

Design of a 1200 V, 100 kW Power Converter: How Good are the Design and Modelling Tools?

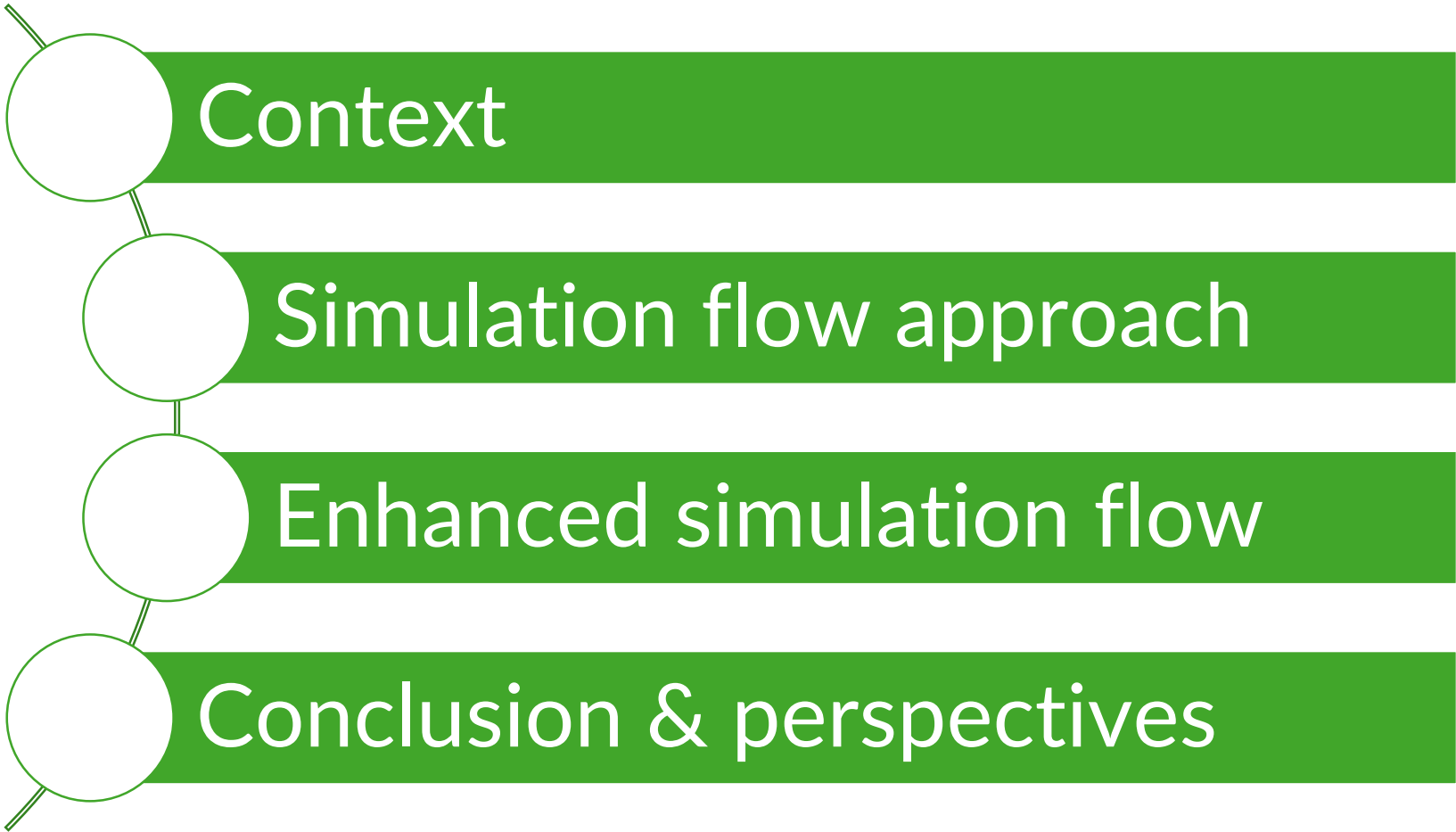
The Future of Simulation in Power Electronics Packaging for Thermal and Stress Management - ECPE Workshop

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Introduction

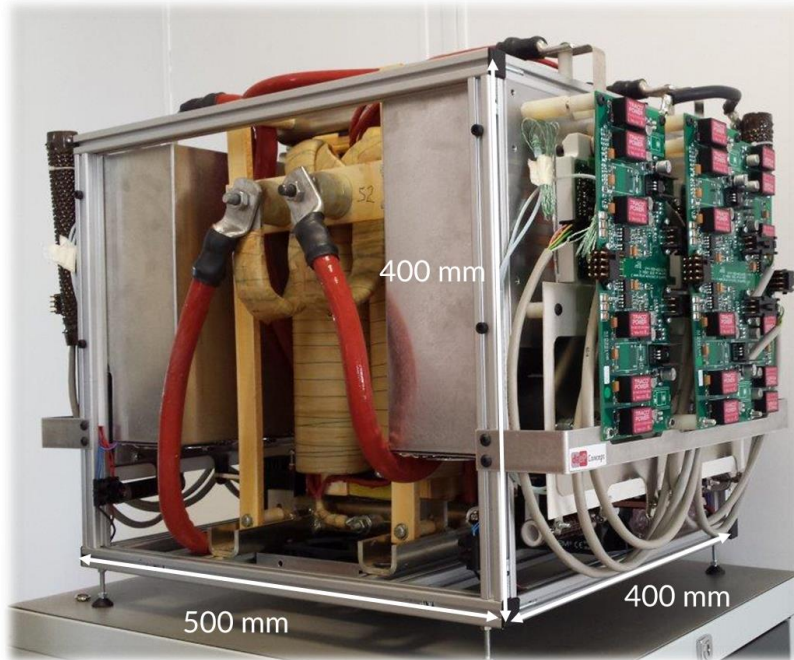
- During the design phases, the mistakes must be reduced
- Accurate simulations can help the designers to reduce the risks
- However, several limitations have been found in the tools
- Purpose of the presentation
 - > To identify the main limitations
 - > To propose an enhanced simulation flow

Agenda



Context

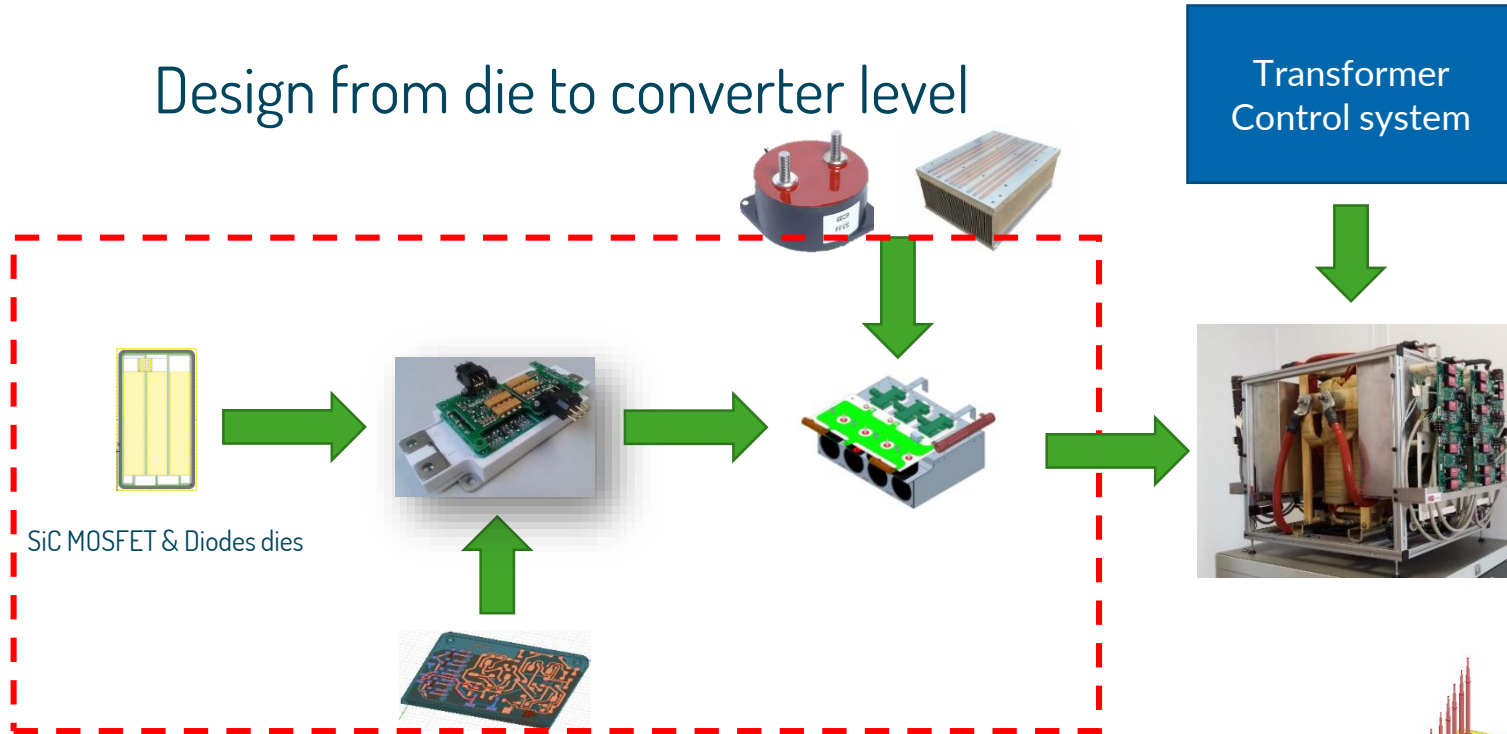
Limiting the design mistakes for high power converters



- **Motivations**
 - Design flow validation
 - Performance estimation
- **1 year design & implementation (2014-2015)**
- **Design from a “blank page”**
- **Specifications of our prototype**
 - Input voltage : 900-1200 V
 - Output voltage : 450-600 V
 - Nominal power : 100 kW
 - Switching frequency : 20 kHz
 - Cooling : Forced air

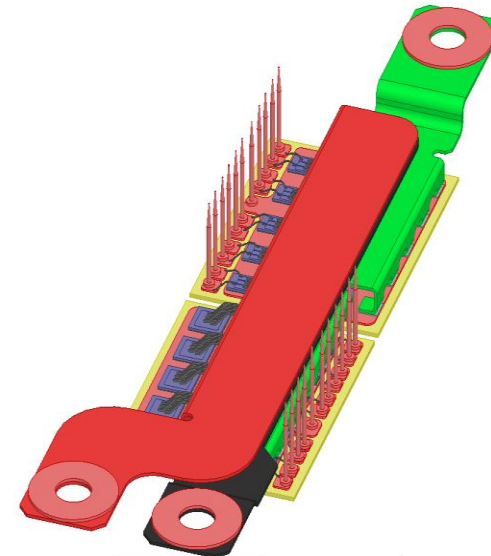
Context

Design from die to converter level



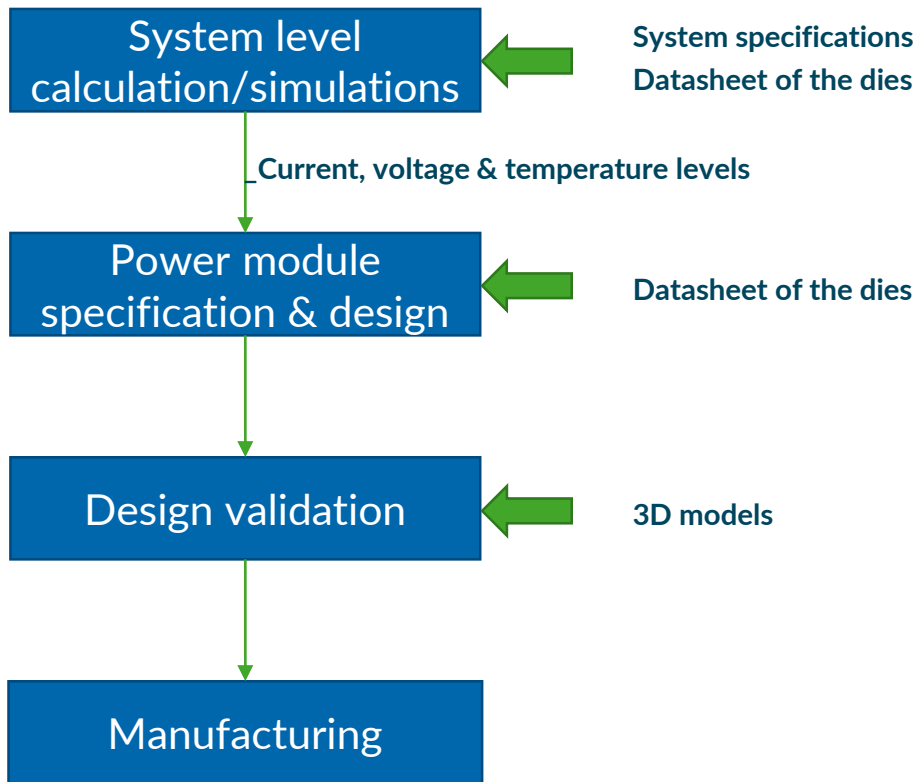
→ Specifications of the power modules

- Half bridge power module
- 5 MOSFET dies & 5 diodes dies per switch position
- 1,7 kV - 2 x 250 A



Design & simulation flows

General approach



→ System level studies

- Use of Matlab calculation scripts
- First estimation of the losses
- Specification of the power modules

→ Power modules design

- Number of dies in parallel
- Use of the datasheet of the dies
- Thermal characteristic of similar power module

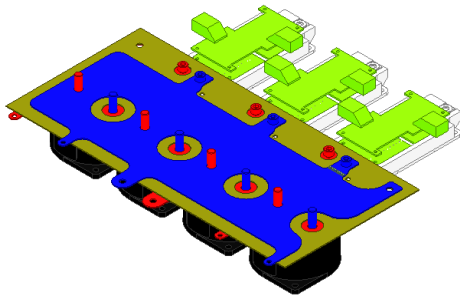
→ 3DFE simulations

- Determination of the parasitic inductance and current distribution
- System simulations

Simulation flow

Electromagnetic simulations

Electromagnetic simulations
(Ansys Q3D ®)



- Parasitic elements (inductances, resistances, capacitances)
- Frequency domain simulation (DC to 100 MHz)

Reduced model

- S parameters matrices
 - RLGC matrices
- Equivalent circuit

Circuit simulations
(Ansys Simplorer ®)



- Overvoltages
- Current repartition between the dies
- Temporal simulation domain

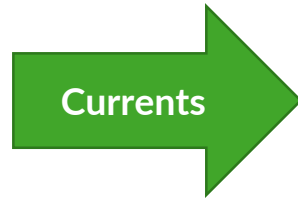
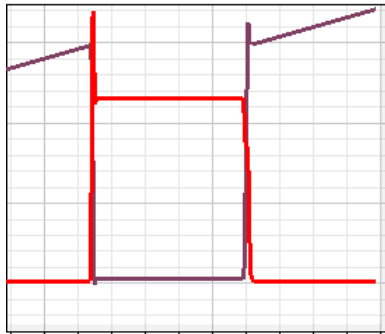
→ Components considered

- > Power modules
- > Busbars
- > Gate driver

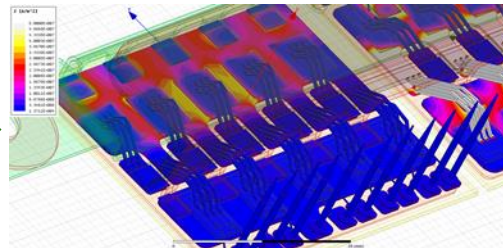
Simulation flow

No electro-thermal transient simulations for multi terminal systems

Circuit simulations
(Ansys Simplorer ®)



Current densities
(Ansys Maxwell 3D ®)



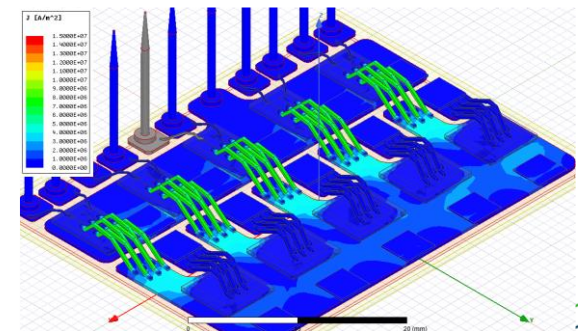
Thermal simulations



→ Multi terminal systems : no transient solver

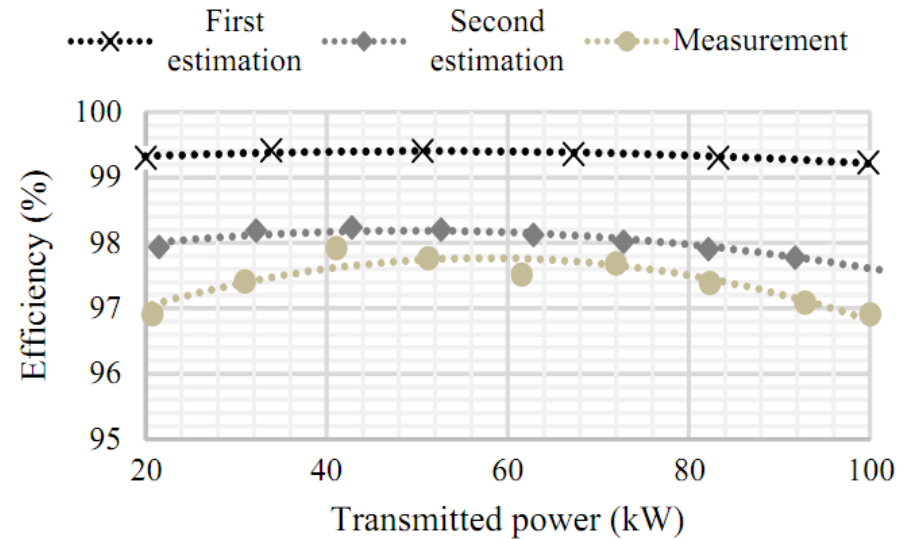
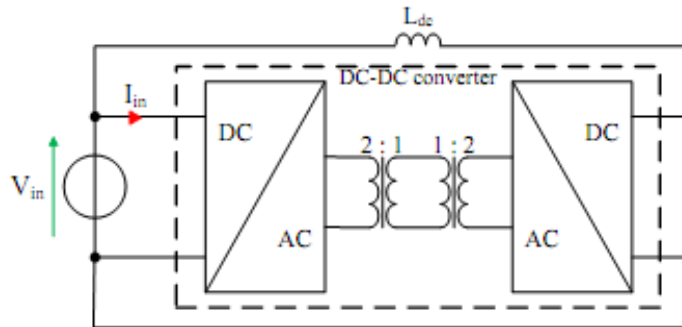
→ Use of “DC conduction solver”

- Consideration of the RMS values of the current
- No proximity/skin effects considered
- Validity for thermal simulations ?



Simulation flow

Accurate models are required to predict the losses



	Hypothesis	Error
First approximation (Matlab script)	Polynomial approximation from datasheets Spontaneous commutation lossless	25 %
Second approximation (Matlab script)	Polynomial approximation from double pulse Spontaneous commutation lossless	15 %

➔ Next step : losses estimation with simulations ?

Simulation flow

Conclusion on the approach used

→ Global system level simulation

- Too complicated electro-magnetic reduced models
- No Behavioral models for the power switches
- No complete simulations of the system (control + power circuits)
- No losses estimation
- Limited ElectroMagnetic Disturbances consideration

→ No accurate thermal simulations

- Complexity to consider both AC+DC excitations
- No coupling between thermal and electromagnetic simulations
- No coupling between thermal and mechanical simulations

→ No dielectric simulations

→ Issues during the tests

- ElectroMagnetic Disturbances
- Thermo-mechanical deformation on the power modules

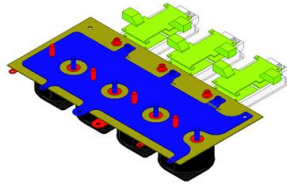
Enhanced simulation flow



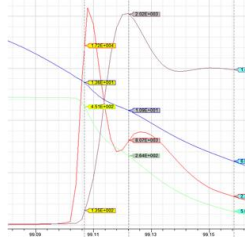
Enhanced design flow

New approach proposed

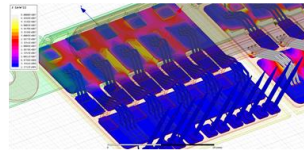
Electromagnetic simulations
(Ansys Q3D ®)



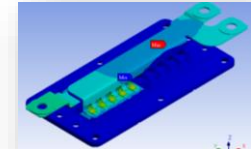
Circuit simulations
(Ansys Simplorer ®)



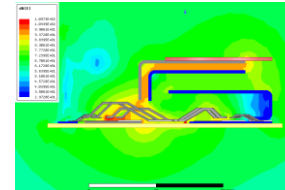
Current densities
(Ansys Maxwell 3D ®)



Thermal simulation



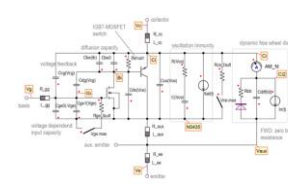
Dielectric simulations



Overvoltage
Losses estimation
Control/power interactions
EMI
...

Temperatures
Electro-mechanical stress
Voltage whistand
...

Switches behavioral models

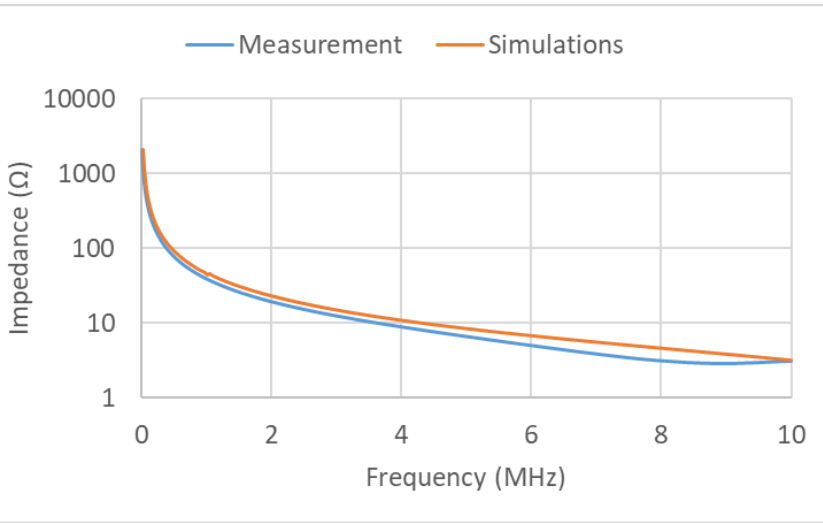


Temperature

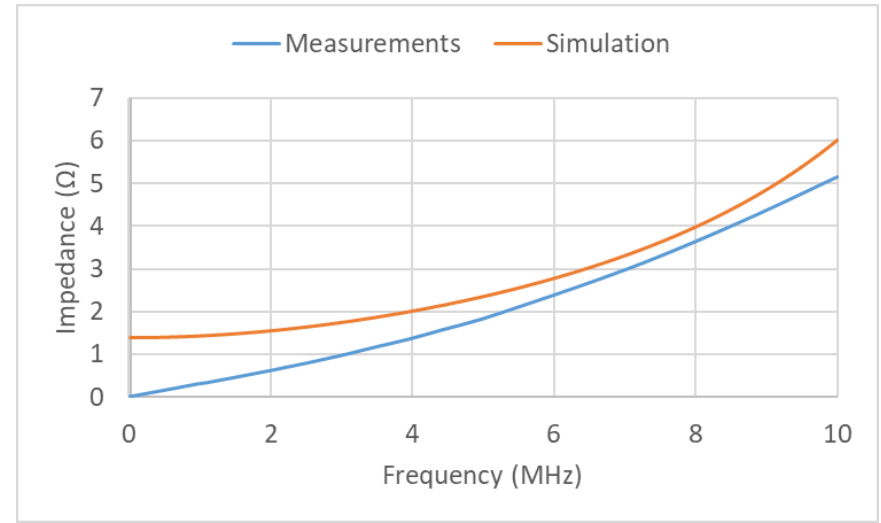
Electromagnetics reduced models

Reduced models are satisfying but the order might be reduced

→ Open circuit



→ Short circuit



→ Capacitance @ 5 MHz

- Measurement : 4,04 nF
- Simulation : 3,95 nF

→ Inductance @ 5 MHz

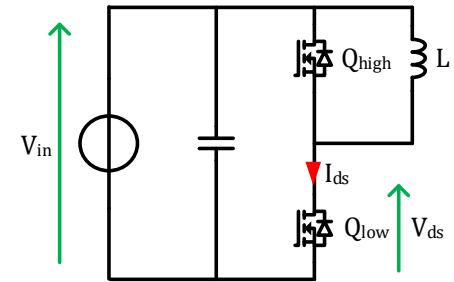
- Measurement : 49,7 nH
- Simulation : 42 nH

→ First order behavior

- Use of simplified models in order to increase the simulation speed ?

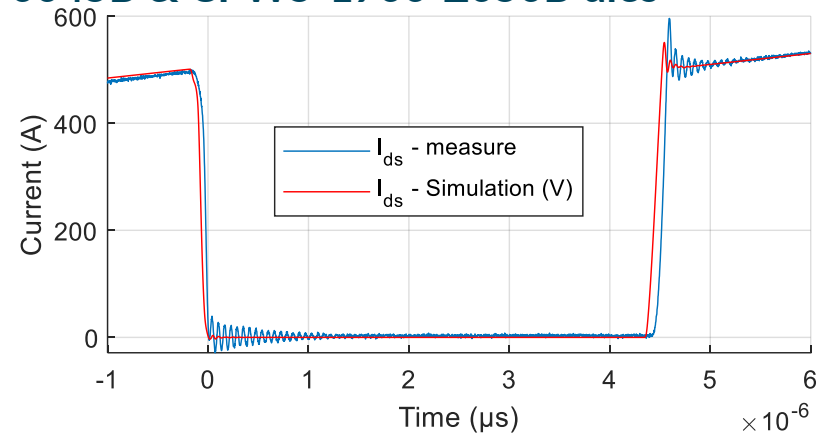
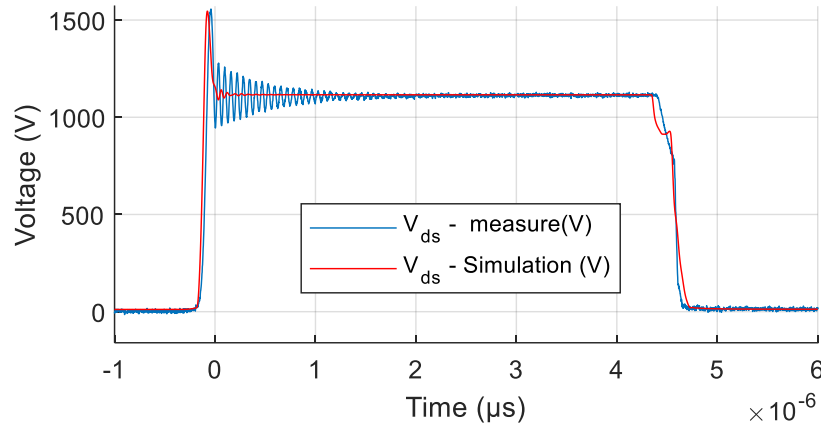
Behavioral models power switches

Behavioral models are good but might be improved



→ Clamped inductive load test

- > 1200 V - 500 A
- > Power module based on CPM2-1700-0045B & CPW5-1700-Z050B dies

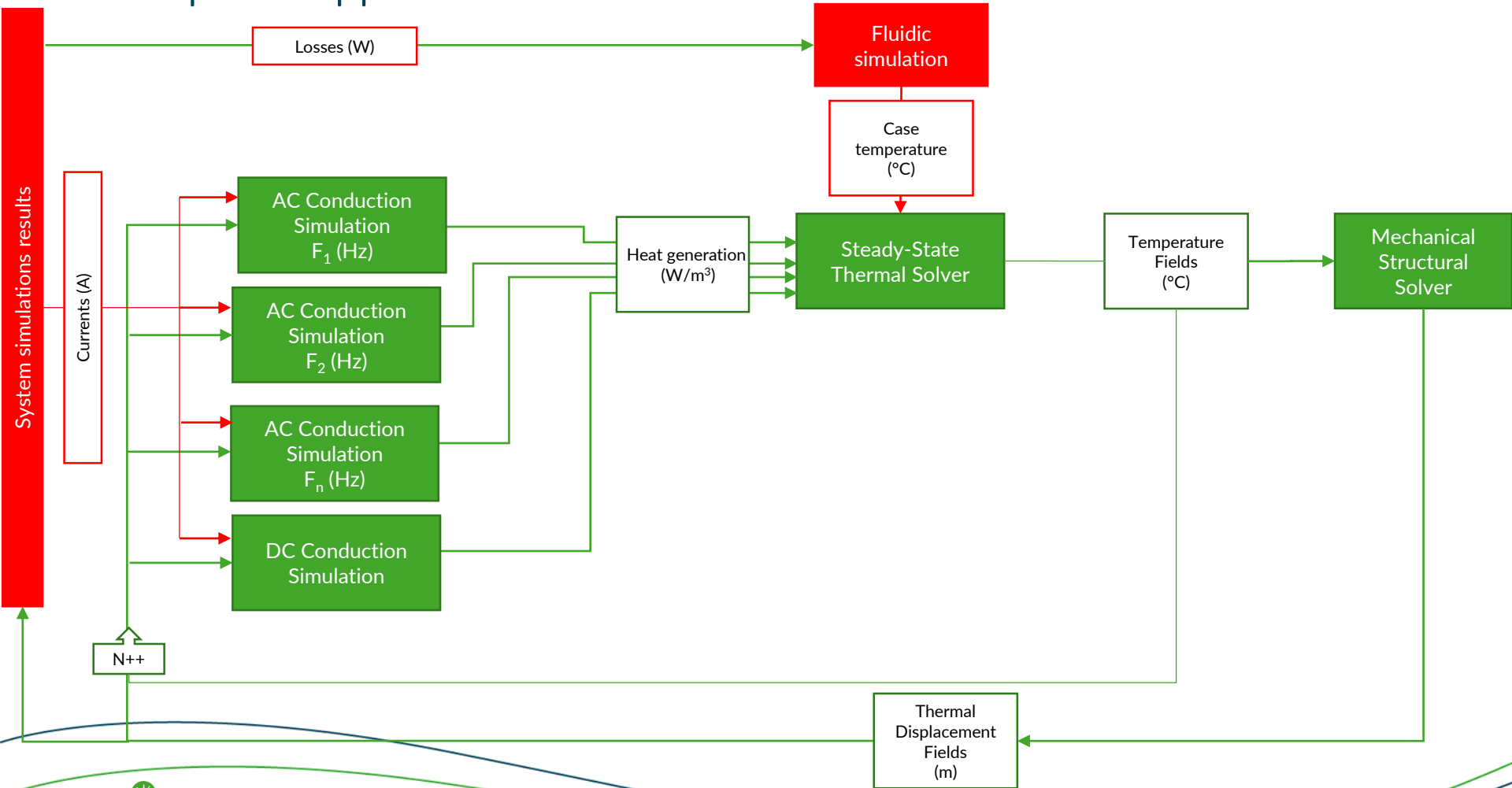
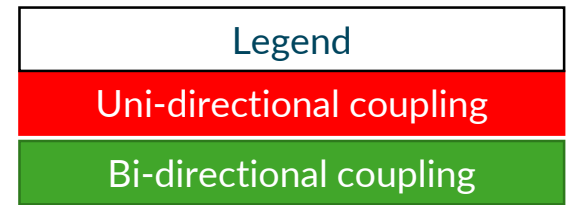


Switching losses comparison (IEC 60474)

	Measure	Simulation	
Turn off (mJ)	40	30	- 25 %
Turn on (mJ)	35	45	+ 30 %

Electro-thermal simulations

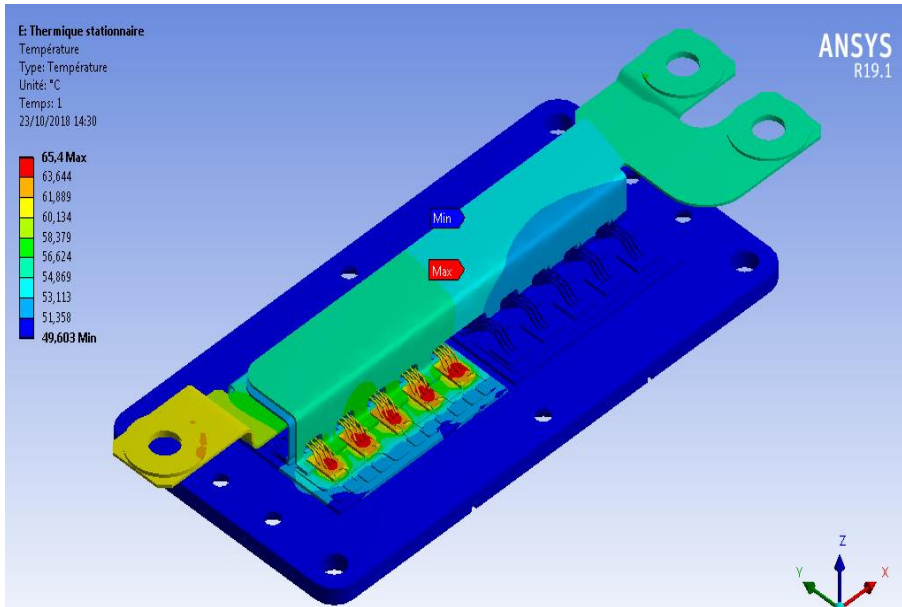
Proposed approach



Electro-thermal simulations

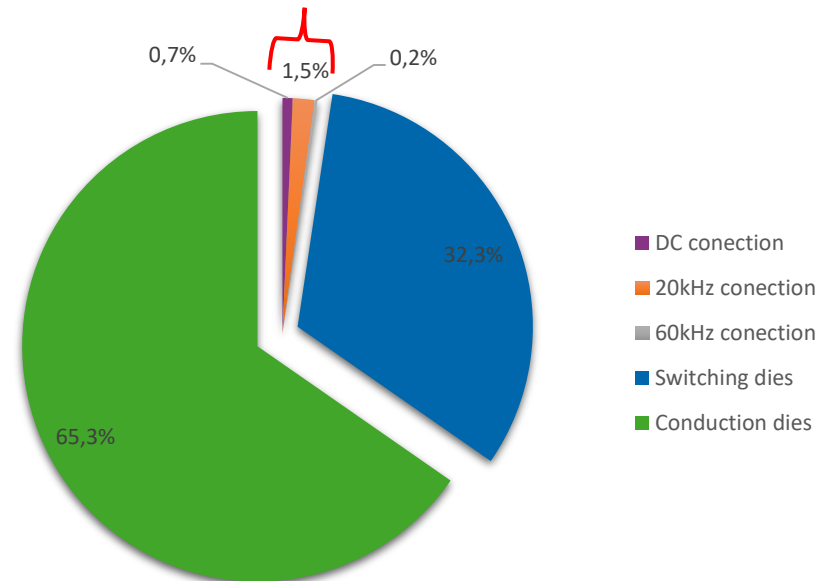
Simulation results

Temperature



Operating point : 1,2 kV – 125 A – 20 kHz
 $T_c = 20\text{ °C}$

Losses in the connections

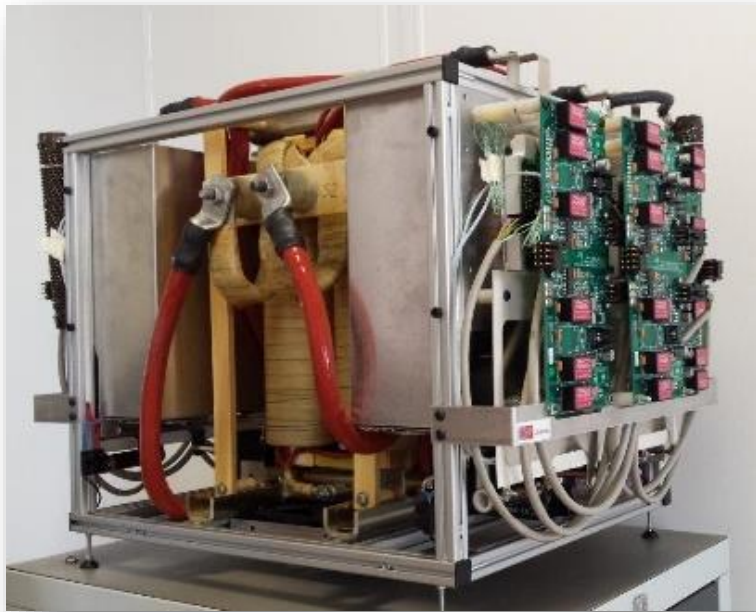


Losses in the power module

- 98 % of the losses are in the dies
- 2 % of the losses in the connections
- Experimental validation to be performed

Conclusion & perspective

- 3DFE simulation is necessary in the design of components
- Global system level simulation helps to validate the design
- Simplified models are the key for system level simulations
 - Behavioral models for power switches
 - Simplified 3DFE reduced models
 - The compromise between accuracy and simulation cost has to be found



Thank you for your attention