Quench protection and detection

status and update – part 1

WP4.5 - Quench detection, protection and diagnostic methods for Nb_3Sn and HTS high-field magnets - CERN

Related presentations

HFM annual meeting 2023
https://indico.cern.ch/event/1302031

- STEAM – E. Ravaioli & M. Wozniak
- WP4.5 – M. Wozniak

Mariusz Wozniak

28th March 2024

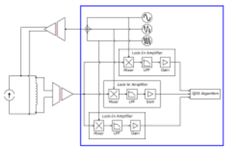
Related HFM Working Groups (WG)

Quench and Analysis of Transients (**QuAT**) WG https://indico.cern.ch/category/18084/

HTS modelling WG https://indico.cern.ch/category/18117/

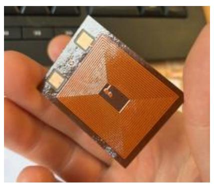
Outline

Part 1



Detection Technology

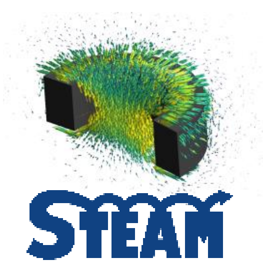
- Quench Detection Through Electrical Stimuli



Protection Technology

- E-CLIQ (External CLIQ) Development Progress
- S-CLIQ (Secondary CLIQ) Simulations
- CLIQ (Coupling Loss Induced Quench) Optimization
- ESC (Energy Shift with Coupling) Concept
- CD (Capacitive Discharge) Protection for HTS
- EE (Energy Extraction) with energy recuperation

Part 2



Transient **Simulations**

- 12T Quench Protection studies
- Reduced order modelling: AC loss and homogenization
- Material properties in Simulations
- 3D FE Simulations of HTS pancakes – FiQuS
- 3D FE Simulations - High Performance Computing
- 3D FE Simulations of HTS pancakes – J/A method
- 2D FD Simulations of HTS pancakes stacks - NICQS
- 3D CCT Quench Co-simulations

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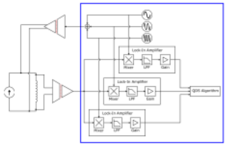

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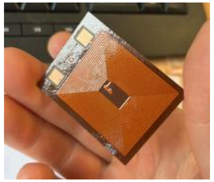

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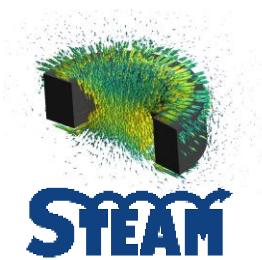

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Quench Detection Through Electrical Stimuli

Concept:

Quench detection and electrical quality assurance based on magnet's response (impedance) to electrical stimuli signal at a range of frequencies

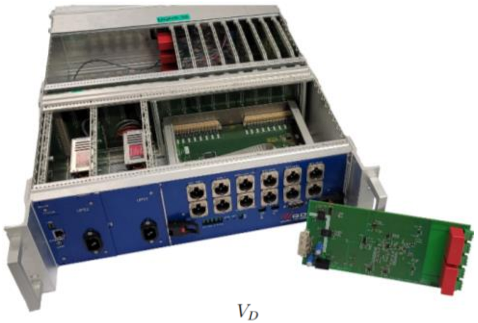
More details: https://doi.org/10.1109/TASC.2024.3369004

Recently achieved goals:

- Implemented differential probing – allows for better isolation of power-converter Impedance.
- Enabled long term and continuous measurements.
- Worked on DSP algorithms to reduce noise impact from the attached power-converter.

Next steps:

- Measurement of an HTS coils at warm/cold and during powering and quenches. Discussions with PSI team on NI HTS coil and with the HFM WP2.5 at CERN on insulated HTS coil. No firm dates agreed yet.
- Performing continuous measurements of a magnet during all powering phases. The most likely magnet is MQXF and scheduled for testing sometime in April 2024 (TBC). Thanks to the SM18 team.



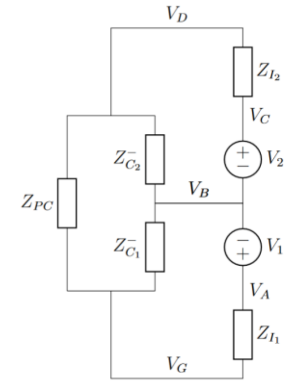
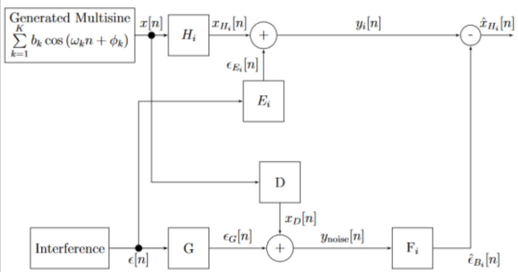


Illustration of differential probing



Noise reduction signal block diagram

Outline

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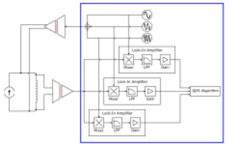

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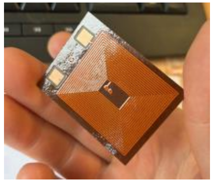

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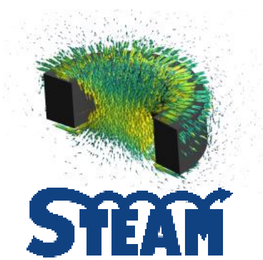

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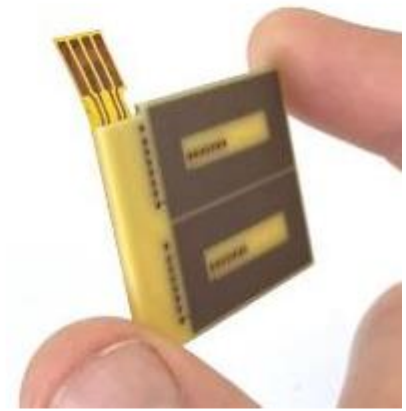
E-CLIQ: successful demonstration on a cable at the Cryolab

- AC in the E-CLIQ device generates a large dB/dt and thus AC loss in a SC cable, potentially significantly increasing the cable temperature within milliseconds after activation.
- The E-CLIQ heats up and, in principle, also acts as a resistive quench heater.
- 116 Measurements performed at CERN cryogenic laboratory using various E-CLIQ frequencies, current amplitudes, number of cycles and external magnetic field values.
- Larger temperature increase measured compared to initially expected.
- Peak temperature is expected to be much larger due to thermal resistance between E-CLIQs, sample and temperature sensors.

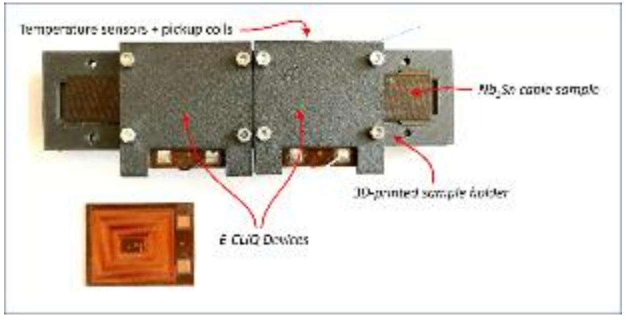
Tested E-CLIQ device, designed for implementation in a SMC11T coil.

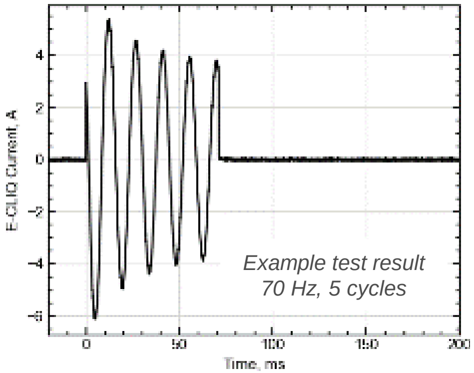


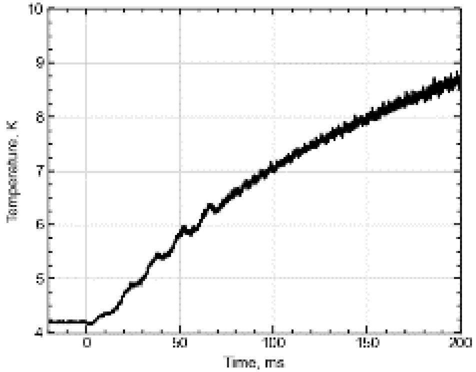
E-CLIQ – External Coupling Loss Induced Quench

Next steps:

- Application and testing of these E-CLIQ devices in an SMC magnet.
- Coil winding, reaction, E-CLIQ implementation and instrumentation planned March-May 2024.
- Potential testing during summer 2024.





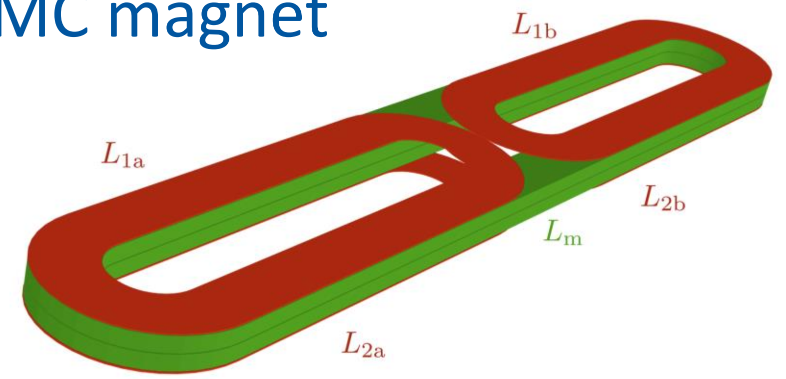


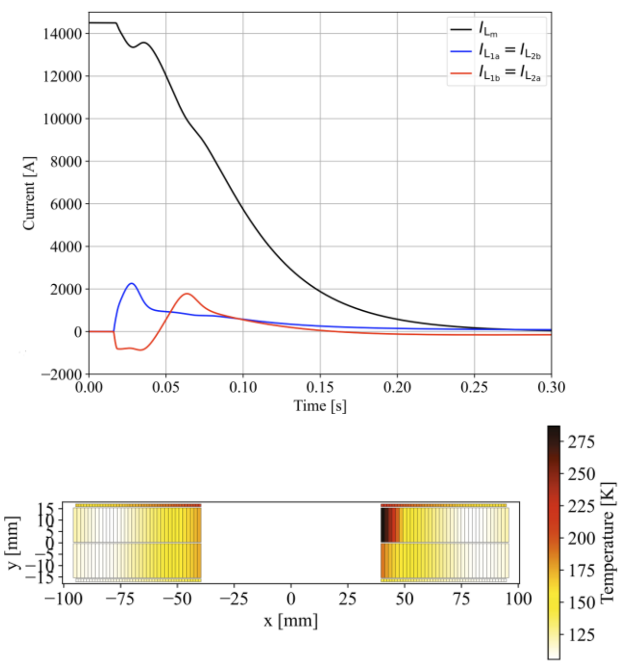
We acknowledge great collaboration with the Cryolab and WP4.6

S-CLIQ: Quench study for the SMC magnet

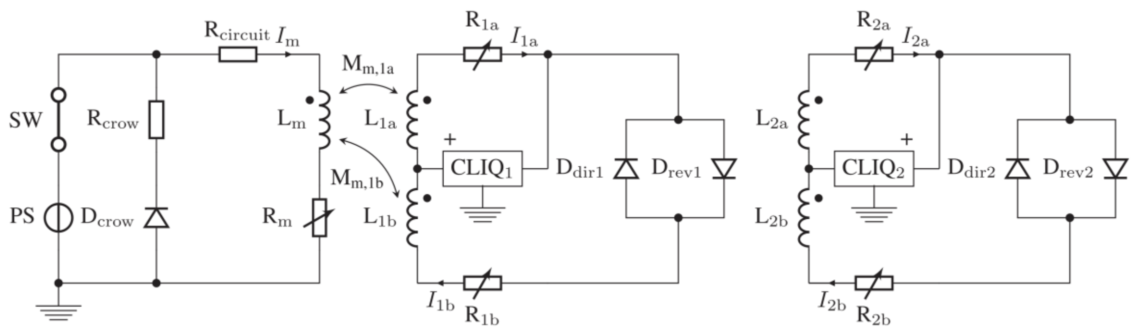
SMC designed by J.C. Perez (CERN)

- ✓ As fast as CLIQ or faster in terms of quenching the magnet
- ✓ Able to extract part of the magnet energy
- ✓ System is electrically insulated from the magnet
- ✓ Good protection redundancy (very important)





S-CLIQ – Secondary Coupling Loss Induced Quench



Next steps:

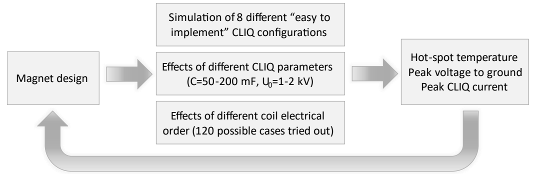
- Activity parked – awaiting ESC results

More details: https://doi.org/10.1109/TASC.2023.3336272

CLIQ: Optimization of connection for the 14 T SMACC magnet

Collaboration with PSI and WP3.14
More magnet details: https://indico.cern.ch/event/1389304/
Quench related task was to study effects of:

- 8 different "easy to implement" CLIQ configurations
- 2 key CLIQ unit parameters (C=50-200 mF, U_0=1-2 kV)
- different coil electrical order (120 possible cases tried out)



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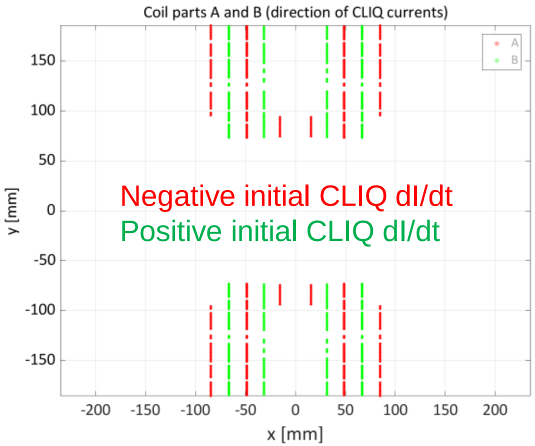
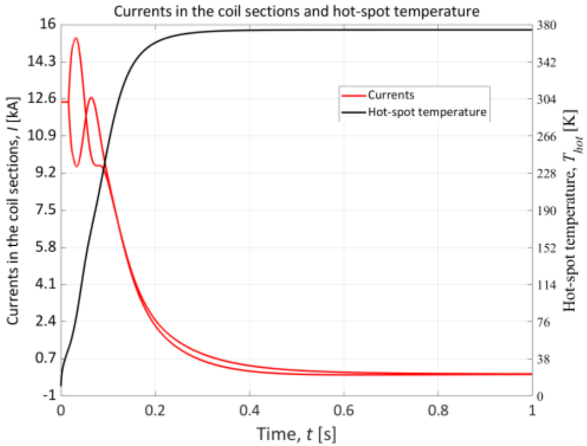
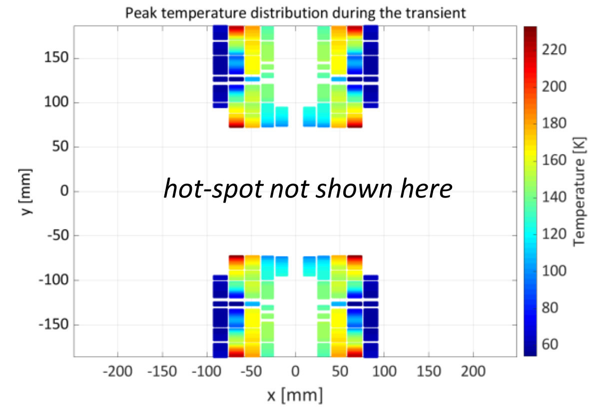
CLIQ – Coupling Loss Induced Quench







Magnet designed by D.M. Araujo (PSI)

For 15 m version: Hot-spot temperature: 375 K, peak voltage to the ground: 1950 V, peak CLIQ current: 5890 A.

Steps:

- Simulations of current design (Q1-2024), Simulations of next design (Q2-2024), Paper (Q4-2024)

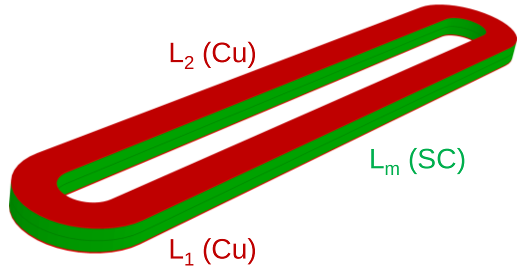
ESC 1/2: Quench study and demonstration on SMC in progress

- ✓ As fast as CLIQ or faster in terms of quenching the magnet
- ✓ The system extracts part of the magnet energy
- ✓ Resulting sudden current decrease → lower ohmic loss
- ✓ System is electrically insulated from the magnet
- ✓ Good protection redundancy (very important)

More details:
https://indico.cern.ch/event/1321217/
https://indico.cern.ch/event/1347179/

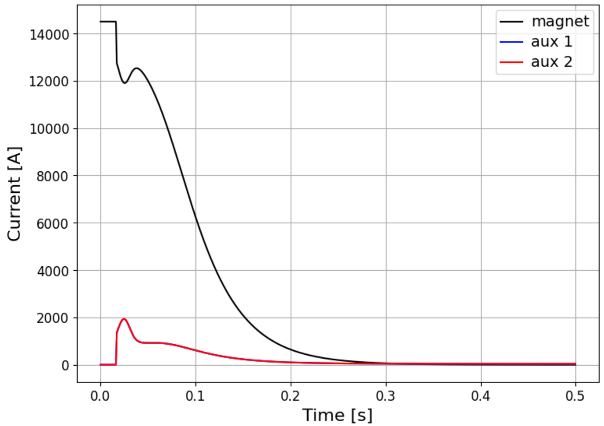
LEDET

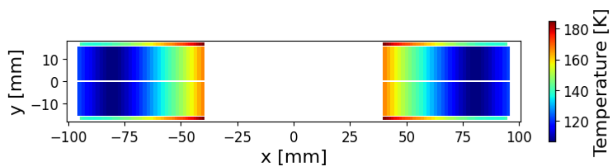
Simulates ESC
circuit without co-simulation
(standard simulation)

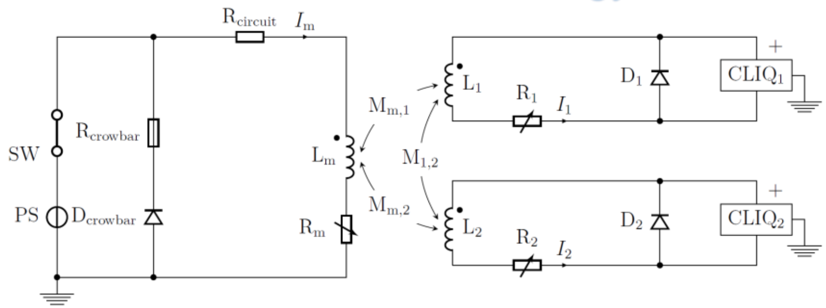


SMC designed by J.C. Perez (CERN)

ESC – Energy Shift with Coupling





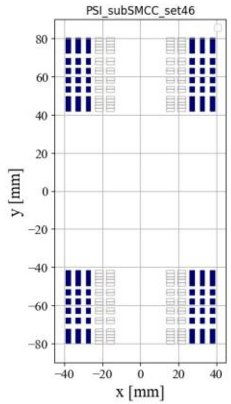


Next steps:

- ESC coil design finalized with contribution from MSC-MDT, MSC-NCM, MPE-PE colleagues
- Tests foreseen in Q3-2024 in SM18, paper in Q4-2024

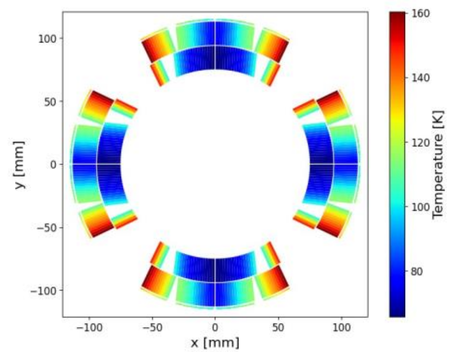
ESC 2/2: Quench study of various magnets (preliminary)

subscale SMCC



Magnet design by D.M. Araujo (PSI)

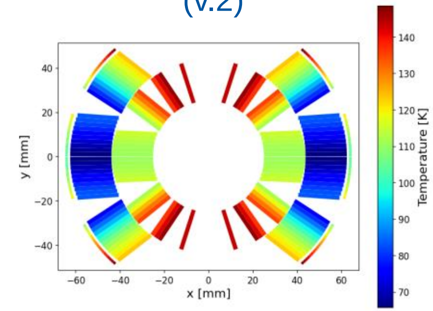
MQXF



7.15 m long, 2x 50 mF & 1 kV

Magnet design by P. Ferracin (CERN)

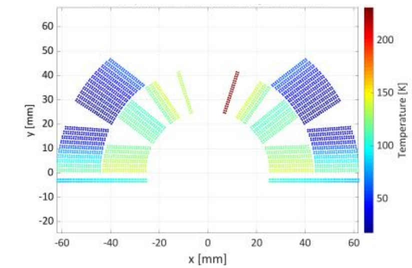
12 T (v.2)



6 m long, 2x 50 mF & 1 kV

Magnet design by L. Fiscarelli (CERN)

12 T mirror (v.2)



2 m long
2x 50 mF & 200 V

Magnet design by L. Fiscarelli (CERN)

Short versions of these magnets were studied and are protected by ESC

Next steps:

- Update the PSI subscale and the 12 T quench models with the latest magnet designs
- Study mechanics with ESC coils in place
- Decision to build

* ESC is not considered for HL-LHC project, HL-LHC magnet design was used

CD: New method for protection of a stack of NI HTS pancakes

The method:

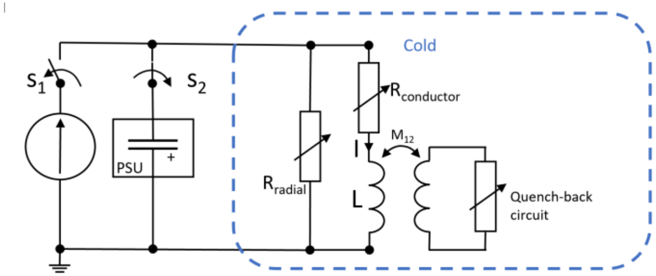
- uses turn-to-turn resistance as an internal quench heater
- is fast and has potential to quench turns within ms
- has a potential to reduce energy redistribution between pancakes and therefore reduce radial peak force density during quench
- can use various strategies (e.g. discharge to all or some pancakes)

Dedicated thermo-electromagnetic simulation tool was developed (more details in part 2 of this talk).

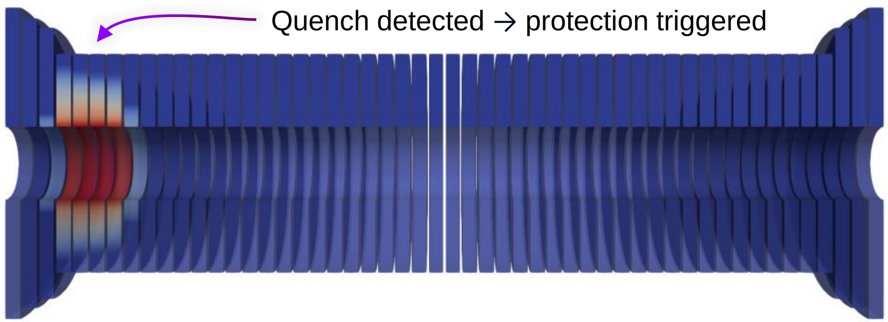
Next steps:

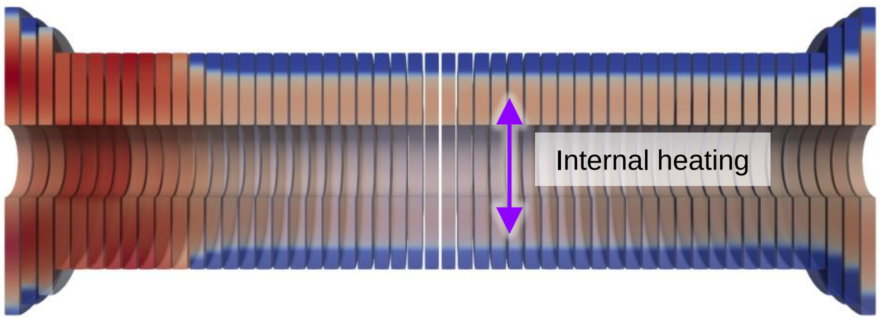
- Extend the tool from 2D axisymmetric to 3D to open a possibility of simulating racetrack coils – by the end of 2024

CD – Capacitive Discharge



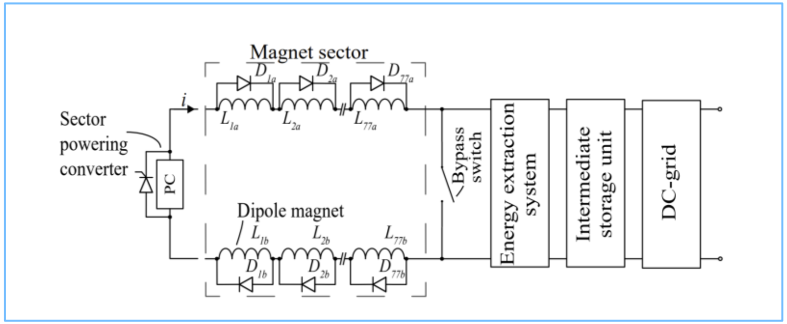
T. Mulder, M. Wozniak, A. Verweij, Quench Protection of Stacks of No-Insulation HTS Pancake Coils by Capacitor Discharge, IEEE Trans. Appl. Supercond., Vol 34, Nr 5, 2024.
https://doi.org/10.1109/TASC.2024.3362755





Energy extraction (EE) with energy recuperation

- A new idea from the recent years proposed an implementation of energy recuperation function in energy extraction (EE) systems
- Principle
  - 1st step: In case of quench or trip, the magnetic stored energy from SC circuit is saved in the storage unit (battery/capacitor) instead of being dumped as thermal losses in a resistor
  - 2nd step: The energy from the storage unit is injected in the network grid or used as a DC source
- A study on the following aspects is foreseen in the coming years:
  - Profitability of such functionality
  - Intermediate storage and technology selection
  - Reliability and circuit protection
  - Design and mock-up manufacturing



- In the light of future and bigger accelerators construction involving huge amount of stored energy, such recuperation function becomes a must.

<u>Next steps:</u>
PhD at ETH Zürich and CERN. Candidate identified and a start date is 1st May 2024.

HFM

High Field Magnets