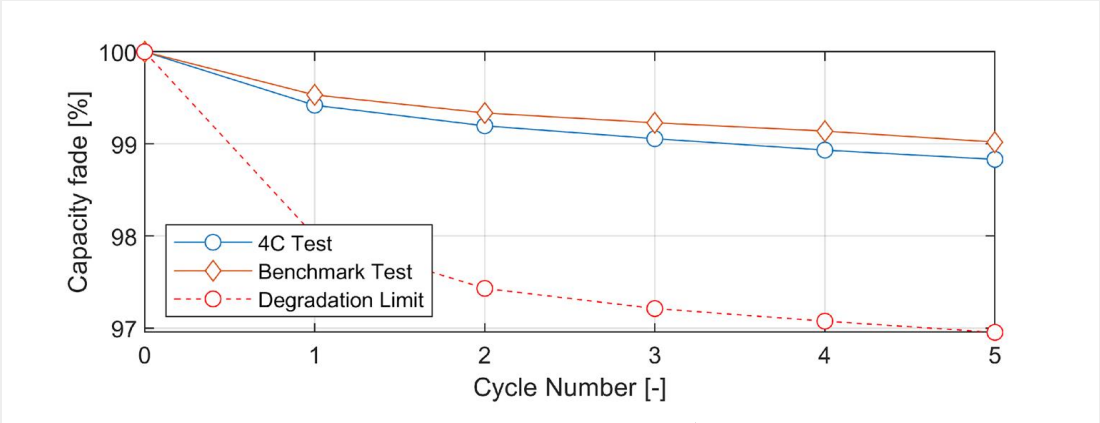




50 endurance runs = 1100 laps

Battery Modelling	Mechanical Design	**Battery Testing**	Cell selection

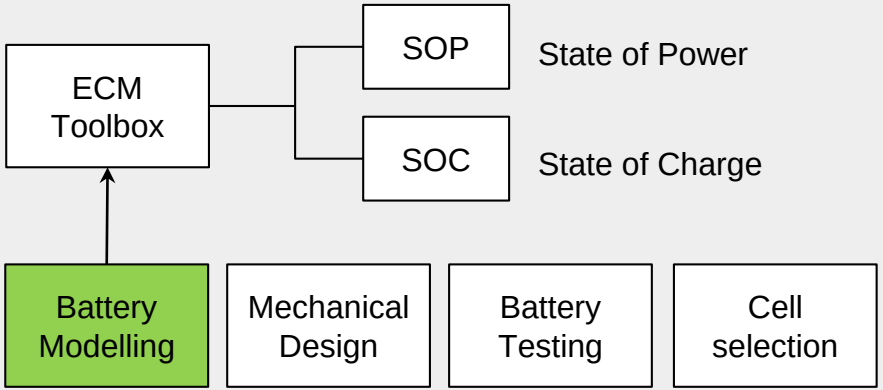
Charging C-rates testing



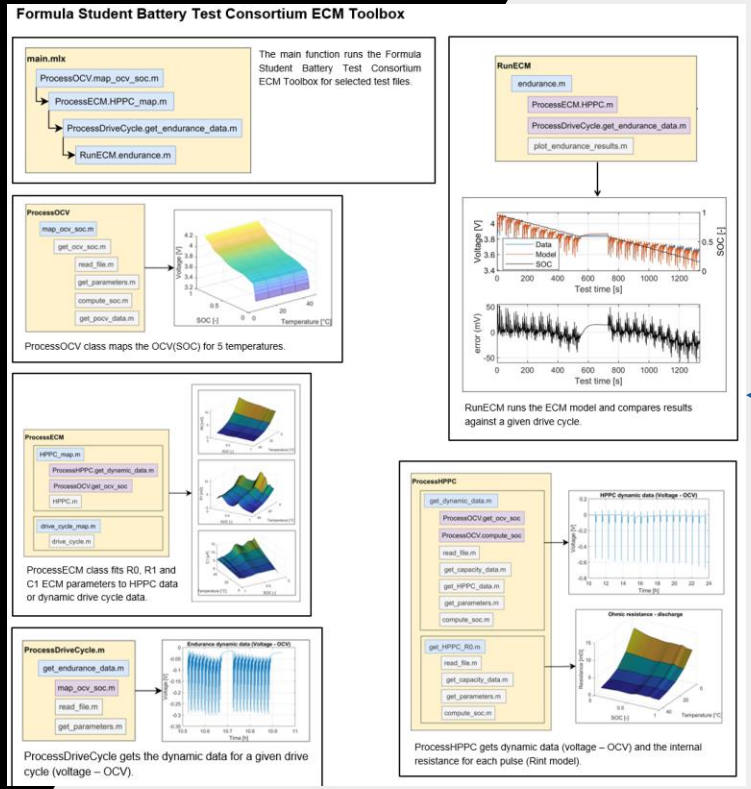
1 Cycle = 10 endurance runs = 220 laps

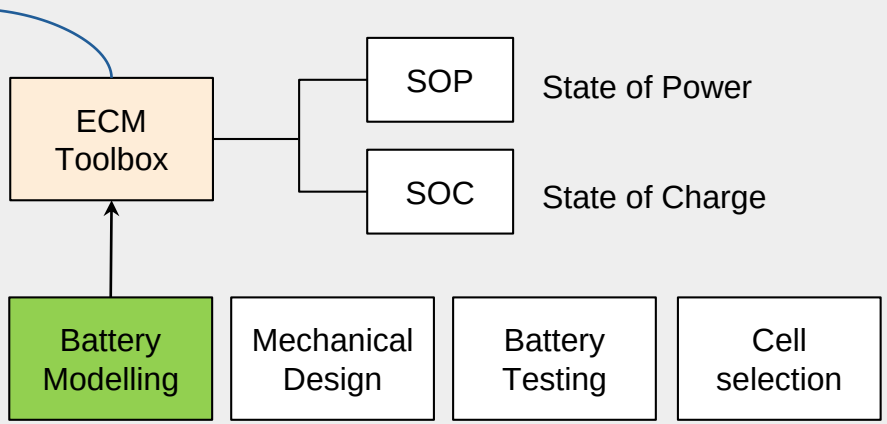
Battery Modelling	Mechanical Design	**Battery Testing**	Cell selection

Battery Modelling

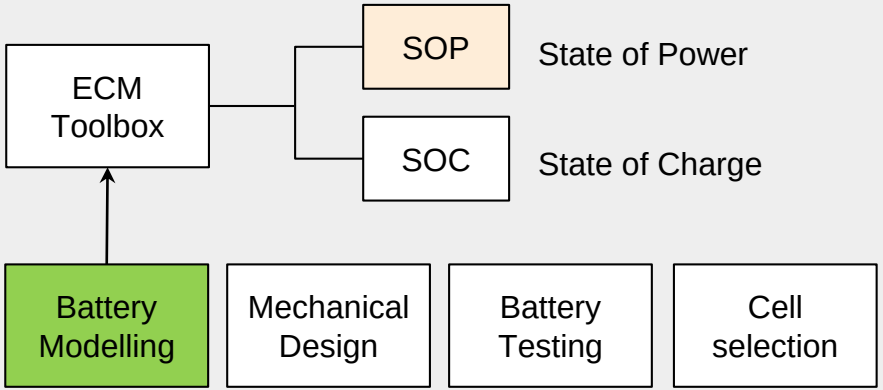


Equivalent Circuit Model





State of Power estimation



State of Power estimation

Battery Pack

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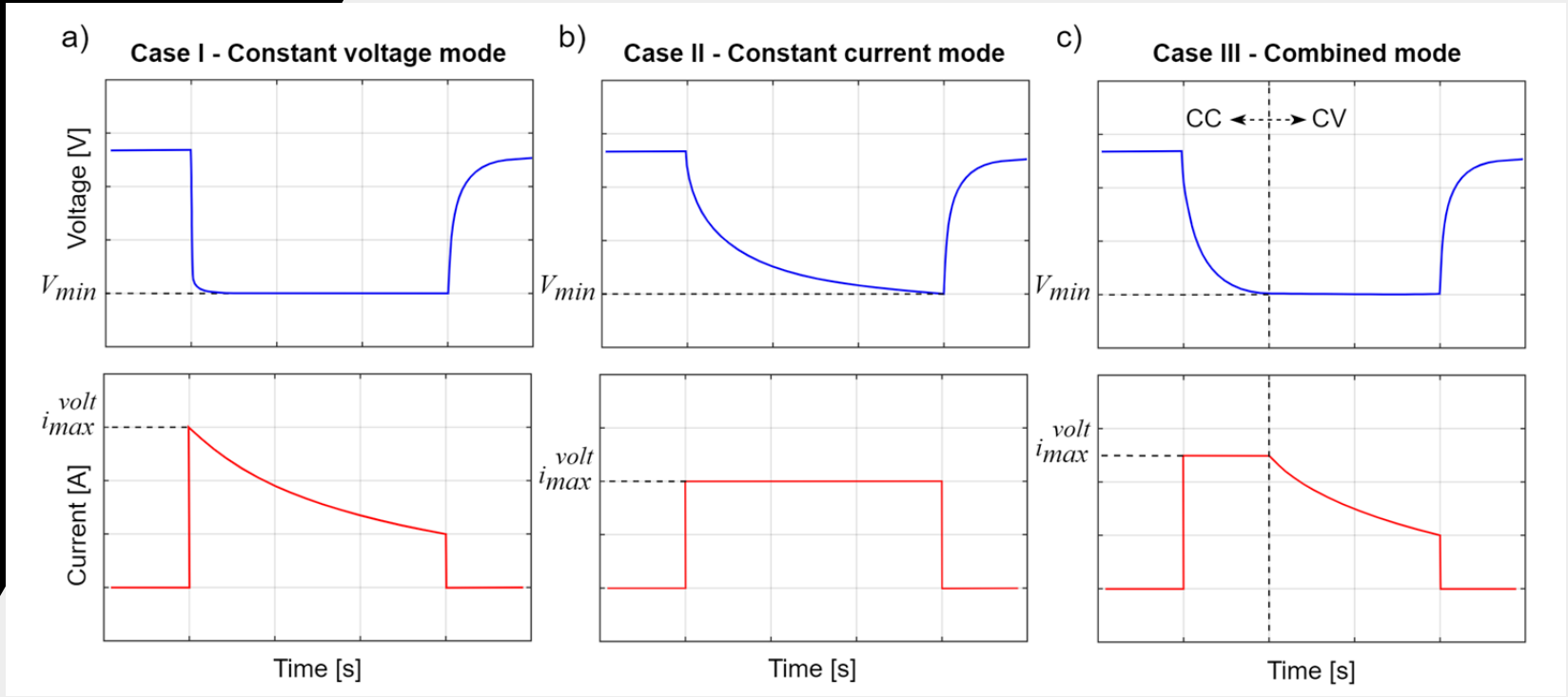
Inverters

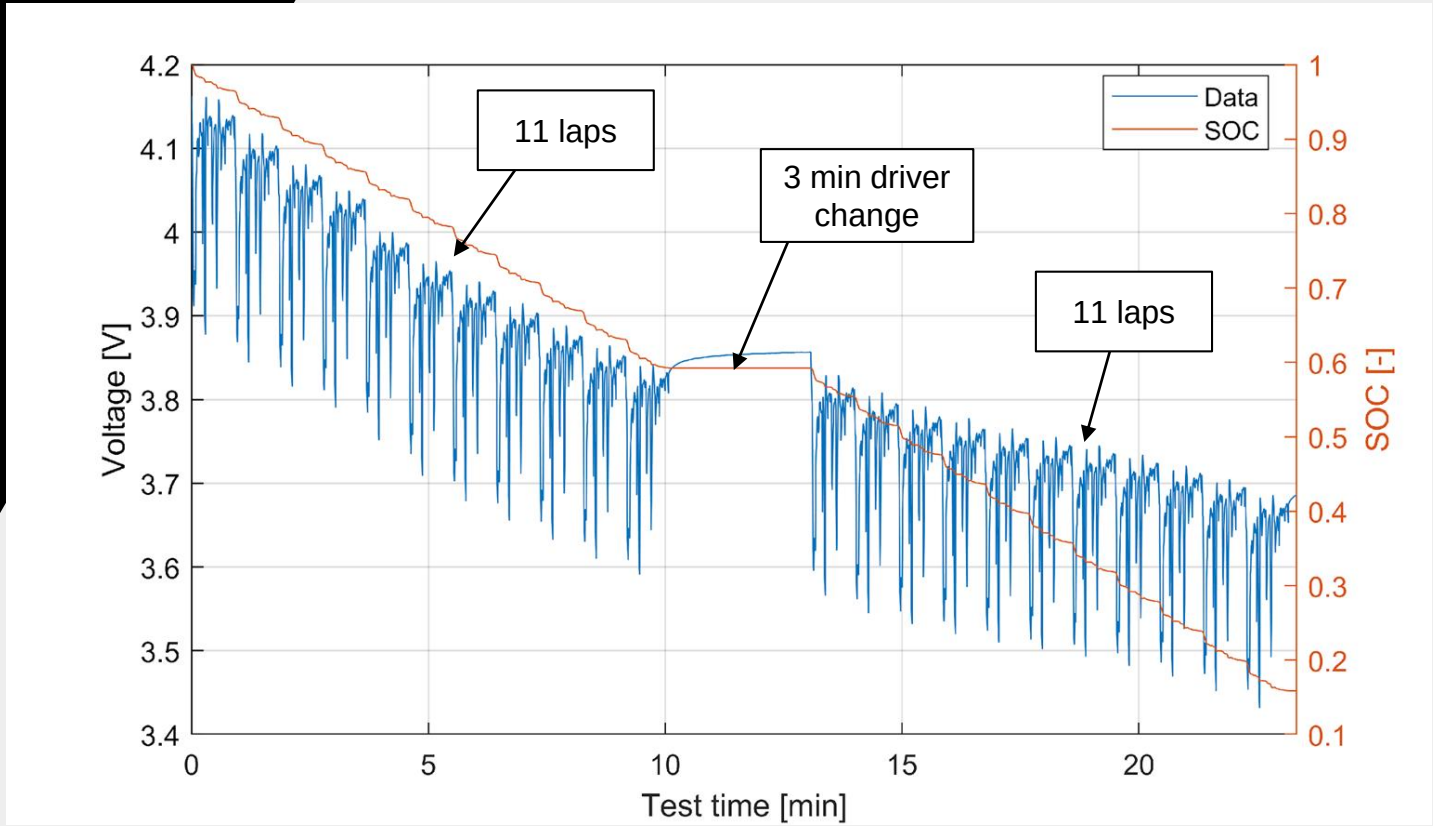
Motors

Limiting layers

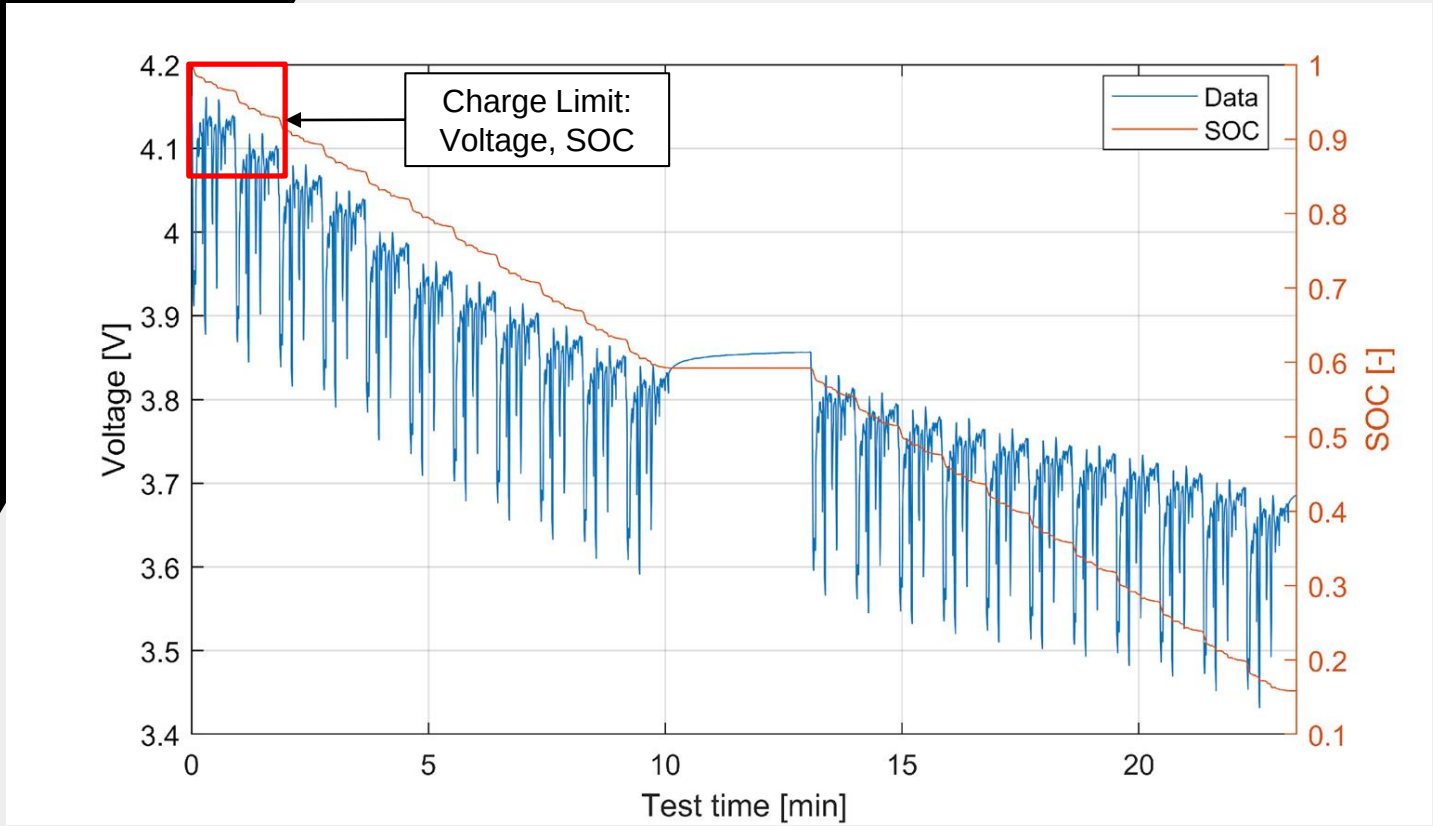
State of Power estimation



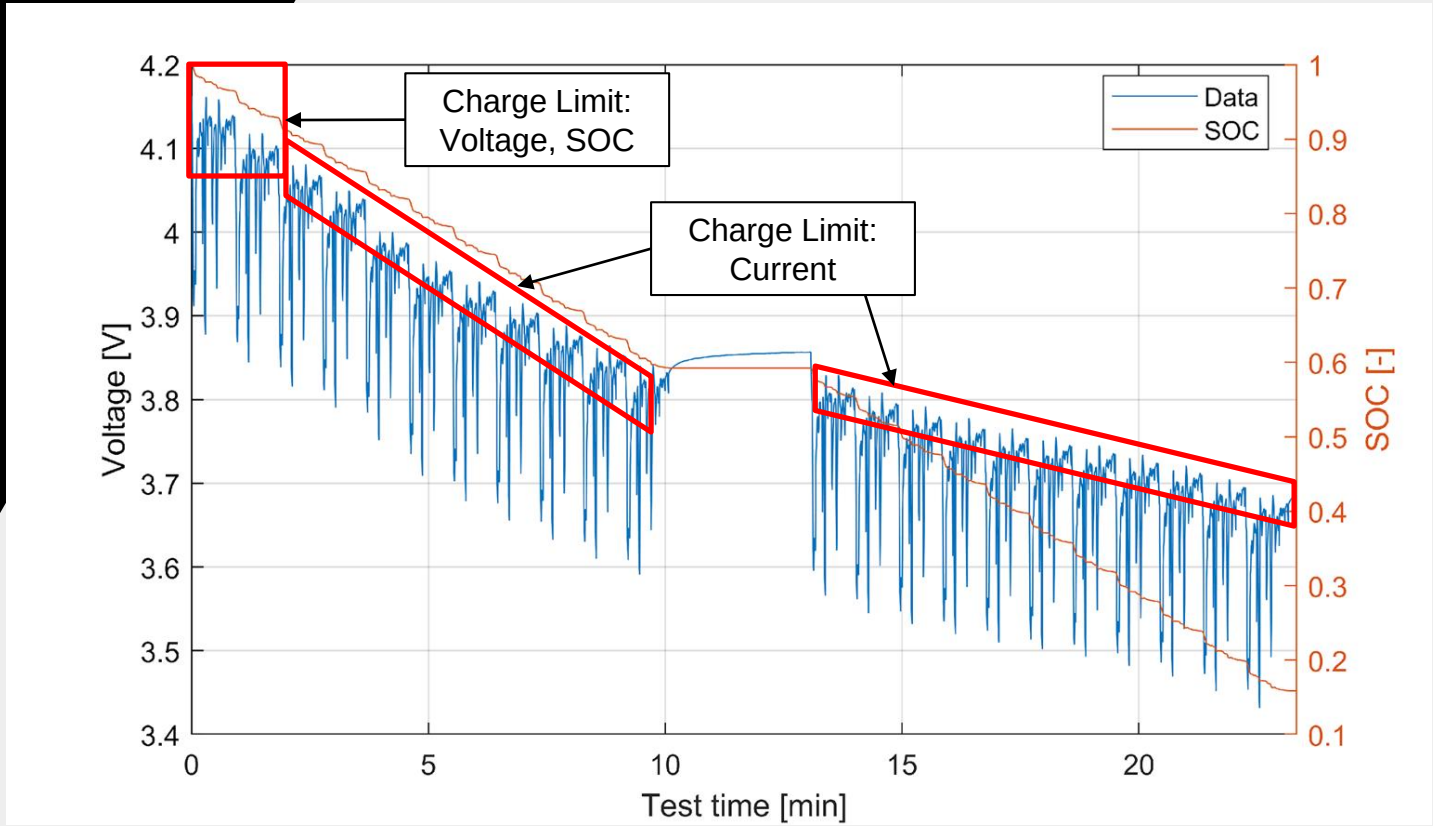
State of Power estimation



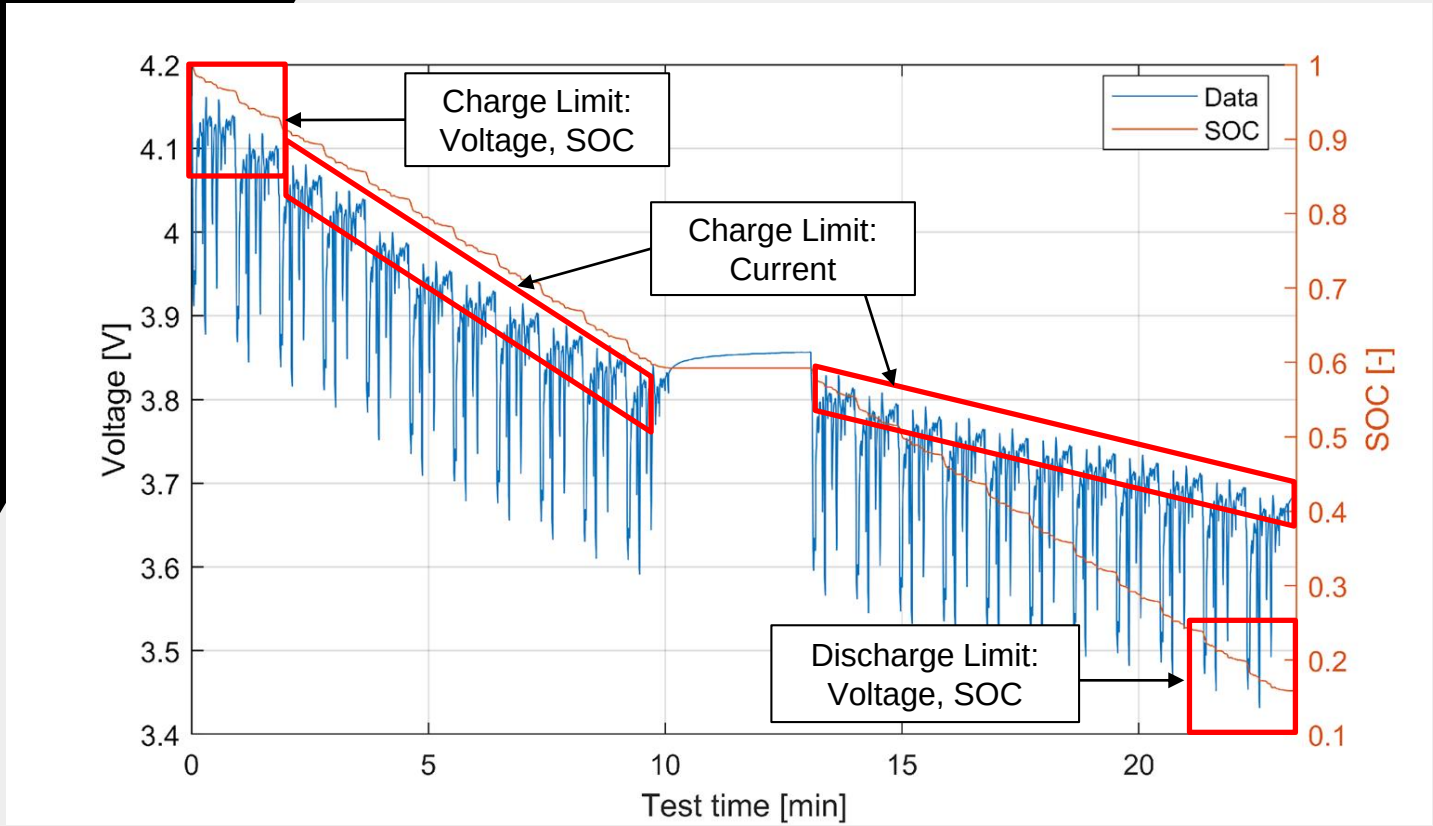
State of Power estimation



State of Power estimation



State of Power estimation



State of Power estimation

How much charge or discharge power is available for the next Δt seconds?

Battery Pack

…

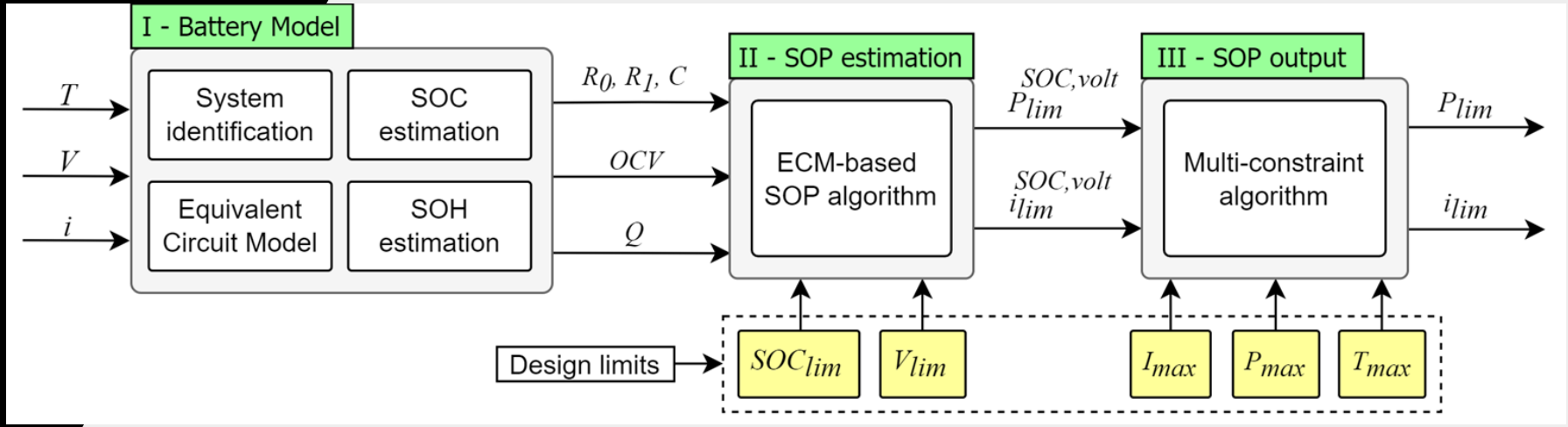
Inverters

Motors

Limiting layers

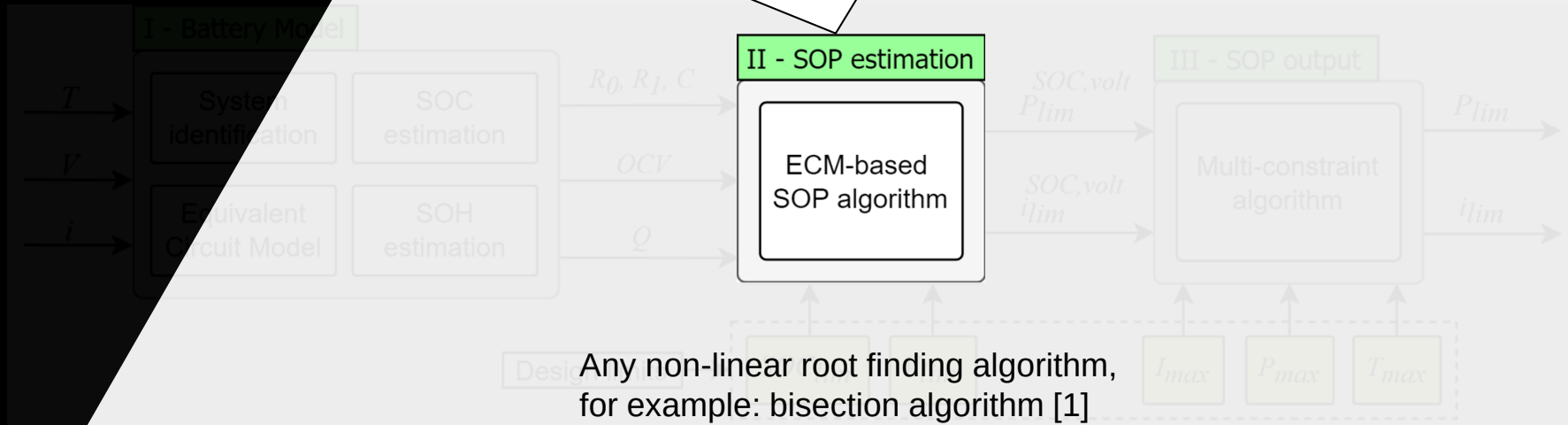
State of Power estimation

Predictive algorithm



State of Power estimation

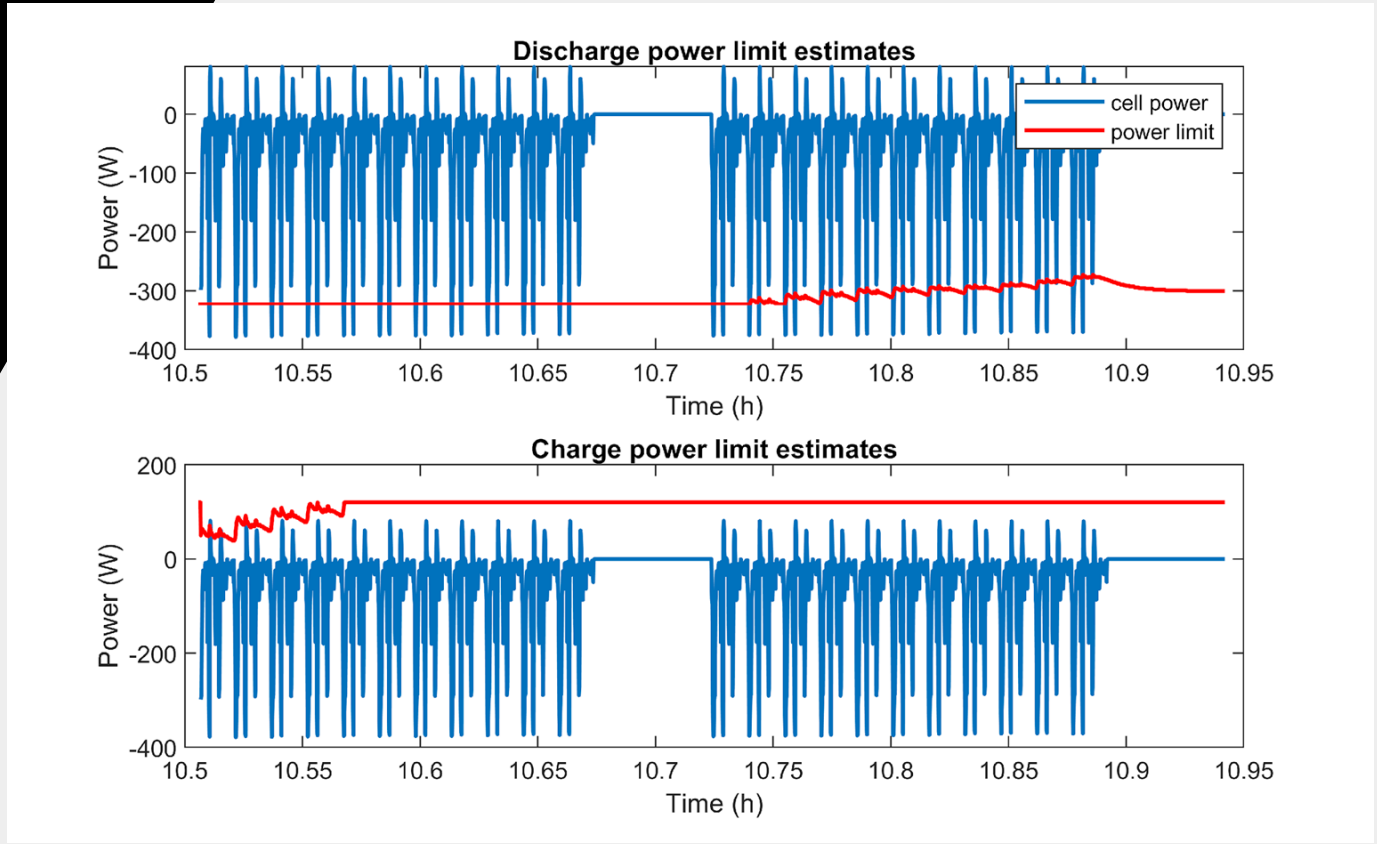
Search for the current that will cause the battery to reach any voltage, SOC or current limits



Any non-linear root finding algorithm, for example: bisection algorithm [1]

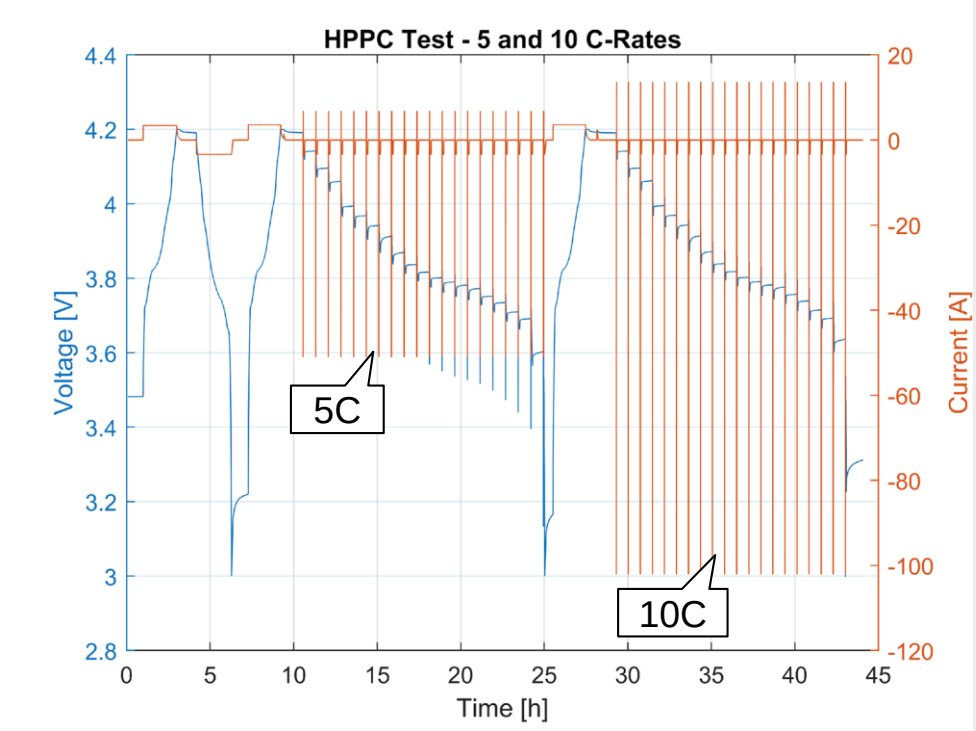
[1] Plett, G. L. (2004). High-Performance Battery-Pack Power Estimation Using a Dynamic Cell Model. IEEE Transactions on Vehicular Technology, 53(5), 1586–1593. https://doi.org/10.1109/TVT.2004.832408

State of Power estimation

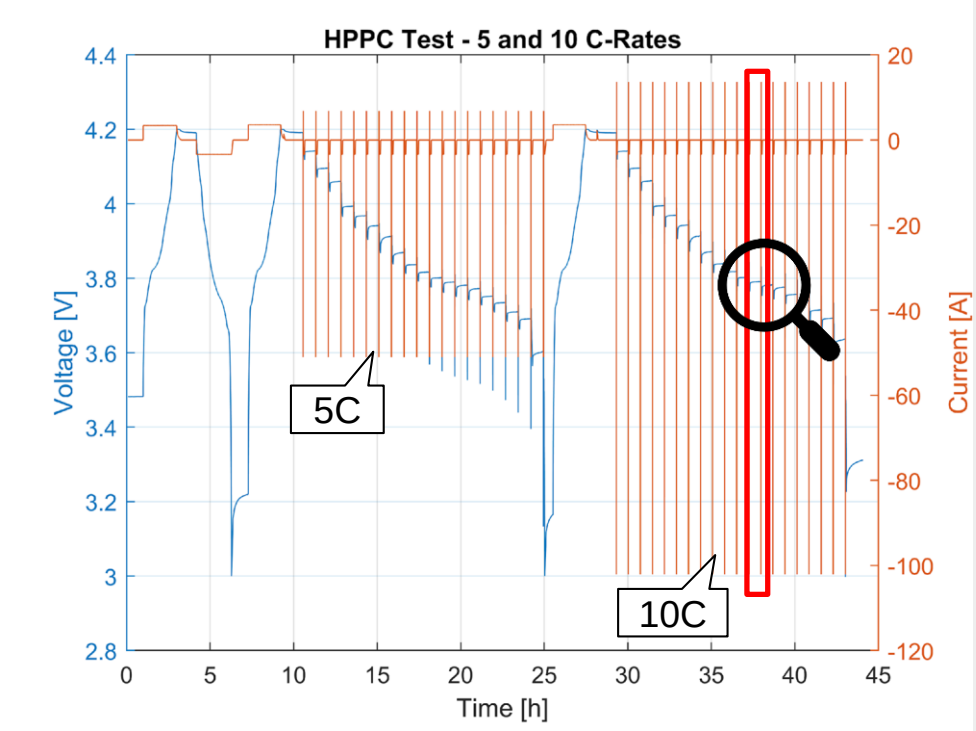


State of Power estimation

Validation approaches

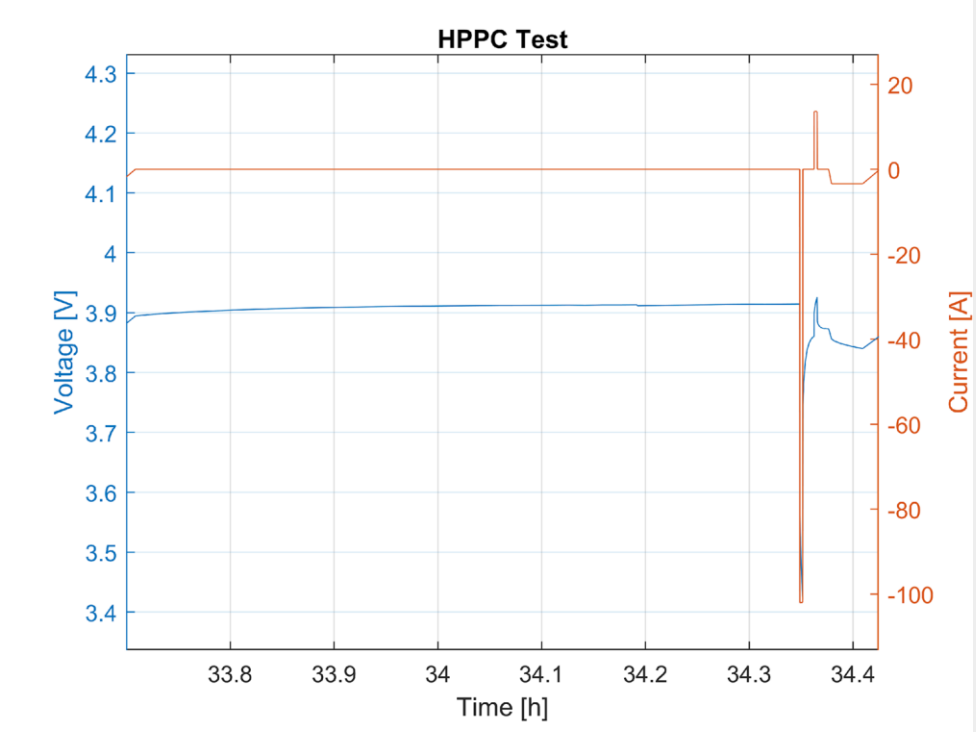


Validation approaches



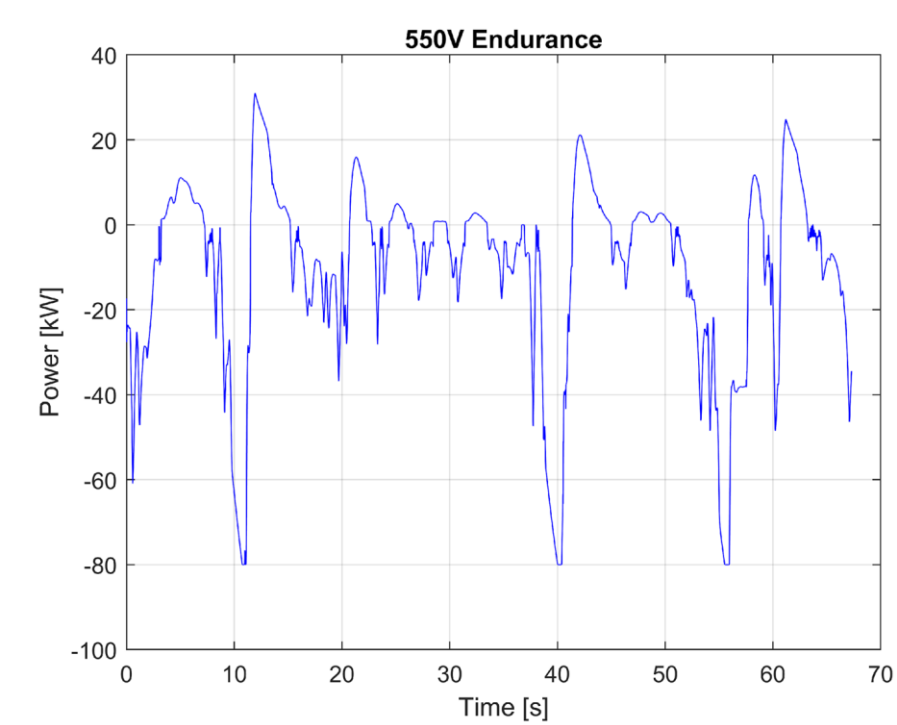
State of Power estimation

Validation approaches



State of Power estimation

Validation approaches



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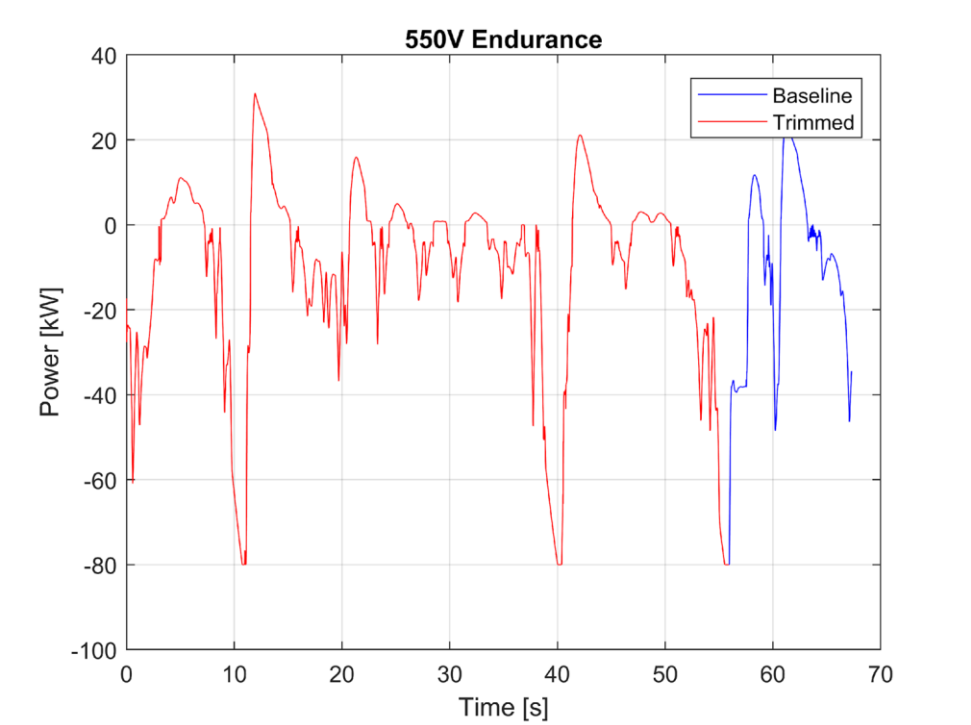

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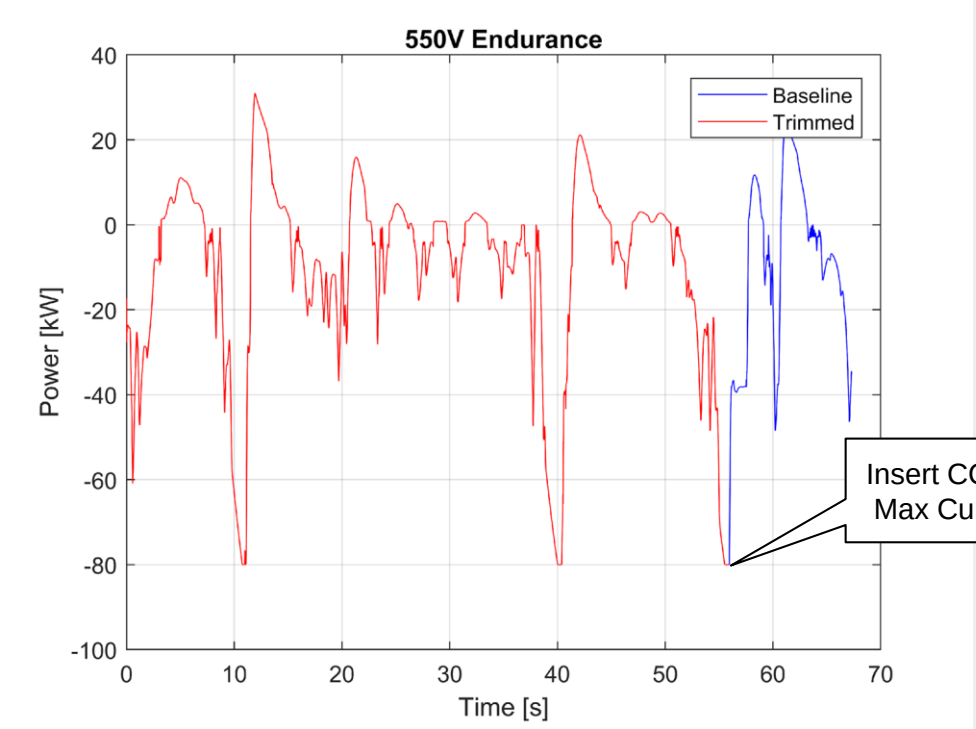

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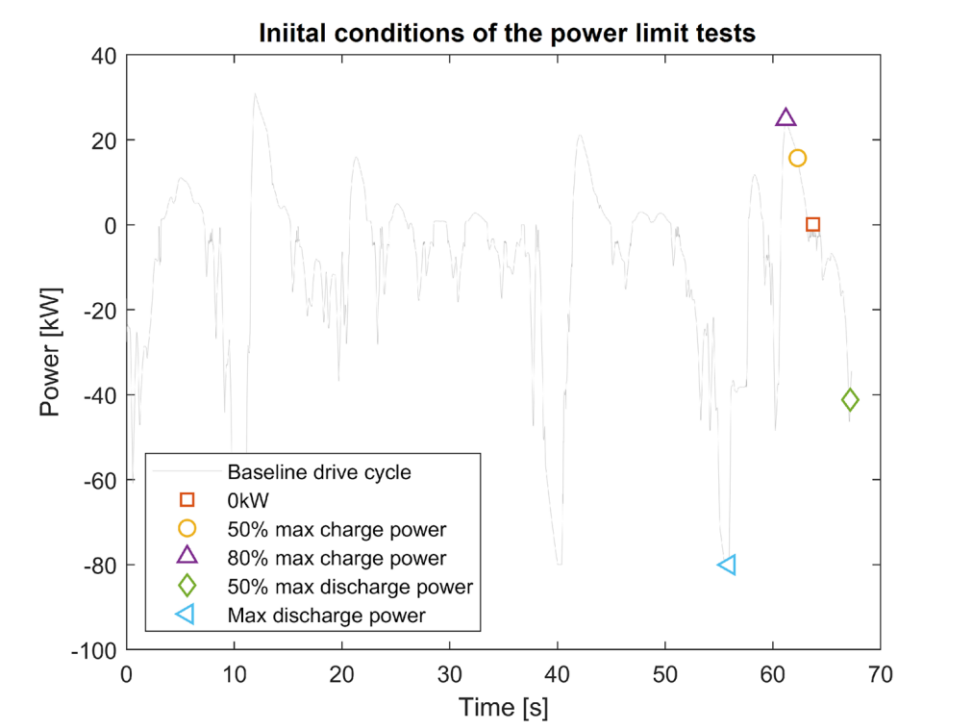
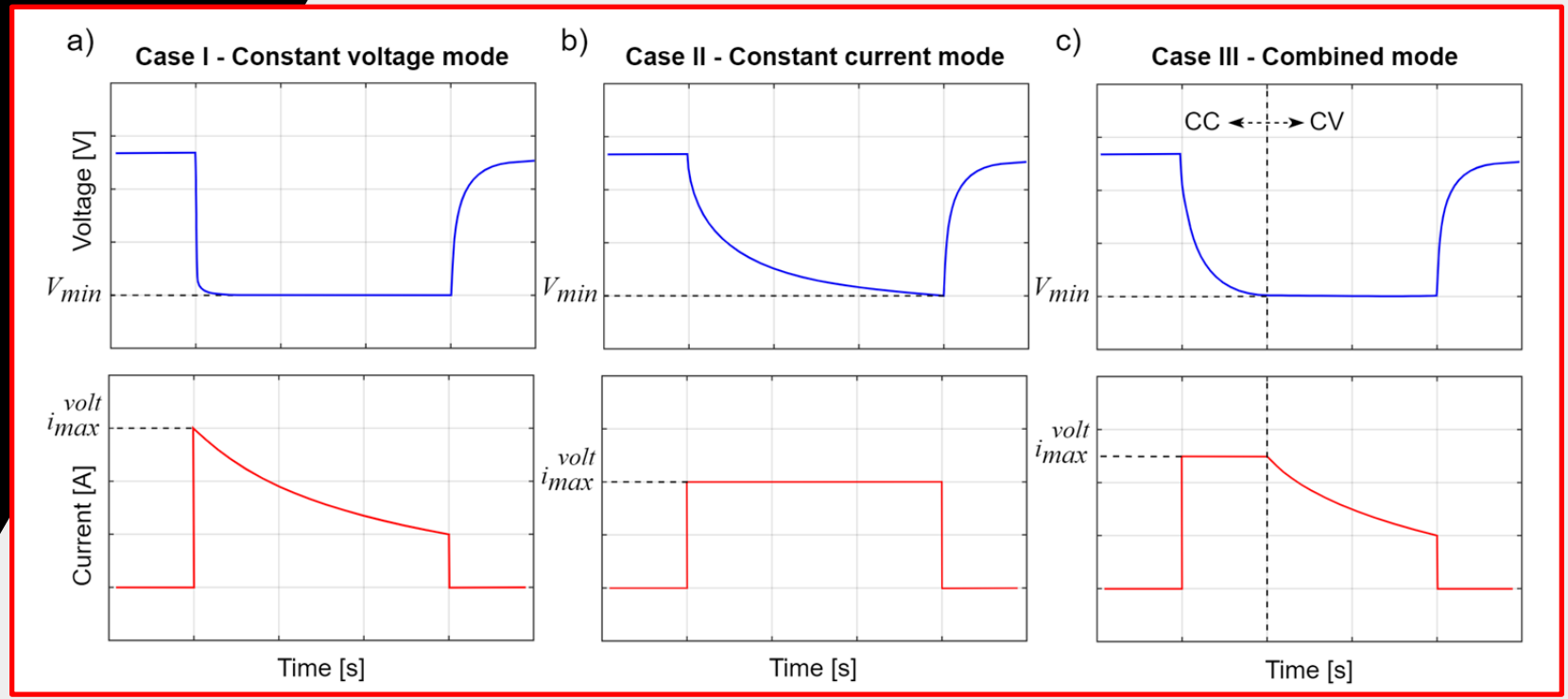


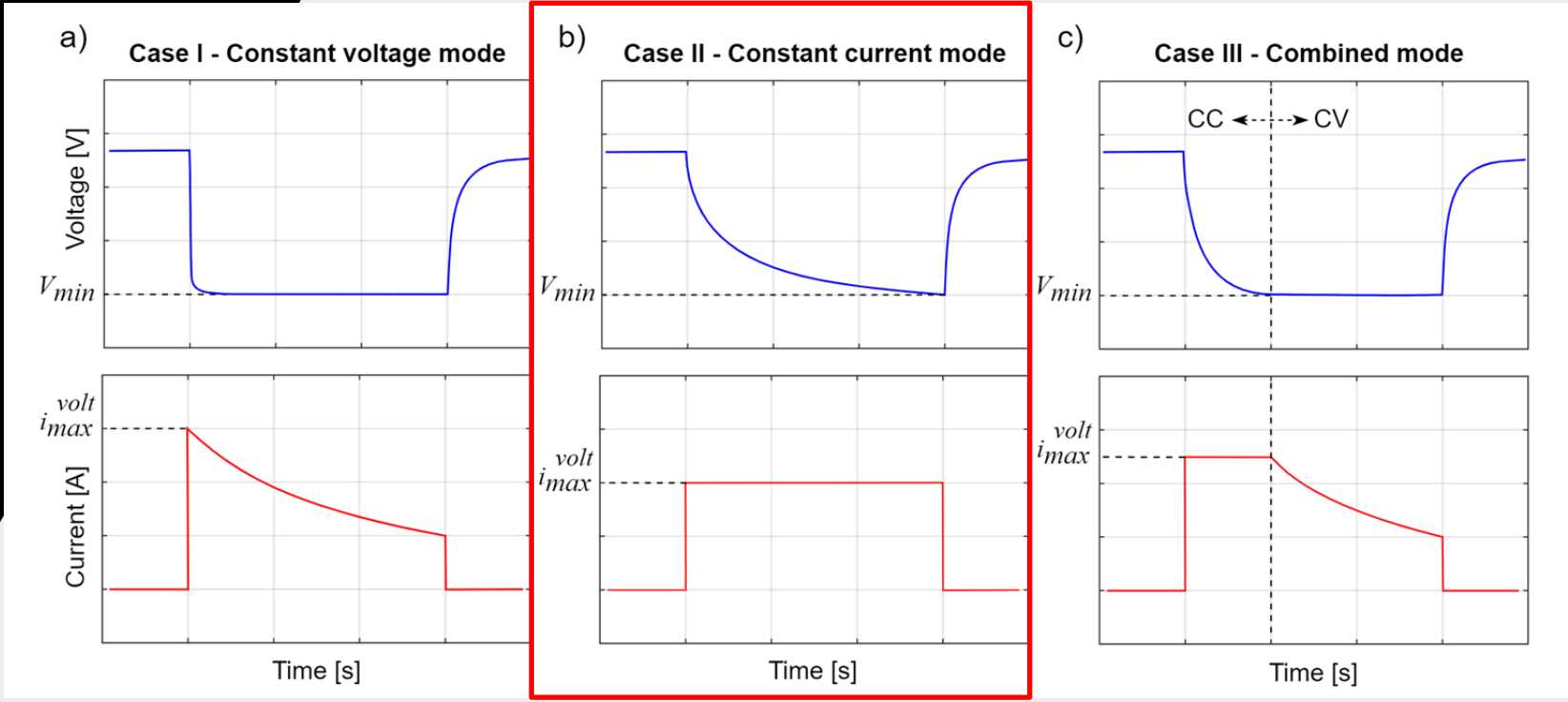
State of Power estimation

Challenges



State of Power estimation

Challenges



State of Power estimation

Next steps

1. Model Predictive Control (MPC)-based SOP estimation [2]

- The bisection algorithm considers the input parameters constant over the future horizon.
- MPC computes optimal power profile to achieve max power up to the constraints boundaries

2. Scale from cell level to pack level considering cell-to-cell variations and temperature gradients

[2] Xavier, M. A., Kawakita De Souza, A., Plett, G. L., & Scott Trimboli, M. (2020). A Low-Cost MPC-Based Algorithm for Battery Power Limit Estimation. *Proceedings of the American Control Conference*, *2020-July*, 1161–1166. https://doi.org/10.23919/ACC45564.2020.9147337

Thank you!

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