Temperature evolution in ITER CSU2 coil module during 15MA plasma scenario

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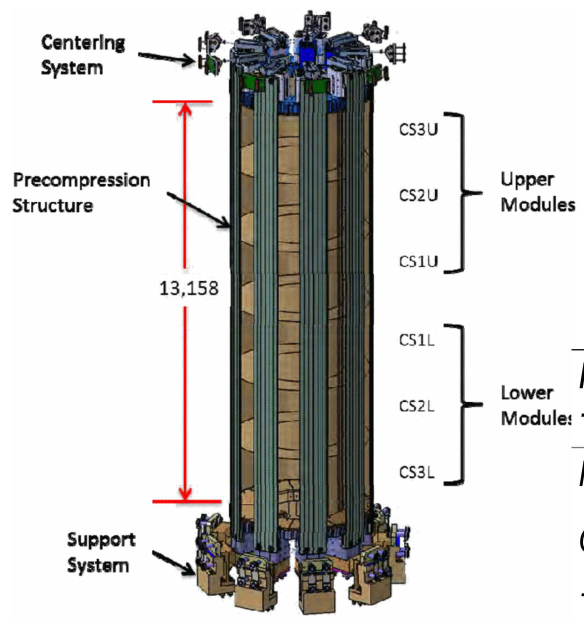
Introduction

The JackPot-ACDC model, an electromagnetic-thermal model for Cable-in-Conduit Conductors, and THEA, a thermo-hydraulic model for superconductors, can be combined to reproduce and predict the behavior of a conductor under any current and magnetic field variation. JackPot+THEA is used to model the most challenged turns of the CSU2 module quadra-pancake of the ITER Central Solenoid. The chosen Nb_3Sn conductor section is about 150 m long from helium inlet to outlet, which are placed in the most inner and outer turns of the pancake respectively . The conductor temperature margin and electric field levels are compared with those obtained at minimum quench energy (MQE) simulations and experiments in order to evaluate possible critical issues. The results confirm adequate stability, both from electrical and thermal point of view. The temperature evolution during the 15MA plasma scenario is also analyzed to evaluate the feasibility of concatenate multiple scenarios without interruption due to accumulative heat storage in the helium slug, necessary for continues energy production for future fusion power plants.

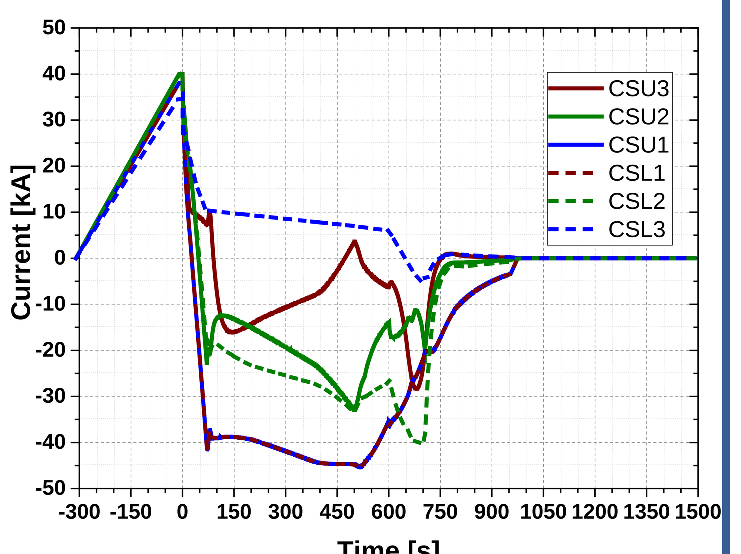
ITER Central Solenoid

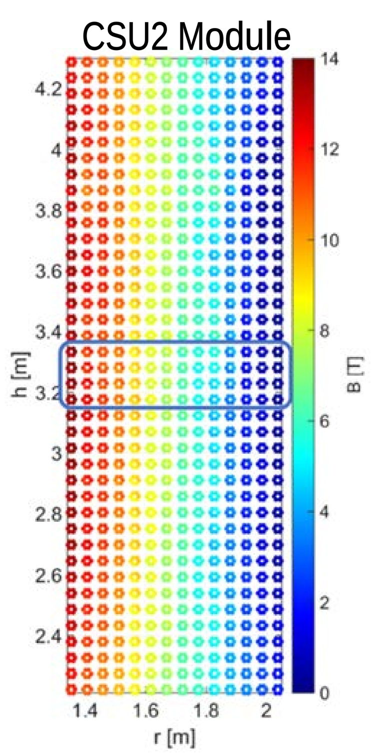


The Central Solenoid consists of a stack of 6 modules. All modules are identical circular coils. Each module is divided in 7 pancakes, wound with in total 40 layers of 14 turns each. The 7 pancakes are divided in 6 hexa-pancakes and 1 quadra-pancake.

Pancake Type	CICC length [m]	n. of unit	Total n. of turns
Hexa	903	6	83.25
Quadra	601	1	55.5
Total module	6019	7	555

The Central Solenoid is part of the ITER magnet system that will be able to contain and shape the plasma generated in the reactor. The plasma scenario chosen for the present study is the 15 MA Plasma Scenario. The 15 MA PS last in total about 1800 s. The start of the discharge begins at *t* = 0 s, and the following seconds are characterized by the highest field gradient.



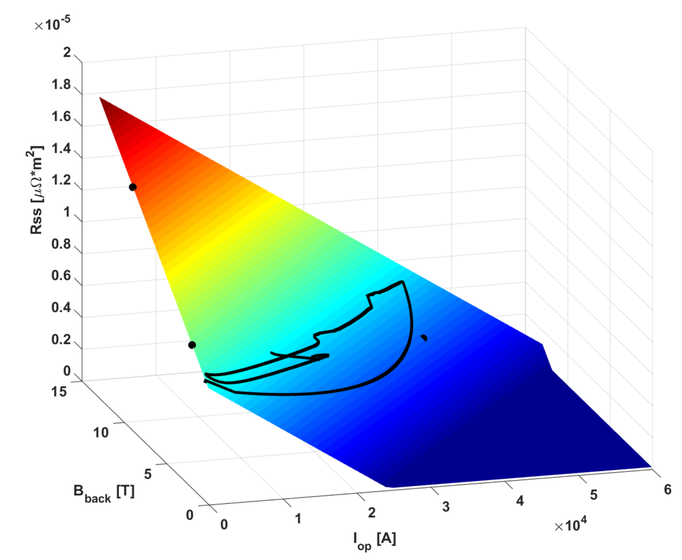


The worst conditions in the CS are located in the CSU2 and CSL2 modules, in particular in the inner turns of the quadra-pancakes. The aim of the study is to model the thermal behavior of one layer of the CSU2 module from the helium inlet to the outlet during a full plasma scenario cycle. Fourteen 1m long sections of CICC are modeled with JackPot, one section for every turn, current and magnetic field are considered homogeneous in every turn. The losses modeled with JackPot are collected in THEA and they are used to calculate the temperature evolution.

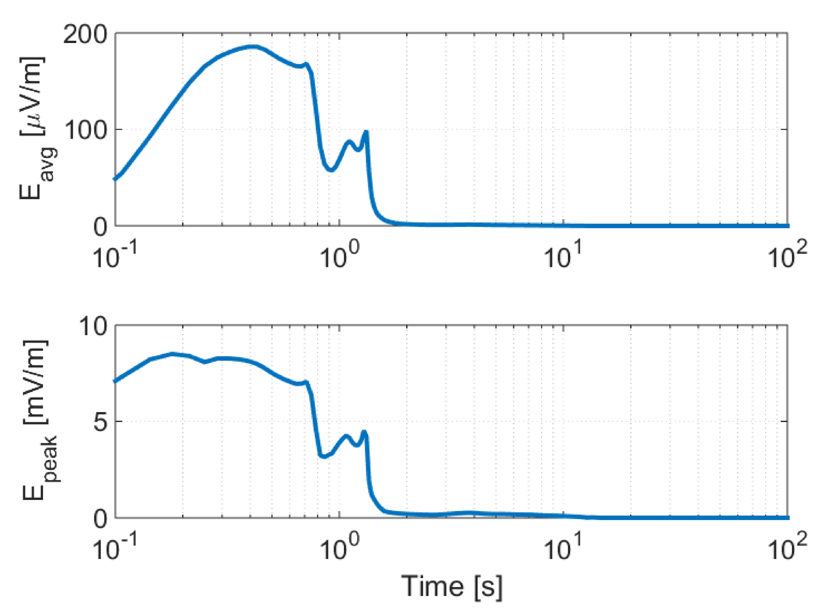
JackPot plasma scenario Short sample simulation

During the coupling loss and MQE experiments, generally, DC magnetic field and current boundary conditions are constant. While during the plasma scenario, they are varying continuously. The copper magneto–resistance variation and the Lorentz' forces, resulting from the applied current and magnetic field, have an effect on the inter-strand resistance, varying the coupling and eddy current losses generated in the conductor. To estimate the effects of current and magnetic field variation on the strand contact resistance the SULTAN AC loss tests are used.

Boundary conditions	CSJA8 inter-strand resistivity
$B_{DC} = 2$ T, $I_{op} = 0$ kA	R_{ss} =
$B_{DC} = 9$ T, $I_{op} = 0$ kA	R_{ss} =
$B_{DC} = 9$ T, $I_{op} = 40$ kA	R_{ss} =

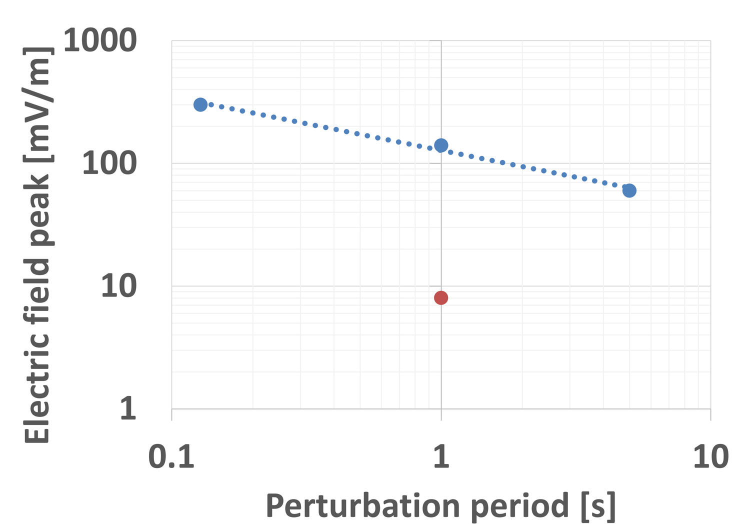


The Inter-strand resistivity depends on the variation of background field and transport current, as first approximation the variation is considered linear. The black dots are the resistivity values summarized in the above table. The black line represents the resistivity variation during the first 100 s of the 15MA PS simulation.



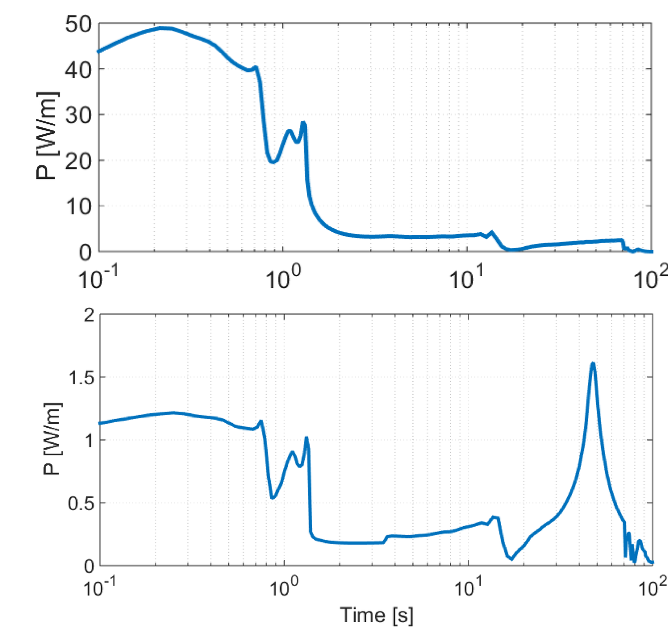
The average electric field and the peak electric field calculated in the conductor longitudinal direction along the superconducting strands, simulated during the first 100 s of 15MA PS.

Comparison between the electric peak field calculated during the stability tests of the CS conductors associated to a quench (blue) and the electric peak field calculated from the 15MA PS during the plasma initiation (red).

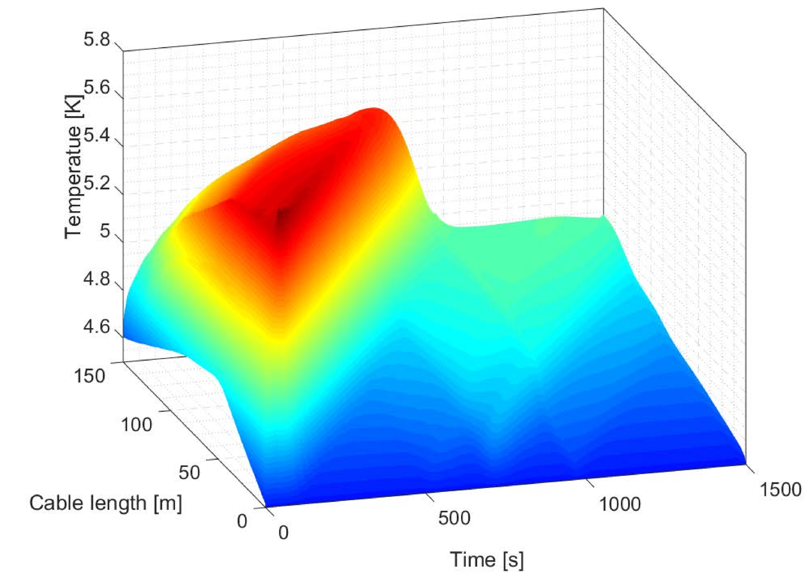


The peak electric field stays one order of magnitude below the expected quench level.

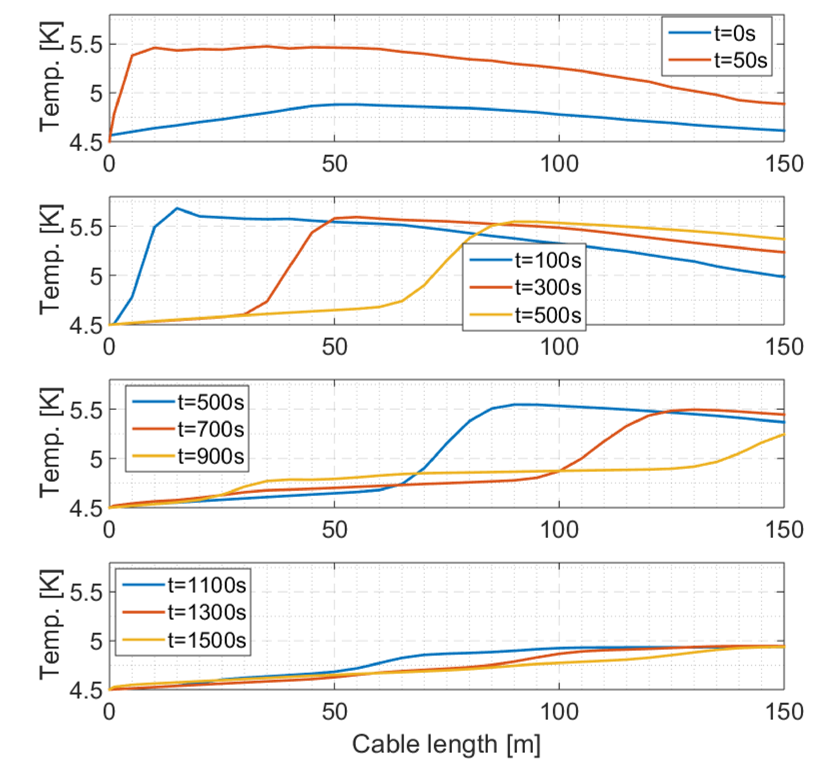
JackPot+THEA stability prediction for the CSJA8 conductor



Coupling and hysteresis losses during the first 100 s of the 15MA PS, modeled with JackPot. Both considered during calculation of the temperature evolution during the PS.



3D temperature evolution inside the CSU2 quadra-pancake during the 15MA PS. The plasma starts at *t* = 0 s, the current ramp up is not shown. At 0 the helium inlet is located, whereas the outlet is at 150 m. The temperature maximum is generated in the first turns of the pancake layer during the plasma initiation. The temperature peak moves along the conductor transported by the helium mass flow.



Temperature evolution inside the CSU2 quadra-pancake during the 15MA plasma scenario. The temperature peak, above 5.5 K, migrates, almost unvaried, inside the conductor. After about 800 s the peak reaches the outlet. After 900 s the temperature decreases progressively to less than 5 K. After 1500 s the plasma scenario starts again with a new cycle.

Conclusions

- The electric field threshold is defined using the results from the JackPot+THEA simulations with different pulse periods. The peak electric field generated in the CSU2 is significantly lower than the threshold.
- The average electric field of the conductor is close but still lower than the critical electric field in DC condition (0.4 mV/m [Rolando et al. 2013]).
- The simulation of the quadra-pancake's layer of the CSU2 module shows a temperature peak reached in the conductor of 5.6 K, and the flow of the heat slug through the 150 m of the pancake layer. The model confirms the capability of the CS coil to handle the 15MA PS.

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