
# Winding and Magnetic Core Selection for Medium-Frequency Transformers

PSMA High-Frequency Magnetic Workshop 2020

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# Motivation

- High-power Medium-Frequency Transformers (MFT) are the main magnetic component for galvanically isolated medium-voltage dc-dc converters of future dc grids.

- MFT prototypes from literature are typically operated between
  - 600 Hz and 20 kHz
  - 800 V and 10 kV

- High requirements on
  - Magnetic core materials
  - Winding types
  - Insulation materials.

- Their adequate selection is mandatory for
  - High efficiency
  - Low material demand
  - Improved reliability

# Content

- Medium-Frequency Transformer
- Winding types and design
- Magnetic core materials and design
- Conclusion

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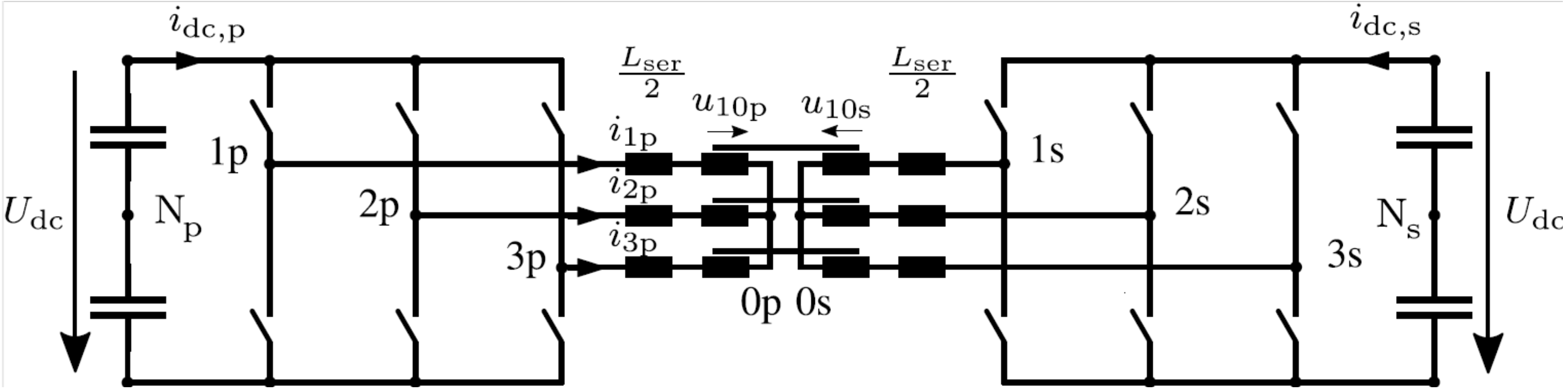
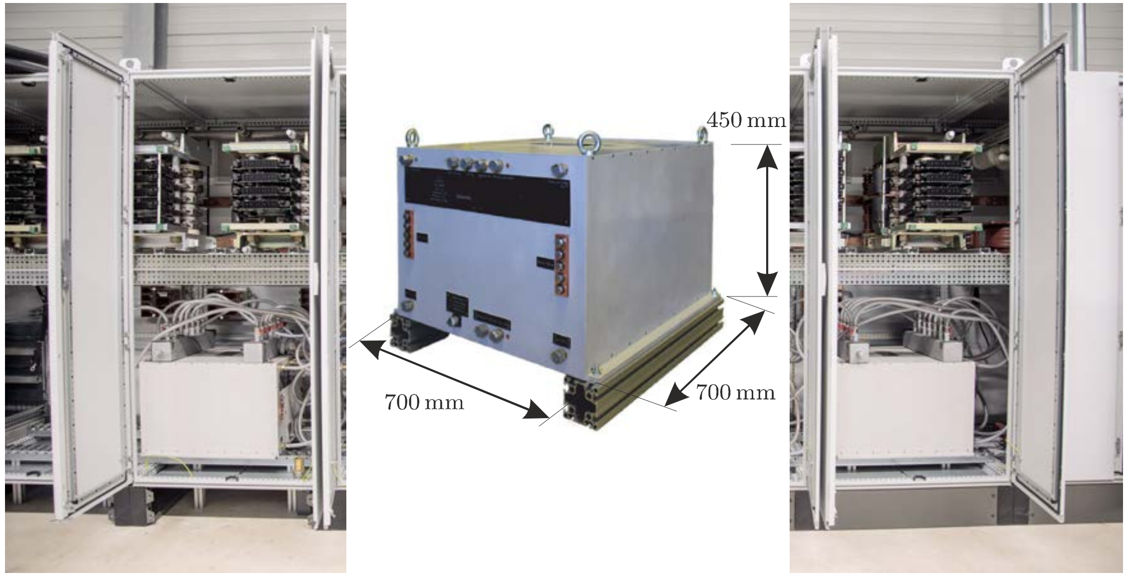
# Medium-Frequency Transformer

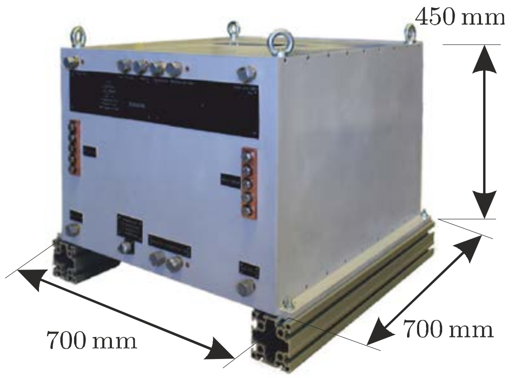
- Galvanically isolated medium-voltage dc-dc converter
  - 5 MW three-phase Dual Active Bridge topology
  - Three-phase or three single-phase MFTs
  - Single-phase dry-type MFT prototype
    - High-frequency litz wire windings
    - Weight 600 kg
    - Series inductance of 185 µH integrated into MFT as enhanced stray inductance
    - Water cooling

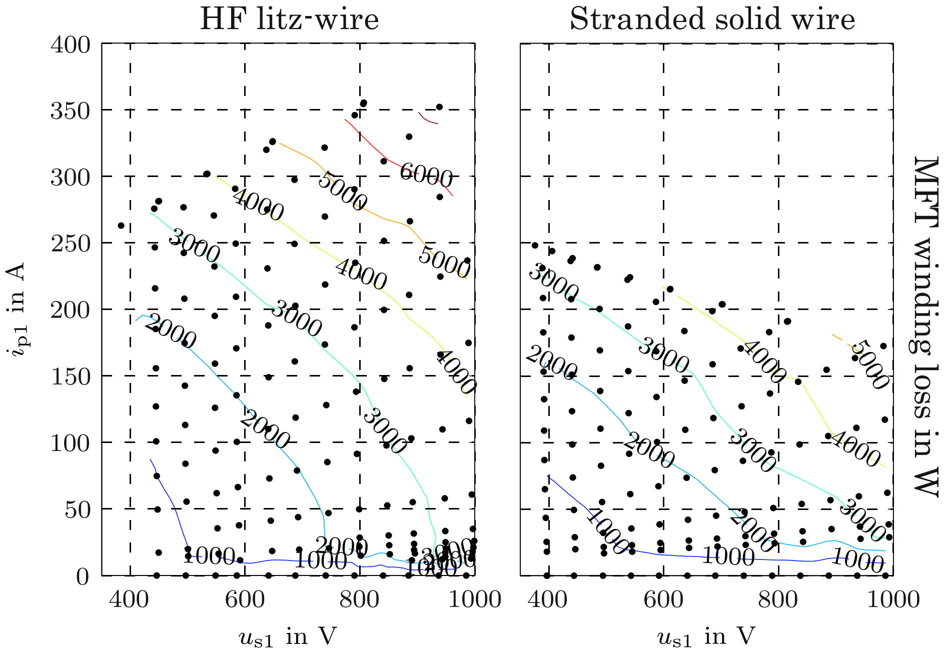


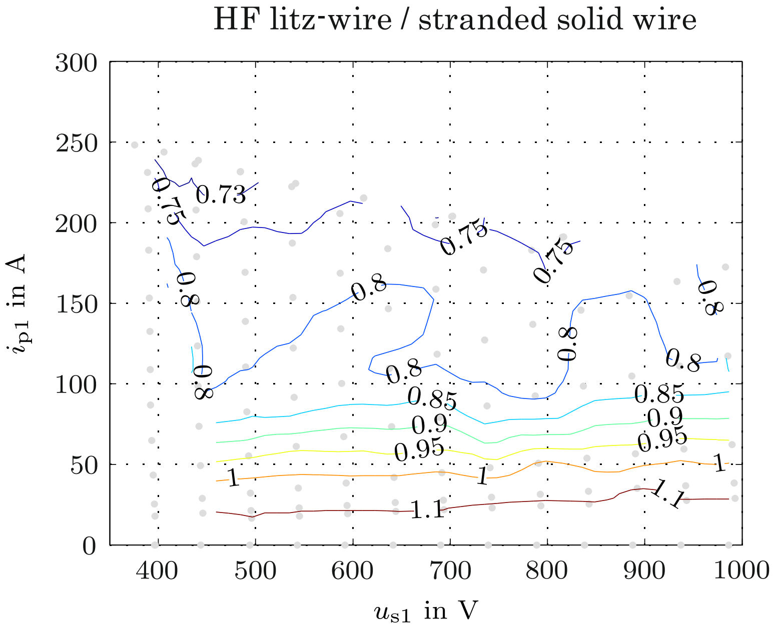




Reference: Multi-megawatt three-phase dual-active bridge dc-dc converter: extending soft-switching operating range with auxiliary-resonant commutated poles and compensating transformer saturation effects, Johannes Voss, Aachen 2019

- Winding loss of MFT with
  - Stranded solid wire
  - HF litz-wire winding
- Comparison and relative winding power loss vs.
  - DC-link voltage
  - Phase current




Reference: High-power medium-voltage DC-DC converters : design, control and demonstration, Nils Soltau, Aachen 2017

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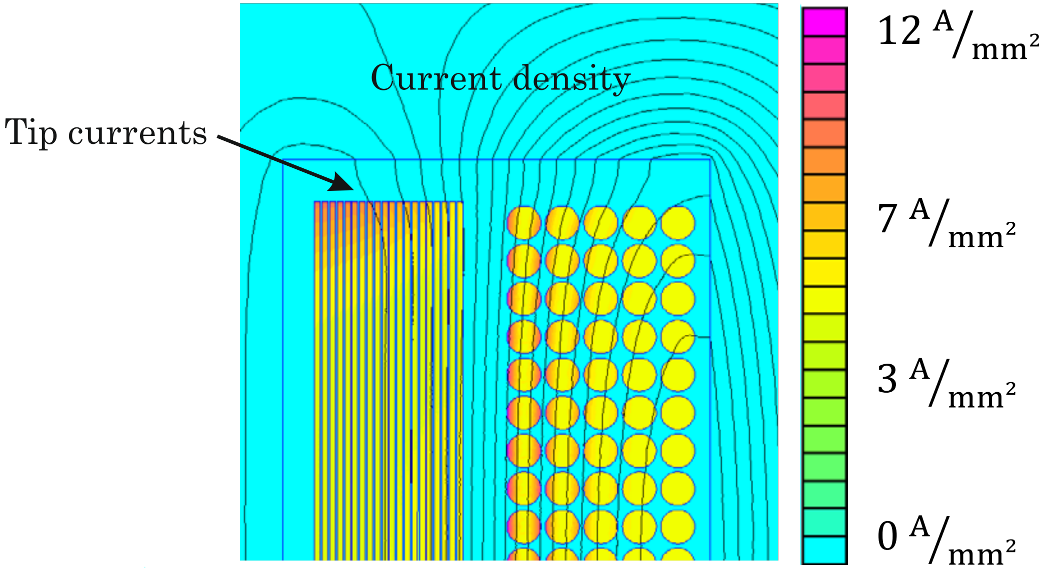
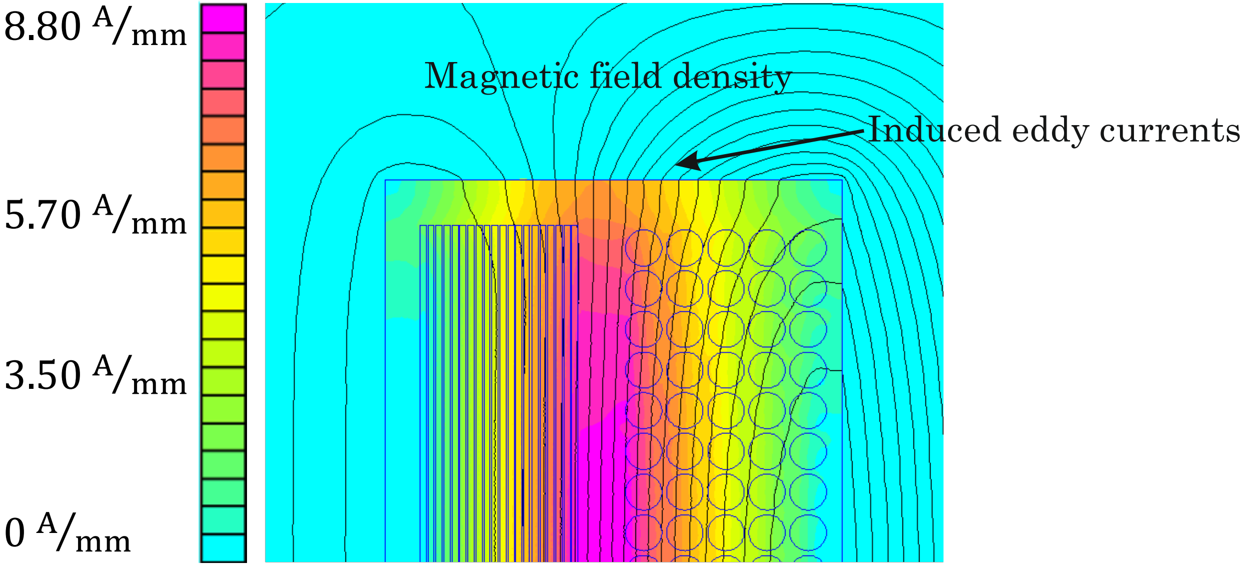
# Winding types and design

- Suitable winding types for high-power MFTs
  - Non-isolated stranded solid wire winding
    - Cost effective, high packaging factor (+)
    - High ac loss (-)
  - Isolated high-frequency (HF) litz-wire winding
    - Low ac loss possible (+)
    - Custom-built and expensive, circulating currents, non-uniform strand currents, low packaging factor (-)
  - Foil winding
    - Standard, easy processing, highest packaging factor (+)
    - High tip currents (-)

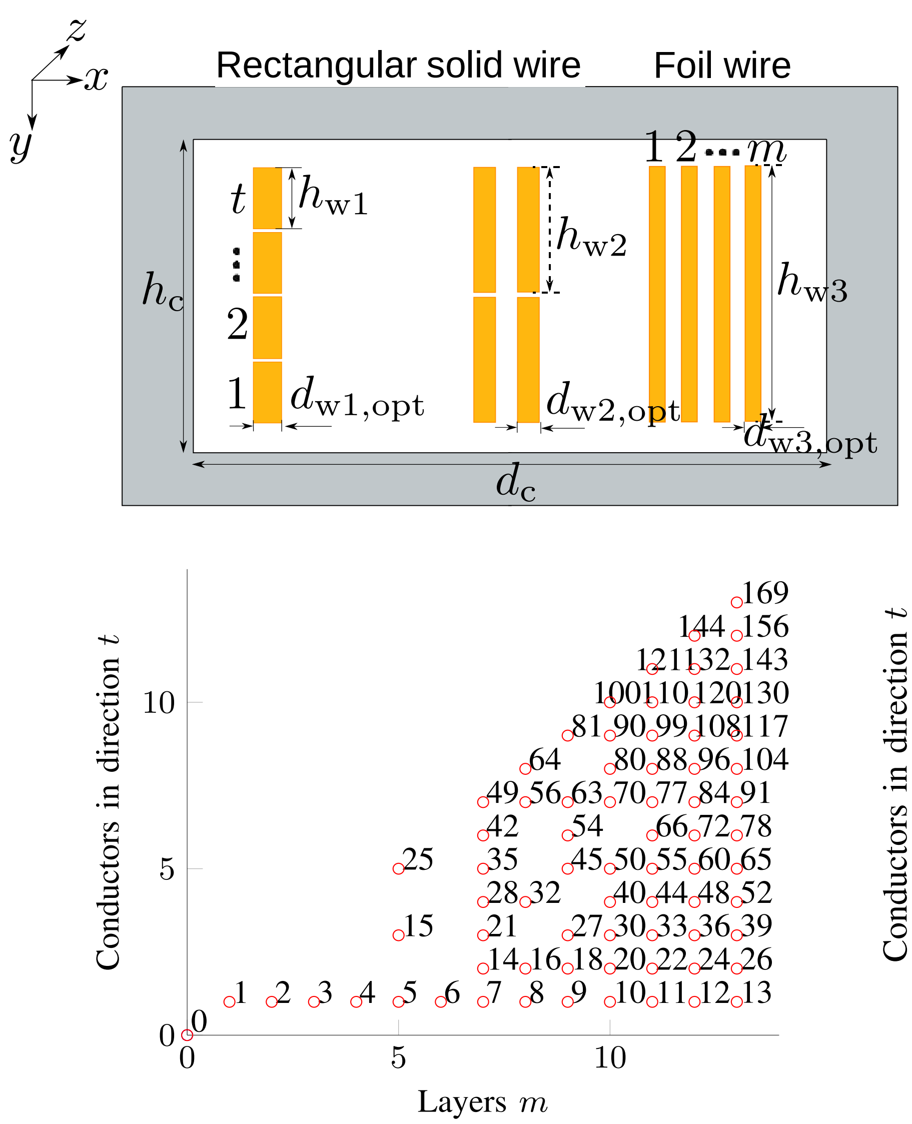
- FEM simulation
  - Foil winding and round litz-wire winding
  - Current density and magnetic field density

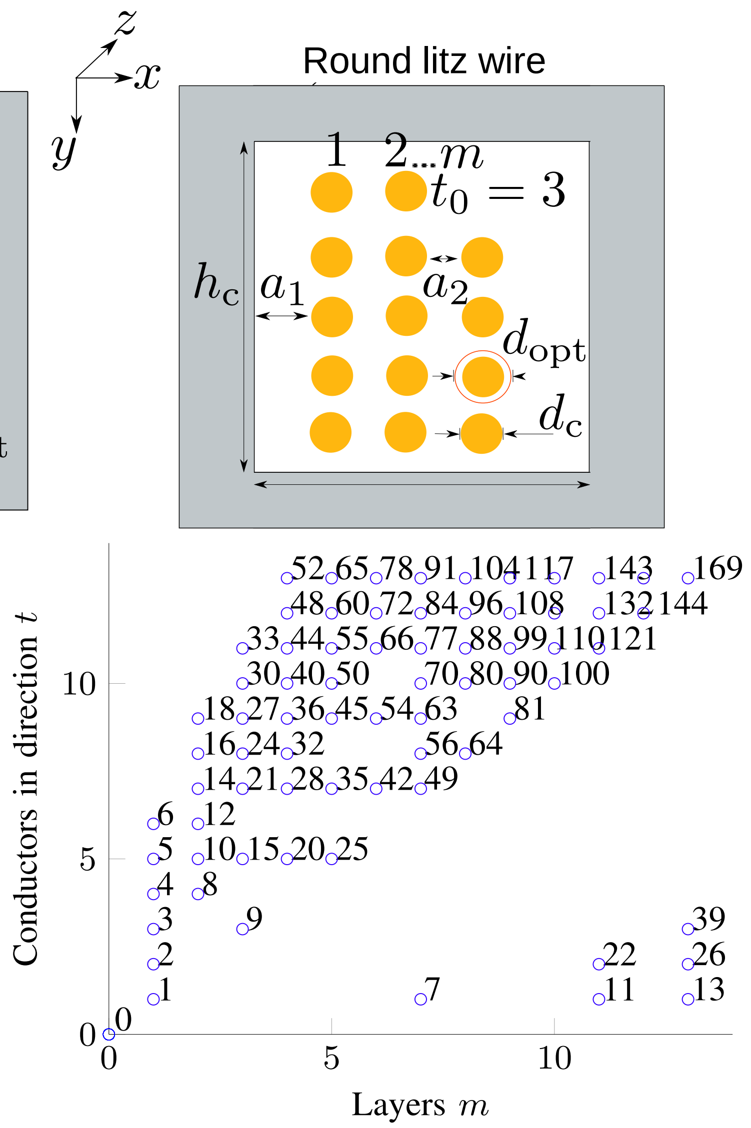


# Winding types and design

- Winding area design method
  - Foil wire or rectangular solid wire winding
  - Round litz wire winding
  - Fixed winding area dimensions
  - Fixed turn number
- Iterative simulation procedure for lowest ac + dc loss
  - Solution of conductor turns in winding area
    - Horizontal direction as winding layers in *x*-axis
    - Vertical direction in *y*-axis

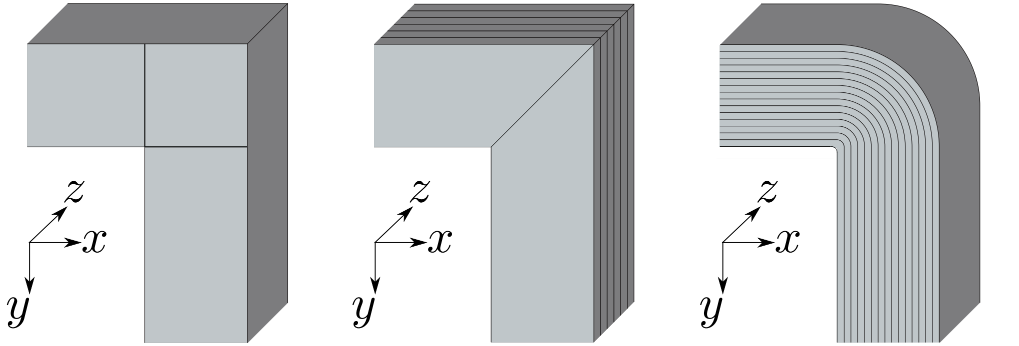


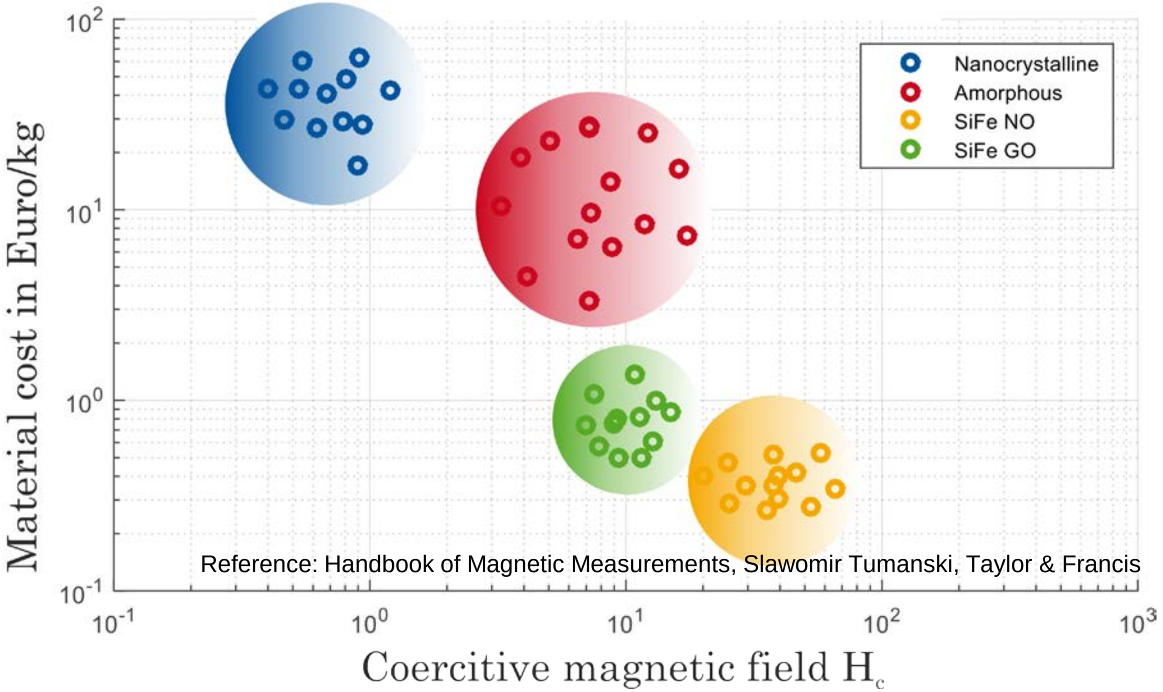



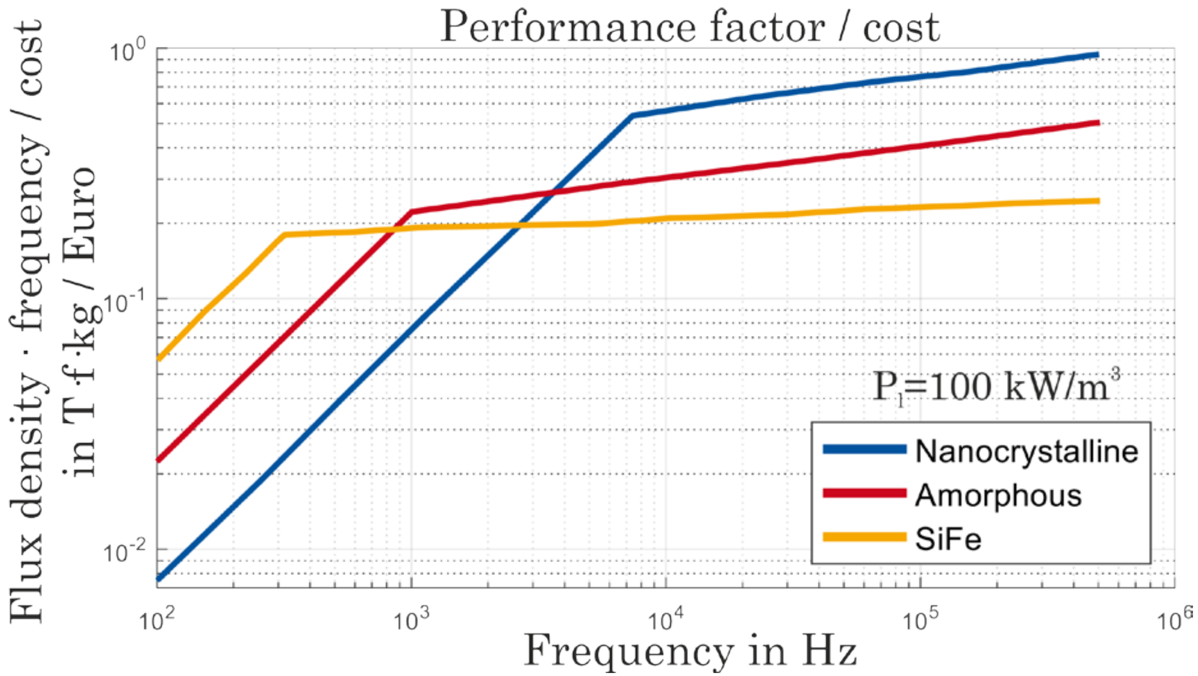
# Content

# Magnetic core materials and design

- Suitable core material for high-power MFTs
  - Silicon steel, amorphous and nanocrystalline core
- Typical core structure technologies
  - Block core, laminated sheet core and tape-wound core
- Selection depends on
  - Frequency, performance factor, costs and efficiency

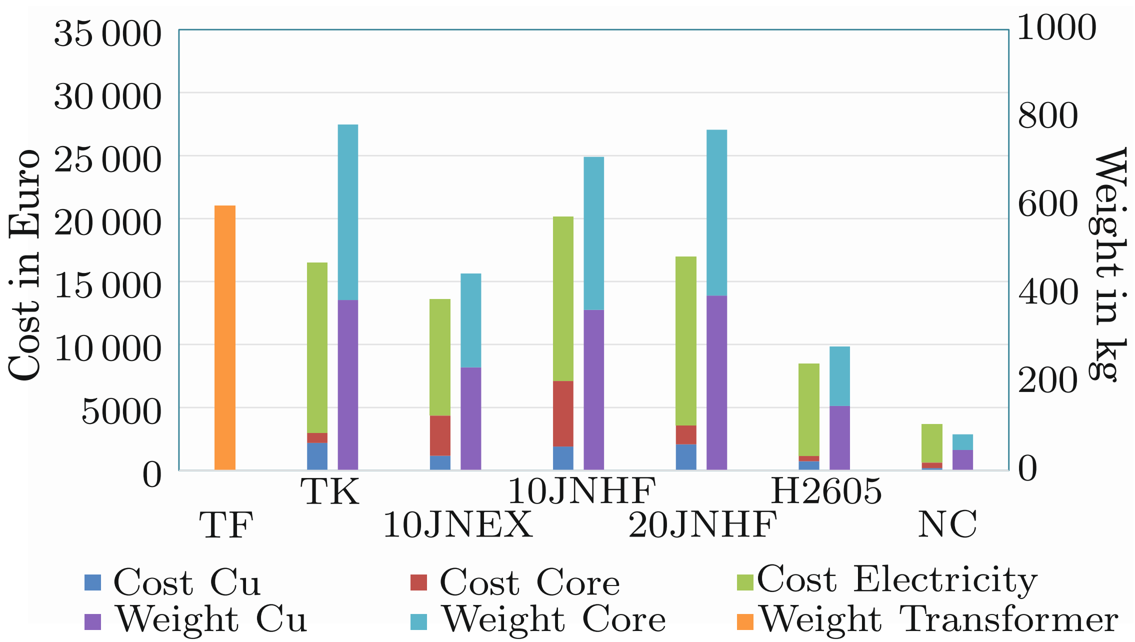


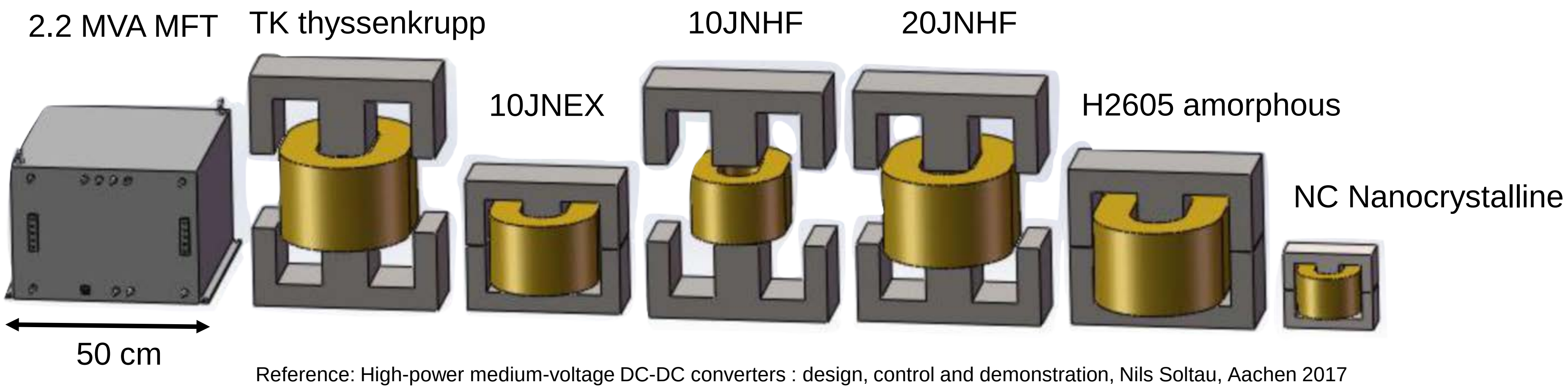



# Magnetic core materials and design

- Design example of 5 MW medium-voltage dc-dc converter
  - Single-phase MFT with silicon steel core and HF litz-wire winding
- Required series inductor with various core materials
  - Silicon steel core materials
  - Amorphous core
  - Nanocrystalline core

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# Conclusion

- Design of high-power Medium-Frequency Transformers (MFT) according to
  - Power density and material demand
  - Efficiency and cooling demand
  - Loss density and hot-spot temperature
  - Total costs including investment costs and lifetime costs

- Selection of adequate magnetic core, winding types and insulation material depends on
  - MFT design goal
  - Construction
  - Reliability

# Thank you!


**Kontakt**

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