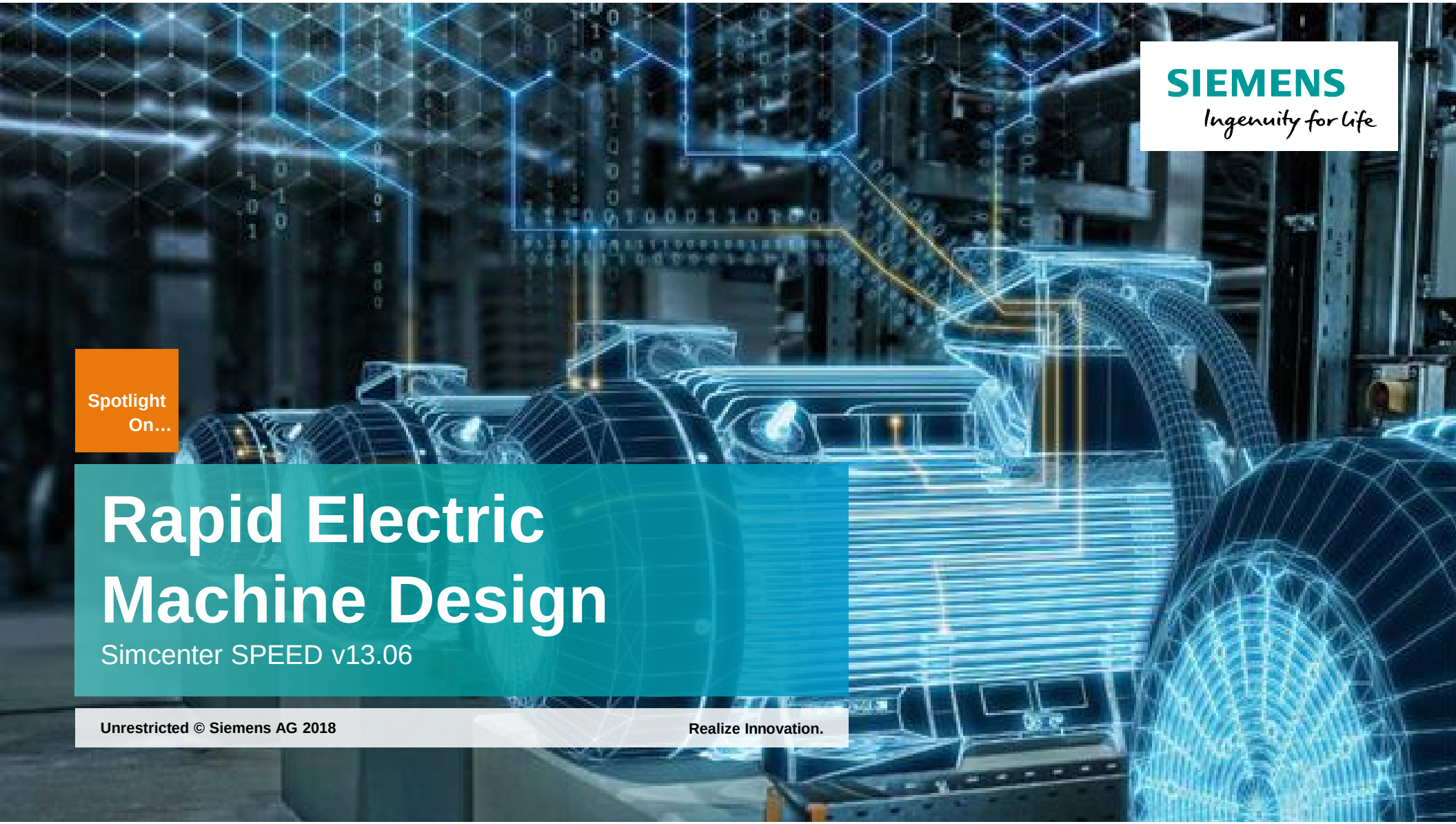

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Spotlight On…

Rapid Electric Machine Design

Simcenter SPEED v13.06

Realize Innovation.

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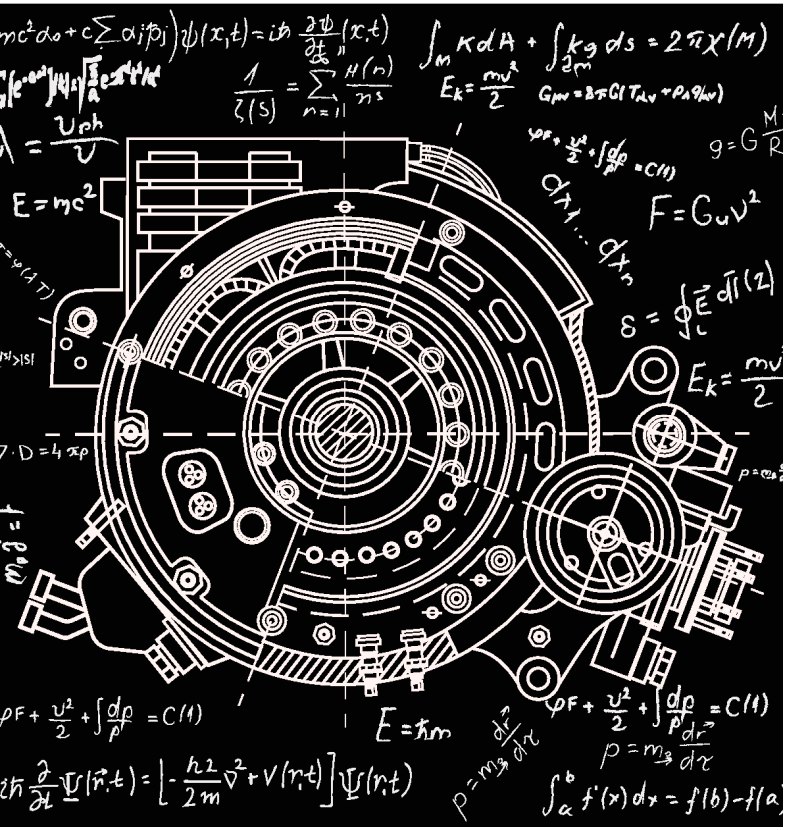

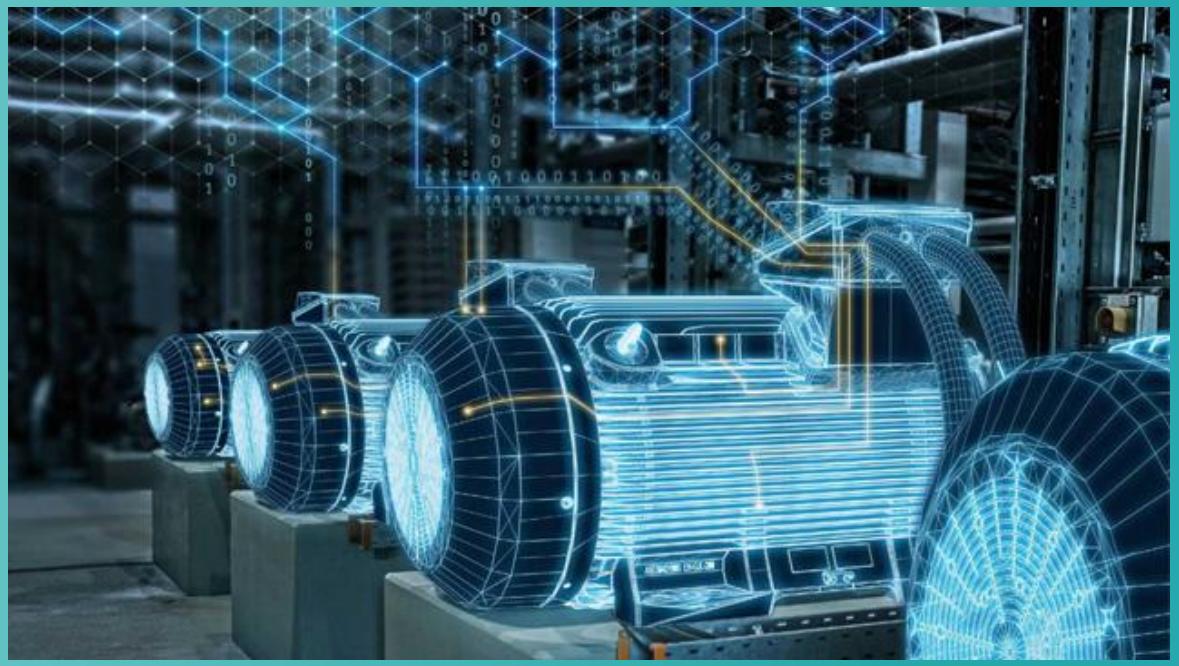

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Overview:
Rapid E-machine Design
using Simcenter SPEED

Why is Rapid E-machine Design Necessary Today?

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Shorten design-to-manufacture time	• Fast analysis of many design variants • Fewer time-consuming prototypes
Drive innovation and improve efficiency	• Better insight earlier in development • “What if” studies and intelligent design exploration
Reduce development costs	• Fewer costly prototypes • Less reliance on simplified models

How Can Rapid E-machine Design Address the Challenges?

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- Fast analysis of many designs variants
- Fewer time-consuming prototypes

- Better insight earlier in development
- “What if” studies and intelligent design exploration

- Fewer costly prototypes
- Less reliance on simplified models

Quickly predict and understand real-world E-machine performance:

- Fast and automated process from setup to solution
- Access to templates to easily define geometry, materials and design parameters
- Accurate prediction of full E-machine performance

Engineer Innovation

Explore design variants early in development using a wide range of design parameters:

- Maximize overall performance
- Maximize efficiency and with that minimize losses
- Reduce overall cost

Electric Machine Applications

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Aerospace


Automotive


Computer and Office


Consumer Electronics


Power Generation

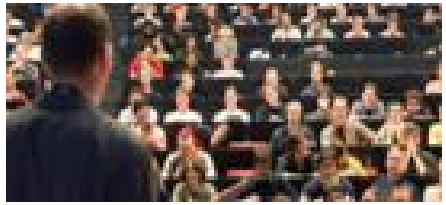
Industrial Machinery


Marine


Medical


Optical Instruments


Public Transportation


Research and Academia


Semi-conductor

Key Requirements

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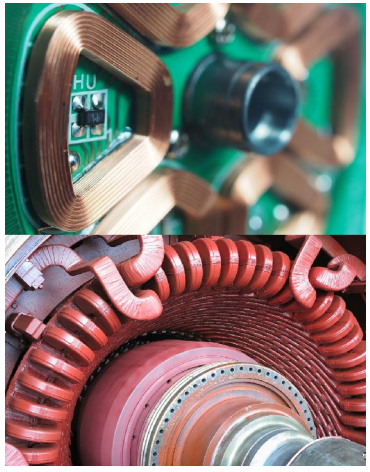
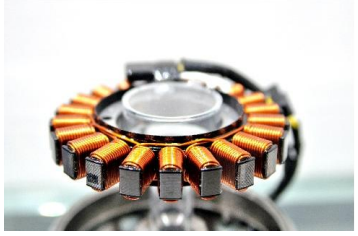
- Breadth of capability
- Quick and easy Setup
- Fast and accurate
- Flexible material data bases
- Intelligent Design Exploration
- Scriptable & Workflow Automation

Complete solution for E-machines:

- Covering a wide range of different types of E-machines
- Including all the necessary theoretical and physics models





Breadth of Capability

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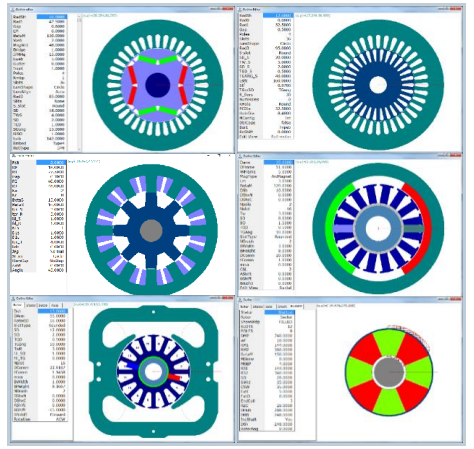
- **Simcenter SPEED** offers six E-machine types:
  - Synchronous machines PC-BDC
  - Induction machines PC-IMD
  - Switched reluctance machines PC-SRD
  - Brushed PM-DC machines PC-DCM
  - Wound-field commutator machines PC-WFC and
  - Axial flux machines PC-AXM
- General purpose 2D and 3D electromagnetic finite element solver within **Simcenter STAR-CCM+** or the dedicated 2D magneto-static PC-FEA program or any other e.g. **Magnet**.



Key Requirements

SIEMENS
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- Breadth of capability
- Quick and easy setup
- Fast and accurate
- Flexible material data bases
- Intelligent Design Exploration
- Scriptable & Workflow Automation

- Application-specific workflow with dedicated input editors
- Terminology and inputs that are familiar to the E-machine designer
- Automated post-processing tailored for E-machine applications

Quick and easy Setup

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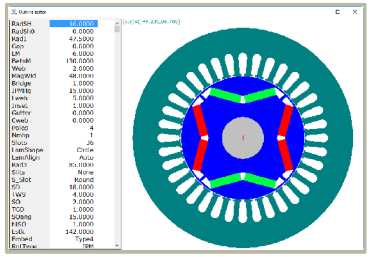
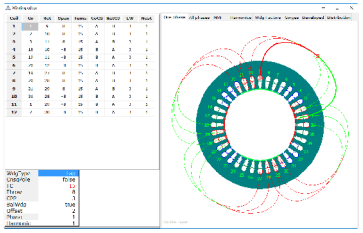
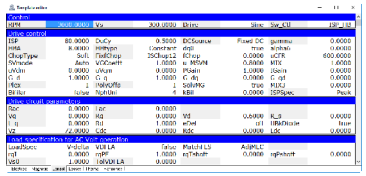
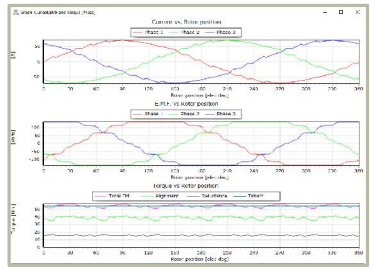
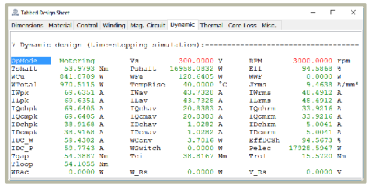
- **Graphical outline editor** showing
  - Parameter list (enables geometry modifications)
  - Radial/axial E-machine cross section
- **Winding editor** showing
  - Single and multiple phases coil distribution
  - MMF and harmonics
  - Görges diagram
  - Winding scheme and the wire distribution in the slot
- **Template editor** to collect all input parameters
- **Design sheet** with
  - Numerical output data
  - Formats: block, tab or customized
- **Output graphs** similar to oscilloscope graphs showing
  - Various physics values
  - Examples: currents, bemf, torque, flux density waveforms











Key Requirements

SIEMENS
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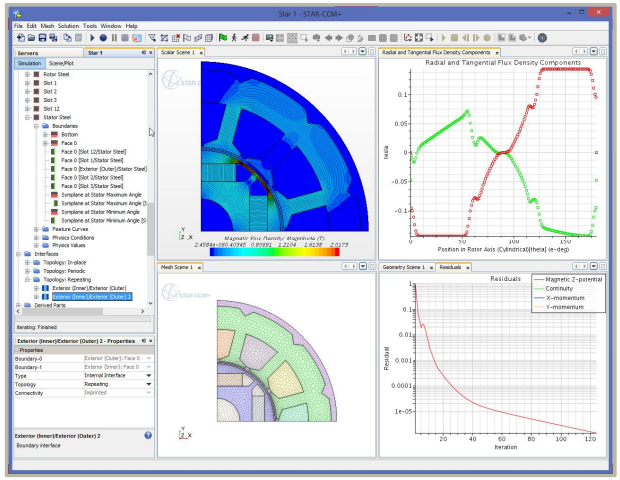
- Breadth of capability
- Quick and easy setup
- **Fast and accurate**
- Flexible material data bases
- Intelligent Design Exploration
- Scriptable & Workflow Automation

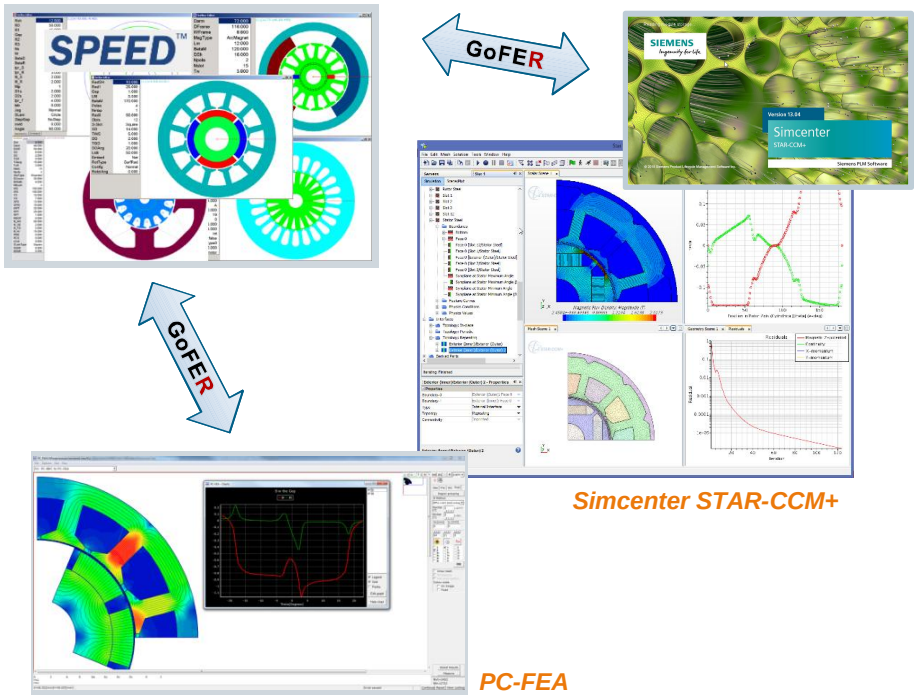
Flexible approach combining methods to balance Simcenter SPEED and accuracy:

- Analytical methods for almost instantaneous results
- FE electromagnetic analysis to model the magnetic saturated regions more precisely if needed



Fast but also accurate

- Achieve fast calculations with simple magnetic equivalent-circuit methods
- Get additional accuracy by accounting for saturation level and complex flux path effects using:
  - An embedded FE solver in Simcenter SPEED
  - An external loop accessing 2D electromagnetic static FE programs in PC-FEA or Simcenter STAR-CCM
    - Uses a fast and automated script (GoFER)
    - Enables quick return of data back to Simcenter SPEED to calibrate settings or compare results

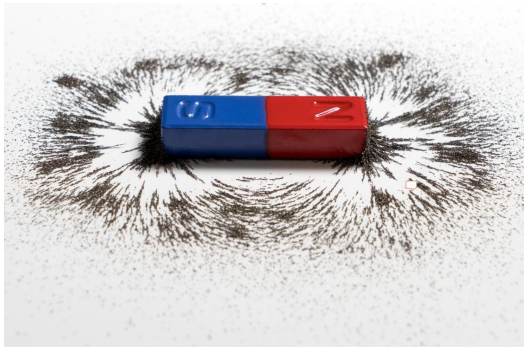


Key Requirements

SIEMENS
Ingenuity for life

- Breadth of capability
- Quick and easy setup
- Fast and accurate
- **Flexible material data bases**
- Intelligent Design Exploration
- Scriptable & Workflow Automation

- Quick access to a common database for material property data.
- Easily create and edit records of material property data
- Access to material plots and charts



Flexible material database

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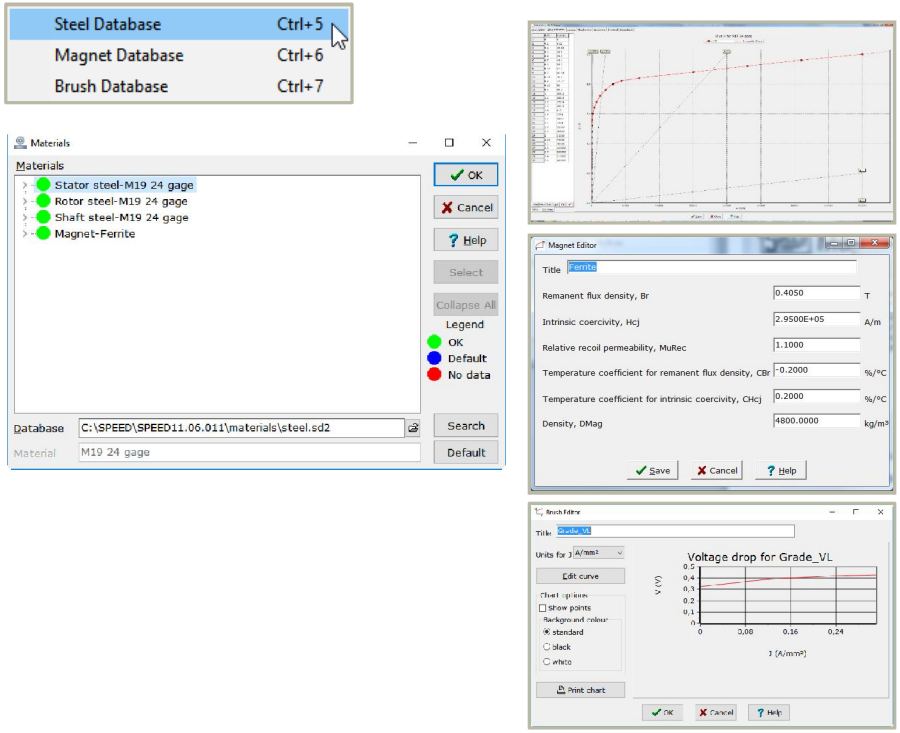
- Material databases available in Simcenter SPEED
  - Includes steels, magnets and brushes
  - Can be edited/created using dedicated database programs
  - New material records are saved in a database and can be accessed and re-used from the interface.
  - Includes various charts such as B/H and V/I curves



Key Requirements

SIEMENS
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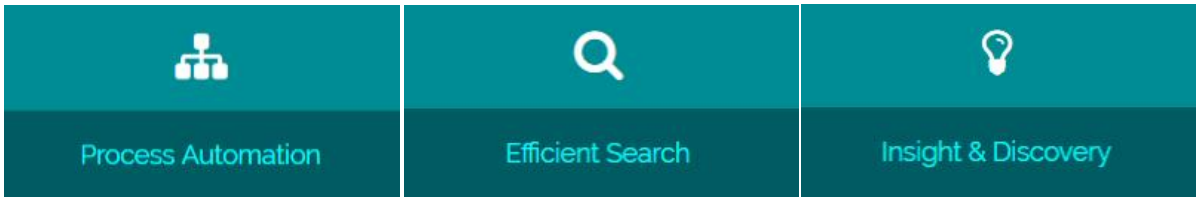
- Breadth of capability
- Quick and easy setup
- Fast and accurate
- Flexible material data bases
- **Intelligent Design Exploration**
- Scriptable & Workflow Automation

- Intelligent design-space exploration algorithm to gain better insight and find better E-machine designs faster
  - Maximize overall performance
  - Maximize efficiency and minimize losses
  - Reduce overall cost



Intelligent Design Exploration

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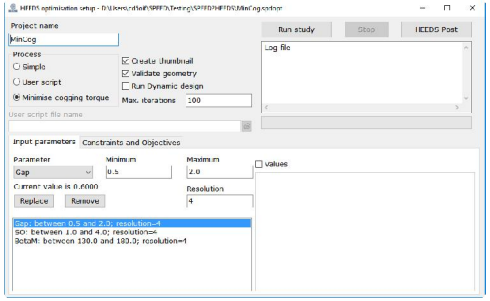
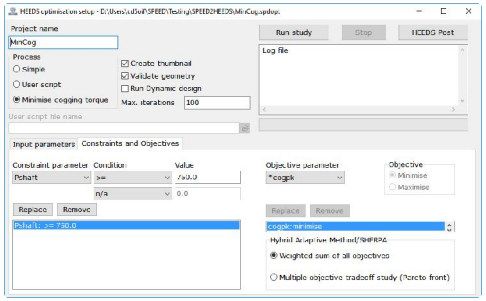
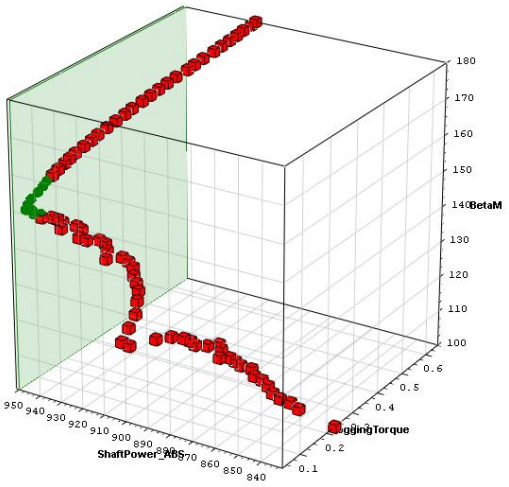
- HEEDS is a powerful software package part of the Simcenter Portfolio that automates the design space exploration process
- Simcenter SPEED provides an in-built GUI to access HEEDS in two ways:
  - A full HEEDS installation
  - An integrated HEEDS Add-on tool







Key Requirements

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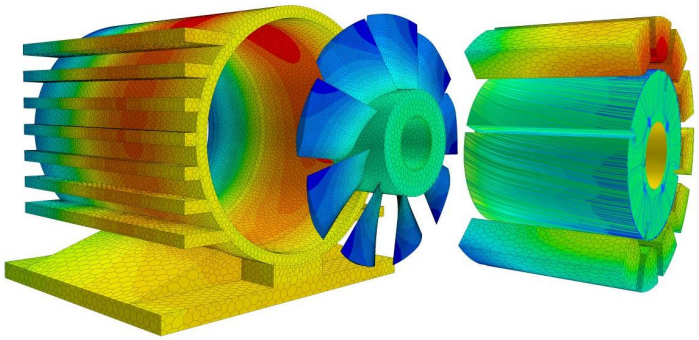
- Breadth of capability
- Quick and easy setup
- Fast and accurate
- Flexible material data bases
- Intelligent design exploration
- Workflow automation

- Enable scripting to link libraries and make analysis easily available for design exploration studies
- Automated workflow that links geometry and analysis tools and facilitates quick design changes
  - In using scripts to automate the various workflows including detailed multi-physics analyses such as electro-magnetics, thermal, mechanical stress and vibro-acoustic.



Workflow Automation

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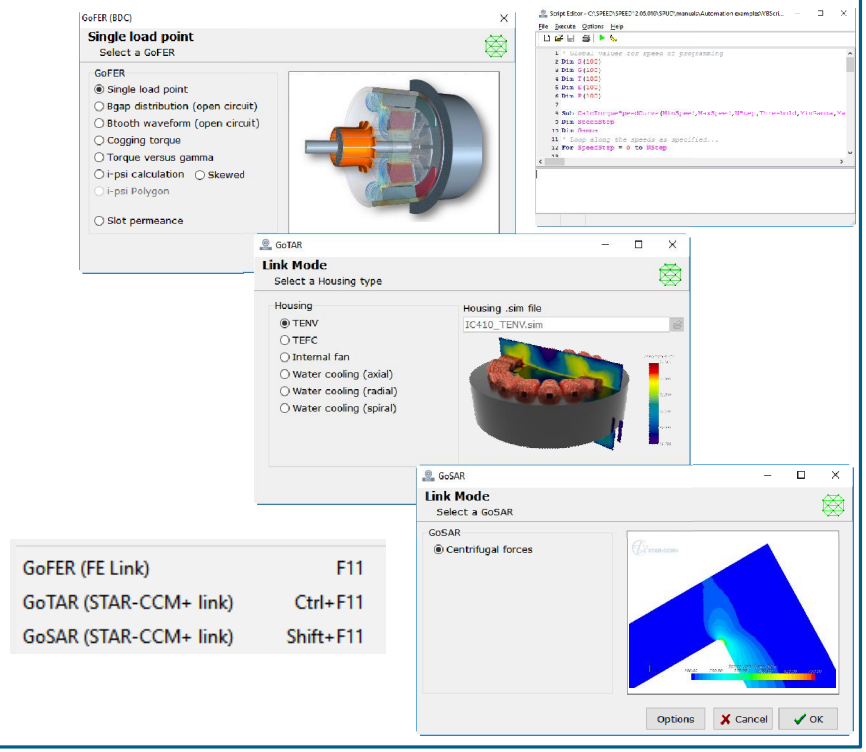
- Users can connect the necessary tools for the complete E-machine solution using various scripting or programming languages.

- Pre-defined scripts to augment Simcenter SPEED with Simcenter STAR-CCM+ are available with download of the software:
  - **Electromagnetic analysis** (GoFER),
  - **Thermal analysis** (GoTAR) and
  - **Mechanical stress analysis** (GoSAR).



Summary

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- Quickly and easily analyze the most E-machine problems
- Incorporate design exploration to discover better designs earlier in the development timeline

Breadth of capability

Quick and easy setup

Fast and accurate

Flexible material data bases

Intelligent design exploration

Workflow automation

E-machine Simulation in Siemens PLM Products

- Simcenter SPEED enables fast design of a wide range of electric machine types
- Very fast computation due to the analytic approach
- Higher accuracy with easily linkable FE based electro-magnetic solver (PC-FEA, Simcenter STAR-CCM+, MagNet)
- Workflow automation allows participation of a the multi-physics platform Simcenter STAR-CCM+
- Integrated, intelligent design exploration using HEEDS

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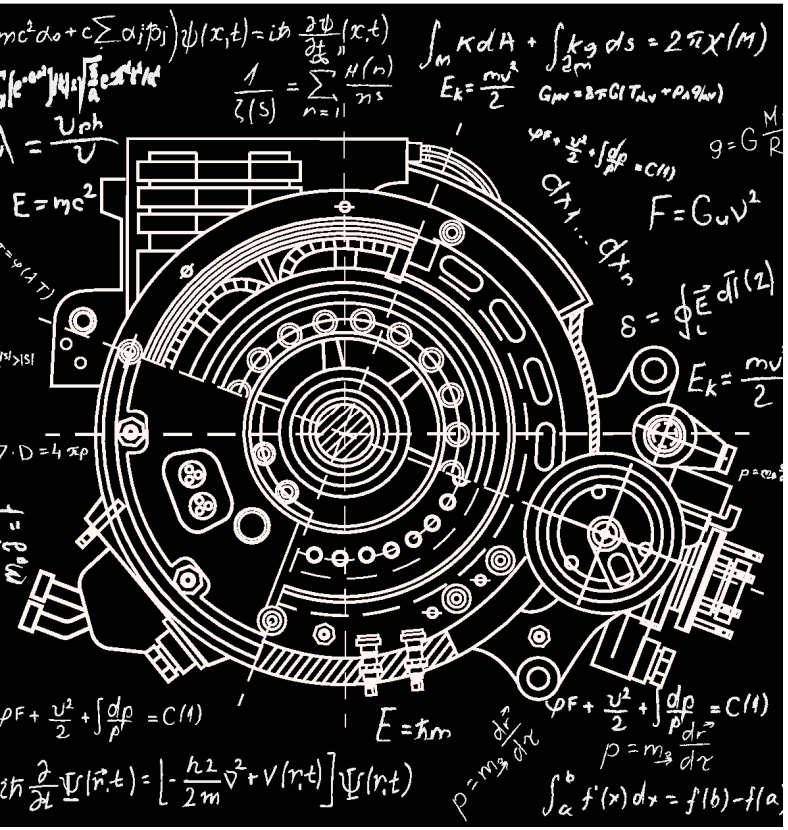

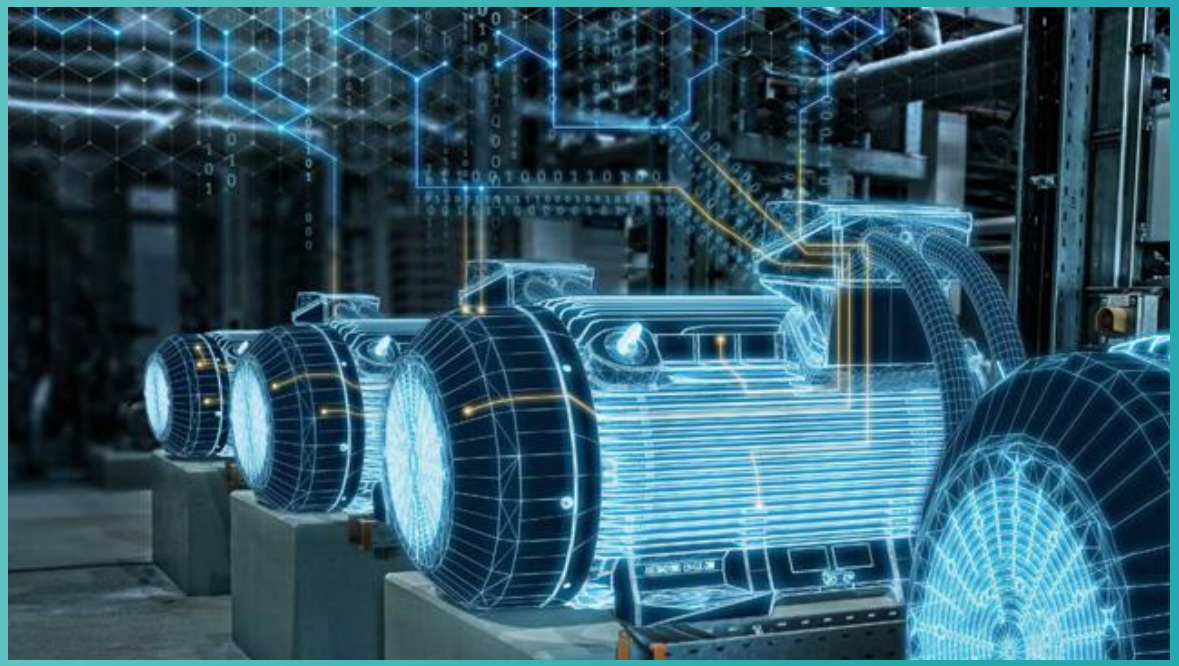

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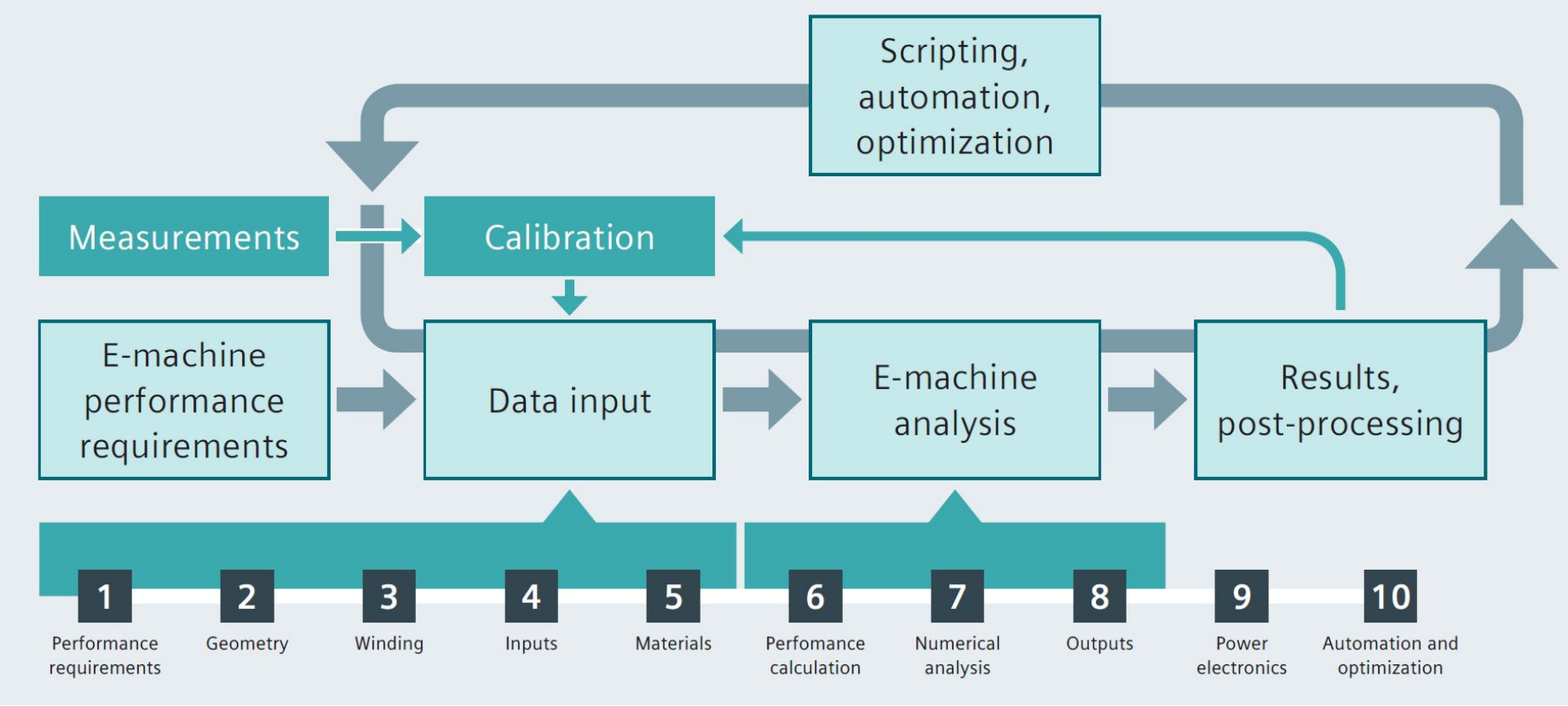
Deep Dive Overview

Overview of Simcenter SPEED workflow



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Performance Requirements

Motor Performance Requirements

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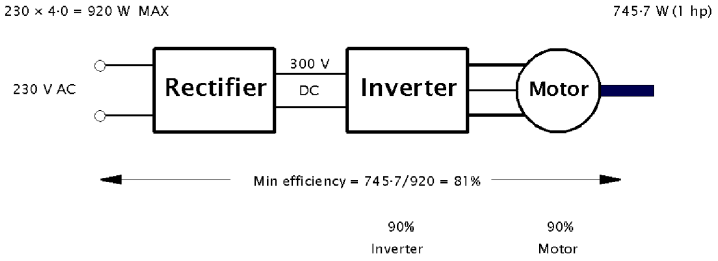
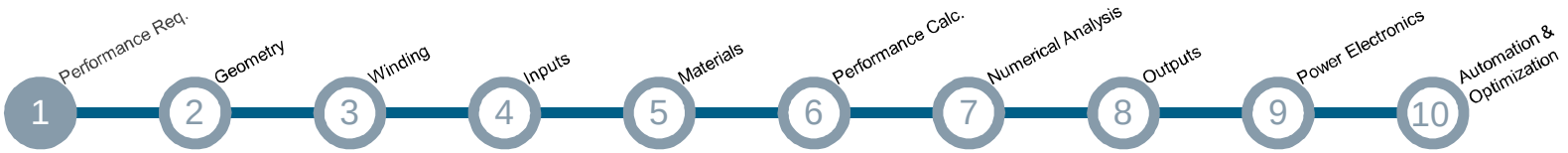
Usually the following requirements or restrictions are provided for the initial design:

- Restrictions in mechanical dimensions
- DC link/terminal voltage
- Rated/peak:
  - Current from the inverter/source
  - Output shaft power
  - Output shaft torque
- Restrictions on the materials
- Ambient temperature
- Limitations due to manufacturing constraints
- Production cost

Dimensions	? mm diameter
	? mm length
DC Link voltage	280 V (rectified from 230 V, AC)
Output power	745 W @ 2,000 rpm
Max. speed	2,000 rpm
Magnet material	Ferrite
Ambient Temp.	40°C
Max. Current	4.0 A_{rms} (from AC source)





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Data Input

Geometry Input – The Outline Editor (i)

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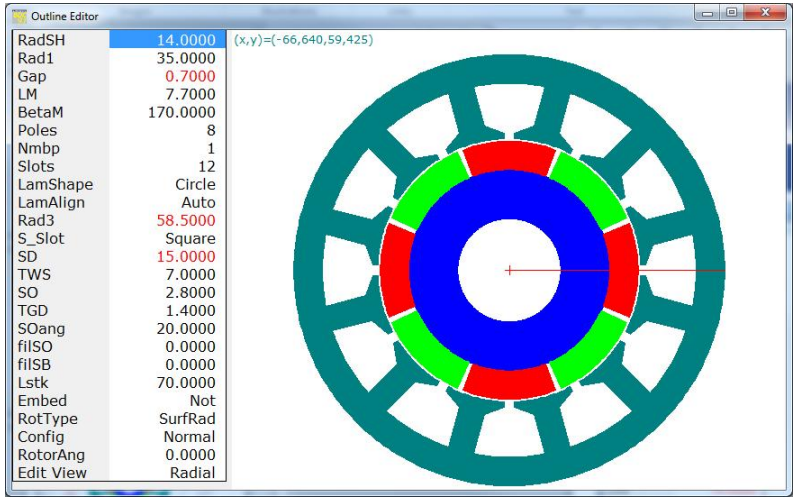
The **Outline Editor** is the main editor for modifying the cross and axial section motor dimensions

Geometry can be selected from various pre-defined standard templates including:

- Inner/outer rotor
- Surface PM, IPM or electric excitation
- Single or double bar/cage
- Square/round slot
- Parallel tooth/slot



Geometry Input – The Outline Editor (ii)

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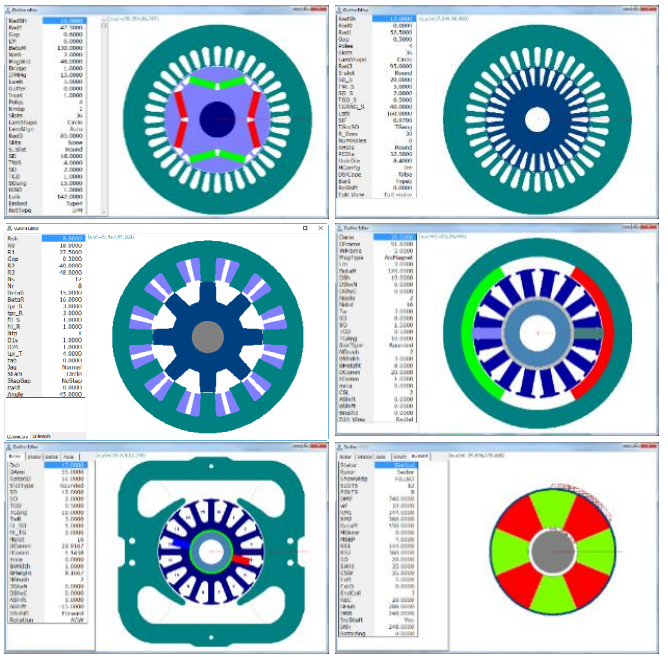
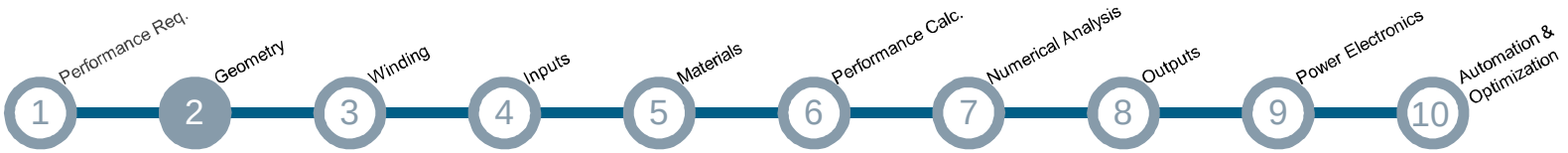
- All templates are fully parametrized allowing modifications to be made easily
- 1000+ combinations for all six main programs
- Templates can be scaled to suit requirements
- Automatic scaling using initial sizing function





Winding Input – The Winding Editor

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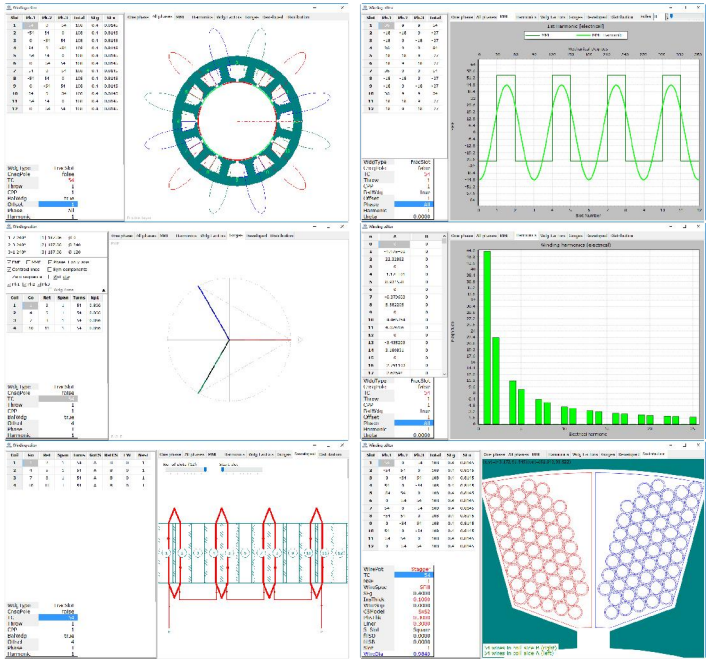
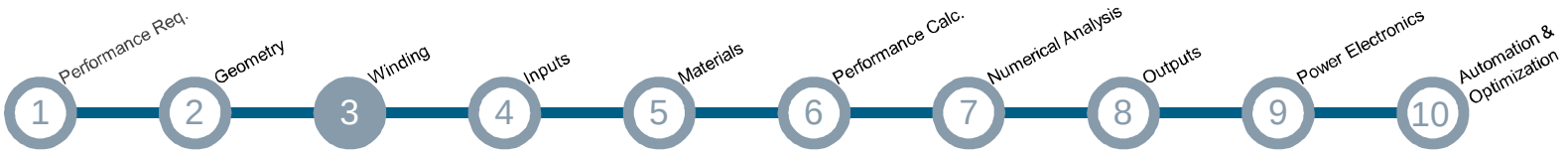
The **Winding Editor** displays:

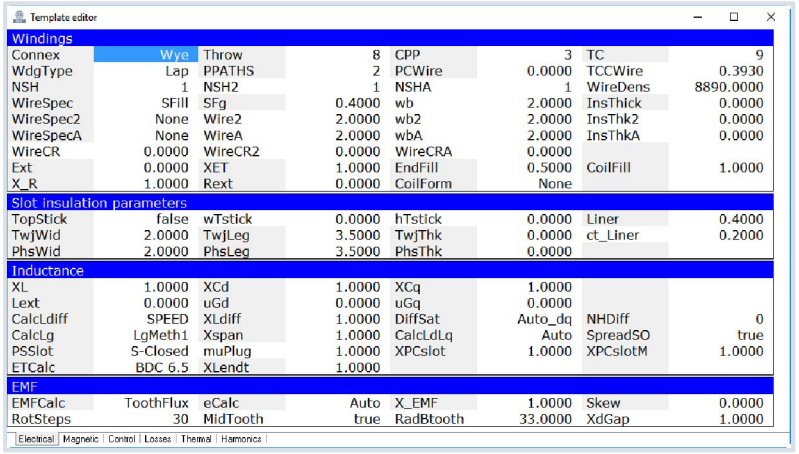
- Winding layout with single & all phase representation
- MMF (magneto-motive force)
- Harmonics
- Winding factors
- Görges Diagram
- Developed winding
- Wire distribution
- Standard as well as custom windings are assembled automatically from the parameters in the edit box

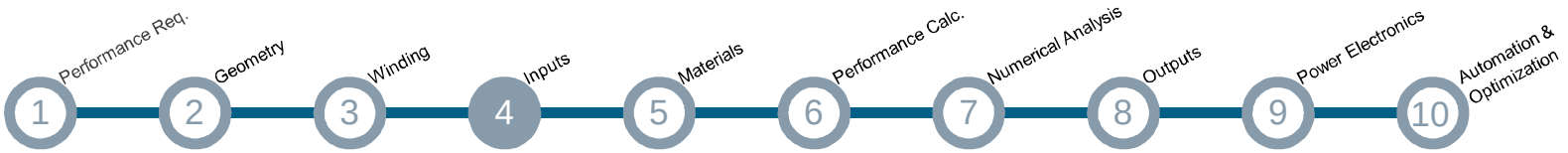




General Input – The Template Editor

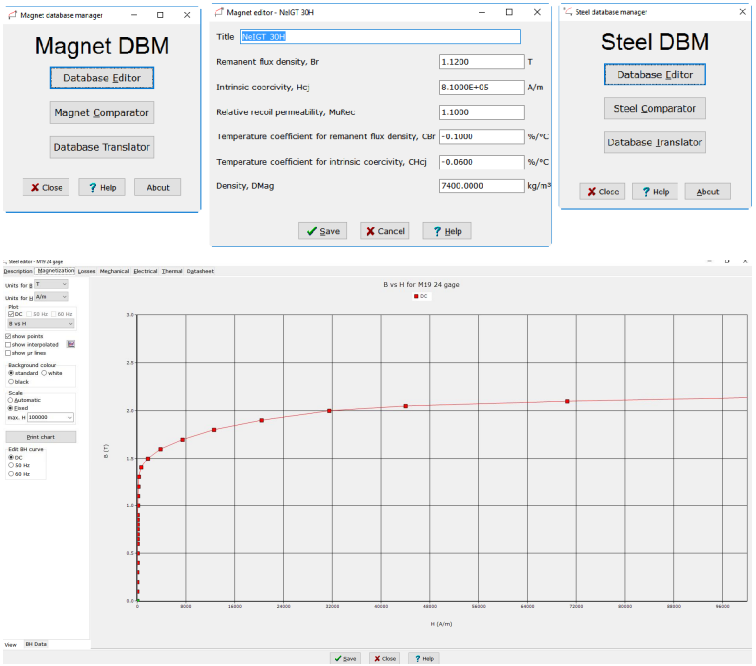
- The **Template Editor** (TED) summarizes input parameters, e.g. electrical, magnetic, drive, loss, thermal and several other inputs arranged in different topological blocks and several tabs
- TED is used for entering or editing all the input parameters of a design and may therefore contain over 100 parameters
- Many non-numerical parameters have a dropdown list box from which a selection can be made
- Unsaved changes are indicated in red





Materials – Selection and Material Databases

- The **Data Base Manager** (DBM) allows users to create, load and edit material data bases for steel, magnet and brushes
- **Database Editor** for
  - Creating/editing DB
  - Creating/editing material
- **Steel Comparator** for displaying different materials' characteristics
- **Database Translator** to convert between different data base versions



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Performance Calculation

Performance Calculation (i)

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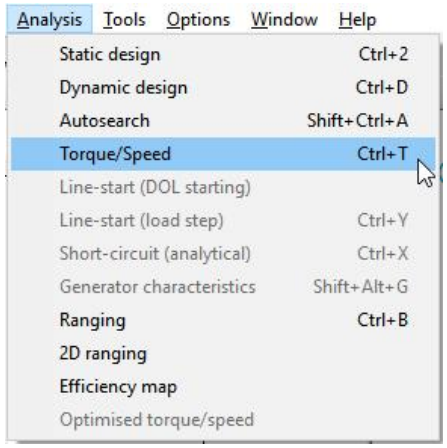
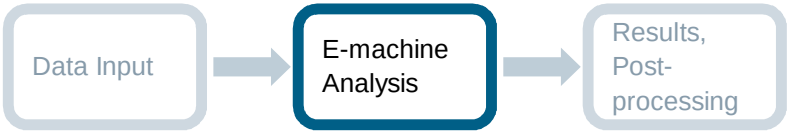
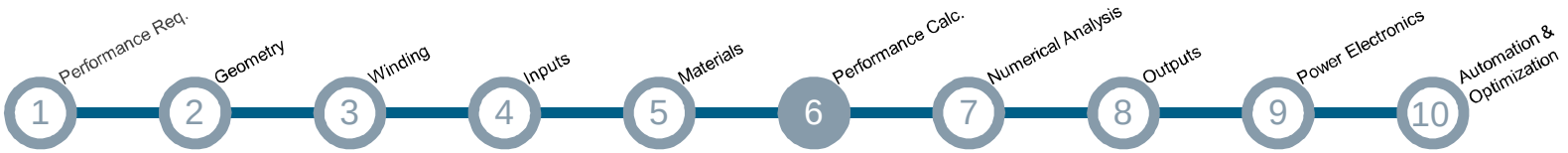
- The analysis is conducted either at a single operating point or over a whole speed/torque range and includes virtually all the electrical and electromagnetic performance of the machine including torque, efficiency, currents, current waveforms, EMF
- In most cases it includes a time-stepping model of the drive, so that current and torque waveforms can be obtained and peak, mean and RMS currents are calculated in the main power transistors and diodes for a range of different drive circuits and control strategies







Performance Calculation (ii)

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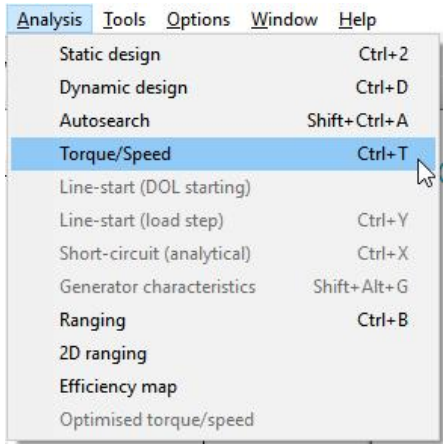
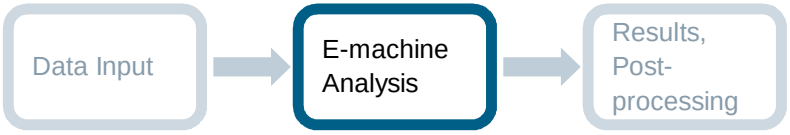
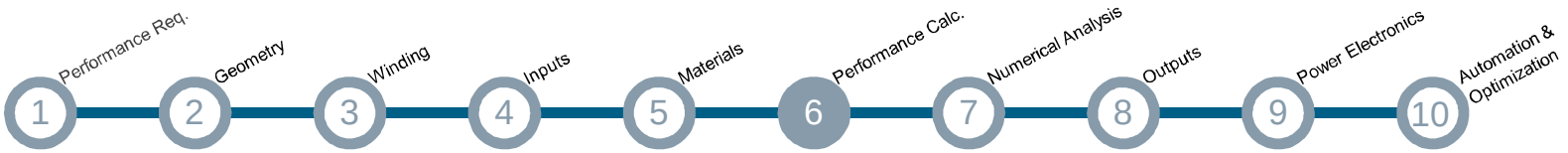
- Electrical parameters such as winding parameters with resistances and inductances are presented in detail in the Design Sheet after the performance calculation
- There are many dimensional and mechanical parameters including weights and inertias, and a comprehensive set of thermal calculations is included as well
- Magnetic flux densities are given in various parts of the machine, together with a detailed breakdown of losses







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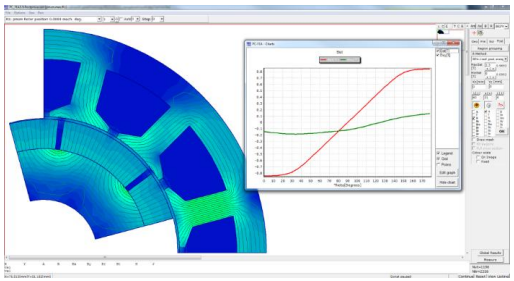
Numerical Analysis

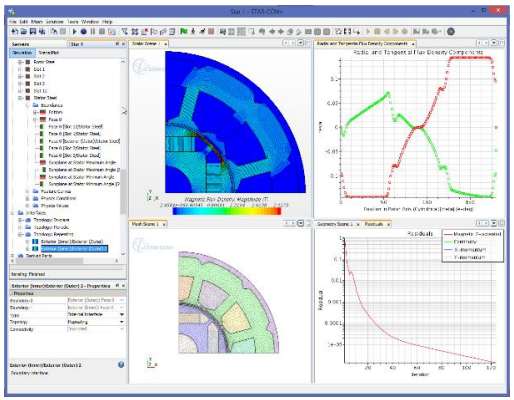
Numerical Analysis (i)

- All Simcenter SPEED programs are closely linked to the finite-element program PC-FEA via the GDF editor or Simcenter STAR-CCM+ through a .xgdf definition file and Java scripts
- Simcenter STAR-CCM+ provides
  - 3D-CAD modeler allowing easily geometry modifications if needed
  - Full transient solver with electric circuit description for e.g. short circuit studies

PC-FEA



Simcenter STAR-CCM+



Numerical Analysis (ii)

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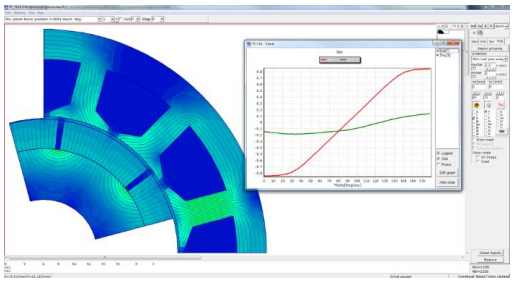
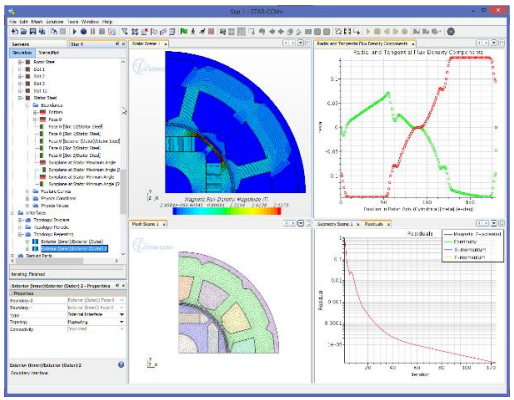
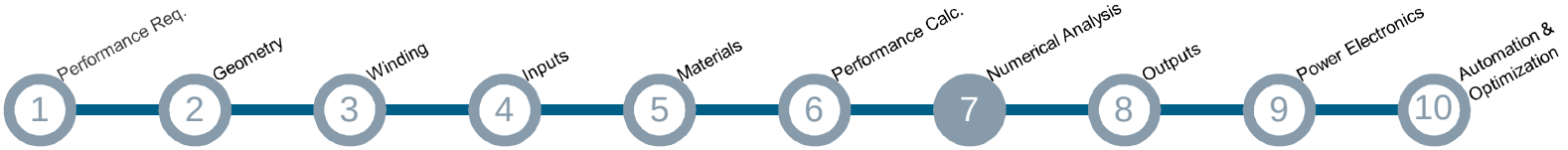
- The link to the electromagnetic numerical analysis is fast and it has many ways to return data back to the Simcenter SPEED programs
  - The so-called GoFERs ("Go to finite elements and return") set up many FE electromagnetic calculations automatically including geometry, materials and boundary conditions, the appropriate symmetries and excitations
  - In some cases an embedded form of the GoFER is used to provide specialized results with automatic adjustment of the equivalent analytic magnetic circuit

PC-FEA



Simcenter STAR-CCM+





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Data Output

Data Output

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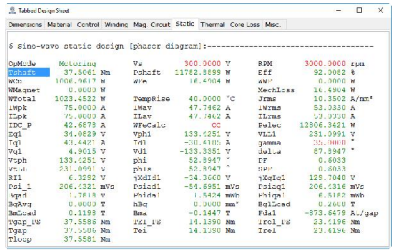
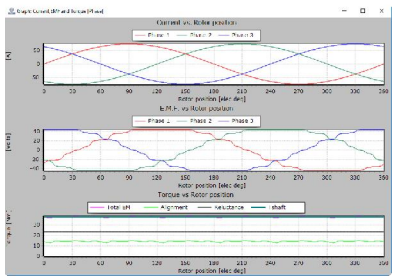
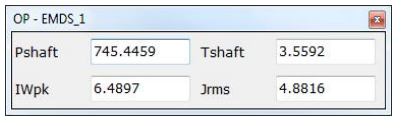
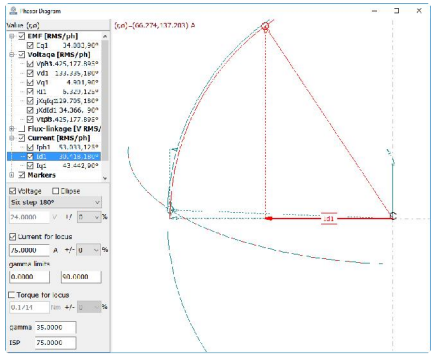
Performance calculation results are presented in the following forms:

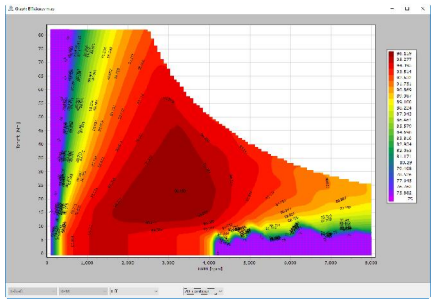
- The DESIGN SHEET containing complete listings of input and output parameters displayed in different colors and grouped/ arranged in thematic blocks or on tabbed pages
- Graphs and waveforms with additional further analysis options such as harmonic analysis
- 2D/3D plots, e.g. 2D or 3D contour plot of efficiency
- Phasor diagram
- Customized Output Table or Sheet

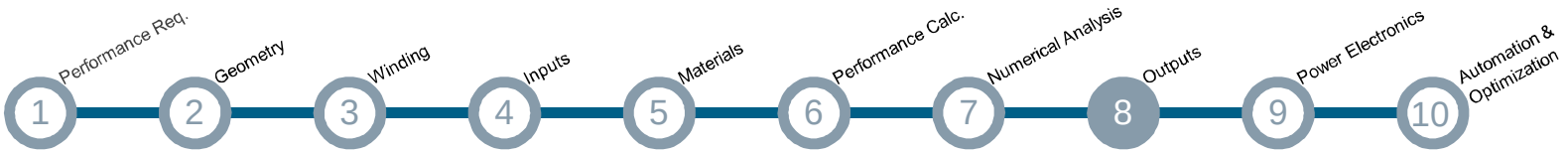












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Power Electronics and Control

Power Electronics and Control

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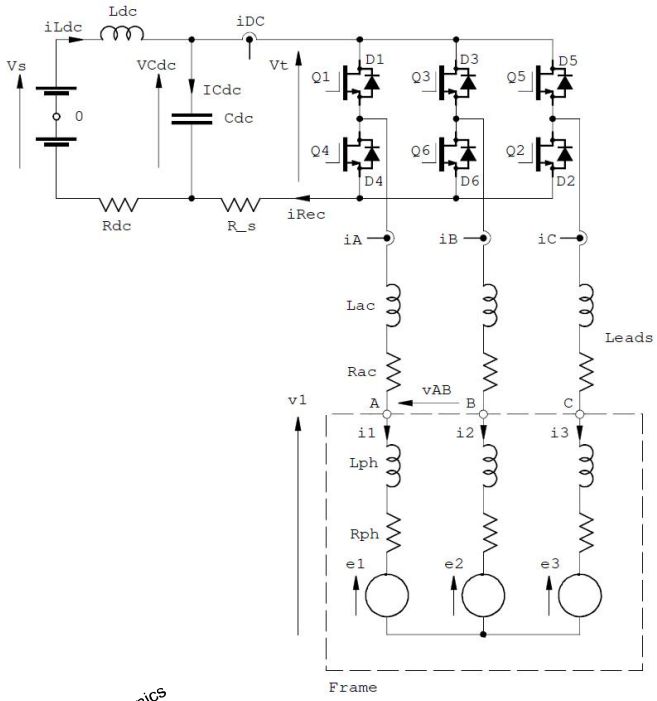
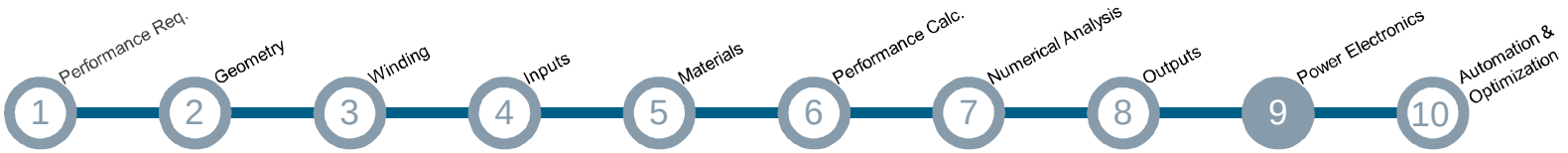
In most cases the drive (electronic control) is modelled in some detail, so that current and torque waveforms can be obtained and peak, mean and RMS currents are calculated in the main power transistors and diodes

A range of different drive circuits and control strategies are supported, including:

- AC Volt
- Square-wave
- Sine-wave





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Scripting, Automation & Optimization

Scripting, Automation & Optimization (i)

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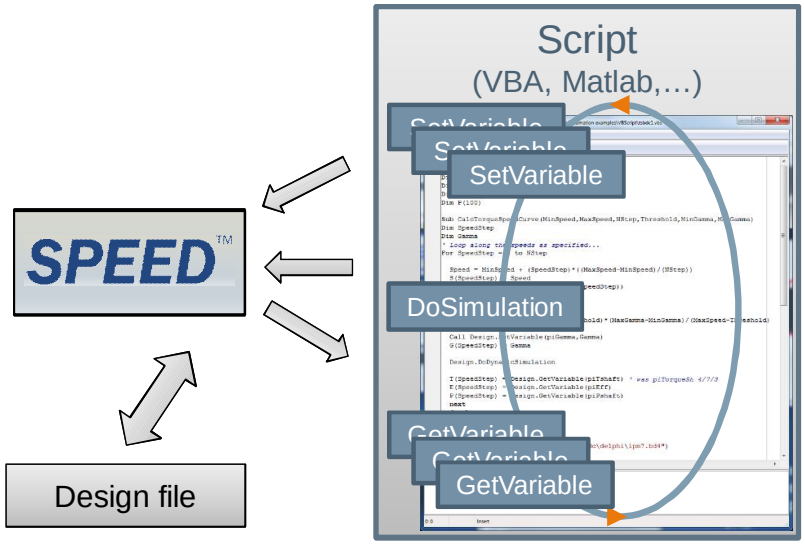
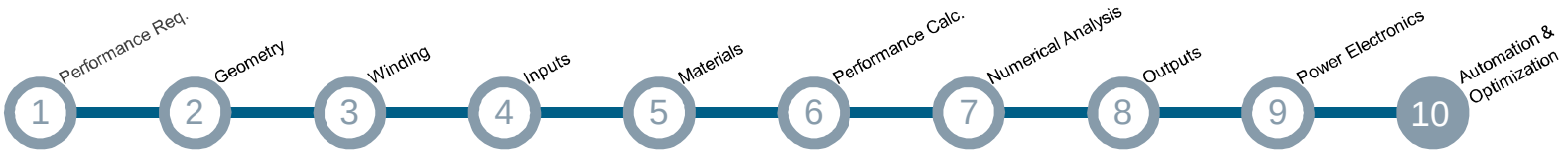
- Scripting enables users to customize functionality as needed. This could include automated design exploration or user defined calculations or outputs
- ActiveX technology used allows Simcenter SPEED to be driven using many scripting languages including Visual Basic, Matlab, Python and more





Scripting, Automation & Optimization (ii)

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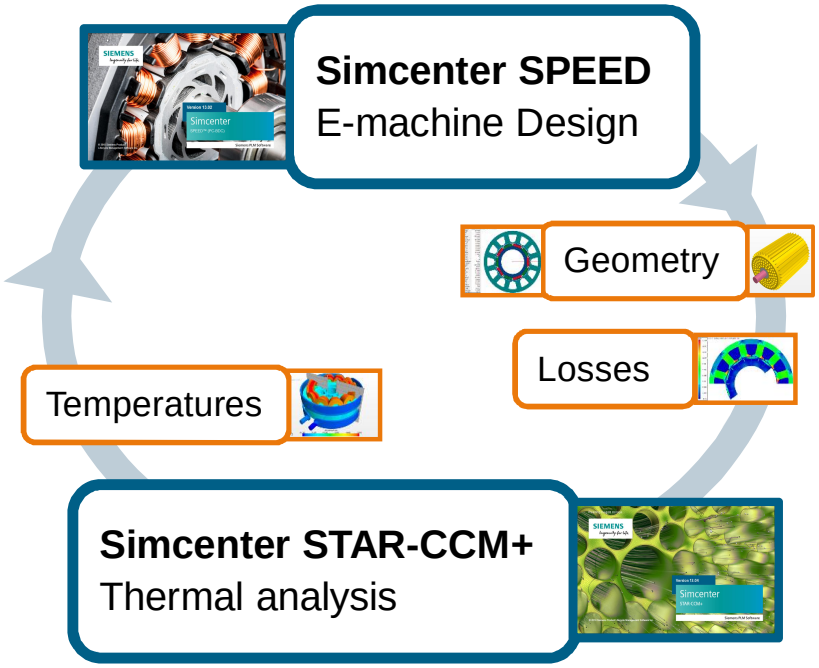
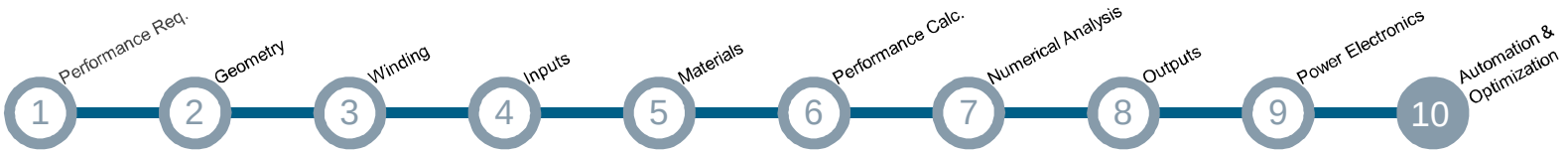
- Simcenter SPEED includes several built-in workflows to enable:
  - Electromagnetic (GoFER)
  - Thermal (GoTAR)*
  - Mechanical Stress (GoSAR)*
- The built-in workflows are based on scripts which allow Simcenter SPEED to interact with Simcenter STAR-CCM+ or PC-FEA

*workflows available in beta form, please contact SPEED support for more information





Scripting, Automation & Optimization (iii)

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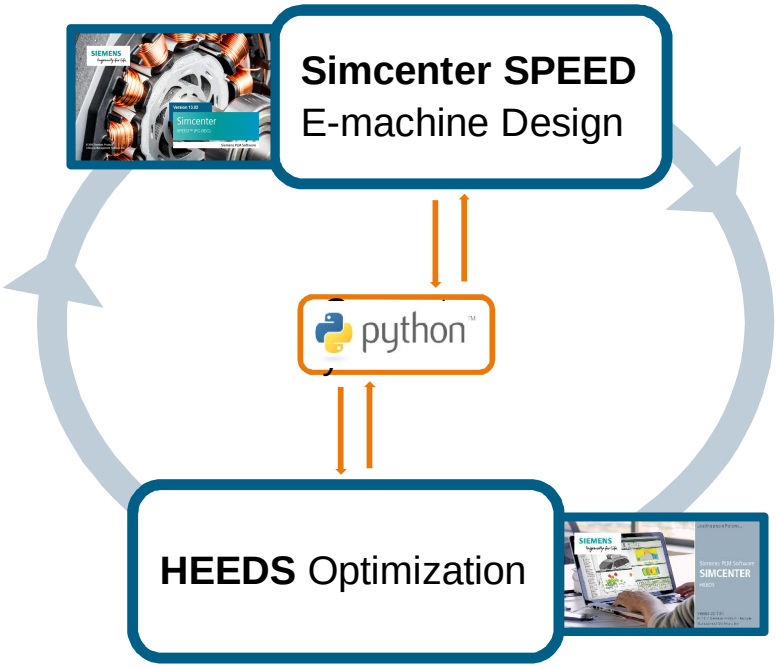
- Automated design exploration and optimization studies can be carried out using HEEDS
- Simcenter SPEED includes an in-built GUI to automatically generate the Python script needed for communication with HEEDS



1 Performance Req. 2 Geometry 3 Winding 4 Inputs 5 Materials 6 Performance Calc. 7 Numerical Analysis 8 Outputs 9 Power Electronics 10 Automation & Optimization

Scripting, Automation & Optimization (iv)

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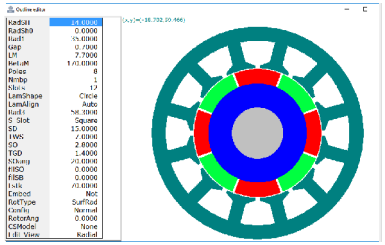
Optimization Case Study: Permanent magnet surface synchronous machine

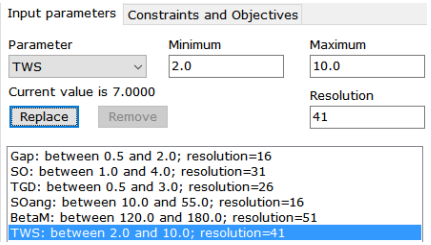
Parameters: HEEDS is allowed to vary six design parameters to vary motor geometry

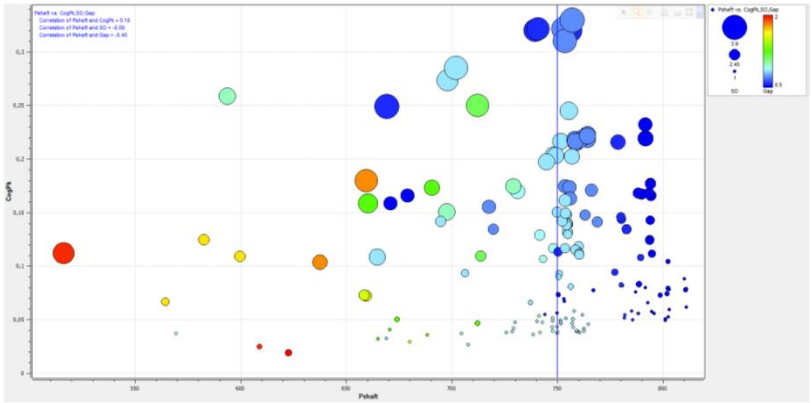
Objective: Minimize cogging torque

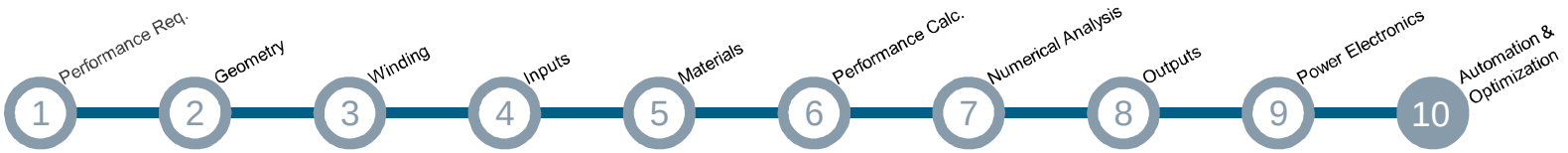
Constraints: Maintain shaft power above a minimum limit (this ensures that adequate machine performance is maintained)

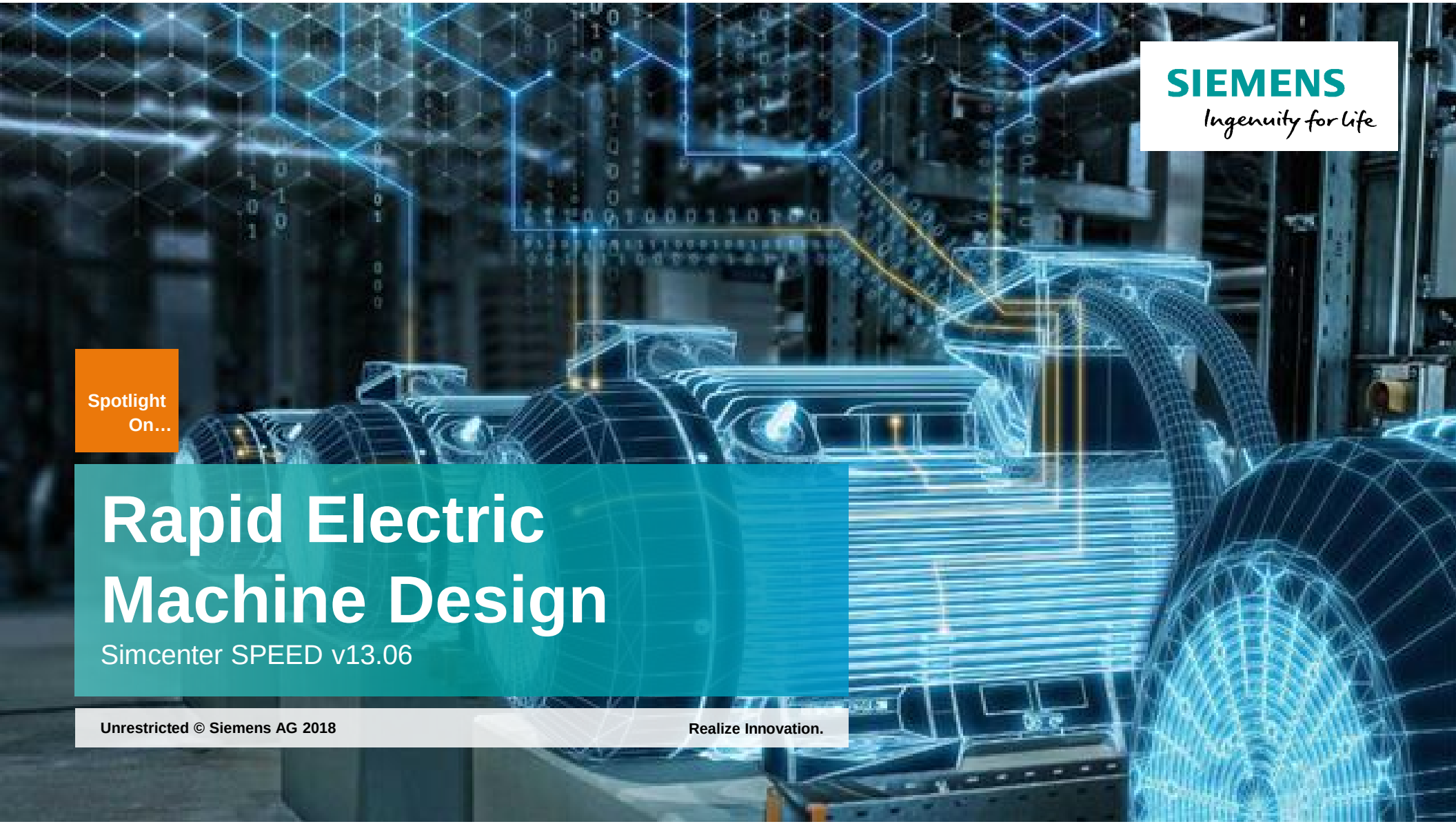
Result: >90% reduction in cogging torque











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Spotlight On…

Rapid Electric Machine Design

Simcenter SPEED v13.06

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