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T18001

Integrated Energy and Thermal Management of Electrified Powertrains

A Material Perspective

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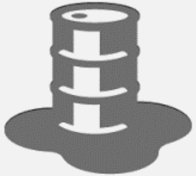
Motivation

CO_2 emission



Fossil fuel

Cost of ownership

Driving comfort

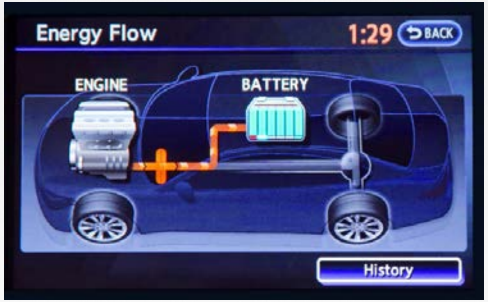
Electrification

Industrial aim

- Chemical domain
- Mechanical domain
- Electrical domain

- Thermal domain
- Material domain

- Energy efficiency
- Cost
- Performance



[1]

CVT

Integrated energy and thermal management of CVT-based electrified powertrains

CVT: Continuously variable transmission

[1] Vehicle Thermal Management Systems Conference and Exhibition - VTMS 13

Scientific aim

Modular and scalable system architecture

⇓

New control-oriented models

⇓

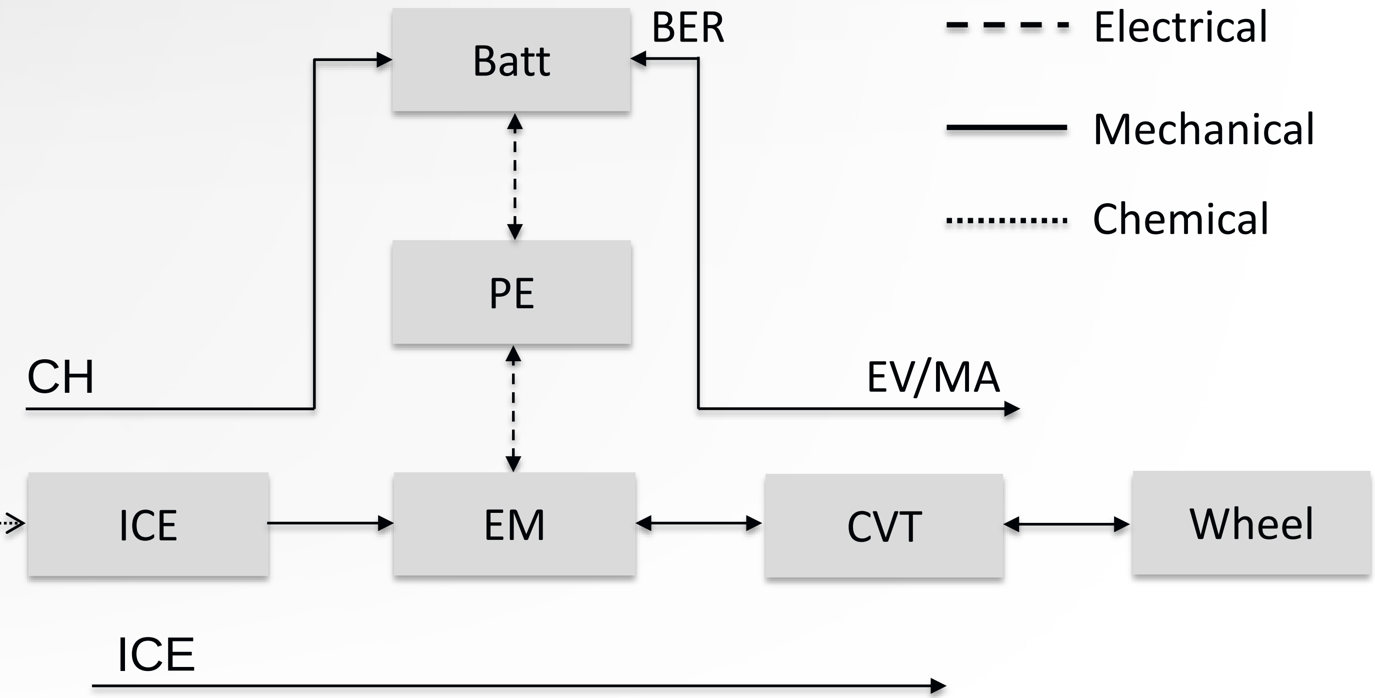
Novel optimal control method

⇓

Detailed requirements and specifications

1. Energy management system

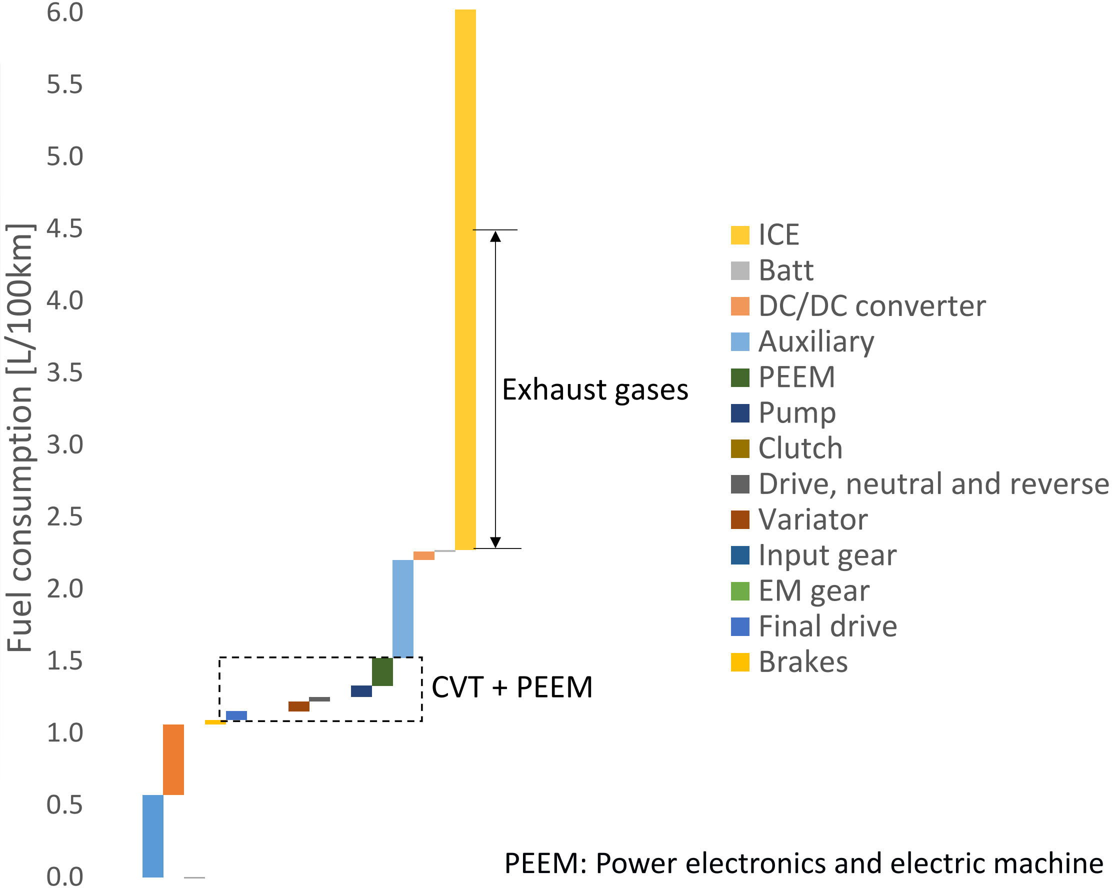
ICE: Engine
Batt: Battery
PE: Power electronics
EM: Electric machine
EV: Electric vehicle
MA: Motor assist
CH: Charging
BER: Brake energy recuperation



Total energy losses

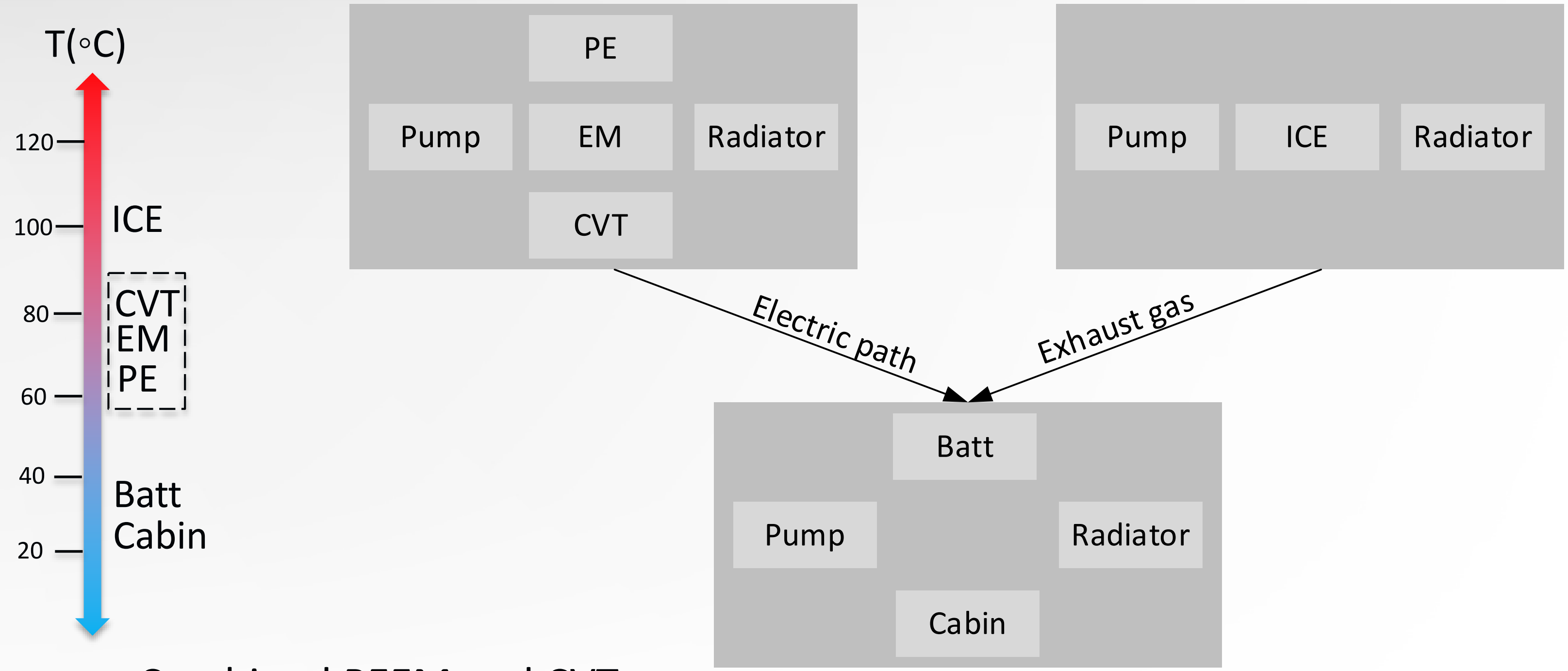
Opportunities:

- Engine exhaust heat
- PEEM waste heat



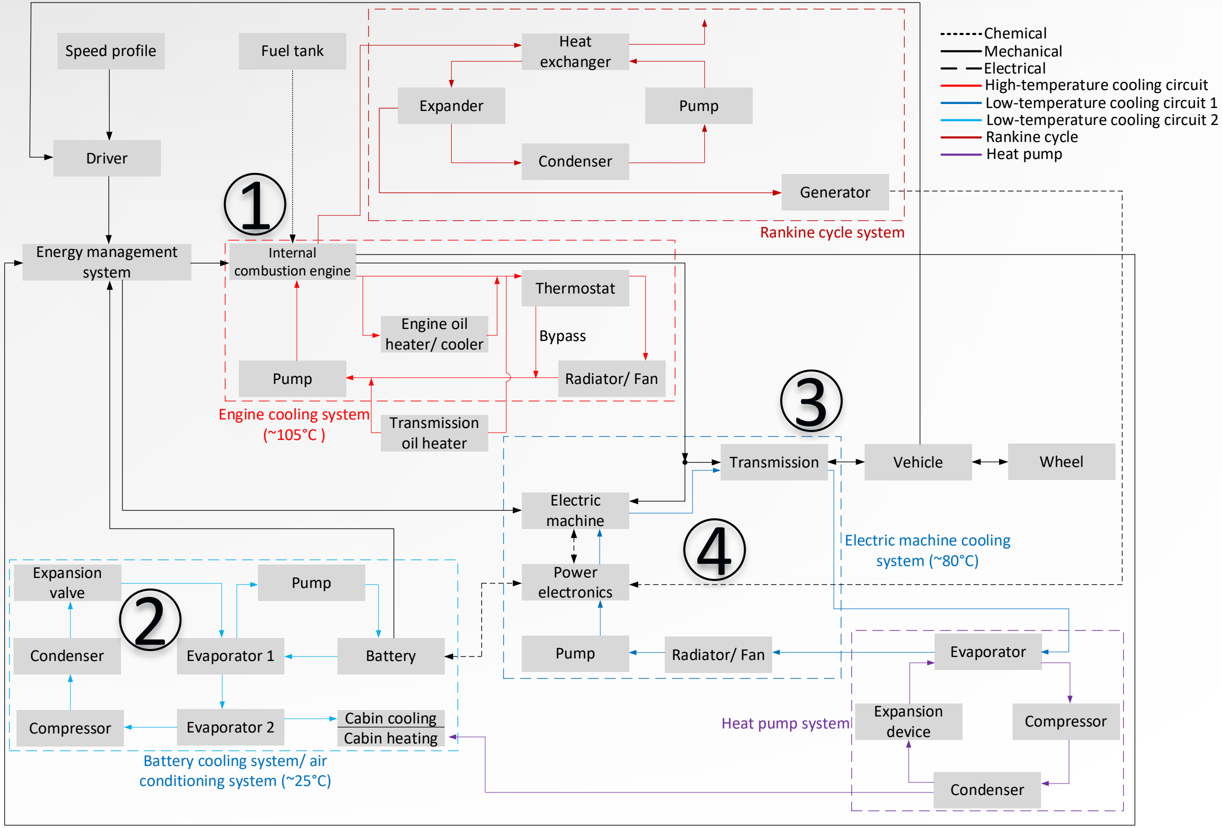
PEEM: Power electronics and electric machine

2. Thermal management system



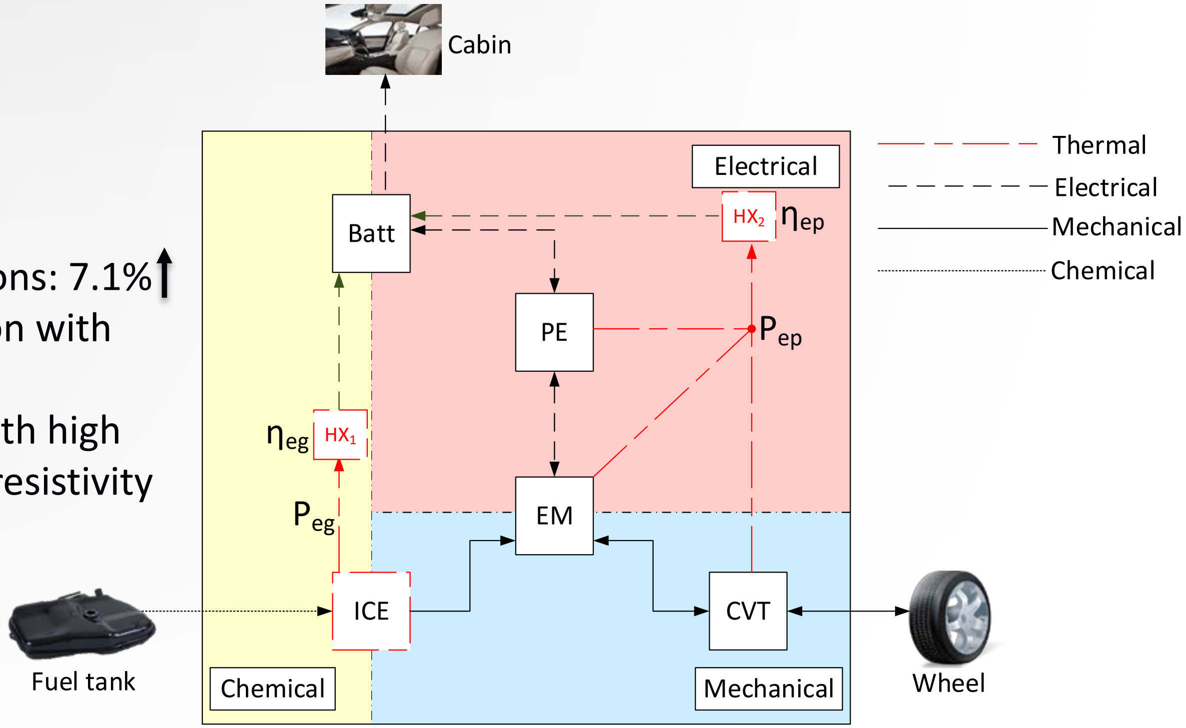
- Combined PEEM and CVT
- Exhaust gas waste heat recovery
- Electric path waste heat recovery

Integrated global system (1+2)

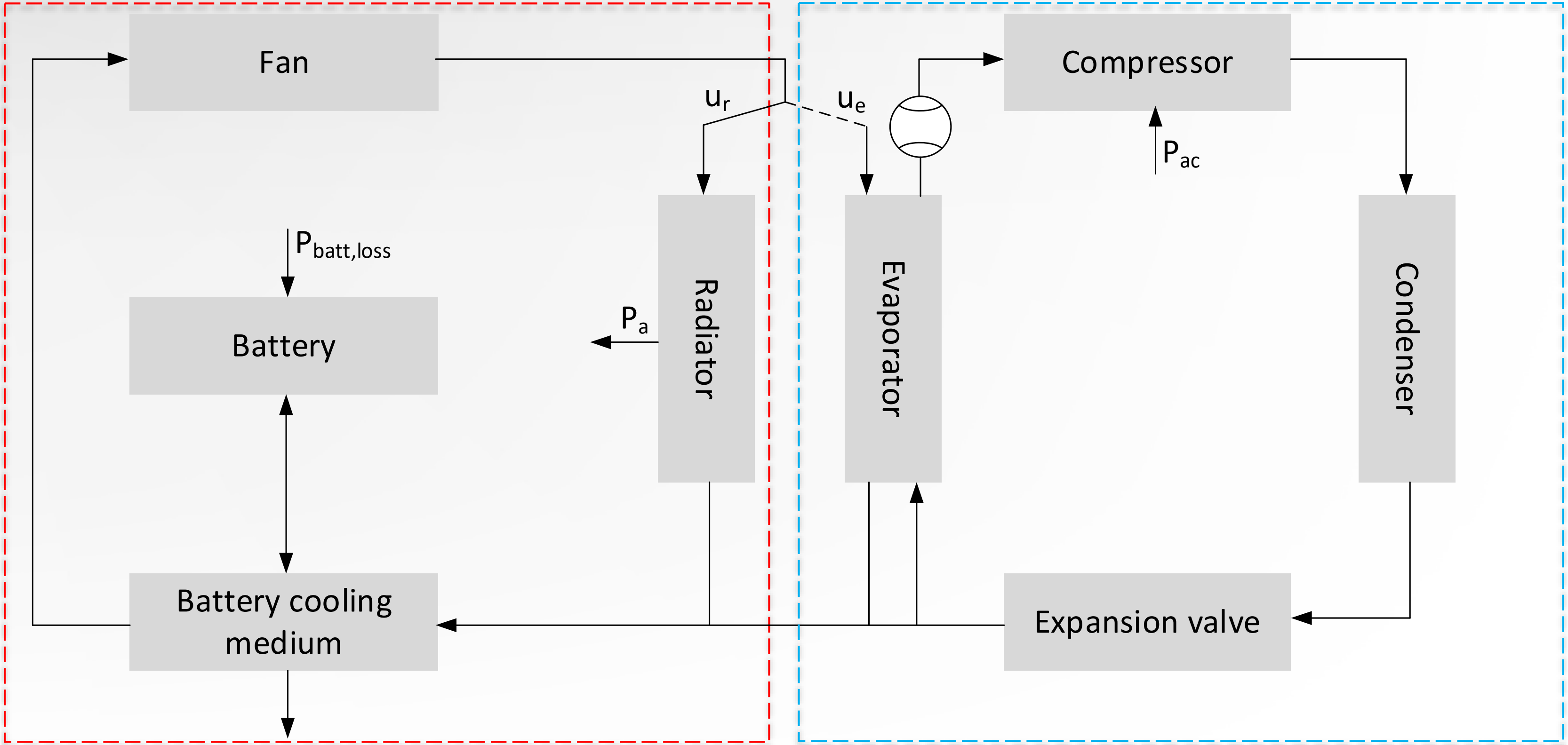


Sub-system 1: Waste heat recovery with cold-start conditions

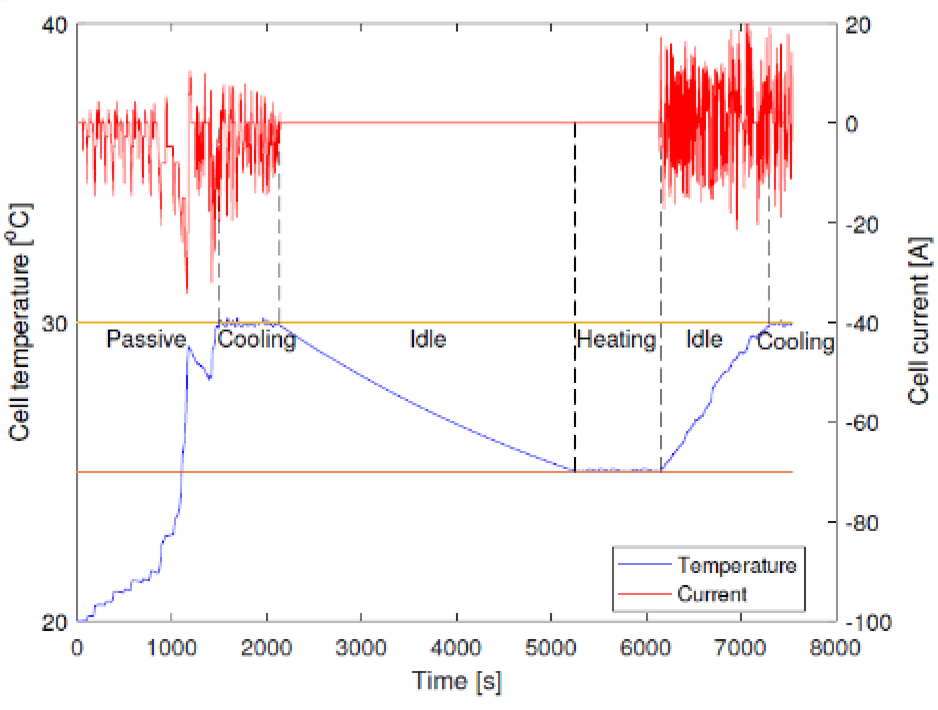
- Significant impact of cold-start conditions: 7.1%↑
- Remarkable fuel consumption reduction with waste heat recovery: 13.1%↓
- Material: thermoelectric generators with high Seebeck coefficient and low electrical resistivity and thermal conductivity materials

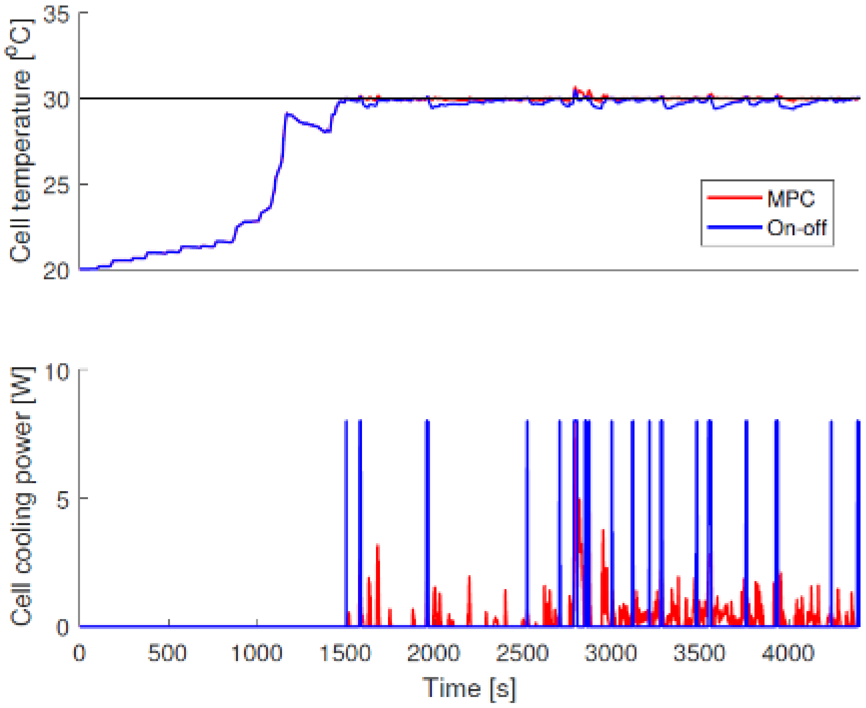


Sub-system 2: Battery thermal management



Results

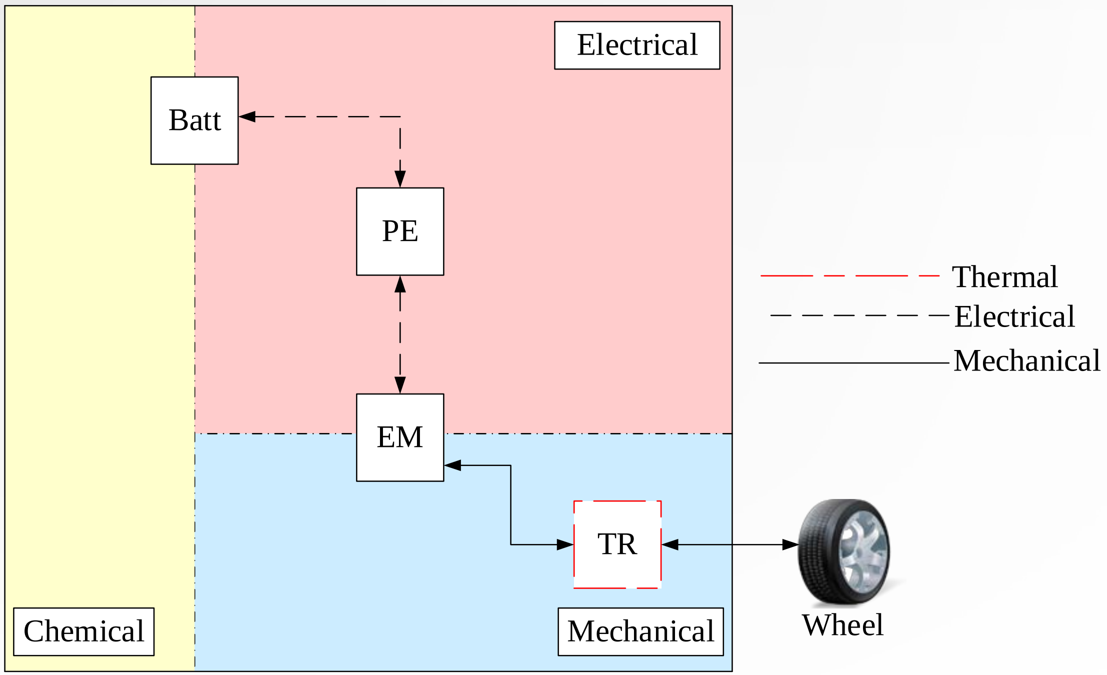




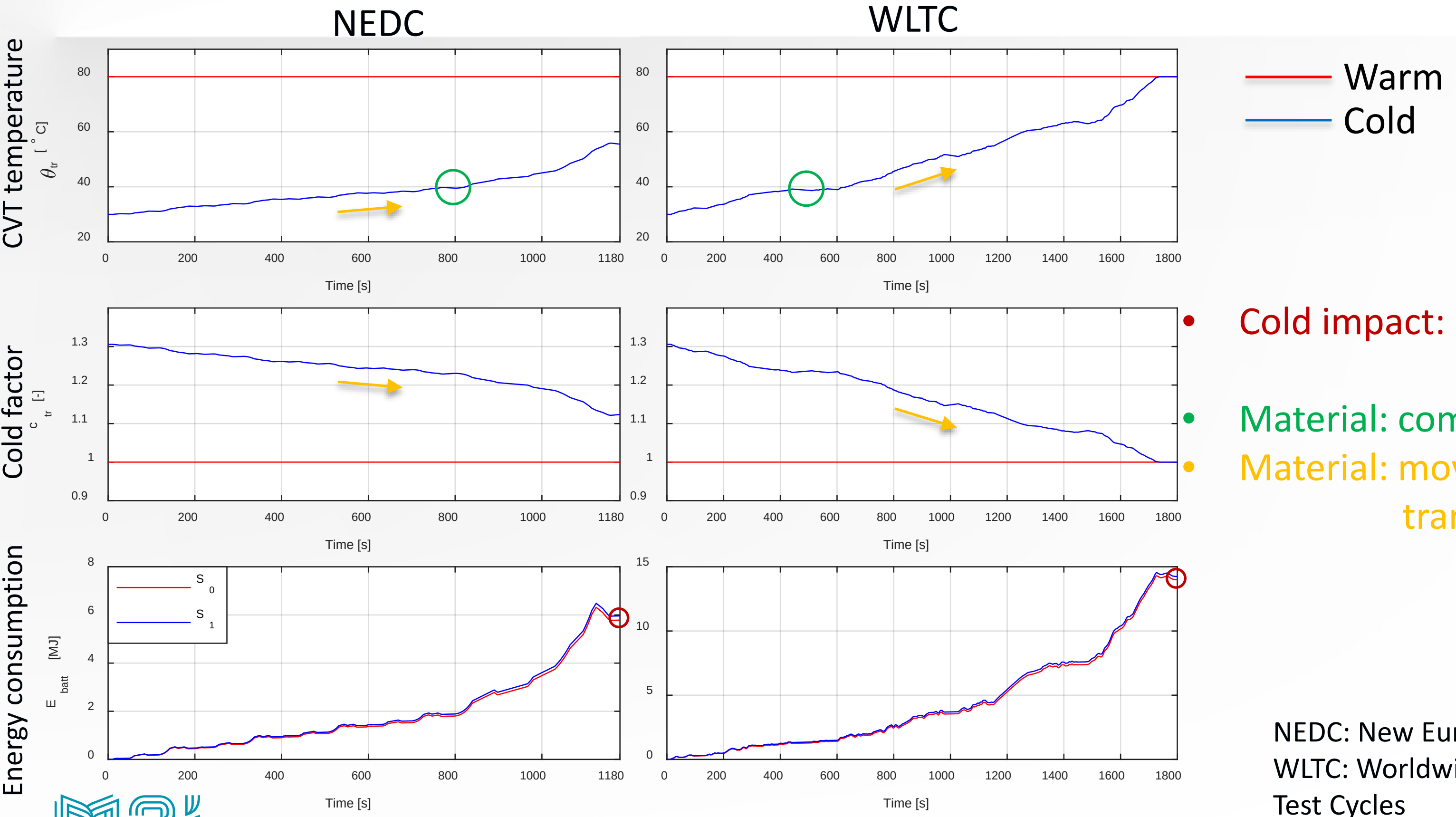
Note: for a single cell

- Cooling power: $P_{MPC} << P_{On/Off}$
- Material: using phase change material to warm up and cool down the battery

Sub-system 3: Transmission transient thermodynamics



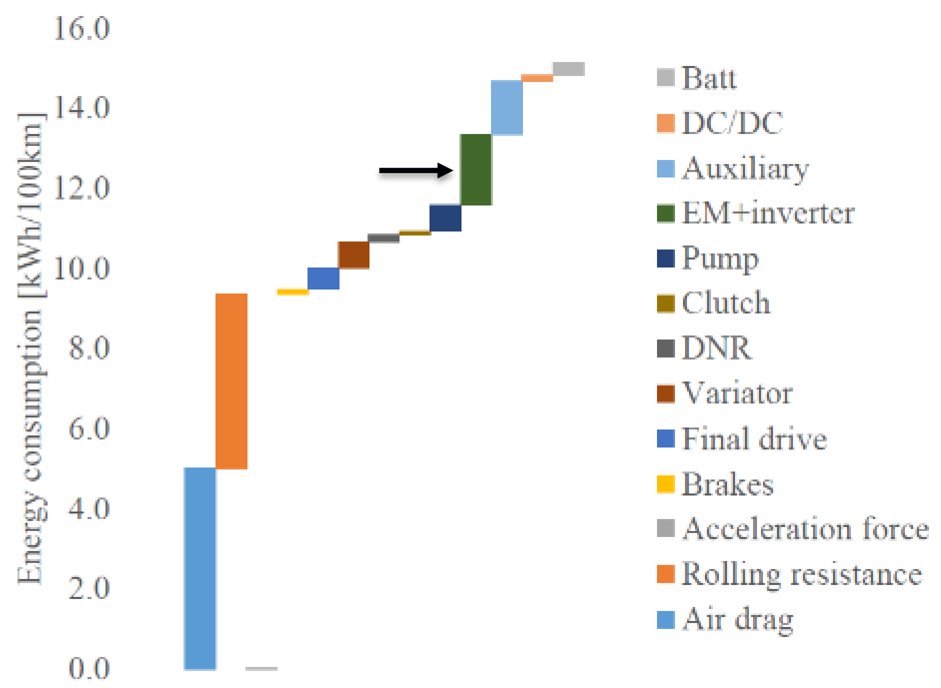
Results



- Cold impact: energy consumption up to around 2.9%
- Material: component encapsulation
- Material: moving to low viscosity transmission fluid

NEDC: New European Driving Cycle
WLTC: Worldwide Harmonized Light Vehicles Test Cycles

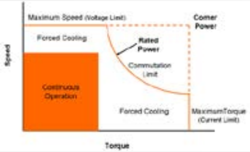
Energy balance



- Using waste heat from the electric drive to warm up the transmission ⇨ Increase transmission lifetime and energy efficiency

Sub-system 4: Co-design of EM and CVT

Cost= weighting factor$_1$* + weighting factor$_2$*(€ + € + €)

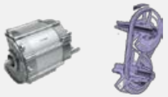
subject to: 

Alternating

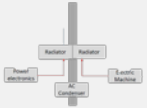
Plant Design

Control Design

Simultaneous



Plant & Control Design

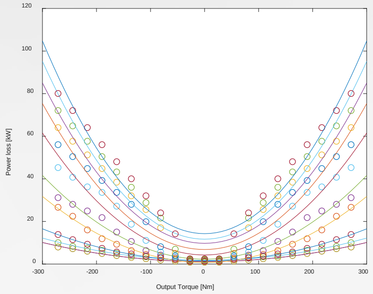


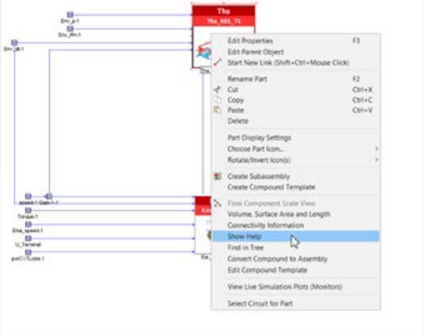
Models: non-linear models
Optimization strategy: nonlinear programming
- sub-optimal design parameters
- long computation time

Models: convex models
Optimization strategy: convex programming
+ optimal design parameters
+ optimal thermal topology
+ short computation time

Modeling and validation

Increasing level of abstraction

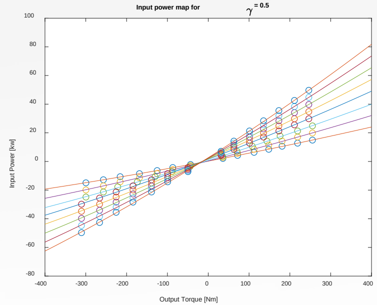


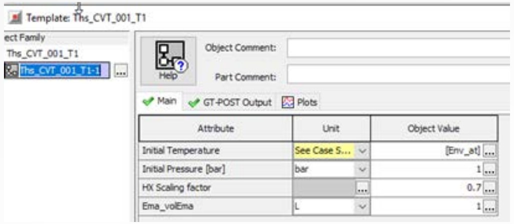


Control models

High-fidelity GT models

Measurement data: E-Golf with CVT

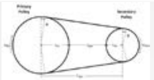




Increasing level of accuracy/complexity

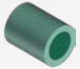
Compact ECVT

KW
Power rating



Center distance

ECVT



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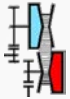
Magnets Dimensions Actuation Ratio coverage

Cooling



Asymmetrical design

- Highly integrated
- Energy-efficient
- Cost-effective
- Compact
- Comfortable

- Material analysis
  - o Reduce high cost/volatile heavy metals and rare earth content (e.g., Cobalt, Neodymium-Iron-Boron (NdFeB)) in EM due to max. torque reduction
  - o Selection of cooling medium for the integrated cooling system (conductivity, corrosion, oxidation, and viscosity)

Conclusions

- Created an integrated system architecture for CVT-based electrified powertrains
- Developed relevant control models and optimal controllers

⇩ Industry

- Including controls in the early design phase
- Generating generic system-level representations
- Bridging the gap between component-level and system-level

Thank you

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