Strategies to reduce the voltage to ground in the FCC main dipole circuits

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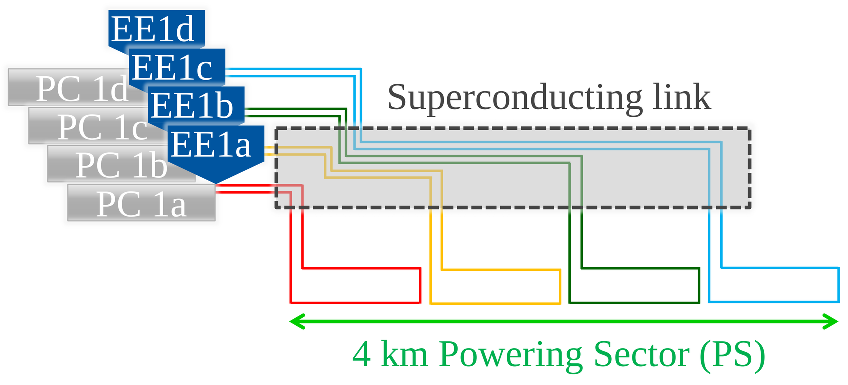
Abstract and goal of the poster

Within the FCC project, the EuroCirCol Work Package 5 is dedicated to the study of the high-field, high-current superconducting dipole magnets. The target performance of these magnets, together with the unprecedented size of the accelerator, poses a number of challenges as, among others, machine integration and protection. As for the LHC, dipole magnets have to be powered in long strings, leading to large stored energy in the circuits. In case of a quench or equipment failure, a safe extraction of the circuit energy in a short amount of time is very challenging, especially due to the development of high voltages to ground. The voltage to ground in the coils of a magnet is composed by two contributions: the voltage drop over the string, from the grounding point to the magnet input, and the coils' internal voltage distribution. Both contributions result from the unbalance of resistive and inductive voltage during the current discharge.

In this poster, we discuss dedicated strategies to reduce the voltage to ground in circuits of superconducting magnets and the simulation tools developed for the analysis. The adopted protection is the Coupling-Loss Induced Quench (CLIQ) system and its behaviour is modelled by means of the LEDET and PSpice co-simulation. This technique allows one to simulate the electrical transients at the circuit level together with magneto-thermal transients occurring at the magnet level during a quench, using dedicated solvers. The FCC block-coil superconducting dipole magnet is considered as a case study.

The problem

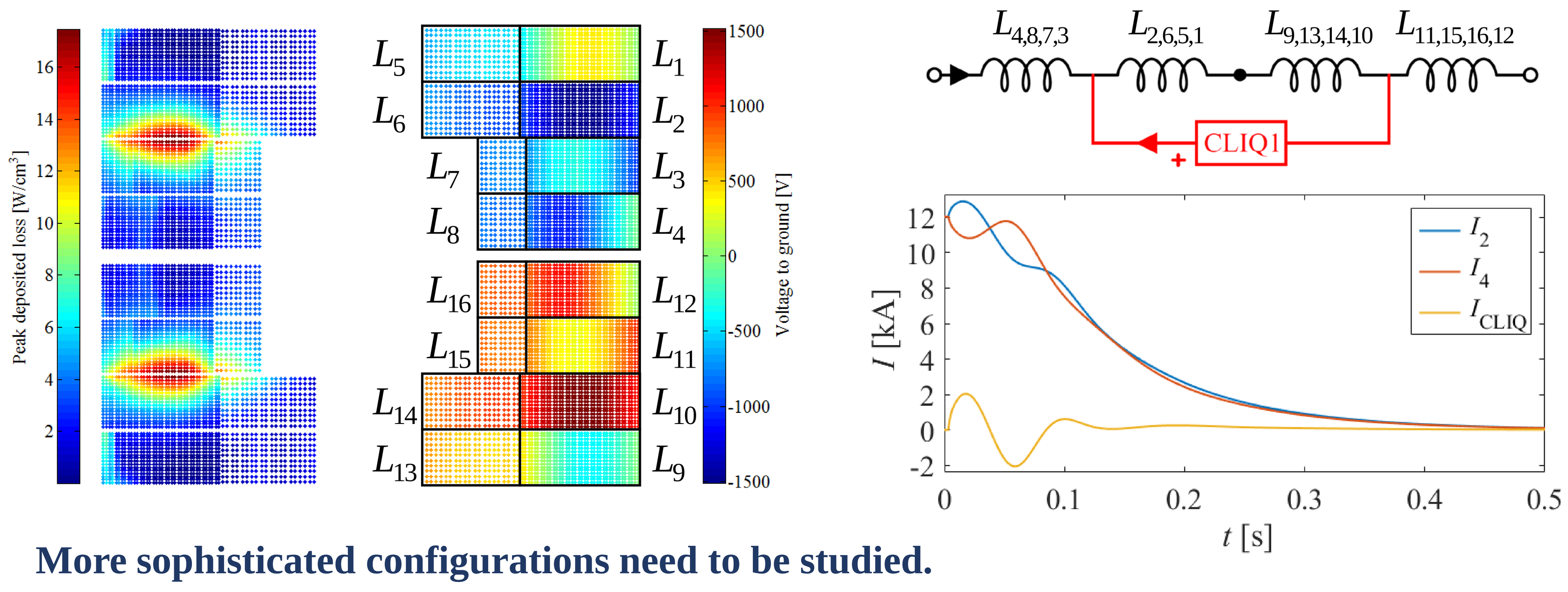
- **Circuit point of view**: voltage to ground decreased by limiting the number of magnet powered in series in a string. Small circuits with one Energy Extractor (EE).



N. of circuits per 4km PS	4	$V_{FPA,max}$ [kV]	1.0
Total n. of circuits	80	$V_{FPA,fault}$ [kV]	2.3
Magnets per circuit	54	τ_{circ} [s]	170
Inductance per cir. [H]	30	t_{ramp} [min]	20
Stored energy per cir. [GJ]	2	V_{PC} [V]	280

- **Magnet point of view**: one CLIQ unit per magnet aperture (FCC week 2016) → insufficient protection during quench.

  20 mF, 1.2 kV CLIQ unit → 345 K hot-spot temperature close to the 350 K limit
  → peak voltage to ground above the 1 kV threshold.

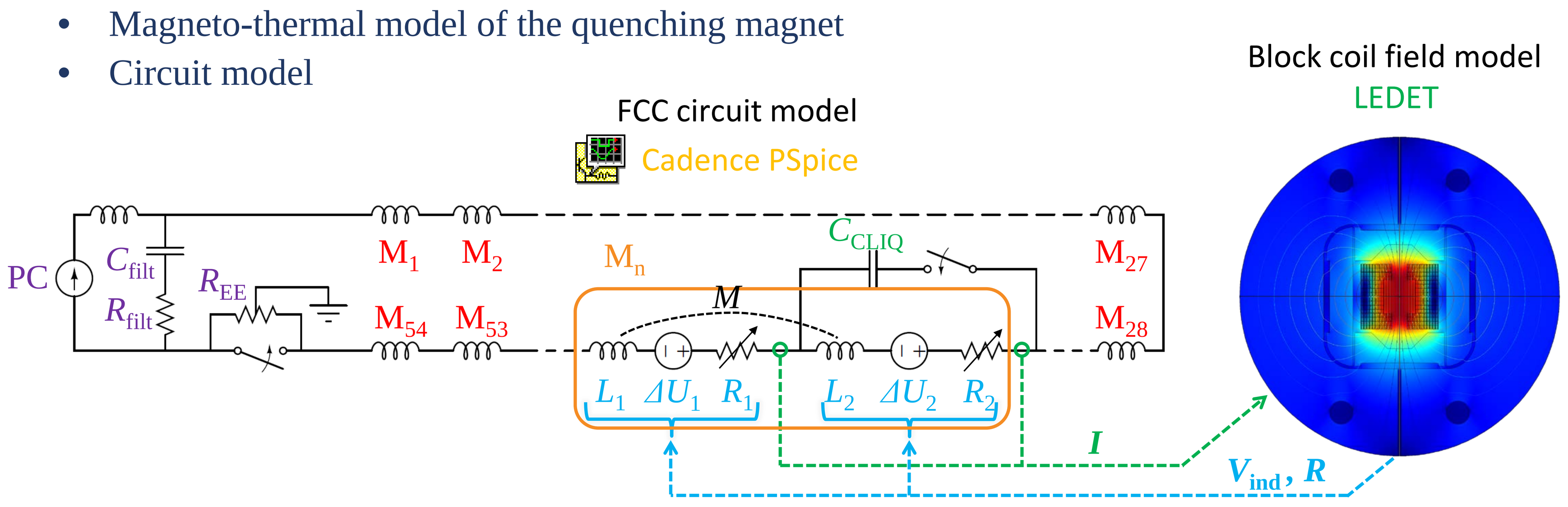


- **More sophisticated configurations need to be studied.**

Simulation tools

The voltage to ground during quench depends on the specific magnet design, the adopted protection systems and the circuit. Two simulation layers can be identified:

- Magneto-thermal model of the quenching magnet
- Circuit model

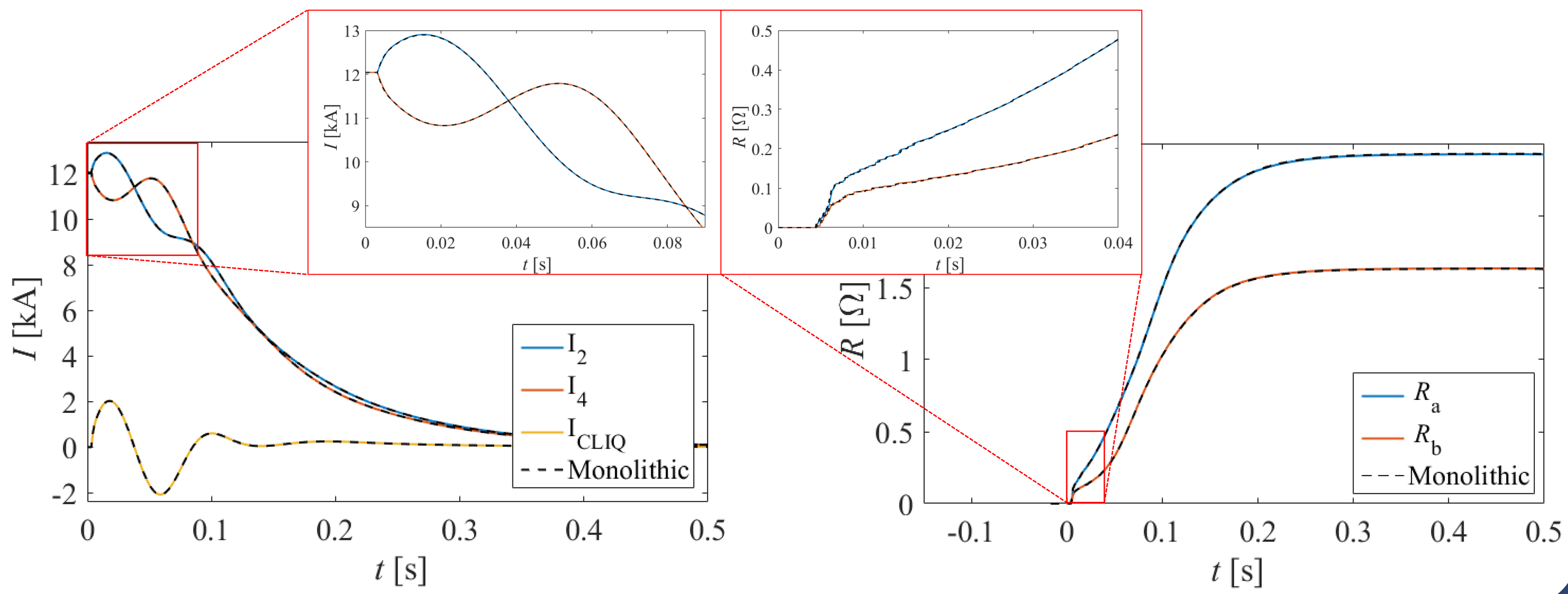


Complex multi-physics, multi-scale, multi-rate problem → co-simulation as a solution

- Dedicated models: Circuit → netlist in Cadence PSpice. Magnet → LEDET [1, 2].
- Waveform relaxation, Gauss-Seidel scheme to exchange information [3].
- Series execution of the two models until convergence.
- **The co-simulation of LEDET and PSpice allows one to study advanced protection system configurations and their effect on the circuit.**

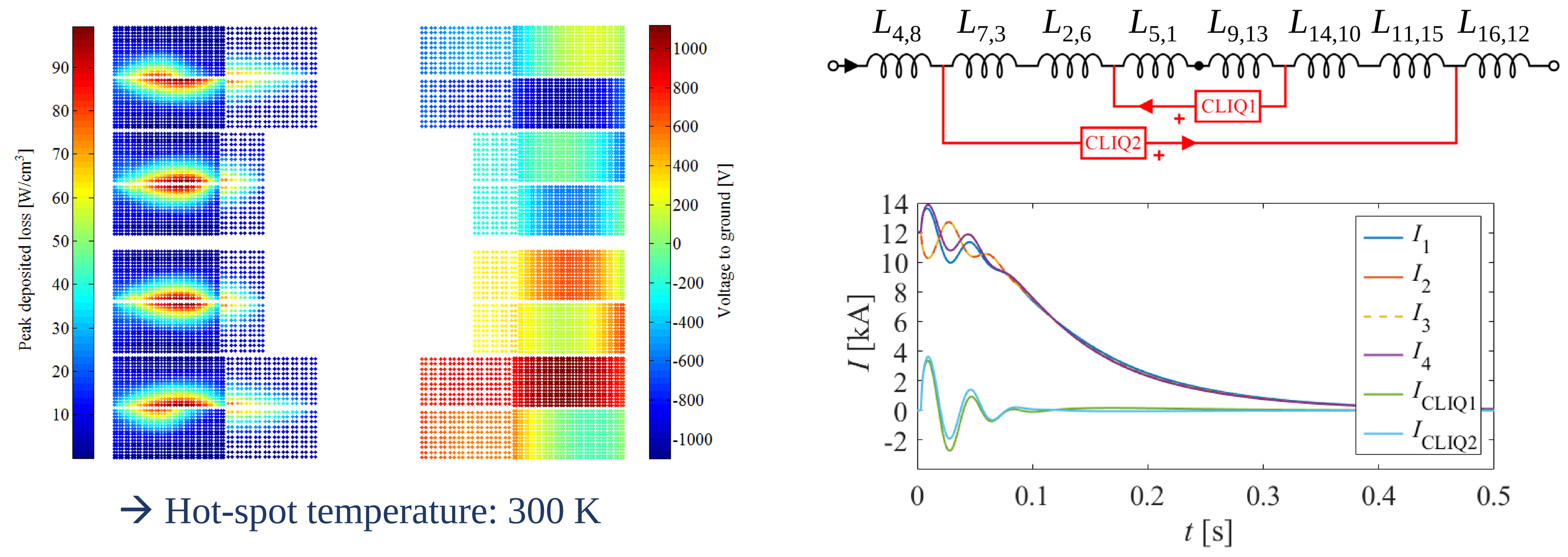
Validation of tools

For the simple CLIQ configuration with one unit per aperture, that can be also simulated using LEDET only (monolithic simulation), **the LEDET and PSpice co-simulation was validated.**



Strategy 1: multi-CLIQ

- Additional CLIQ units: this requires CLIQ leads connected inside the double pancake coils.

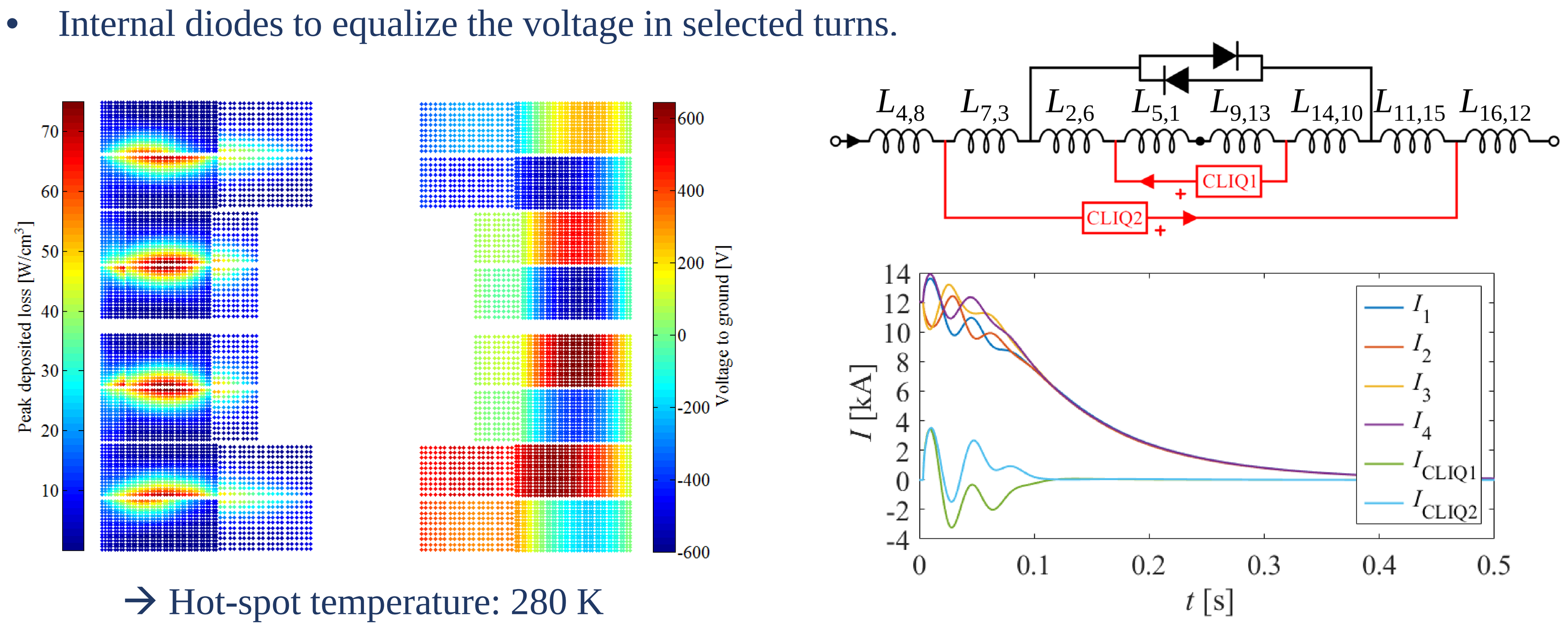


→ Hot-spot temperature: 300 K

- Effective protection for all current levels.

Strategy 2: internal diodes

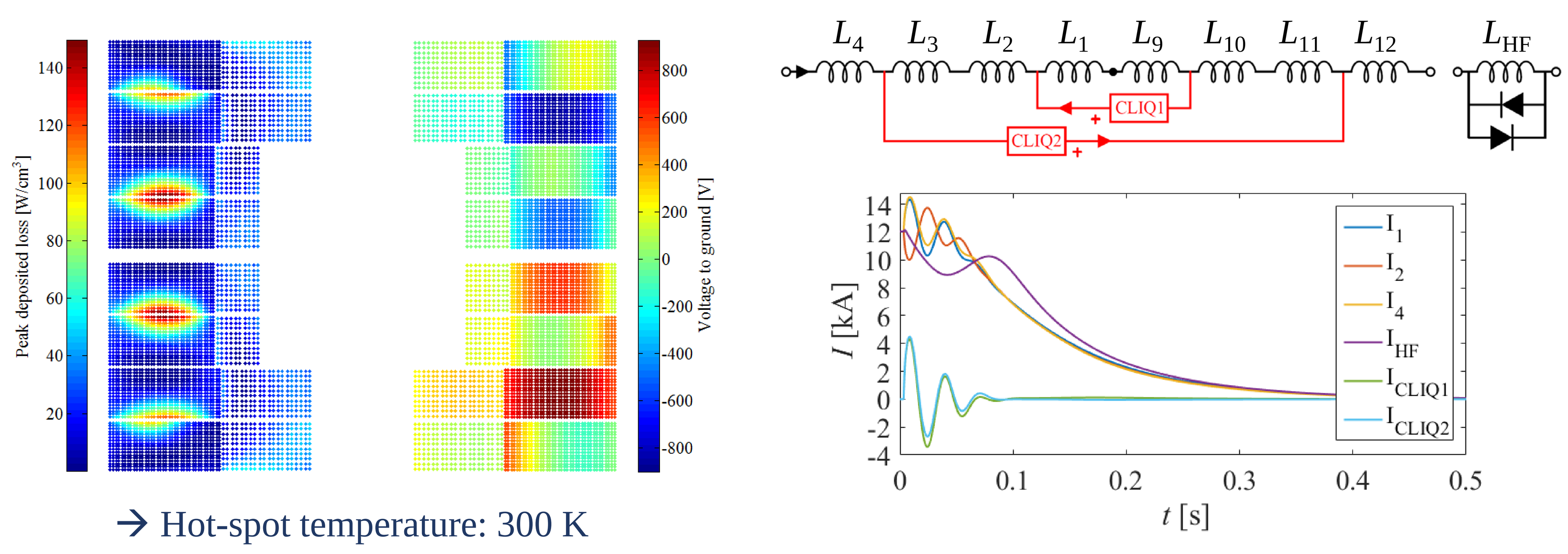
- Internal diodes to equalize the voltage in selected turns.



→ Hot-spot temperature: 280 K

Strategy 3: different circuits for low-field and high-field coils

- High-field (HF) coils powered with a separate circuit: CLIQ is applied to low-field coils only.



→ Hot-spot temperature: 300 K

Further studies

- Optimization of the aforementioned strategies.
- Analysis of the CLIQ compatibility in the FCC main dipole circuit.
- Redundancy studies and failure scenarios, as proposed in [4] for HL-LHC project.

Conclusions

- Co-simulation has proven to be an effective approach for the study of the CLIQ protection system from the circuit and magnet points of view.
- Co-simulation of LEDET and PSpice was validated against LEDET monolithic simulation.
- The multi-CLIQ strategy is a promising option for the quench protection of the FCC block-coil dipole.

References

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STEAM FOR FCC

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