27th International Conference on Magnet Technology (MT27)
Fukuoka, Japan / 2021

Contribution ID: **520** Contribution code: **FRI-OR6-701-06** Type: **Oral**

Simulation of Quench Transients in Self-Protecting Magnets with a 3D Semi-Implicit Finite-Difference Method

Friday, November 19, 2021 8:45 AM (15 minutes)

The quench process in a superconducting magnet is inherently transient and three-dimensional (3D). In many cases, such as magnets protected by active protection systems, it is possible to accurately simulate this transient with a two-dimensional model. However, a more complex 3D model is required in case of a self-protecting magnet. Simulations are particularly challenging due to physical and geometrical features, such as highly non-linear material properties, sudden appearance of localized heat generation, non-isotropic conductor composed of superconducting, resistive, and insulation materials, and relatively thin insulation layers. It is crucial to reduce simulation time in model development and validation in order to perform within an allocated project timeframe all necessary tasks such as evaluating the suitability of model assumptions, generating models of new magnets, and performing parametric analyses. Thus, a simulation time under one hour, and ideally of a few minutes, is beneficial. Finite-element method (FEM) enables simulations of electro thermal coupled problems of complex geometry. Various FEM programs are commercially available, which provide very good flexibility and are bench-marked for a number of cases. However, a very long solution time makes 3D FEM simulation of a quench in a full-scale magnet system often impractical. In this work, it is shown how the quench and heat diffusion in 3D geometry can be accurately yet rapidly simulated using the finite-difference method. The presented numerical implementation has simplifying assumptions that benefit computational efficiency while achieving required accuracy. The coupled electro-thermal problem is solved with a semi-implicit Euler method. This 3D approach is included as a new feature in the STEAM-LEDET quench simulation program. As a study case, a simulation of the transient following a quench occurring in one of the self-protecting LHC magnets is presented and compared to experimental results.

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Session Classification: FRI-OR6-701 Design and Analysis