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
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].

![Interphase region surrounding the filler particles in multi-nanocomposites system](image)

**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 belted 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

![Cable configuration its coordinate axis](image)

**Figure 2.** Cable configuration its coordinate axis
can be located within the thickness of solid insulation materials. The values of the charges can be obtained as follows:

\[ [P]_{mxn} [Q] = [V]_n \]  

(1)

Where, \([P]\) is the potential coefficient matrix, \([Q]\) is the column vector of values of the unknown charges, \([V]\) is the potential of the boundary points, and \(n\) is the number of simulating charges.

It is assumed that the potential and field don’t vary in z-direction and therefore, the infinite line charges are used for simulation. It can be estimated the electrostatic field at any point \((x_k, y_k)\) within solid insulation materials (pure, or nanocomposites, or multi-nanocomposites) and around the cable conductor as follows:

\[
E_x = \sum_{i=1}^{NT} \left( \frac{q_i}{2\pi \varepsilon_0 \varepsilon} \right) \frac{y_k - y_i}{|D_{ij}|^2} 
\]

(2)

\[
E_y = \sum_{i=1}^{NT} \left( \frac{q_i}{2\pi \varepsilon_0 \varepsilon} \right) \frac{x_k - x_i}{|D_{ij}|^2} 
\]

(3)

Where, \(q_i\) is the charges which stated in conductors and its images

3. Suggested Nano-materials

Clay nanoparticles are used to reduce the density of product [37]. Aluminum Oxide is strong high heat-resistance, very stable, high hardness, high mechanical strength, and electrical insulator. Zinc Oxide (ZnO) is used in paints, coatings, cross linker of rubber and sealants, Magnesium Oxide has high thermal conductivity and low electrical conductivity, whatever, Barium titanate is a dielectric ceramic used for capacitors. Cross-linked polyethylene (XLPE) is the most industrial common form of polymeric insulation for fabrication power cables insulations [39, 40]. Table 1 depicts details numerical analysis for original and new polymeric nanocomposites materials.

Table 1. Physical Properties Of Nanocomposites & Multi-Nanocomposites

<table>
<thead>
<tr>
<th>Nanoparticles</th>
<th>(\varepsilon_r)</th>
<th>Nanocomposites</th>
<th>Multi-Nanocomposites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\varepsilon_r)</td>
<td>Base Matrix</td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>2.0</td>
<td>XLPE</td>
<td>Clay/XLPE</td>
</tr>
<tr>
<td>Silica</td>
<td>2.5</td>
<td>XLPE</td>
<td>Silica/ XLPE</td>
</tr>
<tr>
<td>ZnO</td>
<td>1.7</td>
<td>XLPE</td>
<td>ZnO/ XLPE</td>
</tr>
<tr>
<td>SiO₂</td>
<td>4.5</td>
<td>XLPE</td>
<td>SiO₂/ XLPE</td>
</tr>
<tr>
<td>MgO</td>
<td>9</td>
<td>XLPE</td>
<td>MgO/ XLPE</td>
</tr>
<tr>
<td>TiO₂</td>
<td>10</td>
<td>XLPE</td>
<td>TiO₂/ XLPE</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>9.5</td>
<td>XLPE</td>
<td>Al₂O₃/ XLPE</td>
</tr>
</tbody>
</table>

4. Results and Discussion

This paper discusses the effect of multi-nanoparticles on industrial materials. The effective dielectric constant of the composite system is discussed in current work with multi-nanoparticles, and power cables insulations such as XLPE.

A. Effect of individual and multi-nanoparticles technique on dielectric constant of cross linked polyethylene (XLPE)

As shown in Figure’s (3-5) that show the behavior of effective dielectric constant of XLPE nanocomposites with various volume fractions of nanoparticles. It is obvious that clay, ZnO and silica nanoparticles reduce the dielectric constant of XLPE insulation materials, whatever, TiO₂, and Alumina nanoparticles increases dielectric constant property of XLPE
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 5. Effect of MgO, Silica and TiO$_2$ on effective dielectric constant of XLPE

**B. Electric field distribution in new modern insulations of three-phase core belted power cables**

Figure (6, 7) show the effects of nanoparticles and multiple nanoparticles for changing electrostatic field distribution around cores of three-phase core belted power cables. It is obvious that MgO and SiO$_2$ nanoparticles increases the electric field distribution whatever, TiO$_2$ nanoparticles decreases the electric field distribution. Arrangement of nanoparticles inside multi-nanocomposites is more efficient procedure for controlling in the electric field distribution in insulation of power cables.

![Figure 6. Effect of MgO, SiO$_2$ and TiO$_2$ on electric field distribution in Three-phase core belted power cables](image_url)
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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8. References


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