Modeling and simulation of failures in high temperature superconducting cable for detection and location via time-frequency domain reflectometry

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In the areas of high-density power consumption, such as metropolitan areas and industrial facilities, high temperature superconducting (HTS) cable, which is capable of high current density transmission, is expected to play an important role in new electric power systems. However, when installing the cable, there are number of limitations to bend, twist, and load, because of the brittleness of the HTS material. Furthermore, if the superconductivity is lost due to defects from segments of HTS cable, cryogenic failures for example, the electrical resistance will rapidly increase and the quench phenomenon will result in a change in the local temperature and vice versa. If the failures of HTS-based power system occur, they can cause serious consequences such as relatively long recovery time and power shortages due to failures of the large-scale HTS electric power cable. Unfortunately, owing to the structure of cryogenic cooling system of HTS cable, it is difficult to detect the faults of HTS cable by conventional cable diagnosis methods such as partial discharge (PD). Moreover, it is possible to measure the liquid nitrogen's temperature only at the termination of the HTS cable. Thus, it is necessary for us to develop a new non-destructive method that can detect and locate local failures of HTS cable.

In this paper, we propose applications of time-frequency domain reflectometry (TFDR) for HTS cable, which allows us to design reference signal in time- and frequency- domain simultaneously considering physical characteristics of cable under test. Modeling a real-world HTS cable for simulations is carried out using the EMTP/ATP. The HTS cable under test is rated 22.9kV, 50mVA and 7 meters in length. Since the EMTP/ATP program does not provide all the physical components of HTS cable, there are number of difficulties to setup HTS cable model. Thus, we proceed with the modeling considering the following parameters; (1) the internal structure, (2) the resistance variation with temperature, and (3) self-inductance and mutual inductance of layers. Furthermore, as shown in Figure 1, we develop a cryogenic cooling system using a HTS cable, a cooling pool, and a LN2 tank. TFDR system is composed of the followings:

- generating the input signal part using arbitrary waveform generator (AWG),
- receiving the input/reflected signal part using digital storage oscilloscope (DSO),
- connecting part between a HTS cable and probe accessories.

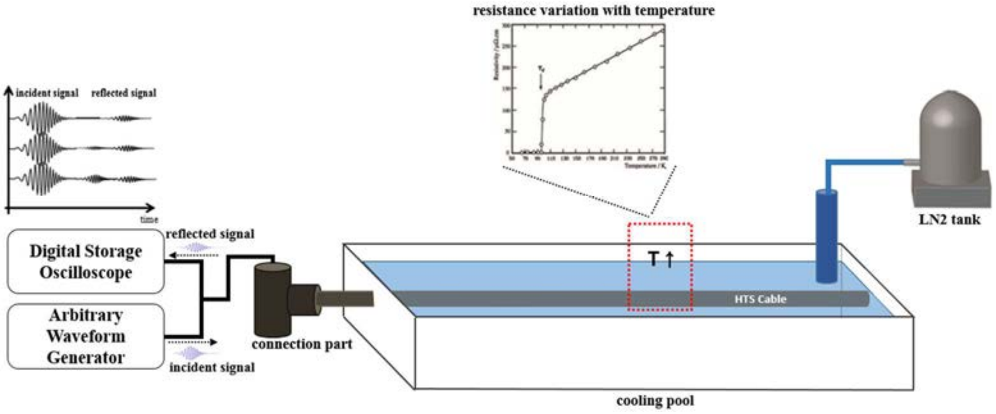

Fig. 1: Cryogenic cooling system and TFDR system.

The analysis results include the validation of the effectiveness for TFDR. The proposed model of the HTS cable in EMTP/ATP and simulation with real-world HTS cable show the new non-destructive method can provide detection and location of local failures of HTS cable. We expect that the proposed method can improve sensitivity of diagnostics of HTS cable so that it will be applicable to real-world electric power systems, and guarantee safe operation. Furthermore, the commercialization of long-distance transmission with HTS cable will be accelerated.