

# Effect of Surface Tracking on LLDPE-NR/TiO<sub>2</sub> Nanocomposite Conductivity Using PDC Technique

M. S. A. Aziz<sup>1</sup>, N. A. Muhamad<sup>1</sup>, N. A. M. Jamail<sup>1,2</sup>, Q. E. Kamarudin<sup>3</sup>

<sup>1</sup> *Institute of High Voltage & High Current, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysi*

<sup>2</sup> *Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia(UTHM), 86400 Batu Pahat, Johor, Malaysia*

<sup>3</sup> *Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia(UTHM), 86400 Batu Pahat, Johor, Malaysia*

friedrice\_90@yahoo.com, norasiah@fke.utm.my, norakmal@uthm.edu.my, ezani@uthm.edu.my

**Abstract**—Composite polymeric insulators recently being widely used to replace porcelain and glass in high voltage application. While Polarization and Depolarization Current (PDC) is a non-destructive measurement technique used to measure charging and discharging current in time domain. This paper presents the experimental and analysis result of PDC measurement technique for new developed Nano-polymeric material samples. The new LLDPE-NR/TiO<sub>2</sub> were developed by blending the polymer material of Linear Low Density Polyethylene (LLDPE), natural rubber (NR) and filled with nanoparticles of TiO<sub>2</sub> as fillers. Several samples at different percentage of filler added (1%, 3%, 5%, and 7%) was prepared and tested with and without surface tracking defect. Surface tracking is developed from surface discharged activity associated with the flow of leakage current on insulator surface under wet and contaminated conditions. Presence of impurities or contaminants on surface of the insulator will affect the insulator conductivity. Aim of this study is to see effectiveness of adding TiO<sub>2</sub> as fillers improve polymer material dielectric properties under surface tracking condition. Result of PDC pattern and conductivity variation of each sample is analyzed using LABVIEW and MATLAB to determine which sample has better dielectric property.

**Keywords:** *Conductivity, polymer nanocomposite, surface tracking, polarization current, depolarization current*

## I. INTRODUCTION

In service, since most polymer insulation is in outdoor application of voltage insulator, the surface of polymer insulation is progressively contaminated. Polymeric insulator that been used for outdoor application having tracking and erosion effect. It's happened on the surface material of the polymeric insulator Tracking is a peculiar phenomenon that occurs on the surface of the insulating structure as a result of creep age discharge from surface contamination, with addition of nanoscale fillers into polymers, robust materials can potentially be produced due to the synergistic effects (cooperating for enhanced effects) arising from the blending process[1].

A lot of research had been done on electrical properties of polymer nanocomposite as insulating material. F. Ciuprina and

I. Plesa had done a research on DC conductivity and the variation of the real part of the complex conductivity with the frequency for three formulations of nanocomposites obtained from polyethylene filled with nanoparticles of Al<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub> and TiO<sub>2</sub>[2].

The nature of polarization and depolarization currents obtain from PDC measurement are believed to be related to aging status and moisture content of the insulation. Application of PDC test has been conducted too many electrical apparatus for monitoring the condition of machine stators, transformer and power cables[3]. Besides, due to advancement in hardware and software interpretation schemes, PDC measurements with the time domain polarization based technique are widely accepted by many utilities. PDC tests are very useful to estimate conductivity and moisture contents of the insulations. PDC measurement can be used to measure the conductivity of nanocomposite that had been done by researchers [4]. From the results, it can be concluded that adding nano particles into LLDPE nanocomposite can reduce the PDC values. However, different amount of nanofillers will give different results.

The main objective of this project is to investigate and analyze the effect of surface tracking on conductivity level of LLDPE-NR nanocomposite material. The nanocomposite material used is natural rubber blend with Titanium oxide (TiO<sub>2</sub>). Besides, this project also to identify the conductivity level of composite material using PDC technique.

## II. SAMPLE PREPARATION

Commercial linear low density polyethylene (LLDPE) from Titan Chemical, Malaysia, is used in this study. It has a density of 0.918 g/cm<sup>3</sup>, a melt index of 25g/10 min. Nanoparticle of Titanium oxide (TiO<sub>2</sub>) is from China with a particle size of about <50nm was used as filler. This nano scale filler has a nearly spherical shape with a specific surface area of about 100 m<sup>2</sup>/g. Before used, the filler must be dried first. For blending and mixing with LLDPE and nanofiller, natural rubber (NR) grade SMR CV 60 supplied by Taiko Plantations was used. Using a Brabender mixer with chamber size of 50 cm<sup>3</sup>, polyethylene nanocomposites were prepared by melt

mixing at 165 0C. The screw speed was controlled at 35 rpm with the mixing time of 2 min and the mixer has a high shear force. With a square shape of 10 cm x 10 cm with the thickness of 3 mm by hot melt pressing at 1 tone pressure at 170 0C for 10 min the polymer nanocomposites were finally prepared. With concentrations of nanofiller of 1, 3, 5 and 7 % wt, four types of LLDPE-NR nanocomposite square shaped with a dimension of 10 cm x 10 cm were prepared. Table I shows the compound formulation and designation of LLDPE-NR/TiO<sub>2</sub>.

All the samples had undergone electrical tracking test for degradation process. Fig. 1 shows the hardware set up for electrical tracking test. Test Voltage that had been applied to the sample is 4.5 kV, contaminant flow rate is 0.60 ml/min (10 rpm) with resistance of 33 k ohm. The experimental works had been conducted to create surface tracking on a new sample without any defect. The sample was mounted at the special stand with the flat test surface on the underside at an angle of 45° from the horizontal with the stainless steel electrodes. The sample was coupled with two high voltage electrodes. With the contaminant flowing uniformly at the specific rate, supply was switched on and raises slowly the voltage up to 4.5 kV. The voltage shall be maintained constant for 5 to 6 hours. Surface tracking and carbon track will be created after 6 hours.



Fig.1. Electrical testing setup

TABLE I  
COMPOUND FORMULATION AND DESIGNATION

Test Sample	Constituent Composition%w			Designation
	LLDPE	Natural Rubber (SMR CV 60)	Nano filler	
LLDPE	80	20	1	B1
+	80	20	3	B3
Natural Rubber+	80	20	5	B5
TiO <sub>2</sub>	80	20	7	B7

III. PDC THEORY AND CONCEPT

A. Insulation Conductivity Concept.

Polarization and Depolarization (PDC) measurement has been recognized to be increasingly popular due to its ability to assess the conductivity of High Voltage insulation within initial periods after application of DC steps voltage. A significant parameter in insulation diagnostic is the dc conductivity of insulation and it is used to determine insulation condition.

The object tested can be in series or in parallel and can be using single dielectric material or an arrangement of several dielectric material  $\sigma$ ,  $\epsilon_r$  and  $f(t)$  represent the composite conductivity, relative permittivity and dielectric response function of this heterogeneous test object for more than one dielectric material. The test object is assumed to be totally discharged and that a step voltage is applied with the following characteristics:

$$U(t) = \begin{cases} 0 & t < 0 \\ U_0 & 0 \leq x \leq tc \\ 0 & t > tc \end{cases} \quad (1)$$

It will result in zero current for times before  $t = 0$ , and for times  $0 \leq t \leq tc$  is called polarization currents. There are two parts of polarization current, one part is related to the activation of the different polarization processes within test Object and the other is related to the conductivity of the test object. The polarization (charging) current through the object can thus be expressed as [5-9]:

$$ip(t) = C_0 U_0 \left[ \frac{\sigma}{\epsilon_r} + f(t) \right] \quad (2)$$

A depolarization current is built up once the step voltage is replaced by a short circuit. The depolarization current magnitude is expressed as;

$$id(t) = c_0 u_0 [f(t) - f(t + tc)] \quad (3)$$

Here,  $tc$  is stand for the time during which voltage has been applied to test object. Hence, it is possible to estimate the dc conductivity  $\sigma$ , of the test object based on measurement of polarization and depolarization currents. If the test object is charged for a sufficiently long time so that  $f(t + tc) = 0$ , equation (2) and equation (3) can be combined to express the dc conductivity of the composite dielectric as

$$\sigma \approx \frac{\epsilon_0}{c_0 u_0} [ip(t) - id(t)] \quad (4)$$

Here,  $\sigma$  is the composite conductivity,  $\epsilon_0$  is the relative permittivity,  $C_0$  is the geometric capacitance,  $U_0$  is the step voltage,  $i_d(t)$  is the depolarization current, and  $i_p(t)$  is the polarization current. For Solid Insulation, the control software was developed in the LabVIEW environment which enables the operator to record voltage and currents automatically during PDC measurements.

*B. PDC Measurement Technique*

By applying a dc voltage step on the dielectric material the polarization currents measurement is performed. For depolarization current, it is measured by removing the dc voltage source incorporating with a switch turn on to short circuit at the under tested objects. The dc voltage applied was 1000 V for about 10,000 seconds for polarization and depolarization time. The voltage and currents will be recorded automatically by the control software that was developing in the Lab View environment. The PDC measurement principal is shown in Fig. 2. PDC testing was done at High Voltage and High Current Laboratory, Universiti Teknologi Malaysia by using PDC equipment setup as shown in Fig.3.

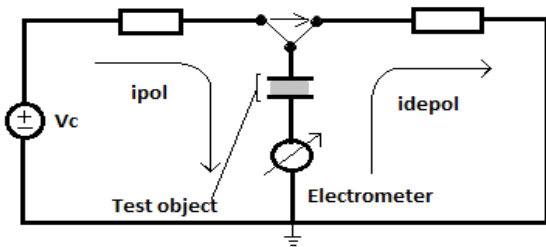


Fig. 2 Principal of test arrangement for PDC measurement.

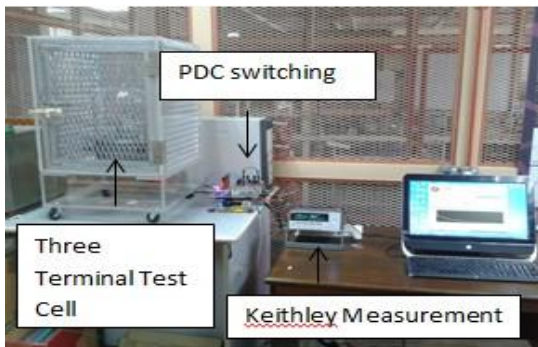


Fig.3 PDC measurement set up

IV. RESULT AND DISCUSSION

*A. Polarization and Depolarization Current Analysis*

The result of polarization current measured for samples B1, B3, B5 and B7 before and after surface tracking is shown in Fig.4, Fig.5, Fig.6 and Fig.7 respectively. Meanwhile, the result of depolarization current is shown in Fig.8, Fig.9, Fig.10 and Fig.11. It is found that sample B1, B3, B5 and B7 before tracking has lower polarization and depolarization current value than sample B1, B3, B5 and B7 after tracking. It is shown that effect of tracking increase the polarization and depolarization current for each sample. For overall sample, it is found that after tracking, sample B5 has lower polarization current than sample B1, B3 and B7. Therefore, the compound of 80% LLDPE and 20% natural rubber (NR) with 5% of TiO<sub>2</sub> filler can improve the resistivity of the material.

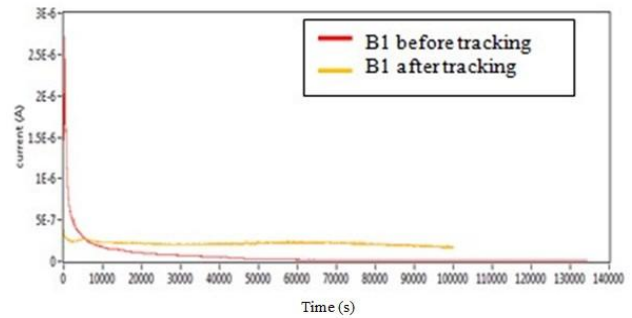


Fig. 4 Polarization current for sample B1

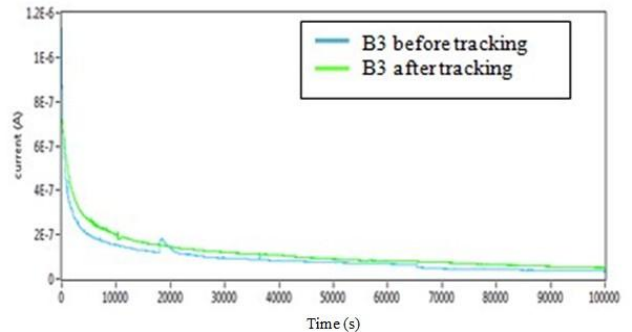


Fig. 5 Polarization current for sample B3

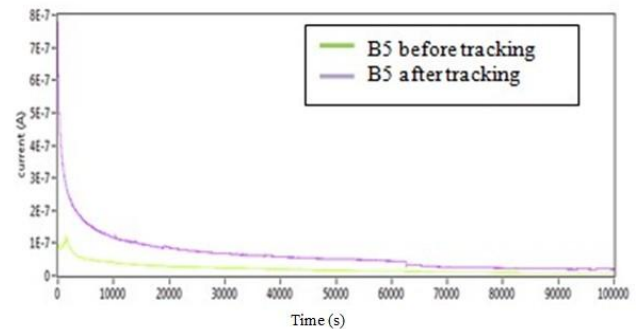


Fig. 6 Polarization current for sample B5

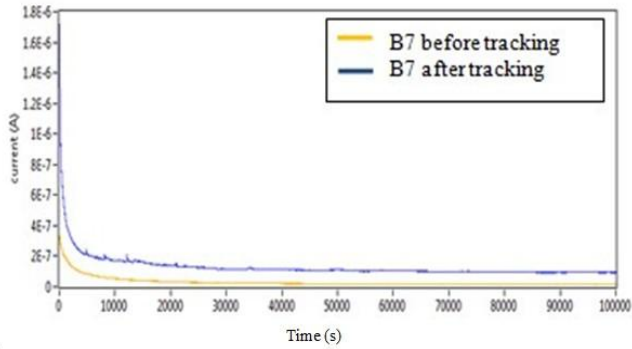


Fig. 7 Polarization current for sample B7

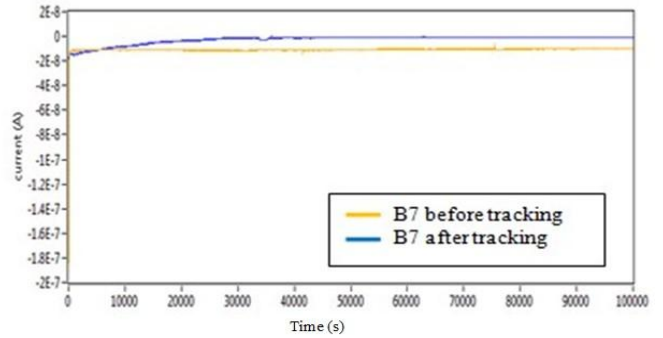


Fig. 11 Depolarization current for sample B7

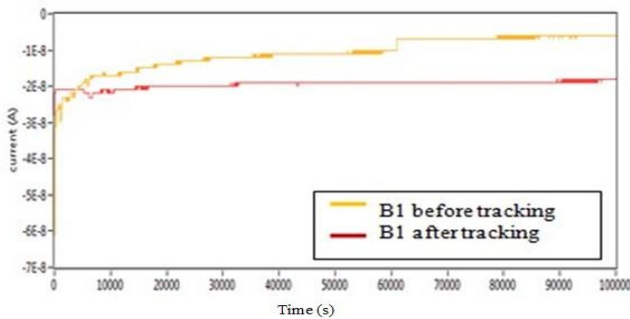


Fig. 8 Depolarization current for sample B1

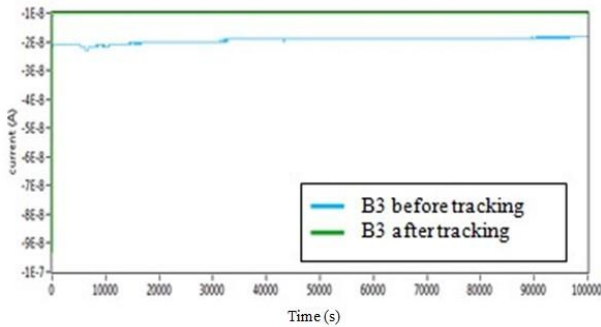


Fig. 9 Depolarization current for sample B3

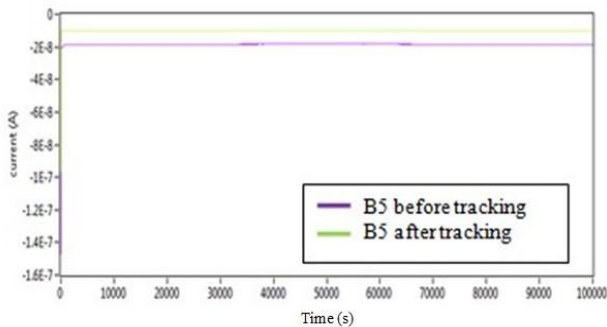


Fig. 10 Depolarization current for sample B5

### B. Conductivity Variation Analysis

Using polarization and depolarization current measurement using conductivity, we are able to estimate the condition (ageing and moisture) of insulation. Equation (4) proves that conductivity of the insulation is influenced by polarization and depolarization current values.

Fig. 12 shows the conductivity variation for the sample B1, B3, B5 and B7 before tracking. Each of the samples hasn't undergone tracking phenomena. Based on the plotted graph, sample B5 with 5% TiO<sub>2</sub> filler has the lowest conductivity compared with other samples.

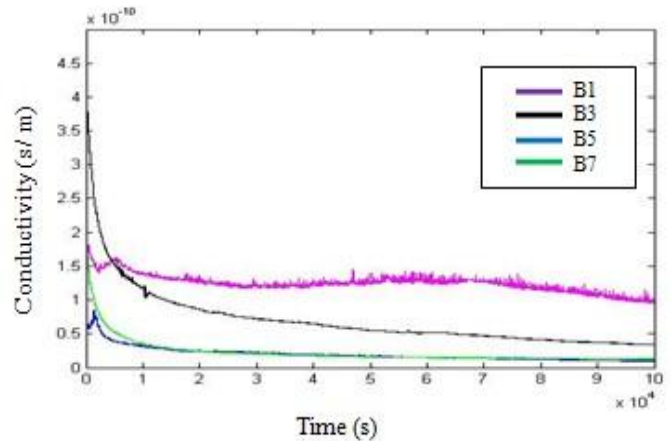


Fig. 12 Conductivity variation before tracking for samples B

Fig. 13 shows the conductivity variation for sample B1, B3, B5 and B7 after tracking. It is clearly shown that the tracking effect the conductivity of the sample. Each of the samples has increase in conductivity because of the tracking phenomena cause increase in the leakage current. Based on the plotted graph, sample B5 with 5% TiO<sub>2</sub> filler was the best sample after tracking effect.

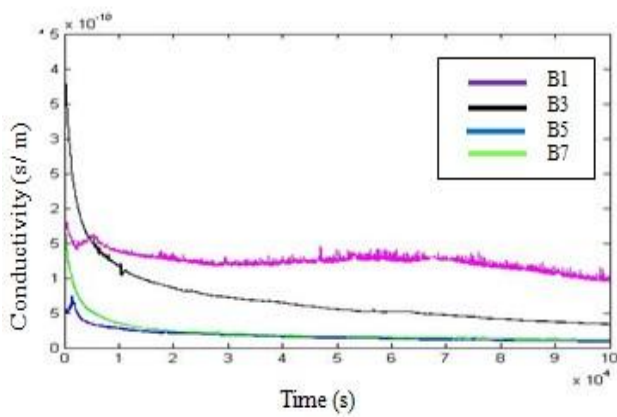


Fig 13. Conductivity variation after tracking for samples B

## V CONCLUSION

Conductivity of LLDPE-NR/TiO<sub>2</sub> samples has been studied in this paper. Based on the PDC measurement result, it is found that sample LLDPE-NR with 5% of TiO<sub>2</sub> as a filler was the best samples in polarization and depolarization current result either before or after surface tracking effect. This samples is believed has improves the resistivity of LLDPE. Additional TiO<sub>2</sub> nanofiller at certain percentage will improve the dielectric properties of LLDPE-NR. Besides, the trend of conductivity shows that it dependent on polarization and depolarization current of the sample. On the other hand, it is found that the tracking phenomena effect the polarization and depolarization current of each samples. The tracking phenomena cause increase for leakage current.

## VI ACKNOWLEDGEMENT

The authors gratefully acknowledge the Malaysia Ministry of Higher Education, Universiti Teknologi Malaysia (Vot 05J82, 4F097 and Vot 4L014).

## VII REFERENCES

- [1] B. Jongsomjit, *et al.*, "Effect of nanoscale SiO<sub>2</sub> and ZrO<sub>2</sub> as the fillers on the microstructure of LLDPE nanocomposites synthesized via in situ polymerization with zirconocene," *Materials Letters*, vol. 61, pp. 1376-1379, 2007.
- [2] F. Ciuprina and I. Plesa, "DC and AC conductivity of LDPE nanocomposites," in *Advanced Topics in Electrical Engineering (ATEE), 2011 7th International Symposium on*, 2011, pp. 1-6.
- [3] N. A. M. Jamail, *et al.*, "Comparative study on conductivity using Polarization and Depolarization Current (PDC) test for HV insulation," in *Electrical Engineering and Informatics (ICEEI), 2011 International Conference on*, 2011, pp. 1-6.
- [4] N. A. M. Jamail, *et al.*, "Effects of SiO<sub>2</sub> nanofillers on Polarization and Depolarization Current (PDC) of LLDPE-NR nanocomposite insulating materials," in *Power and Energy*

- (PECon), *2012 IEEE International Conference on*, 2012, pp. 707-711.
- [5] T. K. Saha, *et al.*, "Optimal Time Selection for the Polarisation and Depolarisation Current Measurement for Power Transformer Insulation Diagnosis," in *Power Engineering Society General Meeting, 2007. IEEE*, 2007, pp. 1-7.
- [6] T. K. Saha and P. Purkait, "Investigation of polarization and depolarization current measurements for the assessment of oil-paper insulation of aged transformers," *Dielectrics and Electrical Insulation, IEEE Transactions on*, vol. 11, pp. 144-154, 2004.
- [7] N. A. Muhamad, *et al.*, "Polarization and Depolarization Current (PDC) tests on biodegradable and mineral transformer oils at different moisture levels," in *Power Engineering Conference, 2009. AUPEC 2009. Australasian Universities*, 2009, pp. 1-6.
- [8] C. Ekanayake, *et al.*, "Application of polarization based measurement techniques for diagnosis of field transformers," in *Power and Energy Society General Meeting, 2010 IEEE*, pp. 1-8.
- [9] T. K. Saha and P. Purkait, "Investigation of an expert system for the condition assessment of transformer insulation based on dielectric response measurements," *Power Delivery, IEEE Transactions on*, vol. 19, pp. 1127-1134, 2004.