Insulation Characteristics of the Model Cable for 22.9 kV Class HTS Power Cable

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Abstract : In this paper, describes the fabrication and dielectric insulation characteristics experimental results of the model cable for the 22.9kV class HTS power cable. The model cable were tested with partial discharge(PD), AC and impulse withstand voltage in liquid nitrogen(LN₂) and liquid nitrogen pressure. In these test results, PD inception stress and AC, impulse breakdown strength increase as the pressure of the liquid nitrogen increases.

Key Words : HTS cable, Insulation design, Multi-layered effect, Electrical breakdown

1. Introduction

The HTS cable consists of a HTS conductor, high voltage insulation paper which have to be impregnated by liquid LN_2. The study of electrical insulation is important to realize HTS cable because the cable is operated under high voltage environment. The insulation of HTS cable has been used dielectric paper and LN_2 composite insulation. In particular, the electrical breakdown characteristics[6] of dielectric paper, such as AC withstand voltage, impulse withstand voltage and PD inception stress, was necessary to insulating design and manufactured of the model cable for 22.9 kV class HTS power cable.

2. Design and Manufacture of the Model Cable

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

Figure 2 shows PD inception stress of LPP using the electrode system. The PD inception stress increase as the pressure of LN_2 increase and almost saturated over 3 kgf/cm^2. This reason is considered as following. A lot of bubbles exist in LN_2 at atmospheric pressure; the PD inception stress is low because PD takes place in the bubbles. However, the occurrence of bubbles is restrained by increasing LN_2 pressure. Hence, the minimum stress is determined to be 20 kV/mm by the PD inception stress assuming that the cable is operated with the LN_2 pressure of 3~5 kgf/cm^2.

Figure 3 shows the Weibull plot of AC and impulse breakdown strength of LPP. As figure 3 (a) indicates, we calculated breakdown strength of 50 % and shape parameter of AC breakdown strength. The value is 65 kV/mm and 21.7 kV/mm, 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 is investigated. As figure 3 (b), the impulse breakdown strength of 50 % is 137 kV/mm and shape parameter is 8.47, respectively. But, the minimum impulse breakdown strength was 76 kV/mm for design of cable.

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

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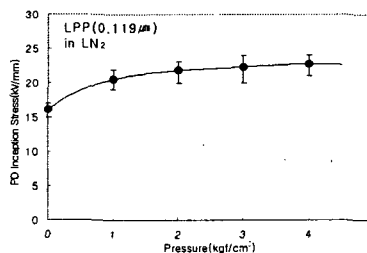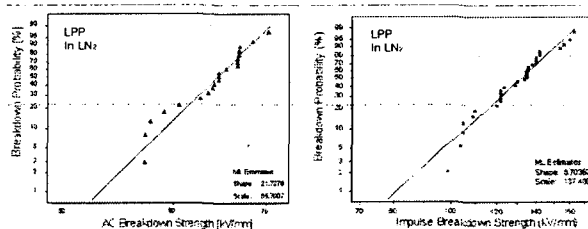

Figure 2. Inception stress of LPP.

(a) AC weibull plot   (b) Impulse weibull plot

Figure 3. Weibull plot of breakdown strength of LPP.

experimental result of PD inception stress. Where, r_1 and r_2 is the inner and outer radius of cable former. Consequently, insulation thickness is difference of r_2 with r_1.

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

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

Table 1. Calculation of the insulation thickness.

	Target 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

Model cable was manufactured by insulation thickness of 4.5 mm. This cable is wrapped carbon paper on flexible SUS former serially starting from the first layer, then LPP is wrapped that overlapped 30 % between LPP. The model cable has 1300 mm of length. The main electrode is used carbon paper that has 100 mm of length and the LPP guard paper is used to decrease field disturbance at the electrode edge. Then we overlapped guard electrode using carbon paper and did 3 mm the gap distance between main electrode and guard electrode.

3. Evaluation of the Model Cable

The insulating tests of AC and impulse withstand voltage of the model cable are carried out under LN₂. These test method were followed standard technical specification of 22.9 kV class power cable of KEPCO in Korea because the test conditions of HTS cable are not defined.

Figure 5 shows AC withstand voltage that keeping condition of LN₂ of the model cable. The high voltage is maintained during 60 minute after we rose to 80 kV for the 60 seconds. After a withstand voltage test, a step rising voltage is applied at the rate of 10 kV/5 minutes. In AC withstand voltage test, there was no breakdown while keeping the voltage of LN₂. And the breakdown of a manufactured model cable is occurred at 120 kV.

Figure 6 shows the impulse withstand voltage test of the model cable. The impulse tests were performed positive and negative each 10 times. Applied impulse voltage is 150 kV of 1.2×50 µs waveform. The breakdown phenomenon is not

occurred under test condition of impulse test.

Finally, PD inception strength of the model cable is happened 28 kV and PD charge was 5 pC. Thus, the insulating test results of 22.9 kV class model cable were satisfied at atmospheric pressure. PD test was done when back-noise of shield room inside does free almost.
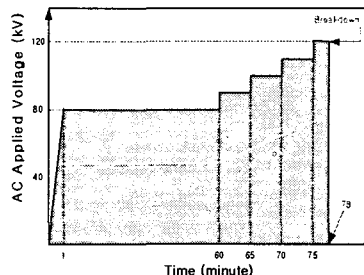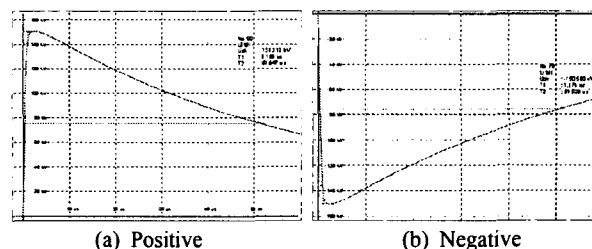

Figure 5. AC withstand voltage of the model cable.

(a) Positive   (b) Negative

Figure 6. Impulse withstand voltage test of the model cable.

4. Conclusions

The insulation efficiency of the model cable for 22.9 kV class HTS power cable was tested in LN₂. In AC withstand voltage test, there was no breakdown while maintained during 60 minute after we rose to 80 kV for the 60 seconds. The impulse tests were performed positive and negative 150 kV of 1.2×50 µs waveform each 10 times. The breakdown phenomenon is not occurred under test condition of impulse test. And in the PD inception strength of model cable is happened 28 kV and PD charge was 5 pC. Thus, the insulating test results of 22.9 kV class model cable were satisfied to KEPCO regulations.

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