A new design of SMES coil for bridging instantaneous voltage dips

T. Kurusu, M. Ono, H. Ogata, T. Tosaka, I. Senda, and S. Nomura
Toshiba Corporation, 2-4, Suehiro-cho, Tsurumi-ku, Yokohama 230-0045, Japan

Abstract. This paper describes a new design concept of SMES coil for bridging instantaneous dips and some experimental results. The technical key point of this work is the design of a NbTi coil composed of a monolith NbTi/Cu wire for DC application. In order to cover the disadvantages of the monolith wire, some solutions have been proposed and tested using a full-scale test coil. Experimental results show the validity of the design concept of the SMES coil.

1. Introduction
The SMES system for bridging instantaneous voltage dips is close to being suitable for practical use in Japan [1]. It is widely considered that cost-reduction is an important key to spreading SMES system as a competitive-price product.

In order to develop a SMES system for bridging instantaneous voltage dips, we designed a SMES coil, which is composed of a NbTi/Cu monolith wire for DC application. As a general rule, a NbTi wire for DC application has low current capacity and greater AC loss, compared with a stranded cable conductor for AC application or a pulse magnet. For the purpose of covering the disadvantages of the monolith NbTi wire, we introduced two concepts; one is a large heat-capacity coil, the other is parallel connection of several coils to a power converter.

A full-scale test coil was manufactured and experiments were conducted to verify the concept.

2. Design concept of SMES coil
2.1 Design concept
Our target is to realize a 10MVA-class SMES system. In this research, the SMES magnet of the system is assumed to be composed of several coils, which are wound with a NbTi/Cu monolith conductor for DC application and connected to a power converter in parallel.

Figure 1 illustrates the design concept. As shown in the figure, each coil is co-wound with an insulated stainless steel wire for a mechanical reinforcement enduring electromagnetic stress. As stainless steel has large specific heat at around 4 K, and thermal diffusion from NbTi wire to stainless steel wire is rapid compared to the SMES operation time: ~1 s, so the effective heat capacity of the coil is almost doubled. In addition, the co-wound stainless steel wire works as a compensation coil of quench detection.
Figure 1. A new design concept of SMES coil for bridging instantaneous voltage dips.

Figure 2 illustrates a quench protection system. Since the compensation coil reduces the inductive voltage of a SMES coil to less than one part per thousand, it has the potential for high-reliability detection when an inductive voltage exceeds several kilovolts. As shown in Fig. 2, since the detector short-circuits between NbTi conductor winding and stainless steel wire winding as soon as quench is detected, an effect of quench propagation acceleration is expected by joule-heating of the stainless steel wire winding.

2.2 Full-scale test coil

Figure 3 shows a full-scale test coil. The test coil is composed of two element coils, which are set coaxially and connected in parallel. Coil parameters are listed in table 1.
Table 1. Parameter of full-scale test coil

| Wire                        |                        |
|-----------------------------|------------------------|
| Diameter (bare / insulated) | 1.5mm / 1.6mm          |
| Cross section               | 1.77mm²                |
| NbTi / OFC / Cu2%Ni         | 1 / 2 / 0.3            |
| Filament diameter           | 20 μm                  |
| Twist pitch                 | 15mm                   |
| Critical current at 4.2K, 5T| 1400A                  |

| Coil                        |                        |
|-----------------------------|------------------------|
| Test voltage                | ~8kV                   |
| Operate current             | ~390A                  |
| Inner diameter / Outer diameter / height | 780mm / 940mm / 1200mm |

3. Experiments
A test circuit for experiments is shown in figure 4. In order to simulate SMES operation, coil current has been decayed steeply with an external resistor, by means of power-off in the charging condition.

![Figure 4](image_url)

3.1 AC loss and temperature rise
Figure 5 shows measuring results of AC loss and coil surface temperature, respectively, when the test coil released its energy with a maximum voltage of 2 kV. AC loss evaluated by calorimetric measurement was 930 J, which corresponds to 950 J, a numerical result based on AC loss measurement of NbTi wire. As for coil temperature, surface temperature measured by CERNOX sensor also corresponds to numerical analysis as shown in figure 5 (b).

![Figure 5](image_url)

3.2 Energy release with a maximum voltage of 8 kV
Figure 6 shows the result of energy release with a maximum voltage of 8 kV, which corresponds to the condition of actual equipment. Normal operation was demonstrated. In addition, the quench detector was demonstrated to monitor without error.

![Figure 6. Coil voltage and current changes during simulated SMES operation](image)

3.3 Quench detection and coil protection

Figure 7 shows the quench signal and current change, respectively, when quenching occurred in the process of coil training. As shown in figure 7 (a), quench initiation has been captured in detail. Since the successive sequence: detection, power-off, and current decaying was rapid, current transfer from the quenched coil to the other coil was hardly observed as shown in figure 7 (b). From the viewpoint of coil protection, validity of the parallel-connection SMES coils was demonstrated.

![Figure 7. Quench signal and current change when quenching occurred.](image)

4. Summary

We proposed the new design concept of a SMES coil for bridging instantaneous voltage dips, which is composed of a NbTi/Cu monolith wire for DC application. A full-scale test coil was manufactured and experiments were conducted to verify this design concept. Experimental results show the validity of the designed coil.

References

[1] Nagaya S, Hirano N, Kondo M, Tanaka T, Nakabayashi H, Shikimachi K, Hanai S, Inagaki J, Ioka S and Kawashima S 2004 Development and Performance Results of 5MVA SMES for Bridging Instantaneous Voltage Dips *IEEE Trans. Appl. Supercond.* 14 699