China's 30m, 35kV/2kA ac HTS Power Cable Project

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Abstract. The project of a 30m, 35kV/2kA$_{rms}$, 3 phase, warm dielectric HTS power cable system is underway in China. This system will be installed in China Southern Power Grid at Puji substation of Kunming, Yunan province in 2004. We have carried out a series of experiments to investigate the possible winding angles and layer configurations of the cable conductor with Ag sheathed Bi-2223 tapes, different LN_2 cooling mechanisms, termination configurations, and fabrication techniques. For better understanding of the basics of a HTS cable system and practicing new fabrication techniques, a 4m-superconductor cable with terminations and a close cycle cryogenic system was built and tested. In this paper, we will give out the detailed parameters of the 30m-cable system and the work plan of the project.

1. Introduction

Upgrading power utility industry is one of the fields to which the HTS technology can contribute. Among all possible power utility applications of HTS, power transmission cable is of great importance.

The main advantages of superconductor cables over conventional cables are high capacity, superior efficiency, and compactness. Use of superconductor for transmitting electricity can reduce the energy loss due to extremely small Joule losses. Superconductor cables will also allow low voltage and large current transmission systems to be constructed. This will reduce the cost of high voltage auxiliary equipment and the impact on environment.

Researches on superconductor power cable and its applications have been carried out in tens of programs around the world since 1992([1-5], for example). Different conductor configurations and different dielectric designs have been intensively investigated. Quite a few prototype superconductor cables and terminations have been fabricated and tested ([6-9], for example). Evaluations of the impact of application of superconductor cable on power grid and environment have been conducted [10-12]. Two superconductor cable systems were installed in live power transmission lines for trial operation. One of them is at Southwire Company's power supply system in Carrollton, Georgia, USA. Southwire Company, Oak Ridge national Lab and other collaborators developed the cable system. The installation was finished at the end of 1999. The other is in the Danish power grid close to Copenhagen, which was completed by NKT and its collaborators in May, 2001.

With the support from Beijing municipal government and the Chinese Ministry of Science and Technology, we started our superconductor cable project at the end of 2001. Our plan is to complete the manufacturing of the cable conductors, the terminations, and the liquid nitrogen cooling system by the end of 2003. This cable system will be installed at Puji Substation in Kunming, Yunnan, China in the spring of 2004. This substation is the provider of electricity to 4 industrial customers (including 2 metallurgical refineries) and about 100,000 residential population.

2. System description and technical parameters

The goal of our ongoing project is to develop a 30 meter 3 phase, 35 kV/2 kA_{rms}, and ac power transmission cable system. The detailed technical parameters of the cable system are listed in table 1.

The 3-phase system is made of three single-phase cables. Each cable consists of 6 layers of total 112 BSCCO 2223 tapes. The 61filament silver sheathed BSCCO tapes were produced by Inmost of China, which have a I_c >60A at 77 K, self field.

The geometrical and dimensional descriptions of the former, conductor, the cryostat, and the dielectric of the cable are given in table 2.

The drawing of the design and the product photo picture of the termination are demonstrated in figure 1a and figure 1b respectively. In the termination's design, we emphasize simplicity and genericness. The basic structural design could be used for warm dielectric cables in a great current and voltage ranges. Since the terminations are at high voltage under working condition, epoxy tube is used as the connection path of flowing liquid nitrogen from the refrigeration unit to the cable. The cryostat of the termination is made of two coaxial stainless steel tubes. The space between the walls of the tubes is vacuumed at <0.1 Pa. Getter is used for enhancing the performance of the cryostat.

The cable's liquid nitrogen cooling system consists of 8 Cryomech AL 300 refrigerators, a Bob Nickels BNCP-30-000 liquid nitrogen pump, a sub-cooling tank with heat exchangers, a liquid nitrogen tank, and a mechanical pump. The cooling capacity is about 2000 watts at 75 K. The 8 GM refrigerators are working in parallel. Figure 2 is the flow diagram of cooling system of the cable. Figure 3 gives the schematic drawing of the configuration of the sub-cooling tank. There are 2 advantages by using 8 refrigerators for the cable cooling system: the first is that some refrigerators can be turned off when the load of the cable is much lower than the rated value so the cooling energy consumption can be reduced under such situation; the second is that it makes it possible to do maintenance and repair without shutting down the whole system.

Table 1. Cable Parameters

Subject	**Specification**	**Subject**	**Specification**
Mode of Cable	Three, single phase,outdoor	Operation Altitude	2,000 m
Length	33 m(flange to flange)	Outer Diameter of Cable	<115 mm
Rated Voltage	35 kV	Total Loss of Termination	<120 W/unit
Rated Current	2 kA(rms)	Cooling Fluid	LN_2
Shortcut current	20 kA	Cooling Capacity	2,000W at 75K
Dielectric	Warm	Inlet Temperature	70~72K
Ac Loss of Cable	<1.0 W/m	Outlet Temperature	74~76K
Heat Leak of Cable	<1.5 W/m	Reliability Requirement	>20000 hours

Table 2. Major design parameters of the cable conductor

Item	**Specification**
Former Length	33 m
Former ID/OD(with Braiding)	30/35 mm
Layers of HTS Tape	6
Winding Angle	TDT, angle varies in different layers
ID of Cryostat	43 mm
OD of Cryostat	70 mm
Dielectric Type	XLPE
Nominal Thickness of Dielectric	11 mm

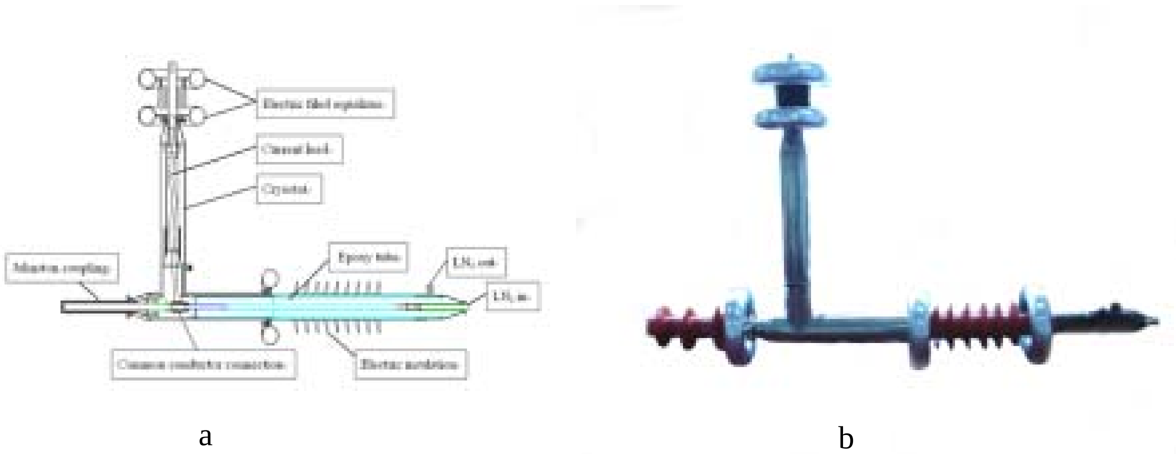

Figure 1. a. Design of the termination. b. Photo picture of the termination.

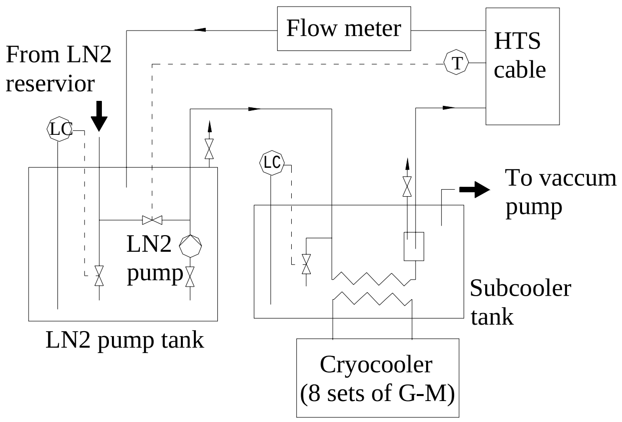

Figure 2. The flow diagram of cooling system of the cable.

3. Project participants

The developer of the 30-meter power cable project is Innopower Superconductor Cable, Co, Ltd. of Beijing, China. Major collaborators include Yunnan Electric Power Group, Institute of Plasma Physics, Academia Sinica, 16^{th} Research Institute of China Electronics Technology Corporation, Shanghai Cable Works, Innova Superconductor

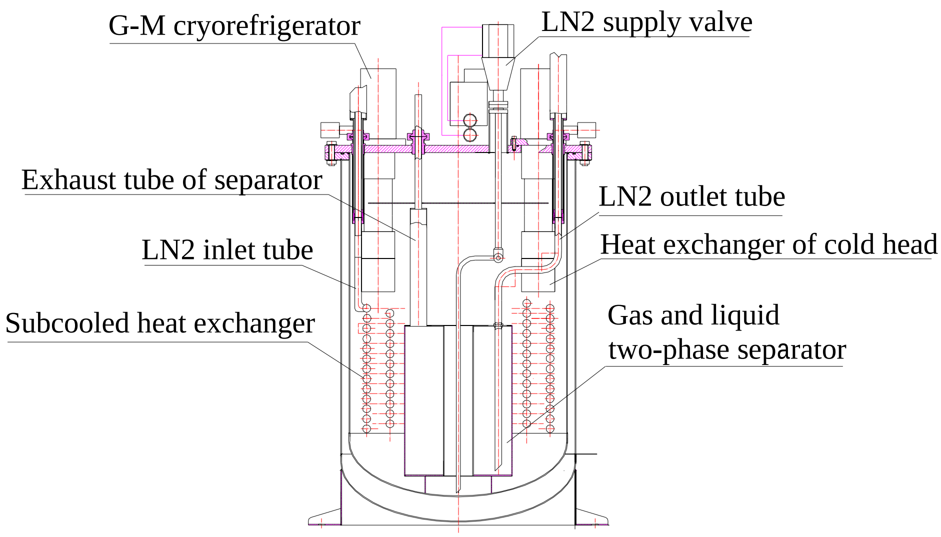

Figure 3. The schematic drawing of the configuration of the sub-cooling tank.

Technology, Co, Ltd, Applied Superconductivity Research Center of Tsinghua University, Huazhong University of Science and Technology, and NEXANS.

The participants of the project come from a wide spectrum of disciplines, including superconducting material and device manufacturer, power utility company, national research lab, power transmission cable manufacturer, and university.

4. Project work plan and progress

This project was started at the end of 2001 and the expected installation completion date is March 31, 2004.

To test and refine the designs of the system and to develop manufacturing techniques, we have carried out numerous experiments and made 6 short cable conductor models and a pair of termination models. These experiments include the influences of mechanical strain and stress, magnetic field, and thermal cycling on I_c of the BSCCO tapes, thermal conductivity test of the materials in the cable structure, test on different liquid nitrogen cooling configurations, cable current carrying capacity test, current distribution test among the conductor layers, conductor ac loss measurement, ac withstand voltage test on the terminations.

Besides the 6 conductor models mentioned above, to test our design on a system level, we made a complete superconductor cable system, which consists of a 4 meter superconductor cable with thermal and electrical insulation, a pair of terminations, and a close cycle refrigeration system. Figure 4 is a photo picture of the system. Current carrying capacity test, heat load test, and system cooling rate test have been performed on this system.

The winding of the 30-meter cables will be started in the second half of October, and finished in the first half of November 2003. The completion date of the fabrication of terminations is set at the end of October 2003. Field preparation of the installation of the 30-meter superconductor cable system at Puji substation is underway. The installation work is planed to be started in January and completed at the end of March 2004. Trial operation will begin afterwards.

Figure 4. The photo picture of the 4-meter superconductor cable system.

5. Summary

With the support from Chinese government, China's 30m, 35kV/2kA$_{rms}$, 3 phase, HTS power cable system, its first superconductor cable system being planed to be installed in a power grid for trial operation, is under construction. Significant progress has been made in this project. This system will be installed in China Southern Power Grid at Puji substation of Kunming, Yunan province in the spring of 2004. It will be the third superconductor cable system installed in a power grid in the world, following the Southwire cable in the US and the NKT cable in Denmark.

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