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Development of YBCO power devices in Japan

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ABSTRACT

A new Japanese national project, called M-PACC, to develop high temperature superconducting electric power devices started in June last year (FY2008–FY2012). This project aims to develop three different types of electric power devices that are expected to provide stable power supplies with large capacity and small size by using YBCO coated conductors. The first program is the development of a 2 GJ class superconducting magnetic energy storage system to control stable electric power systems. It is planned to develop several sets of element coils for a 20 MJ class system as a technological feasibility study for a 2 GJ class coil. The second program is the development of two different types of power cables with higher performance than existing power cables; one is a three-core 66 kV–5 kA class large current cable and the other is a single-phase 275 kV–3 kA class high voltage cable. These cable were required several technological developments, namely, large current and low AC loss, high voltage insulation and low dielectric loss, and power and heat balance for both cables. The third program is the development of a 20 MVA class power transformer with 66 kV/6.9 kV as a distribution transformer. In this project, power transformer systematization technology including 2 kA class large current coil technology, anti short-circuit wire winding technology, AC loss reduction technology, and winding technology will be developed.

1. Introduction

The performance of YBCO coated conductor (CC) has recently remarkably improved. YBCO CC has also advanced in terms of cost, mechanical strength, high critical current density (J_c) under a self-field as well as an external electric field, and losses due to their architectures in AC applications. Moreover, a significant amount of long YBCO wires have been stably manufactured. As a result, numerous high temperature superconducting (HTS) power devices using YBCO CCs have been demonstrated in practical usage all over the world.

HTS electric power devices are compact and have a large power capacity with instantaneous supply. In addition, they make it not only possible to reduce power transmission losses significantly and improve power system stability but also to alleviate global environmental problems and allow more efficient use of energy resources. In the future, it is supposed that these devices will be installed in electric power grid systems, as shown schematically in Fig. 1, replacing existing power devices. In particular, three HTS devices – a superconducting magnetic energy storage (SMES) system, a HTS cable and a HTS transformer – are being developed in a project that the authors started in 2008 [1]. An overview and the development progress concerning these devices are presented in the following sections.

2. SMES

2.1. Outline

Aiming to be installed in a standard power grid, a 2 GJ class SMES will be developed in the future [2]. In this project, it aimed to establish the technologies and know-how for creating 2 MJ class SMES. YBCO SMES is smaller than Nb–Ti SMES and can function under higher temperatures owing to its high I_c/J_c-B properties. Because of their different electrical properties, YBCO SMES and Nb–Ti or Bi SMES must have different systems [3].

2.2. Insulation design and conduction-cooled coil

The electrical insulation and conduction-cooling characteristics of a YBCO coil for SMES in a specified temperature range were estimated and improved on the basis of the characteristics of YBCO CC. The insulation characteristics of a conduction-cooled coil as a toroid-unit coil for 2 GJ class SMES were designed (Table 1), and its conduction-cooling characteristics were estimated. The estimation results revealed the compatibility between withstand voltage and conduction-cooling performance of the conduction-cooled. The

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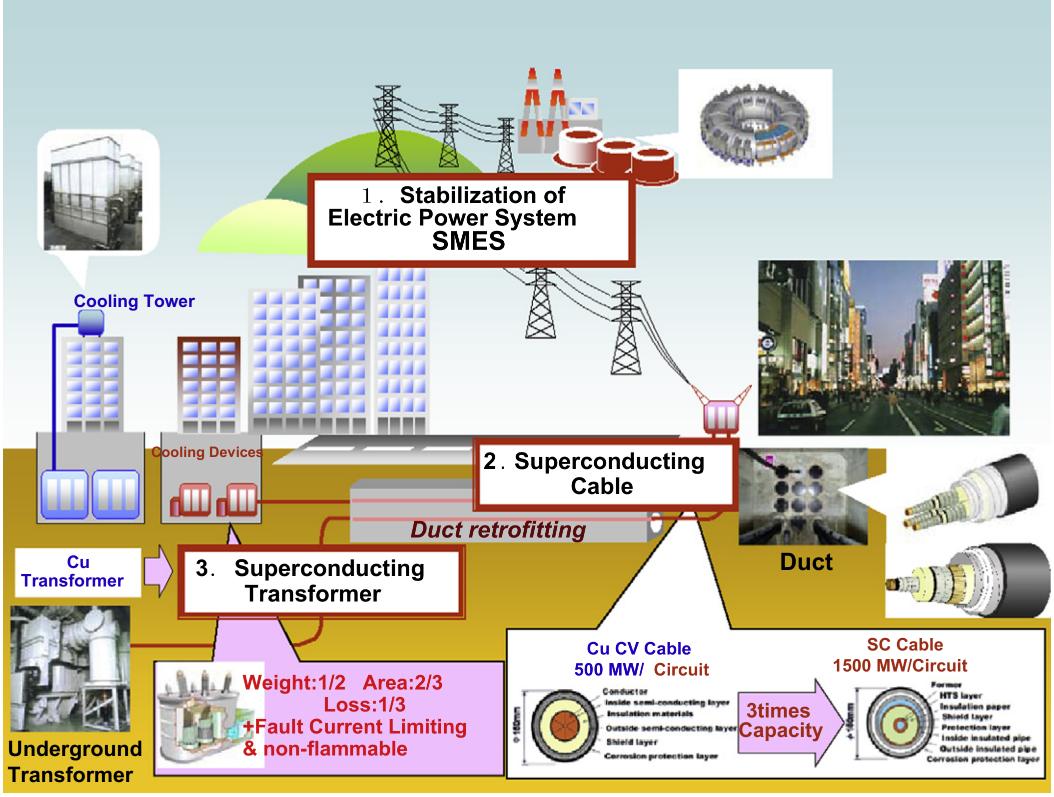

Fig. 1. Conceptual view of an electric power transmutation with HTS power devices.

Table 1
Specifications of the 2 GJ class SMES coil.

Stored energy	2.4 GJ
Operating temperature	20 K
External size of toroid	φ 10 m × h 2.8 m
Unit coil figure	4 stacked pancakes
Number of unit coils	180
Wire current	540 A
Max. magnetic field	11 T (vertical: 0.67 T)
Hoop stress	600 MPa

design specification of the coil on the basis of a required 6 kV rated voltage is summarized in Table 2. The withstand voltage to ground, between each single coil, and between each coil turn were designed to be 6 kV, 3 kV, and 3.7 V, respectively, in consideration of aging degradation of the insulation materials. The conduction-cooling characteristics of the designed coil were estimated. The temperature difference between the coil center and surface was calculated to be less than 0.27 K. A schematic image of the toroid-unit coil designed according to these estimations is shown in Fig. 2. The coil-cooling system uses gas-cryogen flow between the coil surfaces and the cryo-coolers.

Table 2
Design conditions of the conduction cooled toroid-unit coil for 2 GJ class SMES.

Unit coil	
Outer diameter	2.8 m
Inner diameter	2.0 m
Height	60 mm
Surface area	6.08 m^2
Heat flux	3.0 W/m^2
Heat quantity per unit coil	18 W

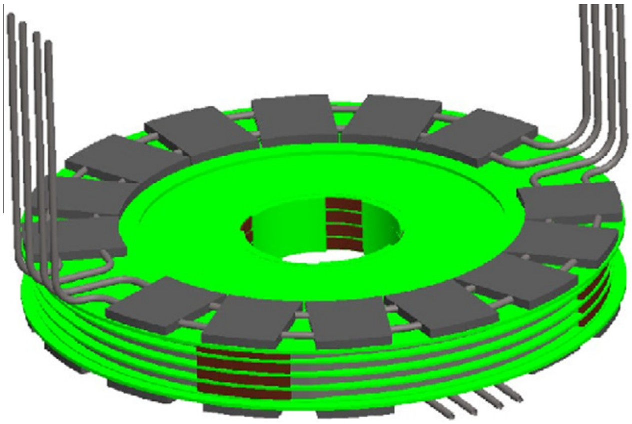

Fig. 2. Schematic drawing of the toroid-unit coil structure.

2.3. Estimation of hoop-stress tolerance

The electromagnetic-stress tolerance of a large-scale YBCO coil (functioning as a toroid-unit coil) was estimated and improved. When a CC is applied to a large-bore coil with high current density and high magnetic-field density, it is subjected to strong hoop stress. A CC therefore requires high mechanical strength and high transport current. The stress–strain characteristics of a CC wire for application in an SMES coil were measured [3,4]. The measurement results are plotted in Fig. 3—which confirms that the elastic limit of the CC is very high, namely, 1.3 GPa, because a Hastelloy® substrate with a high mechanical strength was used for the substrate of the CC and occupied almost the whole volume fraction of the CC.

When SMES charges and discharges repetitively, the CC is subjected to hoop stresses repetitively. The durability of the CC was