Performance comparison of selection nanoparticles for insulation of three core belted power cables

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Article Info	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 PVC 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. This research has focused on studying development of PVC nanocomposite materials performance with electric field distribution superior to the unfilled matrix, and has stressed particularly the effect of filler volume fraction on the electric field distribution.

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1. INTRODUCTION

Nanotechnology science reinforced properties of tradition industrial polymers such as optical, electrical and dielectric properties. The composite insulators should be low maintenance cost, limitations in failures and replacements of broken units [1]. The electrical field distribution on insulators string is varied with respect to types of composites materials. There are excessive levels of electric field like audible noise, electromagnetic pollution, partial discharges, and premature aging of insulation. The sensitivity of traditional composite material to the magnitude and duration restricted the developed excessive electrical field [2, 3]. Whatever, the manufacturers are developed high voltage distribution on the insulator string and provide special grading devices with their insulators [4, 5].

Several approaches are used to modify properties of polymeric nanocomposites different industries applications [6, 7]. 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 [8-15]. Nowadays, electric and dielectric properties of power cables insulation materials can be controlled using nanotechnology techniques under various thermal conditions [16-21].

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. THEORETICAL MODEL FOR MULTIPLE NANOMETRIC INSULATION MATERIALS TECHNIQUE

The goal of this paper is to analyze the dielectric constant of new multi-nanocomposites that are formed for enhancing electrical insulation of three core belted power cables. In case of using individual nanoparticles inside polymer matrix, power law relationships used in dielectric modeling of composite systems; the composite system have three components (matrix and nanoparticle) and an interphase region [1, 2]. Furthermore, the interphase region volume fraction is dependent upon the nanoparticle volume fraction, the nanoparticle surface area and the thickness of the interphase region surrounding each nanoparticle particle [3]. Whatever, it has been proposed a multi-nanoparticles technique for developing the electric and dielectric properties of polymer [4]. Thus, the effective dielectric constant of the inclusion and interphase could be expressed as:

$$\varepsilon_E(b) = \frac{\varepsilon_j \ s(b) + T(b)}{\varepsilon_j U(b) + V(b)} \tag{1}$$

Where, ε_j is the dielectric constant of the second nanonanoparticle.
Once it have been found $\varepsilon_j(b)$ for an inhomogeneous interphase between multi-nanoparticles and base polymer matrix, the dielectric constant of the interphase ε_{phij} can be determined as follows:

$$\varepsilon_E(b) = \varepsilon_{phij} + \frac{\left(\frac{a^3}{b^3}\right)}{\frac{1}{\varepsilon_j - \varepsilon_{phij}} + \frac{\left(1 - \frac{a^3}{b^3}\right)}{3\varepsilon_{phij}}} \tag{2}$$

For instance, the value ε_{phij} calculated from Equ. (2) can be used to find the component composite system, as described by:

$$\varepsilon_{effj}^{\beta} = \varphi_j \ \varepsilon_j^{\beta} + \varphi_{phij}\varepsilon_{phij}^{\beta} + \varphi_{effi} \ \varepsilon_{effi}^{\beta} \tag{3}$$

where, φ_j is the volume fraction of second nanoparticle component of the multi-composite system, φ_{phij} is the volume fraction of the interphase region component of the multi-composite system, φ_{effi} is the volume fraction of the initial matrix component of the multi-composite, ε_{effj} is the dielectric permittivity of the multi-composite system. ε_j is the second nanoparticle permittivity of the multi-composite system, ε_{phij} is the interphase permittivity of the multi-composite system, ε_{effi} is the dielectric permittivity of the individual nanocomposites system. The second nanoparticle volume fraction of Equ. (3), φ_j is directly measured for a given composite system. The matrix volume fraction is given by $\varphi_{effi} = (1 - \varphi_j - \varphi_{phij})$. The interphase volume fraction of multi-composite system, φ_{phij}, is calculated by:

$$\varphi_{phij} = (1 - F)\big(S_j \Delta r\big)\rho_j \varphi_j \tag{4}$$

where, S_j is the specific surface area of second nanoparticle (measured in m^2/g), ρ_j is the density of second nanoparticle (measured in g/m^3), Δr is the thickness of the interphase region, F is an overlap probability function. Estimation of interphase thickness is further developed based on ref. [21-25]. Figure 1 shows the nanoparticles come close together, and the interphase regions surrounding each nanoparticle begin to overlap; hence, reducing the effective interphase volume fraction has been occured.
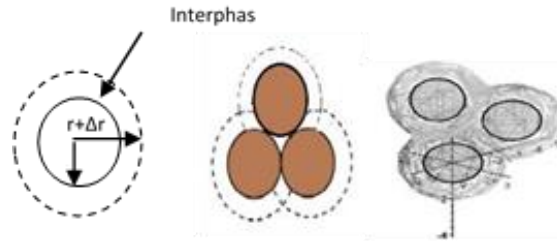
Figure 1. Interphase region surrounding the multi-nanoparticle particles in multi-nanocomposites system

3. ELECTRIC FIELD DISTRIBUTION IN THREE-PHASE CORE BELTED POWER CABLES

Knowledge of the field distribution in three-core belted cables is a practical importance. For a simple physical system, it is usually possible to find an analytical solution for electrostatic field calculations [24]. This paper discusses the electrostatic field distribution in nanocomposites and muliple nanocomposites dielectrics of three-core belted power cables based on charge simulation method (CSM). And so, this paper presents a comparative study with variant dielectric nanocomposites and multiple nanocomposites of three-core belted power cables to reach the beast one withstand AC electrostatic fields. Finally, it can be estimated the electrostatic field at any point (x_k, y_k) within solid insulation nanocomposites or multiple nanocomposites materials and around the cable conductor as follows:-

$$E_x = \sum_{i=1}^{N_T} \left(\left(\frac{q_i}{2\pi\varepsilon_o \tilde{\varepsilon}} \right) \cdot \left(\frac{x_k - x_i}{\left| D_{ij} \right|^2} \right) \right) \tag{6}$$

$$E_y = \sum_{i=1}^{N_T} \left(\left(\frac{q_i}{2\pi\varepsilon_o \tilde{\varepsilon}} \right) \cdot \left(\frac{y_k - y_i}{\left| D_{ij} \right|^2} \right) \right) \tag{7}$$

where, q_i : Charges which stated in conductors and its images

The electrostatic field distribution in insulation material has been studied within various nanocomposites or multiple nanocomposites insulation around cable conductor whenever, the eight points which shown in Figure 2 can be located within the thickness of new solid insulation materials. Physical properties of nanoparticles and polyvinyl chloride are the effective factor for controlling in efifctive nanocomposite and multiple nanocomposite materials [4]. Clay nanoparticles are used to reduce the density of product [12]. Aluminum Oxide is strong high heat-resistance, very s, 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. PVC is the most industrial common form of polymeric insulation for fabrication power cables insulations [10, 15].
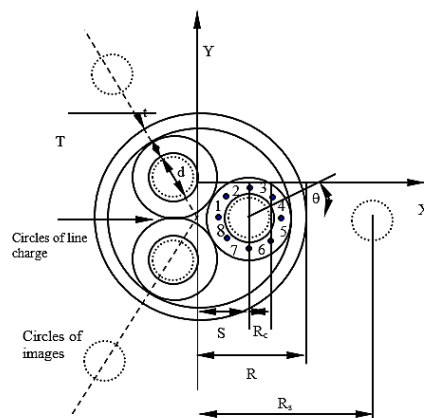

Figure 2. Cable configuration its coordinate axis

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4. RESULTS AND DISCUSSION

This paper discusses the effect of multi-nanoparticles on industrial materials for enhancing electric field distribution of nanocomposite insulation system. The current work discussed the effect of multi-nanoparticles on performance of power cables polyvinyle chloride insulation. Therefore, the aim of this work is reaching to the best nanoparticles and multiple nanoparticles for enhancing electric field distribution in three phase belted power cables.

4.1. Electric field distribution in three core belted cable insulation

This study invistigate the electrostatic field distribution in insulation of power cable (T/D = 1.4) due to individual and multiple nanoparticles. Figure 3 illustrates the electric field distribution in polyvinyl chloride insulation materials with different indvidual or multi-nanocomposite. A characterization of multi-nanocomposite (0.2wt.), PVC appears high electrostatic field distribution due to its low dielectric constant, whatever, a multi-nanocomposite (0.2wt.), PVC has low electrostatic field due to its high dielectric constant and other composite electric distribution graded between the two electrostatic fields levels.
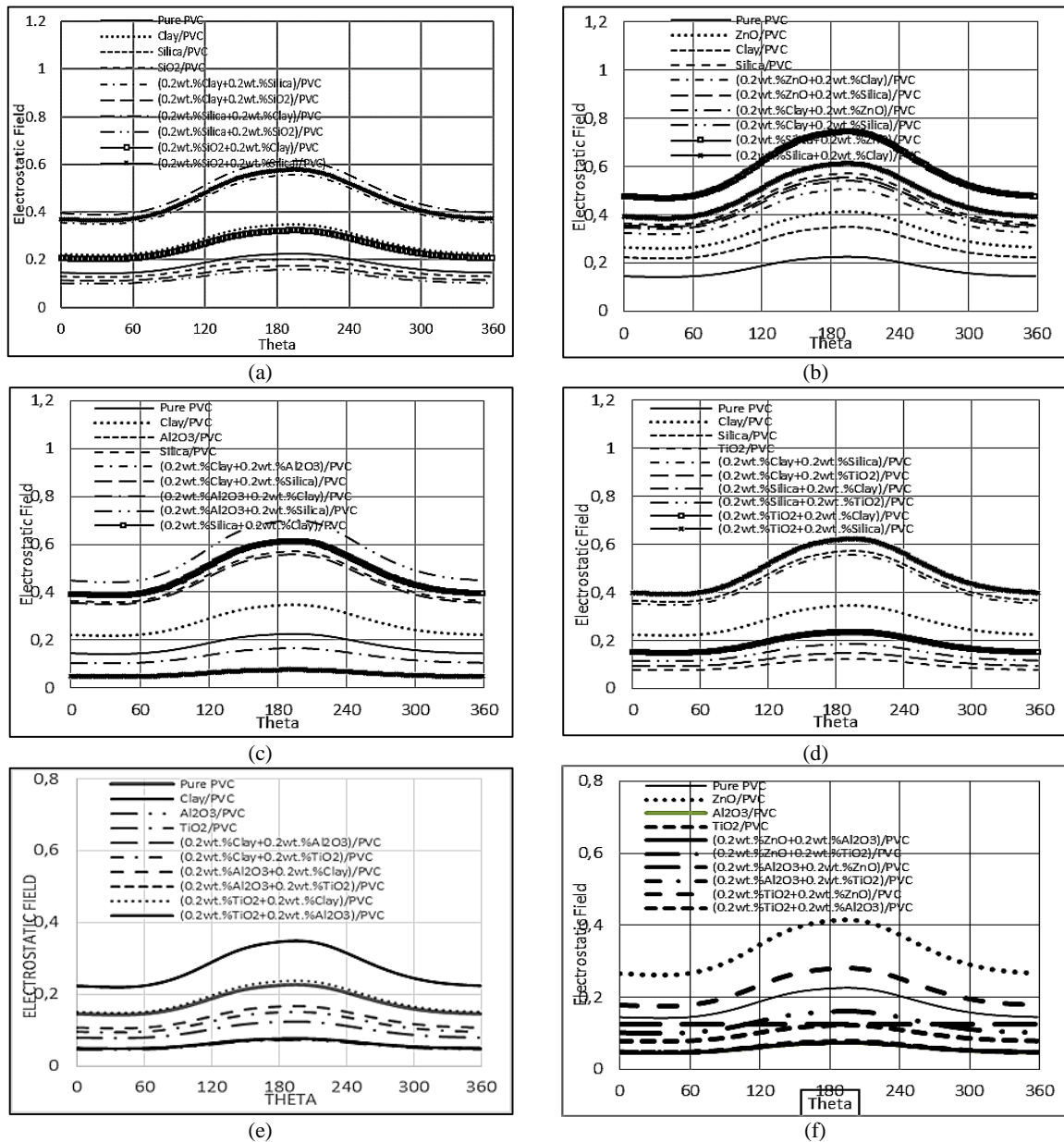

Figure 3. Electrostatic field distribution in insulation of power cable due to individual and multiple nanoparticles: (a) Clay, Silica, and SiO_2; (b) Clay, Silica, and ZnO; (c) Clay, Silica, and Al_2O; (d) Clay, Silica, and TiO_2; (e) Clay, Al_2O_3, and TiO_2; (f) ZnO, $Al2O3$, and TiO_2
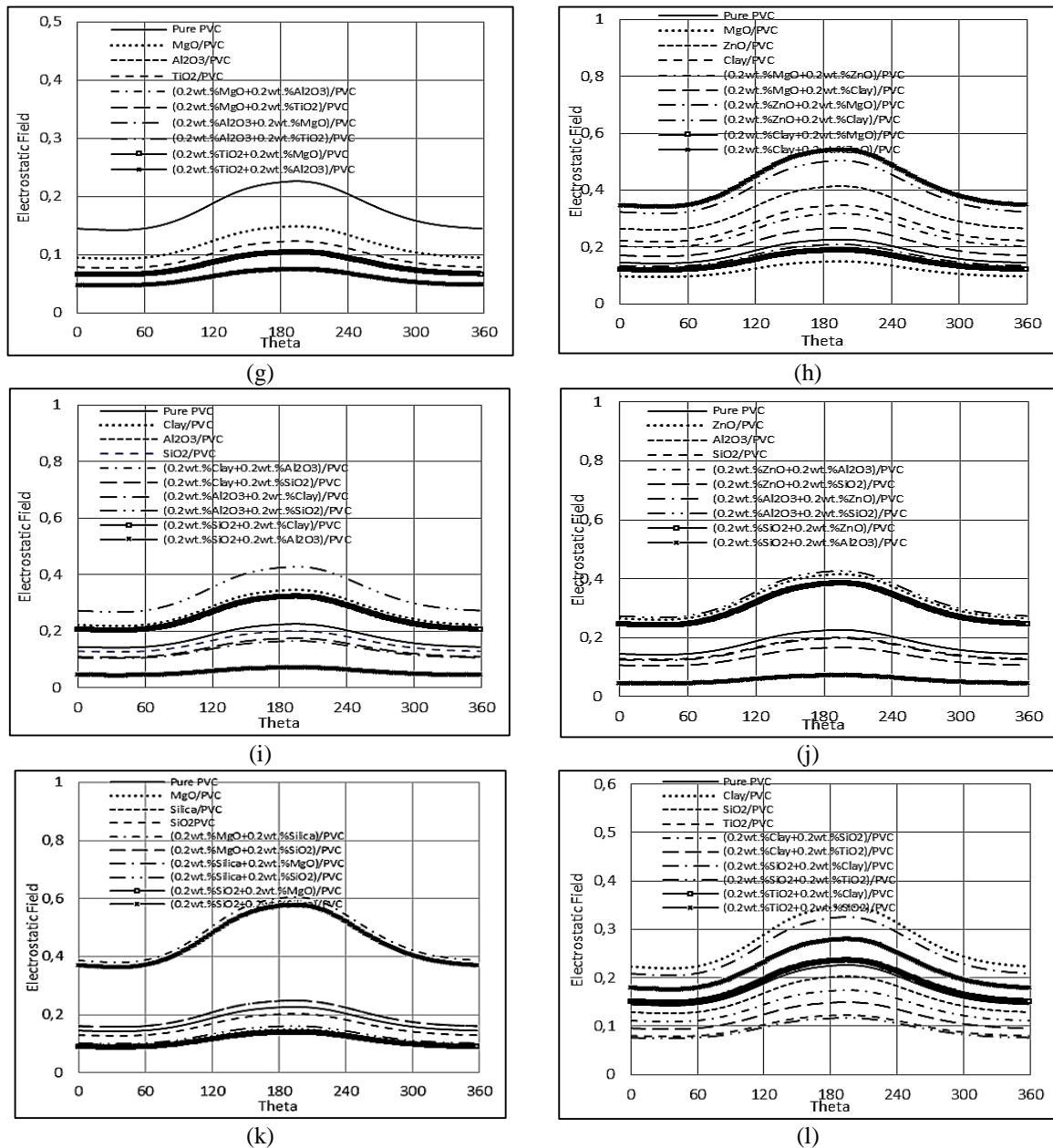
(g)

(h)

(i)

(j)

(k)

(l)

Figure 3. Electrostatic field distribution in insulation of power cable due to individual and multiple nanoparticles: (k) Silica, MgO, and SiO$_2$; (l) Clay, TiO2, and SiO2 (*continue*)

4.2. Effect of concentration of nanoparticles

Concenteration of nanoparticles is playing an important factor for defining electrostatic fields distribution in power cable insulatn materials. Therefore, Figure 4 illustrates the effect of variant concentrations of individual and multiple nanoparticles in PVC. It is noticed that increeasing volume fraction of individual Silica nanoparticles increases electrostatic fields in insulation of three core belted power cables. Whatever, multi-nanoparticles decrease the electrostatic fields in insulation of three core belted power cables. Note, using clay as a first nanoparticle and SiO$_2$ as a second nanoparticles increases electroostatic fields distribution whatever, the electrostatic fields distribution reversed via changing the arrangement of nanoparticles.
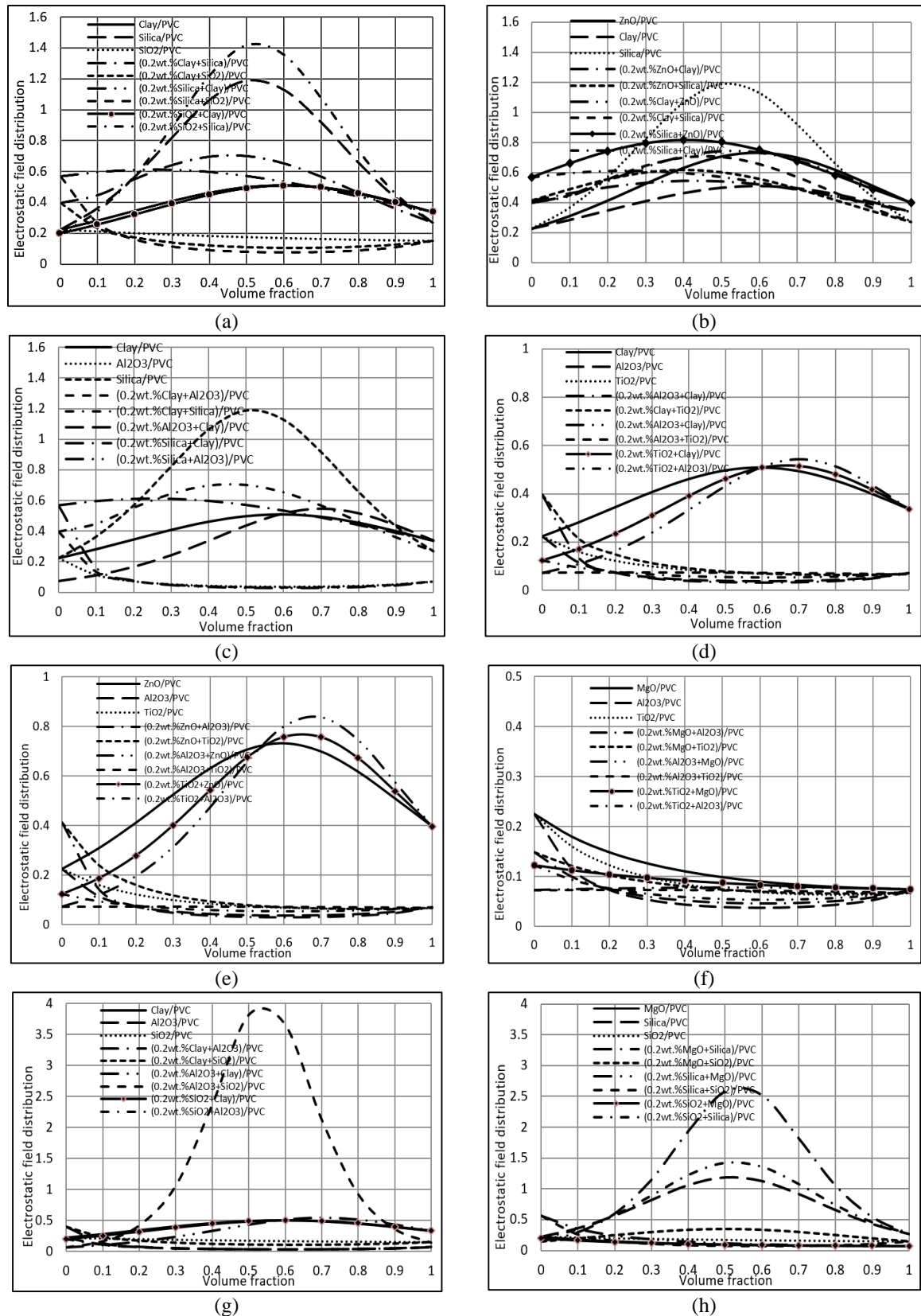
Figure 4. Electrostatic field distribution in insulation of power cable due to individual and multiple nanoparticles: (a) Clay, Silica, and SiO2; (b) Clay, Silica, and ZnO; (c) Clay, Silica, and Al$_2$O$_3$; (d) Clay, TiO$_2$, and Al$_2$O$_3$; (e) ZnO, TiO$_2$, and Al$_2$O$_3$; (f) MgO, TiO$_3$, and Al$_2$O$_3$; (g) Clay, SiO$_2$, and Al$_2$O$_3$; (h) Silica, MgO, and SiO$_2$
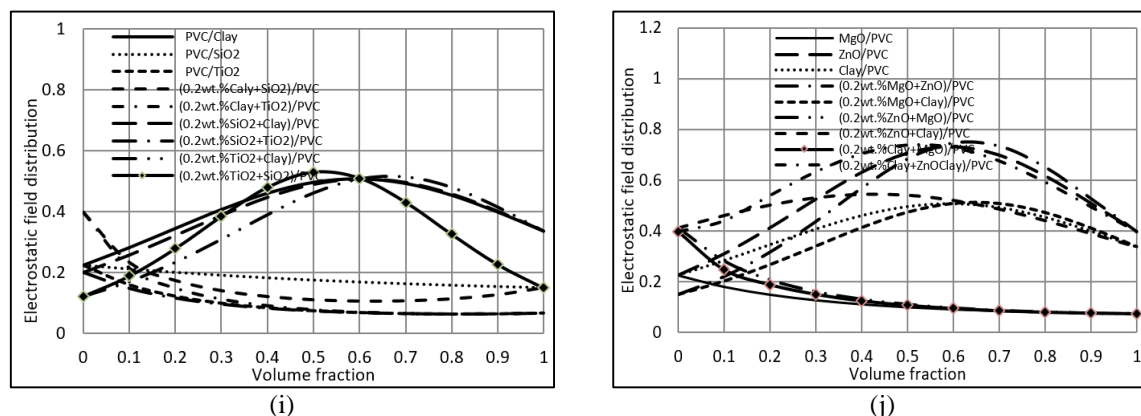
Figure 4. Electrostatic field distribution in insulation of power cable due to individual and multiple nanoparticles: (i) Clay, SiO$_2$, and TiO$_2$; (j) Clay, MgO, and ZnO *(continue)*

5. TRENDS ON USING MULTI-NANOPARTICLES TECHNIQUE

Multi-nanoparticles technique has been investigated the best new trends for enhancing the low electrostatic field with respect to using individual nanoparticles; therefore, the new nanocomposites should be having multi- nanoparticles for enhancing the low electrostatic field of base matrix. 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. CONCLUSION

Individual nanoparticles like, Clay, ZnO, and Silica are interested in increasing the electric field distribution in insulation of polymeric insulation. Whatever, SiO2, MgO, TiO2, and Alumina have interested in decreasing electric field distribution in insulation. The use of multiple nanoparticles is more efficient for controlling both electric field distributions in insulation 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 (Al2O3, TiO2, MgO, ZnO, and SiO2) inside host matrix is an efficient parameter for controlling in the electric field distribution in insulation of multi-nanocomposites.

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