vitesco TECHNOLOGIES

ELECTRIC MACHINE THERMAL MODEL OPTIMIZATION

USING MATLAB AND OPTISLANG

Razvan-George Moisa
Dragan Stojkovic
Weimar Optimization and Stochastic Days, 22.06.2023

AGENDA

1 OVERVIEW ABOUT VITESCO TECHNOLOGIES

2 MOTIVATION

3 WORKFLOW

4 APPLICATION EXAMPLE

5 SUMMARY

AN OVERVIEW OF VITESCO TECHNOLOGIES

€9.1 billion

FY2022 sales

>38,000

employees

1,082

€ million total **electrification sales** during FY 2022.

123

€ million **free cash flow** during FY 2022.

2.5%

adjusted EBIT – Large part of gross price increases passed on to customers.

Leading global provider

of propulsion solutions to make driving more **efficient, cleaner and convenient**

Electrification pioneer

with >**10 years of field experience** and a portfolio covering all major **current and future scenarios**

Electronics champion

with strong DNA in **electronics, software and mechatronics**

Strong position

in **electronic control systems, sensing technologies** and **actuators**

KEY ELECTRIFICATION SOLUTIONS

OUR SYSTEM COMPETENCES ENABLE PRODUCT AND COMPLETE SYSTEM OPTIMIZATION

HIGH VOLTAGE SOLUTIONS

> Battery Electric Vehicles
> Plug-In Hybrids

50-100% CO_2 saving[1]

48 VOLT SOLUTIONS

> Mild Hybrids

10-20% CO_2 saving[1]

ELECTRONIC CONTROLS

Control functions e.g. torque demand and energy mgmt.

MASTER CONTROLLER

DRIVETRAIN ACTUATOR MODULES

DRIVETRAIN CONTROL UNITS

ELECTRIC MACHINE

Electric propulsion and energy recuperation.

ELECTRIC AXLE DRIVE SYSTEM (inverter, electric machine, reducer)

ROTOR SENSORS

INVERTER

Control, efficiency and performance of the e-machine.

HIGH VOLTAGE DC/AC INVERTER

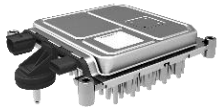
CONVERTER

Supply the board-net and low voltage consumers.

HIGH VOLTAGE DC/DC CONVERTER

HIGH VOLTAGE BOX (on-board-charger + DC/DC converter)

48 V DC/DC CONVERTER



ELECTRIC ENERGY MANAGEMENT

Ensure optimum conditions and charging of battery.

BATTERY MGMT. CONTROLLER

BATTERY MGMT. SYSTEM

BATTERY SENSORS

48 V BATTERY MGMT. CONTROLLER

THERMAL MANAGEMENT

Assuring optimum thermal efficiency of the system.

COOLANT MODULES

PUMPS

VALVES

SENSORS

Temperature

Pressure

Flow

Position

48 V BELT-DRIVEN STARTER GENERATOR (integrated inverter and electric machine)

Air-cooled 12kW peak

Hybrid-cooled 15kW peak

Liquid-cooled 15-25kW peak

[1] "Tank to wheel" saving potential versus combustion vehicle based on WLTP (World Harmonized Light-Duty Vehicles Test Procedure)

vitesco TECHNOLOGIES

ELECTRIC MACHINE THERMAL MODEL OPTIMIZATION

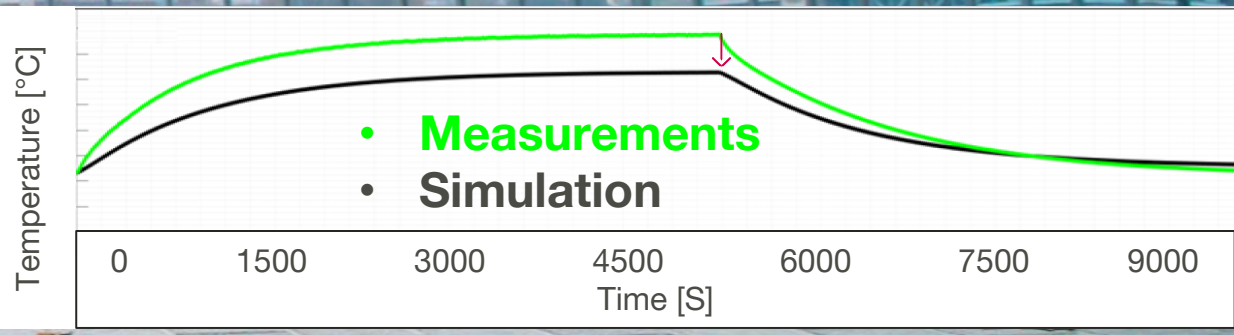
MOTIVATION

PSM EM thermal model accuracy improvement

125 transient measurements
9 optimization parameters

Target

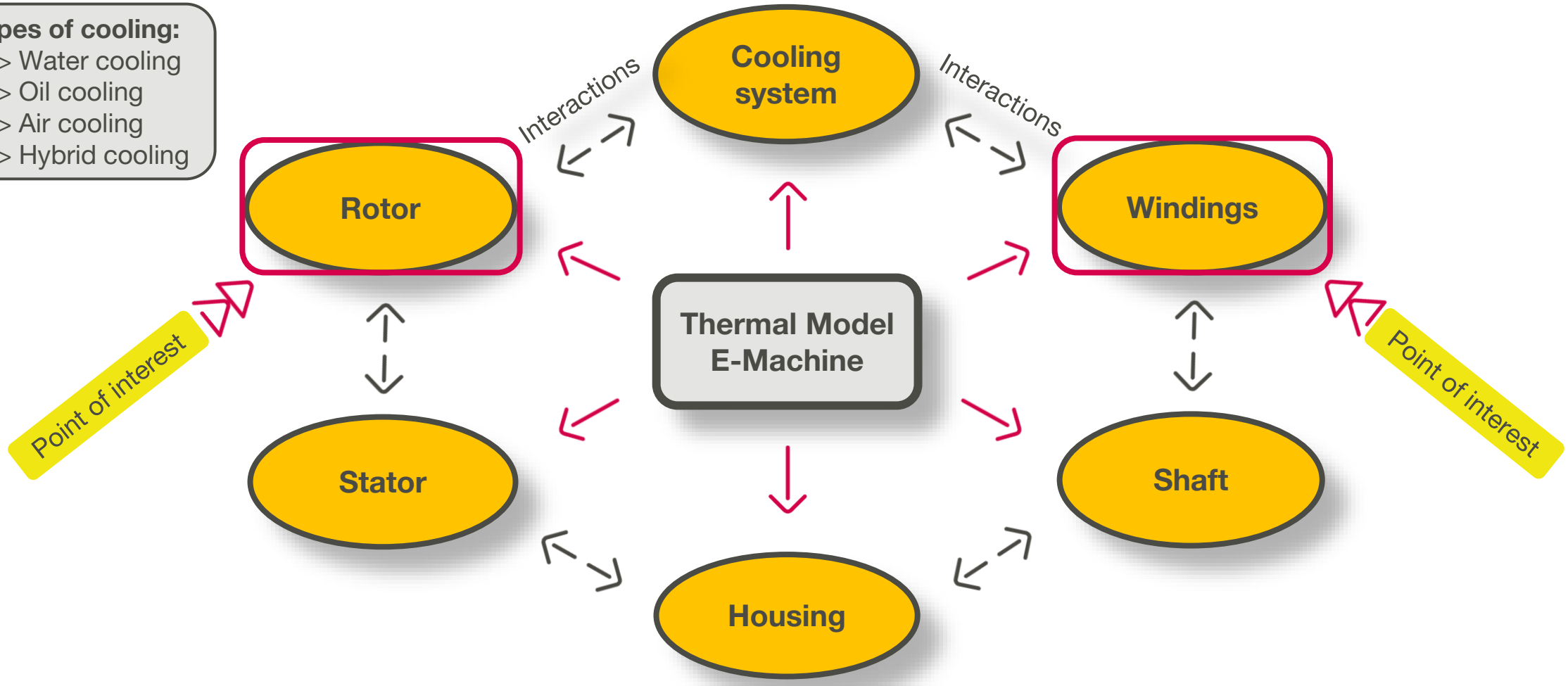
> Robust methodology
> Mean deviation reduction below 5°C
> Calibration time reduction



ELECTRIC MACHINE THERMAL MODEL OPTIMIZATION

MATLAB/SIMULINK EM THERMAL NETWORK MODEL

Types of cooling:
- > Water cooling
- > Oil cooling
- > Air cooling
- > Hybrid cooling

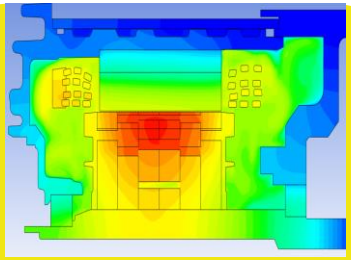


vitesco TECHNOLOGIES

ELECTRIC MACHINE THERMAL MODEL OPTIMIZATION

THERMAL MODELING WORKFLOW

1



CFD+FEM

↓

THERMAL RESISTANCE

↓

1D

2

1D THERMAL NETWORK MODEL

> Variable cooling
> Scalable geometry
> Different materials

Inverter

+

E-Machine

+

Gearbox

3

CALIBRATION

1D vs. measurements

MATLAB

Thermal Model + Testbench

Parameters

Responses

Ansys OPTISLANG

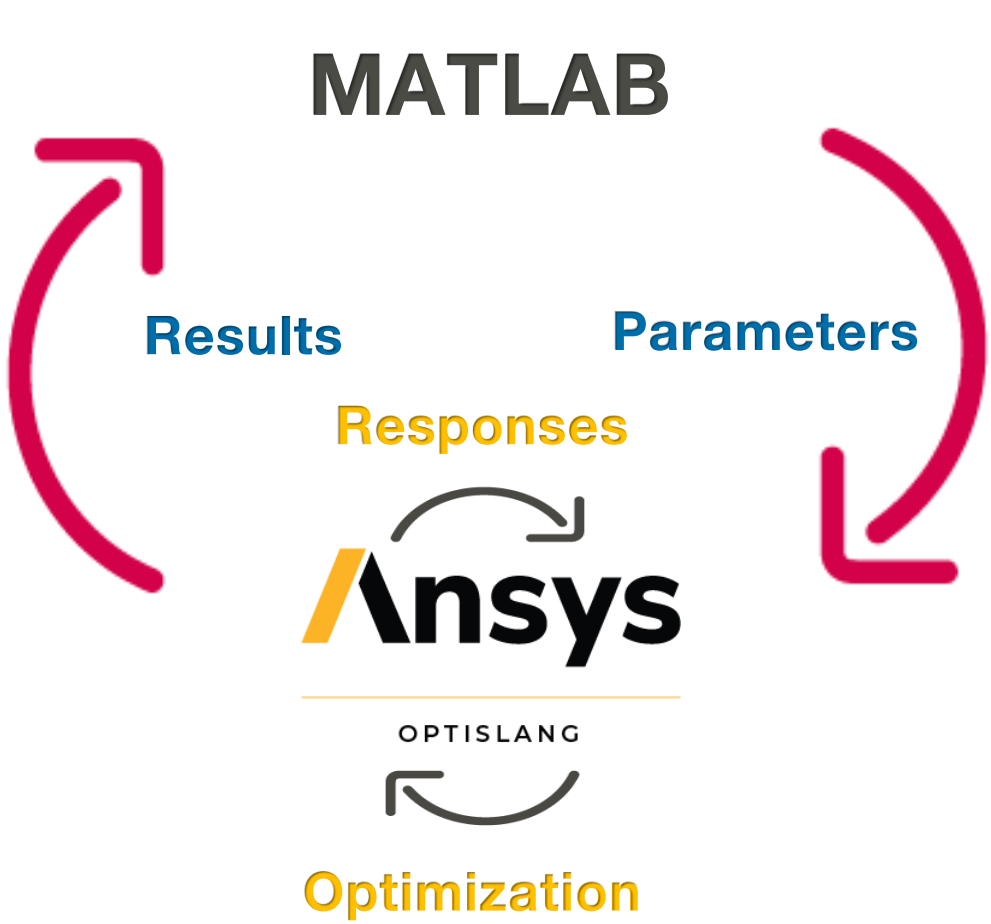
4

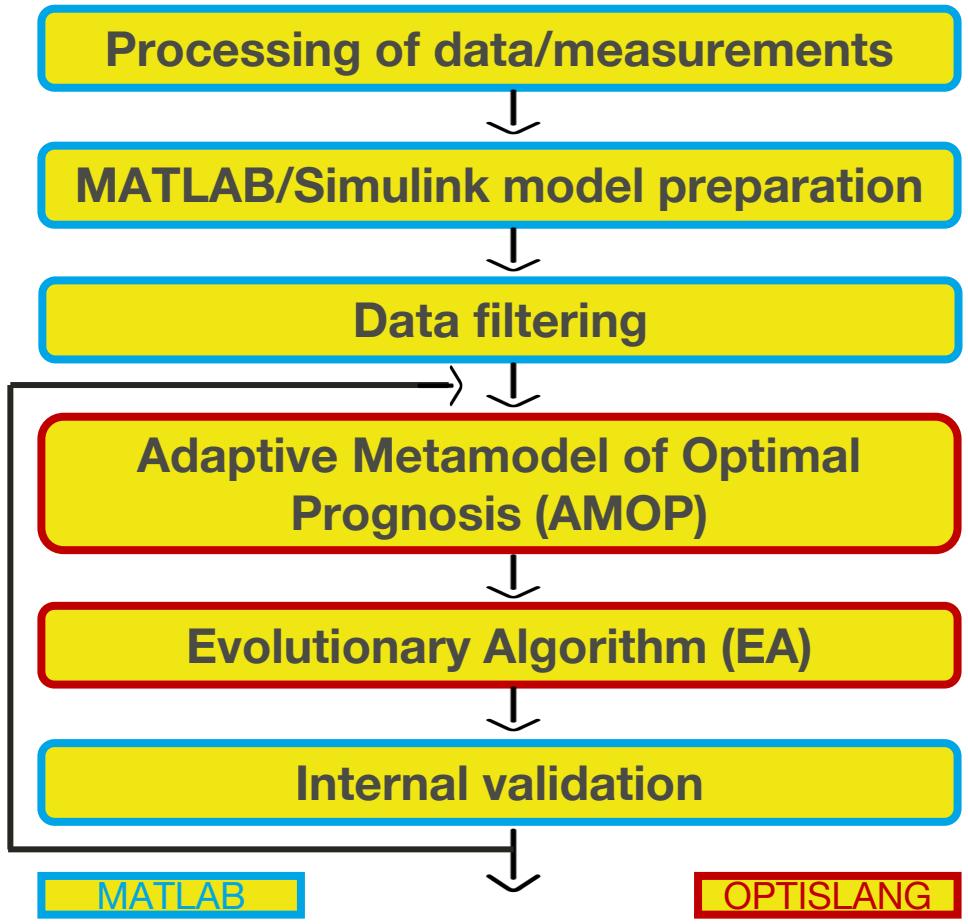
TOOLCHAIN INTEGRATION

MATLAB & CarMaker

ELECTRIC MACHINE THERMAL MODEL OPTIMIZATION

CALIBRATION WORKFLOW

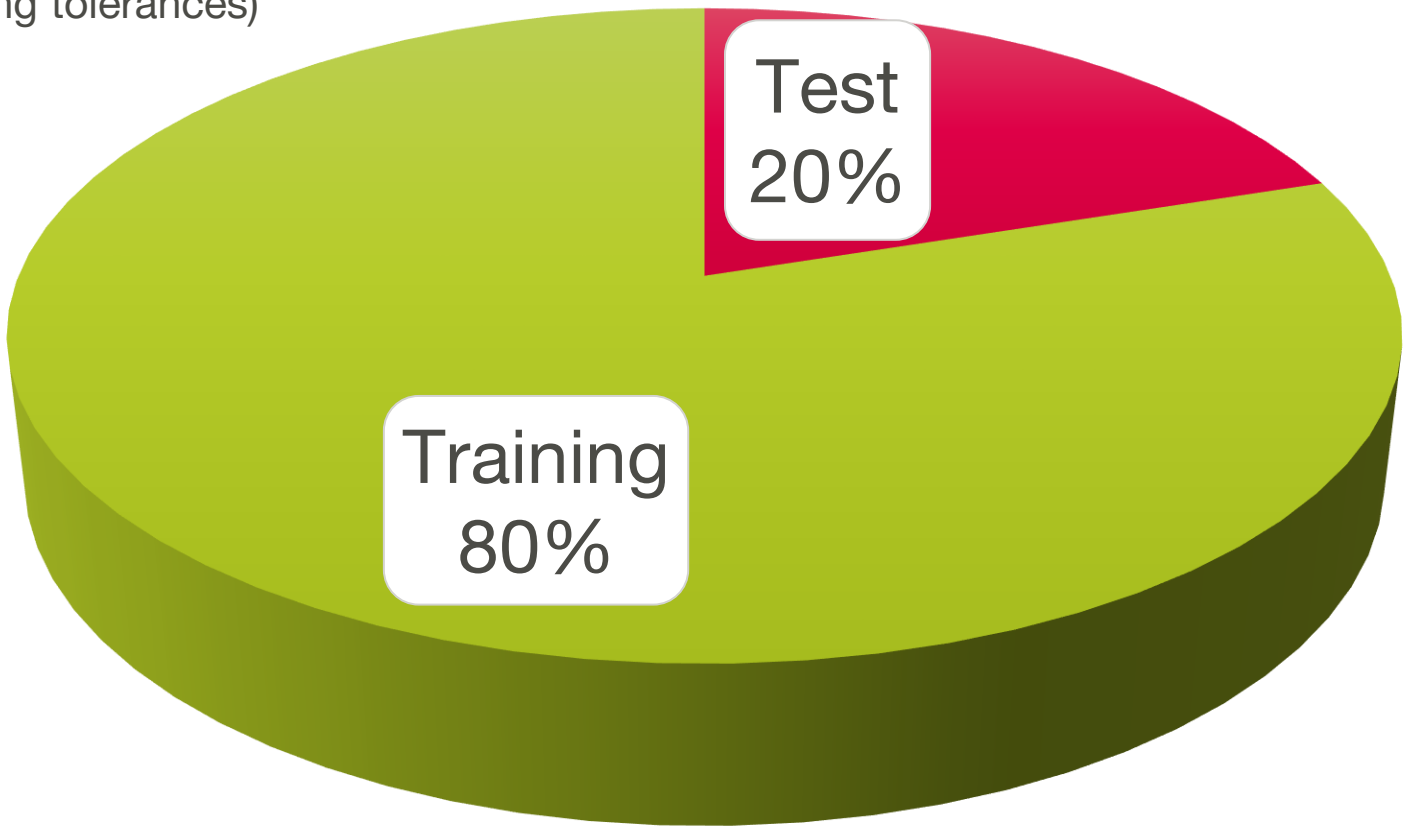




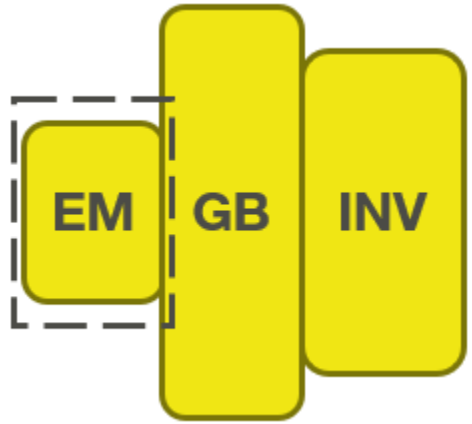
ELECTRIC MACHINE THERMAL MODEL OPTIMIZATION

APPLICATION EXAMPLE - FAMILY OF MEASUREMENTS

9 optimization parameters
(including manufacturing tolerances)



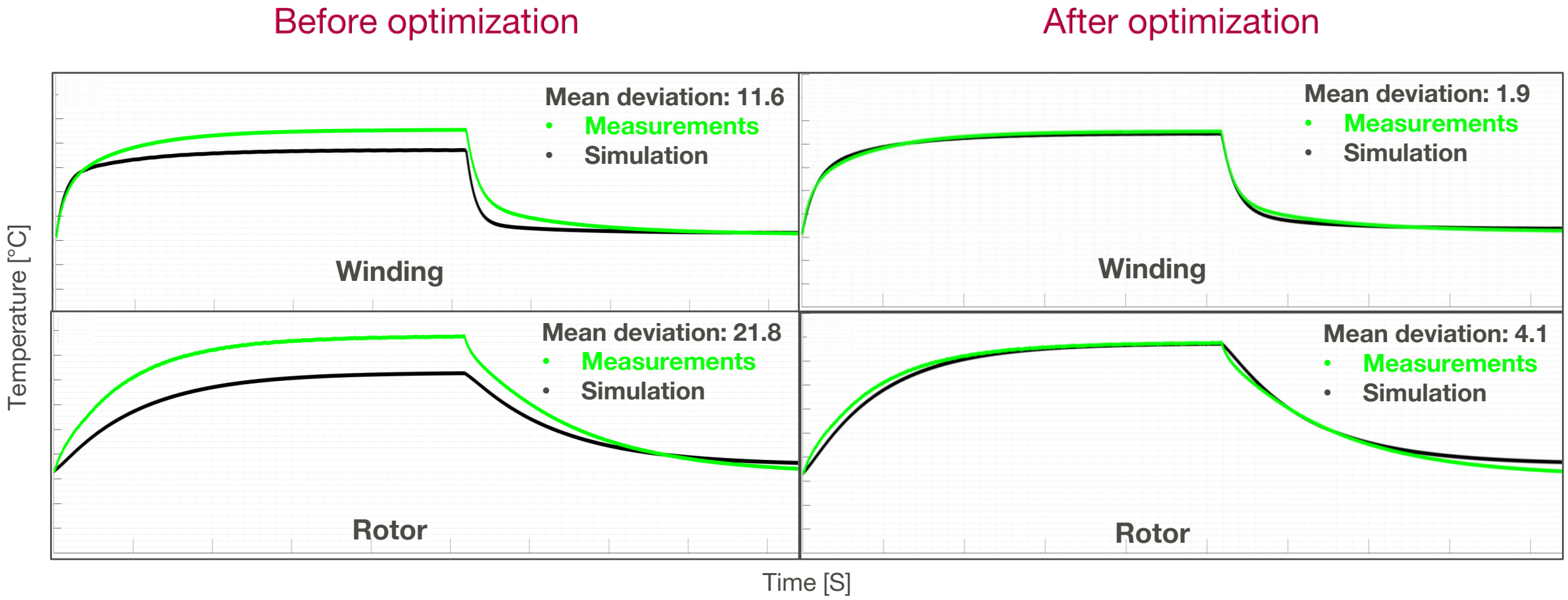
Measurements (125)



vitesco TECHNOLOGIES

ELECTRIC MACHINE THERMAL MODEL OPTIMIZATION

APPLICATION EXAMPLE – TRANSIENT MEASUREMENTS

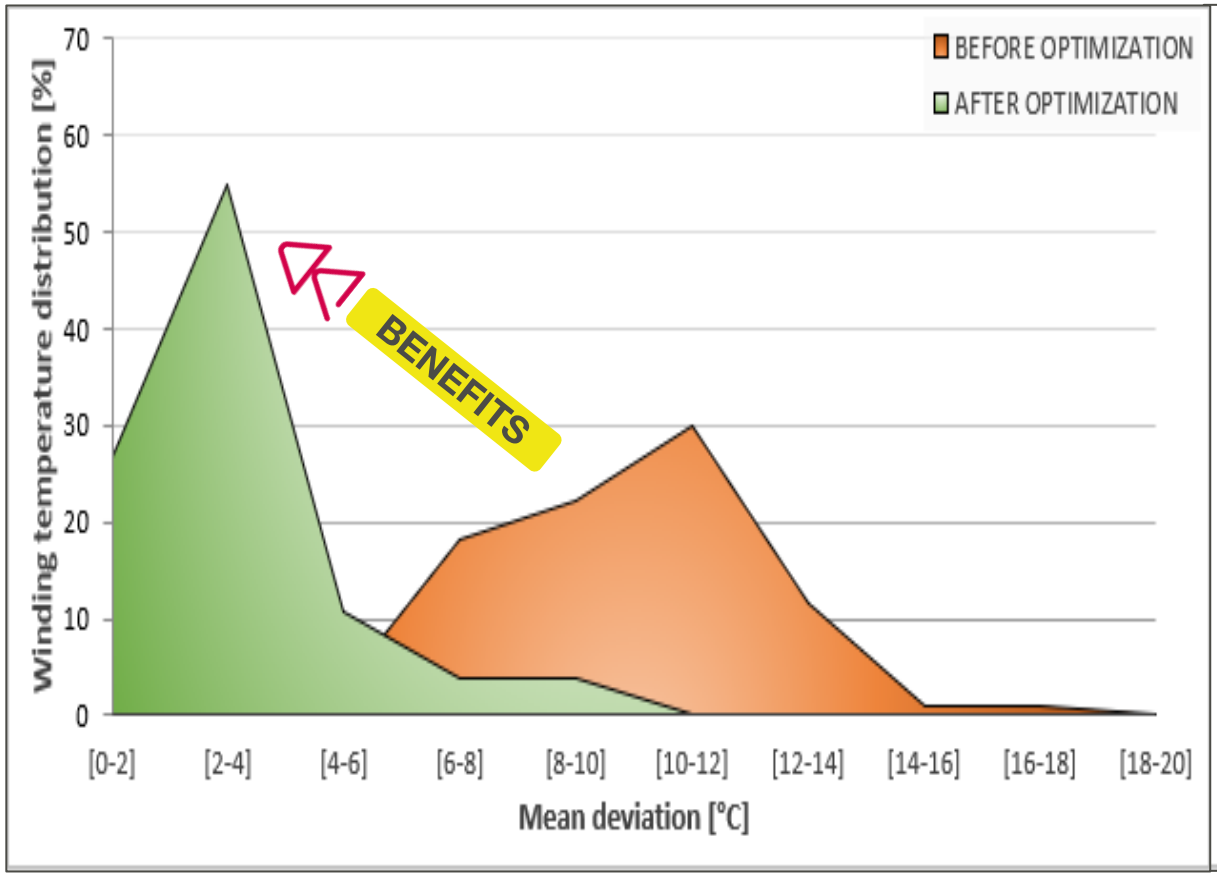


vitesco TECHNOLOGIES

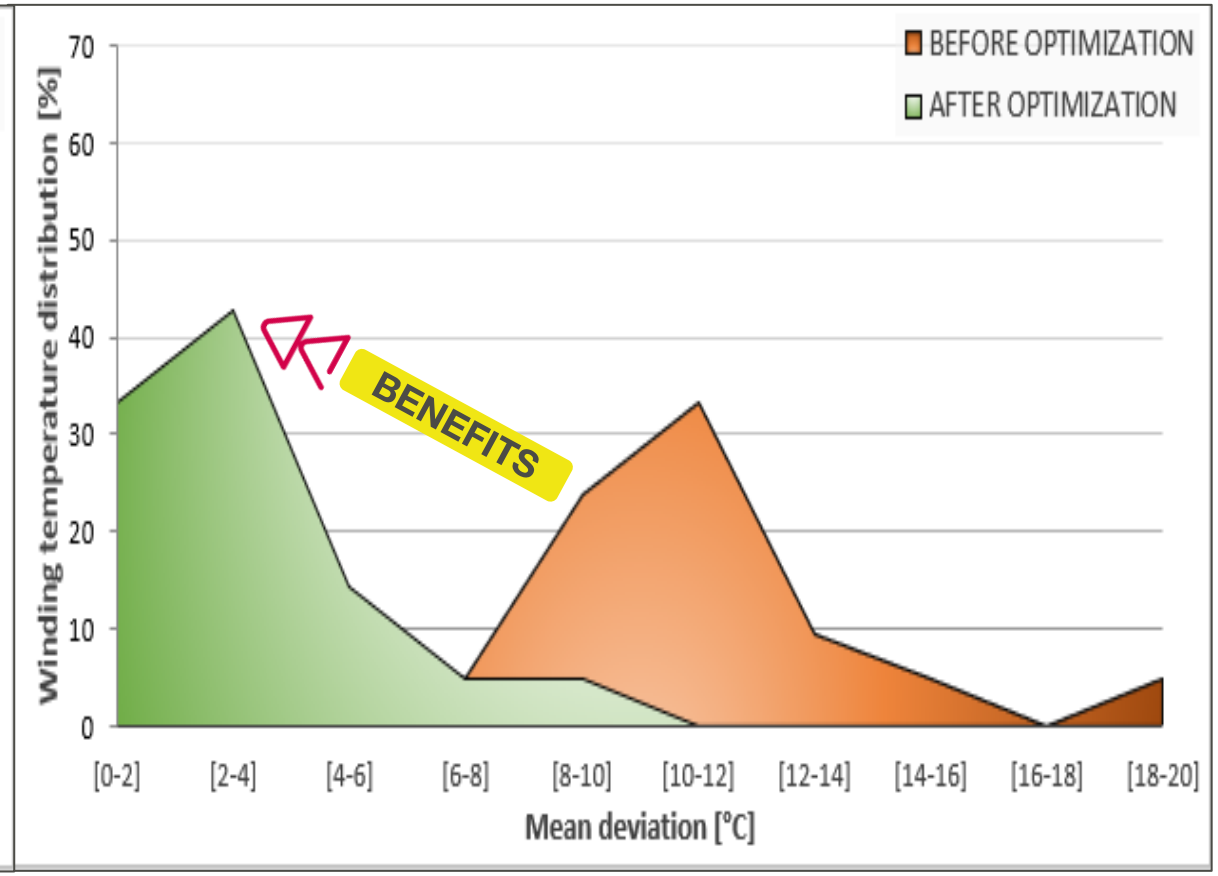
ELECTRIC MACHINE THERMAL MODEL OPTIMIZATION

APPLICATION EXAMPLE - **WINDING TEMPERATURE** DISTRIBUTION

Training data set



Test data set

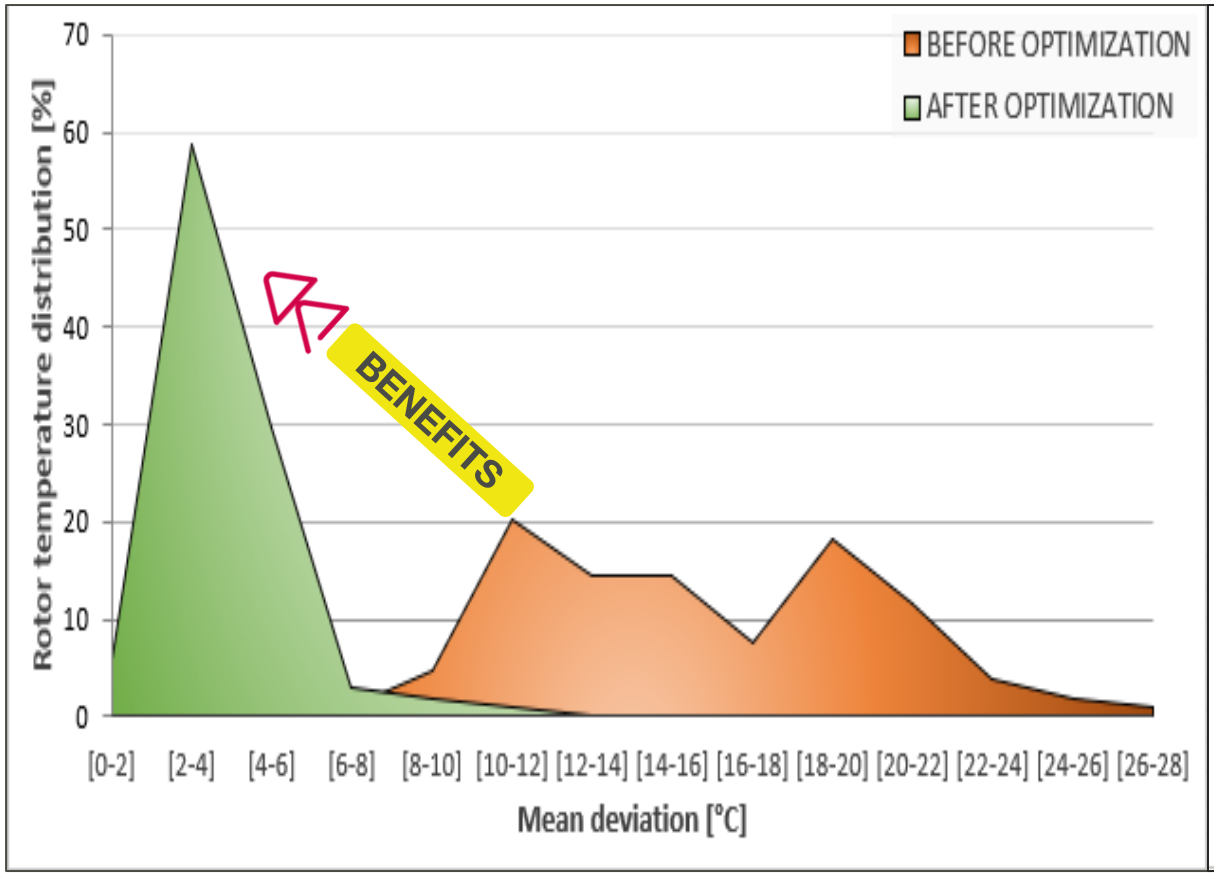


vitesco TECHNOLOGIES

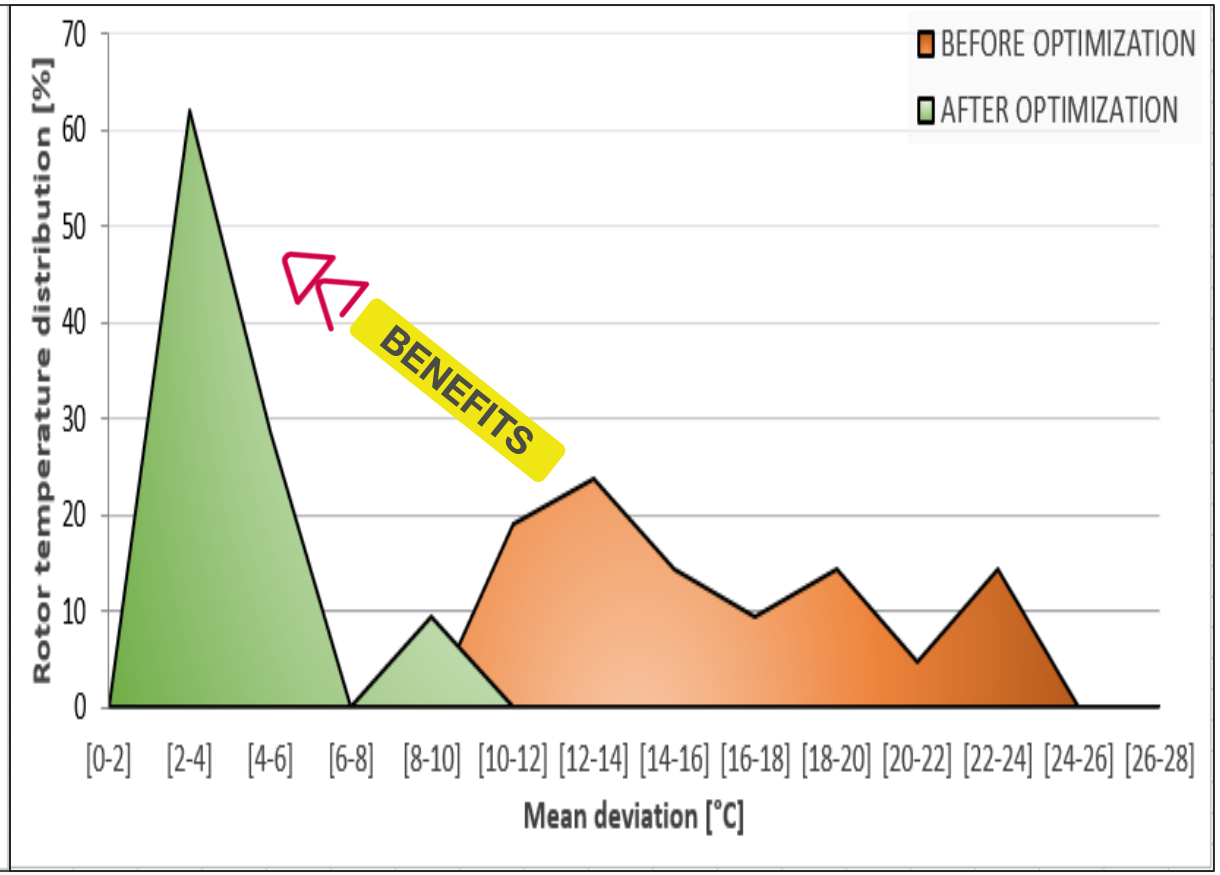
ELECTRIC MACHINE THERMAL MODEL OPTIMIZATION

APPLICATION EXAMPLE - **ROTOR TEMPERATURE** DISTRIBUTION

Training data set



Test data set



vitesco TECHNOLOGIES

ELECTRIC MACHINE THERMAL MODEL OPTIMIZATION

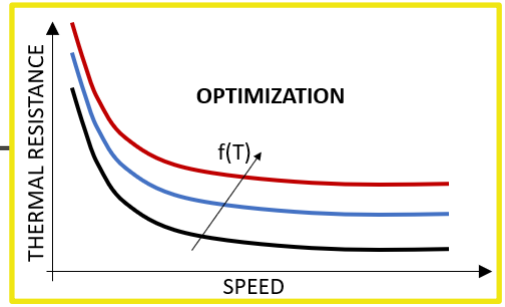
APPLICATION EXAMPLE – GB THERMAL MODEL

eDrive cooling system

EM/COOLANT

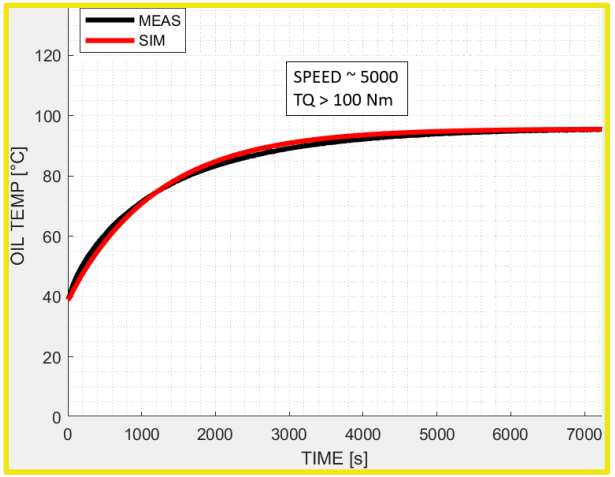
CFD

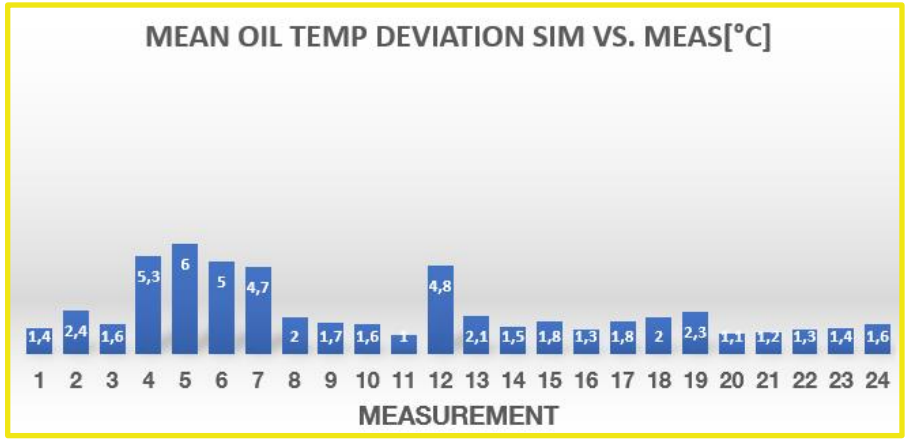
GB/EM



Gearbox

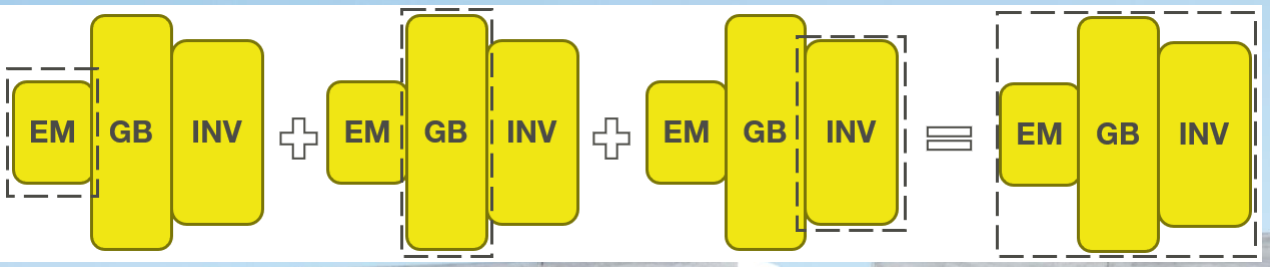
GB/ENVIRONMENT





vitesco TECHNOLOGIES

SUMMARY



> Successful benchmark for EM thermal model optimization
> optiSLang based methodology reducing calibration time by 75%
> 90% of the results showing less than 5°C of mean deviation

Outlook
> Procedure application for other EM technologies
> Procedure application for power electronics
> E-axle thermal model development including thermal interaction