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Understanding AC Losses in state-of-the-art superconducting cables: Physics Insights from 2D to 3D computational modelling

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Producing accurate computational models that forecast the alternating current losses associated with cold-dielectric conductors is pivotal for power grid investors, what in turn can influence the designing and manufacturing of lightweight superconducting cables aspiring to reach high engineering current densities whilst maintaining a compact structure. By utilizing the so-called H-formulation of Maxwell's equations with different critical current density approaches, such as a constant Jc model equivalent to the classical but widely successful critical-state model for type-II superconductors, or tailored Jc (B) functions similar to the acclaimed Kim's model for non-isotropic superconductors, and the most realistic approaches considering the magneto-angular anisotropy Jc (B, θ) of commercial superconducting tapes, we present an extensive electromagnetic analysis for practical cold dielectric conductors, including single phased multi-layer powered cables, triaxial cables, and the state-of-the-art Conductor on Round Core (CORC) and Twisted Stacked-Tape Cables (TSTC) designs. All cables are simulated either within two- or three-dimensional approaches depending on the availability of proper experimental data considering transversal applied magnetic fields and transport currents in the fully assembled cables. Computational results are duly validated by straight comparison with experimental measurements of AC losses, providing further insight on the cumbersome coexistence of magnetization and transport currents inside the superconducting tapes within hysteretic conditions, whose physics can only be resolved within the H-formulation at the expense of increased computational costs. Remarkably, features such as the need to unbalance the current phase distribution in triaxial cables for achieving nearly zero magnetic leakages is shown without the need for recurring to 3D formulations, whilst physically meaningful distributions of current density for both CORC and TSTC cables are shown within our 3D models. Distinctively, CORC cables shows distributions of current density characteristic of Bean's model with well-defined loops of magnetisation currents turning across the thickness of the superconducting tapes, whereas the TSTC cables exhibit distinctive slab-like profiles due to the twisting of stacked tapes, which also reduces the magnetic flux coupling and consequently its AC losses. In conclusion, this paper serves as a benchmark for comparing the electromagnetic performance and actual physics behind different HTS cabling techniques, offering valuable insights for future development.

Topic

Innovative methods and tools for modelling large-scale HTS systems

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