Winding and Magnetic Core Selection for Medium-Frequency Transformers
PSMA High-Frequency Magnetic Workshop 2020
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
Content

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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 and Magnetic Core Selection for Medium-Frequency Transformers

- **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
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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

- Block core
- Laminated sheet core
- Tape-wound core

Reference: Handbook of Magnetic Measurements, Slawomir Tumanski, Taylor & Francis
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!

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