

HTS DC Transmission Line for Megalopolis Grid Development

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Abstract. Using of HTS AC and DC cables in electric power grids allows increasing of the transferred power, losses diminishing, decreasing of exclusion zone areas, the enhancement of the environmental conditions and fire/explosion safety of electric power systems. However, the use of DC superconducting cable lines together with converters brings additional advantages as reduction of losses in cables and suitable lowering of refrigerating plant capacity, as well as the realization of the function of short-circuit currents limitation by means of the appropriate setting of converter equipment. Russian Federal Grid Company and its R&D Center started the construction of the DC HTS power transmission line which includes the cable itself, cryogenic equipment, AC/DC converters, terminals and cable coupling boxes. This line will connect two substations in Saint-Petersburg - 330 kV "Centralnaya" and 220 kV "RP-9". The length of this HTS transmission line will be about 2500 meters. Nowadays are developed all the elements of the line and technologies of the cable manufacturing. Two HTS cable samples, each 30 m length, have been made. This paper describes the results of cables tests.

1. Introduction

The efficiency of electricity generation and its transportation to the consumer are becoming the priorities in the development of power industry in the XXI century. Simultaneously, the demands for environmental and resource-saving parameters in all phases of production and distribution of electricity are increasing. Meeting the growing demands is only possible by using the most progressive and advanced technologies, including superconductivity. AC and DC superconducting cables allow the increase of transmission capacity, the decrease of power losses, reducing of allotment areas and environmental conditions improvement. HTS DC cables give additional advantages including increased capacity without increasing of fault current levels, active and reactive power regulation, lower power losses and bigger crucial length of transmission as compared with HTS AC cables. These advantages generate additional interest to the HTS DC cable lines both from high voltage (HV) transmission [1] and medium voltage (MV) distribution [2-4]. The load growth in metropolitan power systems makes it necessary to put into operation new generating and network equipment. In order to improve the reliability of power supply the reservation of substations is implemented (new transmission lines are built and brought into service) that occurs in multilinked connection network creation. These trends contribute to higher levels of short circuit currents in power systems. To reduce the levels of short circuit currents to safe values current-limiting reactors and network sectioning are used. However current-limiting reactor application leads to additional power losses and network sectioning results in the reduction of consumer power supply reliability. MV DC transmission lines with HTS cable commissioning (instead of AC cross-linked polyethylene (XLPE) insulated cables with current limiting-reactors) are regulating element of the grid capable of power flow regulations and fault current limitation. The Federal Grid Company of Unified Energy System (FGC UES) started the activity aimed to the building of a HTS DC cable link in St. Petersburg by connection substation 330 kV "Centralnaya" and substation 220 kV "RP-9". The design, production technology and first tests of HTS cable for the project are describe below.



2. Choice of the pilot object for HTS DC Cable line.

An analysis of the current state of the power supply in large cities has been conducted in joint-stock company (JSC) "R&D Center of FGC" and JSC «R&D Center of UES». Both, the current state of the power grids of megalopolises, as well as the prospect development up to the year of 2020 have been taken into account. The steady state, overload regimes and short-circuit current value estimation were analyzed. As a result, a pilot research facility for the HTS DC cable line has been selected in St. Petersburg as a link between two substation 330 kV "Centralnaya" and 220 kV "RP-9" (figure 1). As seen from figure 1, HTS DC cable line provides mutual redundancy of two sections of power systems.

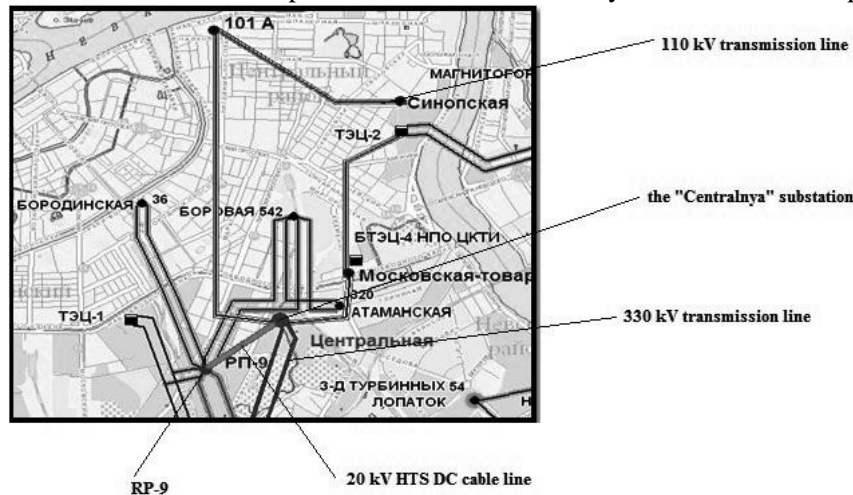


Figure 1. HTS DC cable line installation in the St. Petersburg's electrical grid (project).

As shown in Table 1, HTS DC cable line installation does not increase fault current, unlike the case of the AC cable line, therefore this installation obviates the necessity of circuit breaker replacement.

Table 1. Short-circuit current levels in the proposed facility installation site.

Object	Short-circuit current, kA			
	3-phase AC cable line	HTS DC cable line	1-phase AC cable line	HTS DC cable line
«Centralnaya» subst.	40	18	41	22
«K3-9» substation	40	26	46	27

Increased load capacity of HTS cables can reduce the number of parallel lines, as well as decrease the load on the existing lines. HTS DC cable line parameters are shown in Table 2.

Table 2. HTS DC cable line parameters, data are taken from [4].

HTS DC line length, km	Transmission power, MW	Voltage, kV	Operating current, A	Overload current, A	Power reverse
2.5	50.0	20.0	2500	2750	yes

3. HTS Cable design

As the basic design was chosen unipolar cable with the reverse conductor (figure 2). The cable consists of concentric layers containing the following elements:

- former and stabilizing element;
- superconducting central wire playing a role of the forward conductor;
- high voltage insulation;
- superconducting reverse conductor;
- external stabilizer;

- external (screening) insulation;
- electric (non- superconducting) screen;
- cryostat consisting of two corrugated tubes with the vacuum thermal isolation and protecting layer.

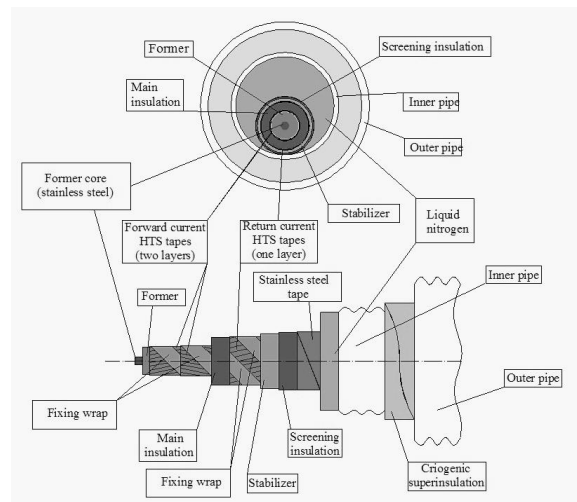


Figure 2. Schematic diagram HTS DC cable.

The external cable diameter is 39 mm. As a basic superconducting material for the cable the 1G HTS tape is used produced by SEI (Japan), type HT-CA. Forward conductor include 22 tapes with $I_c=160A$, placed in two layer. Reverse conductor include 19 tapes with $I_c=180 A$, placed in one layer.

In this cable the forward and reverse currents flowing only through superconducting elements that causes the absence of Joule losses and electromagnetic field location is only between two superconducting poles. The absence of stray fields and using of the liquid nitrogen as a coolant makes these cables environmentally friendly and fire-safe. The requirements to the cable placement are essentially simpler than other designs since there are neither electromagnetic nor thermal stray fields.

Two 30-meters cable samples were made in serial cable plant “Irkutskable”. Current leads and coupling box were designed and produced in NRC Kurchatov Institute [5].

4. Preliminary Cable test results.

Preliminary test was carried out by temporary scheme in NRC Kurchatov Institute. The main goals of the first test were: check of cabling technology and measurement of electrical resistance and vacuum tightness of current leads and coupling box.

Current source “plus” pole was connected to the direct conductor and “minus” pole to the reverse conductor on one side of the test line. Current leads on another side of the line were shorted. Consequently the current flows through four 30 meters HTS cable conductors, two joints and four current leads. Voltage taps were placed on each of the conductors and joints in cold area. Voltage taps on the reverse conductors were attached to the ends of it, and that’s why there is a copper-to-superconductor connection between taps.

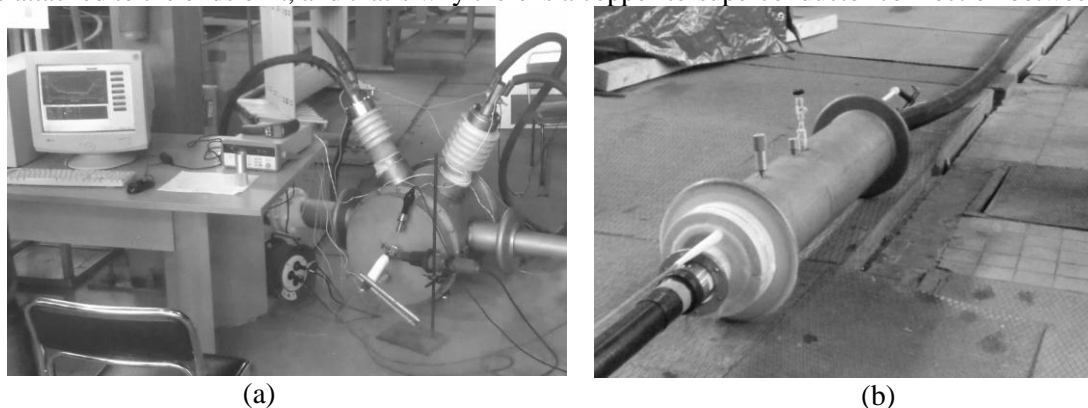


Figure 3. Cable current leads (a) and coupling box (b) during testing.

As a result a small resistive component is present in the measured signal. Cooling cable line was made by the time scheme by pumping liquid nitrogen through the line between the two cryogenic tanks and temperature in the line was 79 K. The results of three conductors (one voltage tap was tear during assembling) critical current measurement are shown on figure 4.

The critical current of HTS conductors was within 3420 - 3550 A. The critical current of the cable is practically equal to the sum of critical currents used superconducting tapes that indicates the development of a reliable cabling technology. Current leads and coupling box (figure 3) has successfully passed the tests on vacuum tightness and overpressure. All fittings demonstrated reliable operation without the appearance of leaks or intensive freezing during two cooling sessions.

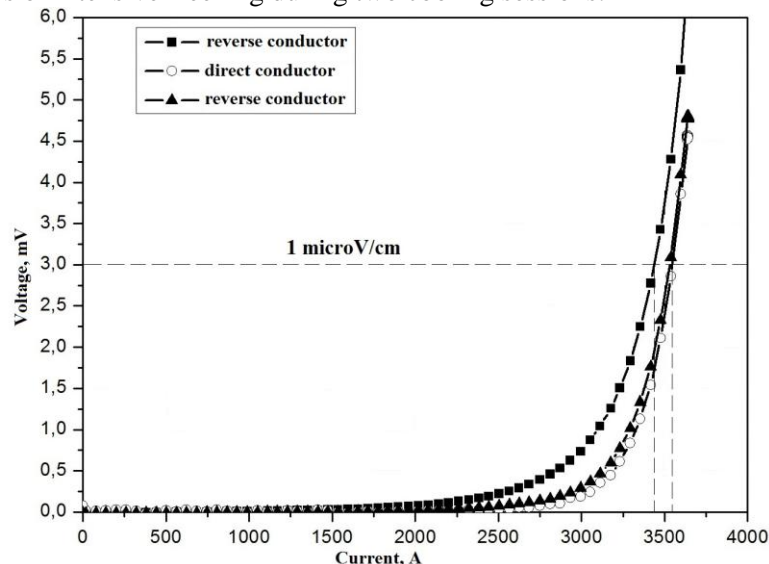


Figure 4. V-I curve of 30 meters pieces of HTS cable.

Electrical resistance of the current leads and joints remained stable in all range of currents. Resistance of two conductors in the coupling box were less than $1 \mu\Omega$. Resistance of the four current leads was within 21-23 mOhm that corresponds to the total Joule heat generation ca. 140 Wt at the rated current.

5. Conclusions

Overall, the HTS DC cable line exerts numerous positive effects concerning power systems' regimes of megalopolises due to the ability to transmit high power, decrease of the load of parallel lines and due to the high level of controllability of these systems. The HTS DC cable line installation improves the reliability of energy supply to the consumers at the expense of mutual redundancy. Along with this, it does not increase short-circuit currents in the place of engagement and, consequently, it obviates the necessity of replacing the switching equipment.

Sant-Petersburg Project is the first network HTS DC cable demonstration in Russia. Cable manufacture technology was developed and two 30 meters samples was made. First tests confirmed the compliance of the measured parameters of HTS cable, current leads and coupling box to design value. All equipment for HTS DC line including cryogenic system and convertors will be made to the end of 2014 year.

6. References

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