Technology and design of inductive HTS shielded fault current limiter: German demonstration project.

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Why a (superconducting) fault current limiter?

inductive Shielded core Fault Current Limiter

→ iSFCL
The Power Grid Today

Centralised Production

Transmission

Distribution

Residential Areas

Industry

Buildings

Data Center
The Power Grid in the future

- Centralised Production
- Transmission
- Distribution
- E-Mobility and Energy Storage
- Residential Areas
- Industrial Customer
- Buildings
- Data Center
- Renewable Energies
- Decentral Production
Aftermath of a Severe Fault
if the safety systems fail
Solution

- Rebuilding of the local power grid
  - Replacement of transformers, switchgear, cables, ...

- Intelligent Limitation of Fault Currents
  - Use of Fault Current Limiting (FCL) Systems
Project Overview

inductive Shielded core Fault Current Limiter

$\rightarrow iSFCL$
Schneider Electric

Overview
• Turnover: €19.6 Milliarden in 2010
• More than 110,000 employees in more than 100 countries

Activity
• Devices for energy distribution in medium and low voltage range
• Industrial automation
• Building automation & security
• Energy management
• Uninterruptable power supplies und cooling systems
• Services
Facts

The utility „Stadtwerke Augsburg“ is the third-largest municipal energy supplier in Bavaria / Germany. It supplies energy, natural gas, drinking water and communal heating as well as easy public transport to its customer.

Energy
Natural gas
Community heating
Drinking water

<table>
<thead>
<tr>
<th>Service</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>997.9 Mio. kWh</td>
</tr>
<tr>
<td>Natural gas</td>
<td>3.846.9 Mio. kWh</td>
</tr>
<tr>
<td>Community heating</td>
<td>463.6 Mio. kWh</td>
</tr>
<tr>
<td>Drinking water</td>
<td>16.8 Mio m³</td>
</tr>
</tbody>
</table>


Power grid data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak load power grid</td>
<td>300 MW</td>
</tr>
<tr>
<td>Length of transmission lines</td>
<td>2400 km</td>
</tr>
</tbody>
</table>
Bruker Corporation
Global Company with Diversified Markets
Bruker Energy and Supercon Technologies (BEST)

- **Bruker EAS & Bruker HTS**
  Low and High Temperature Superconductors (LTS, HTS)

- **Bruker ASC**
  Superconducting Magnets and Devices for Research, Energy / Power, and Industry, Beamlines, Synchrotron Instrumentation / XUV

- **RI Research Instruments**
  (51% Bruker) cavities, RF systems, linacs, special projects

- **Hydrostatic Extrusions**
Before Fault:

- Iron core is inductively shielded by the HTS against the primary coil ⇒ "invisible" in the grid.
- Primary coil smaller than a comparable shunt reactor ⇒ small impedance.

After Fault:

- HTS gets normal conducting ⇒ iron core and screened part of the primary coil becomes "visible" ⇒ large impedance in the grid, which results in current limitation.
Joint project „iSFCL“
Partners and Project

Partner:
Bruker
EST

Function:
Limitation of the fault current in the grid of the utility Stadtwerke Augsburg between a transformer station and the factory of MTU onsite Energy GmbH.

MTU Onsite Energy is a producer of block heat and power plants. They are tested extensively, therefore MTU is a consumer as well as a supplier of electrical energy.

Intended location of the iSFCL (green), of the substation (blue) and of MTU onsite (yellow).
Grid Layout

Customer site:
MTU onsite Energy
U_N=10.6 kV
I_N= 1250 A
I_p=25.1 kA
I_k''=10.25 kA
I_op=817 A
S_f=15 MVA
I_E[1300 A / 200 ms

Transformer:
40 MVA
10/110 kV

Circuit breaker:
I_N=2500 A
release time 1s

10 kV-cable
2x400 mm² Cu
N2XS(F)2Y
R=0.0064 mΩ
X=0.0113 mΩ

Grid connection:
U_N=10.6 kV
S_K''= 380 MVA
I_k''=20.7 kA
R=0.021 Ω
X=0.366 Ω
R/X=0.059
κ=1.84

Circuit breaker I_N=1250 A; release time 0.5 s
Maximum Voltage Drop and Impedance in non-fault Operation

According to IEC 60038 10% voltage drop allowed based on the nominal voltage of 10.6 kV ⇒

\[ Z = \frac{U_{\text{diff}}}{I_{N}} = \frac{1100 \, \text{V}}{817 \, \text{A}} = 1.34 \, \Omega \]

\[ iSFCL \Rightarrow Z_{\text{nom}} < 1 \, \Omega \]

\[ iSFCL \text{ estimated total active losses incl. cooling } \Rightarrow 45 - 50 \, \text{kW} \]

**15 MVA Reactor for comparison with the iSFCL**

Rated inductance at fault 8.6 mH per phase

Impedance (per phase) = 2.7 \( \Omega \) ⇒ Results in \( \approx 20\% \) voltage drop

Total active losses = 95 kW
### Specifications

- **Operating voltage**: 10 kV
- **Power rating**: 15 MVA
- **Operating current (rms)**: 817 A
- **Fault current**
  - Limited maximum aperiodic short-circuit current (1st peak): <5 kA
  - Limited steady state fault current: 2 kA
  - Maximum aperiodic short-circuit current (1st peak): 25.1 kA
  - Initial symmetrical short circuit current $I_k^{"}$: 10.25 kA
- **Tripping time**: ~1 ms
- **Fault duration**: max. 500 ms

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**Current in kA / Voltage in kV**

<table>
<thead>
<tr>
<th>Time in s</th>
<th>Grid Voltage</th>
<th>Current without iSFCL</th>
<th>Maximum aperiodic short-circuit current (25 kA)</th>
<th>Operational current (817 A rms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.05</td>
<td>0</td>
<td>$2\sqrt{2}I_k^{&quot;}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Operational current (817 A)**

- Tripping time: ~1 ms
- Fault duration: max. 500 ms
Advantages of the iSFCL

- Reduction of the voltage drop during normal (non-fault) operation compared to an equivalent air core reactor.

- Reduction of active (ohmic) losses in comparison with other inductive solutions.

- Self-triggering compared to other conventional FCL (e.g. Is-Limiter) ⇒ No active trigger / control unit needed.

- Fail safe compared to resistive type FCL. ⇒ No interruption of the main current path during failure of the HTS or cooling system.

- Short reaction time and autonomous recooling after fault / quench.

- Only small lengths of HTS tape necessary compared to other superconducting types of FCL.
Electromagnetic Design

inductive Shielded core Fault Current Limiter

$\Rightarrow iSFCL$
Schematic Design iSFCL

- Primary coil
- 12 HTS modules stacked vertically (8 HTS tapes with shunts)
- GFRP cryostat
- Iron core
- Safety valves for blow-off during quench
- Support structure
General Design HTS-Shunt Combination

- HTS tapes with protection layer
- Rod for mech. connection of modules
- External shunts
- Supporting basis

Schematic, not drawn to scale
Limitation Behavior

Limited current 1st peak < 5 kA

Limitation Steady state < 2kA

Current in kA vs. Time in s

Limited current
Unlimited fault current

Limited current 1st peak < 5 kA
Limitation Steady state < 2kA
Current Distribution in Coaxial Arranged HTS Rings

[Diagrams showing current distribution and flux density over time]
Current Distribution in Coaxial Systems of HTS Rings stacked along z-axis
Current Distribution in Coaxial Systems of HTS Rings stacked along z-axis
Current Distribution in Coaxial Systems of HTS Rings stacked along z-axis
Cryosystem

inductive Shielded core Fault Current Limiter

$\rightarrow iSFCL$
Cooling – General Design

Blow off during quench

Recooling in normal operation

Only one reservoir tank per system, Coolers are integrated in the tank.

Coldheads

Refilling of volume losses via N₂ tanks. (Gas will be liquefied by cooling system)

Design: ILK Dresden
Summary

• The grid layout and the specifications are typical for MV grids
  → system should be easily adaptable for other locations / grids

• Novel HTS rings structure used which consists of several independent HTS rings
  → easy to adapt to grid power level via change of # of HTS rings

• Current distribution / sharing between HTS rings is studied

• Cryosystem designed for easy use
  → no handling of LN₂ necessary by customer
Project Team

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