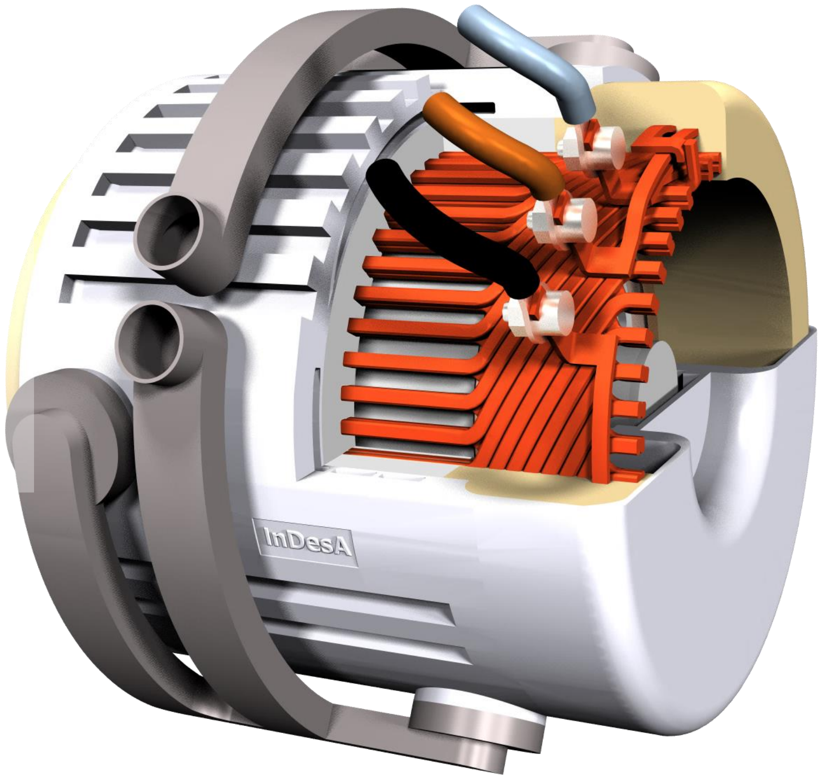
# Towards a Digital Twin of an E-Motor for Thermal and Electromagnetic Analysis with STAR-CCM+

Gerald Seider, Fabiano Bet

- **E-Motor** for automotive drivetrains
- **Thermal and Electromagnetic Analysis**
- **STAR-CCM+** coupled application
- **Digital Twin** road map

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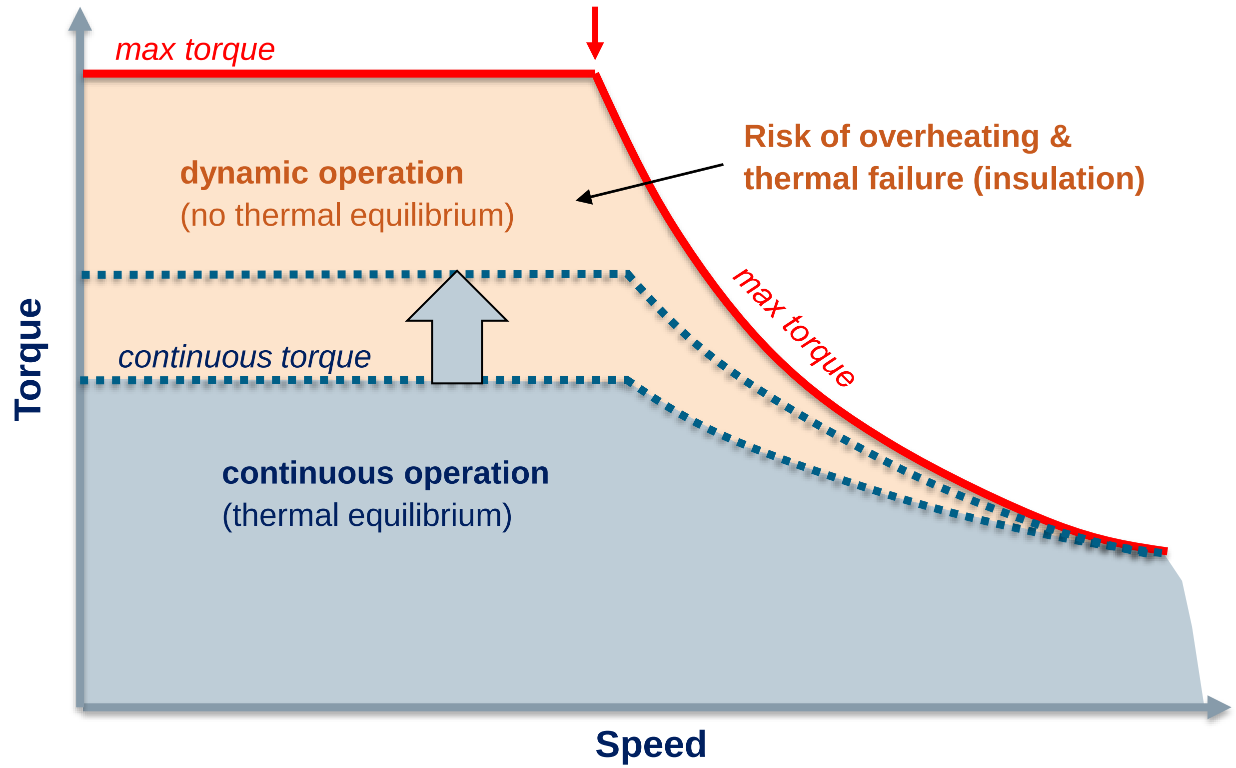
# Why is Thermal Management so essential for E-Motors?

## Typical torque curves of an e-motor




## Optimized cooling can enhance :

- continuous torque
- dynamic performance
- thermal protection
- current resistance
- efficiency
- life time

for same continuous torque

**downscale of**

- motor
- electric system



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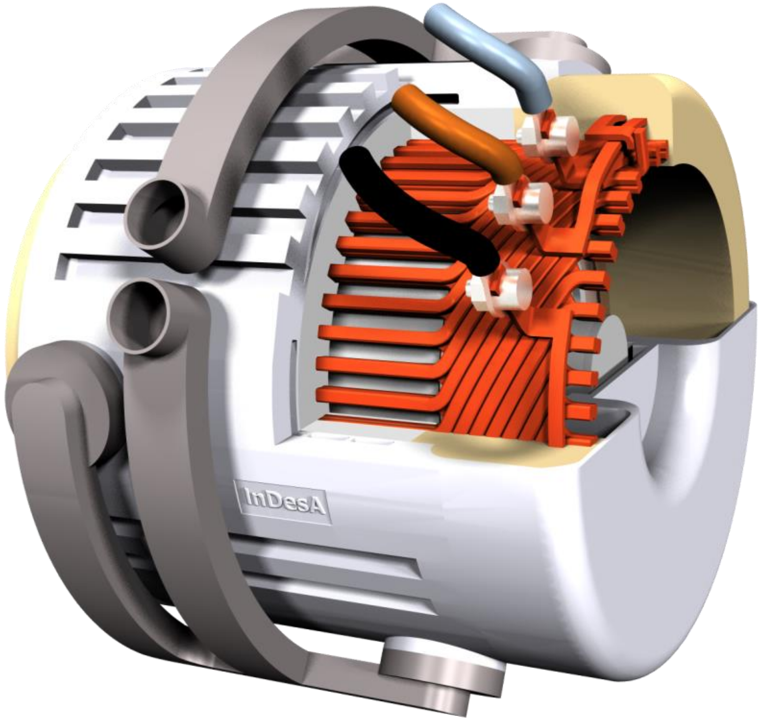
## Pandora E-Motor – Electric Data

**3-Phase Induction Motor (ASM)**

**430 V, 150 kW, 400 Nm**

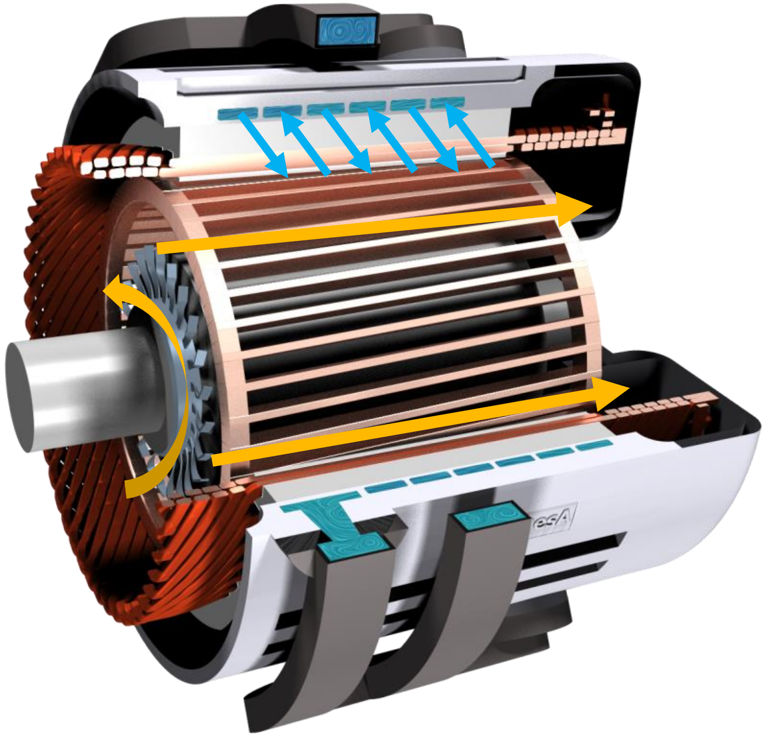



### Stator

- 2 pole pairs
- 48 grooves
- 2 layer copper winding
- water-cooled, crossflow

### Rotor

- cage 44 copper bars, skewed
- cooling fan
- air cooled
- air cooling channels





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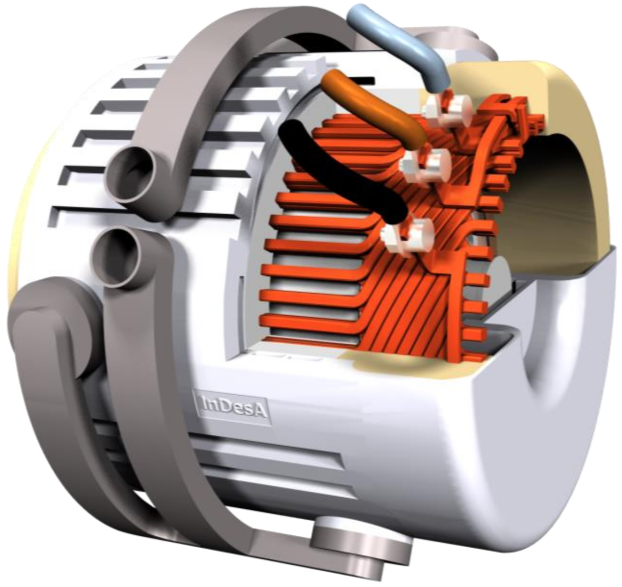


## Key Objective from Thermal Perspective:

**Create heat source and do thermal analysis within one simulation model.**

## Benefits:

- **Physical interaction between**
  ***electric current – electromagnetic field – temperature field***
- **Workflow in ONE tool, i.e. no iterative Co-Simulation**



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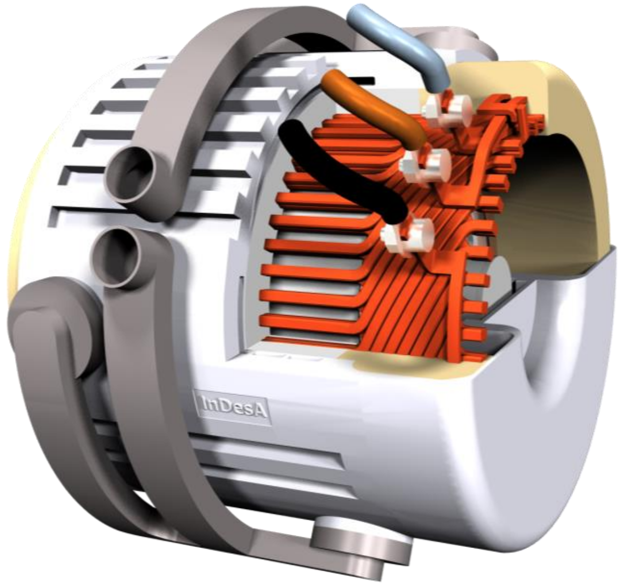
## Heat Sources:

- **Resistive** (Joule) **Losses**
- **Iron Loss** (eddy current, hysteresis)
- **Mechanical Losses** (bearings)
- **Windage Losses** (air gap, fan, etc.)
- **Coolant pressure loss**




## Physical Models:

- Electric Current Flow — 3D
- Electromagnetic flux — 2D
- Coolant & Air flow — 3D
- Thermal flux in structure — 3D

## Model Dimensions:

3D
2D
3D
3D

STAR-CCM+



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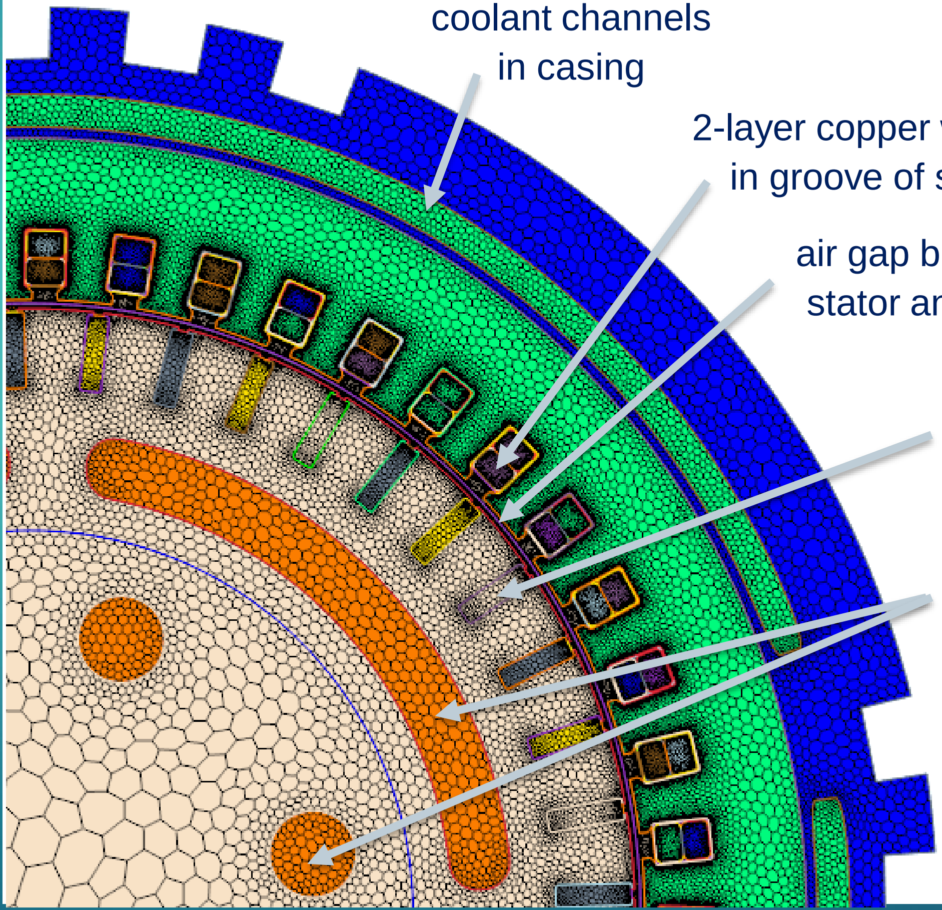
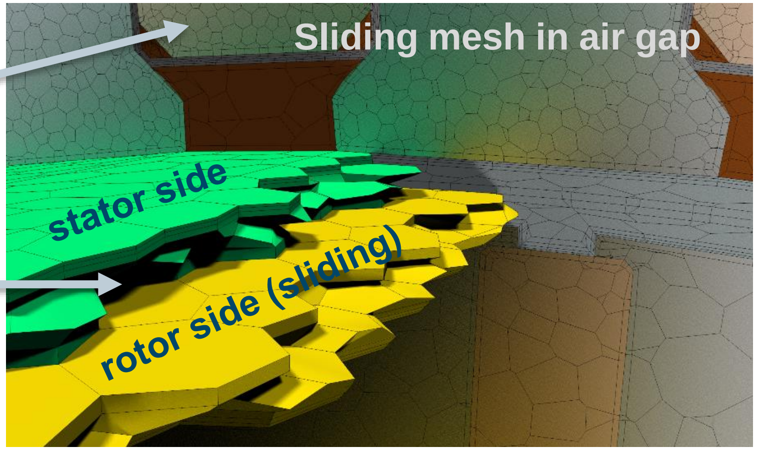
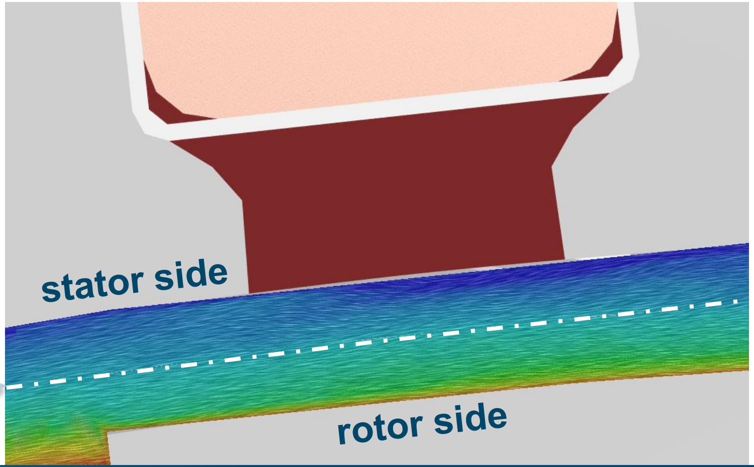
## 2D Mesh
## Electromagnetics Model




## 3D Mesh
## Thermal/Flow/Current Model



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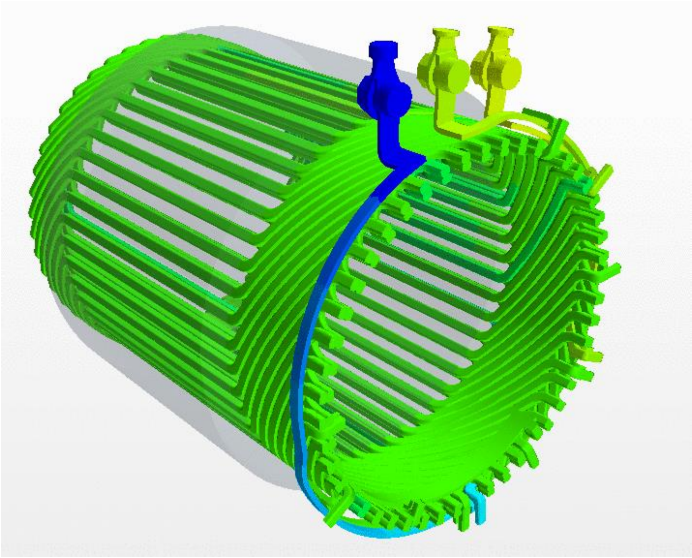
## Towards a Digital Twin of an E-Motor for Thermal and Electromagnetic Analysis

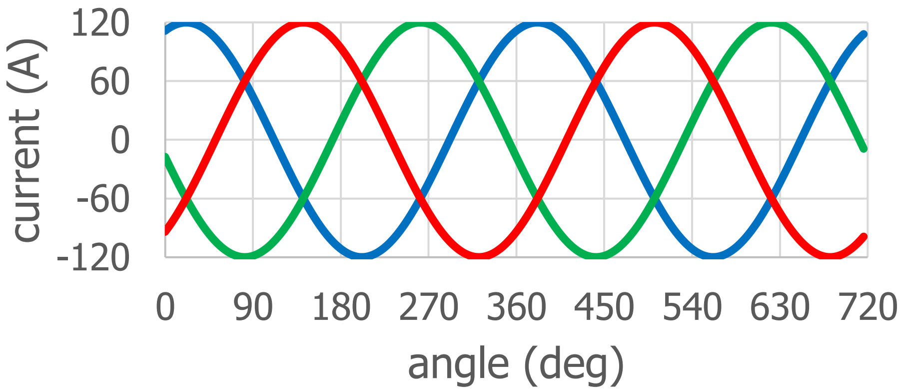
### Boundary Condition

- 3-Phase Current,  120 Ampere
- Frequency: 242 Hz
- Slip 1 %
- Speed: 7200 1/min
- Coolant:  6 l/min @ 60  C



### Initial Condition

Starting temperature





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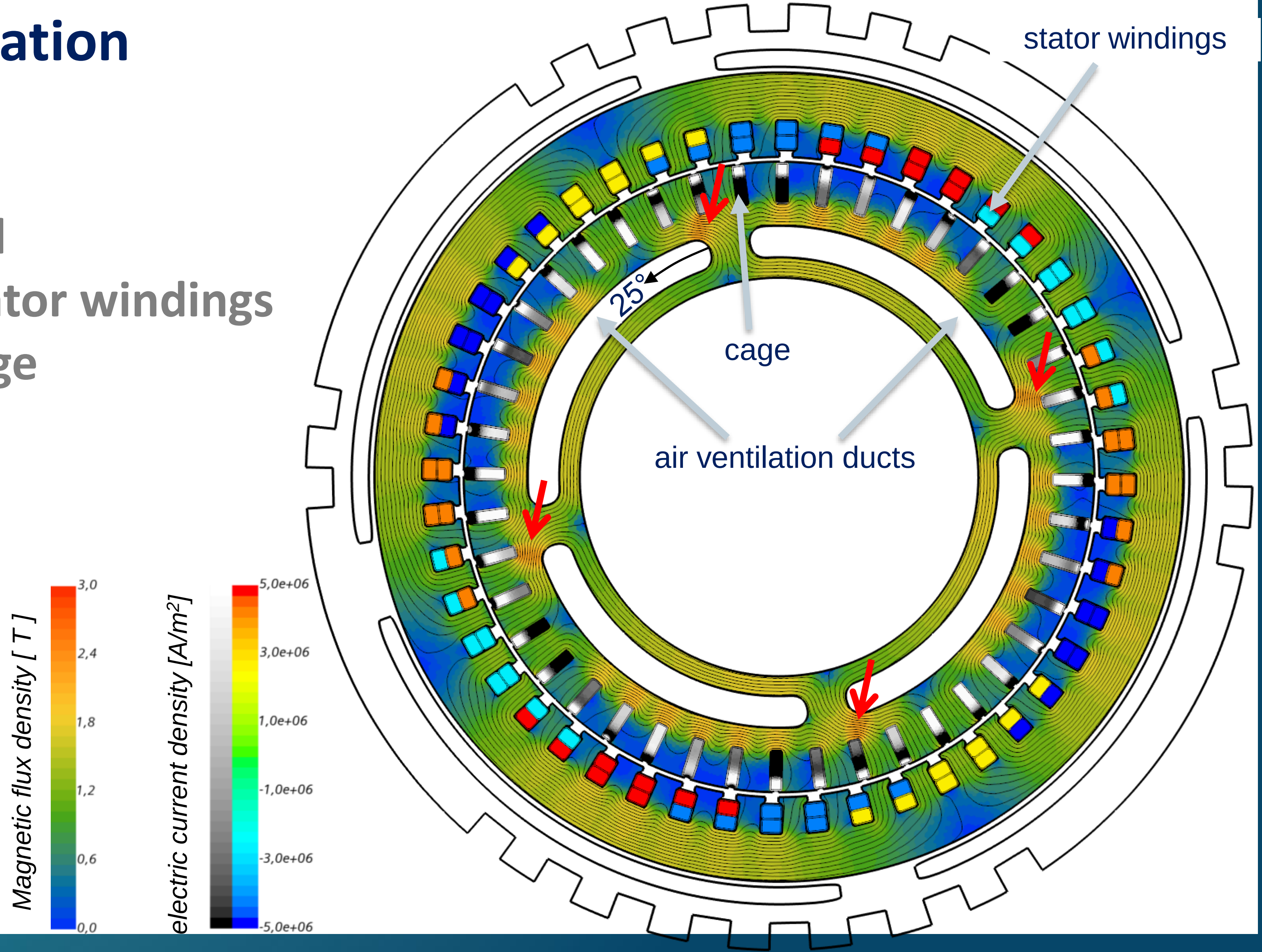
# Towards a Digital Twin of an E-Motor for Thermal and Electromagnetic Analysis

## Electromagnetic Simulation

### 2D Mesh

- Electromagnetic field
- Electric current in stator windings
- Electric current in cage



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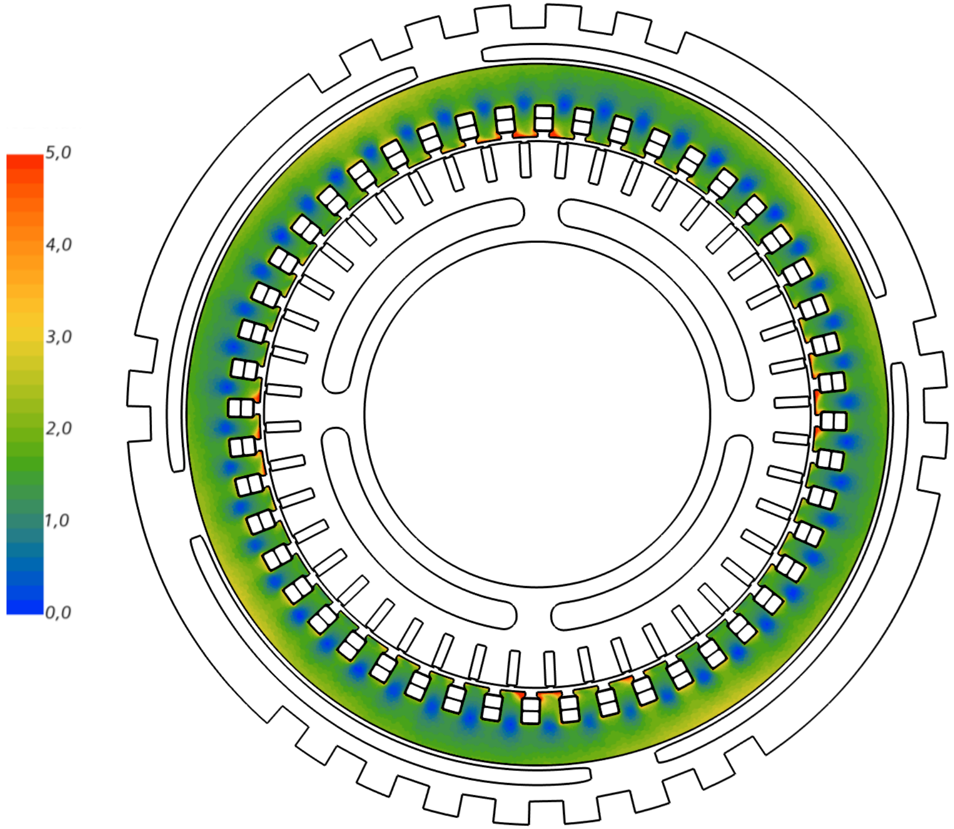
# Towards a Digital Twin of an E-Motor for Thermal and Electromagnetic Analysis

## Electromagnetic Simulation

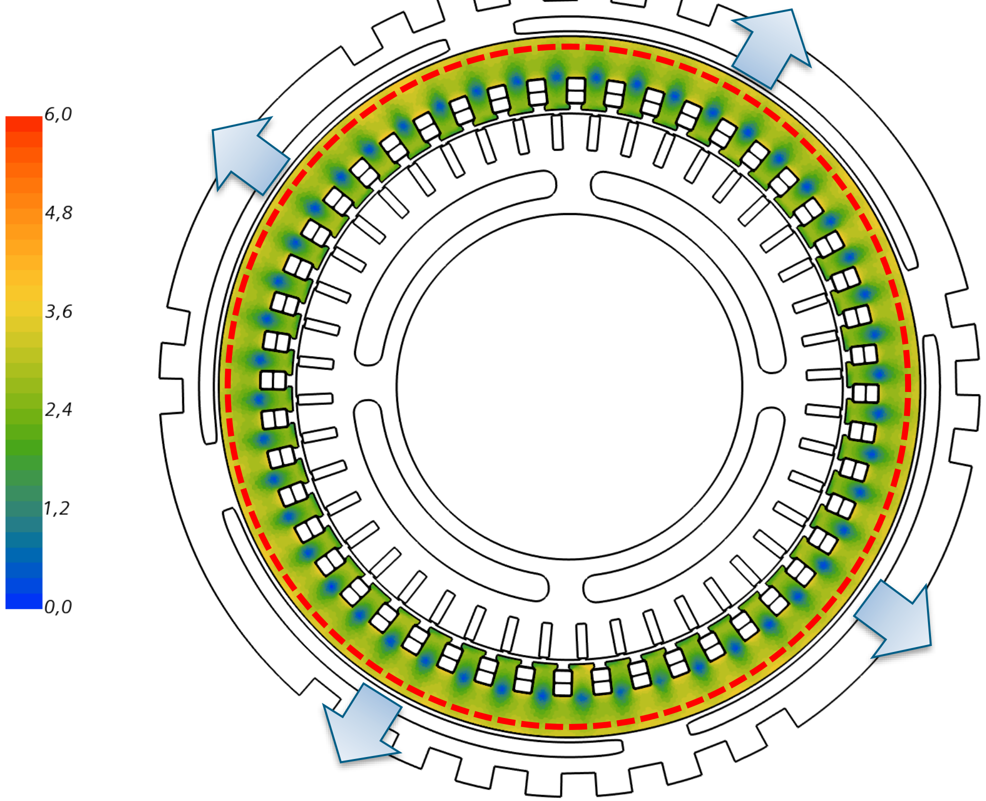
## 2D Mesh

## Losses are transferred to 3D Mesh as Heat Sources

stator eddy current loss [W/kg]




stator hysteresis loss [W/kg]



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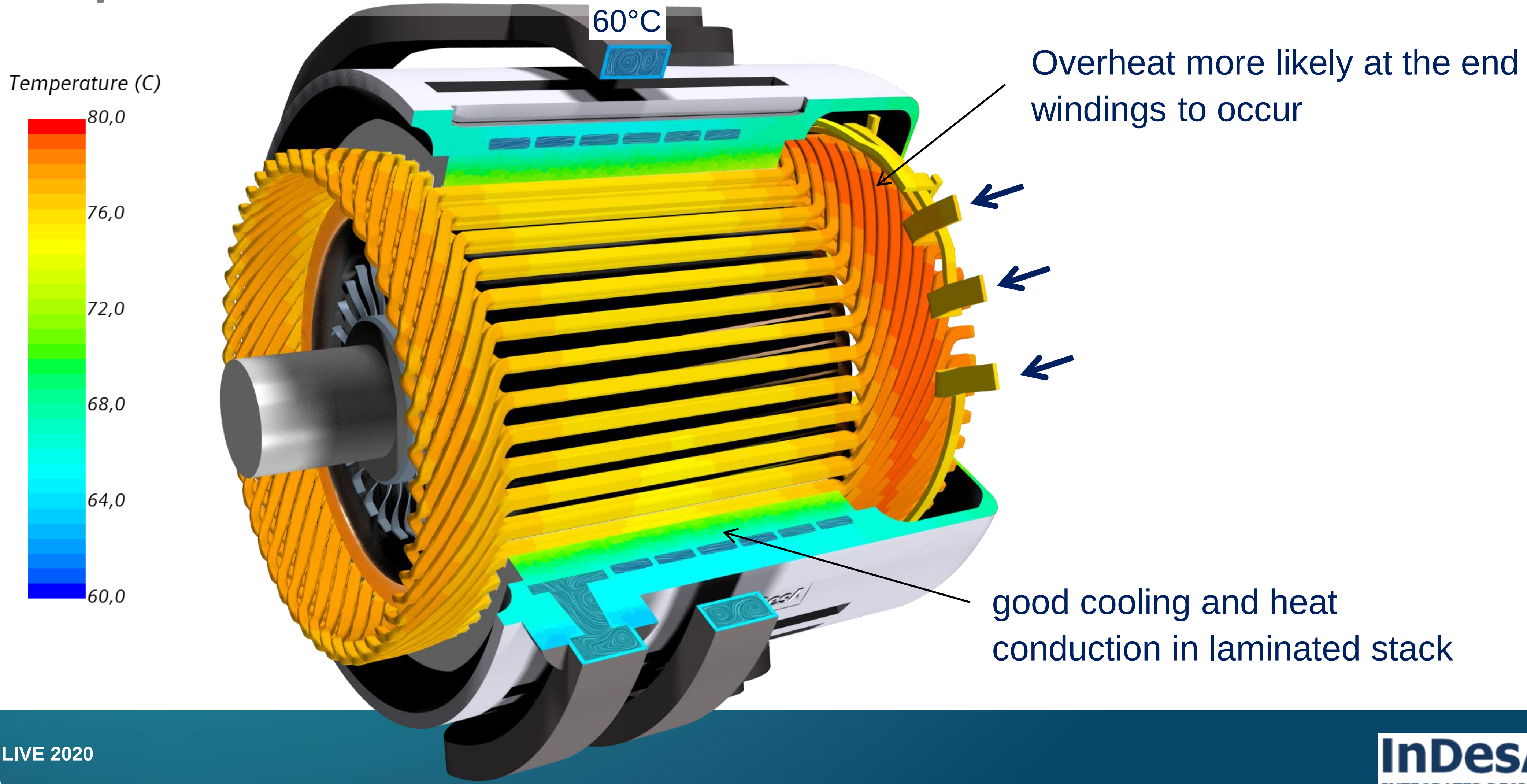
# Thermal Simulation for Steady State Operating Point

## Temperatures



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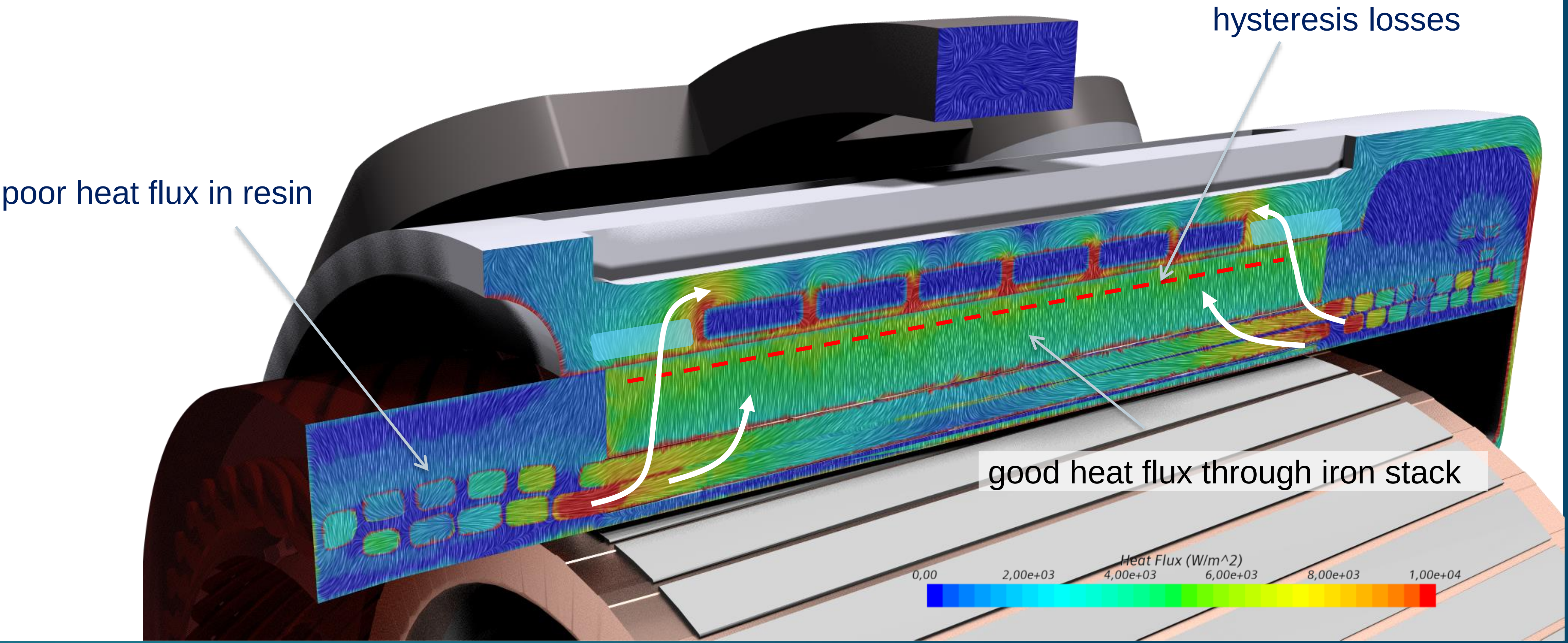
## Thermal Simulation for Steady State Operating Point

### Heat Flux



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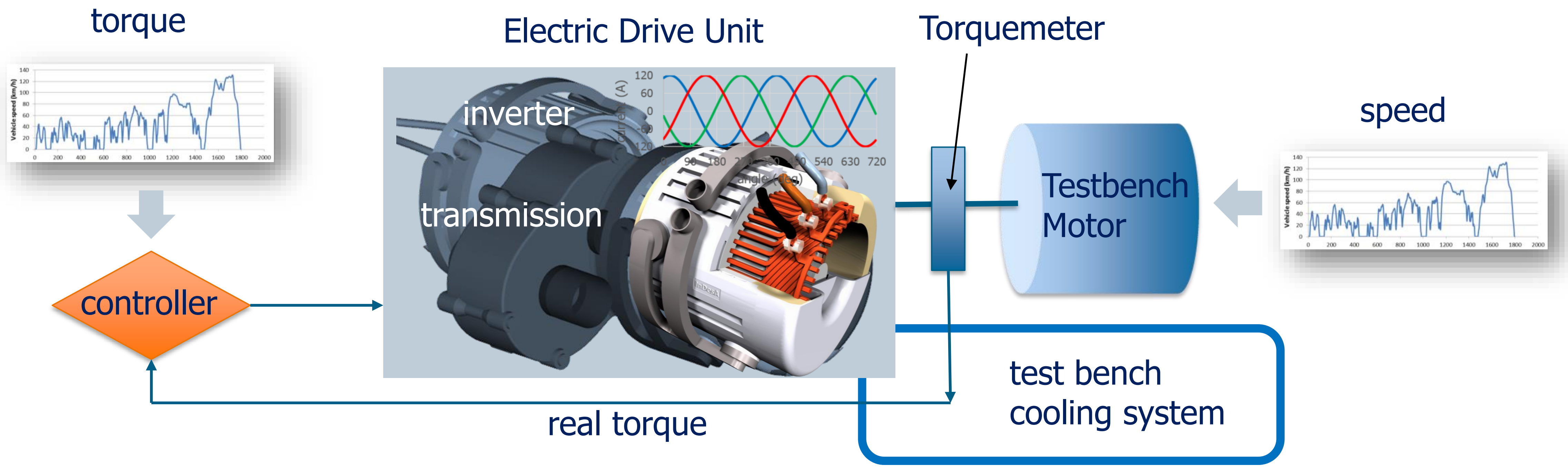
**Towards a Digital Twin …** the digital twin must behave like its real counterpart.

## Set-up of a Digital Twin for a Thermal Test Bench







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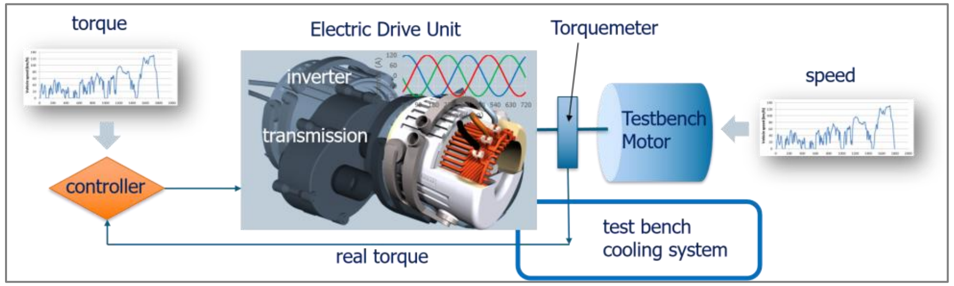
## The Digital Test Bench




Next steps to complete the model:

1. Extension of Star-CCM+ model towards electric drive unit
2. Connection of control functionality from real test bench
3. Calibration of digital twin with results from the real test bench with regard to temperature sensors.

## Benefits

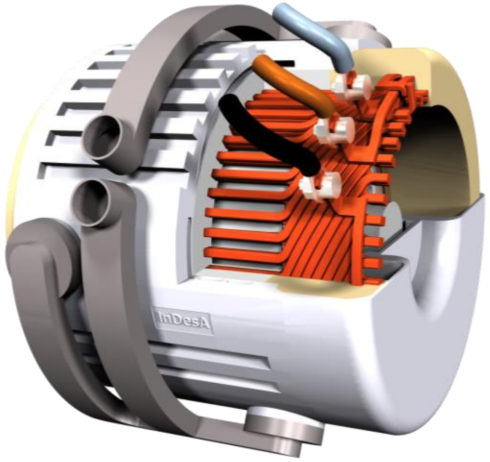
Digital test bench to be used

- to **extent test bench capacity by** running the full test program in a combination of the real and digital test bench.
- to **advance testing** to more realistic coolant circuit response with varying flow rate and temperatures

# Towards a Digital Twin of an E-Motor for Thermal and Electromagnetic Analysis

**Special thanks** for your help and advice

- Illa Kaushik, Siemens Industries Software Inc.
- Raphael Freiberger, IGEL AG



## Thank you for your attention!



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