Superconducting Fault Current Limiters and Magnetic Leviation

European Summer School on Superconductivity 2008
June 11-18, 2008 at Prizztech Magnet Technology Centre, Finland

Prof. Dr.-Ing. Mathias Noe, Forschungszentrum Karlsruhe, Institute for Technical Physics
Outline

Superconducting Fault Current Limiters
• Motivation and Basics of Fault Current Limitation
• Different Types of SCFCLs
• Application of SCFCLs
• State-of-the-Art

Magnetic Levitation
• Principle and Applications
Motivation

„it is impossible to avoid short-circuit currents“
Consequences of Short-Circuits

Damage

Blackout

22.6.2005 – Blackout in swiss train system
Simplified Electrical Circuit

Grid | Transformer | Transfer Line | Load

Stationary Electrical Circuit (Three phase short-circuit)

\[ Z_k = Z_Q + Z_T + Z_L \]

\[ I''_k = \frac{c U_n}{\sqrt{3} |Z_k|} \]

\[ I''_k = \frac{U_n}{\sqrt{3} I_n} \text{ with } Z_b = \frac{U_n}{\sqrt{3} I_n} \text{ we get } \frac{I''_k}{I_n} = c \frac{Z_b}{|Z_k|} \]

Peak short-circuit current \( i_p \leq 2 \sqrt{2} I''_k \)

c=1.1 for high SC currents

c=1 for low SC currents
## Conventional Measures to Limit Short-Circuit Currents

### Passive
- Increase of impedance at nominal and fault conditions
  - Splitting into sub grids
  - Introducing a higher voltage range
  - Splitting of bus bars
  - (Sequential tripping)

### Active
- Small impedance at nominal load, fast increase of impedance at fault
  - High voltage fuses (< 1 kA, < 36 kV)
  - $I_s$-limiter, CLiP (< 4 kA, < 36 kV)
  - FCL circuit breakers

### Novel Concepts
- Superconductors
- Semiconductors e.g. FACTS
- Hybrid systems

### Topological measures

### Apparatus measures
Outline

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- Motivation and Basics of Fault Current Limitation
- Different Types of SCFCLs
- Application of SCFCLs
- State-of-the-Art

Magnetic Levitation
- Principle and Applications
Different SCFCL Types
Resistive SCFCL (pure resistive)

Electric circuit

![Electric circuit diagram](image_url)
Different SCFCL Types
Resistive SCFCL (pure resistive)

Operation modes

<table>
<thead>
<tr>
<th>Normal op.</th>
<th>Short-circuit</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="ac current" /></td>
<td><img src="image2" alt="ac current" /></td>
<td><img src="image3" alt="ac current" /></td>
</tr>
</tbody>
</table>

Time

Electric circuit

- SCFCL
- $R_p$
- $L_Q$
- $R_Q$
- $U_0$
- $R_{SC}=0$
- Switch
- Load
Different SCFCL Types
Resistive SCFCL (pure resistive)

Operation modes

<table>
<thead>
<tr>
<th>Normal op.</th>
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<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without SCFCL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Current vs. Time

Electric circuit

- SCFCL
- $R_p$
- $L_Q$
- $R_Q$
- $R_{SC} > 0$
- $U_0$
- Load
- Switch
Different SCFCL Types
Resistive SCFCL (pure resistive)

Operation modes

<table>
<thead>
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<th>Normal op.</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Without SCFCL</td>
<td>i_{ac}</td>
<td>L_{Q}</td>
</tr>
<tr>
<td>R_{Q}</td>
<td>U_{0}</td>
<td>Switch</td>
</tr>
</tbody>
</table>

Electric circuit

![Diagram of resistive SCFCL circuit](image)
### Different SCFCL Types

#### Resistive SCFCL (pure resistive)

<table>
<thead>
<tr>
<th>Current</th>
<th>Operation modes</th>
<th>Electric circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>i_{ac}</td>
<td>Normal op.</td>
<td>+ compact, low weight</td>
</tr>
<tr>
<td></td>
<td>Short-circuit</td>
<td>+ fail safe</td>
</tr>
<tr>
<td></td>
<td>Recovery</td>
<td>- current leads to low temperatures</td>
</tr>
</tbody>
</table>

**Without SCFCL**

- **Time**
- **R_p**
- **L_Q**
- **R_Q**
- **U_0**
- **Switch**
- **Load**

![Resistive SCFCL Circuit Diagram](image)
Different SCFCL Types
Resistive SCFCL (resistive-inductive)

Electric circuit

![Electric circuit diagram with symbols for R_Q, L_Q, U_0, A, B, i_ac, i_p, i_SC, L_p, R_SC, S, and SCFCL]

Characteristic

- compact, low weight
- fail safe
- current leads to low temperatures
Different SCFCL Types
Bridge Type SCFCL

Diode characteristic

Electric circuit

\[ i_D \]
\[ u_D \]

\[ \frac{I_0}{2} \]

forward

reverse
Different SCFCL Types
Bridge Type SCFCL

Diode characteristic
Normal operation, no limitation
\[ i_{ac} < I_0 \]

Electric circuit

Diode characteristic graph:
- Forward: \[ i_{ac} \]
  - \[ \frac{I_0}{2} \]
- Reverse: \[ \frac{i_{ac}}{2} \]
  - \[ u_D \]

Electric circuit diagram:
- SCFCL
- \( L \)
- \( R_Q \)
- \( U_0 \)
- \( D_1, D_2, D_3, D_4 \)
- \( I_0 \)
- Load
Different SCFCL Types
Bridge Type SCFCL

Diode characteristic
Short-circuit and limitation

\[ i_{ac} > I_0 \]

Electric circuit

Positive half wave \( i_{ac} \)

- \( D_1, D_2 \) conduct
- \( D_3, D_4 \) arrest if \( i_{ac} > I_0 \)
Different SCFCL Types
Bridge Type SCFCL

Diode characteristic

Short-circuit and limitation

\[ i_{ac} > I_0 \]

\[ i_{D1,2} \]

\[ u_D \]

\[ i_{D3,4} \]

\[ u_D \]

Electric circuit

Negative half wave \( i_{ac} \)

\( D_1, D_2 \) arrest if \( i_{ac} > I_0 \)

\( D_3, D_4 \) conduct
Different SCFCL Types
Bridge Type SCFCL

Diode characteristic

Electric circuit

Characteristic

+ no superconductor quench (L can be non-SC)
+ immediate recovery
+ adjustable trigger current (depends on $I_0$)
- not fail safe
- losses in semiconductors
Different SCFCL Types
DC biased Iron Core

Iron core characteristic

Electric circuit

$L_1 = \frac{dB_1}{dH_1}$

$B_1$  

$H_1$  

$H_1$

$H_2$

$B_2$

$L_2 = \frac{dB_2}{dH_2}$

$i_{AC}$  

$L_Q$

$V_{L1}$  

$V_{L2}$

$R_Q$

$C_1$

$U_0$

$S_{CFCL}$

$Load$
Different SCFCL Types
DC biased Iron Core

Iron core characteristic

\[ L_1 = \frac{dB_1}{dH_1} \]

\[ H_{DC1} \]

\[ B_1 \]

\[ H_1 \]

\[ H_2 \]

\[ B_2 \]

\[ H_{DC2} \]

\[ L_2 = \frac{dB_2}{dH_2} \]

Electric circuit

SCFCL

\[ i_{DC1} \]

\[ i_{DC2} \]

\[ U_0 \]

\[ R_Q \]

\[ C_1 \]

\[ L_Q \]

\[ V_{L1} \]

\[ V_{L2} \]

Load
Different SCFCL Types
DC biased Iron Core

Iron core characteristic

Electric circuit

\[ L_1 = \frac{dB_1}{dH_1} \]

\[ H_{DC1} \]

\[ H_1 \]

\[ B_1 \]

\[ U_0 \]

\[ i_{ac} \]

\[ t \]

\[ H_2 \]

\[ H_{DC2} \]

\[ L_2 = \frac{dB_2}{dH_2} \]
Different SCFCL Types
DC biased Iron Core

Iron core characteristic

\[ L_1 = \frac{dB_1}{dH_1} \]

[Graph showing magnetic field components and characteristic equation]

\[ H_{DC1} \]

[Graph showing magnetic field components and characteristic equation]

\[ B_1 \]

[Graph showing magnetic field components and characteristic equation]

\[ U_0 \]

[Graph showing magnetic field components and characteristic equation]

\[ i_{ac} \]

[Graph showing magnetic field components and characteristic equation]

\[ \Delta v = V_1 + V_2 \]

[Graph showing magnetic field components and characteristic equation]

\[ = (L_1 + L_2) \frac{di_{ac}}{dt} \]

[Graph showing magnetic field components and characteristic equation]

\[ H_2 \]

[Graph showing magnetic field components and characteristic equation]

\[ H_{DC2} \]

[Graph showing magnetic field components and characteristic equation]

\[ B_2 \]

[Graph showing magnetic field components and characteristic equation]

\[ L_2 = \frac{dB_2}{dH_2} \]

[Graph showing magnetic field components and characteristic equation]

Electric circuit

[Diagram showing electric circuit with SCFCL, inductors, capacitors, and load]

Characteristic

+ no superconductor quench, immediate recovery
+ superconductor for DC only
+ adjustable trigger current
- high volume and weight
- high impedance during normal operation
Different SCFCL Types

And many other superconducting types

• Shielded core type
• Fault current controller
• Hybrid
• Flux lock type

And many other non-superconducting types

• Solid state breaker
• Series line compensation
• Polymer PTC resistor
• Driven arc switch
• Array of liquid metal switches
• Hybrid switch arrangement
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SCFCL Applications
SCFCL Applications

1 Generator feeder
2 Power station auxiliaries
3 Network coupling
4,5 Busbar coupling
6 Shunting current limiting reactor
7 Transformer feeder
8 Busbar connection
9 Combination with other SC devices, especially SC cables
10 Coupling local generating units
11 Closing ring circuits

Source:
SCFCL Applications

Which voltage level?

- to 36 kV: 87%
- to 145 kV: 11%
- > 145 kV: 2%

Which location?

- Generator feeder: 52%
- Feeder: 18%
- Transformer feeder: 15%
- Busbar coupling: 15%

Source:
Fault Current Limiters
Report on the Activities of CIGRE WG 13.10
by CIGRE Working Group 13.10 (*), CIGRE Session 2004, Paris
Coupling of decentralized Power Generation with SCFCLs

- 110 kV grid
- 10 kV grid
- Generator
- Transformer
- SCFCL
- 5...50 MVA

Coupling of decentralized Power Generation with SCFCLs

- 110 kV grid
- 10 kV grid
- Generator
- Transformer
- SCFCL
- 5...50 MVA
SCFCLs in Power Plant Auxiliaries

a) Medium voltage (e.g. 10 kV)
b) Medium voltage (e.g. 10 kV)
c) Low voltage (e.g. 0.4 kV)
SCFCL in Generator Feeder Location
Two Subgrids coupled with SCFCLs (e. g. RWE)

Details: C. Neumann, SCENET Workshop on Superconducting Fault Current Limiters, Siegen, Germany, June 28-29 2004

Weight: 383 t
Oil: 70 t

18 m
10 m
High Voltage Busbar Coupling

154 kV GIS substation in Seoul
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# Actual and planned SCFCL projects in 1994

<table>
<thead>
<tr>
<th>Lead company</th>
<th>Country / Year</th>
<th>Type</th>
<th>Data</th>
<th>SC type</th>
</tr>
</thead>
<tbody>
<tr>
<td>KfK</td>
<td>Germany / 1980</td>
<td>Resistive</td>
<td>40 MW / 47 kV</td>
<td>NbTi</td>
</tr>
<tr>
<td>GEC Alsthom</td>
<td>France / 1989</td>
<td>Resistive</td>
<td>25 kV / 200 A</td>
<td>NbTi</td>
</tr>
<tr>
<td>GEC Alsthom</td>
<td>France / 1992</td>
<td>Resistive</td>
<td>7.2 kV / 1 kA</td>
<td>NbTi</td>
</tr>
<tr>
<td>GEC Alsthom</td>
<td>France / 1994</td>
<td>Resistive</td>
<td>63 kV / 1.25 kA</td>
<td>NbTi</td>
</tr>
<tr>
<td>NEI</td>
<td>UK, 1979</td>
<td>Sat. iron core</td>
<td>5 MVA</td>
<td>NbTi</td>
</tr>
<tr>
<td>ASC / General Dynamics</td>
<td>US / 1995</td>
<td>Sat. iron core</td>
<td>100 MVA</td>
<td>BSCCO</td>
</tr>
<tr>
<td>ABB</td>
<td>Switzerland / 1989</td>
<td>Shielded iron core</td>
<td>100 VA</td>
<td>BSCCO</td>
</tr>
<tr>
<td>ABB</td>
<td>Switzerland / 1999</td>
<td>Shielded iron core</td>
<td>20 kVA</td>
<td>BSCCO</td>
</tr>
<tr>
<td>Daimler Benz</td>
<td>Germany / 1999</td>
<td>Shielded iron core</td>
<td>-</td>
<td>YBCO</td>
</tr>
<tr>
<td>Hydro Quebec</td>
<td>Canada / 1990</td>
<td>Inductive</td>
<td>100 VA</td>
<td>BSCCO</td>
</tr>
<tr>
<td>Hydro Quebec</td>
<td>Canada / 1995</td>
<td>Inductive</td>
<td>100 kVA</td>
<td>BSCCO</td>
</tr>
<tr>
<td>TEPCO / Toshiba</td>
<td>Japan / 1990</td>
<td>Inductive air coil</td>
<td>400 V / 100 A</td>
<td>NbTi</td>
</tr>
<tr>
<td>TEPCO / Toshiba</td>
<td>Japan / 1990</td>
<td>Inductive air coil</td>
<td>6.6 kV / 1.5 kA</td>
<td>NbTi</td>
</tr>
<tr>
<td>Sekei Uni.</td>
<td>Japan / 1990</td>
<td>Inductive</td>
<td>600 V / 6 A</td>
<td>NbTi</td>
</tr>
</tbody>
</table>
June 27, 2007

DOE Provides up to $51.8 Million to Modernize the U.S. Electric Grid System
Superconductor Research Crucial to Improving Power Delivery Equipment

FAULT CURRENT LIMITERS
American Superconductor - (DOE cost share: $12.7 million)
American Superconductor will also address the development and in-grid testing of a three-phase high-voltage, 115-kilovolt fault current limiter, called a SuperLimiterTM, by using second-generation wire. The SuperLimiterTM features a proprietary Siemens-developed, low-inductance coil technology that makes the fault current limiter invisible to the grid until it switches to a resistive state. The demonstration will occur at a location operated by team member Southern California Edison. The team also includes: Nexans (France), the University of Houston (Houston, TX), Los Alamos National Laboratory (Los Alamos, NM), and Siemens AG (Germany).

SC Power Systems - (DOE cost share: $11 million)
On the Southern California Edison grid, SC Power Systems (San Mateo, CA) will design, test, and demonstrate a 138-kilovolt saturable reactor-type fault current limiter. In this type of fault current limiter, a high-temperature superconductor is used with a direct current power supply to saturate an iron core that interfaces with the line in which the current is to be limited. SC Power’s team includes: DOE’s Los Alamos National Laboratory (Los Alamos, NM); Air Products and Chemicals Inc. (Allentown, PA); Cryo-Industries of America Inc. (Manchester, NH); Consolidated Edison Company (New York, NY); California Edison Inc. (Rosemead, CA); Delta Star Inc. (San Carlos, CA); and Trithor GmbH (Germany).

SuperPower Inc. - (DOE cost share: $5.8 million)
SuperPower Inc. (Schenectady, NY) will design, test, and demonstrate on the American Electric Power grid a 138-kilovolt fault current limiter that features a matrix design consisting of parallel “second-generation” high-temperature superconductor elements and conventional coils. SuperPower’s team includes: Sumitomo Electric Industries Ltd. (Osaka, Japan); Nissan Electric Co. Ltd. (Kyoto, Japan); The BOC Group Inc. (Murray Hill, NJ); American Electric Power (Gahanna, OH); and DOE’s Oak Ridge National Laboratory (Oak Ridge, TN).
# Status of SCFCL development

<table>
<thead>
<tr>
<th>Lead company</th>
<th>Year/Country</th>
<th>Type</th>
<th>Data 2)</th>
<th>Superconductor</th>
<th>Field test</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACCEL/Nexans SC</td>
<td>2004</td>
<td>Resistive</td>
<td>6.9 kV, 600 A, 3-ph.</td>
<td>BSCCO 2212 bulk</td>
<td>+</td>
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<tr>
<td>KEPRI</td>
<td>2004</td>
<td>Resistive</td>
<td>3.8 kV, 200 A, 3-ph.</td>
<td>YBCO thin films</td>
<td>-</td>
</tr>
<tr>
<td>CRIEPI</td>
<td>2004</td>
<td>Resistive</td>
<td>1 kV, 40 A, 1-ph.</td>
<td>YBCO thin films</td>
<td>-</td>
</tr>
<tr>
<td>Mitsubishi</td>
<td>2004</td>
<td>Resistive</td>
<td>200 V, 1 kA, 1-ph.</td>
<td>YBCO thin films</td>
<td>-</td>
</tr>
<tr>
<td>Yonsei University</td>
<td>2004</td>
<td>Diode bridge</td>
<td>3.8 kV, 200 A, 3-ph.</td>
<td>BSCCO 2223 tape</td>
<td>-</td>
</tr>
<tr>
<td>CAS</td>
<td>2005</td>
<td>Diode bridge</td>
<td>6 kV, 1.5 kA, 3-ph.</td>
<td>BSCCO 2223 tape</td>
<td>+</td>
</tr>
<tr>
<td>CESI Research</td>
<td>2005</td>
<td>Resistive</td>
<td>3.2 kV, 215 A, 3-ph.</td>
<td>BSCCO 2223</td>
<td>-</td>
</tr>
<tr>
<td>KEPRI</td>
<td>2007</td>
<td>Res.-hybrid</td>
<td>13.2 kV, 630 A, 3-ph.</td>
<td>BSCCO 2212 bulk</td>
<td>-</td>
</tr>
<tr>
<td>Innopower</td>
<td>2007</td>
<td>DC biased iron core</td>
<td>20 kV, 1.6 kA, 3-ph.</td>
<td>BSCCO 2223 tape</td>
<td>?</td>
</tr>
<tr>
<td>Toshiba</td>
<td>2008</td>
<td>Resistive</td>
<td>6.6 kV, -, 3-ph.</td>
<td>YBCO coated cond.</td>
<td>+</td>
</tr>
<tr>
<td>Siemens / AMSC</td>
<td>2007</td>
<td>Resistive</td>
<td>7.5 V, 267 A, 1-ph.</td>
<td>YBCO coated cond.</td>
<td>-</td>
</tr>
<tr>
<td>Hyundai / AMSC</td>
<td>2007</td>
<td>Resistive</td>
<td>13.2 kV, 630 A, 1-ph.</td>
<td>YBCO coated cond.</td>
<td>-</td>
</tr>
<tr>
<td>Zenergy Power</td>
<td>2008</td>
<td>DC biased iron core</td>
<td>7.6 kV, 1.2 kA, 3-ph.</td>
<td>BSCCO 2223 tape</td>
<td>+</td>
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<tr>
<td>Zenergy Power</td>
<td>2010</td>
<td>DC biased iron core</td>
<td>80 kV, -, 3-ph.</td>
<td>BSCCO 2223 tape</td>
<td>+</td>
</tr>
<tr>
<td>IGC Superpower</td>
<td>2009</td>
<td>Resistive</td>
<td>80 kV, -, 3-ph.</td>
<td>YBCO coated cond.</td>
<td>+</td>
</tr>
<tr>
<td>AMSC / Siemens</td>
<td>2011</td>
<td>Resistive</td>
<td>66 kV, -, 3-ph.</td>
<td>YBCO coated cond.</td>
<td>+</td>
</tr>
<tr>
<td>Rolls Royce</td>
<td>-</td>
<td>Resistive</td>
<td>6.6 kV, 400 A, -</td>
<td>MgB₂</td>
<td>-</td>
</tr>
<tr>
<td>KEPRI</td>
<td>2010</td>
<td>Resistive</td>
<td>22.9 kV, 3 kA, 3-ph.</td>
<td>YBCO coated cond.</td>
<td>+</td>
</tr>
</tbody>
</table>

1) Year of test
2) Phase to ground voltage
First Commercial SCFCL Installation

Bi 2212 component

3-phase arrangement

Rated voltage 12 kV
Rated current 800 A
Max. current 1.8 kA
Lim. time 120 ms
Lim. current < 27 kA
Objective

• Development and in-grid testing of a 3-phase high voltage 115 kV, 1.2 kA SCFCL
• Funded by US DOE; partners AMSC, Siemens, Nexans, LANL; budget $ 25.4 million for 4.5 years (2007-2012)

Benefit

• Enable load growth and higher reliability in grid networks

Siemens

• Grid integration studies
• Development of switching module (coil stack)
• Design of HV and cryogenic system
• Laboratory pre-tests

Nexans

• Current leads

Resistive Type SCFCL
AMSC/Siemens
Resistive Type SCFCL
Superpower

Objective: 138 kV SCFCL until 2009

Test arrangement
12 elements, 40 cm long with four 2G conductors in parallel per element

Current and voltage

Configuration of SuperPower 2G HTS Wire™
DC biased Iron Core

13 kV, 1.2 kA

Bi 2223 DC coil

Short-circuit tests at Powertech Labs British Columbia, December 2007

Courtesy: Zenergy Power
Diode Bridge Type SCFCL in China 10 kV, 1.5 kA

First successful field test of a diode bridge type SCFCL at Gaoxi substation in Hunan / China since October 2005

Data
Voltage 10.5 kV
Lightning voltage 75 kV
Current 1.5 kA
Coil inductance 6.24 mH

Installation at Gaoxi substation

HTS coil

![Diagram of SCFCL system]
**Objective (199’-2005)**
Development and field test of a 10 kV, 10 MVA SCFCL demonstrator

**Partner**
- ACCEL: Coordination, System engineering
- RWE Energy: Field test, Specification
- E.ON: Specification
- Nexans SuperConductors: MCP-BSCCO 2212 development
- ATZ: YBCO development
- EUS: power system simulation
- ACCESS: FEM simulation
- Forschungszentrum Karlsruhe: Material characterization and quench tests

**Data**
- Voltage: 10 kV
- Current: 600
- Power (3 ph.): 10 MVA
- Short-circuit time: 60 ms
- Max. short-circuit current: 8.75 kA (5 ms)
BMBF Project CURL10

ACCEL

Nexans

European Summer School – Superconducting Fault Current Limiters and Magnetic Leviation
BMBF Project CURL10
MCP-BSCCO2212 bifilar coils (Nexans SuperConductors)

**Data:**
- Outer diameter: 58 mm
- Superconductor length: 5.4 m
- Superconductor cross section: 0.24 cm²
- Critical current (65K): 850 A
- Power (65K): >130 kVA

**Most powerful element for resistive SCFCLs!**
BMBF Project CURL10

CURL10 field test in Netphen
April 2004-March 2005

15 MVA
\[ \text{S}_k = 125 \text{ MVA} \]
10 kV
110 kV

\[ \text{u}_k = 12.5\% \]

110 kV

SCFCL

Load
BMBF Project CURL10

Final three phase short-circuit test of CURL10 (October 2003)
BMBF Project CURL10
Current Limiting Systems

Fault current limiting transformer
+ active current limitation
+ less volume, less weight, oil free

Fault current limiting cable
+ active current limitation
+ lower short-circuit rating

High current feeder with generator, SCFCL and cable
+ compact very high current connection
+ high normal current, low short-circuit current
Future R&D on SCFCLs

- Low loss, high current conductors
- Simple and inexpensive SCFCLs for medium voltage application (R&D of prototypes and pre-commercial units for field tests)
- SCFCLs for high voltage applications >100 kV (R&D of first demonstrators)
- Work on standards (e.g. tests, specification, requirements, CIGRE WG A13.16)
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• Different Types of SCFCLs
• Application of SCFCLs
• State-of-the-Art

Magnetic Levitation
• Principle and Applications
Electrodynamic Levitation

Principle

Magnetic forces
Electrodynamic Levitation

Principle

Track

Levitation and guidance coil
Propulsion coil
Wheel support path
Electrodynamic Levitation

Principle

Yamanashi Test Line (Japan)

Source: Railway Technical Research Institute

Opening 1996
Length 42.8 km
581 km/h in 2003
Electromagnetic Levitation with Superconductors

Principle

Absolute contactless transportation system
• Contactless levitation and guidance system
• Contactless propulsion
• Contactless control- and positioning system
• Contactless energy transmission to the vehicle

Small toy

Courtesy: IFW Dresden
Electromagnetic Levitation with Superconductors

**Principle**

- **Superconductor**
- **Permanent magnets**

**Demonstration Supratrans**

Absolute contactless transportation system
- Contactless levitation and guidance system
- Contactless propulsion
- Contactless control- and positioning system
- Contactless energy transmission to the vehicle

Courtesy: IFW Dresden
Superconducting Bearings

Cryostat

Copper

HTC

Permanent magnet

Rotating shaft

Iron
10 kN HTS Bearing (Siemens/Nexans/TU Braunschweig)

Rotor NdFeB permanent magnets

n: 3600 1/min
$T_{op} \leq 65$ K
Weight: 10 kN

270 YBCO single crystal
40×40×14 mm³

HTS and copper

Cryostat with coldhead

Bearing complete
Mathias Noe has received his M.S. in Power Engineering in 1991 and his Ph.D. (thesis on “SCFCLs as new devices in power systems”) in 1998, both from the University of Hanover in Germany. After a Postdoc position at the Ecole Polytechnic Federale de Lausanne in Switzerland, he joined Forschungszentrum Karlsruhe in 1998 and became later group leader for HTS power devices at the Institute for Technical Physics.

Since 2006 he is director of the Institute for Technical Physics at the Forschungszentrum Karlsruhe and full professor for technical applications of high temperature superconductivity at the faculty of electrical engineering and information technology of the University Karlsruhe.

He is board member of the European Society of Applied Superconductivity, board member of the Magnet Technology conference, secretary of the CIGRE working group WG D.15 “Superconducting and insulating materials for HTS power applications”. Prof. Noe is a registered member of the VDE, the German society of electrical engineers.