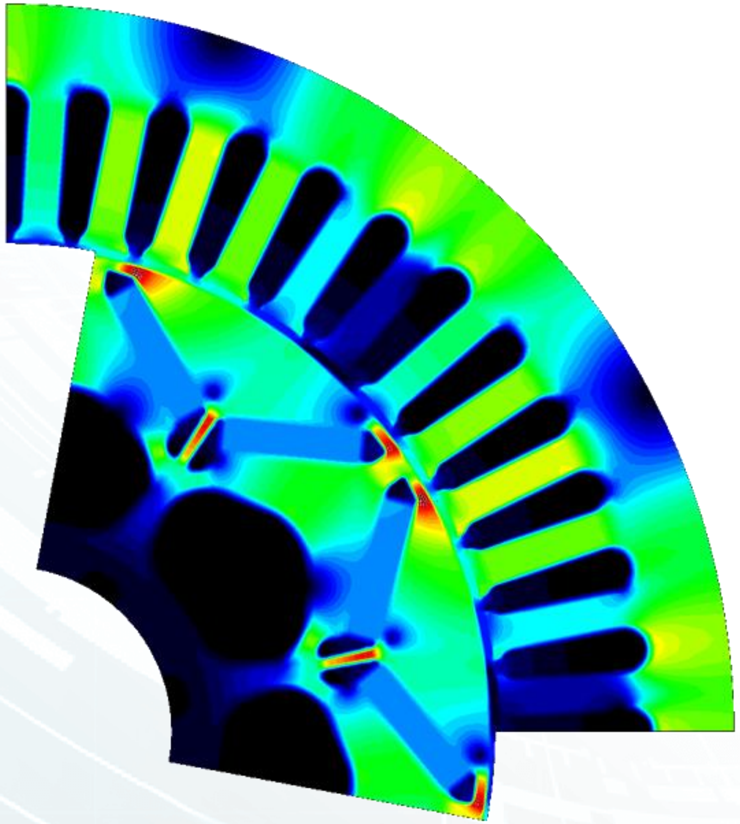
Introduction to AVL eSUITE, e-motor design concept & electro-magnetic analysis

AVL NA Simulation Conference 2019

Content



- Introduction AVL eSUITE
- E-motor Solution Overview
- Concept Designer
- Electromagnetic Analysis
- Parameter Study
- Summary & Outlook

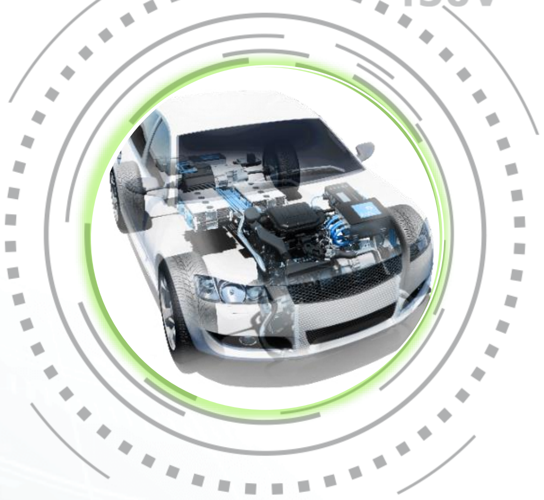
Future Powertrains

Electrified

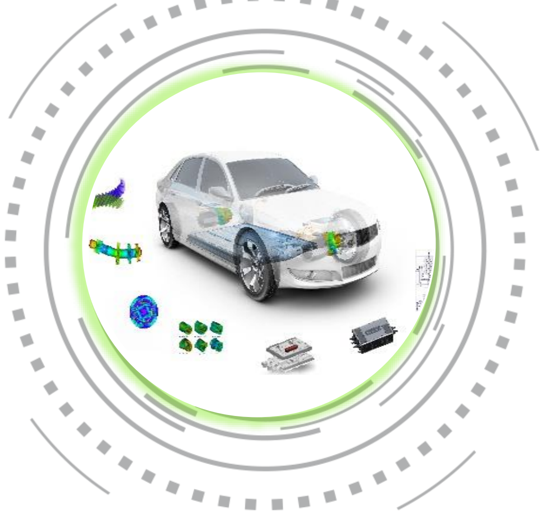
Fully Electric

(M)HEV 48V

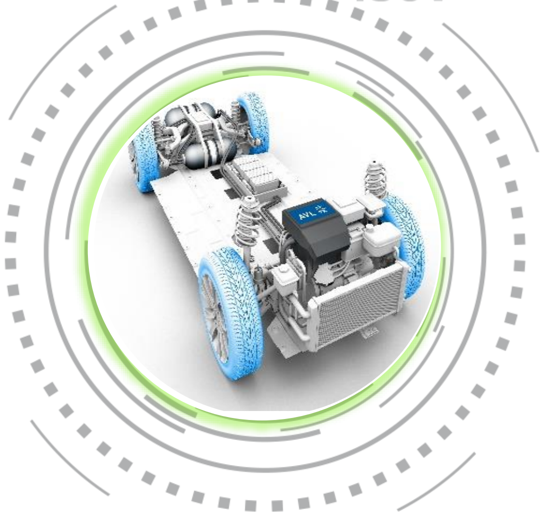
PHEV 450V



BEV 450V/900V



FCEV 450V

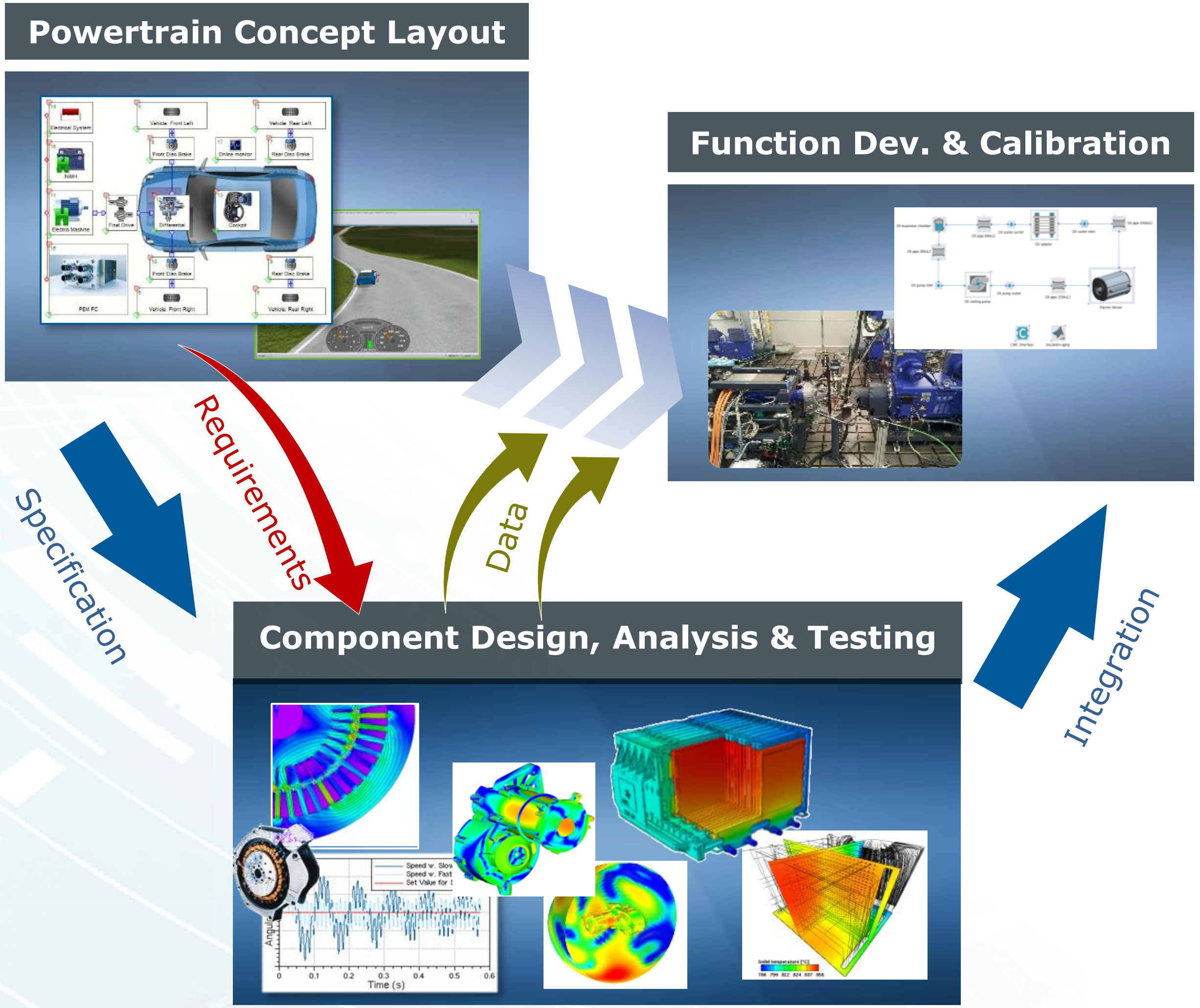


Fossil Fuel

Electric Energy

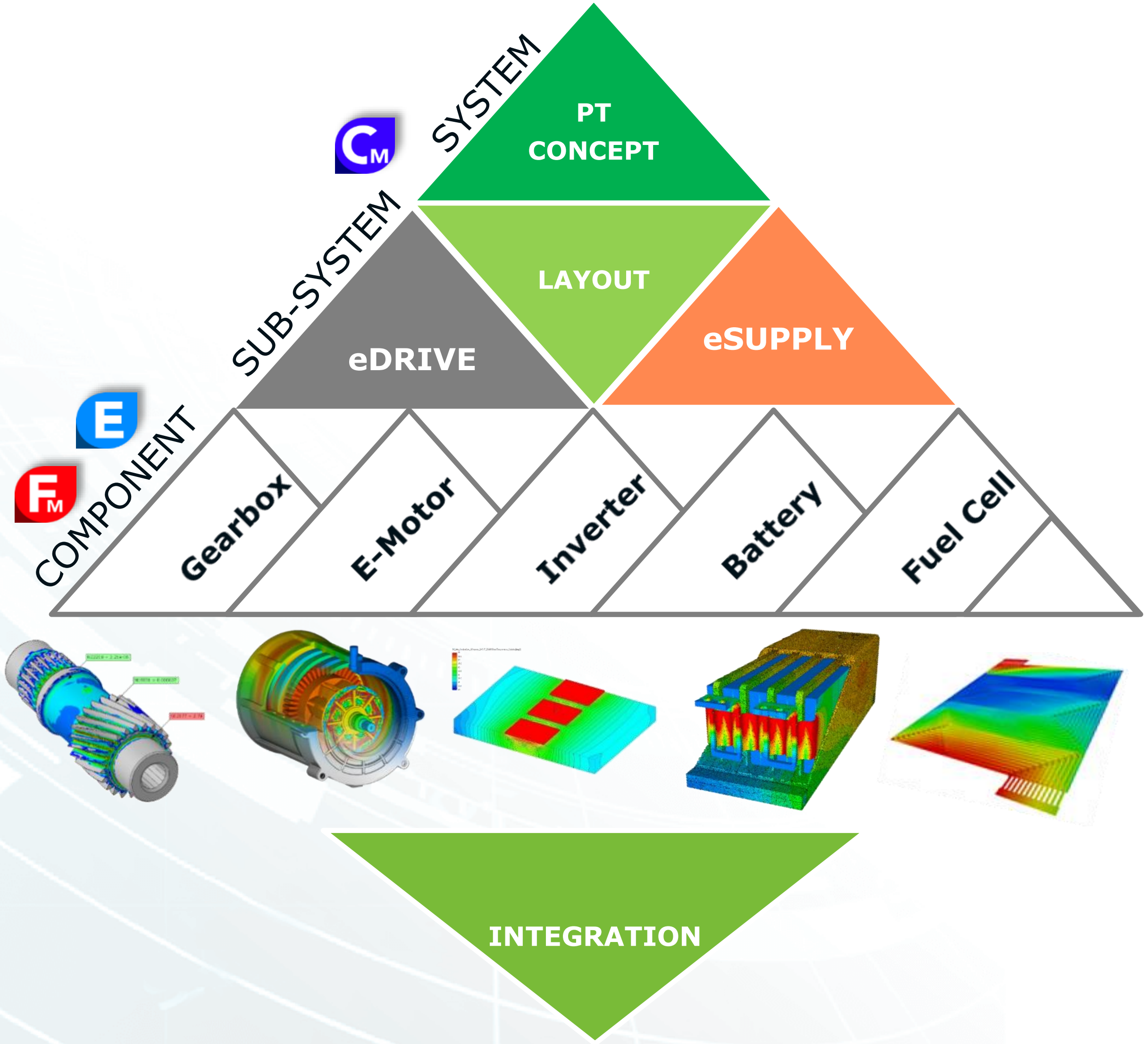
Hydrogen

Electrification Development Process



- Vertical integration from system to component level (concept, system layout, detailed 3D analysis)
- Horizontal integration from specification (office) till testing and calibration (TB, HiL)
- Seamless simulation model evolution over the whole development process

Powertrain Electrification supported by AVL eSUITE™



System and Sub-System Simulation (cooling circuit, electric network, mechanical driveline) based on **AVL CRUISE™ M**

Component Analysis based on **AVL EXCITE™** and **AVL FIRE™ M**

AVL Solution Structure

AST Solution Services
- Process integration
- Customization

AST Simulation Solution — **eSUITE**
- Application tailored
- Task & Workflow oriented
- Eng. Knowhow embedded

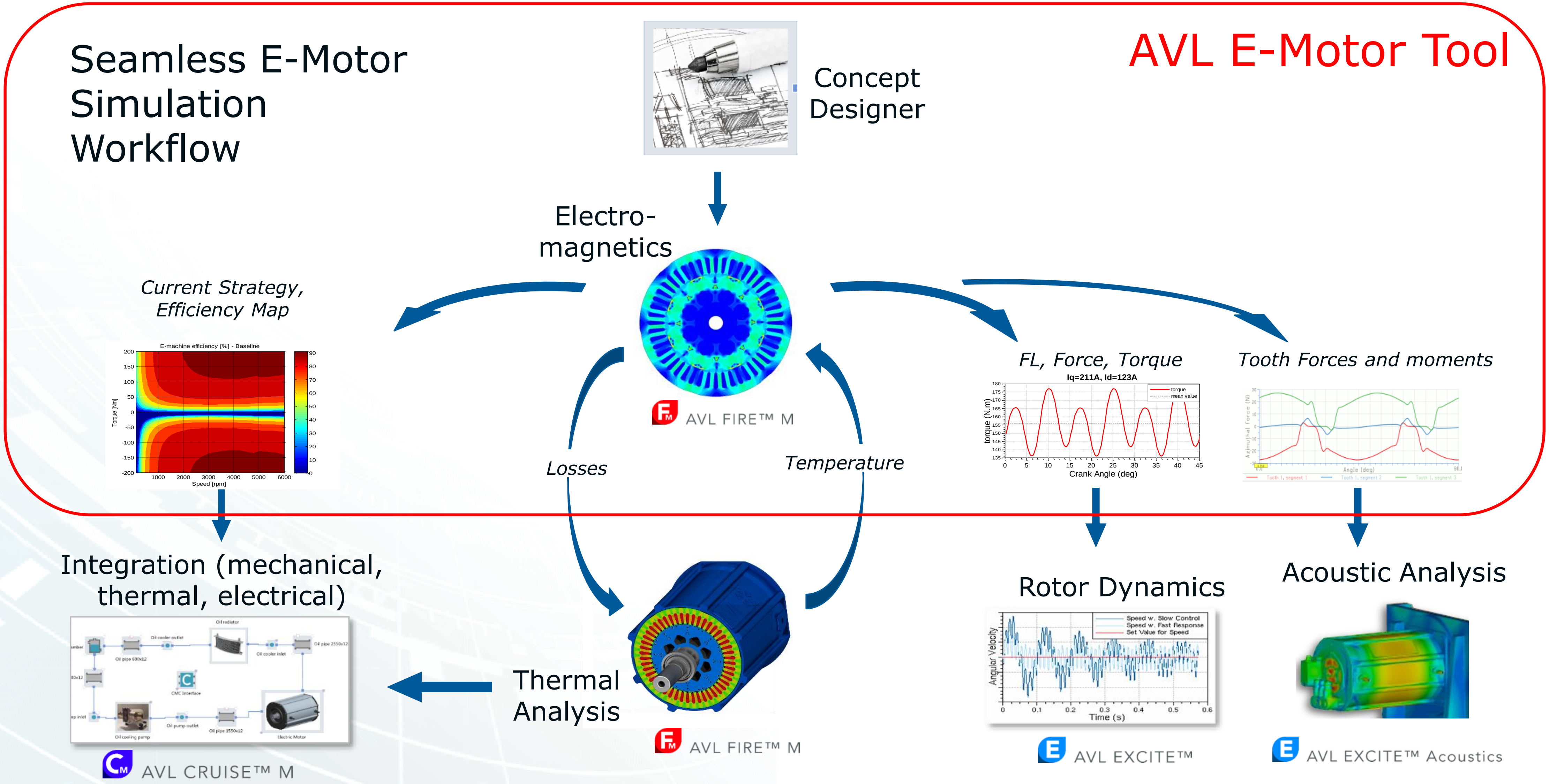
AVL Simulation Products
- General Purpose
- Flexible
- Seamless Scalable

AVL Simulation Platform
- Standardized
- Open
- Intuitive

4 Level Concept

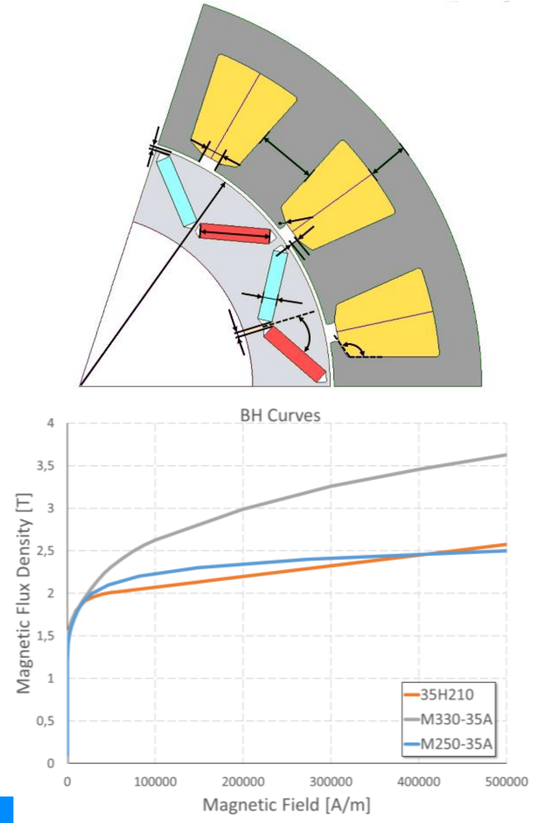
- AVL Software Platform: Simulation Desktop (SDT) acts as the platform
- AVL Software Products offers the simulation capabilities
- AVL Software Solutions: Application tailored solution focusing on engineering tasks
- AVL Services: Customer specific process integration and software customization

AVL Workflow for E-Motor Simulation



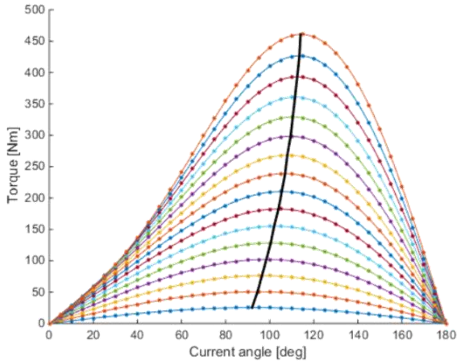
Performance Tasks

Basic Layout



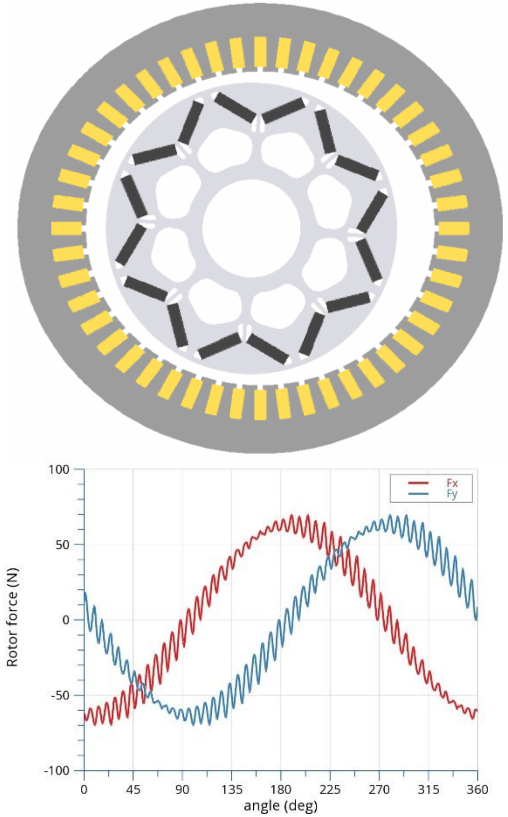
Maps & Strategies

Inverter-driven E-Motor are current controlled



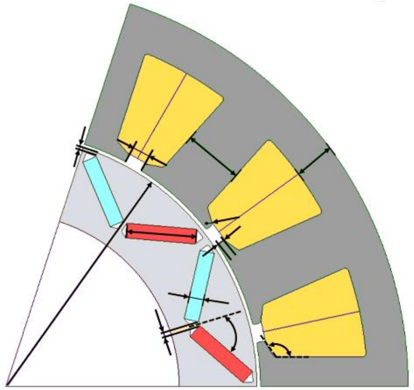
MTPA sets the current tables by maximizing the torque

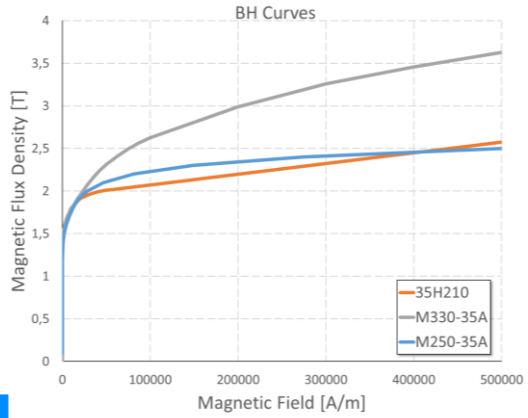
Sensitivities



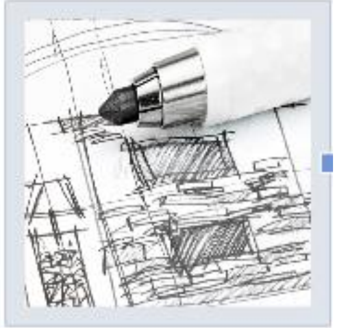
Performance Workflow

Basic Layout



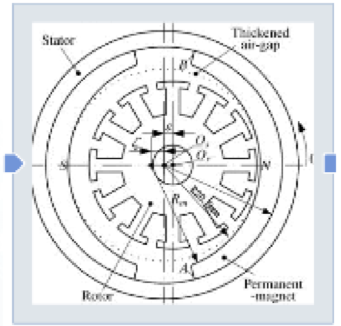


E-Motor Tool (EMT), Purpose and Goals



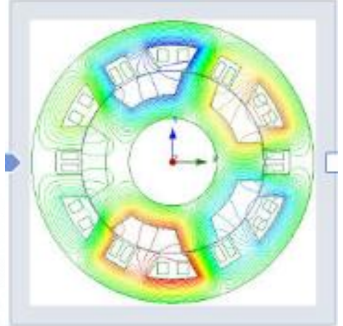
EM Concept Designer

CAD data of existing EM design



EM Geometry Assistant

Existing Mesh

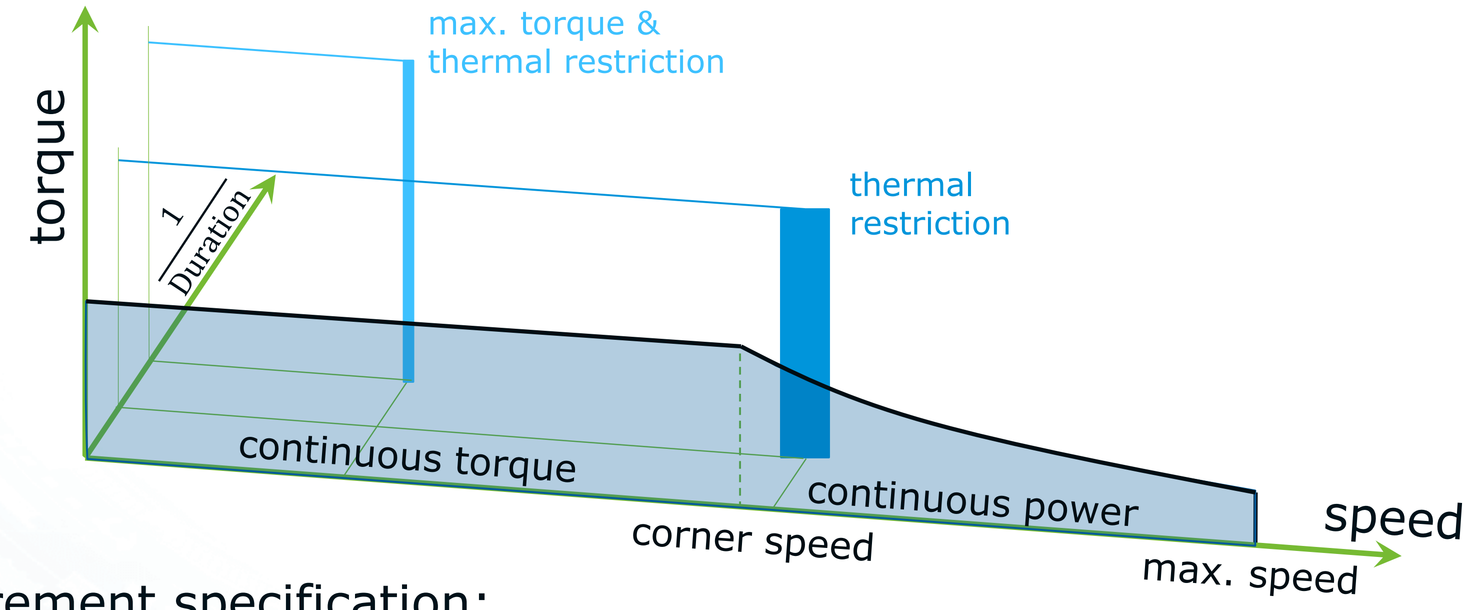


EM Model Assistant

AVL EMT provides **assistance for** the **E-motor**

- **Concept definition** in the early development stage based on target settings
- Electro-magnetic analysis for EM **performance and efficiency**
- EM current **control strategy** definition
- **Power loss density** evaluation for thermal analysis
- **Load determination** for rotor dynamic and NVH analysis

Input for EM tool



Requirement specification:

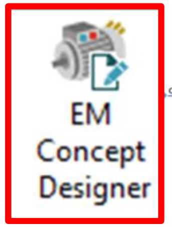
- Minimum **supply voltage** and
- **Continuous torque and power**, max. speed and optional
- One or more cycles defined by **overload** power at speed for duration and base load for recovery time

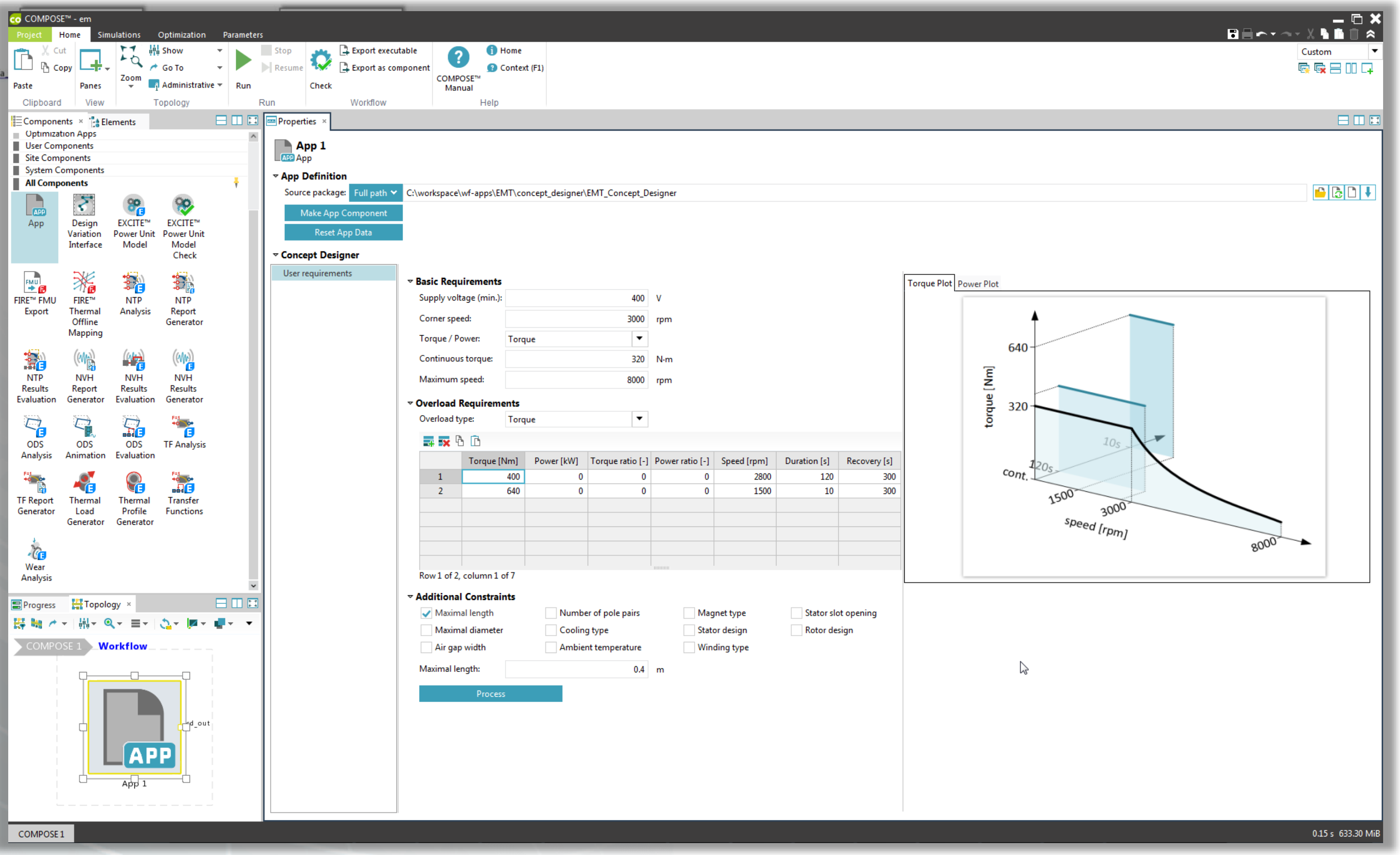
Example:

- 300V
- 100Nm continuous, 50kW continuous, 10.000rpm max. speed
- 100kW at 6.000rpm for 10s and 10kW for 130s
- 25kW at 2.000rpm for 2s and 1kW for 300s

AVL EMT, Concept Designer

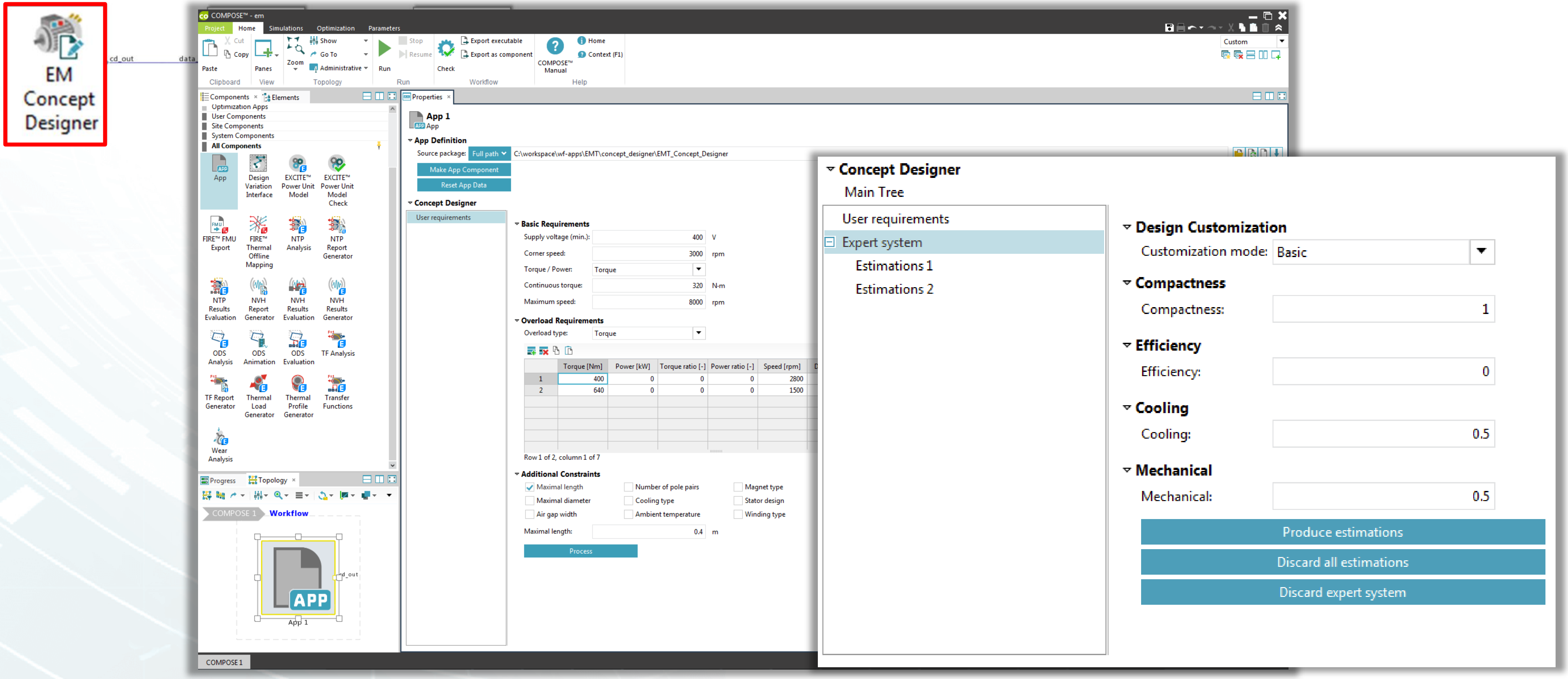
COMPOSE 1 > Workflow



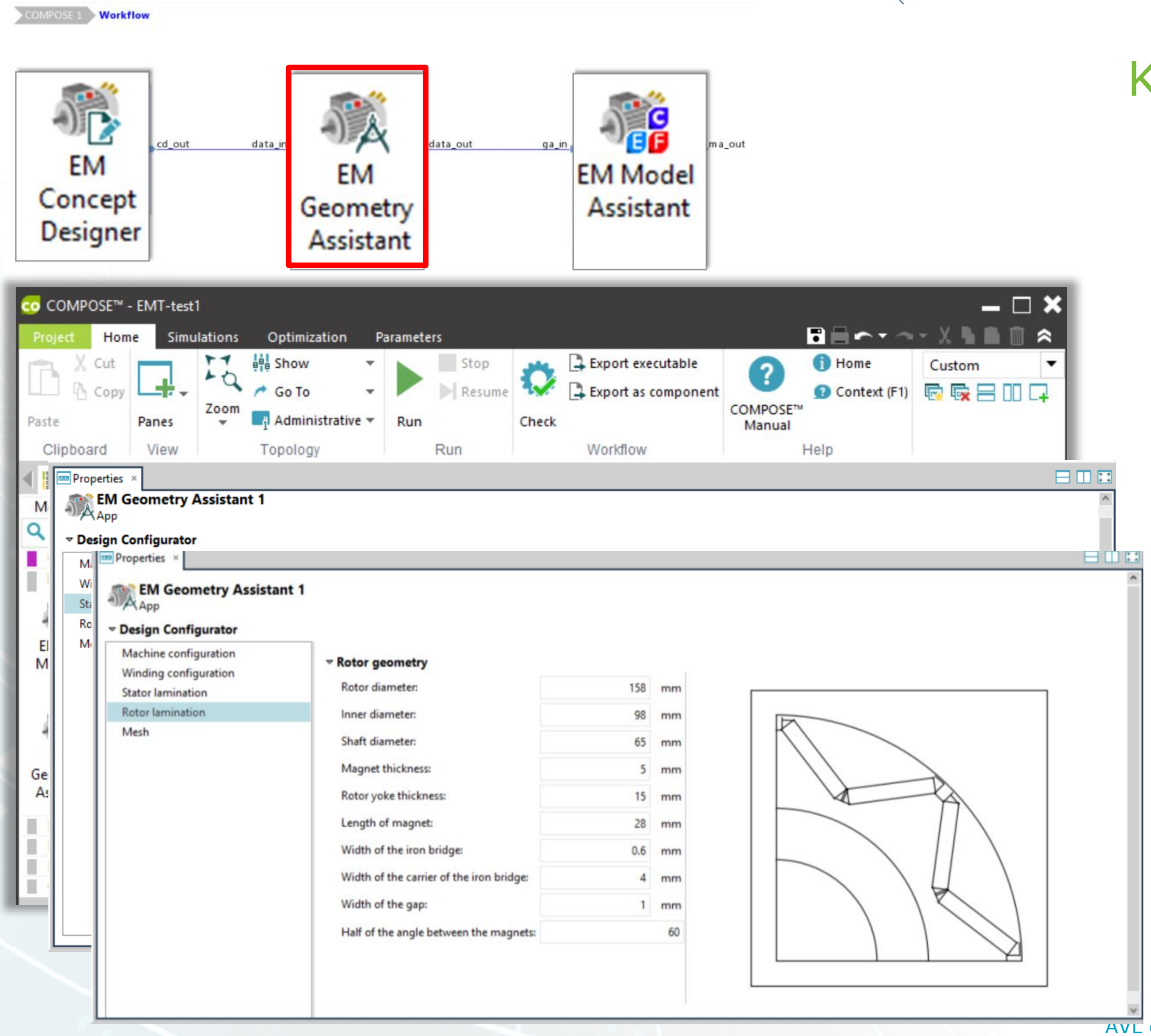


AVL EMT, Concept Designer

COMPOSE 1 Workflow



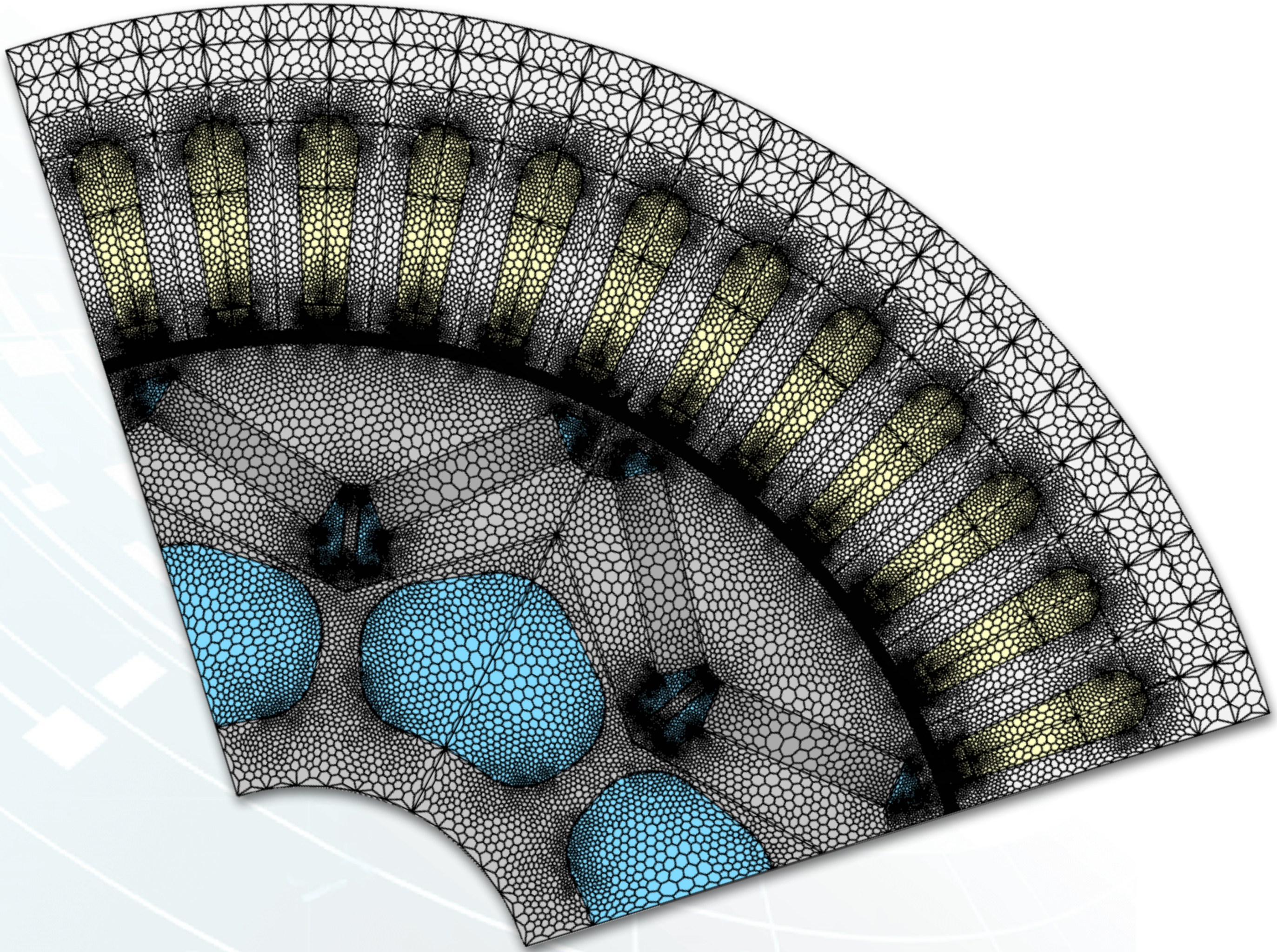
AVL EMT, Geometry Assistent



Key features:

- Concept Designer **automatically provide input** data **for** the **E-motor configuration** and parametrization
- Parameters **can be adjusted** according to specific preferences
- E-motor **configuration** and parameters **can be** defined **manually**
- Definition or **adjustment** of stator and rotor parameters
- **Dynamic sketched** show geometry based in input data

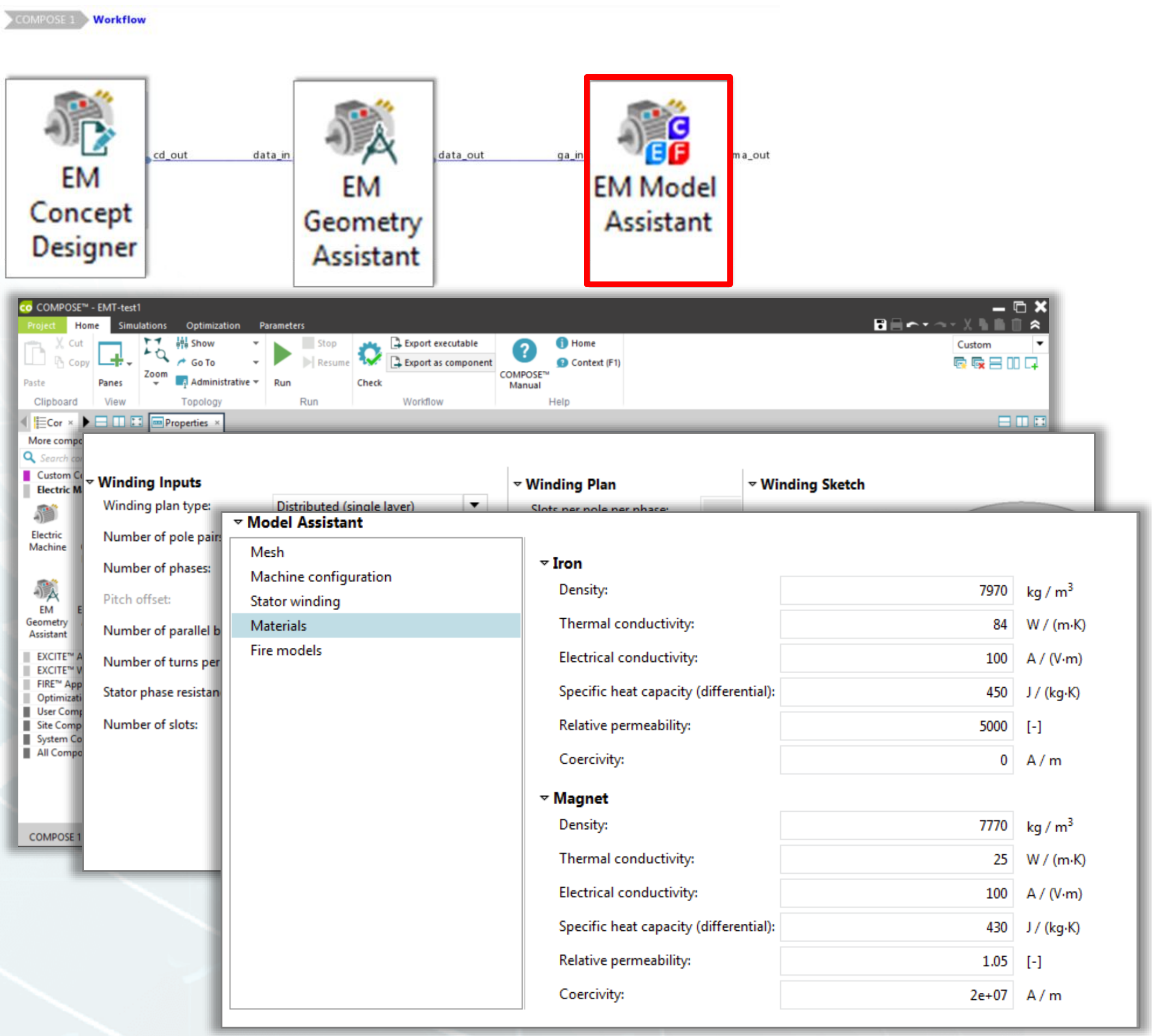
AVL EMT, Mesh preparation



Key features:

- **Automatic** generated high quality mesh (no user interaction required)
- **Polyhedral elements** with block topology in air gap
- AVL EMT dynamically generates topologies (**no CAD required**)
- **CAD import** to analyze complex geometries
- Sliding rotor for full flexibility in angular step control (**arbitrary rotor** position possible)
- Support of rotor and magnet eccentricity (**only one topology** required)

AVL EMT, Model Assistent



Key features:

- Model Assistant **allows** the **import of** an existing **mesh**
- **Setup** of EM winding plan, material properties and operating range (mech & electr.)
- **Create** FIRE M model **and launch simulations** for electro-magnetics

Model assistant

Map-based model

- Used for later system analyis (CRUISE M)
- Evaluation of power losses and efficiency

Fundamental wave model (linear and saturated)

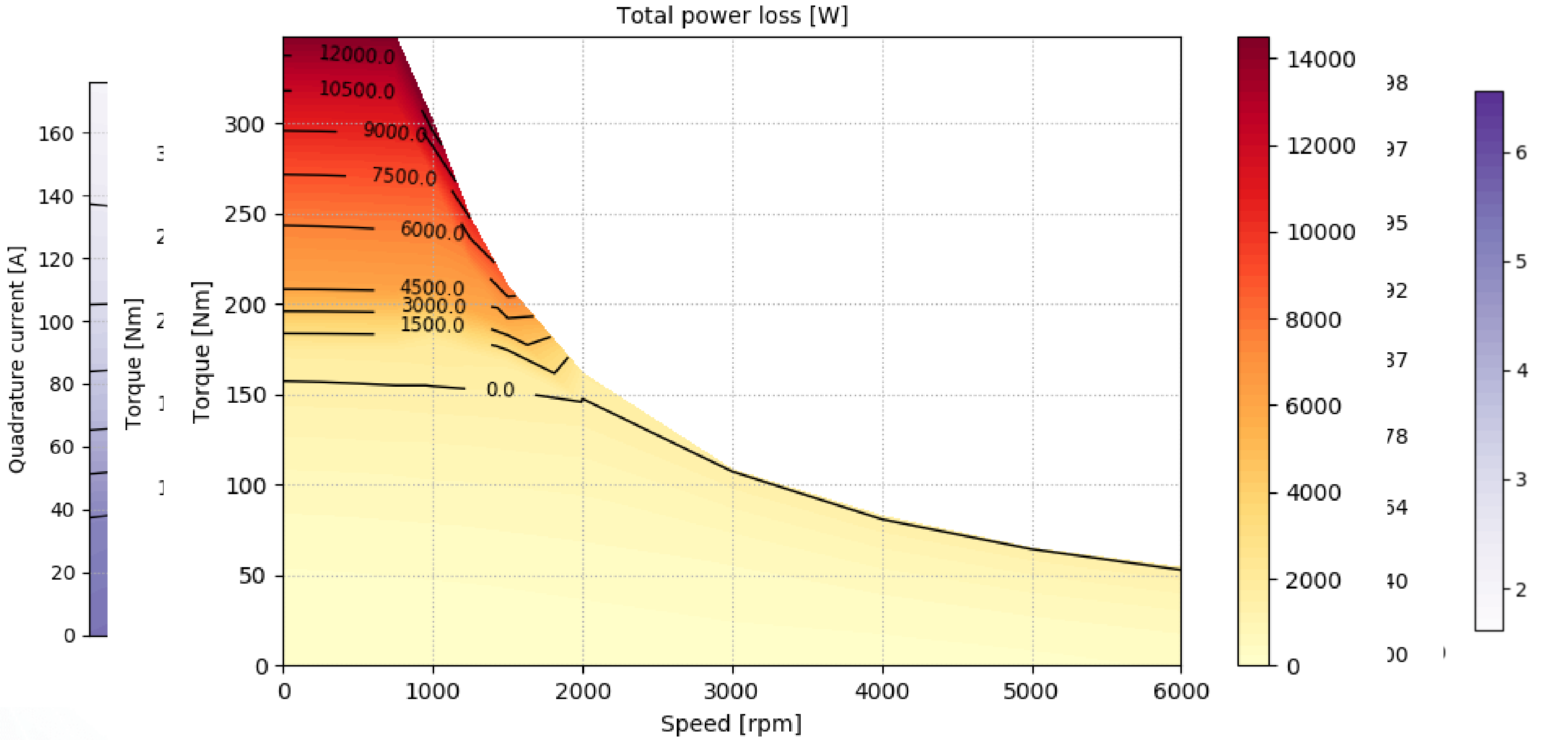
- Sinusoidal distribution of magnetic field in the air gap
- Calulation of inductances
- Main flux linkage
- Torque vs Speed caracteristics

MFC-model

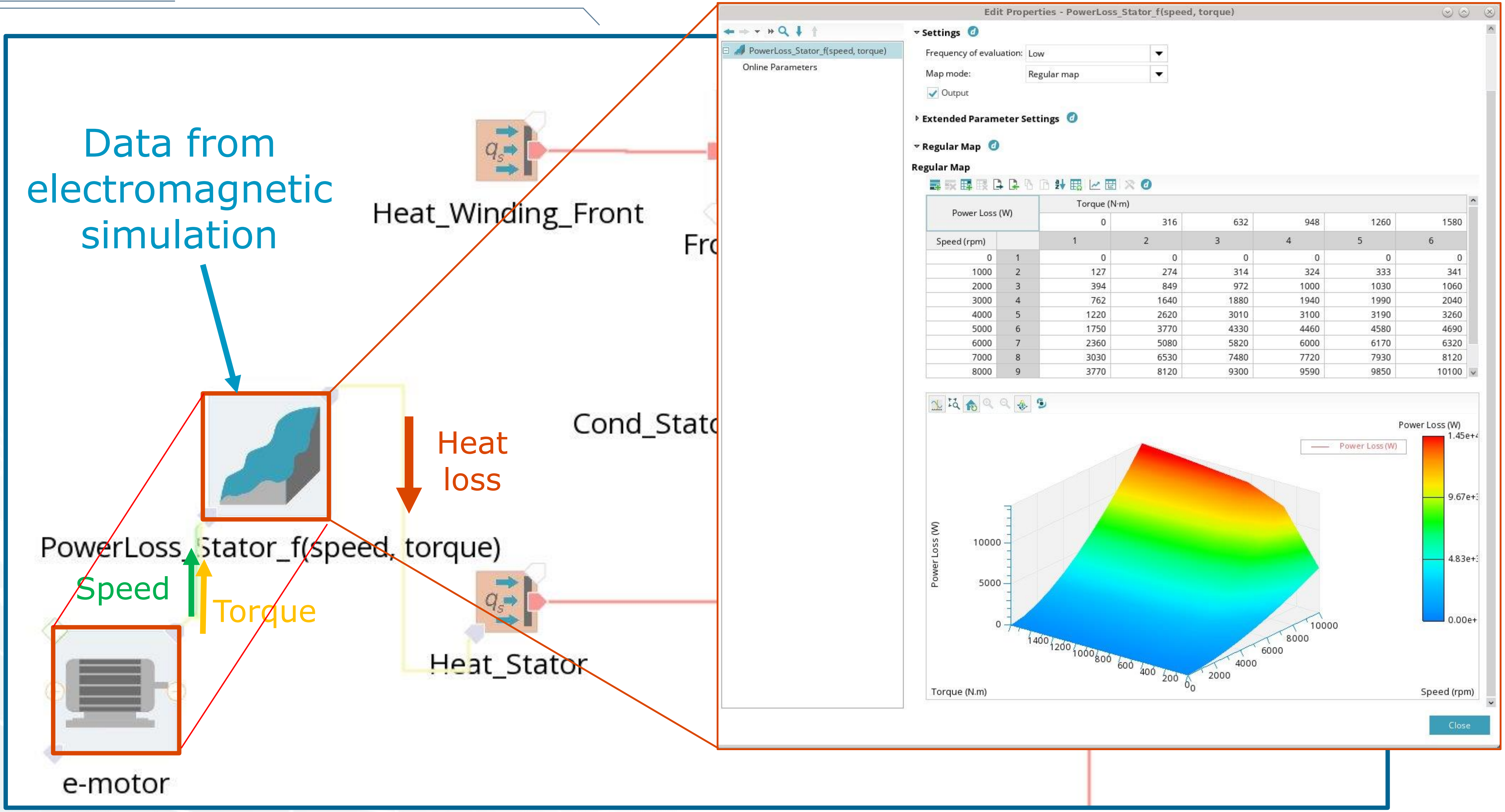
- Used for NVH (Excite)
- Includes harmonics due to slotting
- Torque rippe and forces for NVH

Results

- Inductances (direct and quadrature)
- Main flux linkage
- Torque vs speed characteristic
- Efficiency
- Power loss



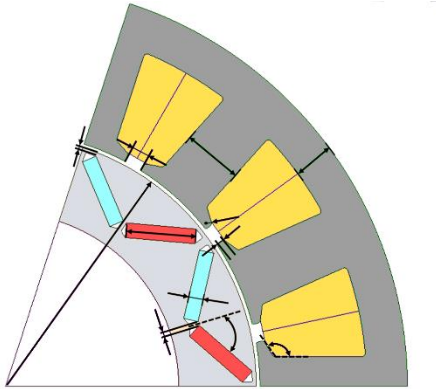
Loss map

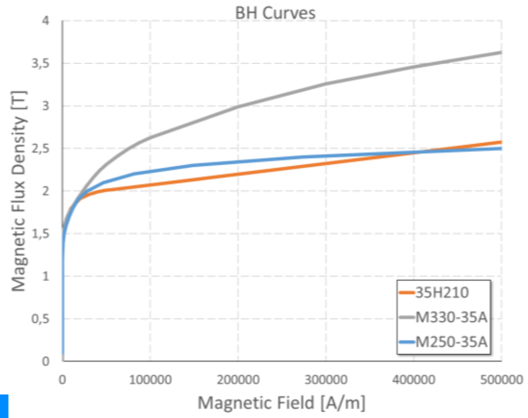


Power Loss (W)		Torque (N·m) 0	316	632	948	1260	1580
Speed (rpm)		1	2	3	4	5	6
0	1	0	0	0	0	0	0
1000	2	127	274	314	324	333	341
2000	3	394	849	972	1000	1030	1060
3000	4	762	1640	1880	1940	1990	2040
4000	5	1220	2620	3010	3100	3190	3260
5000	6	1750	3770	4330	4460	4580	4690
6000	7	2360	5080	5820	6000	6170	6320
7000	8	3030	6530	7480	7720	7930	8120
8000	9	3770	8120	9300	9590	9850	10100

Performance Workflow

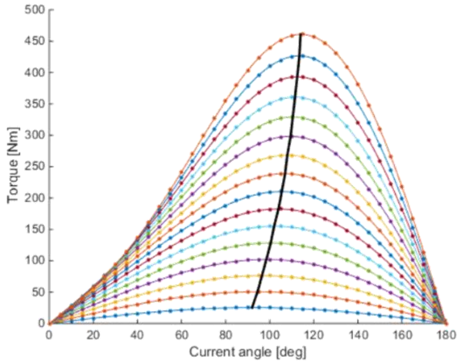
Basic Layout





Maps & Strategies

Inverter-driven E-Motor are current controlled

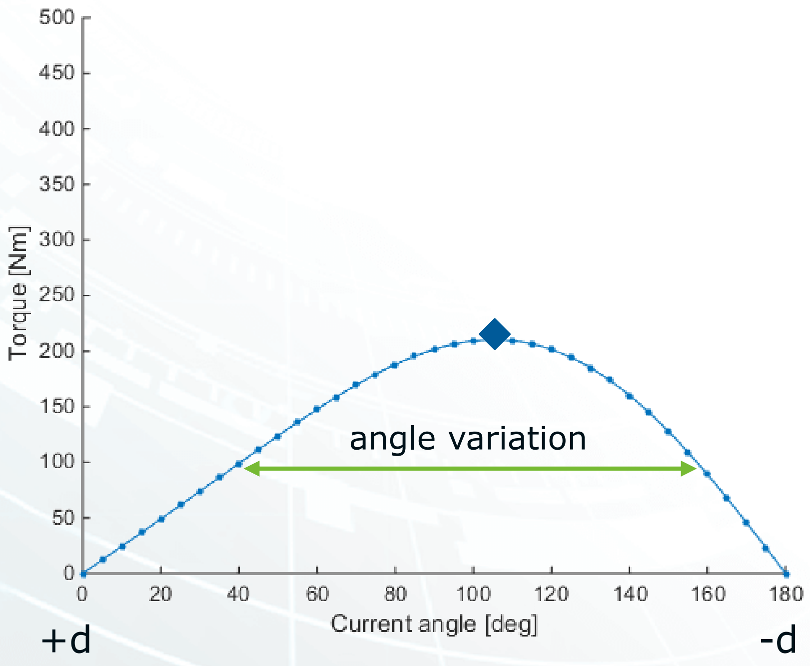


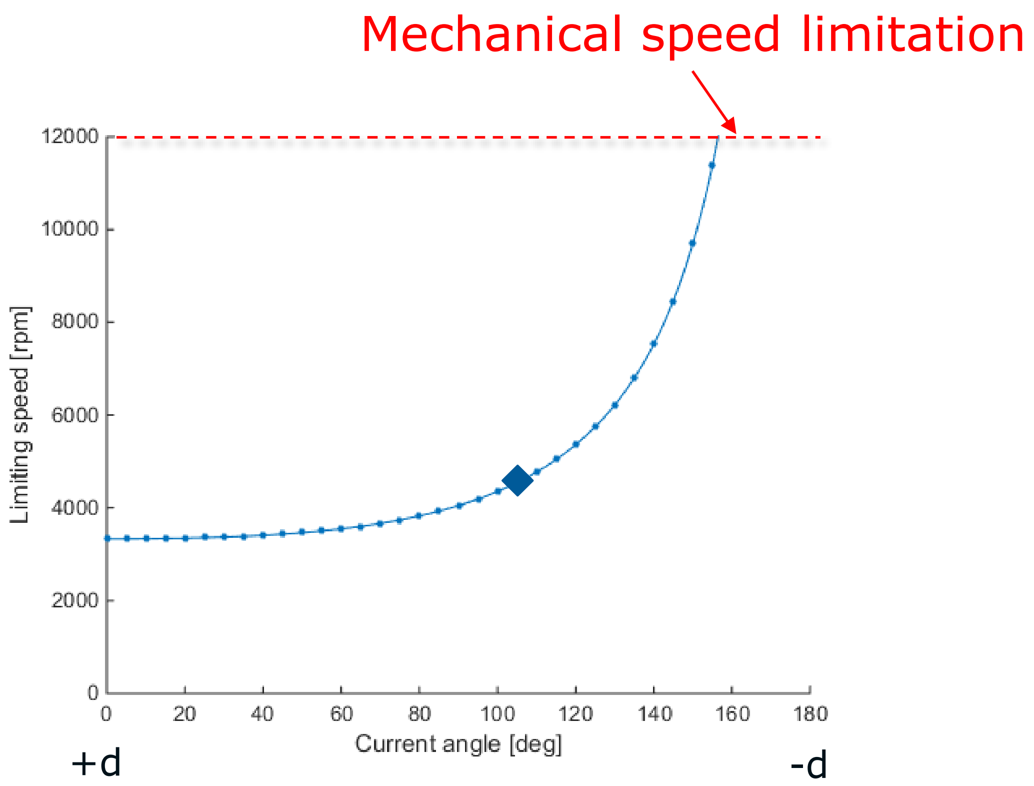
MTPA sets the current tables by maximizing the torque

MTPA – Maximum Torque Per Amperage

Principle of method

- Evaluation of torque and limiting speed (induced voltage < supply voltage)
- Sweep over current angles

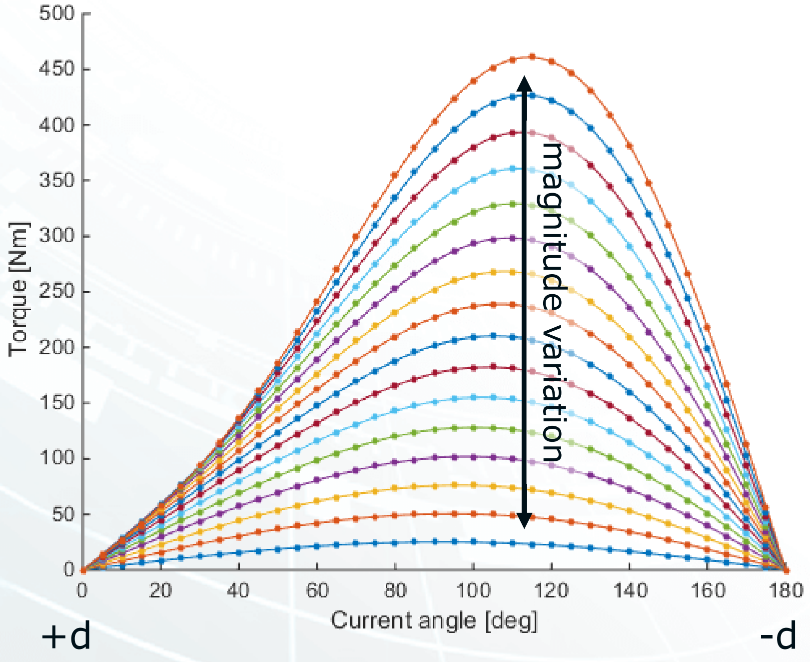


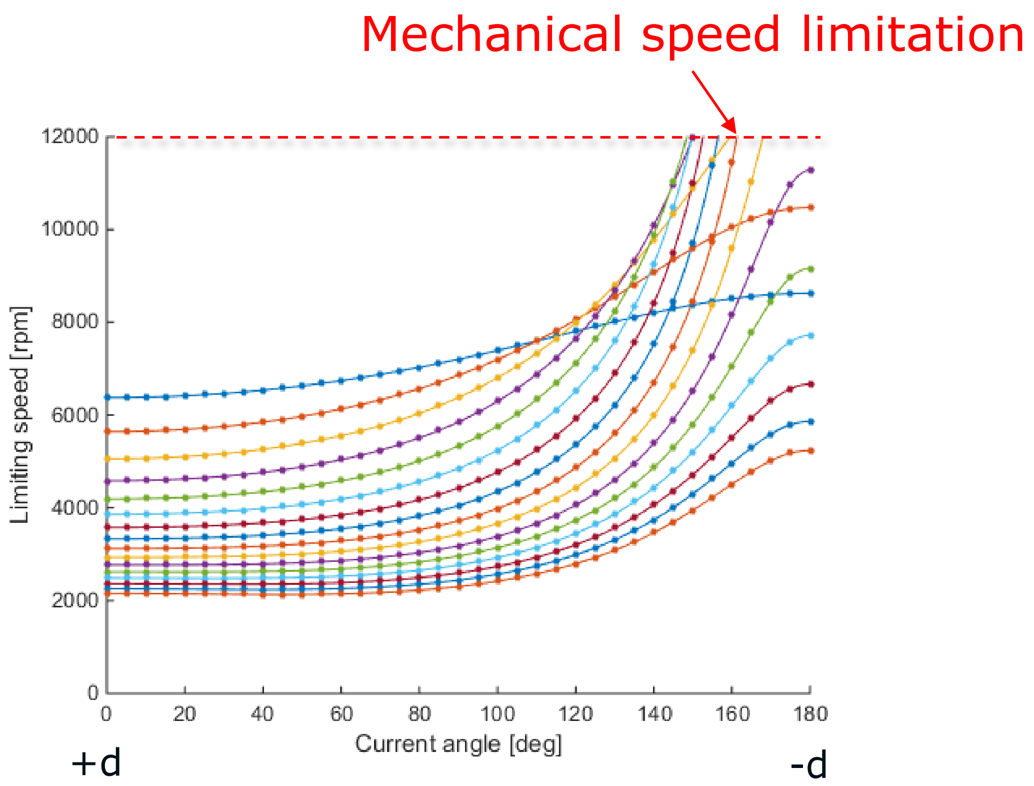


MTPA – Maximum Torque Per Amperage

Principle of method

- Evaluation of torque and limiting speed (induced voltage < supply voltage)
- Sweep over current angles and magnitudes

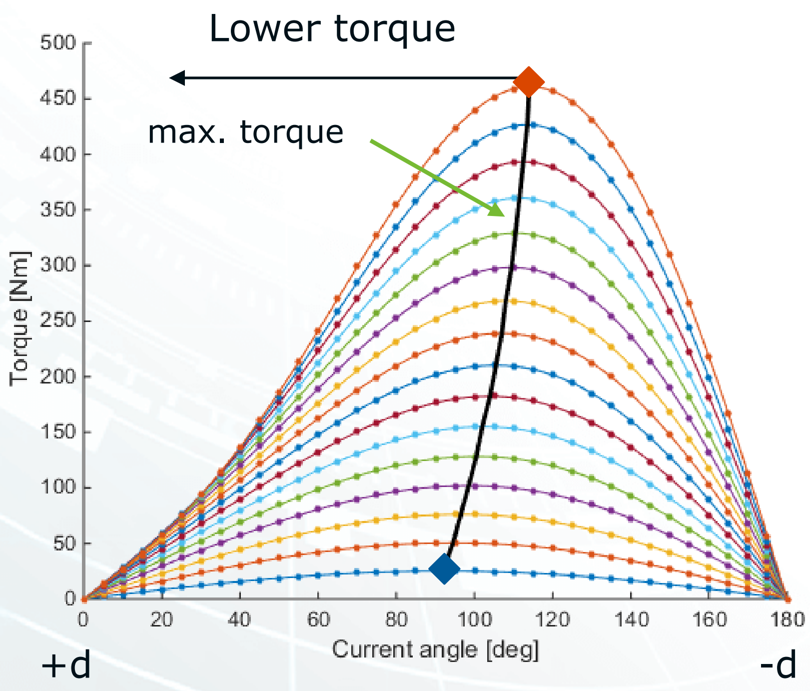


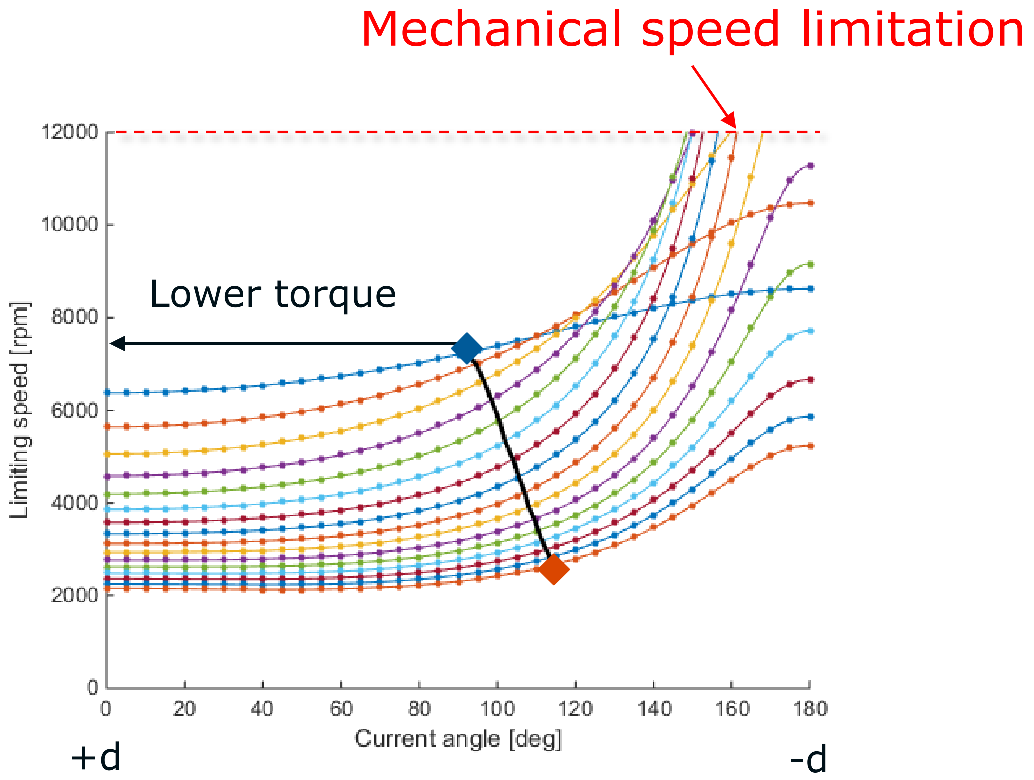


MTPA – Maximum Torque Per Amperage

Principle of method

- Evaluation of torque and limiting speed (induced voltage < supply voltage)
- Sweep over current angles and magnitudes
- Evaluation of maximum torque





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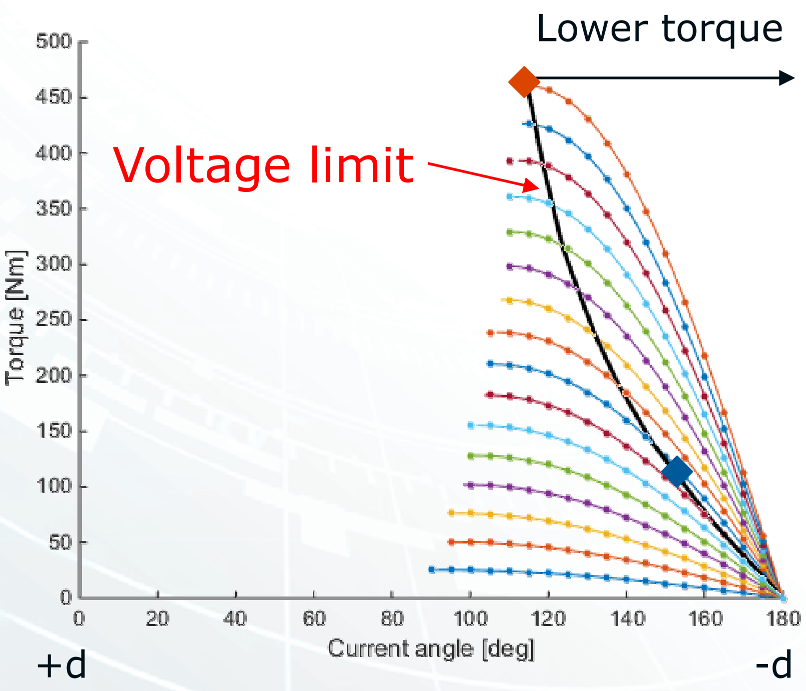
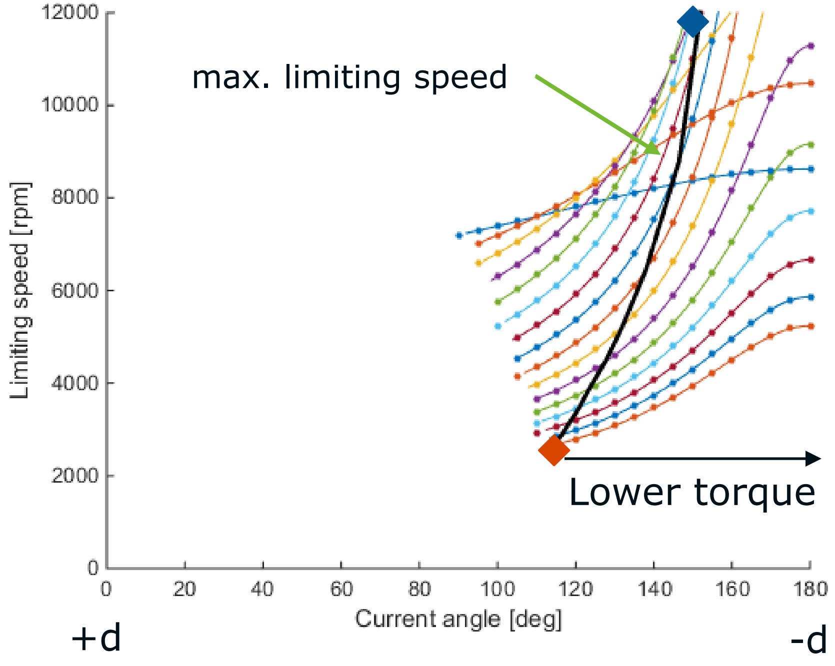
Principle of method

- Evaluation of torque and limiting speed (induced voltage < supply voltage)
- Sweep over current angles and magnitudes
- Evaluation of maximum torque and limiting speed

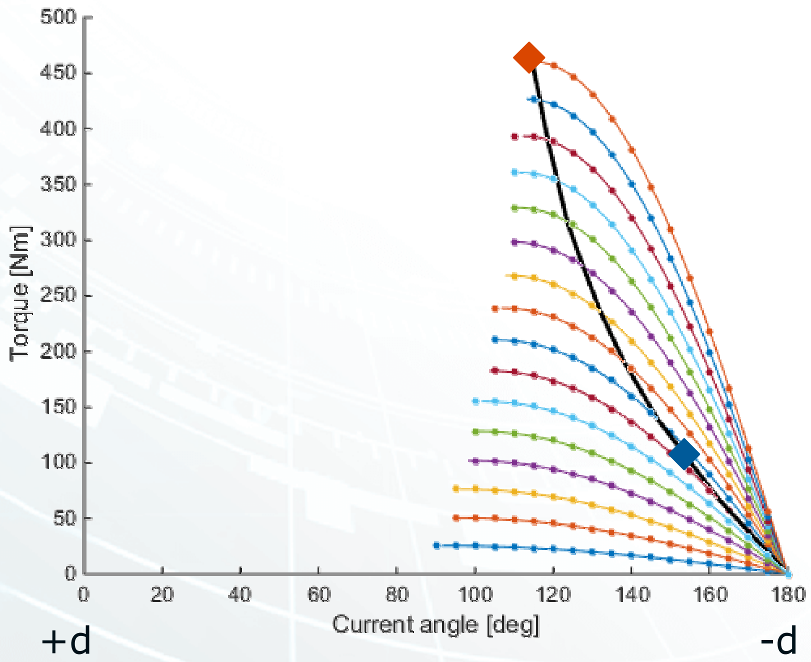


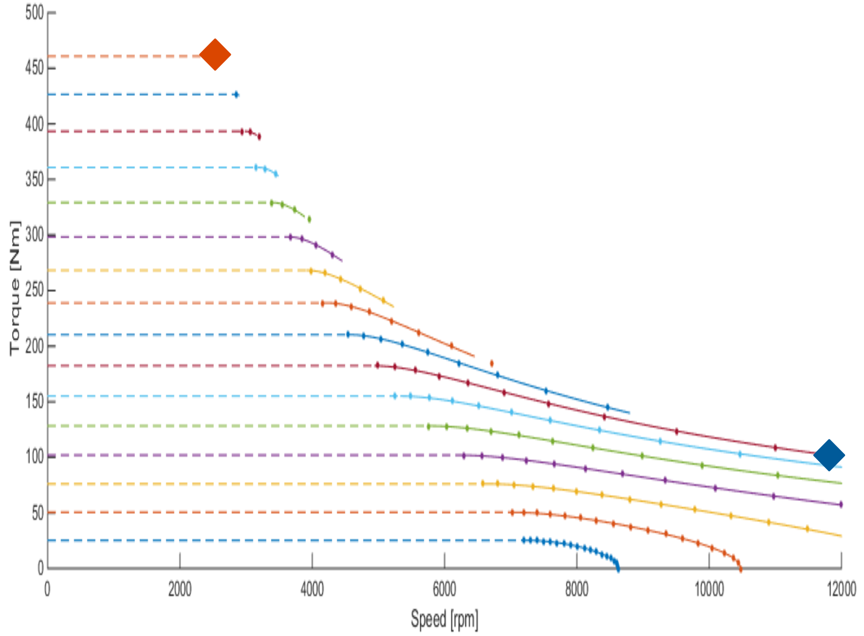


MTPA – Maximum Torque Per Amperage

Principle of method

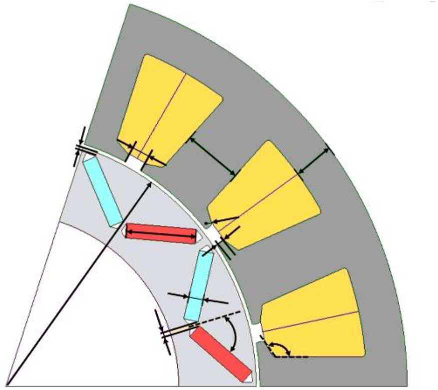
- Evaluation of torque and limiting speed (induced voltage < supply voltage)
- Sweep over current angles and magnitudes
- Evaluation of maximum torque and limiting speed
- Combination of torque and speed vs. current magnitude and angle

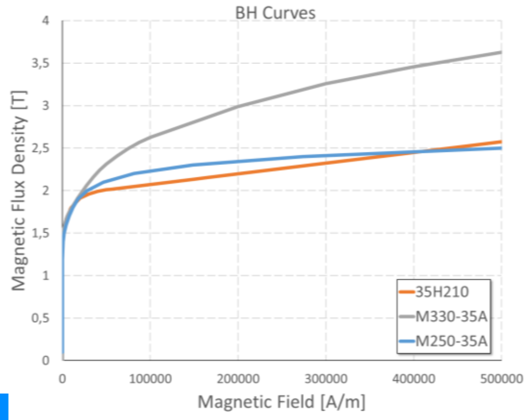




Performance Workflow

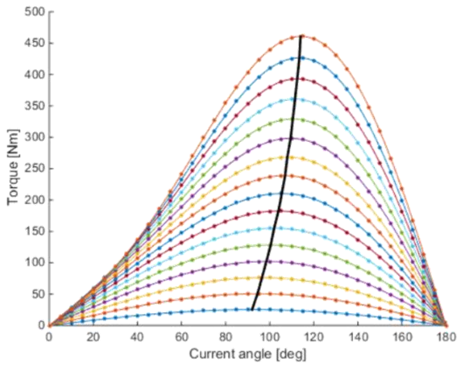
Basic Layout





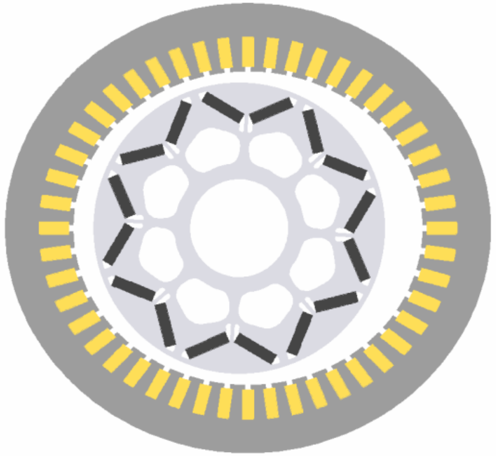
Maps & Strategies

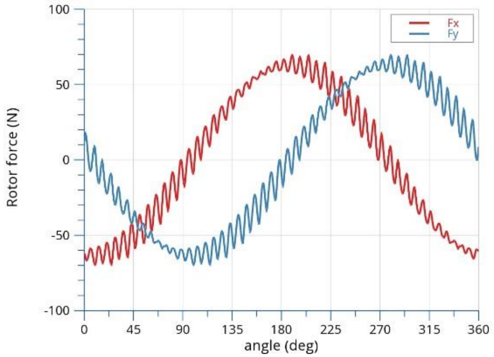
Inverter-driven E-Motor are current controlled



MTPA sets the current tables by maximizing the torque

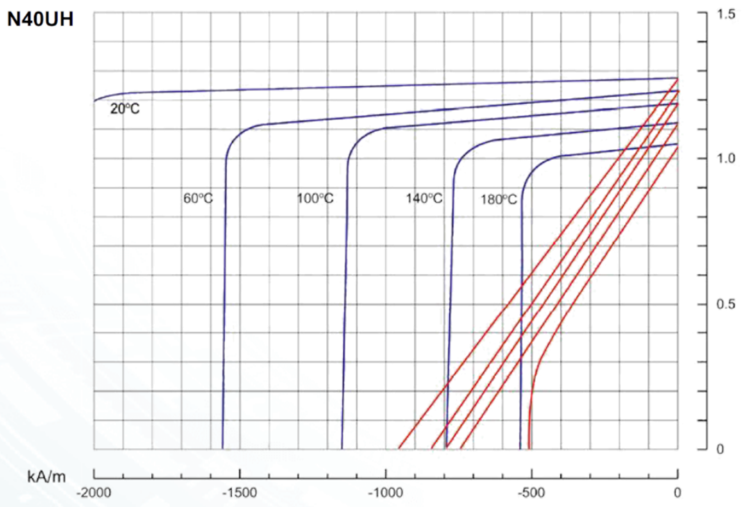
Sensitivities





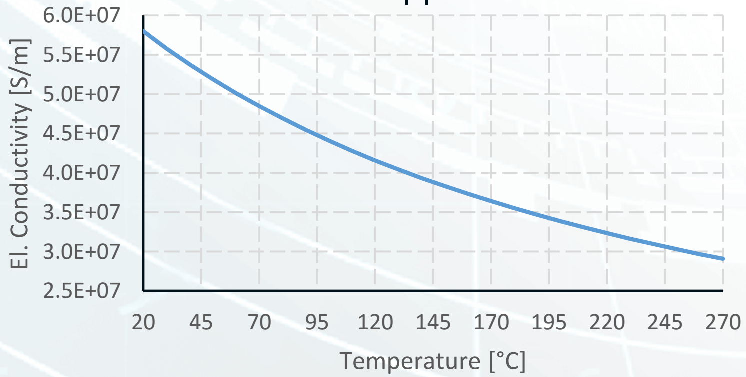
Performance dependency

Magnet



Magnet coercivity at 60°C ~ 840kA/m

Copper



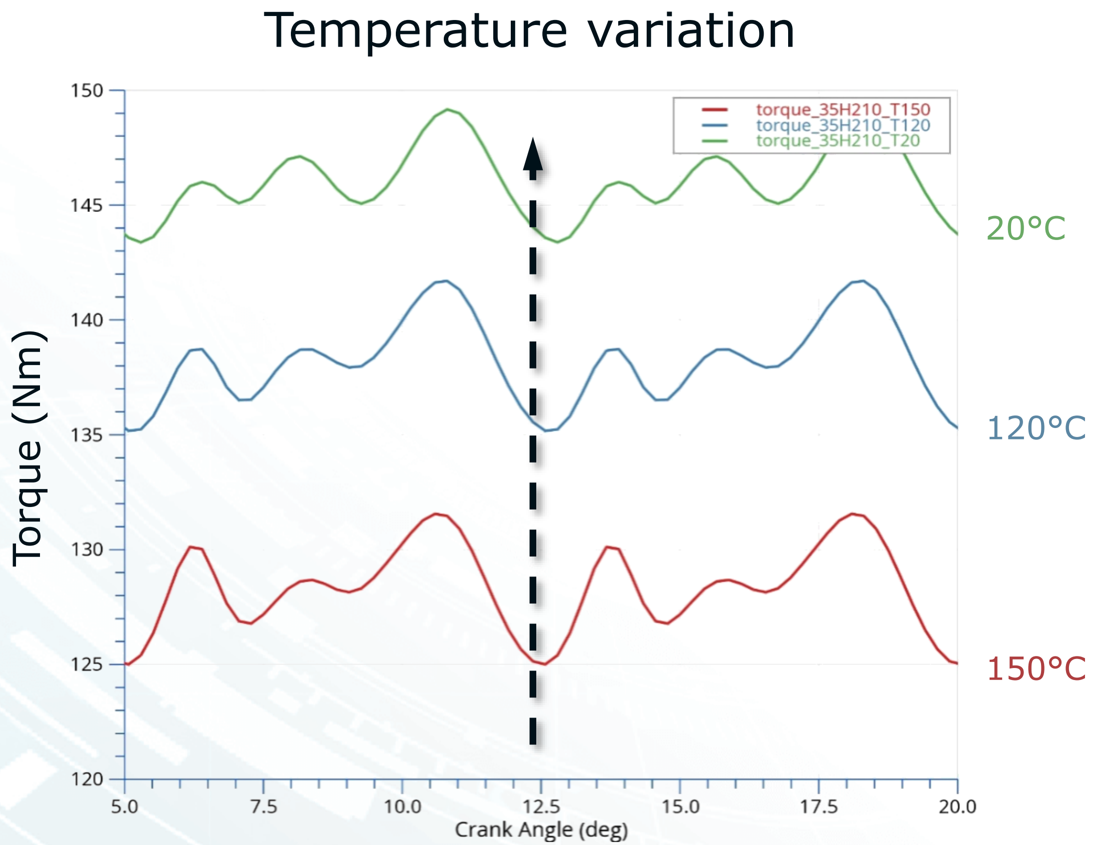
Temperature

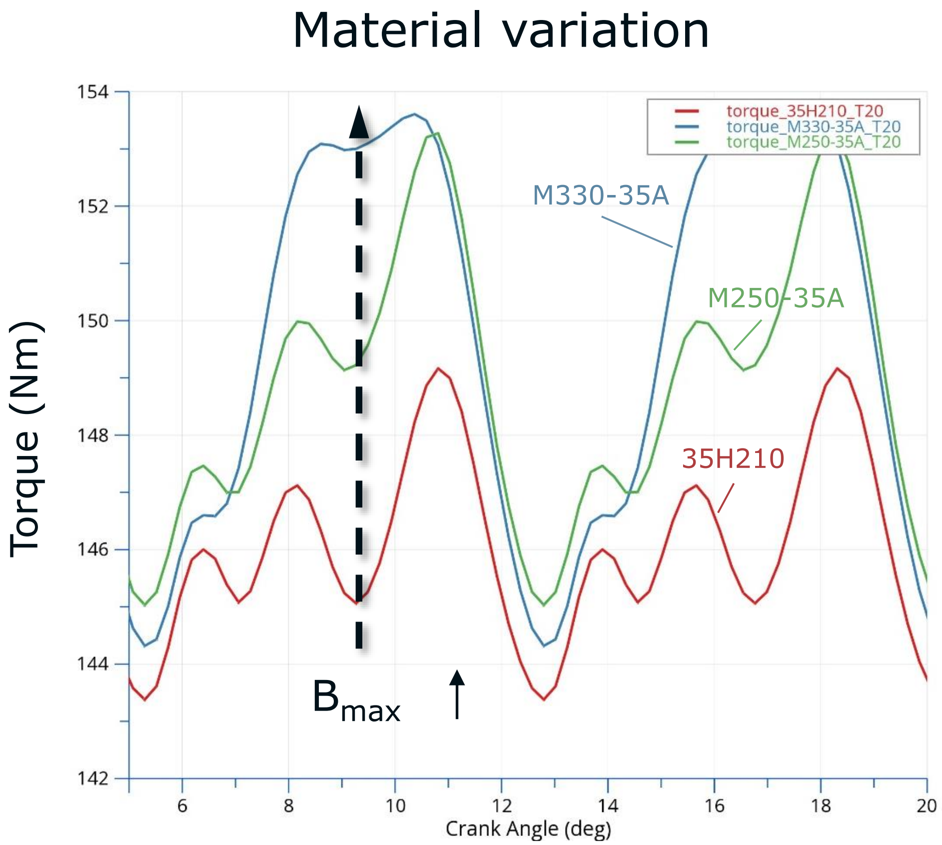
- A higher magnet temperature weakens the magnetic force which also reduces the resulting torque
- A higher copper temperature increases the copper resistivity and consequently increases the copper loss.

Influence on:

- Torque,
- Copper and Magnet losses

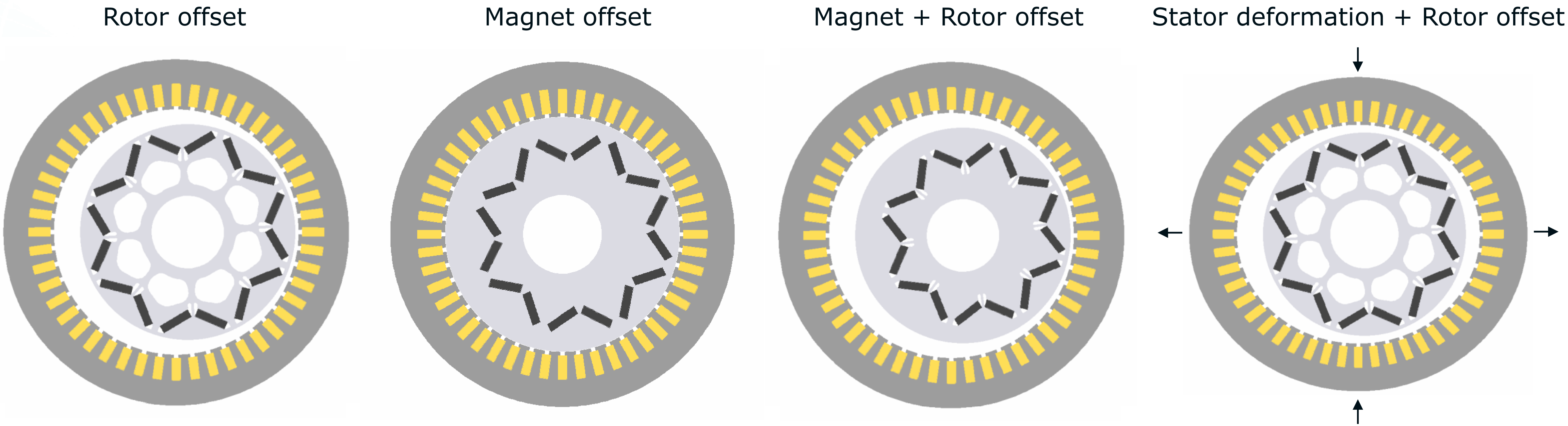
Torque depending on temperature





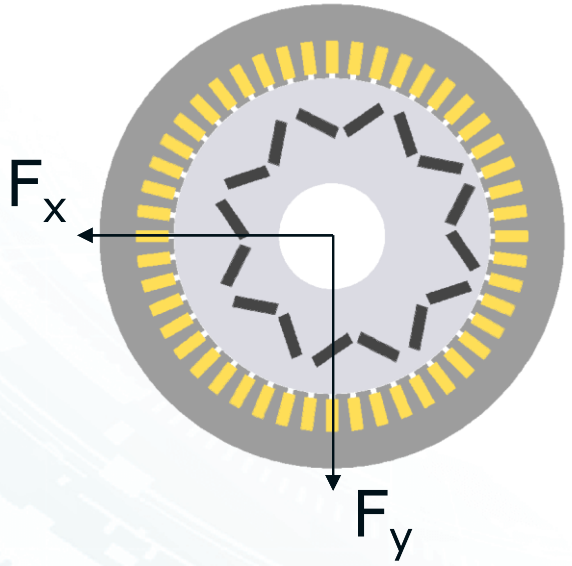
- The mean torque increases with decreasing temperature (stronger magnets).
- With a higher saturation flux density also the mean torque increases. Simultaneously the torque ripple increases .

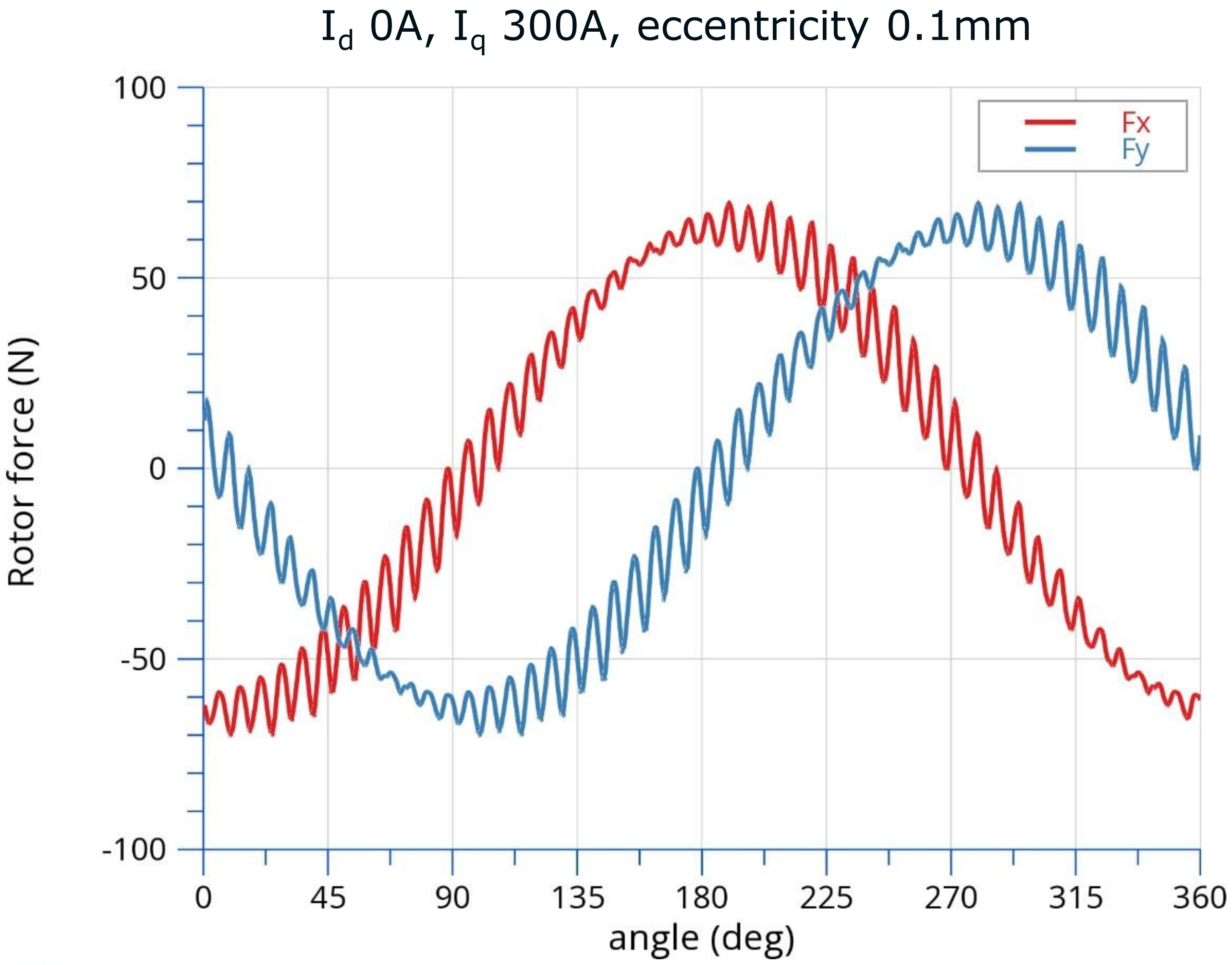
Eccentricity investigations



Altogether over **1100 configurations** (current variation + geometry matrix) are examined and compared. Only one basic geometry is required. The eccentricity and consequent deformation is automatically taken into account by deformation of the base geometry

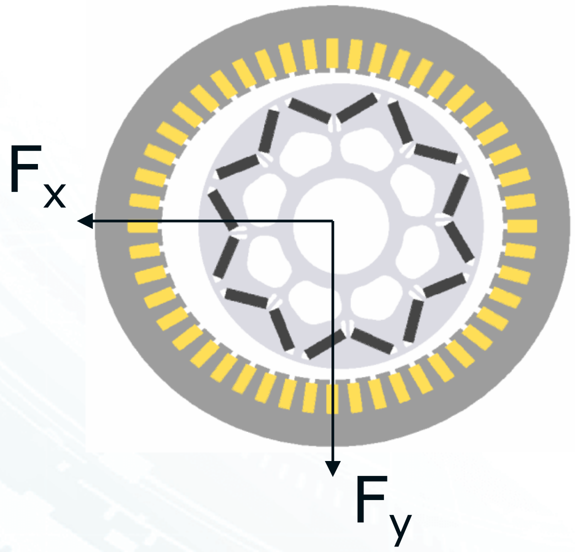
Magnet Offset, Rotor Force

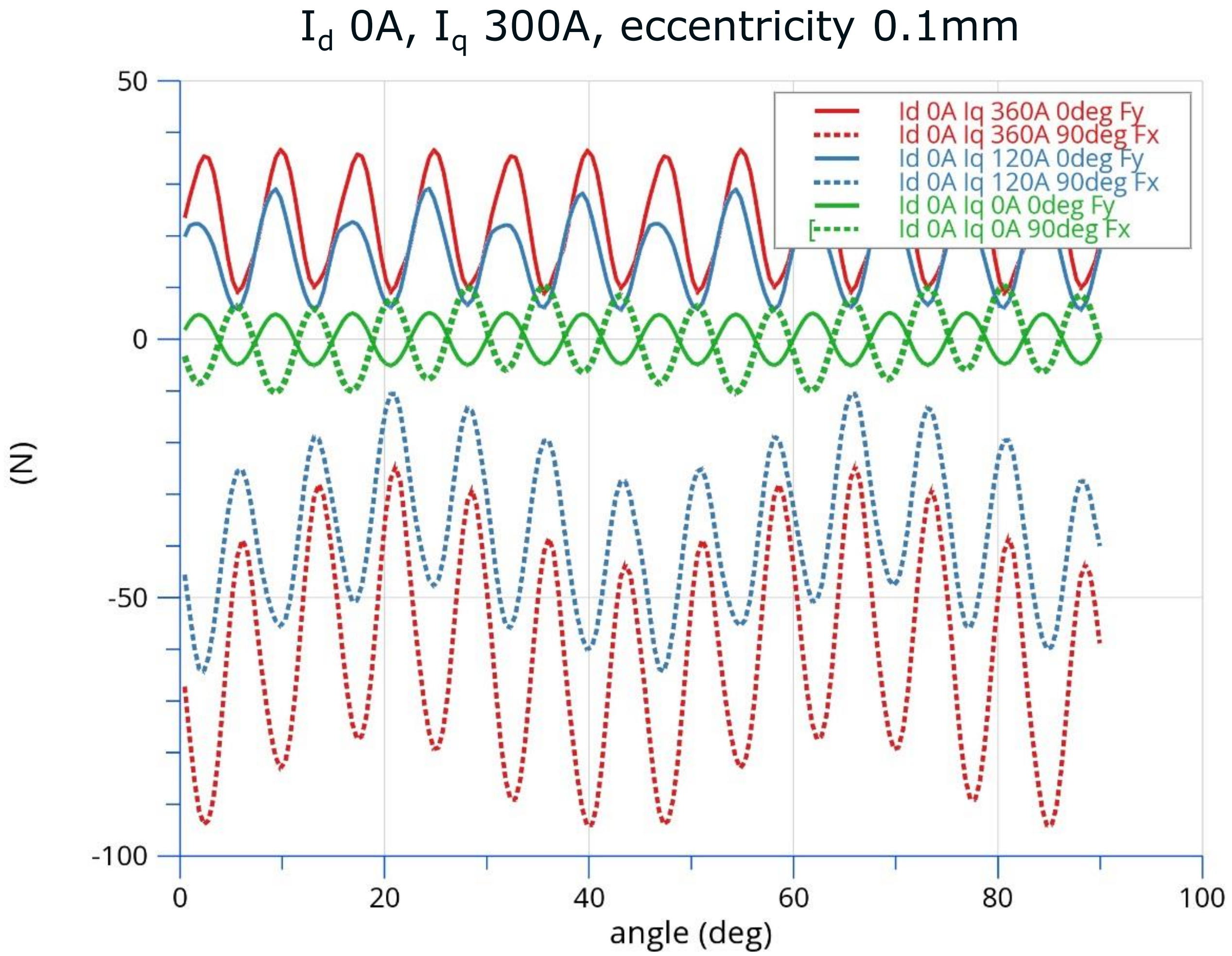




- The rotor force has a period of 360deg

Stator out of Roundness, Rotor Force





- Due to the prescribed current the mean X component is not zero at 90deg, and the Y component is not zero at 0deg offset.
- The force offset increases with the motor current/torque.

Summary

At a glance

- **E-motor** concept and layout **tool.** Can be used **with or without CAD input**
- **No** need to care about **grid generation.** AVL EMT does everything **automatically** in the background and **depending on** the required **simulation task** (system simulation, NVH, ect.)
- **MTBA** analysis and **loss maps** included in workflow
- **Easy data exchange** (e.g. forces, losses) and **automatic handover** to AVL FIRE™ M and AVL CRUISE™ M for further investigations
- **Easy handling of sensitivity investigations** (manufacturing tolerances) and consideration of **rotor misalignment**

Thank You

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