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Transient characteristic analysis of an HTS DC power cable using a multi-terminal based test-bed ☆

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ABSTRACT

The current capacity of a power supply limits the experimental environment of higher capacity HTS power cable. Consequently, the transient characteristic analysis of an HTS DC power cable is difficult to assess. In this paper, a multi-terminal based test-bed is used to overcome those power supply capacity limitations. A 1 kA class HTS DC power cable was designed and the transient characteristics of the HTS DC power cable were analyzed using the multi-terminal based test-bed. Transient characteristics, such as resistance variation and critical current of the 1 kA class HTS DC power cable were successfully measured using small power sources in the multi-terminal based test-bed. Definitely, the suggested test system overcomes the assessment limits of the HTS power cable's current capacity.

1. Introduction

A superconducting power cable uses superconducting materials instead of the copper or aluminum conventionally used to carry electricity in overhead power lines and underground cables. Superconducting materials can carry electrical current over 100 times more than current density of copper or aluminum, which in turn drives system economical, and that is fundamental reason why superconducting DC power cables compare favorably with conventional alternatives for long-distance power transmission.

Secondly, when transmitting DC power, superconductors have no electrical resistance and introduce no electrical losses of their own [1–4]. There are several HTS power cable projects in the world. The critical current values of the Phase II of the Albany HTS cable project were 2.23 kA at 73 K and 2.8 kA at 69 K, respectively [1–3]. Since a 275 kV, 3 kA HTS power cable, which is the target of the Japanese power network project, has a power transmission capacity of 1.5 GVA, the HTS power cable has the potential for practical use as the backbone power line of the future [4]. The target of the NEDO project is to operate at 66 kV, 200 MVA HTS cable in the real grid in order to demonstrate its reliability and stable operation [5–7].

Before applying an HTS cable to a real power system, a characteristic analysis by simulation or experimentation is necessary. The most important advantage of a superconducting cable is its high current density; however, difficulties arise when researchers experiment on HTS cables. An over current test under fault condition is particularly difficult because it needs large current source [5–12]. Furthermore, most HTS power cables whether AC or DC have not been tested for fault conditions in the laboratory scale. Previously, a field test was the only possible method to study HTS cables under fault conditions [13,10].

Another problem is the current distribution in the HTS power cable. Joint resistances between HTS wires and copper terminals are different. The transport currents of each HTS wire depend on their inductance, capacitance, and joint resistance. The inductance and capacitance of each HTS wire are the same because of the same cable structures. However, the connecting resistances of each HTS wire are different depending on the joint conditions. More precisely, the current distribution of the short length HTS DC cable in the laboratory setting depends on its joint resistance.

In this paper, the authors analyzed the transient characteristic of a 1 kA class HTS DC power cables using a 200 A class power source. Multi-terminal based test-bed makes it possible to experiment an high capacity of HTS DC power cable by using a small power source. The structure of copper terminal in the multi-terminal based test-bed is different than a general copper terminal of HTS power cables. The number of copper terminals is the same as the number of HTS wires in the tested HTS DC power cable. Each HTS wire was connected in series through a return path and separate copper terminals. This system can solve both current distribution and power source limitation problems. A 1 kA class HTS DC power cable was designed and fabricated (using eight HTS wires) for transient characteristic analysis in the multi-terminal

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based test-bed. The critical current and transient characteristics of the HTS DC power cable were successfully measured in this test system, using just 1/8 of the current source of the HTS DC power cable. Under this system, the current of each HTS wire has the same value because of its multi-terminal structure.

2. Design of a multi-terminal based test-bed

2.1. Configuration of a multi-terminal based test-bed

The multi-terminal based test-bed system includes an HTS DC power cable, a power source, and control and monitoring system. Power source and monitoring devices are the same as a general experiment system which uses a current amplifier, LabVIEW and SCXI data acquisition system. However, the structure of the HTS DC power cable differed from the general HTS power cable layout. In a general HTS cable, whether AC or DC, all HTS wires were connected in parallel to a single copper terminal. Fig. 1 shows the experimental system configuration of a multi-terminal based test-bed for an HTS power cable experiment. Front and back side cross sectional area of the HTS power cable of this system were shown in Fig. 2. This experiment system for experimentation requires separate copper terminals and a return current path. Thus, each HTS wire of the HTS DC power cable had its own copper terminals as shown in Fig. 2, and copper cables were used for the return current path in this system. Most large capacity current sources has limitation of output terminal voltage level, however, copper terminal may cause the voltage drop between terminals of power sources. Total resistance of series connected copper return cables, terminals, and joint area was 7.34 mΩ in this system.

2.2. Design of the 1 kA class HTS DC power cable

A 1 kA class HTS DC cable was designed to verify the assessment of the cable's transient characteristics in the multi-terminal based test-bed. The fabricated HTS DC power cable is depicted in Fig. 3, being attached to separate copper terminals. In this case, eight HTS wires and copper terminals were used and their specifications are summarized in Table 1. A *SuNAM* second-generation HTS wire was used in this experiment, and its critical current was more than 110 A at 77 K. The cable length was 1 m, and the critical current of the tested short-length HTS wires was 140 A in liquid nitrogen (LN_2). The rated current of the designed HTS DC power cable was 1000 A using eight HTS wires. The former diameter was 20 mm, and the former was made from Fiberglass Reinforced Plastics (FRPs). HTS wires, 8 m long, were used for a 1 m HTS DC power cable. The pitch length of this cable was 2 m. Insulation of the HTS DC power cable was not considered in this system, thus the

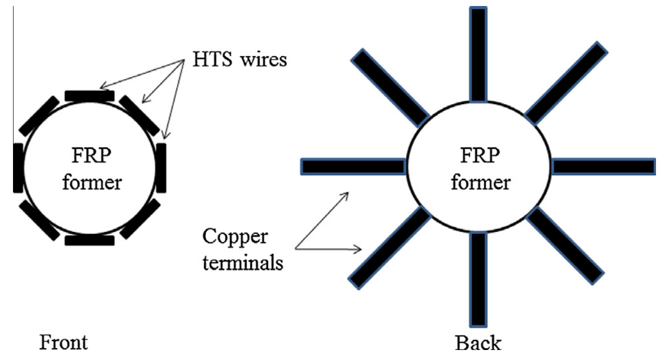

Fig. 2. Cross sectional area of the HTS DC power cable.

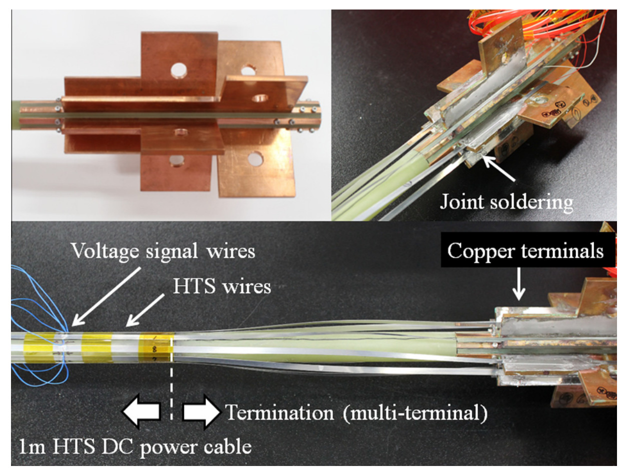

Fig. 3. Fabrication of a multi-terminal HTS DC power cable.

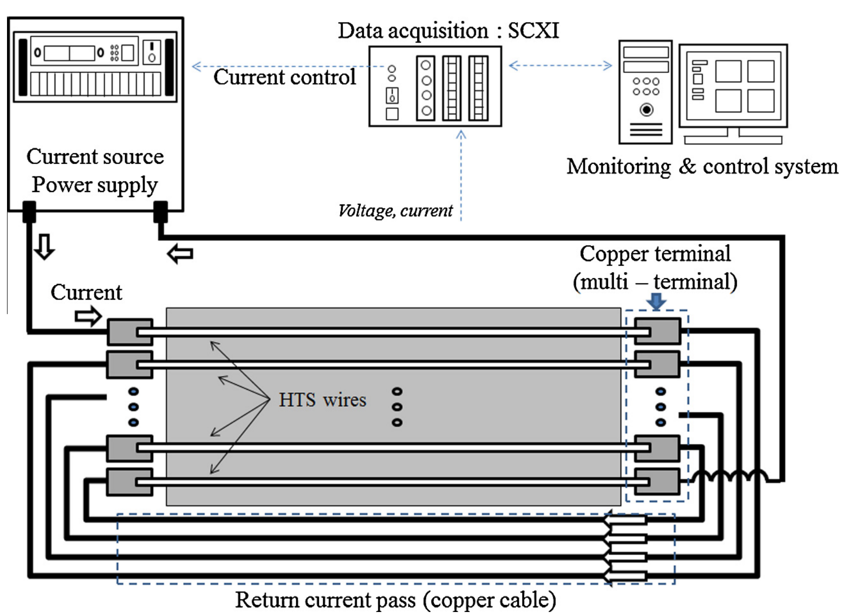

Fig. 1. Configuration of the multi-terminal based test-bed.