Evaluation of insulation performance of modified polypropylene insulating material for HVDC at high temperature under high DC electric field using PEA and Q(t) methods

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ABSTRACT

The electric insulating performance of a newly developed modified polypropylene for high voltage dc (HVDC) power transmission cable was investigated using the PEA (pulsed electroacoustic) and Q(t) (direct current integrated charge measurement) methods at high temperature under high dc electric field. This study estimates its insulating performance at 90°C under dc stress of up to 50 kV/mm. The measurement results showed that the non-modified XLPE exhibited significant space charge accumulation and large current values. In contrast, the newly developed PP-based insulating material did not exhibit significant space charge accumulation, and the current values were low enough, judging from the observed results of the Q(t) measurements.

KEYWORDS

Modified polypropylene; HVDC cable; PEA method; Q(t) method; space charge; conduction current

INTRODUCTION

In recent years, the demand for electricity from renewable energy sources has been increasing due to the rising demand for electric power and heightened environmental awareness. Against this backdrop, the introduction of long-distance DC power transmission cables has been gaining momentum, particularly in Europe. Currently, cross-linked polyethylene (XLPE) is the most commonly used insulation material for power transmission cables. However, XLPE has been observed to accumulate space charge in a DC environment and is difficult to recycle because it has lost its thermoplasticity due to cross-linking. Therefore, we are investigating the possibility of using polypropylene (PP), which has a high melting point and thermoplasticity, as a new insulation material for DC power transmission cables [1]. However, PP is not flexible, making it unsuitable as an insulating material for cables. Therefore, we attempted to improve it by compound matrix modification in order to make it flexible. The modified PP-based material exhibited sufficient flexibility and high specific resistance at room temperature under a relatively low DC electric field. Therefore, in this study, the insulation performance was evaluated under relatively high DC stresses up to 100 kV/mm and at a relatively high temperature of 90°C.

Authors have shown the space charge accumulation characteristics of various materials observed using a pulsed electro-acoustic (PEA) method [2, 3] to show the insulating performance at a relatively low temperature like room temperature and have ignored the current measurement results because it is usually very low and it didn't affect the insulating performance at a such temperature [4]. However, the increased temperature like 90°C, the current usually becomes large and it cannot be ignored for estimating the insulating performance. Therefore, in this study, the current is also estimated. For the current characteristics, a direct current integrated charge measurement (Q(t)) method [5, 6], which is getting familiar with estimating the insulating performance [7-10], was used for current-based characteristics.

SAMPLES AND EXPERIMENTAL PROCEDURES

Samples

Two kinds of samples were used in this experiment. One is a modified PP sample originally developed by the authors. The PP material is modified to be flexible for applying it to the cable insulating layer, and it is called the "PP compound" in this report. The details of the material are not revealed because of confidential reasons. This sample is provided as a film shape by the hot-press method for the experiments, and its thickness was about 350 μm. Another is a cross-linked polyethylene (XLPE) sample used for an insulating layer of the AC power transmission cable, and also made by the authors. In this report, it is called "AC-XLPE". Since the XLPE material of the cable insulating layer usually includes some residual cross-linking by-products, the sample is used in the measurements with the state that it includes them. Details of how the sample was prepared are described elsewhere [11].

Measurement systems

The high-temperature PEA measurement system

The space charge distributions were measured at room temperature and 90°C using the high-temperature PEA measurement system shown in Fig. 1. We can also measure the space charge distribution in insulating materials using this system up to 150°C. In this system, the temperature of the sample immersed in silicone oil is controlled using a band heater put on the upper electrode unit shown in Fig. 1. The details of the high-temperature PEA measurement system are described elsewhere [12].

Q(t) measurement system

The Q(t) was measured using a commercially available Q(t) meter. In the Q(t) measurement, a DC voltage was applied to the sample and the voltage of detective capacitance, connected between a high voltage source and the sample was measured, then the measured voltage data were wirelessly transmitted to a computer continuously. The details of the measurement system and the principle are described elsewhere [5, 6]. Figure 2 shows the measurement circuit of the Q(t) meter for the film samples.