Coupled simulation workflow for the design of optimized power electronic systems

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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
Electronic Systems
From Materials to Power Electronic Applications – Everything from One Source
INITIAL SITUATION

Requirements of the design of power electronic systems

Realization of a certain functionality considering boundary conductions

- Energy transfer
- Mech. / Elect. work
- Operating points
- Interaction on system level

- Installation space
- Efficiency
- Temperature
- Legal requirements
- Time
- Cost

Demonstrator, Prototype, Product
INITIAL SITUATION

Requirements of the design of power electronic systems
Realization of a certain functionality considering boundary conduction

Design & Simulation

Demonstrator, Prototype, Product

Energy transfer
Mech. / Elect. work
operating points
Interaction on system level

Installation space
Efficiency
Temperature
Legal requirements
Time
Cost
WORKFLOW

Sketch of the computer aided design strategy:

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

Reality Simulation

Emag-Simulation
2.5D FEM Model

Circuit-Simulation
LTSpice Model

Litzwire Simulation
Analytic / Numeric Models

Core losses

Circuit losses

Winding losses
WORKFLOW - OVERVIEW

Electromagnetic Simulation
(static / eddy current)

Circuit Simulation
(simplified circuit elements)

Litz wire Simulation
(SlicerPro)

Circuit Simulation
(realistic circuit elements)

Optimization

Geometry Parameter
Masterfiles

P_out, Ranges (f, C_res)
*.net-List

Method
Litz-wire database

Models of
semiconductors, diodes, ...

P_core

P_winding

P_circuit

All power losses
WORKFLOW – OPTISLANG REALISATION

1 Design

Pre-Selection Strategy

Data-Mining Condensing

10 Variations on Circuit level

Varying litz wires
WORKFLOW – PROTOTYPE DESIGN

Input
- Num. Wind. Prim. [fix]
- Num. Sec. [fix]
- Dist. Prim. [fix]
- Dist. Sec. [fix]
- $C_{\text{res}}$

Output
- $L_{11}$
- $L_{22}$
- $k_{12}$
- loss_hysteresis
- loss_solid
- winding_losses
- spice_losses
- Frequency
- all_losses
- Current Prim
- Current Sek

Plot: Geometry of the Prototyp with all $C_{\text{res}}$ 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**

- 5001 Designs
- 4023 Designs fail due to geometry (Installation space limit)
- 425 Designs fail due to Spice (f.e. $f > 1$ MHz)
- 553 designs succeeded
PARAMETER VARIATION – BEST DESIGNS

Plot: (Geometry) Designs with the best circuit variation each, Geometry of the prototype
PARAMETER VARIATION – ALL DESIGNS

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Variation</th>
<th>Correlation Coefficient</th>
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<tbody>
<tr>
<td>L1 plug</td>
<td>N_p</td>
<td>0.09</td>
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<tr>
<td>N_s</td>
<td>d_p</td>
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<tr>
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<td>L22</td>
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<td>bend_s</td>
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<tr>
<td>arch</td>
<td>extra_sses</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Linear correlation: extract_min_winding_losses vs. extract_loss_solid = 0.772

Samples: 3890/3890 (0/0 failed)
PARAMETER VARIATION – ANALYSIS
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:

![Diagram showing the comparison between Winding losses, Fields & Core losses, and Circuit losses](image)

→ **Suitability of MoP for circuit simulations?**
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
PARAMETER VARIATION + PHYSICAL MODEL FOR CORE LOSSES

Physical Model A

- Varying physical models, material data or cost functions can be tested for a large variety of virtual prototypes

Physical Model B

- 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 / installation space by more than 20 % with the same amount of power losses
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.