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Cooling Performance Test of the KEPCO HTS Power Cable

H.S. Yang[1,*], D.L. Kim[1], S.H. Sohn[2], J.H. Lim[2], H.O. Choi[3], Y.S. Choi[1], H.S. Ryoo[3], S.D. Hwang[2]

[1]Korea Basic Science Institute, Daejeon 305-333, Korea
[2]Korea Electric Power Research Institute, Daejeon 305-380, Korea
[3]Korea Electrotechnology Research Institute, Changwon 641-600, Korea

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***Abstract*-- The HTS power cable system of 3-phase 100-m class has been tested at the KEPCO's Gochang power testing center in Korea during 8,000 hours or more for investigating long-term operating performance. The system is rated 22.9 kV, 1250 A and is cooled with subcooled liquid nitrogen. Several cooling performance tests such as cooling capacity, heat load, AC loss, temperature stability and thermal cycle were performed at operating temperature of 66.4 K and several different temperatures.**

1. INTRODUCTION

A high temperature superconducting power cable (HTS-PC) system has been considered as one of the highly-feasible technologies satisfying the rapid increasing of power demand and overcrowded underground space in the cities. The HTS-PC systems are presently being developed and evaluated for practical use in real power grids up to several hundred meters in length [1]. In Korea, a project for verification of the HTS power cable system by KEPCO was started in 2002. As the first step, the HTS power cable system manufactured by Sumitomo Electric Industries has been installed (see Figure 1) and tested at the KEPCO's Gochang power testing center since 2006 [2-3]. A cooling system for the 3-phase, 100-m HTS power cable with 22.9 kV/1.25 kA was also installed and tested. The major items were conducted for the cooling system as follows; heat load test, thermal cycle test which is cool-down to liquid nitrogen temperature and warm-up to room temperature (8 times), loading rated current test, long term rated loading current test (for 30 days), daily loading current cycle test (1250 A for 8 hours and 0 A for 16 hours per one day during 30 days). We ensured the reliability of the cooling system through the demonstration tests for 8,000 hours. This paper describes mainly the heat load test results among the results obtained during the long term demonstration tests.

2. OUTLINE OF COOLING SYSTEM

A schematic illustration of the cooling system of the KEPCO HTS-PC is shown in Figure 2. The HTS cable system consists of a 100-m HTS cable between two terminations, electrical DC and AC power supplies, cooling system, LN_2 return line and the data acquisition system. The open cycle cooling system uses a subcooler to provide up to 3 kW cooling capacity for the HTS system. The subcooler can be pumped by a decompression pumping system consisting of two decompression pumps, a buffer tank and a heating unit to maintain the liquid nitrogen bath temperature in the range of 64 to 77K according to operating temperature. A liquid nitrogen flow in a path from the circulation pump, through the heat exchanger in the subcooler, the supply line, the north termination, HTS cable, the south termination and returns via the return line to the reservoir unit. The liquid nitrogen

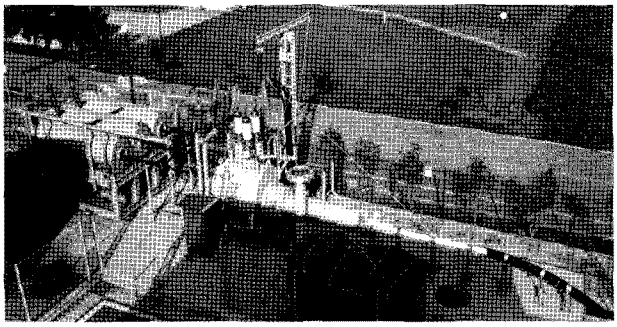

Fig. 1. Photograph of the KEPCO HTS cable system.

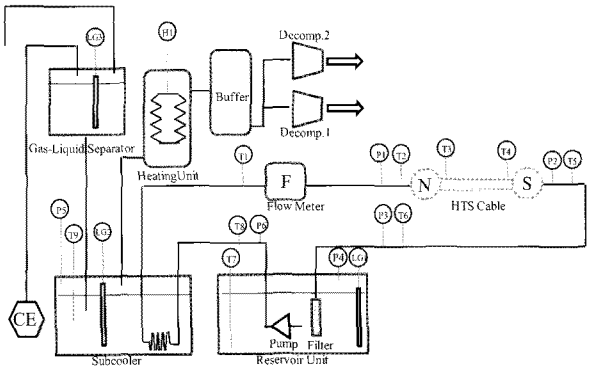

Fig. 2. Schematic illustration of the cooling system for the KEPCO HTS cable. T1 ~ T9; temperature sensors, P1 ~ P6; pressure transducers, LG1 ~ LG3; Liquid level meters, H1; heater, N; North terminal, S; South terminal.

* Corresponding author: yanghs@kbsi.re.kr

storage tank installed outside of the cryogenic room has a five tons capacity. More detailed about cooling system and measurement sensors are described in our previous papers [4-5].

3. HEAT LOAD MEASUREMENT

In order to verify the cable system, various loading current, 0 A, 600 A, 800 A, 1000 A and 1250 A, were loaded to the system with an applying voltage of 13.2 kV (line to ground). Figure 3 shows the heat loads for each part in the KEPCO HTS cable system as a function of loading current at circulation cooling conditions of operating temperature (T1) of 66.4 K and the flow rate of 40 L/min. The heat loads were measured by calorimetric method using the mass flow rate, specific heat and temperature differences for each part as shown at equation (1).

$$Q = \dot{m} C_P \Delta T \tag{1}$$

The total heat load is gradually increased from 1.16 kW at 0 A to 2.3 kW at 1250 A. The total heat load at 1250 A is 1.14 kW higher than that measured at 0 A and is the total AC loss at 1250A. It is known that the AC loss of the superconducting cable is equivalent to 2.2W/m-phase at 1250A from calculating the effective length of the superconducting cable of 91m. It is a good agreement with that of our previous measurement results discussed in our previous papers [4-5]. From this result, we could confirm long term reliability of the HTS cable system for 8,000 hours.

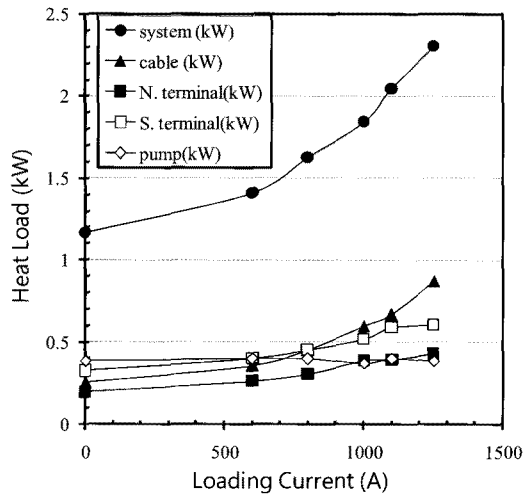

Fig. 3. Heat load of the KEPCO HTS power cable.

4. LIQUID NITROGEN CONSUMPTION RATE

The periodic liquid nitrogen filling is needed to the open cycle cooling system because the temperature of circulating liquid nitrogen is controlled by a decompression pumping system consisting of two decompression pumps. The liquid nitrogen consumption rates under various loading currents at circulation cooling conditions of operating temperature (T1) of 66.4 K and the flow rate of 40 L/min are shown in Figure 4. The consumption rate is increased according as loading current increase. Much liquid nitrogen evaporation is occurred for decreasing pressure in the subcooler in order to maintain the same operation temperature of 66.4 K from the higher temperature at subcooler inlet (T8) induced by increasing heat load. The rates were 470 kg per one day at 0 A and 928 kg per one day at 1250 A, respectively.

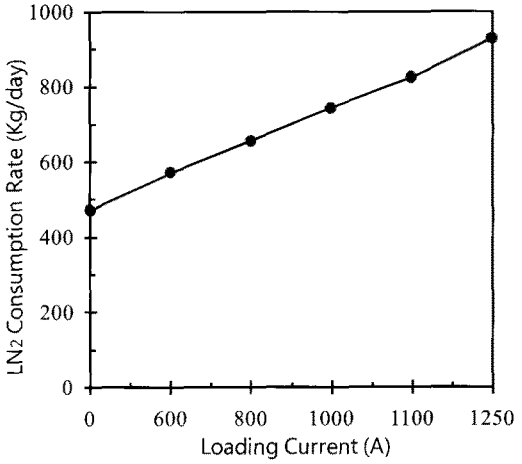

Fig. 4. LN_2 consumption of the KEPCO HTS power cable.

5. SUMMARY

The KEPCO HTS power cable has been tested by the KEPRI, KBSI and KERI team at the KEPCO's Gochang power testing center in Korea. The outline of the cooling system was introduced. The heat loads and liquid nitrogen consumption rates of the HTS cable system under various loading current condition were investigated. It is a good agreement with that of our previous measurement results. From this result, we ensured the reliability of the cooling system through the demonstration tests for 8,000 hours. The testing results will be adapted to a real power grid project that is planned by KEPCO.

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