International Journal of Applied Power Engineering (IJAPE)
Vol.4, No.3, December 2015, pp. 126~136
ISSN: 2252-8792

Practical Measurements for Electric Properties of Polyethylene Nanocomposite Thin Films under Thermal Conditions

Ahmed Thabet*, Youssef Mobarak**
* Nanotechnology Research Centre, Faculty of Energy Engineering, Aswan University, Aswan, Egypt
** Department of Electrical Engineering, Faculty of Engineering, Rabigh, King Abdulaziz University, Saudi Arabia

Article Info

Article history:

Received Oct 1, 2015
Revised Nov 15, 2015
Accepted Nov 26, 2015

Keyword:

Dielectric properties
Electric properties
Nanocomposite
Nanoparticles
Polymers
Polyethylene

ABSTRACT

Polymer properties can be experimentally tailored by adding small amounts of different nanoparticles to enhance its mechanical, thermal and electrical properties; thus, it has been widely anticipated that the combination of nanoparticles with traditional resin systems. This paper has been studied the enhancement and controlling electric and dielectric properties of low density polyethylene (LDPE), and high density polyethylene (HDPE) polymer materials by cost-fewer nanoparticles. Certain percentages of clay and fumed silica nanoparticles have been enhanced electric and dielectric properties of polyethylene nanocomposite films. Dielectric spectroscopy has been measured the electric and dielectric properties of each polyethylene nanocomposite with and without nanoparticles at various frequencies up to1kHz under different thermal conditions (20oC and 60oC). Also, it has been investigated the optimum types and percentages of cost-fewer nanoparticles for enhancing electric and dielectric characterization at low and high temperatures.

Corresponding Author:

Youssef Mobarak,
Department of Electrical Engineering,
Faculty of Energy Engineering, Aswan University,
81528, Aswan, Egypt.
Email: ysoliman@aswu.edu.eg

1. INTRODUCTION

Nanocomposite films represent a very attractive route to upgrade and diversify properties of the polymers. Nano-filler-filled polymers might be differentiated from micro-filler-filled polymers in three major aspects that the nanocomposite films normally contain smaller amounts, are in range of nanoparticles and have tremendously large specific surface area. All these characteristics are reflected in their material properties [1]. In general, fillers are added to polymeric materials in order to enhance thermal and mechanical properties. Over the past few years there have been few numbers of researches on the effect of fillers on di-electric properties of polymers [2-3]. Elemental properties are usually integrated over macroscopic volumes to reach explanations for macroscopic properties [7-9]. The new developments in nano-science and technology stop short of the final integration and consider what special properties are present at the nanometric level and how they might be exploited. This is a meso-world between quantum and continuum science. For instance, di-electric properties of elementary units include macromolecules, mono-layers and mesometric particles. Thus, the dielectric composition characteristics would reflect on the material properties and so it will be affecting on the performance of AC and DC applications [10-12]. The shift from ceramic electric insulating materials (e.g. porcelain and glass) and from oil-paper insulations to polymeric materials has been the major change in the field of high voltage insulation technology during the past three decades. Today polymers are widely used in most of the high voltage equipment, e.g. power transformers, insulators, capacitors, reactors, surge arresters, current and voltage sensors, bushings, power cables and terminations.

The wide possibilities of the existing polymers and, particularly, the huge scenarios of new polymer composites in high voltage technology inspires the researchers of the field to innovate new materials and to study their properties. Research work on novel polymer materials is of great significance both nationally and internationally in the field of power engineering, high voltage technology and environmental technology due to the increasing demands of more cost-effective, efficient, reliable and environmentally satisfactory high voltage equipment. Particularly, there is a need for developing a range of compact devices and accessories, for both outdoor and indoor conditions, in which novel and more reliable insulation systems will play the key role. Nano-materials, in form of polymeric nanocomposites, are foreseen as excellent candidates able to fulfill the new requirements. Nano-filler-filled polymers might be differentiated from micro-filler-filled polymers in three major aspects that the nanocomposites normally contain smaller amounts, are in range of nano-meters in size and have tremendously large specific surface area. All these characteristics are reflected in their material properties [13-18].

Polymer nanocomposite films have attracted wide interest with regard to enhancing polymer properties and extending their utility in recent years. The nanocomposite material which the nanoparticles are evenly distributed in the polymer material attracts attention as an insulating material because the properties of the original material can be drastically improved by adding a few percent of nanoparticles. LDPE is widely used as an insulating material for power cables. Electrical insulating polymers are usually modified with inorganic fillers to improve electrical, mechanical, thermal properties. Generally, inorganic fillers are dispersed non-uniformly in the polymer matrix, and the irregular interfaces are usually electrically weak spots. It is well known that electrical properties of insulating polymer composites depend strongly on their microstructures. In particular, the size and shape of the fillers, the dispersion of the fillers, the filler-filler, filler-matrix interactions including interfacial strain, directly affect the electrical properties of composites [19-25]. LDPE is widely used as a dielectric insulation of power cable. Nanoparticles/polymer composites are now of considerable interest for their specific electrical properties. It is recognized that the interfaces between the host dielectric and the nanometric particles can strongly influence the dielectric properties of the composite material as a whole. Since interfaces dominate dielectric situations at this level, nanodielectrics and interfaces become inextricable. Low frequency polarization is a type of polarization concerning to interface polarization, and it strongly relates to the space charge storage and transportation in dielectric materials [26-32]. As of now, work is underway to examine the physical properties of nanocomposite materials composed of nanoparticles of metals and their compounds stabilized within a polymeric dielectric matrix .In recent years polymer nanocomposite films have attracted wide interest with regard to enhancing polymer properties and extending their utility. It has been found that the dielectric properties have a close relationship with the interfacial behavior between the nanoparticles and the polymer matrix in such nanocomposite films [33-39]. Recently, the effects of nanoparticles in variant polymers have been demonstrated to be highly electric performance dependent on the size, structure, and concentration of the nanoparticles, as well as on the type of polymeric matrix to be reliable in industries [40-48].

With a continual progress in polymer nanocomposite films, the main objective of this study is to synthesize electrical insulating polymer nanocomposite films to achieve more cost-effective, energy-effective and hence environmentally better materials for the electrical insulation technology. This research depicts the effects of types and concentration of cost-fewer nanoparticles in electrical properties of industrial polymer material. Experimental results have been analyzed and discussed the effects of clay and fumed silica nanoparticles with various volume fractions and temperatures on electric and dielectric properties of polyethylene.

2. EXPERIMENTAL SETUP

2.1. Nanoparticles

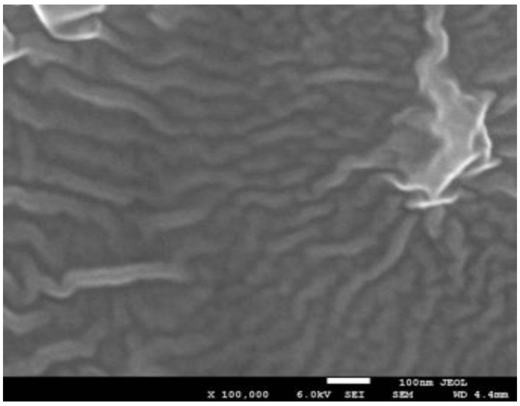
Nanoparticles of Clay and fumed silica are spherical particle shape (Dia.: 10nm) and have the most important characteristics for enhancing polymer applications. Cost-fewer clay nanoparticles are catalyst to be the best filler among nanoparticles industrial materials. On the other wise, fumed silica is a fluffy white powder with an extremely low density.

2.2 Polyethylene base matrix polymer

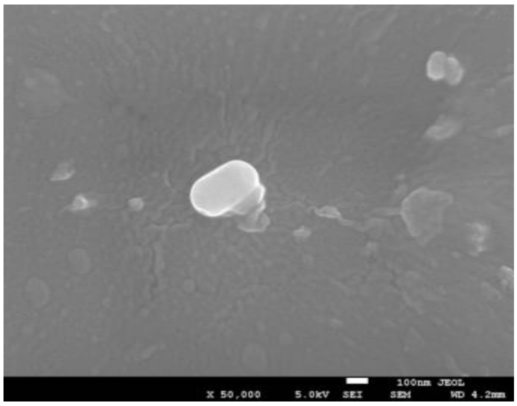
Polyethylene is a thermoplastic made from petroleum, and it is unreactive at room temperatures, except by strong oxidizing agents, and some solvents cause swelling. It can withstand temperatures of 80°C continuously and 95°C for a short time. This polymer is a commercially available material already in use in the manufacturing of high-voltage industrial products. Thus, polyethylene (LDPE and HDPE) has been studied here which has been formulated utilizing variant percentages of nanoparticles of clay and fumed silica. The base of all nanocomposite polymer materials have been measured their electric and dielectric properties after manufacturing and detailed as shown in table 1. Polyethylene nanocomposite films have been prepared and fabricated by using recent nanotechnology stages of melting polyethylene (LDPE, and HDPE), mixing and penetrating nanoparticles inside the base matrix polyethylene by modern ultrasonic devices. SEM images for polyethylene nanocomposite films illustrate penetration of nanoparticles inside low-density polyethylene and high-density polyethylene as shown in Figure1.

Table 1. Dielectric properties of pure and nanocomposite materials

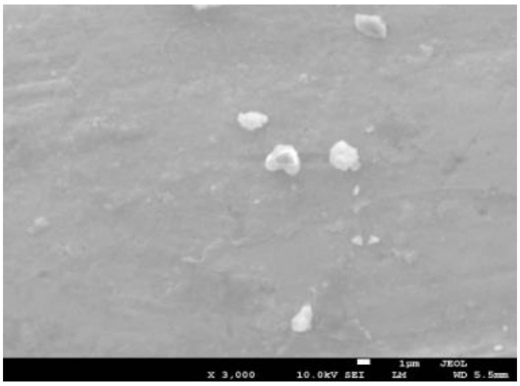
Characteristics	Dielectric constant		Resistivity (Ω.m)	
Materials	LDPE	HDPE	LDPE	HDPE
Pure	2.3	2.3	10^{14}	10^{15}
1%wt Clay	2.23	2.23	10^{15}	10^{16}
5%wt Clay	1.99	1.99	10^{15}-10^{18}	10^{16}-10^{19}
10%wt Clay	1.76	1.76	10^{18}-10^{20}	10^{19}-10^{21}
1%wt Fumed Silica	2.32	2.32	10^{13}	10^{14}
5%wt Fumed Silica	2.39	2.39	10^{13}-10^{11}	10^{14}-10^{12}
10%wt Fumed Silica	2.49	2.49	10^{11}-10^{9}	10^{12}-10^{10}



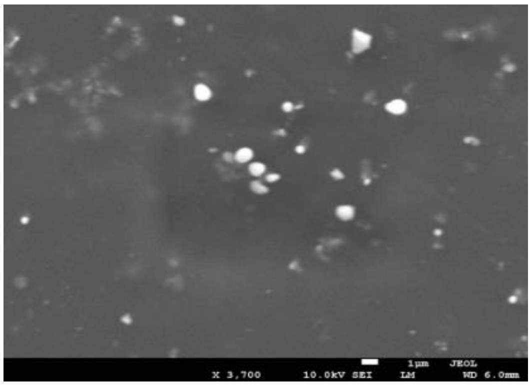
(a) Clay/LDPE nanocomposite



(b) Fumed silica/LDPE nanocomposite



(c) Clay/HDPE nanocomposite



(d) Fumed silica/HDPE nanocomposite

Figure 1. SEM images for polyethylene nanocomposite films

2.3. Electric characterization measurements

Figure 2 shows HIOKI 3522-50 LCR Hi-tester device that measured characterization of nanocomposite insulation industrial materials, it has been used for measuring electrical parameters of nanometric solid dielectric insulation specimens at various frequencies. Specification of LCR is Power supply: 100, 120, 220 or 240V (±10%) AC (selectable), 50/60Hz, and Frequency: DC, 1MHz to 100 kHz, Display Screen: LCD with backlight / 99999 (full 5 digits), Basic Accuracy: Z: ± 0.08% rdg. θ: ±0.05˚, and External DC bias ±40V max.(option) (3522-50 used alone ±10Vmax./ using 9268 ±40Vmax.).

Figure 2. HIOKI 3522-50 LCR Hi-tester device.

3. RESULTS AND DISCUSSION

Dielectric spectroscopy is a powerful experimental method to investigate the dynamical behavior of a sample through the analysis of its frequency dependent dielectric response. This technique is based on the measurement of the resistance, conductance, and susceptance as a function of frequency of a sample sandwiched between two electrodes. The conductance and susceptance were measured as a function of frequency 1 kHz at room temperature (20^{o}C) under different temperatures for all the test samples.

3.1. Electric properties of low-density polyethylene Nanocomposite films

3.1.1. Effects of cost-fewer nanoparticles on conductance property

Figure. 3 depicts the conductance of clay/LDPE nanocomposite films decreases with increasing percentage of clay nanoparticles in the nanocomposite up to 5%wt at room temperature (20^{o}C), but, under high thermal conditions, the conductance of clay/LDPE nanocomposite films increases with increasing percentage of clay nanoparticles in the nanocomposite up to 5%wt. Therefore, rising temperature of nanocomposite materials changes nanoparticles temperatures that changing electric conductance behavior over the normal conditions.

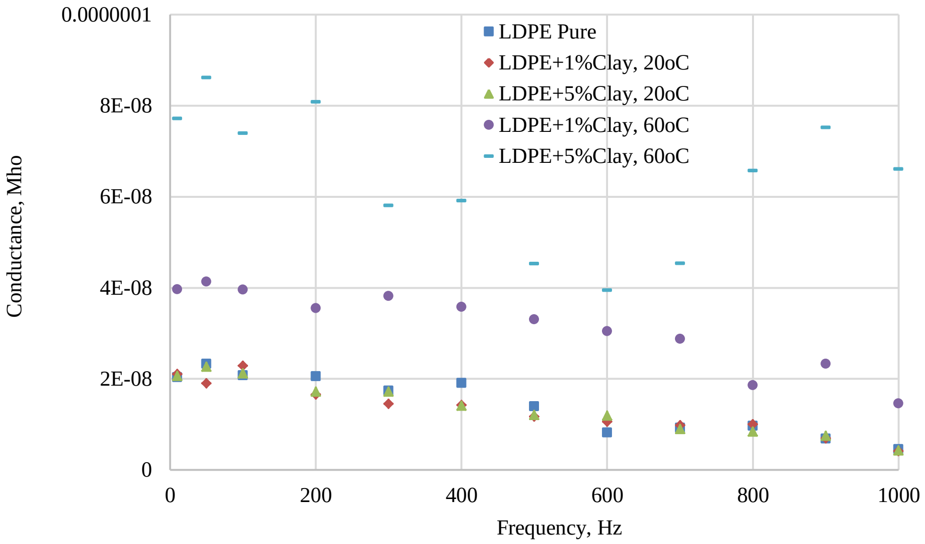


Figure 3: Measured conductance of clay/LDPE nanocomposite films

On the otherwise, Figure 4 shows the conductance of the tested samples as a function of frequency for fumed silica/LDPE nanocomposite films; the measured conductance decreases with increasing fumed silica nanoparticles percentage up to 1wt% but it increases with increasing fumed silica nanoparticles percentage up 5wt% without reaching to pure values of low-density polyethylene. Under high temperature (60^{o}C), the measured conductance of fumed silica/LDPE nanocomposite films increases with increasing percentage of fumed silica nanoparticles in the nanocomposite up to 1%wt., then, it decreases with increasing percentage of fumed silica nanoparticles in the nanocomposite up to 5%wt. Thus, there is no stability in conductance property behavior for using fumed silica nanoparticles in low-density polyethylene that can be reversed conductance property behavior under high temperature (60^{o}C).

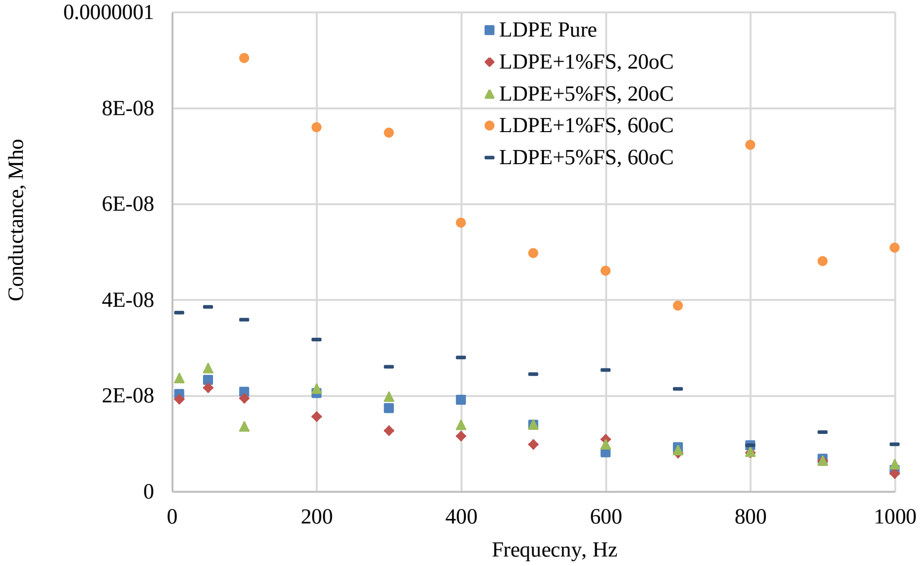


Figure 4. Measured conductance of fumed silica/LDPE nanocomposite films

3.1.2. Effects of cost-fewer nanoparticles on susceptance property

Figure (5, 6) gives the measurements of suscptance as a function of frequency for clay/LDPE, and fumed silica/LDPE nanocomposite films samples under variant thermal temperatures**.** Noting that, Figure 5 shows that increasing the susceptance of clay/LDPE nanocomposite films with increasing percentage of clay nanoparticles in the nanocomposite up to 5%wt under variant thermal conditions (low and high).

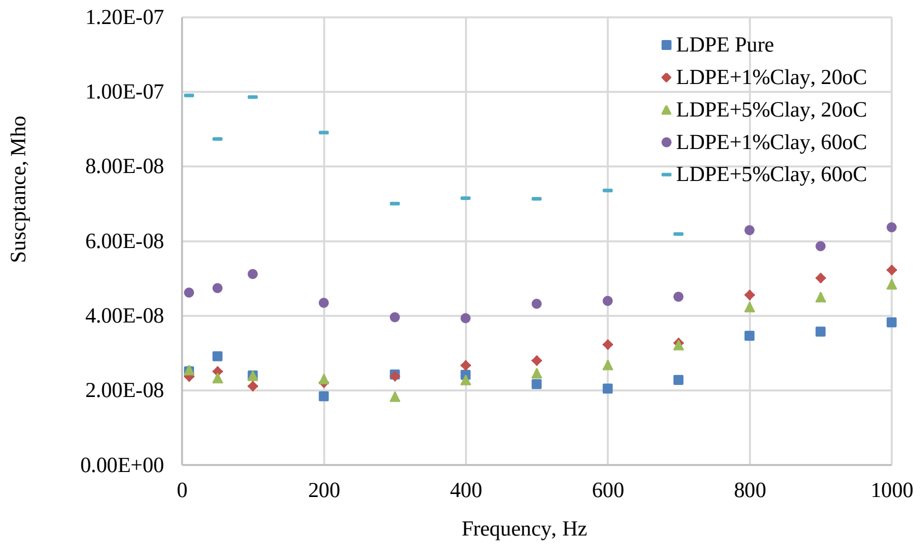


Figure 5. Measured susceptance of cay/LDPE nanocomposite films

So, there is stability in susceptance property behavior for using clay nanoparticles in low-density polyethylene but clay nanoparticles has been affected with high temperatures for increasing the susceptance of low-density polyethylene. However, Fig. 6 shows the measured susceptance of fumed silica/LDPE nanocomposite films behave the same performance of conductance with increasing fumed silica nanoparticles in low-density polyethylene under variant thermal conditions (low and high). Therefore, rising temperature of nanocomposite materials changes nanoparticles temperatures which changing electric behavior over the normal conditions.

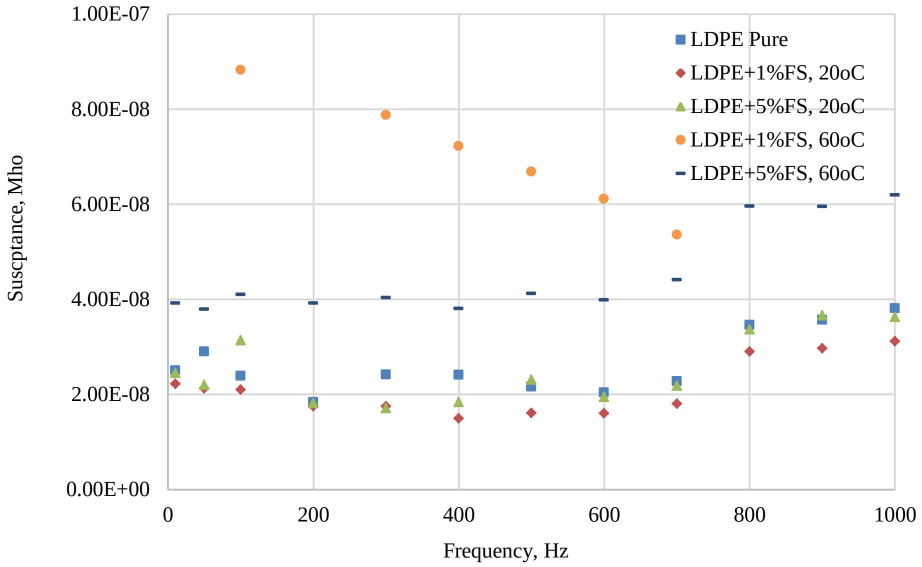


Figure 6. Measured susceptance of fumed silica/LDPE nanocomposite films

3.2. Electric properties of high-density polyethylene Nanocomposite films
3.2.1. Effects of cost-fewer nanoparticles on electric conductance property

For comparing with both types of polyethylene (low and high), thus, figure 7 shows the measured conductance of the tested samples of clay/HDPE nanocomposite films as a function of frequency at variant temperatures (20^{o}C, and 60^{o}C**)**. It is obvious that the measured conductance is closed with increasing the percentage of clay nanoparticles up to 5%wt, specially, at high frequencies.

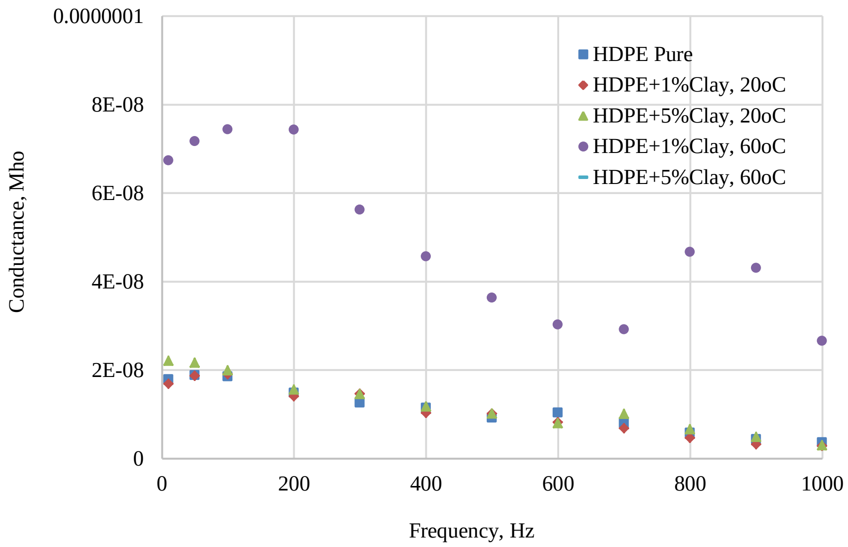


Figure 7. Measured conductance of clay/HDPE nanocomposite films

But, under high thermal conditions (60^{o}C), the conductance increases with increasing percentage of clay nanoparticles in the low-density polyethylene nanocomposite only at 1%wt. On the otherwise, Fig. 8 shows that that the measured conductance is closed with increasing the percentage of fumed silica nanoparticles up to 5%wt. under normal conditions. Whatever, the measured conductance increases with increasing percentage of fumed silica nanoparticles in the nanocomposite up to 5%wt. gradually under high thermal conditions. Thus, the electric properties have a close relationship with the interfacial behavior between the fillers and the polymer matrix in such composites.

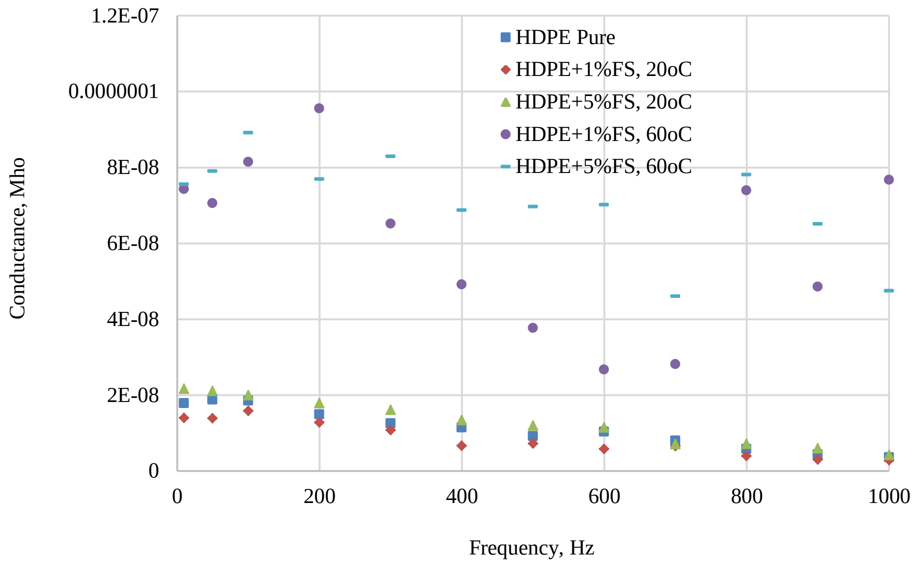


Figure 8. Measured conductance of fumed silica/HDPE nanocomposite films

3.2.2. Effects of cost-fewer nanoparticles on electric susceptance property

Figure (9, 10) gives the measurements of suscptance as a function of frequency for clay/LDPE, and fumed silica/LDPE nanocomposite films samples at variant temperature (20^{o}C and 60^{o}C). Thus, Fig. 9 Contrasts on increasing susceptance with increasing percentage of clay nanoparticles in the nanocomposite up to 1%wt., then, the measured susceptance of LDPE decreases with increasing clay nanoparticles percentage up to 5%wt. Under high thermal conditions (60^{o}C), the suscptance of clay/HDPE nanocomposite films samples increases with increasing percentage of clay nanoparticles in high-density polyethylene nanocomposite only at 1%wt.

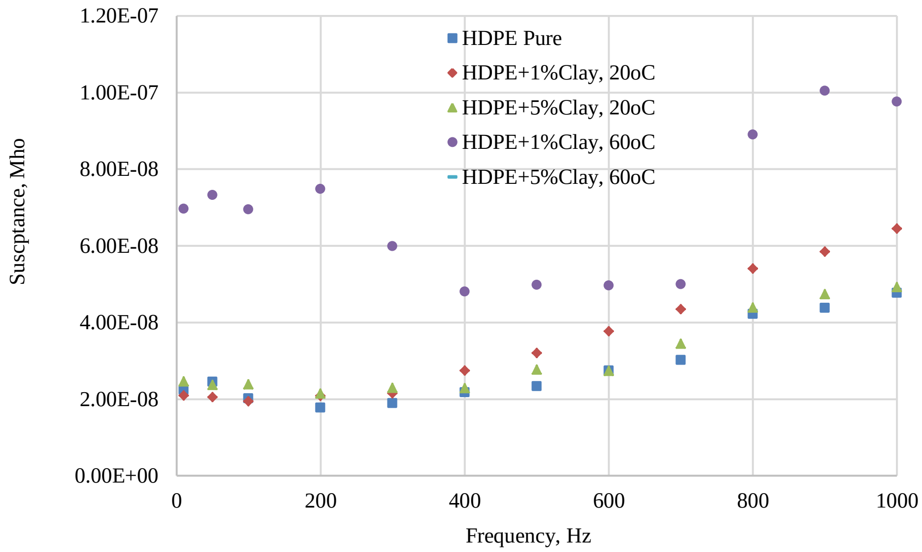


Figure 9. Measured susceptance of clay/HDPE nanocomposite films

While susceptance is increased with increasing fumed silica nanoparticles up to 1%wt. then, it is decreased with increasing fumed silica nanoparticles up to 5%wt. as shown in Fig. 10 under normal and high temperatures. It is cleared that nanoparticles have been changed electric and dielectric polymer properties. The dielectric properties of insulating polymer nanocomposite films have been investigated in the frequency domain from 0.1Hz to 1kHz. Also, it has been found that the dielectric properties have a close relationship with the interfacial behavior between the fillers and the polymer matrix in such composites. On the otherwise, Fig. 10 shows the measured suscptance of fumed silica/HDPE nanocomposite films samples versus frequency at variant temperatures (20^{o}C and 60^{o}C), the susceptance behavior of fumed silica/HDPE nanocomposite films increases with increasing percentage of fumed silica nanoparticles in high-density polyethylene nanocomposite up to 1%wt. but the susceptance behavior of fumed silica/HDPE nanocomposite films decreases with increasing percentage of fumed silica nanoparticles up to 5%wt. It is cleared that nanoparticles have been changed electric and dielectric polymer properties. The dielectric properties of insulating polymer nanocomposite films have been investigated in the frequency domain from 0.1Hz to 1kHz.

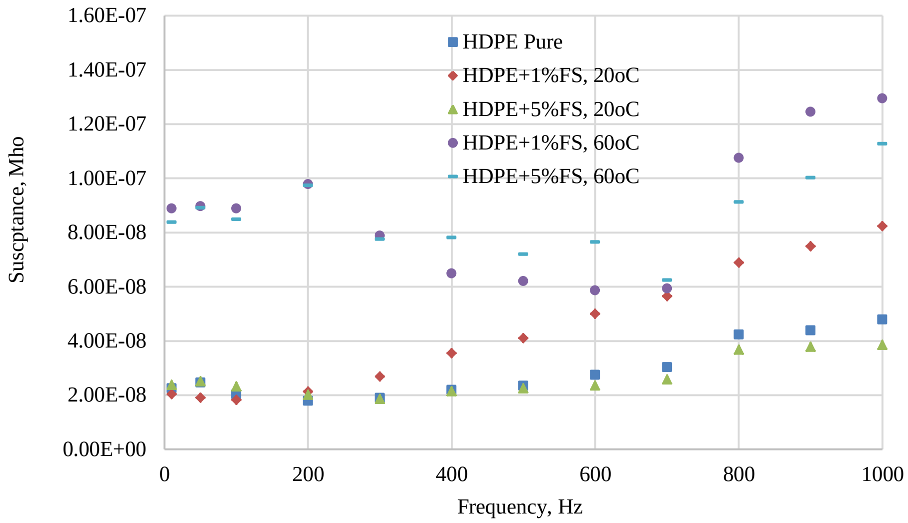


Figure 10. Measured susceptance of fumed silica/HDPE nanocomposite films

4. TRENDS OF COST-FEWER NANOPARTICLES ON POLYETHYLENE NANOCOMPOSITE THIN FILMS UNDER THERMAL CONDITIONS

With respect to the results that obvious the effect of temperature and types of nanoparticles on the electrical characterization, in the beginning, adding fumed silica increased permittivity of the new nanocomposite materials whatever, and adding clay has decreased permittivity of the new nanocomposite materials as tabulated in table 1. With comparing results for depicting the effect of raising concentration of clay and fumed silica nanoparticles are pointed out in figures at room temperature (20^{o}C), the measured conductance or susceptance of polyethylene nanocomposite films depends on changing the certain percentages of nanoparticles inside polyethylene materials under low and high frequencies. The electric properties may be have a close relationship with the interfacial behavior between the nanoparticles and the polymer matrix in nanocomposite thin films based on types and concentations of nanoparticles.With rising samples temperature up to 60^{o}C, it can be noticed that the effects high temperature values on nanoparticles inside the nanocomposite films and so, the effect of raising concentration of nanoparticles is pointed out in figures. i.e the measured conductance has been changed at a certain values of clay or fumed silica nanoparticles percentage up to 5%wt, This is obvious that, rising temperature of nanocomposite materials effects on nanoparticles heating temperatures which changing dielectric behavior over the normal conditions. Therefore, the importance of adding nanoparticles of clay or fumed silica can be concluded in controlling in increasing or decreasing the dielectric strength of pure low-density polyethylene and pure high-density polyethylene by using nanotechnology techniques. Also, increasing environment temperature of nanocomposite materials causes heating in temperatures of nanoparticles that changing dielectric behavior over the normal conditions.

5. CONCLUSIONS

Adding clay has decreased permittivity of polyethylene but fumed silica has increased permittivity of polyethylene nanocomposite films. The variation of conductance and susceptance values in polyethylene nanocomposite films may be resulted and controlled by changing types and percentages of nanoparticles. The influence of the relaxation time of the charge carriers on the electrical insulation of polyethylene nanocomposite films can be ignored. Thus the number of charge carriers and applied frequency become dominating factors of the electrical insulation of polyethylene nanocomposite films. The presence of nanoparticles inside polyethylene will restrict the chain mobility and result in increasing electric insulation as such restriction limited the generation of mobile charge and the movement of charge carriers in polymer dielectrics, especially at low frequency range where the insulation will play a more important role. Thermal stability of new nanocomposite films occurs at small amounts clay or fumed silica nanoparticles but adding large amounts these nanoparticles to polyethylene may be reverse electric and dielectric behavior characteristics gradually. This is obvious that rising temperature of nanocomposite this films effects on nanoparticles temperatures which changing electric and dielectric behavior over the normal conditions.

ACKNOWLEDGEMENTS

The present work was supported by the Science and Technology Development Fund (STDF), Egypt, Grant No: Project ID 505.

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BIOGRAPHIES OF AUTHORS

Ahmed Thabet was born in Aswan, Egypt in 1974. He received the BSc (FEE) Electrical Engineering degree in 1997 and MSc (FEE) Electrical Engineering degree in 2002 both from Faculty of Energy Engineering, Aswan, Egypt. PhD degree had been received in Electrical Engineering in 2006 from El-Minia University, Minia, Egypt. He joined with Electrical Power Engineering Group of Faculty of Energy Engineering in Aswan University as a Demonstrator at July 1999, until; he held Associate Professor Position at October 2011 up to date. His research interests lie in the areas of analysis and developing electrical engineering models and applications, investigating novel nano-technology materials via addition nano-scale particles and additives for usage in industrial branch, electromagnetic materials, electroluminescence and the relationship with electrical and thermal ageing of industrial polymers. Many of mobility’s have investigated for supporting his research experience in UK, Finland, Italy, and USA …etc. On 2009, he had been a Principle Investigator of a funded project from Science and Technology development Fund “STDF” for developing industrial materials of ac and dc applications by nano-technology techniques. He has been established first Nano-Technology Research Centre in the Upper Egypt (http://www.aswan.svu.edu.eg/nano/index.htm). He has many of publications which have been published and under published in national, international journals and conferences and held in Nano-Technology Research Centre website.

Youssef A. Mobarak was born in Luxor, Egypt in 1971. He received his B.Sc. and M.Sc. degrees in Electrical Engineering from Faculty of Energy Engineering, Aswan University, Egypt, in 1997 and 2001 respectively and Ph.D. from Faculty of Engineering, Cairo University, Egypt, in 2005. He joined Electrical Engineering Department, Faculty of Energy Engineering, Aswan University as a Demonstrator, as an Assistant Lecturer, and as an Assistant Professor during the periods of 1998–2001, 2001–2005, and 2005–2009 respectively. He joined Artificial Complex Systems, Hiroshima University, Japan as a Researcher 2007–2008. Also, he joined Faculty of Engineering, King Abdulaziz University, Rabigh, Saudi Arabia as Associate Professor Position at April 2014 up to date. His research interests are power system planning, operation, optimization, and techniques applied to power systems. Also, his research interests are wind energy, and nanotechnology materials via addition nano-scale particles and additives for usage in industrial field.