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First Russian long length HTS power cable

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ABSTRACT

The Russian R&D Program for superconducting power devices is underway, supported both by government and electric power companies. In this program R&D on HTS power cables is considered as most advanced and close to commercialization. In the framework of the program, several, heavily instrumented, 5 m cables have been tested following by the 30 m – 3 phase experimental power cable development and testing in 2008–2009. The latest achievement is development and testing of the first long length 3 × 200 m power cable with rating 1.5/2 kA–20 kV. In parallel with just the cable development the innovative cryogenic system has been developed as well for the cable cooling. The system is using neon as working substance and radial turbo-machines in refrigerator. Cooling power is up to ~8 kW at 65 K, inter-maintenance time ~30,000 h. The cryogenic pump with superconducting motor can be used to provide subcooled liquid nitrogen flow ~0.1–1.5 kg/s at 0.1–2.5 MPa pressure. After extensive tests at special test facility, HTS power cable and cryogenic system are planning to be installed at some substation in Moscow utility grid. In this review some details about Russian HTS power application program, 200 m cable and cryogenic system designs and tests results are presented.

1. Introduction

In our previous presentations [1,2] we reported about Russian R&D Program for superconducting power devices, supported both by government and electric power companies. In this program, the development of HTS power cables is considered as the most advanced and close to commercialization. In the framework of this program, several, heavily instrumented, 5 m long cables have been tested. Both 1G and 2G (first and second generation) HTS wires were used for 5 m cables [3–5]. As the second step, a 30 m long, 3 phase experimental power cable with rated parameters 1500/2000 A and 20 kV has been developed, produced and successfully tested [2,6]. During the experimental cable tests, critical current dependencies on temperature of all phases were measured [2,6]. The cable underwent high voltage, full load and fault current tests, which all have been passed successfully.

The following step has been the development and test of 3 × 200 m power cable with same rating: 1.5/2 kA–20 kV. This cable has a superconducting shield and is made of 1G DI-BSSCO™ HT-CA wires from Sumitomo Electric Industry Co. This cable is the first long length – full size HTS power cable in Russia and biggest HTS power cable developed so far in Europe. The cable successfully passed acceptance test and is being preparing to be reinstalled into the Moscow utility grid.

Along with cable the innovative cryogenic system has been developed as well for the cable cooling. The system is using neon as working substance and radial turbo-machines in refrigerator.

In this review we are presenting more details about 200 m cable and cryogenic system. The details about the test facility with capability to test HTS power devices under full load have been presented in [1,2,7].

2. The Russian program

The Russian program for introduction of superconducting devices to electric power industry has been officially launched on May 16, 2007, by Mr. A. Chubais – at that time the Head of the Russian company "United Energy Systems". The program includes both the R&D and introduction into real grids were HTS power cables are of the first priority as the most advanced and close to commercialization.

The Russian Scientific R&D Cable Institute (known by its Russian abbreviation: "VNIIKP") is the major performer of the R&D works in HTS cables. The HTS cable development path at VNIIKP can be divided into three phases: *Science → Technology → Production.* In each phase the research and developments were completed, sometimes in parallel [1]:

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Science

- Incorporation of previous experience in LTS and HTS cables developments at VNIIKP [8,9].
- Theoretical fundamentals [10–12].
- Basic HTS wire studies [13,14].
- Test facility development and model/prototype/witness samples with 5 m length studies [3–5].
- Experimental test facility for power devices development [1,2,7].
- Experimental 30 m cable test [2,6].

Technology

- Technological experiments [3].
- Development of fabrication machines and equipment [1].
- Current leads (terminations) development [1,2,6].

Upon completion of all tasks above it was possible to start the *Production* phase that eventually led to the production of 3 × 200 m HTS power cable described here.

Along with VNIIKP responsible for HTS cable development, three more teams participated in the 3 × 200 m projects, namely

– Moscow R&D Center for Power Engineering as the major test site permitting test of different HTS superconducting devices under full load [2,7].
– Moscow Aviation Institute – Technical University (MAI) as a developer of cryogenic cooling system and current leads.
– Krzhizhanovsky Energy Institute as a system integrator and general leading of the project.

The synergy aroused from these teams collaboration led to the successful completion of the first stage of the project – HTS power cable development and its acceptance test. The funding of the project was split 50/50 between the Federal Grid Company "United Energy System" and the Ministry of Science and Education of Russian Federation.

3. The 3 × 200 m HTS power cable

The cable nominal rating is similar to that of the 30 m cable: 20 kV–1500 A with possible 30% overload, i.e., 2000 A at 20 kV. This means 50 MVA–70 MVA of transmitted power. Many the design features of this cable are similar to those of the 30 m cable described in [2,6]. For example, three separate phases placed in three different cryostats. The significant difference is that a superconducting shield is used in the 200 m cable. Other features of the 200 m cable are as follows:

- Basic wire: Sumitomo Electric DI-BSCCO™ HT-CA 1-G tapes with Cu alloy lamination.
- Design: Central spiral, copper former, two layers of the cable core and one layer for the superconducting shield, copper protection for superconducting shield.
- High voltage insulation made from a standard cable paper.
- Cryostats: NEXANS flexible cryostats with 92 mm outer diameter, with PE protection cover extending up to the diameter of 102 mm.

The artistic view, a photo of the cable model and cross-section of the cable are shown in Fig. 1.

Several technologies have been developed as mentioned before to produce the cable. The cable has been produced at VNIIKP facilities on the fully industrial basis, as it is shown in Fig. 2. All operations but insulation have been made in VNIIKP. Cable's insulating has been made by the standard method the at the Russian Kamkabel factory in the Perm city some 1500 km from Moscow. Assembling into three flexible cryostats via the pulling-through method has been made in VNIIKP facilities at Protvino city as shown in Fig. 3.

In collaboration between MAI and VNIIKP the highly effective high voltage current leads have been developed and produced. The current leads produce connection of superconducting shields and liquid nitrogen level. The artistic view of current leads and their photo is presented at Fig. 4. The cable produced has been

Fig. 1. Artistic view, photo of the cable model and cross-section of the phase of 200 m cable. 1 – Former – a spiral of stainless steel, surrounded by a bundle of wires made of copper and stainless steel, wrapped in copper tape – 2 and 3; 4 – two layers of HTS tapes; 5 – high-voltage paper insulation; 6 – HTS shield; 7 – flexible copper strips to protect shield, wrapped by tapes of stainless steel; 8 – flexible cryostat, 200 m long.

Fig. 2. Production of the 200 m HTS cable. From left to right: layer's twisting, superconducting shield's twisting, cable on a take on drum.