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Development of industrial scale PVC nanocomposites with comprehensive enhancement in dielectric properties

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Abstract: This study aims to develop large-scale polyvinyl chloride (PVC) nanocomposites for industrial application with power cables. To achieve this goal, PVC/silicon dioxide and PVC/titanium dioxide nanocomposites were fabricated with two different loadings of nanoparticles: 0.3 and 0.6 wt.%, in the presence of a suitable coupling agent that was used to reduce the agglomeration of nanoparticles and enhance the compatibility with polymer matrix. The coupling agent used in this study was the amino silane, and the process followed in the nanocomposites preparation was the melt blending method. The dielectric properties of these synthesised nanocomposites were studied by measuring the AC dielectric breakdown strength under the uniform field, then compared with the simulation results. The relative permittivity ($\boldsymbol{\varepsilon}_r$), loss tangent (tan $\boldsymbol{\delta}$), and DC electrical conductivity ($\boldsymbol{\sigma}$) were also measured under frequencies ranging from 20 Hz to 1 MHz. In addition, the internal discharge measurements are performed using the traditional needle-plane configuration with the help of phase-resolved partial discharge (PD) analyser. This technique is used to analyse the PDs activity with respect to the phase angle of the applied voltage. It was found that the dielectric breakdown strength and PD resistance of the prepared samples are increased higher than that of the neat PVC; however, the $\boldsymbol{\varepsilon}_r$, tan $\boldsymbol{\delta}$, and $\boldsymbol{\sigma}$ at 50 Hz are decreased.

1 Introduction

Polymers have been widely used as electrical insulating materials since the early 20th century [1]. The most commonly used synthetic polymers in large-scale electrical insulating materials of cables are polyethylene and polyvinyl chloride (PVC). These polymeric materials are considered strong and rigid thermoplastic materials, and they have excellent fire resistance; thus, they can be used in many applications such as high-voltage (HV) electrical insulation, capacitor insulation, switchgear spacer insulations etc. [2, 3]. Mechanical performance and electrical properties of the polymers can be improved by introducing a new generation of insulating materials called polymer nanocomposites (PNCs) or nanodielectrics, either for solid or liquid dielectrics [4–8]. PNCs are composite materials having small wt.% of inorganic particles of nanometre dimensions (not exceeding 100 nm) that are homogeneously dispersed into the polymeric matrix.

enhanced the DC breakdown strength of PVC by adding up to 0.5 wt.% of synthesised zinc oxide (ZnO) nanoparticles, and by treating PVC/ZnO nanocomposites in a vacuum oven for 25 days, the enhancement was reached 45% compared with the obtained value of the neat PVC. Recently, *Abdel-Gawad et al.* [18] have improved the insulating ability of PVC by incorporating their matrix with functionalised titanium dioxide (TiO_2) nanoparticles, and the AC dielectric breakdown strength of the obtained nanocomposites was higher than that of un-functionalised TiO_2 or that of neat PVC. Furthermore, the permittivity and dielectric loss were decreased by about 43 and 41%, respectively, over the neat PVC at 50 Hz. In addition, *Eigner* and *Rethmeier* [19] introduced an overview for four techniques of HV PD measurement that has today become one of the most powerful diagnostic methods for the investigation of the performance of cable insulation. Moreover, *Tanaka et al.* [20] enhanced the PD characteristics of low density polyethylene (LDPE) using nanocomposites. They concluded that