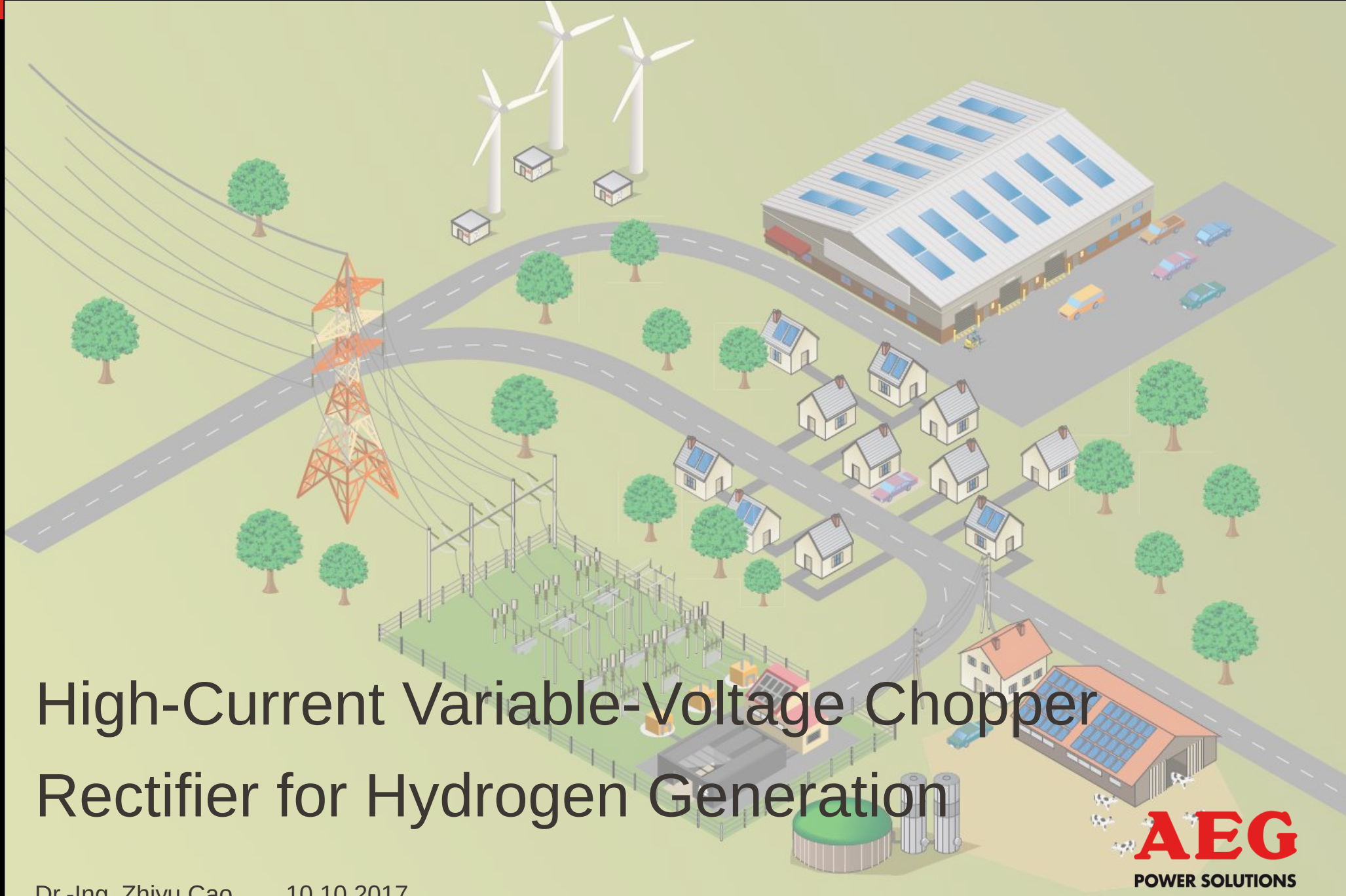

High-Current Variable-Voltage Chopper Rectifier for Hydrogen Generation

Dr.-Ing. Zhiyu Cao 10.10.2017

AEG POWER SOLUTIONS

Outline

1. **Power supply requirements for hydrogen generation**
2. **Development of hydrogen power supplies at AEG**
   - Comparison of rectifier topologies
   - AEG design tool
   - Design of Thyrobox DC-3C sample and verification of AEG design tool
   - Design of Thyrobox DC-3 module
3. **Parallel high-current system**

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Power supply requirements for hydrogen generation

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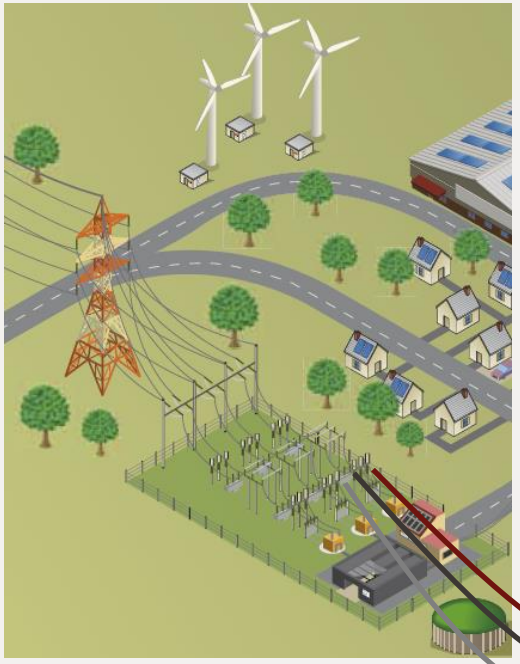
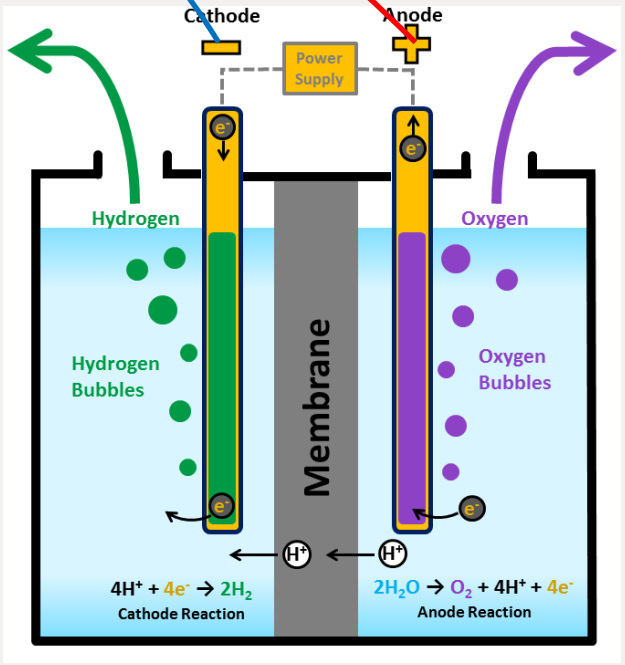
Power supply requirements for hydrogen generation





Grid-side requirements:

- High power factor in whole operation range
- Low THDi

Other requirements:

- High power density
- High efficiency
- Scalable modular design

Stack-side requirements:

- Variable voltage
- High current / high power (up to some kA / MW)
- Low output current ripple

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Development of hydrogen power supplies at AEG

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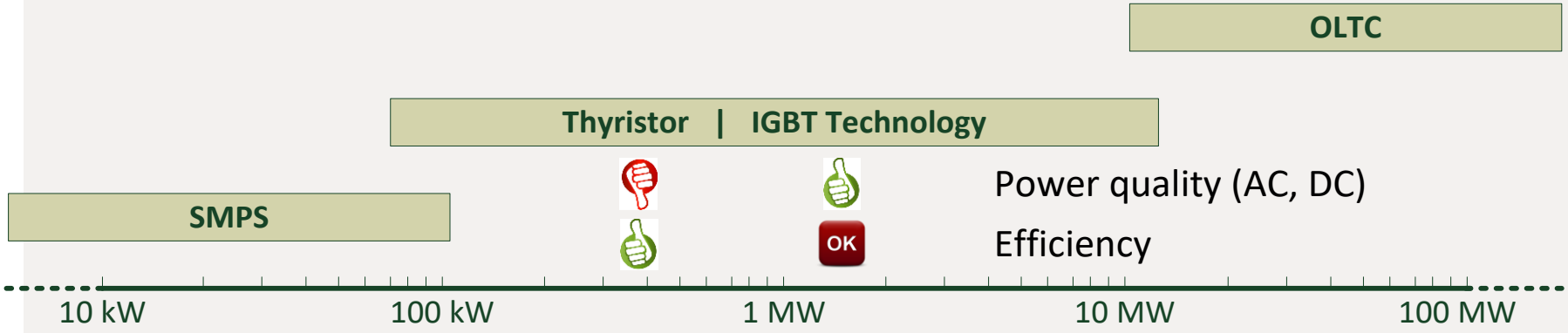
Comparison of rectifier topologies

Topology vs. power ratting

- Switched-mode power supply for low power rating
- Thyristor and IGBT technologies for medium power rating
- On-load tap-changing for high power ratting



	Thyristor (B6 / B12)	B12 + IGBT
DC current ripple	-	+
Operation range	-	+
Power factor / THDi	-	+
Efficiency	++	+

Applied in Thyrobox® DC-3 / Thyrobox® DC-3C

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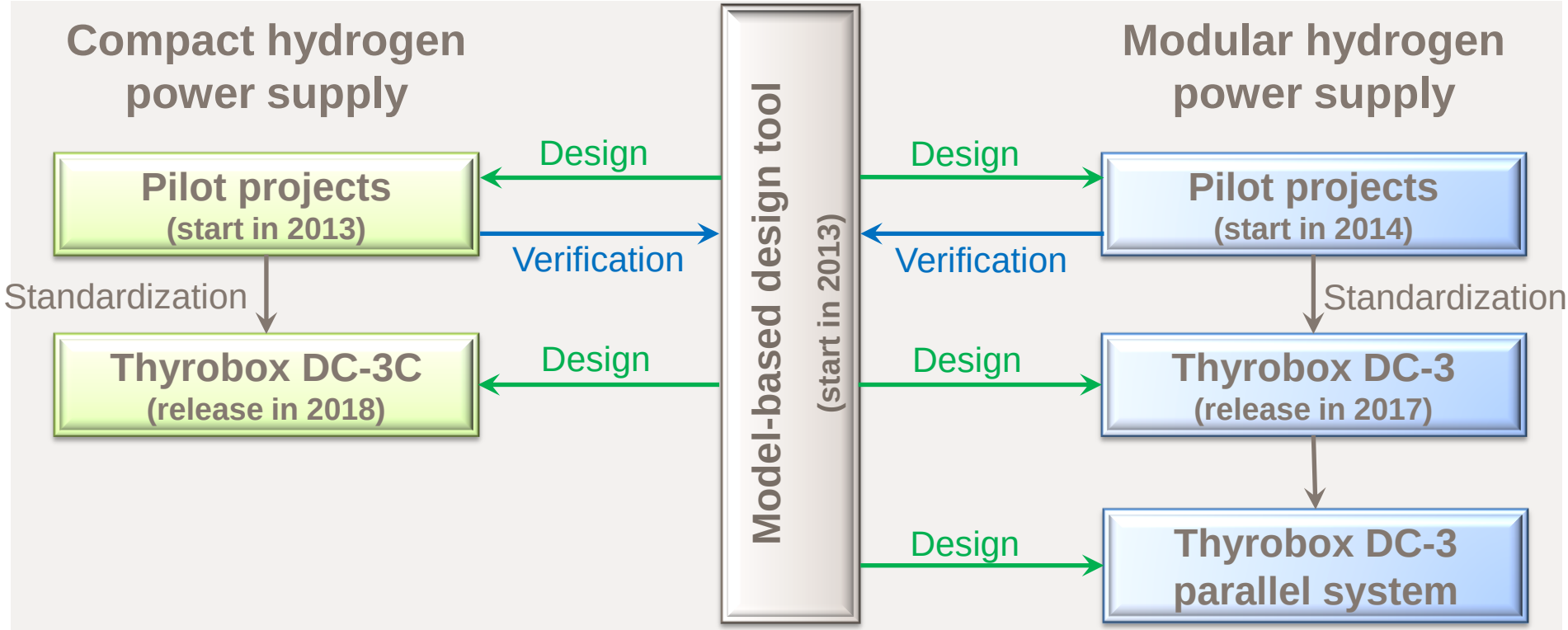
Development of hydrogen power supplies at AEG Power Solutions



	Thyrobox DC-3C	Thyrobox DC-3
Grid connectin	LV (380 / 400V)	LV / MV
Transformer	Integrated	Not integrated
DC-side limit per unit	1000A / 550V / 200 kW	1800A / 700V / 450 kW
Cooling	Forced air (FA)	Water cooling
Parallel operation	No	Yes

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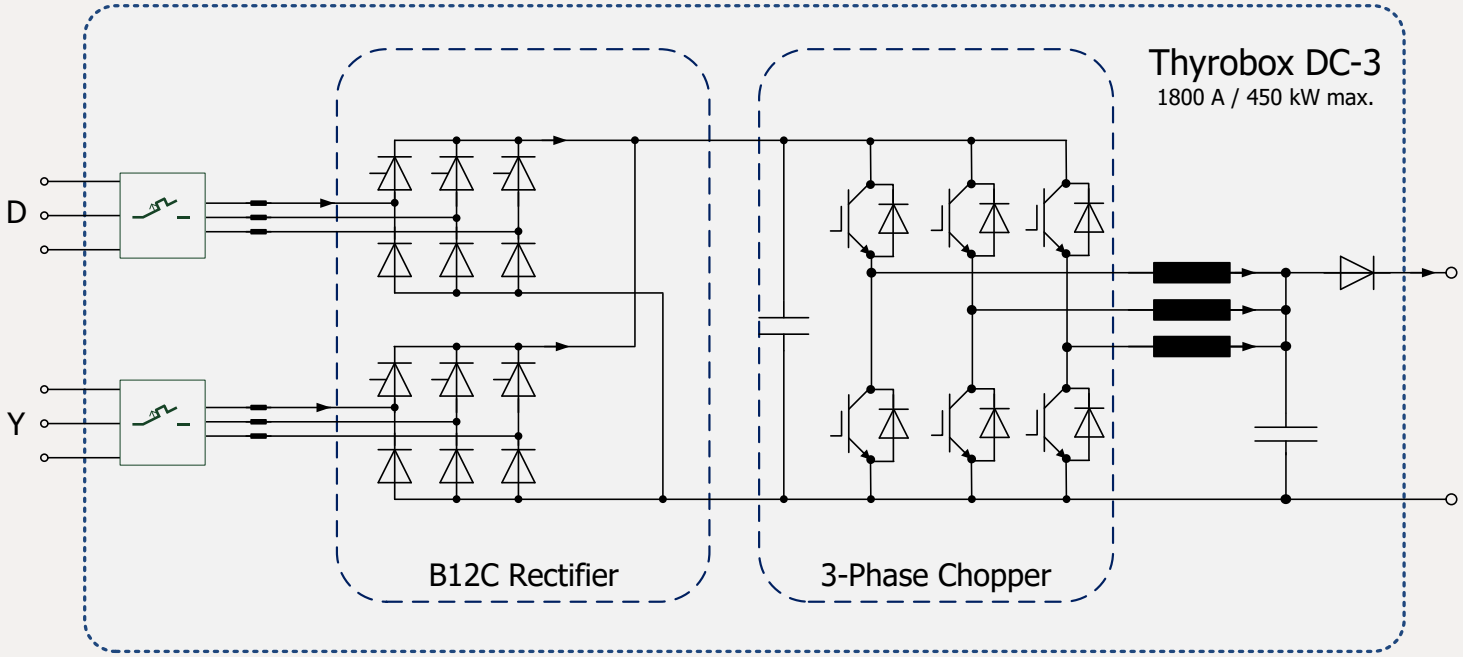
Modeling of power circuit



Electrical modeling:

- Steady-state model of 3-phase IGBT chopper in CCM and DCM
- Steady-state model of B12 rectifier

Semiconductor losses:

- On-state losses:
  $P_{on} = U_0(T_j)\bar{i} + R_{on}(T_j)I$
- Switching losses of IGBTs:
  - Measured by double-pulse test
  - $P_{sw} = \mathrm{LUT}(i, U_{DC}, T_j)$

Choke and transformer losses:

- AC-choke, transformer: R_{Fe}, R_{Cu}
- DC-choke:
  - Core loss: Bertotti formula
  - Winding losses: FEM simulation

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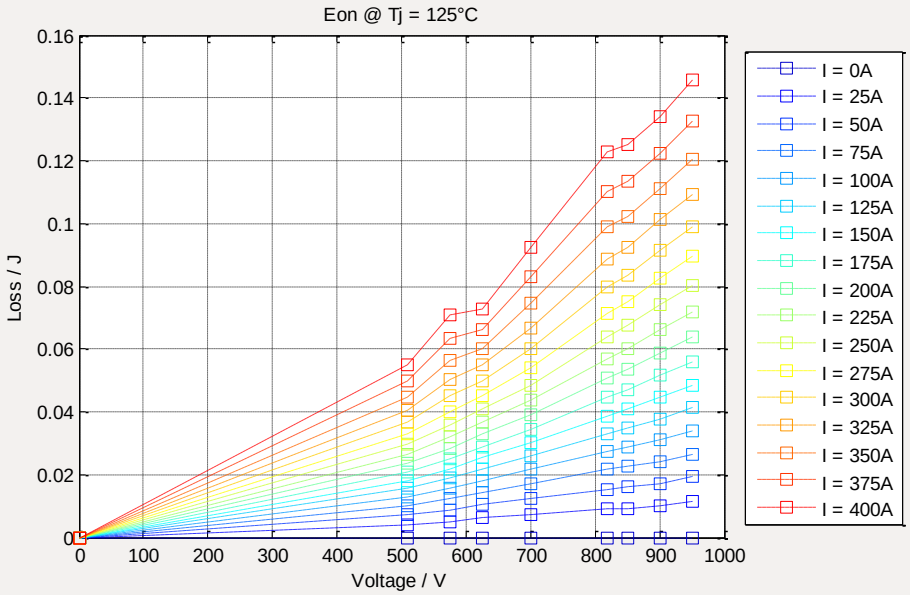
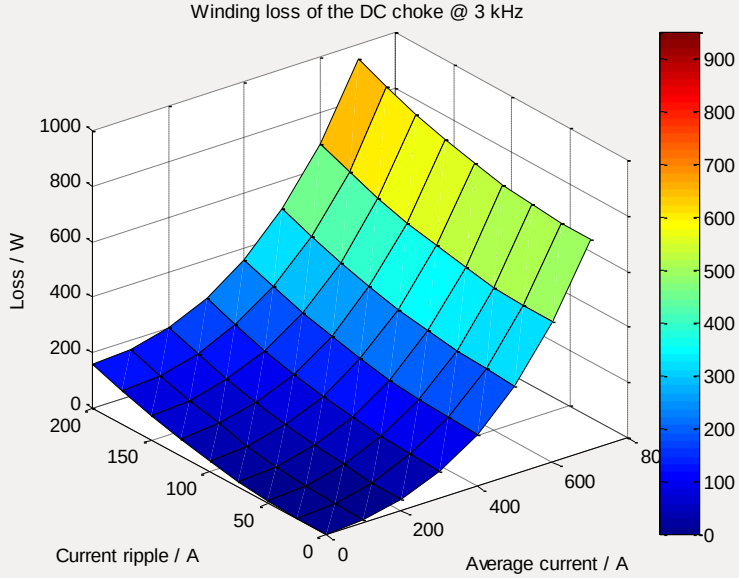
Modeling of power circuit





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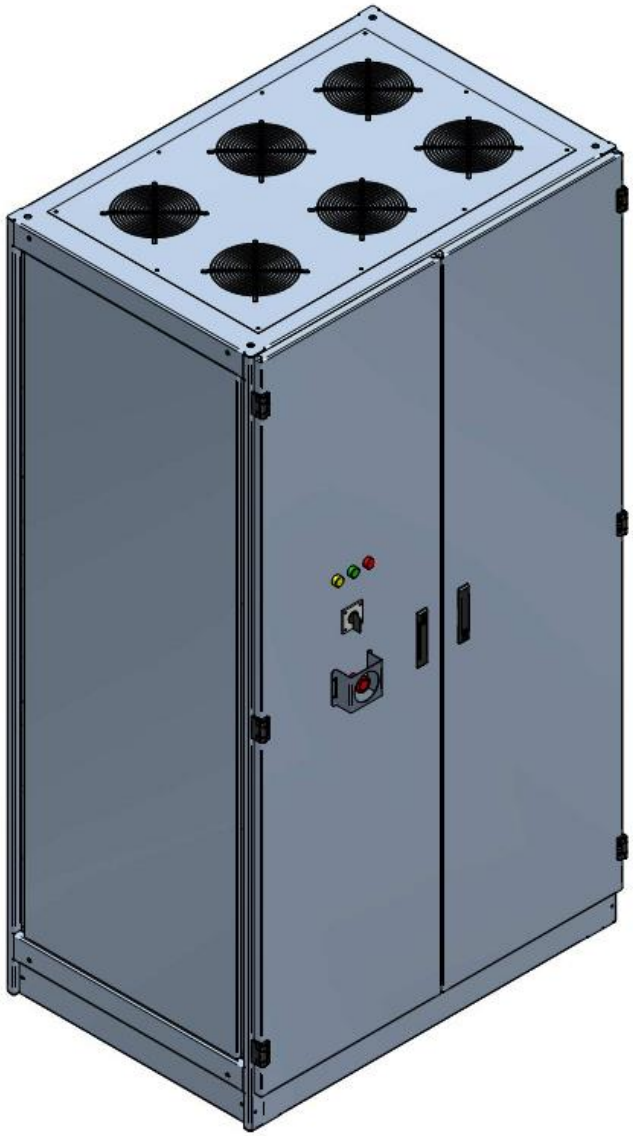
Design of Thyrobox DC-3C sample – specification



Specification of Thyrobox DC-3C sample

- AC input: 3-phase 400 V ± 10% mains
- DC output: DC 210 V, 900 A, 189 kW max.
- Efficiency: 95% at full load
- Power factor: 7% at full load
- Power factor: > 95% at full load
- Forced-air cooling

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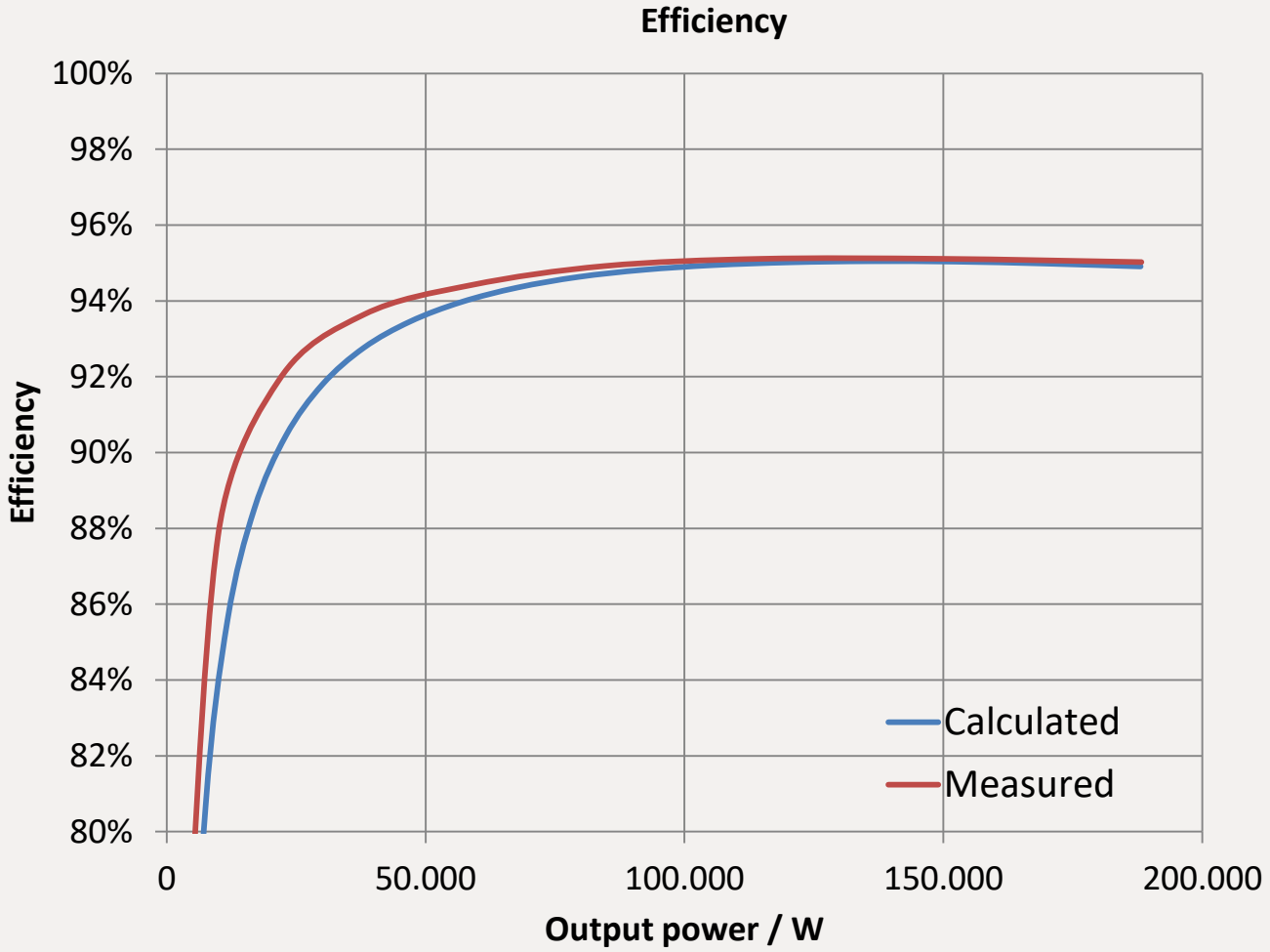
Design of Thyrobox DC-3C sample – verification



Good agreement between analytical model and measurement results !

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Design of Thyrobox DC-3 – specification

Specification of Thyrobox DC-3

- Mains: MV/LV ±10% voltage variation
- Input: customized input voltage / current
- Output: 450 kW, 1800 A max.
- Output voltage/current ripple: < 1% @ full load (FL)
- Power factor (PF), THDi and efficiency exit. transformer (η)

	>10% FL	>20% FL	>40% FL	at FL
PF	> 0.9	> 0.92	> 0.95	
THDi	< 40%	< 30%	< 20%	< 7%
η	> 92%	> 95%	> 96%	> 97%

Power circuit and cooling for worst case: 1800 A, 450 kW !

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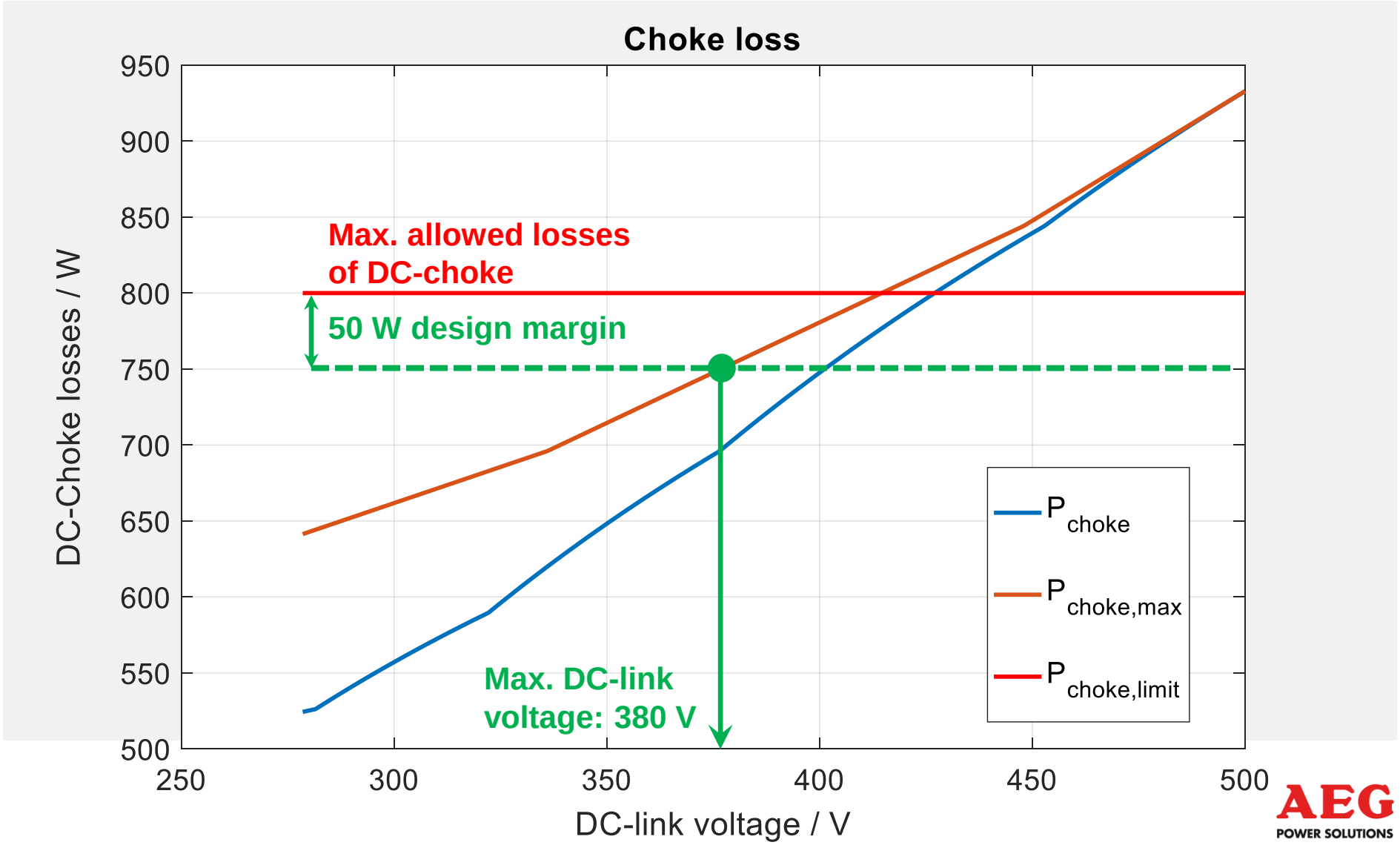
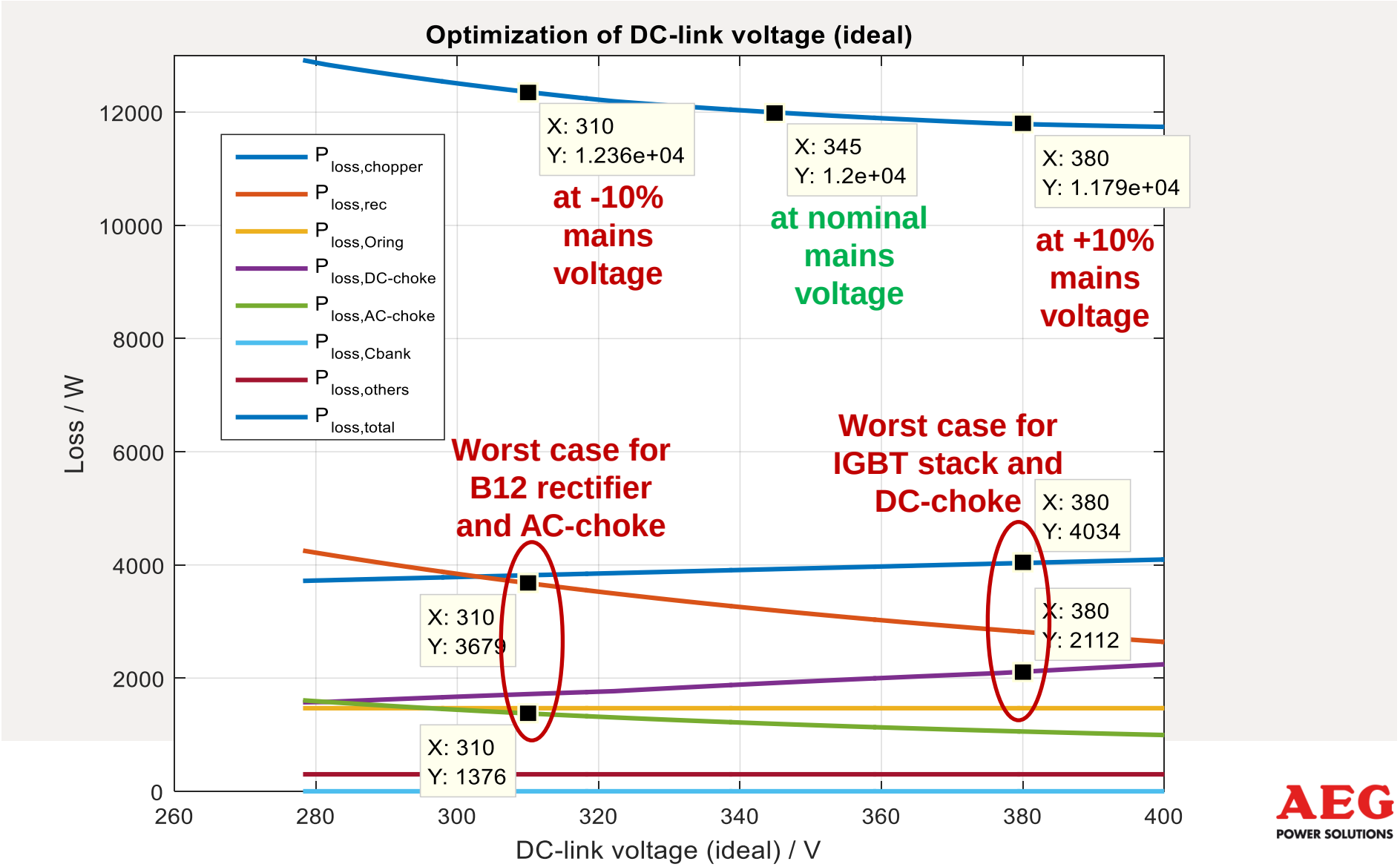
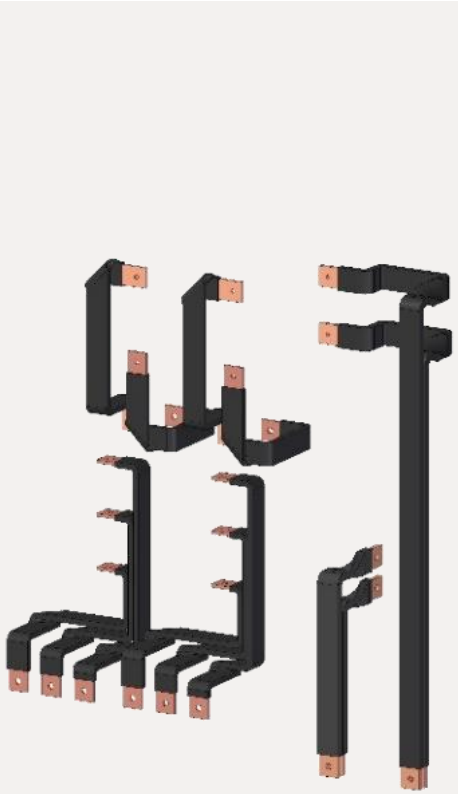
Design of Thyrobox DC-3 – max. allowed DC-link voltage

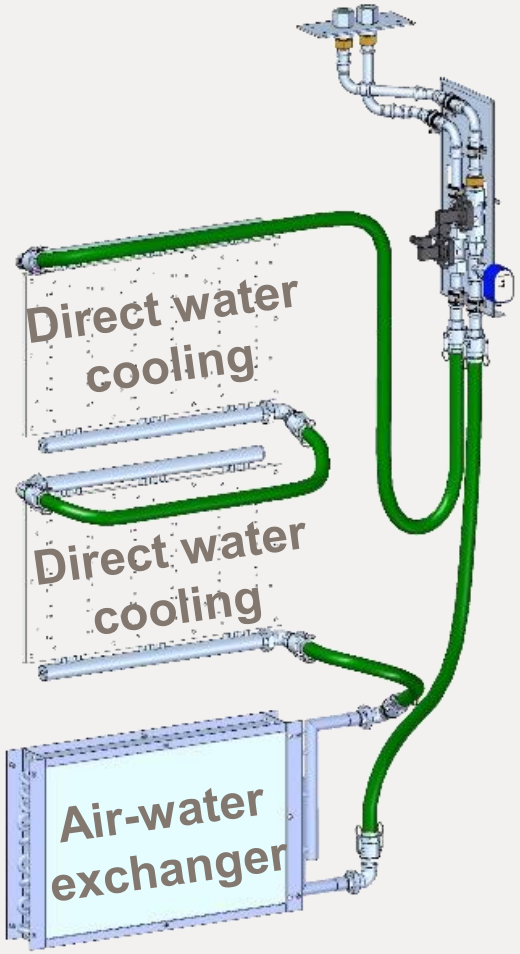


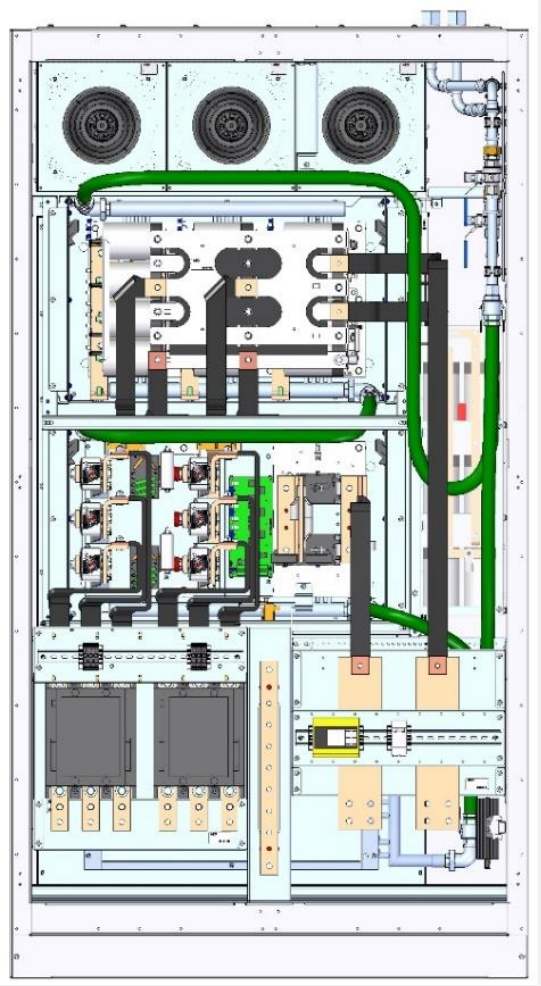
Design of Thyrobox DC-3 – worst cases of components



Design of Thyrobox DC-3 – cooling system and system layout







Bus-bar, cooling system and system layout optimized for worst cases !

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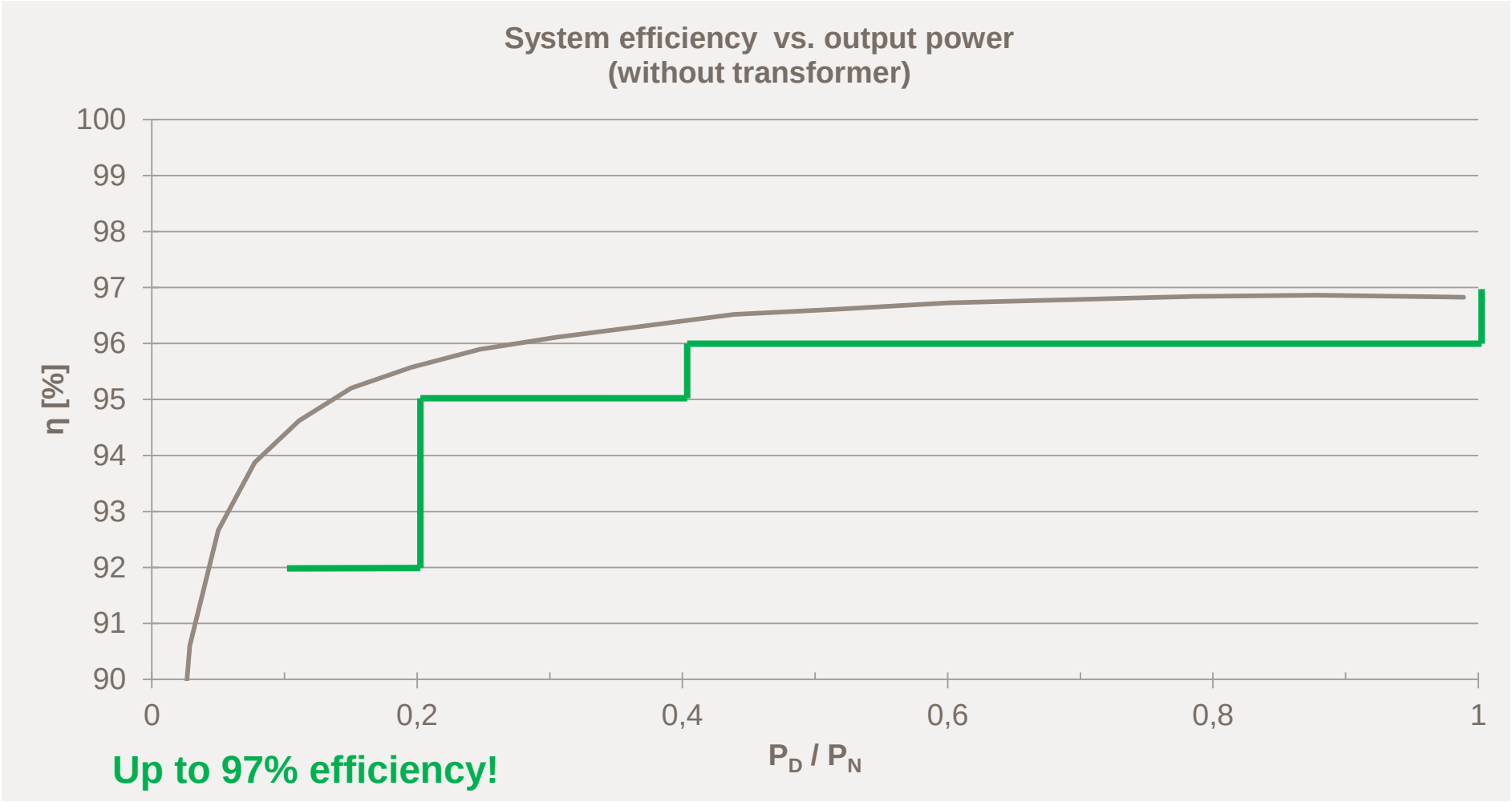
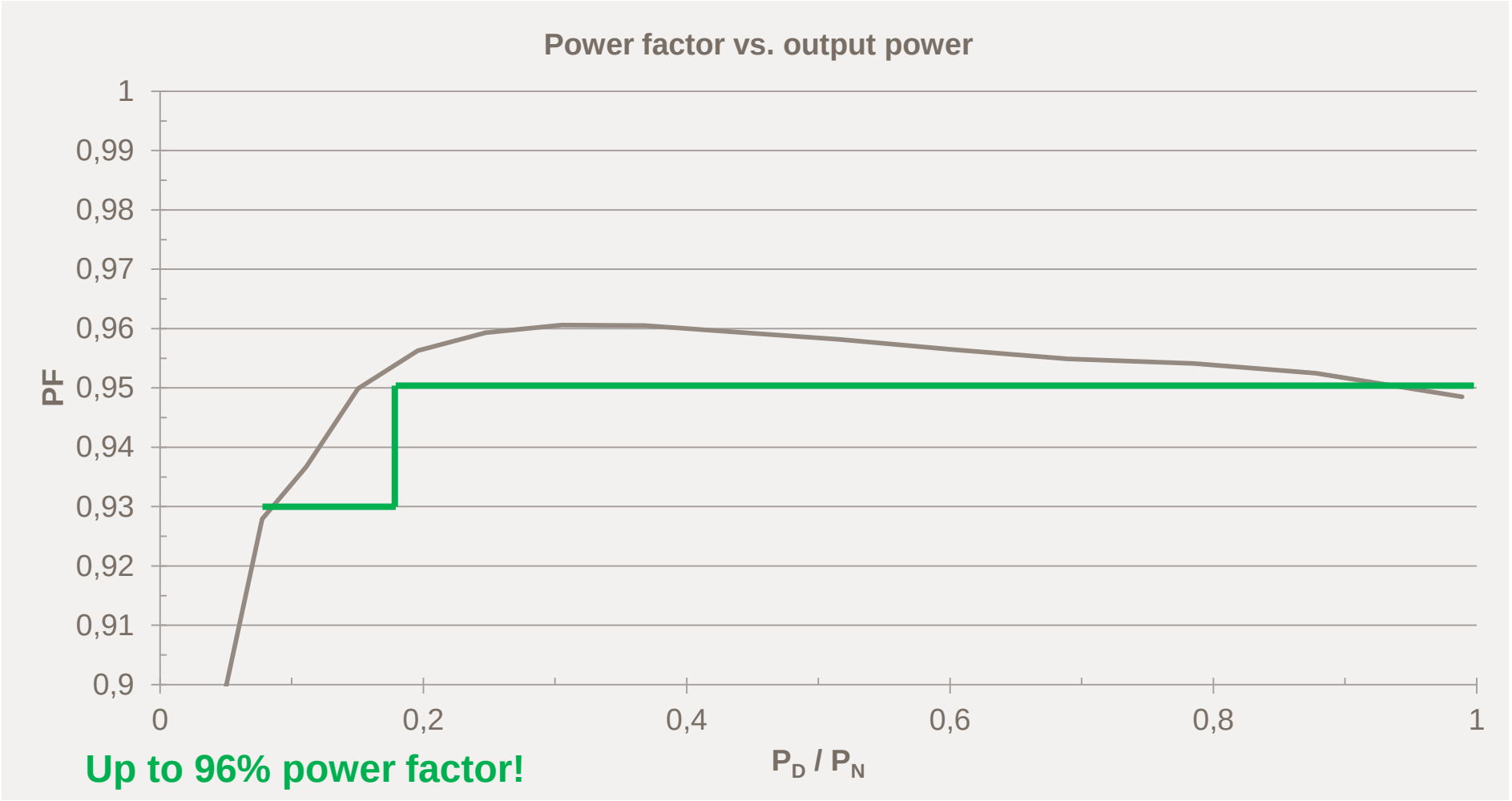
Design of Thyrobox DC-3 – measurement result (efficiency)



Design of Thyrobox DC-3 – measurement result (power factor)



Up to 96% power factor!

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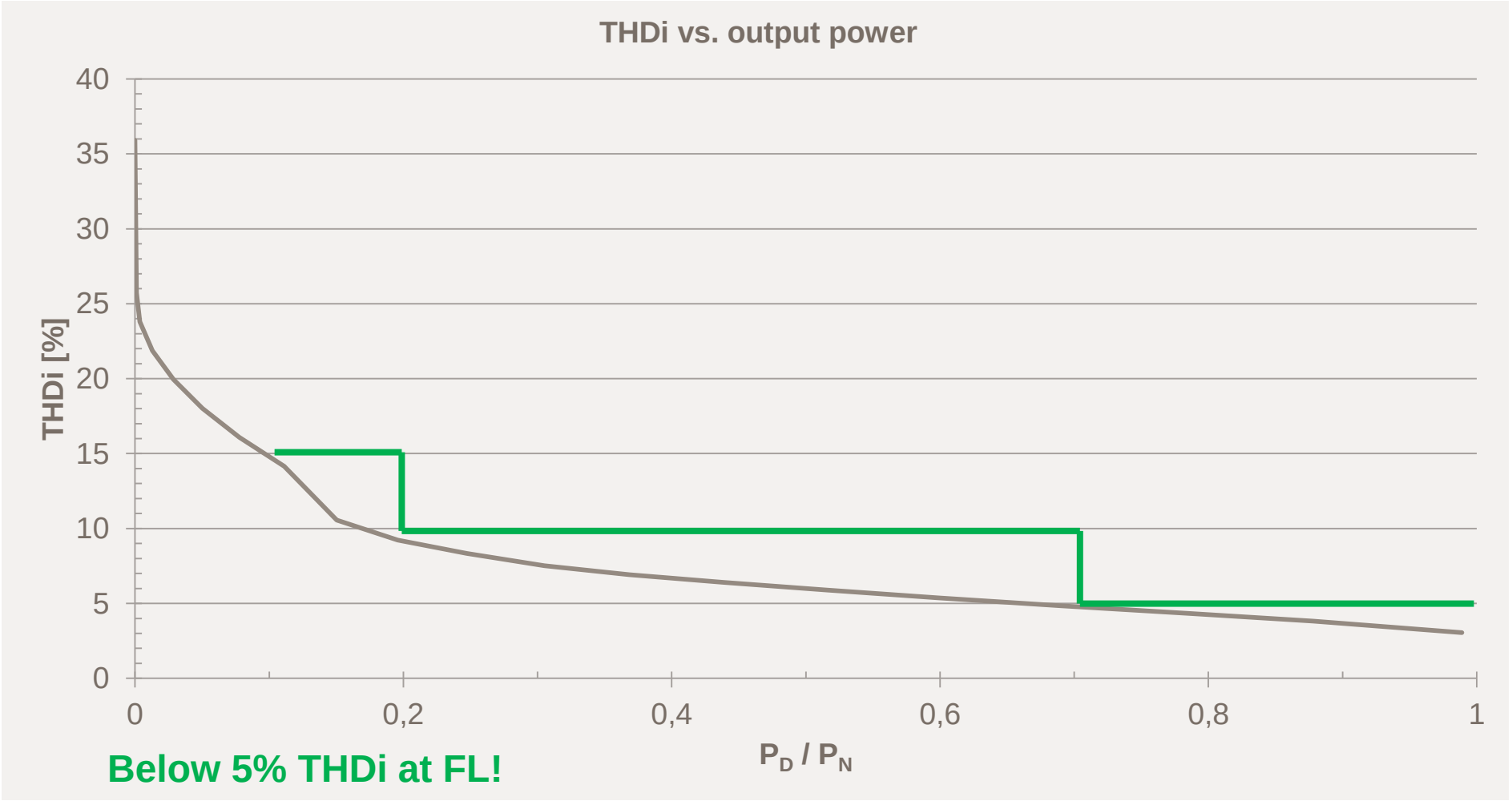
Design of Thyrobox DC-3 — measurement result (THDi)



Parallel high-current system

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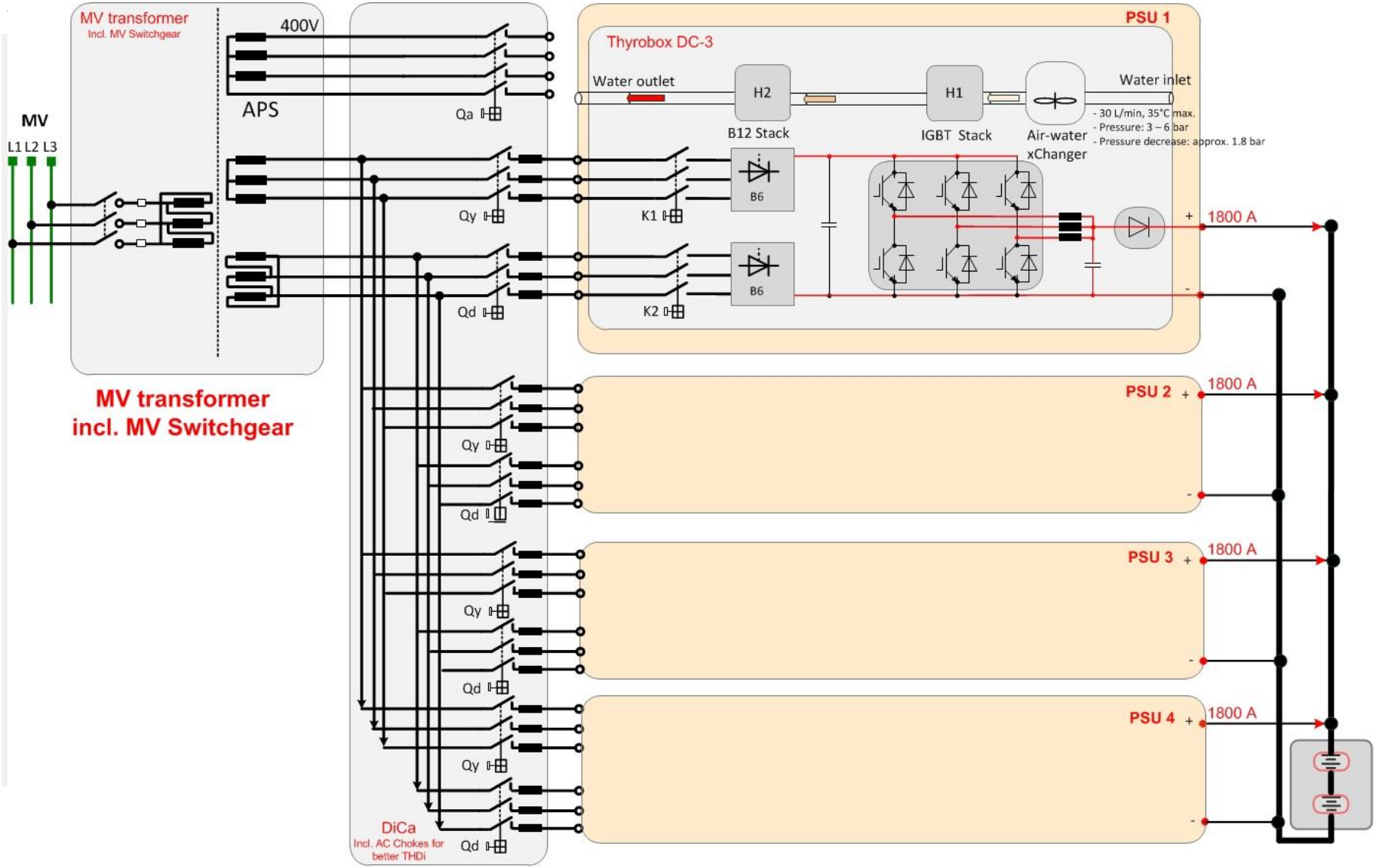
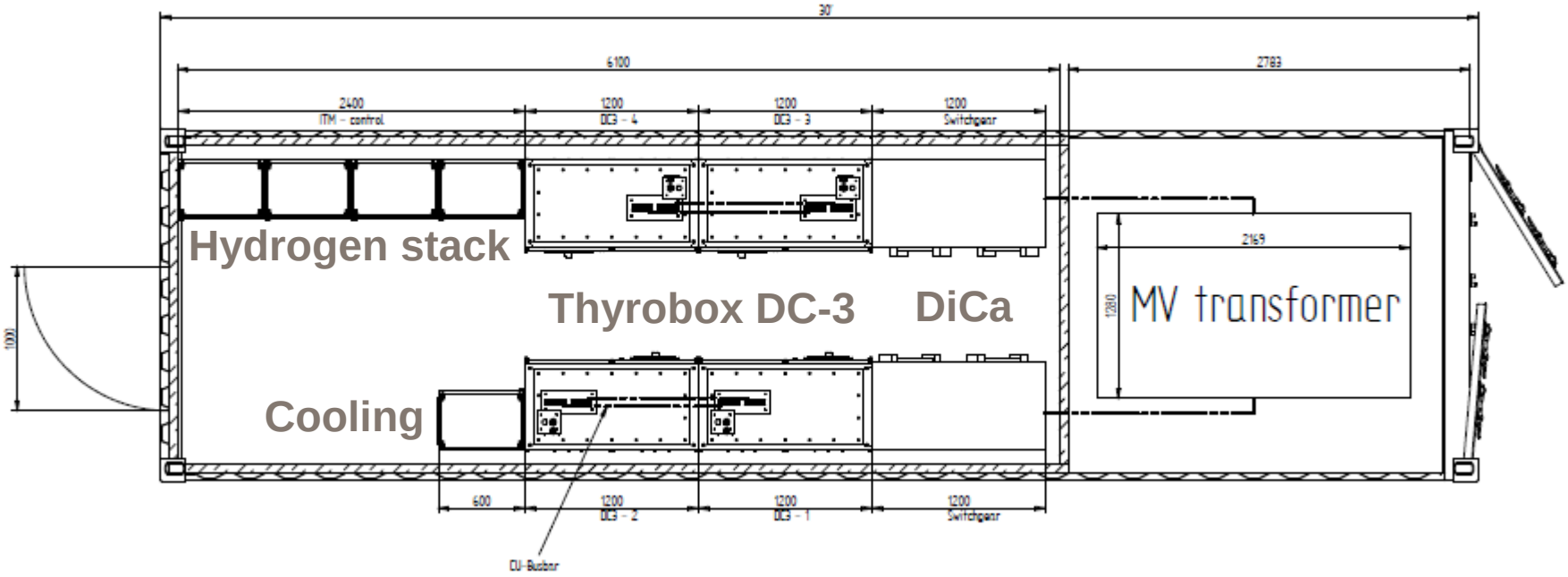
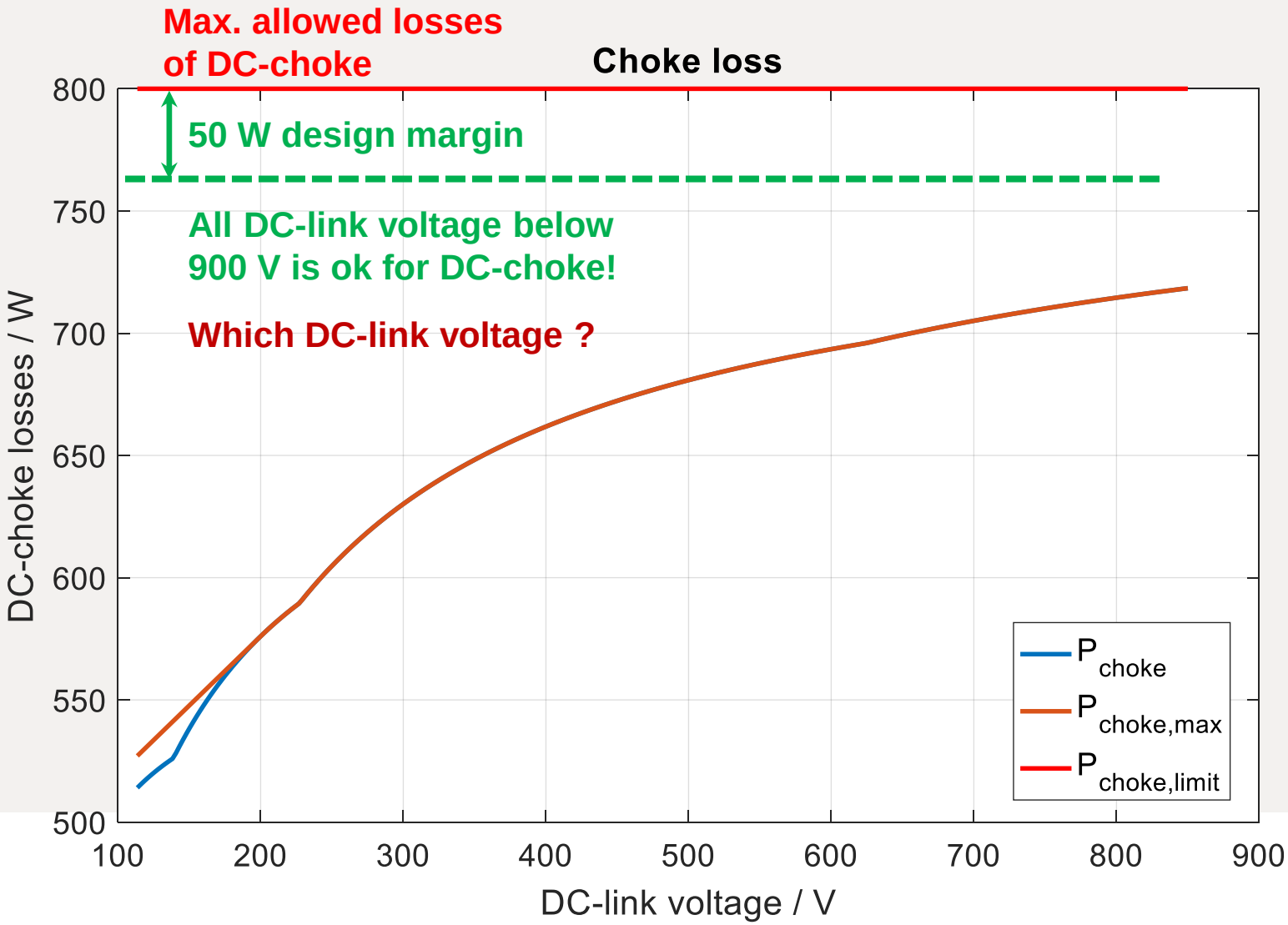
Example of a 100V / 7200A DC power supply system (electrical)



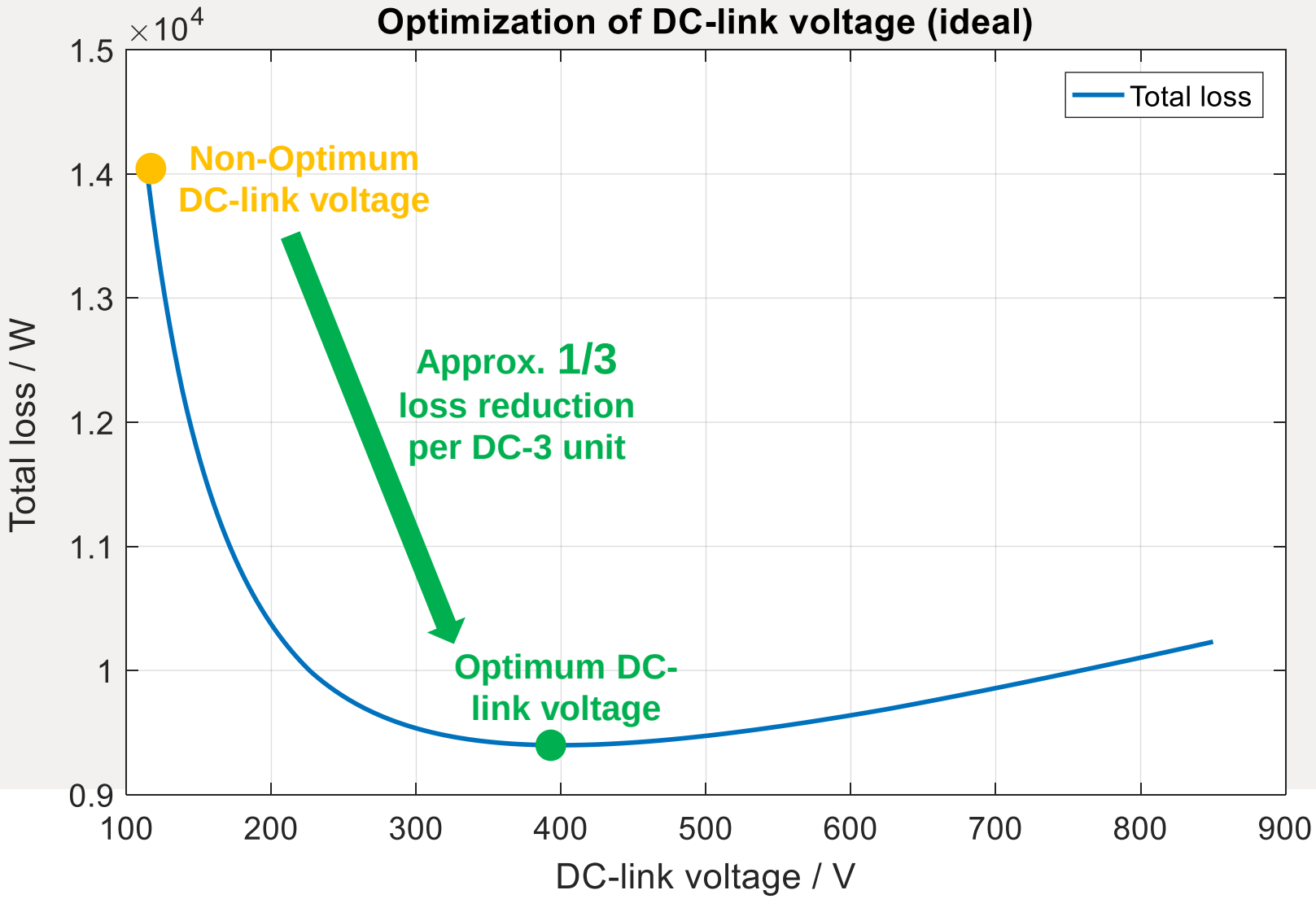
Example of a 100V / 7200A DC power supply system (container design)



Design of the 100V, 7200A system – max. allowed DC-link voltage



Design of the 100V, 7200A system – optimization of DC-link voltage



Thank you very much for your attention !

Dr.-Ing. Zhiyu Cao

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Thyrobox DC-3

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