Inputs for SCCER-FURIES 2017-2020 Activity report

Authors

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1. Description of activity

Pareto-optimized Solid-State Transformer

1.1. Deliverable (s)

- Optimization toolbox for SSTs
- Core functional parts of a Pareto-optimized SST demonstrator

1.2. Goals of the activity

Development of a design and multi-objective optimization toolbox for Solid State Transformer (SST) components with respect to high efficiency and high power density. Optimized laboratory demonstrators of core functional parts of SSTs are realized for the purpose of experimental verifications.

1.3. Executive summary

SSTs are power electronic converters with Medium-Frequency (MF) galvanic isolation linking medium-voltage to low-voltage distribution system. Main benefits of SSTs as compared to low-frequency transformers are full voltage / power flow controllability and DC/DC conversion capability. SSTs are of special interest e.g. for future ultra-fast EV charging, hyperscale data centers, more-electric aircraft, and smart micro-grids.
In this work, a multi-objective design / optimization toolbox for SSTs is developed, including comprehensive models of components and converters to enable the identification of fundamental physical limits and Pareto-optimization with respect to highest efficiency and power density. For the two core SST elements, i.e. the MF transformer and the converter switching stage, functional demonstrators are realized and tested.

2. Result

2.1. Outcomes

- **SST Multi-Objective Optimization Toolbox** - Provides comprehensive models for SST components and allows for full multi-objective optimization and/or full assessment of designs with respect to the key performance indexes (e.g. efficiency, power density), clarification of fundamental limitations of considered technologies, and trade-offs.
- **Pareto-optimized SST Demonstrator** - Two core elements of SSTs are investigated, functional demonstrators are realized and tested:
    - MF transformer
        - Air-Core
        - Magnetic-Core
    - Power semiconductor stage
        - Quasi-2-Level operated Flying Capacitor type half-bridge.

2.2. Image

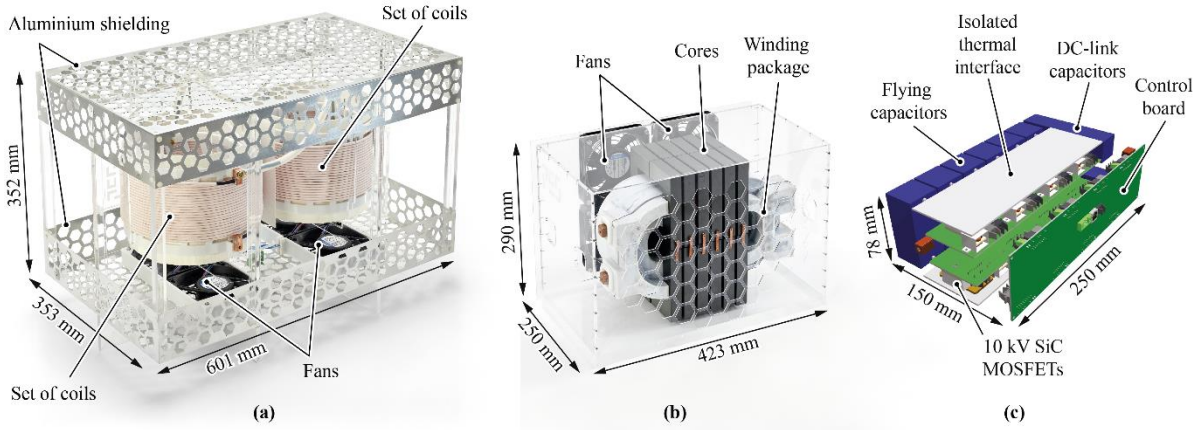

Fig. 1. Realized prototypes of 166 kW / 7 kV MF transformers: (a) Air-Core Transformer. (b) Magnetic-Core Transformer. (c) Rendering of the Quasi-2-Level Flying Capacitor Converter Bridge-Leg (*Super-Switch Power Module*).

3. Innovation

3.1. Description

- Novel systematic and automatic design procedure for SSTs to enable multi-objective optimization and clarification of performance limits;
- Novel key enabling concepts for MV SSTs:
    - Air-Core MV/MF transformer (MV/MV-T): light-weight, high efficiency, simplified insulation coordination;
    - Quasi-2-Level Flying Capacitor Converter: enables very high converter operating voltages, simplified converter realization, module integration, high power density;

- Comparative evaluation of Air-Core MV/MF-T with respect to conventional MV/MF-T with magnetic core;
- Test environments for the core parts of SSTs.

3.2. Impact of Innovation

The Multi-Objective Optimization Toolbox allows to solve the very complex task of optimizing the SST systems and to evaluate designs with respect to key performances, e.g. efficiency, power density. Laboratory demonstrators provide verification of the implemented comprehensive SST component models. With the developed test environments, a reduction of the efforts during the testing phase is achieved, since the core parts of SSTs can be tested without the need for a complete SST system.

4. Resources

4.1. Funding source

Innosuisse - SCCER FURIES

4.2. Activity partners

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4.3. Activity duration and location

2017-2020

5. Further reading – resulted publications & further information

- T. Guillod, F. Krismer, and J. W. Kolar, "Magnetic Equivalent Circuit of MF Transformers: Modeling and Parameter Uncertainties", *Springer Nature, Electrical Engineering*, vol. 100, no. 4, pp. 2261-2275, 2018.
- P. Czyz, T. Guillod, F. Krismer and J. W. Kolar, "Exploration of the Design and Performance Space of a High Frequency 166 kW/10 kV SiC Solid-State Air-Core Transformer," in *Proc. of Int. Power Electron. Conf. (ECCE Asia)*, 2018.
- T. Guillod, D. Rothmund, and J. W. Kolar, "Active Magnetizing Current Splitting ZVS Modulation of a 7kV/400V DC Transformer," *IEEE Trans. Power Electron*., vol. 35, no. 2, pp. 1293 – 1305, 2019.
- T. Guillod, R. Färber, D. Rothmund, F. Krismer, C. M. Franck, and J. W. Kolar, "Dielectric Losses in Dry-Type Insulation of Medium-Voltage Power Electronic Converters," *IEEE J. Emerg. Sel. Topics Power Electron.*, vol. 8, no. 3, pp. 2716 – 2732, 2019.
- P. Czyz, P. Papamanolis, T. Guillod, F. Krismer and J. W. Kolar, "New 40kV / 300kVA Quasi-2-Level Operated 5-Level Flying Capacitor SiC “Super-Switch” IPM," in *Proc. of 10th Int. Conf. on Power Electron. and Expo (ECCE Asia)*, 2019.
- T. Guillod, and J. W. Kolar, "Medium-Frequency Transformer Scaling Laws: Derivation, Verification, and Critical Analysis", *CPSS Transactions*, vol. 5, no. 1, pp. 18-34, 2020.