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Modern Electrical Insulations for Power Cables Using Multi-nanoparticles Technique

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Abstract: This paper presents an investigation on the enhancement of electrical insulations of power cables materials using a new multi-nanoparticles technique. It has been studied the effect of adding specified types and concentrations of nanoparticles to polymeric materials such as XLPE for controlling on electric and dielectric performance. Prediction of effective dielectric constant has been done for the new nanocomposites based on Interphase Power Law (IPL) model. The multi-nanoparticles technique has been succeeded for enhancing electric and dielectric performance of power cables insulation compared with adding individual nanoparticles. Finally, it has been investigated on electric field distribution in the new proposed modern insulations for three-phase core belted power cables.

Keywords: Nanoparticles, nanocomposites, effective dielectric constant, interphase, electrostatic field.

1. Introduction

Nanotechnology science reinforced properties of tradition industrial polymers such as optical, electrical and dielectric properties. The improvements in dielectric properties of polymeric nanocomposites have enhanced insulation power cables and general/industrial applications. Among many high technological manufacture products, polymer nanocomposites are one of vital technologies in engineering science for exhibiting superior properties. Several approaches are used to modify properties of polymeric nanocomposites different industries applications [1, 2]. Cross-linked polyethylene (XLPE) has been created by thermochemical action; the benefit of cross-linking is to inhibit the movement of molecules with respect to each other for enhancing stability at various temperatures compared with the thermoplastic materials. This action permits higher operating temperatures and current rating than polyvinyl chloride. Nanotechnology science gives polymer matrix a reduction in the values of effective permittivity as nanocomposites materials [3-10]. Nowadays, electric and dielectric properties of power cables insulation materials can be controlled using nanotechnology techniques under various thermal conditions [11-21]. This paper explains novel industrial materials with enhanced dielectric characteristics of new multi-nanocomposites industrial materials by Interphase Power Law (IPL) model. The proposed model takes into account interactions between the components of multi-nanocomposites system in the form of interphase regions. The dielectric characteristics of the interphase region have been explored on new industrial materials based on individual and multi-nanocomposites. Also, this paper discusses the electrostatic field distribution in the new modern dielectric insulations of three-core belted power cables based on charge simulation method (CSM). Also, this research success for specifying optimal arrangements of variant types of multi-nanoparticles for enhancing polymeric power cables insulations.

2. Recent Followed Models

A. *Multiple Nanocomposite Insulation Materials Technique*

Maxwell-Garnett dilute concentration solution for the dielectric constant has been explained

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For an inhomogeneous interphase region surrounding each inclusion. Power law relationships used in dielectric modeling of composite systems [22-24]. The determination of the interphase thickness for individual polymeric nanocomposites is further described in detail in [25-28]; whatever, the interphase region of new polymeric multi-nanocomposites has been illustrated in Figure.1. In multi-nanoparticles technique, reduction in the effective interphase volume fraction has been considered many times from nearby of multi-nanoparticles together and the overlap of interphase regions surrounding each nanoparticle. Approximations have been developed to estimate the overlap of such particles using analytical solutions to percolation models [29, 30].

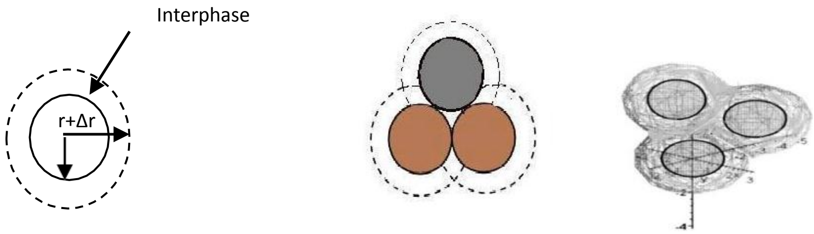

Figure 1. Interphase region surrounding the filler particles in multi-nanocomposites system

B. Electric Field Distribution in Three-Phase Core Belted Power Cables

The distribution of the electric field in a three-core cable is very important for the proper design and the safe operation of power cables. Theoretical model has been detected maximum high voltage stresses for new insulated three core pelted power cables. In case of using individual or multiple nanoparticles techniques inside polymer matrix, power law relationships used in dielectric modeling of composite systems; the composite system have three components (matrix, interphase region and nanoparticles). There are various techniques have been done to make the calculations of the electric field in the three-core belted power cables for determining the stress in cables [31-36]. This paper applied the calculations of the electric field in three-core belted cables by using the best charge simulation technique which uses less number of charges and gives small errors and high degree of accuracy achieved [36]. The electrostatic field distribution in insulation material has been studied within various solid insulation nanocomposites and multi-nanocomposites around cable conductor whenever, the eight points which shown in Figure 2

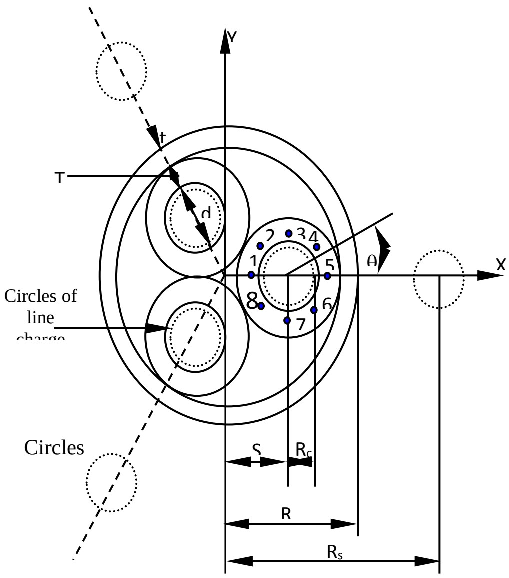

Figure 2. Cable configuration its coordinate axis

insulation materials. Using multi-nanoparticle technique can be changing the arrangement of nanoparticles; hence, controlling of dielectric insulation is more easy and efficient as shown graphically.

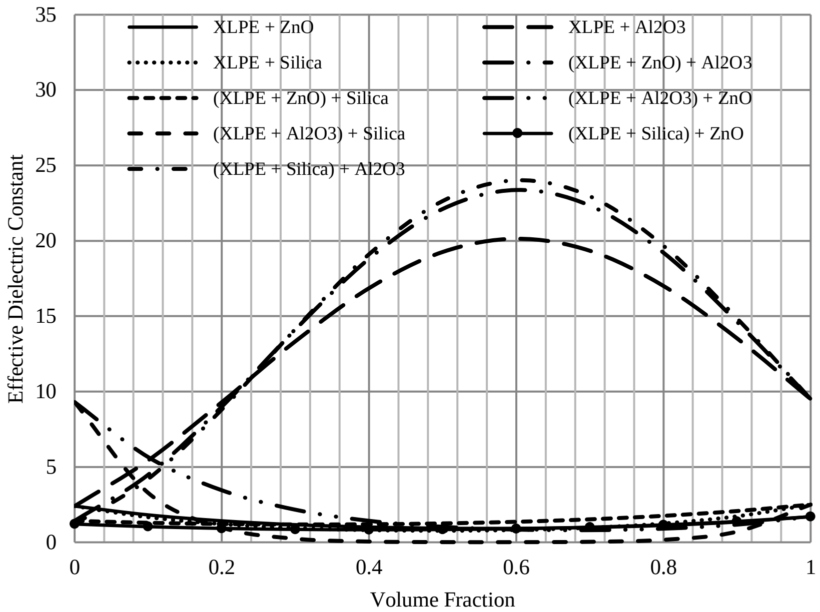

Figure 3. Effect of ZnO, Silica and Alumina on effective dielectric constant of XLPE

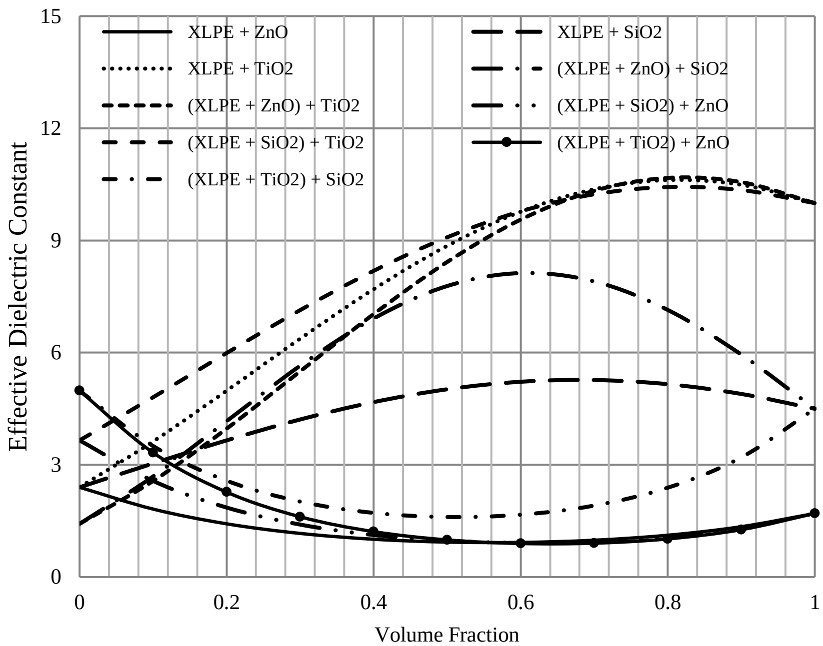

Figure 4. Effect of ZnO, SiO2 and TiO2 on effective dielectric constant of XLPE

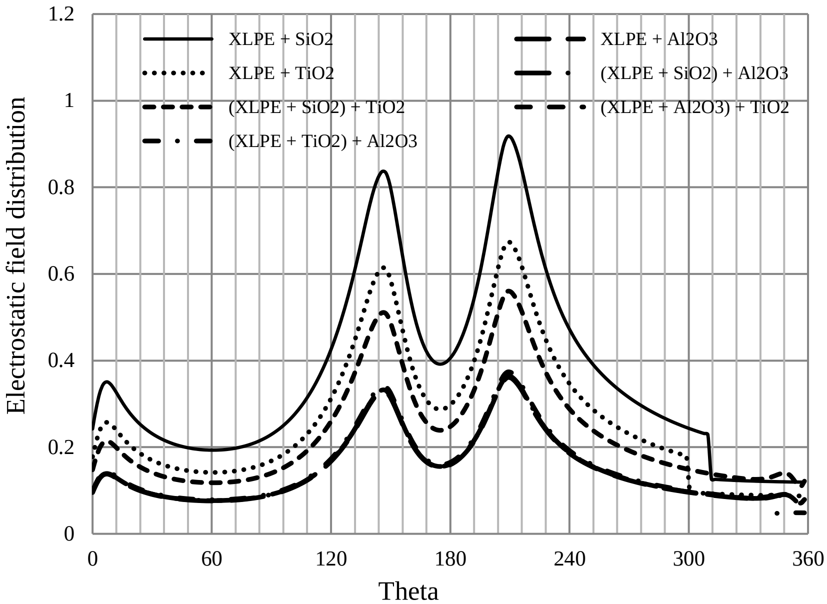

Figure 7. Effect of TiO_2, SiO_2 and Al_2O_3 on electric field distribution in Three-phase core belted power cables

5. Trends of Polymeric Multi-nanocomposites

Multi-nanoparticles technique has been investigated the best new trends for enhancing the effective dielectric constant with respect to using individual nanoparticles; therefore, the new nanocomposites should be having multi- nanoparticles for enhancing the effective dielectric constant of base matrix dielectric material. Arrangement and concentrations of nanoparticles in polymeric base matrix are controlling in dielectric characterization. The proposed study on electric field distribution in the new modern insulations of three-phase core belted power cables shows that multi-nanoparticles technique is more efficient for controlling on electric field distribution in insulation of three-core belted power cables.

6. Conclusions

- Individual nanoparticles like, Clay, ZnO, and Silica are interested in decreasing the effective dielectric constant of polymeric insulation. Whatever, SiO_2, MgO, TiO_2, and Alumina have interested in increasing dielectric characterization. The use of multiple nanoparticles is more efficient for controlling both dielectric properties and physical properties of power cables materials.
- Electric field distribution inside insulation materials of three core belted power cables has been enhanced by using individual and is controlled by using multi-nanoparticles technique.
- The arrangement position of nanoparticles (Clay, ZnO, Silica, SiO_2, and TiO_2) inside host matrix is an efficient parameter for controlling in the effective dielectric constant of multi-nanocomposites.

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[17]. A.A. Ebnalwaled, and A. Thabet, “Controlling the optical constants of PVC nanocomposite films for optoelectronic applications”, *Synthetic Metals Journal* Vol. 220, pp. 374–383, July, 2016.
[18]. A. Thabet, and Y. A. Mubarak “Thermal Experiment Analysis for Dielectric Characterization of High Density Polyethylene Nanocomposites” *Advances in Electrical and Electronic Engineering Journal*, Vol.14, No.3, pp. 295-303, Sept., 2016.
[19]. A. Thabet, and Y. A. Mubarak “Experimental Enhancement for Electric Properties of Polyethylene Nanocomposites under Thermal Conditions” *Advances in Electrical and Electronic Engineering Journal*, Vol.15, No.1, pp. 55-62, March, 2017.
[20]. A. Thabet,” Theoretical Analysis for effects of nanoparticles on dielectric characterization of electrical industrial materials”, *Electrical Engineering (ELEN) Journal*, Springer, Vol. 99, Iss. 2, pp 487–493, June 2017.
[21]. A Thabet, and Y. A. Mubarak,” The Effect of Cost-Fewer Nanoparticles on the Electrical Properties of Polyvinyl Chloride”, *Electrical Engineering Journal*, Springer, Vol. 99, Iss. 2, pp 625–631, June 2017.
[22]. O. Gouda, Y. A. Mobarak, and M. Samir, “A Simulation Model for Calculating the Dielectric properties of Nano-Composite Materials and Comprehensive Interphase Approach” *14th International Middle East Power Systems Conference (MEPCON)*, Cairo University, Egypt, pp. 151-156., Dec. 2010.
[23]. K. K. Karkkainen, A. H. Sihvola and K. I. Nikoskinen, “Effective Permittivity of Mixtures: Numerical Validation by the FDTD Metho”, *IEEE Trans. Geoscience Remote Sensing*, Vol. 38, pp. 1303-1308, 2000.
[24]. M. Todd and F. Shi, “Molecular Basis of the Interphase Dielectric Properties of Microelectronic and Optoelectronic Packaging Materials”, *IEEE Trans. Components Packaging Techn*., Vol. 26, No. 3, pp. 667-672, 2003.
[25]. Polizos, Georgios Tuncer, Enis Sauers, Isidor More, Karren L., "Properties of a Nanodielectric Cryogenic Resin", *Applied Physics Letter*, Vol. 96, Issue 15, pp.152903-152903-3, 2010.
[26]. Tagami, N. Hyuga, M. Ohki, Y. Tanaka, T. Imai, T. Harada, M. Ochi, M., "Comparison of Dielectric Properties between Epoxy Composites with Nanosized Clay Fillers Modified by Primary Amine and Tertiary Amine" *IEEE Dielectrics and Electrical Insulation Transactions*, Vol. 17 Issue: 1, pp. 214-220, 2010.
[27]. M. Todd and F. Shi, “Characterizing the Interphase Dielectric Constant of Polymer Composite Materials: Effect of Chemical Coupling Agents”, *J. Appl. Phys*., Vol. 94, pp. 4551-4557, 2003.
[28]. Y. Yi and M. Sastry, “Analytical Approximation of the Two Dimensional Percolation Threshold for Fields of Overlapping Ellipses”, *Phys. Rev*. E, Vol. 66, pp. 2002.
[29]. X. Jing, W. Zhao and L. Lan, “The Effect of Particle Size on Electric Conducting Percolation Threshold in Polymerr Conducting Particle Composites”, *J. Mat. Sci. Letts*., Vol. 19, pp. 377-379, 2000.
[30]. C. Brosseau, P. Queffelec and P. Talbot, “Microwave Characterization of Filled Polymers”, *J. App. Phys*., Vol. 89, pp. 4532-4540, 2001.
[31]. A. M. Mahdy, “Evaluation of human exposure to 50Hz electric field” PhD. thesis, Cairo University, 1988.
[32]. A. Nosseir and A. A. Zaky, “Representation of three-core cables using line charge simulation” *IEEE Transactions on Electrical Insulation*, Vol.14, pp207-210, August.1979.
[33]. M. M. A. Salama, A. Nosseir, R. Hackam, A. Soliman, and T. El-Shieekh, “Methods of calculations of field stresses in a three-core power cable” *IEEE Transactions on PAS*, Vol.PAS-103, No.12, Dec.1984.
[34]. N. H. M.alik, and A. A. Al-Arainy, “Charge simulation modeling of three-core belted cables” *IEEE Transactions on Electrical Insulation*, Vol.20, No.3, Feb.1985, pp499-503.