Electrical Power and Energy Systems 64 (2015) 469–475

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Experimental enhancement for dielectric strength of polyethylene insulation materials using cost-fewer nanoparticles

Ahmed Thabet Mohamed

Nanotechnology Research Centre, Faculty of Energy Engineering, Aswan University, Aswan, Egypt

ARTICLE INFO

Article history:
Received 5 March 2013
Received in revised form 7 June 2014
Accepted 28 June 2014

Keywords:
Dielectric properties
Nanocomposite
Nanoparticles
Polyethylene
Insulation

ABSTRACT

The use of nanocomposite polymers as electrical insulating materials has been growing rapidly in recent decades. The base polyethylene properties have been developed by adding small amounts of different fillers to the polyethylene material. It is economically to get polymer development by using cost-fewer nanoparticles; therefore, polyethylene dielectric properties are trapped by presence cost-fewer nanofillers like clay and fumed silica which are importance in development manufacture of power cables products. Dielectric strength is a vital pointer for quality of insulation materials of electrical power applications; hence, experimental measurements have been investigated on ac high voltage breakdown of new cost-fewer polyethylene nanocomposites materials. All experimental results of the new polyethylene nanocomposites have been compared with conventional polyethylene insulation materials; therefore, it has been specified the influence types and their concentrations of cost-fewer nanofillers on dielectric strength of polyethylene nanocomposite insulation materials.

Introduction

Polymeric nanocomposites have gained importance in the manufacture of products of high performance properties like light weight, material transparency, enhanced stiffness and toughness, increased barrier properties, decreased thermal expansion, decreased flammability and increase in dielectric properties of electrical and electronics industries [1–8]. Polyethylene (PE) is widely used as an insulation material, particularly cross-linked polyethylene in electrical power transmission cables. Much theoretical and experimental work on its electrical properties has been published over the last 50 years [1–8]. Although its basic chemical composition (–CH2–)*n* is simple, its semi-crystalline morphology is very complex, and thus charge injection at the electrodes and transport through the volume are also complex processes. It is of interest to note that *crystalline* polyethylene has a negative electron affinity, i.e. the bottom of the conduction band is approximately 1 eV *above* the vacuum level, and electron traps with depths in the range 0–0.3 eV formed by the conformations of the polymer chains themselves are to be expected in semi-crystalline polyethylene [9–11]. The dispersion of a very low ratio of inorganic particles having at least one dimension smaller than 100 nm can creates a network of chemical-physical interactions inside an organic matrix, leading to a dramatic change in the macroscopic properties of the material. This can be translated into the enhancements of some very important characteristics of organic dielectrics, such as the thermal stability and the mechanical strength, together with many electrical properties [12–16].

In recent decades, the use of polymers as electrical insulating materials has been growing rapidly. The base polymer properties have been developed by adding small amounts of different fillers but they are expensive to the polymer material. Recently, great expectations have focused on costless nanofillers. However, there are few papers concerning the effect of types of costless nanofillers on electrical properties of polymeric nanocomposite. In different production processes, the interface is in various thickness and layer numbers. In this way, the results of Nano-dielectric properties have little comparability and poor reproducibility, which has been confirmed by the reported data [17–21]. It has been discussed that dielectric material performance, whether conventional or nanocomposite dielectric, it is aging, degradation and breakdown present a strong patio-temporal hierarchy relationship [22–25]. For equipment typified by transformers, cables, generators, motors and gas insulated switchgears (GIS) [26–29], the dielectric breakdown of an insulation element and the voltage–time characteristic (*V*–*t* characteristic) can be well approximated with the inverse-n-power rule [28],

$$V^n t = K \quad (1)$$

where *K* is a constant, "*t*" stands for a time-to-breakdown, and "*V*" is the applied voltage.

E-mail address: athm@aswu.edu.eg

http://dx.doi.org/10.1016/j.ijepes.2014.06.075
0142-0615/

Table 1
Dielectric properties of pure and nanocomposite materials.

Materials	Dielectric constant AT 1 kHz	Resistivity (Ω m)
Pure LDPE	2.3	10^{14}
LDPE + 1 wt.% Clay	2.23	10^{15}
LDPE + 5 wt.% Clay	1.99	10^{15}–10^{18}
LDPE + 10 wt.% Clay	1.76	10^{18}–10^{20}
LDPE + 1 wt.% Fumed Silica	2.32	10^{13}
LDPE + 5 wt.% Fumed Silica	2.39	10^{13}–10^{11}
LDPE + 10 wt.% Fumed Silica	2.49	10^{11}–10^{9}
Pure HDPE	2.3	10^{15}
HDPE + 1 wt.% Clay	2.27	10^{16}
HDPE + 5 wt.% Clay	2.21	10^{16}–10^{19}
HDPE + 10 wt.% Clay	2.16	10^{19}–10^{21}
HDPE + 1 wt.% Fumed Silica	2.35	10^{14}
HDPE + 5 wt.% Fumed Silica	2.42	10^{14}–10^{12}
HDPE + 10 wt.% Fumed Silica	2.51	10^{12}–10^{10}

The cumulative fault probability P generally conforms to the Weibull distribution, P can be expressed as given by the following equation [26,27]:

$$P = 1 - e^{-AV^m} \cdot t^a \quad (2)$$

where A is a constant, "a" is a time shape parameter, "V" is the applied voltage, and "m" is a voltage shape parameter.

With a continual progress in polymer nanocomposites, this research depicts the effects of types and concentration of costless nanoparticles in electrical properties of power cables insulation materials. Also, the current research focus on the electric breakdown failure of low and high polyethylene as a matrix base for various costless nanoparticles added (clay, and fumed silica). All experimental results have been investigated and discussed to detect all effects of nanofillers on electrical properties of nanocomposite Polyethylene (PE) power cables materials.

Experimental setup

Nanoparticles

Spherical nanoparticles shape (Dia.: 10 nm) have been used in our research and in the most polymer applications. Cost less of clay catalyst is the best filler among nanofillers industrial materials. On the other wise, nanoparticles of fumed silica are fluffy white powders with an extremely low density, marketed. And so, fumed silica powders used in paints, coatings, silicone sealants, adhesives, cable compounds and gels, and plant protection.

Polyethylene

It is divided to Low-density polyethylene (LDPE) and high-density polyethylene (HDPE), LDPE is a thermoplastic made from petroleum and it contains the chemical elements carbon and hydrogen. LDPE has more branching than HDPE, its tensile strength is lower, and its resilience is higher. The base of all these polymer materials is a commercially available material already in use in the manufacturing of high-voltage (HV) industrial power cables products and their properties detailed in Table 1.

PE nanocomposites

Polyethylene nanocomposites have been prepared and fabricated by using recent nanotechnology procedures and devices for melting pure type's polyethylene (low density and high density), mixing and penetrating nanoparticles inside the base matrix (PE) by modern ultrasonic devices. Thus, TEM photos illustrate penetration of nanoparticles in polyethylene for LDPE nanocomposites and HDPE nanocomposites as shown in Fig. 1.

Measurement devices

HIOKI 3522-50 LCR Hi-tester device measured characterization of nanocomposite insulation industrial materials as shown in

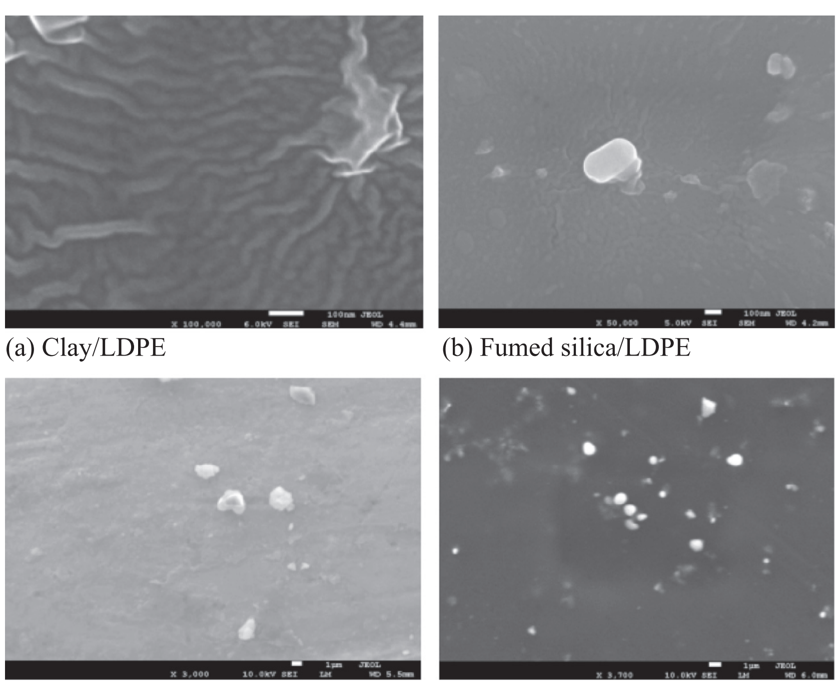
(a) Clay/LDPE (b) Fumed silica/LDPE
(c) Clay/HDPE (d) Fumed silica/HDPE

Fig. 1. TEM photos for polyethylene nanocomposites.