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Examination Results of Power System Control by Experimental SMES

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Abstract—*The authors have developed a solenoid model coil used for superconducting magnetic energy storage (SMES) for power system control, aimed at drastically reducing the costs of the SMES system. The single solenoid model coil of 2.9 MJ is designed with the rated current of 9.6 kA, a maximum magnetic field of 5.5 T and coil charge rates equivalent to those of the practical 100 MW/54 MJ class SMES. The coil is characterized by the use of an aluminum stabilized NbTi CIC (Cable-in-conduit) conductor. The experimental SMES consists mainly of a 2.9 MJ coil, the cooling system for the CIC conductor and the 1 MW class AC/DC converter. The SMES is connected to 6 kV distribution lines at a substation. In the field test, the SMES's 17 ms responses for the step input of active and reactive power were ascertained. Furthermore, its function of compensating for load fluctuation in the 6 kV distribution line was confirmed. The test results show the realization of a practical SMES system for power line control*
Index Terms *-CICC, load fluctuation, power line control, SMES, superconducting coil.*

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I. Introduction

ASMES features highly efficient magnetic power storage and high-speed advanced power control. Therefore manyattractive applications of SMES has been studied [1]–[5]. This allows the SMES to be a key component in power control equipment and is expected to be practically used in the near future, to meet diverse needs including power line control in power systems. The authors have sought the technological development necessary for the practical use of the SMES and have produced a 1 MW/1 kWh SMES prototype that was designed with a module configuration featuring high reliability and extensive application in power system [3]–[5]. Further studies emphasized low-cost superconducting coils and focused on the practical use of SMES for power system stabilization [6], [7]. In this study, an experimental model coil, featuring a uniquely developed conductive material and coil shape, was designed and fabricated. Various tests were conducted to verify whether the model coil with a capacity of 2.9 MJ could perform as designed [8], [9].
The specifications of the SMES model coil as well as various test results are described herein.

II. Components Of The Experimental Smes System

Table I shows the major design specifications of the experimental model coil as well as those of the coil to be used for

TABLE I
MAJOR SPECIFICATIONS OF THE MODEL COIL AND THE COIL OF A 100 MW/15 KWH COMMERCIAL SMES SYSTEM

Item	Commercial system	Model Coil
Operation Input/output power	Rectangular pulses (1 s, 4 cycles)	
Rated voltage	15 kV	
Rated current (Imax)	9.6 kA@5.66T (Bmax)	
Holding current	6.7 kA	
Stored energy/cryostat	96 MJ	2.9 MJ
Ratio of available energy	0.52	
Dump time constant	10.0 s	2.1 s
Conductor	Aluminum stabilized NbTi CIC	
Diameter	1.84 mm	
Al /Cu+CuNi /NbTi	4.4 / 2 / 1	
Coil Diameter (Outer/ Inner)	1.65 m /1.15 m	1.10 m /0.40 m
Length	1.54 m	0.52 m
Number of turns / layers (High / Low field layers)	70 turns /11 layers (6 / 5 layers)	24 turns/16 layers (6 / 10 layers)
Number of coils	4	1
Total conductor length	13,550 m	910 m
Coil configuration	Multi-pole solenoid	Single Solenoid
Cooling condition	0.6 MPa, 4.5 K	0.77 MPa, 5 K
Cryostat size	φ3.98 m×H1.54 m	φ1.65 m×H3.08 m

Commercialized 100 MW/15 kWh SMES system. Similar to that used for the commercial machine, this coil was produced rated current (Imax) of 9.6 kA, a maximum magnetic field (B max) of 5.66 T, a maximum current change rate (dI/dt max) of 7.2 kA/s and a maximum magnetic field change rate (dB/dt max) of 4.3 T/s. The graded conductor was used in the field test.

A. An Experimental Model Coil

Figs. 1 and 2 are schematic diagrams of the conductor and an experimental model coil (single solenoid). The single solenoid model coil with a capacity of 2.9 MJ is designed with a rated current of 9.6 kA, a maximum magnetic field of 5.5 T and coil charge rates equivalent to those of the practical 100 MW/54 MJ class SMES. This coil is characterized by the use of an aluminum stabilized NbTi CIC conductor. The heat balance condition of the model coil is shown in Fig. 3. A coolant, SHe (Super-fluid Helium5.03 K, 7.3 g/s, coil inlet pressure 0.77 MPa) is fed into the coil. The initial cooling tank for the cryostat in which the coil is housed is placed inside the 80 K radiation shield layer, enabling pool cooling for the coil with liquid nitrogen (LN2). To decrease the amount of heat invading from

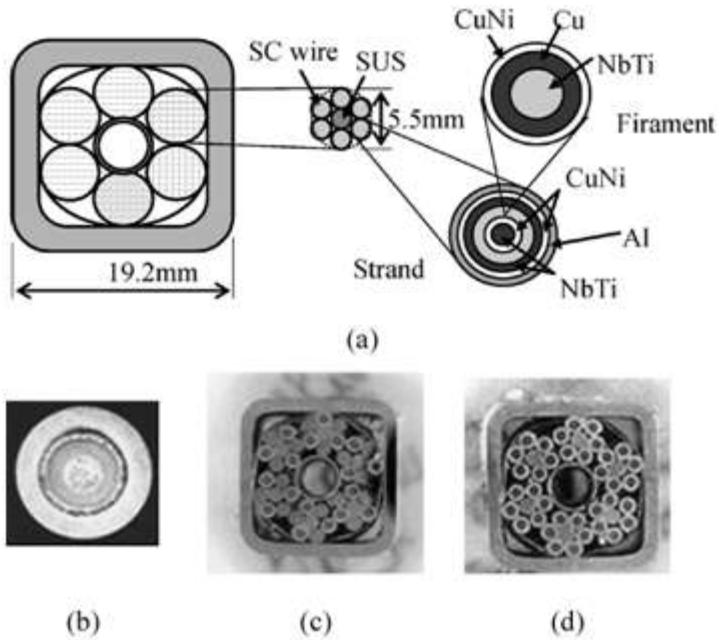

Fig. 1 . Schematic illustrations of the conductor. (a) Cross section of the conductor; (b) Strand; (c) Low magnetic field; (d) High magnetic field

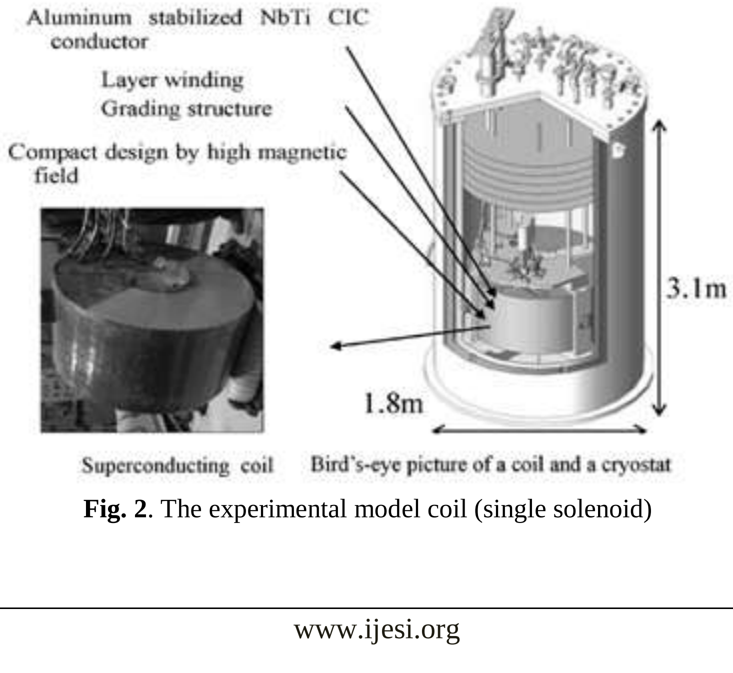

Fig. 2. The experimental model coil (single solenoid)

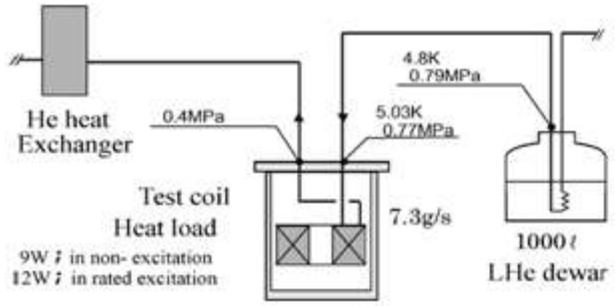

Fig. 3. Hea balance condition of the model coil.

the outside, current lead wires using high-temperature superconductors (Bi2223 Ag sheath tapes) are used. The model coil was installed at Kyushu Electric Power's Imajuku test center.

B. Coil Heating Load Characteristics

The amount of heat invading the coil when not applying cur- rent was obtained by estimating the increase in coolant heating

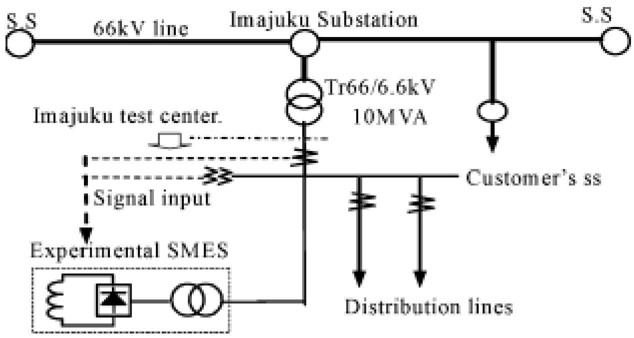

Fig. 4. Examination circuit of a power system and experimental model coil in at Imajuku test center.

Values in the cryostat based on coolant enthalpy at the cryostat inlet/outlet as well as mass flow. Taking into account an effect from error because the absolute value was small, the amount of heat invading the coil was 9 W, as initially designed. The de- signed value of heat invasion mainly includes radiation from the LN_2 shield layer (2.7 W) and the measurement line's heat conduction (2.2 W). The authors observed that heat invasion was found to be almost zero from the HTS current leads. In addition, regarding the amount of heat invading the coil while the current was applied, heat invasion from the current leads was

0.4 W. Even when the Joule heat (1.2 W) caused at the conductor connection part is included, heat invasion of about 11 W is estimated. This value, as a whole, met the designed specifications.

III. Examinations Of The Experimental Smes System

series of field tests was conducted at the Imajuku test

Centre Fig. 4 shows the test circuit of a power system and experimental model coil in at Imajuku test center. Fig. 5 shows the experimental SMES system including the model coil. An experiment was implemented to compensate for load fluctuation, applying PID(Proportional Integral Derivative) control to the SMES. The validity of the SMES has been under investigation by linking its prototype to a 6 kV power system. Other experiments were conducted concerning the compensation of load fluctuation in a 6 kV power system by controlling the degree of the SMES's energy output.

A. Rated Current-Carrying Characteristics

In the test in which a rated 9.6 kA current was applied, the coil current increased up to 9.6 kA in a stepped manner after the coil was excited; and then, a 9.6 kA current-carrying condition was sustained for about 20 minutes. The quench phenomenon was not seen even though the environment for the coil was in a severe condition, demonstrating its adequate stability. The coolant temperature was 5.6 K at the coil inlet (high magnetic field side) and 5.9 K at the coil outlet (low magnetic field side), displaying extremely high values. In short, the value of 0.5–0.6 K increased when compared to the designed value of 5.03 K/5.43 K. How- ever, the values are in the stable range as designed, coinciding with test results. Therefore, it was found that the coil had satis factory stability at 4.5 K in the actual machine.

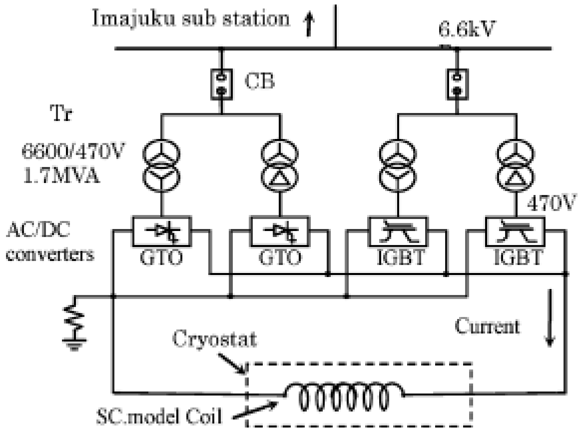

Fig. 5. The experimental SMES system including the model coil.

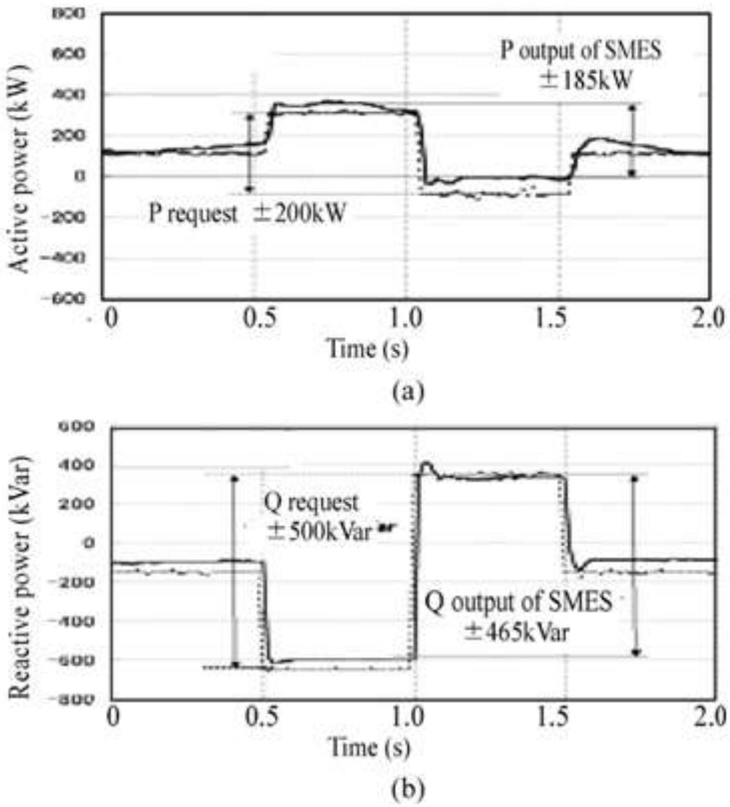

Fig. 6. Examination results of active and reactive power response of the SMES. (a) Active power response; (b) Reactive power response.

B. Response Tests of Active and Reactive Power

To define the characteristics of the SMES system, the SMES response for the step input of reactive power as well as that of active power were measured. Fig. 6 shows the test results of the SMES's response characteristics in the case of P request (Pr) 200 MW and Q request (Qr) 500 MW. In Fig. 6, test results of P output (Po) 185 MW and Q output (Qo) 465 MW were shown. Po and Qo are about 7% smaller than Pr and Qr depending on the AC/DC converter loss. But they are possible to complement by the SMES system control. Fig. 7 illustrates the test results in the case of reactive powers of 300 MW and 10 Hz rectangular pulse operation on the SMES. A delay of 16.6 ms for both active and reactive power input was observed. These test results revealed that the response of the SMES is sufficient for compensation control for the power line.

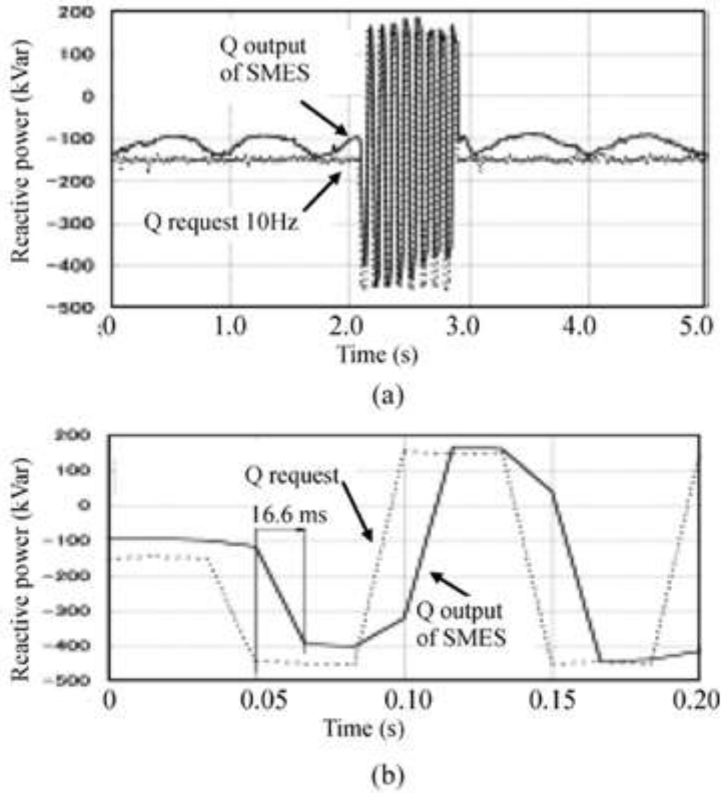

Fig. 7. Examination results of reactive power characteristics of 10Hz rectangular pulse operation for the SMES. (a). Full figure of 10 Hz pulse operation; (b) Enlargement figure of delay characteristics.

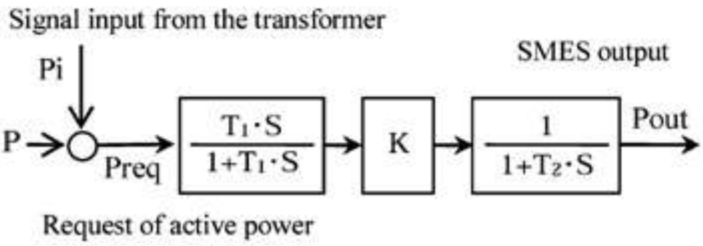

Fig.8 The PID control block of the SMES.

C. Compensation for Load Fluctuation

The PID control block of the SMES is shown in Fig. 8. Energy balance in the SMES was taken into account. T1(0.5 s) means the initial control value, requiring its deviation to be controlled. When a constant K becomes larger, compensation for long-cycle load fluctuation becomes effective and consumption of coil energy becomes larger. Conversely, when K becomes smaller, control of long-cycle load fluctuation becomes effective. The results of the experiment for non control and SMES control for the transformer's active power are illustrated in Fig. 9. The figure includes (a) active power of the transformer, (b) output power of the SMES, and (c) coil current of the SMES. In Fig. 9, Load fluctuation in controlling storage capacity was smaller than that without control. The coil current varies between 3,020 A and 3,400 A. The results proved that load fluctuation can be regulated by controlling the SMES.

The authors decided to compensate for active power up to 5 s or for a voltage fluctuation with a relatively short cycle, because the model coil has less storage energy. The results of analysis clearly indicate a sufficient control effect of the SMES against such fluctuation with a periodic component of 1 to 3 s. In addition

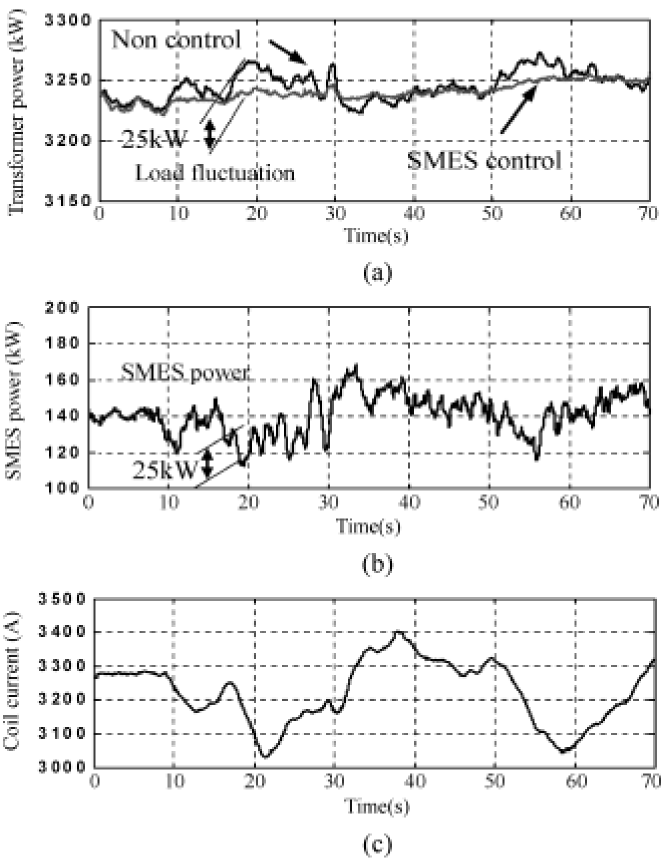

Fig. 9. Examination results of non control and SMES control for the transformer's active power. (a) Active power of the transformer; (b) Output power of the SMES;(C) Coil Current of the SMES

a relatively large voltage fluctuation with a periodic component of about 20 s could be controlled because few limitations are found in the coil's storage energy. The effect of SMES control was confirmed. These results suggest that applicability of a practical SMES for active power control with a larger capacity will be effective for stabilizing voltage fluctuations in power systems over the long-term.

IV. Conclusion

The authors developed a 2.9 MJ solenoid model coil with a rated current of 9.6 kA, which will be used for the SMES for power system control. In a series of field tests, the SMES's 16.6 ms response in the step input of both active and reactive power was observed. Furthermore, the SMES's superior performance in compensating for the load fluctuation of the 6 kV distribution line was also defined. The test results suggest actualization of a practical larger-scale SMES for power line control. In re- cent years, High-Tc SMES has been studied. The authors also designed and fabricated a small High-Tc coil of Bi2223 wires for a future High-Tc SMES [10], [11]. The results of this paper suggest to be effective for a future practical High-Tc SMES.

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References

[1]. J. D. Rogers et al., "Operation of the 30 MJ superconducting magnetic energy storage system in the Bonneville power administration electrical grid," IEEE Trans. on Magnet, vol. Mag-21, no. 2, pp. 752–755, 1985.

[2]. C. A. Luongo et al., "A 100 MJ SMES demonstration at FSU-CAPS,"IEEE Trans. on Applied SC., vol. 13, no. 2, pp. 1800–1805, 2003.

[3]. T. Imayoshi et al., "Development of a 1 kWh-class module-type SMES-design study," IEEE. Trans. on Applied SC., vol. 7, no. 2, pp. 844–847, 1997.

[4]. H. Hayashi et al., "Result of tests on components and the system of 1 kWh/1 MW module-type SMES," IEEE. Trans. on Applied SC., vol. 9, no. 2, p. 313, 1999.

[5]. H. Okada et al., "Study on a module type SMES," IEEE Japan, vol. 115-b, no. 1, pp. 52–60, 1995.

[6]. ISTEC, Annual Reports to NEDO on, Technology Development of Su- per conductive Magnetic Energy Storage System Vols. Mar. 2000, Mar. 2001 and Mar. 2003.

[7]. K. Asano et al., "A study of cost reduction on the SMES system," Cryogenic Engineering, vol. 37, pp. 106–113, 2002.
[8]. K. Terazono and M. Arika et al., "Verification test results of the experimental model coil for power system stabilization," Physica C, pp. 1251–1255, 2004.
[9]. H. Hayashi et al., "Development of cost-reduction SMES for power system stabilization," J. Cryo. Soc. Jpn., vol. 40, no. 5, pp. 167–174, 2005.
[10]. Ichinose et al., "Feasibility study on high-Tc SMES," J. Cryo. Soc. Jpn, vol. 40, no. 5, pp. 150–158, 2005.
[11]. H. Hayashi et al., "Fabrication and test of a 4 kJ Bi-2223 pulse coil for SMES," IEEE. Trans. on Applied SC., vol. 13, no. 2, pp. 1867–1870, 2003.

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