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Partial Discharge of Polyurethane/Organoclay Composite Coated on Aluminum Conductor Overhead Lines

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ABSTRACT

Aluminum conductors have been used worldwide as the primary conductive materials for high voltage electrical transmission lines. The aluminum conductor's partial discharge behavior has been observed during operation due to the transmission line's performance to serve electricity. The Partial Discharge of aluminum alloy coated by polyurethane/organoclay (PClay) composite material was studied. PClay composites were prepared by adding organoclay with different content in polyurethane as a matrix then coated on an aluminum conductor sample. A partial discharge test was conducted to obtain the behavior of partial Discharge versus voltage. It was found that an escalation of organoclay content in the polyurethane reduces partial Discharge appears.

Keywords: *Polyurethane, Organoclay, Composites, Partial Discharge*

1. INTRODUCTION

Electric utilities in modern society should be provided power reliably and at all times with minimal interruption. The generator power plant used a transmission line with an aluminum conductor as a primary material to evacuate electricity from the generator power plant. The occurrence of partial Discharge on aluminum conductor during the operation was made attention due to corona losses[1–4]. The presence of partial discharge in high voltage equipment generally indicates a defect and weakness in the insulation and high-voltage systems [5].

Efforts to reduce partial Discharge was the attention to prevent corona losses by coating on the conductor. The material requires which features to prevent partial Discharge has mandatory. In recent years there has been growing interest in polyurethane coating containing additives [6]. Polyurethane has a large variety of forms. They are the most useful commercial polymer materials used in both industry and daily life. Based on previous research, polyurethane/clay composite has good properties for multifunction applications, including coating material [7,8]. The addition of clay to the polyurethane improves the composites' mechanical properties and flame retardant [9]. Extensive research was carried out on partial Discharge, especially of material insulators. For the epoxy resin insulator, it has been confirmed that the discharge resistance could be improved by adding a small amount of inorganic nanofiller [1,10,11].

In this study, we would like to report polyurethane/organoclay composite performance, which is applied as a coating to aluminum conductor overhead lines to prevent partial discharges.

2. EXPERIMENTAL

Polyurethane composite was fabricated with organoclay as a filler (1%, 3%, and 5% wt organoclay)[12–14]. Polyurethane was obtained from a commercial product. The polyurethane contains diisocyanate (MDI), MDI-based polyisocyanate 4.4' – Diphenylmethane, Aromatic Solved Blend, and Isobutyl Acetate. The urethane group's molecular unit -NH-(C=)-O- as shown in Figure 1.

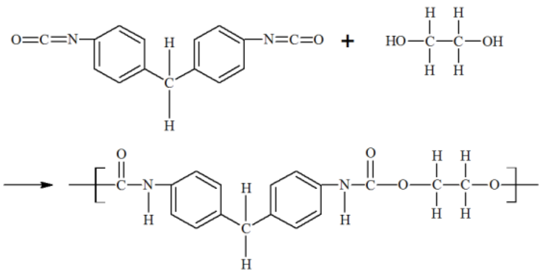

Figure 1. The molecular units of the urethane group [15]

Aluminum conductor overhead lines were obtained from commercial products (All Aluminum Alloy Conductor - AAAC). Aluminum wire was melted first and then molded becomes a substrate plate. The substrate plate size has size 2cmx2cm x 0.5 cm. The aluminum alloy contains 0.5% Si, 0.7% Mg, 0.5% Fe, 0.1% Cu, 0.03% Mn, 0.03% Cr, 0.06% B, and 1%Zn. Organoclay was purchased from a commercial. Product Nanolin DK 8. The carbon graphite powder with a 30 Mesh (0.23 inch or 95 microns) was used as a filler material

The fabricated process of composites was carried out by mixing polyurethane and organoclay using a magnetic stirrer. There were three types of composites: 1) P0 or polyurethane without filler 2) PClay1 or Polyurethane filled by organoclay 1% wt) 3) PClay3 or Polyurethane filled by organoclay 3% wt) 4) PClay5 or Polyurethane filled by organoclay 5% wt). Table 1 shows the composition of the composite samples coated on the aluminum substrate.

Table 1. Composition of polyurethane base composite

Sample composite	Composition [wt.%]		Total [wt.%]
	polyurethane	organoclay	
P0	100	-	100
PCClay1	99	1	100
PCClay3	97	3	100
PCClay5	95	5	100

The stirring process was conducted at a speed of 500 rpm for 120 minutes. After the stirring process, the composites sample was printed on the aluminum substrate plate and dried at an ambient temperature for 24 hours, and the thickness of the sample is 0,35 mm.

The Partial Discharge test wiring diagram is shown in Figure 2. Partial discharge measurement was carried out using a partial discharge meter Omicron MPD 600 measurement system. The aluminum plate coated with the coating material is mounted on the electrode side and confronted with a feed needle to provoke the partial discharge occurrence, as shown in Figure 3. The distance between the aluminum plate and the feeder needle is 10 cm. The voltage is increased gradually from 0 to 15 kV.

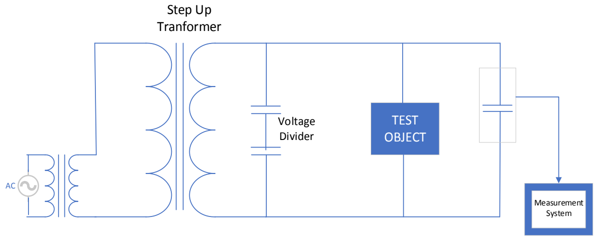

Figure 2. Schematic wiring circuit test

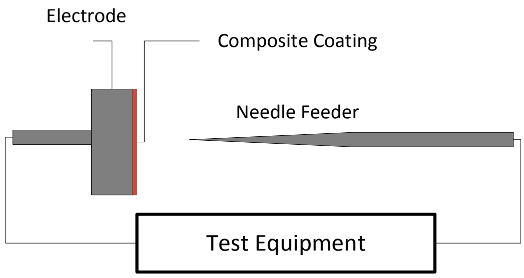

Figure 3. wiring partial discharge test

The coated composite capacitance was measured to obtain the relations between partial Discharge and coating material's capacitance. Agilent HP 4284A was used to measure capacitance as a frequency function with a range between 50 kHz-1MHz[16–18]. The sample was plated between aluminum places as an electrode. The relative dielectric constant ε' was obtained by calculating the permittivity value (ε) divided by the permittivity value in a vacuum:

$$\varepsilon' = \frac{\varepsilon}{\varepsilon_0} \quad (1)$$

The permittivity value was obtained by calculating capacitance, area, and sample thickness based on the fundamental principle, as shown in Figure 4.

$$C = \varepsilon \frac{A}{d} \quad (2)$$

Where C is capacitance (F), ε is the permittivity of the material (F/m), ε0 is the permittivity in a vacuum (8.85 x 10-12 C2/Nm2), A is the area of the sample area (mm2), and d is sample thickness (0.35mm).

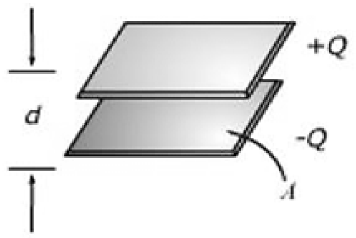

Figure 4. Parallel capacitor principle

3. RESULTS

3.1 Partial discharge

Figure 5 shows the form of partial Discharge of an aluminum conductor's coated with composite. Table 2 shows the average partial Discharge for each voltage step. It appears that all samples tested showed an increase in the number of partial discharges. But it is seen the difference in partial Discharge that occurs in each sample tested.

Each sample shows differences in the number of partial discharges. It shows that increasing the number of fillers reduce the partial Discharge; for example, in the step voltage of 14 to 15 kV, the addition of a concentration of 5 wt% can reduce partial Discharge from 1012.17 x 10^{-12} C to 117,28 x 10^{-12} C.

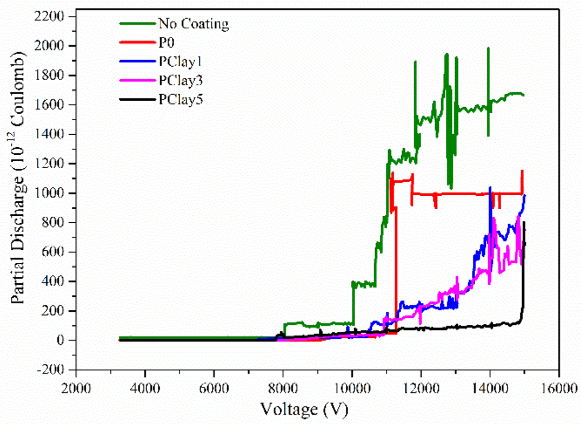

Figure 6. Partial Discharge of composites

Table 2. Average partial Discharge on step voltage of PClay

No	Voltage (Volt)	partial discharge average 10^{-12} Coulomb			
		P0	PClay1	PClay3	PClay5
1	0	0,00	0,00	0,00	0,00
2	s/d 8 kV	2,57	10,50	1,26	3,89
3	8 s/d 9 kV	2,74	14,50	4,87	26,68
4	9 s/d 10 kV	22,60	21,58	28,26	39,23
5	10 s/d 11 kV	28,11	42,56	95,79	54,24
6	11 s/d 12 kV	961,04	168,56	186,58	66,93
7	12 s/d 13 kV	989,97	221,39	305,21	80,21
8	13 s/d 14 kV	994,83	321,39	405,02	92,36
9	14 s/d 15 kV	1012,17	674,91	596,82	117,28

These results show carbon/organoclay filler's effectiveness in reducing partial Discharge, reducing the possibility of corona phenomena. Figure 5 shows a partial discharge pattern in the form of a bar diagram.

The test concluded that polyurethane /organoclay coatings with 1,3 and 5 wt% fillers in the aluminum conductor succeeded in reducing the conductor's partial Discharge compared to using a coating addition the amount of filler also decrease Partial Discharge.

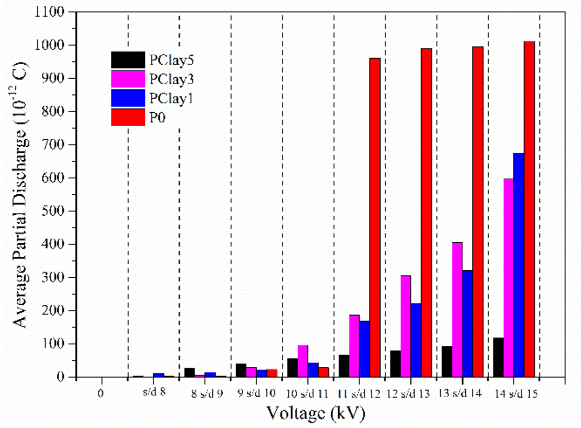

Figure 5. Graph of average partial Discharge

3.2 Capacitance

Figure 6 and 7 is a graph obtained from the capacitance test results. Tests were carried out by giving the frequency with a range of 50 kHz to 1000 kHz. Figure 6 is a graph of test result with full scale 0 – 2,5 x 10^{-9} F, while figure 7 is with scale 0 – 0,5 x 10^{-9} F.

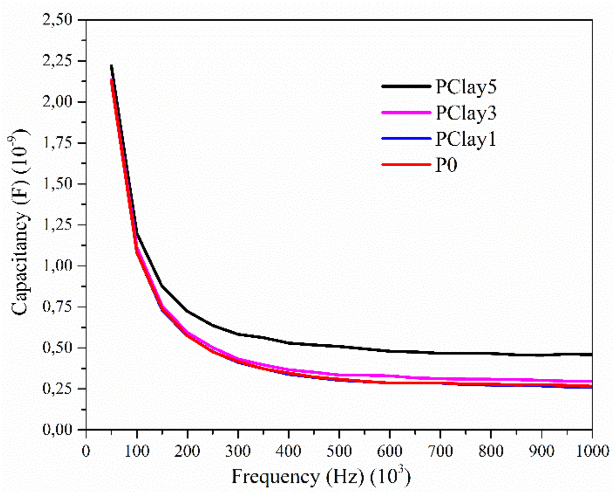

Figure 6. Capacitance scale 0 – 2,5 x 10^{-9} F

The graph shows that filler 1,3 and 5% wt organoclay on polyurethane succeeded in increasing each frequency's capacitance value.

The observations were made at frequencies 50, 400, 600, 800, 1000 kHz, as shown in table 3. At 50 kHz frequency, as the initial measurement, it shows that there is an increase in the capacitance value for each filler addition, the capacitance value in the coating without filler P0 is 2,13 x 10^{-9} F, and the coatings filled with fillers PClay1, PClay3, and PClay5 increase the capacitance values to 2,38 x 10^{-9} F, 2,82 x 10^{-9} F and 2,10 x 10^{-9} F.

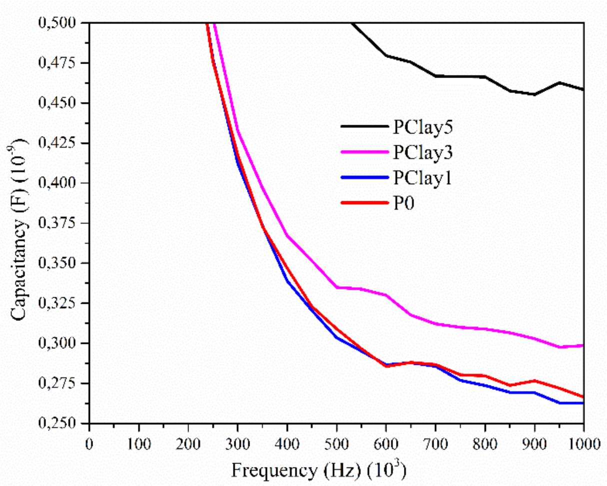

Figure 7. Capacitance scale 0 – 0,5 x 10^{-9} F.

At 400 kHz observations, which is the curves in each sample are more stable the capacitance of P0 is 0,35 x 10^{-9} F and PClay1, PClay3, PClay5 are 0,66 x 10^{-9} F, 0,78 x 10^{-9} F and 0,86 x 10^{-9} F. The same pattern also occurs at frequencies 600, 800 and 1000 kHz.

Tabel 3. Composite capacitance

Frequency 10^3 Hz	Capacitance (10^{-9} F)			
	P0	PCLay1	PCLay3	PCLay5
50	2,13	2,37	2,82	3,10
400	0,35	0,65	0,78	0,86
600	0,28	0,64	0,76	0,83
800	0,279	0,63	0,74	0,82
1000	0,266	0,63	0,75	0,82

The test results show that adding organoclay filler material into polyurethane has succeeded in increasing the capacitance value [19,20]. It appears that increasing the amount of carbon/clay also shows the value of capacitance also increases.

4. DISCUSSIONS

Partial Discharge (PD) is an electrical discharge across a localized area of the insulation between two conducting electrodes without ultimately bridging the gap. When the local electrical field strength is sufficient to breakdown that small portion of the dielectric material, partial Discharge may occur[21]. The imperfections such as discontinuities, voids, cavities, and delamination in the insulation system may cause partial Discharge.

The imperfection or discontinuity, or void in the samples may come from the insufficient mixing time during the composite production. The imperfection may also come from the low wettability of polyurethane to wet the carbon or organoclay surface[22,23].

Figure 8 shows that partial discharge increase as the filler content decrease. Organoclay is solid amorphous and less conductive or insulator. Polyurethane is an organic material and is more prone to deterioration than carbon and organoclay.

If the materials are not strong enough to withstand the electric field, deterioration may occur. The charge's path to pass the material in the region where the materials' local electrical resistance is the lowest. It seems that the organoclay fillers dominate the suppression of the partial Discharge.

The high values in the low-frequency range can exist in one or more of the following processes: (i) electrode polarization, (ii) interfacial polarization, and (iii) conductivity phenomena. Electrode polarization is usually a parasitic effect due to the electrode-samples contact. Interfacial polarization or Maxwell–Wagner–Sillars (MWS) effect might occur in systems exhibiting heterogeneity. This might be the case in polymer matrix–inorganic filler composites and the accumulation of mobile charges at their fillers' interface[24].

The Partial discharge testing showed that the addition of organoclay filler to polyurethane had reduced partial Discharge of aluminum conductor coated with composites material. On the other hand, the addition of organoclay has increased the capacitance of composites.

The relationship between adding a filler to the composite with increasing capacitance and decreasing partial Discharge is illustrated in figure 8.

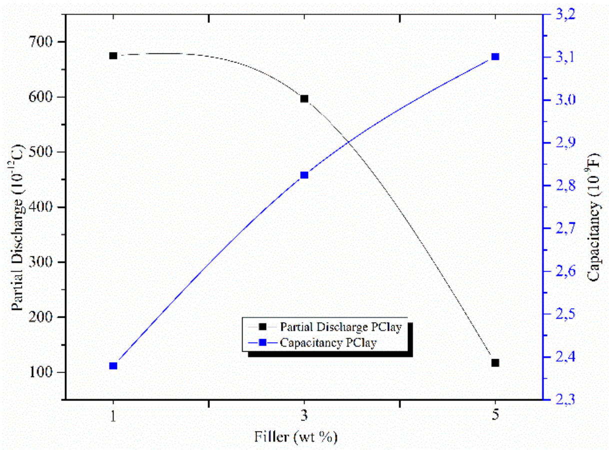

Figure 8. Partial Discharge and capacitance as a function filler at 50 kHz Frequency.

5. CONCLUSION

The application of the PClay composite as a coating to the aluminum conductor succeeded in reducing partial Discharge. The increasing number of fillers also was decreased partial discharges. The filler's addition also increases the capacitance of the PClay composite, and increasing filler also was increased capacitance. There is a correlation between adding filler with increasing capacitance and decreasing Partial Discharge.

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