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Design and manufacture of a toroidal-type SMES for combination with real-time digital simulator (RTDS)

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ABSTRACT

The authors designed and manufactured a toroidal-type superconducting magnetic energy storage (SMES) system. The toroidal-type SMES was designed using a 3D CAD program. The toroidal-type magnet consists of 30 double pancake coils (DPCs). The single pancake coils (SPCs), which constitute the double pancake coils, are arranged at an angle of 6° from each other, based on the central axis of the toroidal-type magnet. The cooling method used for the toroidal-type SMES is the conduction cooling type. When the cooling method for the toroidal-type SMES was designed, the two-stage Gifford–McMahon (GM) refrigerator was considered. The Bi-2223 HTS wire, which was made by soldering brass on both sides of the superconductor, is used for the magnet winding. Finally, the authors connected the toroidal-type SMES to a real-time digital simulator (RSCAD/RTDS) to simulate voltage sag compensation in a power utility.

1. Introduction

Power quality issues are becoming more important than ever before in daily life. The cause of the poor quality of a given system could be voltage fluctuation, the undesirable harmonics introduced by other system loads, or momentary interruptions or voltage sags due to faults in the power system [1]. The superconducting magnetic energy storage (SMES) system is a direct energy storage system that is believed to be a potential solution to power quality issues. High energy density, fast response time, and excellent conversion efficiency are considered the main advantages of using SMES over other energy storage systems. With the development of cryogenic technology and high-temperature superconducting (HTS) wires, HTS wires are becoming more competitive in SMES applications. Several SMES projects using HTS wires have been carried out around the world [2,3].

The operation of an SMES system can be divided into the three steps of charging, operating, and discharging. AC losses may occur in the SMES system, however, due to the operating current and magnetic field variation according to the energy charging or discharging behavior. The AC losses cause the heat generation of the SMES magnet. The performance of the SMES magnet is directly affected by the aforementioned AC loss characteristics [4]. Thus, a pancake-type SMES, which is strongly affected by perpendicular magnetic fields, is not suitable for use in continuous charging and discharging conditions such as frequency stabilization of a power system. To overcome the defect of the pancake-type SMES magnet, the authors designed an alternative toroidal-type SMES, which can reduce the AC losses caused by charging and discharging.

In addition to the aforementioned design of a novel type of SMES, the authors also proposed a combination of a real-time digital simulator (RTDS) and a small-scale toroidal-type SMES system for power quality enhancement simulation. This simulation can consider not only electrical characteristics such as inductance and current, but also temperature characteristics using the real SMES system.

In this paper, the design of a toroidal-type SMES is described and the thermal characteristics of the toroidal-type SMES system is analyzed. Also, voltage sag compensation is simulated by connecting an RSCAD/RTDS with the toroidal-type SMES. The simulation results are discussed in detail.

2. Design of the toroidal-type SMES

2.1. Specifications of the HTS wire

The dimensions of the wires used to produce the toroidal-type magnet in this paper are shown in Table 1. The Bi-2223 HTS wire, which was made by soldering brass on both sides of the superconductor, was used for the magnet winding. The critical current (I_c) is 105 A at a temperature of 77 K. The minimum double-bend

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Table 1
Characteristics of Bi-2223 brass hermetic wire.

Wire property	Test criteria	Values
Max. width	Continuous measurement entire length	4.45 mm
Min. double-bend diameter	5% I_c degradation (300 K)	70 mm
Max. rated wire tension	5% I_c degradation (300 K)	20 kg
Max. rated tensile stress	5% I_c degradation (300 K/77 K)	175/ 200 MPa
Critical current	Self-field, 1 μV/cm (77 K)	105 A

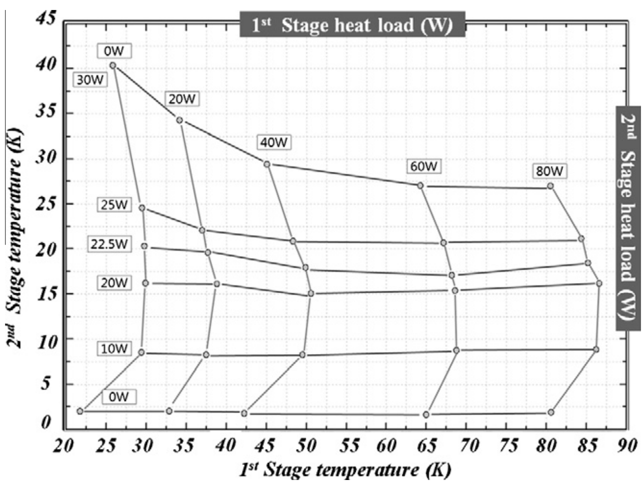

Fig. 1. Specification load map of RDK-415D.

Table 2
Dimension of the toroidal-type magnet.

Items	Values
Number of DPC	30 EA
Inner diameter of SPC	90 mm
Outer diameter of SPC	150 mm
Inner diameter of magnet	270 mm
Outer diameter of magnet	600 mm

diameter of the superconducting wires was 70 mm, the maximum wire tension was 20 kg, and the maximum tensile stress at 77 K was 200 MPa.

2.2. Conduction cooling system

The SMES needs a cryogenic system. The operating temperature of the toroidal-type magnet was under 20 K. The cooling method used for the toroidal-type SMES was the conduction cooling type. When the cooling method for the toroidal-type SMES was designed, the two-stage Gifford–McMahon (GM)-type refrigerator RDK-415D was considered [5]. Fig. 1 shows the specifications load map of RDK-415D. The first-stage temperature section of the GM refrigerator is responsible for cooling the current leads and shields, and the second-stage temperature section is responsible for cooling the toroidal-type magnets [6]. The coil is cooled by aluminium conducting bars assembled at the top and bottom of the coil. In addition, between each coil and the refrigerator, a heat exchanger made of oxygen-free copper (OFCu), aluminium, and flexible copper blades is installed to simultaneously support and cool the 30 double pancake coils.

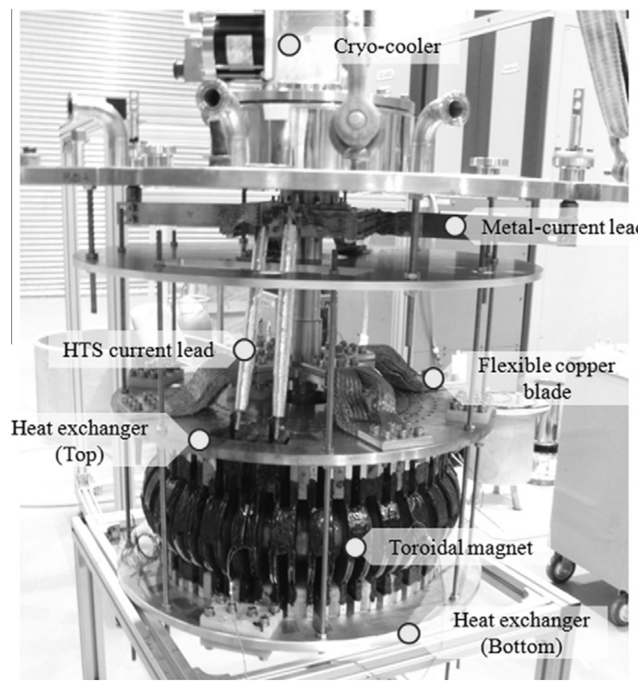

Fig. 3. Manufacture of the toroidal-type SMES.

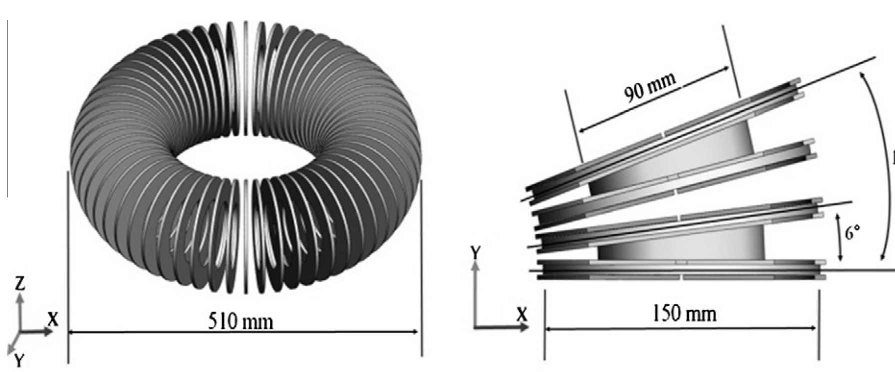

Fig. 2. Design concept of the toroidal-type SMES magnet.