ISSN No:-2456-2165

Enhancement of Dielectric and Tensile Strengths for Tree Retardant Cross-Linked Polyethylene (TR-XLPE)

Loai Nasrat, Abd Allah Ibrahim
Electrical Power and Machines Eng. Dept.
Aswan University, Aswan, Egypt

Esraa Sayed
Kom Ombo Industrial Secondary School.
Aswan, Egypt

Abstract- The use of the polymeric materials in high voltage applications is considered especially interesting in the electrical and industrial materials sectors. In this context, the purpose of this paper is to improve the electrical properties of tree retardant cross-linked polyethylene (TR-XLPE) with respect to mechanical characteristics by adding Kaolin filler with 15%, 30%, 40% and 50% concentration percentages. The dielectric strength of the composites was tested under several conditions such as (dry, wet and salty wet at (20000µS/cm, 30000µS/cm and 50000µS/cm)).

Tensile strength test was applied to investigate the mechanical properties of TR-XLPE after adding Kaolin filler with 15%, 30%, 40% and 50% concentration percentages. Soft program (Curve fitting) is used to select the most proper equation between dielectric strength values under each condition and different percentages of Kaolin filler also between tensile strength and the same percentages of Kaolin filler. Grey Wolf Optimizer (GWO) was applied to find the best suitable percentages of Kaolin filler to obtain the best optimal values of dielectric strength and tensile strength.

Keywords – *TR-XLPE; Kaolin; Dielectric strength; Tensile strength; GWO.*

I. INTRODUCTION

Underground cables are an important part of any Power distribution system. These cables are laid in ducts or may be buried in the ground. Unlike in overhead lines, air does not form part of the insulation and the conductor must be completely insulated. This means that the selection of cable must be based on the losses, cost and environmental factors surrounding [1].

Since the 1960s, polyethylene and later cross-linked polyethylene (XLPE) have been used as insulation materials for low, medium and high voltage power cables that operate in both wet and dry environments on underground electric utility systems. In the early 1980s, tree retardant cross-linked polyethylene (TR-XLPE) was introduced which claimed improved cable performance compared with XLPE. The degradation of XLPE insulation due to moisture (water trees) has been a trouble for many years and extensive studies have been made to improve the resistance of XLPE to water treeing. Water trees result from the combined effects of water, ionic impurities and electrical stress enhancements in the insulation and at the semiconducting shield/insulation interfaces. TR-XLPE insulation materials are expected to retard the growth of water trees in a manner that will slow cable aging when operated in wet environments [2-4].

Kaolin has particle size of 42 µm and density 2.23 g/cm^3 and melting point 1755°C.It is available in high purity and large quantity at low cost [5].

Optimization is the act of obtaining the best result under given circumstances. Optimization can be defined as the process of obtaining the conditions that give the maximum or minimum value of a function. Thus without loss of generality, optimization can be taken to mean minimization since the maximum of a function can be found by seeking the minimum of the negative of the same function [6].

➢ *Grey Wolf Optimizer (GWO)*

Mirjalili for the first time simulated the mathematical model of the behavior of the Grey Wolf Optimizer (GWO). GWO is a meta-heuristics natural inspired method belongs to swarm intelligence (SI) algorithms. SI is "The emergent collective intelligence of groups of simple agents". The inspirations of SI techniques originate mostly from natural colonies, flock, herds and schools. It imitates the grey wolves behavior in attacking and hunting a prey. Grey wolves prefer living in packs with a robust social dominant hierarchy.

The first three fittest wolves are considered as alpha, beta and delta who guide other remaining wolves (*ω)* toward promising areas of the search space. For an optimization problem, the best solution is represented by alpha wolves, the second and third best solutions are beta and delta wolves while omega wolves provide all the other solutions [7-8].

II. SAMPLES PREPARATION

The preparation of TR-XLPE depends on different parameters such as the ratio of TR-XLPE, types and concentrations of filler that affect on properties of the base material and final product. Samples have been prepared in the laboratory of the polymers and pigments department National Research Center (NRC). Polymer composite was prepared by mixing different ratios of Kaolin filler (0, 15, 30, 40 and 50 wt. %). The samples preparation were operated at the room temperature (25°C ±1), until curing occurred. The samples codes were represented in the table (I) with different concentration of Kaolin filler.

Table I

Samples code	TR-XLPE ratio	Kaolin filler percentage (%)
Blank	100	0
$Kaolin_{15}$	85	15
$Kaolin_{30}$	70	30
$Kaolin_{40}$	60	40
$Kaolin_{50}$	50	50

Dielectric strength is measured through the thickness of specimen (which is equal to 1 mm) and it is expressed in (kV/mm). Mechanical tests such as: tensile strength test is performed to illustrate the ability of composite samples to withstand the mechanical forces. The dimensions of the sample are 5 cm length and 1 mm thickness for tensile strength.

III. RESULTS AND DISCUSSIONS

➢ *Dielectric break down strength test*

The dielectric strength of a material is a measure of the electrical strength of an insulator. It is defined as the maximum voltage required to produce a dielectric breakdown through the material and is expressed in terms of Volts per unit thickness. The higher the dielectric strength of a material the better an electrical insulator it makes.

The failure is characterized by an excessive flow of current (arc) and by partial destruction of the material. Dielectric strength is measured through the thickness of the specimen (which is equal to 1mm) and is expressed in volts per unit of thickness. Samples are in the form of disc with diameter 5 cm and thickness 1 mm. For each test, the average result of five samples has been taken to minimize the error. Fig (1) shows the circuit used for dielectric break down strength test.

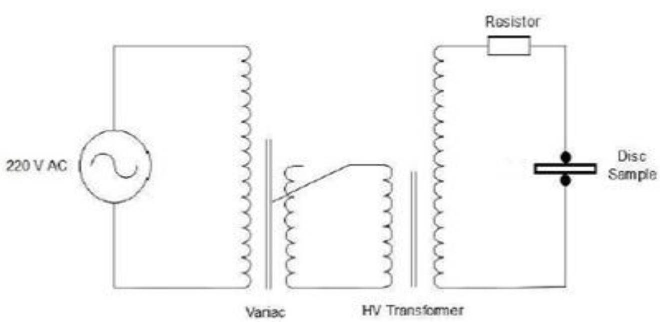

Fig 1:- Schematic diagram for the dielectric strength testing circuit.

By using curve fitting methods, we can create access and adjusted curve fitting objects. That allowed to like plot and integrate, to perform operations that uniformly process the entirety of information encapsulated in a curve fitting object. Dielectric properties were inspected at five conditions; dry, wet and salty wet at (20000 µS/cm, 30000µS/cm and 50000µS/cm).

The average of dielectric strength (kV/mm) for TR-XLPE with different percentages of Kaolin filler under several conditions, i.e.: dry, wet and salty wet at 20000µS/cm, 30000µS/cm and 50000µS/cm shown in table (II) and Fig (2).

Table II

Kaolin filler percentages (%)	The average of dielectric strength (kV/mm) for five samples under several conditions				
	Dry	Wet	Salty wet (20000 µS/cm)	Salty wet (30000 µS/cm)	Salty wet (50000 µS/cm)
0	31.03	26.52	22.12	20.94	17.58
15	33.83	29.79	26.24	24.22	21.57
30	36.11	32.09	29.56	27.68	25.23
40	31.09	26.14	23.04	20.59	17.86
50	23.29	20.24	19.51	17.12	15.76

From table (II), It can be observed that the dielectric strength of TR-XLPE was improved by adding Kaolin filler until definite value then the dielectric strength decreased, the dielectric strength decreased in wet condition as compared with those in dry condition and the exposure to salt water solution drastically affected the dielectric strength where the dielectric strength is inversely proportional with the amount of salinity.

Applying Curve fitting (regression analysis) using Matlab program, the best curve fitting for the obtained results from the test are shown in Fig (2) for dry condition. Representing the data by a 3rd degree polynomial equation to minimize the error as possible we get.

The equations of curve fitting results for the dielectric strength of blends under dry, wet and salty wet at (20000µS/Cm, 30000µS/Cm and50000µS/Cm) are as follows:

- 1-Under dry condition is:

$$Y = -0.00029*X^3 + 0.0082*X^2 + 0.16*X + 31 \quad (1)$$

- 2-Under wet condition is:

ISSN No:-2456-2165

$$Y = -0.00022*X^{3} + 0.0021*X^{2} + 0.28*X + 26 \quad (2)$$

- 3- Under salty wet at 20000µS/cm condition is:

$$Y = -5.6e^{-0.005X\wedge 3} - 0.0079*X^{2} + 0.48*X + 22 \quad (3)$$

- 4-Under salty wet at 30000µS/cm condition is:

$$Y = -7.9e^{-0.005X\wedge 3} - 0.0058*X^{2} + 0.4*X + 21 \quad (4)$$

- 5- Under salty wet at 50000µS/cm condition is:

$$Y = 9.9e^{-0.006X\wedge 3} - 0.012*X^{2} + 0.54*X + 17 \quad (5)$$

Where Y parameter is the dielectric strength value (KV/mm) at all different conditions, X is the percentage of concentration of Kaolin filler in the samples.

GWO was applied to find the best percentage of Kaolin filler by inserting the negative of the equations (1-5) in the code of the program to obtain the best optimal value of dielectric strength in each condition.

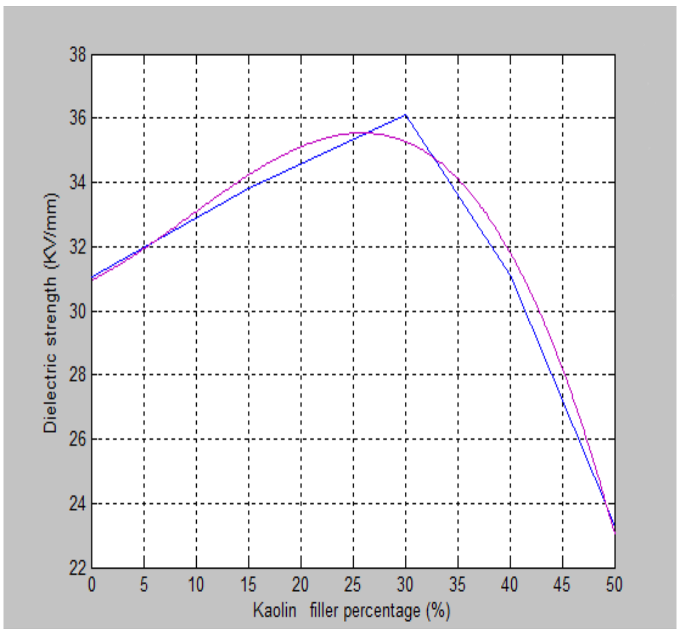

Fig 2:- Dielectric strength of TR-XLPE/Kaolin under dry condition.

After applying GWO under dry condition by inserting the negative of equation (1), the best solution obtained by GWO is 25.94% of Kaolin filler to obtain the best optimal value of dielectric strength as evident in Fig (3).

At wet condition by inserting the negative of equation (2), the best solution of Kaolin filler percentage obtained by GWO is 24.02% to obtain the best optimal value of dielectric strength.

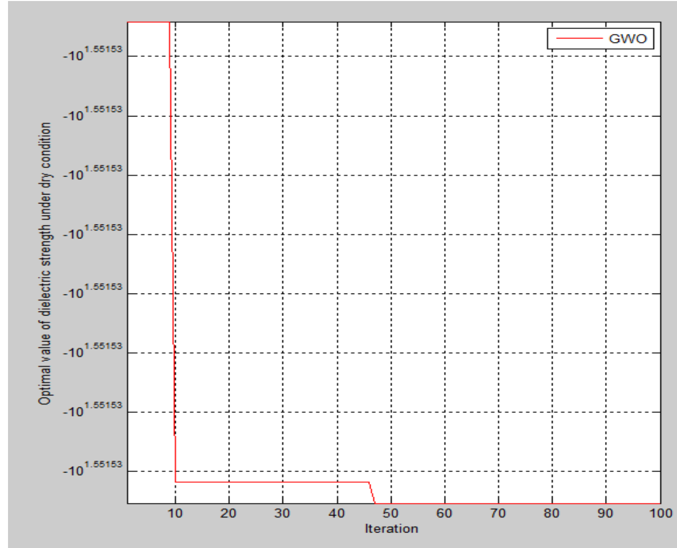

Fig 3:- The optimal value of dielectric strength under dry condition.

At salty wet condition the best solution obtained by GWO is 30% of kaolin filler to obtain the best optimal value of dielectric strength for 20000 µS/cm and 30000 µS/cm while 22.51% of Kaolin filler to obtain the best optimal value of dielectric strength for 50000µS/cm.

Note: The optimal value of dielectric strength is negative in Fig (3) because of inserting a negative sign to equation (1).

➢ *Mechanical analysis*

Tensile strength tests (TS) are carried out in order to illustrate the ability of TR-XLPE filled with different percentages of Kaolin filler to withstand the mechanical forces.

➢ *Tensile strength test*

It can be defined as the maximum tensile sustained by the material being tested to its breaking point.

Tensile strength = F/A.

It is measured in units of force (F) divided by units of area (A). The tensile strength of TR-XLPE filled with 0%, 15%, 30%, 40% and 50% of Kaolin filler has been tested.
Fig (4) shows the tensile strength of TR-XLPE with kaolin filler.

From Fig (4) it's obviously seen that the tensile strength increased gradually with increasing the percentage of Kaolin filler until 40% then the tensile strength decreased.

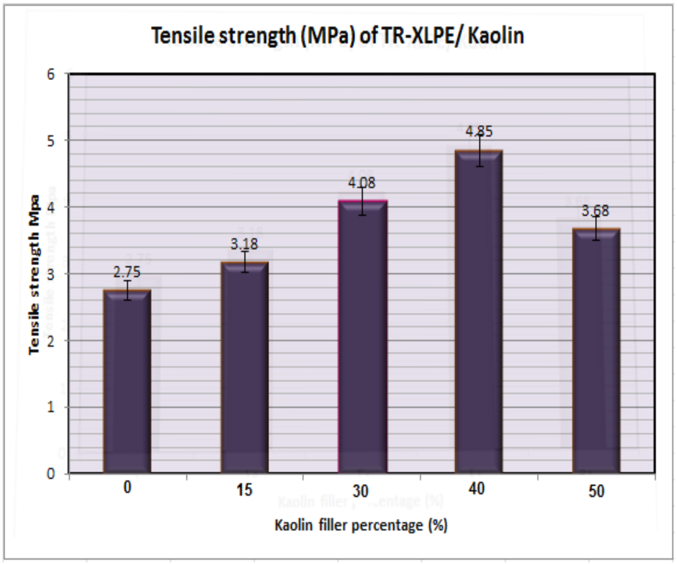

Fig 4:- Tensile strength (MPa) of TR-XLPE/Kaolin

Applying Curve fitting (regression analysis) using Matlab program, the best curve fitting for the obtained results from the test are shown in Fig (5).

The equation of curve fitting results for the tensile strength of blends is:

$$Y = -0.00011*X^3 + 0.007*X^2 - 0.061*X + 2.8 \qquad (6)$$

Where Y parameter is the tensile strength (MPa), X is the percentage of concentration of Kaolin in the samples. GWO was applied to find the best percentage of Kaolin filler by inserting the negative of the equation (6) in the code of the program to obtain the best optimal value of tensile strength.

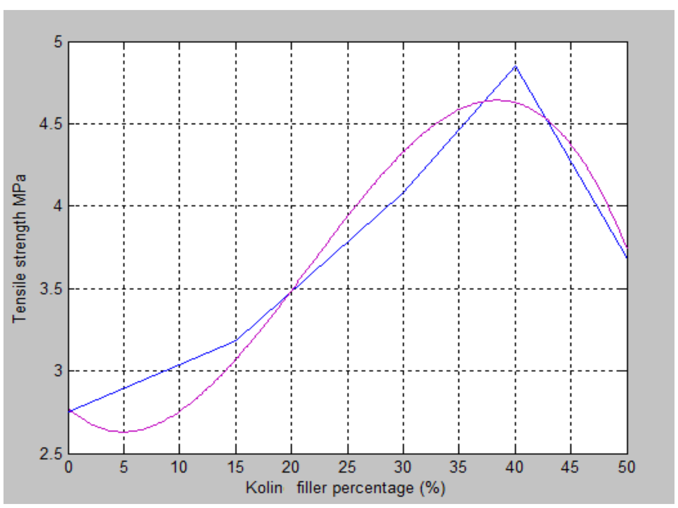

Fig 5:- Tensile strength (MPa) of TR-XLPE/Kaolin

After applying GWO by inserting the negative of equation (6), the best solution obtained by GWO is 37.49% of Kaolin filler to obtain the best optimal value of tensile strength as evident in Fig (6).

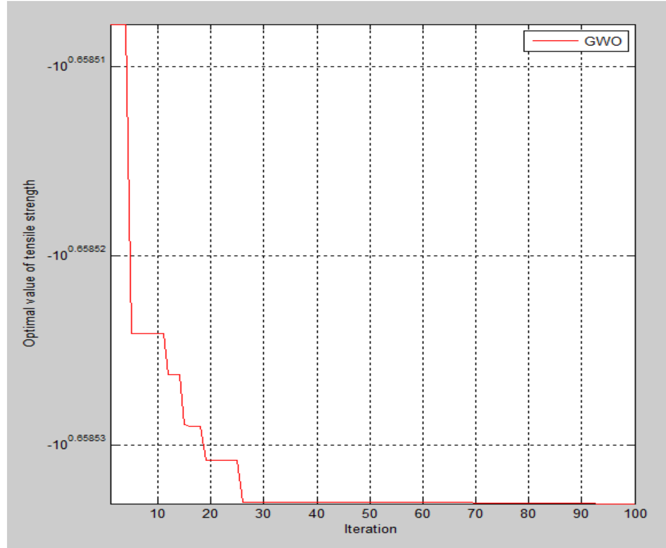

Fig 6:- The optimal value of tensile strength.

Note: The optimal value of tensile strength is negative because of inserting a negative sign to equation (6).

From this study both dielectric and tensile strengths increased with increasing the Kaolin filler percentage until definite value then they decreased. This is due to the saturation that happened in the lattice of TR-XLPE and the more addition of Kaolin filler to TR-XLPE made the composites brittle so both dielectric and tensile strength decreased, also the values of dielectric strength in wet and salty wet conditions are less than dry condition. This is due to increasing flow of leakage current that increases the opportunity of break down to occur.

IV. CONCLUSION

The addition of Kaolin filler had resulted some improvement in the electrical and mechanical properties of TR-XLPE. GWO gives definite indications of filler percentage to obtain the optimal values of dielectric strength and tensile strength.

It can be concluded that, the suitable percentages of Kaolin filler can be added to TR-XLPE which determined by applying GWO are:

➢ *In electrical properties*

- *Under dry condition*

  The best solution obtained by GWO is 25.94% of Kaolin filler to obtain the best optimal value of dielectric strength.

- *Under wet condition*

  The best solution obtained by GWO is 24.02% of kaolin filler to obtain the best optimal value of dielectric strength.

- *Under salty wet condition*

  The best solution obtained by GWO is 30% of kaolin filler to obtain the best optimal value of dielectric strength for 20000 µS/cm and 30000 µS/cm while 22.51% of Kaolin filler to obtain the best optimal value of dielectric strength for 50000µS/cm.

- *In mechanical properties*

The best solution obtained by GWO is 37.49% of Kaolin filler to obtain the best optimal value of tensile strength.

It may be recommended to use the average between 22.51% and 37.49% of Kaolin filler in the blend for the industrial application.

ACKNOWLEDGEMENTS

The authors would like to thank the staff of High Voltage Laboratory, Electrical Engineering Dept. Aswan University and National Research Center, Polymers and pigments Dept.; where most of the samples preparation and experimental work were carried out.

REFERENCES

[1]. J. R. Lucas, "High Voltage Engineering", Book, 2001.
[2]. S. Pelissou, R. Harp and R. Bristol, "A Review of Possible Methods for Defining Tree Retardant Cross Linked Polyethylene (TR-XLPE)", IEEE Journals & Magazines, IEEE Electrical Insulation Magazine, Volume: 24 , Issue: 5, PP. 22 – 30, 2008.
[3]. P. J. Caronia, P. J. Brigandi, T. J. Person and S. Cree, "A Next Generation Advanced Water Tree-Retardant Cross-Linked Polyethylene Insulation for Long Life Power Cables", IEEE Conferences, 2016 IEEE/PES Transmission and Distribution Conference and Exposition (T&D), PP. 1-5, 2016.
[4]. V. Vahedy, "Polymer Insulated High Voltage Cables", IEEE Journals & Magazines, IEEE Electrical Insulation Magazine, Volume: 22, Issue: 3, PP.13-18, 2006.
[5]. Z. Y. Shnean, " Effect of Grain and Calcinations Kaolin Additives on Some Mechanical and Physical properties on Low Density Polyethylene Composites", Al-Khwarizmi Engineering Journal, Volume: 4, No. 4, PP. 37-44, 2008.
[6]. S. S. Rao, "Engineering Optimization Theory and Practice 4th Edition", Book, Canada, 2009.
[7]. S. Mirjalili, S. M. Mirjalili, and A. Lewis, "Grey Wolf Optimizer", Advances in Engineering Software, Volume: 69, PP. 46–61, 2014.
[8]. A. Agarwal, A. Chandra, S. Srivastava and R. K Singh, "Grey Wolf Optimizer: A New Strategy to Invert Geophysical Data Sets", Geophysical Prospecting, Volume: 66, Issue: 6, 2018.