HTS DC Cable Line for St. Petersburg Project

Victor Sytnikov
R&D Center at Federal Grid Company United Energy System

11th EPRI Superconductivity Conference
Houston, Texas
October 28 – 30, 2013
CONTENT

✓ Background
✓ HTS DC Cable Line in St. Petersburg Grid
✓ Cable and cable fittings
✓ Cryogenics
✓ Converter
✓ Testing
✓ Conclusion
Federal Grid Company of United Energy System

Substation number 806
Grid length, thousands km 122
Transformer power, GVA 312
Staff 23,000

At the present time the company consolidates with a distribution company. New company assets will increase several times.
Actual problems of modern megalopolis

Characteristics of power systems in metropolitan areas:

- rapid growth of energy consumption that, in general, exceeds the increase of consumption throughout the country;
- high density of energy consumption;
- areas’ deficiency and branching of distribution networks of large cities;
- partition of the electrical grids to reduce short-circuit currents.

Main problems of power grids in metropolitan areas:

- high levels of short-circuit currents that in some cases exceed the breaking capacity;
- low levels of network controllability and steadiness;
- high level of power losses in distribution networks;

Many of these problems can be solved by combination of two technologies:
Superconductivity and DC Transmission.
HTS DC transmission advantages

1. Loss reduction at electric power transmission
2. Possibility of high power transmission at low voltage
3. Limitation of short-circuit current
4. Enhancement of electrical grid controllability
5. Cable line area reduction
6. Mutual redundancy of grid sections
The concept of perspective development of power systems of megalopolises using superconducting DC cable lines
Project cooperation

**FGC UES**

- STC UES
  - Feasibility study
  - Cable route design

- UNCOMTECH Irkutskkabel
- Kurchatov Institute
  - Cable manufacturing
  - Testing and analysis

- FGUP VEI
  - IEDs group, Electrovypyraymtel
  - AC→DC converters

- R&D Center @FGC UES
  - Tests of the parts and entire system

- All stakeholders
  - Cryogenic system development

*R&D Center @ FGU UES participates on every stage and in every part of the project*
CONTENT

✓ Background
✓ HTS DC Cable Line in St. Petersburg Grid
✓ Cable and cable fittings
✓ Cryogenics
✓ Converter
✓ Testing
✓ Conclusion
HTS DC cable line installation in the St. Petersburg’s electrical grid

<table>
<thead>
<tr>
<th>Object</th>
<th>3-phase short-circuit current, kA</th>
<th>1-phase short-circuit current, kA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AC cable line</td>
<td>HTS DC cable line</td>
</tr>
<tr>
<td>«Tsentrlnaya» substation</td>
<td>39</td>
<td>18</td>
</tr>
<tr>
<td>RP-9 substation</td>
<td>40</td>
<td>26</td>
</tr>
</tbody>
</table>
**St. Petersburg HTS DC CL project**

**HTS DC Line Specification**
- Transmission power – 50 MW;
- Operating current 2.5 kA;
- Operating temperature 65 – 75K;
- Operating voltage 20 kV
- Length – about 2500 m
Comparison of different variants of execution of the links between 330 kV SS “Tsentalnaya” and SS 220 kV RP-9

Current loading of the power lines in areas SS “Tsentalnaya” and SS RP-9 in the post-emergency mode.

<table>
<thead>
<tr>
<th></th>
<th>I(_{\text{allowable}}), А</th>
<th>I, А</th>
<th>I/I(_{\text{al}}), %</th>
<th>δP, MW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Enter the cable line 110 kV, 200 MW</strong> SS “Tsentalnaya” and SS RP-9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OL 110 kV SS Chesmenskaya – ЭС-1</td>
<td>600</td>
<td>656</td>
<td>109</td>
<td>70</td>
</tr>
<tr>
<td>CL 110 kV SS “Tsentalnaya” - SS RP-9</td>
<td>1210</td>
<td>1248</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td><strong>Enter HTS DC line capacity of 200 MW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OL 110 kV SS Chesmenskaya – ЭС-1</td>
<td>600</td>
<td>592</td>
<td>98</td>
<td>0</td>
</tr>
<tr>
<td><strong>Enter GIL 110 kV, 200 MW</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OL 110 kV SS Chesmenskaya – ЭС-1</td>
<td>600</td>
<td>658</td>
<td>110</td>
<td>70</td>
</tr>
</tbody>
</table>

Short-circuit currents in different variants of connections between SS “Tsentalnaya” and SS RP-9

<table>
<thead>
<tr>
<th>Calculation points of short-circuit current</th>
<th>I(_{\text{breaking}}), kA</th>
<th>HTS DC Cable line</th>
<th>AC Cable line</th>
<th>AC Cable line + CLR</th>
<th>GIL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Busbar 110 kV SS “Tsentalnaya”</td>
<td>40,0</td>
<td>18,4, 20,9</td>
<td>39,2, 43,1</td>
<td>21,9, 24,6</td>
<td>40,0, 43,9</td>
</tr>
<tr>
<td>Busbar 110 kV SS RP-9</td>
<td>31,5</td>
<td>26,4, 27,1</td>
<td>40,3, 43,9</td>
<td>29,4, 30,4</td>
<td>40,7, 44,4</td>
</tr>
</tbody>
</table>
Main purposes of the project:

- Making HTS DC link - 20kV, 50 MW for St. Petersburg network.
- Creation of scientific – production cooperation for manufacturing HTS cables, cable fittings, convertors and cryogenic equipment.
- Creation and demonstration replicated HTS DC link.
- During line operation to gain new experience and define real operating costs.

DC line include:

- HTS cable with accessories,
- Cryogenic system,
- Two converter stations,
- Monitoring and control system.

Two DC lines in prospect (2020) with transmission power 150-250MW

Cable pass scheme

**SS RP-9, 220 kV**

**HTS Cable**

**SS Tsentralnaya, 330kV**

---

**Specification**

- Transmission power – 50 MW
- Power reverse
- Operational current - 2.5 kA
- Operational voltage - 20 kV
- Length – about 2500 m
- Pieces – 6
- Joints – 5
- Depth of occurrence – 15 - 18 m.
- Two starting pit diameter of 9.8 m.
- Two receiving pit with diameter of 8.5m.
CONTENT

- **Background**
- **HTS DC Cable Line in St. Petersburg Grid**
- **Cable and cable fittings**
- **Cryogenics**
- **Converter**
- **Testing**
- **Conclusion**
Cable design

Unipolar cable with the reverse conductor
- former and stabilizing element;
- superconducting forward conductor
  (22 tapes SEI with Ic=160A);
- high voltage insulation;
- superconducting return conductor
  (19 tapes SEI with Ic=180A);
- external stabilizer;
- external (screening) insulation;
- electric (non-superconducting) screen;
- cryostat Nexans
- protecting layer.

Cable prototype
Development of the technology was performed on “Irkutskcable” plant
Direct conductor manufacturing
Technology development and manufacture of cable samples

Application of copper screen

30 meters samples
Current Leads and Joints design

Developer NRC “Kurchatov Institute”

Current leads

Joints
**Current Leads and Joints**

<table>
<thead>
<tr>
<th>Material</th>
<th>Brass rod</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>0.45 meter</td>
</tr>
<tr>
<td>Diameter</td>
<td>48 mm</td>
</tr>
<tr>
<td>Heat input @ I=0 A</td>
<td>58.5 W</td>
</tr>
<tr>
<td>Heat input @ I=2.5 kA (only rod)</td>
<td>113.0 W</td>
</tr>
</tbody>
</table>

Temperature distribution along the brass current lead and heat leakage into the cold zone

Soldered joints resistance

Temperature distribution along the brass current lead and heat leakage into the cold zone
CONTENT

✓ Background
✓ HTS DC Cable Line in St. Petersburg Grid
✓ Cable and cable fittings
✓ Cryogenics
✓ Converter
✓ Testing
✓ Conclusion

Temperature difference (left) and pressure drop (right) in corrugated direct flow cryostats 2.5 km of length.
Temperature difference (left) and pressure drop (right) over the 2.5 km return flow cryostat

Total temperature difference (left) and pressure drop (right) over the 2.5+2.5 km cryogenic loop
Diagram of the cryogenic system.

Cooling capacity – 12 kW @ 70K
Pressure LN – up to 1.4MPa
Temperature 66– 80 K
Mass flow - up to 45 L/min
CONTENT

✓ Background
✓ HTS DC Cable Line in St. Petersburg Grid
✓ Cable and cable fittings
✓ Cryogenics
✓ Converter
✓ Testing
✓ Conclusion
Circuit layout

SS Tsentralnaya

Converter circuit Twelve-pulsed
Matching transformer 65 MVA; 110/8.27/8.27 kV
DC voltage 20 kV
Rated current 2500 A
Rated power 50 MW
Transmission reverse mode present

SS RP-9

Specification of the rectifier – inverter circuit
### DC filter and current harmonics

- \( L_{p/2} = 3.2 \, \text{mH} \)
- \( C_\Phi = 10.66 \, \mu\text{F} \)
- \( L_\Phi = 6.6 \, \text{mH} \)
- \( Q_{pl} = 120 \, \text{kW} \)

#### Operating mode

<table>
<thead>
<tr>
<th>№</th>
<th>Harmonics</th>
<th>Eq. Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( I_{12} = 0, ; I_{24} = 4 , \text{A} )</td>
<td>( \lambda = 15^0, \gamma = 20^0; ; I_d = 2500 , \text{A} )</td>
</tr>
<tr>
<td>2</td>
<td>( I_{12} = 0, ; I_{24} = 2 , \text{A} )</td>
<td>( \lambda = 15^0, \gamma = 3^0; ; I_d = 200 , \text{A} )</td>
</tr>
<tr>
<td>3</td>
<td>( I_{12} = 0, ; I_{24} = 7 , \text{A} )</td>
<td>( \lambda = 80^0, \gamma = 1^0; ; I_d = 250 , \text{A} )</td>
</tr>
</tbody>
</table>
**Thyristor module**

**Module specification**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permissible current</td>
<td>2500 A</td>
</tr>
<tr>
<td>Voltage on the valve</td>
<td>6 kV</td>
</tr>
<tr>
<td>Frequency range</td>
<td>48.5 -50.5 Hz</td>
</tr>
<tr>
<td>Number of thyristors</td>
<td>6</td>
</tr>
<tr>
<td>Type of cooling</td>
<td>Water cooling</td>
</tr>
<tr>
<td>Type of control</td>
<td>Fiber optical</td>
</tr>
</tbody>
</table>
CONTENT

✓ Background
✓ HTS DC Cable Line in St. Petersburg Grid
✓ Cable and cable fittings
✓ Cryogenics
✓ Converter
✓ Testing
✓ Conclusion
The tapes with original critical current 180 A

Thus the developed technology ensures the high current carrying ability of the superconducting tapes
Voltage breakdown verification test

Sample № 1

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Paper thickness</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.7 mm</td>
<td>Breakdown at 52.7 kV</td>
</tr>
<tr>
<td>7</td>
<td>0.7 mm</td>
<td>Breakdown at 46.6 kV</td>
</tr>
<tr>
<td>2</td>
<td>1.0 mm</td>
<td>No breakdown</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energized 30 min. at 70 kV</td>
</tr>
<tr>
<td>3</td>
<td>1.0 mm</td>
<td>No breakdown</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energized 30 min. at 70 kV</td>
</tr>
<tr>
<td>4</td>
<td>1.0 mm</td>
<td>Breakdown at 70 kV after waiting</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 min</td>
</tr>
<tr>
<td>5</td>
<td>1.5 mm</td>
<td>No breakdown</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Energized 30 min. at 70 kV</td>
</tr>
</tbody>
</table>

Russian standard requirement – 50 kV application during 10 minutes
2x30 meters HTS DC line test
Current leads resistance $R=20 \mu\Omega$ ($I^2r=125W$)

Joints: $R_+ = 0.65 \mu\Omega$; $R_- = 0.26 \mu\Omega$
(+$I^2r=4.1W$; -$I^2r=1.6W$) will be reduced.
Main purposes of this testing were:
- Cable design verification
- Cabling technology verification
- Current leads and joint design verification
- Direct measure of the all joint resistance and V-I curve the line.

RESULTS
- Cable critical current equal to the sum of the tapes critical current.
- Cabling technology reliability was confirmed.
- Resistance of all joints is stable up to cable $I_c$.
- Design of the cable, joint and current leads was confirmed.

Results of this test allow us to start manufacturing of full-scale cable lengths.
Experimental facility for superconducting device testing at the R&D Center @ FGC UES

1 - HTS cable
2, 3, 6, 7, 17, 20
   - Cryogenic system
4 - Current leads
5, 11, 12, 16, 18, 21, 22 - Facility power system
8, 9 - Facility control center
10 - DC current source
13, 14, 15 - Air compartment
19 - Load
Transformers up to 120 MVA with step like voltage regulation (6 kV, 10 kV, 16 kV, 20 kV, 66 kV, 110 kV, 154 kV) and with currents up to 4 000 A. Modern certified testing laboratory. Highly experienced staff. The test facility will be able to test of experimental, pilot and commercial samples of superconducting power devices **UNDER FULL LOAD.**
Conclusions

✓ Combination of two technologies: superconductivity and DC transmission bring a new quality to the megalopolis network. The HTS DC cable line installation improves the reliability of energy supply to the consumers by mutual redundancy grid sectors and enhancement of controllability of the link. Along with this, it does not increase short-circuit currents.

✓ St. Petersburg Project is carried out in accordance with the schedule. All units of equipment have been developed.

✓ Successful tests of 2 x 30 m. cable samples allowed us to start manufacturing of full-scale cable length.

✓ The successful introduction of this HTS DC CL into the St. Petersburg electric power system will allow checking up the basic technical solutions for this technology and get an experience for the commercial application. It will be first step for the further building of circular DC electric power chain in a megalopolis.