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Development of a 3 MJ/750 kVA SMES system

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Abstract

Research and development on superconducting magnetic energy storage (SMES) system have been carried out to realize efficient electric power management for several decades. Korea Electrotechnology Research Institute (KERI) has developed a 3 MJ/750 kVA SMES system to improve power quality in sensitive electric loads. It consists of an IGBT based power converter, NbTi mixed matrix Rutherford cable superconducting magnet and a cryostat with HTS current leads. A computer code was developed to find the parameters of the SMES magnet which used minimum amount of superconductors for the same energy storage capability, and the 3 MJ SMES magnet was designed based upon that. This paper describes the fabrication and experimental results of the 3 MJ/750 kVA SMES system.

Keywords: SMES; IGBT; Cryostat; HTS current leads; UPS

1. Introduction

Many machines used for special purposes which include military and industrial applications are very sensitive to the power quality and can have very serious problems in the case of electrical mal-function. Unexpected interruption and deterioration of electric power in these machines can cause a great socio-economical loss. Although uninterruptible power supply (UPS), has been widely used to maintain the power quality, it has several problems: short life time of batteries, environmental problems caused by chemicals, and the need for a large space. The SMES system has been suggested as a fast responding compensation system for interruption and voltage sag. The SMES system not only has the ability to control active and reactive power simultaneously, but also has a long life time because the superconducting magnet does not have degradation problem which the battery has. Therefore, the SMES system is more effective in compensating the power interruption, more economical, and more environment-friendly than UPS.

The SMES system can basically respond to the unexpected interruption and voltage sag effectively. To develop and manufacture the 3 MJ-class SMES system that can effectively protect very sensitive military and industrial electric power loads from disturbance, full field evaluation of the system is required for not only improving the performance of the system, but also obtaining the required reliability for military and industrial purposes. The final goal of this study is the commercialization of the SMES system. And so, it is important to develop the design and the manufacturing technologies of the SMES system which will be transferred to the industry. In this paper, the fabrication and experimental results of a 3 MJ/750 kVA SMES system are described.

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2. SMES system

2.1. Magnet

Since the stability rather than ac losses of the 3 MJ SMES system is the focus of this study, the magnet of the SMES system was made of a Rutherford type cable [1]. The Rutherford cable consists of 36 strands, without insulation between them, and its cross-section is nearly rectangular. A Kapton tape of 25 μm thick and 10 mm wide was helically wrapped with 30% overlap around the conductor to provide insulation between turns. The cross-section of the conductor is shown in Fig. 1, and its main parameters are listed in Table 1.

The design criterion of the 3 MJ SMES magnet was to obtain the required energy storage capability with the minimum amount of conductor [2]. The bobbin was made of a non-metallic material, which was fiberglass reinforced plastic G-10, to avoid eddy current losses during a pulse operation. The magnet consists of 64 layers, and a gap was placed with 1 mm thick spacers between two layers for cooling channels. These cooling channels carry the evaporated helium to radial channels in the end flanges. The magnet was wound with a tension of 20 kgf. The operating current was determined according to the recovery current characteristics tested by a sample coil [3]. The SMES magnet was designed based on the above results.

For quench detection, voltage taps to divide the magnet into two sections were placed at the position where inductance of each section is equal. This is because such arrangement makes it possible to detect a quench in each section with an equal sensitivity [4]. The quench detection level has been set to 200 mV resistive voltage.

Table 2 shows the specifications of the 3 MJ SMES magnet, and a photo of the assembled SMES magnet is shown in Fig. 2. Fig. 3 shows the charge currents measured in the magnet and its load line. As a preliminary test, the magnet itself was excited by a DC power supply up to 1000 A, and the maximum field was measured.

2.2. Cryostat

A cryostat keeps a superconducting magnet in liquid helium temperature. Therefore when we design a cryostat, it is necessary to minimize the heat leakage into the cryostat. This requires minimization of the supporting structure to reduce conduction heat. However, for a movable cryostat, we also need to take mechanical strength of the support structure into account. We tried to find the optimal size and number of supporting pieces to minimize the heat loss while maintaining the required mechanical strength.

Table 1
Parameters of the Rutherford cable

Strand	
NbTi/CuNi/Cu ratio	1/0/1.85
Diameter	0.648 mm
Filament diameter	6 μm
Filament twist pitch	13 mm
Number of filament	4182
RRR	50
Cable	
Dimensions	11.8 mm × 1.3 mm
Number of strands	36
Transposition pitch	94 mm
Transposition direction	Left
Insulation	25 μm × 10 mm
Critical current	9780 A at 5.6 T, 4.2 K

Table 2
Specifications of the SMES magnet

Type of magnet	Solenoid
Inner diameter	865.6 mm
Outer diameter	1160 mm
Height	475.2 mm
Number of layer	64
Number of turns	2400
Total conductor length	8137 km
Inductance	6 H
Rated current and field	1 kA at 4.2 T
Stored energy	3 MJ

Four cryocoolers were attached; two cryocoolers to current leads, another to 60 K shield and the last one to recondenser in the cryostat. The cryostat was manufactured according to this cryocooler capacity, and basic measurements such as temperature and stress were carried out. After that, the cryostat was packed by welding. Fig. 4 shows drawing of the cryostat before connecting to the control part and cooling part. The explanation of the parts numbered in Fig. 4 are as follows; ① vacuum vessel, ② 60 K shield, ③ LHe vessel, ④ top plate, ⑤ vacuum vessel, ⑥ current lead, ⑦ HTS current lead, ⑧ support, ⑨ support, ⓐ 1.5 W@4.2 K cryocooler, ⓑ 1 W@4.2 K cryocooler, ⓒ 80 W@80 K cryocooler, and ⓓ 180 W@80 K cryocooler.

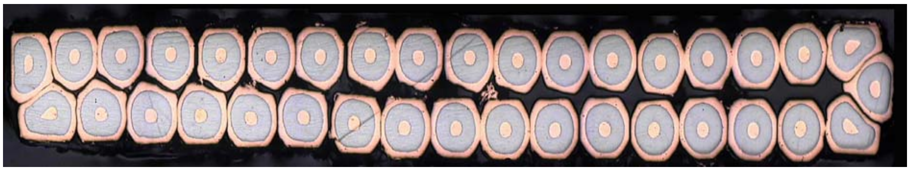

Fig. 1. Cross-section of the Rutherford cable.