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A 3D electromagnetic model for eddy currents analysis in superconducting magnets for fusion applications

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Bulky metallic structures are needed in the toroidal field (TF) superconducting magnets for fusion applications to withstand the large Lorentz forces acting on the winding. The pulsed coil operation during the plasma scenario and the fast current discharge or a plasma disruption in off-normal operating conditions cause magnetic field variations, inducing eddy currents in the TF structures. The eddy currents generate heat in the structures close to the winding pack, eroding the temperature margin of the superconducting cables: such power generation is a key input for reliable thermal-hydraulic (TH) analyses. However, the computation of eddy currents in fusion magnets is a challenging topic since a transient, fully 3D electromagnetic (EM) model is required.
The EM problem is faced here by means of the finite element (FE) open source code FreeFEM++, the same adopted for the thermal analysis of the structures in the 4C TH code. First, the correct implementation of the EM problem is verified by means of suitable benchmarks against both simple analytical cases and the results obtained with state of the art FE commercial codes. Then, the following strategy is pursued: the EM code is applied to the evaluation of magnetic fields and induced eddy currents during the normal and off-normal transient operation; the output of the EM analysis is used as input to the TH analysis carried out with the 4C code, aimed at computing the temperature margin evolution. The effect of the thermal feedback on the steel electrical resistivity (and thus on the induced eddy currents) will also be assessed.
The application of this strategy to the analysis of a fast current discharge in the TF coil of a tokamak is presented here, with particular focus on the new 3D EM model. The results of the complete (EM + TH) analysis are also presented and discussed.

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