Virtual sensing power electronics

eMachine use case

NEWTWEN

Customer background

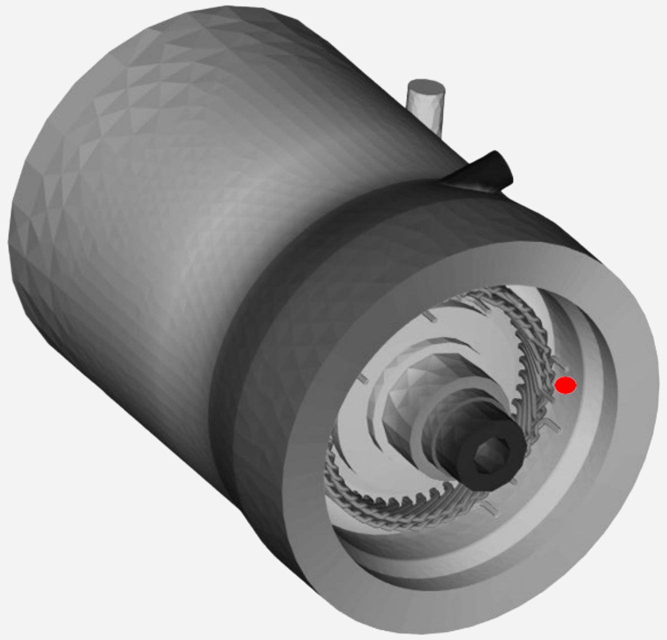
The customer eMachine team was in search of a solution to:

1. Increase the nominal performance of the eMachine
2. Decrease the Billing of Material of the system

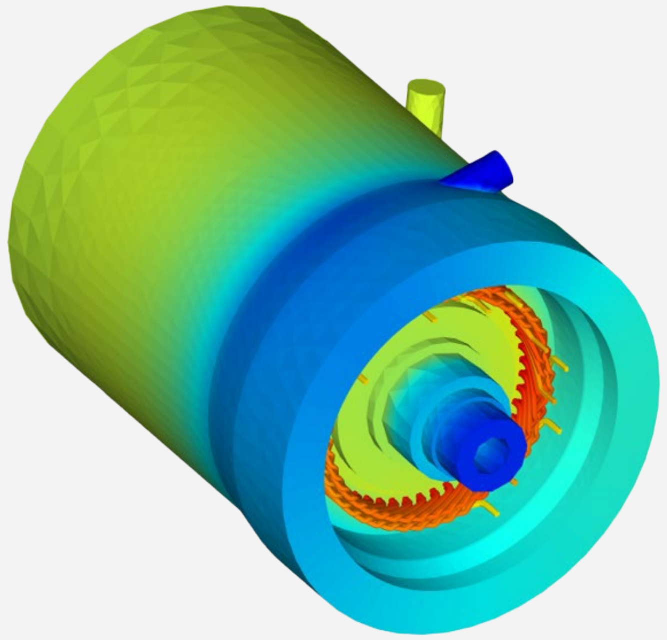
Problem statement reframed

Thermal Management & Control

High-current-density motors increasingly feature complex cooling systems, ranging from the classic water jacket to new oil spray systems that cool both the stator and rotor. The issue is that temperature is not uniformly distributed; a single thermal sensor cannot identify the system's hot spot. As a result, large safety margins are applied to insulation classes, significantly reducing the effectiveness of advanced cooling systems and the motor's performance.



Where the sensor is placed



How the temperature is distributed

Virtual thermal sensors

VTS Impact

Virtual thermal sensors-based control KPI:

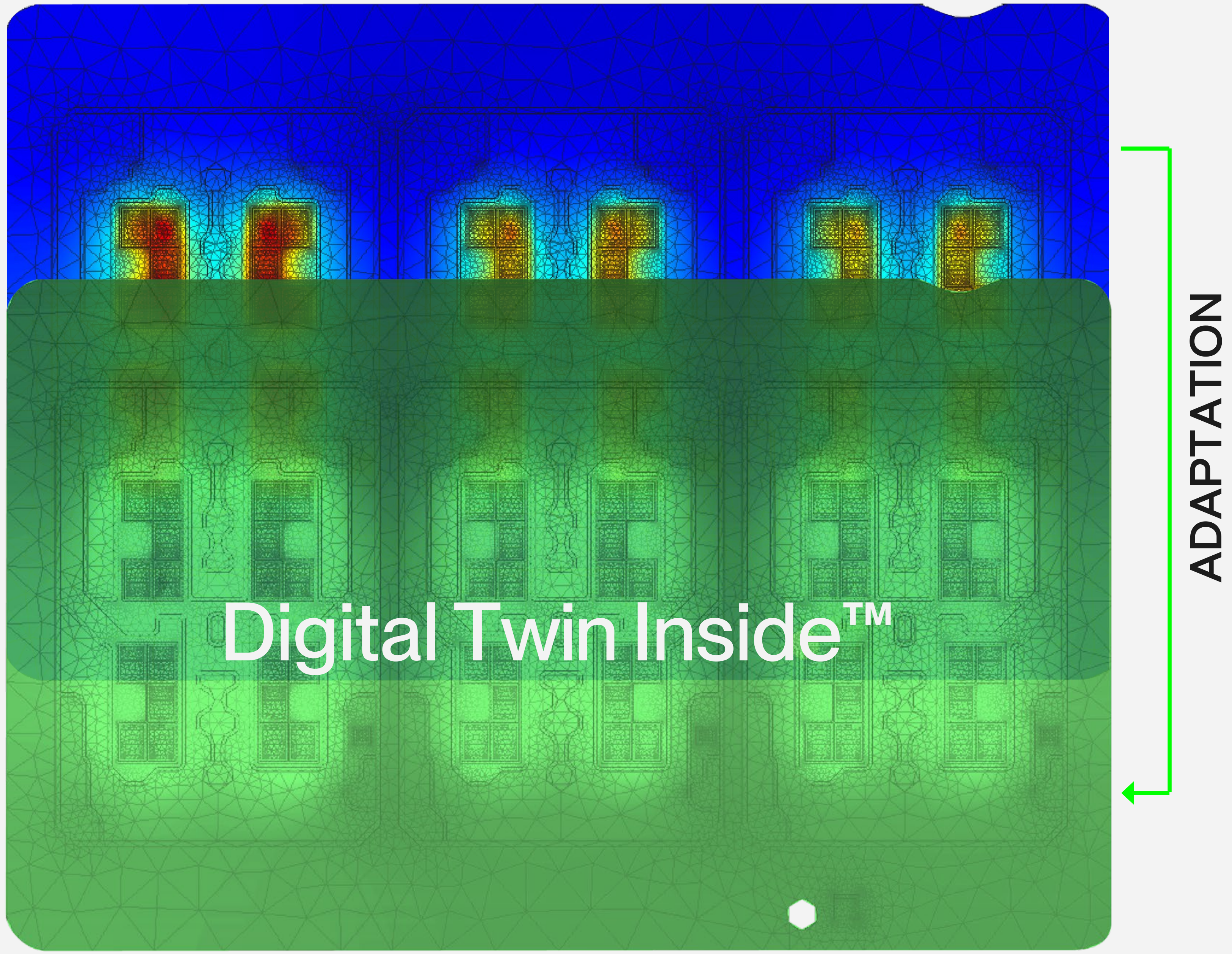
- 5°C safety margin (instead of 20°C) thanks to high model reliability extensively tested in R&D
- 12% increased nominal torque
- 8% improved rated speed of the e-drives
- Enhanced insulation class and temperature class of the e-machine

Virtual thermal sensors explained

Virtual Thermal Sensors

A **real-time software solution** with **no sensing placement limitations**, capable of **predicting future outcomes** to optimize control decisions. **Embedded directly in the control unit**, virtual thermal sensors replace and enhance traditional hardware sensors with unprecedented flexibility and intelligence.

Real device thermal analysys

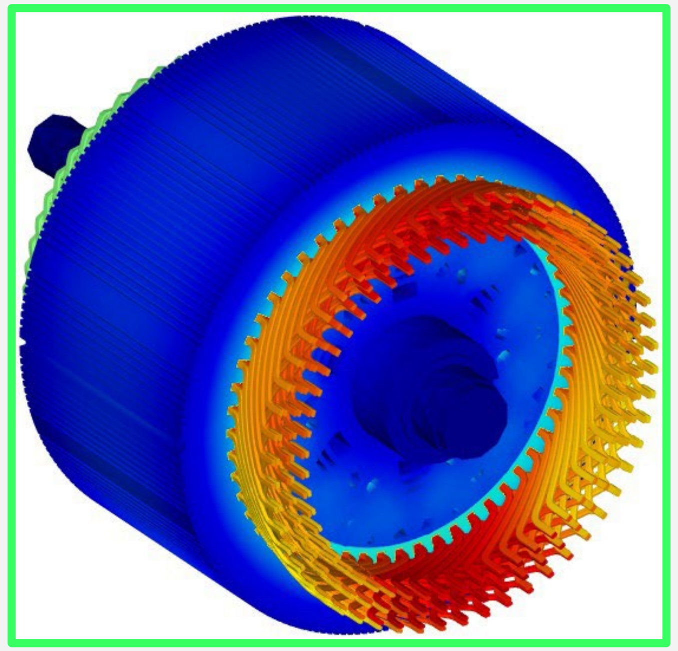


Virtual thermal sensors methodology

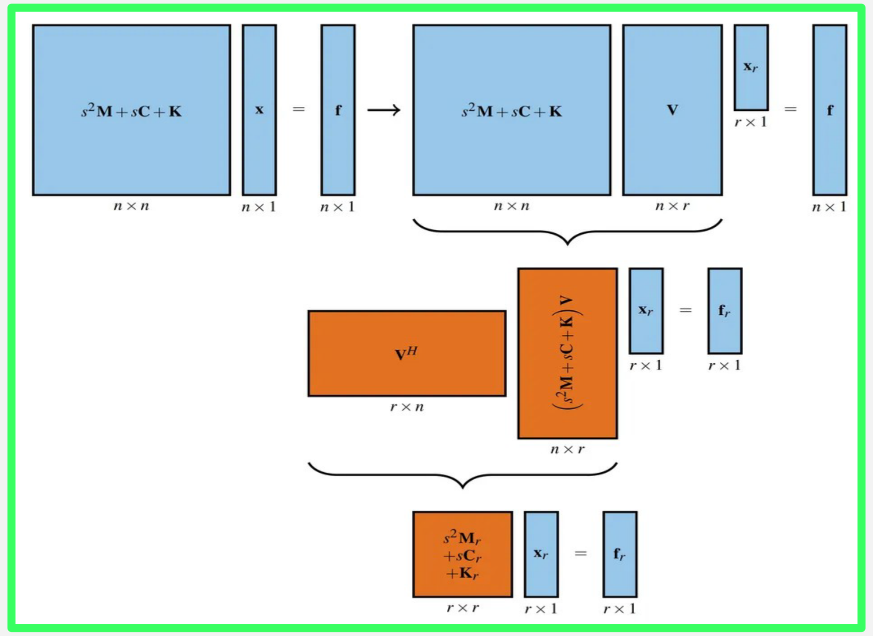
Technology

Input
Measurement from testbench

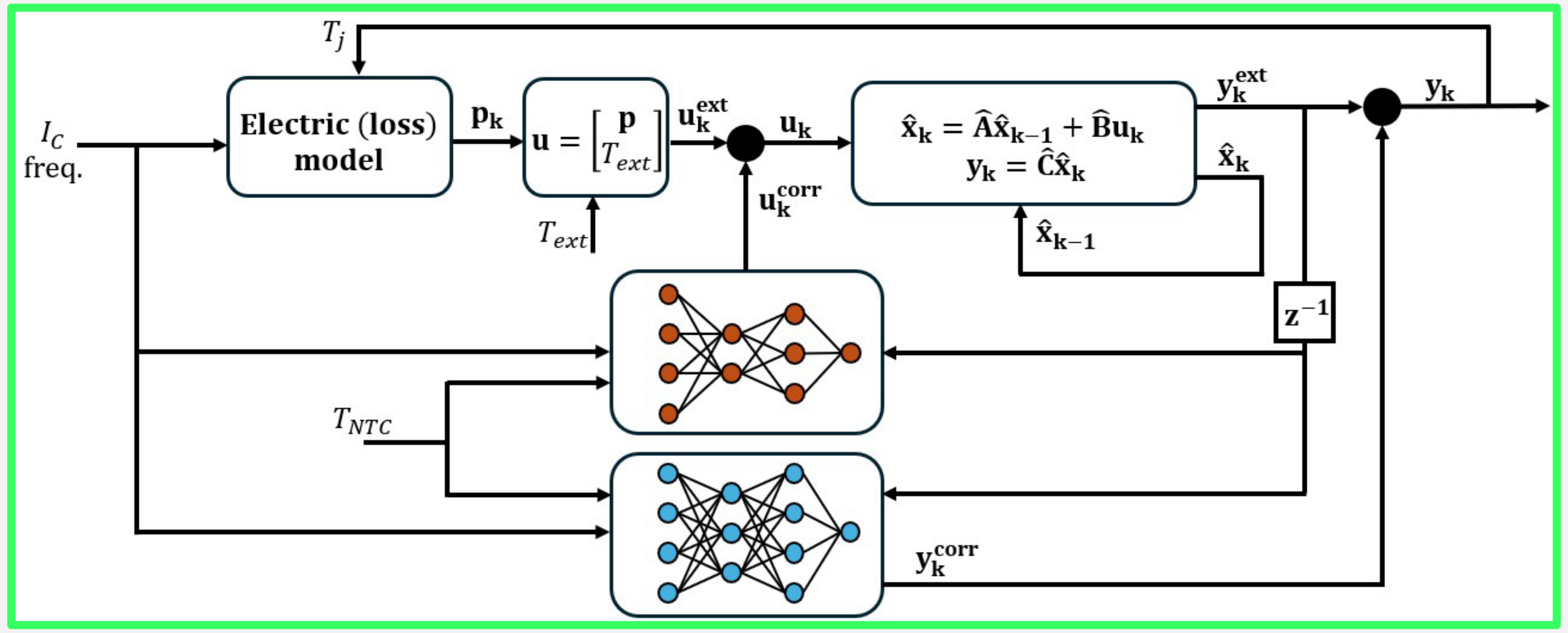
Input
CAD, material properties, and power loss characterisation



Finite element analysis (FEA)
~ 5 milion of degrees of freedom (DOF)



Model order reduction (MOR)
From 5 milion DOF to just 21 DOF



Physics AI virtual sensors
Calibration with real sensor measurements

Output
Final software architecture to be embedded into third party platforms

Technical KPIs

Customer Requirements

1. Multiple stator winding and rotor magnet virtual sensor placement.

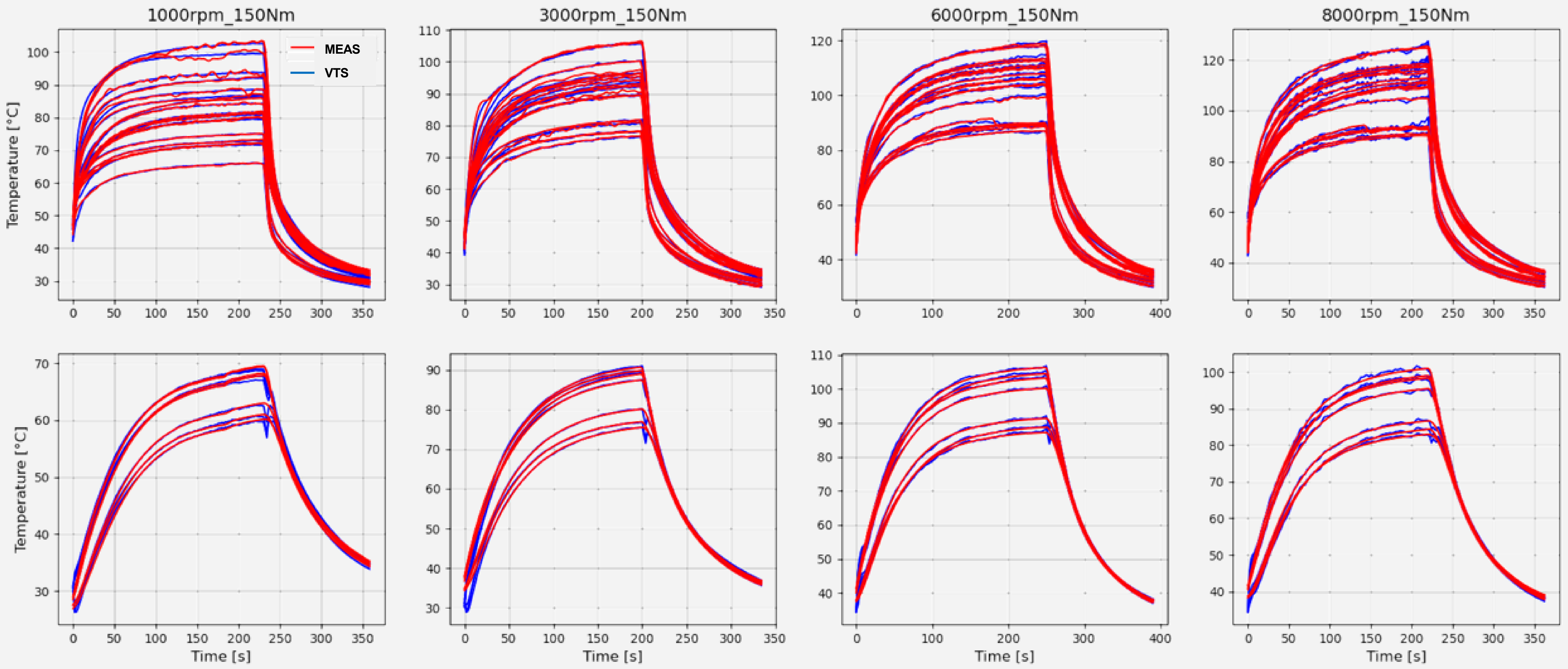
2. Delta (Real sensor to virtual sensor) prediction $< \pm 3$ °C in transient and steady state for all the operating conditions of the motor (torque, speed, coolant flowrate, and coolant temperature).

3. Model size for control unit < 2 kB of RAM and <100 kB of FLASH as target.

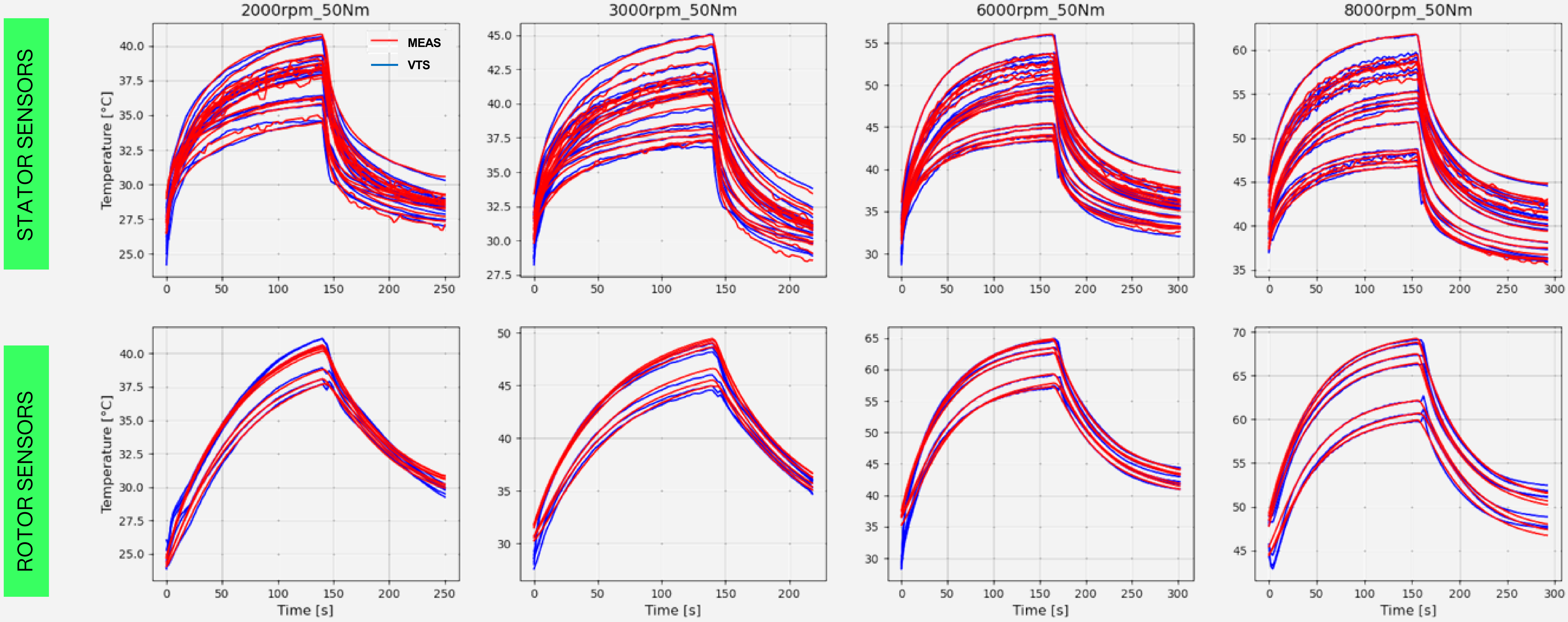
Final Results @ 150Nm

STATOR SENSORS

ROTOR SENSORS

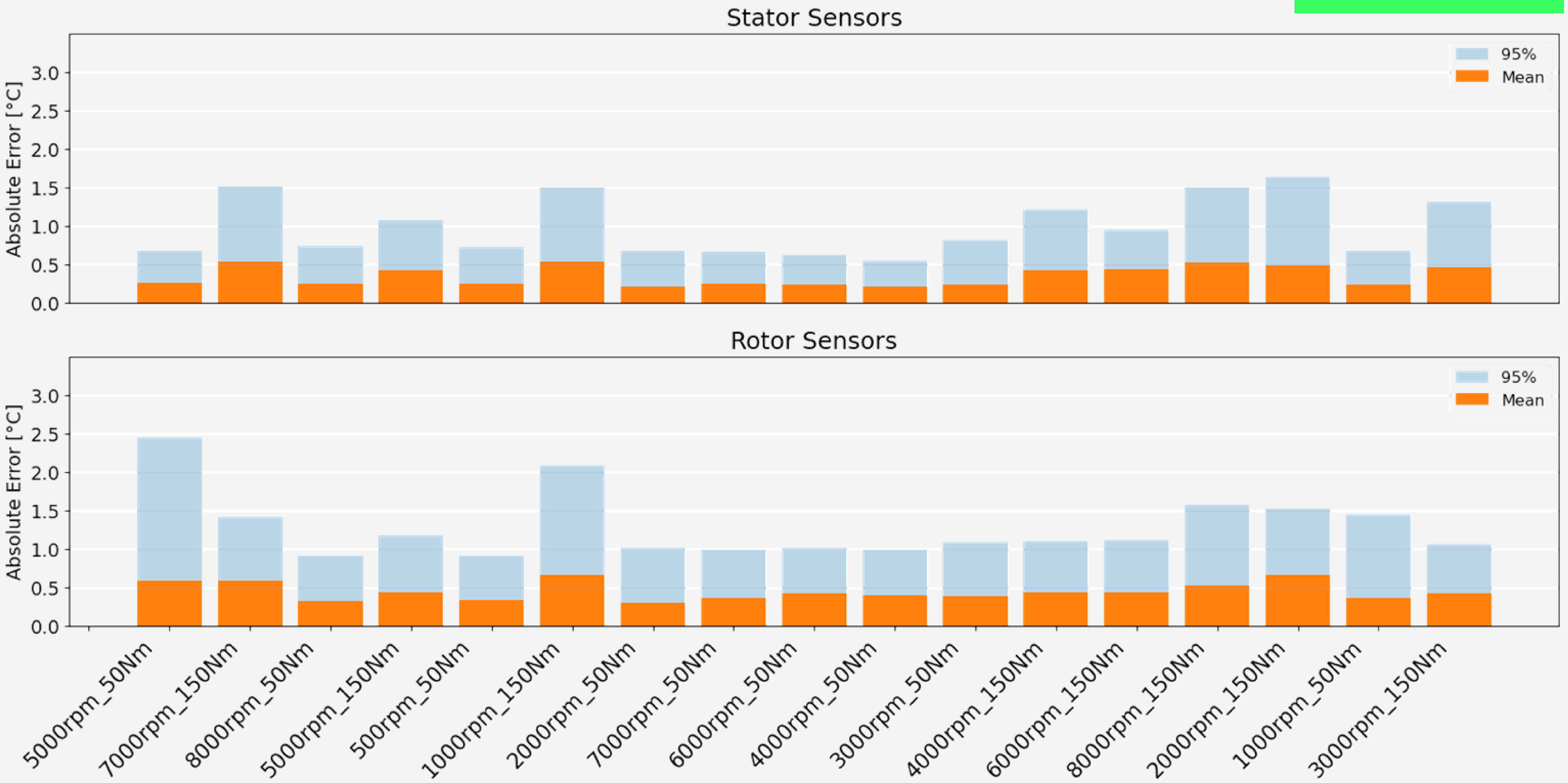


Final Results @ 50Nm



Performance

KPI ΔT +/− 3°C



Implementation

Digital Twin in real-time:

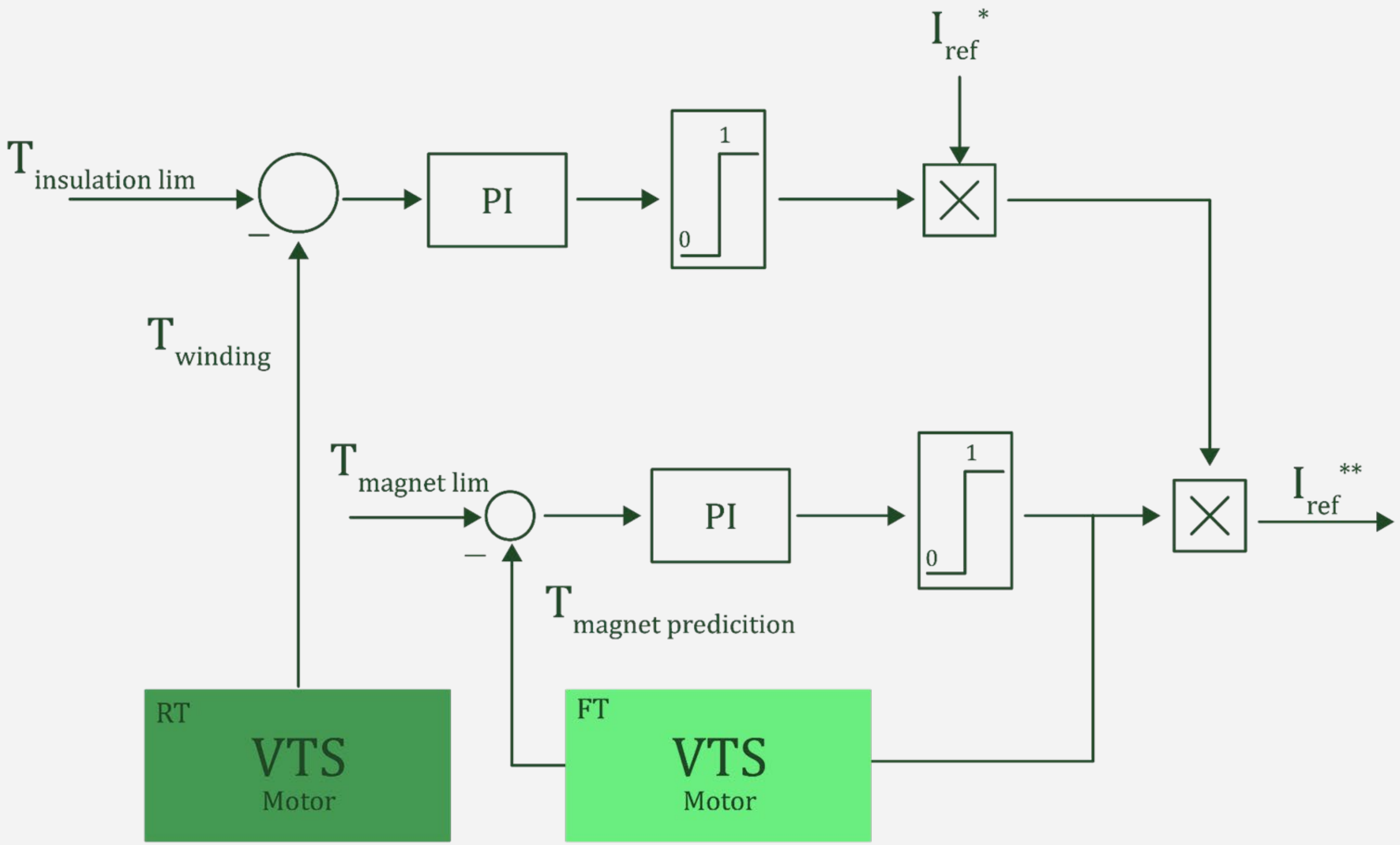
- Flash: 54kB
- RAM: <1kB
- Execution time 76 us in Aurix TC3

Impact on control

Implementation

Digital Twin in real-time:

A derating strategy limits current via a two-stage control loop: one stage monitors real-time maximum temperature in the stator windings using virtual sensors, while the other predicts rotor magnet temperature at 100 times faster than real time. This dual approach ensures stability in the derating control architecture.

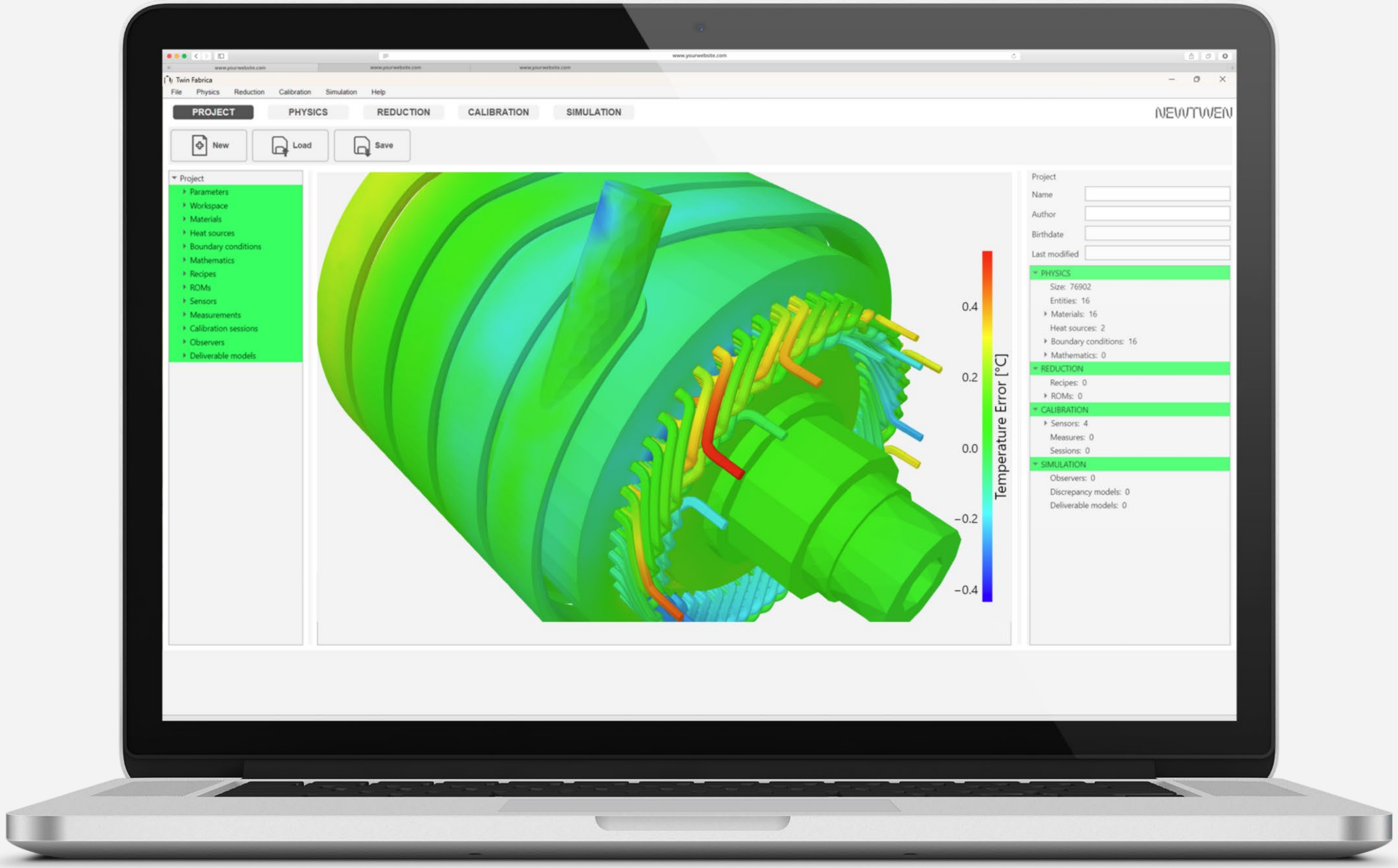


Tooling

Twin Fabrica

The entire project has been carried out with Twin Fabrica, Newtwen engineering software platform to create and deploy **virtual sensors** with the **streamline methodology reviewed above**:

1. Import your geometry
2. Make multiphysics simulation
3. Get reduced order model (ROM)
4. Import your real data measurement
5. Empower your ROM with AI
6. Export you virtual sensing setup



Virtual sensing power electronics

eMachine use case

NEWTWEN