Motor Design Limited

Motor Design Software by Motor Design Engineers

Optimisation of Electric Machines using Motor-CAD and optiSLang

22 June, 2018

Topics

Introduction

I. Motor-CAD & optiSLang

II. Case study

III. Problem setup

IV. Results

V. To go further…

Conclusion

Introduction

Electrical machine development workflow

Product development workflow

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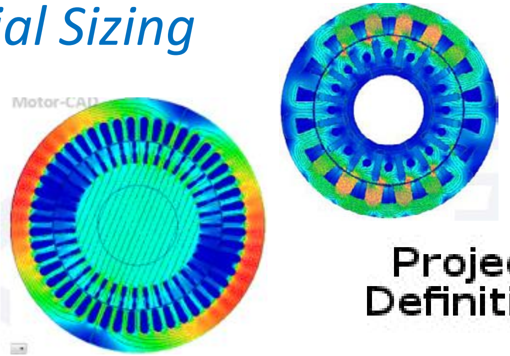
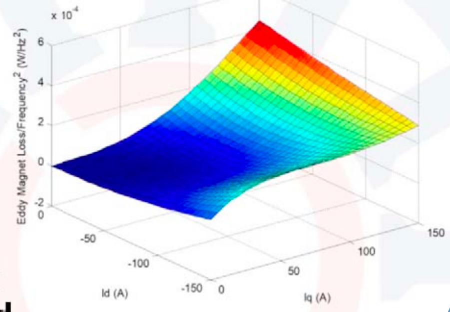
Test & Design Engineer

Model Calibration

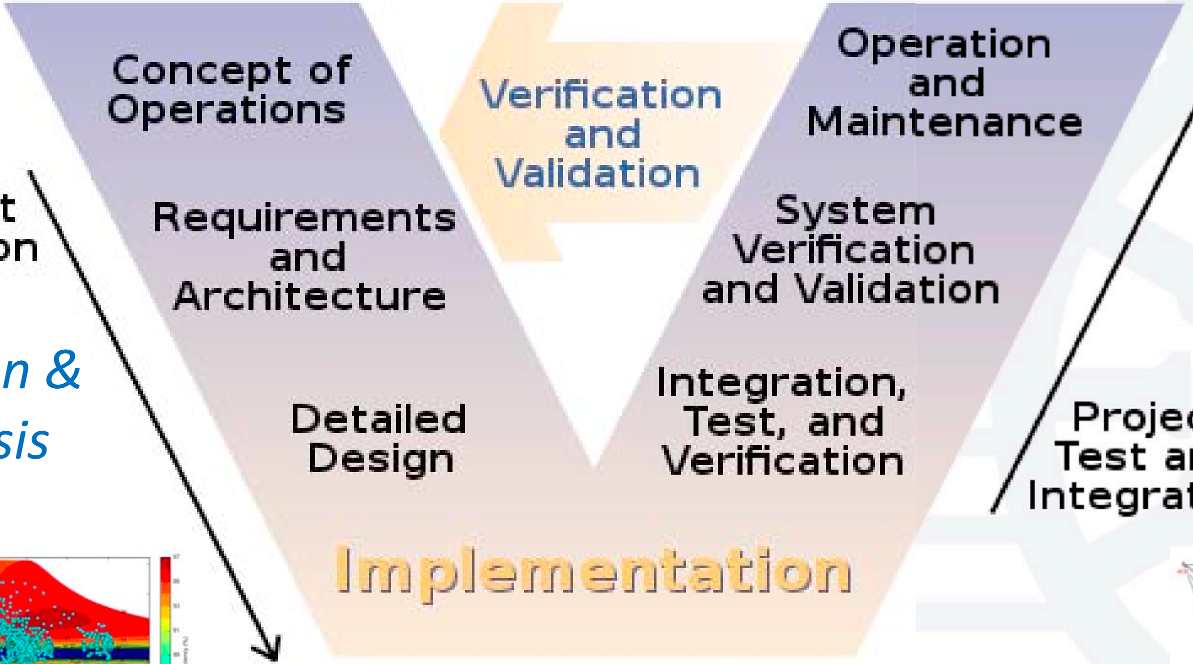
Motor Type & Topology + Initial Sizing



Reduced Order Models & Flux Linkage/Loss Maps

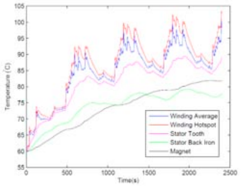


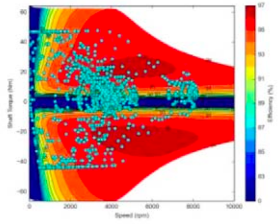
Project Definition

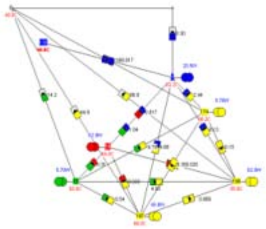


Project Test and Integration

Design Optimisation & Drive Cycle Analysis







Design Engineer

System Engineer

Motor-CAD & optiSlang

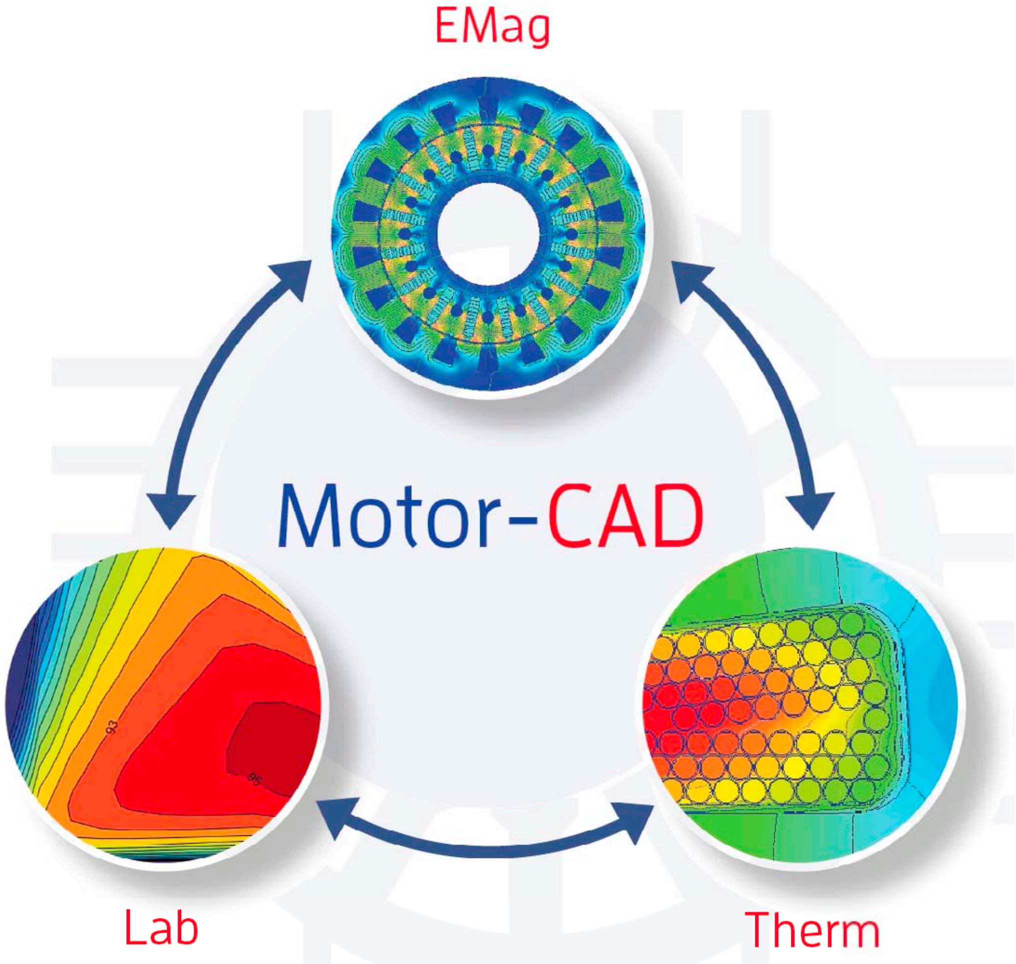
Electrical machine design with Motor-CAD and optiSLang

Motor-CAD software

Application specific tool for design and simulation of electric motors

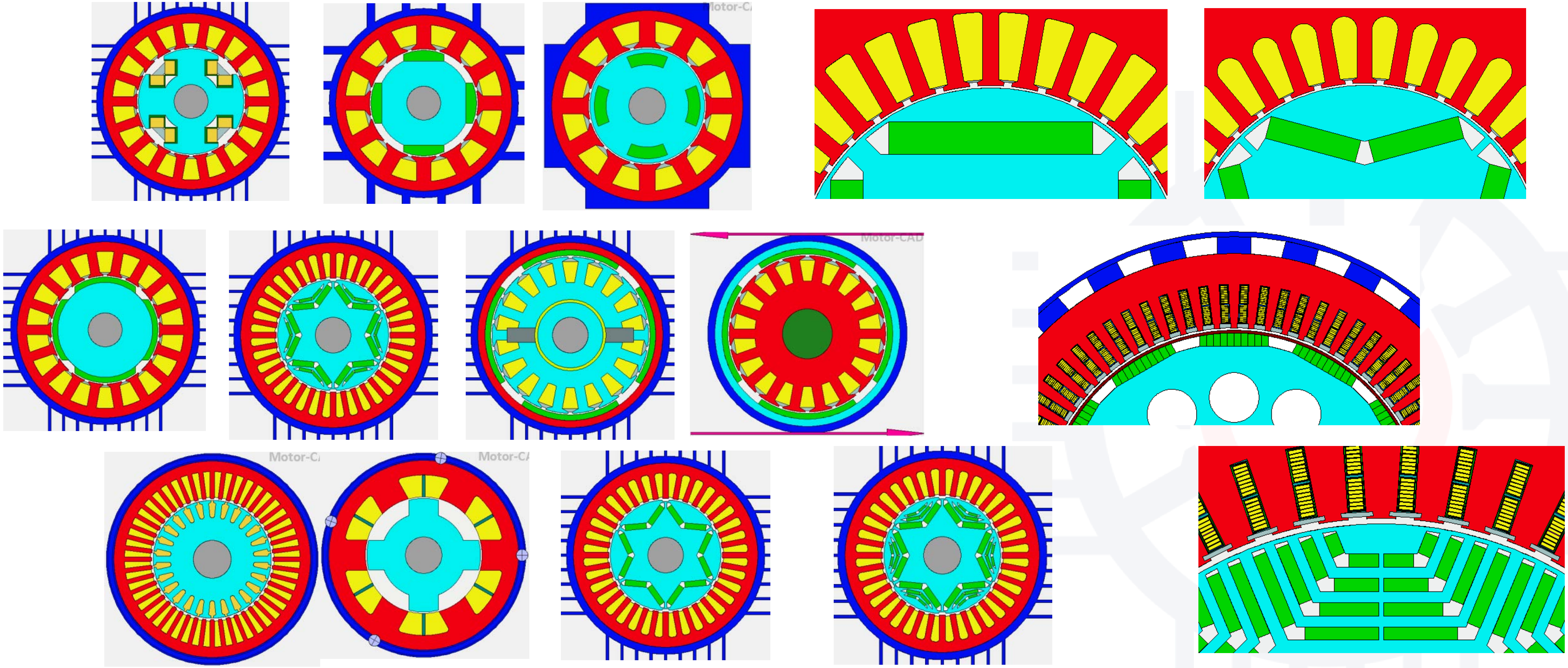
- **EMag**: template driven 2D FEA combined with analytical equations for fast calculation of motors electromagnetic/electrical performance
- **Therm**: heat transfer and flow network circuits automatically set up to give quick steady-state & transient thermal predictions
- **Lab**: provides efficiency mapping, continuous & peak torque envelopes and duty cycle transient thermal analysis within seconds/minutes

Easy and fast model setup and calculation adapted to motor design concept studies and optimisation



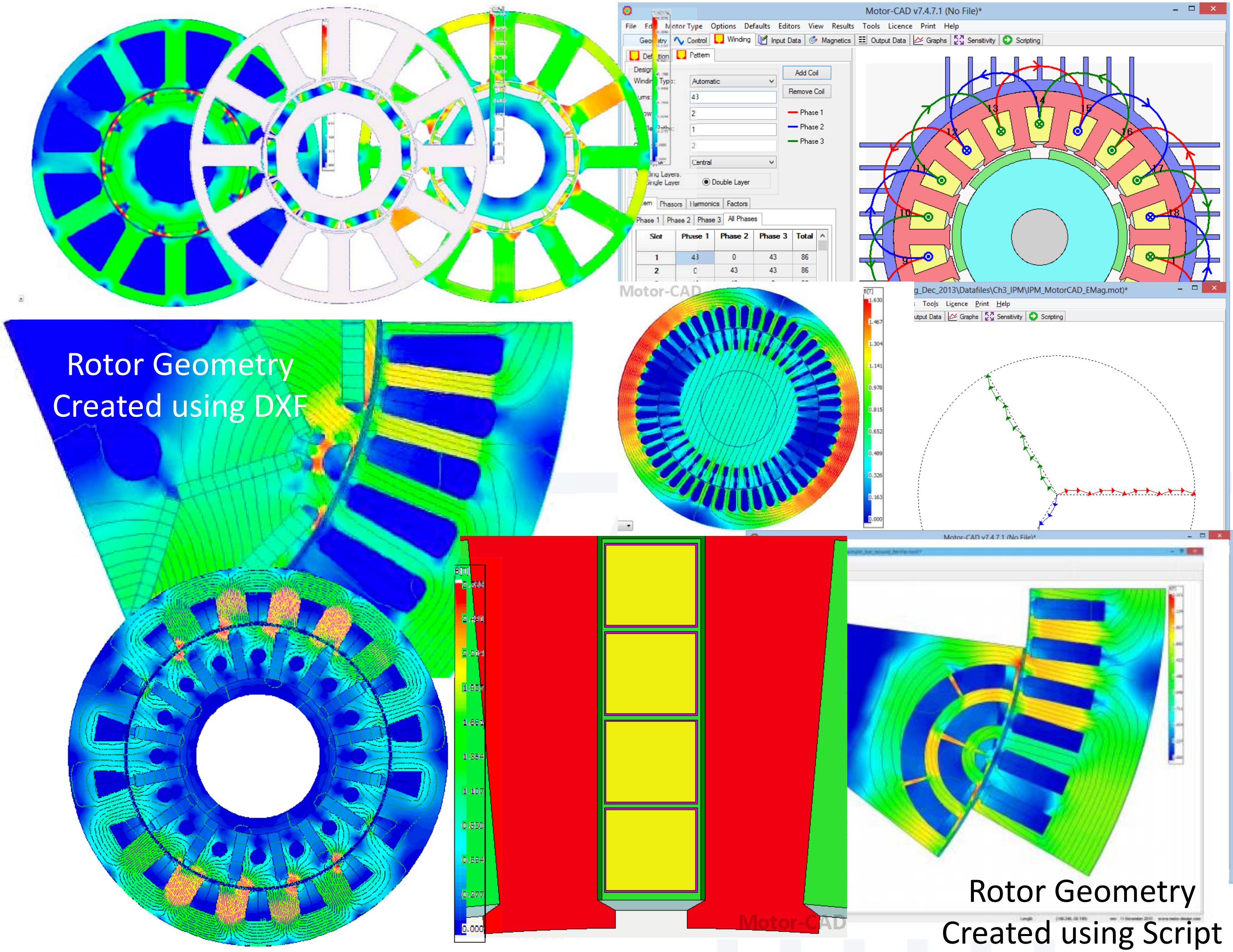
Motor-CAD EMag

Many geometry options for housings, rotors, slots, windings…



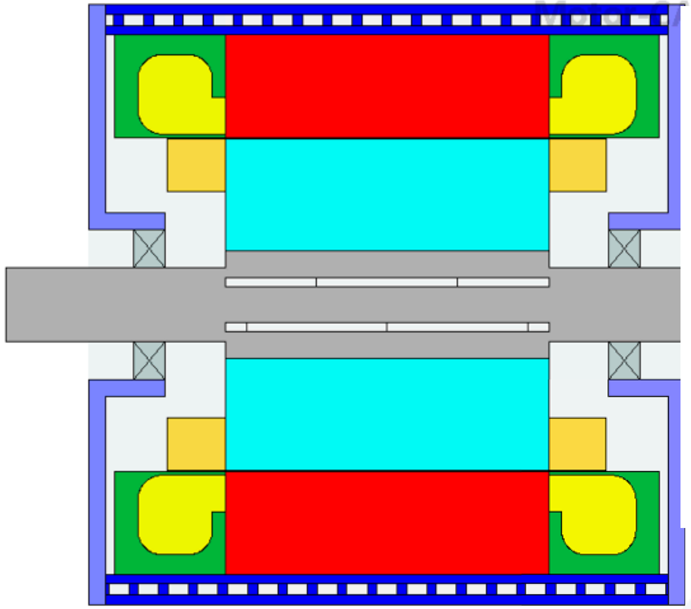
Motor-CAD EMag

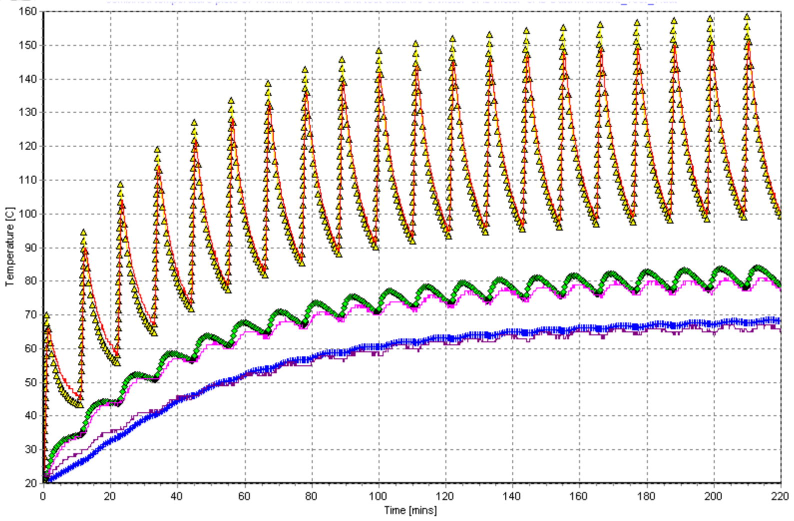
- Extensive range of parametrised templates geometries
- Additional flexible DXF or script based geometry definition
- Fastest FEA electromagnetic solver
- Smart loss calculation algorithms speed up solving
- Standard or custom winding designs

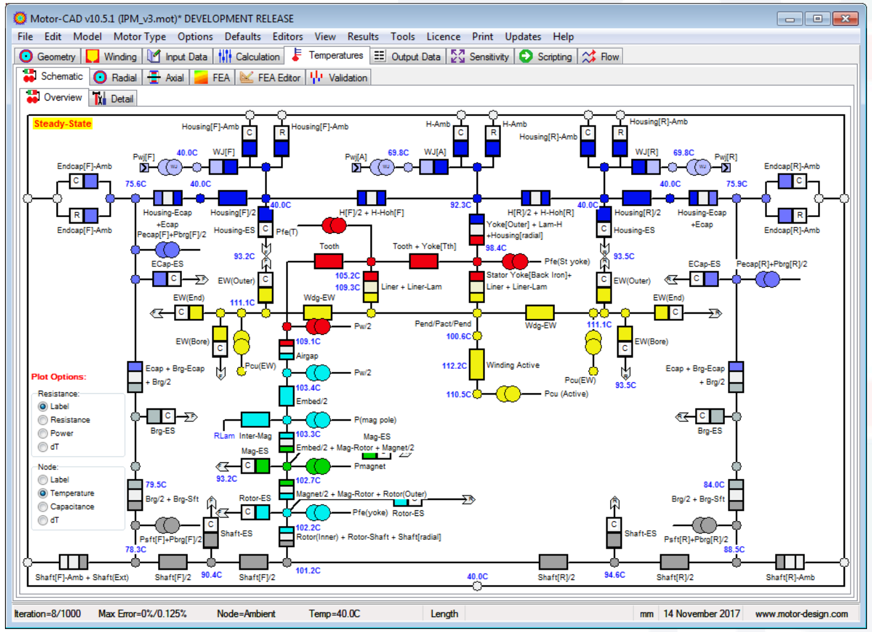


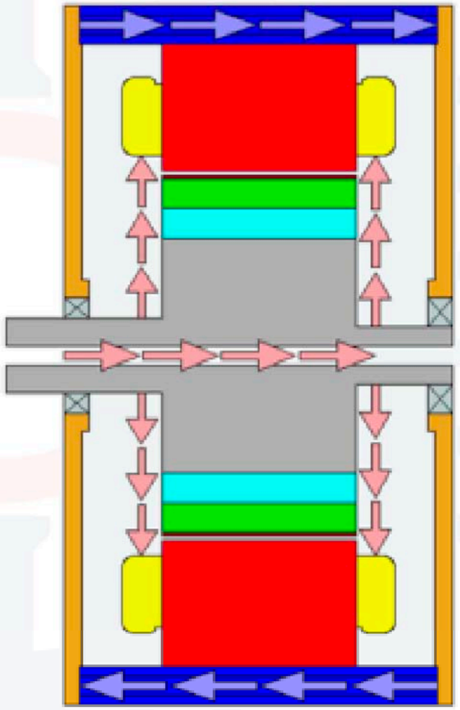
Motor-CAD Therm

- Thermal and flow network analysis of electric motors & generators
- Network set up automatically using proven mathematics for heat transfer and air/fluid flow
- Extensive range of cooling types
- 20 years of practical manufacturing experience built in to assist quantify manufacturing issues
- Able to run complex thermal transient duty cycle analysis



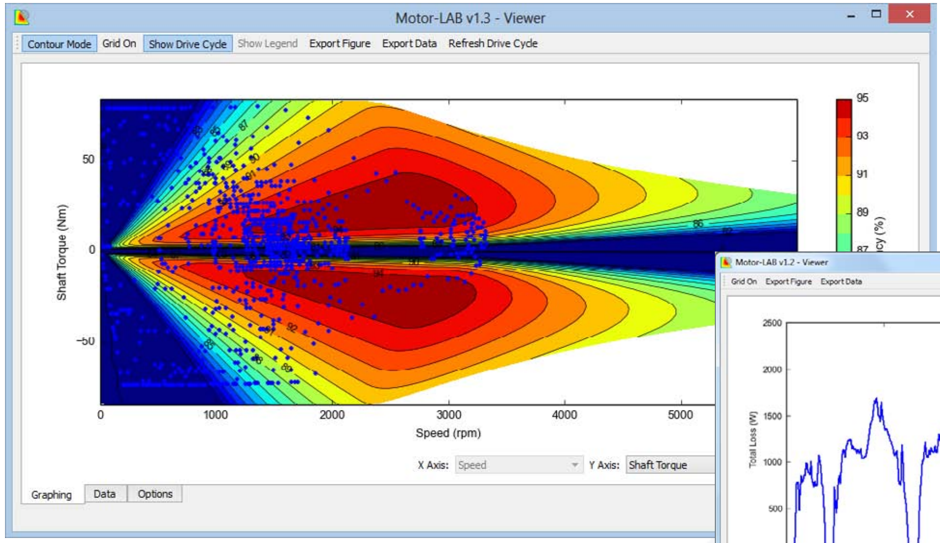


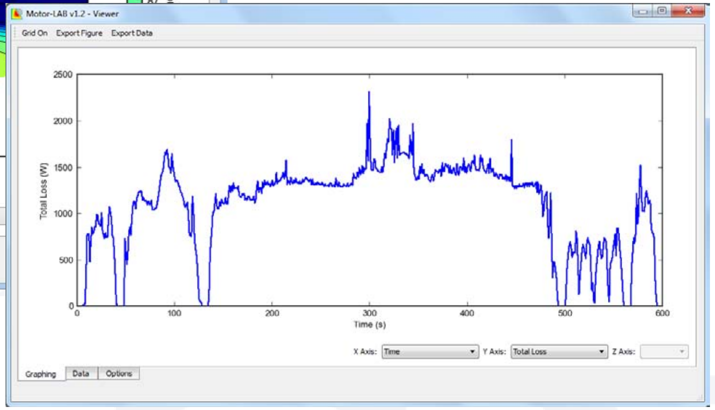


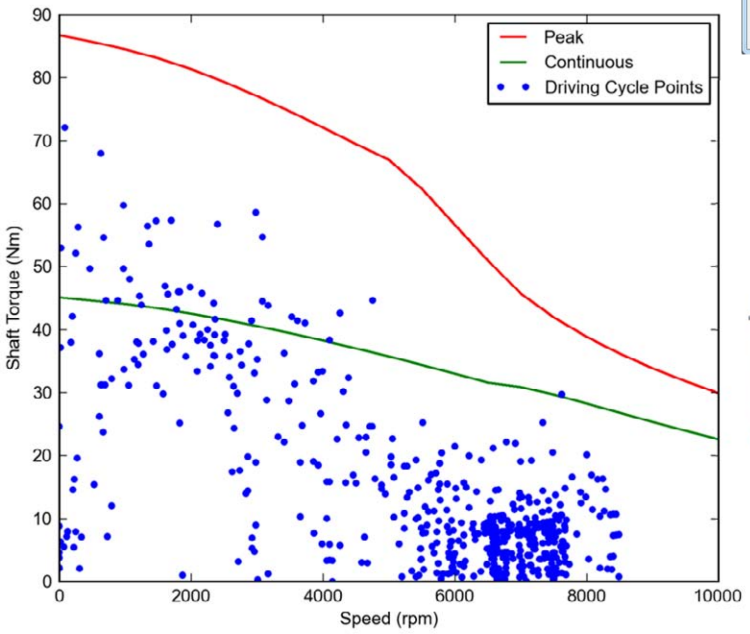


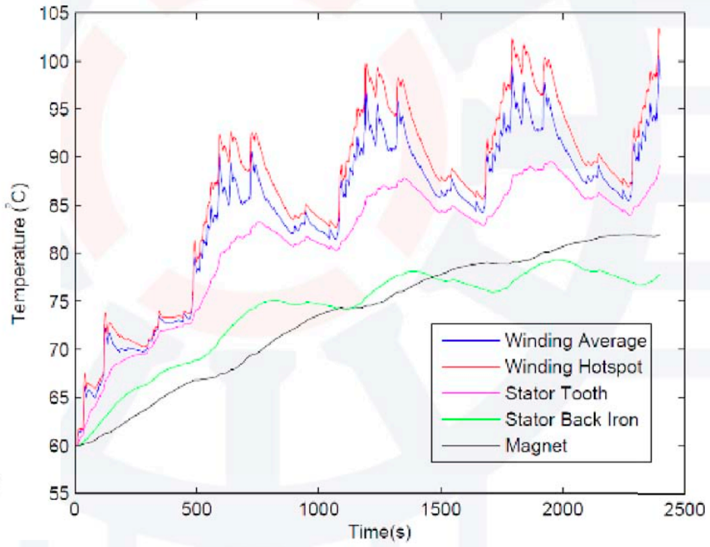
Motor-CAD Lab

- Fast and accurate calculation of the motor electromagnetic and thermal performance over the full torque/speed envelope
- Automated calculation for maximum torque/amp or maximum efficiency control
- Co-simulation between EMag and Therm gives a quick and accurate prediction of the continuous or peak torque envelope within the electrical and thermal limits of the machine

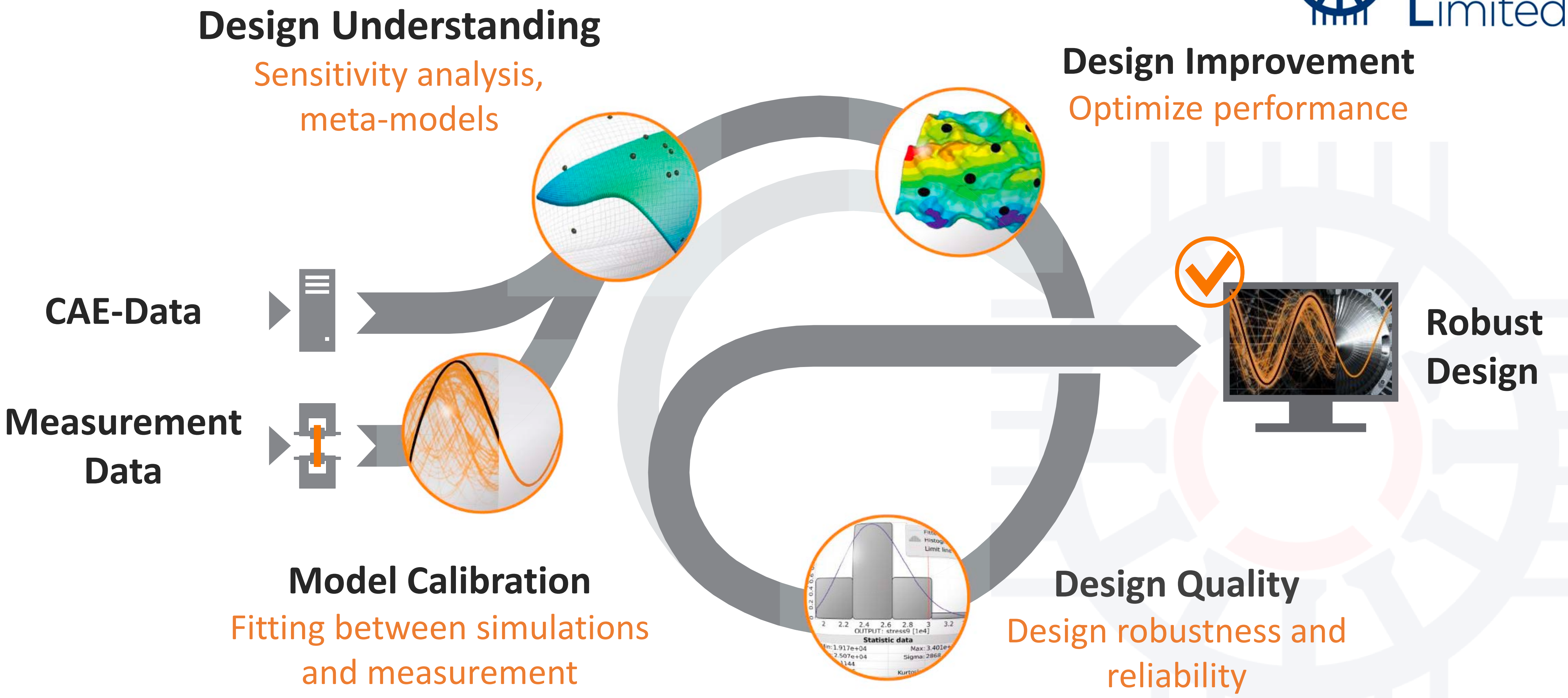








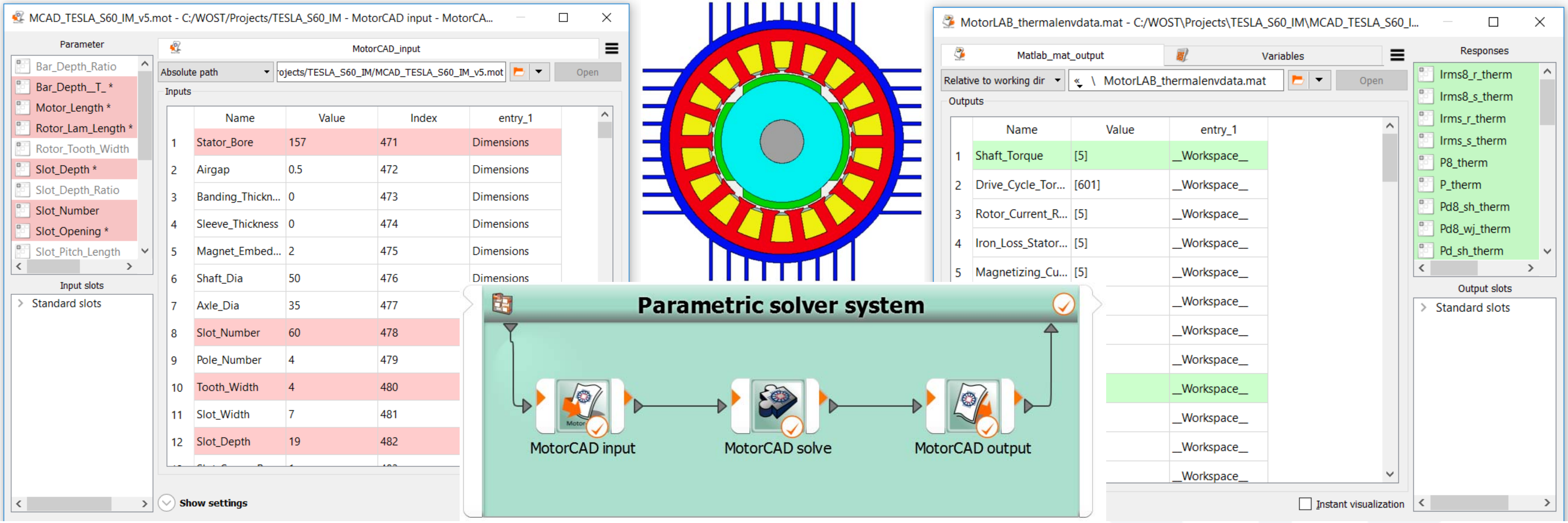
optiSLang software



Motor-CAD and optiSlang

Two process integration using Activex connection and Python scripts

1. Custom integration: convenient solution, easy to use



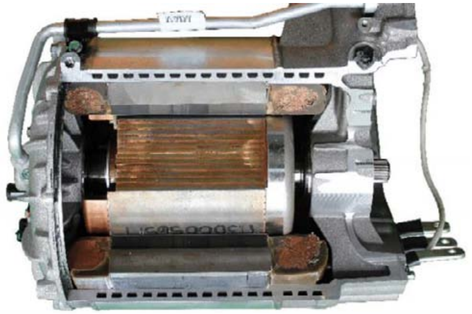
2. Self-made script: more effort required, more flexibility

Case study

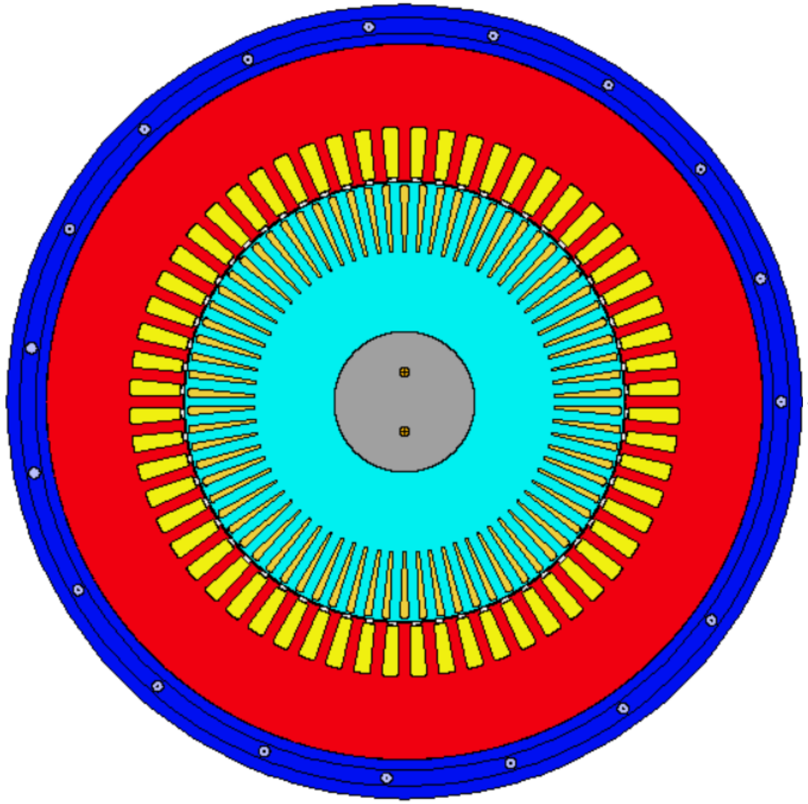
Cage induction motor: TESLA model 60S

Baseline: TESLA 60S

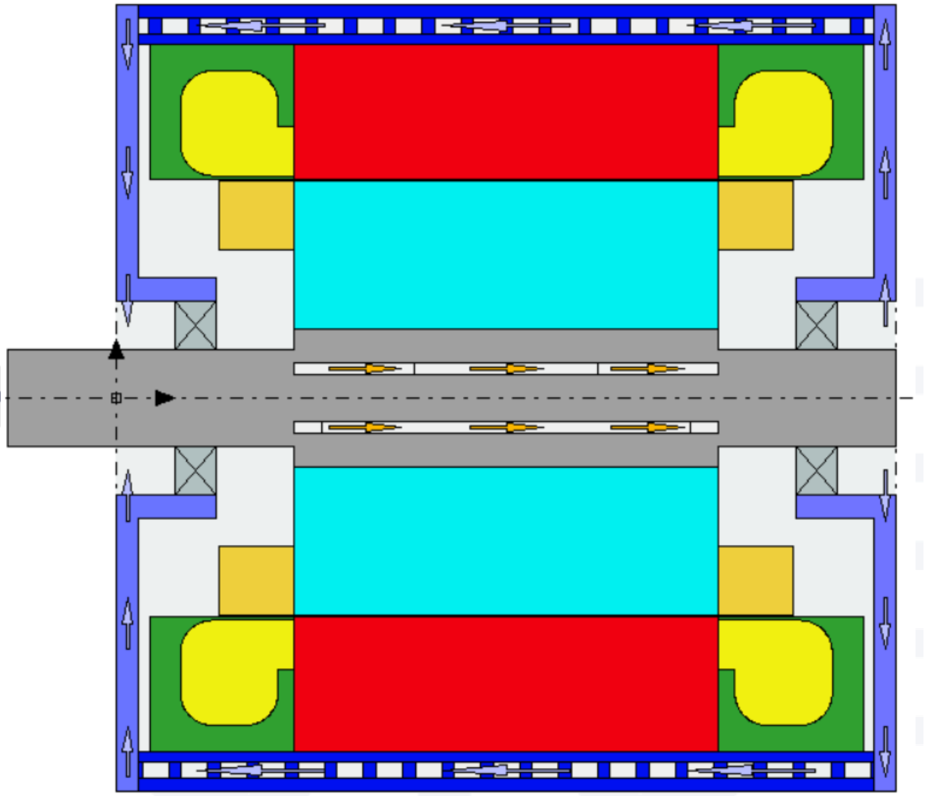
Copper rotor induction motor



Main dimensions	Value [mm]
Stator diameter	254
Housing diameter	282
Stator bore	157
Tooth width	4
Slot depth	19
Slot opening	2.9
Bar depth	23.87
Airgap	0.5
Active length	152
Machine length	280



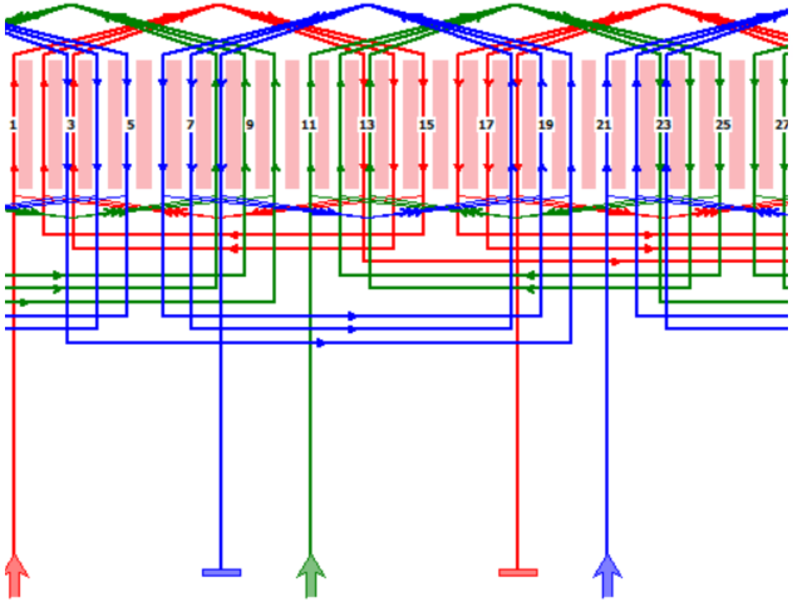
4 poles/60 slots/74 bars

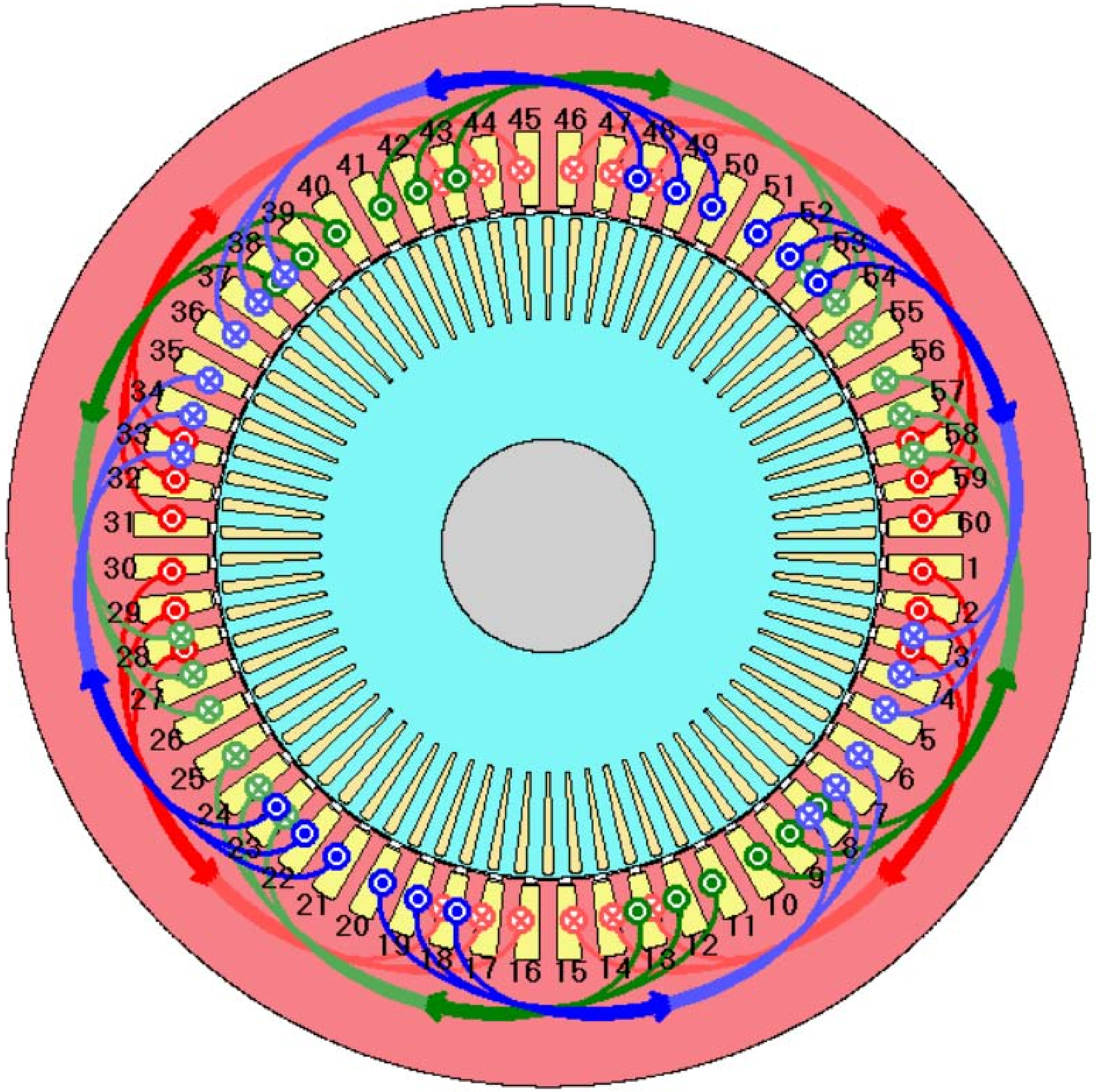


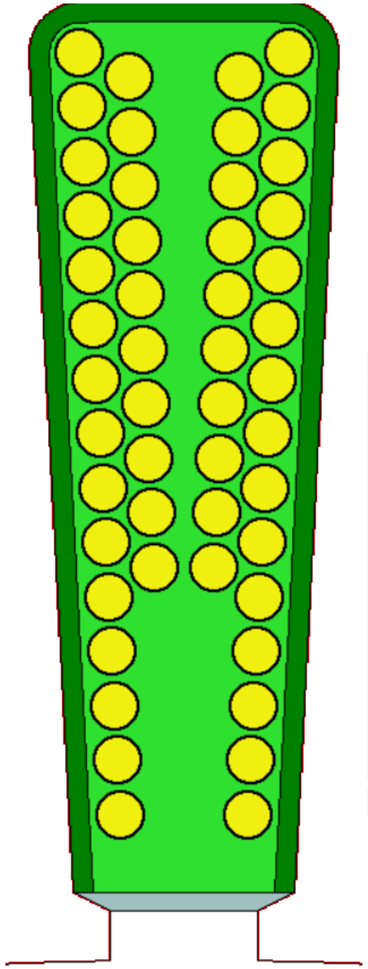
Housing & Shaft cooling

TESLA 60S: winding

Parameter	Value
Parallel paths	2
Turns/coil	1 or 2
Slot fill factor	0.37
Coils/phase	12

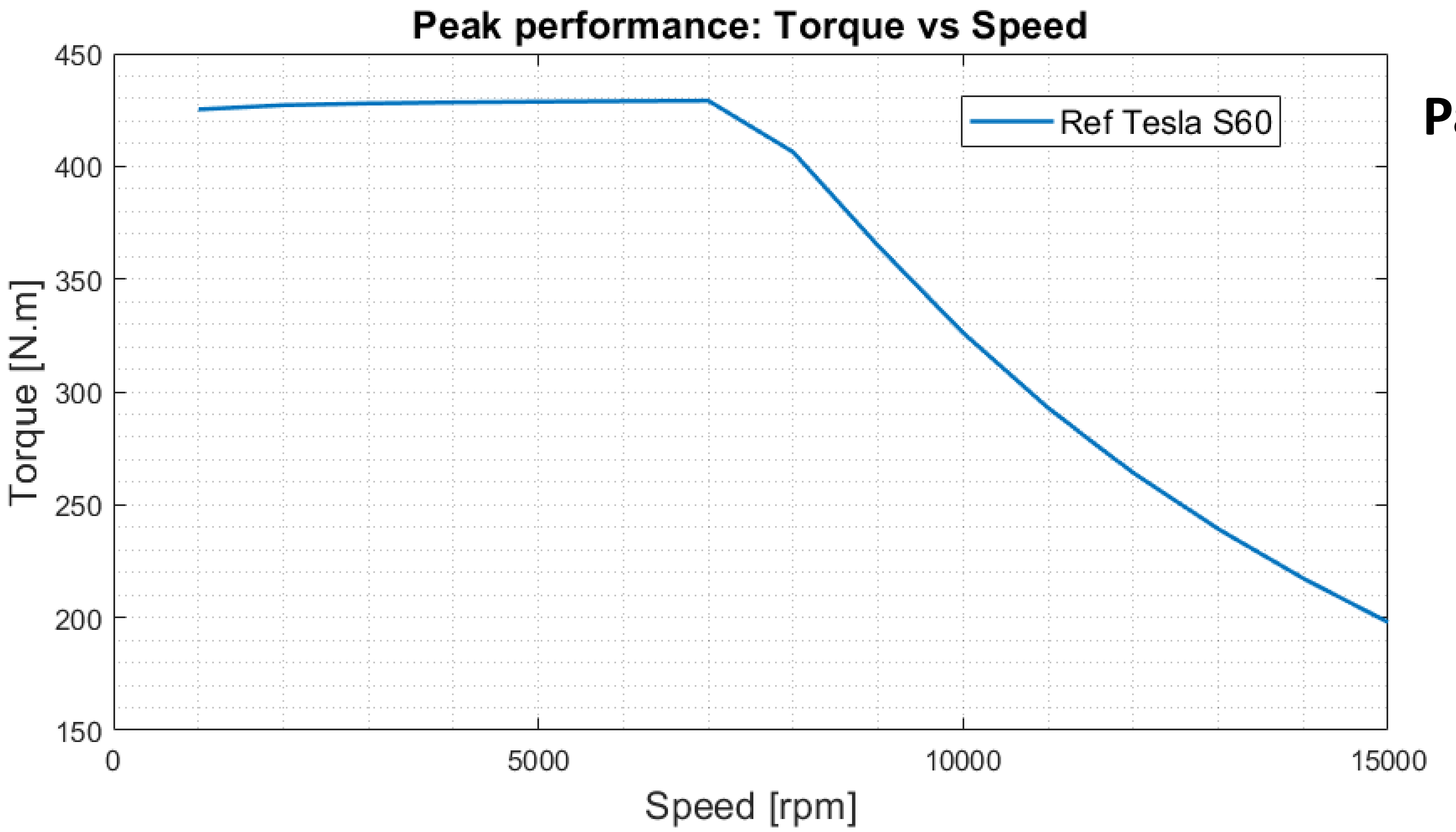






Estimated performance (Motor-CAD Lab)

Peak torque characteristic

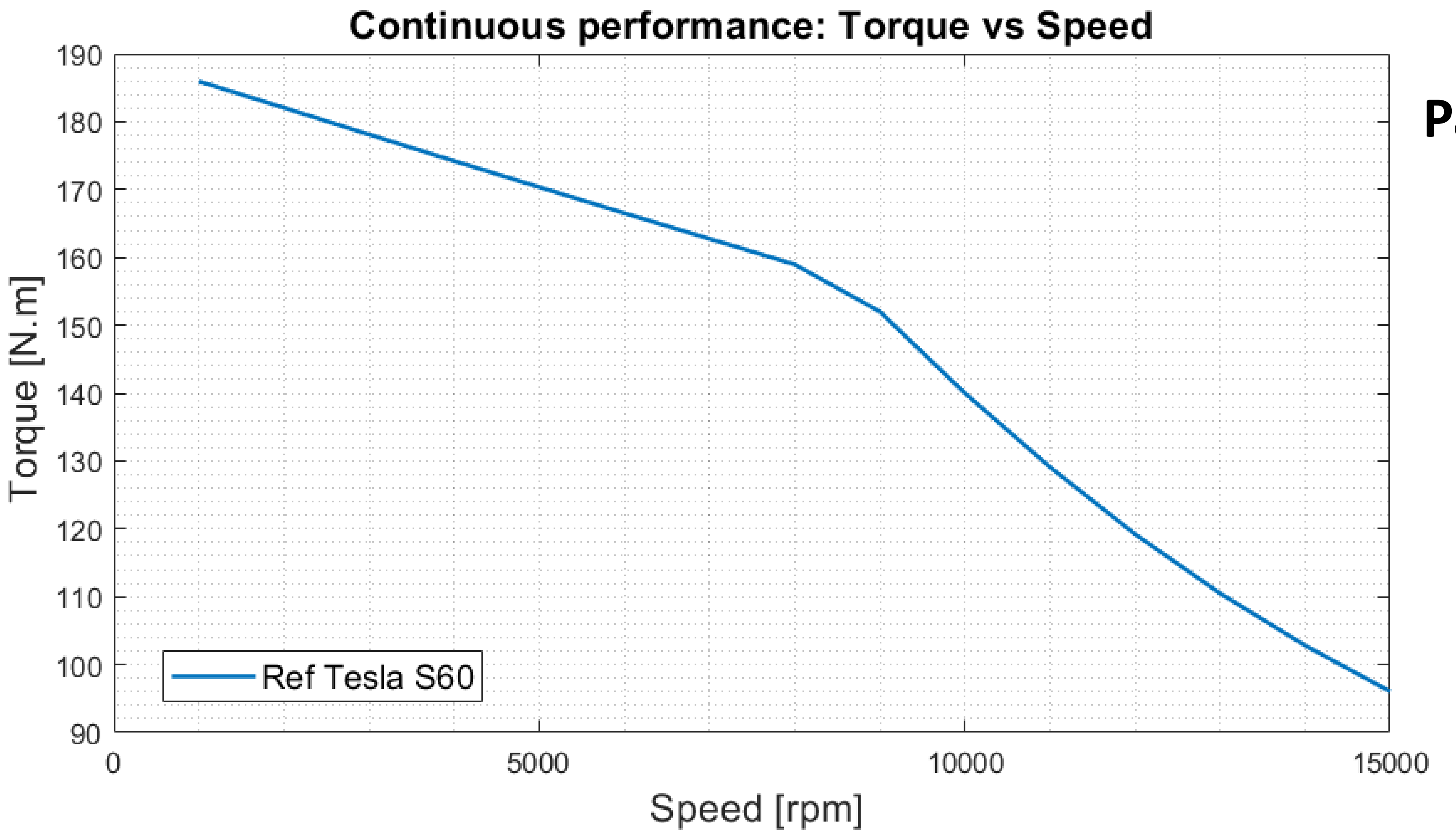


Parameters

- Max. speed: 15krpm
- Max. current: 900Arms
- DC voltage: 366V

Estimated performance (Motor-CAD Lab)

Continuous torque

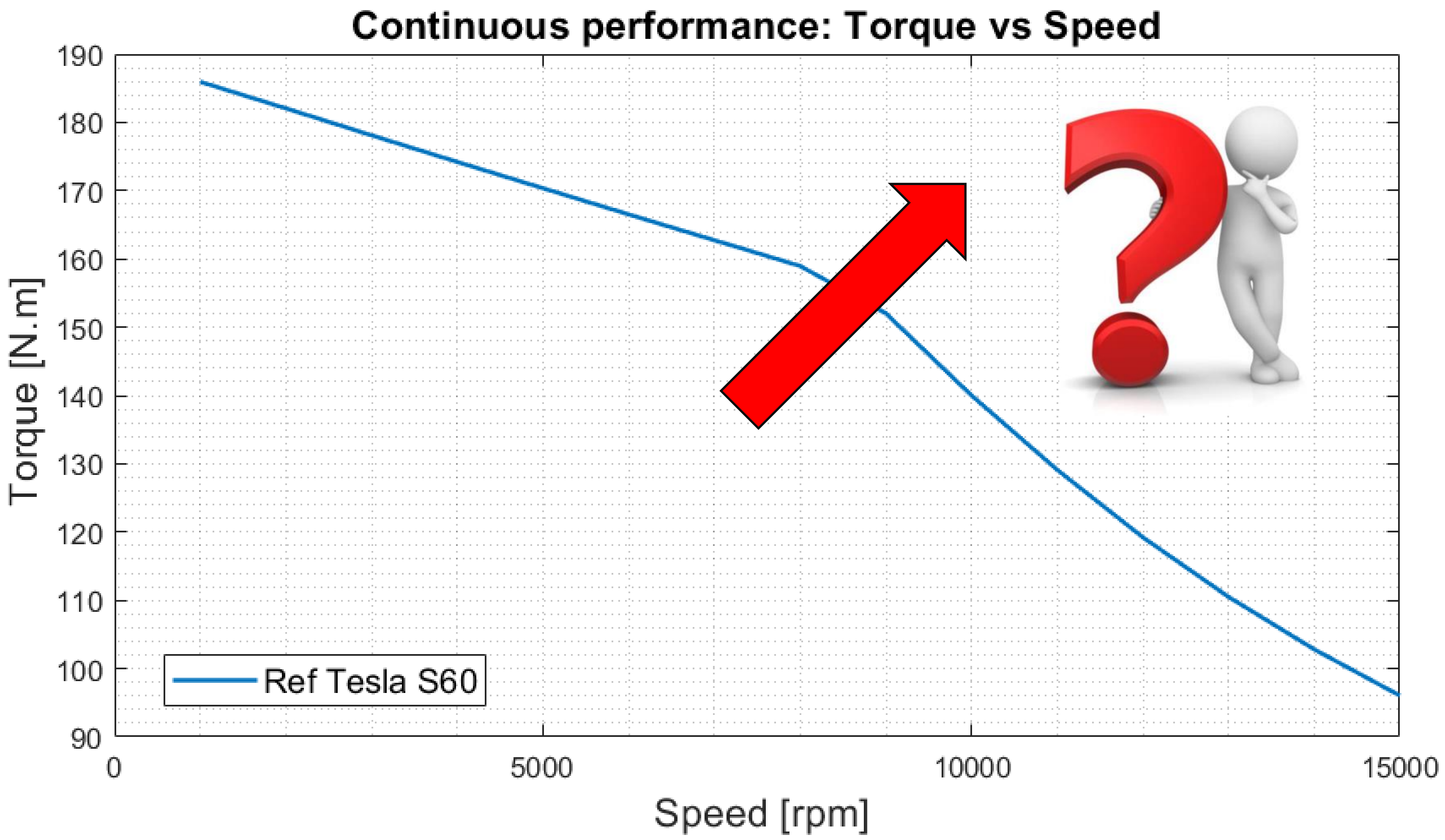


Parameters

- Max. rotor cage temperature: 220C
- Max. stator winding temperature: 180C

Scope of work

Maximize continuous performance



Questions

- How?
- Which drawbacks?
- Which solutions?

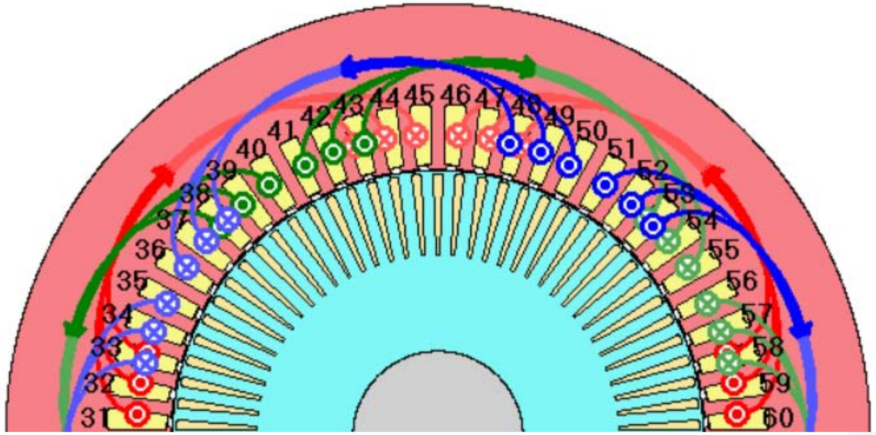
Problem setup

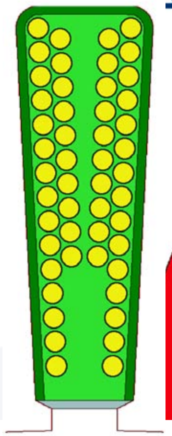
Motor-CAD Lab & optiSlang workflow

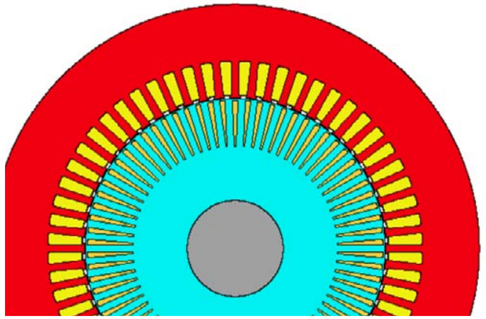
Motor-CAD

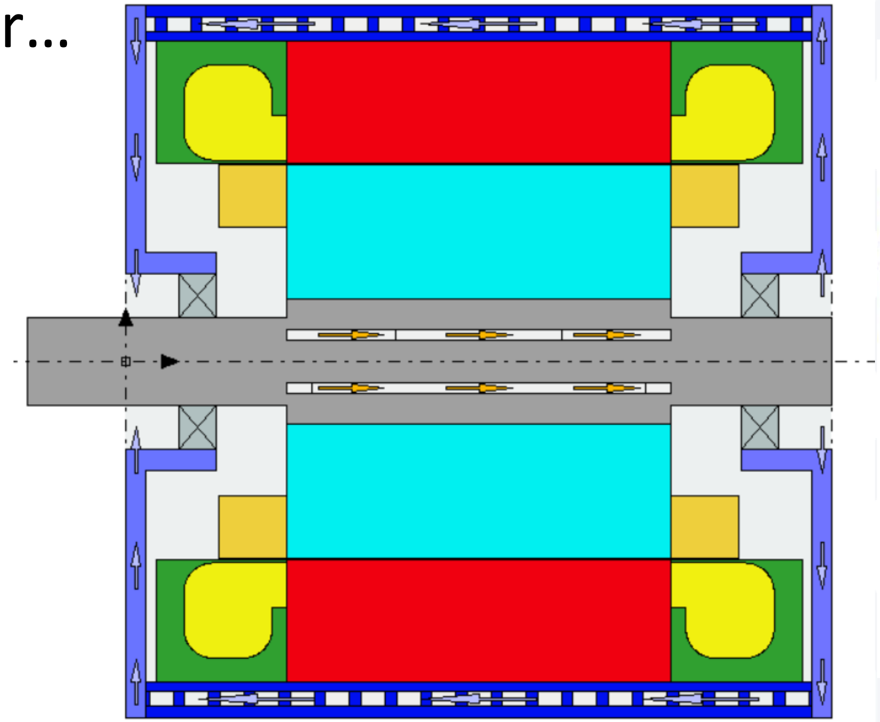
Fixed parameters

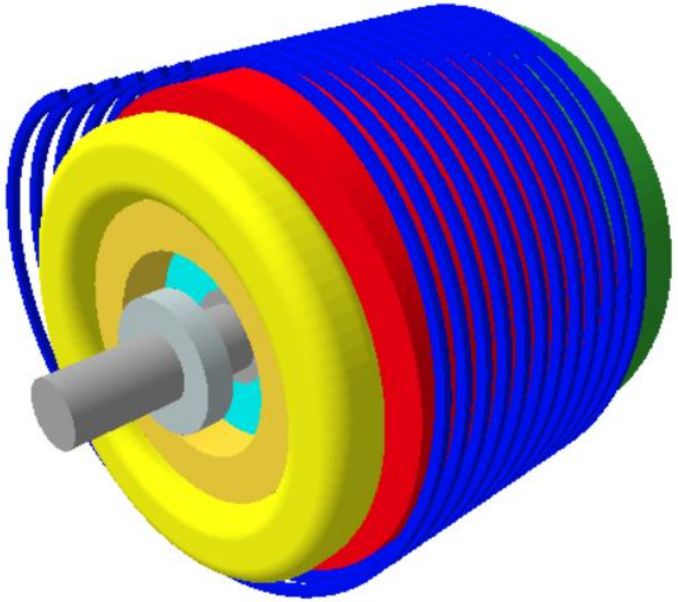
- Maximum envelope
  - ➢ Stator OD, max length
- Winding configuration
  - ➢ Turns/coil, slot fill factor…
- Slot/bar combination
- Cooling system, materials
- Drive settings
  - ➢ Maximum current
  - ➢ DC voltage
- Temperature limits
  - ➢ Rotor & Stator





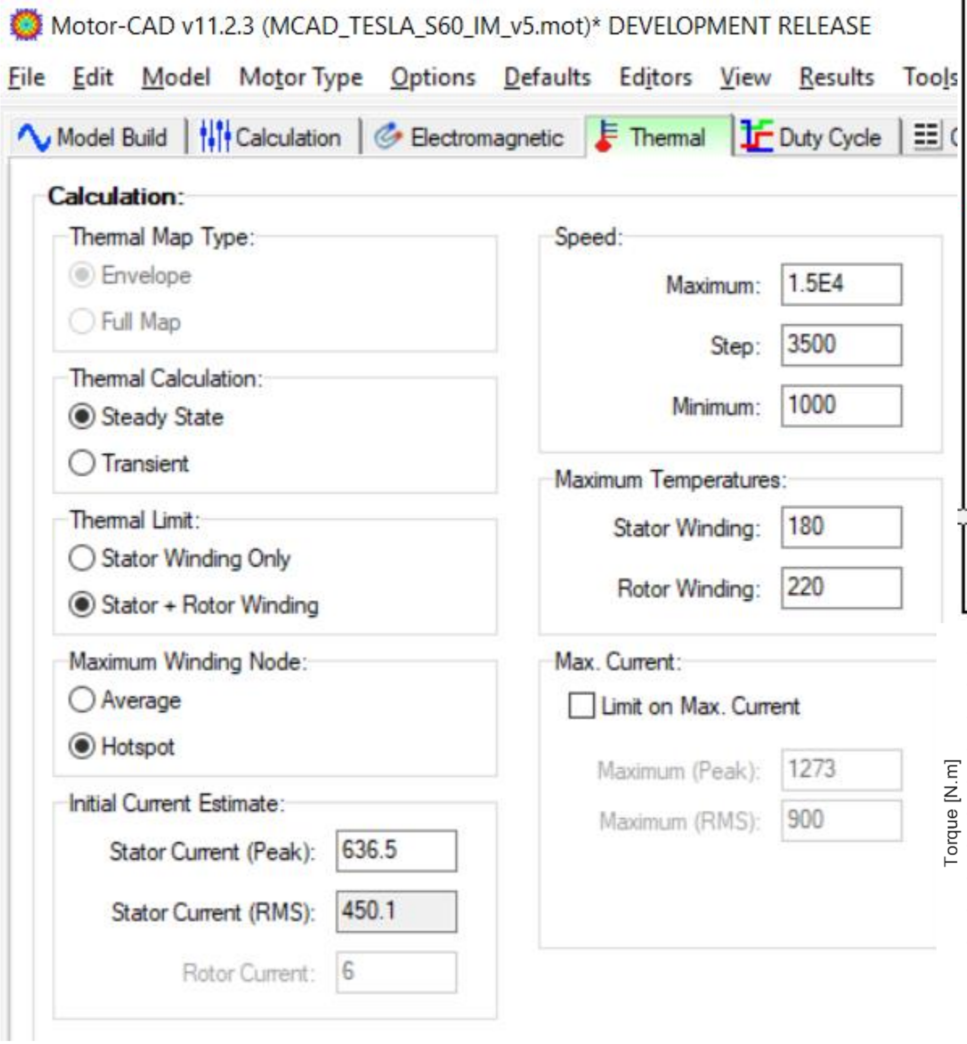


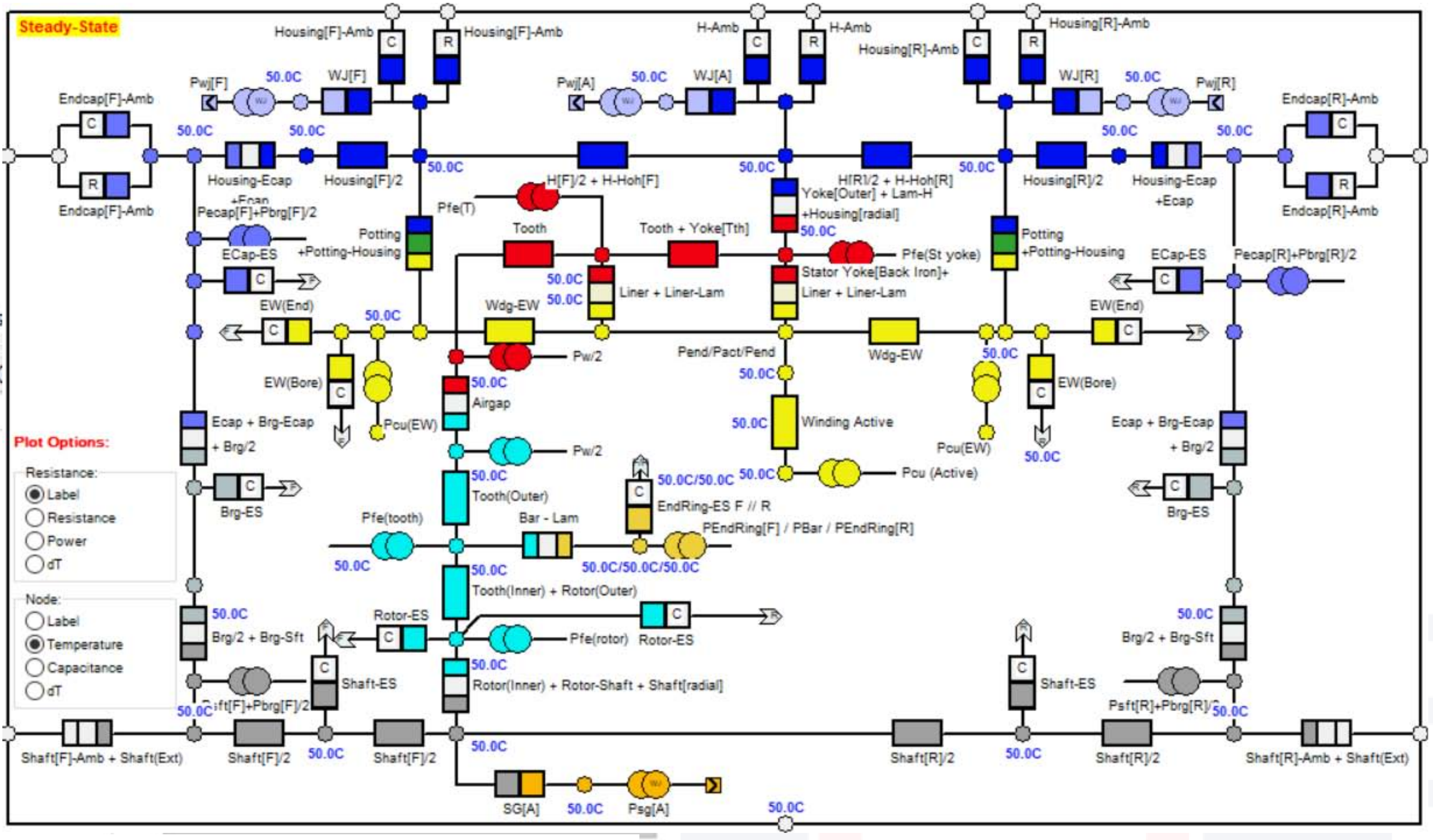


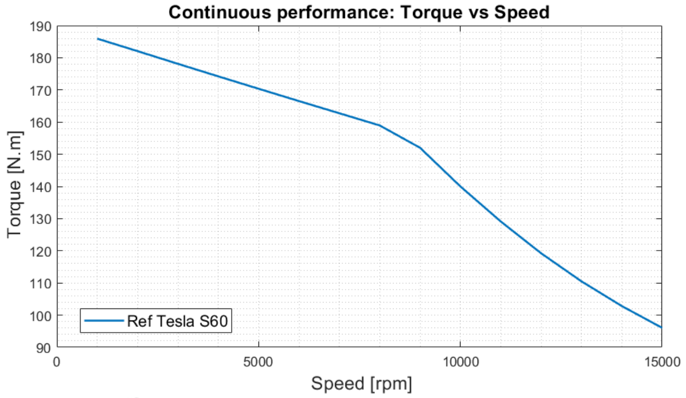


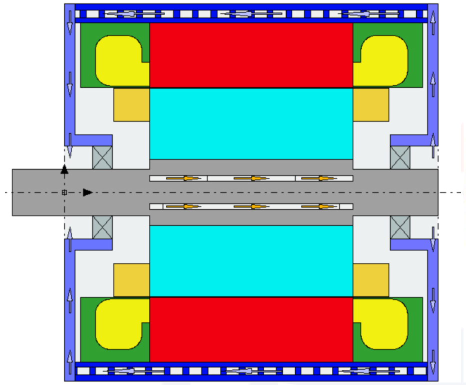
Motor-CAD

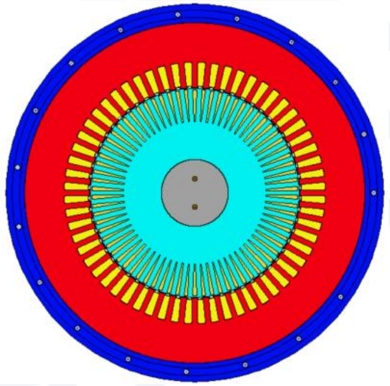
Lab module ⇔ Thermal module





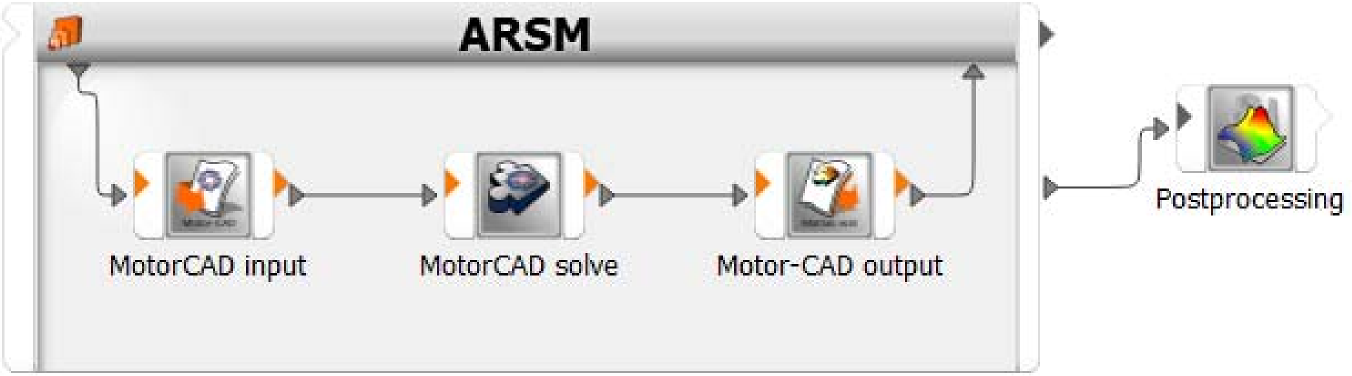






optiSLang

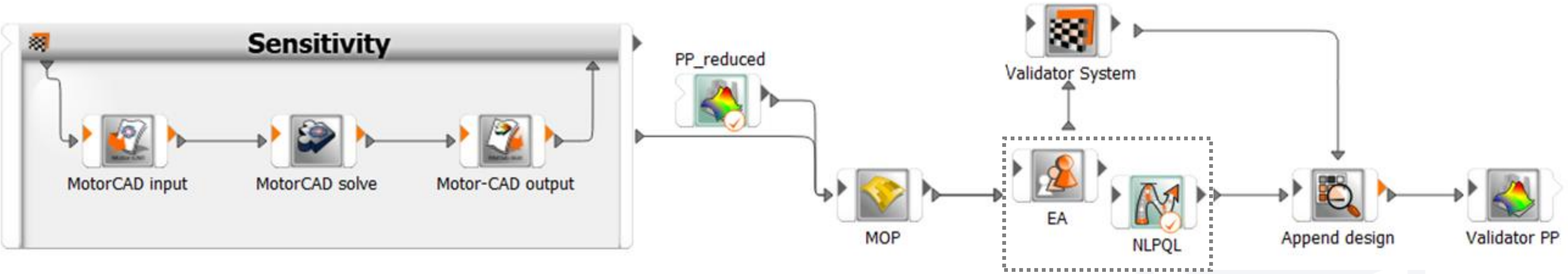
Optimization directly applied to Motor-CAD system



+ More accuracy

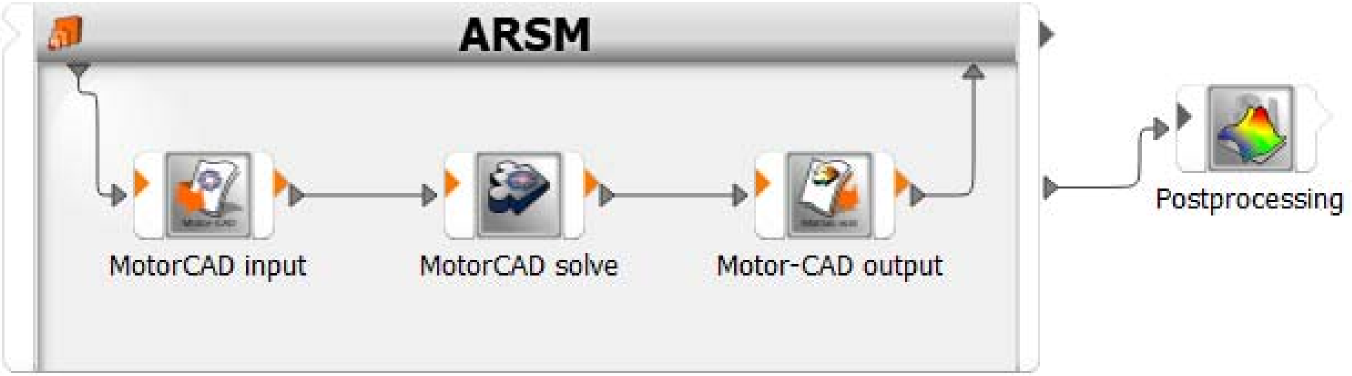
- No understanding of the causality of the problem

Optimization based on sensitivity analysis and meta-models generations



optiSLang

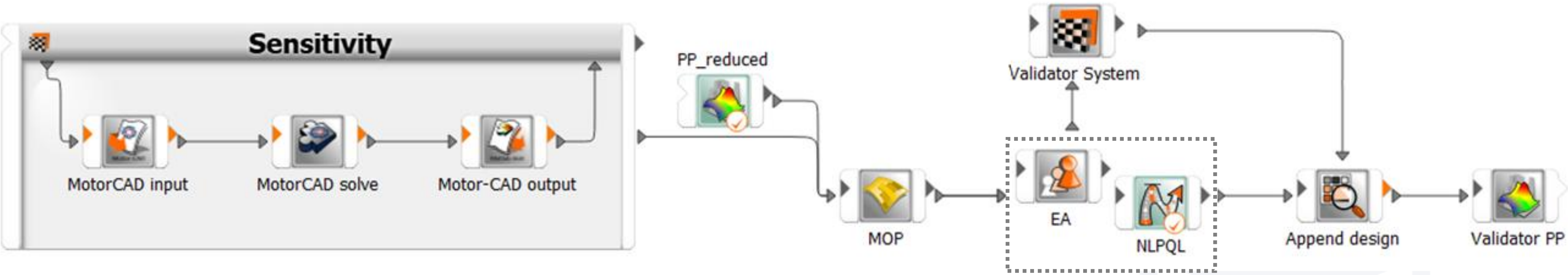
Optimization directly on the Motor-CAD system



- Loss of accuracy

+ Great understanding of the causality of the problem

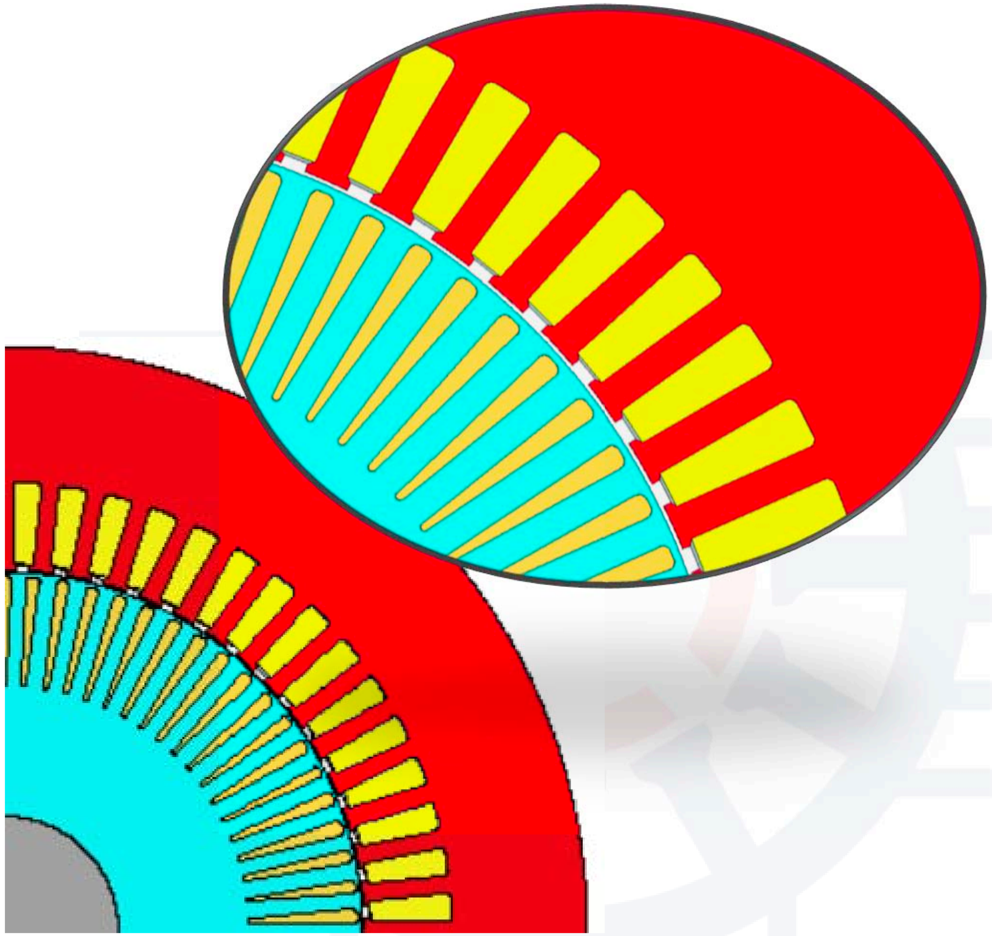
Optimization based on sensitivity analysis and meta-models generations



optiSLang

Variables and bounds

Parameter	Value
Slot depth/Stator thickness	[0.3; 0.6]
Stator ID/stator OD	[0.55; 0.75]
Stator tooth width/Slot pitch	[0.3; 0.6]
Rotor bar depth/Rotor thickness	[0.55; 0.75]
Active length	[90; 152] mm
Rotor tooth width	[2.5; 3.7] mm



Results

From the sensitivity analysis to the optimization

Sensitivity analysis

Advanced Latin Hypercule Sampling, 250 designs, all succeeded

Motor Design Limited

Sensi_LAB - Sensitivity

Parameter | Start designs | Criteria | Dynamic sampling | Other | Result designs

	Id	Feasible	Duplicates	Status	Bar_Depth_Ratio	Bar_Depth__T_	Motor_Length	Rotor_Lam_Length	Rotor_Tooth_Width	Slot_Depth	Slot_Depth_Ratio
1	0.1	true		Succeeded	0.2535	11.1638	262.02	134.02	3.1984	33.3775	0.5898
2	0.2	true		Succeeded	0.2995	13.22	263.012	135.012	3.3808	29.2503	0.5178
3	0.3	true		Succeeded	0.3615	17.7564	252.844	124.844	3.4096	22.4692	0.4362
4	0.4	true		Succeeded	0.4155	18.8469	260.284	132.284	2.7712	21.058	0.381
5	0.5	true		Succeeded	0.3025	14.5511	278.388	150.388	3.6352	22.8493	0.435
249	0.249	true		Succeeded	0.4815	29.3744	272.932	144.932	3.5632	21.8487	0.5514
250	0.250	true		Succeeded	0.4895	25.1378	245.404	117.404	3.6976	19.7203	0.4002

Selection mode: Designs Columns Individual Cells

Instant visualization

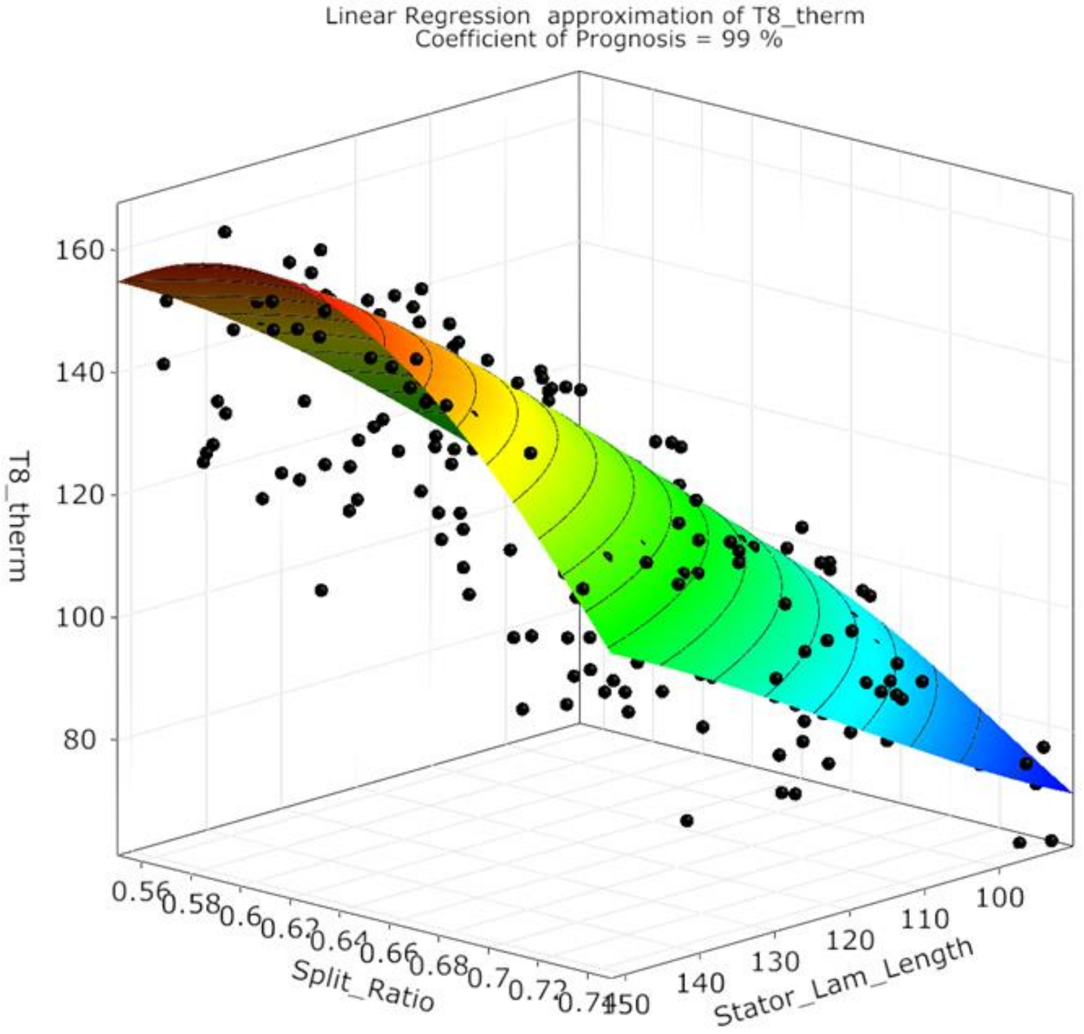
Use as start design(s)

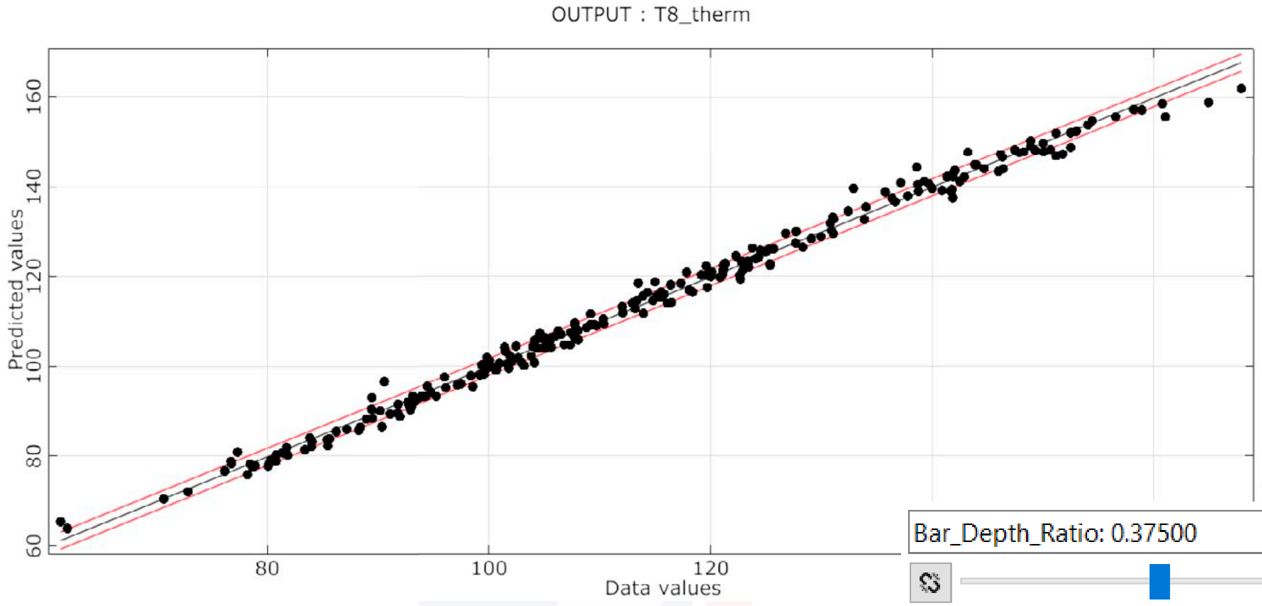
Show additional options

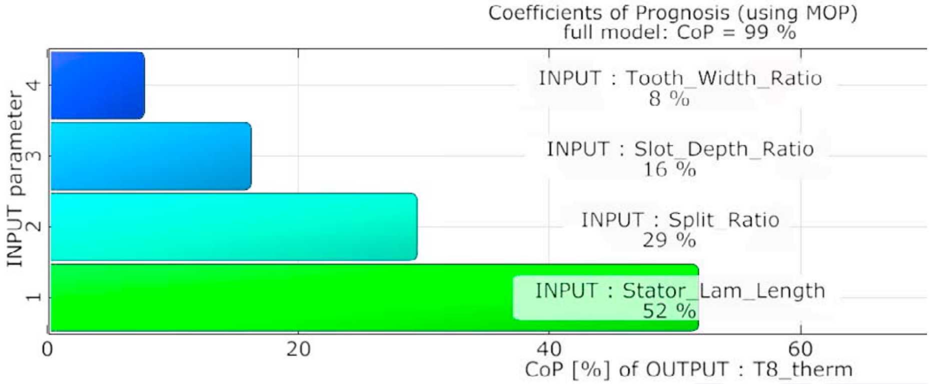
OK Cancel Apply

Meta model of prognosis (MOP)

Meta-model for the torque at 8000rpm







Bar_Depth_Ratio: 0.37500

Slot_Depth_Ratio: 0.45000

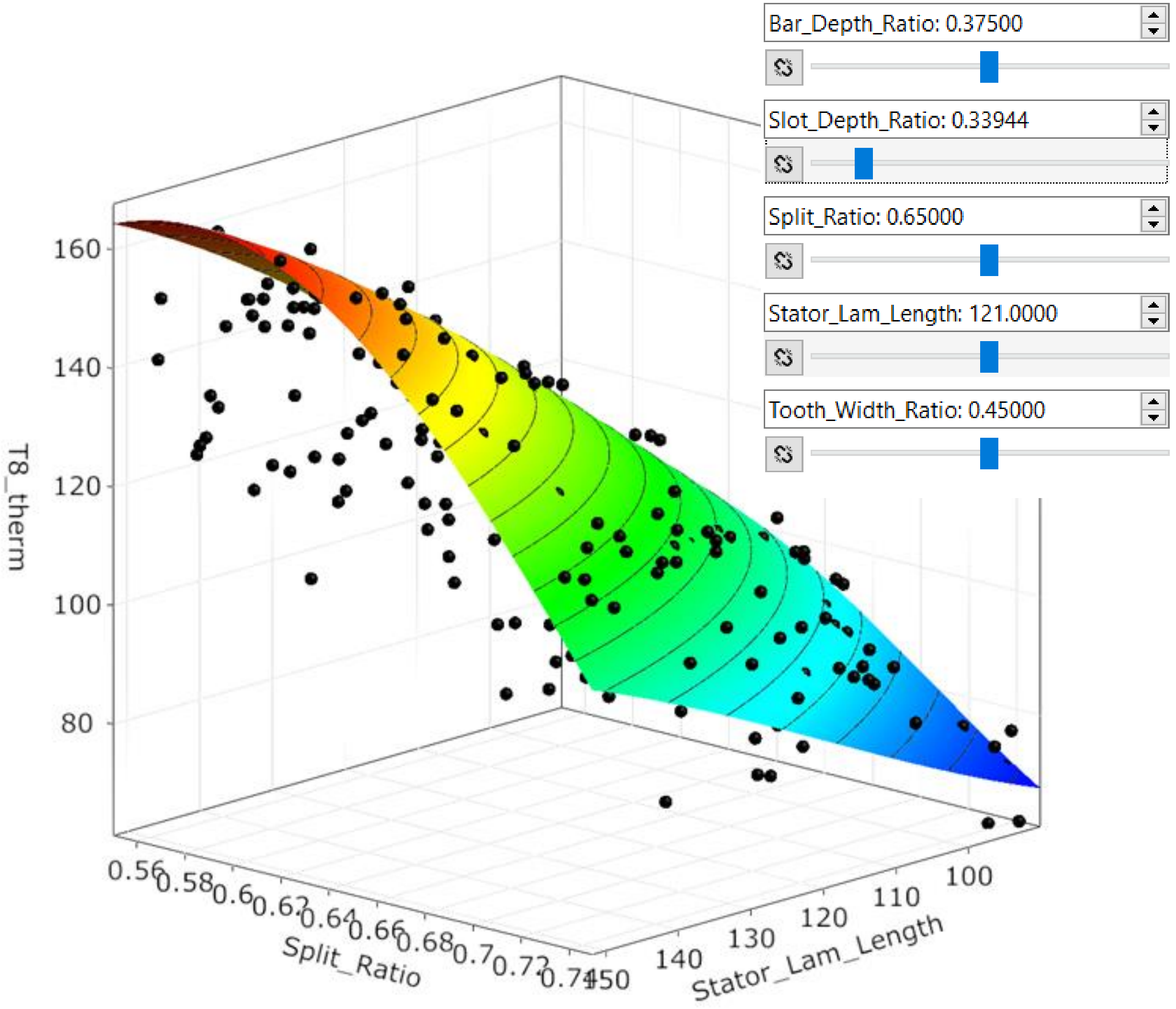
Split_Ratio: 0.65000

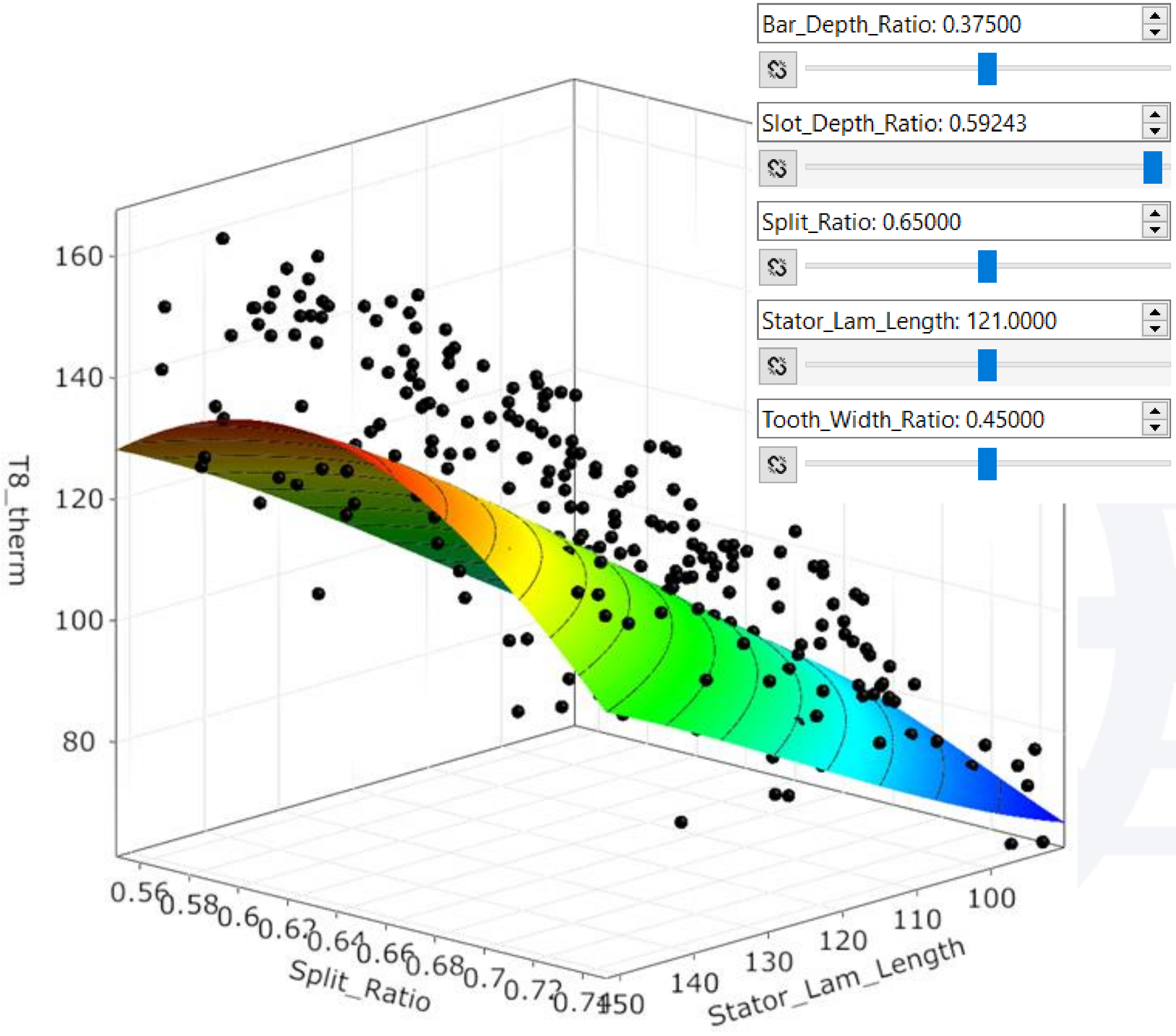
Stator_Lam_Length: 121.0000

Tooth_Width_Ratio: 0.45000

Meta model of prognosis (MOP)

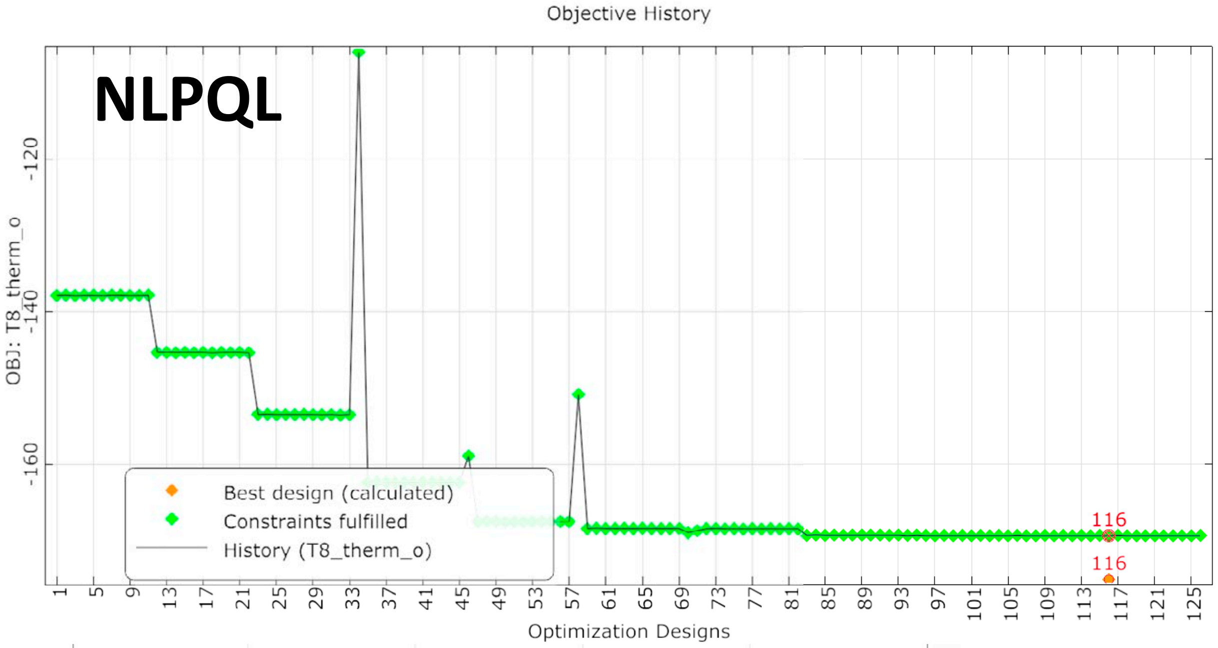
Slot depth ratio impact

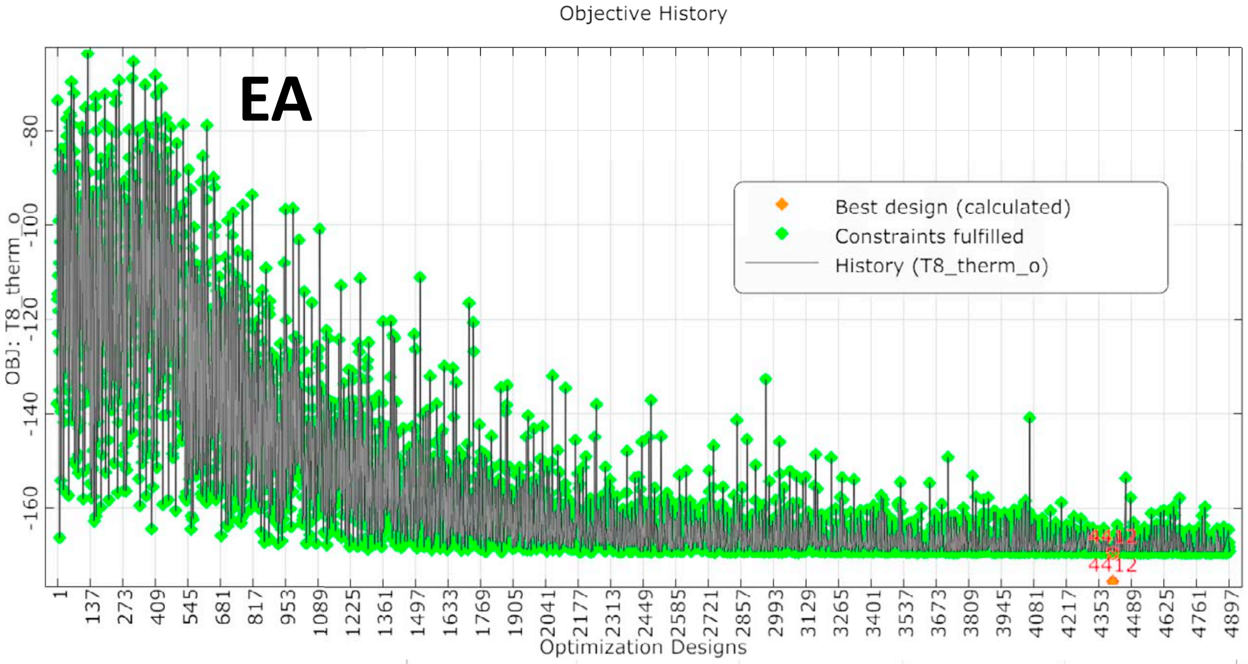


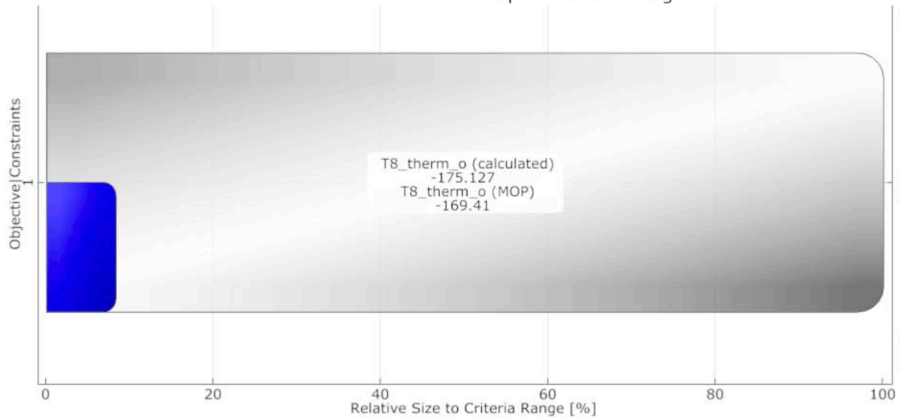


Single-objective optimization: EA & NLPQL

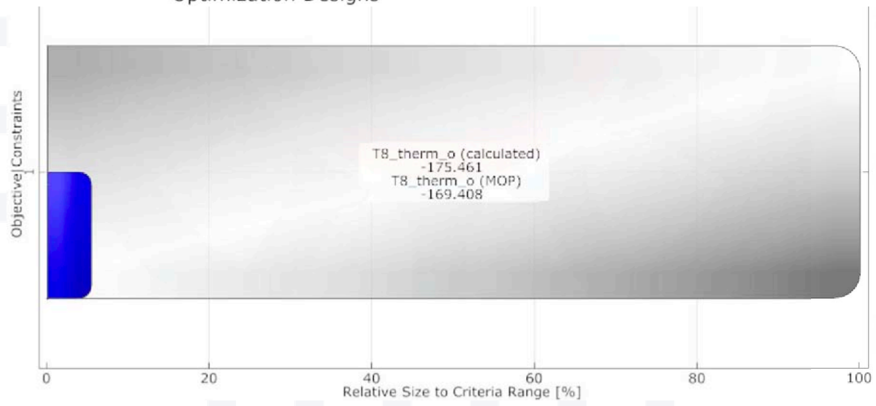
- Similar designs obtained from EA and NLPQL optimizers





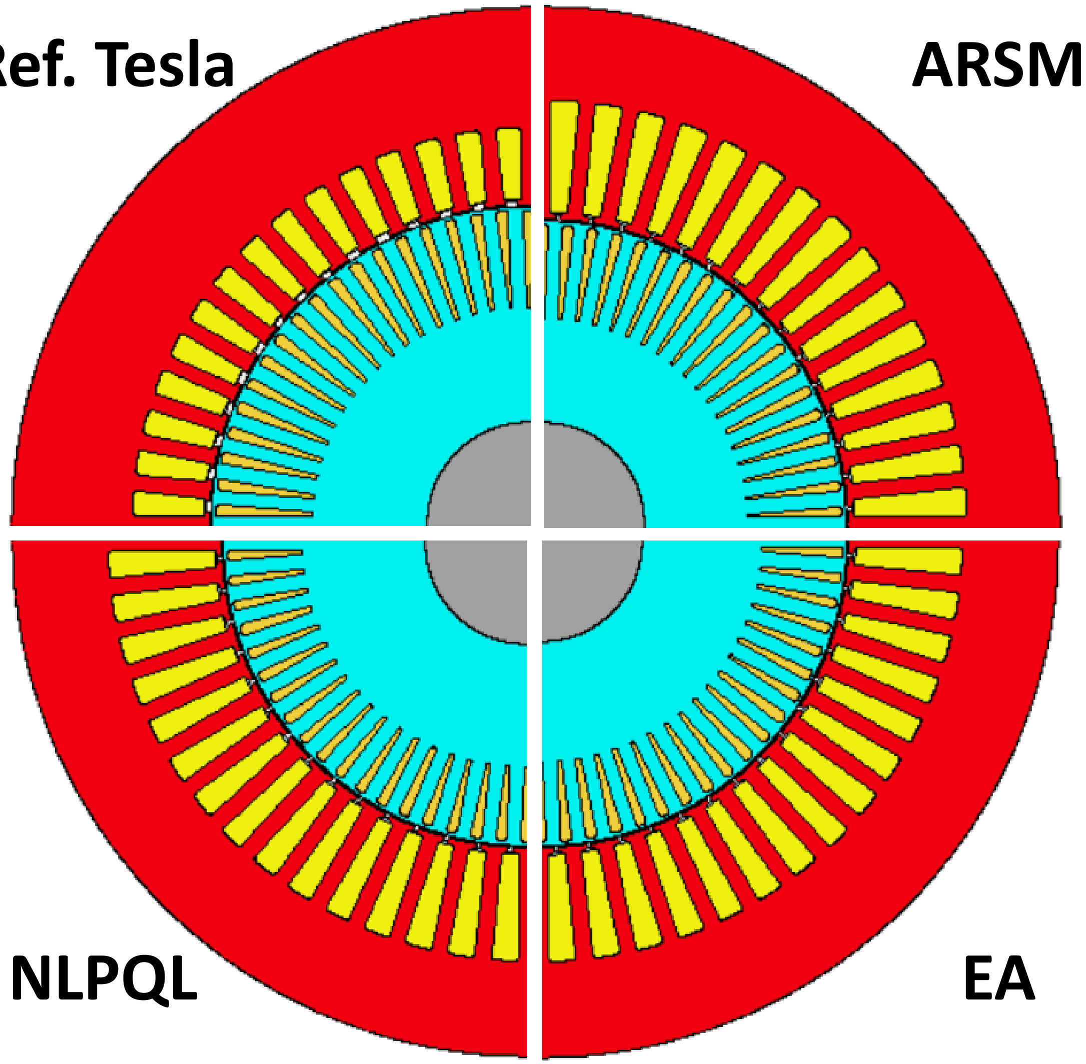


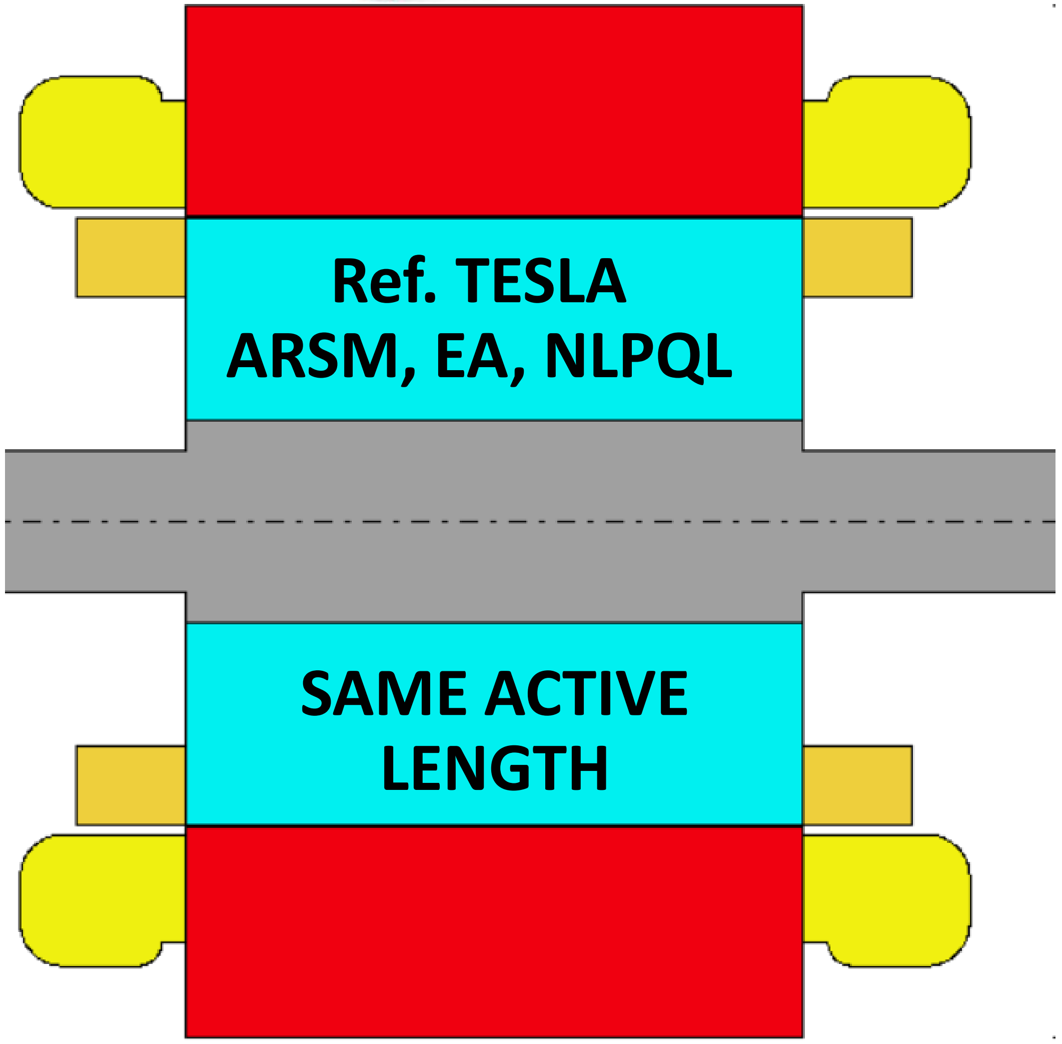
~ 3.5% error between MOP & Motor-CAD



Single-objective optimization

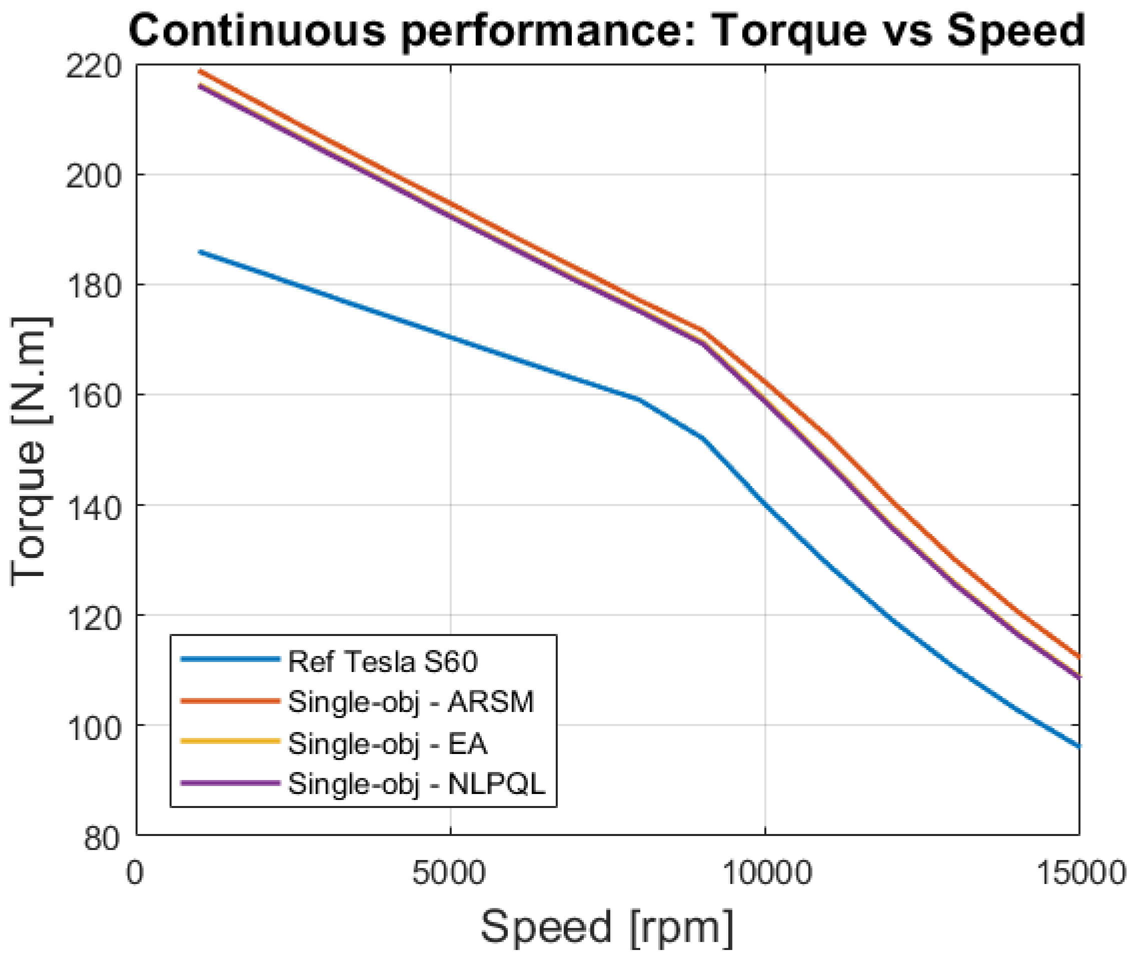
Torque maximisation (continuous operation, 8000rpm)

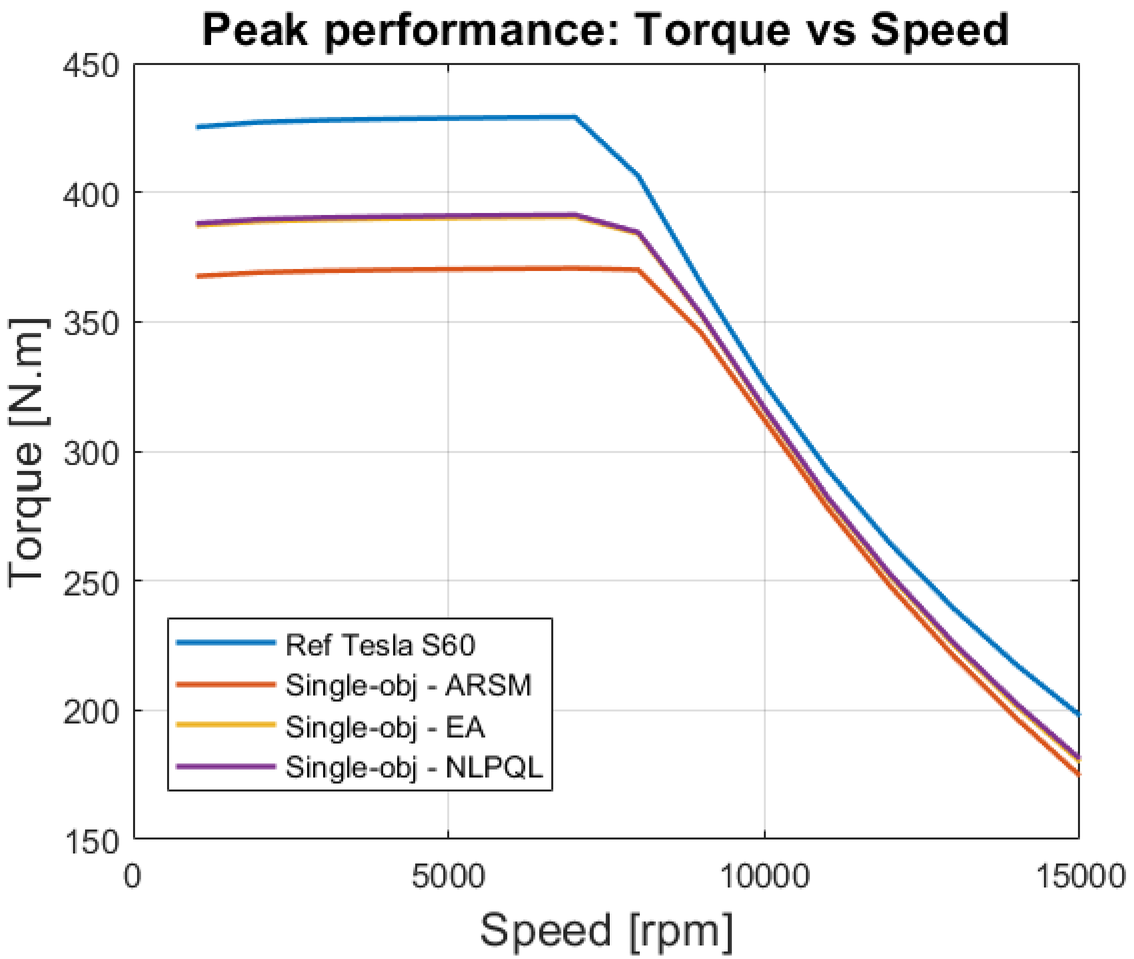




Single-objective optimization

Trade-off between continuous & peak performance!



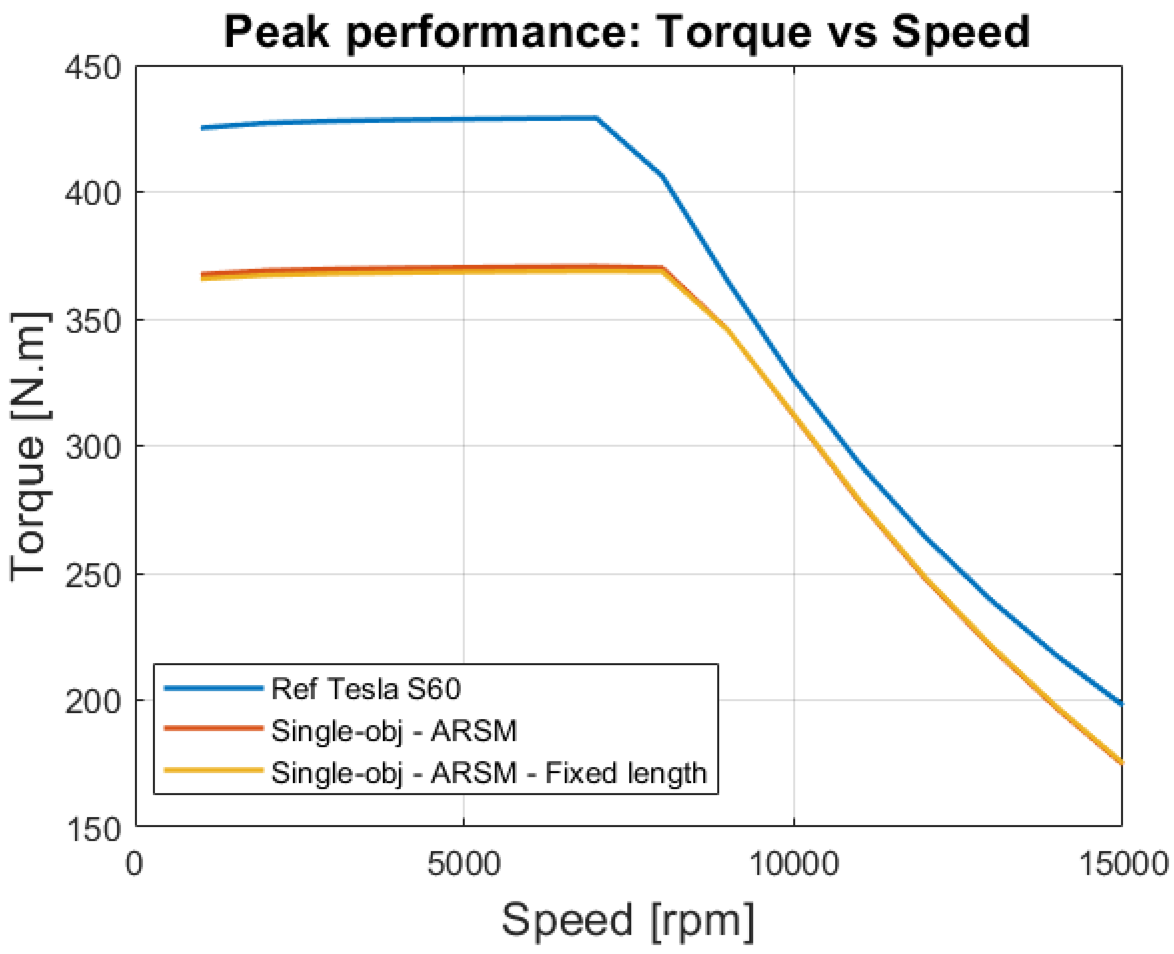


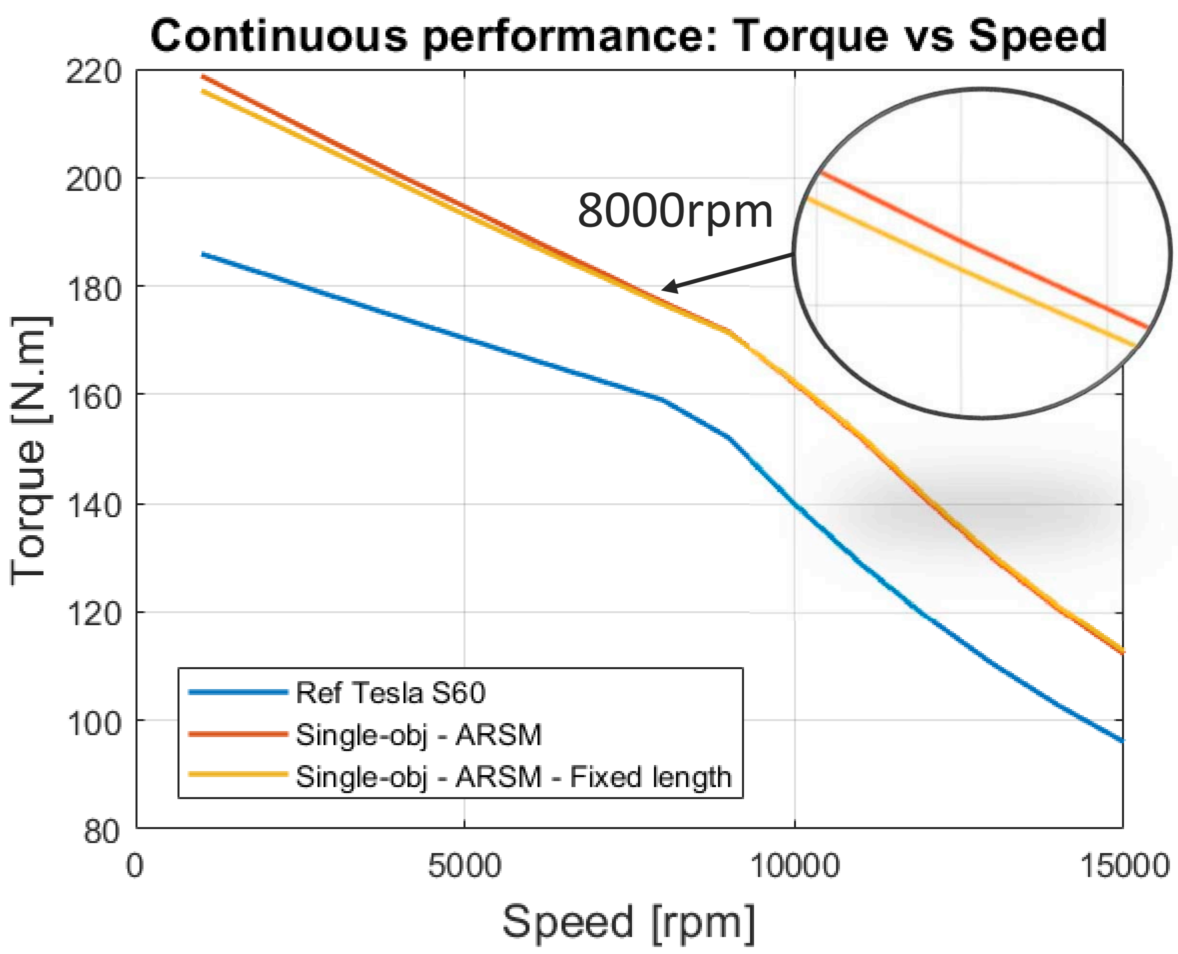
To go further…

From the sensitivity analysis to the optimization

Single-objective optimization: ARSM

Active length set to the maximum value (152mm)

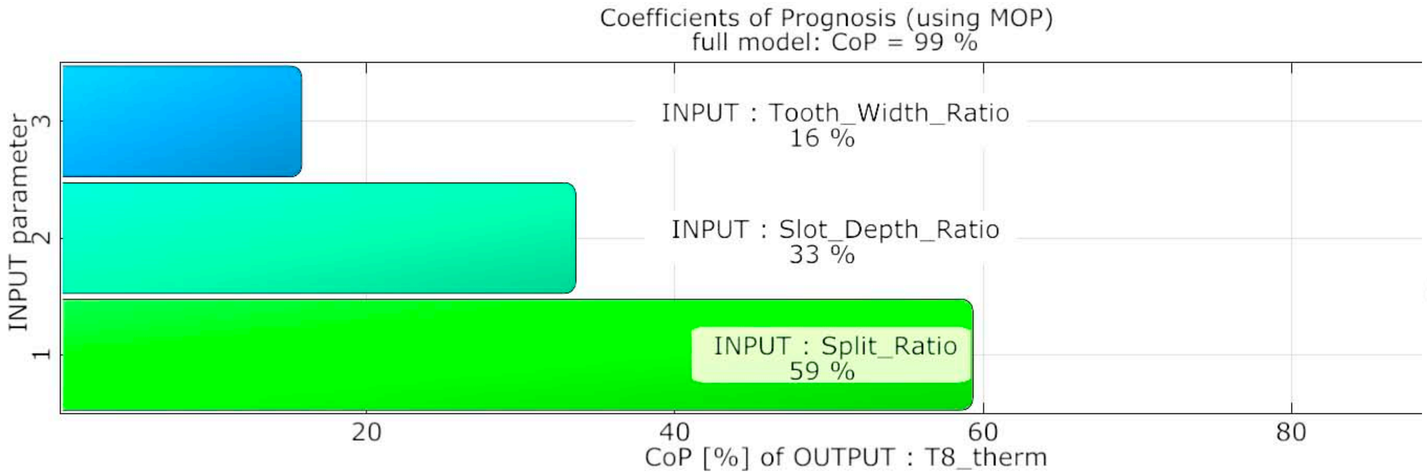


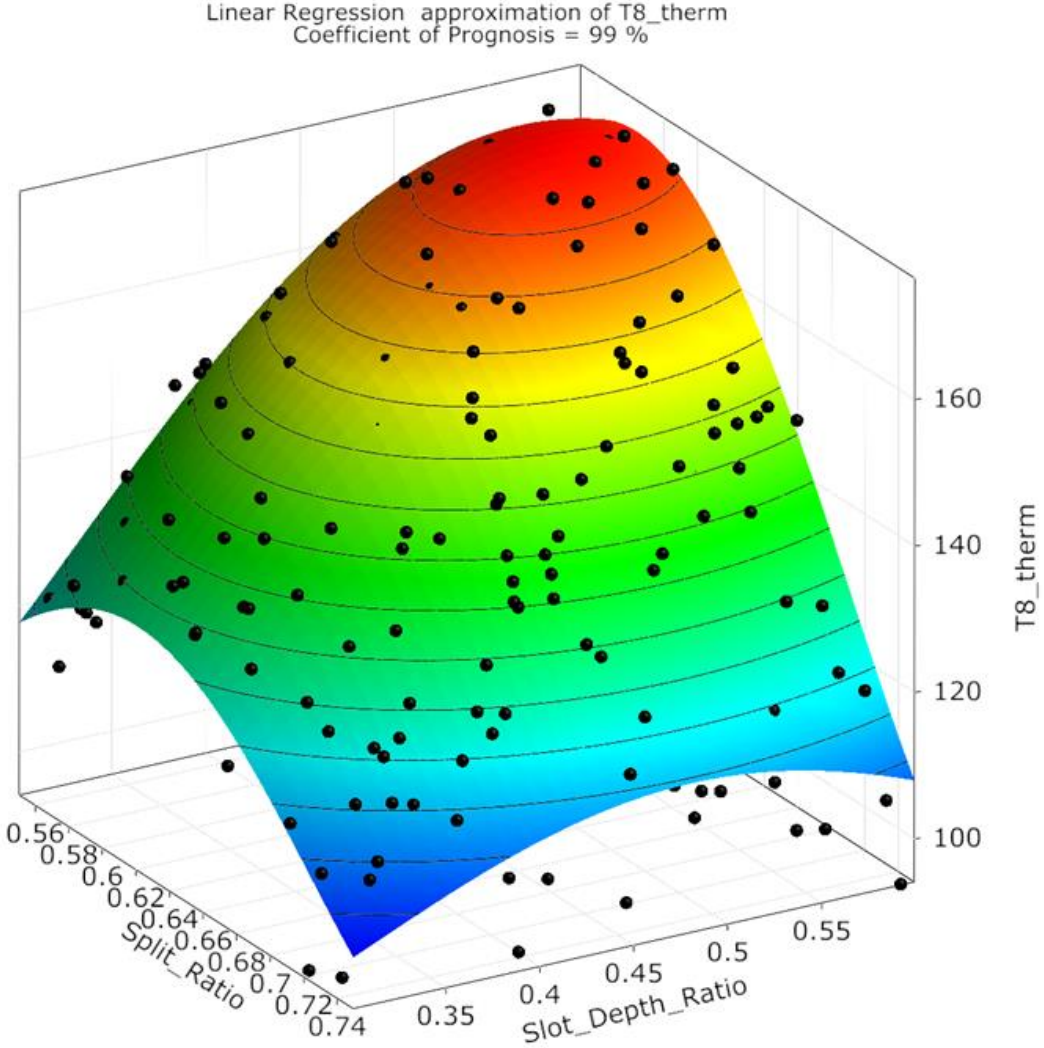


New MOP (300 designs)

MOP for the continuous torque at 8000rpm

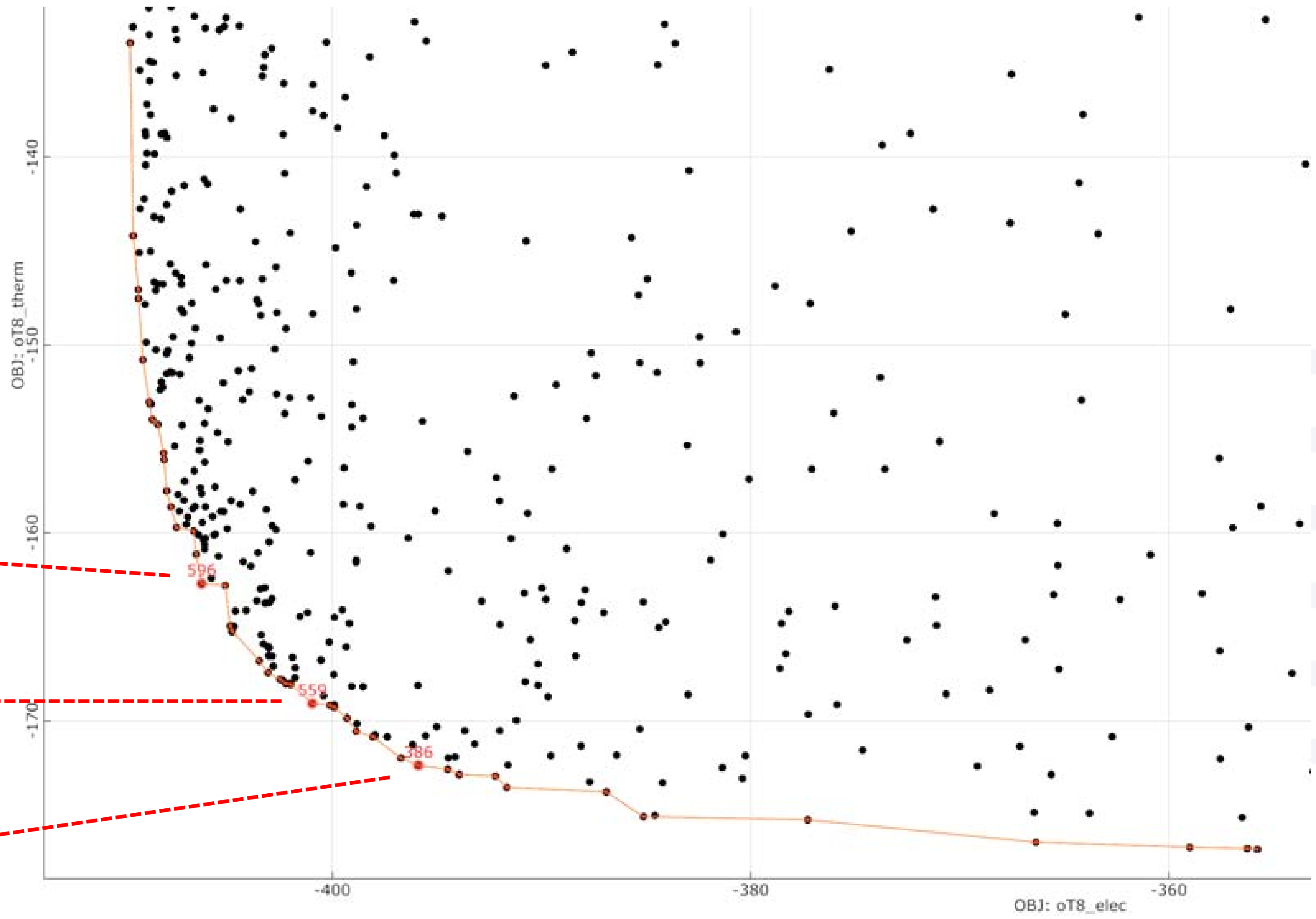
- Continuous torque limited by the stator
- Allocated space for copper and iron materials determines the density levels in the machine (current density, magnetic flux density)
- Temperature hotspot increases due to higher resulting losses





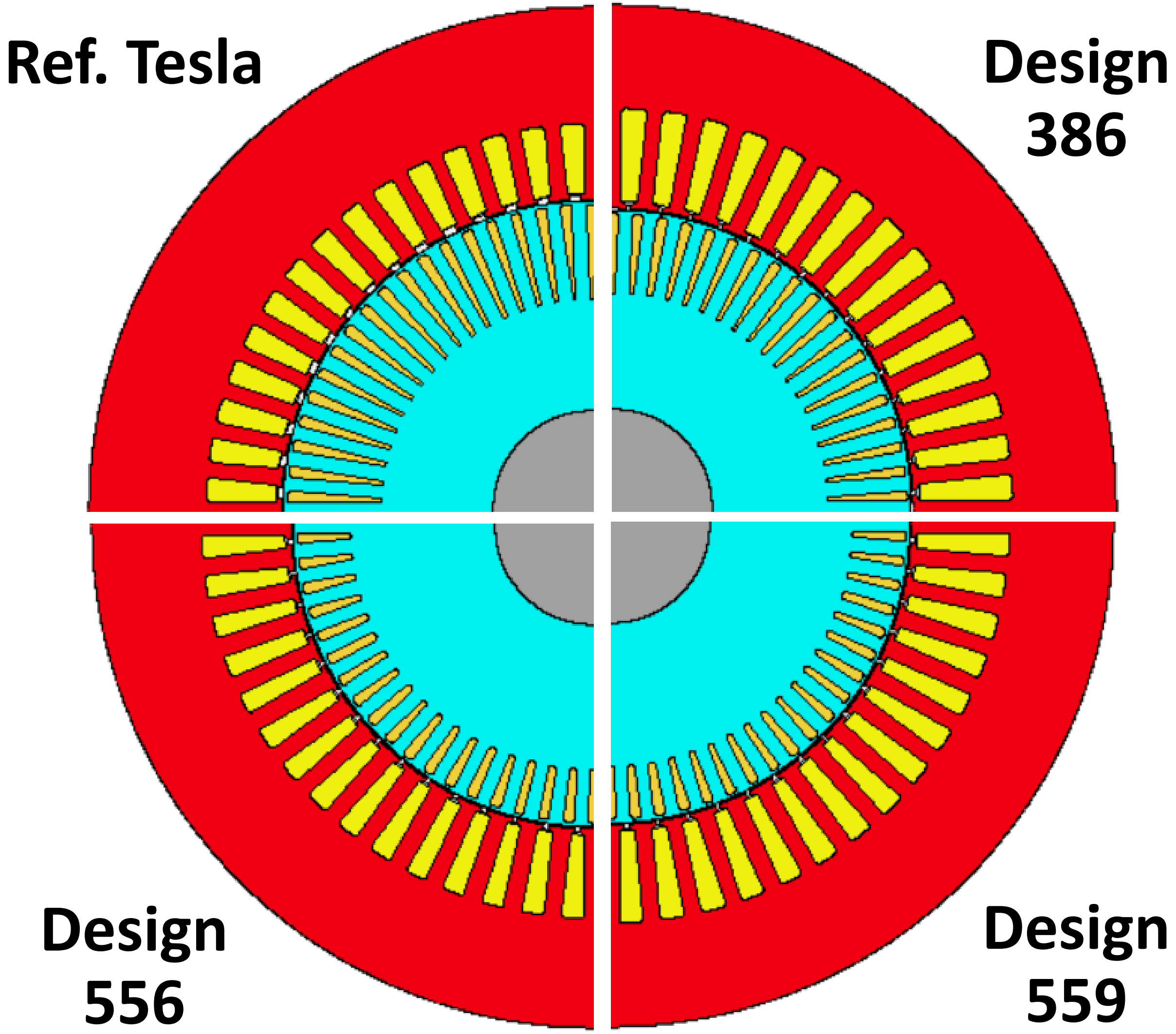
Multi-objective optimization on the new MOP

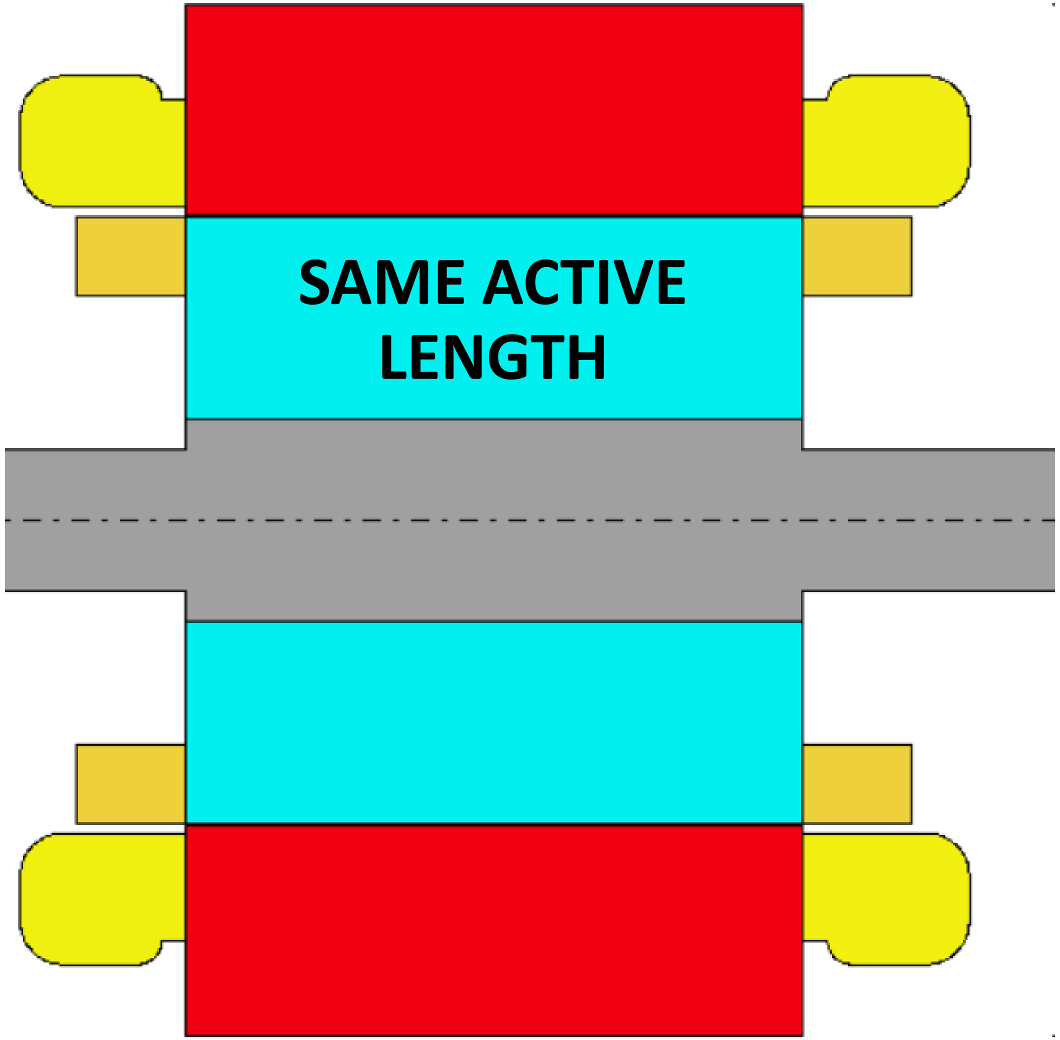
- Maximisation of the continuous AND the peak torque at 8000rpm (EA)
- Pareto front shows trade-off between peak and continuous performance
- 3 designs selected
  - ➢Design 596
    - → ~ 163/406 N.m
  - ➢Design 559
    - → ~ 169/401 N.m
  - ➢Design 386
    - → ~ 172/395 N.m



Single-objective optimization

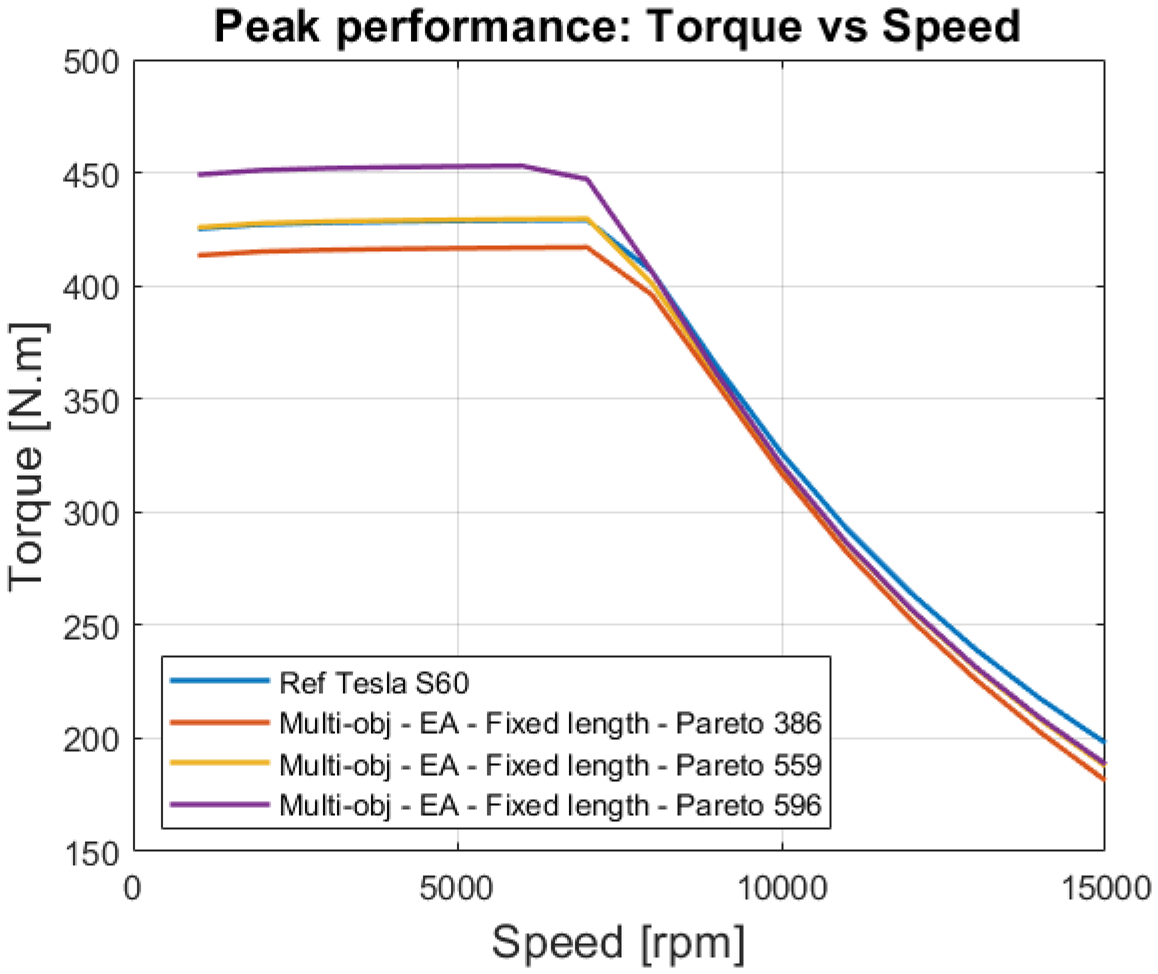
Torque maximisation (continuous operation, 8000rpm)

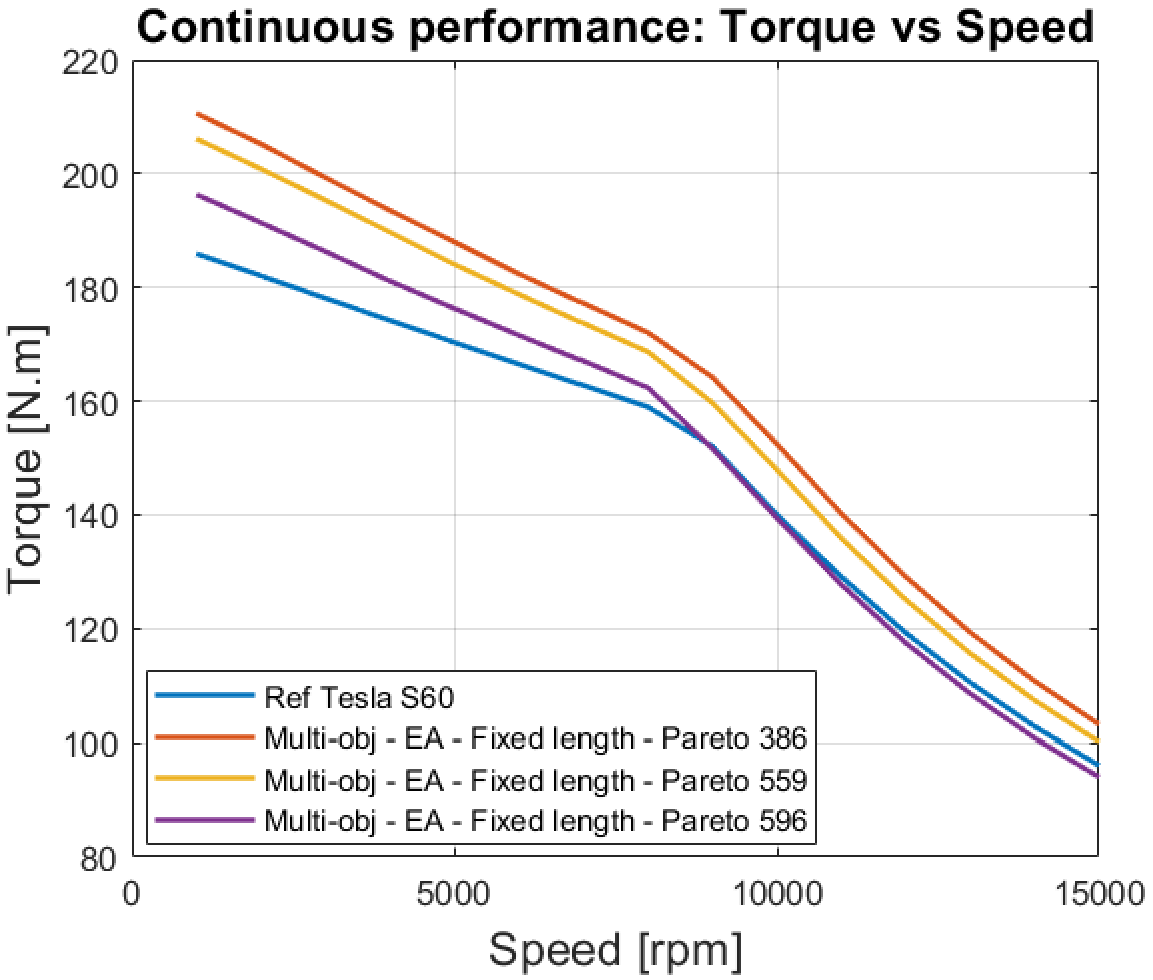




Single-objective optimization

Trade-off between continuous & peak performance!





Conclusion

Conclusion

Motor-CAD and optiSlang together

- Easy integration of Motor-CAD into optiSlang environment
- Optimization applied either on the best model resulting from a sensitivity analysis or directly on Motor-CAD.
- Possibility to optimize an electrical machine over its full speed range and within the thermal/electrical limits.

Case study: Tesla 60S

- Pareto front obtained from a multi-objective optimization showed that Tesla design presents a good compromise between continuous and peak performance.

Outlooks

- Different operating points from the torque speed curve may be considered
- Constraints on other performance (efficiency, power factor…) may be added.

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Thank you for your attention

Any questions?

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