

DC electrical conductivity of LDPE-based nanocomposites

Anh T. HOANG, Le WANG*, Yuriy V. SERDYUK, Stanislaw M. GUBANSKI

Chalmers University of Technology, Gothenburg, Sweden (* presently with Kabeldon, ABB, Alingsås, Sweden)

anh.hoang@chalmers.se, le.wang@se.abb.com, yuriy.serdyuk@chalmers.se, stanislaw.gubanski@chalmers.se

Dongming LIU, Love PALLON, Carmen COBO SANCHEZ, Wangshu LI, Ulf W. GEDDE

Royal Institute of Technology, Stockholm, Sweden

donliu@kth.se, lovep@kth.se, carmencs@kth.se, gedde@kth.se

ABSTRACT

This work presents studies of the effect of nanofillers on dc electrical conductivity of polymeric materials, potentially applicable in high voltage direct current (HVDC) cable insulation. Samples of low-density polyethylene (LDPE) filled with nanoparticles of aluminium oxide (Al₂O₃) and magnesium oxide (MgO) up to 3 wt% were prepared, on which charging currents were measured at 40 and 60 °C and electric stress of 32 kV/mm. Experimental results for nanocomposites were compared with those of reference LDPE. It was found that the addition of nanofillers led to a significant decrease in electrical volume conductivity and the decline depended strongly on filler type, its content and surface treatment. Further, the influence of specimen thickness on the conductivity was examined for verifying the operating conduction mechanisms. An indication was found that the space charge limited current (SCLC) mechanism dominated the conduction process in the reference material, while this effect ceased for the nanocomposites.

KEYWORDS

Low-density polyethylene, nanocomposite, electrical conductivity, charging current, surface treatment.

INTRODUCTION

There has been a growing interest in developing high voltage direct current (HVDC) cables based on polymeric insulation due to their various technological, economical, and environmental benefits over the traditional paper-impregnated insulation [1]. Cross-linked polyethylene (XLPE) based HVDC cables are presently operating at voltage level up to 320 kV, providing transmission capacity of around 1000 MW [2]. The forecasted increase in worldwide demand for electrical power energy and the requirement of longer transmission distances are the incentives for upgrading the technology in manufacturing extruded HVDC cables with the major focus on higher rated voltages (e.g. 800 kV or 1 MV) and much larger power transmission capability (several GW). To realize this, several technological challenges must be overcome. For instance, the enhanced electrical stress is anticipated in cable insulation as a linear expansion of insulation thickness for maintaining its today's level is no longer a desired solution.

As known, the electric field distribution under dc stress is governed by material conductivity that results in complicated dependence of the field on radial position in a cable [3], able to trigger in worst cases an onset of thermal runaway [4]. The requirements of precise field control and thermal stability of HVDC cable insulation can be tackled by further reducing material's dc conductivity. One possible way of achieving this goal is through further

purification of the used polymeric insulation [5]. However, the cleaning approach is believed to be no longer feasible and too expensive as XLPE currently employed is already relatively clean.

The recent trend in developing nanometric dielectrics opens for new options in the design of HVDC cable insulation. The most significant alterations in nanocomposites rely on increase and modification of interfacial regions between nanofillers and base polymer. The ratio of surface area to volume rises greatly and the interfacial regions become deterministic in the control of nanocomposite properties [6-8]. Improvements of practically important properties of nanocomposites have been reported not only in terms of their electrical performance, but also in thermal and mechanical ones [9]. The concept of nanostructured dielectrics for HVDC cable insulation relies today mainly on use of inorganic oxides, e.g. silica (SiO₂), zinc oxide (ZnO), magnesia (MgO) [6, 7, 10-12]. Even with low filler loading of a few weight percent, three-fold advantages were achieved. In addition to the desired reduction in dc conductivity, nanofilled polyethylene (PE) is capable to suppress space charge accumulation and withstand enhanced electric stress. Following these promising outcomes, various efforts have been undertaken to gain an in-depth understanding of the physical mechanisms responsible for the advancements in material properties.

In the framework of the Swedish project aiming at developing insulating materials for the next generation of HVDC cables [13], we developed two types of nanocomposites by introducing into low-density polyethylene (LDPE) nanofillers of Al₂O₃ and MgO. The nanofillers were own manufactured and distinguished by very high purity and narrow size distribution as compared to the nanofillers available on the market. For improving the dispersion, some of them were also surface treated by hydrophobic silanes. Electrical conductivity was measured on them and the obtained results compared with those of reference LDPE. Furthermore, the influence of sample thickness on the conductivity was investigated. In a coming series of publications further results will be reported, showing the importance of the surface treatment of the ultra-pure nanoparticles (Al₂O₃ and MgO) on the dispersion, crystalline morphology of the polymer, the strain-induced cavitation, and the treeing resistance of the nanocomposites.

MATERIAL SAMPLES AND EXPERIMENTS

1. Nanocomposite manufacturing

The nanocomposites were manufactured with untreated and surface treated Al₂O₃ and MgO nanofillers. The Al₂O₃