Introduction of Superconducting Fault Current Limiter Research at KIT

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INSTITUTE FOR TECHNICAL PHYSICS (ITEP)

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CURL10 Project (2000-2004)

- **Objective:** Development and field test a 10 kV, 10 MVA resistive type SCFCL with Bi2223 bulk material
- **Partners:** ACCEL, Nexans SuperConductors, RWE
- **KIT Tasks:** Characterization and test of Bi2223 FCL components

Data	Value
Voltage	10 kV
Current	600 A
Power	10 MVA
Fault duration	60 ms
HTS	Bi 2223 bulk
Op. Temp.	77 K, LN_2
Cooler	Stirling

Worldwide first field test of a resistive type SCFCL.

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Worldwide first field test of a resistive type SCFCL.

Ensystrob Project (2009-2011)

- **Objective:** Development and test of a 12 kV, 800 A resistive type SCFCL with REBCO coated conductor tapes
- **Partners:** BTU, Nexans SuperConductors
- **KIT Tasks:** Development and test of REBCO SCFCL component

Data	Value
Voltage	12 kV
Current	800 A
Lim. Current	< 30 kA peak
Fault duration	120 ms
HTS	YBCO cc
Op. Temp.	77 K, LN_2

Successful field test at Power Station Boxberg in Germany.

Ensystrob Project (2009-2011)

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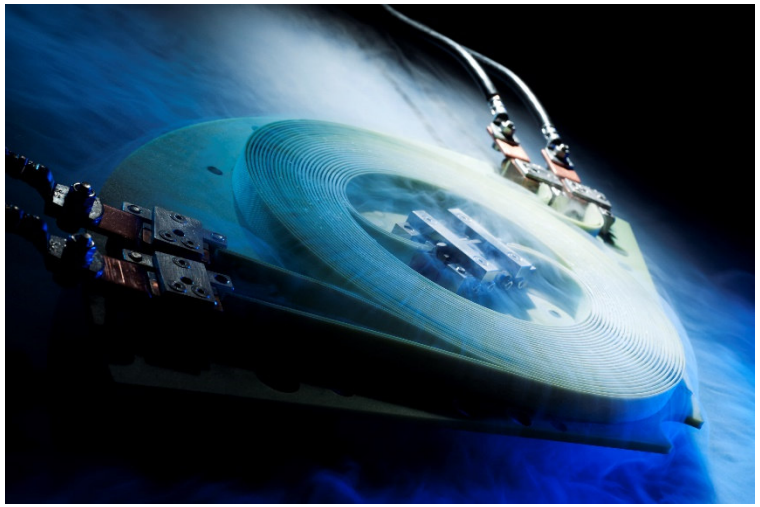


Successful field test at Power Station Boxberg in Germany.

Eccoflow Project (2010-2014)

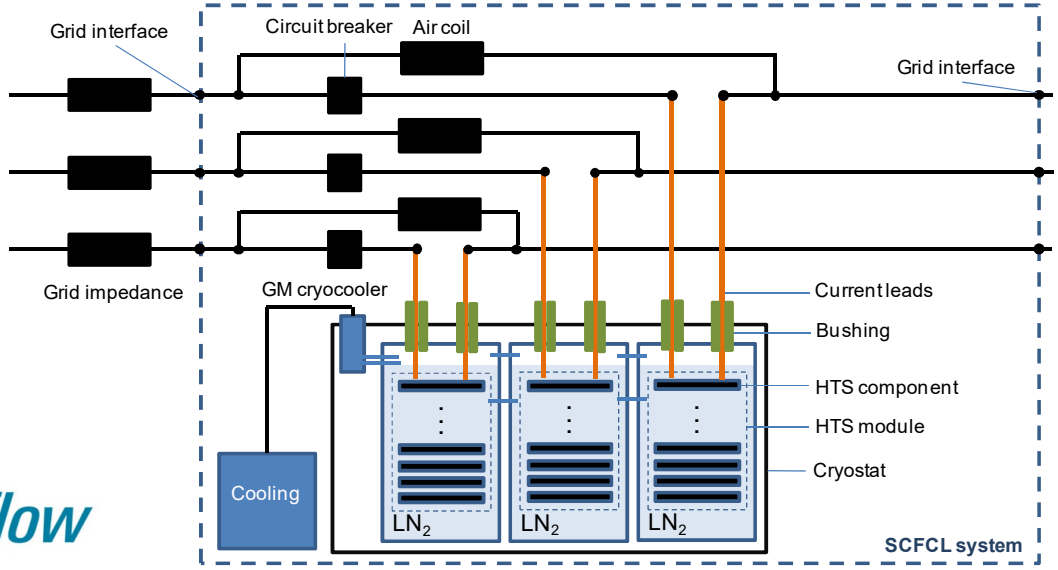
- **Objective:** Development and field test of a 24 kV, 1 kA resistive type SCFCL
- **Partners:** A2A, Air Liquide, CNRS, ENDESA, EPFL, RSE, ICMAB, LABEIN, Nexans, RWE, Vattenfall, KSE
- **KIT Tasks:** Task Leader SCFCL Design, Test and characterization

Data	Value
Voltage	24 kV
Current	1005 A
Lim. Current	< 17 kA peak
Fault duration	1 s
HTS	YBCO cc
Cooler	GM 300 W

Successful test at CESI high power laboratory in Milano.

Eccoflow Project (2010-2014)

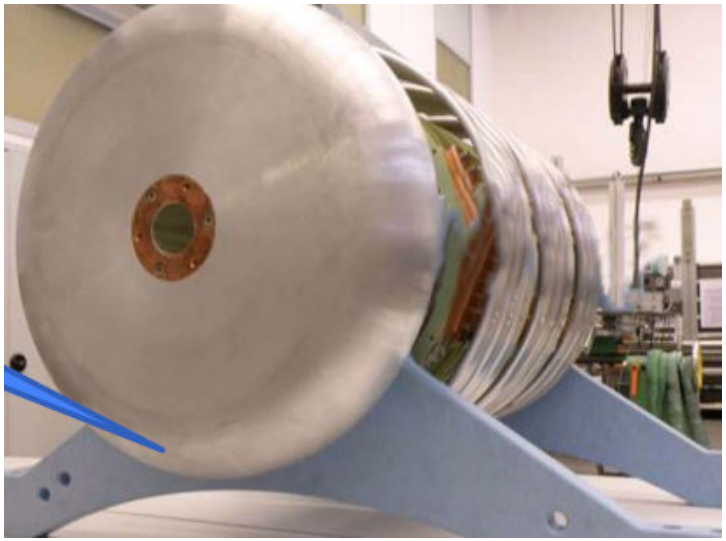
- **Objective:** Development and field test of a 24 kV, 1 kA resistive type SCFCL
- **Partners:** A2A, Air Liquide, CNRS, ENDESA, EPFL, RSE, ICMAB, LABEIN, Nexans, RWE, Vattebfall, KSE
- **KIT Tasks:** Task Leader SCFCL Design, Test and characterization



Successful test at CESI high power laboratory in Milano.

High Voltage Current Limiters (2008 and 2012)

- **Objective:** High Voltage Design of 115 kV and 154 kV resistive type SCFCL
- **Contractors:** Siemens CT, KEPRI
- **KIT Tasks:** Detailed High Voltage Design Study of Components, Cryostat and Bushings



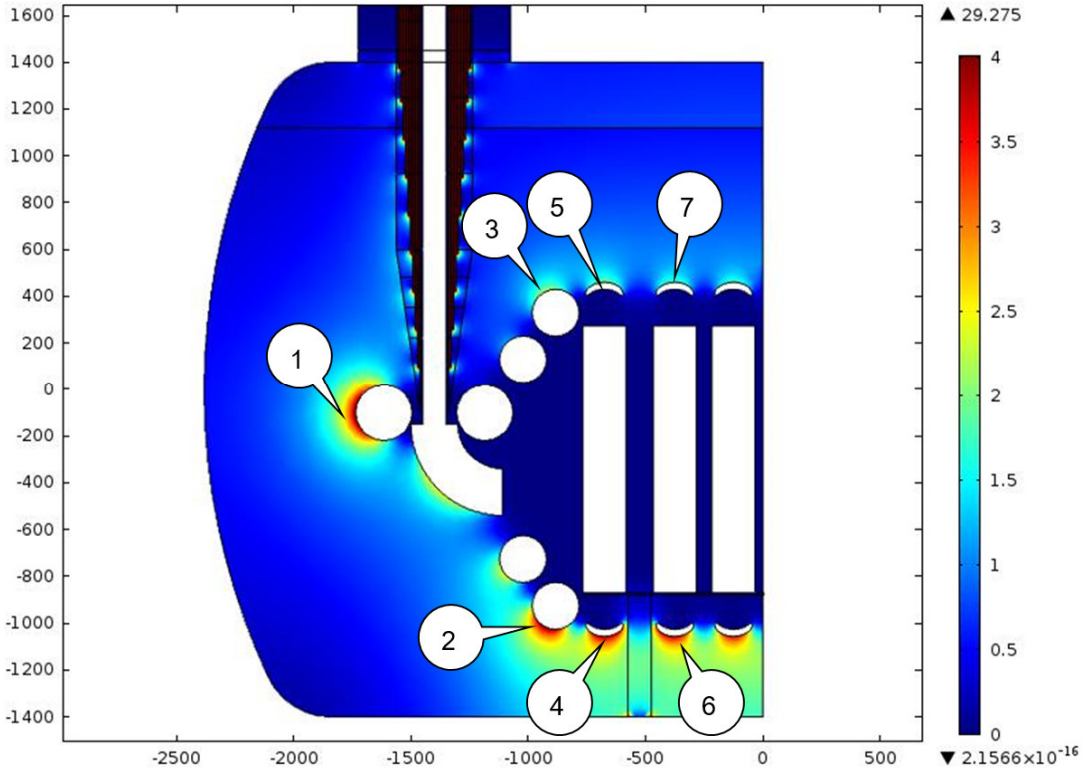
Successful high voltage tests in projects according to IEC standard insulation coordination.

High Voltage Current Limiters

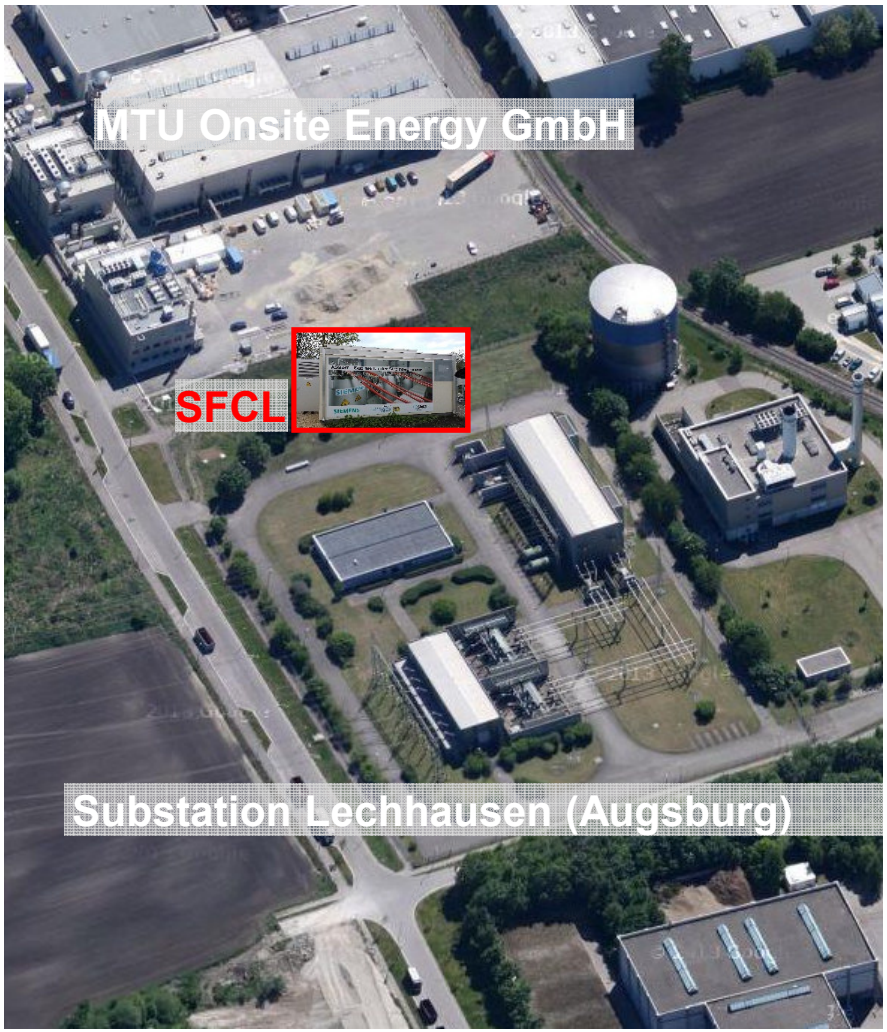
- High Voltage Design Study for 154 kV SCFCL

Main content

- Conceptual design
- Design of critical components
- Applicable test standards
- Test configurations

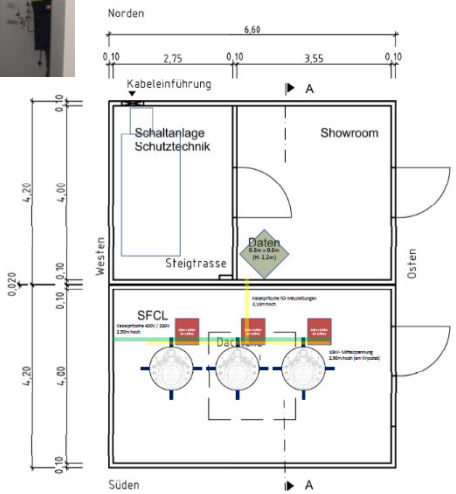


ASSiST – Superconducting Fault Current Limiter in public grid (2012-2015-today)



- Objective:
  Design, Test and Installation of a MV-SFCL in a „feeder“ of a public electric power grid – follow-up long-term operation agreed right from the beginning.
- Partners:
  Siemens EM, 3x Siemens CT, Trench, Stadtwerke Augsburg
- Contribution (Siemens-team):
  design, manufacturing, testing, FAC, installation, operation
- Contribution (Stadtwerke):
  providing space, infrastructure, workforce, data for specification
- Contribution (ta):
  Motivation, setting up of project consortium, planning, funding, boundary conditions, specifications

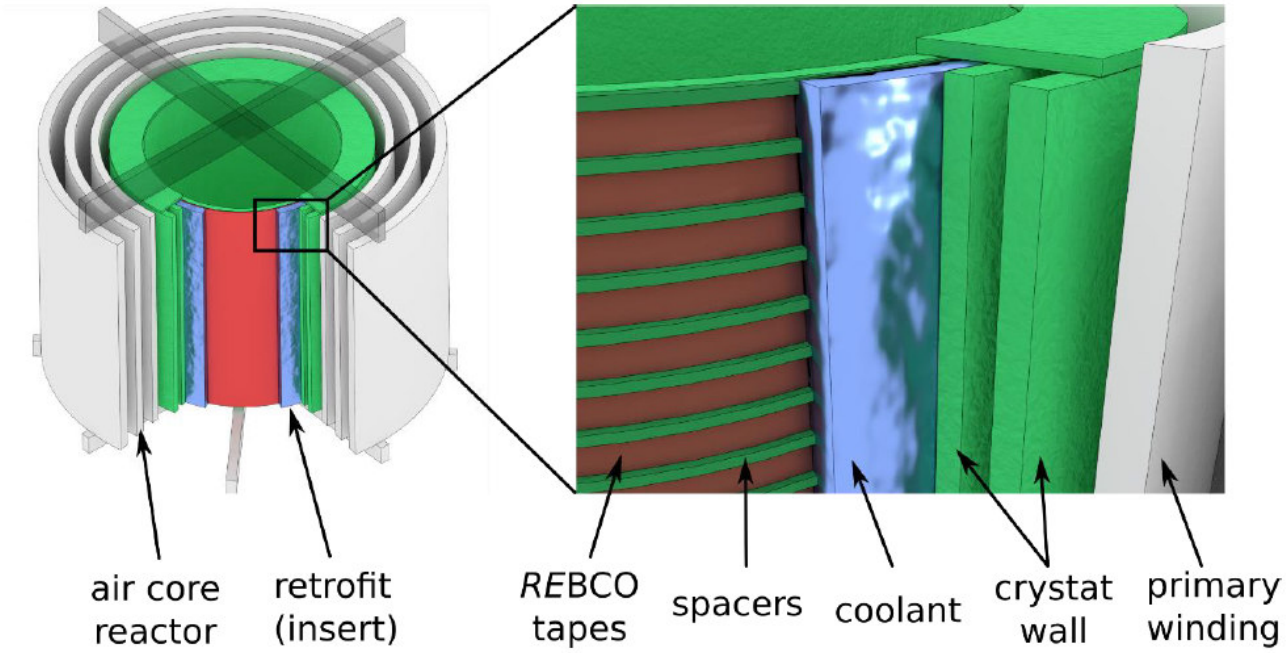
ASSiST: 11 kV; 15 MVA SFCL



- Combination of HTS-technology and high-performance conventional components and products yields
  - high security level,
  - fast acting (37ms for switching, fast recooling ≤12 s.)
  - high compactness
- Redundant and re-condensing cooling system allows "life-time enclosed" operation with only electrical power supplies with high reliability and easy maintenance (yearly) (a failure of **2 coolers** can be handled for 4h until LN2-blow-off)→"*invisible cooling system*"
- Remote monitoring of operation offers new insights of grid conditions on MV level
- Maintenance on cooling system by order of the utility (once a year)
- The system is in continued operation.

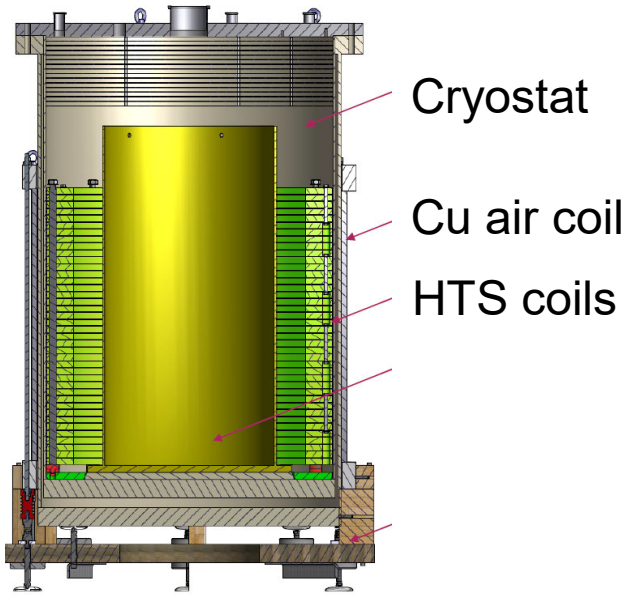
SmartCoil Project (2014-2018)

- **Objective:** Development and laboratory test of a 10 kV, 10 MVA air coil limiter type SCFCL
- **Partners:** Siemens
- **KIT Tasks:** Component test and Cryostat Design



SmartCoil Project (2014-2017)

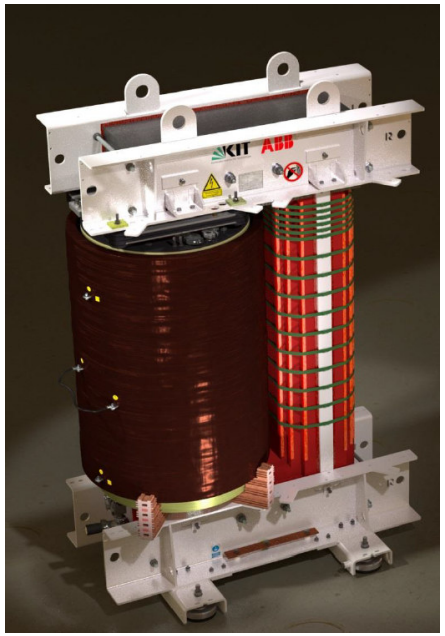
- **Objective:** Development and laboratory test of a 10 kV, 1o MVA air coil limiter type SCFCL
- **Partners:** Siemens
- **KIT Tasks:** Component test and Cryostat Design

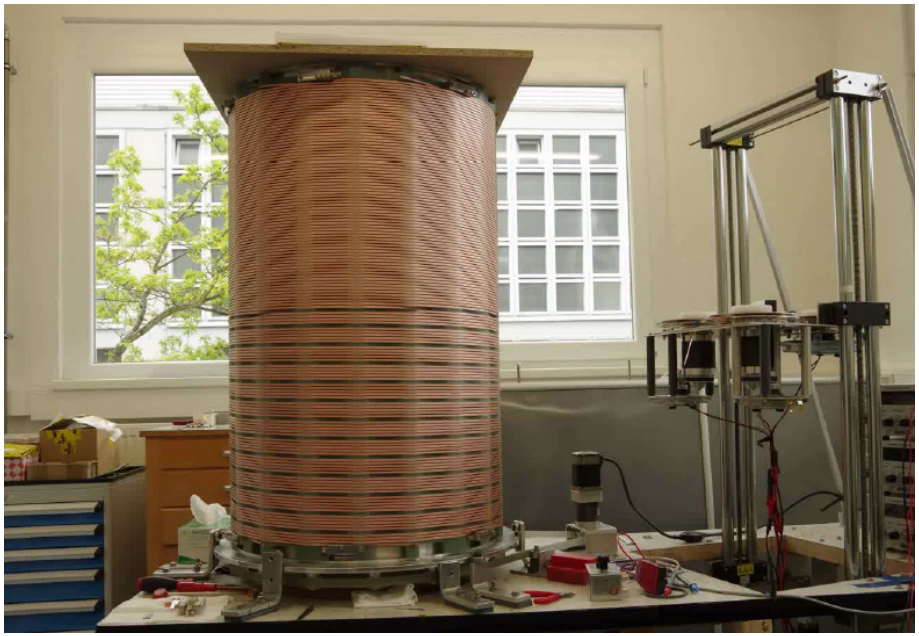


Successful small demonstrator test and manufacturing of 10 MVA demonstrator finished by 12/2017.

Fault Current Limiting Transformer (2013-2017)

- **Objective:** Development and laboratory test of a 1MVA current limiting transformer with recovery under load
- **Partners:** ABB
- **KIT Tasks:** Development of Superconducting winding and cryostat



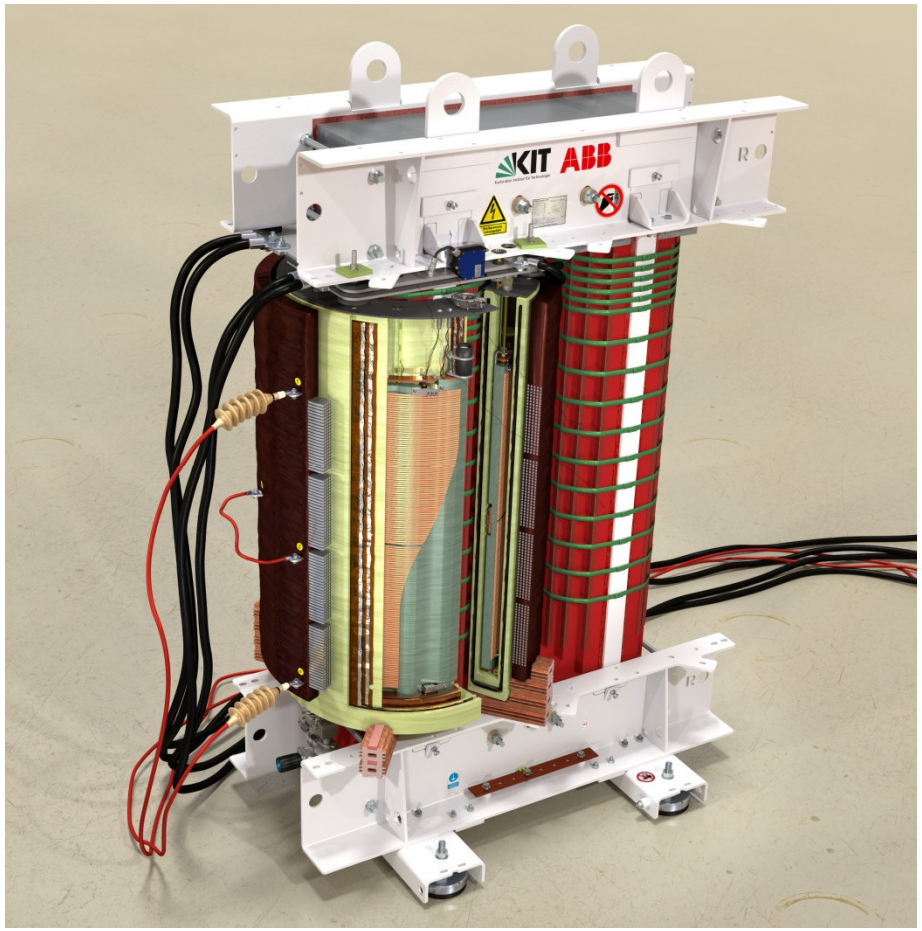


Successful Design Confirmation and Current Limiting Tests.

Fault Current Limiting Transformer (2013-2017)

- Main data

Name	Value
Nominal power	577.4 kVA
Primary winding (normal-conducting winding)	20 kV 28.9 A
Secondary winding (superconducting winding)	1 kV 577.4 A
Fault duration	60 ms
Current limitation 1st HW	13.55 kA
Limitation 1st HW in resp. to prosp. current	71.4 %
Current limitation 6th HW	6.5 kA
Limitation 6th HW in resp. to prosp. current	35.7 %



FASTGRID Project (2017-2020)

Cost effective FCL using advanced supercon. tapes for future HVDC grids

FastGrid

Significant advances of the economical attractiveness of SCFCLs by improving REBCO tapes, especially in their current limitation mode

- **Advanced REBCO tape**
  - Low standard deviation in term of critical current (I_c) over the tape length
  - Electric field higher than 100 V/m (50 ms)
  - Critical current higher than 1000 A/cm-w at 65 K (self-field)
- **Emerging REBCO tape**
  - Tape with enhanced propagation velocity (CFD concept)
  - Sapphire substrate REBCO tape with ultra high electric fields
- **Smart module of a HVDC apparatus**
  - Current and voltage in the range of 0.5/1 kA and 30/50 kV
  - New functionality such as quench detection through optical fiber
  - Extensive testing of the module in relevant operating conditions

KIT Task Leader:
Component Test

- H2020 project
- 42 months
- Starting: 01/2017
- Coord.: CNRS (FR)
- Total budget: 9 M€

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Cryogenic High Voltage Laboratory

- 2 experimental cabins (one full screened)
- AC: 230 kV, 20 kVA
- Impulse: 360 kV
- DC: 200 kV (soon 300 kV)
- Schering-Bridge
- Partial discharge measurement
- 4 bath cryostats (till 0.3MPa)
- Cryogenic bushings
  (up to 230 kVrms AC,
  550 kV standard lightning impulse)

Impulse testing of liquid nitrogen

Unique expertise in testing and characterization.

Cryogenic High Voltage Laboratory

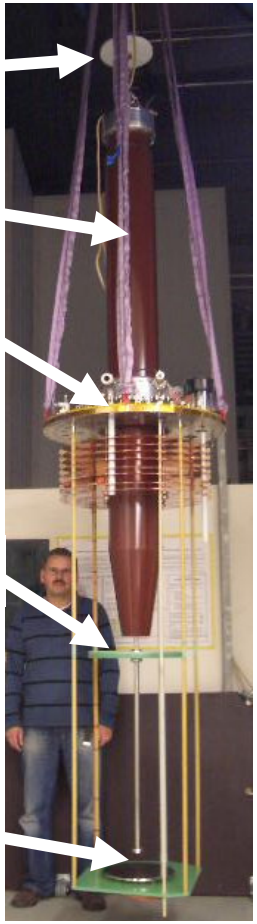
Hand wheel

Bushing

Cryostat cover

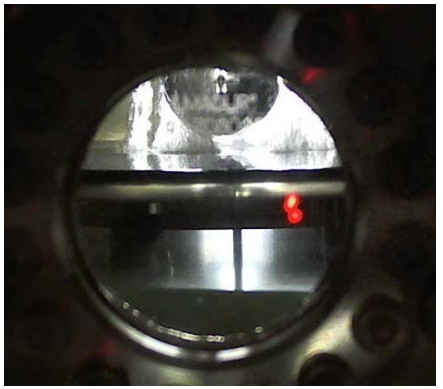
Bubble protector

Simple sample:
Sphere – plane
electrodes

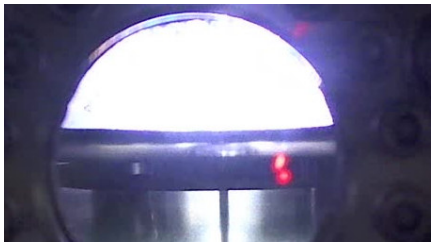


Inner cryostat setup

Cryostat and 230 kVrms AC supply



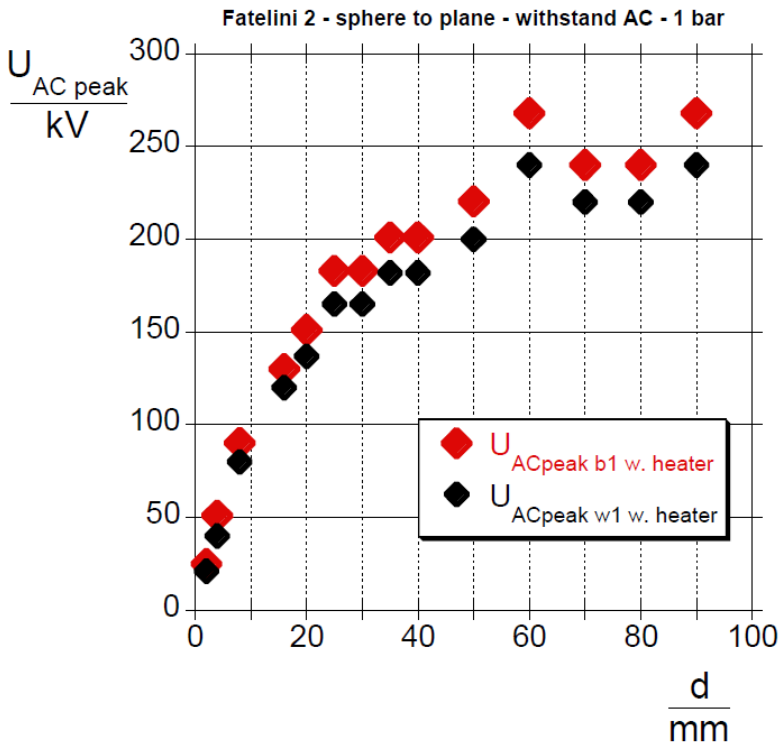
Nitrogen bubble gen-
eration during heating



Breakdown within
liquid nitrogen

Cryogenic High Voltage Laboratory

- AC breakdown and withstand voltages with bubbles caused by heating



Strong saturation around 250 kV peak

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International Working Groups of Prof. Dr. M. Noe with respect to SCFCLs and Cables

- Secretary of Working Group D1.15 “HTS materials and electrical insulation”, International Council of Large Electric Systems (CIGRE)
- International Expert of Working Group D3.23, “Fault current limiters”, International Council of Large Electric Systems (CIGRE)
- Convenor of Working Group D1.38 “Emerging test techniques common to HTS power equipment”, International Council of Large Electric Systems (CIGRE)
- IEEE Task Force for Guide for Fault Current Limiter (FCL) Testing
- International Expert of Working Group D1.69 “Assessing emerging test guidelines for HTS applications in power systems”, International Council of Large Electric Systems (CIGRE)
- International Expert of Working Group D1.64 “Cryogenic dielectric insulation”, International Council of Large Electric Systems (CIGRE)

Our Experts

- Prof. Dr.-Ing. Mathias Noe, Director
- Prof. Dr. Tabea Arndt, Co-Director
- Andrej Kudymow, Head of Superconductivity for Energy Applications Laboratory
- Stefan Fink, Head of Cryogenics High Voltage Group
- Giovanni de Carne, Head of Power-Hardware-in-the-Loop Laboratory
- Prof. Steffen Elschner, Consultant from University Mannheim
- Plus engineers and technicians

Key SCFCL References

- Noe, M, et.al. , Common Characteristics and Emerging Test Techniques for High Temperature Superconducting Power Equipment CIGRE Technical Brochure, Nr. 644, 2015
- Naeckel, O, Noe, M, Design and test of an air coil superconducting fault current limiter demonstrator, IEEE Transactions on Applied Superconductivity, 24, 3, 1-5, 2014, DOI: 10.1109/TASC.2013.2286294
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- Noe, M, Oswald, B, R, Technical and economical benefits of superconducting fault current limiters in power systems, IEEE Transactions on Applied Superconductivity, 9, 2, 1347-1350, 1999