by Y. Ohki

Japan's First In-Grid Operation of a 200-MVA Superconducting Cable System

Recently, demands for replacement of over-aged, large-capacity cables, such as oil-filled or pipe-type oil-filled, have been increasing in Japan. In some cases, replacement of these cables by conventional cross-linked polyethylene (XLPE) cables necessitates construction of additional power lines, because of the low transmission capacities of XLPE cables. However, construction of extra power cable lines is becoming difficult, especially in urban areas, since the available underground space is already congested with existing electric cables, water and gas supply lines, and subways. Under these conditions, use of high-temperature superconducting (HTS) cables is considered as a solution. An HTS cable offers high electric power capacity and compact cable size, because it can carry a high current density.

In this context, Tokyo Electric Power Company and Sumitomo Electric Industries have together been conducting research and development of HTS cable systems since 1990. Based on the results of these studies, in 2007 the two companies started a new HTS cable demonstration project, supported by the New Energy and Industrial Technology Development Organization in cooperation with Mayekawa Manufacturing. Mayekawa is a manufacturer of large-scale cooling machines, and its role in the project was to develop a cooling system for the HTS cables. The aim of the project was to connect an HTS power cable system to a 66-kV conventional power grid in the Asahi substation in Kanagawa Prefecture, as shown in Figure 1. Two HTS cables with a total length of 240 m were to be connected by a joint and then connected to the 66-kV bus line through terminations at both ends.

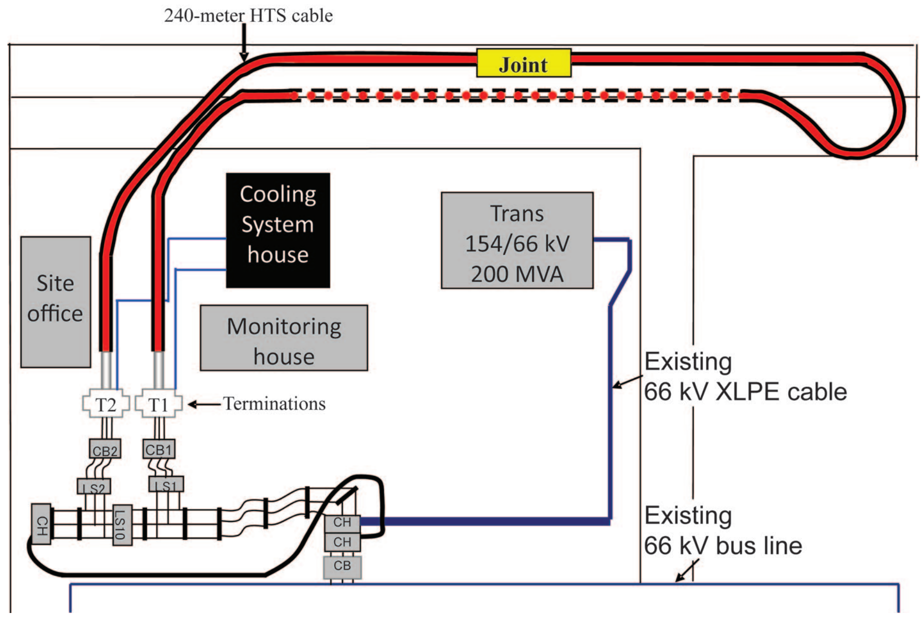

Figure 1. Layout of high-temperature superconducting (HTS) cable system in the Asahi substation.

Figure 2 shows the "three-in-one" HTS cable structure. Three identical HTS cables for three-phase alternating current were placed in one corrugated stainless steel cryostat with multilayered vacuum thermal insulation. The HTS conductor was DI-BSCCO®, and PPLP® was used for electrical insulation. DI-BSCCO® and PPLP® are trade names of Sumitomo Electric Industries, the former standing for dynamically innovative Bi2223 or $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ and the latter for polypropylene laminated paper. Four layers

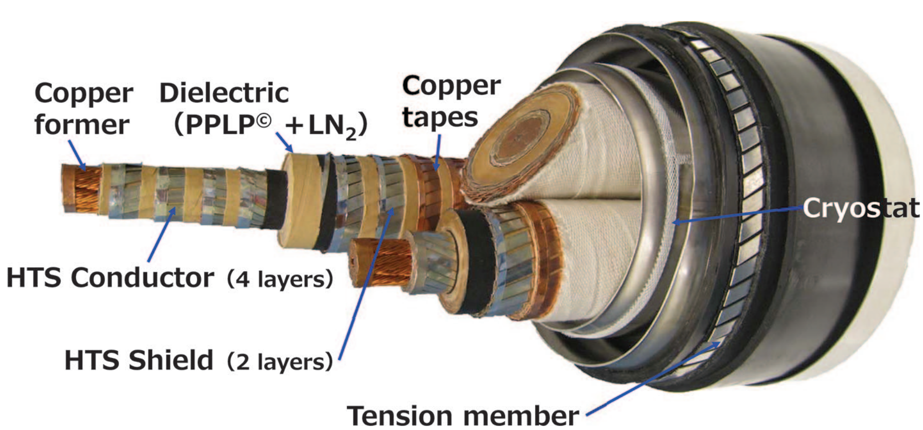

Figure 2. High-temperature superconducting (HTS) cable configuration.

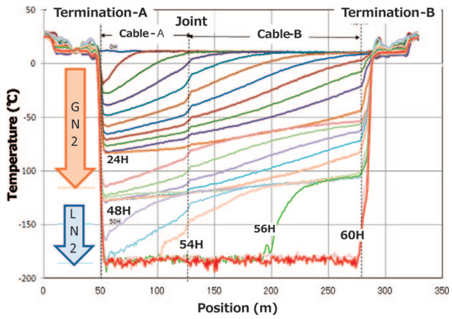

Figure 3. Layout of LN_2 cooling system.

of HTS conductors were wound spirally around a stranded copper former, together with two kinds of shielding layers, HTS and Cu, and the PPLP® insulation, which consisted of an HTS core. Three such HTS cores were stranded and housed in the corrugated cryostat, forming the HTS cable.

Figure 3 shows the layout of a liquid nitrogen (LN_2) cooling system, designed to cool the cable system to a temperature below 77 K in order to maintain the superconducting state. It consists of six Stirling-type refrigerators, two circulation pumps, and other supplementary equipment. The LN_2 was pressurized to 0.2 MPaG ("G" stands for the gauge pressure, added to the ambient pressure) in order to prevent it from vaporizing.

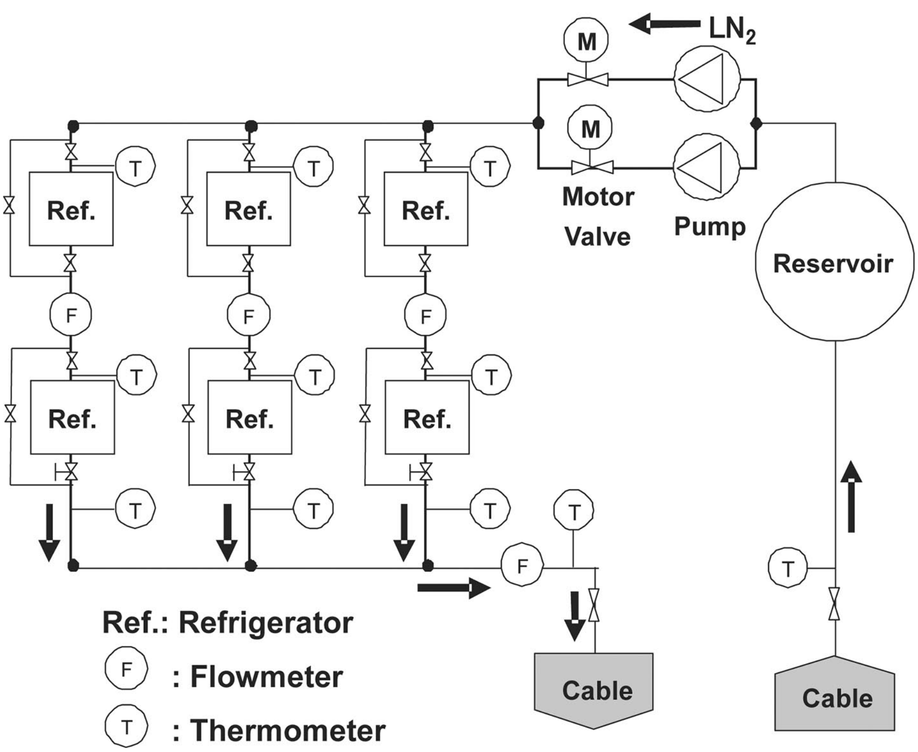

Figure 4. Time-dependent change in temperature of the high-temperature superconducting cable system during the initial cooling process. GN_2 = gaseous N_2, LN_2 = liquified N_2.

During the first two years of the project, basic designs were determined for all the elements in the HTS cable system and cooling system. Thus, the cable was required to transmit a large current with minimal transmission loss and to withstand short-circuit currents. At the same time the demonstration site was determined and the grid conditions carefully scrutinized. In 2009 a 30-m cable system was manufactured to verify the design, and several tests were completed successfully. The cable for the Asahi substation was then manufactured and shipped to the site in 2011. Simultaneously, the cooling system was developed, and its operation, maintenance requirements, and efficiency were checked. The HTS cable system and the cooling system were installed at the site in 2011, and performance tests were carried out on both in 2012. After the successful completion of all tests, in-grid operation began on October 29, 2012.

Before connection to the 66-kV bus line, preoperation tests were conducted to check various aspects of the performance of the total system, e.g., initial cooling ability, heat loss, critical current, DC applied voltage, and so on. The performance of the cooling system was also tested. The complete system functioned as expected,

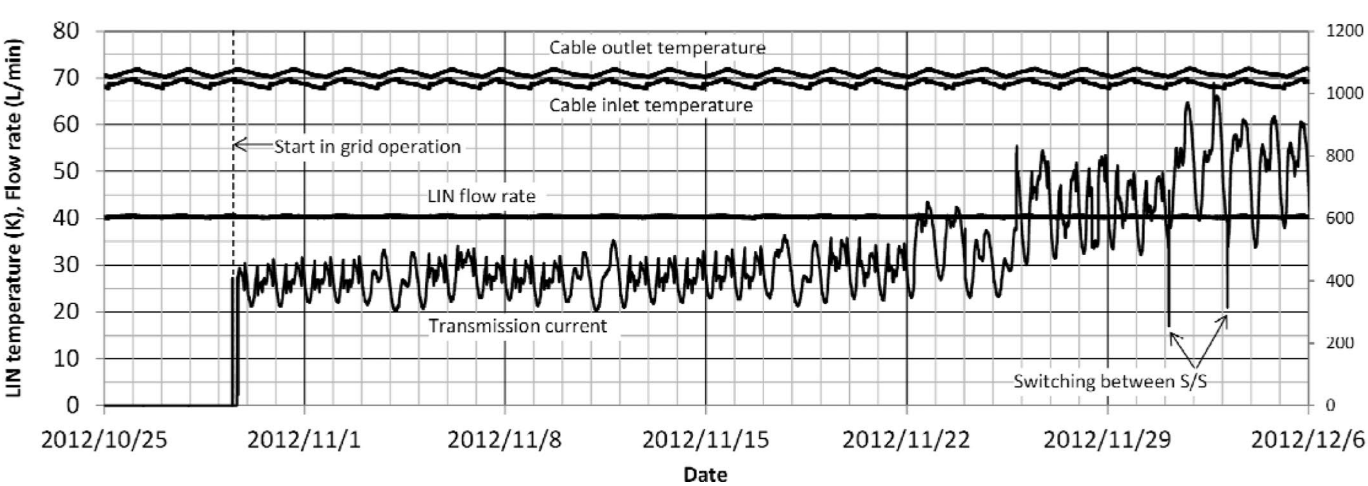

Figure 5. Various parameters of the in-grid operation (1).

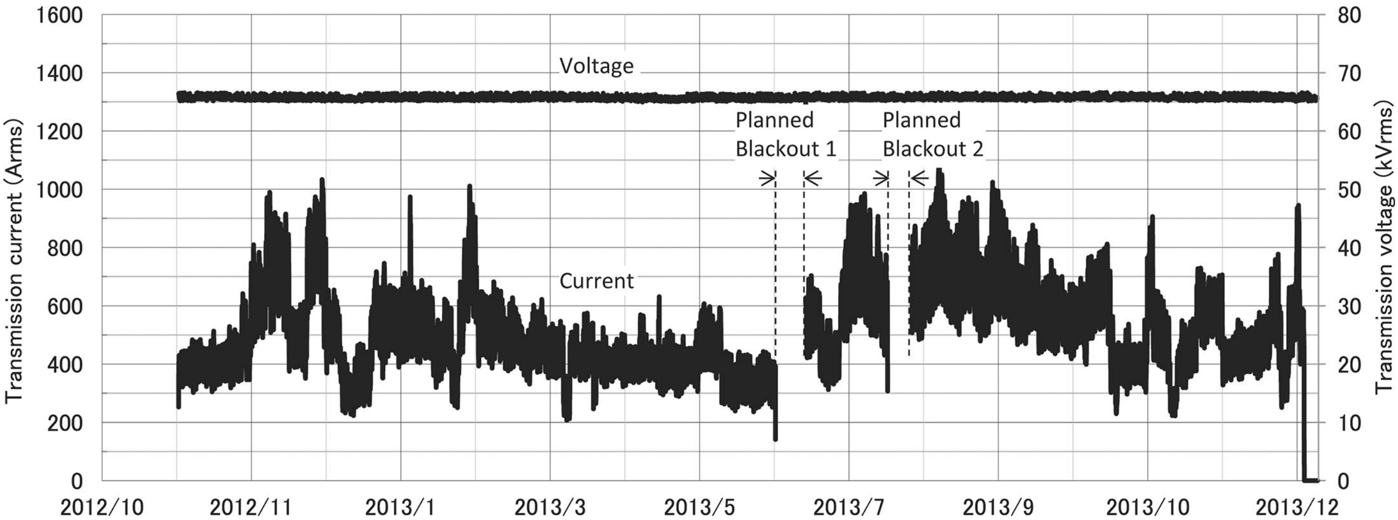

Figure 6. Various parameters of the in-grid operation (2).

showing no deterioration during manufacture, transportation, installation, and cooling.

Figure 4 shows the result of the initial cooling performance. The cable system was first cooled to −100 or −150°C by nitrogen gas, and LN_2 was then poured into the system. The nitrogen gas cooling and the LN_2 filling took two days and one day, respectively.

In-grid operation started on October 29, 2012, and continued for 400 days without any serious problems. The maximum current transmitted through the HTS cable during the operation was 1,127 kA_{rms}, and the long-term stability of the cooling system was also verified. Figure 5 shows various parameters of the operation, e.g., LN_2 temperature control, flow rate, and load current fluctuation. The cable inlet temperature was controlled at 69 ± 1 K in order to maintain stable operation during load fluctuation. Figure 6 shows the variation of voltage and current throughout the in-grid operation period.

Subsequently, some of the characteristics of the cable system, e.g., critical current I_c of the HTS conductor, and the capacitance and loss tangent of the cable dielectric, were measured. No deterioration was found. Thus, good performance and stability of the HTS cable system over more than one year of in-grid operation were confirmed.

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