2011년도 대한전기학회 하계학술대회 논문집 2011. 7. 20 - 22

축소형 초전도 직류 케이블 시스템의 제작 및 시험

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Fabrication and test of a miniaturized superconducting DC cable system

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Abstract - The DC side voltage and current of a HVDC transmission system are directly affected by non-linear switching devices such as the thyristor valve which causes real power losses, even under the superconducting conditions of a high temperature superconducting (HTS) power cable. This paper deals with the development of miniaturized superconducting DC cable system. The authors designed and fabricated two thyristor converters for DC transmission system. One is operated as a rectifier and the other is an inverter. The HTS model cable was connected between the DC side of the rectifier and inverter. Real DC transport current and voltage were applied to the miniaturized HTS DC cable. Experimental results are discussed in detail.

1. Introduction

High voltage direct current (HVDC) technology has characteristics which make it especially attractive in certain transmission applications. HVDC transmission is widely recognized as being advantageous for long-distance, bulk-power delivery, asynchronous interconnections and long submarine cable [1-3].

In case of HTS power cable in HVDC system, we have to consider AC loss even though it is used in DC application. Most of the HVDC systems use line commutated converter (LCC) system with thyristor converters. However, the main problem with LCC HVDC systems is the harmonic components generated between thyristor valves. When AC power is converted to DC power, the thyristor converter generates a harmonic component of which problem cannot be bypassed on both the AC and DC sides. It may affect the DC current and include some ripples in the harmonic component. It is a major problem with current source HVDC transmission systems and consequently, filters of large scale are needed to compensate for the harmonics. Regardless of filters, the loss must be affected by DC side current of the HVDC system, which is not negligible. The effects of the harmonics have to be seriously considered when applying HTS DC power cable to the HVDC system [4-6].

In this research, in order to understand the effect of harmonics to HTS DC power cable as the first step, a small scale thyristor converter system including both rectifier and inverter was manufactured and also a miniaturized HTS DC power cable was designed and fabricated, too. Using the fabricated system, real DC transport current and voltage were applied to the miniaturized HTS DC cable. The test and experiment results of HTS DC power cable system are discussed in detail.

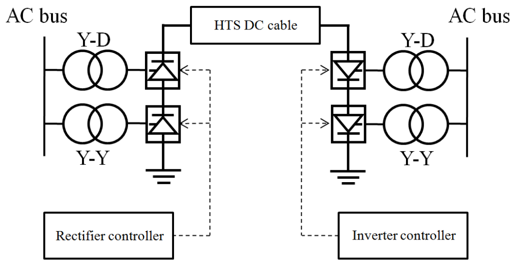
2. System configuration

2.1 Design of thyristor converters

A DC transmission system was designed in this paper. Fig. 1 shows the configuration of designed system which consists of two thyristor valves and the specifications are depicted in Table 1. The DC voltage level of thyristor converter is controlled by firing angle and the relation is given in (1)

$$V_d = \frac{3\sqrt{2}}{\pi} \cdot V_l \cdot \cos(\alpha) - \frac{3}{\pi} X_c \cdot I_d \tag{1}$$

where α is the firing angle of controller, V_l is AC voltage, and X_c is the leakage reactance of converter transformer.

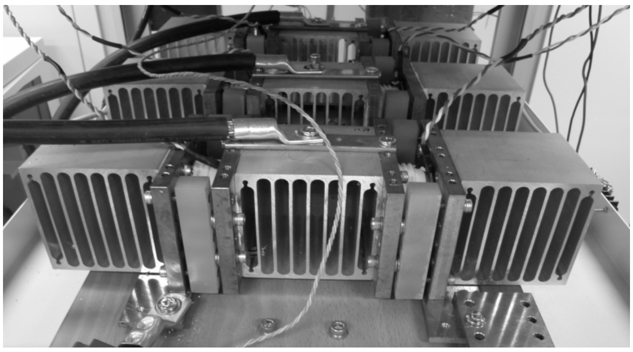


<Fig. 1> Superconducting DC cable system configuration

<Table 1> Specifications of thyristor converter

Item	Value
Thyristor (IOR T08)	1200 A, 1500 V
Number of thyristor	12
Converter transformer	380/50 V Y-Y
Leakage reactance	0.1 mH
DC rating	100 V, 200 A
DC power	20 kW

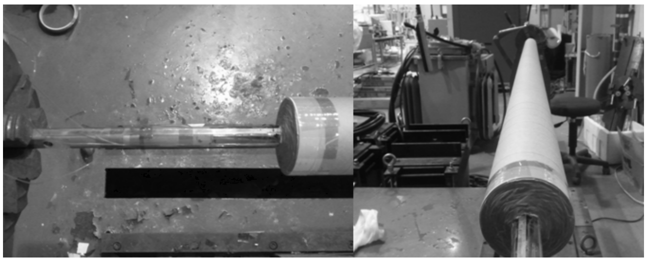
The rectifier changes AC to DC and the DC power is changed using an inverter to AC power. Both ends connected to 380/50 V transformers. The designed DC transmission system was connected to a commercial AC network, 380 V, 60 Hz. The rated power of the DC side is 20 kW (200 A, 100 V). A current controller was used to maintain the required current level in rectifier side and a voltage controller was used to maintain the required voltage level in inverter side. 12 thyristors were used for rectifier and inverter for the fabricated system shown in Fig. 2.



<Fig. 2> Fabrication of thyristor converter

2.2 Superconducting DC cable

The HTS model cable was connected between the DC side of the rectifier and inverter. YBCO wires were used for the miniaturized HTS DC cable. Fig. 3 shows the structure of the model cable and the specifications are shown in Table 2. Two different wires were attached onto the same core in order to maintain the same thermal conditions. The PPLP (poly propylene laminated paper) was used to wrap HTS wire and the thermal conductivity of PPLP is 0.1~0.3 W/ m•K at 77 K. The temperature was measured using E-type thermocouples to obtain the initial data for estimating the AC loss caused by harmonics.



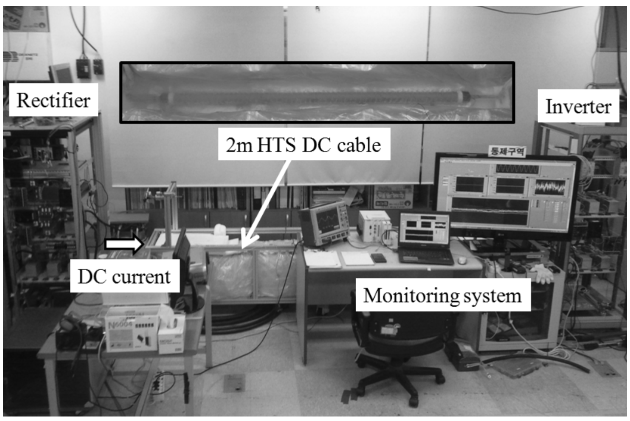
<Fig. 3> HTS DC cable

<Table 2> Specifications of HTS DC cable

Wire type	YBCO
Wire length	2 m
Width	4 mm
Critical current @ 77 K, self field	140 A
Thickness of PPLP	5 mm

2.3 Experimental setup

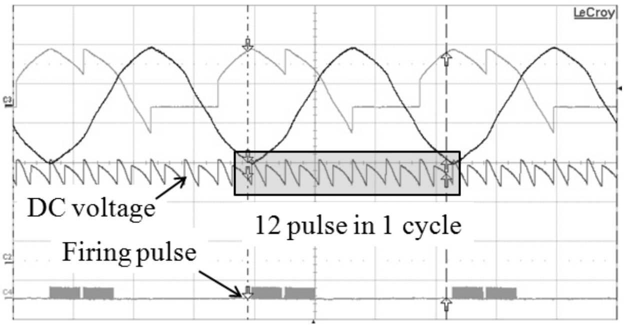
The miniaturized HTS power cable was connected to the DC terminal side of the designed DC transmission system as shown in Fig. 4 which describes the overall system configuration for experiment. The AC side of the rectifier was connected to the three phase 380 V of 60 Hz power network. As the general HVDC system, the DC side voltage was controlled by the inverter side and the current was operated by the rectifier side. These controllers produced a firing pulse to operate the thyristors. The AC side of inverter was connected to the 380 V AC power network through a transformer and inductor. The miniaturized HTS model power cable was used and tested between the DC side of the rectifier and inverter.



<Fig. 4> Experimental setup

2.4 Operating results

The HTS cable was connected to the DC side of fabricated system. The temperature of HTS cable was measured while the thyristor converters were operated. The firing angle of rectifier was controlled to increase the DC current. Experiment results are shown in Fig. 5. Thyristor converter well operates with HTS cable and DC current applied to the HTS cable. Critical current of the YBCO model cable was 140 A and DC transport current was changed from 0 A to 150 A. Even DC current include ripple and harmonic component, temperature was not increased during thyristor converters were operated. Thus the loss was assumed by FEM analysis and the model HTS DC cable generated 4.6 mW/m when DC current included harmonics.



<Fig. 5> Operating results

3. Conclusions

The HTS DC transmission system has more advantages compared with the conventional HVDC system or superconducting AC power cable system but there are harmonic component problems at the LCC HVDC system. In this paper, a small DC transmission system was fabricated using thyristors and a HTS model cable was tested on the DC side of a fabricated system. The DC side ripple current generated the variation of the magnetic field and magnetization in the superconductor but temperature of HTS DC cable was not increased in the fabricated system. However, the loss is still exist and it will affect the cooling system. The loss of large scale and long distance HTS DC cable must be considered for the proper cooling system design.

[Acknowledgment]

This work was supported by Korea Electric Power Corporation

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