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EFFECT OF NANOPARTICLES ON WATER TREEING CHARACTERISTICS IN XLPE INDUSTRIAL I NSULATING MATERIALS

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Water treeing is still now one of the main causes of cable deterioration and so, it is widely known that water treeing is the responsible for the reduction of the service life of polymeric cables. This paper has been studied the effects of adding various amounts of nanoparticles as ZnO, and Al2O3 on water treeing characteristics in XLPE industrial materials. This research has focused on studying development of the nano-composite materials performance with water tree growth resistance superior to the unfilled matrix, and has stressed particularly the effect of filler volume fraction on the water tree length and via various frequencies. Finally, this research aims to present a systematic and comparative study about the effect of adding nanoparticles to change dielectric insulation properties, and to understand the role effect of these nanoparticles in the industrial insulation materials which can make significant improvement in water tree resistance, life-time of insulation and decreasing the water tree length in the industrial insulation materials.

KEYWORDS: *Water treeing, Water void, Nanoparticles, Nano-composite materials.*

1. INTRODUCTION

Over the recent years particulate composites have received much attention particularly with the introduction of nanoparticles. Nanoparticles offer improved mechanical, electrical, and thermal properties of composites at relatively low concentrations. One of the important properties of composites in general is their dielectric properties which have been studied extensively. The dielectric properties of composites play an important role in areas such as microelectronic and optoelectronic packaging materials. It has long been known that an interphase region forms around each inclusion within the composite material. With the existence of the interphase region, some researchers have gone on to consider this region as being a homogeneous region with constant properties. However, current research tends to suggest that the properties of the interphase would best be modeled not by a constant but by a smooth variation in properties. Such a material is called inhomogeneous or a functionally graded material [1-3]. It is shown that the Equ's derived using the replacement method [4] on the Maxwell-Garnett mixing rule. These results however, are only valid for a low concentration of suspended inclusions since the interaction among the inclusions has been neglected in the construction of these models. The Equ's derived for calculating effective dielectric properties are applied to three power law profile PLP which model the inhomogeneity of the interphase. A way to incorporate the inhomogeneous model with Vo and Shi's homogeneous model is therefore proposed [5-7]. Since the water treeing has been realized for nearly 30 years, much research has been devoted to the phenomenon. It is generally accepted that, water tree is a hydrophilic network, and for the generation of water trees, an electric field, humidity and specific initiation points are necessary. And water tree itself cannot cause breakdown, however, water trees facilitate the initiation of electrical tree which give rise in the long run to costly cable failure [8-10]. Deterioration with water tree phenomenon is the one of typical problem on the electrical insulation of the high-voltage class power cable. The factors that affect water tree propagation include voltage, frequency, and time, and temperature, amount of water, water quality and type of solvent [11-14]. As well known in the previous researches on the water tree initiation and growth, there exist two main types of water tree, that is, vented water tree and bow-tie water tree. Generally, the main researches are focused on individual vented trees because these trees are more dangerous under service aging conditions than bow-tie trees and they grow very rapidly compared to bow-tie trees. A great deal of the early laboratory work was carried out with "water needle" configurations, which produce extremely high electric fields at the tip of a needle-shaped, water filled cavity. The electrical field at the tip was usually high enough to produce an electrical tree if the cavity were not filled with water, and the water tree growth in hours to days, rather than months to years as for water treeing is generally considered as one of the most important causes of breakdown in power cables with polymeric insulation [15].

With respect to nanotechnology techniques, the application of nanotechnology has shown promise in the dielectric arena, and nanocomposites are believed to have applications in the cable industry. However, the influence of moisture on nanocomposites is an area not fully explored. Because moisture migration and electrochemical treeing affect the performance of cable insulation in a vital way, it is important to investigate the performance of nanocomposite dielectrics in an aqueous environment before commercialization. Dielectric polymer nanocomposites have attracted much interest due to their improved electrical properties in comparison with the polymeric materials that do not use nanofillers. Treeing studies reported here supplement the previous effort devoted to develop crosslinked polyethylene (XLPE) based nanocomposites with functionalized nano-fillers as the material system of choice for underground cables. The vinyl silane (VS) treated nanocomposite at an optimized loading of nanofiller percentage (which was found to have the highest AC breakdown strength) is chosen. Comparison is made with the base resin, a lighter loading of nanofiller percentage, and nanocomposites with unfunctionalized nano particles at the same two loadings. At present, only vented water tree growth is investigated and documented in this report. All four kinds of nanocomposites were found to resist the growth of water trees compared to the XLPE base resin. Work is ongoing to examine the allied issue of water migration and uptake in nanodielectrics. Also, Water tree growth in nanocomposites is restricted in comparison with the base resin. With the increasing nanoparticle loading and improved bonding, this effect is more obvious.

The different behavior is attributed to the interfacial region introduced by nano particles. The development of water trees is inhibited through scattering by the internal interfaces in nanocomposites, which leads to a broader water tree profile, while, in XLPE, the tree profile is slim and develops towards the ground plane. With proper treatment of the nanoparticles, more robust interfacial region is achieved which further resists the development of water treeing. It is pertinent to observe that this improvement occurs despite an increased propensity to absorb water [16-22]. Thus, this paper describes how can controlling in water tree characteristics by using various nanoparticles in Cross-linked Polyethylene. Also, it has been investigated that electric field strength distribution on water void, interfacial energy between water void and dielectric, water treeing length for new nanocomposite insulation materials. Finally, it can be compared between water tree characteristics in pure and nanocomposite insulation materials.

2. ANALYTICAL MODEL

Water treeing is a long-term degradation phenomenon in polymeric materials, which lowers the breakdown strength of insulation. The water trees originate in micro voids and impurities in the bulk of the material. Water tree initiation and growth require the presence of moisture at a point of high stress concentration. The fields required for water trees are much lower than those tor electrical trees. The influence of high electrical fields on water treeing, electrical treeing, relaxation, conductivity and charge mobility in various polymers is reviewed within the context of a molecular model. The real value of the ac field acting on water trees is questioned and it is shown that the strain induced by very large fields may affect the water tree growth in solutions with large dielectric constant. Power cables are used in the transmission network in cities and for overseas power transmission. The polyethylene cables used for medium voltage were vulnerable to breakdown due to water treeing. Water treeing significantly reduces the electric breakdown strength of the insulation. The presence of water tree results in the reduction of their dielectric strength. Here the finite element simulation technique is used to evaluate the electric field inside the power cables. Water trees can cause service breakdown of the cable when they reach a critical length. The service life of cables without any metallic water barrier can be prolonged by delaying the water ingress into the cable. The water ingress is dependent on the diffusion rate, water sorption, initial water content in the cable materials, and the temperature of the cable. Let us consider a micro-void [15], which is relative larger in volume than voids around it. The electrical field close to the void is intensified as shown in figure (1). The suggested model of water void is built up as follows:

The electric field surface (E_{sur}) on the surface of an ellipsoid can be expressed as follows:-

$$E_{sur} = v_x \frac{E_0}{n} \qquad (1)$$

Where:

v_x **:** represent the component of unit length normal vector starting from the surface of the ellipsoid in the direction of electric field.

$$n = \frac{1-e^2}{2e^3}\left(\ln\frac{1+e}{1-e} - 2e\right) \qquad (2)$$

$$e = \left[1 - \frac{b^2}{a^2}\right]^{\frac{1}{2}} \qquad (3)$$

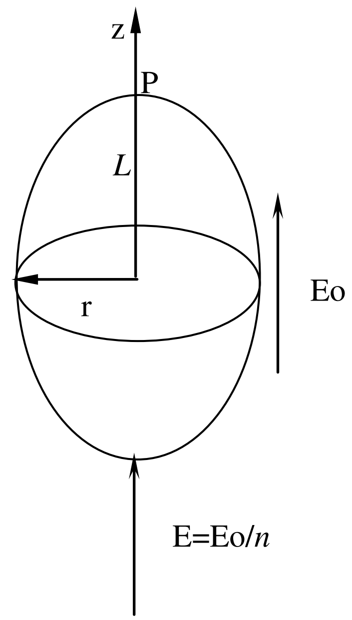


Fig. 1 Water void in water tree model

The value of the electric field inside the micro-void (E_1) could be calculated as follows:

$$E_1 = \frac{E_o}{1+\left(\frac{\varepsilon_2^*}{\varepsilon_1}-1\right).n} \tag{4}$$

$$\varepsilon_2^* = \varepsilon_2 - \frac{J\sigma_w}{w\varepsilon_o} \tag{4.1}$$

$$f_m = \frac{\sigma_w}{2\pi\varepsilon_2\varepsilon_o}\left(\frac{\sqrt{1+a}}{\frac{1}{n}\frac{\varepsilon_1}{\varepsilon_2}+\left(1-\frac{\varepsilon_1}{\varepsilon_2}\right)}\right) \tag{5}$$

$$a = \frac{\frac{q}{n}}{1+q\left(\frac{\varepsilon_2}{\varepsilon_1}-1\right)+\left(\frac{\varepsilon_2^*}{\varepsilon_1}-1\right)n} \tag{6}$$

The value of (n) given in equation (4) may be calculated from the two equations (5, 6) .therefore by substituting q=0.02 so the value of (n) can be determined to be equals $4.5*10^{-3}$. Considering f_m equal different values depends on dielectric constant of insulation.

Where,

E_O: electric field strength of insulation (V/m).

ε_1: specific inductive capacity of insulation or Nano-composite material.

ε^*_2: complex specific inductive capacity of water.

ε_2: specific inductive capacity of water

σ_w: conductivity of water

a: the long axis of ellipsoid.

b: the short axis of ellipsoid.

e: eccentricity of the ellipsoid.

f_m: the frequency which gives the maximum value of the dielectric loss tangent

q: water content ratio to insulation material

The total pressure applied to the water is

$$P_{total} = P_e + P_s \tag{5}$$

$$P_e = \left(\frac{1}{2}\,\varepsilon_o K_o \rho E_1^2 - P_s\right) \Big/ \left(1 + \frac{3}{2}\cdot\frac{R_o^2\rho^2}{\eta_m D}\right) \tag{6}$$

$$P_s = \frac{2\alpha}{R} - \frac{3}{2}\varepsilon_o E_o^2 \tag{7}$$

Viscosity of the dielectric mixture can be calculated with respect to volume fraction of each component in the mixture (main dielectric material and filler) as follows:

$$\eta_m = (1-q)\eta_{insulation} + q\,\eta_{filler} \tag{8}$$

$$\eta_{insulation} = 10^{\frac{-17.44(T-T_g)}{51.6+T-T_g}} \cdot \eta_{T_g} \tag{9}$$

The rate of void radius increase due to the presence of Pe was stated by [8] as follows:

$$\frac{dR}{dt} = \frac{3}{2}\frac{P_e}{\eta_m}R_o \tag{10}$$

Where:-

P_e: pressure of water in micro-void due to mechanical stress of insulation material (N/m^2)

P_s: pressure of water in micro-void due to interfacial tension (N/m^2)

ε_o: dielectric constant of vacuum

ρ: density of water (kg/m^3)

K_o: constant ($=7.9*10^{-2}\ m^3/kg$)

R_o: the initial radius of water void (m)

$\eta_{insulation}$: is the viscosity of the main dielectric of the mixture

η_{filler}: is the viscosity of the filler

D: diffusion constant of water ($=1.3*10^{-13}$ $kg.sec/m^3$)

T_g: glass transient temperature of insulation material (C^o)

T: temperature (C^o)

η (T_g): the viscosity at temperature T_g

dR/dt: is the rate of void radius increase with respect to the time

The performance of water treeing length with time for various Nano-composite materials as follows:

$$L = R_o \exp\left(\frac{t}{\tau_o}\right) \tag{11}$$

Where,

t: is the time of water treeing growth (sec)

τ_o: is the time constant of growth of water treeing

$$\tau_O = \frac{4}{3}\frac{\eta_m}{\rho\varepsilon_O k_O E_1^2} \tag{12}$$

3. SELECTED INDUSTRIAL MATERIALS

3.1 Nanoparticles

- Zinc oxide (ZnO): is a popular cross-linker for rubber and for various resins, it is also used as an UV stabilizer, and it has a relatively high refractive index which makes it an efficient white pigment. Zinc oxide is an inorganic compound with the formula ZnO. It has high refractive index, high thermal conductivity, non-toxic, and compatible with skin, making it a suitable additive for textiles and surfaces that come in contact with humans. Zinc Oxide is also used as a catalyst for methanol synthesis. The increase in surface area of Nano scale zinc oxide compared to larger powders has the potential to improve the efficiency of these processes.
- Aluminum oxide (Al_2O_3): Aluminum oxide is the family of inorganic compounds with the chemical formula Al_2O_3. It is an amphoteric oxide and is commonly referred to as alumina. Aluminum oxide is an electrical insulator but has a relatively high thermal conductivity alumina is a favored filler for plastics. It is used for its hardness and strength. It is widely used as a coarse or fine abrasive, including as a much less expensive substitute for industrial diamond.

3.2 Industrial insulation materials

- Cross-linked polyethylene (XLPE): Cross-linked polyethylene, commonly abbreviated PEX or XLPE, is a form of polyethylene with cross-links. It is formed into tubing, and is used predominantly in hydronic radiant heating systems, domestic water piping and insulation for high tension electrical cables. It is also used for natural gas and offshore oil applications, chemical transportation, and transportation of sewage and slurries. Recently, it has become a viable alternative to polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC) or copper pipe for use as residential water pipes. It has been widely used as insulating materials for extruded cables because they have good electrical properties together with other desirable properties such as remarkable mechanical strength and flexibility, good resistance to chemicals, easy processing and low cost.

4. RESULTS AND DISCUSSION

The electric field strength in micro-void, and the interfacial energy between water and insulation material have been studied with respect to uniform electric field strength of insulation for the suggested model of water treeing in solid insulations (unique, binary-, and multi-mixtures). Also, according to the importance of high frequencies on the performance of dielectric insulations (unique, binary mixtures, and multi-mixtures), the electric field strength in micro-void, and the interfacial energy between water and insulation material have been studied with respect to uniform electric field strength. Thus, the dielectric insulations and its specifications which have been used in suggested forms are stated later as in table (1).

Table1. Characteristics of Industrial Insulation Materials

Polymers	Dielectric constant	Nanoparticles	Dielectric Constant
XLPE	2.3	ZnO	1.7
		Al_2O_3	9
Nano-composite (XLPE + 5wt% ZnO)			1.96
Nano-composite (XLPE + 10wt% ZnO)			1.71
Nano-composite (XLPE + 15wt% ZnO)			1.54
Nano-composite (XLPE + 5wt% Al_2O_3)			2.7
Nano-composite (XLPE + 10wt% Al_2O_3)			3.07
Nano-composite (XLPE + 15wt% Al_2O_3)			3.43

4.1. Effect of ZnO nanoparticles on water treeing characteristics in Cross-Linked Polyethylene

Figures ((2.a) - (2.h)) illustrate the water tree length, the rate of void radius, the pressure of water in micro-void due to mechanical stress in XLPE, and the time constant of growth of micro void respectively for pure XLPE and various nanocomposites of (5%wtZnO+ XLPE, 10%wtZnO+ XLPE, and 15%wtZnO+ XLPE) with varying electric field strength and frequency. Also, it has been described the characteristics of water tree length with the time for pure XLPE and various nanocomposites of (5%wtZnO+ XLPE, 10%wtZnO+ XLPE, and 15%wtZnO+ XLPE) as shown in figure (2.i).

Figure (2.a) shows the effect of ZnO nanoparticles on the water tree length with varying field strength insulation, it is cleared that increasing percentage of ZnO nanoparticles in the XLPE matrix decreases the water tree length. Figure (2.b) shows the effect of ZnO nanoparticles on the water tree length with varying frequency. Also, it is cleared that increasing percentage of ZnO nanoparticles in the XLPE matrix decreases the water tree length up to 1 kHz, but increasing ZnO nanoparticles increases the water tree length more than 1 kHz.

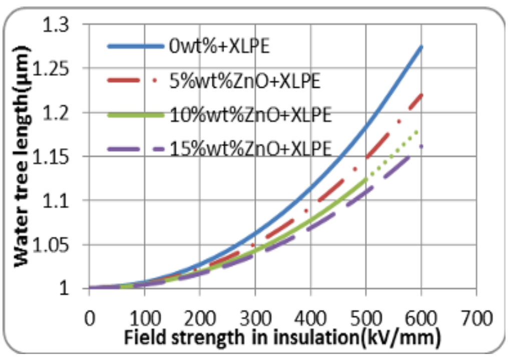


Fig. (2.a)

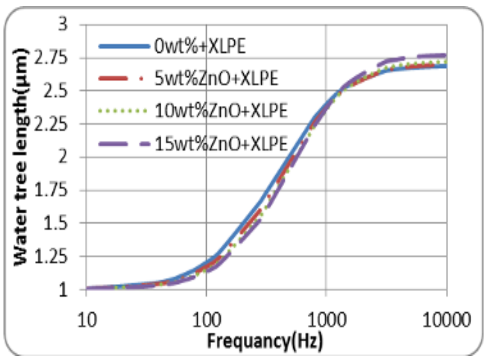


Fig. (2.b)

Figure (2.c) shows the effect of ZnO nanoparticles on the rate of void radius with varying field strength insulation, it is cleared that increasing percentage of ZnO nanoparticles in the XLPE matrix decreases the rate of void radius. Figure (2.d) shows the effect of ZnO nanoparticles on the rate of void radius with varying frequency. Also, it is cleared that increasing percentage of ZnO nanoparticles in the XLPE matrix hasn't change the rate of void radius up to 2 kHz, but increasing ZnO nanoparticles increases the rate of void radius more than 2 kHz.

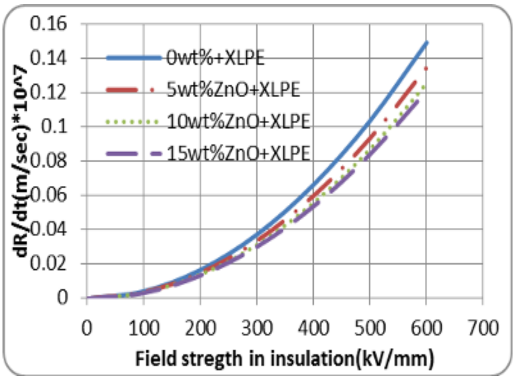


Fig. (2.c)

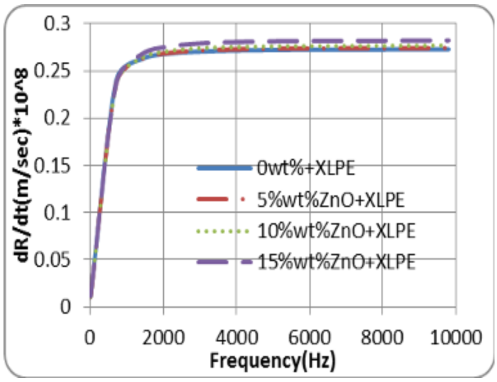


Fig. (2.d)

Figure (2.e) shows the effect of ZnO nanoparticles on the pressure of water in micro-void due to mechanical stress in XLPE with varying field strength insulation, it is cleared that increasing percentage of ZnO nanoparticles in the XLPE matrix decreases the rate of void radius. Figure (2.f) shows the effect of ZnO nanoparticles on the pressure of water in micro-void due to mechanical stress in XLPE. Also, it is cleared that increasing percentage of ZnO nanoparticles in the XLPE matrix hasn't change the rate of void radius up to 1 kHz, but increasing ZnO nanoparticles decreases the pressure of water in micro-void due to mechanical stress in XLPE more than 1 kHz.

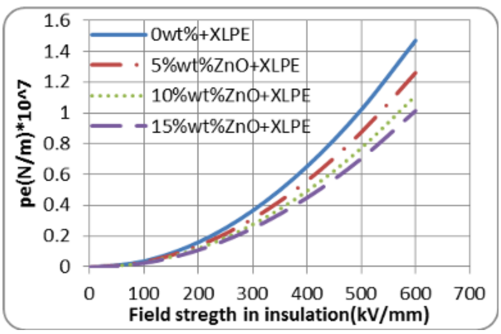


Fig. (2.e)

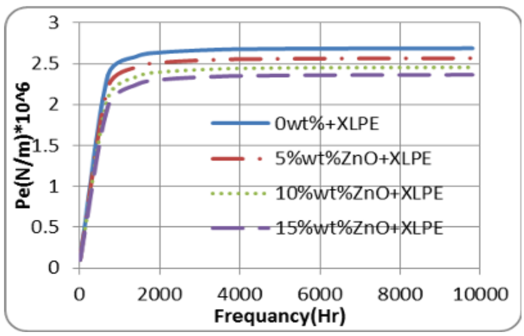
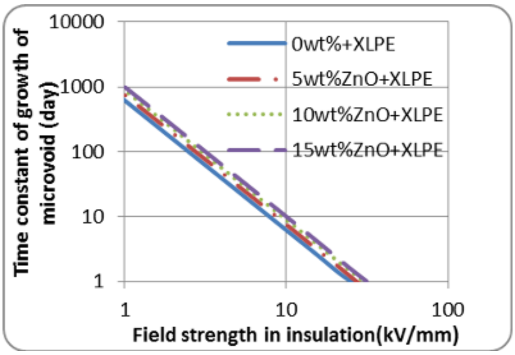


Fig. (2.f)

Figure (2.g) shows the effect of ZnO nanoparticles on the time constant of growth of micro void in XLPE with varying field strength insulation, it is cleared that increasing percentage of ZnO nanoparticles in the XLPE matrix increases the time constant of growth of micro void. Figure (2.h) shows the effect of ZnO nanoparticles on the time constant of growth of micro void in XLPE. Also, it is cleared that increasing percentage of ZnO nanoparticles in the XLPE matrix has small changes in the time constant of growth of micro void in XLPE up to 1 kHz, but there is nochanges on the time constant of growth of micro void in XLPE by increasing ZnO nanoparticles more than 1 kHz. Finally, figure (2.i) shows the effect of ZnO nanoparticles on the water tree length with time, it is cleared that the water tree length increases with increasing time but increasing percentage of ZnO nanoparticles in the XLPE matrix decreases the time constant of growth of micro void.



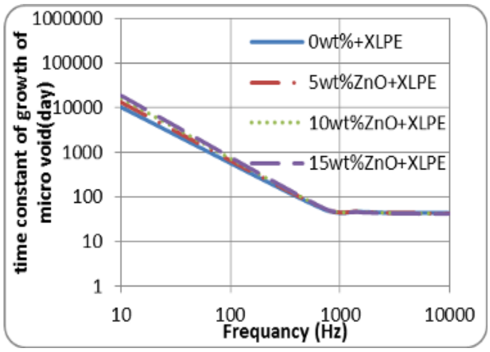


Fig. (2.g) Fig. (2.h)

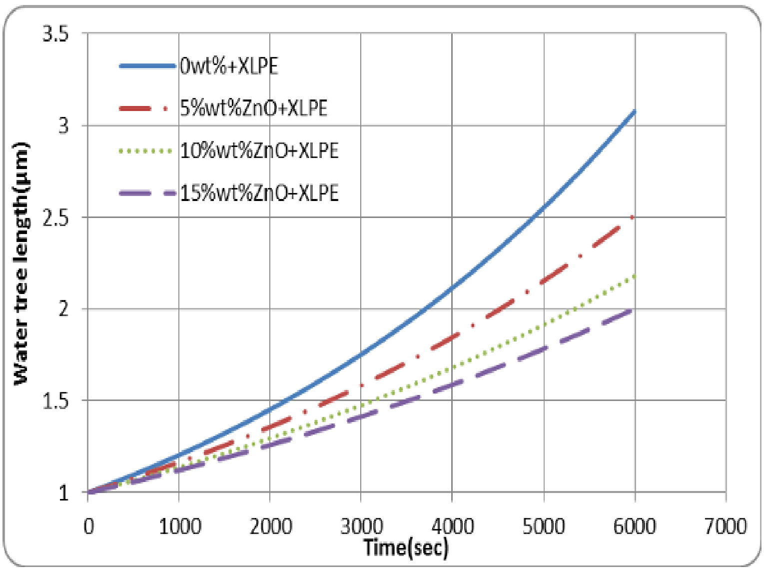


Fig. 2 Effects of ZnO nanoparticles concentration on water tree characteristics in XLPE

4.2. Effect of Al2O3 nanoparticles on water treeing characteristics in Cross-Linked Polyethylene

Figures ((3.a) - (3.h)) illustrate the water tree length, the rate of void radius, the pressure of water in micro-void due to mechanical stress in XLPE, and the time constant of growth of micro void respectively for pure XLPE and various nanocomposites of (5%wt Al_2O_3+ XLPE, 10%wt Al_2O_3+ XLPE, and 15%wt Al_2O_3+ XLPE) with varying electric field strength and frequency. Also, it has been described the characteristics of water tree length with the time for pure XLPE and various nanocomposites of (5%wt Al_2O_3+ XLPE, 10%wt Al_2O_3+ XLPE, and 15%wt Al_2O_3+ XLPE) as shown in figure (3.i).

Figure (3.a) shows the effect of Al2O3 nanoparticles on the water tree length with varying field strength insulation, it is cleared that increasing percentage of Al_2O_3 nanoparticles in the XLPE matrix increases the water tree length. Figure (3.b) shows the effect of Al_2O_3 nanoparticles on the water tree length with varying frequency. Also, it is cleared that increasing percentage of Al2O3 nanoparticles in the XLPE matrix increases the water tree length up to 10 kHz.

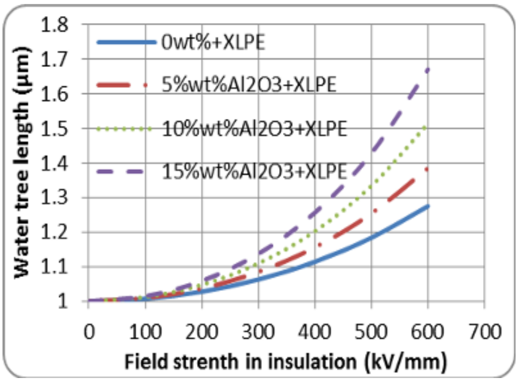


Fig. (3.a)

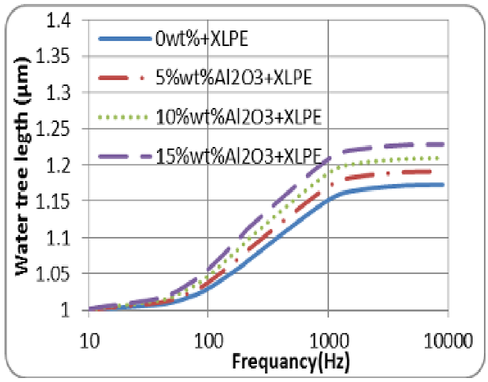


Fig. (3.b)

Figure (3.c) shows the effect of Al_2O_3 nanoparticles on the rate of void radius with varying field strength insulation, it is cleared that increasing percentage of Al_2O_3 nanoparticles in the XLPE matrix increases the rate of void radius. Figure (3.d) shows the effect of Al_2O_3 nanoparticles on the rate of void radius with varying frequency. Also, it is cleared that increasing percentage of Al_2O_3 nanoparticles in the XLPE matrix increases the rate of void radius up to 10 kHz.

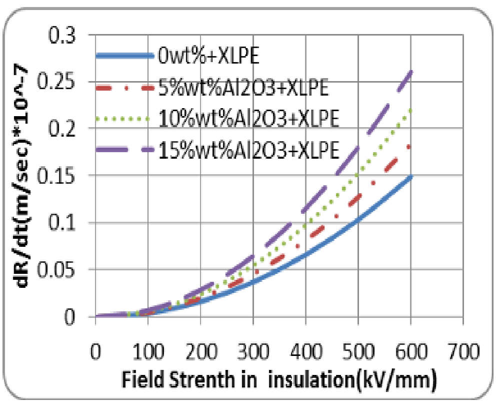


Fig. (3.c)

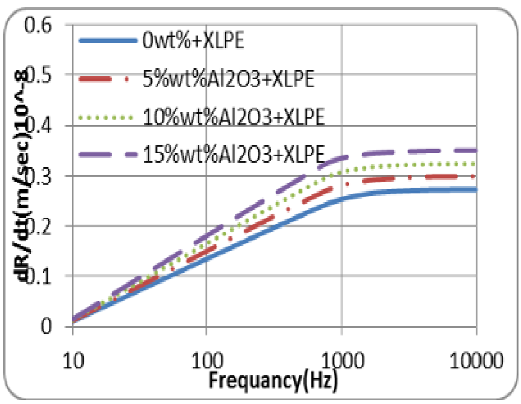


Fig. (3.d)

Figure (3.e) shows the effect of Al_2O_3 nanoparticles on the pressure of water in micro-void due to mechanical stress in XLPE with varying field strength insulation, it is cleared that increasing percentage of Al_2O_3 nanoparticles in the XLPE matrix increases the rate of void radius.

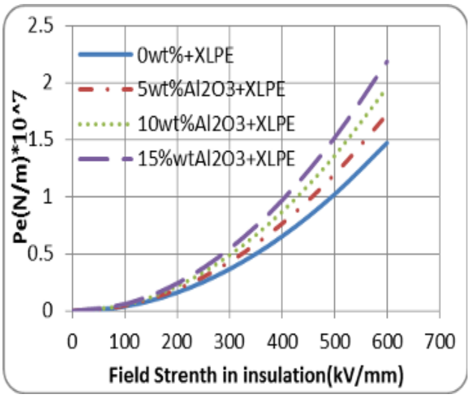


Fig. (3.e)

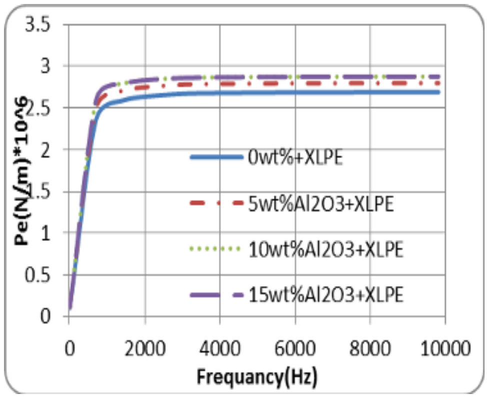


Fig. (3.f)

Figure (3.f) shows the effect of Al_2O_3 nanoparticles on the pressure of water in micro-void due to mechanical stress in XLPE. Also, it is cleared that increasing percentage of Al_2O_3 nanoparticles in the XLPE matrix hasn't change the rate of void radius up to 1 kHz, but increasing Al_2O_3 nanoparticles decreases the pressure of water in micro-void due to mechanical stress in XLPE more than 1 kHz. Figure (3.g) shows the effect of Al_2O_3 nanoparticles on the time constant of growth of micro void in XLPE with varying field strength insulation, it is cleared that increasing percentage of Al_2O_3 nanoparticles in the XLPE matrix decreases the time constant of growth of micro void. Figure (3.h) shows the effect of Al_2O_3 nanoparticles on the time constant of growth of micro void in XLPE. Also, it is cleared that increasing percentage of Al_2O_3 nanoparticles in the XLPE matrix decreasing in the time constant of growth of micro void in XLPE up to 1 kHz, but there is small changes on the time constant of growth of micro void in XLPE by increasing ZnO nanoparticles more than 1 kHz.

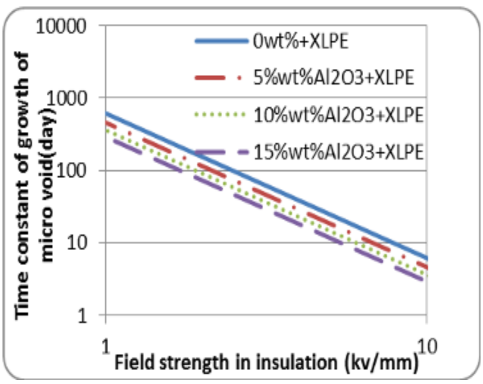


Fig. (3.g)

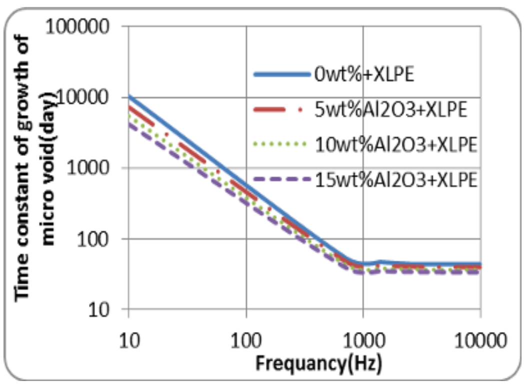


Fig. (3.h)

Finally, figure (3.i) shows the effect of Al_2O_3 nanoparticles on the water tree length with time, it is cleared that the water tree length increases with increasing time but increasing percentage of Al_2O_3 nanoparticles in the XLPE matrix increases the time constant of growth of micro void.

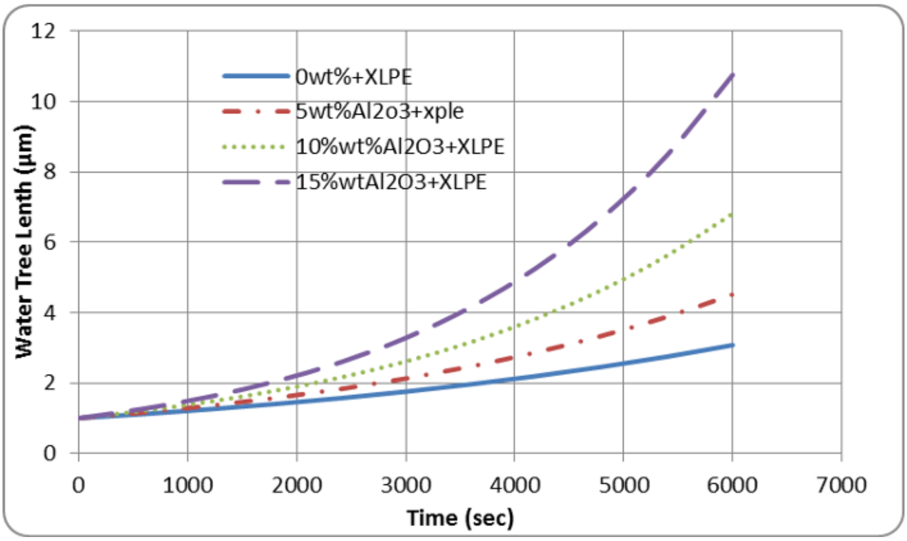


Fig. (3.i)2.i

Fig. 3 Effects of Al_2O_3 nanoparticles concentration on water tree characteristics in XLPE

4.3. Comparison between water treeing characteristics of pure and nanocomposite insulation materials

This section depicts a comparison between effects of ZnO and Al_2O_3 nanoparticles on the water treeing characteristics on XLPE industrial insulating materials. The comparison shows that effects of ZnO and Al_2O_3 nanoparticles on the water tree length, the rate of void radius, the pressure of water in micro-void due to mechanical stress in XLPE, the time constant of growth of micro void, of water tree length with the time. All these characteristics will be described as follows:

4.3.1 Effect of nanoparticles on water tree length in XLPE

Figure (4) shows the relationship between the water tree length and field strength of insulation and frequency for various studied insulation materials (PURE XLPE, 15%wt ZnO + XLPE, and 15%wt Al_2O_3 + XLPE). Figure (4.a) shows that the water tree length increases with increasing field strength of insulation. Also, in the same figure (4.a), it has been shown that adding ZnO nanoparticles in the XLPE matrix decreases the water tree length but adding Al_2O_3 increases the water tree length. Figure (4.b) shows that the water tree length increases with increasing frequency. And, it has been shown that adding Al_2O_3 increases the water tree length but adding ZnO nanoparticles in the XLPE matrix decreases the water tree length up to 1 kHz small values, then, there is a small increasing more than 1kHz.

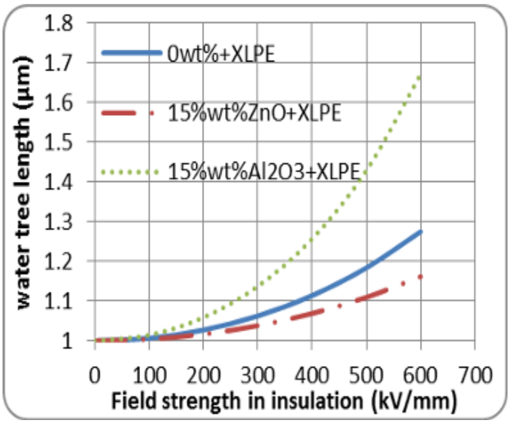


Fig. (4.a)

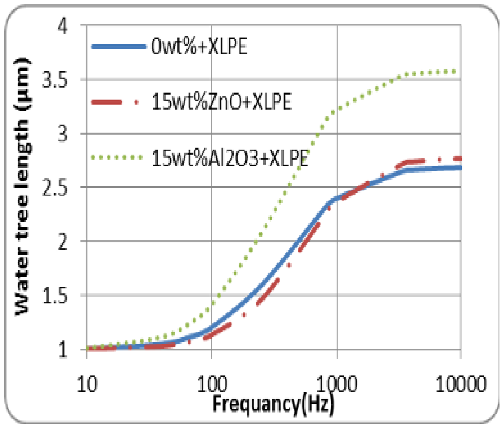


Fig. (4.b)

Fig. 4 Effects of nanoparticles on water tree characteristics in XLPE

4.3.2 Effect of nanoparticles on the rate of void radius in XLPE

Figure (5) shows the relationship between the rate of void radius and field strength of insulation and frequency for various studied insulation materials (PURE XLPE, 15%wt ZnO + XLPE, and 15%wt Al_2O_3 + XLPE). Figure (5.a) shows that the rate of void radius increases with increasing field strength of insulation. Also, in the same figure (5.a), it has been shown that adding ZnO nanoparticles in the XLPE matrix decreases the rate of void radius but adding Al_2O_3 increases the rate of void radius. Figure (5.b) shows that the rate of void radius increases with increasing frequency up to 1 kHz, after that the rate of void radius will be constant. And, it has been shown that there is high increasing in the rate of void radius by adding Al_2O_3 in XLPE but there are small changes in the rate of void radius by adding ZnO nanoparticles in the XLPE matrix.

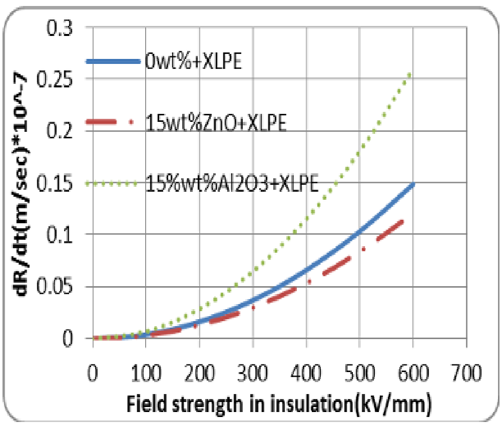


Fig. (5.a)

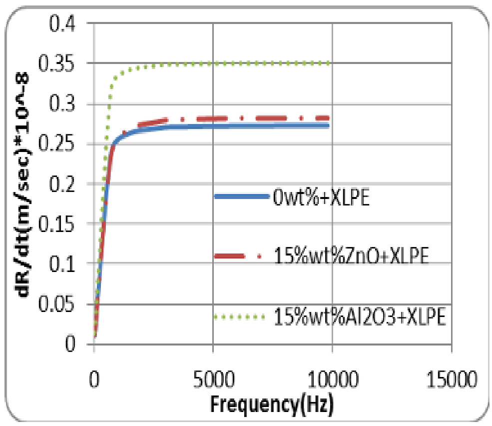


Fig. (5.b)

Fig. 5 Effects of nanoparticles on the rate of void radius characteristics in XLPE

4.3.3 Effect of nanoparticles on the pressure of water in micro-void due to mechanical stress in XLPE

Figure (6) shows the relationship between the pressure of water in micro-void due to mechanical stress in XLPE and field strength of insulation and frequency for various studied insulation materials (PURE XLPE, 15%wt ZnO + XLPE, and 15%wt Al2O3 + XLPE). Figure (6.a) shows that the pressure of water in micro-void due to mechanical stress in XLPE increases with increasing field strength of insulation. Also, in the same figure (6.a), it has been shown that adding ZnO nanoparticles in the XLPE matrix decreases the pressure of water in micro-void due to mechanical stress but adding Al_2O_3 increases the pressure of water in micro-void due to mechanical stress in XLPE. Figure (6.b) shows that the pressure of water in micro-void due to mechanical stress in XLPE increases with increasing frequency up to 1 kHz small values, then, the pressure of water in micro-void due to mechanical stress has been constant. And, it has been shown that adding Al_2O_3 increases the pressure of water in micro-void due to mechanical stress in XLPE but adding ZnO nanoparticles in the XLPE matrix decreases the pressure of water in micro-void due to mechanical stress in XLPE.

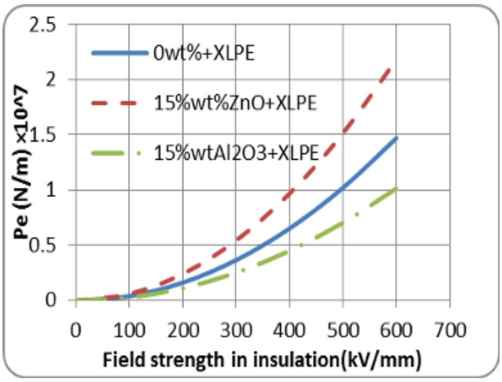


Fig. (6.a)

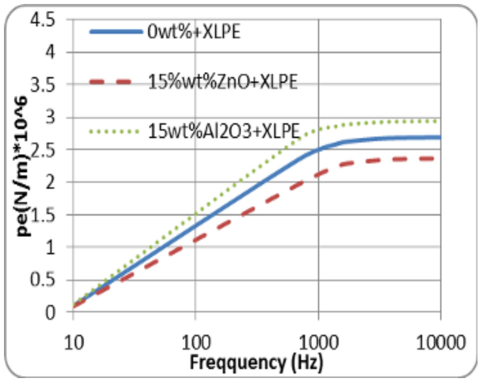


Fig. (6.b)

Fig. 6 Effects of nanoparticles on the pressure of water in micro-void due to mechanical stress in XLPE

4.3.4 Effect of nanoparticles on the time constant of growth of micro void in XLPE

Figure (7) shows the relationship between the time constant of growth of micro void in XLPE and field strength of insulation and frequency for various studied insulation materials (PURE XLPE, 15%wt ZnO + XLPE, and 15%wt Al2O3 + XLPE). Figure (7.a) shows that the time constant of growth of micro void in XLPE decreases with increasing field strength of insulation. Also, in the same figure (7.a), it has been shown that adding ZnO nanoparticles in the XLPE matrix increases the time constant of growth of micro void but adding Al_2O_3 decreases the time constant of growth of micro void in XLPE. Figure (7.b) shows that the time constant of growth of micro void in XLPE decreases with increasing frequency up to 1 kHz, then, the time constant of growth of micro void in XLPE still constant for more than 1 kHz. And, it has been shown that adding Al_2O_3 decreases the time constant of growth of micro void in XLPE but adding ZnO nanoparticles in the XLPE matrix increases the time constant of growth of micro void in XLPE.

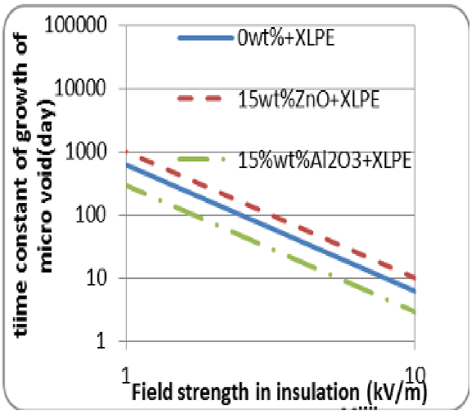


Fig. (7.a)

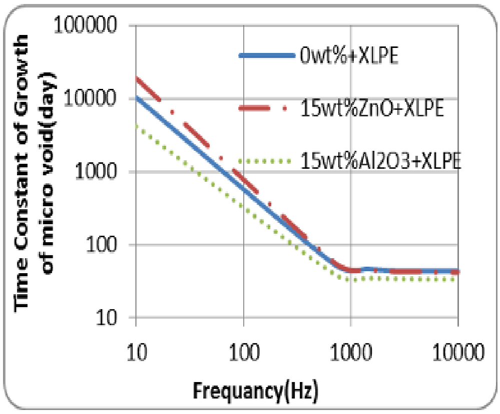


Fig. (7.b)

Fig. 7 Effects of nanoparticles on the time constant of growth of micro void in XLPE

4.3.5 Effect of nanoparticles on time of water tree length in XLPE

Figure (8) shows the relationship between the water tree length and time for various studied insulation materials (PURE XLPE, 15%wt ZnO + XLPE, and 15%wt Al_2O_3 + XLPE). It has been shown that the time of water tree length in XLPE increases and, adding ZnO nanoparticles in the XLPE matrix decreases the water tree length but adding Al_2O_3 increases the water tree length in XLPE.

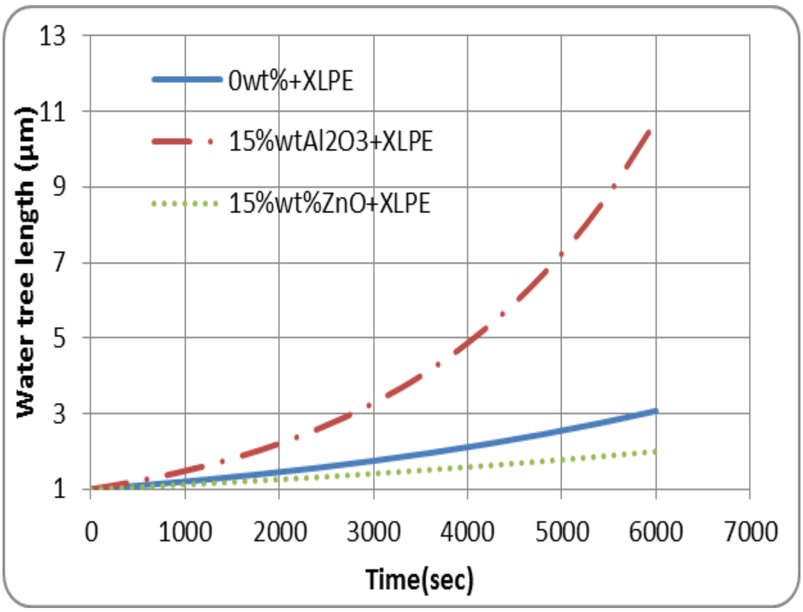


Fig. 8 Effects of nanoparticles on the time of water tree length in XLPE

5. CONCLUSIONS

- Adding ZnO nanoparticles in the XLPE matrix decreases the water tree length, rate of void radius, and the pressure of water in micro-void due to mechanical stress in XLPE, but increasing percentage of ZnO nanoparticles in the XLPE matrix increases the time constant of growth of micro void in XLPE.
- Adding Al_2O_3 nanoparticles in the XLPE matrix increases the water tree length, rate of void radius, and the pressure of water in micro-void due to mechanical stress in XLPE, but increasing percentage of Al_2O_3 nanoparticles in the XLPE matrix decreases the time constant of growth of micro void in XLPE.
- It can be controlled in the dielectric properties up or down according to types and percentage of nanoparticles which add to the pure industrial insulation materials.

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تأثير حبيبات متناهية فى الصغر على سلوك التشجير المائى فى المواد العازلة الصناعية XLPE

التشجير المائى لايزال حتى الان واحد من الاسباب الرئيسية فى انهيار الكابلات ويعرف كذلك التشجير المائى بأنة المسئول فى تقليل العمر الخدمى لبوليمرات الكابلات. فقد تمت فى هذا البحث دراسة التأثيرات فى اضافة مختلف الكميات من الحبيبات المتناهية فى الصغر مثل أكسيد الزنك وأكسيد الالومنيوم على سلوك التشجير المائى فى المواد العازلة الصناعية كروس لينك بولى اثيلين (XLPE). فهذا البحث يركز على دراسة تطوير أداء المواد المركبة فى نمو التشجير المائى من تأثير الحبيبات المتناهية فى الصغر عن المواد الخالية منها. وكذلك فقد تم دراسة تاثير نسبة حجم الحبيبات المتناهية فى الصغر على طول التشجير المائى عند مختلف الترددات و الاجهاد ات الكهربية. وأخيرا فان هذا البحث يهدف الى تقديم دراسة مقارنة منهجية عن تأثير اضافة الحبيبات المتناهية فى الصغر على تغيير خواص العزل الكهربية وتفهم قاعدة تأثير هذة الحبيبات على مواد العزل الصناعية فى تحسين مقاومة التشجير المائى والعمر الزمنى للعزل وتقليل طول التشجير المائى فى المواد العازلة الصناعية.

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Ahmed Thabet was born in Aswan, Egypt in 1974. He received the BSc (HIE) Electrical Engineering degree in 1997, and MSc (HIE) Electrical Engineering degree in 2002 both from High Institute of Energy, 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 High Institute of Energy in South Valley University as a Demonstrator, Lecture, and as Assistant Professor from 1999 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. A lot of mobility's has 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.ghson.net/FOLDERS_INDEX/nano/index.htm). He has more than 55 publications which have been published and under published in IEEE journals and conferences and held in Nano-Technology Research Centre website (http://www.ghson.net/FOLDERS_INDEX/nano/dr_athabet.htm).