Improvement of Dielectric Strength for Polyvinyl Chloride Cables Loaded with Alumina Trihydrate

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***Abstract*—** High voltage insulators are essential element for a reliable performance of electric power systems, these insulators are classified into ceramic insulators (porcelain and glass types) and non-ceramic insulators (polymers), the use of polymers became important due to their good properties over porcelain and glass types. One of the most important characteristics on which the choice of electrical insulators depends on is the dielectric strength of the insulator. This paper investigated the electrical properties (dielectric strength) of Polyvinyl chloride (PVC) cables that are used in high voltage by loading Alumina Trihydrate (ATH) filler under different temperature conditions. The results showed improvement of the dielectric strength with increasing the ATH content in the composite samples also the value of dielectric strength is inversely proportional with temperature condition.

Keywords*—*PVC, ATH, Dielectric Strenght, Polymeric Insulators

I. INTRODUCTION

The insulation system is the basic of HVDC power cables, the performance of the insulation influence on the safety of the HVDC cable. The function of insulating system is to insulate voltage-carrying conductors against one another as well as against earth also advanced insulation materials with unique comprehensive performance provide effective solutions to perform mechanical functions against thermal, chemical stresses and electric stress. [1]

In fact, there are hundreds of insulation materials which are used in the electrical power industry, all these materials can be classified into different categories: such as gases, liquids, solids, vacuum and composites. Solid insulation materials are used to provide electrical isolation over the metallic conductors of underground cables to protect the conductor and provide safety . Insulation is one of the most vital parts of the cable components, its thickness proportional with the operating voltage any higher in the voltage increased insulation thickness, the insulation type depends on operating voltage, temperature surrounding the cable, and type and degree of cable sheath protection. [2]

A history of insulators started together with electrical communications evolution. The materials used for insulators were from Ceramic materials and rubber at 1800. In 1850, the first porcelain post insulators were presented. A few years later the pin and cap type insulators have been used since the last quarter of the 18th century. Glass and porcelain insulators were the only type available before the introduction of newer polymeric insulators and thus had fully ruled over the market till late second half of the 20th century.[3]

Composite Insulator (Polymeric Insulators) has been used as insulation material in the power transmission and distribution systems for more than 50 years as it has great mechanical properties, excellent electrical properties, good hydrophobic surface, volume resistivity and high flashover strength, the density of polymer materials is much lower than ceramics. Hence, the polymer products are significantly lighter and easier to handle and install. The reduced weight also permits the use of lighter and less costly structures. The polymeric materials resist wetting; these properties make polymer insulator an appropriate dielectric material for producing high voltage insulators. Common applications of polymeric insulators include cable terminations, surge arresters, insulators, bus bar insulation and bushings [4].

Epoxy resins were the first polymers used for electrical equipment, such as mold-type transformers, current transformers (CT), potential transformers (PT), metering out-fit (MOF), and gas switching gears in the fields of solid electrical insulators, they are used to as electrical insulators for indoor and outdoor applications because of they have good mechanical and thermal properties as well as excellent electrical properties. [5]

Composite insulators are made of polymers. A polymer is used to describe a long molecule. A molecule made up of thousands repeated units called monomers tied together by chemical bonds, but polymerization is the process of linking monomers together forming a polymer. Synthesise polymers can be divided in to thermoplastic, thermosetting, elastomers, or fiber. Thermoplastic materials lose their form upon heating. Thermoset materials maintain their form in spite of heat.[6- 7]

Composite Insulators is consisting of:

1. Core: the core is the internal insulating part of a composite insulator; it is intended to carry the mechanical load.
2. Housing: the housing is external to the core and protects it from the weather. It may be equipped with weather sheds.
3. Weathersheds: Weathersheds are insulating parts projecting from the housing or sheath, intended to increase the leakage distance.
4. End Fitting: end fitting transmits the mechanical load to the core. [8]

Many scientific investigations and researches are made to enhance the optical and electrical properties of polymers through suitable doping. Mixing two or more polymers by specific percentages of weigh to produce one material, enable the production of blends and composites with required properties and to improve a specific property (electrical, mechanical, physical), this technique is called “polymer blending”. [9]

Power cables is used in extra high voltage (EHV), high voltage (HV) transmission and distribution, medium voltage (MV) sub-transmission and low voltage (LV) distribution applications.

Power cable consist of three essential parts:

1. Conductors tinned stranded aluminium conductors.
2. Insulation to insulate the conductors from direct contact or contact with earth, not allow leakage of power the amount of insulation used in the cables increases, when the voltage level increase so materials that used for cables must have better insulation properties, this layer is made from polymers.
3. Protecting cover (sheath or jacket) against mechanical damage, electrochemical and chemical attack or any e external dangerous to cables. [10]

The requirements that must be met in insulation material:

- Higher dielectric strength.
- Long and default service life.
- Higher heat resistance.
- Mechanical flexibility.
- Resistance to moisture.

Polymeric cables are used greatly due to high reliability, low maintenance and low cost with respect to paper oil cables so we tend to use polymeric insulators in high voltage cables. The polymeric insulation material is varied with the voltage class of the cable such as cross-linked polyethylene (XLPE), an ethylene propylene rubber (EPR), or polyvinyl chloride (PVC).

Polyvinyl chloride (PVC) is a polymeric material that is used extensively in the field of electrical insulation due to its great advantages as cheap, durable, good electrical properties, good physical and mechanical properties, high insulation resistance, resistant to flame, moisture, and abrasion. They display resistance to acids, alkalis, alcohols oils and gasoline, and Self-extinguishing, it is stronger and more rigid so PVC used for power cables insulation.[11-12]

The chemical structure of PVC which is presented in Fig. 1

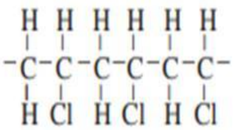

Fig. 1. The chemical structure of PVC

Alumina trihydrate (ATH) is widely used as inorganic filler , it is non-reinforcing filler and it is a flame retardant. It is extensively used as a filler material to improve the tracking and erosion resistance of polymeric materials many investigations have been carried out using ATH and treated ATH for wire and cable insulation due to smoke suppression, thermal conductivity, and chemical stability. [13]

This paper aims to improve PVC electric properties such as dielectric strength by adding ATH filler with different concentration under different temperature condition (25,60,100 and125) °C to select the best percentage of ATH that give the optimum value of dielectric strength of PVC power cables.

II. EXPERIMENTAL WORK

A. Materials

The base polymer was PVC, it is a polymeric material that is used in the electrical insulation for power cables, it was provided by EGY Gates International trading S.A.E.The ATH filler was supplied by Nanotech, Egypt.

B. Samples Preparation

Five PVC/ATH composite samples were prepared by mixing the percentage weight (% wt.) of ATH filler and the ratio of PVC as base polymer, the preparation is done in the laboratory of National Research Centre at room temperature (25°C).

The samples were cut and prepared as a sheet for each blend sample and then cropped to the shape as disc with 5 cm diameter and 1 mm thickness.

The composite samples were prepared as show in Fig. 2

Case (A): pure PVC (100) %
Case (B): PVC/ATH (80/20) %
Case (C): PVC/ATH (70/30) %
Case (D): PVC/ATH (60/40) %
Case (E): PVC/ATH (50/50) %

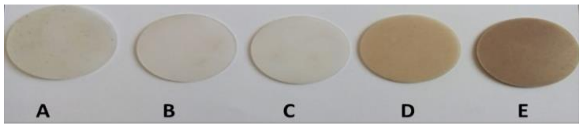

Fig. 2. Different types of composite samples for PVC/ATH.

C. Testing Apparatus

The experiments were carried out in a high voltage laboratory which is shown in Fig. 3

Fig. 3. High voltage laboratory

The A.C high voltage obtained from a single phase high voltage auto transformer 100KV-5KVA-50Hz, has been used which is supplied by the main board from its primary, as shown in Fig. 4 The main board is controlled by variac (0-220V).

Fig. 4. High voltage auto transformer used in dielectric strength test

The control disk which connected to the primary of the autotransformer and supplying it and also controlled its output voltage by a (0-220V) variac as show in Fig. 5

Fig. 5. Control desk of high voltage laboratory

A resistor of 1MΩ was connected to the secondary winding of the high voltage testing transformer in order to protect the high voltage transformer from the high current during the test. The high voltage setup has been enclosed in an earthed cage. The power supply is connected in series to two electrodes. The earthed rod is used to remove electrical charges and discharge the test system after doing the experiment.

The transformer is connected to the sample and to a brass cylindrical electrode that made of copper with a diameter of 25mm.The upper electrode is contacted to high voltage and the lower is grounded. Fig. 6 show the sample between the two electrode during the electrical break down strength.

Fig. 6. Sample between the two electrodes during dielectric strength test

D. Dielectric Strength Test

Dielectric strength of a dielectric material is maximum electric field strength that it can withstand intrinsically without breaking down. It is expressed in voltage per thickness (kV/mm). Sets of samples have been prepared and tested using A.C voltage. Dielectric strength can be tested according to standards such as ASTM D149 or IEC 60243. Fig. 7 show Schematic diagram used for dielectric strength test.

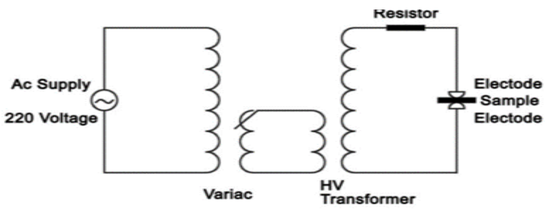

Fig. 7. Schematic diagram of dielectric strength test

For an accurate reading for all samples during the dielectric strength test, the following procedures and precautions were follow:

1. Before beginning high voltage tests the samples should be clean and dry
2. The samples should be fixed between the two electrodes, on at the top and the other at the bottom end.
3. Circuit connection must be correct before applying the electrical test to insure safety.
4. The time intervals between the voltages applied to each sample should be suitable and adequate
5. The voltage was gradually increased at a constant rate of 2kV/sec until the voltage breakdown occurs.
6. Recorded all test' s reading.
7. After each test and after replacing specimen, earth rod should be used to remove the electrical charges.

III. RESULTS AND DISCUSSION

Dielectric strength test was applied to pure polyvinyl chloride (PVC) sample and polyvinyl chloride(PVC) with different concentration of Alumina trihydrate (ATH) samples under different temperature as (25,60,100 and125) °C to detect the best weight percentage of ATH filler that enhance the electrical performance (dielectric strength) of polyvinyl chloride cables and investigate the influence of different temperatures (25,60,100 and125) °C on PVC/ATH samples, The average result for samples of each test has been taken to minimize the error.

Each sample has been tested ten times to check the accuracy of the results and these readings were ordered progressively to be easy for reading.

The results proved that the value of dielectric strength for PVC/ATH composite samples will be high at 25 °C also the obtained results show that adding ATH filler cause the value of dielectric strength to improve until specific value next this value reduced.

Table I show the data recorded that obtained from the dielectric strength test of PVC/ATH samples at room temperature (25 °C).

Table 1: Dielectric Strength (Kv/Mm) Of Pvc/Ath Samples At 25 °C.

FILLER (ATH)%	THE DIELECTRIC STRENGTH (KV/MM) AT TEMPERATURE OF (25°C)									
0	31.99	31.03	31.07	30.88	31.00	31.29	32.01	31.44	31.56	31.98
20	35.24	35.01	35.27	35.04	35.99	36.21	36.44	36.17	35.84	35.94
30	12.31	38.11	38.91	38.74	38.15	39.07	39.00	38.15	38.41	38.92
40	42.31	43.00	42.15	42.15	13.13	42.92	42.91	42.31	42.97	43.00
50	39.49	40.11	40.21	40.00	39.15	39.49	39.92	39.11	38.90	40.03

Hint: under line number is false reading

From the results recorded in table (1) it can be observed that there is a relationship between dielectric strength kV/mm and percentages of Alumina trihydrate filler (ATH)% filler at room temperature and noticed that:

1. For pure PVC or (0% ATH) sample the dielectric strength was the smallest value 31.43 kV/mm.
2. For (20% ATH) sample the dielectric strength enhanced by 13.65% to reach 35.72 kV/mm
3. For (30% ATH) sample the dielectric strength enhanced by 22.84% to reach 38.61 kV/mm
4. For (40% ATH) sample the dielectric strength enhanced by 35.67% to reach the highest value 42.64 kV/mm.
5. For (50% ATH) sample the dielectric strength decreased to reach 39.64 kV/mm with a decrement percentage of 7.1% compared with (30) % ATH sample.

Table 2: Dielectric Strength (Kv/Mm) Of Pvc/Ath Samples At A Temperature Of (60°C)

FILLER (ATH)%	THE DIELECTRIC STRENGTH (KV/MM) AT TEMPERATURE OF (60°C)									
0	38.13	29.01	29.12	30.66	11.10	29.55	30.16	28.15	28.81	28.55
20	33.91	33.72	32.90	32.88	31.99	32.00	31.12	30.79	32.00	31.02
30	35.64	35.47	35.92	36.11	36.14	36.82	37.00	37.01	35.14	35.02
40	40.25	40.91	40.83	40.51	40.11	41.90	41.82	41.31	41.00	40.96
50	37.14	37.92	38.01	38.27	38.00	15.14	37.94	37.59	38.62	37.59

Table II shows the results were recorded from dielectric strength test done on the samples and the percentage of

ATH% filler at a temperature of 60 °C and it can be observed that:

1. For pure PVC or (0% ATH) sample the dielectric strength was the smallest value 30.24 kV/mm.
2. For (20% ATH) sample the dielectric strength is reached to 32.233 kV/mm.
3. For (30% ATH) sample the dielectric strength is reached to 36.027
4. For (40% ATH) sample the dielectric strength of samples is reached to 40.96 kV/mm.
5. For (50% ATH) sample the dielectric strength of samples is reached to 37.90 kV/mm.

Table 3: Dielectric Strength (Kv/Mm) Of Pvc/Ath Samples At 100 °C

FILLER (ATH)%	THE DIELECTRIC STRENGTH (KV/MM) AT TEMPERATURE OF (100°C)									
0	28.00	27.31	27.02	26.33	26.15	26.00	26.01	26.21	26.37	26.09
20	27.91	28.81	28.97	28.00	28.02	28.75	29.01	5.22	29.02	28.55
30	30.17	31.02	31.09	30.45	31.00	31.09	31.21	31.33	30.99	30.98
40	4.52	35.82	35.04	36.00	35.47	35.92	35.91	35.55	35.14	36.09
50	33.02	32.92	32.88	33.04	33.14	33.44	33.15	33.70	33.08	33.09

Table III shows the results recorded from dielectric strength test done on the samples and the percentage of ATH% filler at a temperature of 100 °C it can be noticed that:

1. For pure PVC or (100) % PVC/ (0) % ATH the dielectric strength was the smallest value 26.55 kV/mm.
2. For (20% ATH) sample the dielectric strength enhanced by 7.57% to reach 28.56 kV/mm
3. For (30% ATH) sample the dielectric strength enhanced by 16.49% to reach 30.93 kV/mm
4. For (40% ATH) sample the dielectric strength enhanced by 34.31% to reach the highest value 35.66
5. For (50% ATH) sample the dielectric strength decreased to reach 33.15 kV/mm

Table 4: Dielectric Strength (Kv/Mm) Of Pvc/Ath Samples At 125 °C

FILLER (ATH)%	THE DIELECTRIC STRENGTH (KV/MM) AT TEMPERATURE OF (125°C)									
0	25.21	4.92	25.01	25.37	26.12	24.87	24.90	24.00	25.14	25.09
20	26.14	26.02	27.54	30.91	30.84	29.01	26.11	26.00	26.03	26.01
30	29.20	29.00	28.91	29.51	28.39	30.00	29.09	29.11	29.45	8.77
40	33.99	34.66	34.21	33.92	34.05	32.99	34.44	35.00	34.87	34.85
50	32.00	31.47	31.91	31.66	31.21	31.07	31.17	30.99	31.93	31.04

Table IV shows the results that recorded from dielectric strength test done on the samples and the percentage of ATH% filler at a temperature of 125 °C so it can be observed that:

1. For pure PVC or (0% ATH) sample the dielectric strength was the smallest value 25.08 kV/mm.
2. Adding ATH with 20% to PVC the dielectric strength of new sample is reached to 27.46 kV/mm
3. Adding ATH with 30% to PVC, the dielectric strength of new sample is reached to 29.18 kV/mm.
4. When adding ATH with 40% to PVC, the dielectric strength of new sample is reach to highest value 34.30 kV/mm.
5. When adding ATH with 50% to PVC, the dielectric strength of new sample will be decreased to reach 31.45 kV/mm.

Table 5: Dielectric Strength (Kv/Mm) Of Pvc/Ath Composite Samples At Various Temperature Condition With Different Content Of Ath Filler.

Temperature °C	Dielectric strength(kV/mm) At various temperatures °C at different weight percentage of ATH filler				
	100/0	80/20	70/30	60/40	50/50
25	31.43	35.72	38.61	42.64	39.64
60	30.24	32.23	36.03	40.96	37.90
100	26.55	28.56	30.93	35.66	33.15
125	25.08	27.46	29.18	34.30	31.45

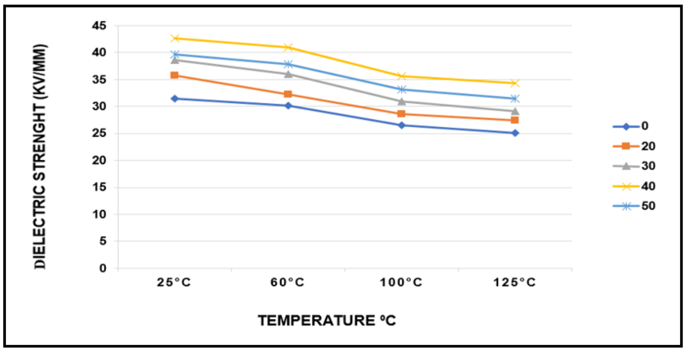

Fig. 8. The relation of dielectric strength(KV/mm) of PVC/ATH samples and different temperature condition with different weight percentage of ATH filler

From table V and Fig. 8 results are:

- The highest value of dielectric strength is 42.64 kV/mm at 25 °C, 40.96 kV/mm at 60 °C, 35.66 kV /mm at 100 °C and 34.30 kV/mm at 125 °C, when the percentage of filler is 40%
- The dielectric strength increases by adding the ATH filler up to 40% but when increase over that the dielectric strength decreases
- It can note that reduction in dielectric strength with temperature increases from 25 °C room temperature to 125 °C, this is due to When the temperature increases, the chemical bonds become weaker, so the current passes easily contributing to the decrease in breakdown strength.
- From the previous results there is a limit for adding ATH filler and after that, the sample dielectric strength becomes weak because the sample which has a large percentage from ATH exceeds 40% become non-homogenous and weak.

CONCLUSION

Based on the results obtained from dielectric strength test for PVC/ATH specimens at various temperature condition, the following conclusions are drawn:

- With increased concentration of the filler ATH, the dielectric strength increases up to 40% but when increase over that the dielectric strength decreases.
- The best composite sample from the view of dielectric strength is (40) % ATH sample.
- ATH is a good solution to improve the dielectric strength of Polyvinyl chloride
- At low temperature, the dielectric strength of PVC/ATH samples is high but when temperature is increased the value of dielectric strength of PVC/ATH is decreased.

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