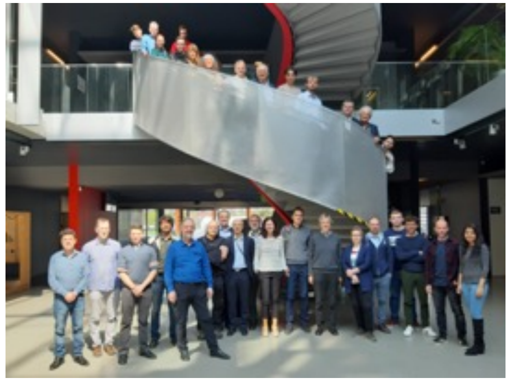
Clustering & Global Challenges
April 07-09, 2021
Online international conference

Health
Smart Energy
Quantum Tech.
Advanced Materials

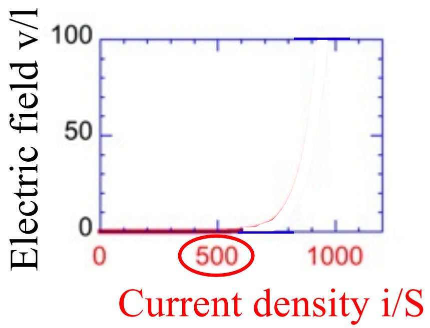
Some results of the EC project FASTGRID

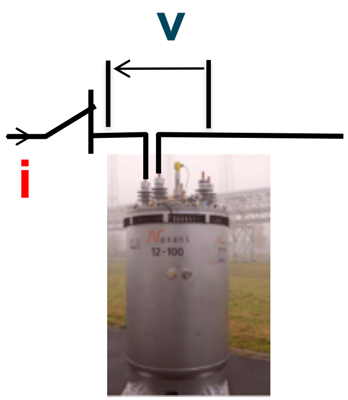
P. Tixador; M. Bauer; C. Creusot; A. Calleja; G. Deutscher; B. Dutoit; F. Gomory; G. Angeli; M. Noe; X. Obradors; M. Pekarčíková; F. Sirois.

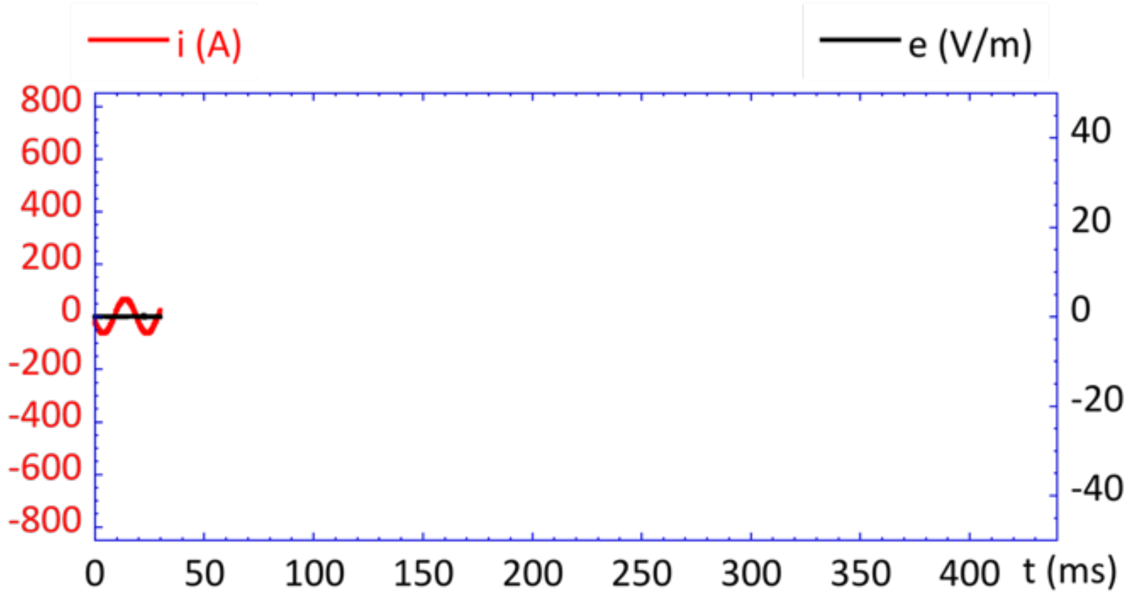


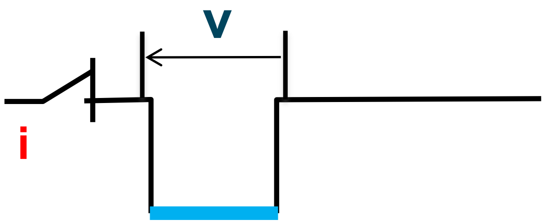
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 721019

FASTGRID project – Introduction: SFCL









Normal operation

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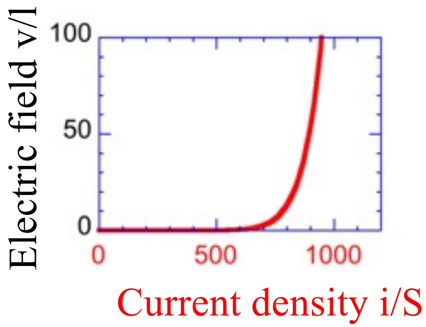
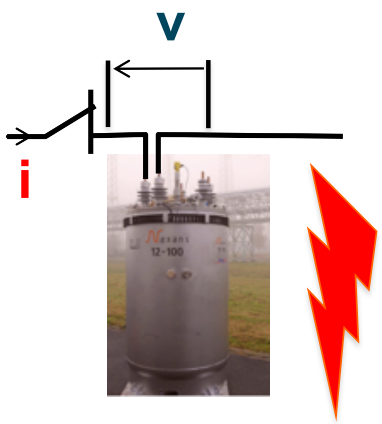
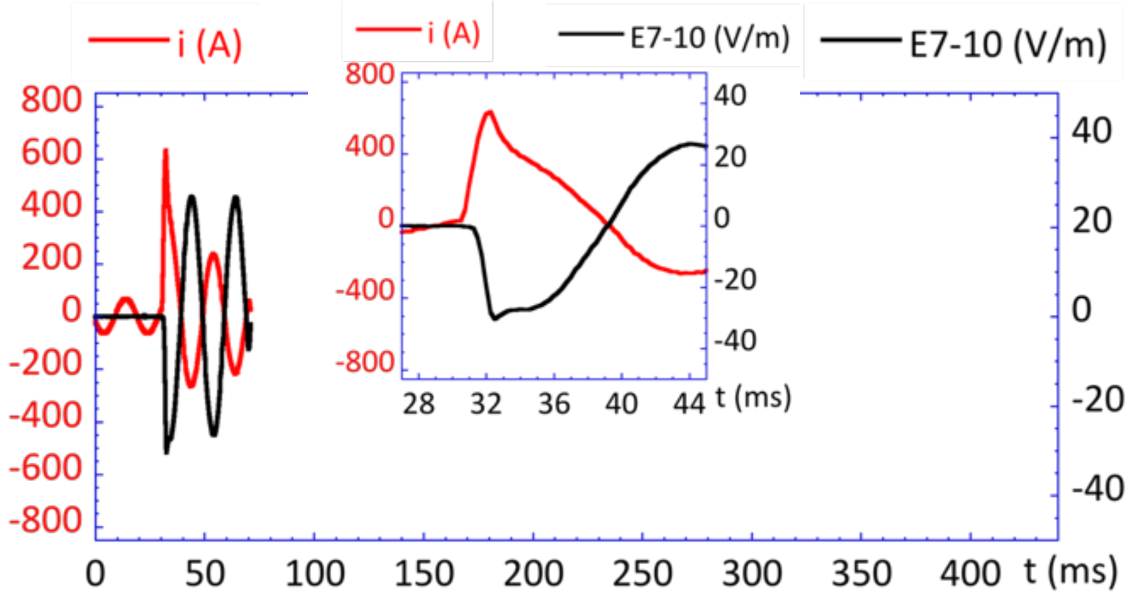
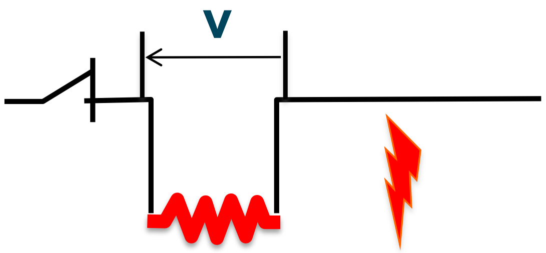
FASTGRID project – Introduction: SFCL









Fault

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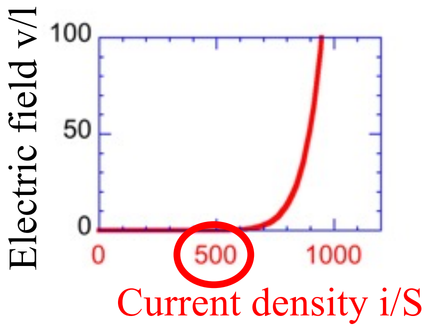
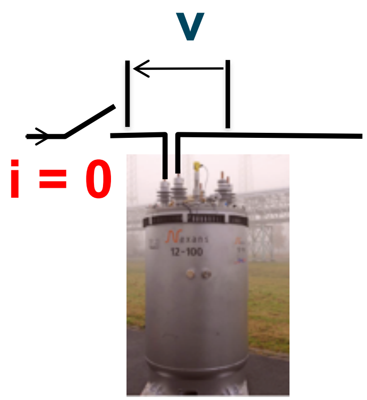
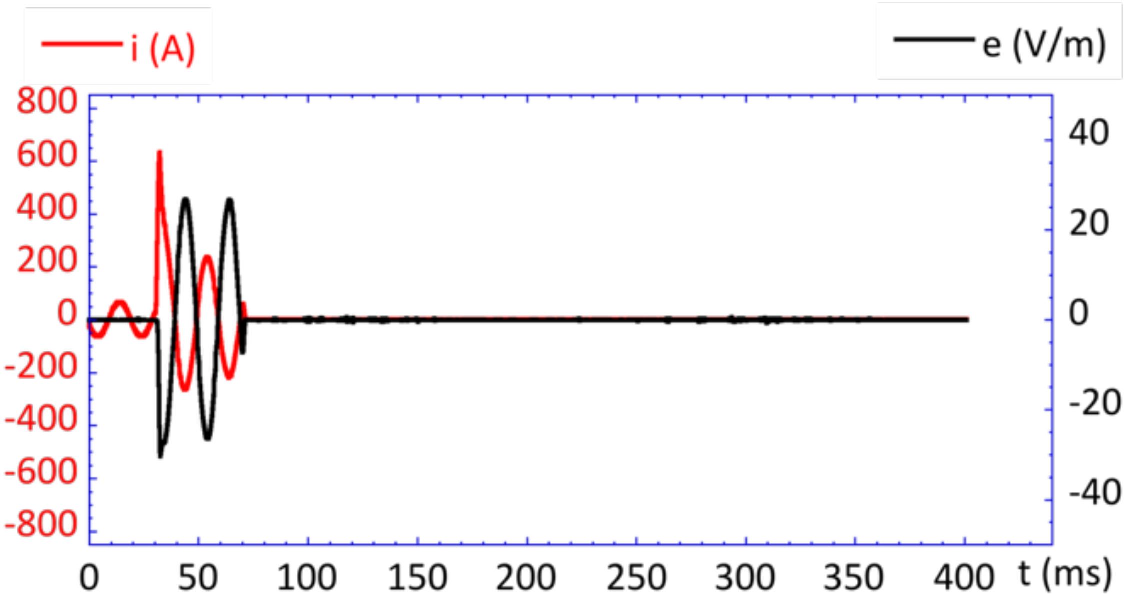
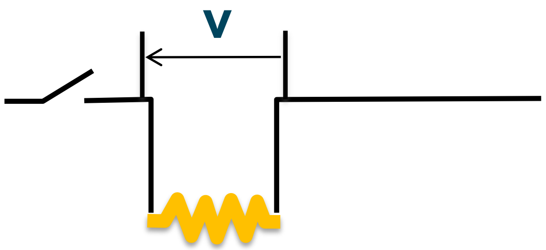
FASTGRID project – Introduction: SFCL









Isolation
Recovery

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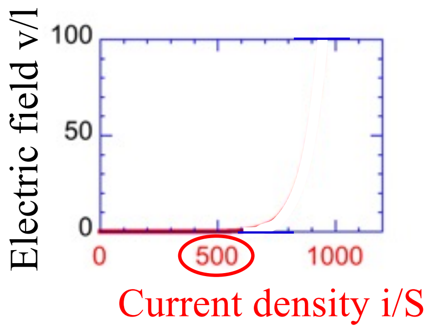
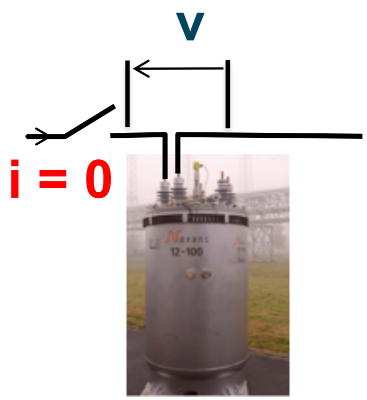
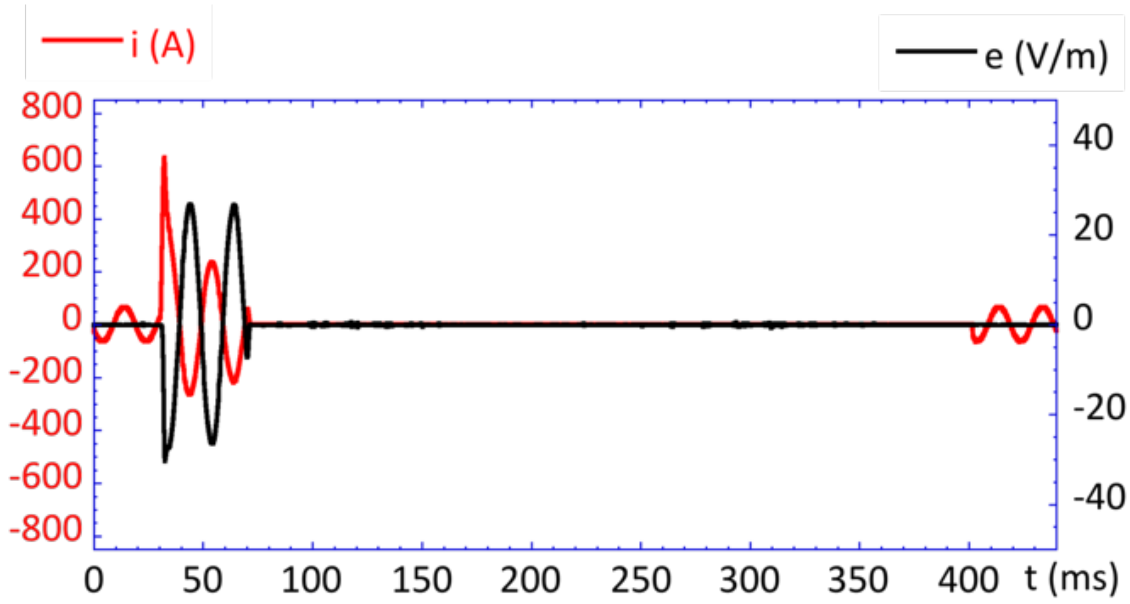
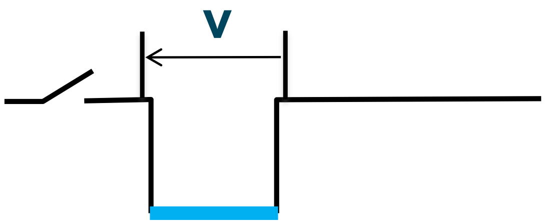
FASTGRID project – Introduction: SFCL









Return to operation

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CGC2021 Online Conference
April 7-9, 2021

Content

- Main objective of FASTGRID
- Cost reduction
- Electric field increase
- Thick Hastelloy® shunt conductor
- CFD implementation
- Representative module and tests
- FASTGRID at a glance
- Quench detection
- Conclusion

FASTGRID project – Main objective

Context: SFCL

"Innovation for the electric grids"

Essen

Birmingham

- Intrinsic phenomena: 100 % fail safe
- Innovative solution without equivalence
- SFCL guarantees current limitation useful in AC & DC applications
- SFCL simplifies the circuit breaker design for DC grid
- Automatic recovery

- **Cost**
- **Foot print**

Medium voltage

FASTGRID project – Main objective

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- **Cost**
- **Foot print**

High voltage

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FASTGRID project – Main objectives

Context: SCFCL

"Innovation for the electric grids"

Essen

Birmingham

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- SFCL guarantees current limitation useful in AC & DC applications
- SFCL simplifies the circuit breaker design for DC grid
- Automatic recovery

- **Cost**
- **Foot print**

Medium & high voltages

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Cost reduction

$$Cost = \ Cost_{/m}^{Cond} \ \ell$$

Cost reduction

$$Cost = Cost_{/m}^{Cond}\ \ell \approx Cost_{SC}\, I_c\, \frac{V_{grid}}{E_{lim}}$$

(€/kA/m)

$$Cost_{SC} = \frac{Cost_{/m}^{Cond}}{I_c}$$

Cost reduction

$$Cost = Cost_{/m}^{Cond}\ \ell \approx Cost_{SC}\, I_c \frac{V_{grid}}{E_{lim}} = \boxed{\frac{Cost_{SC}}{E_{lim}}}\, k\, V_{grid}\, I_{grid}$$

Grid

(€/kA/m)

$$Cost_{SC} = \frac{Cost_{/m}^{Cond}}{I_c}$$

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Cost reduction

$$Cost = Cost^{Cond}_{/m}\ \ell \approx Cost_{SC}\, I_c \frac{V_{grid}}{E_{lim}} = \frac{\boxed{Cost_{SC}}}{E_{lim}}\, k\, V_{grid}\, I_{grid}$$

(€/kA/m)

$$\boxed{Cost_{SC}} = \frac{Cost^{Cond}_{/m}}{I_c}$$

Cost reduction:

$\boxed{Cost_{SC}}$

- Elaboration process improvement, higher yield
- I_c increase
  - Work on the tape elaboration
    - 300 A/cm-w => 600 A/cm-w (77 K, sf)
  - Temperature decrease
    - 77 K => 65 K (liquid nitrogen)

Cost reduction

$$Cost = Cost_{/m}^{Cond}\ \ell \approx Cost_{SC}\, I_c \frac{V_{grid}}{E_{lim}} = \frac{Cost_{SC}}{\boxed{E_{lim}}}\, k\, V_{grid}\, I_{grid}$$

(€/kA/m)

$$Cost_{SC} = \frac{Cost_{/m}^{Cond}}{I_c}$$

Cost reduction:

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$\boxed{E_{lim}}$

- Electric field under limitation increase

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Electric field increase

E_{lim}: thermal design
(temperature rise limitation before isolation after Δt)

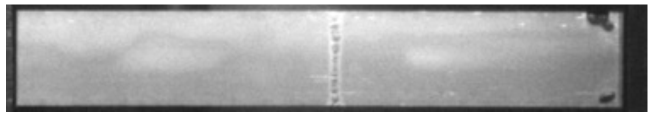
Adiabatic conditions:
(Voltage source)

$$\int_0^{\Delta t} \frac{v(t)^2}{R} dt = Volume \int_{T_o}^{T_{max}} c_p \, dT$$

$$E_{lim} \approx \sqrt{\frac{\rho \, c_p \, \Delta T}{\Delta t}}$$

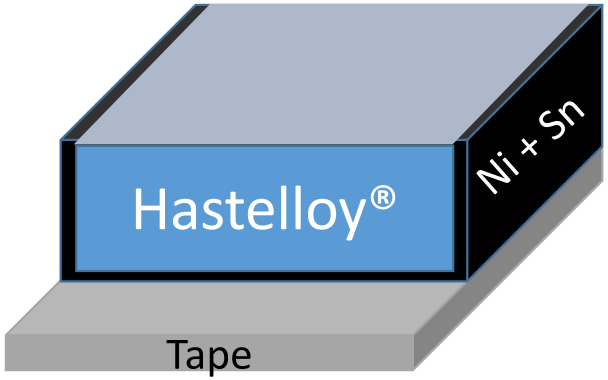
But SFCL should operate whatever is the fault current, for high but also low prospective currents

For $I_{pros} \approx I_c$: only one/a few localized spot quenches with little extension (hot spot regime)

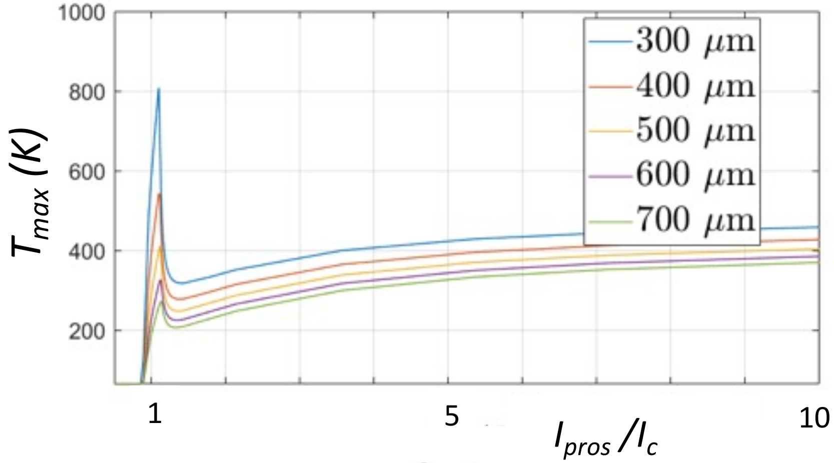


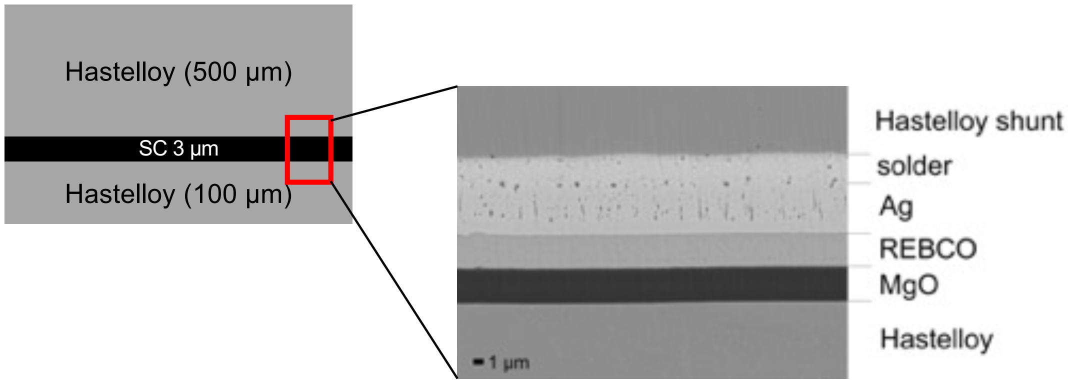
To cope with the hot spot regime a thick shunt must be added

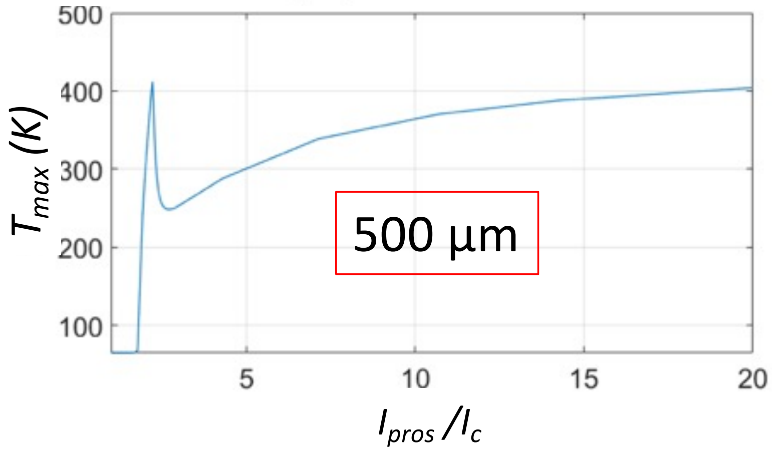
Thick Hastelloy shunt conductor



Shunt: hot spot regime
(low prospective current)







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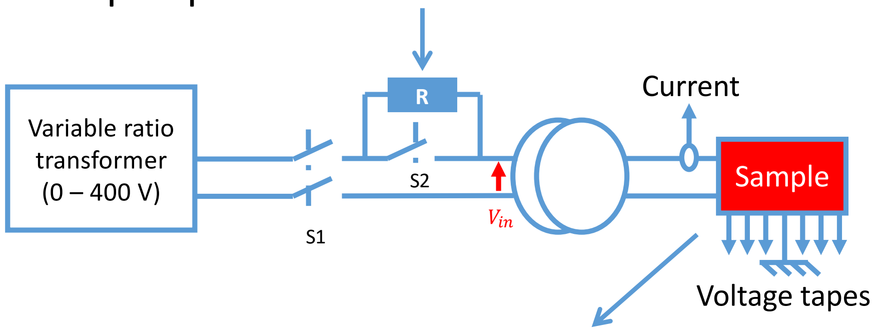
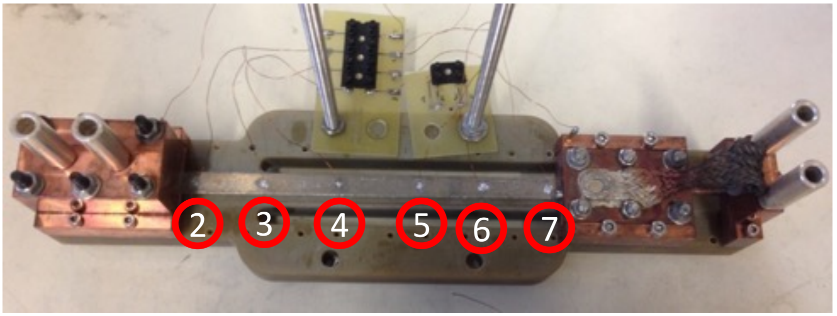
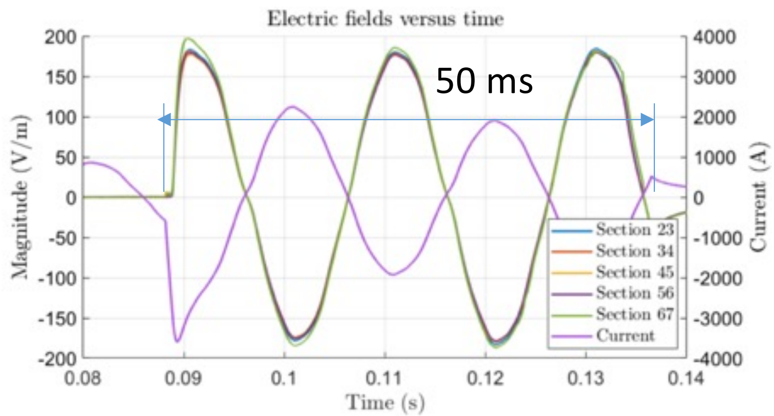
AC power circuit

R: prospective current from 0 to 7000 A





Typical test



- Electric field of 140 V_{RMS}/m – 50 ms
- Very homogeneous quench
- Up to 64 GW/m^3 and 40 MW/m^2!
- $T_{max} \approx 400$ K

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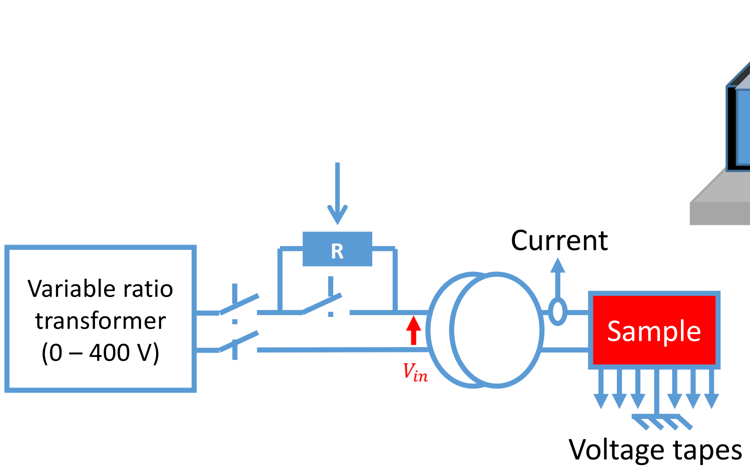
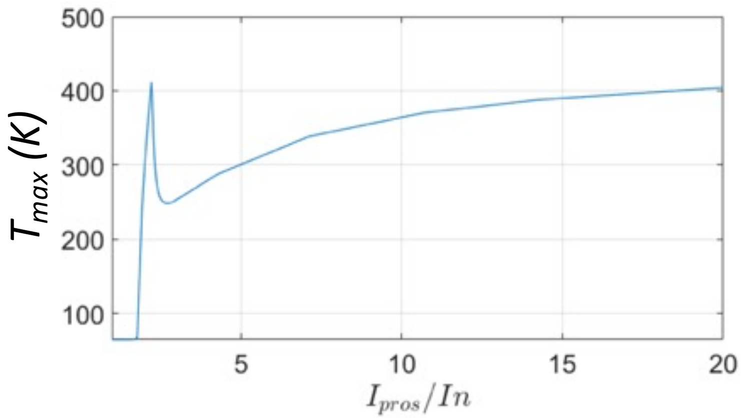
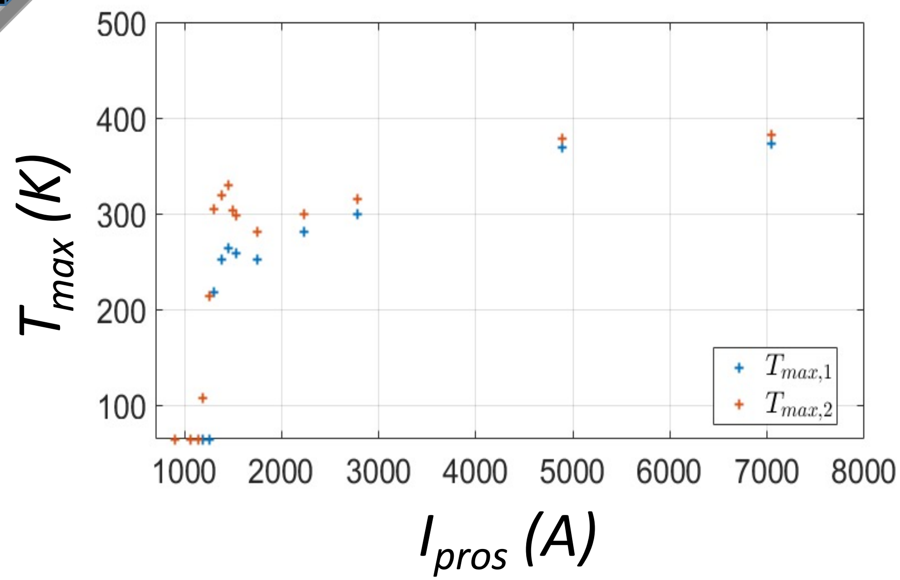
Thick Hastelloy shunt conductor







Conductor operates for any regime as designed

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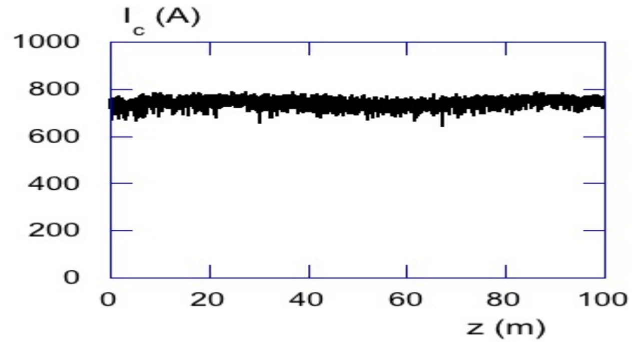
CFD implementation

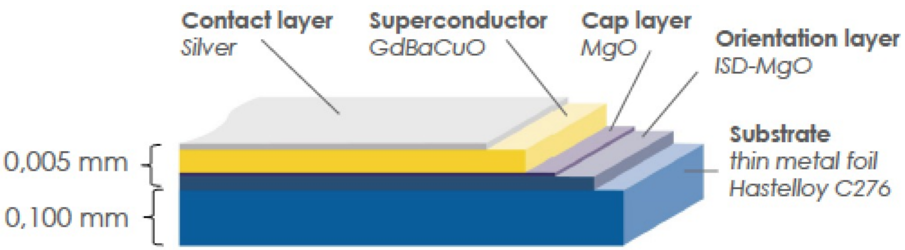
Hot spot issue due to:

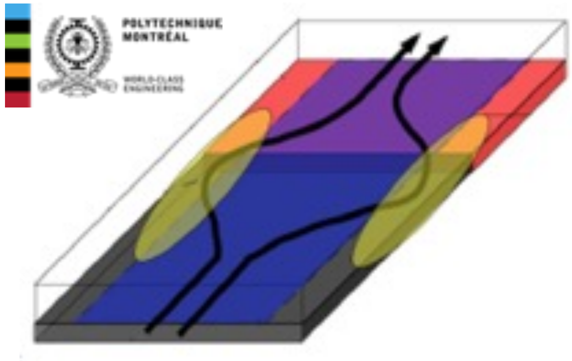
- Inhommogeneous I_c along the sample
  - ΔI_c from > 10 % to 3-4 %



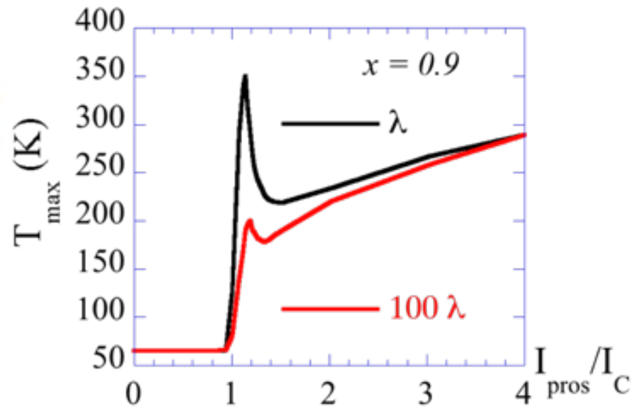
Hot spot issue due to:

- Inhommogeneous I_c along the sample
  - ΔI_c from > 10 % to 3-4 %
- Low Normal Zone Propagation Velocity NZPV
  - Increase the NZPV thanks to Current Flow Diverter (CVD)





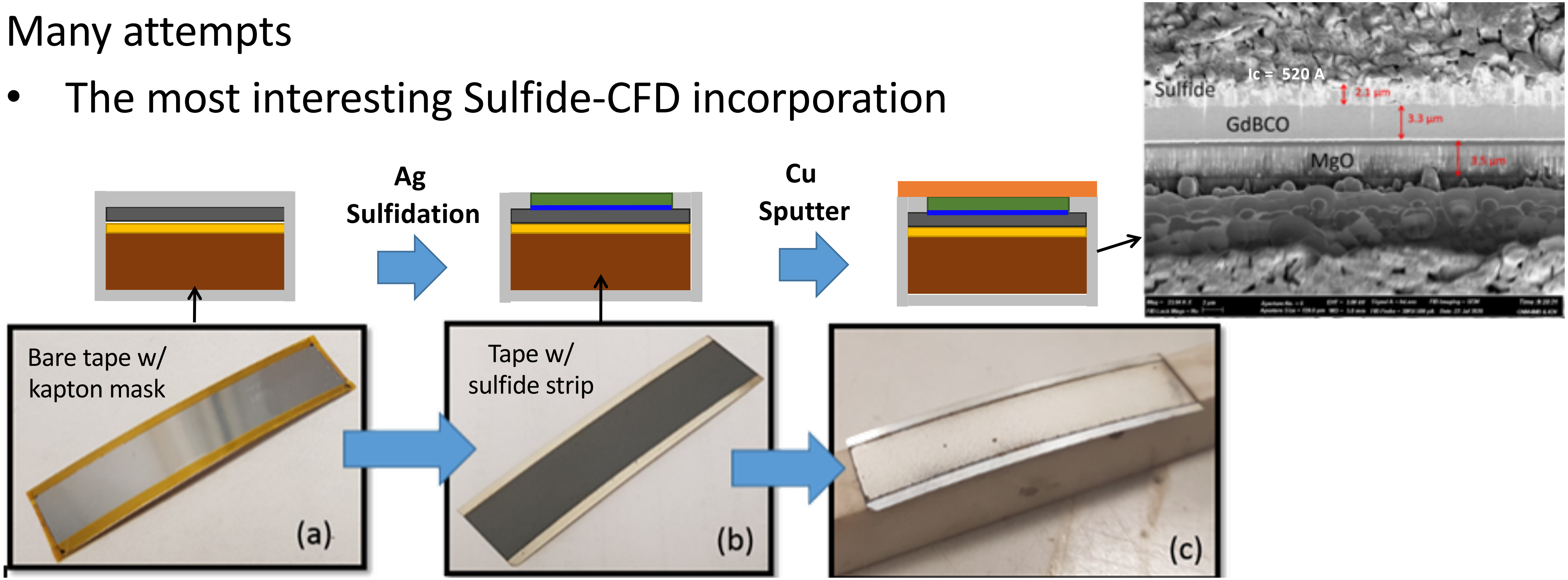
Current Flow Diverter



Courtesy J. Vialle

Many attempts

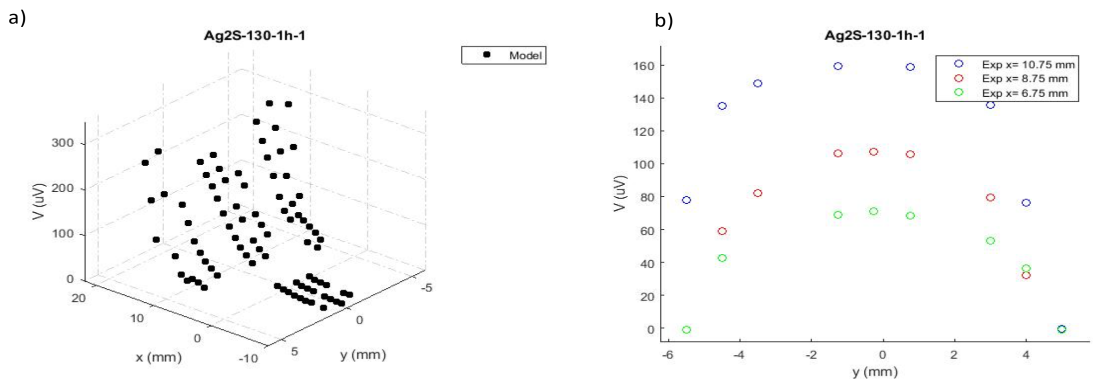
- The most interesting Sulfide-CFD incorporation



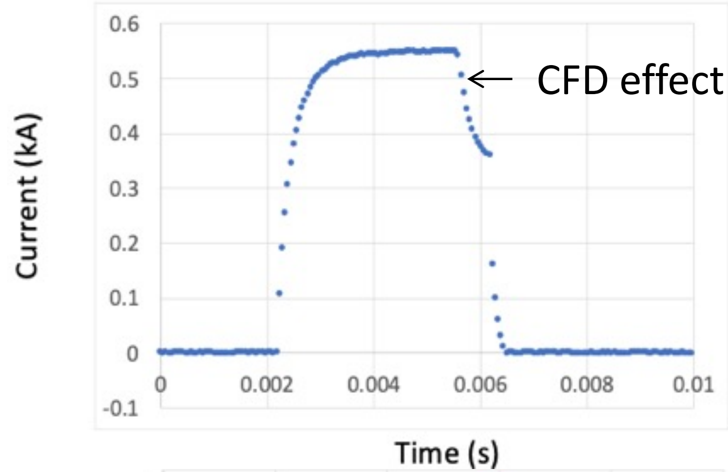
Easy incorporation of the CFD concept!

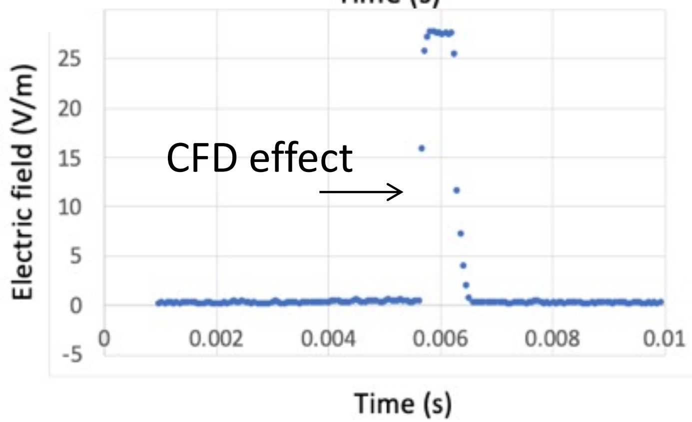
CFD implementation

Test of sulfide route CFD tapes (ICMAB)



Current transfer from silver in HTS was measured at EPM, which confirmed the CFD effect in sulfide-CFD samples





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Content

- Main objective
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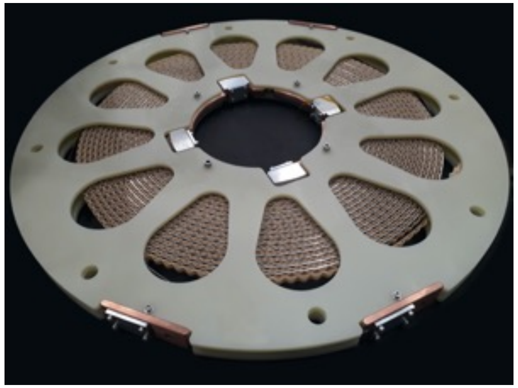
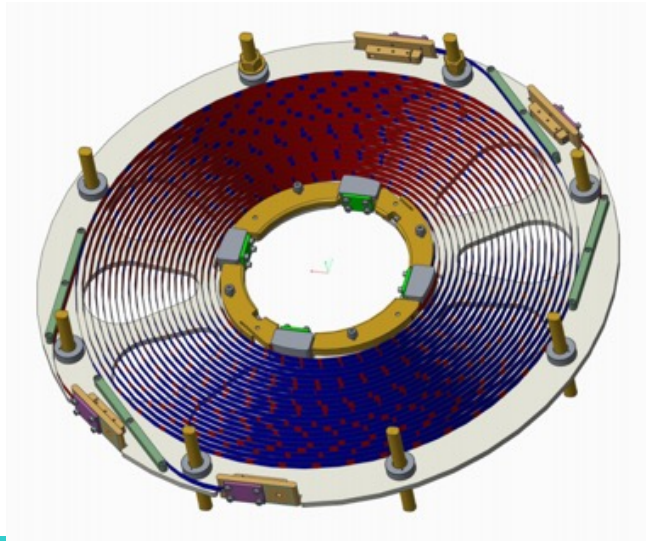
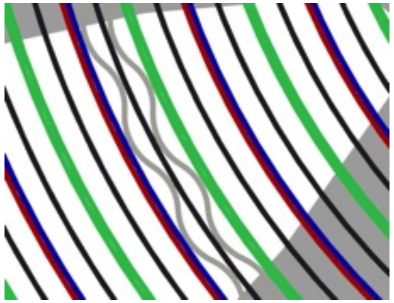
- Thick Hastelloy® shunt conductor
- CFD implementation
- Representative module and tests

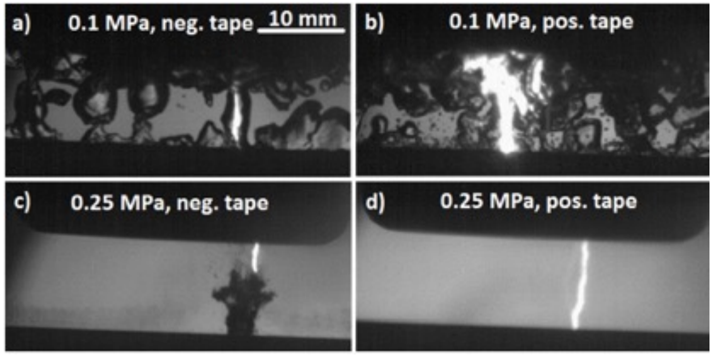
- Conductor modelling and definition
  - Hot spot and limitation finite element modelling
- Pancake mechanical & electrical design + manufacturing
  - Design for 5 kV nominal voltage and 65 K
  - 34 m long winding
- Dielectric tests in liquid nitrogen at various pressures





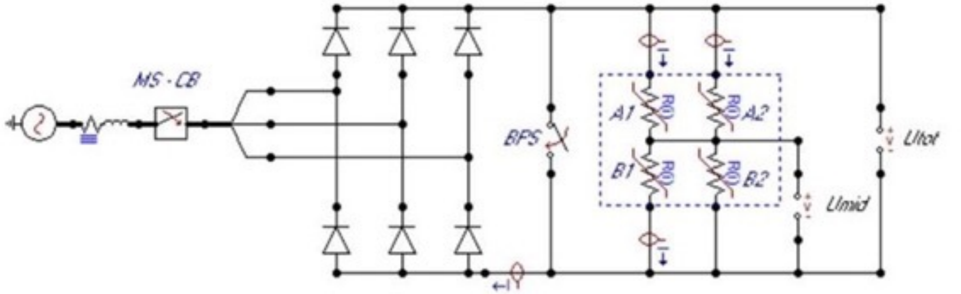


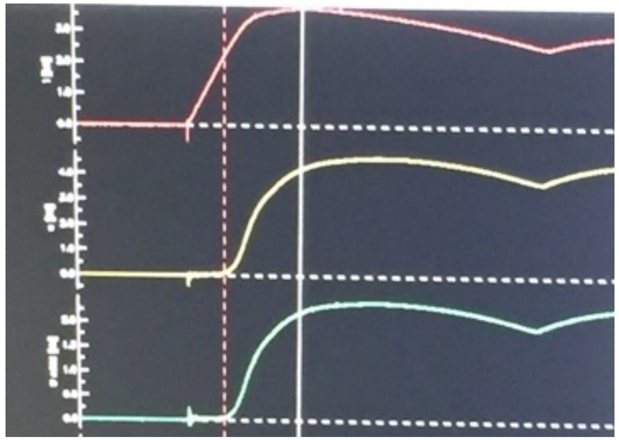
Isolation design



Dielectric tests

Pancake tests carried out in Berlin in DC conditions (IPH)

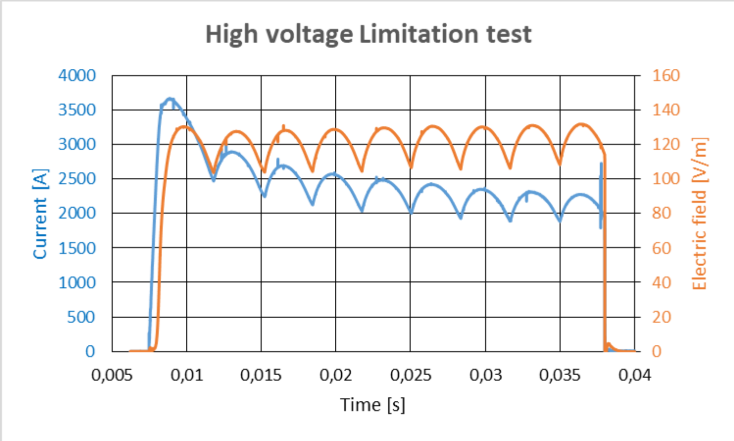




Berlin – IPH - July 2020

Pancake tests carried out in Berlin in DC conditions (IPH)

- Conductors with Hastelloy® shunt as per sample tests
- **Test voltage @ 6 kV, 14 kA prospective**
- Limitation achieved 130 V/m during 30 ms @ 77 K
- Electrical endurance: 5 successive limitation tests
- Hot spot test performed before and after limitation test



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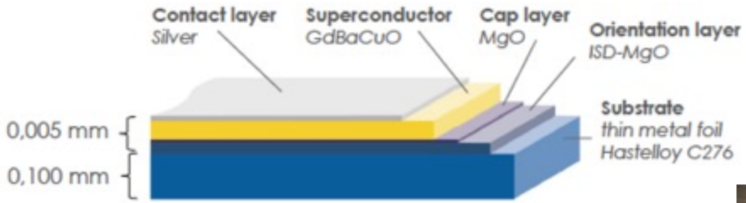
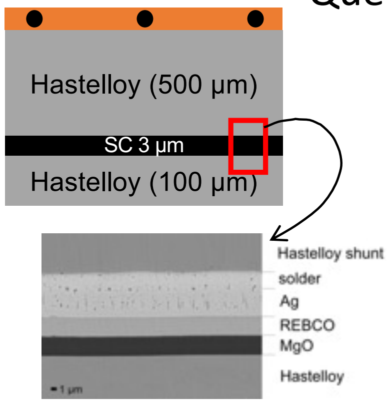
FASTGRID at a glance

Hastelloy® substrate (THEVA (OXO))

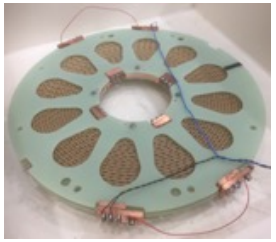


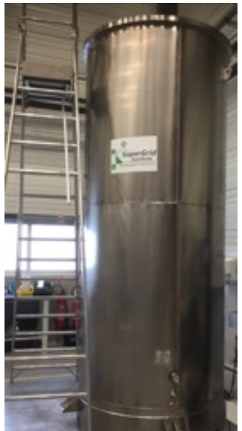
Hastelloy® shunt
Basic line

Smart conductor

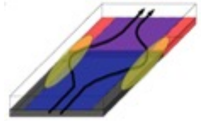


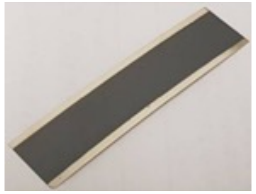
Quench detection





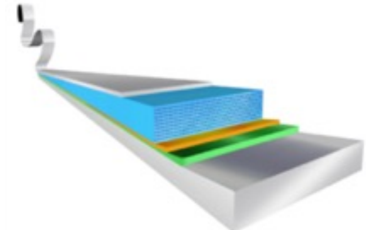
CFD arch.





High c_p shunt
Innovative way

Sapphire substrate



Breakthrough tape
- 1000-2000 V/m

Low TRL, progress

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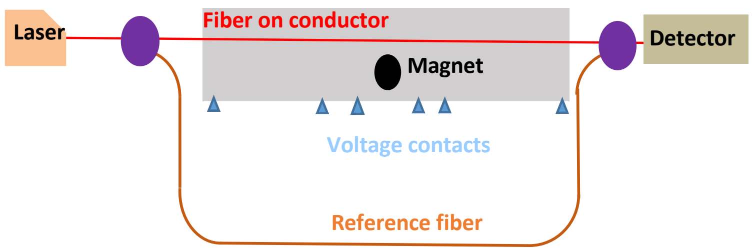
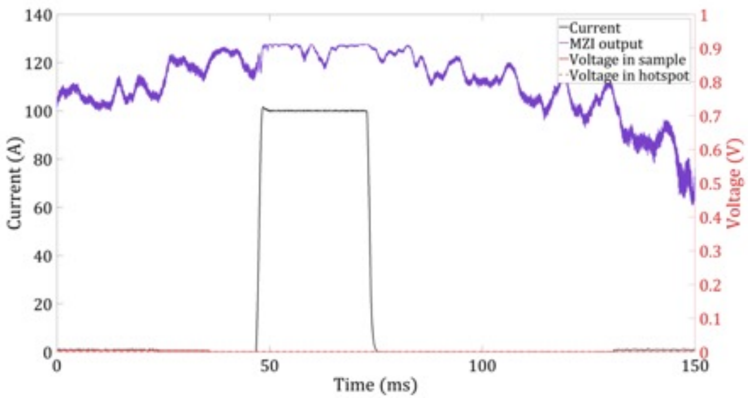
Smart conductor: optical fiber sensing for SFCL hotspot detection

EPFL

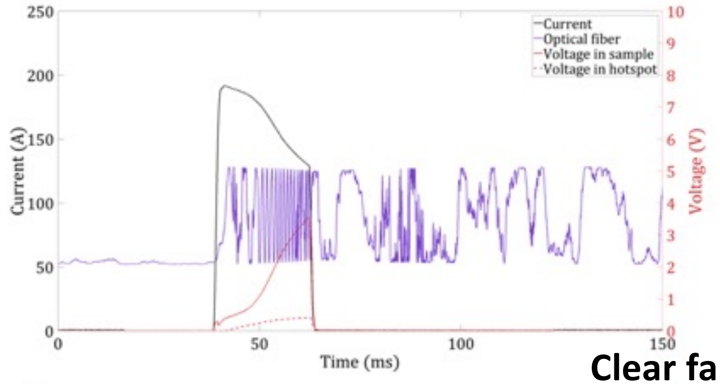
Mach-Zehnder configuration

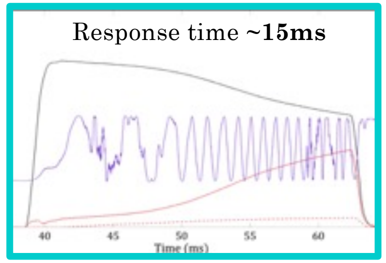


Without hotspot

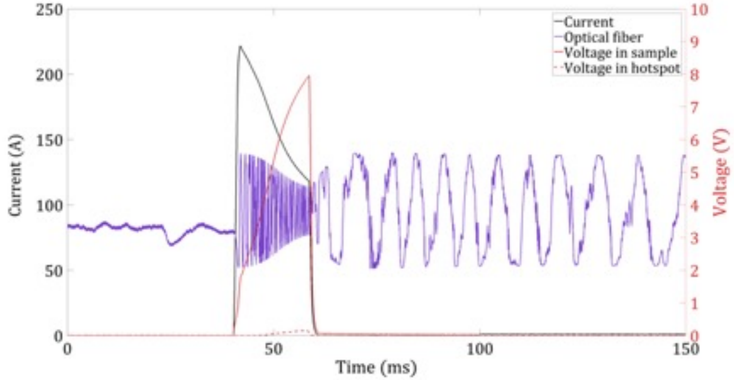


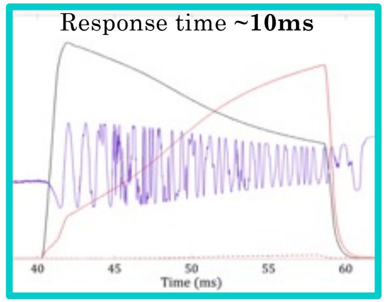
Multiple hotspots





Clear fault





Highly efficient, extremely low cost hotspot and very quick detection system

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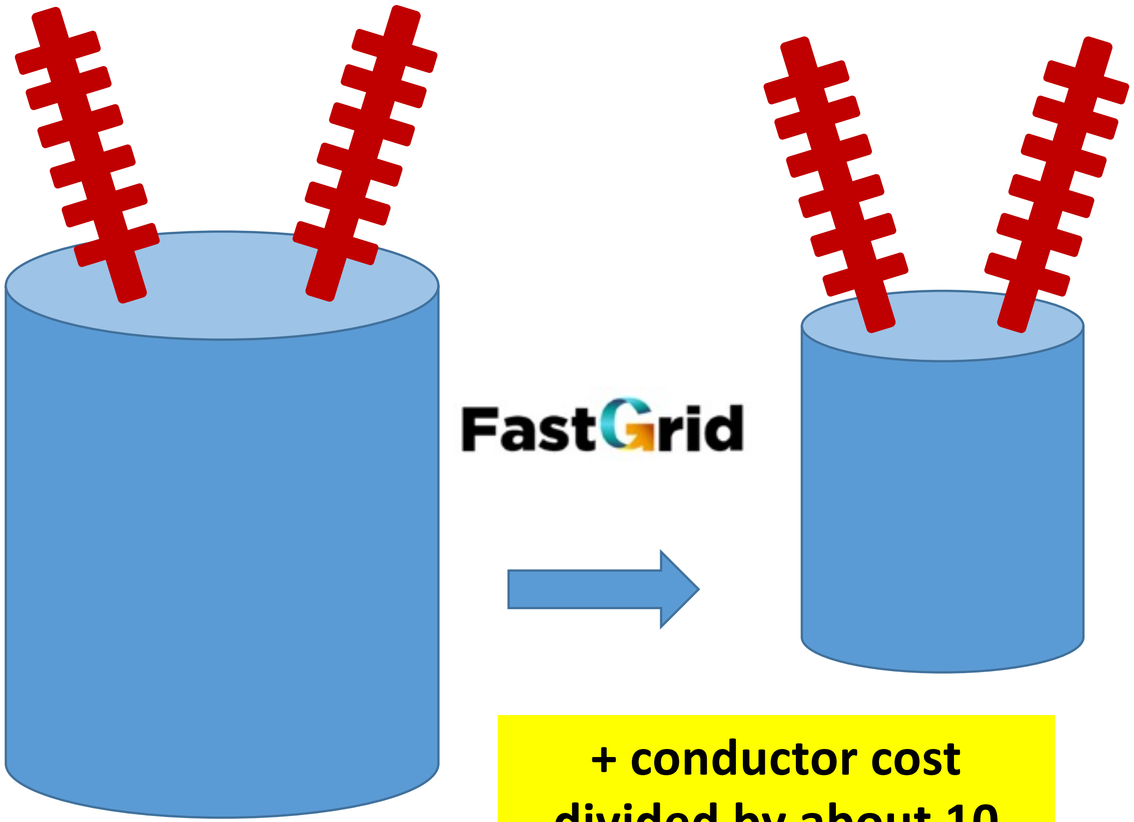
Clustering & Global Challenges
April 07-09, 2021
Online international conference

Health
Smart Energy
Quantum Tech.
Advanced Materials

Summary and conclusion

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement n° 721019

FASTGRID project – Summary



+ conductor cost divided by about 10

$$Cost: \frac{C_{SC}}{E_{\lim}} \quad [€/VA] \qquad C_{SC} \propto C_{Cond}/I_C$$

	Eccoflow	FastGrid	Gain
T_o	77 K	65 K	Little drawbacks
$I_{c\text{-}w}$ (A/cm-w) (T_o, sf)	320	1200	3.75
E_{lim} (V/m) – 50 ms	50	130	2.6

Total gain of 9.75 *(cond. & cryo.)*

+ breakthrough solutions

- CFD implementation
- Sapphire substrate
- High c_p
- Optical fiber
- ....

Conclusions

In short **FastGrid** has made possible a leap forward in the performances and cost of SFCL besides the many advances about CFD implementation, quench detection, sapphire substrate tapes, high c_p shunt, simulation and experimental tools…

Most of these advances are valid for other SC applications.

All the more there is a clear and real demand today for SFCL (Nexans).

Work continues!

A beautiful adventure with Barcelona (ICMAB & OXOLUTIA)

Clustering & Global Challenges

April 07-09, 2021

Online international conference

Health

Smart Energy

Quantum Tech.

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Thank you!

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