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Recovery characteristics of YBCO tapes against DC over current impulse

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ABSTRACT

With the fast development of voltage source converter based high voltage direct current (VSC−HVDC) power system, an effective fault current method is in demand. In HVDC systems, the short-circuit current generally exceeds the capacity of the fast circuit breaker. Meanwhile, a superconducting fault current limiter (SFCL) is able to limit the short circuit current level. If installed in an overhead line system, SFCL has to meet the requirement of the reclosing time. The fault current is much larger than the critical current of superconducting tapes, which generates huge heat and the temperature of the tapes in the resistive type SFCL will increase sharply. After removing the fault, the tapes need certain time to recover to the superconducting state. Thus, the recovery characteristics in DC faults are an important feature of the resistive type SFCL, and they are mainly determined by the corresponding features of the superconducting tapes. In this paper, a method is presented to measure the recovery time under transient DC over current impulse. The recovery characteristics of high temperature superconducting (HTS) tapes under transient DC over current impulse are studied. The recovery time under different impulse duration and different impulse amplitude are measured by experiments. The influence factors of the recovery characteristics are discussed, which will be useful for the design of SFCL.

1. Introduction

VSC−HVDC power system is a good transmission option with the advantages of long distance, high capacity and low loss [1–3]. It has been studied for many years, and two VSC−HVDC systems are already built in China (i.e., Zhoushan five-terminal VSC−HVDC systems and Nan'ao three-terminal VSC−HVDC systems) [4,5]. In the near future, more VSC−HVDC projects are expected in more countries such as China and South America, since they require more infrastructure constructions to power their growth.

However, the short-circuit fault of the system has not been effectively handled till now. The difficulty lies in the short fault time and the high current level. The operating time of traditional AC circuit breakers is at least 20 ms. ABB has reduced the operating time of the fast DC circuit breakers (DCCBs) to 5 ms recently. However, the fast DCCBs still cannot remove the DC short circuit fault due to the large interrupting capability [6]. They need devices to limit the fault current level during the fault, and SFCLs can reduce the fault current dramatically in several milliseconds. Therefore, the combination of fast DCCBs and SFCLs will well solve the short circuit fault [7].

The recovery characteristics of SFCLs are very essential for the reclosing requirements of HVDC power systems. The recovery time of RSFCLs under AC over current impulse has been measured and discussed by many authors [8–10]. It has shown the recovery time is influenced by the impulse current amplitude and the stability layers. However, their research results mainly focus on the time range of several seconds, and the reclosing requirement of conventional HVDC system is at hundred millisecond level. Thus, it is necessary to set up a system to simulate the process of the DC over current impulse flowing through the superconducting tapes and measure the recovery process of them.

Nevertheless, building a system able to generate transient DC over current impulse and measuring the recovery time simultaneously are both very difficult. Thus, little research in this area has been done. In this paper, the DC over current impulse system is established, and a measurement method of recovery time is presented. The recovery time of YBCO tapes was measured under different over current levels and different impulse duration. Repeat experiments are done to study the stability of recovery process. Finally, the recovery characteristics of YBCO tapes are discussed and the impacting factors are analyzed.

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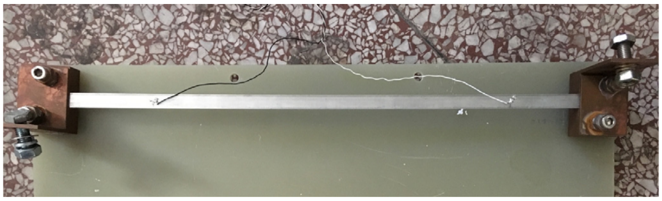

Fig. 1. The sample placed in the specimen holder.

Table 1
The parameters of the 8602 type YBCO superconducting tape.

Type	8602
Manufacturer	AMSC
Width	12 mm
Total thickness	0.25 mm
Stabilizer thickness	75 μm × 2 (Stainless steel)
Critical current	260 A @ 77 K, 0 T
Resistance	0.125 Ω/m @ 300 K, 0 T

2. Experimental setup

2.1. Test sample

The sample is 8602 type YBCO tapes produced by American Superconductor (AMSC). The total length is 50 cm, and the voltage measure length is 30 cm. The sample is placed in the specimen holder shown in Fig. 1. The terminals of the sample are crimped by copper connectors. The indium film is placed between the YBCO tape, and the copper connectors are to reduce the contact resistance. The parameters of the tape are shown in Table 1.

2.2. Experiment system

The experiment system includes two parts, including a DC over current impulse and a recovery time measuring device respectively. The diagram is shown in Fig. 2.

The DC over current impulse part generates high current by the discharge of the capacitance C. Firstly, the pulse charging power supply charges the capacitance C. Then the power supply is switched off, and the capacitance C discharges and generates DC over current. The voltage of capacity is controllable, and different combinations of L, C and R lead to different impulse duration.

The recovery time measuring part utilizes a constant current source to generate a constant current on the sample. The voltage of the sample is measured in the whole process. There is a diode in series with the constant flow source. Thus, the over current will not flow the source. The sample can be superconducting tape or superconducting coil through adjusting L, C, R and the constant flow source.

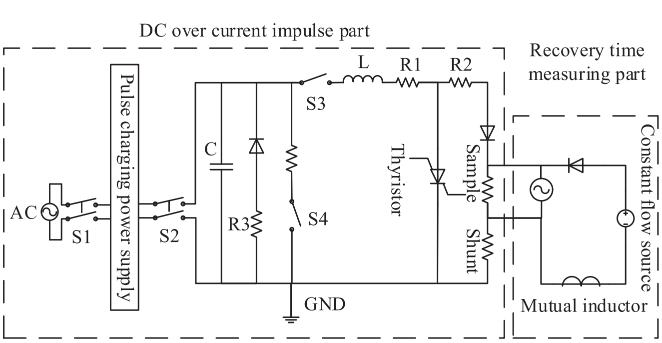

Fig. 2. The experiment system.

2.3. Conditions for the experiment

The sample and the specimen holder are placed in the liquid nitrogen bath. The impulse durations have been chosen from 1 ms to 10 ms. As the reclosing requirement of HVDC system is about 0.3 s, the recovery time should be measured from 50 ms to 1400 ms. The over current has been chosen from 1030 A to 4338 A. The resistance change during a whole impulse experiment can be obtained from the voltage across the sample. Besides, the repeat experiments have been done to analyze the stability of the recovery characteristics.

3. Results and discussion

3.1. The recovery times

The recovery time is from the start of the quench to recovering to the superconducting state again. It can be calculated as:

$$t_{recovery} = t_{recoverd} - t_{quenched} \tag{1}$$

The evaluation criterion is 10 μV/cm. As the voltage measure length of the sample is 30 cm, the corresponding evaluation is 0.0003 V.

The recovery time was all measured from 50 ms to 1400 ms during the impulse time of 1 ms to 10 ms. As the constant current source generates the current of 2 A, the resistance curve can be calculated by the voltage of the sample. The recovery process of the impulse time of 8 ms is shown in Fig. 3. It illustrates that the recovery time rises with the increase of the impulse current amplitude, and the rate of rise is not linear. The shape of the curves indicates that the recovery process consists of two parts. When the resistance is less than 0.018 Ω, the recovery speed is faster. When the resistance is greater than 0.018 Ω, however, the recovery speed is slower. The recovery process is related to the temperature of the sample after the impulse and the heat transfer with the liquid nitrogen.

The heat flux curve of the liquid nitrogen is shown in Fig. 4. The processes of bubbles formation and the whole heat exchange of the liquid nitrogen can be divided into three phases: i.e., free convection, nucleate boiling and film boiling [11]. Fig. 5 is the measured resistance-temperature curve of 8602 type YBCO tape. Clearly, when the resistance is bigger than 0.06 Ω/m, the temperature of the sample is above 105 K. The temperature difference of the sample and the liquid nitrogen is above 28 K, and the liquid nitrogen is in the film boiling phase. When the temperature difference is about 50 K, the heat flux is in the bottom of the curve in this phase. So the heat exchange is slow. Thus the temperature and the resistance decrease slowly. That makes

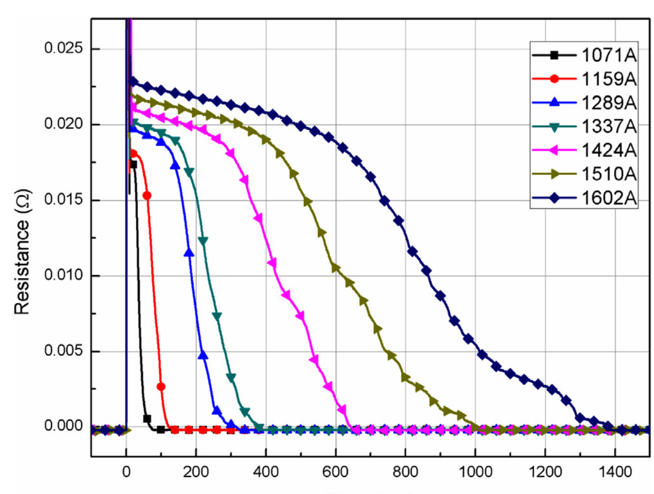

Fig. 3. The recovery process with the impulse time of 8 ms. The legends are the maximum impulse current amplitude.