Experimental investigations on space charge accumulation in thermally aged LDPE and associated breakdown

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ABSTRACT

Space charge is one of the leading causes of polymeric HVDC cable failure. As cables operate under prolonged thermal stress, insulation undergoes thermal ageing. Until now, space charge measurement up to breakdown is reported only for fresh material, while thermal ageing investigations are limited to short-term ageing and low electric fields. In this paper, space charge is measured for thermally aged LDPE samples using PEA method at medium and high fields. FTIR spectroscopy is done to understand chemical changes in aged LDPE. The co-relation of space charge and breakdown is discussed in case of highly aged samples. A comparison is made of space charge accumulation at medium (i.e. expected operating field) and higher field. The results are believed to be useful for the cable manufacturing industry.

KEYWORDS

Space charge, LDPE, HVDC Cable, PEA Method, Thermal Ageing, Charge Accumulation, Breakdown, FTIR.

INTRODUCTION

Polymeric materials, particularly Low-density polyethene (LDPE), are widely used as base insulation material in high-voltage cables after cross-linking (XLPE), owing to its excellent electrical properties [1]. Despite its numerous advantages, LDPE is vulnerable to thermal ageing (causing degradation under prolonged thermal stress) [2] and space charge accumulation [3, 4]. The phenomenon of space charge is crucial in HVDC cable systems, much more when compared to HVAC systems, particularly in long-term continuous operation. In HVDC polymeric cables, the space charges are found to accumulate inside insulation, which may be attributed to the presence of physical charge trapping sites as well as the non-linear DC resistivity [5]. These charges tend to distort the electric field, causing local field enhancement. This continuous overstress may result in premature breakdown. There have been attempts at examining the effect of space charge accumulation at pre-breakdown of fresh LDPE films [6, 7]. Also, due to thermal ageing, LDPE is known to undergo irreversible physico-chemical changes [8], which lead to its gradual deterioration. The effect of space charge is expected to be enhanced in the case of thermally aged insulation. Also, [2] reported an increase in the charge accumulation in LDPE, when aged for a short duration of 15 days at 90℃. Thus, until now, the phenomena of space charge, breakdown and their inter-relation seem to have not been reported for long-term thermally aged LDPE, which assumes significant importance taking into consideration the ever-increasing demand to push greater load current through HVDC cables and also load cycles, which the cable has to experience.
In this paper, the authors investigate the effect of thermal ageing on the space charge characteristics of LDPE. The samples prepared in the authors' lab are thermally aged at expected in-service cable temperatures (up to 80℃), for long durations (up to 256 days). In order to understand the structural changes in LDPE with thermal ageing, Fourier Transform Infra-red (FTIR) spectroscopy measurements were performed. The space charge is experimentally measured at medium and high electric fields for each batch of samples using the Pulsed Electro-acoustic (PEA) measurement setup. The accumulated charge density and FE (Field Enhancement) factor are calculated for thermally aged samples and compared with fresh samples.

SAMPLE PREPARATION

LDPE samples were prepared from the granules received from a local cable manufacturing company. The granules were first melt-blended in a two-roll mill at 110℃ and then subjected to hydraulic press at temperature and pressure of 120℃ and 90 bar respectively to obtain uniformly thick sheets of $110 \pm 10\ \mu m$ The prepared samples were kept in hot air oven for thermal ageing.

EXPERIMENTS

Thermal Ageing

The prepared samples were subjected to long-term thermal ageing by keeping them in batches inside hot air ovens maintained at 70℃ and 80℃. The ageing durations were chosen to be 32, 64, 128 and 256 days. Selected fresh and aged samples are shown in Fig. 1.

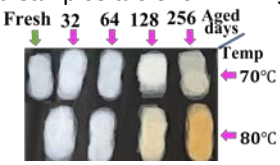

Fig. 1. Prepared LDPE samples.

FTIR Spectroscopy

FTIR measurements have been done for fresh and different aged LDPE samples at room temperature and atmospheric pressure condition, using BRUKER TENSOR II instrument. The spectrum was measured in the range of wavenumber 600 to 4000 (cm^{-1}).

Space Charge Measurement

A Pulsed Electroacoustic (PEA) setup was used for space charge measurements, as shown in Fig. 2 (a), as per IEC TS 62758:2012.

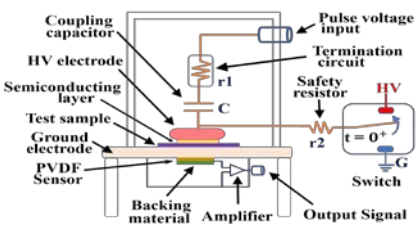

Fig. 2. PEA space charge measurement setup