Field Test and Short-circuit Test of HTS Power Cable

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Abstract. In order to cope with the increase in the electric power demand and an alternative technology to the conventional electric power transmission cables, it’s hoped that high temperature superconducting (HTS) cable is developed. In case the HTS cable is introduced into the actual power grid, its length can extend up to several kilometers. The flow properties of liquid nitrogen (LN2) that is a coolant of the HTS cable have not been understood yet. Thus, CRIEPI, Furukawa Electric and Super-GM had constructed an HTS cable test system with its length of 500 m. The rated voltage is 77 kV corresponding to one of the major voltage level of medium-voltage transmission lines. The rated current is 1 kA. We had carried out a numerous set of tests such as measurement of LN2 flow properties, current flow properties, electrical insulation properties, thermal insulation properties and so forth. In addition, short-circuit test was carried out using 10 m HTS cables that is same structure as the 500 m HTS power cable. The test was conducted with the supply voltage of 16 kV and the prospective short-circuit current of 31.5 kA using a short-circuit generator.

1. Introduction

In order to put high temperature superconducting cables into commercial use, it is crucial to identify in detail the fundamental operational characteristics and the issues potentially caused by the long-distance circulation of liquid nitrogen because kilometres long cables need to be constantly cooled. Therefore, field test of a 500 m HTS cable was planned as part of the Super-ACE project. HTS cable manufactured by Furukawa Electric was installed at the Yokosuka Laboratory of CRIEPI and various tests were carried out from March 2004 to March 2005[1-5].

2. Field test

The structure of 500 m HTS cable is single core. Figure 1 shows the structure of the HTS cable and Table 1 shows the specifications of the HTS cable. The HTS cable consists of conductor, electrical insulating layer, magnetic shielding layer, thermal insulating layer and protecting layer. The superconductor is Ag sheathed Bi2223 tape that is 0.25 mm thick and 4 mm wide.

As the field test, the following tests were conducted to identify the characteristics of a high temperature superconducting cable:

1) Basic property test: the confirmation test of the thermal behaviour in response to temperature increase and decrease and the basic characteristics (heat invasion, pressure losses, critical current, and AC loss) of the cable.
2) Rated loading test: the accelerated deterioration test by supplying voltage and conducting electricity for 1 month to simulate a 30-year use of the cable.

3) Load fluctuation test: the load test on a cable such as applying a rapid current change.

4) Severe test: the operation test by applying an over current, a high voltage or with a malfunctioning cooling system.

In this paper, the severe test is described.

2.1.1. Refrigerator fault tests. Refrigerator fault tests were carried out while monitoring the temperature, the pressure and the occurrence of PD (partial discharge) at a voltage of 45 kV to ground, a current of 1 kA, and an average LN2 temperature in the test start was 73.5 K and 77.8 K, flowing at 30 L/min and a tank pressure of 0.4 MPa-abs.

Figure 2 and 3 shows the temperature and the pressure of the 500 m HTS cable system. When the initial average LN2 temperature in the test was 73.5 K, the pressure reached its limit in 3 hours 30 minutes. When the initial average LN2 temperature in the test was 77.8 K, the pressure reached its limit in 2 hours 15 minutes. In all tests no PD was found (noise level, 250 pC).

2.1.2. LN2 pump fault tests. LN2 pump fault tests were carried out while monitoring the temperature, the pressure and the occurrence of PD (partial discharge) at a voltage of 45 kV to ground, a current of 1 kA, and an average LN2 temperature in the test start was 73.6 K and 77.7 K, flowing at 30 L/min and a tank pressure of 0.4 MPa-abs.

When the LN2 pumps were stopped for an hour, no PD was found (noise level, 250 pC).

2.1.3. Over current tests. An over-current test was carried out with current increasing in steps of 50 A per hour starting from 1 kA and with monitoring of temperature and pressure, input electric power for CT and any occurrence of PD under test conditions of 45 kV, an LN2 flow rate of 30 L/min, tank pressure of 0.4 MPa-abs and the initial average LN2 temperatures in the test was 73.5 K and 77.6 K.

Figure 4 shows the change of the input power, when the initial average LN2 temperature in the test was 77.6 K. When the current reached 1450 A and was kept for 30 min at 73.5 K, the input power...
increased by 10%. When the current reached 1250 A and was kept for 45 min at 77.6 K, the input power increased by 10%. In all tests no PD was found (noise level, 250 pC).

![Figure 4](image)

Figure 4 Change of the input power. (The initial LN$_2$ temperature was 73.5 K)

3. Short circuit test

The short-circuit test was carried out using 10 m HTS cables with the same structure as the 500 m HTS power cable. Figure 5 shows the diagram of test circuit. Figure 6 shows the overview of the testing place. Test conditions were set with a prospective short-circuit current 31.5 kA and a current duration 0.5 s.

![Figure 5](image)

Figure 5 Diagram of the test circuit.

![Figure 6](image)

Figure 6 Overview of the testing place.

![Figure 7](image)

Figure 7 Current waveforms at the 3-phase ground fault short-circuit test.
Figure 7 shows the current waveforms at the 3-phase ground fault short-circuit test and Table 2 shows the current distribution of each layer. After the test, there was no damage in the HTS cables.

4. Conclusion
In this paper, the field test results assured us that, under various conditions, the high temperature superconducting cable maintains a healthy condition across the entire length of 500 m, which is almost comparable to the length in commercial use. The series of tests we have conducted brought about detailed findings required for the design, test method, and operation of superconducting cables in the commercialization stage, allowing us a significant step towards the commercial use of superconducting cables to meet various needs.

Acknowledgements
This test project was carried out as part of the Super-ACE (R&D on fundamental technologies for superconducting AC power equipment) project of METI (the Ministry of Economy, Trade and Industry), also cosigned by NEDO (the New Energy and Industrial Technology Development Organization).

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| Phase | Circuit current | Conductor current | Shielding current |
|-------|----------------|------------------|------------------|
|       | Max. crest value | RMS value | HTS layer | Protective layer | HTS layer | Protective layer |
| kA | kA | kA | kA | kA | kA |
| R   | 91.2 | 31.5 | (7.6)* | 25.7 | (3.3)* | 26.8 |
| S   | 65.9 | 32.1 | (13.1)* | 25.0 | (9.8)* | 25.1 |
| T   | 73.2 | 31.7 | (11.8)* | 21.5 | (7.0)* | 25.1 |

* Parenthetic values were calculated value.