Superconducting Fault Current Limiter technology
application for power grids
About SuperOx

2006  SuperOx company was founded in Moscow

2011  SuperOx Japan LLC was founded in Tokyo

2012  Sales of high temperature superconductors worldwide

2019  HTS is delivered to customers in 20 countries

2019  Installation of 220 kV SFCL in HV substation in Moscow

- Private high-tech group of companies
- 100 employees
- Over 20 patents and 50 know-hows
- Over 25 years of experience in superconductivity
- Full chain of SFCL production

SuperOx production facilities
Current Limiting technology

**Operation principle**

Current: **nominal (≈ 1000 A)**  SFCL: **no resistance**
Current: **fault (5 – 60+ kA)**  SFCL: **40 Ohm**

**SFCL position**

- Bus-tie SFCL
- SFCL in line with cable

Substation A  Substation B

**Short circuit currents through switchgear with and without SFCL**

- Current without SFCL
- DC component without SFCL
- Current with SFCL
- DC component with SFCL

*based on KERI tests of SuperOx SFCL*
SFCL Applications in 110 - 220 kV grids

Technology enables:

- Increase grid capacity
- Reduce number of division points
- Reduce damage from fault currents
- Reduce grids equipment requirements, reducing it’s cost
- Extend life of already used equipment
- Improve fire safety
- Reduce losses
- Improve quality of power supply
City grid protection

10 SFCLs in Moscow grid - reduction of switchgear replacement

$1138 m  switchgear replacement

$321 m  10 SFCLs installation

$817 m  direct effect

\textit{power stability, no consumer downtime, no grid downtime}  indirect effect

$2.3 b  Total economic effect
SFCL in Moscow 220 kV grid

- First SFCL in Russia, commissioning in 2019
- Unique solution for 220 kv grids
- High reliability: secondary systems have triple redundancy

### Specification

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal voltage</td>
<td>220 kV</td>
</tr>
<tr>
<td>Maximum operating voltage</td>
<td>252 kV</td>
</tr>
<tr>
<td>Lightning impulse withstand voltage</td>
<td>950 kV</td>
</tr>
<tr>
<td>Power frequency withstand voltage</td>
<td>440 kV</td>
</tr>
<tr>
<td>Nominal frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Nominal current</td>
<td>1200 A</td>
</tr>
<tr>
<td>Switching current</td>
<td>3400 A</td>
</tr>
<tr>
<td>Normal (superconducting) operation active resistance, less than</td>
<td>0.01 Ohm</td>
</tr>
<tr>
<td>Current limitation active resistance, at least</td>
<td>40 Ohm</td>
</tr>
<tr>
<td>Switching time (superconductor-resistor), less than</td>
<td>2 ms</td>
</tr>
<tr>
<td>Location</td>
<td>Outdoor</td>
</tr>
<tr>
<td>Dimensions per phase with bushings (Length x Width x Height)</td>
<td>5500 x 2850 x 6500 mm</td>
</tr>
<tr>
<td>Weight per phase (dry/with coolant)</td>
<td>16 / 27 ton</td>
</tr>
<tr>
<td>Test standard</td>
<td>IEEE C37.302-2015</td>
</tr>
</tbody>
</table>
Acceptance tests of SFCL 220 kV

- SFCL was tested according IEEE C37.302-2015 test guide
- Test programme has developed by international team of experts from Russia, South Korea, Netherlands, Germany and Japan
- World record of limiting power: 37.1 kA -> 7.0 kA, 2000 MW -> 300 MW
- SFCL successfully completed:
  - Acceptance tests (HV, PD, nominal and fault current tests) at KERI (South Korea)
  - Onsite tests (HV, PD, cooling system, control system)
  - Grid compatibility tests (EM, relay protection - RTDS)

<table>
<thead>
<tr>
<th>No</th>
<th>Name of the test</th>
<th>Confirmed value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lightning impulse</td>
<td>950 kV</td>
</tr>
<tr>
<td>2</td>
<td>Power frequency voltage withstand</td>
<td>440 kV</td>
</tr>
<tr>
<td>3</td>
<td>Partial discharge</td>
<td>Less than 25 pC</td>
</tr>
<tr>
<td>4</td>
<td>Heating rated current</td>
<td>1200 A</td>
</tr>
<tr>
<td>5</td>
<td>Short-term overcurrent</td>
<td>2000 A</td>
</tr>
<tr>
<td>6</td>
<td>Short-circuit current (prospective/limited)</td>
<td>37.1 kA / 7.0 kA</td>
</tr>
</tbody>
</table>
Switchgear reacts too slow to disconnect sensitive plant equipment from the affected part of the grid. Thus, short circuits lead to voltage drops and process interruption.

SFCL protects the plant 100 times faster, keeping the process safe

- **Voltage out of range** → **Process malfunction**
- **Voltage is nominal** → **Process stays intact**
Production plant protection

5 SFCLs in Republic of Tatarstan (Russia) – continuous production

- Less voltage drop
- No downtime
- Continuous production

Result: SFCL payback 5-7 years
Application of SFCL in grids of 3 - 10 kV

Transport system protection
- Increase average speed
- Reduce number and time of downtime
- Decrease unit cost of transportation

Mining industries protection
- Reduce damage due to accidents and emergencies
- Reduce costs of restoration and reconstruction of underground mines
- Reduce forced suspension of production
- Reduce costs for maintenance and modernization of equipment

SFCL 3.3 kV for Russian Railways
### SFCL application

<table>
<thead>
<tr>
<th>Voltage class</th>
<th>3-6</th>
<th>10-20</th>
<th>35</th>
<th>110</th>
<th>220</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Applications</strong></td>
<td>Industry</td>
<td>Increasing safety</td>
<td>Industrial power supply</td>
<td>Uninterrupted production</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport</td>
<td>Minimal vehicle downtime</td>
<td>City grid</td>
<td>Cost-effective development of electric grid infrastructure</td>
<td></td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td><img src="image1.jpg" alt="Image" /></td>
<td><img src="image2.jpg" alt="Image" /></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Square / phase</td>
<td>m(^2)</td>
<td>0,6</td>
<td>1</td>
<td>1,5</td>
<td>10</td>
</tr>
<tr>
<td>Weight / phase</td>
<td>kg</td>
<td>550</td>
<td>800</td>
<td>800</td>
<td>11000</td>
</tr>
<tr>
<td>Power</td>
<td>MW</td>
<td>1-5</td>
<td>5-20</td>
<td>10-30</td>
<td>150-200</td>
</tr>
<tr>
<td>Nominal current</td>
<td>kA</td>
<td>0,6</td>
<td>5</td>
<td>0,6-2,4</td>
<td>1,2-2,4</td>
</tr>
<tr>
<td>Resistance at fault current</td>
<td>Ohm</td>
<td>0,5</td>
<td>1</td>
<td>6-8</td>
<td>20</td>
</tr>
</tbody>
</table>
Roadmap for SFCL implementing

Estimation of potential spots for SFCL
(Dense high power grids, continuous cycle plants)

Grid regimes study
(Fault current and voltage levels)

Economical confirmation

Project development and realization
Thank you for your attention!