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High Performance of Power Cables Using Nanocomposites Insulation Materials

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Article Info	ABSTRACT
	Partial discharges occur the biggest failure problem in power cable insulation due to distortion of electrical stress. In this paper, it has been investigated on the effect of spherical nanoparticles of Barium titanate ($BaTiO_3$) and Clay for enhancing electrostatic field distribution in single and three-core power cables. It has been applied new strategies of nanotechnology techniques for designing innovative polyvinyl chloride insulation materials by using nanocomposites and multi-nanocomposites. Moreover, it has been studied the electrostatic field distribution within power cable nanocomposites insulation in presence of air voids, water voids and cupper impurity voids. The electrostatic field distribution in power cable insulation has been calculated by finite element method (FEM). A comparative study has been investigated on the effect of nanocomposite insulation for enhancing electric field stress in power cables.

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1.   INTRODUCTION

In a power cable, insulation strength of materials has serious role in long time function. In high voltage equipment, local electric field will rise due to humidity, impurity and water, and therefore it leads to increasing electric field. Absorbed water which maybe happens during manufacture process or service period, can cause a major problem and can lead to decrease in cable insulator life time. In polyvinyl chloride cables, existence of electric field with high frequency, water and other electric tensions, can be led to water tree phenomena inside cables and then electric field intensity will increase and results in partial discharge in water location [1]. Partial discharge occurs in places which their electric field intensity is higher than accepted value of insulator in a power cable, Nowadays, Finite Element Method (FEM) has been used to study bubbles effect in high voltage power cable insulations as a basic method. The Finite Element Method can be easily used to calculate the maximum stress inside the void [2]. This finally leads to exact evaluation of electric field distribution in cable insulation system. By using 2-dimension Maxwell software, it is possible to calculate electric field values in each boundary and zone [3]. With the calculation of the magnitude of the electric field intensity and its spatial distribution within the cable, it is possible to set a limit on the voltage rating for a given insulation thickness, or alternatively [4]. The main dissolution products were found to be hydrogen, carbon monoxide, methane and carbon dioxide which are produced in a power cable when exposed to PD activity [5]. In recent years, the progress of nanotechnology science is fast for innovate new insulation materials that have advanced physical and electrical properties [6-18]. It has been studied the electric field calculation in insulation of power cables around conductor and partial discharges in insulation [19-24]. There is a big deal of opportunity to make up the properties of the resulting material to specific applications. From the viewpoint of insulating systems most

of the activity has been on inorganic oxides (particularly Fe_2O_3, Al_2O_3, MgO andTiO_2) [25]. The aim of this paper is enhancing performance of single and three-core belted power cable that is exposed to manufacture defects like voids, metal impurities. Thus, it has been studied the electrostatic field distribution inside traditional and nanocomposites insulation of power cables in presence of different air void, water void and cupper impurity void. In this study, the importance of using individual and multiple nanoparticles techniques have been tabulated for electrostatic field distribution inside nanocomposites and multiple nanocomposites insulation respectively.

2. MATHEMATICAL MODEL

   Electric field calculation requires solution of Laplace and Poisson equations. In Past studies, electric field is defined as a source of corona around conductor imperfect partial discharge and early insulation failure. by assuming there is no free surface change at the insulation surface and void boundary, Internal and External electric field of cylindrical void is calculated by following equations [5],[19],[20].

$$E(r) = E_\circ \left(i_r \left\{ 1 + \left(\frac{\varepsilon_r - \varepsilon_\circ}{\varepsilon_r + \varepsilon_\circ} \right) \times \frac{r^2_v}{r^2} \right\} \cos\theta - i\theta \left\{ 1 + \left(\frac{\varepsilon_r - \varepsilon_\circ}{\varepsilon_r + \varepsilon_\circ} \right) \times \frac{r^2_v}{r^2} \right\} \sin\theta \right) \quad \text{for} (r > r_v) \quad (1)$$

$$E(r) = E_\circ \left(\frac{2\varepsilon_\circ}{\varepsilon_r + \varepsilon_\circ} \right) (i_r \cos\theta - i\theta \sin\theta) \quad\quad\quad \text{for} (0 \leq r < r_v) \quad (2)$$

Internal and External electric field of spherical void is calculated by following equations, [5],[19],[20].

$$E(r) = E_\circ \left(i_r \left\{ -1 - \left(\frac{\varepsilon_r - \varepsilon_\circ}{\varepsilon_r + 2\varepsilon_\circ} \right) \times \frac{r^3_v}{r^3} \right\} \cos\theta + i\theta \left\{ 1 - \left(\frac{\varepsilon_r - \varepsilon_\circ}{\varepsilon_r + 2\varepsilon_\circ} \right) \times \frac{r^3_v}{r^3} \right\} \sin\theta \right) \quad \text{for} (r > r_v) \quad (3)$$

$$E(r) = E_\circ \left\{ -\left(\frac{3\varepsilon_\circ}{\varepsilon_r + 2\varepsilon_\circ} \right) \right\} (i_r \cos\theta - i\theta \sin\theta) \quad\quad\quad \text{for} (0 \leq r < r_v) \quad (4)$$

Where, r_v is radius of void, r distance from void center, $E_\circ$ uniform dielectric field, i_r and i_θ are unit vectors of the co-ordinate system in the insulation, ε_r is the permittivity of insulation, $\varepsilon_\circ$ is the permittivity of air void. All the times irregular problem geometry for void is so complicated that analytical solution is so hard, therefore, researches tried to find new calculating methods to obtain electric field. FEM is chosen for computation use. Electric field equations solution by this method is based on Maxwell equations with boundary conditions. The effective dielectric constant of the inclusion and interphase could be expressed for individual nanocomposite model that contains an interphase region according to [9]- [12] as

$$\varepsilon^\beta_{effi} = \varphi_i \varepsilon^\beta_i + \varphi_{phi} \varepsilon^\beta_{phi} + \varphi_m \varepsilon^\beta_m \tag{5}$$

Where φ_i is the volume fraction of first filler component of the composite system, φ_{phi} is the volume fraction of the interphase region component of the composite system, φ_m is the volume fraction of the matrix component of the composite, ε_{effi} is the dielectric permittivity of the composite system, ε_i is the filler permittivity of the composite system, ε_{phi} is the interphase permittivity of the composite system, ε_m is the the matrix permittivity of the composite system.

Whatever, the effective dielectric constant of the inclusion and interphase could be expressed for multiple Nanocomposite model that contains an interphase region according to [13], [18] as

$$\varepsilon^\beta_{effj} = \varphi_j \varepsilon^\beta_j + \varphi_{phij} \varepsilon^\beta_{phij} + \varphi_{effi} \varepsilon^\beta_{effi} \tag{6}$$

Where, φ_j is the volume fraction of second filler component of the composite system, φ_{phij} is the volume fraction of the interphase region component of the composite system, φ_{effi} is the volume fraction of the matrix component of the composite, ε_{effj} is the dielectric permittivity of the composite system, ε_j is the second filler permittivity of the composite system, ε_{phij} is the interphase permittivity of the composite system, ε_{effi} is the dielectric permittivity of the individual nanocomposites system.

3. MODEL CONFIGURITION

   This paper investigates two models of cable configuration. The first model is single core power cable as shown in Fig 1 and the second model is three core belted power cable as shown in Fig 2. The two-model configuration setup according to standard dimensions designed by Nexans Energy Networks Company, Design

Standards 6622 - BS 7835[22]. Table (1) shows the two models configuration of Single- and Three-Core power cables. The void diameter is considered 1mm located between the conductor surface and the insulation inner surface [23]. Finite Element Methods Magnetics (FEMM) software is used for this simulation. Finite Element Method Magnetics (FEMM) software is a finite element package. This software is used for solving 2-dimensional planar and axisymmetric problems in electrostatics, current flow, heat flow and low frequency magnetics [2].

Table 1 Configuration of Single- and Three-Core Cables [22]- [24]

Single-Core Power Cables		Three-Core Power Cables	
Specification	**Rating**	**Specification**	**Rating**
Rated voltage (kV)	11	Rated voltage (kV)	33
Number core	1	Number core	3
Nominal cross-sectional area (mm)	150	Nominal cross-sectional area (mm)	150
Diameter over conductor (mm)	14.3	Diameter over conductor (mm)	14.3
Approximate diameter over insulation (mm)	22.2	Approximate diameter over insulation (mm)	26.5
Approximate overall diameter (mm)	38	Approximate overall diameter (mm)	83
Insulation dielectric constant (PVC)	3	Insulation dielectric constant (PVC)	3
Water permittivity	81	Water permittivity	81
Air permittivity	1	Air permittivity	1
Cupper impurity permittivity	5.6	Cupper impurity permittivity	5.6
Radius of bubble (mm)	0.5	Radius of bubble (mm)	0.5
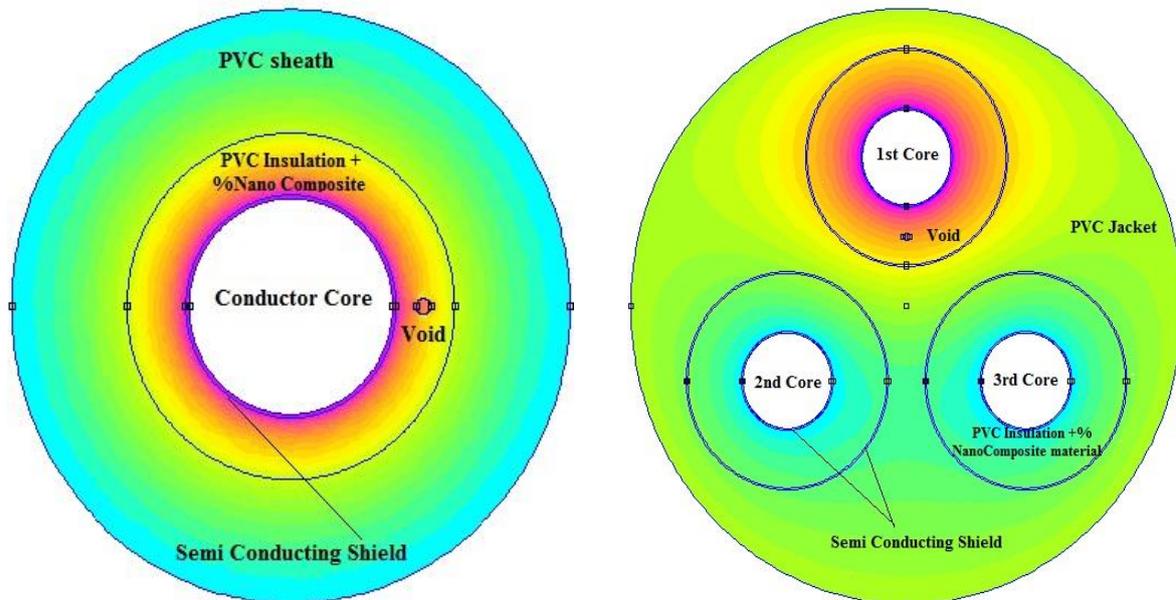
Figure 1. Cross section of single core cable with void   Figure 2. Cross section of Three core cable with void

4.   SELECTED MATERIALS AND PARAMETERS

Polyvinyl Chloride (PVC) is the most widely used of any of cables, thermoplastics, polymerized vinyl chloride and is produced from ethylene and anhydrous hydrochloric acid. PVC is stronger and more rigid than other general-purpose thermoplastic materials, tough, strong, resist water, abrasion, and are excellent electrical insulators [16]. Clay nanoparticles are used to reduce the density of product [17]. Aluminum Oxide (Al_2O_3) is strong high heat-resistance, very stable, high hardness, high mechanical strength, and electrical insulator. Magnesium Oxide (MgO) has high thermal conductivity and low electrical conductivity, whatever, Barium titanite ($BaTiO_3$) is a dielectric ceramic used for capacitors. Ferric oxide (Fe_2O_3) is used in Pigment, Polishing, Photocatalysis. Titanium dioxide (TiO_2) is used in electrical ceramics, metal patinas, catalysts, electric conductors and chemical intermediates. Table 2 depicts the details of numerical dielectric constant values of selected nanocomposite and multi-nanocomposite is computed by MATLAB Program depended on modified power law model equations for enhancing the performance of Polyvinyl Chloride insulators [7]. Also, electric conductivity of selected nanocomposite and multi-nanocomposite is computed by electrical conductivity equation [21].

Table 2. Dielectric Constant of Polyvinyl Chloride Nanocomposites and Multi-Nanocomposites Materials

Nanoparticles	Dielectric constant	Materials	Dielectric constant
Clay	2	Pure PVC	3
BaTiO3	3.8	10wt.% Clay/ PVC	2.625
MgO	9	(10wt.%Clay+15wt.%BaTiO3)/PVC	2.802
TiO2	48	(10wt.%Clay+15wt.%MgO)/ PVC	3.913
Al2O3	9.5	(10wt.%Clay+15wt.% Fe2O3)/ PVC	45.2
Fe2O3	25	(10wt.%Clay+15wt.% TiO2)/ PVC	4.469
		10wt.% BaTiO3/PVC	3.084
		(10wt.% BaTiO3+15wt.% Clay)/PVC	2.507
		(5wt.% BaTiO3+15wt.% MgO)/ PVC	4.336
		(5wt.% BaTiO3+15wt Fe2O3)/ PVC	44.01
		(5wt.% BaTiO3+15wt.% TiO2)/ PVC	4.888
		10wt.% Al2O3/ PVC	6.041
		(10wt.% Al2O3 +15wt.% Clay)/ PVC	3.669
		(10wt.% Al2O3 +15wt.% BaTiO3)/ PVC	5.616
		(10wt.% Al2O3 +15wt.% MgO)/ PVC	6.793
		(10wt.% Al2O3+15wt.% Fe2O3)/ PVC	38.58

5. RESULTS AND ANALYSIS

The electric field stress can be controlled by changing relative permittivity of insulator material by adding individual nanocomposite or multi-nanocomposite materials to insulator material. Also getting new dielectric materials due to our needs for enhancing electric applications. The following results illustrate the behavior of electric field stress inside nanocomposites and multi nanocomposites insulation materials of power cables which having (air – impurity – water) voids.

5.1. Electric Stress in Single-Core Cables

Figures 3-5 illustrate the behavior of electric stress within variant polyvinyl chloride insulation materials pure and nanocomposites in case of presence air void. It has been observed that adding concentration of $(10wt.\%Al_2O_3+15wt.\%Fe_2O_3)$ nanoparticles to polyvinyl chloride decreases the electric field distribution about 82.9% inside air void and decreases the electric field distribution inside power cable insulation about 86.8% due to the effect of high dielectric constant of Al_2O_3 and Fe_2O_3 nanoparticles. On the other side it has been observed that adding concentration of $(10wt.\%Al_2O_3+15wt.\%Clay)$ nanoparticles to polyvinyl chloride decreases the electric field distribution about 6.95% inside air void and decreases the electric field distribution inside power cable insulation about 11.4% due to the effect of low dielectric constant of Clay nanoparticle. And other composite electric distribution graded between them as shown in Fig. 3. Moreover, it has been observed that adding concentration of $(10wt.\%BaTiO_3+15wt.\%Fe_2O_3)$ nanoparticles to polyvinyl chloride decreases the electric field distribution about 84.8% inside air void and decreases the electric field distribution inside power cable insulation about 88.4% due to the effect of high dielectric constant of Fe_2O_3 nanoparticles. On the other side, it has been observed that adding concentration of $(10wt.\% BaTiO_3+15wt.\%Clay)$ nanoparticles to polyvinyl chloride increases the electric field distribution about 5.34% inside air void and increases the electric field distribution inside power cable insulation about 10.6% due to the effect of low dielectric constant of $BaTiO_3$ and Clay nanoparticles. And other composite electric distribution graded between them as shown in Fig. 4. Finally, it has been observed that adding concentration of $(10wt.\%Clay+15wt.\%Fe_2O_3)$ nanoparticles to polyvinyl chloride decreases the electric field distribution about 85.1% inside air void and decreases the electric field distribution inside power cable insulation about 88.7% due to the effect of high dielectric constant of Fe_2O_3 nanoparticles. On the other side, it has been observed that adding concentration of $(10wt.\%Clay +15wt.\% BaTiO_3)$ nanoparticles to polyvinyl chloride increases the electric field distribution about 2.13% inside air void and increases the electric field distribution inside power cable insulation about 4.25% due to the effect of low dielectric constant of $BaTiO_3$ and Clay nanoparticles. And other composite electric distribution graded between them as shown in Fig. 5. And so, increasing the concentration of Fe_2O_3 nanoparticle causes more effect for decreasing electric field distribution inside air void. And so, it has observed different behavior to electric stress performance in case of adding multiple nanoparticles inside polyvinyl chloride.
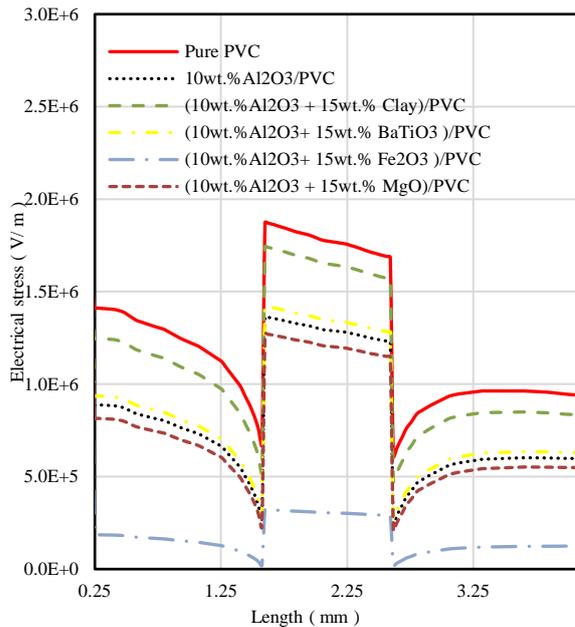
Figure 3. Electric field distribution in cable insulation with air void
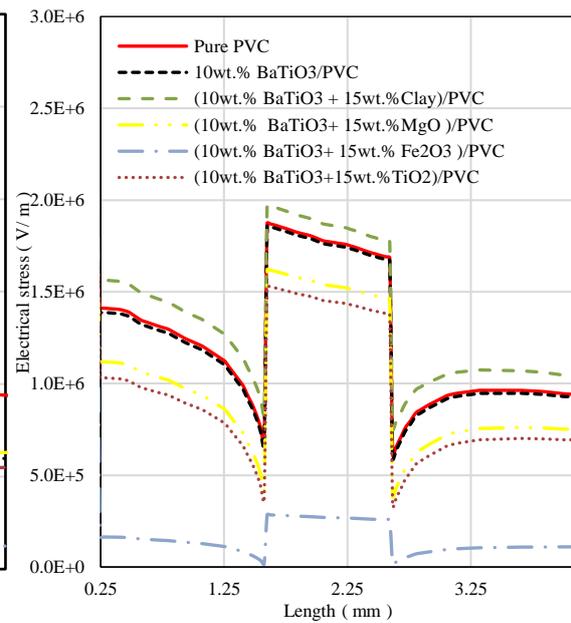
Figure 4. Electric field distribution in cable insulation with air void
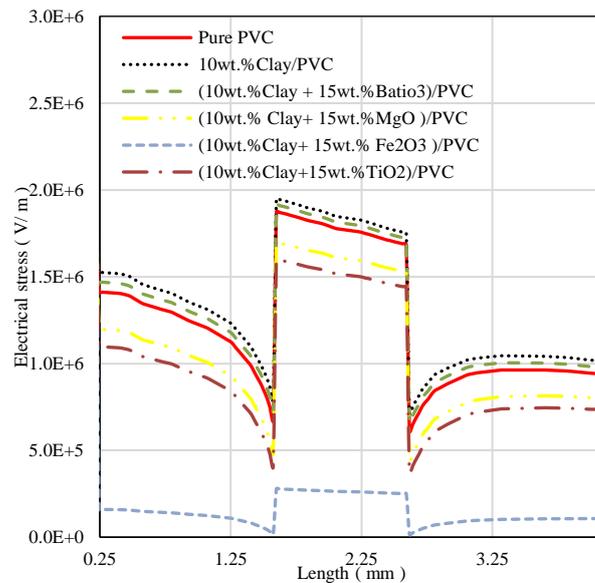
Figure 5. Electric field distribution in cable insulation with air void

Figures 6-8 illustrate the behaviour of electric stress within variant polyvinyl chloride insulation materials pure and nanocomposites in case of presence water void. It has been observed that adding concentration of (10wt.%Al_2O_3+15wt.%Fe_2O_3) nanoparticle to polyvinyl chloride decreases the electric field distribution about 13.02% inside water void and decreases the electric field distribution inside power cable insulation about 88% due to the effect of high dielectric constant of Al_2O_3 and Fe_2O_3 nanoparticles. On the other side it has been observed that adding concentration of (10wt.%Al_2O_3+15wt.%Clay) nanoparticles to polyvinyl chloride decreases the electric field distribution about 7.21% inside water void and decreases the electric field distribution inside power cable insulation about 12.2% due to the effect of low dielectric constant of Clay nanoparticle. And other composite electric distribution graded between them as shown in Fig. 6. (a). Electric stress distribution inside water void shown in Fig. 6. (b), it has been observed that adding concentration of (10wt.%$BaTiO_3$+15wt.%Fe_2O_3) nanoparticles to polyvinyl chloride decreases the electric field distribution about 8.71% inside water void and decreases the electric field distribution inside power cable insulation about 89.5% due to the effect of high dielectric constant of Fe_2O_3 nanoparticle. On the other side, it has been observed

that adding concentration of (10wt.% $BaTiO_3$+15wt.%Clay) nanoparticles to polyvinyl chloride increases the electric field distribution about 7.31% inside water void and increases the electric field distribution inside power cable insulation about 10.4% due to the effect of low dielectric constant of $BaTiO_3$ and Clay nanoparticles. And other composite electric distribution graded between them as shown in Fig.7. (a). Electric stress distribution inside water void shown in Fig.7(b).
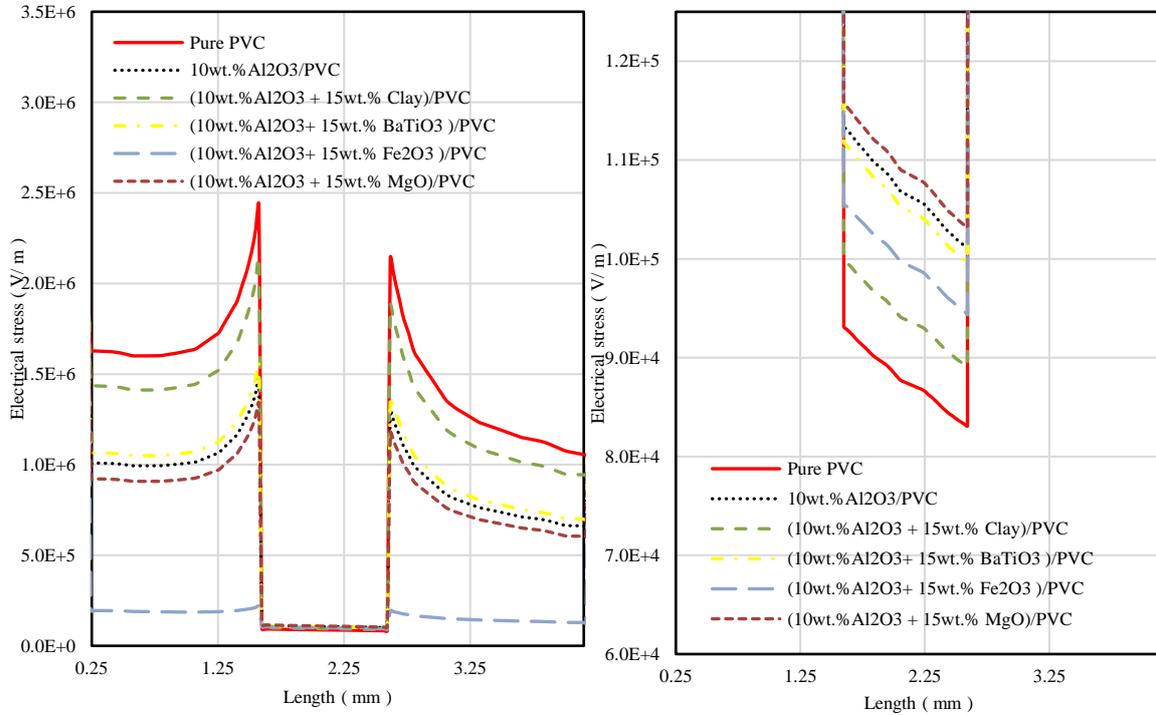
Figure 6. (a) Electric field distribution in cable insulation   Figure 6. (b) Stress distribution inside water void
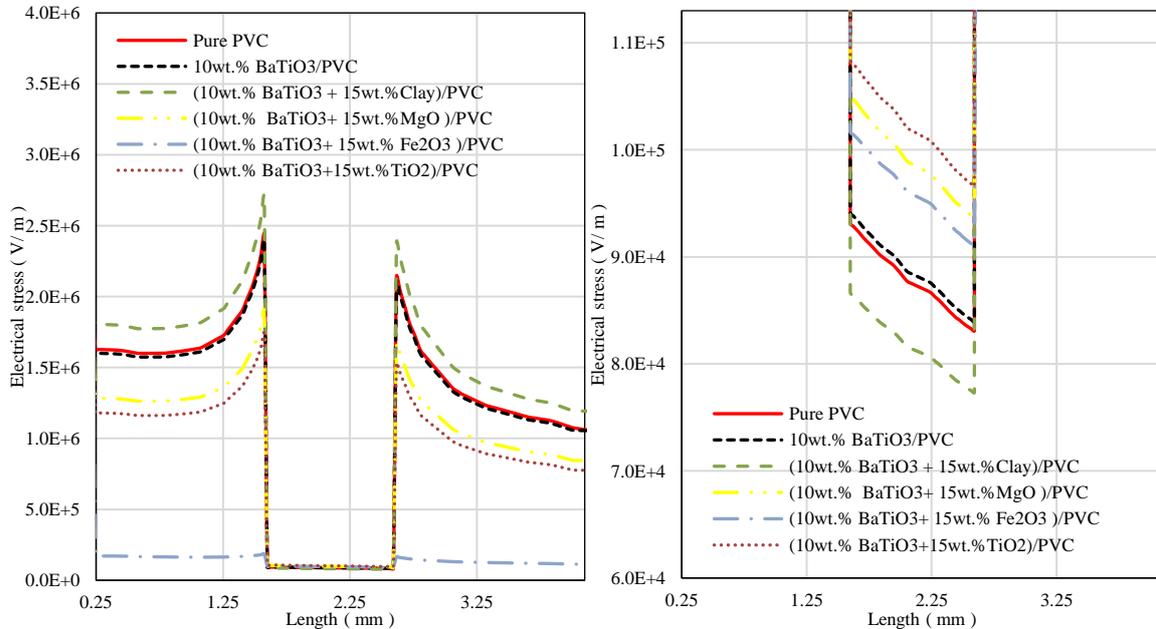
Figure 7. (a) Electric field distribution in cable insulation   Figure 7. (b) Stress distribution inside water void
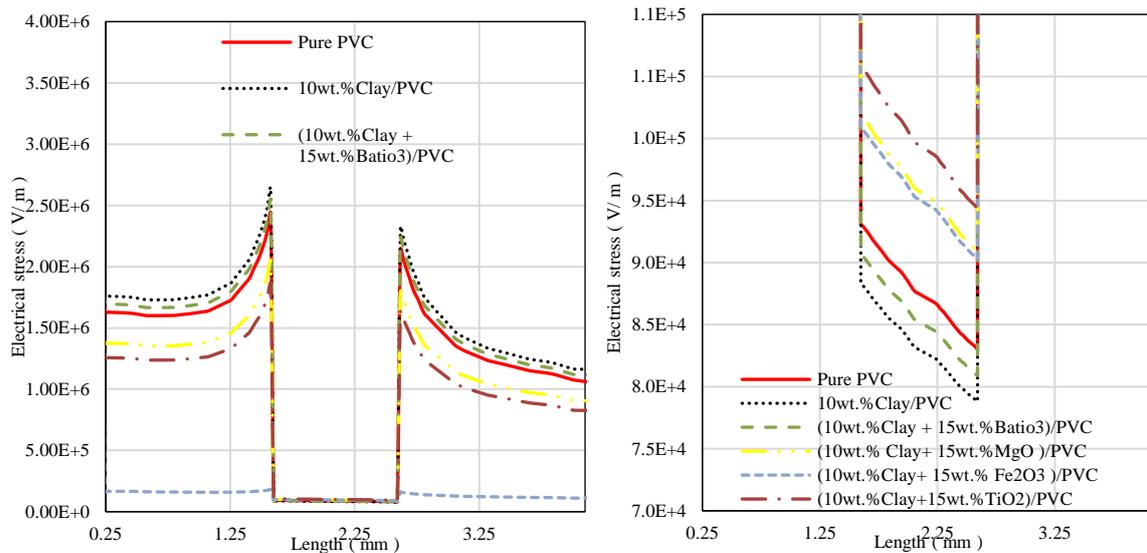
Figure 8. (a) Electric field distribution in cable insulation   Figure 8. (b) Stress distribution within water void

Finally, it has been observed that adding concentration of (10wt.%Clay+15wt.%Fe$_2$O$_3$) nanoparticles to polyvinyl chloride decreases the electric field distribution about 7.64% inside water void and decreases the electric field distribution inside power cable insulation about 89.7% due to the effect of high dielectric constant of Fe$_2$O$_3$ nanoparticle. From the other side it has been observed that adding concentration of (10wt.%Clay +15wt.% BaTiO$_3$) nanoparticles to polyvinyl chloride increases the electric field distribution about 2.69% inside water void and increases the electric field distribution inside power cable insulation about 3.68% due to the effect of low dielectric constant of BaTiO$_3$ and Clay nanoparticles. Also, when adding concentration of (10wt.% Clay) nanoparticles to polyvinyl chloride electric stress inside cable insulator be in higher value than adding concentration of (10wt.% Clay+15wt.% BaTiO$_3$) nanoparticles to polyvinyl chloride and other composite electric distribution graded between them as shown in Fig.8. (a). Electric stress distribution inside water void shown in Fig.8. (b), it is obvious that increasing the concentration of Fe$_2$O$_3$ nanoparticles causes more effect for decreasing electric field distribution inside water void. And it has observed different behaviour to electric stress performance in case of adding multiple nanoparticles inside polyvinyl chloride.

Figures 9-11 illustrate the behaviour of electric stress within variant polyvinyl chloride insulation materials pure and nanocomposites in case of presence cupper impurity void. It has been observed that adding concentration of (10wt.%Al$_2$O$_3$+15wt.%Fe$_2$O$_3$) nanoparticles to polyvinyl chloride decreases the electric field distribution about 67.7% inside impurity void and decreases the electric field distribution inside power cable insulation about 87.8% due to the effect of high dielectric constant of Al$_2$O$_3$ and Fe$_2$O$_3$ nanoparticles. On the other side, it has been observed that adding concentration of (10wt.%Al$_2$O$_3$+15wt.%Clay) nanoparticles to polyvinyl chloride decreases the electric field distribution about 0% inside impurity void and decreases the electric field distribution inside power cable insulation about 12.4% due to the effect of low dielectric constant of Clay nanoparticle. And other composite electric distribution graded between them as shown in Fig. 9. Moreover, it has been observed that adding concentration of (10wt.%BaTiO$_3$+15wt.%Fe$_2$O$_3$) nanoparticles to polyvinyl chloride decreases the electric field distribution about 71.1% inside impurity void and decreases the electric field distribution inside power cable insulation about 89.2% due to the effect of high dielectric constant of Fe$_2$O$_3$ nanoparticle. On the other side it has been observed that adding concentration of (10wt.% BaTiO$_3$+15wt.%Clay) nanoparticles to polyvinyl chloride increases the electric field distribution about 2.13% inside impurity void and increases the electric field distribution inside power cable insulation about 11.1% due to the effect of low dielectric constant of BaTiO$_3$ and Clay nanoparticles. And other composite electric distribution graded between them as shown in Fig.10(a). Electric stress distribution inside cupper impurity void shown in Fig.10(b).
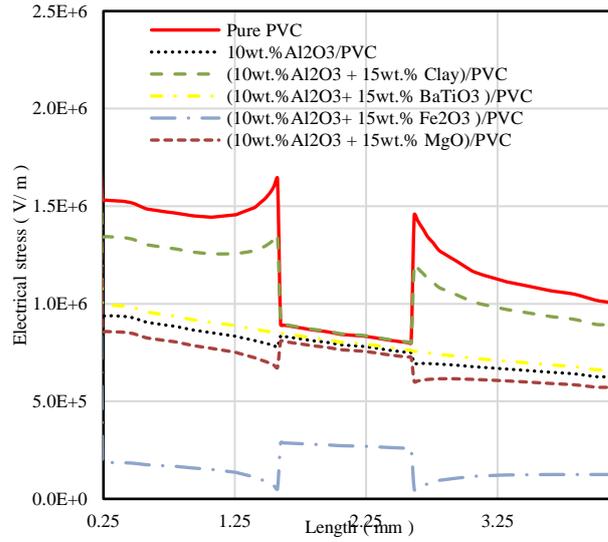
Figure 9. Electric field distribution in cable insulation with copper impurity void
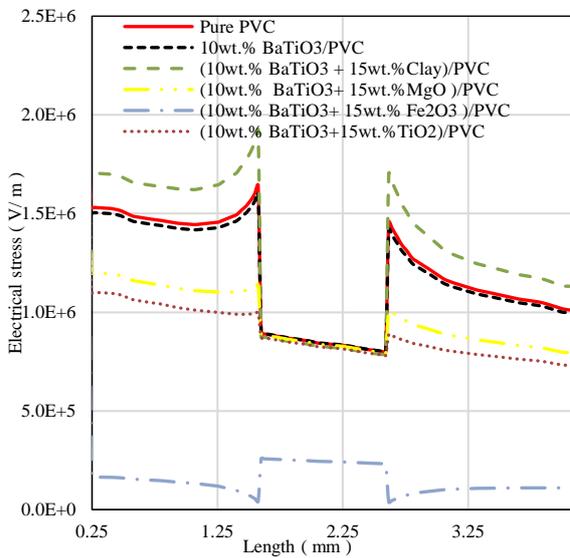
Figure 10. (a) Electric field distribution in cable insulation
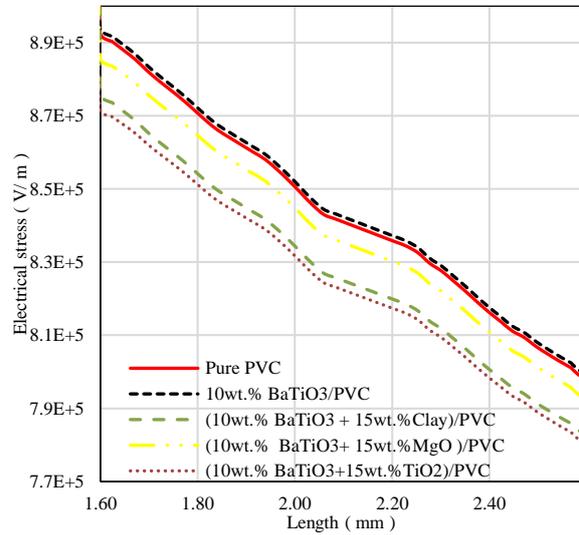
Figure 10. (b) Stress distribution inside
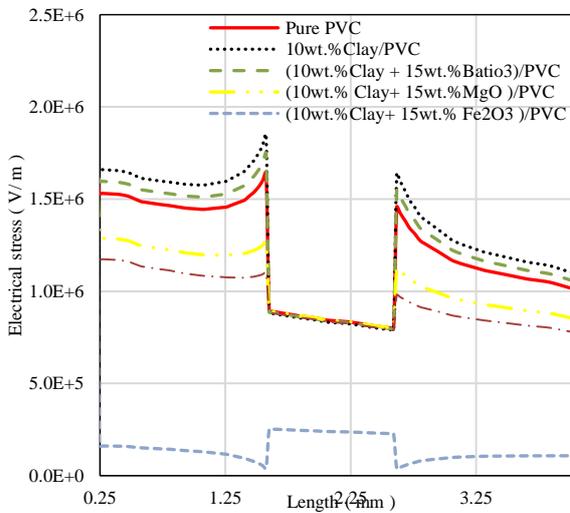
Figure 11. (a) Electric field distribution in cable insulation
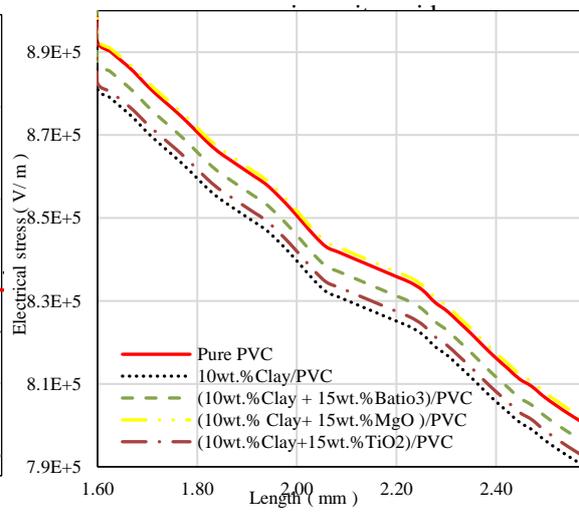
Figure 11. (b) Stress distribution inside impurity void

Finally, it has been observed that adding concentration of (10wt.%Clay+15wt.%Fe_2O_3) nanoparticles to polyvinyl chloride decreases the electric field distribution about 71.7% inside cupper impurity void and decreases the electric field distribution inside power cable insulation about 89.5% due to the effect of high dielectric constant of Fe_2O_3 nanoparticle. From the other side it has been observed that adding concentration of (10wt.%Clay +15wt.% $BaTiO_3$) nanoparticles to polyvinyl chloride increases the electric field distribution about 0.56% inside impurity void and increases the electric field distribution inside power cable insulation about 4.57% due to the effect of low dielectric constant of $BaTiO_3$ and Clay nanoparticles. In case of adding concentration of (10wt.% Clay) nanoparticles to polyvinyl chloride, the electric stress inside cable insulator be in higher value than adding concentration of (10wt.% Clay+15wt.% $BaTiO_3$) nanoparticles to polyvinyl chloride and other composite electric distribution graded between them as shown in Fig.11. (a). Electric stress distribution inside impurity void shown in Fig.11. (b). it is obvious that increasing the concentration of Fe_2O_3 nanoparticle causes more effect for decreasing electric field distribution inside cupper impurity void. And so, it has observed different behavior to electric stress performance in case of adding multiple nanoparticles inside polyvinyl chloride.

5.2. Electric Stress in Three-Core Power Cable

Figures (12-14) illustrate the behaviour of electric stress within variant polyvinyl chloride insulation materials pure and nanocomposites in case of presence air void in three core belted power cable. Electric stress distribution is drawn around first core axis passes through air void. It has been observed that adding concentration of (10wt.%Al_2O_3+15wt.%Fe_2O_3) nanoparticles to polyvinyl chloride decreases the electric field distribution about 82.4% inside air void and decreases the electric field distribution inside power cable insulation about 82.1% due to the effect of high dielectric constant of Al_2O_3 and Fe_2O_3 nanoparticles. On the other side, it has been observed that adding concentration of (10wt.%Al_2O_3+15wt.%Clay) nanoparticles to polyvinyl chloride decreases the electric field distribution about 6.38% inside air void and decreases the electric field distribution inside power cable insulation about 7.69% due to the effect of low dielectric constant of Clay nanoparticle. And other composite electric distribution graded between them as shown in Fig.12. (a). Electric stress distribution inside air void shown in Fig.12. (b). it has been observed that adding concentration of (10wt.%$BaTiO_3$+15wt.%Fe_2O_3) nanoparticles to polyvinyl chloride decreases the electric field distribution about 84.3% within air void and decreases the electric field distribution inside power cable insulation about 84.1% due to the effect of high dielectric constant of Fe_2O_3 nanoparticle. On the other side it has been observed that adding concentration of (10wt.% $BaTiO_3$+15wt.%Clay) nanoparticles to polyvinyl chloride increases the electric field distribution about 4.72% within air void and increases the electric field distribution inside power cable insulation about 6.83% due to the effect of low dielectric constant of $BaTiO_3$ and Clay nanoparticles. And other composite electric distribution graded between them as shown in Fig.13. (a). Electric stress distribution inside air void shown in Fig.13. (b).
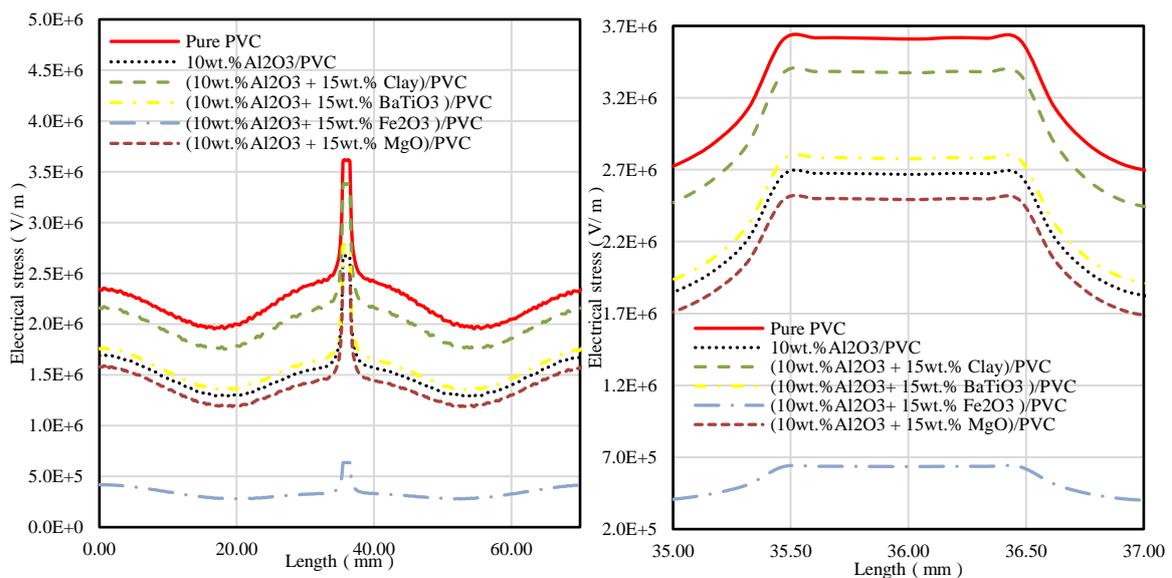
Figure 12. (a) Electric field distribution in cable insulation

Figure 12. (b) Stress distribution inside air void
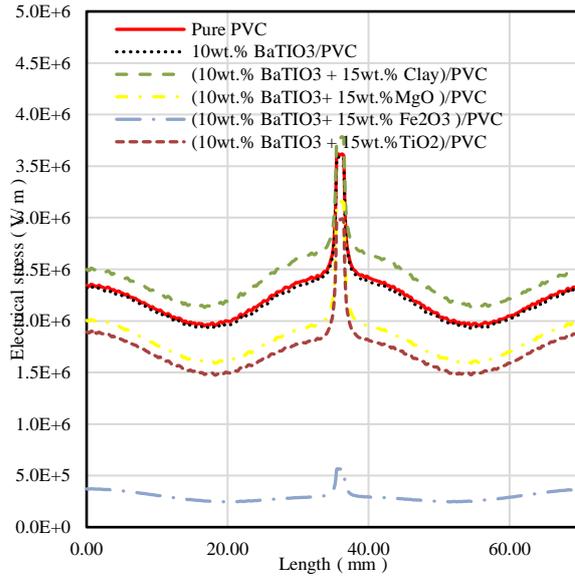
Figure 13. (a) Electric field distribution in cable insulation   Figure 13. (b) Stress distribution inside air void
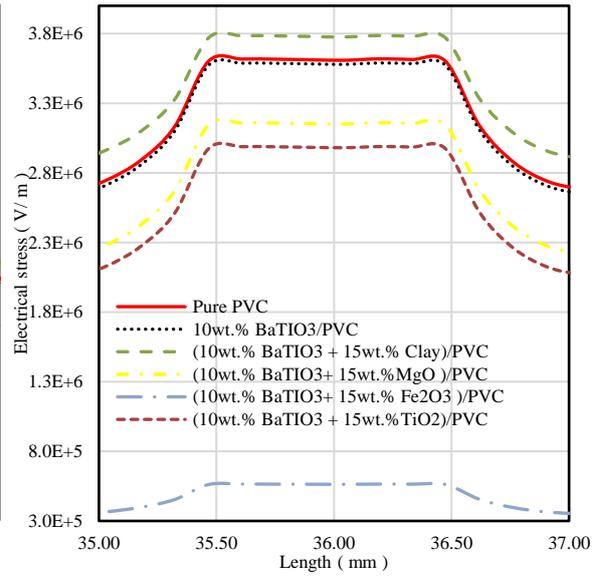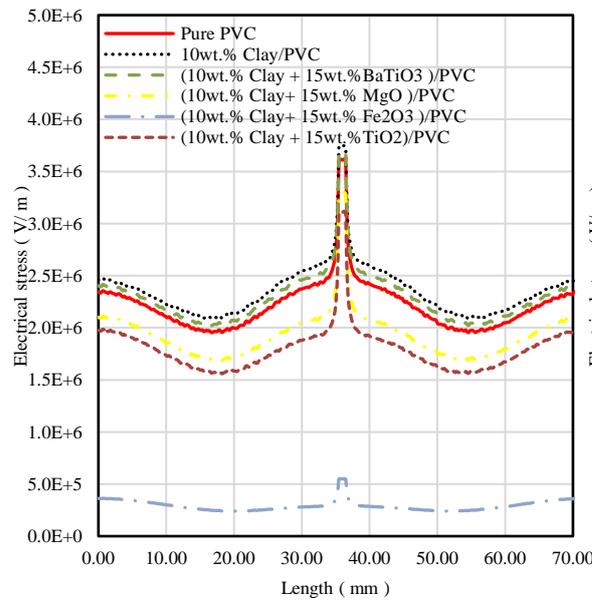
Figure 14. (a) Electric field distribution in cable insulation   Figure 14. (b) Stress distribution inside air void
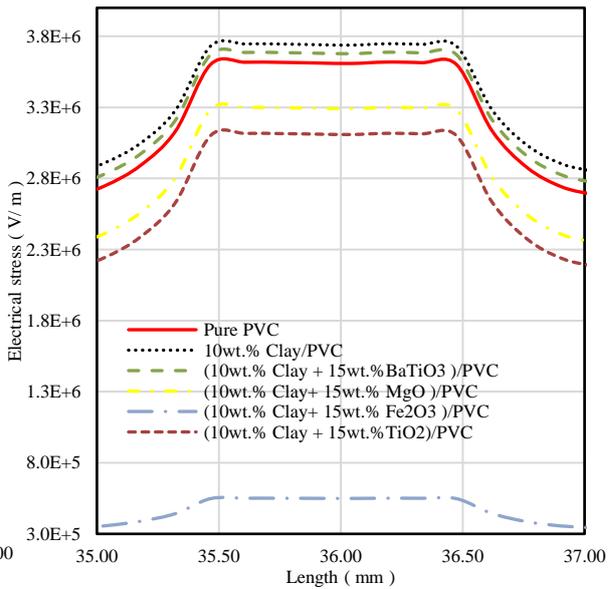
Finally, it has been observed that adding concentration of (10wt.%Clay+15wt.%Fe$_2$O$_3$) nanoparticles to polyvinyl chloride decreases the electric field distribution about 84.7% inside air void and decreases the electric field distribution inside power cable insulation about 84.5% due to the effect of high dielectric constant of Fe$_2$O$_3$ nanoparticle. On the other side, it has been observed that adding concentration of (10wt.%Clay +15wt.% BaTiO$_3$) nanoparticles to polyvinyl chloride increases the electric field distribution about 1.94% inside air void and increases the electric field distribution inside power cable insulation about 2.56% due to the effect of low dielectric constant of BaTiO$_3$ and Clay nanoparticles. Also, when adding concentration of (10wt.% Clay) nanoparticles to polyvinyl chloride, electric stress inside cable insulator be in higher value than adding concentration of (10wt.% Clay+15wt.% BaTiO$_3$) nanoparticles to polyvinyl chloride and other composite electric distribution graded between them as shown in Fig.14. (a). Electric stress distribution inside air void shown in Fig.14. (b). it noticed that increasing the concentration of Fe$_2$O$_3$ nanoparticle causes more effect for decreasing electric field distribution inside air void. It has observed different behavior to electric stress performance in case of adding multiple nanoparticles inside polyvinyl chloride.

6. TRENDS OF USING MODERN NANOCOMPOSITES INSULATION

For the manufacturing of power cables, insulating fillers such as layered silicates, montmorillonite clays, Al_2O_3, TiO_2 and SiO_2 are used in the case of conducting fillers, graphite platelets and carbon nanotubes are among the most commonly used congeners. Such conducting fillers can enhance the mechanical properties of nanocomposites and electrical conductivity. With respect to insulating fillers, layered silicates or clays are in the range of a few nm in thickness and in the range of 100 nm in the other two dimensions, while the sizes of nanoparticles such as SiO_2, TiO_2 and Al_2O_3 are in the range of 30-40 nm [26-28].

In our research, Table 3 shows a comparison results between the electric stress inside variant nanocomposites insulation, and across air voids, water voids and copper impurities respectively for single-core power cable.

Table 3. Electric Stress inside Single-Core Cable Insulation Having Variant Voids

Modern Nanocomposites Insulation Material	Electric Stress in Single Core Cable (kV/m)	
	Air Void	Inside Insulation
PURE PVC	1.87E+3	1.41E+3
(10wt.% $BaTiO_3$ +15wt.% Fe_2O_3)/ PVC	2.84E+2	1.64E+2
(10wt.% $BaTiO_3$ +15wt.%Clay)/ PVC	1.97E+3	1.57E+3
(10wt.% Clay+15wt.% Fe_2O_3)/ PVC	2.77E+2	1.60E+2
(10wt.% Clay+15wt.% $BaTiO_3$)/ PVC	1.91E+3	1.47E+3
Modern Nanocomposites Insulation Material	Electric Stress in Single Core Cable (kV/m)	
	Water Void	Inside Insulation
PURE PVC	93.2	1.63E+3
(10wt.% $BaTiO_3$+15wt.% Fe_2O_3)/ PVC	102	1.71E+2
(10wt.% $BaTiO_3$ +15wt.%Clay)/ PVC	86.7	1.81E+3
(10wt.% Clay+15wt.% Fe_2O_3)/ PVC	101	1.67E+2
(10wt.% Clay+15wt.% $BaTiO_3$)/ PVC	98	1.70E+3
Modern Nanocomposites Insulation Material	Electric Stress in Single Core Cable (kV/m)	
	Cupper Impurity Void	Inside Insulation
PURE PVC	8.93E+2	1.53E+3
(10wt.% $BaTiO_3$+15wt.% Fe_2O_3)/ PVC	2.58E+2	1.65E+2
(10wt.% $BaTiO_3$ +15wt.%Clay)/ PVC	8.76E+2	1.71E+3
(10wt.% Clay+15wt.% Fe_2O_3)/ PVC	2.52E+2	1.61E+2
(10wt.% Clay+15wt.% $BaTiO_3$)/ PVC	8.88E+2	1.60E+3

On the other side, Table 4 shows a comparison results between the electric stress inside variant nanocomposites insulation across air voids, respectively for three-core power cable.

Table 4. Electric Stress inside Three-Core Cable Insulation Having Variant Voids

Modern Nanocomposites Insulation Material	Electric Stress in Three-Core Cable (kV/m)	
	Air Void	Inside Insulation
PURE PVC	3.60E+3	2.34E+3
(10wt.% $BaTiO_3$+15wt.% Fe_2O_3)/ PVC	5.62E+2	3.70E+2
(10wt.% $BaTiO_3$ +15wt.%Clay)/ PVC	3.77E+3	2.49E+3
(10wt.% Clay+15wt.% Fe_2O_3)/ PVC	5.48E+2	3.61E+2
(10wt.% Clay+15wt.% $BaTiO_3$)/ PVC	3.67E+3	2.40E+3
Modern Nanocomposites Insulation Material	Electric Stress in Three-Core Cable (kV/m)	
	Water Void	Inside Insulation
PURE PVC	86.7	2.36E+3
(10wt.% $BaTiO_3$+15wt.% Fe_2O_3)/ PVC	149	2.85E+2
(10wt.% $BaTiO_3$ +15wt.%Clay)/ PVC	80.3	2.59E+3
(10wt.% Clay+15wt.% Fe_2O_3)/ PVC	149	2.77E+2
(10wt.% Clay+15wt.% $BaTiO_3$)/ PVC	84.8	2.45E+3
Modern Nanocomposites Insulation Material	Electric Stress in Three-Core Cable (kV/m)	
	Cupper Impurity Void	Inside Insulation
PURE PVC	1.16E+3	2.40E+3
(10wt.% $BaTiO_3$+15wt.% Fe_2O_3)/ PVC	7.99E+2	2.91E+2
(10wt.% $BaTiO_3$ +15wt.%Clay)/ PVC	1.08E+3	2.63E+3
(10wt.% Clay+15wt.% Fe_2O_3)/ PVC	7.86E+2	2.84E+2
(10wt.% Clay+15wt.% $BaTiO_3$)/ PVC	1.13E+3	2.49E+3

The dielectric strength of the polyetherimide is varies between 28 to 35 kV/mm but when mixing Polyetherimide with 15wt.% multi walled carbon nanotubes (MWCNT) with dielectric constant about 300 The dielectric strength of the polymer matrix is improved to 41 kV/mm [29]. As a while as, this research has been depicted the electric field distribution in power cables with using new PVC nanocomposites material like (10wt.%Clay+15wt.% BaTiO3)/ PVC. The dielectric strength of the polymer matrix has been improved than

use only PVC insulation material in Power Cables. Whatever, the effect of nanoparticles for enhancing electric stress in XLPE insulation material has been studied in some recent refs. [30-32].

7. CONCULASION

Type and concentration of nanoparticles which are added to insulation material of power cable have been changed the dielectric constant of insulation material weather effect in changing in self-capacitance of insulator then it is effect on the electric field distribution. Using individual nanocomposite materials and multi-nanocomposite material instead of pure PVC insulation material decreases and increases the electric stress distribution from 2.14% to 89.2% according to type and concentration of nanoparticles. Adding multiple nanoparticles composed of (Clay, Al_2O_3, Fe_2O_3 and $BaTiO_3$) that have controlled in the electric field distribution inside power cable insulation. and the electrostatic field distribution inside the voids (Air, water and impurities). The main feature of using multiple nanocomposites insulation is the controlling in multidisciplinary electrical, mechanical and physical properties of the insulation of single-and three-core power cables.

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