

HTS DC Cable Line Project: On-going Activities in Russia.

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Abstract—Previous research has shown that implementing HTS DC power cables in electrical grids of large metropolitan areas will have major positive impacts on power system operation and control. Current activities in Russia comprise developing a 2.5 km HTS DC cable and its installation in St. Petersburg electrical grid. This work includes five major parts: installation site selection, cable calculation, development and manufacturing, cryogenic equipment development, AC/DC converter development and testing of all DC line elements. As of today, the list of subcontractors has been approved. The purpose of this report is to summarize current results and future work.

Index Terms— HTS DC cable, electrical grid, AC/DC converters, cryogenic equipment.

I. INTRODUCTION

The use of HTS technologies in power systems provides the following benefits: enhancement of the transmission capacity, lower losses, lowering of allotment areas, improvement of environmental conditions, ensurance of fire and explosion safety. There can be built both the DC and AC HTS power transmission lines [1].

HTS DC cables give additional advantages including increased capacity without increasing of fault current levels, active and reactive power regulation (in this case – with use of voltage converters) and lower power losses as compared with HTS AC cables. Moreover, modern HTS DC cables may be equipped with a special automatic adjustment system that damps power system oscillations caused by various dynamic disturbances. It should be also noted that at the length of several kilometers, HTS DC cables are less expensive than HTS AC ones transmitting the same power [1]. Using HTS DC systems for the asynchronous unification of large power systems seems to be promising.

Therefore, when using HTS DC cables we acquire a new quality of power transmission which becomes a controlled element of the grid able to adjust the distribution of power and to limit fault currents. According to the estimations performed by some Russian utilities HTS DC cables can provide solutions of many problems existing in electric grids of megalopolises at 50 – 250 MW cable power levels

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transmitted. The modern level of development of power engineering and properties of HTS materials reached nowadays allow transmission of these power values at typical voltages (10-35 kV). Since there are a lot of obvious advantages of HTS DC cables, in many countries, e.g., in the USA, Korea, China, Japan etc. had begun works to construct these lines for various purposes [2-6].

II. ST. PETERSBURG PROJECT OF HTS DC TRANSMISSION LINE

The development of HTS technologies in Russia is attributed to successful tests of experimental 30 m and 200 m HTS AC lines [1, 7]. Based upon this experience the Federal Grid Company of Unified Energy System (FGC UES) started a series of projects aimed to the building of a HTS DC cables including the cryogenics, AC/DC converters, terminations and cable coupling joints. This project will be realized in one of St. Petersburg regions, where the problem of increasing the reliability of electric power supply together with the fault current limitation are of special importance.

The FGC UES financed the project. Naturally, one of the project aims is the creation of an effective scientific and industrial cooperation of various organizations which will be able to use the results obtained for any other object of electric power engineering. The general schematic diagram of the organization of works is shown in Fig. 1. The FGC UES is the customer, its 100% affiliate Research & Design Center for Power Engineering (RDCPE) is the general contractor. The project consists of five principal tasks shown in Fig. 1. The tasks of direct manufacturing of the HTS DC cable elements are solved both by the industrial enterprises and scientific organizations.

The grid investigations carried out gave more than ten possible versions of this project. They included an analysis of the power balance in promising layout of power systems of St. Petersburg and its region and also estimation of the feasibility of using HTS DC cables taking into account the acceptability of electric operation modes and fault current levels in the power system. The results of these investigations allowed choosing as a pilot draft a HTS DC cables in the electric power system of St. Petersburg connecting 330 kV substation «Tsentralnaya» and 220 kV substation «RP-9». This connection will be performed from the low voltage side what is caused by the advantages of this approach as compared with linkage from the high voltage [8].

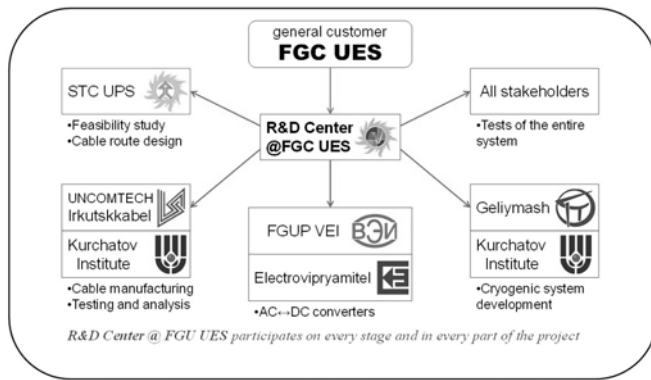


Fig. 1. Project cooperation.

The schematic diagram of the electric power grid of 220 kV and 330 kV in the region of St. Petersburg where the HTS DC transmission line is to be built is given in Fig. 2.

The investigations performed show that in the central region of St. Petersburg there is an opportunity of a lot of post-fault oscillation modes causing malfunctions of the power supply. The subsequent calculations showed that the reservation of the electric power supply by building and putting into operation a new XLPE cable or gas-insulated line between the substations 330 kV «Tsentralnaya» and 220 kV «RP-9» worsens these post-fault modes since there appear additional current overloads in adjacent transmission lines and substations bus.

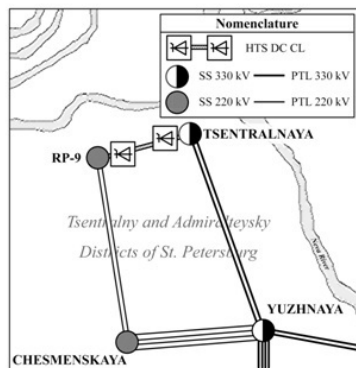


Fig.2. The HTS DC cable link of two substations in St. Petersburg.

III. BASIC CHARACTERISTICS OF THE CABLE LINE

The HTS DC transmission line consists of the cable itself, cryogenic system, and two converting substations at each end. The block diagram of the DC transmission is shown in Fig. 3 and the integrated technical characteristics of the line are given in Table 1.

A. HTS Cable

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

- former and stabilizing element;

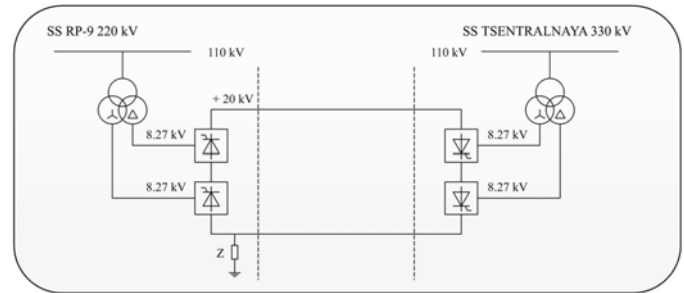


Fig. 3 – Block diagram of the transmission with the HTS DC cable.

TABLE I
 TECHNICAL CHARACTERISTICS OF THE LINE

No	Parameter	Value
1	transmission arrangement	0±I _{nom}
2	rated current	2,5 kA
3	rated voltage	20 kV
4	approximate length	2500 m
5	rated power	50 MW

- 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 insulation;
- protecting layer.

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

In a cable of this design the forward and reverse currents are flowing only via superconducting elements what causes the absence of Joule losses. The electromagnetic field of this cable is only inside its cross-section. The absence of stray fields and using of the liquid nitrogen as an impregnating agent makes these cables environmentally friendly and fire-safe. The requirements to the cable placement are essentially simpler than for other designs since there are neither electromagnetic nor thermal stray fields.

The cable schematic diagram is shown in Fig. 4.

B. Cryogenic Part of the Cable Line

The cooling of the HTS cable is performed by the liquid nitrogen pumping through the space between the outer cable surface and internal cryostat surface. The schematic diagram of the line cooling system is shown in Fig. 5.

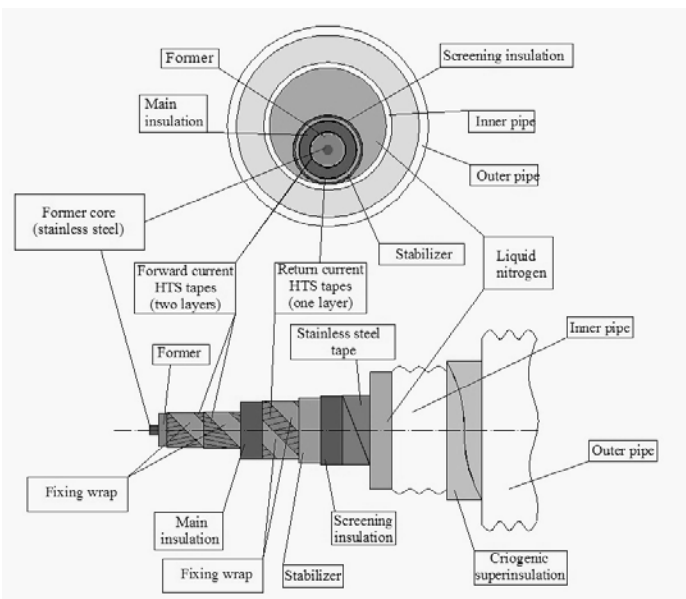


Fig. 4. Schematic diagram HTS DC.

One of the basic problems of the long-length cryogenic systems design is the heat and mass transfer calculation of the systems flow pass. It is due to a very narrow range of the operating temperatures and pressures of a HTS cable. The liquid nitrogen operating temperature range is limited below

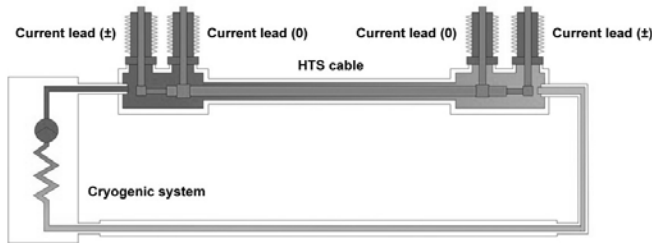


Fig. 5. HTS DC cable cooling diagram.

by the solidification and above by the boiling temperature and is $77,4\text{ K} - 63,3\text{ K} = 14,1\text{ K}$ only under 1 atm, though it can be expanded at higher pressures (e.g., to $20,6\text{ K}$ under 2 atm.). But expanding of the temperature range leads to the increasing of the temperature at the cryogenic tube outlet and, hence, to the undesirable lowering of the critical current. The operating pressure range lies within the 1.0 – 15.0 atm. Therefore, there are obvious strong restrictions of ΔT and ΔP for long cable lines, which, in practice, are absent for the short ones. For the project considered is accepted $\Delta T_{max} \leq 12\text{ K}$ over the cable length 5.0 km and $\Delta T_{max} \leq 6\text{ K}$ over the cable length (2.5 km.). In this case is desirable to limit the pressure drop in the forward and reverse cryostats by 5-6 Bar for each of them. The results of calculation of the pressure drop and temperature difference over the cable length 2,5 km and cryostats with the internal corrugated tube diameter of 60 mm, 64 mm and 66 mm are given in Fig. 6.

As it can be seen from Fig. 6 the parameters given above may be reached when using the Nexans cryostat with the

internal diameter of the corrugated tube 64 mm and the external tube diameter 110 mm. In this case the operating

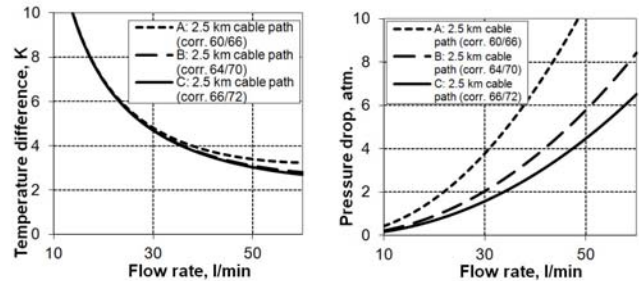


Fig. 6. Temperature difference (left) and pressure drop (right) in corrugated cryostats 2,5 km of length.

range of flow rates is 25-50 liters per minute.

The schematic diagram of the cryogenic system is shown in Fig. 7. The nitrogen circulating through the cryostat with the cable is super cooled in the heat exchanger immersed into the liquid nitrogen the vapor over which are evacuated by the vacuum pump. Due to this is obtained the temperature decreasing.

The liquid nitrogen circulation through the cable (pos. 6) is performed by a cryogenic pump (pos. 7). In the heat exchanger (pos. 5), immersed into the supercooled nitrogen, it is cooled down up to the temperature of 65 K. After the cable pass the liquid nitrogen returns to the cryogenic pump inlet at

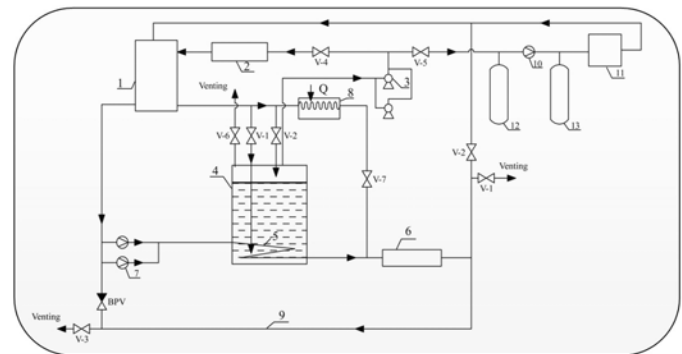


Fig. 7. schematic diagram of the HTS cable cryogenic system. 1 – liquid nitrogen storage vessel; 2 – cryogenic condenser of the nitrogen vapor; 3 – vacuum pump; 4 - liquid nitrogen vessel with the supercooling heat exchanger; 5 – heat exchanger; 6 - cable; 7 – circulating pumps; 8 – atmospheric evaporator; 9 - pipeline for the circulating nitrogen return; 10 - compressor; 11 – nitrogen liquefier; 12 – high pressure receiver; OK - back-pressure valve.

the temperature about 75 K which is supported by the circulating nitrogen flow rate due to the cryogenic pump rotation frequency. The nitrogen supercooling in the vessel (pos. 4) is supported due to the vacuum pump operation (pos. 3). The nitrogen vapor ejected by the vacuum pump is recondensed in the cryogenic condenser (pos. 2) and then as a liquid nitrogen return storage vessel (pos. 1).

The scheme considered provides the circulating nitrogen feed at the cryogenic pump inlet. To ensure the system operation reliability the cryogenic and vacuum pumps are dubbed. There are following modes of the system operation: line cooling down, normal operating mode, stop and the

heating up.

C. AC/DC Conversion Units

The DC transmission system of the HTS DC transmission line has two complex rectifier converter units positioned at the ends of the DC transmission line and connecting the latter with AC grids. These units are two-bridge twelve-pulse network commutated current converters. The DC poles of both units are connected via the HTS cable. The transformers of the converters are three-phase and triple wound. The reactive power compensation and suppression of the higher harmonics of the rectifier converters is performed by capacitor filter compensating units positioned on the AC network side. On the DC side are provided signal filtration circuits tuned to the sixth and twelfth harmonics.

The project provides bilateral power transmission, and each of the converters can operate in both the rectifier and inverter mode. The adjustment of the transmitted power is also provided. The variations of the transmitted power cause in turn that ones of the reactive power and that's why the adjustment of the latter is provided too. It is performed by the commutations of the filtering compensating capacitors batteries. The basic parameters of the converting unit are given in Table 2.

TABLE II
 TECHNICAL CHARACTERISTICS OF THE CONVERTER.

converter circuit	twelve-pulsed
network voltage	110/8,7 kV
DC voltage	20 kV
rated current	2500 A
rated power	50 MW
Transmission reverse mode	present

IV. PERIOD OF THE PROJECT REALIZATION

The first full scale sample tests will be made in 2013 year. Development and testing of all elements of the HTS DC cables are planned to be completed in 2014 year. In current year started the design and exploratory work of cable lying and creation of the necessary infrastructure of the substations connected by this line. The cable lying should be performed to the middle of 2015 and final mounting and energizing of the HTS DC transmission line in St. Petersburg – to the end of that year. Experimental operation will occur in 2016.

V. CONCLUSIONS

1. Deployment of HTS DC transmission lines is a competitive and effective solution for the electric power systems of megalopolises including the enhancement of the transmission capacity, mutual reservation without an increasing of fault current levels, enhancement of control and maneuverability of electric grids.

2. The results of the studies performed showed that the putting into operation HTS DC cable link between substation 330 kV «Tsentralnaya» and 220 kV «RP-9» was the most appropriate site for the pilot project implementation

3. To the present time there have been chosen the list of

contractors/subcontractors of the St.-Petersburg HTS DC transmission line project, developed the design of basic elements and determined the periods of manufacture.

4. The successful introduction of this HTS DC transmission line into the St. Petersburg electric power system will allow checking up the basic technical solutions for this technology and gaining an experience of the commercial operation of it what in turn will provide further building of circular DC electric power grids in megalopolises.

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