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Exploring the Limits of Passive Quench Protection in High-Stored-Energy Non-Insulated Superconducting Magnets

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***Abstract*–Non-insulated (NI) magnets made of rare-earth barium copper oxide (REBCO) high-temperature superconducting tapes are of interest for a variety of different magnet applications, such as in the toroidal field magnets of fusion devices. One of the primary reasons for this is the potential ability for NI coils to passively protect themselves against damage during a rapid global loss of superconducting behavior, known as a quench. Some prior tests of NI coils have demonstrated robust self-protection against thermal quench damage, but this does not appear to be universal; for example, during the intentional quench test of the SPARC Toroidal Field Model Coil (TFMC), the coil incurred significant thermal damage [1]. Consequently, the specific design and operational space in which NI coils, particularly coils with large stored magnetic energy, are intrinsically self-protected against thermal quench damage is not well understood. To explore this self-protection regime, a variety of multiphysics quench models of NI coils have been developed. Chief among these is a self-consistent axisymmetric 2D model of sudden-discharge in NI coils that was built using COMSOL Multiphysics [2]. This model has been validated against, and shows good agreement with, experimental sudden-discharge tests of NI and metal-insulated (MI) coils [2]. In addition, a slab model of individual conductor turns was developed and coupled to this 2D model to study how non-uniform I_c and T_{cs} within conductor turns impact the thermal and electromagnetic evolution of quench in non-axisymmetric coils, such as tokamak toroidal field coils. This coupled 2D-Slab model has been used to model the full winding pack of the SPARC TFMC, and validation against the experimental results of the TFMC test campaign is currently underway. The developed models are currently being used to identify the primary coil design and operating conditions that enable self-protection in NI coils with large stored magnetic energies; in particular, the impacts of current density, stored magnetic energy density, and macroscopic I_c and T_{cs} nonuniformity along conductor turns have been explored as potential key drivers of thermal quench damage. This presentation will discuss the details of the developed quench models, validation of the models, including against the SPARC TFMC, and preliminary exploration of the passively-safe quench space and potential implications for the design and operation of high-stored-energy NI coils.**

***Keywords (Index Terms)*–HTS Magnet, HTS Coils, Toroidal Field Coils, Magnet design, Quench**

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[1] Z. S. Hartwig et al, "The SPARC Toroidal Field Model Coil Program." IEEE Trans. Appl. Supercond., no. Special Issue on the SPARC Toroidal Field Model Coil Project, 2024.

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