# Experimental Enhancement for Electric Properties of Polyethylene Nanocomposites under Thermal Conditions

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***Abstract.*** *Polymer properties can be experimentally tailored by adding small amounts of different nanoparticles for enhancing their mechanical, thermal and electrical properties. The work in this paper investigates enhancing the electric and dielectric properties of Low Density Polyethylene (LDPE), and High Density Polyethylene (HDPE) polymer materials with cheap nanoparticles. Certain percentages of clay and fumed silica nanoparticles are used to enhance electric and dielectric properties of polyethylene nanocomposites films. By using the Dielectric Spectroscopy; the electric and dielectric properties of each polyethylene nanocomposites have been measured with and without nanoparticles at various frequencies up to 1 kHz under different thermal conditions (20 °C and 60 °C). And so, we were successful in specifying the optimal nanoparticles types and their concentrations for the control of electric and dielectric characterization.*

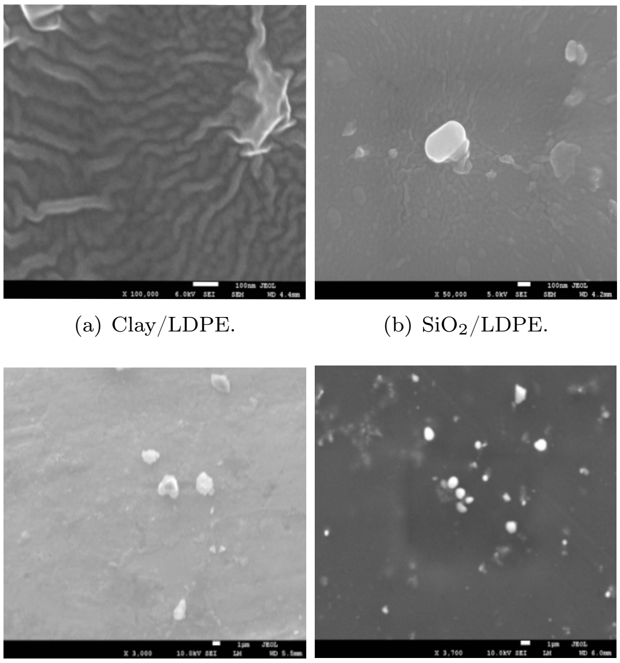
## Keywords

***Dielectric properties, electric properties, nanocomposite, nanoparticles, polyethylene, polymers.***

## 1. Introduction

Nanocomposites 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 and so the 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 many researches on the effect of fillers on dielectric properties of polymers [2] and [3]. Polymer nanocomposites films have attracted wide interest for enhancing polymer properties and extending their utility in recent years. PolyEthylene (PE) 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 the 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 and filler-matrix interactions including interfacial strain, directly affect the electrical properties of composites [4], [5], [6], [7], [8], [9] and [10]. Nanoparticles/polymer composites are now interested 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 [11], [12], [13], [14], [15], [16] and [17].

As of now, work is underway to examine the physical properties of nanocomposites materials composed of nanoparticles of metals and their compounds stabilized within a polymeric dielectric matrix. 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 nanocomposites films [18], [19] and [20]. Nowadays, the effects of nanoparticles in many polymers have been enhanced electric and dielectric behaviour depending on the size, structure, and concentration of the nanoparticles, as well as the type of polymeric matrix [21], [22], [23], [24], [25], [26], [27], [28], [29] and [30]. With a continual progress in polymer nanocomposites films, the main objective of this paper is studying the effects of nanoparticles on conductance and susceptance of insulating polyethylene nanocomposites films to achieve more cost-effective, energy-effective and hence environmentally better materials for the electrical insulation technology. Also, this research depicts the effects of types and concentrations of cheap nanoparticles on electrical properties of industrial polymer material. Our experimental results show the effects of clay and fumed silica nanoparticles on electric and dielectric properties of polyethylene under thermal conditions.



(a) Clay/LDPE. (b) $SiO_2$/LDPE.

(c) Clay/HDPE. (d) $SiO_2$/HDPE.

**Fig. 1:** SEM images for polyethylene nanocomposite films.

## 2. Experimental Setup

### 2.1. Nanoparticles

Clay and fumed silica nanoparticles are cheap catalysts that change the properties of industrial materials with respect to physical manufacture process.

### 2.2. Polyethylene Base Matrix Polymer

Polyethylene is a thermoplastic made from petroleum, unreactive at room temperatures, and with all but strong oxidizing agents, and some solvents causing swelling. It can withstand temperatures of 80 °C and 95 °C for a short time. This polymer is a commercial material that is used in the manufacturing of high-voltage industrial products. Polyethylene nanocomposites films have been manufactured by using melting polyethylene (LDPE and HDPE), then, mixing and penetrating nanoparticles inside the base matrix polyethylene by modern ultrasonic devices.

SEM images for polyethylene nanocomposites films illustrate the penetration of nanoparticles inside low-density polyethylene and high-density polyethylene as shown in Fig. 1. And so, Tab. 1 depicts the measured electric and dielectric properties of polyethylene nanocomposites materials.

### 2.3. Electric Characterization Measurements

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

**Fig. 2:** HIOKI 3522-50 LCR Hi-tester device.

**Tab. 1:** Electric and dielectric properties of pure and nanocomposite materials.

| Characteristics | Dielectric constant | | Resistivity ($\omega \cdot$m) | |
|---|---|---|---|---|
| materials | LDPE | HDPE | LDPE | HDPE |
| PurePure | 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.% $SiO_2$ | 2.32 | 2.32 | $10^{13}$ | $10^{14}$ |
| 5 wt.% $SiO_2$ | 2.39 | 2.39 | $10^{13}-10^{11}$ | $10^{14}-10^{12}$ |
| 10 wt.% $SiO_2$ | 2.49 | 2.49 | $10^{11}-10^{9}$ | $10^{12}-10^{10}$ |

# 3. Results and Discussion

Dielectric Spectroscopy is a powerful experimental method to investigate the dynamical electric and dielectric behavior of the polymeric sample through frequency response analysis. This technique is based on the measurement of the resistance, conductance, and susceptance as a function of frequency for a sample sandwiched between pin-plate electrodes. Thus, the conductance and susceptance were measured for all samples as a function of frequency up to 1 kHz under variant temperatures of (20 °C and 60 °C).

## 3.1. Measurements on LDPE Nanocomposites Films

### 1) Effect of Nanoparticles on Conductance Property

Figure 3 depicts the conductance of clay/LDPE nanocomposites films that decreases with increasing concentration of clay nanoparticles in the nanocomposites up to 5 wt.% at room temperature (20 °C). However, at high temperature (60 °C), the conductance performance of clay/LDPE nanocomposites films is reversed within the same concentration range of nanoparticles.

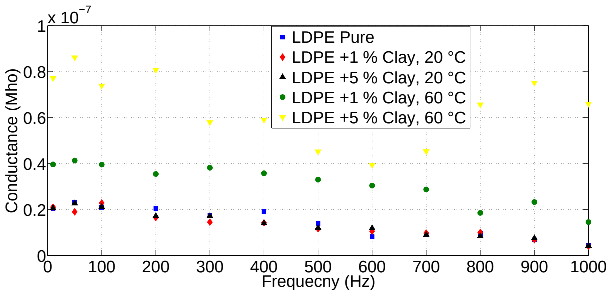



**Fig. 3:** Measured conductance of clay/LDPE nanocomposite films.

Therefore, increasing temperature of nanocomposites materials changes temperature degrees of nanoparticles that are changing the electric conductance behavior against normal conditions. On the other hand, Fig. 4 shows the conductance of $SiO_2$/LDPE nanocomposites films as a function of frequency. Note that the measured conductance decreases with increasing concentration of fumed silica nanoparticles up to 1 wt.% but it increases with increasing concentration of fumed silica nanoparticles up to 5 wt.% without reaching to values of low-density polyethylene.

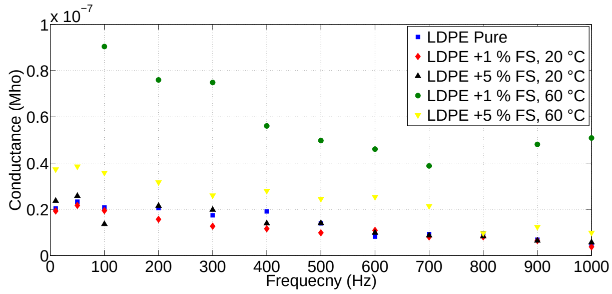



**Fig. 4:** Measured conductance of $SiO_2$/LDPE nanocomposite films.

Under high temperature (60 °C), the measured conductance of fumed silica/LDPE nanocomposites films increases with increasing concentration of fumed silica nanoparticles in the nanocomposites up to 1 wt.%, then, it decreases with increasing percentage of fumed silica nanoparticles in the nanocomposites up to 5 wt.%. Therefore, there is no stability in conductance property behavior for using fumed silica nanoparticles in low-density polyethylene that can reverse conductance property behavior under high temperature (60 °C).

### 2) Effect of Nanoparticles on Electric Susceptance Property

Figure 5 and Fig. 6 show the results of the measurements of susceptance as a function of frequency for clay/LDPE, and $SiO_2$/LDPE nanocomposites films samples under varying thermal temperatures. Note that, Fig. 5 shows that the susceptance of clay/LDPE nanocomposites films increases with the increasing concentration of clay nanoparticles in the nanocomposites up to 5 wt.% under varying thermal conditions (low and high). However, Fig. 6 shows the measured suscep-

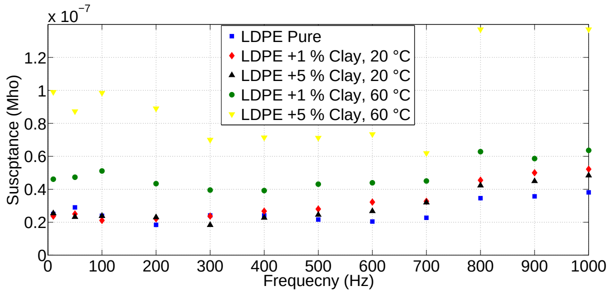



**Fig. 5:** Measured susceptance of cay/LDPE nanocomposite films.

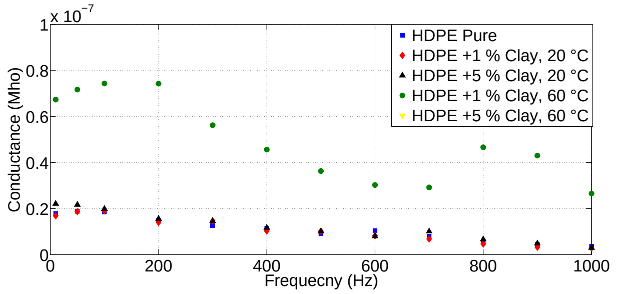



**Fig. 7:** Measured conductance of clay/HDPE nanocomposite films.

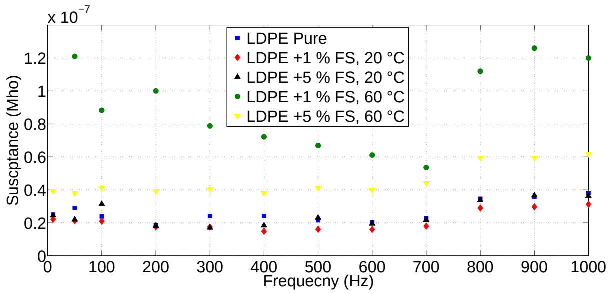



**Fig. 6:** Measured susceptance of $SiO_2$/LDPE nanocomposite films.

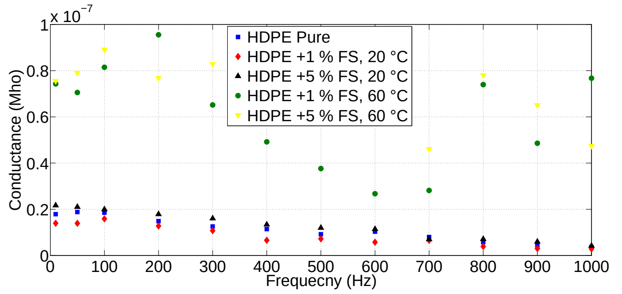



**Fig. 8:** Measured conductance of $SiO_2$/HDPE nanocomposite films.

tance of $SiO_2$/LDPE nanocomposites films that display the same performance of conductance with increasing fumed silica nanoparticles in low-density polyethylene under varying thermal conditions (low and high). Therefore, rising temperature of nanocomposites materials changes the temperature of nanoparticles that is changing the electric behavior against the normal conditions. Thus, presence of clay nanoparticles in low-density polyethylene causes instability of susceptance property behavior in case of high temperatures with respect to room temperature.

## 3.2. Measurements on HDPE Nanocomposites Films

### 1) Effect of Nanoparticles on Electric Conductance Property

In case of high density polyethylene, Fig. 7 shows the measured conductance of the tested samples of clay/HDPE nanocomposites films as a function of frequency at temperatures of (20 °C and 60 °C). It is obvious that the measured values of conductance are convergent and increases with the increase of the concentration of clay nanoparticles up to 5 wt.%. However, there is no convergence between the measured values of conductance of high-density polyethylene nanocomposites at high temperature (60 °C). On the other hand, Fig. 8 shows the convergence between the measured values of conductance for $SiO_2$/HDPE nanocomposites films with increasing concentration of fumed silica nanoparticles up to 5 wt.% at room temperature (20 °C). Thus, the measured conductance increases with increasing concentration of fumed silica nanoparticles in the nanocomposites up to 5 wt.% gradually under high thermal conditions.

### 2) Effect of Nanoparticles on Electric Susceptance Property

Figure 9 and Fig. 10 give the results of the measurements of susceptance as a function of frequency for clay/HDPE, and $SiO_2$/HDPE nanocomposites films samples at temperatures of (20 °C and 60 °C). It is obvious that Fig. 9 focus on increasing susceptance with increasing concentration of clay nanoparticles in the nanocomposites up to 1 wt.%, then, the measured susceptance decreases with increasing concentration of clay nanoparticles up to 5 wt.%. On the other hand, the susceptance of clay/HDPE nanocomposites films increases with increasing concentration of clay nanoparticles up to 5 wt.% at high temperature (60 °C).

Figure 10 shows the measured susceptance of $SiO_2$/HDPE nanocomposites films samples versus frequency at temperatures of (20 °C and 60 °C), the susceptance of $SiO_2$/HDPE nanocomposites films increases with increasing concentration of fumed silica nanoparticles in high-density polyethylene nanocomposites up to 1 wt.% at room temperature (20 °C),

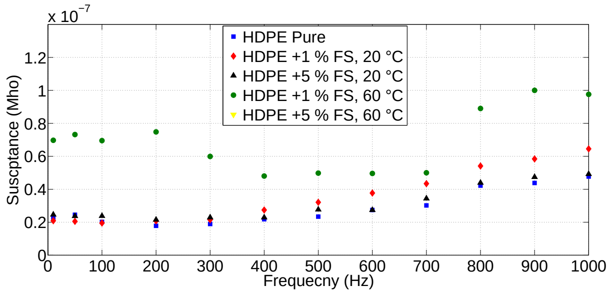



**Fig. 9:** Measured susceptance of clay/HDPE nanocomposite films.

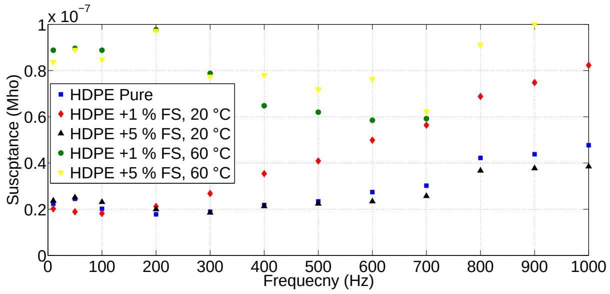



**Fig. 10:** Measured susceptance of $SiO_2$/HDPE nanocomposite films.

but it decreases with increasing concentration of fumed silica nanoparticles up to 5 wt.% at high temperature (60 °C).

It is clear that the dielectric properties of insulating polymer nanocomposites films have been investigated in the frequency domain from 0.1 Hz to 1 kHz and there is a convergence between the measured values of electric and dielectric polymer properties at room temperature (20 °C).

## 4. Trends of Nanoparticles on Polyethylene Under Thermal Conditions

The experimental results focused on effects of nanoparticles on electric characterization under variant thermal conditions. In the beginning, adding fumed silica nanoparticles increased permittivity of the fabricated polyethylene nanocomposites materials, however, adding clay has decreased permittivity of the new nanocomposites materials as shown in Tab. 1. Increasing concentration of clay and fumed silica nanoparticles at room temperature (20 °C) affects behavior of conductance and susceptance of polyethylene nanocomposites films and depends on changing the concentration of nanoparticles inside polyethylene materials under low and high frequencies. Types and concentations of nanoparticles display the relationship between electric properties with interfacial medium behavior between the nanoparticles and the polymer matrix in nanocomposite thin films. The aim of adding nanoparticles of clay or fumed silica is controlling on the dielectric strength of commercial polyethylene by using nanotechnology techniques.

## 5. Conclusion

The variation of conductance and susceptance values in polyethylene nanocomposites films can be controlled by changing the types and concentrations of nanoparticles. Increasing concentration of clay nanoparticles in polyethylene decreases the effective permittivity. But, increasing concentration of fumed silica nanoparticles increases effective permittivity of polyethylene nanocomposites films.

Presence of special types of nanoparticles inside polyethylene will restrict the chain mobility, then, the result is increasing electric insulation and limiting the generation of mobile charge for the movement of charge carriers in polymer dielectrics. Therefore, the number of charge carriers and applied frequency become dominating factors of the electrical insulation of polyethylene nanocomposites films.

New fabricated polyethylene nanocomposites films have high thermal stability at small concentrations of clay or fumed silica nanoparticles. Adding large amounts of these nanoparticles to polyethylene may reverse electric and dielectric behavior characteristics gradually. In addition, rising thermal conditions of nanocomposites materials affect temperatures of nanoparticles and hence change the electric characterization.

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**Ahmed THABET** was born in Aswan, Egypt in 1974. He received the B.Sc. (FEE) Electrical Engineering degree in 1997 and M.Sc. (FEE) Electrical Engineering degree in 2002 both from Faculty of Energy Engineering, Aswan, Egypt. Ph.D. 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. 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. 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.

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