Development of HTS Cable System for ALBANY Project

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Abstract. High temperature superconducting (HTS) cable is anticipated to transmit a large amount of electricity with a compact size and can reduce the transmission loss and greenhouse gas emission. The Albany project is being undertaken to verify the practicability of a long HTS cable in the real grid by performing a long-term operation test. The cable is 350-meter long and carries 800 A at 34.5 kV between two electric power substations (Menands and Riverside) in Albany, N.Y. [1]. The project is scheduled to run from 2002 to 2007 and is proceeding as planned. The HTS cable and its apparatus were manufactured in Japan, and the cable was shipped to the U.S.A. in the middle of August. After it arrives at the site, the cable installation and the apparatus assembly will be carried out sequentially. This system is expected to begin operating early next year after initial cooling. This paper gives an overview and the current status of the development of the HTS cable system.

1. Introduction
After studying the system specifications of site layout, cable length, electrical and mechanical properties and so on, the design and manufacturing of cable system has been started. This paper provides the cable system overview, for example the development of a long-length cryostat, which is an important element of the system, in addition to the status of manufacturing and shipping the HTS cable and the future schedule.

2. Cable system outline
Table 1 shows specifications of the HTS cable system for the project. The HTS cable will be installed in a 6-inch underground conduit. The joint system that joins two separate sections of the HTS cable, a 320-meter section and a 30-meter section, will be in a vault to simulate an actual system. Liquid nitrogen is cooled to the sub-cool state in the cooling station, pressure-pumped to the HTS cable system, and returned to the cooling station through the return cryostat of the remote termination [2].

| Item                      | Specification                          |
|---------------------------|----------------------------------------|
| Voltage/Current           | 34.5 kV, 800 Arms                      |
| Length                    | 350 m (320 m + 30 m)                   |
| Apparatuses               | EB-A (at both sides), Joint (assembled in a vault) |
| Install condition         | 6-inch Underground conduit             |
| Short circuit current condition | 23 kA, 8 cycles (38 cycles)            |
The structure of the HTS cable is shown in Figure 1. The cable has a 3-in-one structure that allows downsizing. The conductor and the superconducting shielding are helically wound with a Bi-2223 wires in a double layers for the conductor and a single layer for the superconducting shielding. The Bi-2223 wire is manufactured using a newly developed controlled over pressure (CT-OP) process [3], which is a type of overpressure sintering process. For electrical insulation, a composite insulating method has been adopted, using PPLP© (Polypropylene Laminated Paper) impregnated with liquid nitrogen. The shield section is stranded with Cu tape to pass a short-circuit current. The three cores are stranded loosely to provide protection against thermal contraction. The cryostat consists of double-wall SUS corrugated tube and insulating material and employs a tension member outside the cryostat to sustain the tension applied when the cable is pulled.

Trial fabrication of an HTS cable with this structure established that manufacturing processes did not cause any Ic degradation, and a short circuit current test and cable installation test showed that this structure is optimal for the HTS cable system [4].

![Figure 1. Structure of the HTS cable](image1)

![Figure 2. Seal-off test of 350 m cryostat](image2)

### 3. Development of a long-length cryostat

Development of a long-length cryostat is indispensable because an HTS cable is required to be 300 meters or longer for practical use. Technological goals for the development of a long-length cryostat include devising a process for its evacuation, ensuring that the cryostat maintains a vacuum state for longer than 10 years to reduce its heat invasion. To achieve these goals, we evaluated the vacuum characteristics and cooling characteristics of the cryostat, using its 350-meter and 50-meter prototypes. Table 2 shows the specifications of the cryostat.

| Item                | Specification                              |
|---------------------|--------------------------------------------|
| Structure           | Coaxial, stainless corrugated pipe         |
| Size                | Outer diameter: app. φ120 mm               |
| Heat insulation type| Vacuum and multi-layer insulation          |

To evaluate its vacuum characteristics, the 350-meter prototype underwent a long-term seal-off test at room temperature after it was evacuated as shown in Figure 2.

Figure 2 shows the lifetime of the 350-meter cryostat that is defined as duration to excess normalized vacuum state. Remaining at around seven months was better than that required when cooling the cryostat, indicating that the cryostat will last 10 years or longer.
The 50-meter prototype was cooled with liquid nitrogen to measure heat invasion. The prototype was placed at around 35-meter straight section of the cable and an arc section with a radius of 5 meters. Heat invasion was evaluated by flowing a specific volume of liquid nitrogen through the prototype and measuring temperatures at the inlet and outlet. The heat invasion was measured to be approximately 1.5 W/m at straight section, as was designed.

4. Manufacturing results of the HTS cable system
Manufacturing of the HTS cable was completed and was shipped from Japan to the U.S.A. on middle of August. Figure 3 shows a picture of the completed 320-meter HTS cable.

![Completed 320-meter HTS cable](image)

To evaluate the performance of the HTS cable as manufactured, pre-shipment tests were carried out using samples taken from the excess portion of the cable. The contents and results of each test are as follows:

4.1. Measurement of the critical current (Ic)
The Ic measurement of each conductor and HTS shielding of samples taken from each phase core of the excess cable was carried out. The results are shown in Table 3. Each Ic was approximately 1,800 A (a direct current at 77 K and 1 micro-V/cm), as designed.

![Table 3. Results of Ic measurements](image)

| Results (at 1 μV/cm) | Conductor | Shielding |
|----------------------|-----------|-----------|
| White phase          | 1,800 A   | 1,780 A   |
| Red phase            | 1,790 A   | 1,790 A   |
| Blue phase           | 1,800 A   | 1,770 A   |

4.2. Measurement of AC loss
The AC loss of a sample taken from the excess cable was electrically measured using a lock-in amplifier. The AC loss of 0.7 W/m/ph at 800 A, 60 Hz was measured.

4.3. Bending test
A 7-meter 3-in-one sample cable was twice bent through 180° around a diameter 18 times that of the cable. Ic measurements before and after the test showed no degradation. A dismantle examination of the sample found no defects with electrical insulation and the HTS wire.

4.4. Voltage test
A voltage test employed a test vessel in which a 5-meter single-core cable was conducted. During the test, the temperature and pressure of liquid nitrogen were constant at 72 K and 0.1 MPa G, respectively. As shown in Table 4, results were satisfactory.
Table 4. Voltage test results for cable

| Test               | Condition                | Result      |
|--------------------|--------------------------|-------------|
| AC voltage test    | Voltage: 69 kV Time: 5 min. | Satisfactory |
| Impulse test       | Voltage: ±200 kV Cycles: 10 times, each | Satisfactory |

5. Design and manufacture of apparatuses

The HTS cable needs an EB-A type termination, because the cable is connected to overhead lines at its ends. The structure of the EB-A type termination is basically identical to the previously developed 66-kV class termination, but it employs a 3-in-one structure this time for downsizing.

To put an HTS cable system into practical use, separate cables need to be joined because only limited lengths of cable can be manufactured and transported. To this end, a new joint was developed in this project to connect a cable that is divided into two sections.

Voltage application test was performed using the newly developed termination. Table 5 shows conditions of the test, in which satisfactory results were obtained.

Table 5. Results of a voltage test for 3-in-one termination

| Test               | Condition                | Result      |
|--------------------|--------------------------|-------------|
| AC voltage test    | Voltage: 90 kV Time: 1 hr. | Satisfactory |
| Impulse test       | Voltage: ±200 kV Cycles: 10 times, each | Satisfactory |

6. Future schedule of the project

The HTS cable will arrive in the U.S.A. in the middle of September to be installed. The apparatus will arrive in the U.S.A. in the middle of October to be assembled and combined with the cable. After the completion of the assembly, an initial cooling test and acceptance test will start in early 2006, followed by a long-term system operation test in the real grid. In early 2007, the 30-meter section of the HTS cable using Bi wire will be replaced with YBCO cable. The HTS cable system will undergo a series of tests until 2007.

7. Conclusions

After evaluating the design and basic specifications of the HTS cable system, the HTS cable and the accessories required for actual use were manufactured and evaluated. The cable cores proved to have favorable post-manufacturing electrical and mechanical characteristics and were shipped together with a long-length cryostat that provides long-term reliability. The termination and joint were also designed and manufactured. Soon after these products arrive at the testing site in the U.S.A., the installation of the HTS cable and the assembly of the apparatus will begin sequentially, followed by a long-term operation test in early 2006.

References

[1] C.S. Weber et. al., Overview of the underground 34.5 kV HTS power cable program in Albany, NY, IEEE transactions on applied superconductivity, vol. 15, No. 2, June 2005, pp1793-1797
[2] Ron C. Lee et. al., Cryogenic refrigeration system for HTS cables, IEEE transactions on applied superconductivity, vol. 15, No. 2, June 2005, pp1798-1801
[3] S. Kobayashi et. al., Controlled over pressure processing of Bi2223 long length wires, IEEE transactions on applied superconductivity, vol. 15, No. 2, June 2005, pp2534-2537
[4] T. Masuda et. al., Design and experimental results for Albany HTS cable, IEEE transactions on applied superconductivity, vol. 15, No. 2, June 2005, pp1806-1809