Contribution ID: **3** Type: **not specified**

Superconductor Thermohydraulical and Resistive Electrical Analytical Model (STREAM) applied to WEST TF Coil Quench Analysis

Thursday, September 23, 2021 1:50 PM (25 minutes)

The Toroidal Field (TF) system of the WEST tokamak comprises 18 NbTi superconducting coils, cooled in a static superfluid helium bath at 1.8 K and carrying a nominal current of 1255 A. The 19th December 2017, at the end of plasma run #52205, a quench of TFC-09 was detected first on a secondary thermohydraulical signal (helium level) and triggered the current Fast Safety Discharge (FSD).

The quench was found to be induced by a neutron and gammas flux caused by highly energetic runaway electrons (30 MeV) colliding the outboard plasma facing components. Some previous analyses [2] with SuperMagnet (CryoSoft) code confirmed a so called "smooth" quench with small initial heat deposition length (0.4 m) at low field region (external leg) and with an initial number of quenched conductor nearly equal to 100. The whole TFC-09 circular coil is modelled by a singular bath with one conductor of length equal to coil average perimeter.

A Superconductor Thermohydraulical and Resistive Electrical Analytical Model (STREAM) has been developed. This model comprises as input the Minimum Quench Energy (MQE) and an adaptation of the well known "short coil – low pressure" law for the propagation of quenched normal length. This model comprises the electrical equations (magnetic field, current sharing temperature, Joule energy, resistive voltage, resistance and current) as well as the thermodynamical and hydraulical evolution in two phases:
- The first one comprises the helium pressure evolution with an isentropic compression (closed volume) of a cold volume by a hot (and heated) volume
- The second one comprises the determination of expulsed helium mass flow in the exhaust circuit (from a given pressure threshold) with a limit at atmospheric pressure or Mach number equal 1. The evolution of helium pressure inside the coil follows, what is called, an "equi-baro-chore" evolution.

For WEST TFC09 Quench, STREAM calculated results shows good agreements with the measurements as well as the calculated SuperMagnet results. The maximal resistive voltage, Joule energy and resistance are respectively at 1400 V, 18 MJ and 5 Ω. The maximal values of helium pressure, conductor temperature and expulsed helium mass flow are respectively 0.9 to 1.0 MPa, 90 K, and 5 kg/s. This STREAM analytical model can be useful, with adaptation to Cable-In-Conduit Conductor configuration, for other tokamak magnets safe operation and protection as the execution time is reduced, compared to other existing codes.

Keywords

Fusion, Magnets, Thermohydraulics, Quench, Simulation

Category

Tools to support commissioning and operation phases of superconducting magnet systems

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Session Classification: Tools D4