Implementation of new non-destructive diagnostic system for high temperature superconducting cable via time-frequency domain reflectometry

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ABSTRACT

Owing to structure of the cryogenic cooling test-bed and the high temperature superconducting (HTS) cable, new diagnostic methodology is needed. In this paper, time-frequency domain reflectometry (TFDR) is proposed for new non-destructive diagnostic methodology for HTS cable. The TFDR methodology utilizes the Gaussian envelope with a linear chirp signal which provides both time localization and frequency localization. To validate the new diagnostic methodology, TFDR is compared with traditional reflectometry technique. Also new diagnostic system is described including cryogenic cooling test-bed and TFDR system.

KEYWORDS

HTS cable, time-frequency domain reflectometry (TFDR), chirp signal, time-frequency cross-correlation function, non-destructive diagnostic system.

1. INTRODUCTION

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. For example, in the United States, Korea, China, Japan and Russia, HTS power cable systems have been installed and demonstrated to evaluate the feasibility under the real world utility grid. Also, methodology for installation, operation, and maintenance of the HTS power system have been developed [1]. However, when installing the HTS 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 the local temperature and vice versa [2]. 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 transmission and distribution system. 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. Moreover, it is possible to measure the temperature of the liquid nitrogen 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 failures of HTS cable, which will be extremely important challenge for future long-distance HTS cable systems.

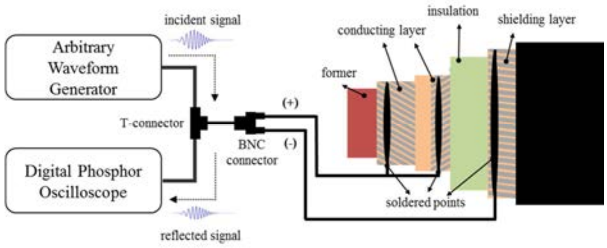

Fig. 1: The diagram of the connection between one phase HTS cable and TFDR system

In this paper, we propose applications of time-frequency domain reflectometry for HTS cable, which allows us to design reference signal in time- and frequency- domain simultaneously considering physical characteristics of HTS cable [3], [4]. The structure of the paper is arranged as follows; in Section 2, the description of new diagnostic system which is composed of cryogenic cooling test-bed and time-frequency domain reflectometry (TFDR) system. In Section 3, the basic concept of TFDR is introduced including comparison with TDR, design of the reference signal and methodology to detect and localize the fault. To demonstrate and verify the new diagnostic methodology, experimental setup are described and discussed in Section 4. The results of the experiment show the validation of the new proposed methodology in Section 5.

2. DESCRIPTION OF NON-DESTRUCTIVE DIAGNOSTIC SYSTEM

We implement a cryogenic cooling test-bed using a HTS cable, a cooling pool, a temperature monitor and a LN2 tank. Also, TFDR system is composed of arbitrary waveform generator (AWG), digital phosphor oscilloscope (DPO) and probe accessories.

2.1 Cryogenic Cooling Test-bed

Cryogenic cooling test-bed is composed of one-phase HTS cable, the liquid nitrogen tank, the cooling pool, and the temperature monitor. HTS cable is composed of conducting layer and shielding layer, and two layers are coupled magnetically [5]. As shown in Fig. 1, the characteristic of the structure is used to apply the TFDR reference signal to HTS cable and to detect the reflected signal. Conducting layer is used as an input port and shielding layer is used as a ground port. The HTS cable is cooled with liquid nitrogen inside cooling pool which is made of stainless steel as shown in Fig. 2. For the purpose of insulation and lagging of the cooling pool, polyethylene (PE) vinyl is used.