3.4 SI, Superconducting Transmission Lines.

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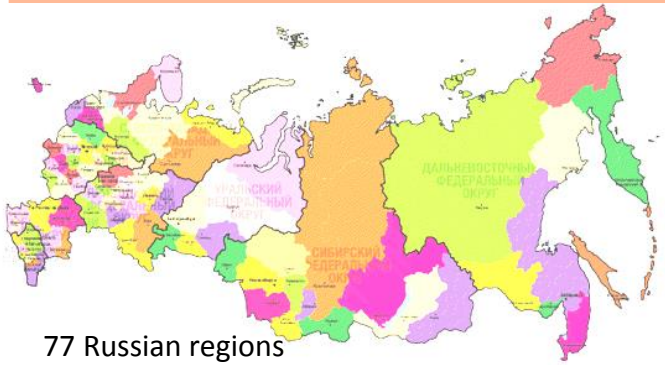
Federal Grid Company is the operator and manager of Russia's unified electricity transmission grid system

COMPANY SIZE

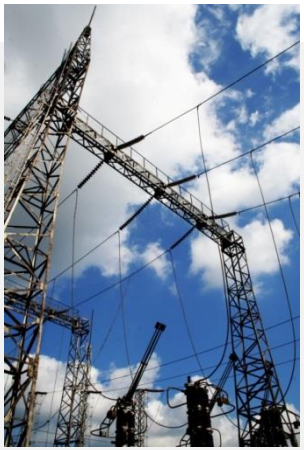
Transmission lines	**139 116** km
Power	**336 182** MVA
Number of Substation	***944***
Personnel	**25 392**
Annual income	**173 billion rubles**

GEOGRAPHY OF PRESENCE



77 Russian regions
territory of 15.1 million square kilometres

R&D Center – daughter company of Federal Grid Company of United Energy System
Staff - 570 employees
Three divisions (R&D, Design and EPC, Testing and Certification)
More than 50 years experience and knowledge in power generation and distribution



High-temperature superconductivity. Areas of application.

High-temperature superconductivity (HTSC): superconductivity at relatively high temperatures with a critical temperature above the boiling point of nitrogen (77 K or -196 ° C)

Russia and Japan along with US, EU and South Korea are one of the leaders in the field of high-temperature superconductors.

Power transmission

– Cables *(regional networks, power output systems)*
– Energy bridges
– Current limiters, compensator generators
– Generators of wind power plants

Medicine

– NMR tomography
– Cyclotrons for mobile laboratories
– Ion-proton therapeutic centers

Transport

– Electromotive systems on railway
– Magnetic Levitation Transport
– Commercial Fleet Motors

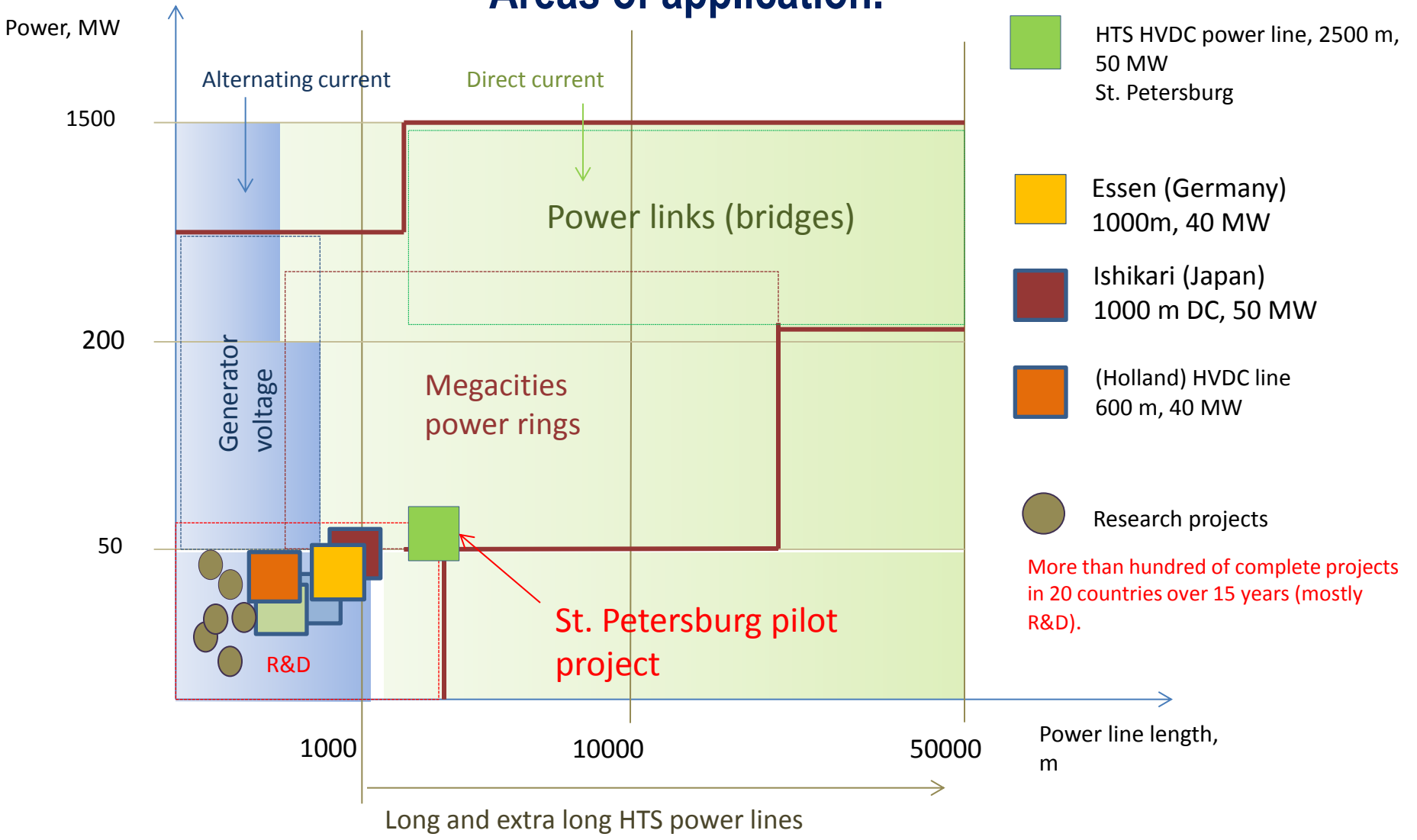
Defense industry

– Ship Propulsion System
– Ship demagnetization systems
– Weapons on new physical principles

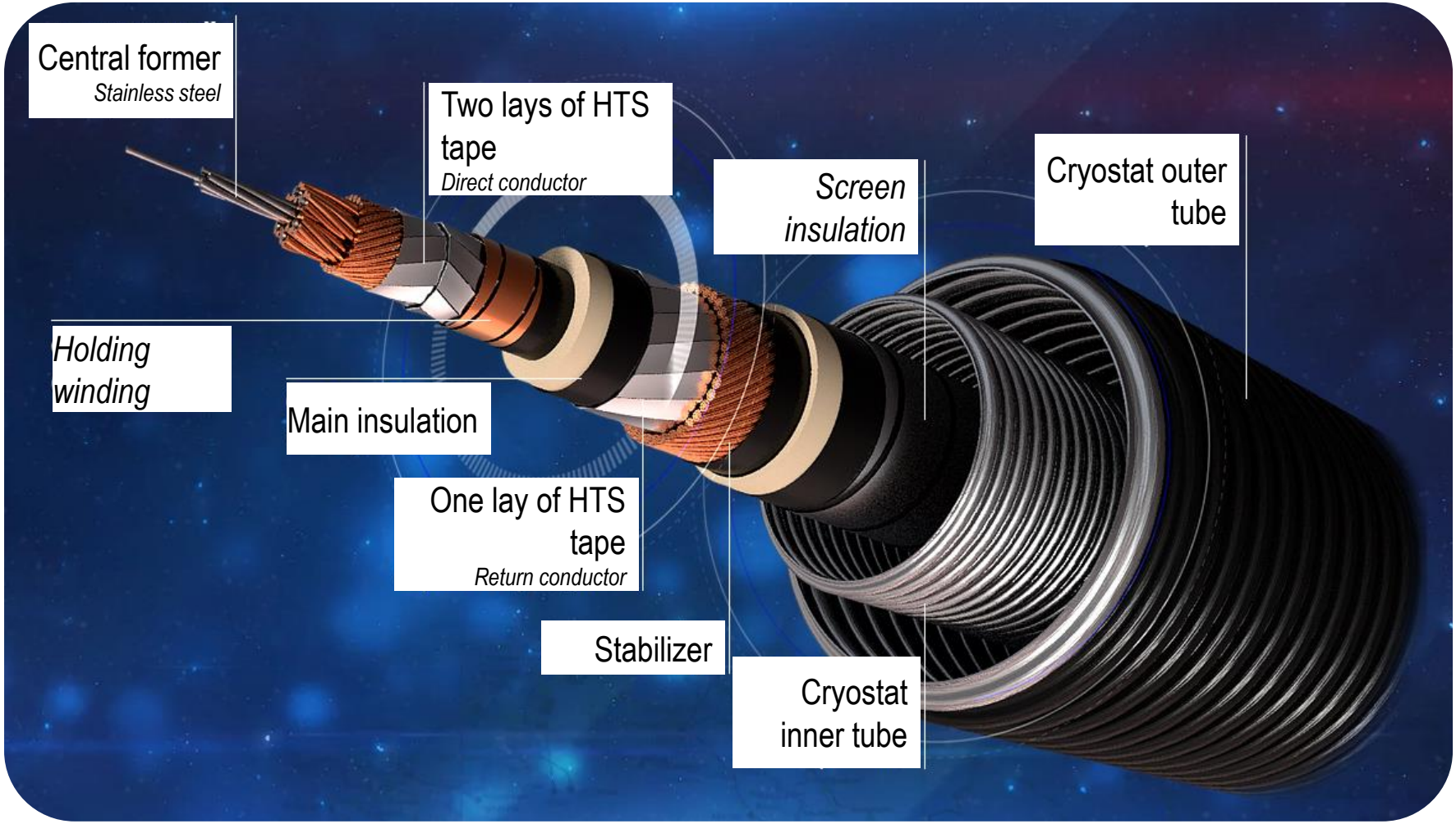
Infrastructure companies

– Powerful motors for rolling mills and gas pumping stations
– Large data centers
– Non-ferrous metallurgy enterprises

High-temperature superconductivity. Areas of application.



High-voltage direct current cable of the Research and Development Center of FGC UES (JSC “R&D Center @ FGC UES")



Advantages of HTSC DC transmission

1. *Reduction of energy losses in the HTSC cable and life cycle increase*
2. *Ability to transfer high power at low voltage*
3. *Reduction of right-of-way areas and city ecology improvement*
4. *Network controllability increase*
5. *Fault current limiting*
6. *Cross-reservation of electric grid sections*

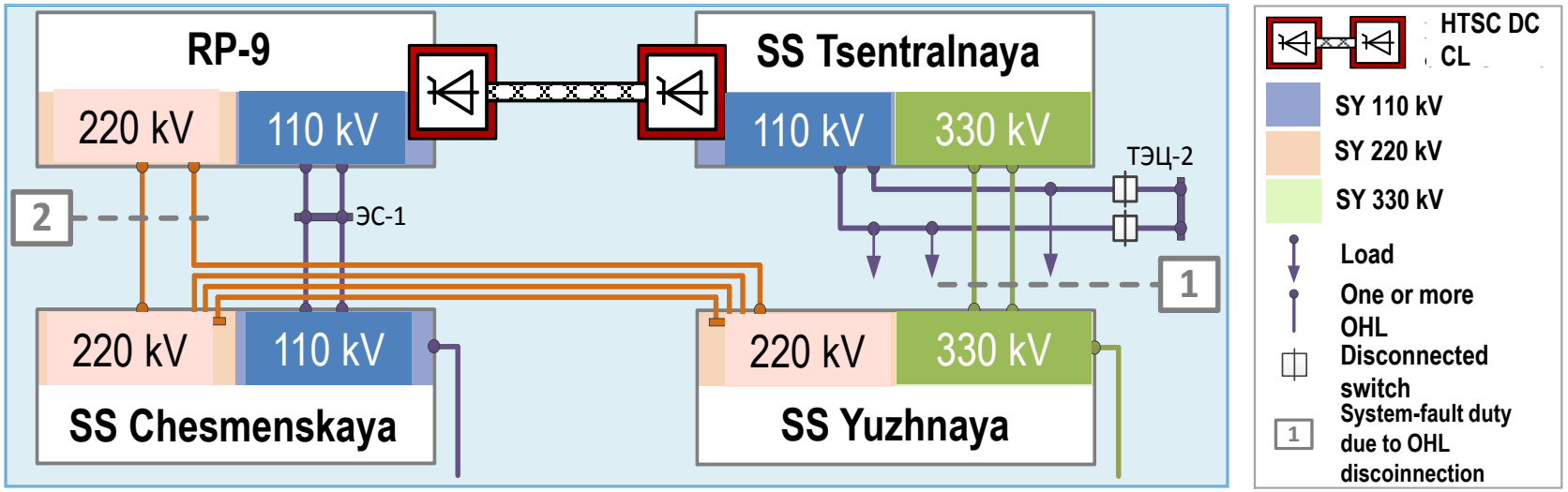
Project
«Development and construction of a high-temperature cable line length - 2500 meters, power level - 50 MW in St. Petersburg Substation Central 330 kV - Substation RP-9 220 kV»

Project Objectives:

- Development of HTSC DC Cable 20 kV, 50 MW for St. Petersburg.
- Creation of scientific and production cooperation for the manufacture of high-temperature superconducting cables, couplings, converters and cryogenic equipment.
- Creation and demonstration of replicable HTSC DC insertion
- During the experimental operation, accumulate experimental data and determine the real cost of operation.

Project Tasks:

- Development, manufacturing and implementation of the unique, the world's largest HTSC cable line of direct current;
- Formation of a complex of technologies for the design and production of high-temperature superconducting lines;
- Creation of a unique pilot production and testing base
- Formation of the competence of the design of "ring networks" in megacities on medium voltage without increasing the currents of short circuits.

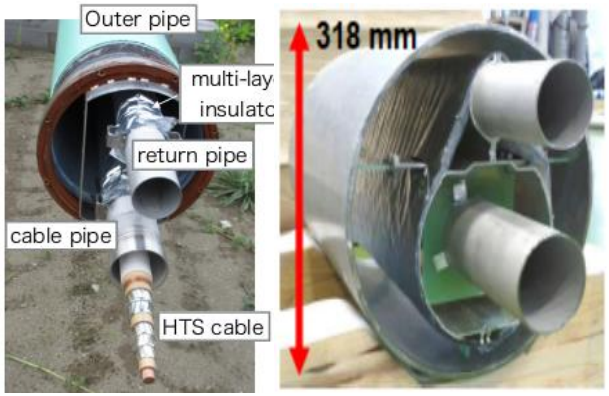


Ishikari HTS DC project (500m and 1000m) , Japan

Data center power supply.

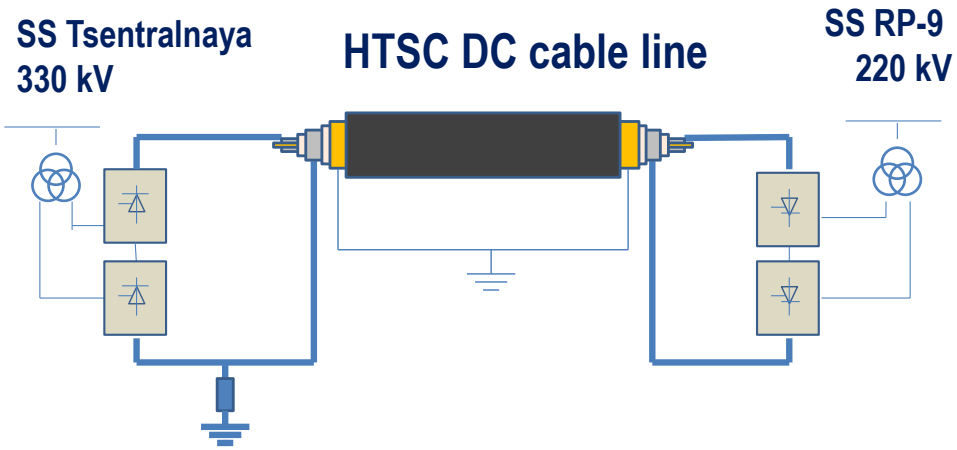
U-shaped line with a length of 1000 meters and two couplings.
The direct and reverse flow of liquid nitrogen is organized inside a common cryostat 1000 m. Cable 10 кV, 2500 A.

Optimized design of smooth cryostat allowed to reduce heat input to the pipe with the cable to an extremely low value of 0.034 W/m.



The main goal of the project is to carry out researches and obtain basic knowledge for the development of longer lines.

Project specification



Specifications

Power transmitted	50 MW
Rated voltage	20 kV
Rated current	2500 A
Operating temperature	66-80K
Length	2500 meters
Type of convertors	12-pulse
Possibility of reverse	Provided
Cooling capacity of the cryogenic system	12 kW @ 70K
LN_2 pressure	до 1.4MPa
LN_2 flow rate	0.1 ÷ 0.6 kg/s

Milestones of HTSC DC Cable Project in St. Petersburg

2010
- The project to create a high-voltage superconducting cable line was initiated by FGC UES
- JSC “R&D Center @ FGC UES" is defined as the main organization for the implementation of the Project

2015
- Design documentation for SURZA equipment, high-voltage DC cable and design of HTSC cable line for direct current
- HTSC cable line is made in full *(HTSC-cable and reverse cryostat, 4 end and 6 connecting cable couplings, components of RMS, block of high-voltage thyristor valves)*

2016
- An experimental base has been prepared at the JSC "STC FGC UES" testing site for carrying out large-scale resource tests of high-voltage superconductors of a direct-current cable line, assembled with a regular cryogenic system

2018
- A set of measures for resource testing on two cable lengths of the cable route is completed.
- Received a positive conclusion of Glavgosexpertiza
- Emergency modes are being developed and a system of locks and protections

2020
- HTSC cable line of direct current is installed and put into operation at the facility in St. Petersburg between 330 kV Substation "Tsentralnaya" and 220 kV "RP-9"

Four main parts of HTSC DC cable line

HTS cable consists of 6 lengths (429 m each) with couplings and terminations

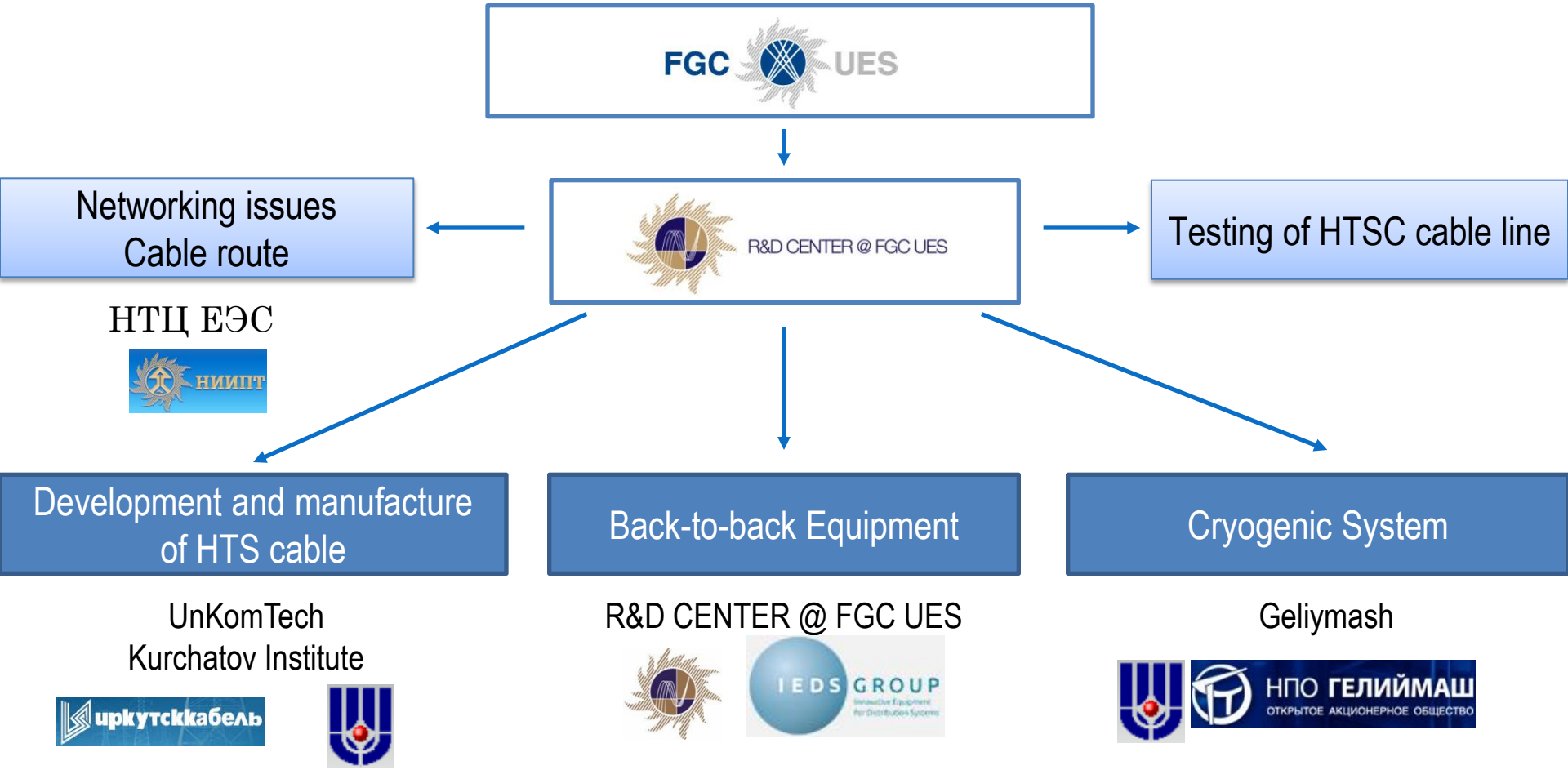
–Two converters 20kV including two transformers 63 MVA.

– Cryogenic system 12 kW, 67K, consists of two loops – Nitrogen and Helium

–Monitoring and control system.

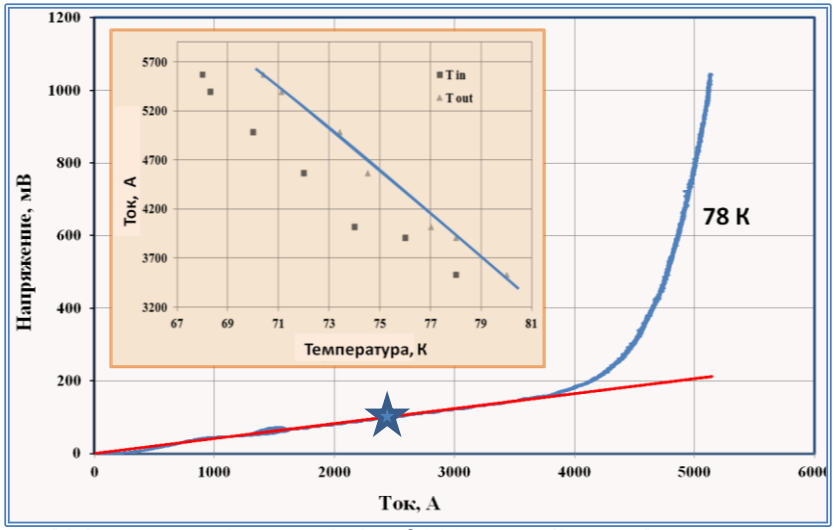
All parts of HTSC DC line are mounted and tested at R&D center test rig in Moscow in 2017-2018

Development and construction of HTSC DC cable line in St. Petersburg, Collaboration



R&D CENTER @ FGC UES is engaged in every single stage of the project

Testing of HTS DC cable line



Volt-ampere characteristic of 860 meter line and temperature. Dependence of the critical current on temperature for a 60 meter line.

Tested

1. In the SRC "Kurchatov Institute" 2x30 meters at 80K
2. At JSC “R&D Center @FGC UES" 2x30 meters at 68K - 78K
3. At JSC “R&D Center @FGC UES" 2x430 meters at 78K

Test Results

➢The critical current of the cable is equal to the sum of the critical currents of the original HTSC tapes. The reliability of the developed design and technologies has been confirmed.

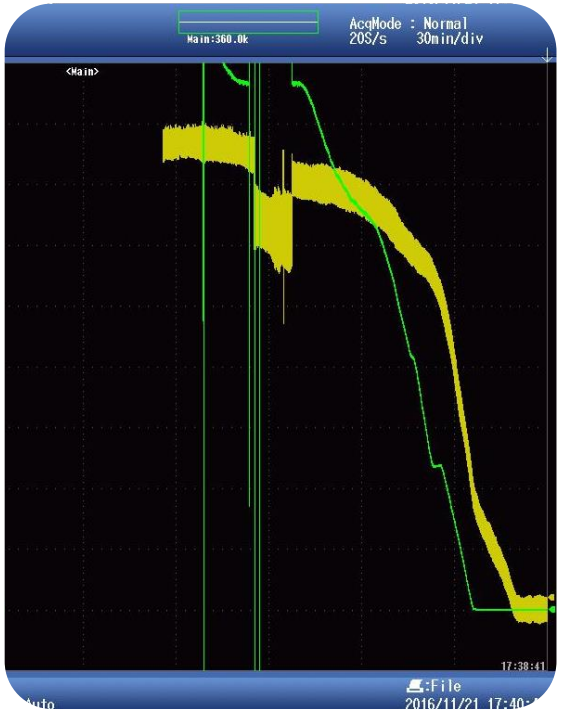
➢The resistance of the joints is stable up to 5000 amperes.

➢ All calculated characteristics have been achieved or exceeded.

➢All cables were successfully tested with a high voltage of 50 kV, 30 minutes.

Installation of the cryogenic supply

- ✓ *The HTS cable is connected to the Cryogenic system*
- ✓ *Cooldown of HTSC cable is carried-out.*
- ✓ *Within 2 hours, HTSC cable (direct line - 860 meters long) passed into a superconducting state*



Cable cooldown curve
(Resistance control)

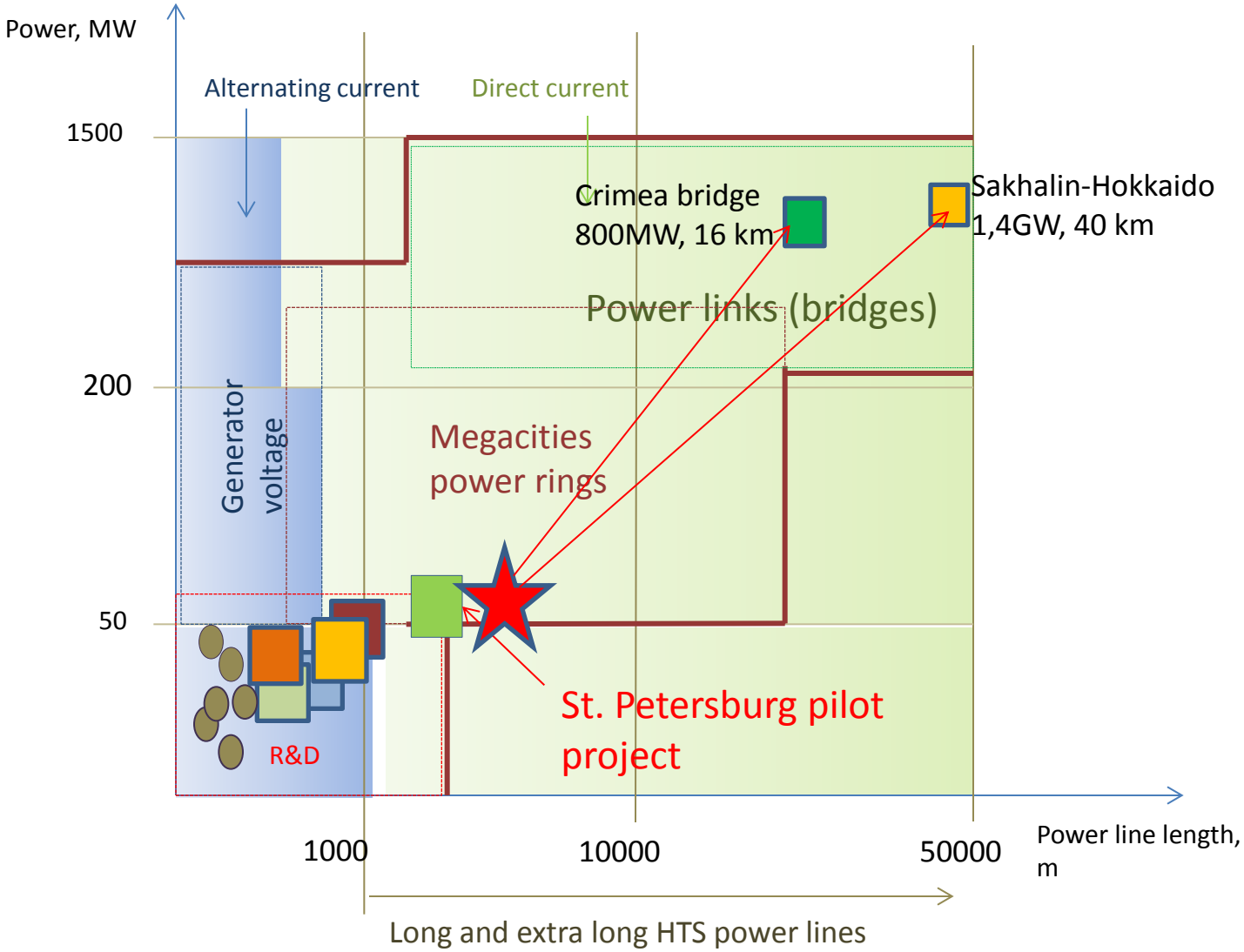
Connection of the HTS cable to the Cryogenic System

Cryogenic system start-up results

- ✓ Correct installation of main systems and nodes of the Cryogenic System was confirmed
- ✓ Correct installation and the operability of the decentralized control system of the Cryogenic System was confirmed
- ✓ The joint work of the HTSC cable line with the Cryogenic System was tested.
- ✓ Various start-up regimes, modes of cooldown and heating of the HTSC cable line were tested.
- ✓ Operation life testing of HTSC DC cable line are performed.

✓ Reliable provision of a superconducting effect in HTSC DC cable line

Opportunities for feather development of HTSC DC cable lines



Success of St. Petersburg project will open new perspectives for energy bridges and longer HTSC DC lines.

Evaluation of the possibility to transfer large flows of energy over long distances through HTSC cables

- Power Transmission
- Loss of energy in the line
- Line cooling

Power Transmission

- Transmission type - HTS DC cable line
- The possible level of current at the level of characteristics of HTSC materials reached is (10.0 - 20.0) kA. Assume in the estimates of 15.0 kA.T
- Transmitted power for different voltage classes (in MW).

Voltage, kV	Monopolar transmission		Bipolar transmission	
	One line	Two lines	One line	Two lines
20	300	600	600	1200
50	750	1500	1500	3000
70	1050	2100	2100	4200
100	1500	3000	3000	6000

Evaluation of the possibility to transfer large flows of energy over long distances through HTSC cables

Loss of energy in the line

The energy losses in a HTSC DC cable line are composed of:

1. Loss of energy in the converters is about 2% of the line power.
2. Energy losses in current leads (units of kW)
3. Losses associated with heat inflows into the cold zone through the cryostat multiplied by the refrigeration ratio.

The first two quantities do not depend on the length. Let's take 2% of the transmitted power.

The heat influx through the envelope of modern cryostats is (1.0 - 1.5) W / m. The refrigeration ratio is 12-18, then the power loss per meter of line length will be (12-27) W / m. We take 20 W / m.

Limit the total loss in the transmission of energy 3%. Then the maximum length of the high-temperature superconducting line, the loss in which will be no more than 3% of its power:

Power rate (MW)	100	300	500	1000	3000	6000
Length (km)	50	150	250	500	1500	3000

Conclusion

- At present, we are witnessing the beginning of the introduction of HTS cable lines into the real power industry.
- With the current level of development of superconducting and cryogenic technologies, it is now possible to create long superconducting direct-current cable lines to transmit energy over distances of tens of kilometers. In this case, the power of a single medium voltage line can reach several gigawatts, and the energy losses in it will be significantly lower than in overhead transmission lines.
- Cryogenic stations can be located at its ends with a line length up to 20 - 30 km. When creating longer lines, cryogenic stations should be located along the route in increments of 20 to 60 km. The maximum length of a line with this approach has no technical limitations.
- The successful experimental operation of the first HTSC cale lines can become a significant accelerator of the processes of introduction of HTSC devices and equipment into the electric power industry.
- Through implementation of current project implementation, innovative solutions that can seriously compete with the traditional solutions for the transmission of electrical energy to its unique characteristics have been developed and tested.
- For a full-scale replication of the Project results is possible through comprehensive survey of megacities' power systems to identify promising sites for the introduction of HTSC DC and AC cable lines.

THANK YOU FOR ATTENTION

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