TLK Energy GmbH

MODEL BASED COOLING PLATE DESIGN FOR BATTERY SYSTEMS

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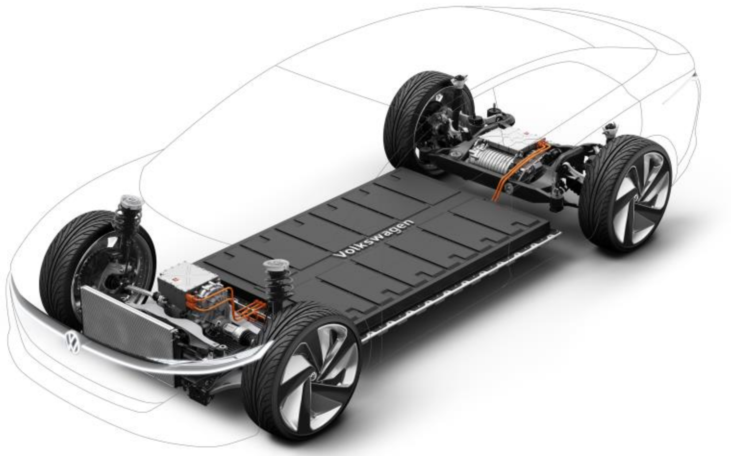
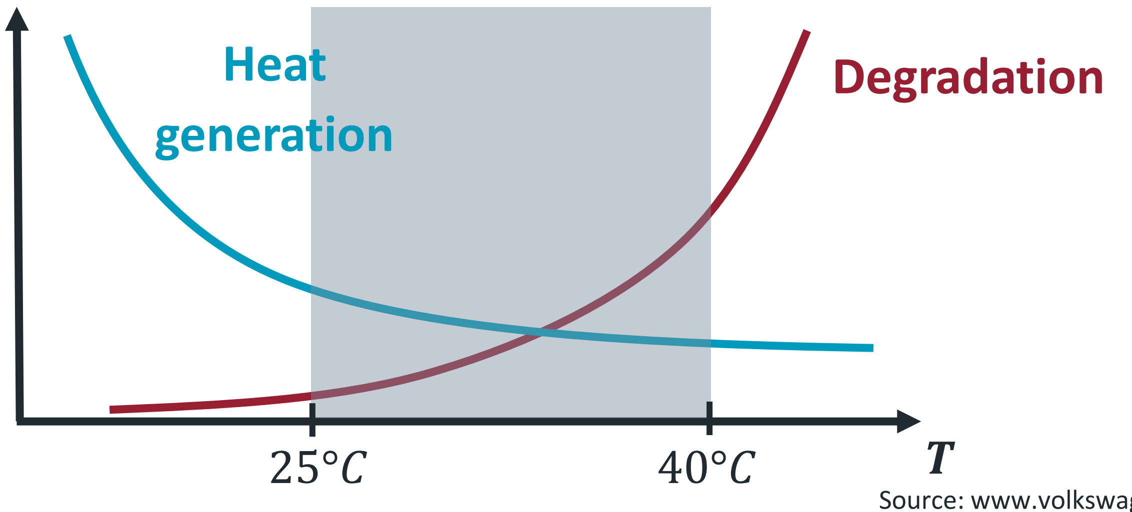
TLK ENERGY

WHY IS A COOLING PLATE DESIGN FOR BATTERY SYSTEMS IMPORTANT?

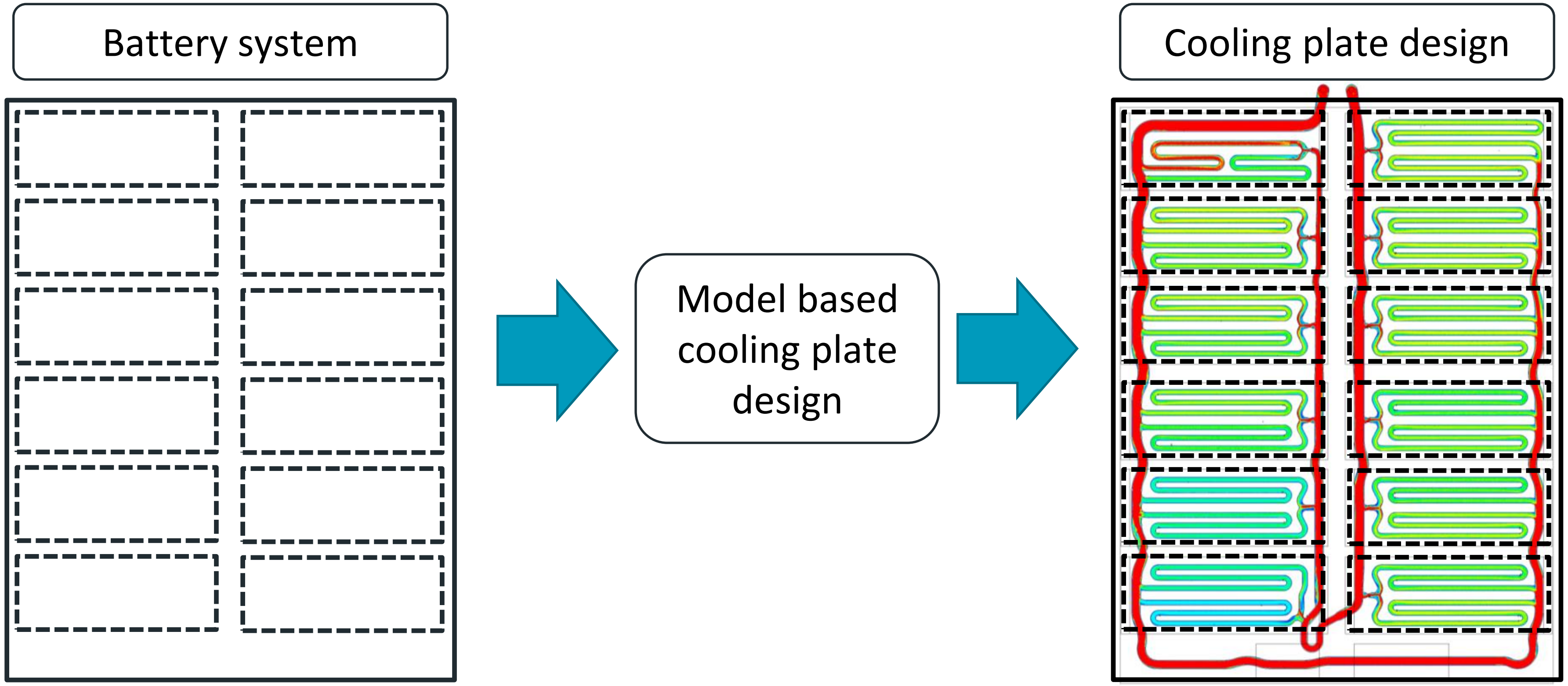
- Battery temperature is the key for **safety**, **lifetime** and **performance**
- Cooling plate design necessary to fulfill the conflicting requirements:
  - Temperature level between 25 °C and 40 °C
  - Temperature between pouch cells under 5 K
  - Minimization of pump energy consumption





Source: www.volkswagen-newsroom.com; Picture ID: DB2018AU00146

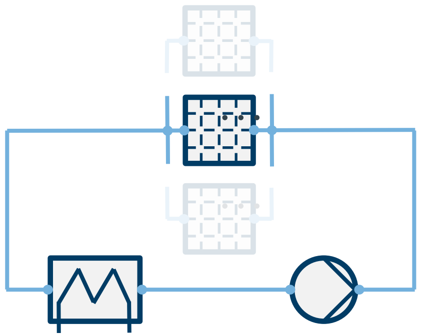
OBJECTIVE: FIND OPTIMAL COOLING PLATE DESIGN FOR A GIVEN DESIGN SPACE



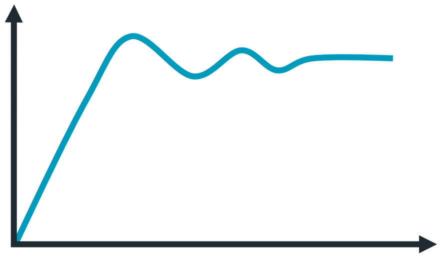
Establish a fast and profound model to perform optimizations

METHOD: SYSTEM SIMULATION USING MODELICA AND TIL-SUITE

System level



Complex thermodynamic framework



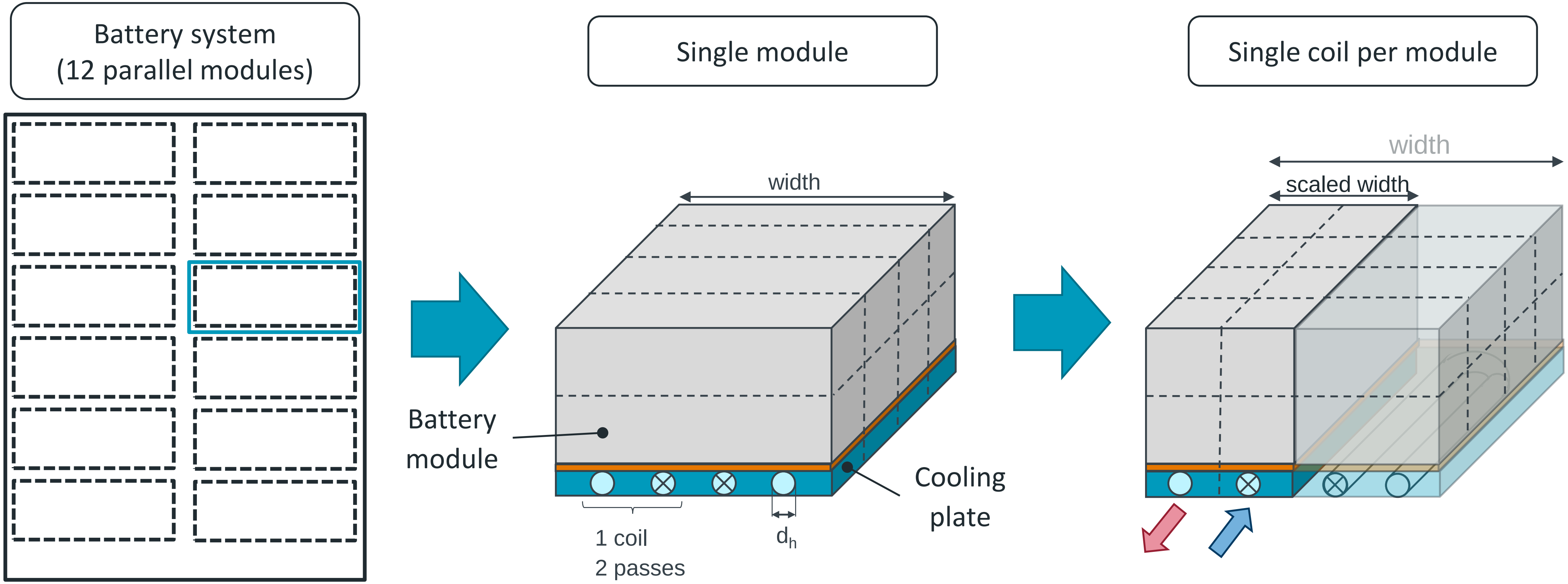
Dynamic

1. MODELICA + TIL-Suite

2.
$$\min_{x(\cdot)} c(x)$$
$$s.t. \;\; \cdots$$

Optimization

APPROACH TO MODEL COOLING PLATE: REDUCTION TO SINGLE COIL

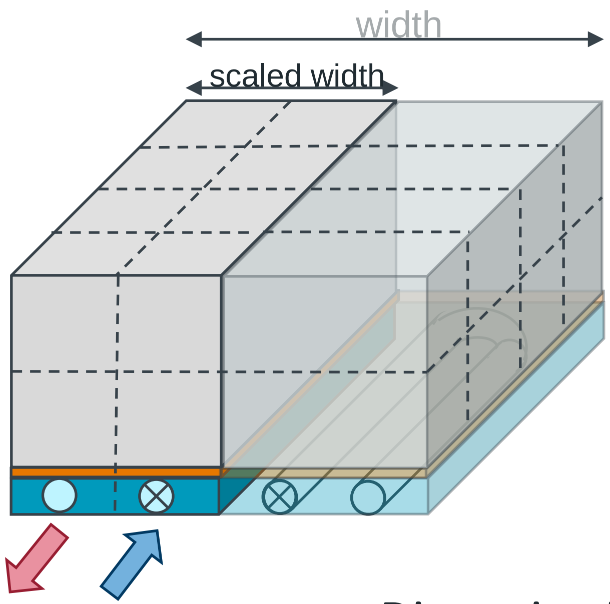


One module is considered

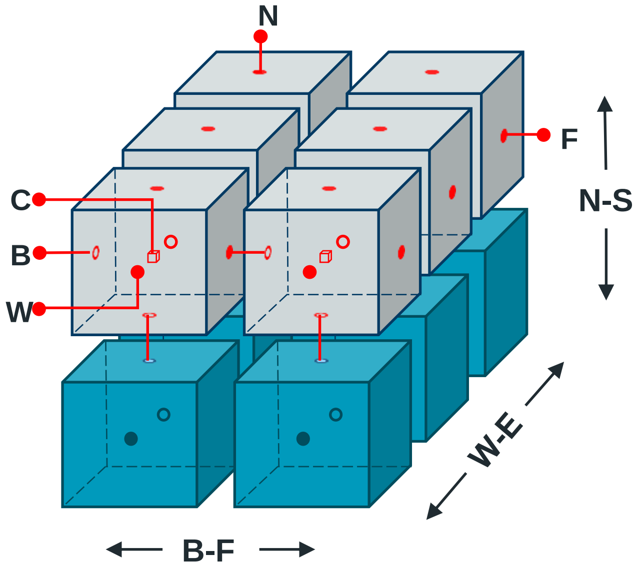
Reducing module to single coil

MODELING OF SINGLE COIL

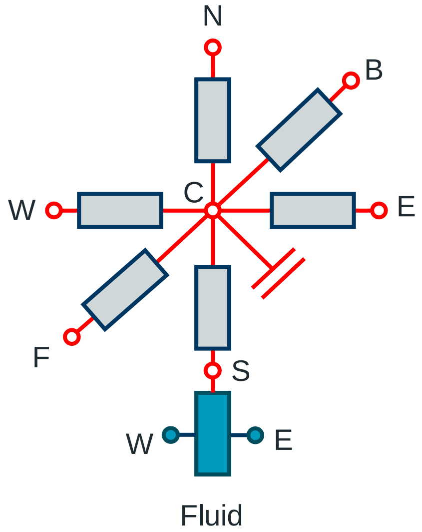
Single coil per module



Discretization of single coil



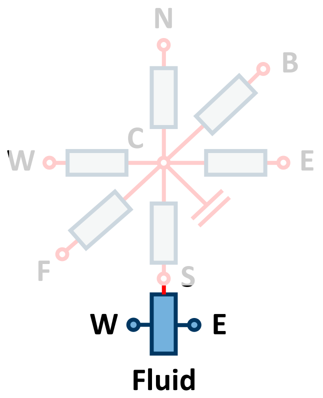
Single element

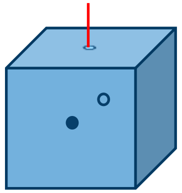


Discretization of single coil using battery cells and liquid cells

System model of lumped masses in thermal- and liquid resistance network

MODELING OF A SINGLE ELEMENT: LIQUID CELL





- Approach: finite-volume-based-approach (ideally mixed volume)
- Properties of fluid calculated by TIL Media
- Transient balance equation for mass, energy and momentum:

(1) $$\frac{dm_{Liquid}}{dt} = \dot{m}_{in} + \dot{m}_{out}$$

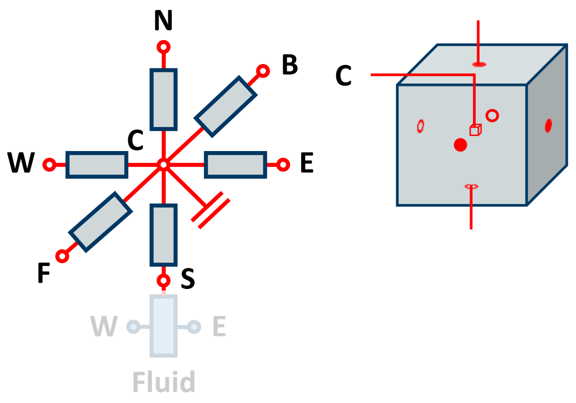
(2) $$\frac{dU_{Liquid}}{dt} = \dot{m}_{in}h_{in} + \dot{m}_{out}h_{out} + \dot{Q}_{Conv}$$

(3) $$p_{in} - p_{out} = dp$$

Pressure loss dp $= f(Re, \nu, \ldots)$

Liquid-tube heat transfer coefficient $\alpha = f(Re, Pr, \ldots)$

MODELING OF A SINGLE ELEMENT: BATTERY CELL



- Approach: Solid medium with $\rho,\ c_p = const.$
- Constant thermal resistances
- Transient balance equation for energy:

$$m c_p \frac{dT_{Battery}}{dt} = \sum_i \dot{Q}_i + \dot{Q}_{Bat}$$

Conduction in battery cell, e.g. $\dot{Q}_W = \frac{T_W - T_{Battery}}{\frac{R_{WE}}{2}}$

Ohmic heat generation of battery: $\dot{Q}_{Bat} = R(SOC, T) I^2$

MATHEMATICAL FORMULATION OF THE STEADY STATE OPTIMIZATION PROBLEM

Objective function

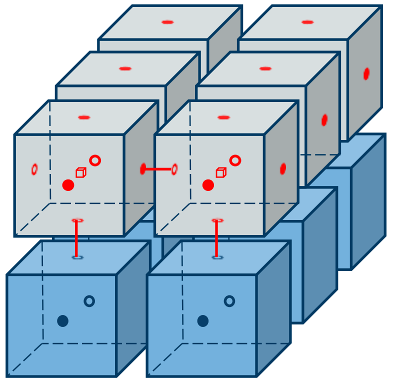
$$\min_{x(\cdot),p} P_{pump}(x,p)$$

$$s.t. \frac{dx}{dt}(t) = f(x(t),p), \quad \text{with } x(t_0) = x_0$$

$$f(x(t),p) = 0$$

$$\mathrm{T_i} \leq 40\ °\mathrm{C} \quad \forall i \in \{1, \ldots, n\}$$

$$(\max\{\mathrm{T_1}, \ldots, \mathrm{T_n}\} - \min\{\mathrm{T_1}, \ldots, \mathrm{T_n}\}) \leq 2\ \mathrm{k} \quad \forall i \in \{1, \ldots, n\}$$



Constraint:
Steady state constraint

Constraint:
Maximum temperature

Constraint:
Temperature difference

Degrees of freedom:
Cooling plate design parameters
and control parameter

$$p = \begin{pmatrix} d \\ n_{pass} \\ x_{channel} \\ n_{pump} \end{pmatrix}$$

T_i = Battery cell temperature i

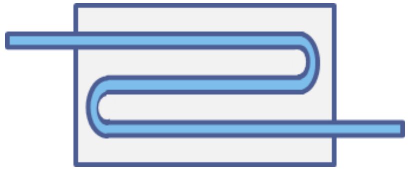
DEGREES OF FREEDOM: DESIGN PARAMETERS AND CONTROL PARAMETER

$$p = \begin{pmatrix} d \\ n_{pass} \\ x_{channel} \\ n_{pump} \end{pmatrix}$$

Cooling plate design parameters:
Diameter d
Number of passes n_{pass}
Channel orientation $x_{channel}$

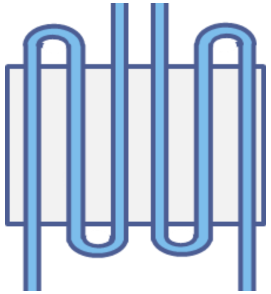
Control parameter:
Pump speed n_{pump}

$x_{channel}$:



parallel

or



perpendicular

IMPLEMENTATION OF OPTIMIZATION PROBLEM USING MoBA AUTOMATION

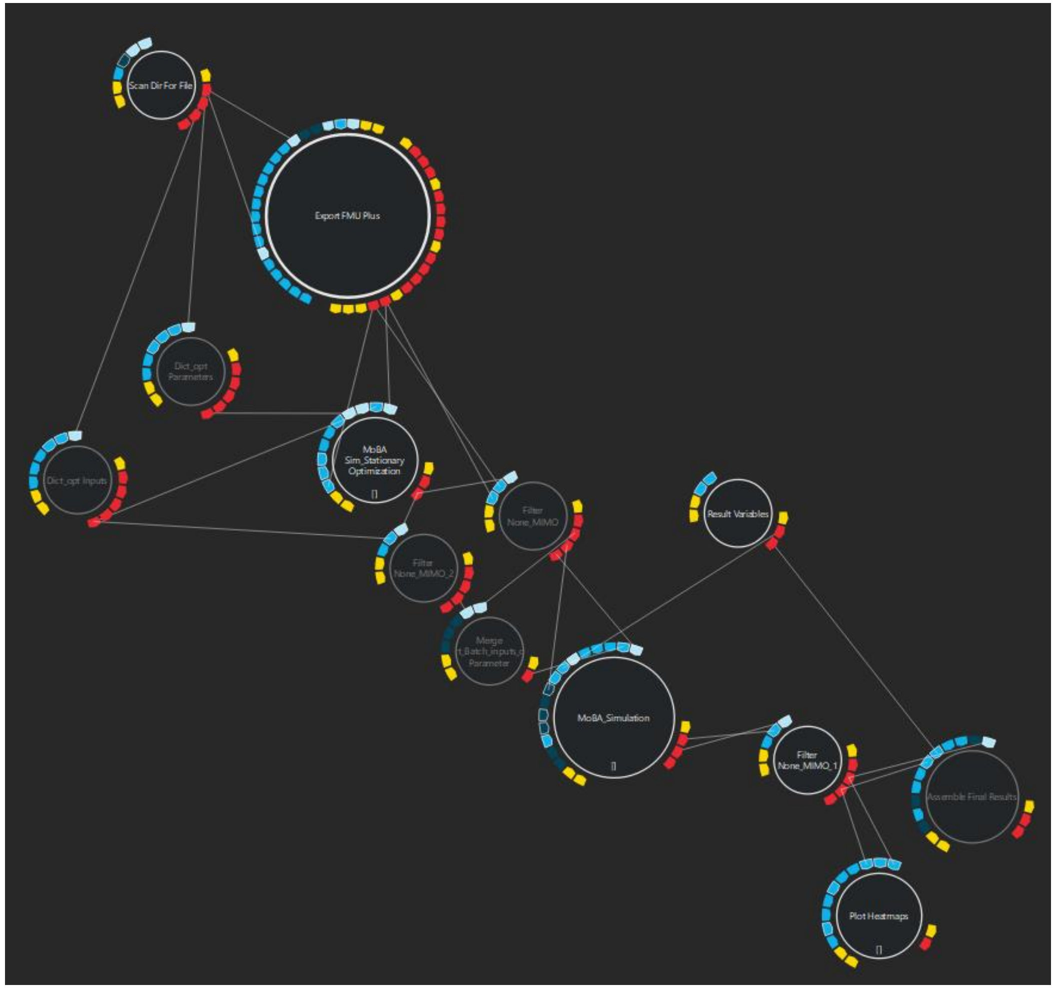
Approach

Mix between parameter variation and steady state optimization:

$$p = \begin{pmatrix} d \\ n_{pass} \\ x_{channel} \\ n_{pump} \end{pmatrix}$$

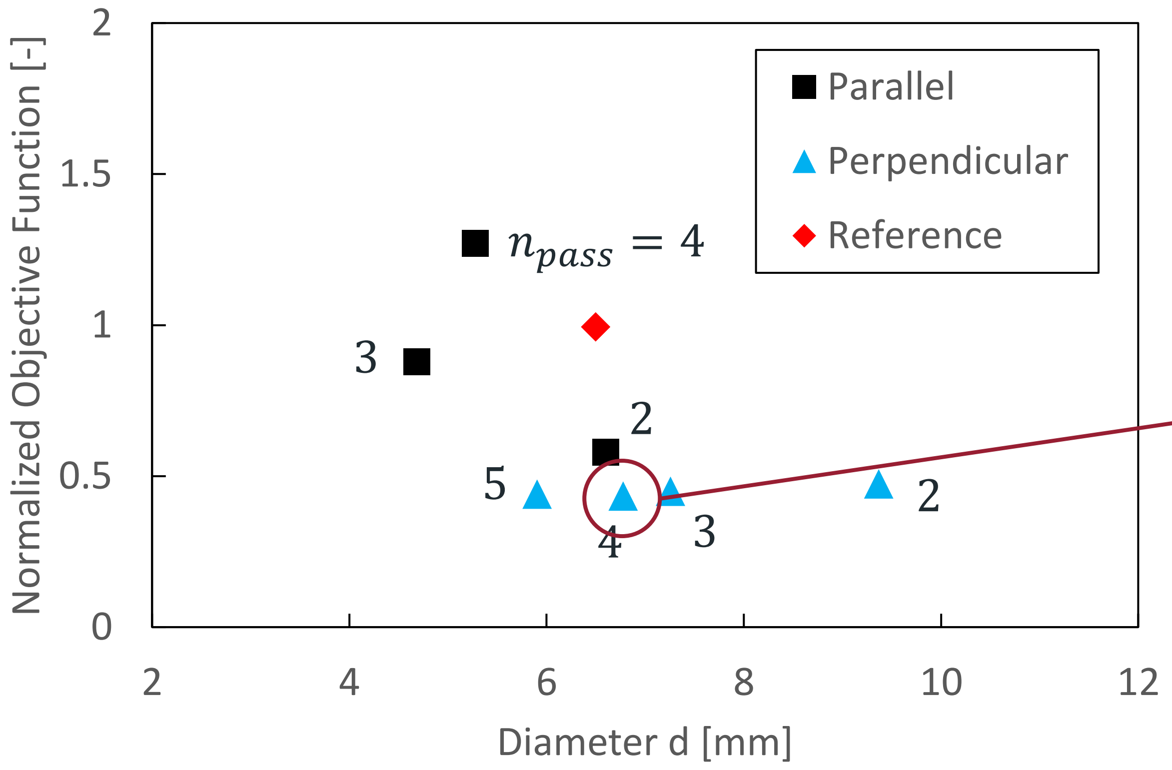
Continuous values allowed: Steady state optimization using a NLP solver

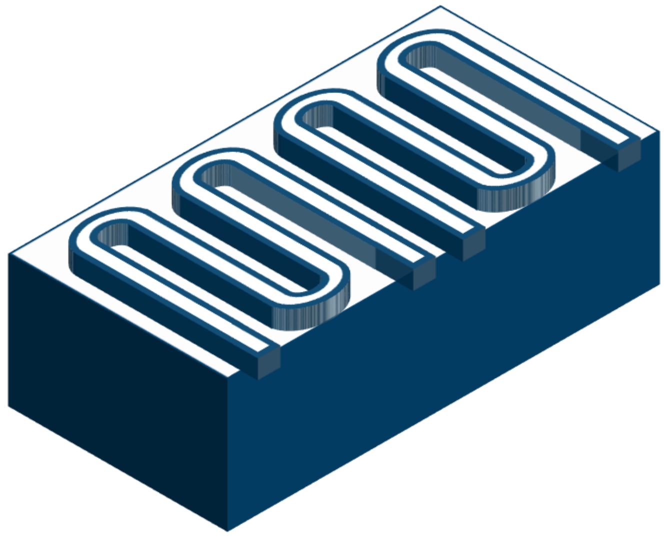
Only **integer** values allowed: Parameter variation



Optimization of cooling plate design and evaluation is automized using MoBA Automation

RESULT: OPTIMAL COOLING PLATE DESIGN FOR 200A ELECTRICAL LOAD

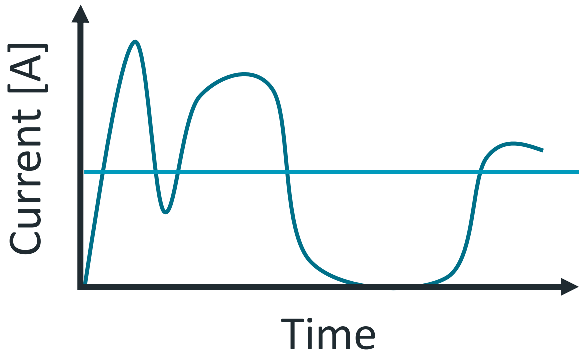




- Perpendicular orientation reveals higher potential than parallel orientation
- Reduction of pump power: up to 55 %

USE CASE FOR DYNAMIC MODEL: DYNAMIC OPTIMIZATION PROBLEM

Optimization of pump speed for a **transient load** and a **fixed cooling plate** design:



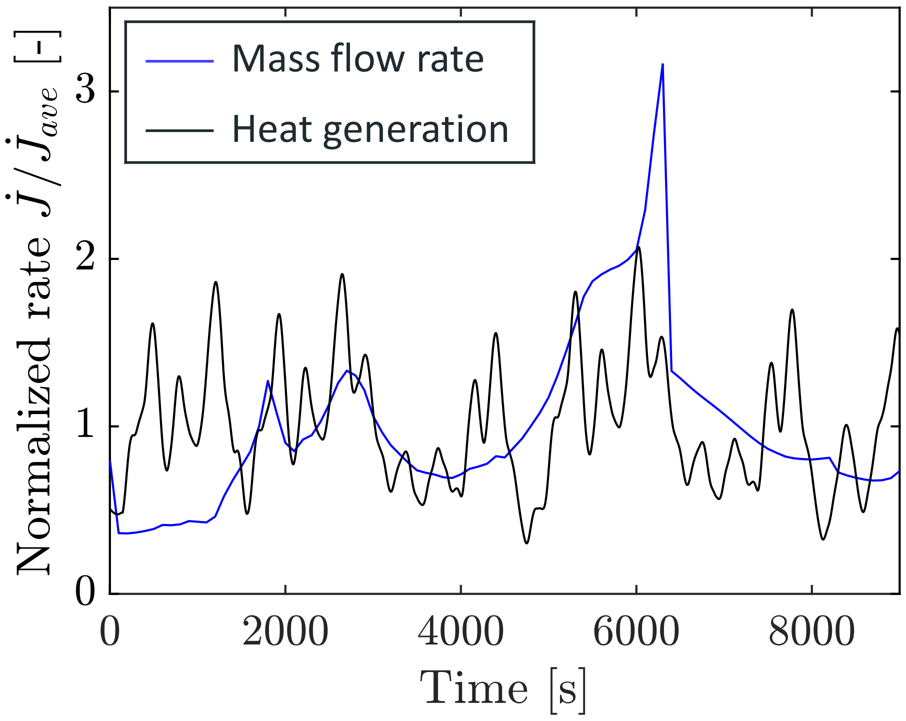
$$p = \begin{pmatrix} d & = \text{const.} \\ n_{pass} & = \text{const.} \\ x_{channel} & = \text{const.} \\ n_{pump} & = n_{pump}(t) \end{pmatrix}$$

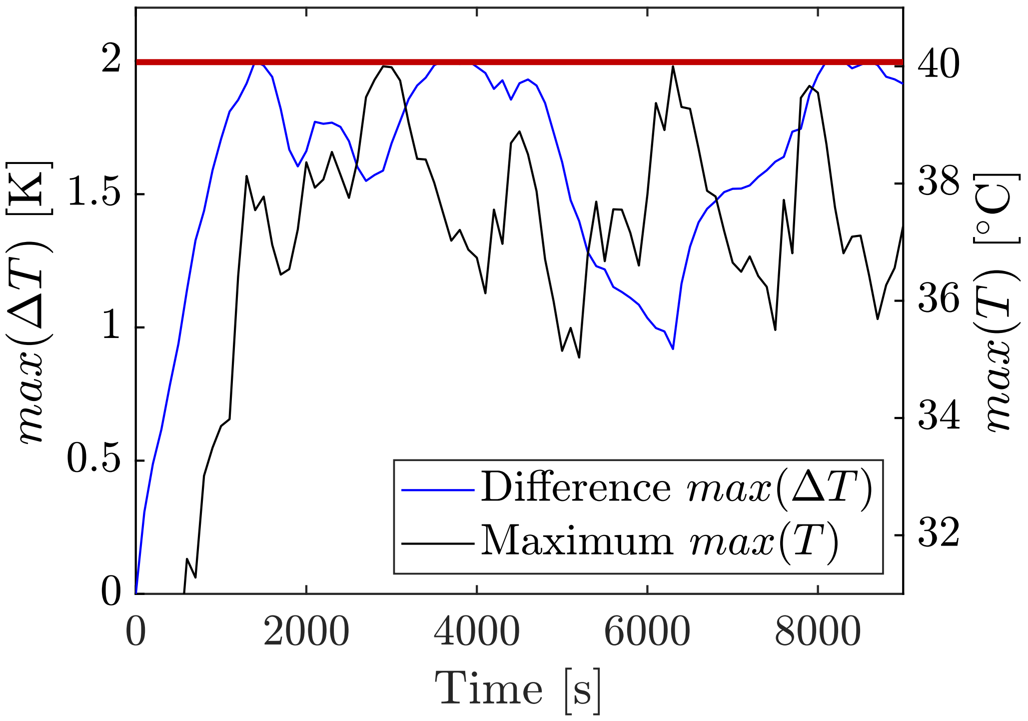
Are boundaries met for a dynamic load?

$$\min_{x(\cdot),p} \int P_{pump} \ (t, x, p) dt$$

Solve a dynamic optimization problem using a NLP solver

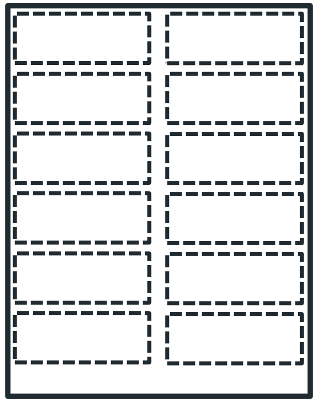
RESULT: OPTIMAL PUMP SPEED FOR TRANSIENT LOAD



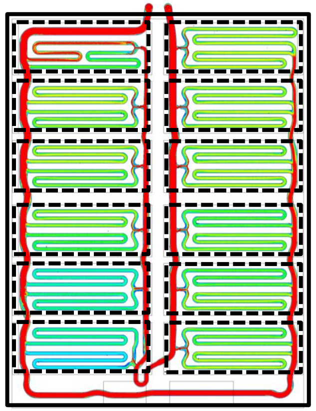


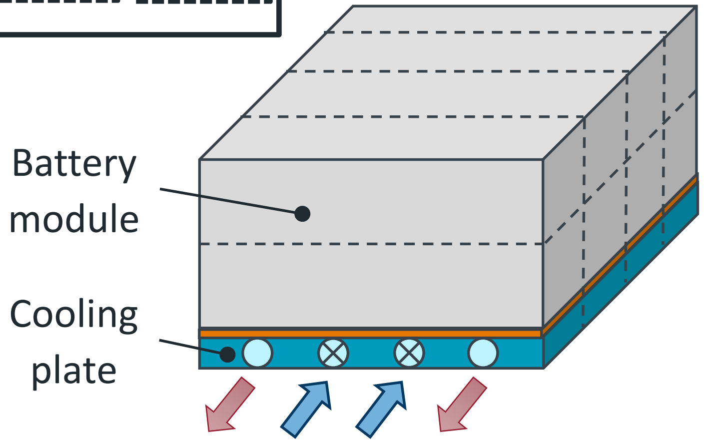
Temperature boundaries can be met using an optimal controller

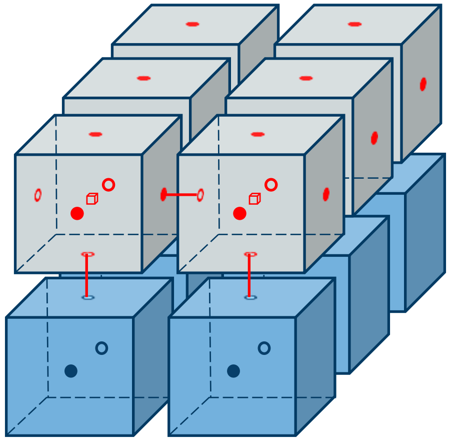
SUMMARY AND CONCLUSION



Model based cooling plate design







$$\min P_{pump}$$
$$s.t.\ \ T_{max} \leq 40\ °C$$
$$T_{max} - T_{min} \leq 2\ K$$

Parameters: $\begin{pmatrix} d \\ n_{pass} \\ x_{channel} \\ n_{pump} \end{pmatrix}$

Modelica was successfully used to develop a dynamic cooling plate model applicable for fast design optimizations

THANK YOU FOR YOUR ATTENTION

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