The research on the current capability and insulating properties of 35 kV/1 kA CD HTS cable witness samples

Jichun Li, Liyong Zhang, Xinyu Ye*, *, Fangmin Xia, and Yujun Cao
Futong Group (Tianjin) Superconductor Technologies and Applications Co., Ltd., Tianjin, China

*Corresponding author e-mail: yexinyu927@126.com, ftxfm@ftjt.net

Abstract. Due to the high capacity and low loss, high temperature superconducting (HTS) cable using Liquid N\textsubscript{2} as the coolant has attracted the widespread attention in the field of the modern power technology. A 35 kV/1 kA cold dielectric (CD) high temperature superconducting (HTS) cable demonstration line, which is in the length of 100 m, has been established. To verify the design of the superconducting cable structure, the witness samples in the length of ~1.0 m were fabricated to evaluate the current capability and insulating properties, such as lightning impulse voltage and alternating voltage tests. The results showed that the critical current ($I_C$) of the superconducting layer and superconducting shield layer was measured to be 1650 A and 3000 A respectively, and the voltage waveform of superconducting layer revealed no apparent increase during the testing process. Meanwhile, it could be also indicated from the results of high voltage tests that the insulating properties of HTS cable conform to the requirements of the standard GB/T3048.8-94.

1. Introduction

Due to the high loss of the conventional power cable using copper or aluminum as conductors, it is necessary to design a novel transmission line for the construction of urban power grid in the near future [1, 2]. Recently, the superconductors with the unique properties, such as zero resistance and Meissner effect, have attracted much attention in the field of the modern power technology, aiming to increase the energy efficiency by fabricating superconducting cables with high capacity and low loss [2, 3]. However, the low temperature superconductors (LTS, such as NbTi and Nb3Sn) have to use liquid helium as the coolant with high cost, which limits the application of LTS. With the preparation of high temperature superconductors (HTS, such as BSCCO and YBCO), liquid nitrogen with low cost has been used as the coolant to achieve a superconducting-state, and therefore, it could be indicated that HTS cable would have better practicability and market prospect.

Major industrial countries successively carried out the HTS cable projects at the beginning of the 21st century. For example, the HTS cable projects in USA (Albany, Columbus, and Long Island) and China (Yunnan, Gansu, Henan and Shanghai Baosteel) have obviously promoted the transition from experimental investigation to engineering application. In 2014, a 10 kV/40 MVA HTS cable line in the length of 1 km was established in Essen to replace the conventional transmission line.

Usually, a HTS demonstration line system is composed of the cable, terminals, cryogenic system and monitoring system. Herein, the design and fabrication of the HTS cable play an important role in the
operation of the demonstration line system. Therefore, it is a key issue to be addressed to research the current capability and insulating properties of a HTS cable.

2. Cable design
According to the different insulation structure, HTS cables could be divided into two types, that is, warm dielectric (WD) and cold dielectric (CD) superconducting cables. Comparing with the WD HTS cable, the CD HTS cable has better practicability, because of the reduction of AC losses and critical current ($I_C$) degradation.

In this work, the single superconducting layer of the cable was composed of 12 YBCO tapes in the width of 4.0±0.2 mm produced by SWCC (SHOWA CABLE SYSTEMS Co., Ltd.). Prior to be twisted onto the former, a copper layer with the thickness of ~20 μm was electroplated on the surface of the superconducting tape. Figure 1 shows the configuration design of CD HTS cable at Futong Group. In brief, the HTS cable core is composed of the copper former, superconducting layer, insulation layer, superconducting shield layer and copper shield layer. The witness samples in the length of 1.0 m were prepared for the DC and AC current capability testing, and AC and lighting impulse withstand voltage measurements.

3. Results and discussion
In reference to GB/T 18502-2001, the I-V curve of witness samples was measured by the DC four-probe method, and the critical current ($I_C$) was calculated using the value of 1 μV/cm as a criterion. As shown in Figure 2 and 3, the IC of superconducting layer and superconducting shield layer was respectively 1650 A and 3000 A, being in line with the requirements of cable design (1500 A and 2700 A).

Meanwhile, the AC I-V curves of superconducting layer were measured using an AC power, with the short connection of superconducting shield layer, when the current value ($I_{max}$) was respectively promoted to 1.5 kA (Fig.4) and 2.5 kA (Fig.5). During the process of testing, the voltage waveform of superconducting layer showed no apparent increase.
According to GB/T16927.1-1997, the lighting impulse voltages of witness samples were measured by a 400 kV impulse voltage generator, and no breakdown or flashover was observed for the samples during the 3 times testing. Moreover, the samples showed no breakdown under the voltage of $2.5 U_0$ (53 kV) for 30 min using a 220 kV AC voltage generator. The results (Table 1) indicated that the insulating properties of HTS cable conform to the requirements of the standard.

**Figure 2.** The DC I-V curve of superconducting layer.

**Figure 3.** The DC I-V curve of superconducting shield layer.

**Figure 4.** The AC I-V curve of superconducting layer ($I_{\text{max}}=1.5$ kA).
Figure 5. The AC I-V curve of superconducting layer ($I_{\text{max}}=2.5$ kA).

Table 1. The results of electrical insulation tests.

| Items                        | Conditions                              | Results |
|------------------------------|-----------------------------------------|---------|
| AC voltage test              | 53 kV/30 min                            | pass    |
| Lightening impulse voltage test | $\pm 200$ kV, 3 times for each voltage | pass    |

4. Conclusion
The development and application of superconducting technology would bring great innovation for the power industry and overcome the growing energy shortages. For the demonstration line, the design and research of HTS cable is the key to the practical utilization. At Tianjin Futong Group, the HTS cable based on YBCO tapes has been fabricated, and integrated with the terminals, cryogenic system and monitoring system. The establishment of HTS cable demonstration line would be a milestone for the modern power transmission.

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