Coupled simulation workflow for the design of optimized power electronic systems

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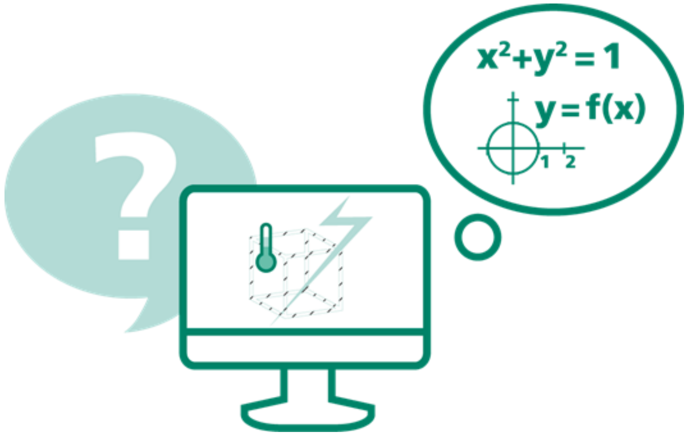
Andreas Rosskopf

AGENDA

1. Initial situation
2. Design workflow for power electronic systems
3. Parameter variation
4. Practical applicability of the MoP
5. Genetic optimization
6. Conclusion



OVERVIEW INSTITUTE

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INITIAL SITUATION

Requirements of the design of power electronic systems

Realization of a certain functionality considering boundary conductions

Demonstrator, Prototype, Product

Energy transfer

Mech. / Elect. work

operating points

Interaction on system level

Installation space

Efficiency

Temperature

Legal requirements

Time

Cost

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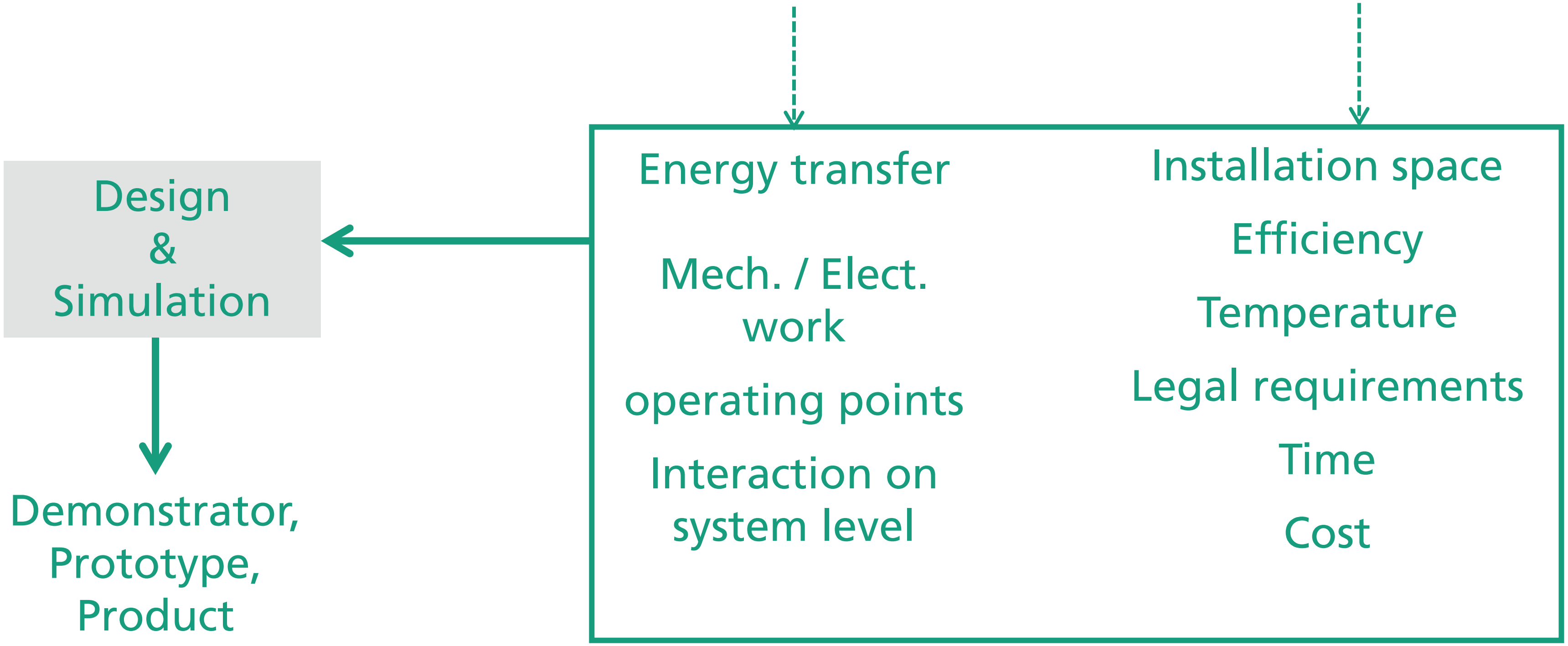
INITIAL SITUATION

Requirements of the design of power electronic systems

Realization of a certain functionality considering boundary conductions



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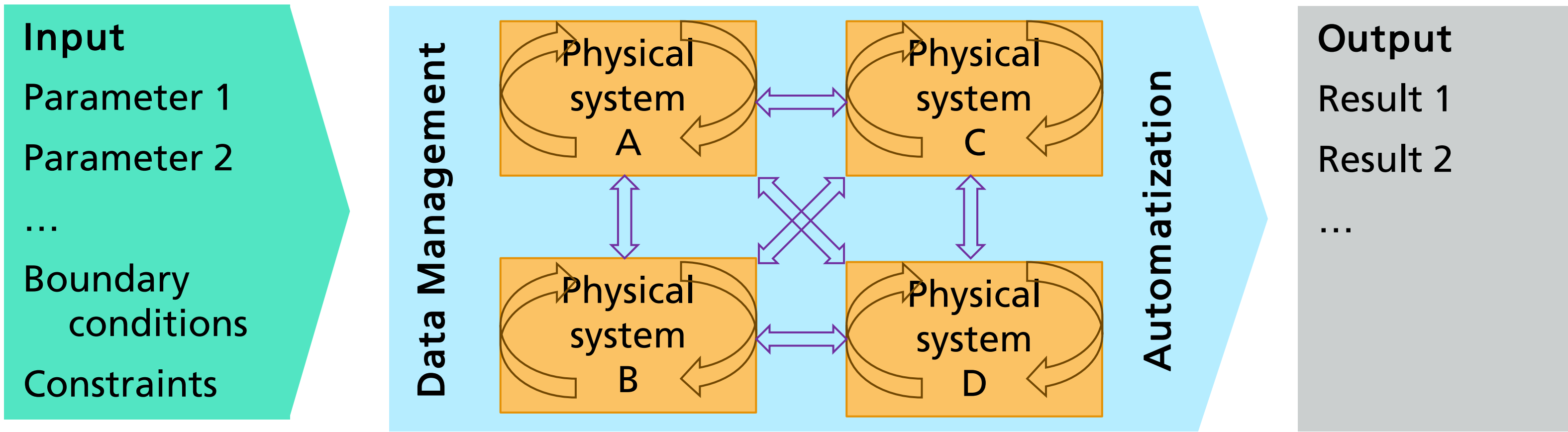
WORKFLOW

Sketch of the computer aided design strategy:



Test application: Inductive connector – Power transfer: **1 kW**

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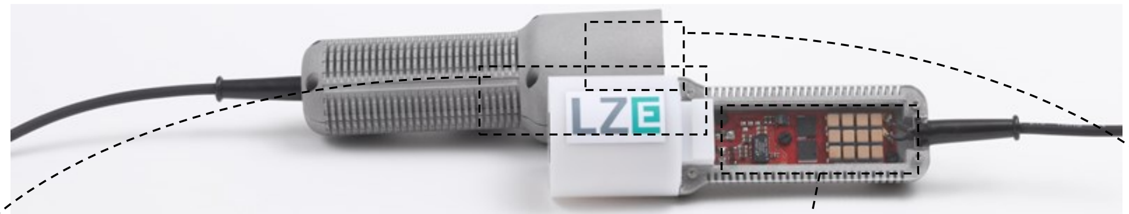
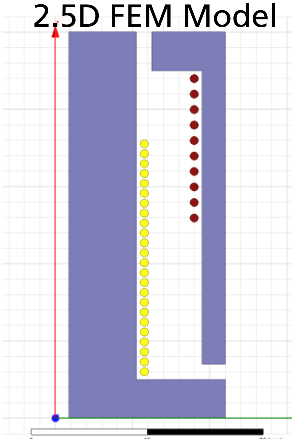
WORKFLOW



Reality

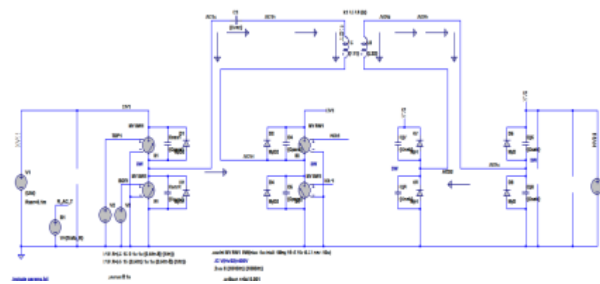
Simulation

Emag-Simulation
2.5D FEM Model



Core losses

Circuit-Simulation
LTSpice Model



Circuit losses

Litzwire Simulation
Analytic / Numeric Models

Winding losses

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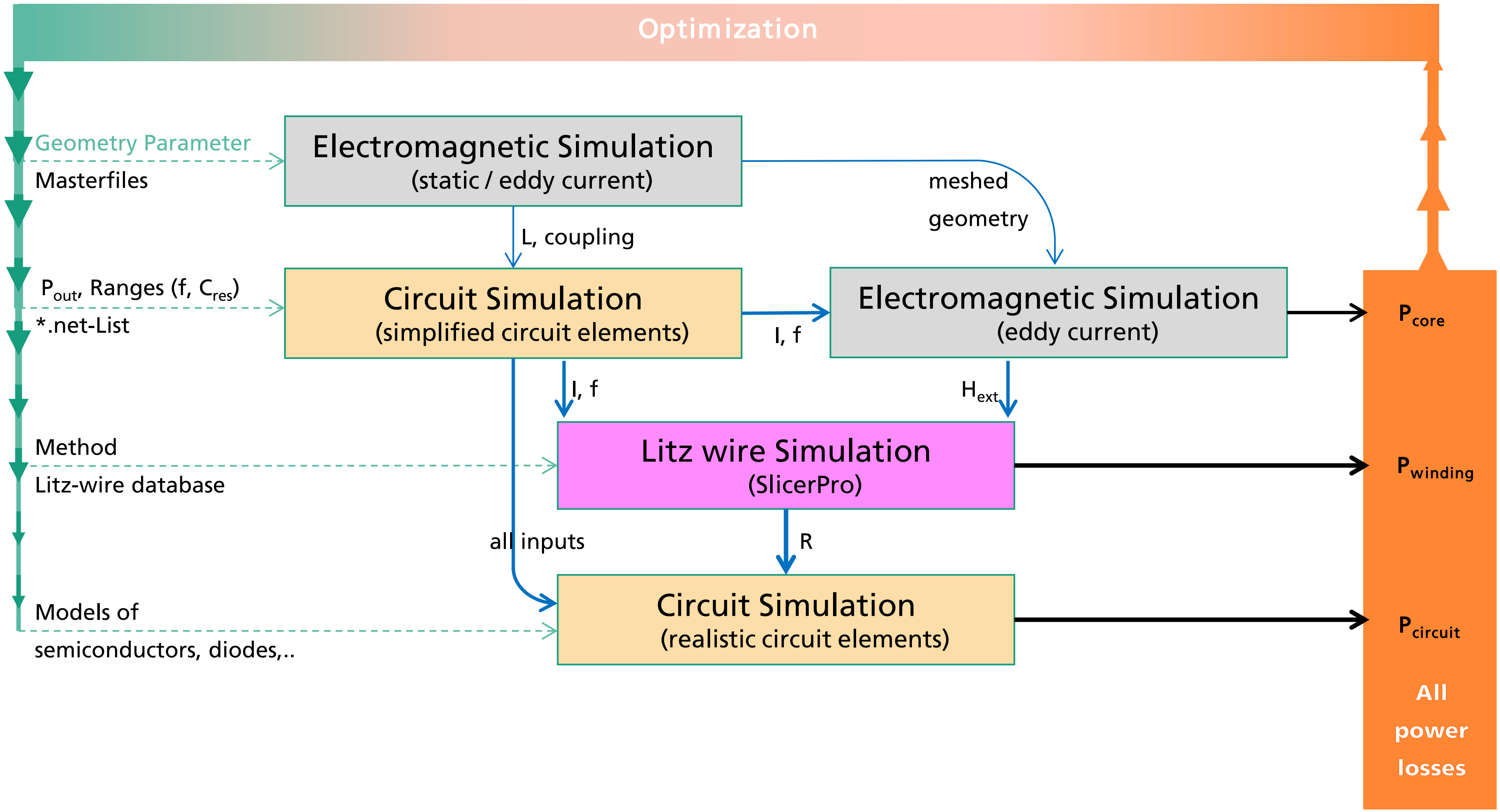
WORKFLOW - OVERVIEW



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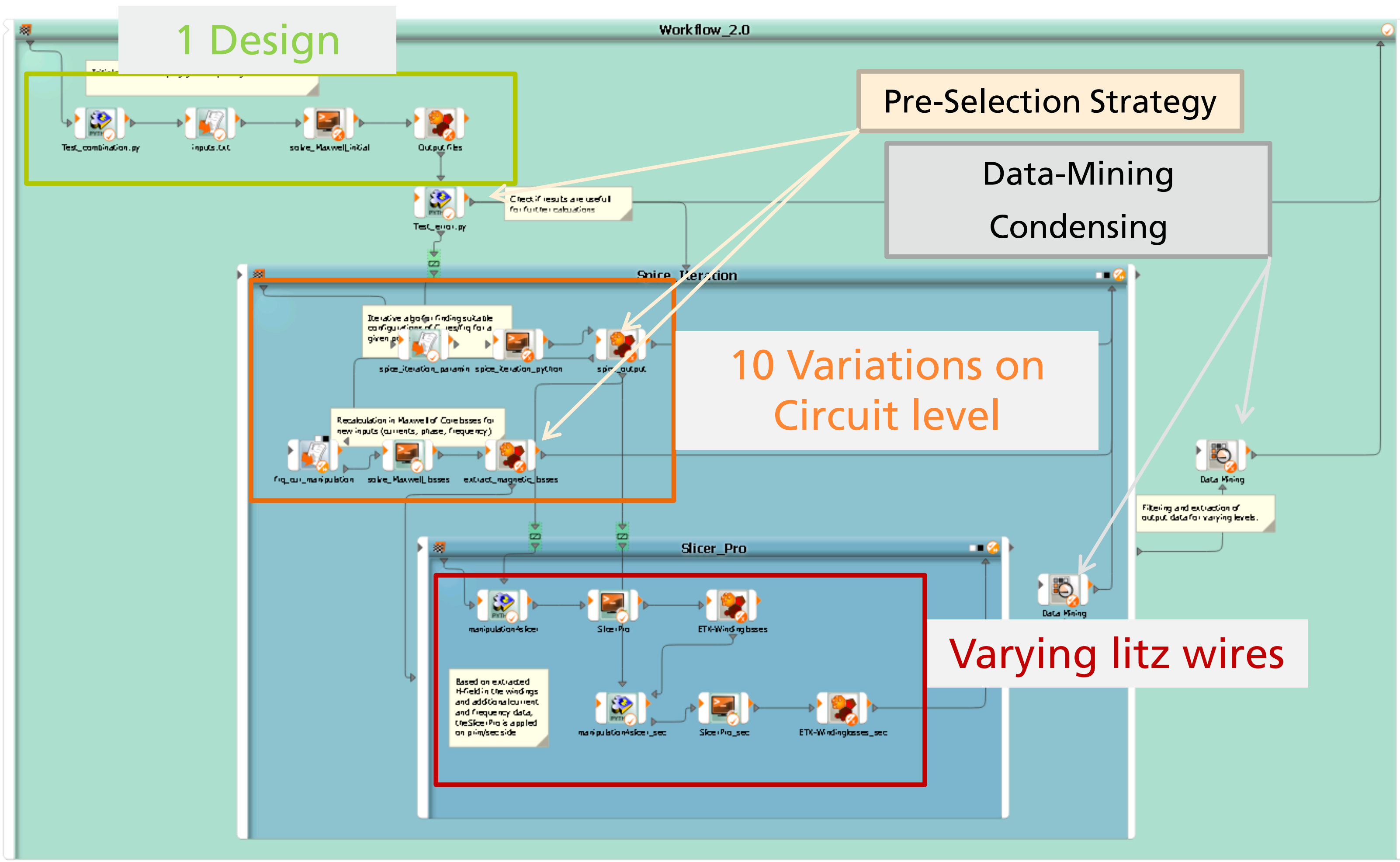
WORKFLOW – OPTISLANG REALISATION



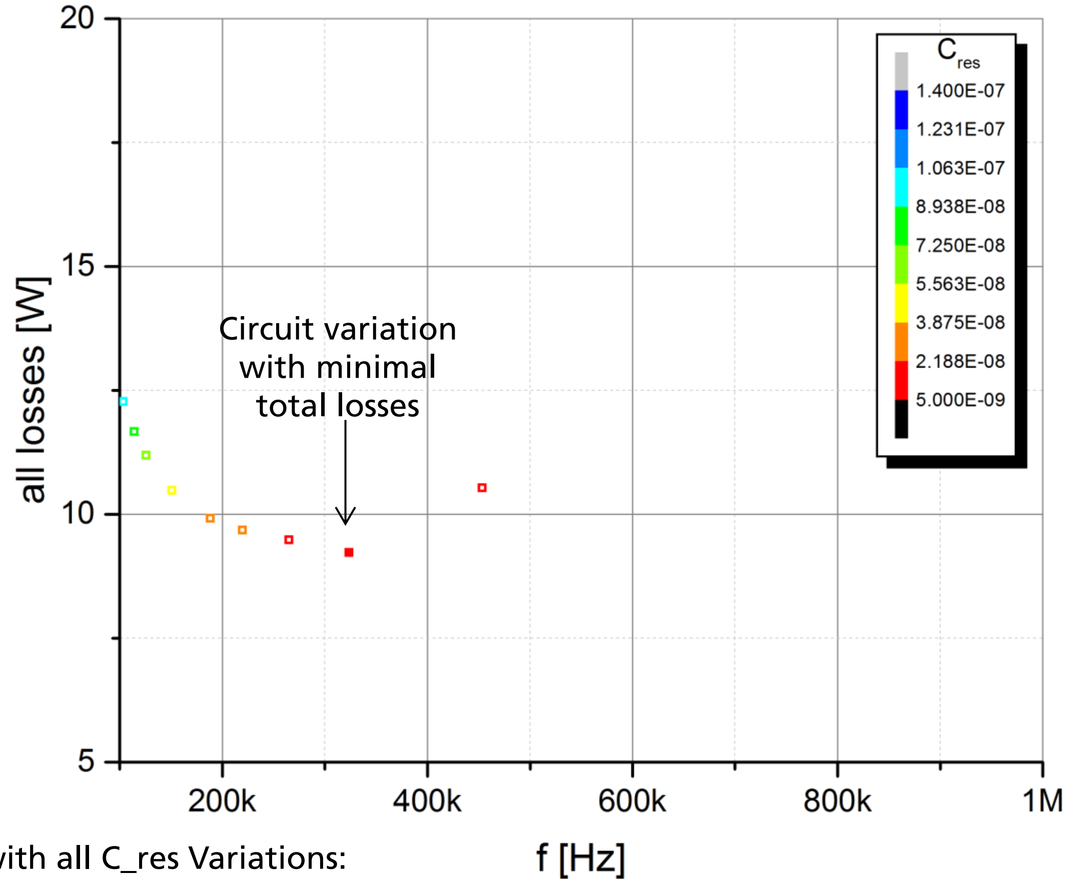
WORKFLOW – PROTOTYPE DESIGN

Input

- Num. Wind. Prim. [fix]
- Num. Sec. [fix]
- Dist. Prim. [fix]
- Dist. Sec. [fix]
- *C_res*

Output

- L11
- L22
- k12
- loss_hysteresis
- loss_solid
- winding_losses
- spice_losses
- *Frequency*
- *all_losses*
- Current Prim
- Current Sek



Plot: Geometry of the Prototyp with all C_res Variations:
[filled]: best variation of on (Geometry)Design,
[shell]: “looser”

PARAMETER VARIATION

Parameter variation and sensitivity analysis for varying geometry and circuit parameters:

Parametric space

Geometry / Magnetic:

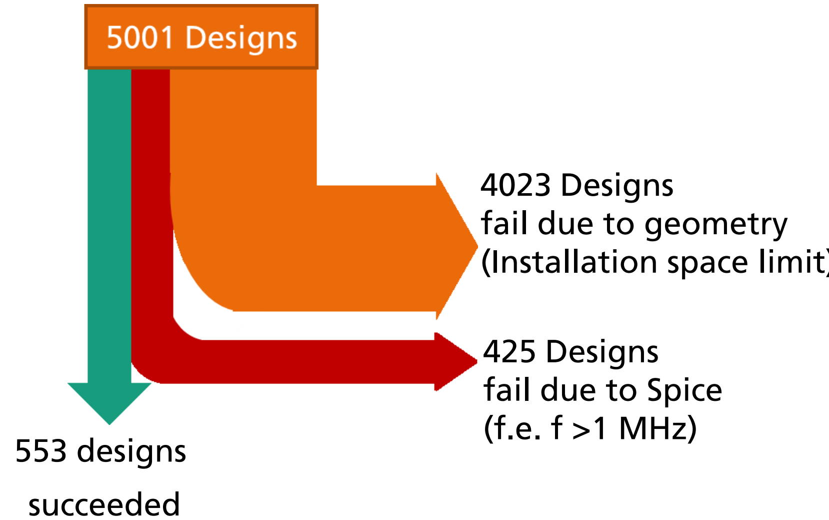
Num. Wind. Prim. = 7-30
Num. Wind. Sec. = 6-30
Distances Prim. = 0.1-3 [mm]
Distances Sec. = 0.1-3 [mm]

Circuit

10 variations of C_{res}

Target: 1 kW P_{trans}

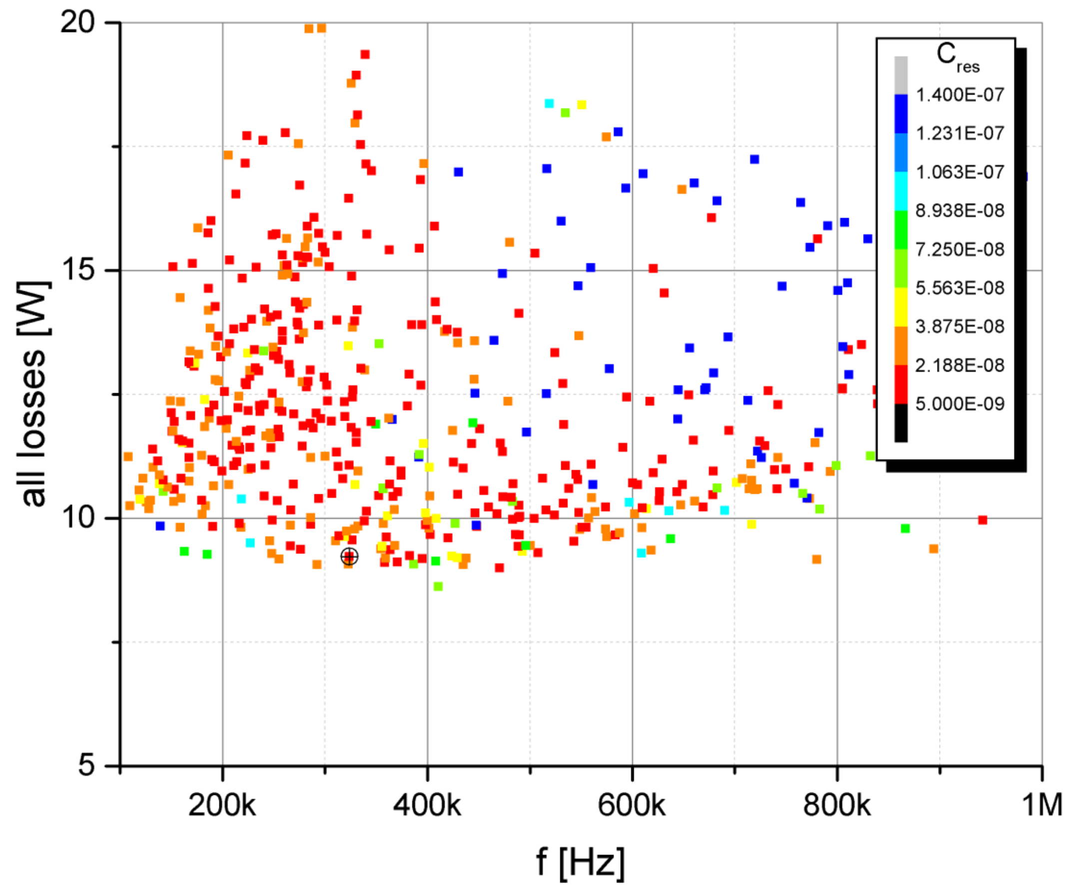
Design-Variations / Workflow



PARAMETER VARIATION – BEST DESIGNS

Input
- Num. Wind. Prim.
- Num. Sec.
- Dist. Prim.
- Dist. Sec.
- *C_res [best]*

Output
- L11
- L22
- k12
- loss_hysteresis
- loss_solid
- winding_losses
- spice_losses
- *Frequency*
- *all_losses*
- Current Prim
- Current Sek



Plot: (Geometry)Designs with the best circuit variation each, ⌖Geometry of the prototype

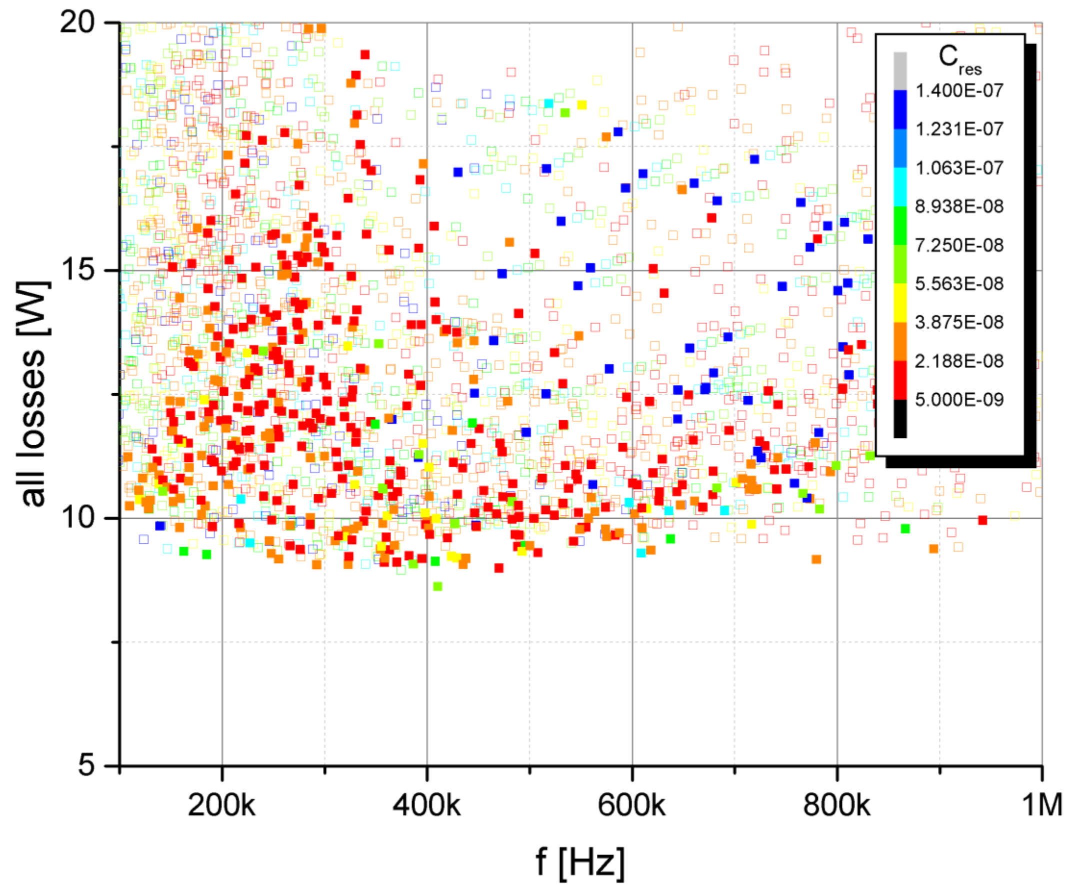
PARAMETER VARIATION – ALL DESIGNS

Input

Num. Wind. Prim.
Num. Sec.
Dist. Prim.
Dist. Sec.
C_res [all]

Output

L11
L22
k12
loss_hysteresis
loss_solid
winding_losses
spice_losses
Frequency
all_losses
Current Prim
Current Sek



Plot: All variations ca. 3500 – [filled]: best variations of one circuit design each, [shell]: “looser”

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PARAMETER VARIATION – ANALYSIS

Linear correlation
OUTPUT : extract_min_winding_losses vs. OUTPUT : extract_loss_solid r=0.772

Parameter | Responses	l_plug	N_p	N_s	d_o	d_ws	d_wp	L11	L22	all_...es_W	best_C_H	best_F	best_...s_W	extrac...esis	extra...solid	extra...sses	extr..._C_H	extra...r_frq	extra...arch	extra...sses	k12
k12	-0.229	0.537	0.111	0.147	0.333	0.142	0.499	0.067	-0.021	0.068	-0.321	-0.093	0.05	0.075	-0.163	0.07	-0.153	-0.005	0.008	1
ex...s	-0.056	-0.101	-0.264	-0.022	0.28	0.139	-0.109	-0.243	0.725	0.005	-0.089	0.405	-0.17	0.447	0.573	0.2	-0.102	-0.049	1	0.008
ex...h	0.024	-0.055	0.115	0.01	-0.065	0.026	-0.042	0.105	-0.144	0.084	0.114	-0.094	0.016	-0.182	-0.108	0.01	0.116	1	-0.049	-0.005
ex...rq	0.069	-0.49	0.512	-0.008	-0.317	0.181	-0.452	0.503	-0.462	0.745	0.766	-0.061	-0.378	-0.638	-0.319	-0.183	1	0.116	-0.102	-0.153
ex...H	-0.064	-0.181	0.118	0.014	-0.039	0.136	-0.182	0.096	0.294	0.174	0.17	-0.074	-0.075	0.236	0.32	1	-0.183	0.01	0.2	0.07
ex...s	-0.023	-0.06	-0.245	-0.066	0.189	-0.079	-0.081	-0.191	0.919	-0.113	-0.169	0.504	-0.211	0.772	1	0.32	-0.319	-0.108	0.573	-0.163
ex...id	0.014	0.275	-0.494	0.013	0.384	-0.045	0.242	-0.462	0.909	-0.426	-0.518	0.352	-0.077	1	0.772	0.236	-0.638	-0.182	0.447	0.075
ext...s	-0.029	0.177	-0.216	0.003	0.115	-0.048	0.171	-0.22	-0.166	-0.329	-0.278	-0.033	1	-0.077	-0.211	-0.075	-0.378	0.016	-0.17	0.05
be...W	0.116	0.019	-0.127	-0.055	0.272	-0.049	0.035	-0.07	0.479	0.117	-0.161	1	-0.033	0.352	0.504	-0.074	-0.061	-0.094	0.405	-0.093
best_F	0.072	-0.68	0.377	0	-0.282	0.225	-0.639	0.374	-0.343	0.559	1	-0.161	-0.278	-0.518	-0.169	0.17	0.766	0.114	-0.089	-0.321
be...H	0.055	-0.301	0.632	0	-0.281	0.145	-0.269	0.62	-0.25	1	0.559	0.117	-0.329	-0.426	-0.113	0.174	0.745	0.084	0.005	0.068
al...W	-0.018	0.082	-0.411	-0.025	0.341	-0.01	0.056	-0.369	1	-0.25	-0.343	0.479	-0.166	0.909	0.919	0.294	-0.462	-0.144	0.725	-0.021
L22	0.228	0.111	0.987	0.016	-0.539	-0.205	0.153	1	-0.369	0.62	0.374	-0.07	-0.22	-0.462	-0.191	0.096	0.503	0.105	-0.243	0.067
L11	0.085	0.987	0.153	0.058	0.027	-0.388	1	0.153	0.056	-0.269	-0.639	0.035	0.171	0.242	-0.081	-0.182	-0.452	-0.042	-0.109	0.499
d_wp	0.274	-0.37	-0.226	-0.051	0.211	1	-0.388	-0.205	-0.01	0.145	0.225	-0.049	-0.048	-0.045	-0.079	0.136	0.181	0.026	0.139	0.142
d_ws	0.197	0.043	-0.526	-0.032	1	0.211	0.027	-0.539	0.341	-0.281	-0.282	0.272	0.115	0.384	0.189	-0.039	-0.317	-0.065	0.28	0.333
d_o	0.032	-0.008	-0.026	1	-0.032	-0.051	0.058	0.016	-0.025	0	0	-0.055	0.003	0.013	-0.066	0.014	-0.008	0.01	-0.022	0.147
N_s	0.179	0.115	1	-0.026	-0.526	-0.226	0.153	0.987	-0.411	0.632	0.377	-0.127	-0.216	-0.494	-0.245	0.118	0.512	0.115	-0.264	0.111
N_p	0.031	1	0.115	-0.008	0.043	-0.37	0.987	0.111	0.082	-0.301	-0.68	0.019	0.177	0.275	-0.06	-0.181	-0.49	-0.055	-0.101	0.537
l_plug	1	0.031	0.179	0.032	0.197	0.274	0.085	0.228	-0.018	0.055	0.072	0.116	-0.029	0.014	-0.023	-0.064	0.069	0.024	-0.056	-0.229

Samples 3890/3890 (0/0 failed)

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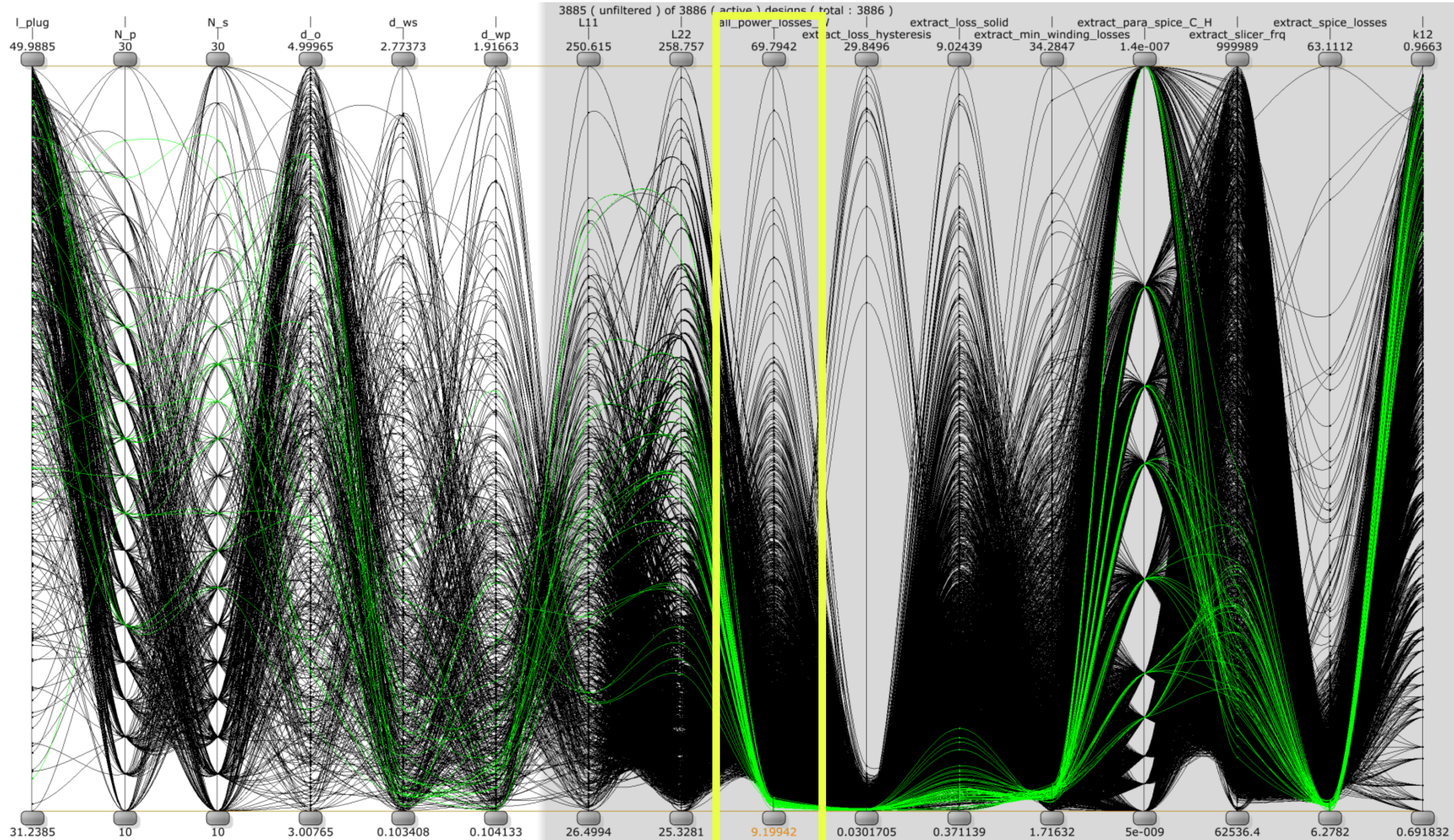
PARAMETER VARIATION – ANALYSIS



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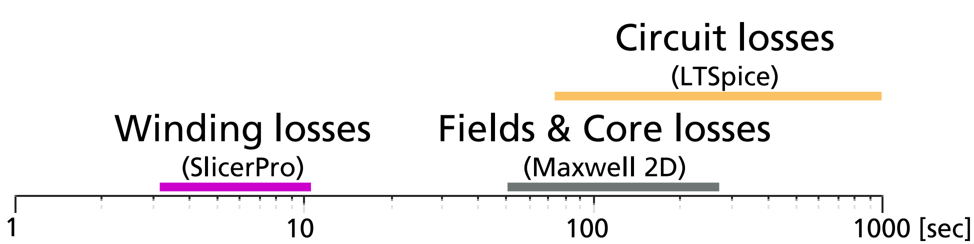
PARAMETER VARIATION – ANALYSIS

Evaluation of the process:

- Workflow runs (stable), efficient for adaption of the physical models, scriptings and implementation of pre-selection strategies
- Manipulation of the omdb files for extracting vectorised multi-layer data requires additional scripting
- A restart after stop is risky [V. 5.1.1]

Main problem, due to calculation time:



→ Suitability of MoP for circuit simulations?

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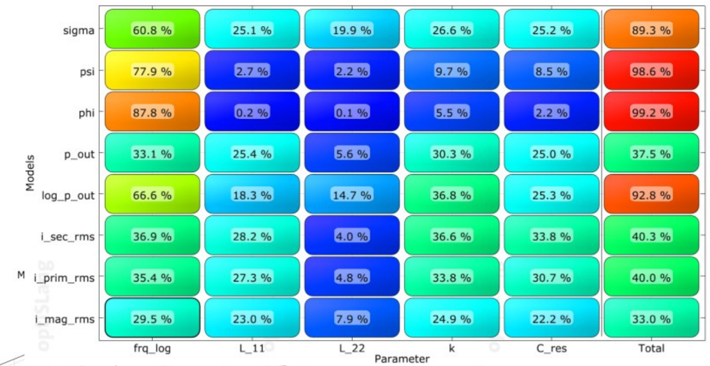
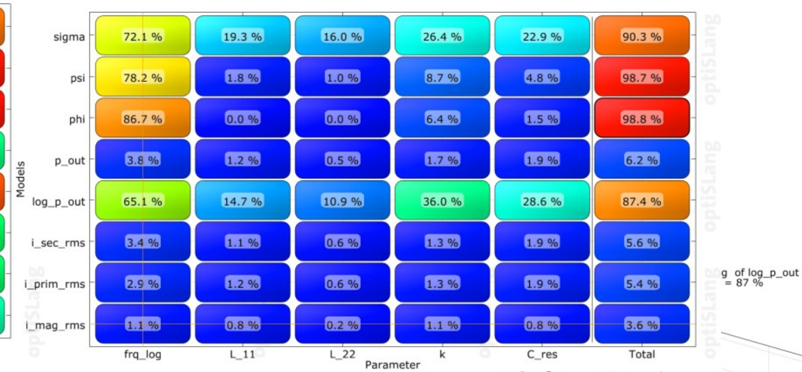
PARAMETER VARIATION – MOP

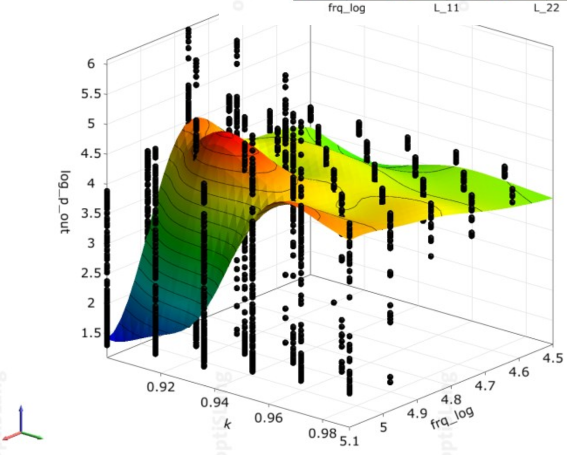
Generation of different MoP for a partial parameter space of the circuit simulation using more than 5k data samples [V5.1.1]:



Full factorization



Advanced Latin Hyper Cube

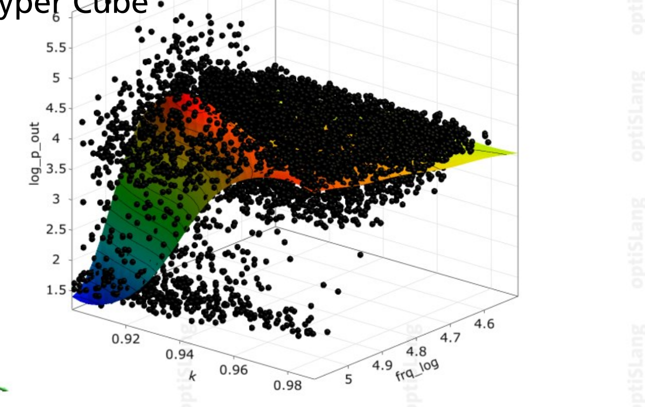


Prediction of phi: TOP

→ Validation of the operation point quality

Prediction of the output-power: imprecise

→ Comparison criteria of varying designs



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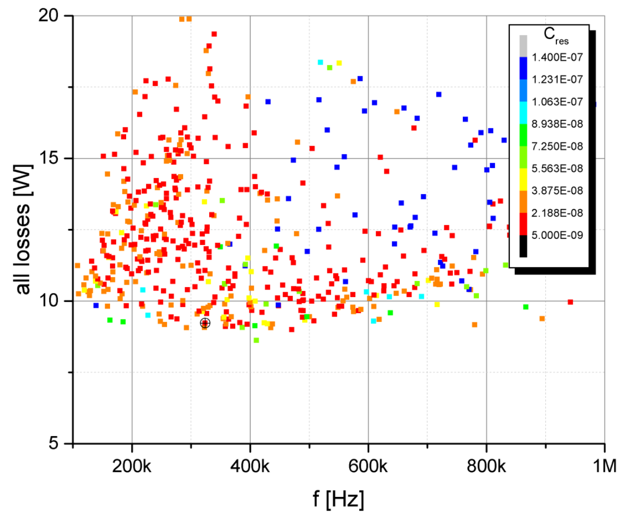
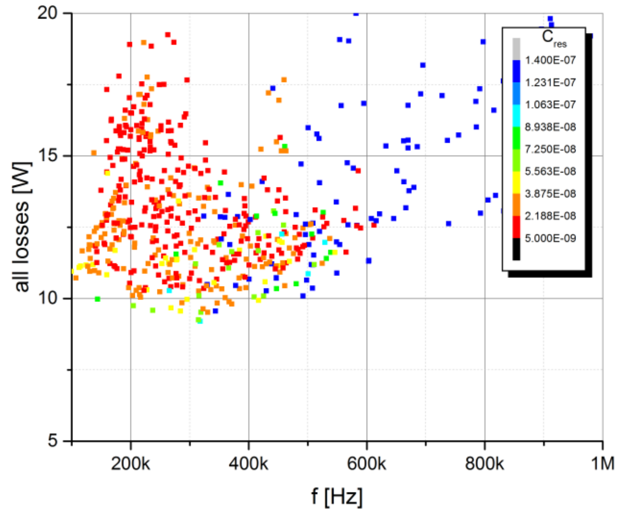
PARAMETER VARIATION + PHYSICAL MODEL FOR CORE LOSSES



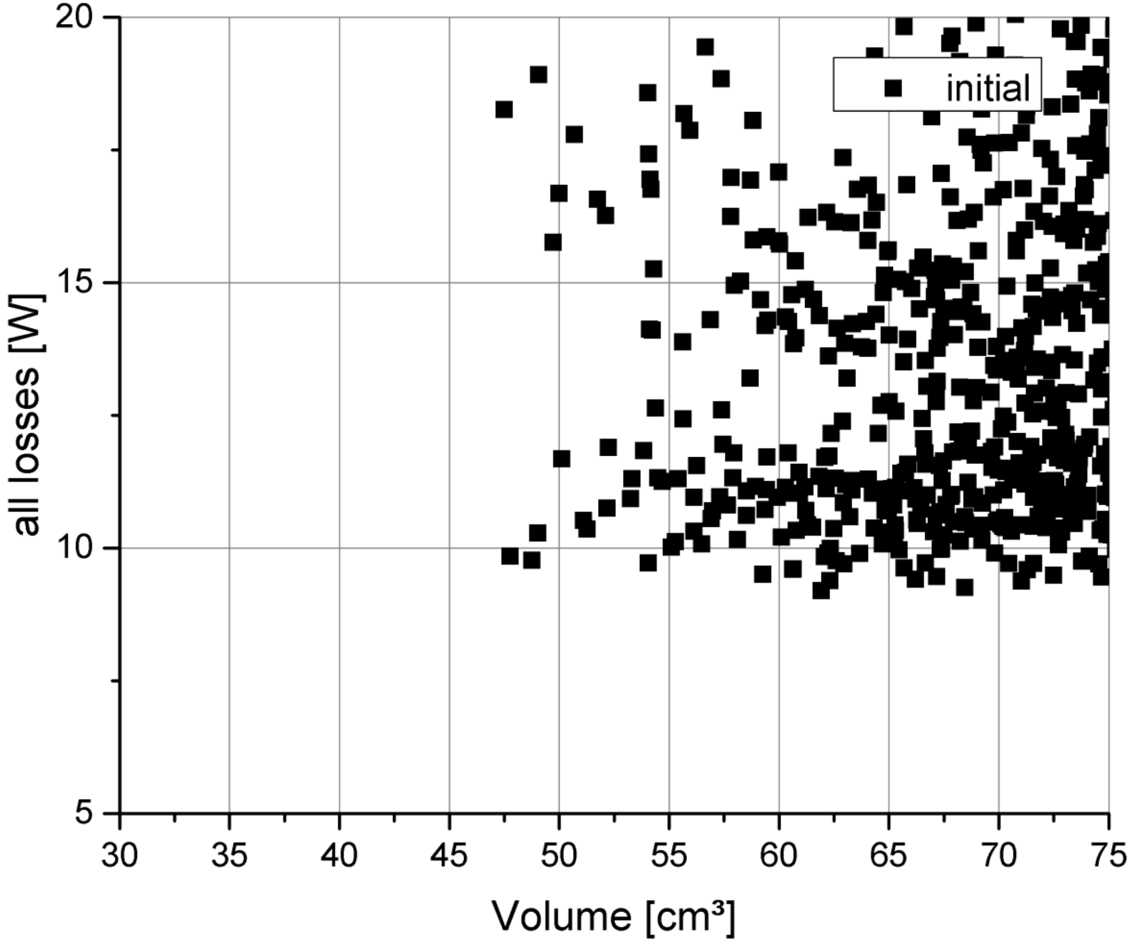
Physical Model A



Physical Model B

- Varying physical models, material data or cost functions can be tested for a large variety of virtual prototypes
- Relevant benchmark setups can be detected for building up experimental prototypes

PARAMETER VARIATION + GA



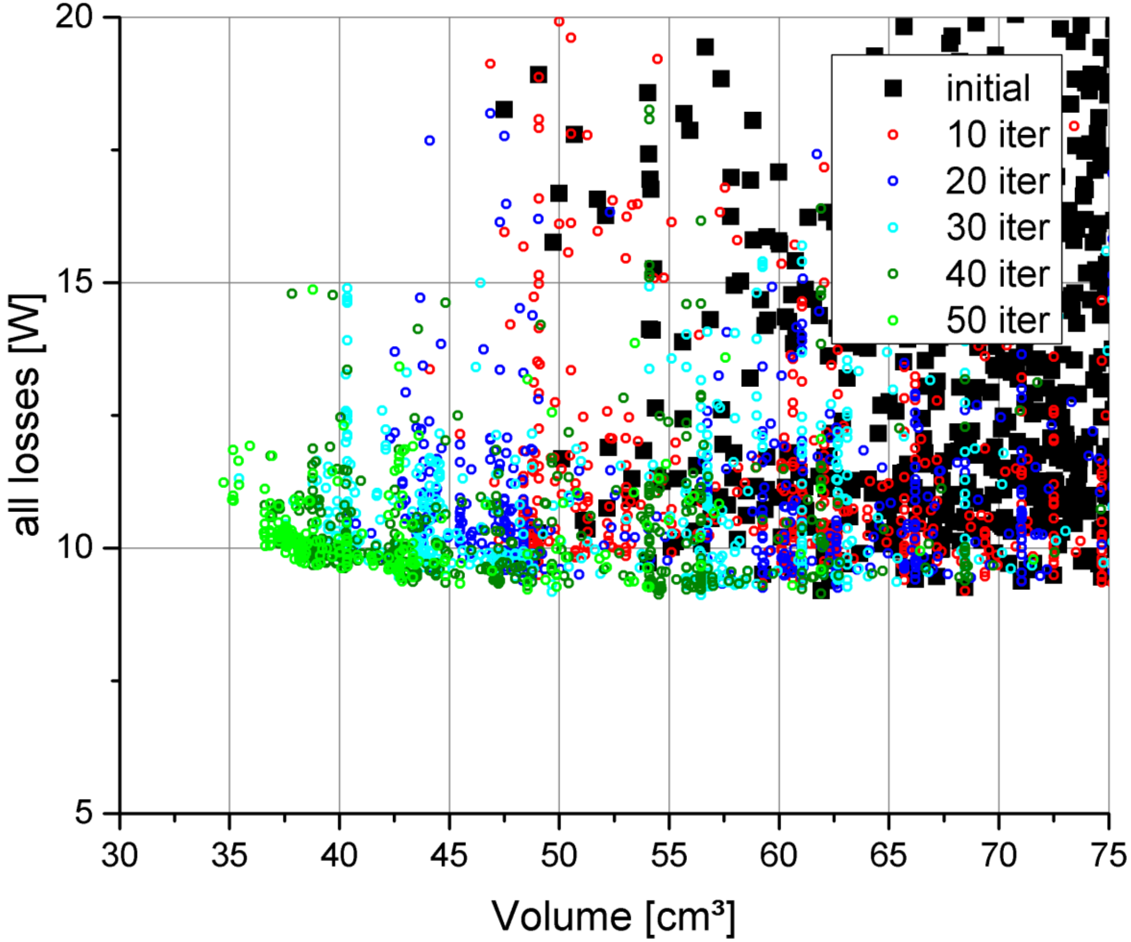
Objective:

min all_losses

+

min Volume

PARAMETER VARIATION + GA



Reduction of the volume / install-ation space by more than 20 % with the same amount of power losses

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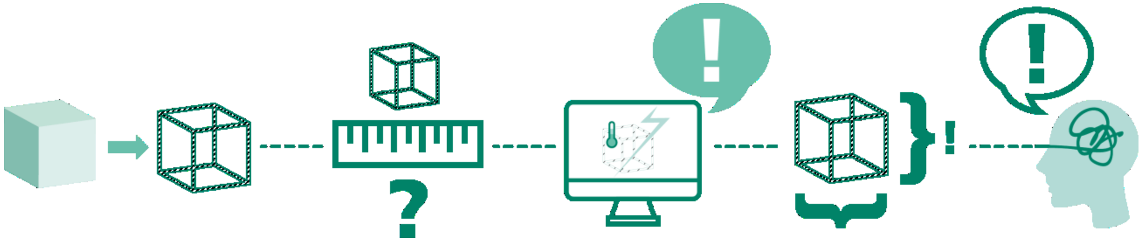
CONCLUSION

- The coupling of different physical domains and tools, is implemented in the current workflow and provides a significant enhancement compared to "multi-physics software"
- Multidimensional optimization enables a customer / user specific optimization of power electronic systems – providing a better interaction of all components of system within the defined working environment
- Partial tasks of the workflow can be re-started with new input data by re-using old data for the start and initialization. Significant reduction of time and invest by adapting parameters, boundary conditions or constraints.



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