Abstract

The International Thermonuclear Experimental Reactor, known as ITER ("the way", in latin) will be the largest superconducting tokamak of the world. It is currently being built in Cadarache, France, and it aims at becoming the first large scale superconducting nuclear fusion reactor to overcome the main challenges faced by the achievement of fusion energy. After the ITER prototype, according to the European roadmap towards electricity form fusion, the next step of fusion research is the development of EU DEMO, the demonstrator which should prove the capability to produce electricity from a fusion power plant on a commercial scale. Due to the huge costs of technology research for fusion, in order to cap the budget, engineers aim at developing optimized computational tools, needed to support the design activities and predict the operation of complex systems never built before.

For example, in superconducting tokamaks like ITER and the EU DEMO, some of the most expensive and complex components are the magnets, which must be built and operated with very tight tolerances and thus their design requires reliable and detailed computational tools. In this framework, the Cryogenic Circuit Conductor and Coil (4C) code, developed at Politecnico di Torino, is the state-of-the-art tool for the thermal-hydraulic analysis of superconducting magnets for fusion application. The code was born in late 2009 to simulate the thermal-hydraulics of the ITER superconducting magnets. In the successive years, the 4C code has been successfully validated against data collected during various experiments, including the ITER Toroidal Field Model Coil (TFMC) and Central Solenoid Model Coil (CSMC), the ITER Insert coils, namely the Central Solenoid, the Poloidal Field insert coils, and more recently, the Toroidal Field insert. In addition to these validation exercises, the code has been used for the thermal-hydraulic analysis of other

magnets, like those of the W7-X, EAST, KSTAR, JT-60SA and the EU DEMO tokamaks.

In this work, the 4C code is used for the analysis of the experimental data collected during the experimental campaigns on the ITER insert coils performed in the last four years. The tests have been carried out in conditions fully relevant for the ITER superconducting magnets operation, thus allowing to challenge the numerical tools in a relevant setup and deduce the constitutive relations for thermal-hydraulic, electromagnetic and thermos-electrical phenomena. The developed models for the Central Solenoid Insert and Toroidal Field Insert coils are used in a series of successful validation and prediction exercises on different kind of transients, including the cooldown, the AC losses assessment and the quench propagation.

Following the model qualification and lessons learnt from the Inserts experience, predictive simulations of the ITER Central Solenoid and Toroidal Field coils operation are performed in normal and off-normal conditions, including e.g. mass flow rate reduction in critical conductors, quench propagation and fast discharge.

The outcomes of the analyses show that the ITER magnets satisfy the design requirements during the normal and off-normal operation, without presenting any critical issues in terms of temperature margin or hot-spot temperature. As a final remark, it is stressed the importance of suitable quench lines for the Toroidal Field magnets to avoid an excessive pressurization of the circuit.

The outcome of the predictive simulations is also useful to the definition of the test plan of ITER Central Solenoid modules in the final qualification tests, foreseen before their installation in the ITER bore. In perspective, the whole chain code development – test of sub-size magnets – interpretation of the results to deduce or validate constitutive relations – application to full-size magnets can be applied to the design of magnets for future tokamaks like the Italian Divertor Tokamak Test (DTT) facility and the EU DEMO.