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Insulation Test for the 22.9 kV Class HTS Power Transmission Cable

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Abstract— **HTS power transmission cable is expected to transport large electric power with a compact size. We are developing a 3-core, 22.9 kV, 50 MVA class HTS power cable, and each core consists of a conductor and shield wound with Bi-2223 tapes, electrical insulation with laminated polypropylene paper (LPP) impregnated with liquid nitrogen.**

This paper describes the design and experimental results of the model cable for the 22.9 kV, 50 MVA class HTS power transmission cable. The model cable was used the SUS tapes instead of HTS tapes because of testing the electrical characteristics only.

The model cable was 1.3 m long and electrical insulation thickness was 4.5 mm. The model cable was evaluated the partial discharge (PD), AC and Impulse withstand voltage in liquid nitrogen. The AC and Impulse withstands voltage and PD inception stress was satisfied with the standard of Korea Electric Power Corporation (KEPCO) in the test results. The 3-core 22.9 kV, 50 MVA class HTS power cable has been designed and manufactured based on these experimental results.

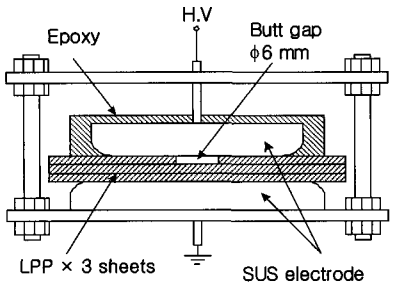
1. INTRODUCTION

The underground power transmission systems have to be expanded according to the increasing power demand in urban area, but it is almost impossible to construct new cable tunnels and ducts to install additional underground transmission lines in the metropolis. And it is very difficult to retrofit larger diameter cables in the existing underground tunnels. HTS power transmission is one of the most feasible solutions for solving the above problems. HTS power transmission cables appear to be the replacement and retrofitting of underground cable in urban areas and HTS power transmission cable offers a number of technical and economic merits compared to normal conductor cable system [1-3]. The Korea Electrotechnology Research Institute (KERI) and LG cable Ltd. are developing a 3-core, 30 m, 22.9 kV class HTS power cable that is one of 21st century frontier project [4-5]. The HTS power cable consists of a HTS conductor, insulation layer impregnated with liquid nitrogen (LN_2) and thermal insulation with cryostat. The study of electrical insulation is one of the most important areas to realize the HTS power cable, as the cable must be operated under high voltage environment. The insulation of HTS power cable has used dielectric paper and LN_2 composite insulation. The electrical breakdown characteristics of dielectric paper, such as AC withstand voltage, impulse withstand voltage and PD inception stress, were indispensable to insulation design and fabrication of the 22.9 kV class HTS power cable [6].

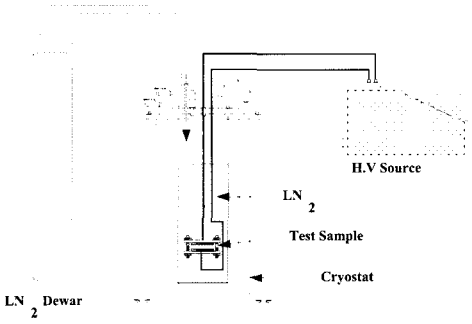
2. ELECTRICAL CHARACTERISTICS OF LPP

The electrical characteristics of the LPP impregnated with LN_2 and pressure dependence were investigated of sheet sample including butt gap. Figure 1 shows electrode configuration and schematic of the experimental apparatus. The dielectric paper was adopted LPP that has 0.119 mm of thickness and 0.89 g/cm^2 of density from Finland company. The electrode in figure 1 (a) was molded with epoxy resin to avoid the edge effect for measuring of PD. Figure 1(b) shows the schematic of the experimental apparatus. The electrodes were made of stainless steel (SUS) and the diameter of the upper and lower electrode were 30 mm and 40 mm, respectively. The diameter of the circular butt gap was 6mm and butt gap sample was arranged in the upper hole of the LPP layer. The experiments were performed in stainless steel cryostat and pressure was carried out by applying 1~5 kgf/cm^2 at atmosphere.

Figure 2 shows PD inception stress of LPP using above electrode system. The PD inception stress increased as the pressure of LN_2 increased and almost saturated over 3 kgf/cm^2. This reason was considered as following. A lot of bubbles existed in LN_2 at atmospheric pressure and the PD inception stress was low because PD took place in the bubbles. However, the occurrence of bubbles was restrained by increasing LN_2 pressure. The minimum stress is determined to be 20 kV/mm by the PD inception



(a) Electrode Configuration



(b) Schematic of the Experimental Apparatus

Fig. 1. Electrode configuration and schematic of the experimental apparatus.

stress; at least cable must be operated over the LN_2 pressure of 3 kgf/cm^2.

Figure 3 shows the typical Weibull pot of AC and Impulse breakdown strength of LPP. We calculated breakdown strength of 50 % and shape parameter of AC breakdown strength like figure 3 (a). The values were 65 kV/mm and 21.7, respectively. But, the minimum AC breakdown strength is adopted 52 kV/mm for design of cable because of stability of cable insulation. And Impulse breakdown strength of LPP was investigated. As shown in figure 3 (b), the Impulse breakdown strength of 50 % was 137 kV/mm and shape parameter was 8.47, respectively.

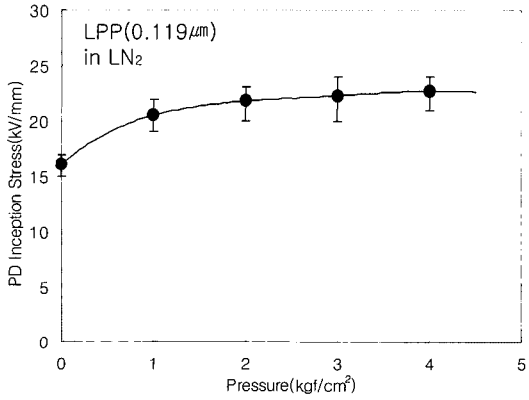
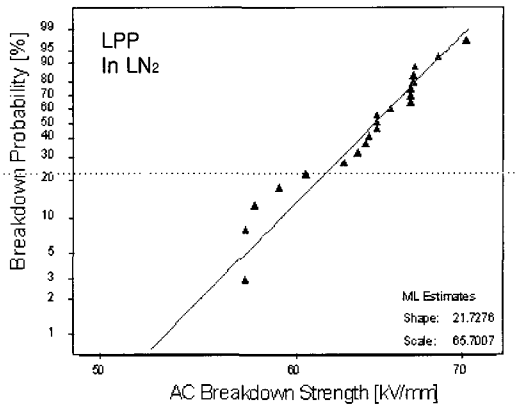
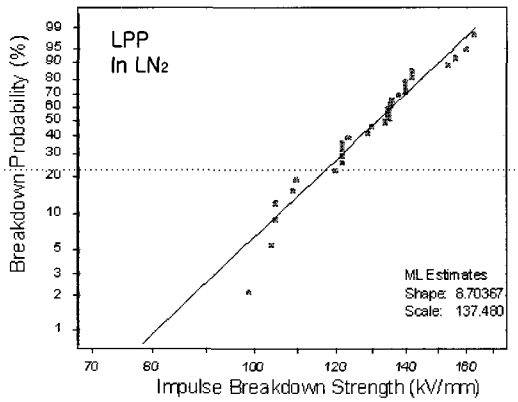


Fig. 2. Characteristics of PD inception stress of LPP as increasing LN_2 pressure.



(a) AC weibull plot



(b) Impulse weibull plot

Fig. 3. Weibull plot of AC and impulse breakdown strength of LPP in butt gap.

But the minimum impulse breakdown strength was 76 kV/mm for design of HTS power cable.

3. DESIGN AND MANUFACTURE OF THE MODEL CABLE

For the withstand test of 22.9 kV power cable, the AC target voltage was 80 kV and the impulse voltage was 154 kV. Based on the above experimental results, the electrical insulation of HTS cable was designed. For the design, there are three kinds of withstand voltage. One is AC design withstand voltage, another is impulse design withstand voltage and the other is PD inception stress.

For PD inception voltage design, the calculation is expressed by equation (1). Where, the target voltage was 80kV. And E_{max} was determined to be 20 kV/mm by the experimental result of PD inception stress.

$$E_{max} = \frac{V}{r_1 \ln \frac{r_2}{r_1}} \text{ [kV/mm]} \quad (1)$$

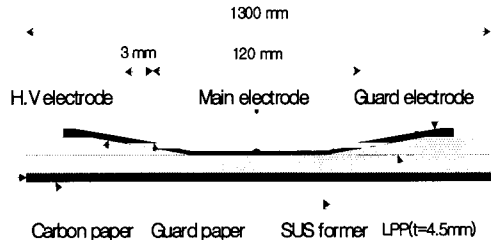
where r_1 and r_2 are the inner and outer radius of cable. Consequently, insulation thickness has difference of r_2 with r_1.

Table 1 lists the results of the calculated insulation thickness of cable. The target breakdown voltage was assumed to be 1.2 times higher than the designed withstand voltage. The insulation thickness was derived by breakdown strength of target design voltage. The insulation thickness of 22.9 kV power cable was designed to 4.5 mm because insulation degradation was oriented with PD inception stress butt gap of cable.

Figure 4 shows the schematic and photograph of the manufactured model cable. Table 2 presents parameters of the model cable. This cable was wrapped carbon paper on flexible SUS former serially starting from the first layer, then LPP was wrapped that overlapped 30% between LPP. The model cable was 1300 mm of length and 4.5 mm of insulation thickness. The stress relief cone was adopted to prevent surface flashover in the cable terminal. The main electrode was made of carbon paper with 100 mm width and the LPP guard used to decrease field disturbance at the electrode edge. Then, model cable was overlapped guard electrode using carbon paper. The gap between main electrode and guard electrode was 3mm. The PE (Polyethylene) wire was wound to remove the several gaps between electrode and LPP.

Table 1. Calculation of the Insulation Thickness.

	Target design voltage	Breakdown strength (minimum value)	Insulation thickness
AC	107 kV	52 kV/mm	2.1 mm
Impulse	198 kV	76 kV/mm	2.7 mm
PD	80 kV	20 kV/mm	4.5 mm



(a) Schematic of the model cable

(b) Photograph of the model cable

Fig. 4. Schematic and photograph of the manufactured model cable.

Table 2. Parameters of the Model Cable

Material	Parameters
SUS former	O.D : Ø 12.75 mm
SUS tape	Thickness : 0.15 mm × 1 sheet
Carbon paper	Thickness : 0.13 mm × 2 sheet
LPP	Thickness : 0.119 mm × 38 sheet
PE wire	Ø 2.7 mm

4. EVALUATION OF THE MODEL CABLE

The withstand tests of AC and Impulse voltage of the model cable were carried out under LN_2 at atmospheric pressure. These test methods were followed the standard technical specification of 22.9 kV class power cable of KEPCO because the test conditions of HTS cable are not defined. A manufactured model cable has been not exceeding 0.1% of moisture and dried around 105 ℃. The cable was immersed in LN_2 during 5 hour. The high voltage was applied by high voltage test apparatus (Tokyo transformer 300 kV/1 A) for withstand voltage and breakdown. And impulse test voltage was applied by Impulse apparatus (1.2×50 μs waveform, maximum 300 kV). The PD inception stress was measured according to the IEC 6027 and used a partial discharge detector made by Nihonkesoki Co..

Figure 5 shows the test results of AC withstand and breakdown voltage of the model cable at LN_2. The high voltage was maintained during 60 minute after being risen to 80 kV for the 60 seconds. After withstand voltage test, a step rising voltage was applied at the rate of 10 kV /5minutes. In AC withstand voltage test, there was no breakdown while keeping the voltage of LN_2. And the breakdown of a manufactured model cable is occurred at 120 kV.

Figure 6 shows the waveforms of the impulse withstand voltage test of the model cable. The Impulse tests were performed positive and negative each 10 times.

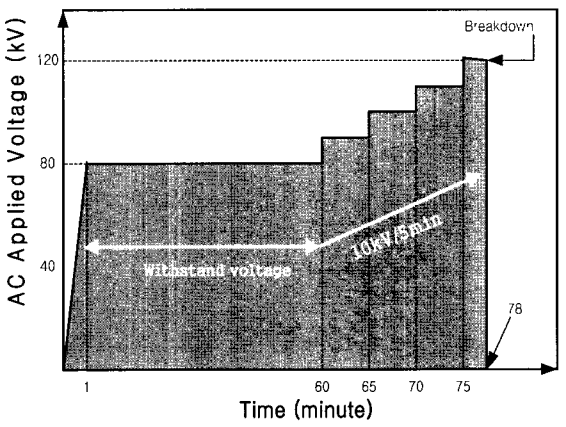
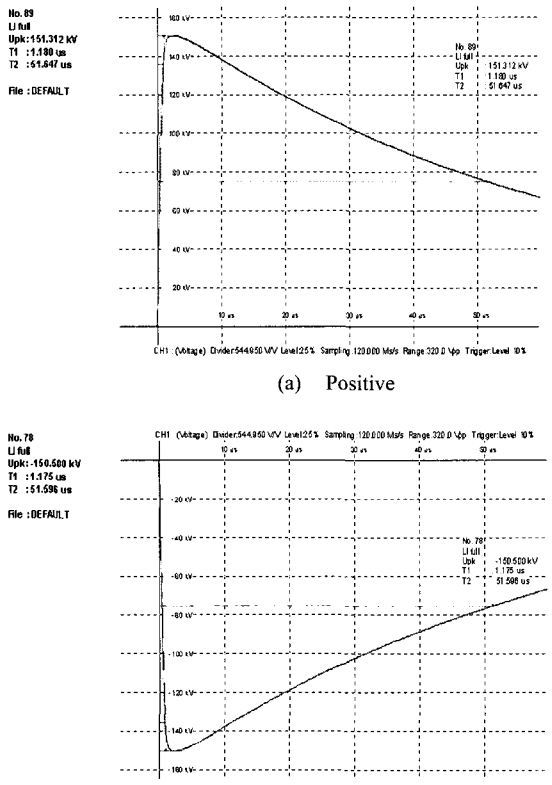


Fig. 5. AC withstand and breakdown voltage of the model cable.

Applied Impulse voltage was 150 kV with 1.2×50 μs waveform. There was no breakdown and surface flashover at impulse test condition.

PD inception strength of the model cable was 28kV and PD charge was 5 pC at this voltage. Thus, the insulating test results of 22.9kV class model cable were satisfied at atmospheric pressure. PD test was done when back-noise of shield room inside did free almost by 1pC or less. Figure 7 shows PD test scene and discharge waveform.



(a) Positive

(b) Negative

Fig. 6. Waveform of the Impulse withstand voltage test of the model cable.

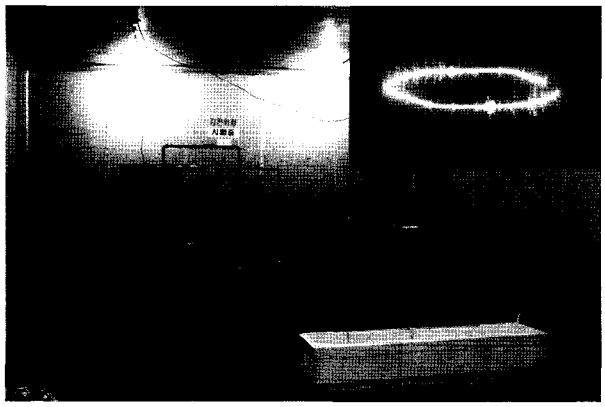


Fig. 7. PD Test of the Model Cable.

5. CONCLUSIONS

We tested the insulation characteristics of model cable for 22.9kV class HTS power cable. For the AC withstand voltage test, 80 kV was rose for the 60 seconds and successfully maintained during 60 minutes in LN_2. There was no breakdown and flashover during this test. The 10 times of impulse tests were performed both positive and negative without any breakdown. Applied impulse voltage was 150 kV with 1.2×50 μs. The PD inception strength of model cable was 28 kV and PD charge was 5 pC at this voltage. Thus, the insulating test results of 22.9 kV class model cable in LN_2 at atmospheric pressure, such as AC withstand, Impulse test and PD inception test, were satisfied to KEPCO regulations. These test results prove that our HTS cable insulation design was appropriate. The 3-core, 22.9 kV, 50 MVA class HTS power cable has been designed and manufactured based on these experimental results.

ACKNOWLED GMENT

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