Structural analysis of solid-state transformers using the inductive power transfer technology through a multiphysics computational framework

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Abstract

Solid-State Transformers (SSTs) are power electronic systems that are increasingly seen as replacements for conventional grid transformers, offering improved adaptability for the demands of smart grids and the integration of renewable energy sources. A critical aspect of SST design is efficiently modeling thermal behavior to assess potential material degradation. Achieving this requires a multiphysics approach that couples electromagnetic, thermal, and fluid dynamics models, particularly when forced cooling is involved. Building on the authors' previous works (1,2), this study assesses the structural aspects of high-frequency, high-voltage SSTs employing inductive power transfer (IPT) technology, within SSTAR, a Horizon Europe research project (3). To achieve this, a one-way coupled simulation strategy is developed that integrates electromagnetic, thermal, computational fluid dynamics (CFD), and mechanical models. This approach initially calculates the power loss distribution and the associated temperature fields within transformer components. The obtained results are used to calculate thermal stress and strain by using the Finite Element Method (FEM) in order to evaluate the mechanical performance and structural integrity of the system. A key focus is the design and optimization of the supporting structures for the primary and secondary systems (shield, core, and windings). Various configurations of these structures are being evaluated to ensure structural integrity. Furthermore, fatigue analysis is performed to estimate the operational lifespan of the SST, providing insights into its long-term performance and durability. In conclusion, this research provides a comprehensive framework for assessing the thermal, mechanical, and structural performance of SSTs, ensuring that they meet the demanding requirements of modern power grids.

(1) Rogkas N, Karampasakis E, Fotopoulou M, Rakopoulos D. Assessment of heat transfer mechanisms of a novel high-frequency inductive power transfer system and coupled simulation using FEA. Energy 2024;300:131530. https://doi.org/10.1016/j.energy.2024.131530.

(2) Rogkas N, Manios A, Pelekis M, Karampasakis E, Fotopoulou M, Spitas V, et al. Coupled EMAG-CFD-Thermal analysis of a novel SST system utilizing forced-liquid cooling with biodegradable dielectric fluid. Appl Therm Eng 2024;257:124293. https://doi.org/10.1016/j.applthermaleng.2024.12

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(3) SSTAR - Innovative HV Solid-State TrAnsformer for maximizing Renewable energy penetration in energy distribution and transmission systems n.d. https://cordis.europa.eu/project/id/101069702 (accessed November 20, 2024).