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Modular partial power converter for fully electric marine applications

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Presenter: Erik Garayalde Perez

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Introduction

Electrification of maritime sector

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Background

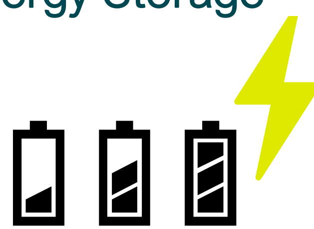
UE 2030

32,5% Energy efficiency improve

Reduce our dependency on fossil fuels

40% CO2 Reduction

Energy Storage



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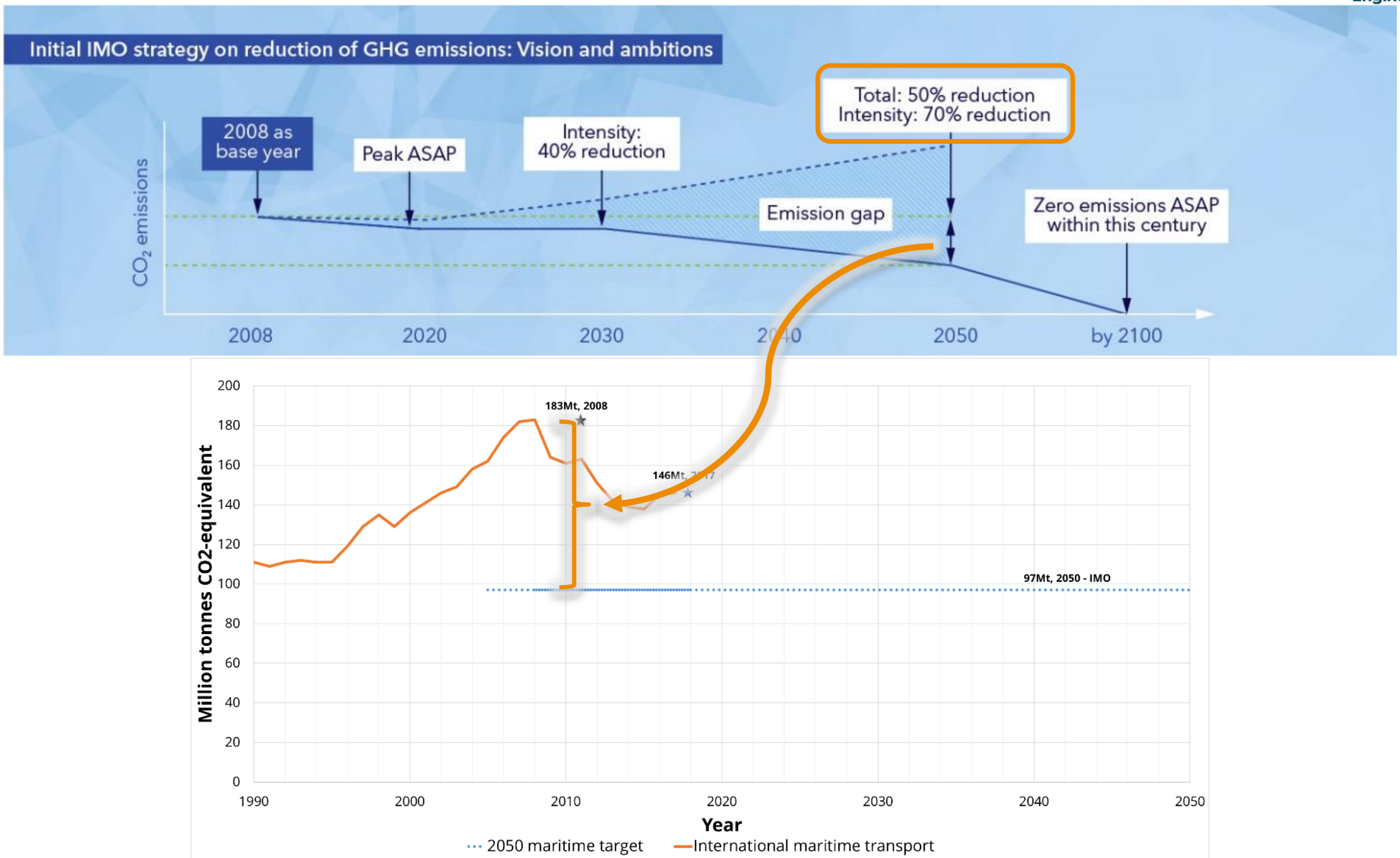

*Source: DNV-GL (https://www.dnv.com/expert-story/maritime-impact/How-newbuilds-can-comply-with-IMOs-2030-CO2-reduction-targets.html)

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Benefits of installing batteries on board ships:

Spinning reserve
- Backup for running generators
- Fewer turbines needed online

Peak shaving
- Act as a buffer
- Level power seen by engines

Optimise load
- Optimise the operating point of the generators
- Reduce maintenance

Harvest energy
- Recover energy from cranes, drilling equipment, etc.
- Accommodate energy from renewables

Immediate power
- Instant power in support of generators

Backup power
- Battery system provides backup power, UPS like functionality

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What are the main challenges to electrify a ship?

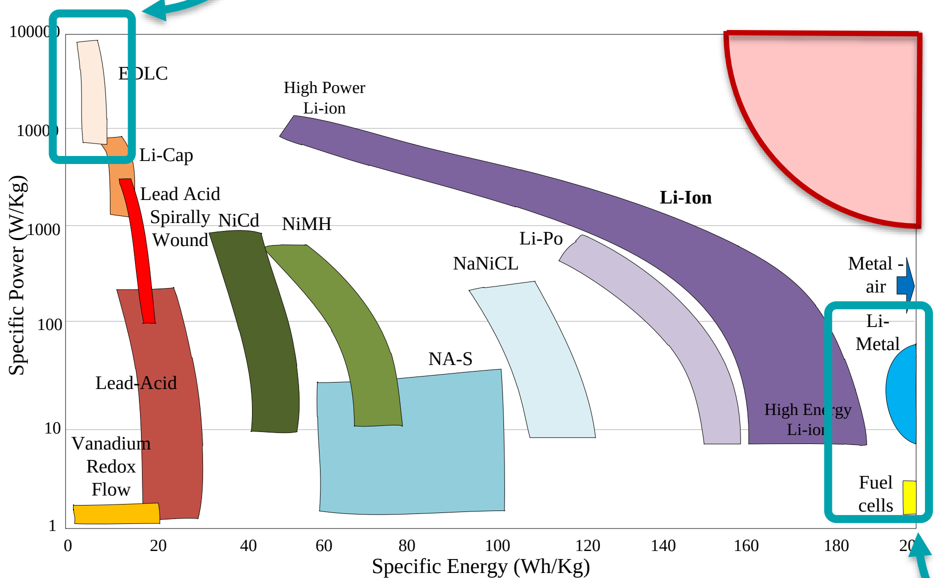
Selection of **battery technology**

&

Battery-pack **sizing**

Selection of the technology

HIGH Power density
LOW Energy density



HIGH Energy density
LOW Power density

Can we combine both?

HP + HE

Energy Storage Hybridization

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Hybrid Energy Storage System

Design and Analysis

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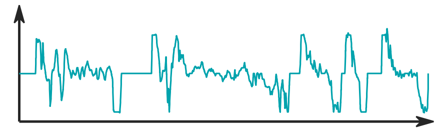
Why Energy Storage System Hybridization?

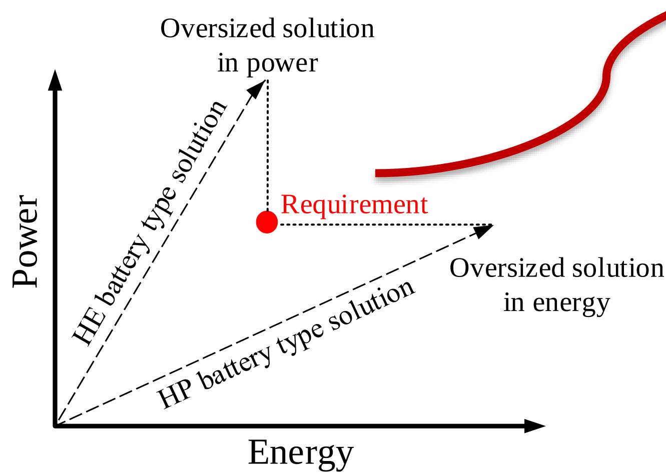
Why ESS Hybridization?

Application Power Profile



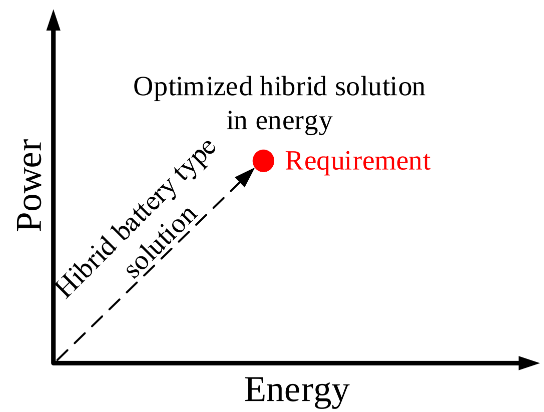
Average consumption
+
Power transients

Energy Storage Power and Energy Ratio improvement



Energy Storage Hybridization

Optimal sizing!



Sizing

- Power Sharing dependence
- Application Power Profile
- Cost Optimization

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First Step

Power Sharing method selection

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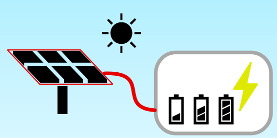
Power Sharing

Typical Power Sharing Techniques

Rule Based Control

- Power Threshold
- Look-up Tables
- Weighting Factors

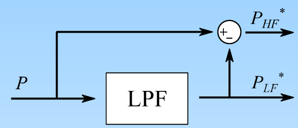
Field of Application:



Photovoltaic Systems

Filter Based Power Sharing

- Split of HF and LF



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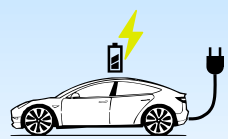
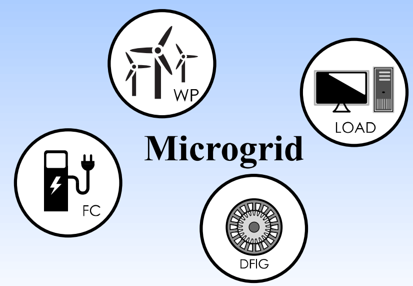


Electric Vehicle

Virtual Impedance

- Droop Control
- Virtual RC impedances

Field of Application:



Power Sharing

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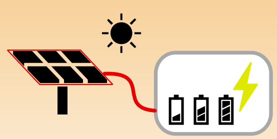

Photovoltaic Systems

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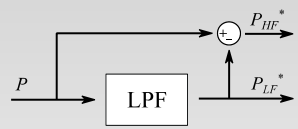

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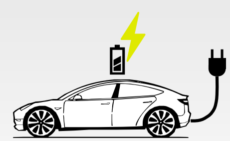

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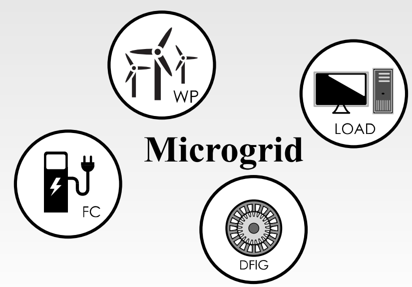

Rule Based Control

Rule Based Control

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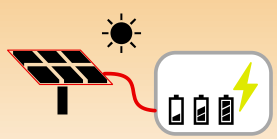
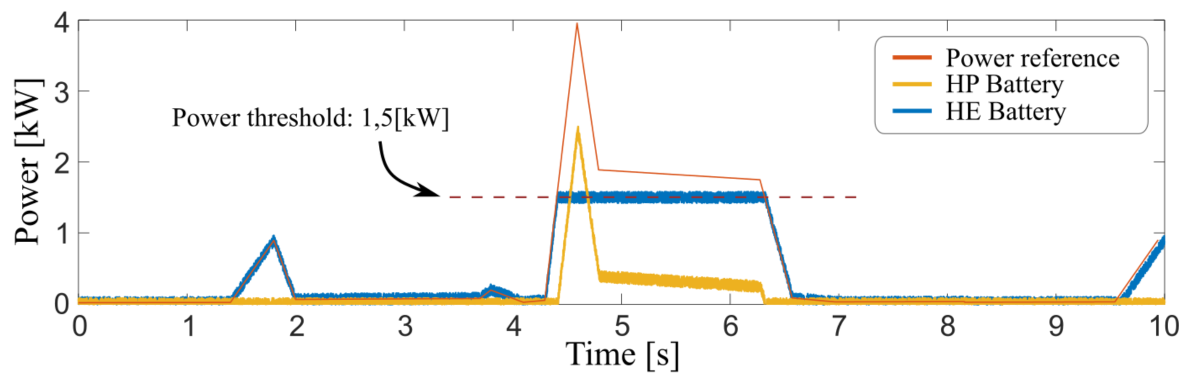


Photovoltaic Systems

Power Threshold

$$P_{tot} = \begin{cases} P_{HP\_batt} + P_{HE\_batt}, & if \;\; P_{tot} > P_{batt\,max} \\ P_{batt}, & Otherwise \end{cases}$$



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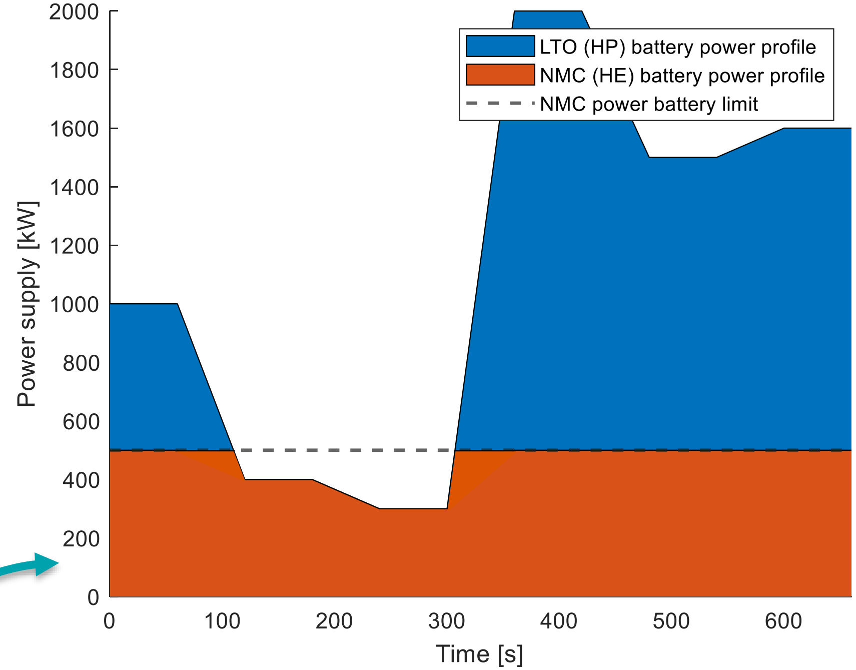

HE Battery

- NMC Battery
- Sized for the main consumption.
- The maximum power is limited.

HP Battery

- LTO Battery
- Should provide the rest of the power.
- Able to work with high dynamics.

Complementary working mode

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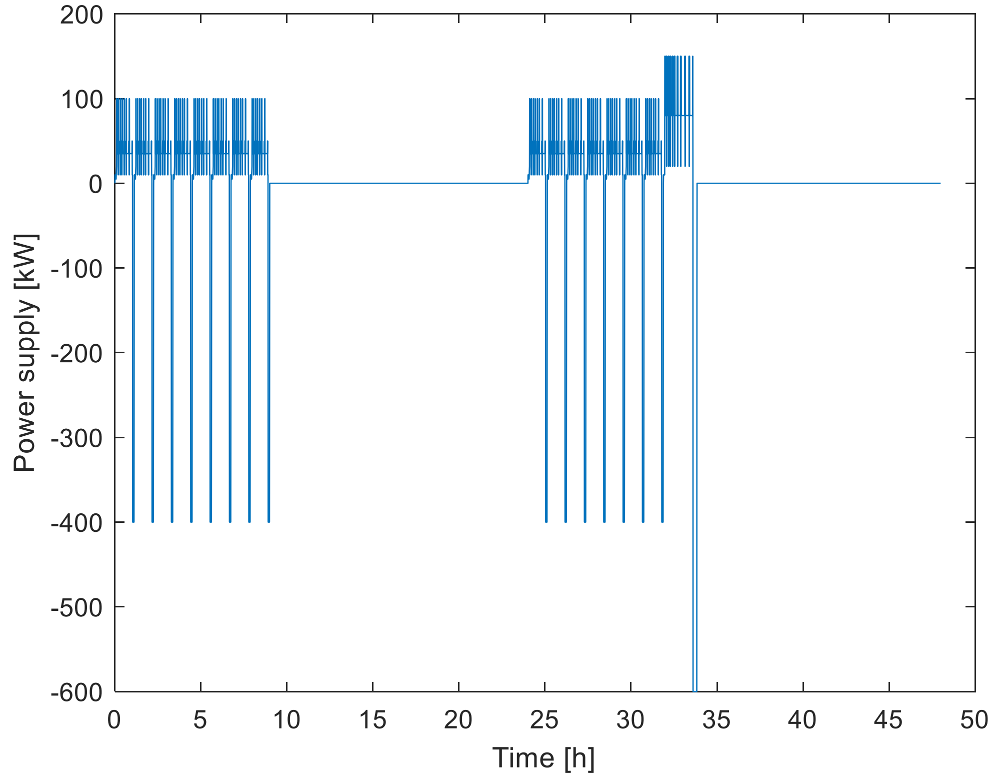
Application Requirements and Power Profile

Electric Urban Ferry (Design Parameters):

- Service Life: 10 Years
- End of Life: 80% of initial capacity.
- Max. Power: 150 kW
- Min. Energy: 136 kWh
- DC bus Voltage: 1000V
- SoC Range: 90% - 10%



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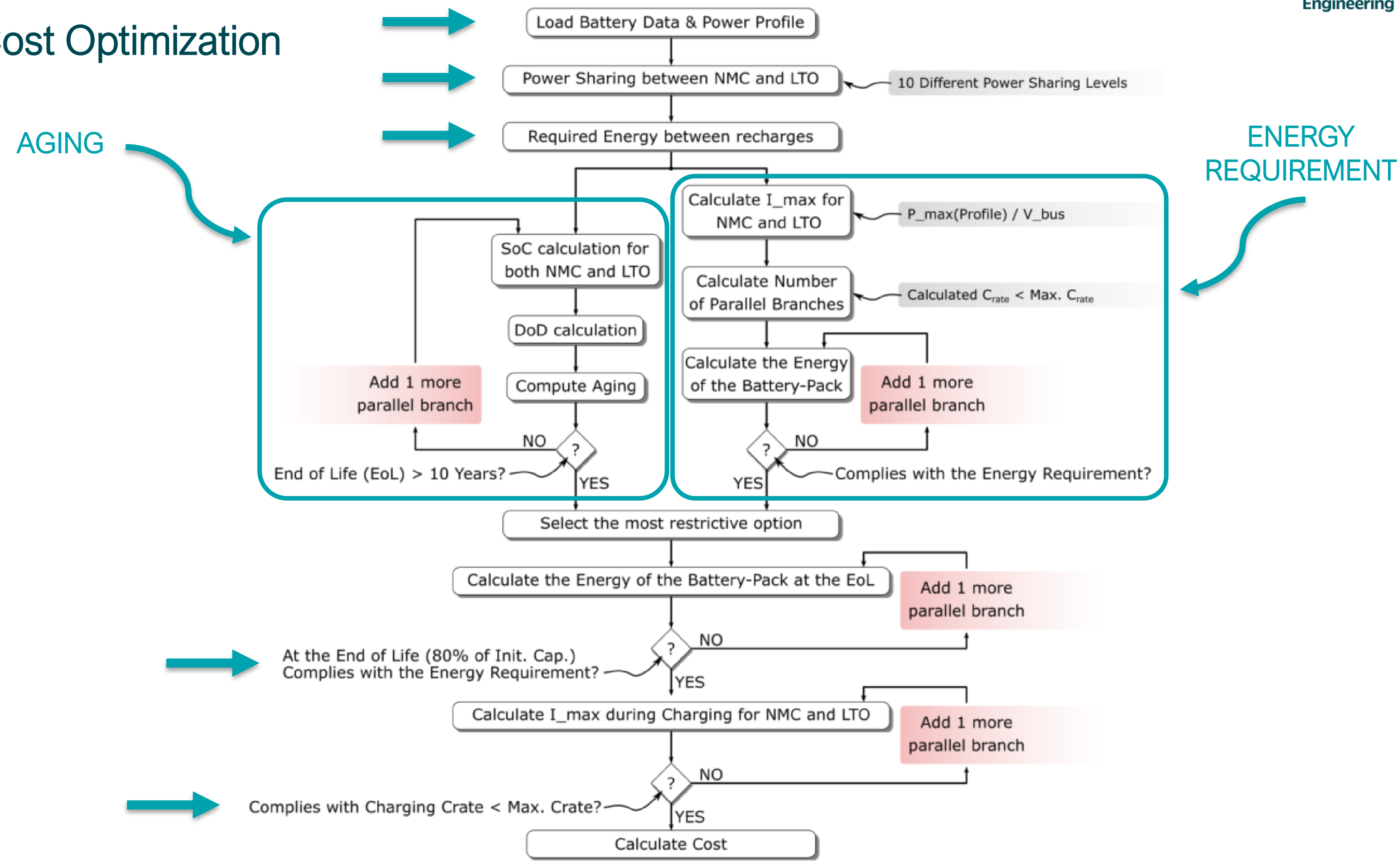
Cost Optimization



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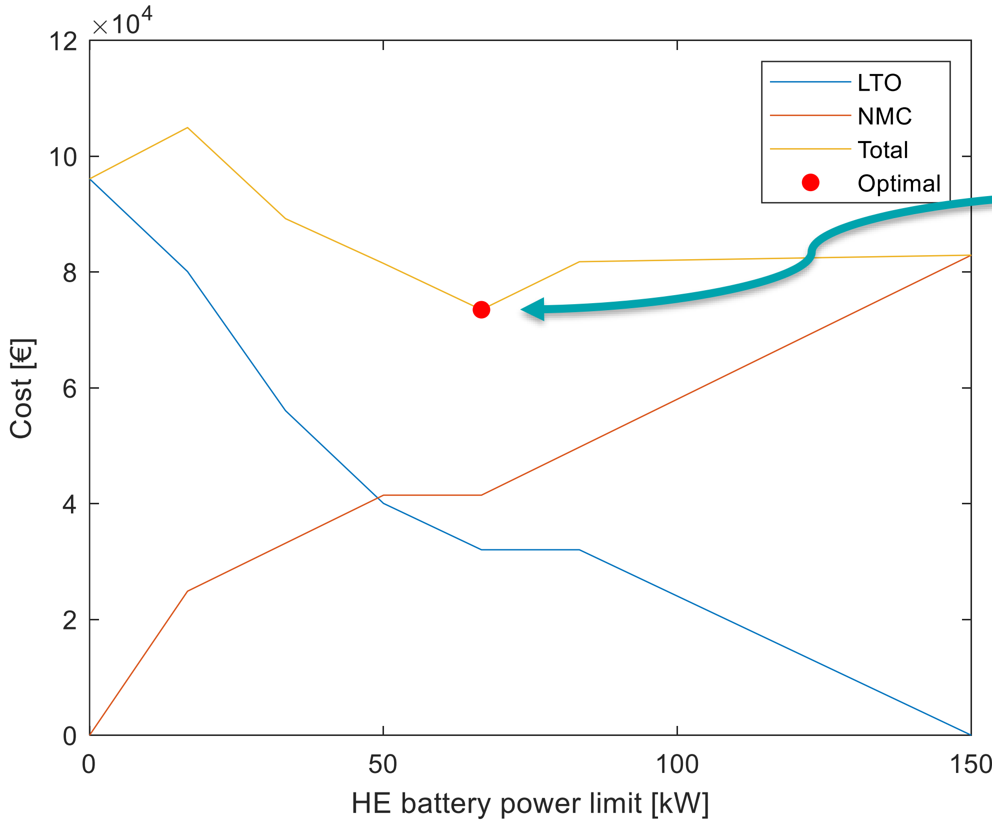
Cost of the hybrid battery



Full LTO Battery-Pack

Full NMC Battery-Pack

Hybrid Battery Sizing Results

Battery type	Hybrid battery (HE + HP)		Total
	HE	HP	HE + HP
Cells layout	224S5P	352S4P	
Power	696.5 kW	349.7 kW	1046.2 kW
Energy	387.4 kWh	74.5 kWh	461.9 kWh
Cost	32028 €	41455 €	73483 €

⚠ Strong cell cost dependency

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Partial Power Converter

3.1 Architecture Description

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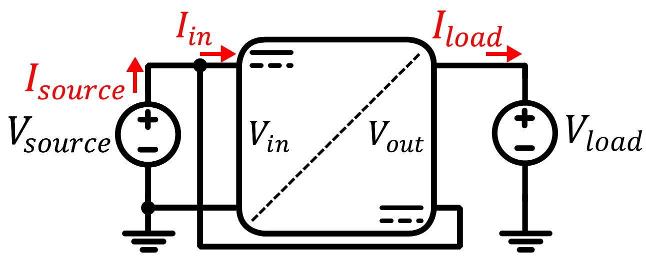
Two main PPC architectures

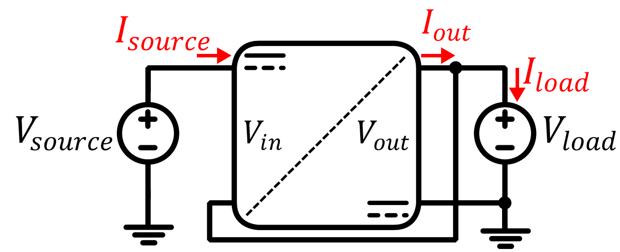
IPOS

Input Parallel Output Series



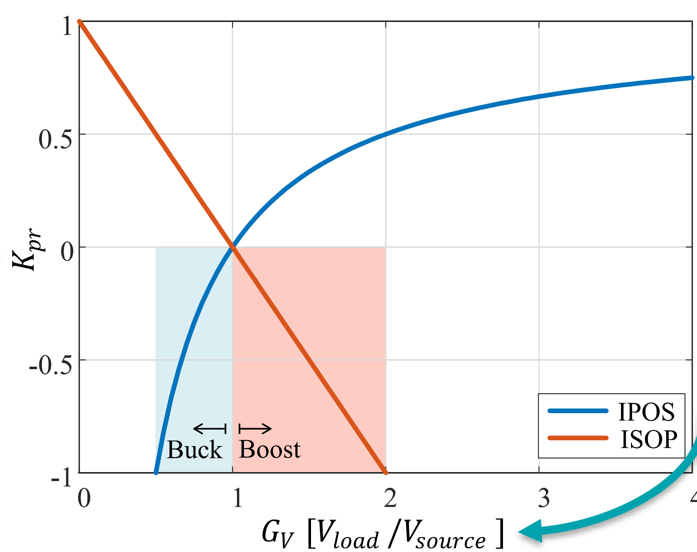
ISOP

Input Series Output Parallel



Partial Power Ratio

$$K_{pr} = \frac{P_{conv}}{P_{source}}$$



Voltage Gain

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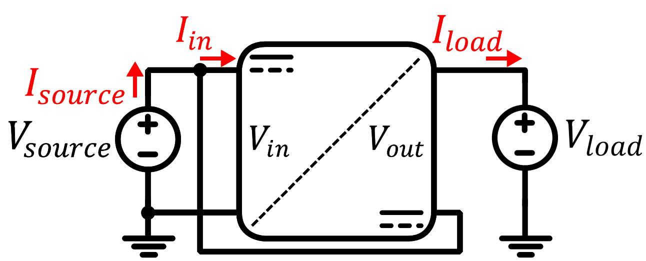
Selection of IPOS architecture

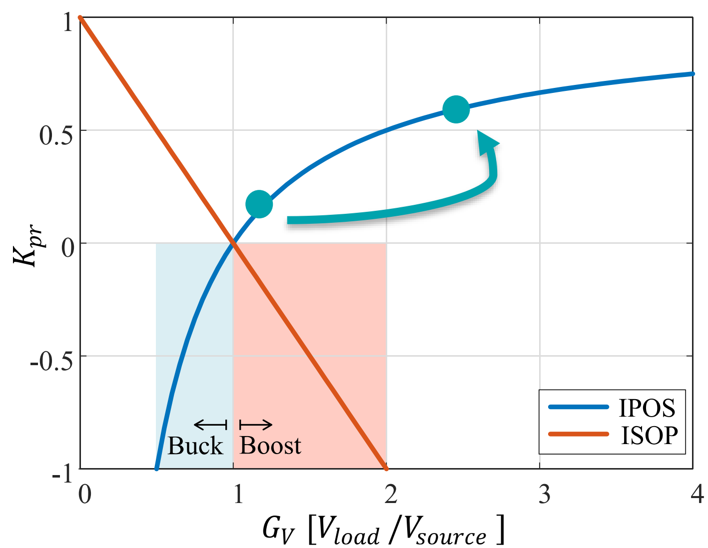
Why? → Due to Voltage Gain: (Boost mode)

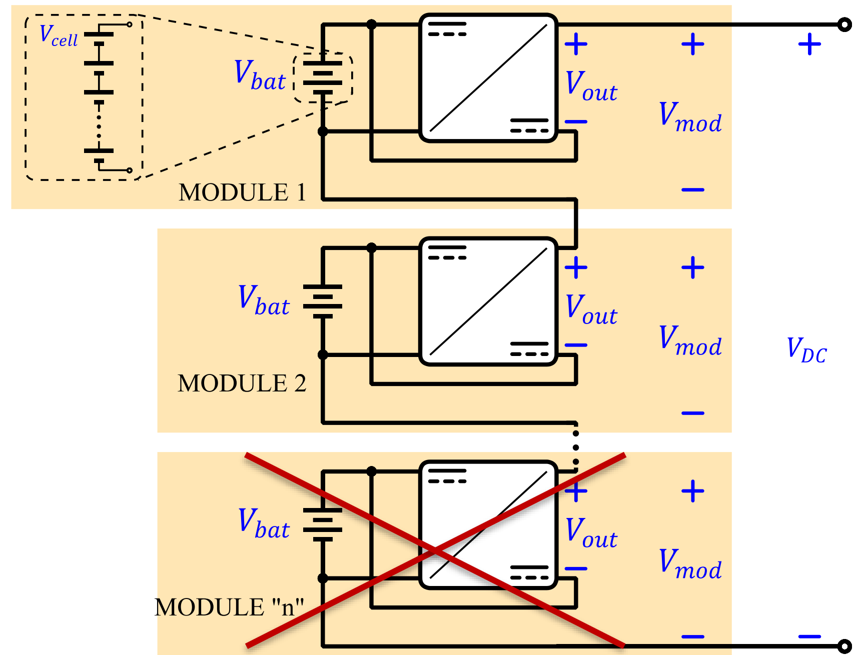
$$G_V = \frac{V_{out}}{V_{battery}}$$

IPOS

Input Parallel Output Series







If 1 module fails
The operating point changes

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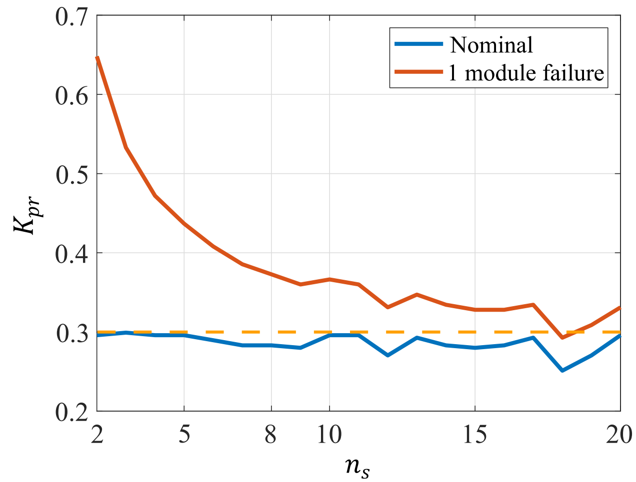
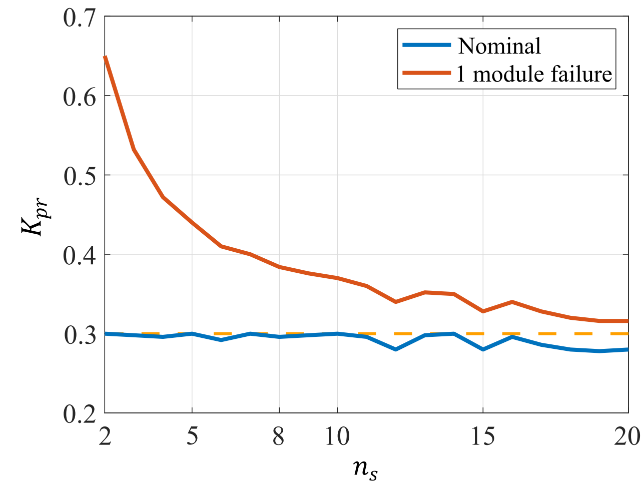
1 module failure

K_{pr} increment for 1 module failure

NMC

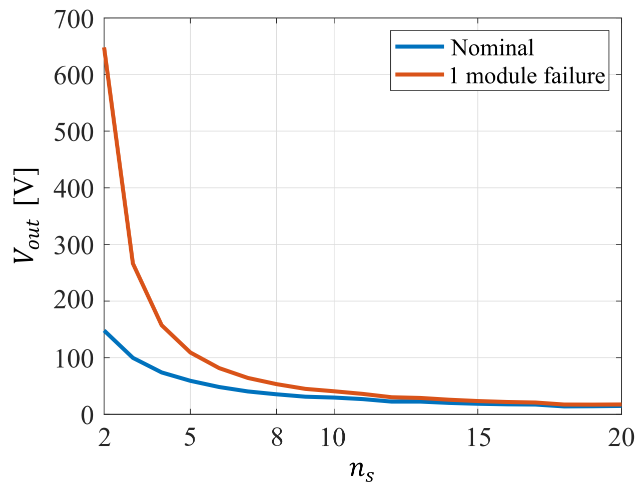


LTO

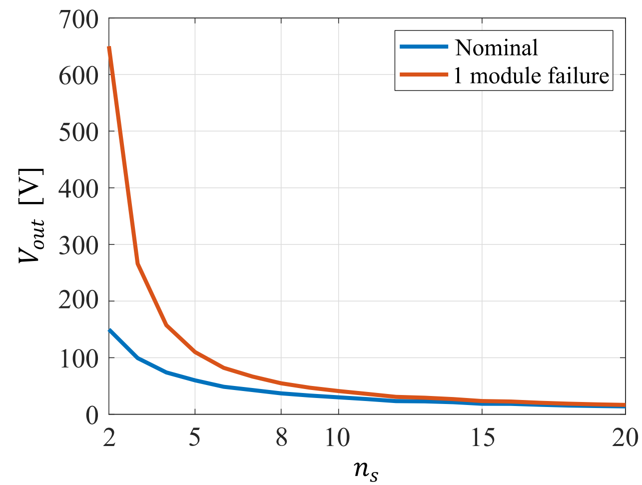


V_{out} increment for 1 module failure

NMC



LTO



3.2

Simulation

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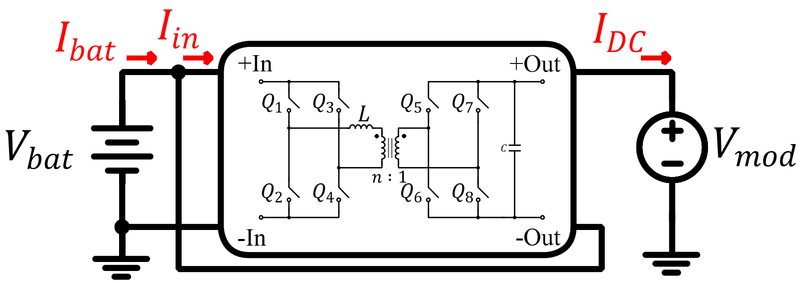
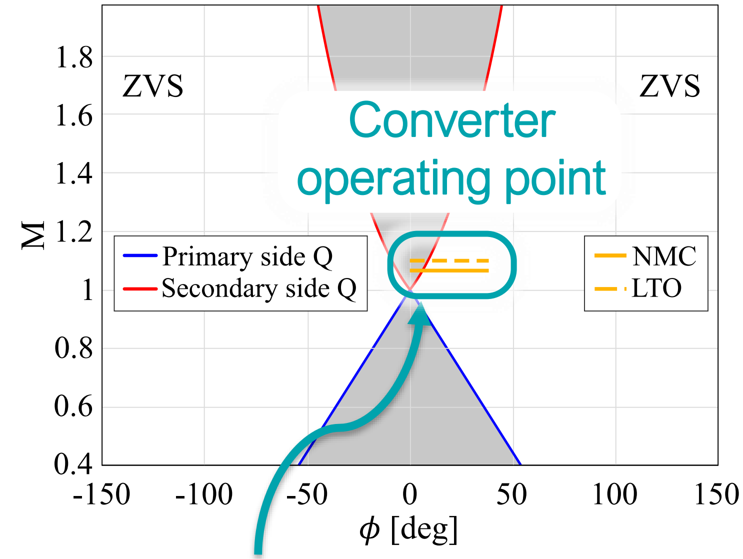
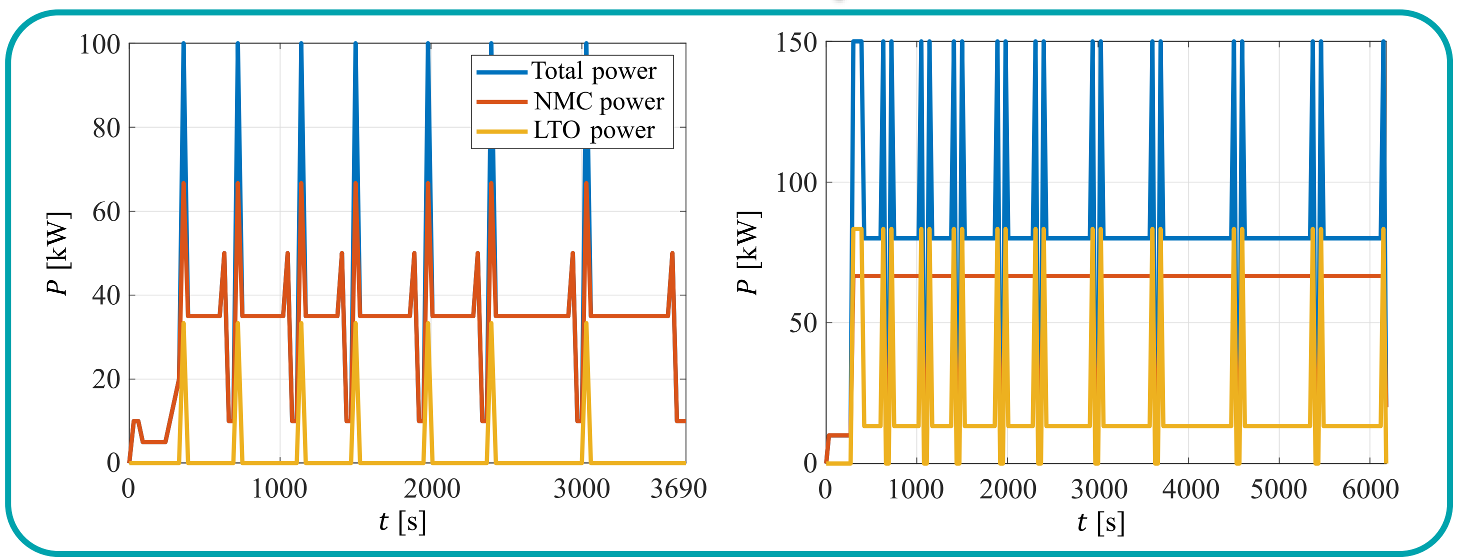
Dual Active Bridge PPC

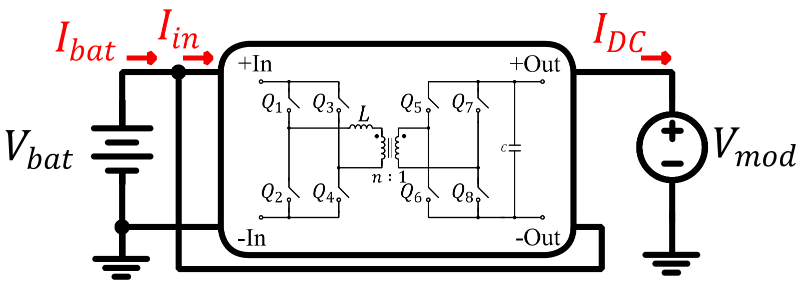


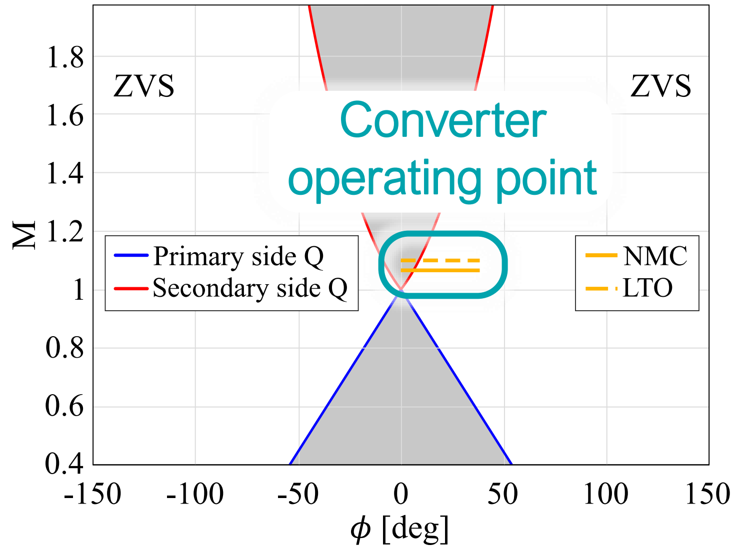


Power Profiles for Urban Ferry



Dual Active Bridge PPC

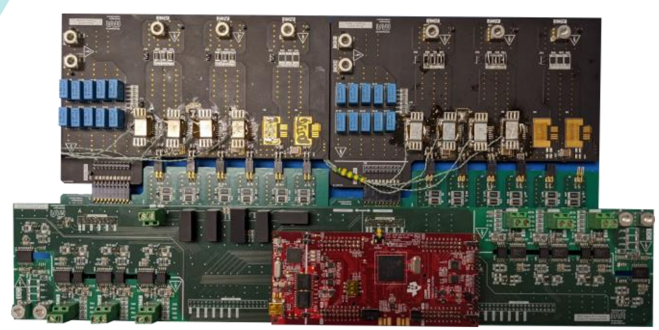




- Both batteries work in soft switching most of the time.
- **NMC** works under **soft switching** for a **longer** period than LTO.
- The **hard switching** occurs with very **low voltage**, so the **switching losses** are **low**.

3.3

Experimental Results



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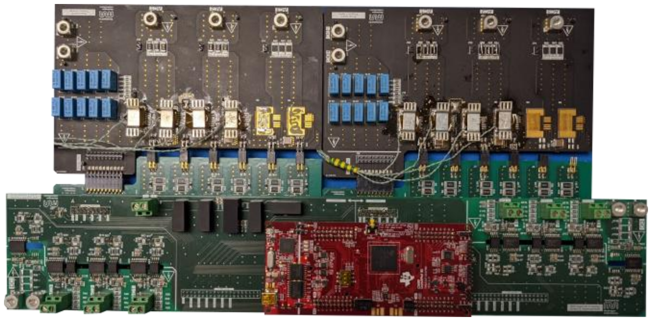
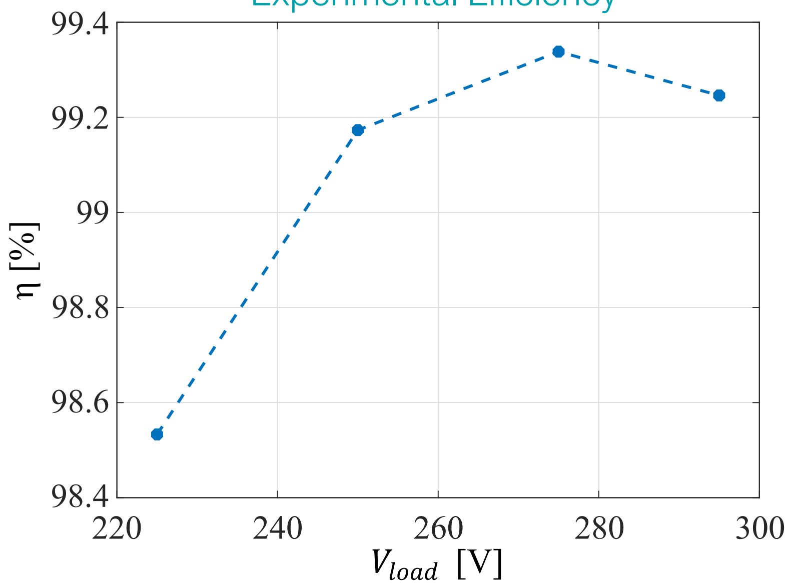
Testing at different points



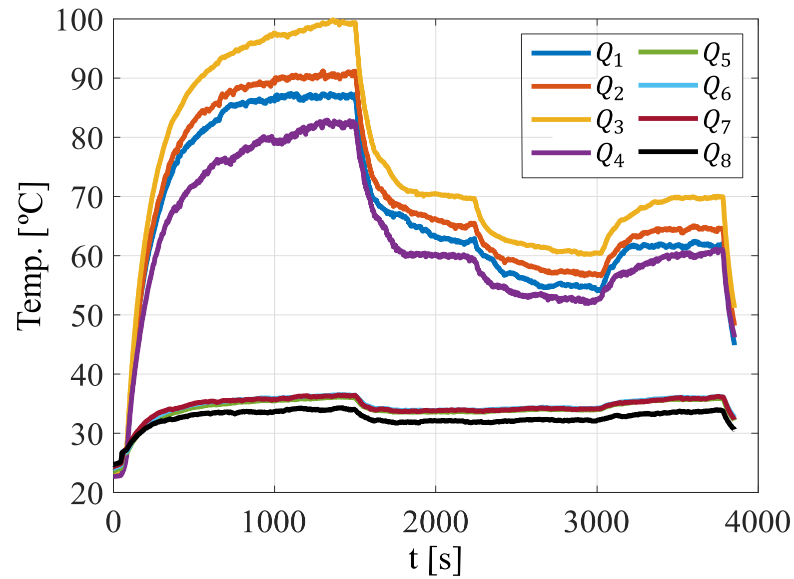
Parameter	Test point 1	Test point 2	Test point 3	Test point 4
P_{bat} [kW]	2.27	2.53	2.78	3
V_{mod} [V]	300	300	300	300
V_{bat} [V]	225	250	275	295

Battery charging process

Experimental Efficiency



Semiconductors temperature



4

Conclusions

Conclusions:

- Hybridization of Energy Storage Systems can be the optimal solution.
  - Nevertheless, it will depend on several factors:
    - **Power Sharing** method.
    - Consumption **Power Profile**.
    - Cell **Cost**.

- The Partial Power Converter can provide higher efficiencies.
  - It only processes a small part of the total power.
  - The Dual Active Bridge PPC can work in soft switching most of the time.
  - 1 module failure can be assumed without compromising its operation.
  - It works better for small voltage differences between the input and the output.
  - There is no galvanic isolation.

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SEA BAT

Eskerrik asko
Muchas gracias
Thank you

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