IEEE/CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), January 2014. Presentation given at the 11th EPRI Superconductivity Conference, October 2013

R&D CENTER @ FGC UES

HTS DC Cable Line for St.Petersburg Project

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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;

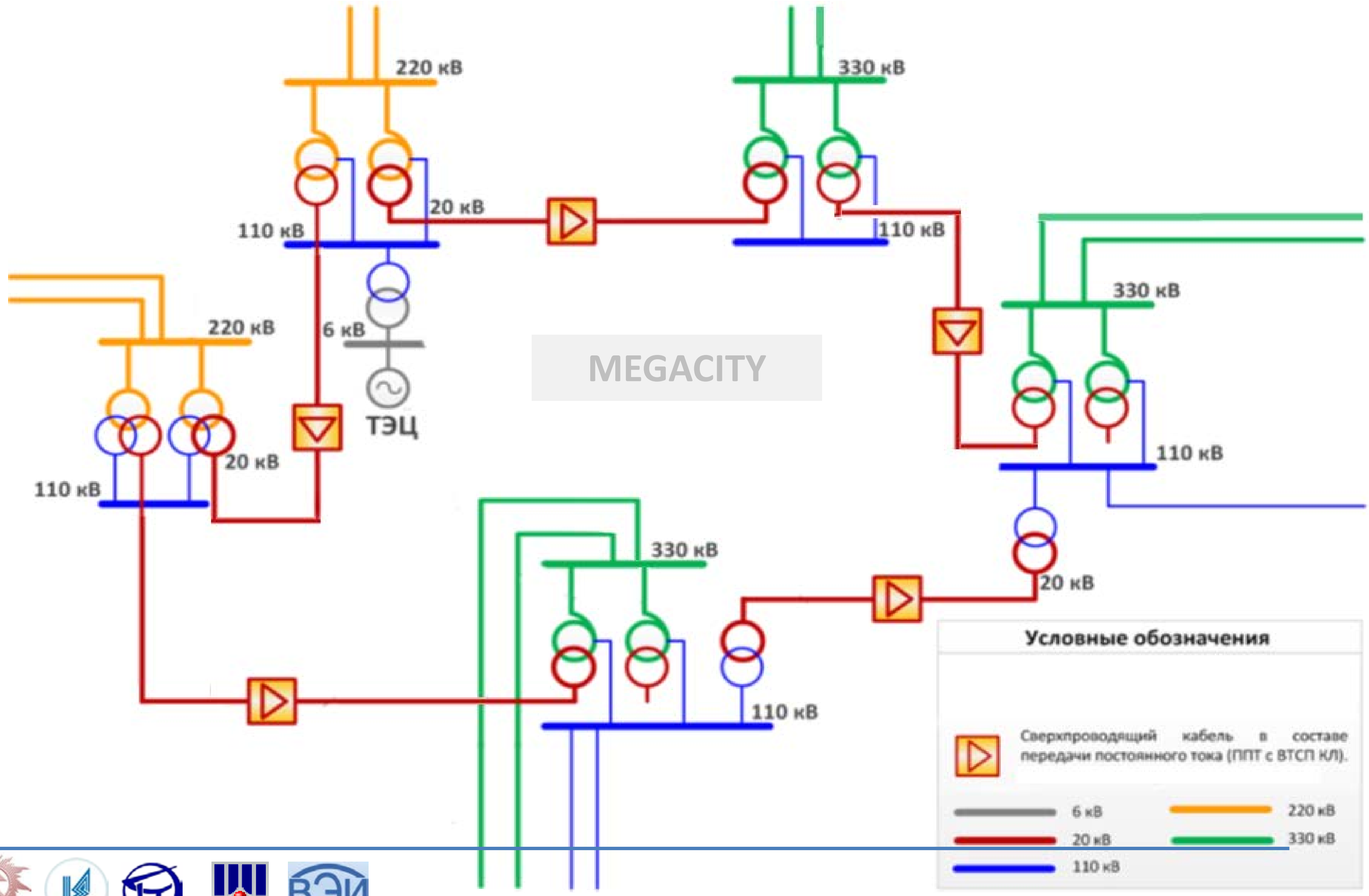
Many of these problems can be solved by combination of two technologies: Superconductivity and DC Transmission.

HTS DC transmission advantages

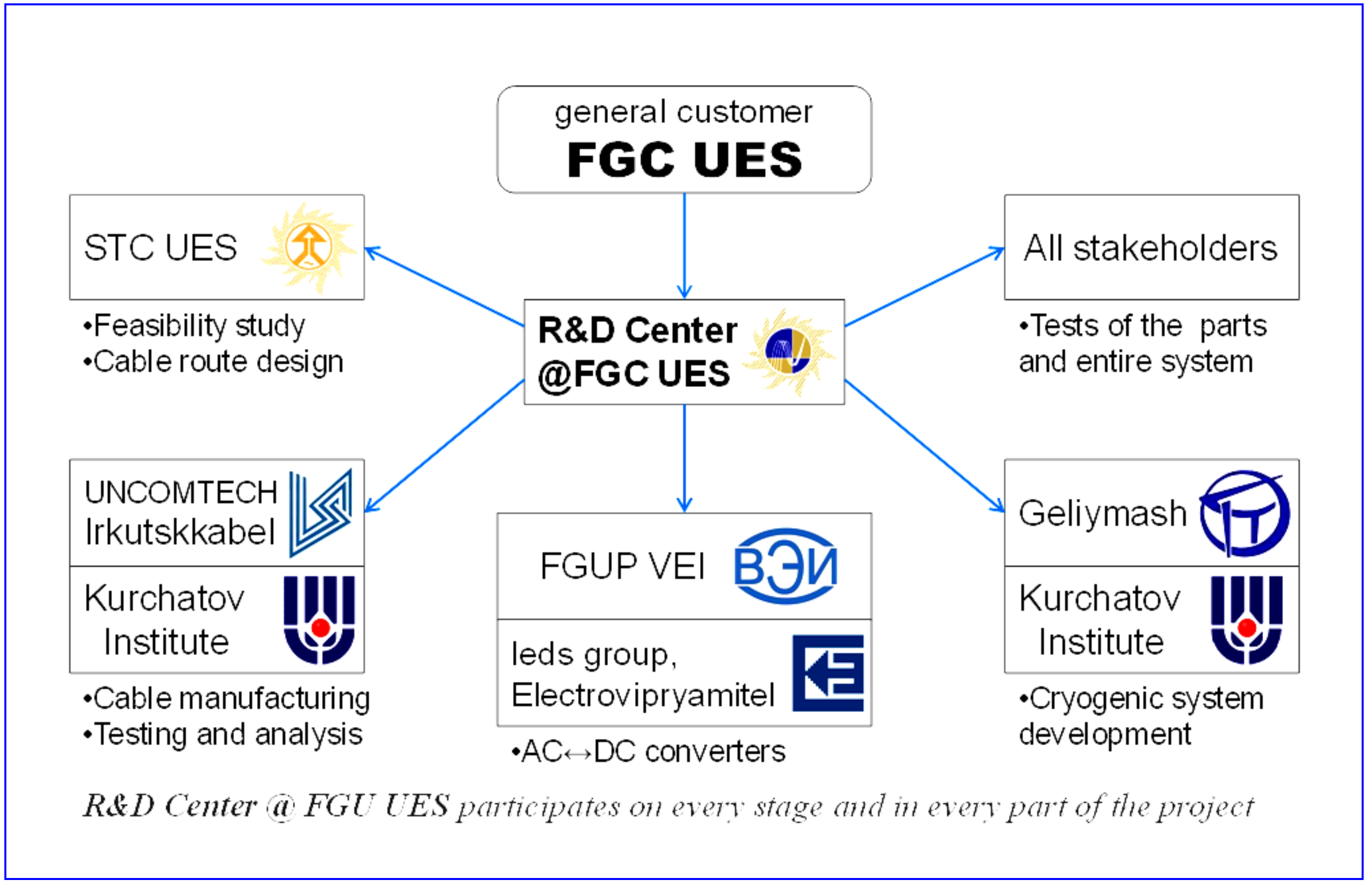
1. Loss reduction at electric power transmission
2. Possibility of high power transmission at low voltage
3. Limitation of short-circuit current
4. Enhancement of electrical grid controllability
5. Cable line area reduction
6. Mutual redundancy of grid sections

Project development prospects

The concept of perspective development of power systems of megalopolises using superconducting DC cable lines



Project cooperation



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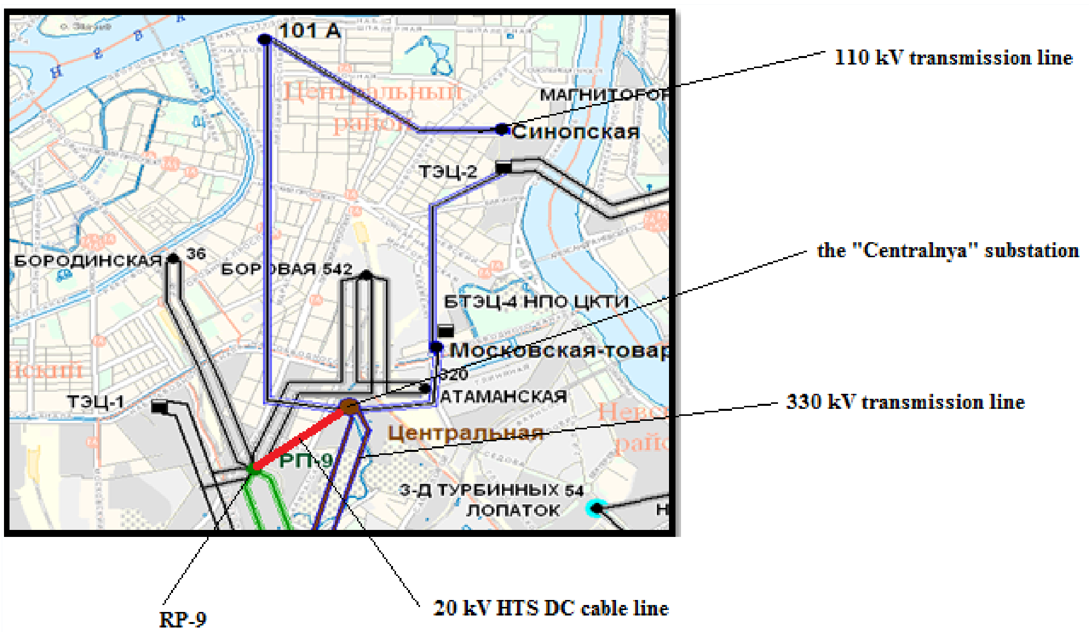
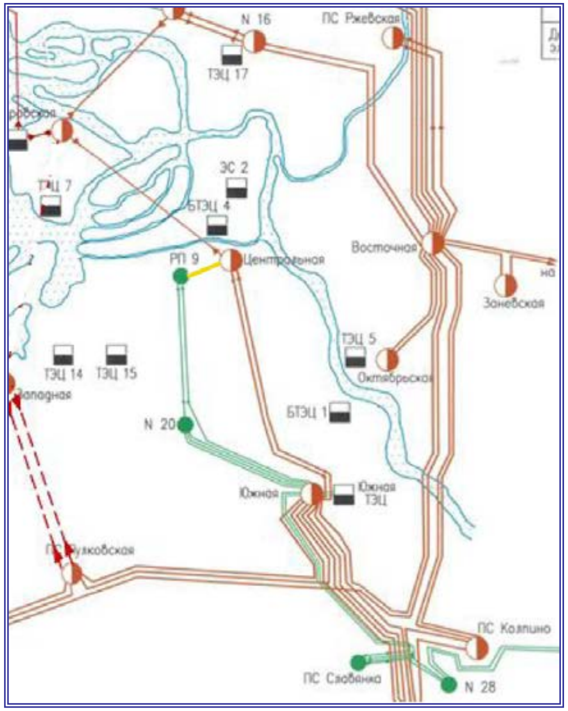
St. Petersburg HTS DC CL project

HTS DC cable line installation in the St. Petersburg's electrical grid

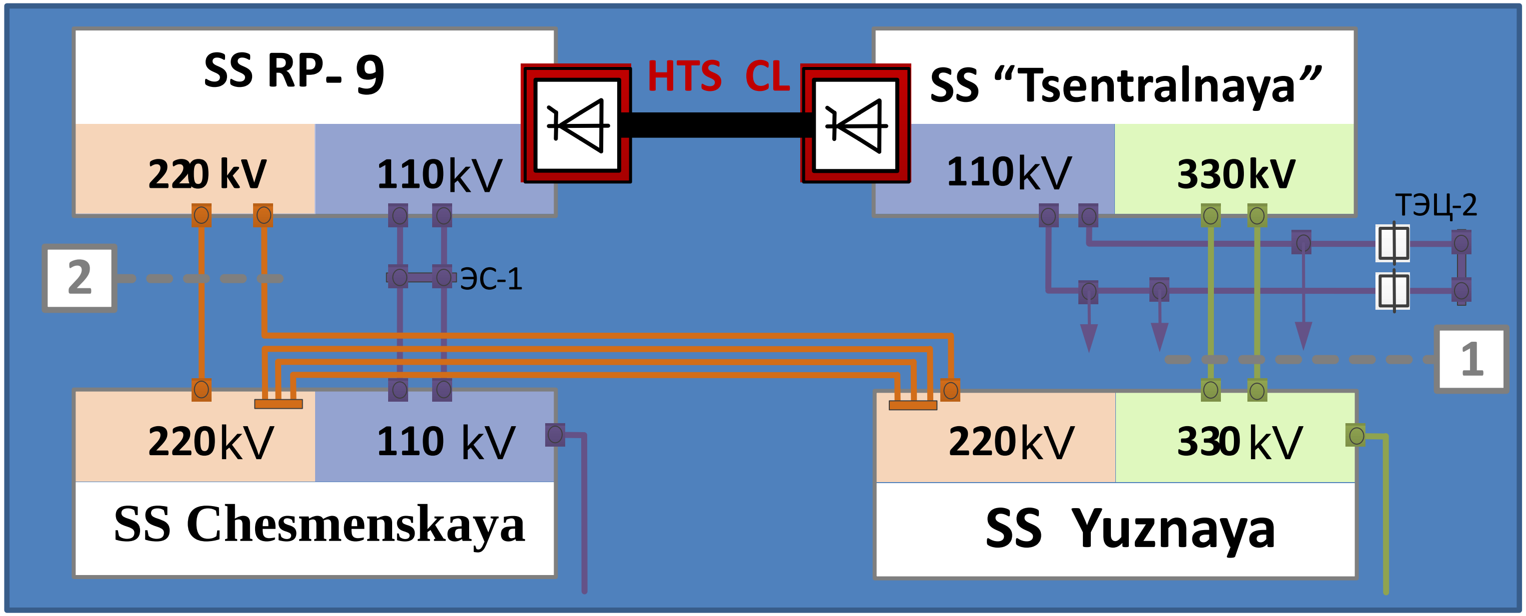




Short-circuit current in the installation site

Object	3-phase short-circuit current, kA		1-phase short-circuit current, kA	
	AC cable line	HTS DC cable line	AC cable line	HTS DC cable line
«Tsentralnaya» substation	39	18	43	21
RP-9 substation	40	26	44	27

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

St. Petersburg HTS DC CL project

Comparison of different variants of execution of the links between 330 kV SS "Tsentralnaya" and SS 220 kV RP-9

Current loading of the power lines in areas SS "Tsentralnaya" and SS RP-9 in the post-emergency mode.

	$I_{allowable}$, A	I, A	I/I_{al}, %	δP, MW
Enter the cable line 110 kV , 200 MW SS "Tsentralnaya" and SS RP-9				
OL 110 kV SS Chesmenskaya – ЭС-1	600	656	**109**	70
CL 110 kV SS "Tsentralnaya" - SS RP-9	1210	1248	**103**	
Enter HTS DC line capacity of 200 MW				
OL 110 kV SS Chesmenskaya – ЭС-1	600	592	98	0
Enter GIL 110 kV, 200 MW				
OL 110 kV SS Chesmenskaya – ЭС-1	600	658	**110**	70

Short-circuit currents in different variants of connections between SS "Tsentralnaya" and SS RP-9

Calculation points of short-circuit current	$I_{breaking}$, кА	HTS DC Cable line		AC Cable line		AC Cable line + CLR		GIL	
		I^3,kA	I^1, kA	I^3, кA	I^1, kA	I^3, кA	I^1, kA	I^3,кA	I^1,kA
Busbar 110 kV SS"Tsentralaya"	40,0	18,4	20,9	39,2	**43,1**	21,9	24,6	40,0	**43,9**
Busbar 110 kV SS RP-9	31,5	26,4	27,1	**40,3**	**43,9**	29,4	30,4	**40,7**	**44,4**

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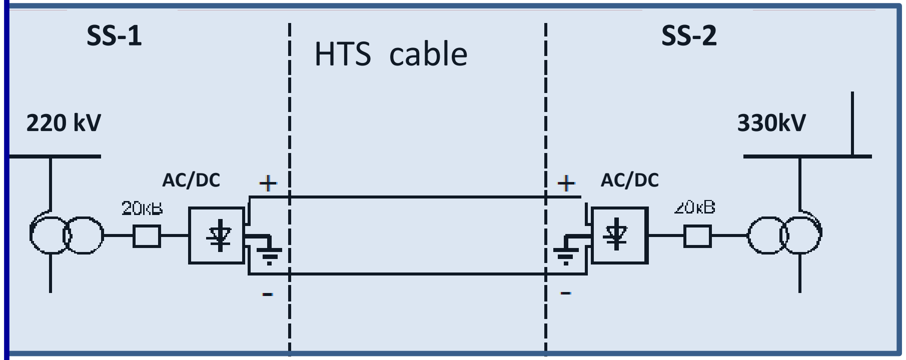
St. Petersburg HTS DC CL project

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

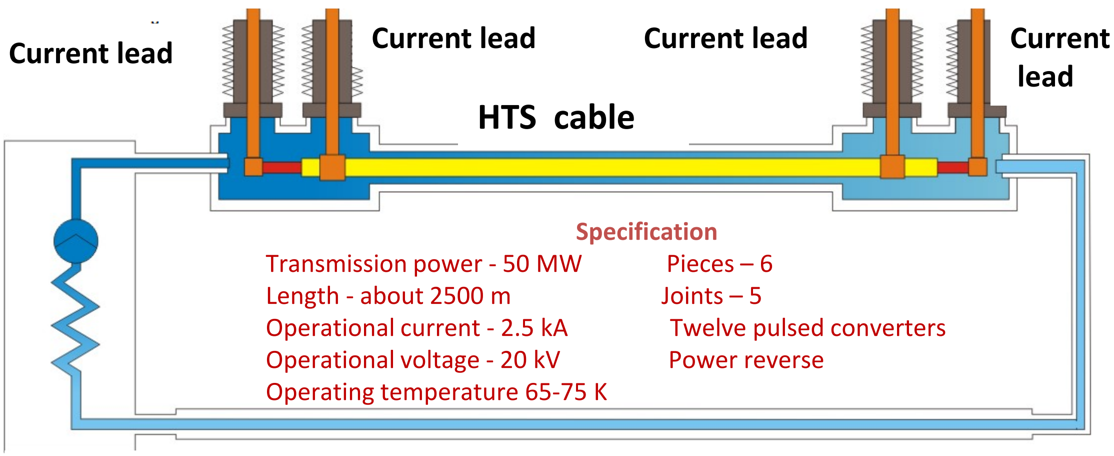


Main purposes of the project:

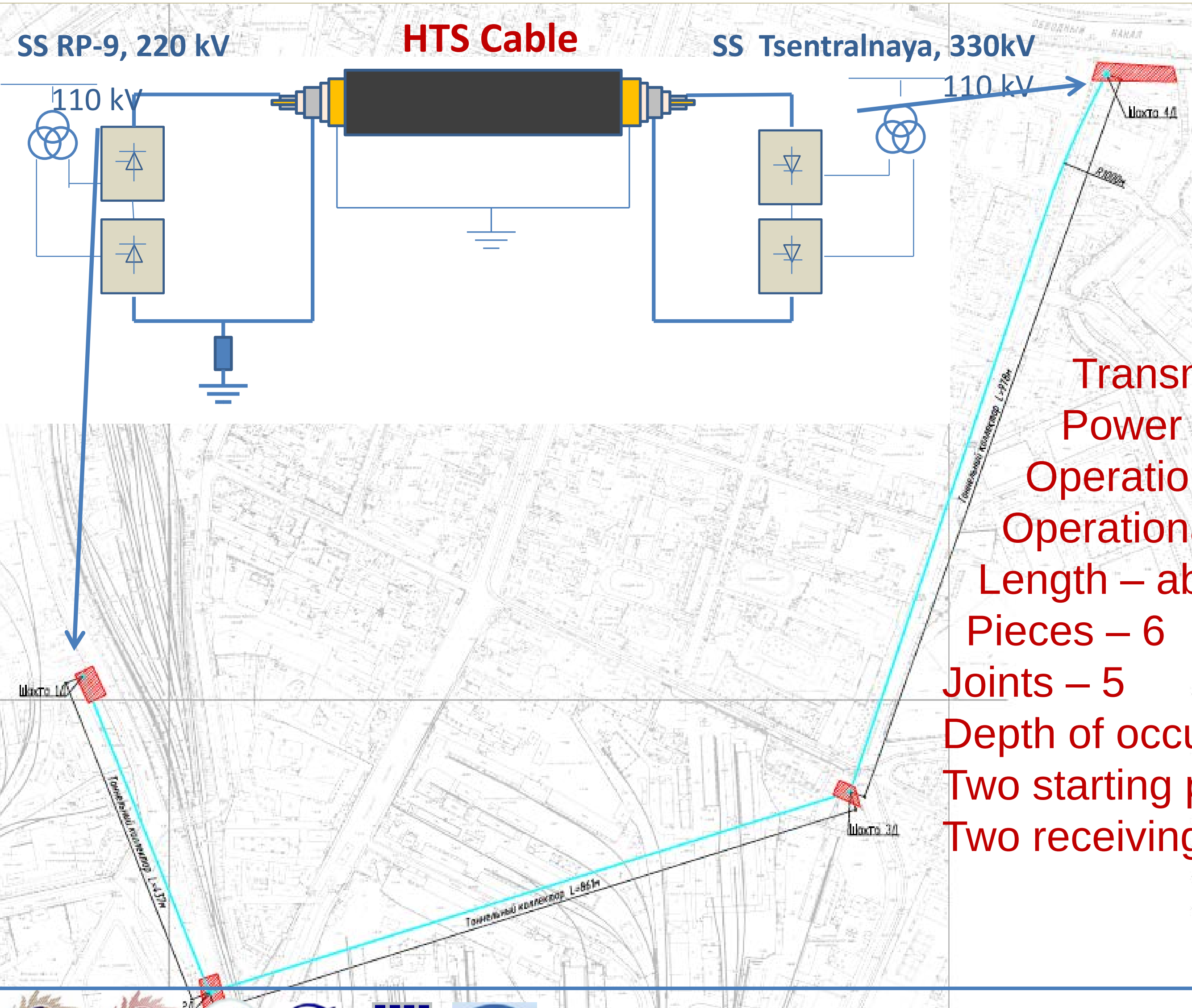
- Making HTS DC link - 20kV, 50 MW for St. Petersburg network.
- Creation of scientific – production cooperation for manufacturing HTS cables, cable fittings, convertors and cryogenic equipment.
- Creation and demonstration replicated HTS DC link.
- During line operation to gain new experience and define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

DC line include:

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



Cable pass scheme



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.

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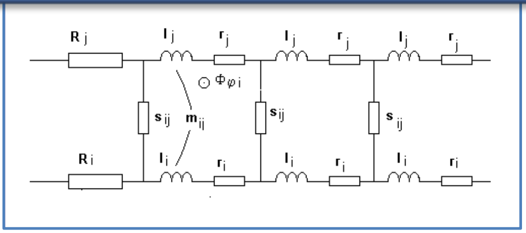
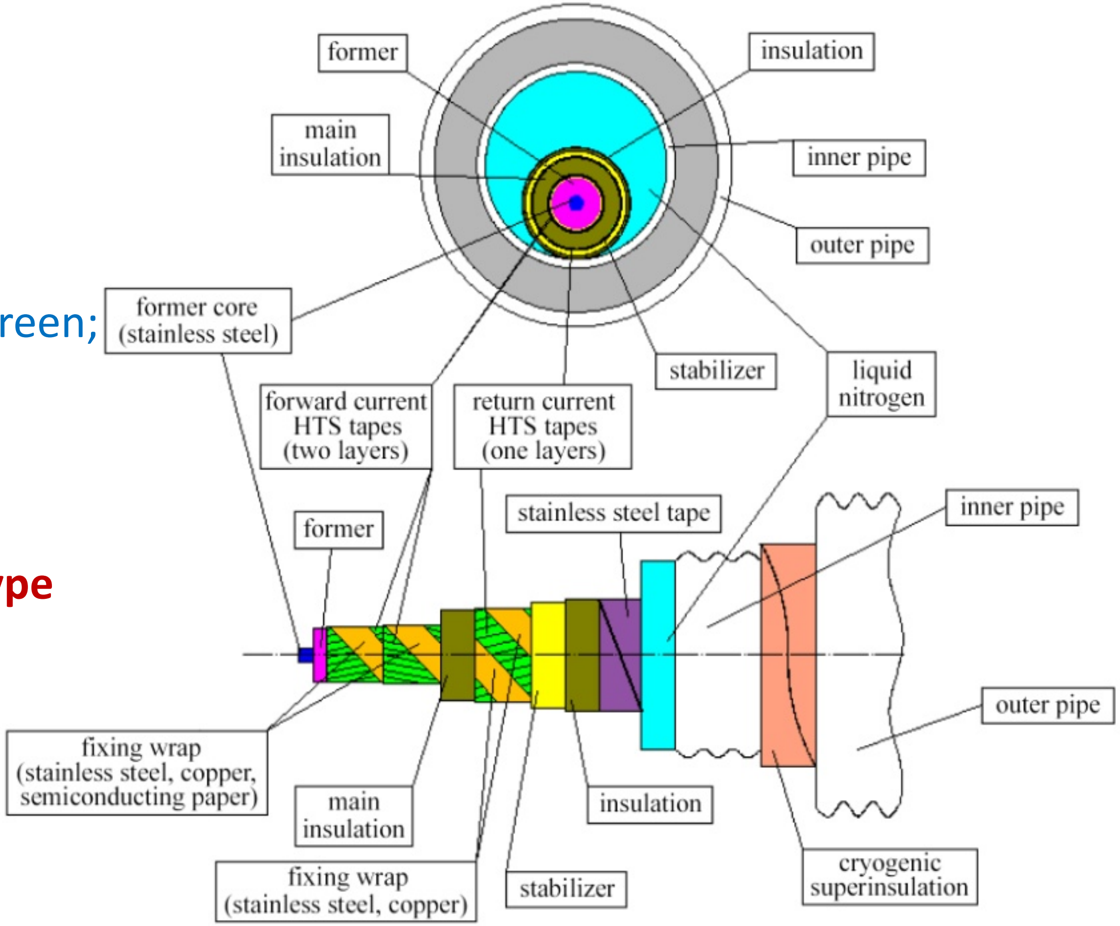
Cable design



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.



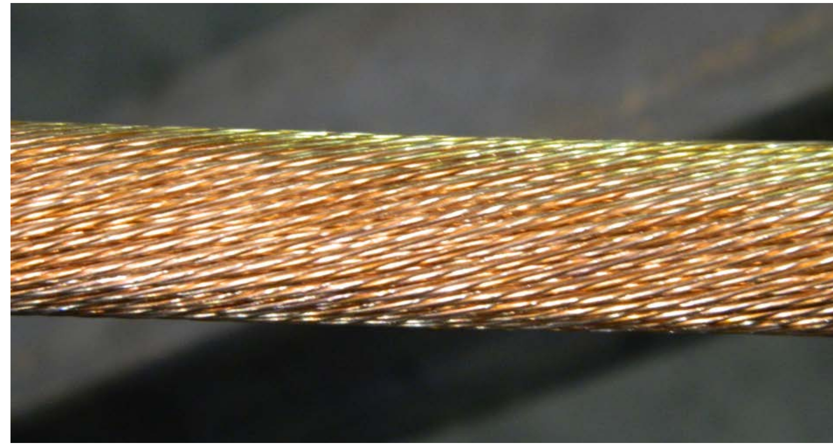
Cable prototype

Technology development and manufacture of cable samples

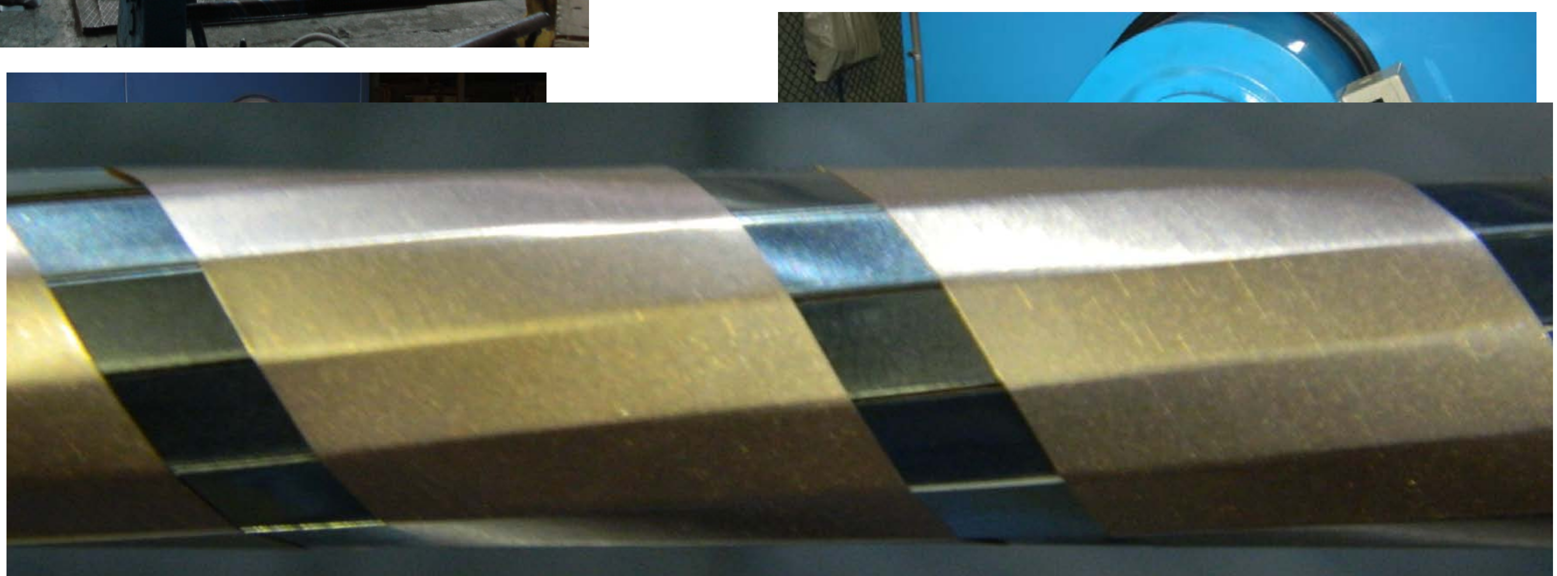
Development of the technology was performed on "Irkutskcable" plant

Direct conductor manufacturing

Former

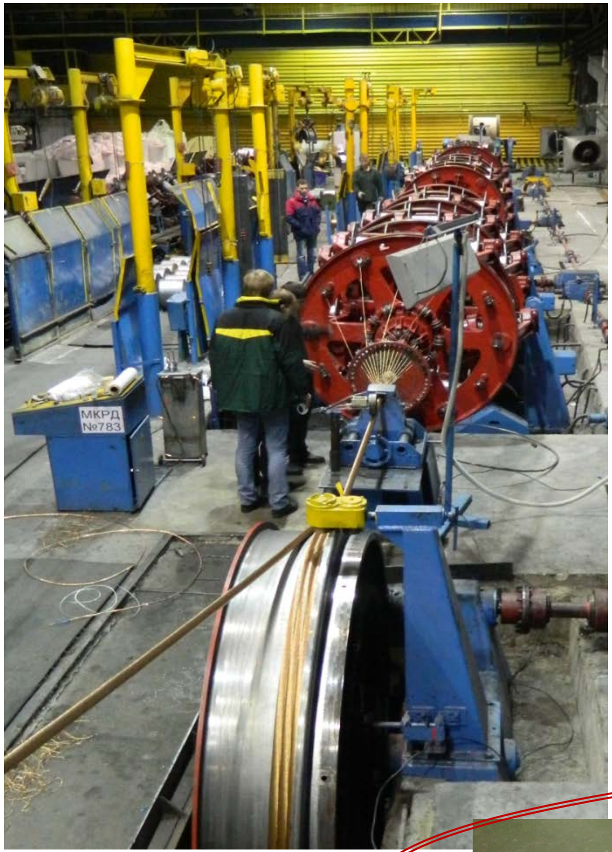


Direct conductor



Technology development and manufacture of cable samples

Application of copper screen



30 meters samples

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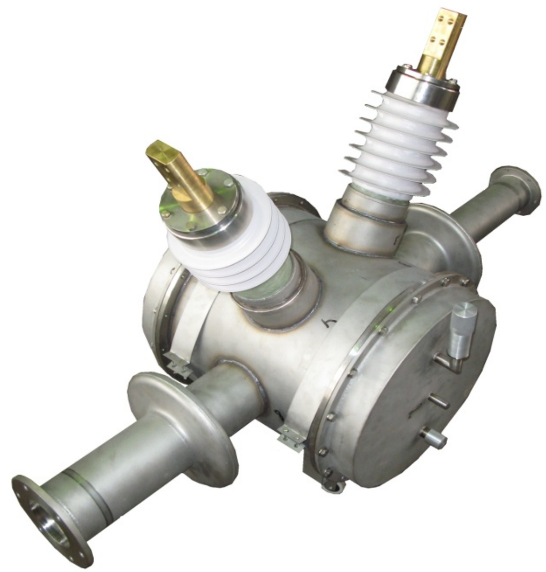
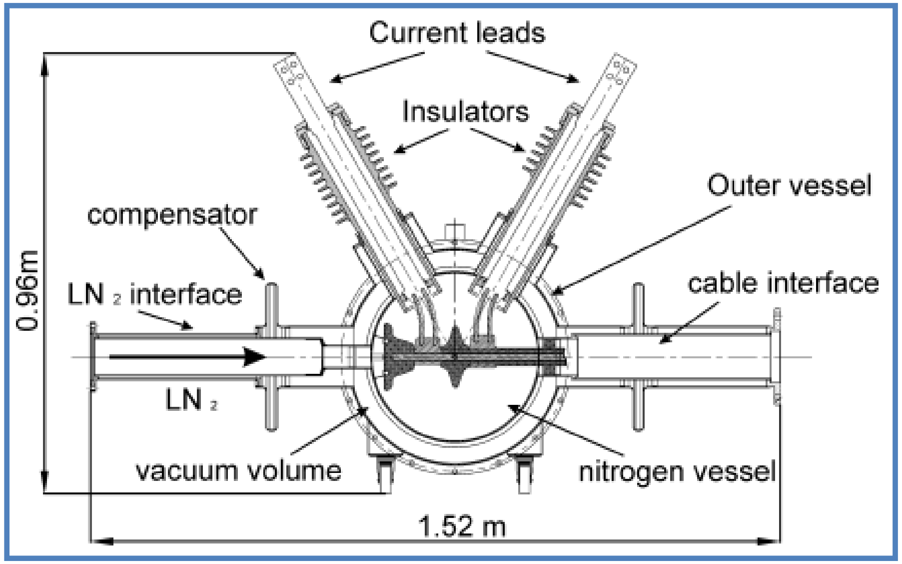
Current Leads and Joints design

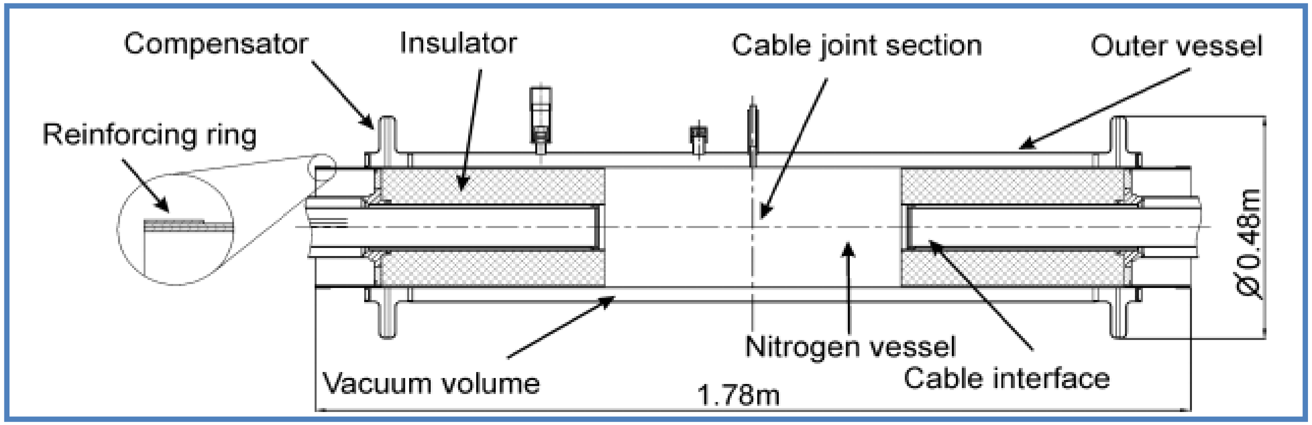
Developer NRC "Kurchatov Institute"



Current leads

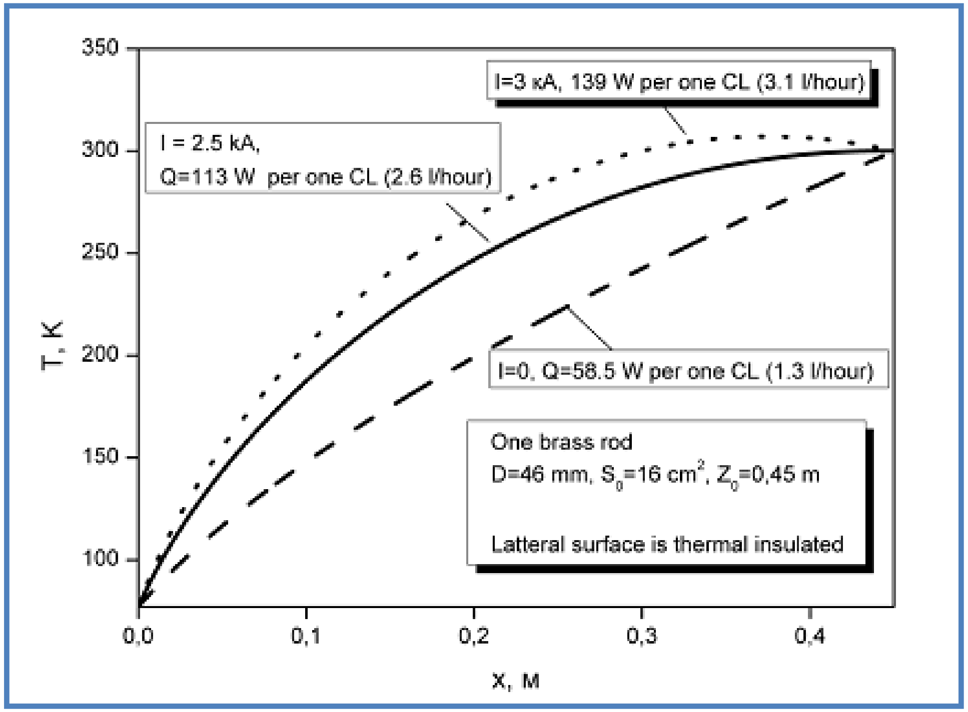


Joints

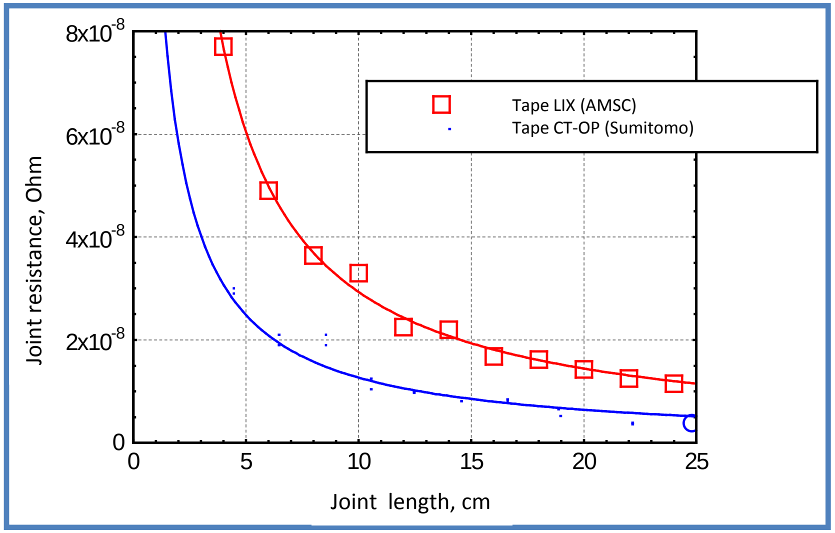


Current Leads and Joints

Material	Brass rod
Length	0.45 meter
Diameter	48 mm
Heat input @ I=0 A	58.5 W
Heat input @ I=2.5 kA (only rod)	113.0 W



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



Soldered joints resistance

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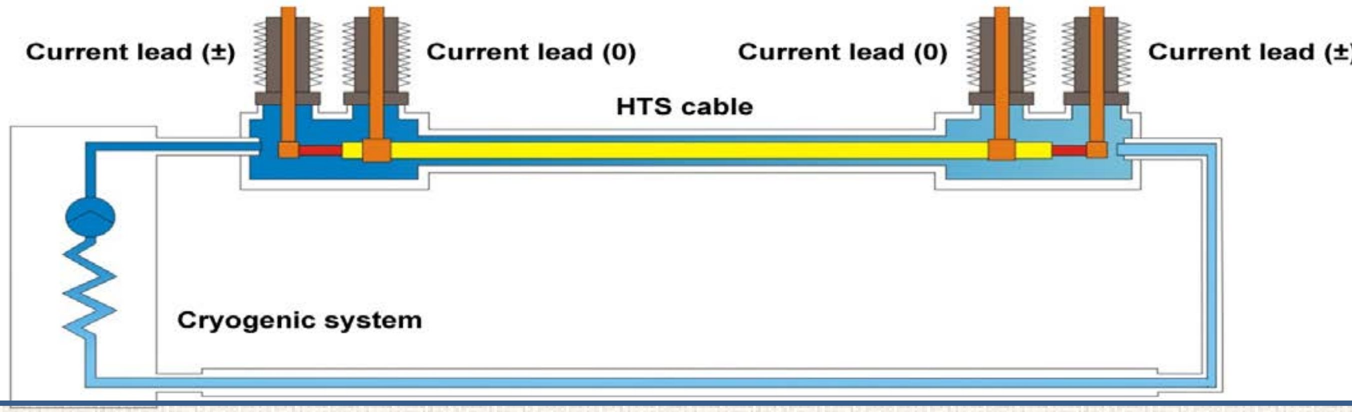
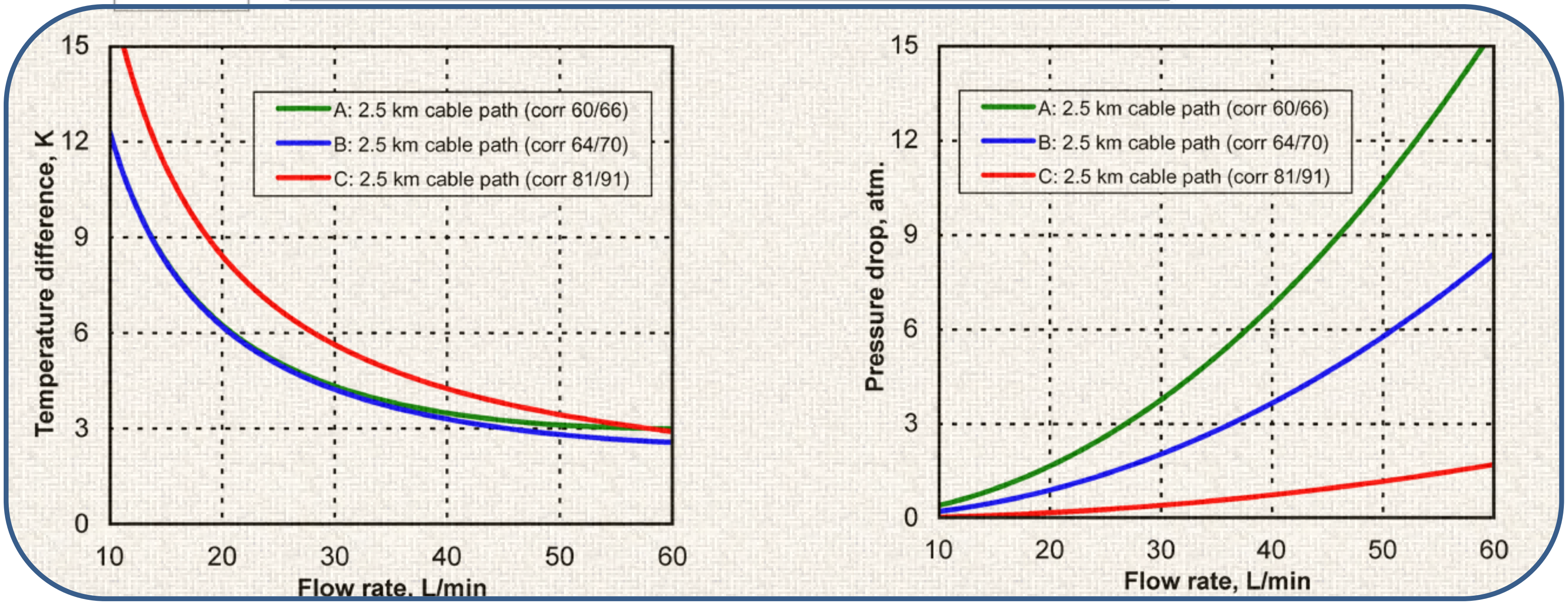
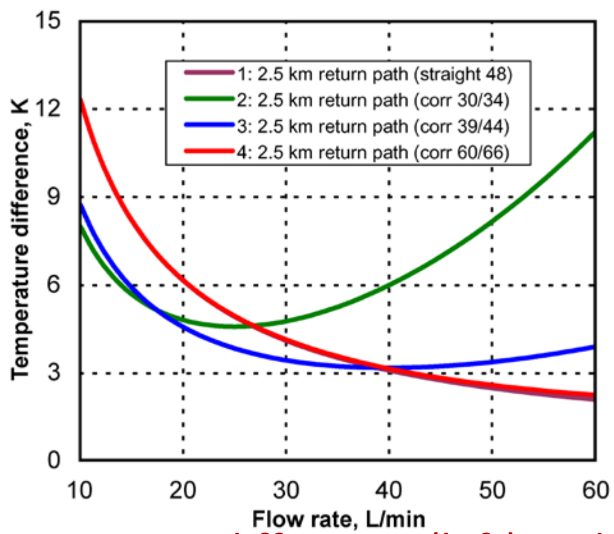
5 km cryogenic loop

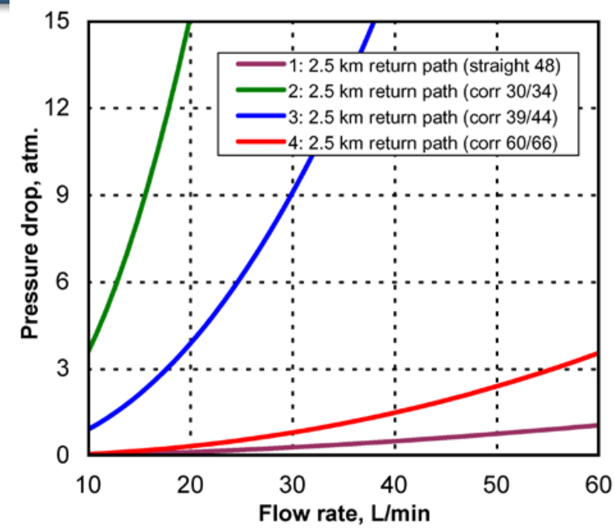




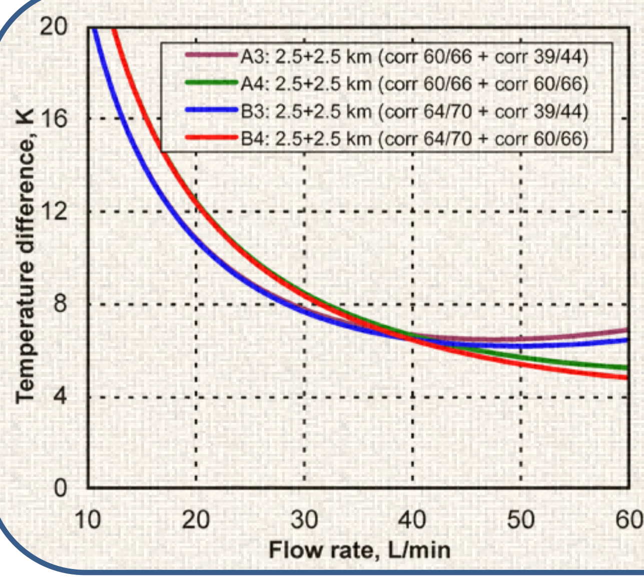
Temperature difference (left) and pressure drop (right) in corrugated direct flow cryostats 2,5 km of length.

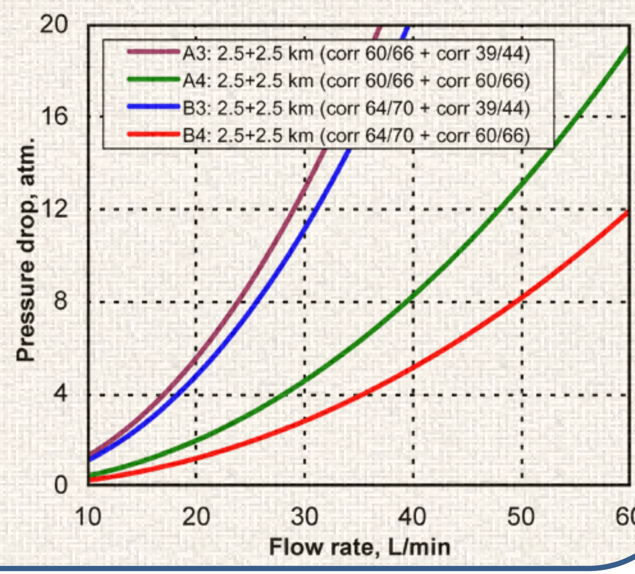
5 km cryogenic loop





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

Cryostat scheme.

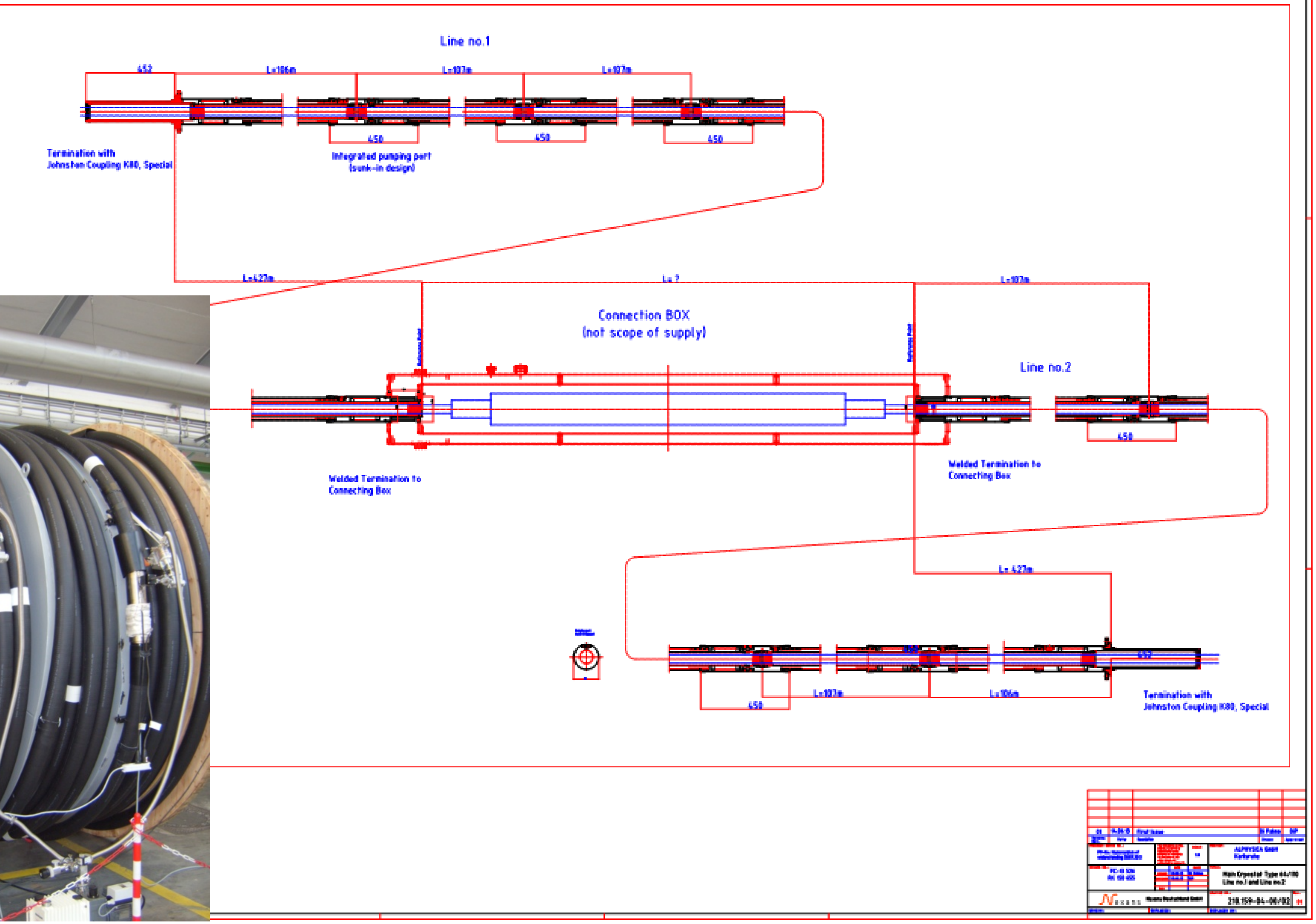
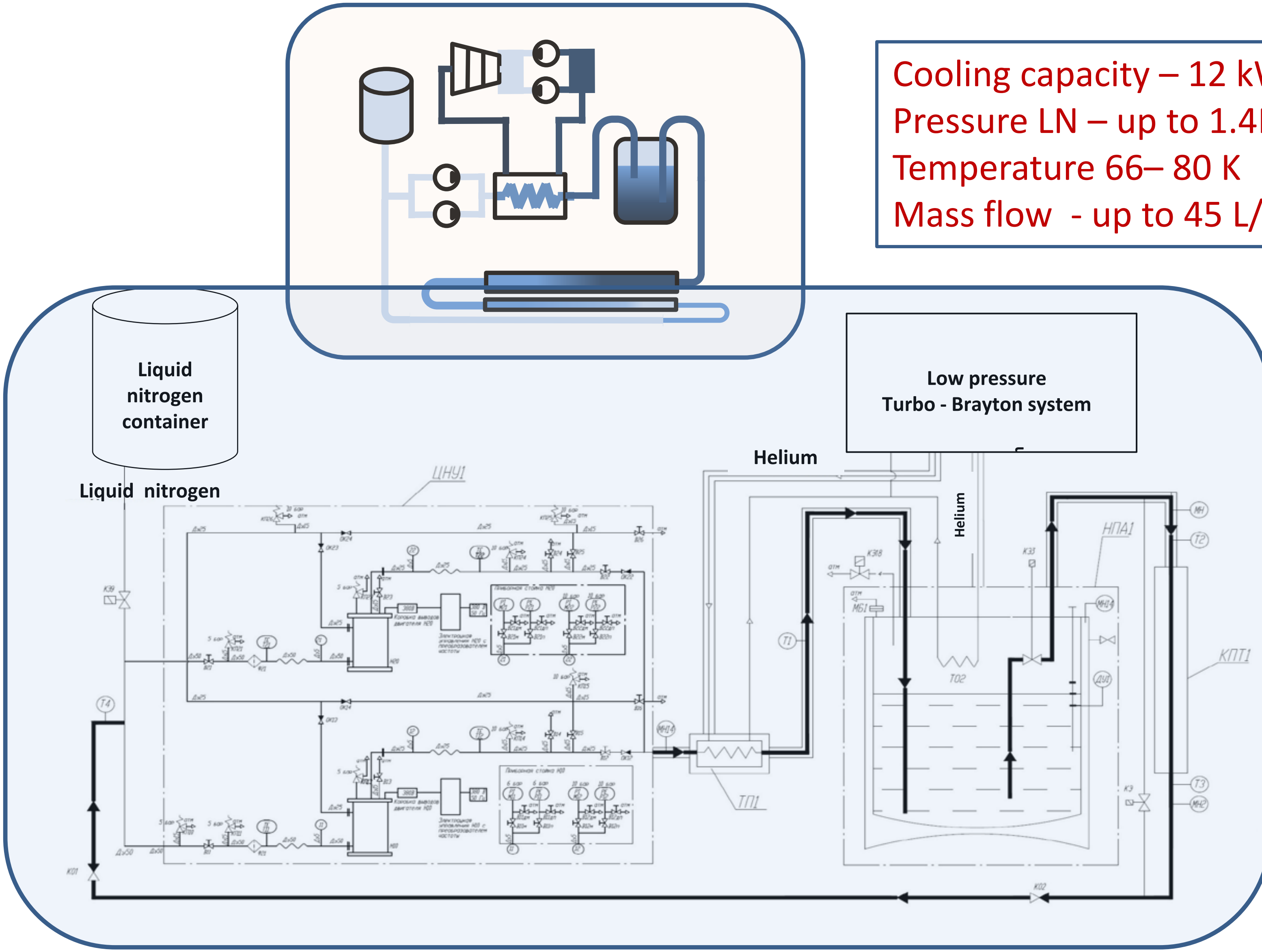


Diagram of the cryogenic system.

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



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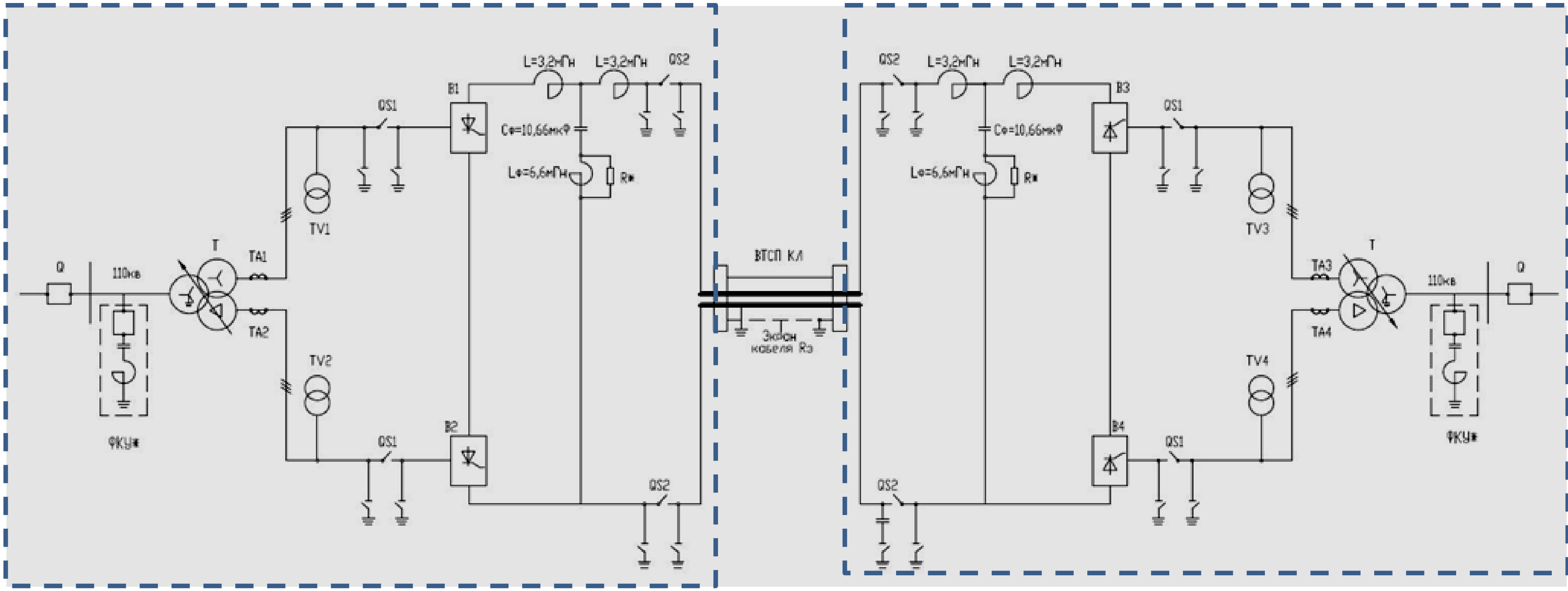
Circuit layout

SS Tsentralnaya   SS RP-9



Specification of the rectifier – inverter circuit

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

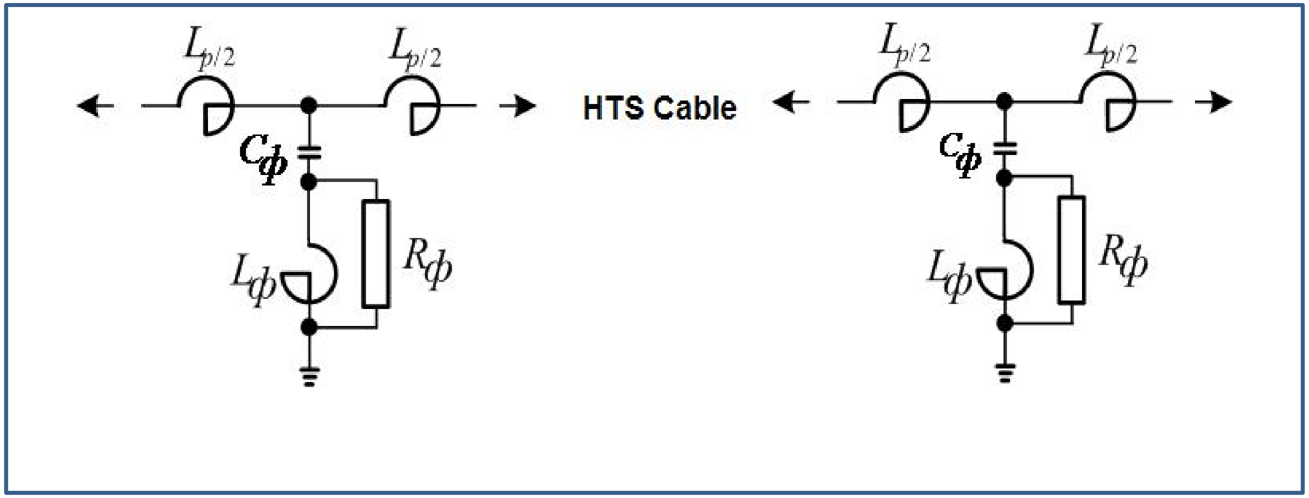
DC filter and current harmonics

$L_p/2$= 3,2 mH

C_ϕ= 10,66 µF

L_ϕ= 6,6 mH

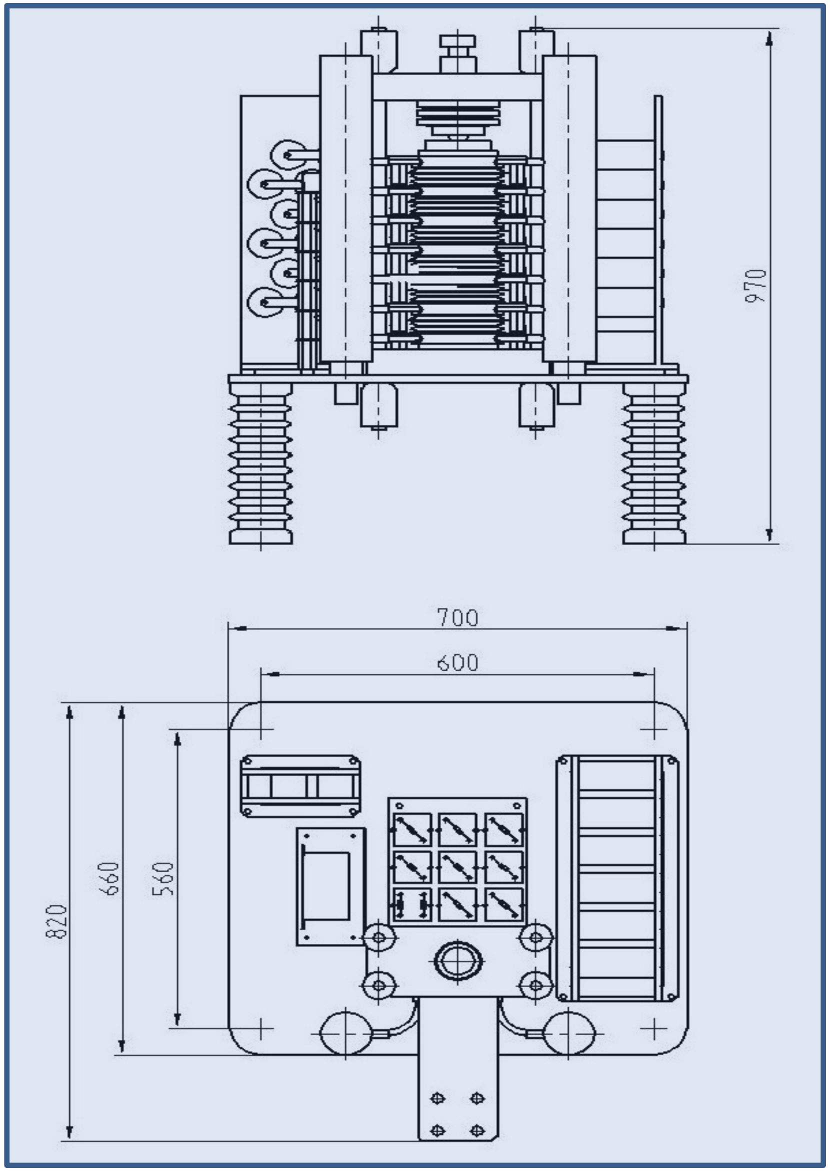
Q_{pl} = 120 kW



Operating mode

№		Harmonics
1	$\lambda=15^0;\gamma=20^0;$ I_d=2500 A	I_{12}~0, I_{24}=4 A
2	$\lambda=15^0;\gamma=3^0;$ I_d=200 A	I_{12}~0, I_{24}=2 A
3	$\lambda=80^0;\gamma=1^0;$ I_d=250 A	I_{12}~0, I_{24}=7 A

Thyristor module



Module specification

Permissible current	2500 A
Voltage on the valve	6 kV
Frequency range	48.5 -50.5 Hz
Number of thyristors	6
Type of cooling	Water cooling
Type of control	Fiber optical

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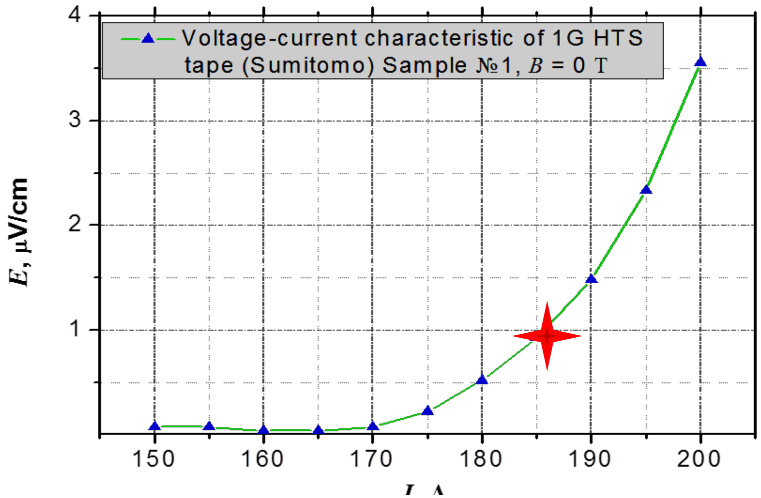
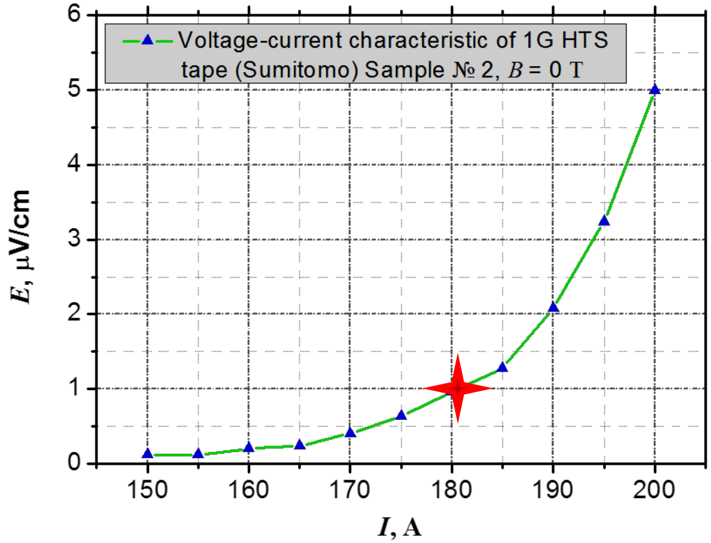
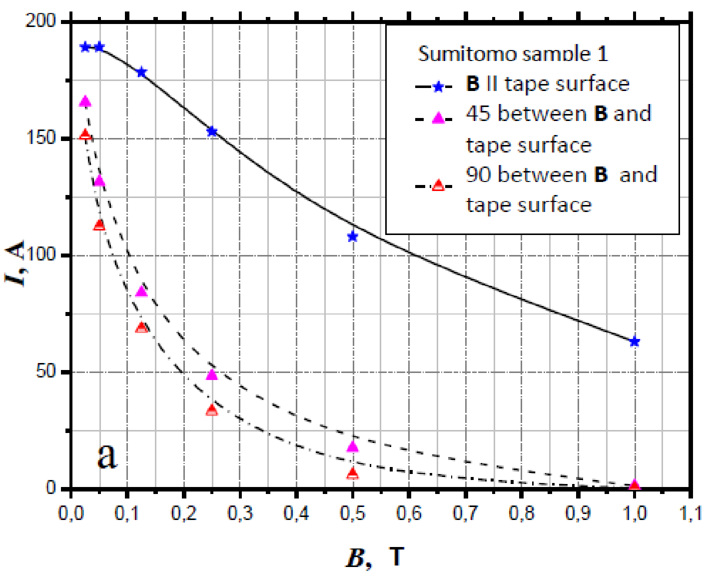
Tape test after removing from the cable

The tapes with original critical current 180 A

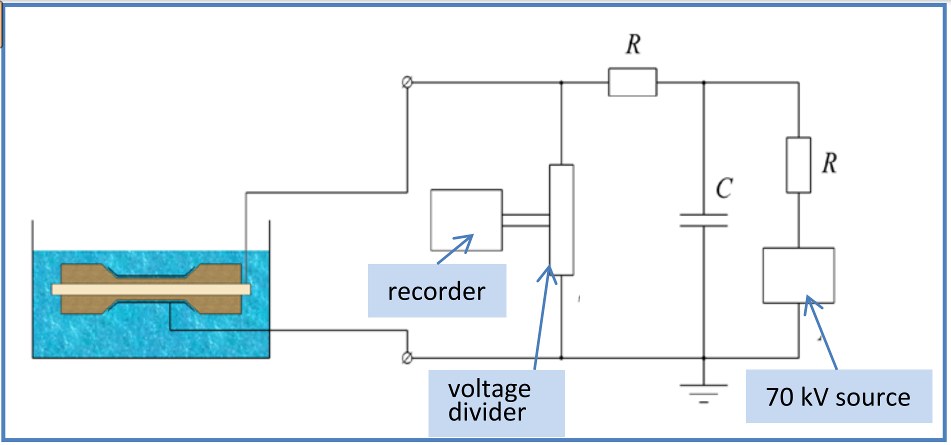


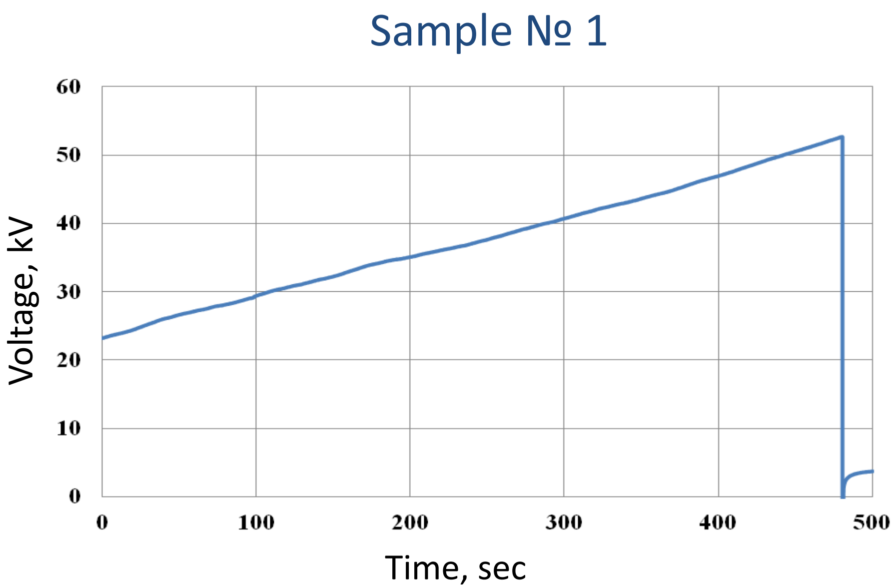




Thus the developed technology ensures the high current carrying ability of the superconducting tapes

Voltage breakdown verification test





Sample number	Paper thickness	Results
1	0.7 mm	Breakdown at 52.7 kV
7	0.7 mm	Breakdown at 46.6 kV
2	1.0 mm	No breakdown Energized 30 min. at 70 kV
3	1.0 mm	No breakdown Energized 30 min. at 70 kV
4	1.0 mm	Breakdown at 70 kV after waiting 7 min
5	1.5 mm	No breakdown Energized 30 min. at 70 kV

Russian standard requirement – 50 kV application during 10 minutes

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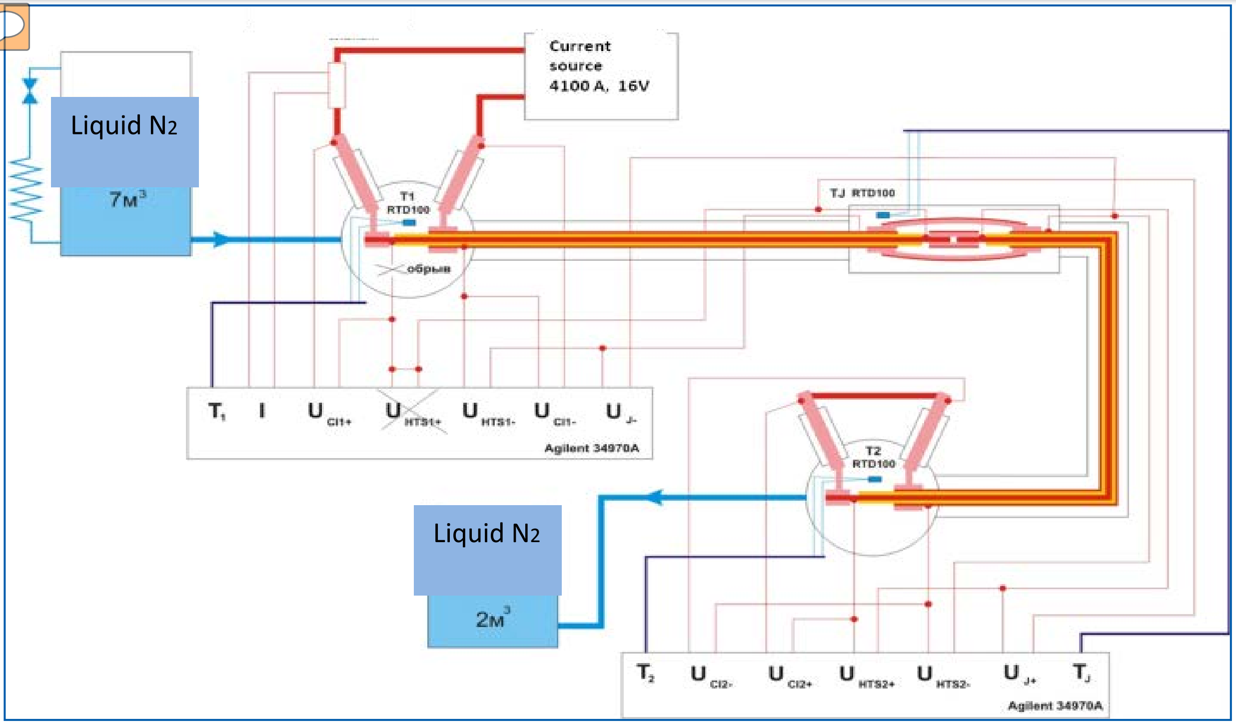
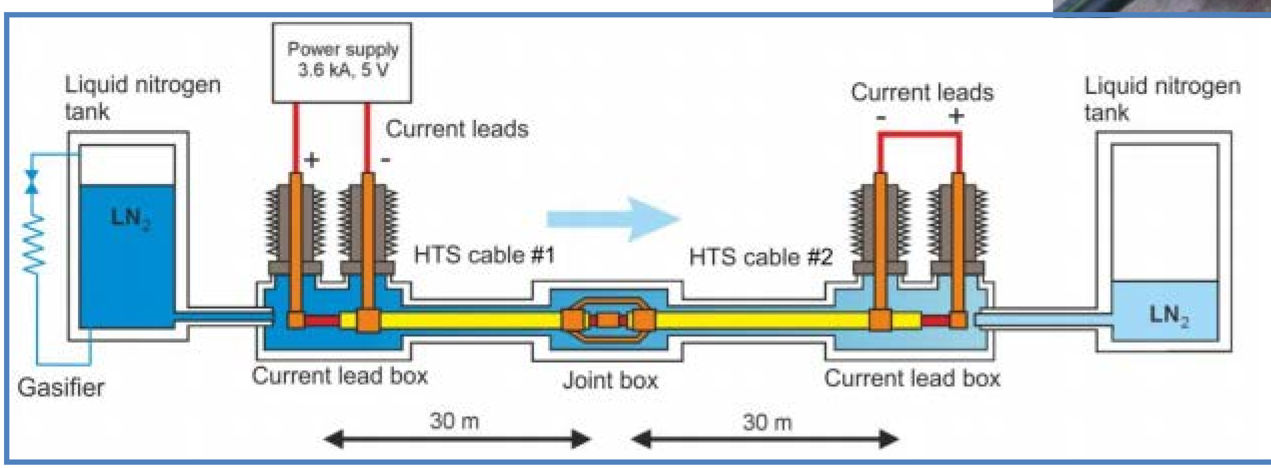
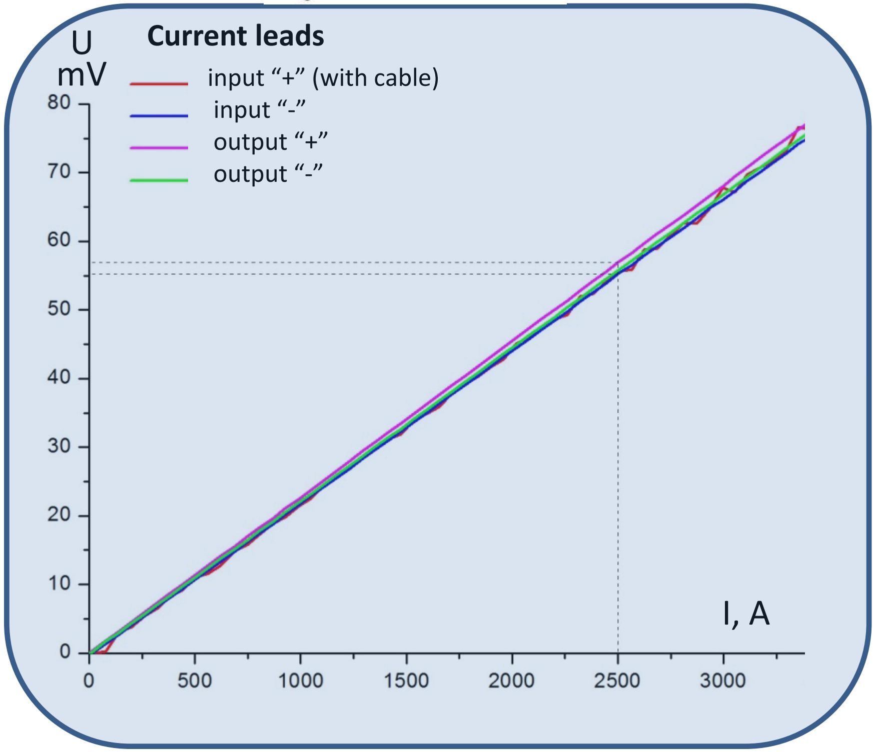
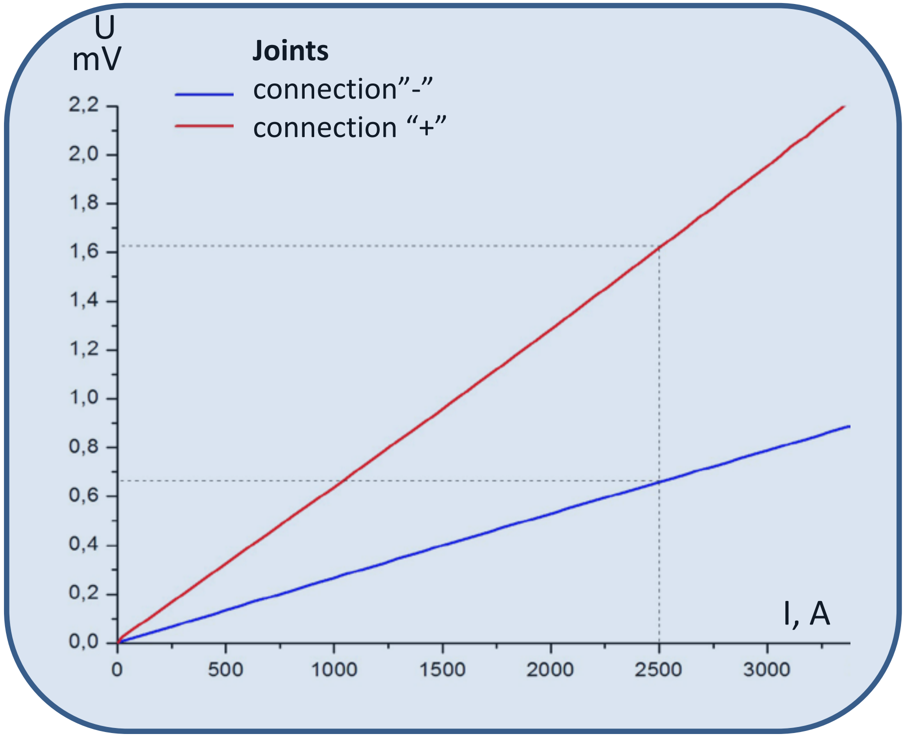
2x30 meters HTS DC line test





2x30 meters HTS DC line test





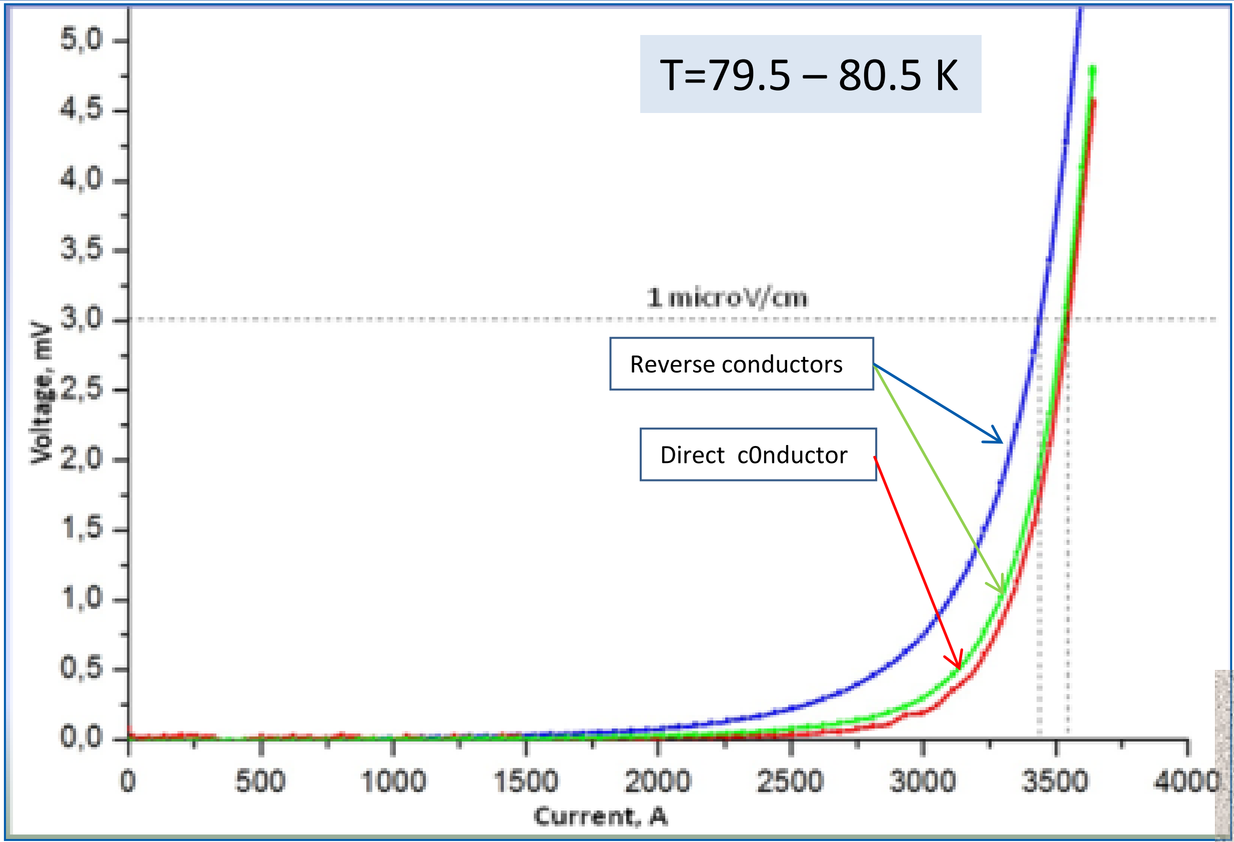
Current leads resistance R=20 μΩ (I^2r=125W)

Joints: R_+=0,65 μΩ; R_-=0,26 μΩ
(+I^2r=4.1W; -I^2r=1.6W) will be reduced.

2x30 meters HTS DC line test

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 Ic.
- Design of the cable, joint and current leads was confirmed

Results of this test allow us to start manufacturing of full-scale cable lengths

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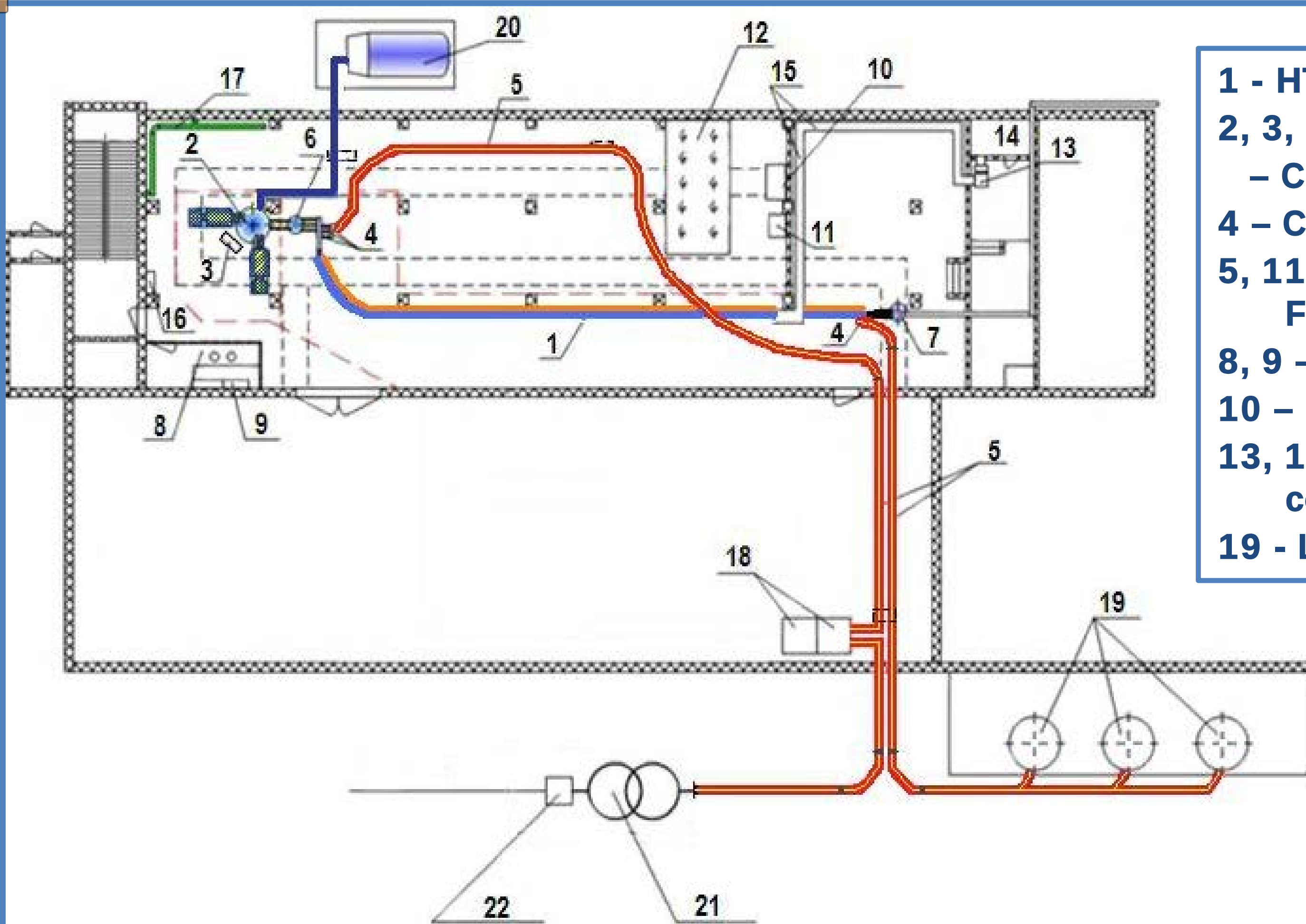
Experimental facility for superconducting device testing at the R&D Center @ FGC UES



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

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Experimental facility for superconducting device testing at the R&D Center @ FGC UES

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.