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Development of a 3MJ/750kVA SMES System

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Abstract-- **Research and development on superconducting magnetic energy storage (SMES) system have been done to realize efficient electric power management for several decades. Korea Electrotechnology Research Institute (KERI) has developed a 3MJ/750kVA 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 has minimum amount of superconductors for the same stored energy, and the 3MJ SMES magnet was designed based upon that. This paper describes the fabrication and experimental results of a 3MJ/750kVA SMES system.**

1. INTRODUCTION

Many military machines on special purposes are very sensitive and can be very serious due to the effect of mal-function. Unexpected interruption and deterioration for electric power in many military machines cause a great loss to us in economical and national. Although Uninterruptible Power Supply (UPS), used widely, can make a bit clear that, UPS has been faced with several problems; short life time of batteries, environmental problems caused by chemicals, and the necessity of a large space. The SMES system, however, suggests as a fast responding compensation system for interruption and voltage sag. This SMES system has not only the ability of controlling active and reactive power simultaneously, but has a long life time because the superconducting magnet does not have degradation like the battery. Therefore, the SMES system saves resources basically.

SMES system can basically improve in quality and make clear deterioration for electric power due to an unexpected interruption and voltage sag. To develop and manufacture the 3MJ-class SMES system that can protect effectively the very sensitive military and industrial electric power loads, full field evaluation of the system is essential for not only improving the performance of the system, but also obtaining the required reliability for military and industrial purposes. In case of transferring the design and the manufacturing technologies of the SMES system to an industry, which is involved the project, we can produce the SMES system on a commercial basis and can cope with the situation such as the increment of electric power demand and the requirement of high quality electric power, in future.

2. SMES SYSTEM

2.1. Magnet

We put weight on stability rather than ac losses of the SMES system. The main magnet of the SMES system was made of a Rutherford type cable. The Rutherford cable consists of 36 strands, without insulation among them and its cross-section is nearly rectangular approximately. A Kapton tape of 25 μm thickness and 10 mm width was helically wrapped 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.

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

TABLE I
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	11.8mm × 1.3mm
	Number of wires	36
	Transposition pitch	94 mm
	Transposition direction	Left
	Insulation(Kapton)	25 μm × 10 mm
	Critical current	9780A at 5.6T

The design criterion of the 3MJ SMES magnet was to obtain the required storage energy with the minimum conductor [1]. At the fabrication of the magnet, the bobbin was made of a non-metallic material, that is fiberglass reinforced plastic namely G-10, to avoid eddy current losses during a pulse operation. A magnet consists of 64 layers and placed 1 mm thick between two layers which are forming cooling channels. These cooling channels carry the evaporated helium to radial channels in the end flanges. To avoid wire movements we wound the magnet with a prestress of 20 kgf. We determined the operating current according to the recovery current characteristics tested by a sample coil [2]. The SMES magnet was fabricated based on the above results. For quench detection a 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 [3].

Table 2 is the specification of 3MJ 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 tested by a DC power supply. The magnet was energized the 1000A and measured the maximum field.

TABLE II

SPECIFICATIONS OF THE SMES MAGNET.

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

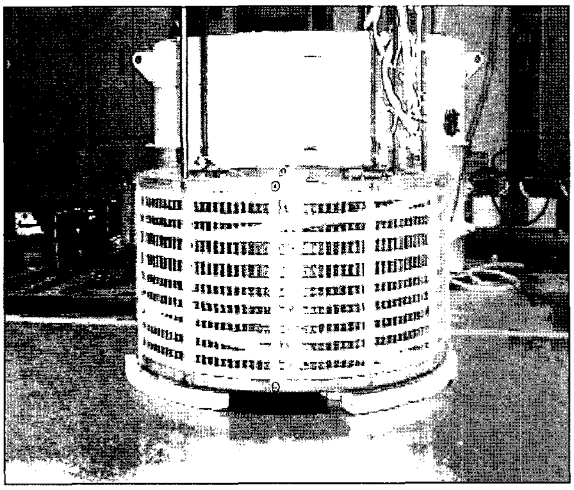


Fig. 2. Assembled 3MJ SMES magnet.

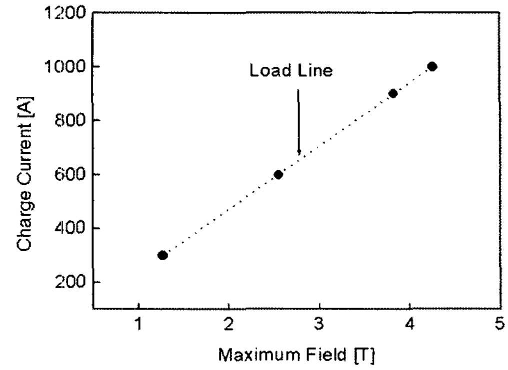


Fig. 3. Charge current and load line vs. maximum field of magnet.

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 from the environment. 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 in account. We tried to find the optimal size and number of supporting pieces to minimize the heat loss, keeping the mechanical strength over the requirement.

Four cryocoolers are attached two cryocoolers for cold head and two cryocoolers for recondenser in the cryostat. The cryostat was manufactured through this design, and basic measurements, such as temperature and stress measurements, were done. After that, the cryostat was packed by welding.

Fig. 4 shows picture of the cryostat before connecting to the control part and cooling part. In a cryostat containing liquid helium and a low temperature superconducting magnet, a large part of the heat loss passes through the current leads.

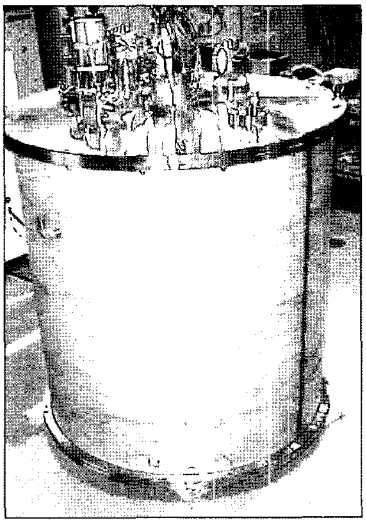


Fig. 4. Cryostat for 3MJ SMES.

2.3. HTS current leads

A progressive way to reduce the heat loss through current leads is using HTS for current leads, and many superconducting system developers are adopting HTS current leads.

In this study we developed current leads of Bi-2223/AgAu tape and copper [4]. Fig. 5 shows side view of the hybrid current leads. Table 3 shows specifications of the hybrid type HTS current leads.

Fig. 6 show a test result. This figure shows heat leakage into liquid helium during one ramp up and down cycle through one current lead. In this test, cold ends of the leads were shorted by copper bar, and the heat loss was measured by a calorimetric method.

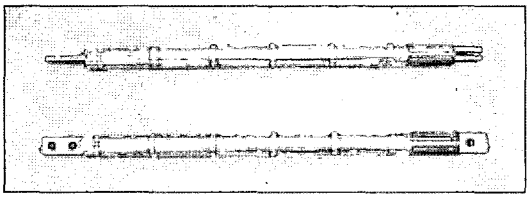


Fig. 5. The HTS current leads.

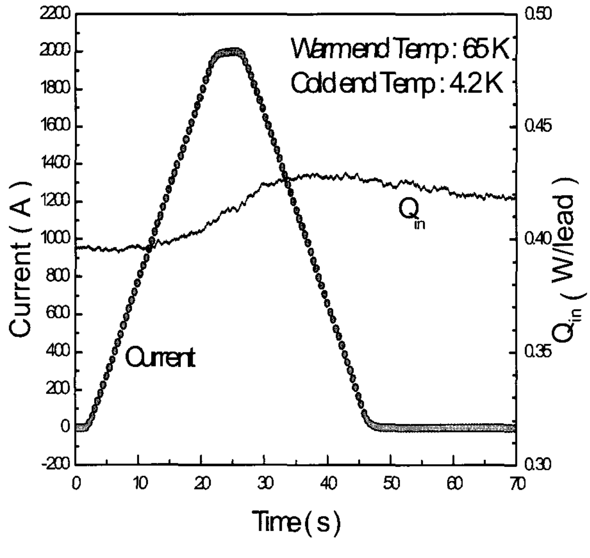


Fig. 6. Heat leakage into liquid helium during one ramp up and down cycle.

TABLE III

SPECIFICATION OF THE HTS CURRENT LEADS.

Length	350 mm
Critical current	1625 A at 77K
Number of HTS tapes	112 (7 ×16)
Former	Stainless steel
Terminal	OFC
Heat loss	0.35 W/lead

2.4. Power Converter

The power conversion module is required to charge up electric energy to the SMES and to back up power line. In this paper, a 750 kVA uninterruptible power supply (UPS) is designed and built up. An on line UPS topology is chosen to achieve reliable power back up as shown in Fig. 7. The on-line UPS topology consists of a back-to-back inverters and a chopper for SMES charging and discharging. The ac/dc converter corrects input power factor regulating dc-link voltage while the dc/ac converter regulates the ac output voltage. The SMES magnet is charged up by the dc charger and freewheels through the chopper switch at the normal operation mode. When some kind of power interrupt comes in, the stored energy in the SMES is discharged by the chopper, which regulates dc-link voltage as a constant so that the dc/ac converter keeps controlling the three phase output voltages.

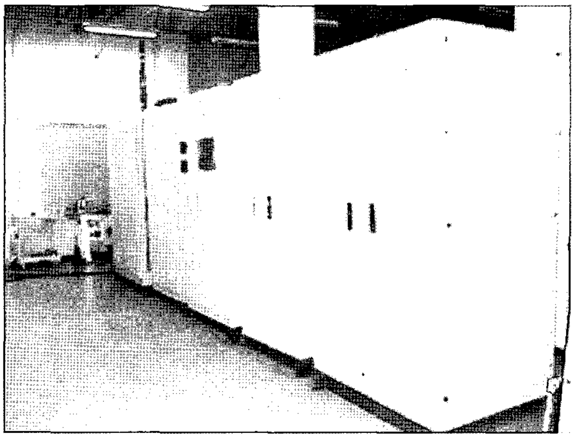


Fig. 7. 750kVA Power Converter for 3MJ SMES.

3. SMES SYSTEM TEST

The SMES system is tested under short time power interrupt to verify the feasibility of the SMES system as a 750kVA uninterruptible power supply. Fig. 8 shows the test scene of 3MJ/750kVA SMES System.

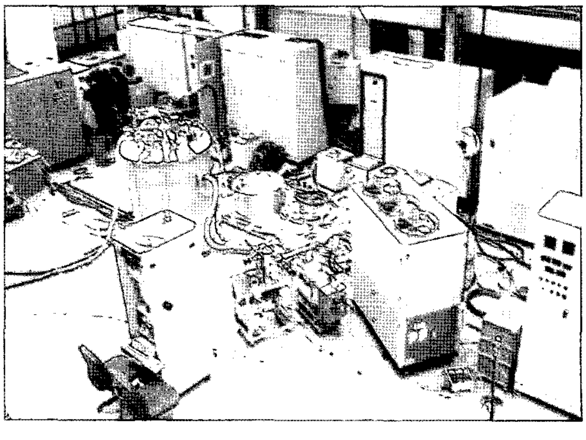


Fig. 8. Test scene of 3MJ/750kVA SMES system.

Fig. 9 shows the waveform of the input voltage, current, magnet current and the output voltage when the power interrupt occurs. The input voltage and current become zero but the output voltage keeps alive and regulated thanks to the power back-up by the discharge of magnet. And Fig. 9 shows the enlarged waveforms at the starting and the end of the power interrupt. At the starting transient, the input voltage and current are abruptly collapsed but the output voltage is well regulated except a little distortion. At the end transient, however, the input current is slowly increased because of soft start algorithm and there is no distortion in the output waveform. Fig. 10 shows photo of the assembled mobile 3MJ/750kVA SMES system.

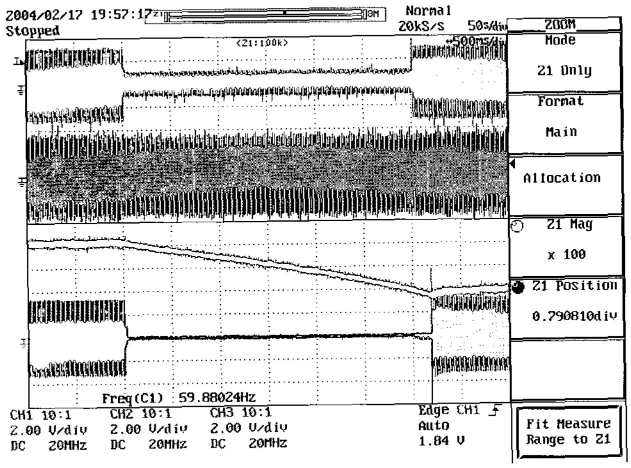
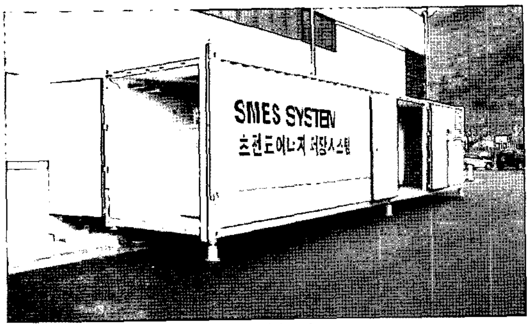
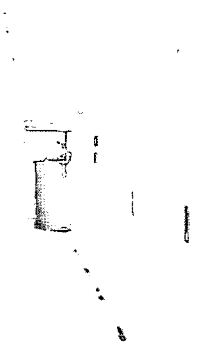


Fig. 9 Experimental waveforms of the power line back-up during short time power interrupt.



(a) Outside view



(b) Inside view

Fig. 10. Mobile 3MJ/750kVA SMES system.

4. CONCLUSIONS

This paper presents the fabrication and experimental results of the 3MJ/750kVA SMES System. Magnet is able to operate to the design current without quench, and get to 3MJ SMES magnet. Cryostat is able to the recondensation at SMES system operator. This SMES system was tested under short time power interrupt. It is shown that the short time power interrupt is successfully compensated using the stored energy in the SMES system.

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