3D Modeling of All-Superconducting Synchronous Electric Machine By Finite Element Method

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Abstract

Introduction: All-superconducting synchronous machines [1] can achieve higher efficiency and smaller volume than conventional copper-wound machines due to the higher current density of high-temperature superconducting (HTS) materials and their lossless nature for DC current. However, AC losses in the stator can be a significant problem for all-superconducting synchronous machine, which increase the refrigeration load and therefore reduce the efficiency of the machine.

The Finite Element Method (FEM) has been widely applied for the simulation of HTS materials, as well as devices, to calculate various electromagnetic properties. There are three main formulations for FEM calculations: H-formulation [2,3], A-V formulation [4,5] and T-Ω formulations [6,7].

To our knowledge, there is no research involving in 3D modelling of all-superconducting machine by applying the H-formulation using commercial FEM software. Here a 3D finite element model of an all-superconducting machine is developed based on this formulation in COMSOL Multiphysics®. Calculations of the AC loss in an HTS armature winding can be carried out and an effective method to decrease AC loss can be proposed, which can increase the efficiency of the HTS machine.

Use of COMSOL Multiphysics®: The equations governing the motor properties are written in the form of a General Form Partial Differential Equation (PDE) in COMSOL Multiphysics®. The model consists of two sub models: the model of the all-superconducting machine and the model of the HTS stator coils. The models use the H-formulation based on a bulk approximation. The bulk model can be used to replace the layers of coated conductors in the HTS coils to improve speed and convergence [8], which will overestimate transport loss and underestimate magnetization loss. However, the error of total AC loss comparing to analytical model is not so large [9]. The model of the 3D HTS machine is simulated firstly. The magnetic boundary conditions for the 3D stator coil model are derived from the 3D HTS machine model. The combination of the two models can help estimate the total AC loss in the all-superconducting machine. Magnetic materials are also added to the coil model to divert flux, which can decrease the AC loss [10].

Results: The geometry and the magnetic field distribution of the 3D all-superconducting machine are shown in Figure 1. The 3D HTS stator coil model with the bulk approximation is presented in Figure 2. With the application of these two models, the AC loss from the coil model can be estimated. With magnetic material acting a flux divider, the AC loss from the coil model can be recalculated. The effects of flux divider on AC loss reduction can be analyzed comprehensively.

Conclusion: In this paper, the 3D numerical analysis of all-superconducting machine and HTS coils with bulk approximation is carried out using the H-formulation, which allows a completely integrated 3D model, including both the electromagnetic properties of the superconductor and motor, to be developed. The methods of calculating and decreasing AC loss from a 3D all-superconducting machine are investigated, which allows the simplification of HTS machine design and improvements in the efficiency of the machine.

Reference

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Figures used in the abstract

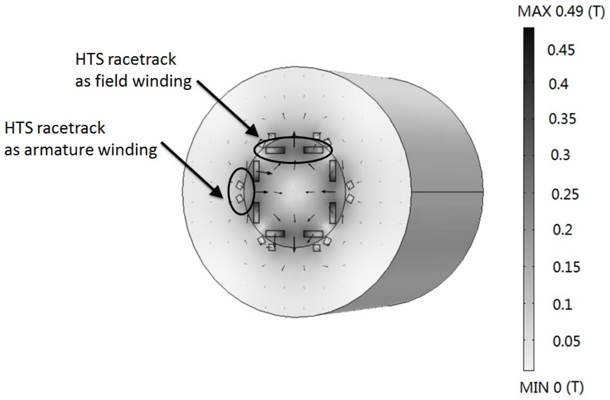

Figure 1: The geometry and the magnetic field distribution of the 3D all-superconducting machine

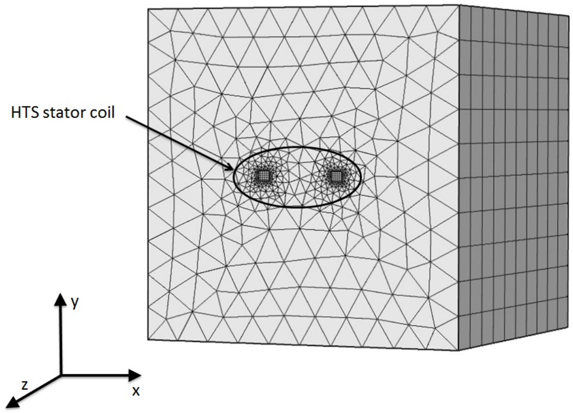

Figure 2: The geometry and mesh of the 3D HTS stator coils model