JAUES

Journal of Al-Azhar University Engineering Sector

Vol. 14, No. 53, October, 2019, 1392-1402

# A REDUCED GAMMA RADIATION EFFECTS ON THE ELECTRICAL INSULATING CABLES USING XLPE/CLAY NANOCOMPOSITES

***WalaaAbd-Elmonem El-kattan[1], Mohamed Reda Ezz-eldin[1], El-Sayed Soliman A. Said[2], and El Saeed Abdul El-Aziz Othman[2]**

[1] Department of radiation safety, Egyptian Nuclear & Radiological-Regulatory Authority (ENRRA) Nasr City, Cairo, Egypt 11762

[2] Department of Electrical Engineering, AL-Azhar University, Cairo, Egypt

*Corresponding author E-mail: binkpenther@yahoo.com

## ABSTRACT

The direction to enhance the electrical, dielectrica and mechanical characteristics of insulating materials used in cables has become essential in order to plan new insulation systems used in the nuclear power plant. The current study is to investigate the improvement in these properties of Cross-linked polyethylene (XLPE) due to the addition of clay nanoparticles. The XLPE/Clay - Nanocomposites, with different weight fragments of nanoparticles up to 5 %, were fabricated using the mixing of XLPE with the aid of nanoparticles dispersion within the melted polymeric matrix. The irradiation experiment was performed on both the pure XLPE cable insulation and the filled one, by using $^{60}Co$ gamma-ray source with an irradiation dose rate of 1.87 KGy/h at 50 $^{o}C$ temperature of the chamber. The surface morphology of synthesized XLPE / Clay-nanocomposites was characterized by Scanning Electron Microscopy (SEM) and the dielectric and mechanical properties were measured. It is found that the breakdown strength of XLPE / Clay was increased with incorporating clay nanoparticles into their matrix compared to that case of unfilled XLPE. This reveals that XLPE / Clay - nanocomposites had better electrical properties, 1 % was found the optimal loading fraction of clay nanoparticle. This may be referring to the low surface energy of the clay nanoparticles that prevented the agglomeration of nanoparticles and repressed the free space charges resulting in a decrease in the capacitance and losses inside the nanocomposites. Furthermore, both electrical capacitance and dielectric constant are increased by about 20%, for the XLPE / Clay at 50 KGy compared to pure XLPE at 1% (the optimal loading fraction). Also, it is found that the optimal loading fraction of clay nanoparticle is 4% for improved mechanical properties in XLPE cable insulation.

**KEYWORDS: A Reduced Gamma Radiation Effects on The Electrical Insulating Cables Using Xlpe/Clay Nanocomposites .**

**تأثير أشعة جاما على خليط مركبات الطين النانوية مع** البولي إيثيلين المتصالب **المستخدمة في كابلات العازل الكهربائية**

**ولاء القطان[١] و محمد رضا[١] والسعيد عثمان[٢] و السيد سليمان[٢]**
**[١]قسم الأمان الإشعاعي - هيئة الرقابة النووية والإشعاعية القاهرة – جمهورية مصر العربية ،**
**[٢]قسم الهندسة الكهربية - كلية الهندسة – جامعة الأزهر – مدينة نصر -القاهرة – جمهورية مصر العربية ،**

**الملخص**
أصبح الاتجاه لتعزيز الخصائص الكهربائية والميكانيكية للمواد العازلة المستخدمة في الكابلات أمر ضروري من أجل تخطيط أنظمة العزل الجديدة المستخدمة في محطة الطاقة النووية. يهدف البحث الحالي إلى دراسة التحسن في هذه الخصائص للبولي إيثيلين المتصالب بسبب إضافة جسيمات الطين النانوية. تم تصنيع ، مع نسب مختلفة من الجسيمات النانوية تصل إلى ٥ ٪ ، وذلك باستخدام مزيج XLPE مع مساعدة من تشتت الجسيمات النانوية داخل المصفوفة البوليمرية المذابة. تم إجراء تجربة التشعيع على كل من عزل كبل النقي والتعبئة الممتلئة ، باستخدام مصدر أشعة غاما وهو كوبلت ٦٠ بمعدل جرعة تشعيع يبلغ ١.٨٧ كجم / ساعة عند درجة حرارة ٥٠ مئوية. اتسمت التشكل السطحي للمركبات النانوية المركبة بالتصوير المجهري الإلكتروني وكذلك تم قياس الخواص الكهربائية والميكانيكية. لقد وجد أن قوة انهيار قد زادت مع دمج الجسيمات النانوية الطينية في المصفوفة الخاصة بهم مقارنة مع تلك الموجودة في غير المملوءة. هذا يكشف أن s لها خواص كهربائية أفضل ، ووجد أن جزء التحميل الأمثل من جسيمات الطين النانوية هو ١ ٪ و الذي أدى إلى أن الطاقة السطحية المنخفضة للجسيمات النانوية الطينية حالت دون تكتل الجسيمات النانوية وقمعت شحنات المساحة الحرة مما أدى إلى انخفاض السعة داخل المركبات النانوية. علاوة على ذلك ، زادت السعة الكهربائية وثابت العزل الكهربائي بنحو ٢٠ ٪ و ٢٠ ٪ ، على التوالي عند جرعة اشعاعية ٥٠ كيلوجراي مقارنة مع كبل النقي في جزء التحميل الأمثل. أيضًا ، وجد أن نسبة التحميل الأمثل لجسيمات الطين النانوية هي ٤٪ لتحسين الخواص الميكانيكية في عزل كبل ،

**الكلمات المفتاحية : عزل الكابلات ، الطمي النانو متري ، التشعيع الجامي ، المنشأت النووية ، جهد الانهيار ، السعه الكهربائية ، مقاومة العزل ، المسح الإلكتروني المجهري، الخواص الميكانيكية**

## 1. INTRODUCTION

Approximately 1,000 km of cables are found in a nuclear power plant (NPP). The integrity of NPP cable insulation is essential for successful reactor shut-down after loss-of-coolant happening in containment, and life-extending of NPPs beyond their initial operating life requires the safe operation of cables. It is important for the safety and reliability of cables, the integrity of polymeric insulation materials. Cable insulation materials suffer from degradation due to exposure to heat and radiation over extended periods of time [1-2]. In spite of the recommendations presented in IAEA, it is report that the acceleration factor for absorbed dose should not exceed 250 KGy [3-4]. The value in many conducted experiments is often higher. Therefore, in our studies nanoparticles play an important role in improving electrical polymeric cable insulators for this purpose. Polymer (nano) composites have been extensively studied over a long period of time. Many studies have been conducted on nanopolymers, which are organic polymer compounds that are filled with inorganic filler (nanoparticles). Their properties combine the advantages of the two compounds as hardness, thermal stability, and flexibility. The nanoparticles are characterized by an increase in the interfacial area as compared with the ordinary composites. This interfacial area then creates a considerable volume fraction of the interfacial polymer with the properties different from the original polymers, even at low filler loadings [6-7]. Thus, studies into polymer nanocomposites have been underway in order to use them as an insulating material for electrical cables [8-9]. Many scientific research groups were interested in enhancing the electrical and mechanical properties of insulating cables used in NPP by functionalizing the surface of nanoparticles. Duckworth, Robert C., et al. [10] had used PVA / XLPVA nanodielectrics, in situ methods were developed to allow for the uniform dispersion of $SiO_2$, $TiO_2$, and $MgO_3$. Within the dispersion, agglomeration was found only for XLPVA nanodielectrics with $TiO_2$, with particles on the order of 100 μm in diameter at 3 wt %. Improvements in dielectric breakdown strength and conductivity were observed for certain configurations of PVA / XLPVA nanodielectrics between 1 and 5 wt %, depending on the specific nanoparticle composition. Greve, Eric

[11] Studies of the impact of functionalized $TiO_2$ in the dielectric performance of polyvinylidene fluoride (PVDF) / $TiO_2$ nanocomposite are given in This results showed that a suitable silane coupling agent is necessary for enhancing the nanoparticles dispersion, and hence in strengthening the polymer-particle interface. In addition, the dielectric permittivity of the designed samples was decreased as increasing the concentration of functionalized $TiO_2$ nanoparticles.The purpose of this study has been carried out to find the optimum mixing technique that leads to a better gain in mechanical, and electrical properties of XLPE based nanocomposites. Specifically, five combinations of incremental mixing intensity were applied to five groups of samples that were made of XLPE reinforced by 1 wt. %, 2.5 wt. %, 4 wt. % and 5 wt. % of nanoclay and results have been compared with an unfilled cable with increasing gamma radiation dose.

## 2 EXPERIMENTAL WORK

### 2.1 Raw and additive materials

The most widely electrical cable insulation used in the nuclear power plant is XLPE because of its perfect tensile properties, chemical and abrasion resistance, wear resistance, and high melting point. This performance gave it the label "Engineering Thermosets". Furthermore, the high voltage and low dielectric loss of XLPE cables insulation is one of the related important advantages. The higher of both resistance to thermal disfigurement and aging feature of the XLPE cable, permit it to carry large current under normal (90 $^{o}$C), emergency (130 $^{o}$C) or short circuit (250 $^{o}$C) conditions [12-13].

Clay is used widely in the synthesis of nanocomposites. They have an unique structure consisting of multilayers in the nanometer size of their thickness [14, 15]. They can be used as dielectric materials with excellent electrical properties. The nanoclays are formating strong and tough char structure via well-dispersed and intercalated / exfoliated silicate layers then shielding there is of the underlying polymer matrices from heat and mass transfer[16-17], nanoclays are contributing factor to the flame retardancy mechanisms.

### 2.2 Samples preparation

XLPE polymer material of the cable insulator blended with nanoclay use pilot extruder of screw diameter 45mm and compounding temperature 120 $^{o}$C to integrate the components homogenously. The novel nanocomposite cable insulation materials and the pure cable insulator granules had been cooled by water then dried by hot air at temperature (55-65) $^{o}$C The obtained compound XLPE and XLPE/clay granules had molded in hot press machine at temperature of 180 $^{o}$C for Period of 15 minutes then cooling till 60 $^{o}$C sheet thicknesses (1- 2) mm, with dimension 20x20 cm and Pressure 300 Pa.These molded sheets are cut into two types:

- Dumbbell shape samples according to ISO 527 for testing the mechanical characteristic.
- Cubic shape with dimensions 10x10x10 cm testing the electrical characteristic.

## 3. Testing and Measurements

### 3.1 Scanning Electron Microscope (SEM)

The samples microstructure surfaces were examined using the Scanning Electron Microscope (SEM) of type Jeol-T 20 – 200,000 (Japanese Brand) at various magnifications at different zones of composite material [18].

**Fig. 1: Scanning Electronic Microscope SEM (Jeol – KSM 5400)**

## 3.2 Mechanical Measurements

Tensile strength and elongation tests were done according to BS EN 60811 as shown in Fig. 2. These were done in El-Sewedy Electric –Egyplast laboratory measurements in Egypt. Dumbbell shape samples were cut parallel and perpendicular to the extrusion direction [19]. All the tests were performed at room temperature.

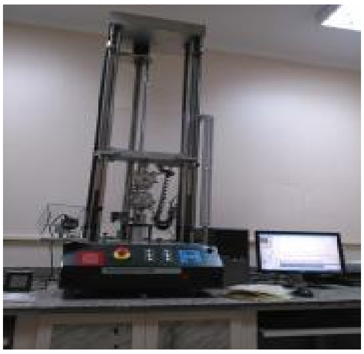


**Fig. 2: Mechanical measurements tester, (BS EN 60811)**

## 3.3 Electrical Measurements

The capacitance and dielectric properties of the materials were measured at room temperature (25 ± 1°C) by tester ASTM D-150[20] electrodes were deposited onto both surfaces of the specimens by sputtering. The diameter of sputtered electrodes is 7cm shown in Fig. 3.

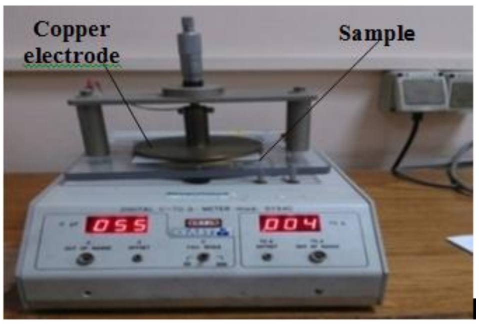



**Fig. 3: Capacitance tester *(ASTM-D150)*, with two sputtered electrodes**

The breakdown voltage and the leakage current were carried according to the American National Standard (D 149-97a) [21]. These measurements were done in the National Institute for Standards / the Ministry of Scientific Research, Egypt. The Alternating voltage at power frequency (50 Hz) was applied to a test sample and the voltage is increased from zero until the dielectric failure of the test sample occurs. The test voltage was applied using simple test electrodes on opposite faces of specimens. The suitable rate-of-rise is 1500 V/s and an average time of breakdown was 18 s. The Test was repeated 2 times.

### 3.4 Gamma-ray radiation measurements

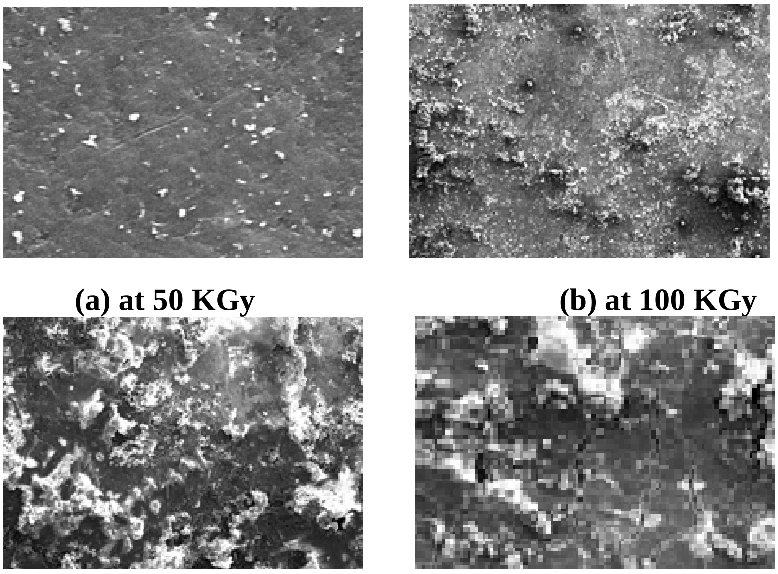
The gamma radiation source used for Irradiation of Samples was $^{60}$Co source of gamma facility Canadian Gamma cell (Ge-220) and represented at Egyptian Atomic Energy Authority (EAEA), National Center for Radiation Research and Technology (NCRRT), Cairo, Egypt. The device can produced irradiator activity 2651 curie and dose rate1.87 KGy/h at a temperature of chamber 50°C.

## 4 RESULTS AND DISSECTION

The system measurements will be accomplished as follows

### 4.1 Scanning electron microscopy (SEM)

The Scanning Electron Microscope used to examine the samples microstructure surfaces, are shown in Fig. 4 (a, b, c and d). the SEM micrographs of XLPE polymer material blends with 1wt% of nano-clay with exposure to different irradiation doses, 50,100,300and 500 KGy as respectively are represented By observing the SEM micrographs, the trend of good mechanical properties is well clear. The changes in density value are associated with changes in crystallinity degree and morphology of polyethylene. XLPE has a lamellar and spherulitic morphology, an increase in crystallinity, hence an increase in density, of polyethylene increases the stiffness and tensile yield strength of material.



**(a) at 50 KGy** **(b) at 100 KGy**

**(c) at300 K** **(d) at 500 KGy**

**Fig. 4: XLPE with 1% of nano-Clay contents as a function of irradiation doses,**

### 4.2 Mechanical properties of the cable

Figure 5 shows the value of tensile strength for (1%, 2.5%, 4% and 5%) XLPE/clay which are (15.69), (21.48), (17.87), (11.06) N/mm$^2$ respectively, without exposed to radiation. While exposure the samples to different radiation dose, it is observed that tensile strength is gradually decayed as the radiation dose increase to 50 kGy, then the particle are rearranged together and cross-linked. This causes the filling to be at the surface area, observe tensile strength began to increase again at 100 kGy for 4% and 5% XLPE/clay than the other two types. The changed reactions appeared at the interfaces have failed to characterize the exact role of nanoparticles in enhancing the features of clay nanocomposites compound with XLPE cable insulation under the effect of gamma radiation. The common suggestion in all proposed results is that structural properties in the interface layer are changed, which results in structural and chain dynamic changes around the clay nanoparticles. This may be a good reason for the change in the surface structure of nanocomposite. Shown in fig.5, once mixing the cable XLPE insulation with 4% of the nano-clay, it gives the best performance of resistance to radiation. It is noted that the dose of (50- 300) KGy causes gradually a decrease tensile strength with stability for a period. The interruption is gradual rather than rapid.

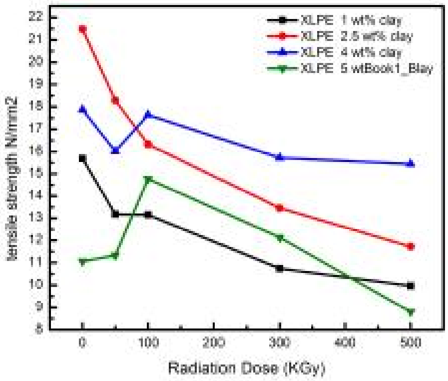



**Fig. 5: Tensile strength for different XLPE/ Nanoclay concentration cables that exposed to different radiation doses**

It is also noticeable that, when the nanoclay is injected in, different proportions and better mechanical behavior for the most cable corresponding to radiation dose at 50kGy as shown in fig. 6. The elongation value of XLPE / clay is 465.36, 456.94, 415.2 and 194.13 for the following mixing percentages (1%, 2.5%, 4%, and 5%), respectively, without exposure to gamma irradiation. In the case of an increase in radiation doses to 100kGy, there is an exponential decrease in the value of elongation for both cables in proportions 1% and 2.5% while the elongation value of the other two type's increases. As the radiation dose increases to 200 and 500, we find that the elongation of all the cables is gradually decreasing. We note that the 4% cable retains a more stable behavior with increased radiation and represents the ideal value of mixing. Thus, the mechanical properties of cable insulators are improved at low doses of radiation, when mixed with 4% percentages of nanoclay.

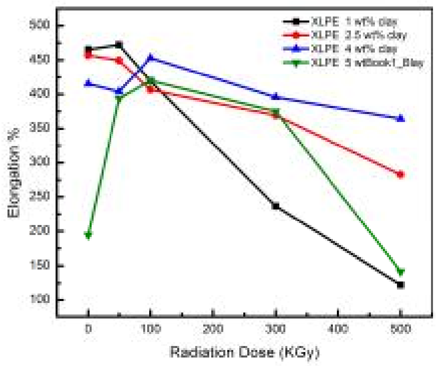



**Fig.6: Percentage elongation for different XLPE/ Nanoclay concentration cables that exposed to different radiation doses**

## 4.2 Electrical properties

The ac breakdown voltages of all tested cable samples with nanocaly shown in fig. 7. It shows variable values with increase the radiation dose. For increase, the area under the curve represents the enhancement in breakdown voltage so gives beast electric property for cable insulation, it is also shown that the 1% and 4% XLPE/Clay curves offers the better breakdown voltage in the range of radiation doses. It is also cllear that when cables are exposed to low doses of radiation, they increase the interfacial interaction region as well as, improve the electric property. At 100 kGy the value of the breakdown voltages are 30kV, 29KV, 30kV and 27kV for 1%, 2.5%, 4% and 5% respectively. As the radiation dose increases, It is found that the value of the breakdown voltage for all samples except the 5% is gradually decreasing. The density of the internal structure of the material is increased as a result of the removal of the stresses and is more suitable for this electrical characteristic. This is achieved with material of mixing rates of 1% and 4%. The nanofiller has no linear characterization. A lot of testes and results are, therefore, required for the neat description of the under test material used for cables.

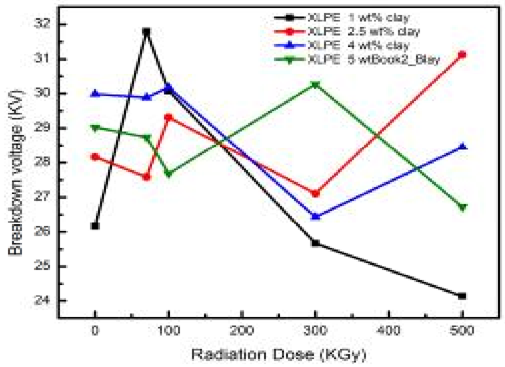



**Fig.7: Breakdown strength for different XLPE/ Nanoclay concentration cables that exposed to different radiation doses**

Figure 8 shows the leakage current for different XLPE/Clay concentration used for cables that exposed to different gamma irradiation doses, that it starts at zero radiation dose, the value of leakage current is (0.8 mA, 1 mA, 1.2 mA, and 0.6 mA) for 1%, 2.5%, 4%, and 5% nano clay concentration respectively, and quickly increases to a final value of 1.6 mA for XLPE with 1% and 4% nanoclay at 100 kGy. By increasing the radiation dose at 300, the leakage current value increased for XLPE/Clay with 2.5%, as opposed to all other species. This is the way that good insulation behaves. The other change may be that, instead of going up quickly to the end value and the leveling out, the leakage current simply may continue to increase and decrease with different radiation dosing rate.

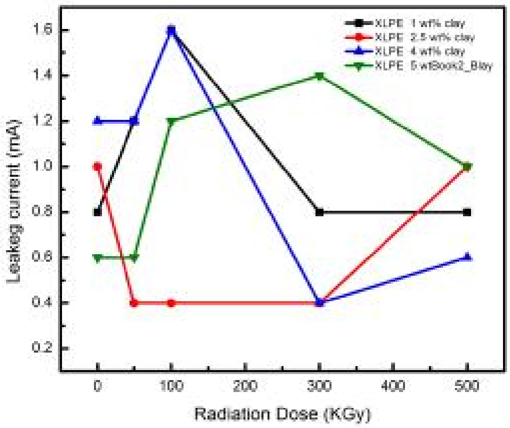



**Fig.8 : The leakage current for different XLPE/ Nanoclay concentration cables that exposed to different radiation doses**

The capacitance for different XLPE/Clay cables insulation is decreased with increasing the radiation dose except for 5wt %, its capacitance jumps to 75pF at 50 kGy as shown in Fig. 9. On the other hand, fillers of 1%, 2.5%, and 4% cause gradually decay of cable insulation capacitance. During radiation doses from 100 kGy to 300 kGy, find that all insulations with different mixing rates have stability. XLPE assorted with the nanoclay has a distinguish changes of the insulation capacitance at each filing time with the radiation doses, zero dose yields (74pF) for XLPE/Clay with 1% nano filler, while for example, 5% produces 60pF. Improved electrical capacitance is more appropriate, when mixing the cable with 1% of the nano for stability with increased radiation dose.

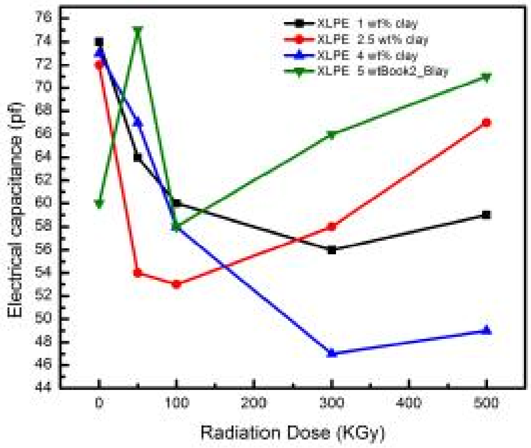



**Fig. 9: Capacitance for different XLPE/ Nanoclay concentration cables that exposed to different radiation doses**

The dielectric constant as shown in fig.10, has similar behavior corresponds to the electrical capacitance characteristic in the previous fig.9. During the low doses of radiation (50 to KGy), high significant increasing of dielectric constant for XLPE/clay insulation with the concentration of 5wt % , the concentrations (1%, 2.5%, and 4%) cause gradual decay of dielectric constant. The other doses of radiation from (200 - 500KGy), showed gradually increase of dielectric constant for all XLPE/clay insulators.

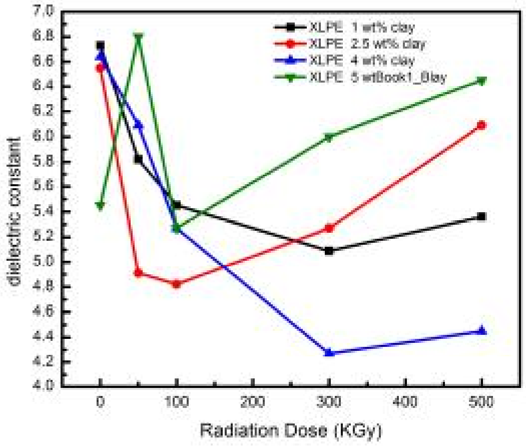



**Fig. 10: Dielectric constant for different XLPE/Nanoclay concentration cables that exposed to different radiation doses.**

## 5. COMPARISON BETWEEN PURE XLPE INSULATION MATERIAL AND AN IDEAL CASE OF XLPE / NANOCLAY IN CABLE

The XLPE /Clay in insulated cable at 4% concentration had the highest elongation and tensile strength without exposure to gamma radiation as shown in Figs. 11 and 12, while at a dose of 50 KGy and 100 KGy the elongation values are 400 and 550 for the XLPE / Clay cable and for the pure cable XLPE are 360 and 450 respectively. Tensile strength is an indication of the strength of the insulation material through a tensile test, but not sufficient alone to judge its suitability to cables. It must be accompanied by a measurement of elongation properties to ensure that no cracks and brittleness are made to the cable insulation. The nanoclay is a good indicator of improved mechanical properties of the insulation of XLPE at low doses

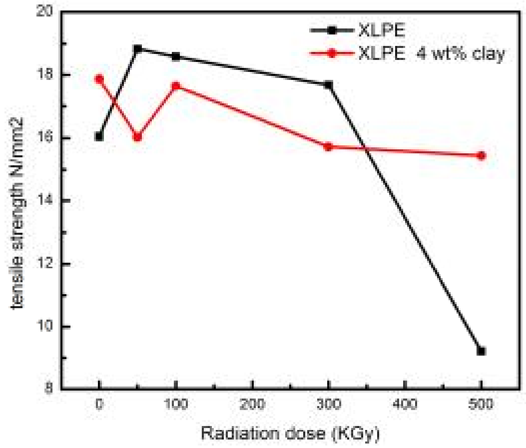



**Fig (11): Comparison between XLPE and XLPE / Nanoclay specimen with 4% concentration for tensile strength properties, when exposed to different radiation doses.**

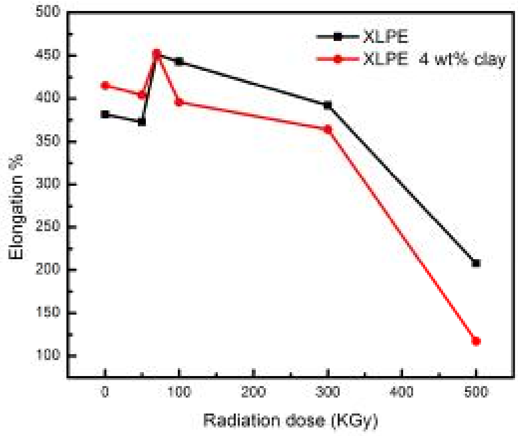



**Fig (12): Comparison between XLPE and XLPE/Nanoclay specimen with 4% concentration for elongation properties, when exposed to different radiation doses.**

Comparing the specimen mixed by nanoclay for 1% concentration with the pure XLPE insulation as shown in Fig. 13, the highest value of AC breakdown voltages was 32 KV for XLPE / Clay cable while 27 KV for XLPE radiated at 50 KGy. The internal structure of the material becomes more intense and the porosity and interior voids decrease as a result of the removal of the mechanical stresses influence the material when exposed to small doses of radiation as given at 50 KGy and 100 KGy. The material becomes more suitable for electrical properties and leading to improved breakdown voltages and leakage current. From this, we conclude that nanocaly has functioned to improve the electrical properties when using to plain XLPE in cable insulation.

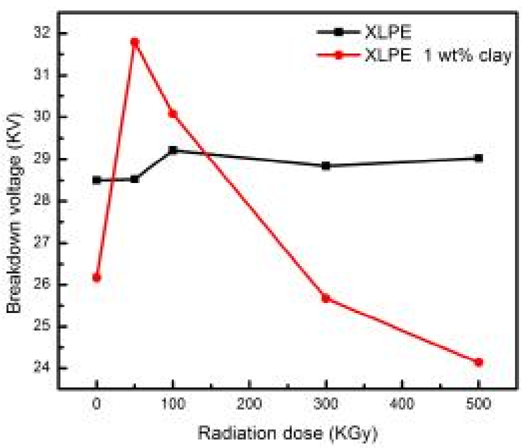



**Fig (13): Comparison between XLPE and XLPE / Nanoclay specimen with 1% concentration for breakdown voltage properties, when exposed to different radiation doses.**

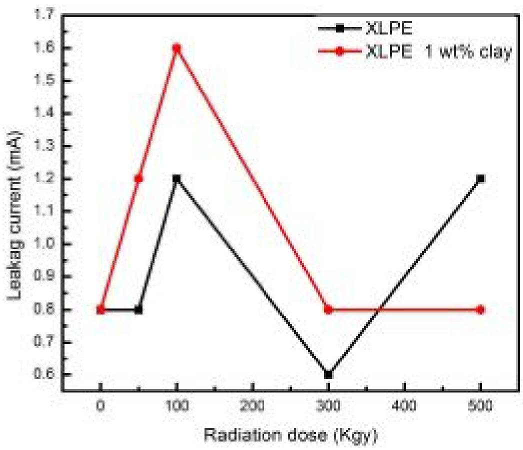



**Fig (14): Comparison between XLPE and XLPE / Nanoclay specimen with 1% concentration for leakage current properties, when exposed to different radiation doses.**

Figs. 15 and 16 show the increase in the values of electric capacitance and dielectric constant characteristics of the XLPE specimen mixed with nanoclay for the pure XLPE cable at 50 KGy. As the radiation dose increases to 100 KGy and 300 KGy, these two properties gradually decrease with the XLPE / Clay cable and, conversely, slightly increase when using pure XLPE.

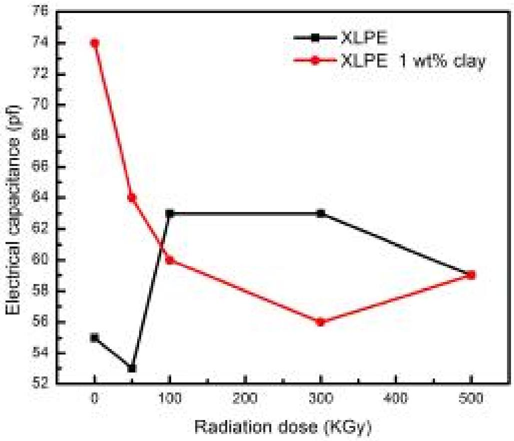



Fig (15): Comparison between XLPE and XLPE / Nanoclay specimen with 1% concentration for capacitance properties, when exposed to different radiation doses.

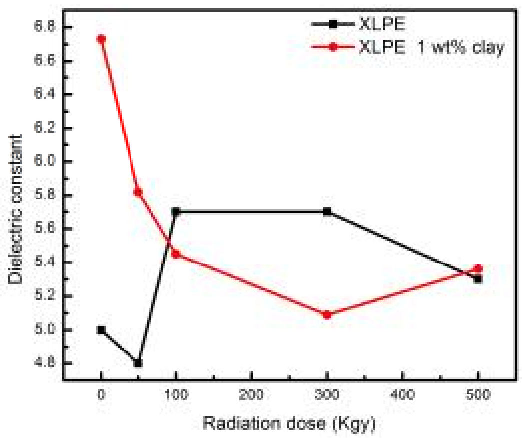



Fig (16): Comparison between XLPE and XLPE / Nanoclay specimen with 1% concentration for dielectric constant properties, when exposed to different radiation doses.

## 6. CONCLUSIONS

Nanocomposites displayed a significant potential improvement in the physical properties compared to the conventional composites. Blending mechanism plays a critical role in the transference the normal composites to nanocomposites. This study simultaneously compares four types of mixing technique for identifying the optimum mixing technique that maximized gain in the various electrical , dialectical and mechanical properties. Compares the XLPE / Clay insulation with the pure XLPE specimen at the optimum value of mixing the clay material under gamma irradiation effect. The breakdown voltages and the leakage current are 32 kV, 1.2 mA respectively, for XLPE / Clay with 1% at radiation 50KGy, realize an improvement of the electrical properties by 14% w.r.t the pure XLPE. Furthermore, 20% higher of electrical capacitance and dielectric constant are accomplished for the XLPE/Clay at 50 KGy compared to pure XLPE at optimal loading fraction. Hover an optimal loading fraction of clay nanoparticle is found at 4% for improved mechanical properties in XLPE insulation used for cables. This structure material could therefore, be used dominantly for high strength and low weight applications with.

## Acknowledgment

The authors would like to thanks *El-Sewedy Electric –Egyplast group, Egypt and Eng. Abd El-Basit.*, for his help in the different measurements.

## REFERENCE:

[1]. Bowler, N., & Liu, S. (2015). Aging Mechanisms And Monitoring Of Cable Polymers. International Journal Of Prognostics And Health Management, 6.
[2]. AC09446779, A. (Ed.). (2012). Assessing And Managing Cable Ageing In Nuclear Power Plants. Internat. Atomic Energy Agency.
[3]. Aggarwal, S. K. (2000). Assessment And Management Of Ageing Of Major Nuclear Power Plant Components Important To Safety: Incontainment Instrumentation And Control Cables (Volumes 1 &2). IAEA-TECDOC-1188.
[4]. Przybytniak, G., Boguski, J., Placek, V., Verardi, L., Fabiani, D., Linde, E., & Gedde, U. W. (2015). Inverse Effect In Simultaneous Thermal And Radiation Aging Of EVA Insulation. Express Polymer Letters, 9(4).
[5]. Balazs, A. C., Emrick, T., & Russell, T. P. (2006). Nanoparticle Polymer Composites: Where Two Small Worlds Meet. Science, 314(5802), 1107-1110.
[6]. Krishnamoorti, R., & Vaia, R. A. (2007). Polymer Nanocomposites. Journal Of Polymer Science Part B: Polymer Physics, 45(24), 3252-3256.

[7].
Polyethylene/Metal-Oxide Nanocomposites For Ultrahigh-Voltage Insulating Materials. Advanced Materials, 30(4), 1703624.

[8]. Chung, T. M. (2012). Functionalization Of Polypropylene With High Dielectric Properties: Applications In Electric Energy Storage. Green And Sustainable Chemistry, 2(02), 29.

[9]. Duckworth, R. C., Aytug, T., Paranthaman, M. P., Polyzos, G., & Leonard, K. J. (2018). Radiation Resistant Electrical Insulation Materials For Nuclear Reactors (No. ORNL/SPR-2017/580). Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States).

[10]. Khodaparast, P., & Ounaies, Z. (2013). On The Impact Of Functionalization And Thermal Treatment On Dielectric Behavior Of Low Content Tio 2 PVDF Nanocomposites. IEEE Transactions On Dielectrics And Electrical Insulation, 20(1), 166-167.

[11]. Kocar, I., & Ertas, A. (2004, May). Thermal Analysis For Determination Of Current Carrying Capacity Of PE And XLPE Insulated Power Cables Using Finite Element Method. In Proceedings Of The 12th IEEE Mediterranean Electrotechnical Conference (IEEE Cat. No. 04CH37521) (Vol. 3, Pp. 905-908). IEEE.

[12]. Lofaro, R., Grove, E., Villaran, M., Soo, P., & Hsu, F. (2001). Assessment Of Environmental Qualification Practices And Condition Monitoring Techniques For Low-Voltage Electric Cables: LOCA Test Results (No. NUREG/CR-6704 (Vol. 1); BNL-NUREG-52610). Brookhaven National Lab.(BNL), Upton, NY (United States).

[13]. Nelson, J. K. (2007, October). Overview Of Nanodielectrics: Insulating Materials Of The Future. In 2007 Electrical Insulation Conference And Electrical Manufacturing Expo (Pp. 229-235). IEEE.

[14]. Henk, P. O., Kortsen, T. W., & Kvarts, T. (1999). Increasing The Electrical Discharge Endurance Of Acid Anhydride Cured DGEBA Epoxy Resin By Dispersion Of Nanoparticle Silica. High Performance Polymers, 11(3), 281-296.

[15]. Kaynak, C., & Ibibikcan, E. (2014). Contribution Of Nanoclays To The Flame Retardancy Of Polyethylene-Based Cable Insulation Materials With Aluminum Hydroxide And Zinc Borate. Journal Of Fire Sciences, 32(2), 121-144.

[16]. David, E., Fréchette, M., Zazoum, B., Daran-Daneau, C., Ngô, A. D., & Couderc, H. (2013). Dielectric Properties Of PE/Clay Nanocomposites. Journal Of Nanomaterials, 2013, 65.

[17]. Lee, B. C., Yoo, J. S., Ogay, V., Kim, K. W., Dobberstein, H., Soh, K. S., & Chang, B. S. (2007). Electron Microscopic Study Of Novel Threadlike Structures On The Surfaces Of Mammalian Organs. Microscopy Research And Technique, 70(1), 34-43.

[18]. Standard, A. S. T. M. (2003). Standard Test Method For Tensile Properties Of Plastics. ASTM International. Designation: D, 638, 1-13.

[19]. American Society For Testing And Materials. (2013). Standard Test Method For Dielectric Breakdown Voltage And Dielectric Strength Of Solid Electrical Insulating Materials At Commercial Power Frequencies. ASTM.

[20]. Mathes, K. N. (2000). ASTM Committee D09—A History Of Success. In Electrical Insulating Materials: International Issues. ASTM International.