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Operating characteristic analysis of a 400 mH class HTS DC reactor in connection with a laboratory scale LCC type HVDC system

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ABSTRACT

High temperature superconducting (HTS) devices are being developed due to their advantages. Most line commutated converter based high voltage direct current (HVDC) transmission systems for long-distance transmission require large inductance of DC reactor; however, generally, copper-based reactors cause a lot of electrical losses during the system operation. This is driving researchers to develop a new type of DC reactor using HTS wire.

The authors have developed a 400 mH class HTS DC reactor and a laboratory scale test-bed for line-commutated converter type HVDC system and applied the HTS DC reactor to the HVDC system to investigate their operating characteristics. The 400 mH class HTS DC reactor is designed using a toroid type magnet. The HVDC system is designed in the form of a mono-pole system with thyristor-based 12-pulse power converters.

In this paper, the investigation results of the HTS DC reactor in connection with the HVDC system are described. The operating characteristics of the HTS DC reactor are analyzed under various operating conditions of the system. Through the results, applicability of an HTS DC reactor in an HVDC system is discussed in detail.

1. Introduction

In recent years, researchers have been trying to apply high temperature superconducting (HTS) materials for power system devices, such as magnet application devices: superconducting fault current limiter, superconducting transformer, and superconducting magnetic energy storage system; and superconducting power cables to make use of their advantages. Some HTS devices have already been connected to real utility grids in many countries [1,2].

DC reactor is an essential part of a line commutated converter based high voltage direct current (HVDC) transmission process. Large capacity of DC reactors are required in the HVDC systems to protect the converters during DC side faults, such as line-to-ground faults or commutation failures, and reduce the ripple of DC current; however commercial copper winding DC reactors cause electrical losses during operation period and difficulties in winding to get the large inductance. Thus, an HTS DC reactor is being developed and applied to an HVDC transmission system [3–7]. It should be examined to apply HTS devices to the HVDC system under conditions that closely resemble real installation in advance.

The authors have developed a 400 mH class HTS DC reactor and a laboratory scale test-bed for line-commutated converter (LCC) type HVDC transmission system. The HTS DC reactor was connected to the HVDC system in series to analyze the major operating characteristics including the operability in connection with the HVDC system, the temperature characteristics according to the increase of the DC current level, and the interaction between the HTS DC reactor and the harmonics present in the HVDC system for the precise estimation of the AC loss of the HTS DC reactor.

The 400 mH HTS DC reactor has taken the form of toroid magnet using the 30 D-shape double pancake coils (DPCs), with two-stage cryo-cooler and cryostat. The LCC type HVDC system is designed using thyristor-based 12-pulse rectifier and inverter, with three-phase wye-wye and wye-delta transformers and AC reactors in form of the mono-pole system [8].

In this paper, the operating characteristics of the HTS DC reactor in connection with the HVDC system and effects of the HTS DC reactor on the HVDC system are analyzed and described under various operating conditions of the system. The harmonic components of the DC current are analyzed according to the level of DC current.

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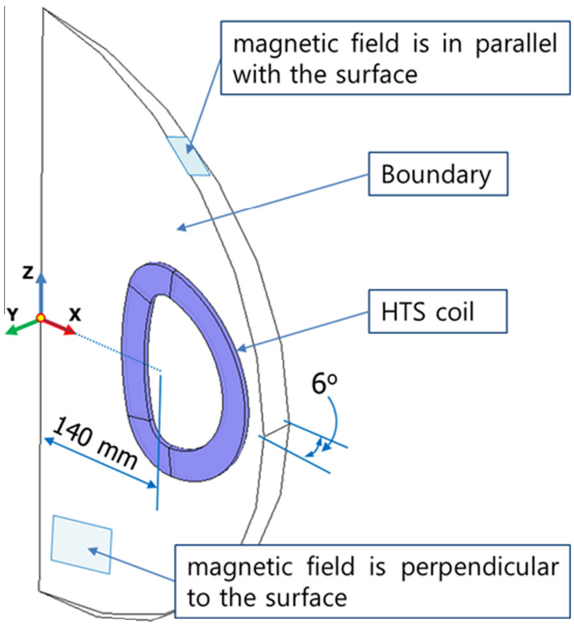

Fig. 1. 1/60 single pancake coil model of toroid-type HTS DC reactor.

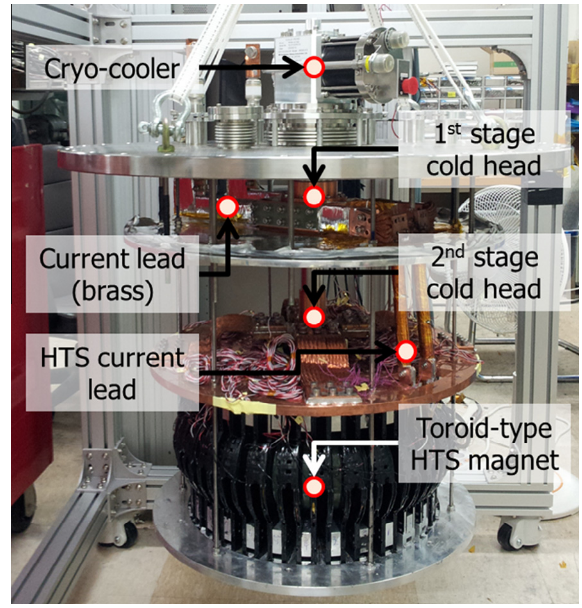

Fig. 3. The fabricated toroid-type 400 mH class HTS DC reactor.

Table 1
The specifications of the HTS wire for HTS DC reactor.

Contents	Value
Maximum width	4.3 mm
Maximum thickness	0.315 mm
Thickness of substrate (SUS)	0.06 mm
Thickness of copper plating and brass lamination	0.1 mm
Critical current at 77 K, self-field	200 A

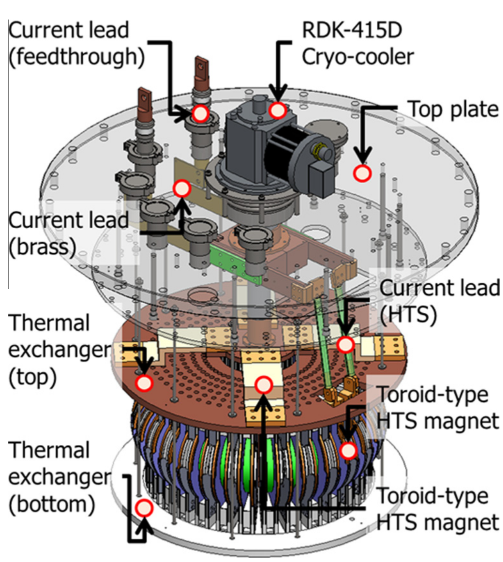

Fig. 2. The structure of the toroid-type 400 mH class HTS DC reactor.

The results demonstrate the effectiveness and applicability of an HTS DC reactor in a HVDC system.

2. Design of an HTS DC reactor and an HVDC system

2.1. Design of the 400 mH class HTS DC reactor

The 400 mH class HTS DC reactor is designed using 2G HTS wire to investigate its operational characteristics in connection with an HVDC system and modelled using 3D FEM analysis program to obtain the design parameters. In the FEM model, the HTS DC reactor was divided one thirtieth of the whole magnet for the reactor as shown in Fig. 1. The specifications of the HTS wire for the HTS DC reactor are described in Table 1. The HTS DC reactor is composed of GdBCO-based 30 D-shape DPCs which are arranged in the identical interval as a toroidal structure, a two-stage RDK-415D Gifford–McMahon cryo-cooler, and a cryostat as shown in Fig. 2. The D-shape DPCs are devised to reduce perpendicular magnetic field and electromagnetic force to the HTS wire on the center of the toroid magnet. The design parameters of the toroid-type HTS DC reactor magnet are described in Table 2. The fabrication result of the toroid-type HTS DC reactor including the overall cooling and current paths for the HTS DC reactor magnet is shown in Fig. 3.

2.2. Design of the LCC type HVDC system

A laboratory scale LCC type HVDC transmission system is designed as a test-bed. The HVDC system is composed of thyristor-based 12-pulse converters including rectifier and inverter, four gate driver boards, two sets of 3-phase step-down *Y–Y* and *Y–Δ* transformers, four 3-phase AC reactors, and short length

Table 2
The specifications of the designed toroid-type HTS DC reactor magnet.

Contents	Value	Contents	Value
Wire width/thickness	4.3/0.32 mm	Average critical current of DPCs	98.12 A
Number of turns	85 turns	Inner radius of reactor magnet	95 mm
Length of HTS wire in a DPC	76.44 m	Outer radius of reactor magnet	235.5 mm
Number of D-shape DPC	30 ea	Inductance of magnet	410 mH