Superconducting Fault Current Limiters

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SuperOx

- 2006: SuperOx company founded in November 2006 in Moscow
- 2011: SuperOx Japan LLC founded in Tokyo
- 2012: starts production of HTS* wire in Russia and Japan
- 2016: delivers HTS wire to customers in 12 countries worldwide

* HTS – high-temperature superconductor
SuperOx

- 100% private company with the long-term strategy
- The only HTSC-wire producer in Europe
- Over 70 orders completed for 14 countries
- ~ 50 employees (20 PhD’s) in Russia, Japan and Korea

Owner and the chairman of the board Andrey Vavilov
Fault currents

| FAULT CURRENTS | inevitable in any grid |
|               | 10-100 times beyond the nominal value |
|               | create a massive overload of the whole system |
| CONSEQUENCES  | explosions, fire outbreaks etc. |
|               | Increase of the the capital investment needed for equipment repair |
|               | losses caused by the manufacturing shut down |
| NEW SOLUTION  | **Fault Current Limiter (FCL)** |
Current limiting

Potential damage

Secure level

Potential damage

Voltage

-20 0 20 40 60 80 100 120

Time, ms

Fault current

Lightning impulse

Current without FCL
Current with FCL

HTS Fault Current Limiters
Technical benefits of FCL

- Power flow combined with current limitation,
- Invisible to grid in normal operation (when no fault present),
- Self-recovery after fault current,
- NO harmonics, fully resistive device,
- Compact,
- Environment-friendly and fireproof.

The main function – limiting current, therefore reducing the overload of the system in case fault current

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*Is-limiter – explosive FCL
**CLR – current limiting reactor
Economical benefits of FCL

Low fault currents

Less powerful CB

Less cost for CB and size of equipment

30% reduction of CAPEX

Reduction of CAPEX:
- For substation renovation
- For new building

Better electricity quality

Less faults

Less expenditures for equipment maintenance

Reduction in OPEX
World experience

- Nobel prize awarded technology
- Cost-effective, reliable
- Over 20 successful projects worldwide

SuperOx projects

- Germany/ 12kV /0,8kA 2009
- Italy/ 9kV /0,25kA 2010
- USA/ 13kV /1,2kA 2010
- Germany/ 12 kV /2,4kA 2014
- Korea/ 23kV /0,6kA 2010
- Spain / 24 kV / 1 kA 2013
- Russia / 3.3 kV / 5 kA 2016
- Russia / 220 kV / 1,2 kA 2017
- China / 220 kV / 0,8 kA 2010
- USA / 115 kV / 0,9 kA 2012

HTS Fault Current Limiters
Suggested FCL installation spots

1 - Generator connection
2 - Power station auxiliaries
3 - Transformer bushing
4 - Networks connection
5 - ВПТ, superconductor cables
6 - Bus-tie connection
7 - Local generation
8 - Outgoing connection
Power flow between stations

### Issue

- Fault current $> 50$ kA
- Fault current level higher than switchgear rating

### Solution

- Fault current $\sim 5$-10 kA
- Low Fault current

### Examples

- Essen, Germany
  - SFCL «Hercules»-SS «Delbrugge» (Nexans)
- Thailand (Applied Materials)
- Incheon, S/Korea (KEPCO)
- Mnevni, Moscow (SuperOx)

### Fault current levels

- $> 50$ kA
- $\sim 5$-10 kA
- $~ 10$-15 kA

HTS Fault Current Limiters
Outgoing connections

**Issue**

Fault current 63 kA

50 kA

50 kA

**Solution**

Fault current ~ 5-10 kA

**Examples**

- Boxberg, Germany, feed through Auxillaries (Nexans)

- Saint-Petersburg, SS «Metallstroy», railway feeder

Fault current level higher than switchgear rating

Low Fault currents

HTS Fault Current Limiters
Bus-tie connection

**Issue**

Opened, high Fault currents

No power transfer, Unstable voltage, Grid splitting vs High Fault currents

**Solution**

FCs ~ 5-10 kA

Low Fault currents combined with power transfer

**Examples**

- Birmingham, Great Britain, SS«Chester Street» SS«Bouneville» (Nexans, 2 SFCL)
Local generation

**Issue**
- Power deficit
- High Fault currents
- Insufficient protection sensitivity

**Solution**
- High power
- Low Fault currents

**Examples**
- Augsburg, Germany, SS «Leichhausen» (Siemens)
Grounding with SFCL

**Issue**
- High Fault currents > 20 kA

**Solution**
- Fault currents < 5 kA
  - Triple phase simultaneous protection

**Example**
- NY, USA
  - SS «Poughkeepsie»
  - (Applied Materials)
Inrush current reduction for motors

- **Direct start**: High start current
  - Current: 1240 A
  - Torque: 691 N*m

- **Variable frequency drive (VED) start**
  - Current: 200 N*m
  - Torque: 200 N*m

- **FCL start**
  - Current: 700 A
  - Torque: 341 N*m
  - Features:
    - Start current reduction
    - High voltage
    - No harmonics

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**HTS Fault Current Limiters**
Thermal stress reduction

**Issue**

- Fault currents: 16 500 A
- Time: 100 ms
- Energy: 3.2 MJ

**Solution**

- Fault currents: 330 A
- Time: < 1 ms
- Energy: 0.06 MJ

- 50000 times less heat
- Inhibition of combustion process

**Diagram**

- HTS Fault Current Limiters
SuperOx masters full chain

HTS production
the main component of the device

SFCL assembly

Grid integration

HTS Fault Current Limiters
SFCL module

$U_{\text{rated}} = 1 \text{ kV}$

$I_{\text{rated}} = 500 \text{ A}$

HTS Fault Current Limiters
R&D CPE test results

Fault current, no limiting
Fault current with SuperOx SFCL

HTS Fault Current Limiters
## HTS FCS classification

<table>
<thead>
<tr>
<th>Voltage</th>
<th>0.4 kV</th>
<th>3-6 kV</th>
<th>10-20 kV</th>
<th>110 kV</th>
<th>220 kV</th>
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</thead>
<tbody>
<tr>
<td><strong>Figure</strong></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td><img src="table1.png" alt="Table" /></td>
<td><img src="table2.png" alt="Table" /></td>
<td><img src="table3.png" alt="Table" /></td>
<td><img src="table4.png" alt="Table" /></td>
<td><img src="table5.png" alt="Table" /></td>
</tr>
<tr>
<td><strong>Weight (phase), kg</strong></td>
<td>550</td>
<td>800</td>
<td>800</td>
<td>11000</td>
<td>22500</td>
</tr>
<tr>
<td><strong>Power, MW</strong></td>
<td>1-5</td>
<td>5-20</td>
<td>10-30</td>
<td>150-200</td>
<td>300-500</td>
</tr>
<tr>
<td><strong>Resistance, Ohm</strong></td>
<td>0.5</td>
<td>1</td>
<td>6-8</td>
<td>20-25</td>
<td>25-50</td>
</tr>
<tr>
<td><strong>Approximate cost, $/kW</strong></td>
<td>~100</td>
<td>~80</td>
<td>~80</td>
<td>~60</td>
<td>~60</td>
</tr>
</tbody>
</table>
Fault Current Limiter 3,3kV (SFCL)

- Made for medium-voltage direct current
- Placing in a standard switch box
- Installed in a traction substation (2016)
- Mutual project with «NIEFA-ENERGO», LLC (St.Petersburg)

**Specification**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td>3.3 kV</td>
</tr>
<tr>
<td>Rated current</td>
<td>Up to 5 kA</td>
</tr>
<tr>
<td>Limitation speed</td>
<td>100 ms</td>
</tr>
<tr>
<td>Resistance (w/o fault)</td>
<td>0.001 Ohm</td>
</tr>
<tr>
<td>Resistance (during fault)</td>
<td>1 Ohm</td>
</tr>
<tr>
<td>Power consumption</td>
<td>&lt; 6 kW</td>
</tr>
<tr>
<td>Cryosystem</td>
<td>closed, cryocooler</td>
</tr>
<tr>
<td>Dimensions, mm</td>
<td>800 x 1740 x 2100</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>700</td>
</tr>
</tbody>
</table>
Testing FCL 3 kV (Test-Energo, LLC)

- Dielectric strength – passed
- Fault current limiting – passed
- Load current and overload current – passed

Installation at «Metallostroy» substation - 2016

FCL overload current tests

FCL high-voltage tests
220 kV SFCL for Moscow City grid

• In 2015 SuperOx won a contract from Moscow City-owned grid company UNECO for the first SFCL in Russia
• Long-term savings for the Moscow city grid from SFCL use are >$4 billion

With the Mayor of Moscow Sergey Sobyanin
Presentation of SFCL project (2014)
Conclusion

SFCL features unique performance:

• Provides **controlled power flow, but limits fault current**
• Invisible to grid in normal operation
• **Self-recovery after fault current**
• NO harmonics, fully resistive device
• Compact, environment-friendly and fireproof

Benefits:

• **CAPEX & OPEX reduction for substation equipment**
• Better electricity quality
• Blackout probability reduction
Thank you for your attention!

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Additional materials
## Technical characteristics

### Symbol

<table>
<thead>
<tr>
<th>Symbol</th>
<th>CLR</th>
<th>Is-limiter</th>
<th>DCI</th>
<th>HTS FCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage/Power</td>
<td>10 kV / 17 MW</td>
<td>12 kV / 25 MW</td>
<td>10 kV / 20 MW</td>
<td>12 kV / 25 MW</td>
</tr>
<tr>
<td>Current limiting</td>
<td>6 times</td>
<td>2.5 times</td>
<td>70 times</td>
<td>8 – 16 times</td>
</tr>
<tr>
<td>Operate time</td>
<td>–</td>
<td>5 ms</td>
<td>5 ms</td>
<td>&lt;1 ms</td>
</tr>
<tr>
<td>Self-recovery</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

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**CLR** - current limiting reactor  
**DCI** - direct current insert  

**Graph**:  
- **CLR** - current limiting reactor  
- **Is-limiter**  
- **HTS FCL**  

**Axes**:  
- **current, kA**  
- **time, ms**

**Legend**:  
- CLR – current limiting reactor  
- DCI – direct current insert  
- HTS FCL – HTS Fault Current Limiters  

**Time of operating CB**
Overall dimensions

HTS Fault Current Limiters

<table>
<thead>
<tr>
<th></th>
<th>DCI</th>
<th>CLR</th>
<th>Is - limiter</th>
<th>HTS FCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>No data</td>
<td>1100 kg</td>
<td>1200 kg</td>
<td>1000 kg</td>
</tr>
<tr>
<td>Footprint</td>
<td>82 m²</td>
<td>19 m²</td>
<td>6,2 m²</td>
<td>3,5 m²</td>
</tr>
<tr>
<td>Overall dimensions</td>
<td>8500 mm</td>
<td>9600 mm</td>
<td>7500 mm</td>
<td>1400 mm</td>
</tr>
<tr>
<td></td>
<td>2500 mm</td>
<td>1500 mm</td>
<td>1200 mm</td>
<td>2500 mm</td>
</tr>
<tr>
<td></td>
<td>1700 mm</td>
<td>1000 mm</td>
<td>1700 mm</td>
<td>1400 mm</td>
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</table>