



INSULATION CHARACTERISTIC OF LLDPE-NR COMPOUND WITH MMT/CLAY NANOFILLER FOR HV INSULATION PURPOSES

M. I. H. M. Razali, N. A. M. Jamail, M. A. A. Azmi, N. H. Zulkifli, and N. A. A. N. Zarujhan

Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia

E-Mail: muhdiqbal57@gmail.com

ABSTRACT

A study on the dielectric characteristics of various polymer nanocomposite materials should be conducted to design an electrically reliable high-voltage superconducting apparatus. Especially, the dielectric characteristics of solid insulation materials are important for designing current lead parts, and solid insulation materials are indispensable for designing superconducting coil parts. In this paper, dielectric experiments on Linear Low Density Polyethylene with Natural Rubber (LLDPE-NR) with different weight percentages of Montmorillonite (MMT) nanofiller are conducted under High Voltage Alternating Current (HVAC) and Impulse voltage for various types of electrode arrangement. Different types of electrode arrangement systems are used to examine the dielectric characteristics of insulation materials according to electric field concentration. During the first stage, several samples of LLDPE-NR are made by using hot compressed moulding processes which consists of different percentages of MMT nanofiller such as 3%, 5%, and 7% with thickness of 3mm. All these sample preparations are done according to steps with specific time of heating and cooling processes in order to produce the samples with the best condition and need to retain their morphological structures and also chemical compositions. Then, those samples are tested using both HVAC and Lightning Impulse Test until breakdown process occur. Based on collected and analyzed data results from both tests, 7wt % of nanofillers is the most suitable percentage of nanofillers that will enhance the electrical insulation characteristic.

Keywords: polymer nanocomposite, LLDPE-NR, MMT, HVAC, impulse.

INTRODUCTION

Dielectric materials are the backbone of all electrical and electronic devices. These materials not only separate the high voltage from ground potential in power devices, such as generators, motors, transformers, capacitors and cables but also provide the required electrical insulation in electronics for electromagnetic shielding, junction devices, solar cells and others. A vast number of dielectric materials are integrated into complex insulation systems for a host of specialized applications and have become a vital component of high voltage electrical and electronic equipment.

During normal operation, dielectric materials are not only subjected to electrical stress, but could also be subjected to thermal, mechanical, chemical and environmental stresses, which often play a role in their insulating properties. Insulation integrity is extremely important for all electrical power applications, the lack of it often results in catastrophic breakdowns and power failures with losses of millions of dollars in productivity to a country's economy. Using dielectric materials that can withstand high electric stress, dissipate large amounts of heat, resist partial discharges, and remain less prone to environmental stress cracking would enhance the performance of an electrical device. Furthermore, to be cost effective and utilize fewer raw materials, new applications demand a compact and highly efficient high voltage devices and this can only be achieved by combining the dielectric polymer like LLDPE with the other composite material substances that can enhance the insulator with greater intensity and higher repetition rates.

By adding a small amount of weight percentage (wt. %) of nanofiller, the physical, mechanical, and

electrical properties of polymers can be greatly enhanced. For instance, nanofiller in nanocomposites such as Silicon Dioxide (SiO₂), Montmorillonite (MMT) and Titanium Dioxide (TiO₂) play a big role in providing a good approach to increase the dielectric strength and partial discharge resistance of nanocomposites that may give major benefit to high voltage insulation system

LITERATURE REVIEW

Polymer nanocomposite

Polymer nanocomposites are defined as composites in which small amounts of nanometer sized fillers are homogeneously dispersed in polymers by several weight percentages. As defined, the fillers added to the matrix are very small in quantity, which normally less than 10% (P. Dielectrics, 2008). Polymers such as Polyethylene (PE), Polypropylene (PP), Polyamide (PA), epoxy, and rubber are combined with nanofiller that can be Aluminium Oxide (Al₂O₃), Titanium Dioxide (TiO₂), Silicon Dioxide (SiO₂), Magnesium Oxide (MgO), Montmorillonite (MMT)/clay, or other new materials are proposed (Jamail and Piah, 2014).

The comparison between nanocomposite and microcomposite polymer materials can be done based on three major properties which are content of fillers, size of fillers, and specific surface area of fillers. Nanocomposites require a smaller amount of fillers than microcomposites. Therefore, polymer nanocomposites are almost pure polymer, given that some properties of the polymer remain unaffected even after becoming polymer nanocomposites, such as the density of the composites. Besides, with smaller amounts of fillers, the distance between



neighboring filler in nanocomposites will be smaller than in conventional microcomposites. Lastly, nanocomposites have a specific surface area that is three orders larger than microcomposites. Thus, interaction of polymer matrices with fillers is expected to be much greater in nanocomposites (Tomassini, 2009).

Linear low-density polyethylene (LLDPE)

Linear low-density polyethylene (LLDPE) is a substantially linear polymer (polyethylene), with significant numbers of short branches, commonly made by copolymerization of ethylene with longer-chain olefins. In general, LLDPE is produced at lower temperatures and pressures by copolymerization of ethylene and such higher alpha-olefins as butene, hexene, or octene. The copolymerization process produces a LLDPE polymer that has a narrower molecular weight distribution than conventional LDPE and in combination with the linear structure, significantly different rheological properties (Zainir and Muhammad, 2013).

LLDPE has higher tensile strength and higher impact and puncture resistance than LDPE. It is very flexible and elongates under stress. It can be used to make thinner films, with better environmental stress cracking resistance. It has good resistance to chemicals and also possesses good electrical properties (Marquis and Guillaume, 2005). LLDPE is less shear sensitive because of its narrower molecular weight distribution and shorter chain branching. During a shearing process, such as extrusion, LLDPE remains more viscous and, therefore, harder to process than an LDPE of equivalent melt index. The lower shear sensitivity of LLDPE allows for a faster stress relaxation of the polymer chains during extrusion. In melt extension, LLDPE has lower viscosity at all strain rates (Marquis and Guillaume, 2005).

Polymeric insulating materials, such as polyethylene and polypropylene, are extensively used in power devices because these materials have excellent electrical properties such as high breakdown strength, low dielectric permittivity and losses, high DC resistance and, they require less maintenance than the oil based insulation systems. In addition, good mechanical stiffness, high corrosion resistance, ease of formation and the low cost of manufacturing often make them the best choice of insulating material for underground high voltage cables, transformers, electrical machines, and capacitors (Lau and Piah, 2011).

Montmorillonite (MMT)

Nanofiller can be natural or synthetic clays, as well as phosphates of transition metals. The most widely used reinforcement is clay due to its natural abundance and its very high form factor. Clay-based nanocomposites generate an overall improvement in physical performances. The most widely used ones are the phyllosilicates (smectites). They have a shell-shaped crystalline structure with nanometric thickness. Clays are classified according to their crystalline structures and also to the quantity and position of the ions within the

elementary mesh. The elementary or primitive mesh is the simplest atomic geometric pattern, which is enough for duplicating the crystalline network, by repeating itself indefinitely in the three directions. The most common usage concerns organomodified Montmorillonite (MMT), a natural phyllosilicate extracted from Bentonite. Chemically it is hydrated sodium calcium aluminium magnesium silicate hydroxide (Tanaka, 2011).

Montmorillonite is a very soft phyllosilicate group of minerals that typically form in microscopic crystals, forming clay. It is named after Montmorillon in France. Montmorillonite, a member of the smectite group, is 2:1 clay, meaning that it has 2 tetrahedral sheets sandwiching a central octahedral sheet. The particles are plate-shaped with an average diameter of approximately one micrometer (Montmorillonite, 2001).

Nanoclay, treated and untreated montmorillonite were incorporated to strengthen a composite material. Only the treated montmorillonite can increase the strength of some composite material. An increase of 20% of the mechanical properties is obtained for a rate of nanofillers between 5% and 7%. Without surface treatment, performances are comparable to those lacking of nanofiller (Poly and Your). The withdrawal is a major drawback of some composite material, because it causes dimensional changes and distortion of composite parts. The withdrawal of a neighbor virgin composite is lowered from 7.5% to 5.8% with only the addition of 1 wt% clay nanofiller. The breaking strength of a nanocomposite with 4% nanofillers is increased by 108% and Young's modulus of 53%. The organophile montmorillonite clays generate improvements in the mechanical properties without losing impact strength. An even or perfect dispersion of clay like an exfoliated structure will show an important increase in the stiffness of the composite material for low load rates. The synergy existing between the traditional reinforcements, such as glass fibres and nanoclays is of particular interest. The association of glass fibres and montmorillonite produces a much more rigid material with a larger temperature range than the traditional composite material that has the same reinforcement rate (Voltage and Procedure).

SAMPLE PREPARATION

LLDPE used in this study is a commercial linear low density polyethylene from Titan Chemical, Malaysia. It has a density of 0.918 g/cm³, a melt index of 25g/10 min. Nanoparticle of montmorillonite (MMT) is from China with a particle size of about < 50nm was used as filler. This nanoscale filler has a nearly spherical shape with a specific surface area of about 100 m²/g. The filler was dried before use. Natural Rubber (NR) grade SMR CV 60 supplied by Taiko Plantations was used for blending and mixing with LLDPE and nanofiller. Polyethylene nanocomposites were prepared by melt mixing at 165°C using a Brabender mixer with chamber size of 50 cm³. The mixer has a high shear force and the screw speed was controlled at 35 rpm with the mixing time of 2 min. The polymer nanocomposites were finally



prepared into square shape of 10 cm x 10 cm with the thickness of 3 mm by hot melt pressing at 1 tone pressure at 170 °C for 10 min. Three types of LLDPE-NR nanocomposite square shaped with a dimension of 10 cm x 10 cm were prepared with concentrations of nanofiller of 3, 5 and 7 % wt respectively. Table-1 shows the compound formulation and designation of LLDPE-NR/MMT (Kasri and Kamarudin, 2013).

Table-1. Compound formulations and designation.

Test Sample	Constituents composition %wt		
	LLDPE	Natural Rubber	Nanofiller
LLDPE	100	0	0
LLDPE + NR	80	20	0
LLDPE + NR + MMT	80	20	3
	80	20	5
	80	20	7

EXPERIMENTS SETUP

HVAC test

The purpose of this test was to verify the adequacy of electrical insulation to withstand the sort of transients that can occur during transient (surge) events. Dielectric experiments were conducted under AC voltage conditions that have a capacities of below than 100 kV at 60 Hz frequency. The voltage used for testing HVAC must take into consideration the intent of the test, which is to stress the insulation being tested. The higher the voltage, the more stress is applied to the insulation. At other points of the sinusoidal AC waveform, the electrical stress is lower of lower operation of differential evolution. This will produce offspring solution, if these offspring solutions have better fitness values, it will replace the original solution. If not, the original solution will be remain unchanged until next iteration.

When dielectric tests was performed using an HVAC test voltage, an electric current flowed between the two points that are being tested due to the capacitance between the two conductors. This current does not represent a failing test result due to a low insulation resistance. Therefore, during HVAC testing, allowable flow of current had been compensated by the tester. The most common method to accomplish this is to allow the tester to supply a significant amount of current typically at 10mA or less without indicating an excess current failure.

Impulse test

Impulse test is also known as 'flash-over' test. The flash-over is due to a breakdown of air at the insulator surface, and it is independent to the material of the insulator. These test was carried out in order to investigate the influence of surges in transmission lines, breakdown of insulators and of the end turns of transformer connections to line.

Impulse testing is done in order to represent surges generated due to lightning. The lightning impulse power supply has a capacity of 600 kV with a waveform of 1.2/50 μ s. By the use of spark gaps, conditions occurring on the flash over to line are simulated. The total duration of a single lightning strike is about 10 μ s, although the total duration of the lightning stroke may be a few seconds. Table-2 shows the standard withstand impulse voltage by I.E.C. It has been stated that the electrical prestressing of polyethylene by means of a series of reduced-voltage impulses increases the impulse breakdown strength of the material (Dielectric and Testing).

Table-2. Standard withstand impulse voltage by I. E.

System Voltage	I.E.C Impulse Withstand Voltage
11kV	75kV
33kV	170kV
66kV	325kV
132kV	550kV
275kV	1050kV

Single-stage Impulse testing will be used with the rated DC charging voltage is about 140kV, for maximum stored energy with: a) HV9112 (25nF) is 245J, b) HV9112-50 (50nF) is 490J, c) HV9112-100 (100nF) is 980J and for the voltages efficiency (HV Training set).

RESULTS AND DISCUSSION

HVAC test

In this test experiment, the thickness of the sample had been fixed at 3mm while the air gap also had been fixed at 4cm. Parameter used in this test was the different types of the electrode arrangement used during the test. To get the accurate reading of voltage discharge of each tested insulator, six reading were taken during each different parameter used and average reading was calculated apart from those six different voltages reading collected. Table-3 shows the sample voltages and currents produced that were gained from HVAC testing.

Table-3. Sample voltages and currents produced by using HVAC test.

HV Electrode Arrangements	Percentages of MMT Nanofiller (%)	Secondary Voltage (kV)	Primary Voltage (V)	Sample Current (A)
Pin – Plate	3	27.0	64	0.6
	5	28.5	68	0.7
	7	29.1	69	0.7
Rod – Plate	3	27.8	64	0.6
	5	29.2	68	0.7
	7	30.9	71	0.7
Plate – Plate	3	36.1	86	1.0
	5	41.8	97	1.2
	7	42.9	103	1.3
Sphere – Plate	3	46.9	114	1.6
	5	48.3	117	1.8
	7	49.6	119	1.8



Figure-1 shows a graph that represents all the graph plotted by different shapes of the electrode conductor through HVAC testing. The purpose was to give the clear vision about the comparison between each graph and from that, the observation and conclusion also can be made. According to the legend in Figure-1, data 1 was referred to the pin type electrode, data 2 referred to the rod type electrode, data 3 referred to the plate type electrode and lastly data 4 referred to sphere type electrode.

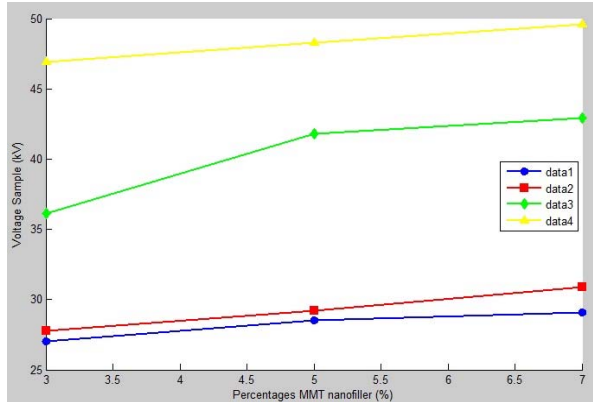


Figure-1. Graph of comparison between different arrangements of electrodes for HVAC test.

Impulse test

In this test experiment, the thickness of the sample had been fixed at 3mm while the air gap also had been fixed at 4cm. The parameter used in this test was the different types of the electrode arrangement used during the test. To get the accurate reading of voltage discharge of each tested insulator, six reading were taken during each different parameter used and average reading was calculated apart from those six different voltages reading collected. Table-4 shows the sample voltages and currents produced that was gained from Impulse testing.

Table-4. Sample voltages and currents produced by using impulse test.

HV Electrode Arrangements	Percentages of MMT Nanofiller (%)	Impulse Voltage (kV)	DC Voltage (kV)	Primary Voltage (V)	Sample Current (A)
Pin – Plate	3	49.61	46.45	120	1.0
	5	50.36	48.41	120	1.0
	7	51.57	51.31	120	1.0
Rod – Plate	3	51.42	51.07	120	1.0
	5	52.02	53.77	120	1.0
	7	53.19	56.13	120	1.0
Plate – Plate	3	51.75	55.47	120	1.0
	5	52.43	58.32	120	1.0
	7	54.98	60.17	120	1.0
Sphere – Plate	3	52.76	58.11	120	1.0
	5	54.83	60.32	120	1.0
	7	55.76	61.58	120	1.0

Figure-2 shows a graph that represents all the graph plotted by different shapes of the electrode conductor through Impulse testing. The purpose was to give the clear vision about the comparison between each graph and from that, the observation and conclusion also can be made. According to the legend in Figure-1, data 1 was referred to the pin type electrode, data 2 referred to the rod type electrode, data 3 referred to the plate type electrode and lastly data 4 referred to sphere type electrode.

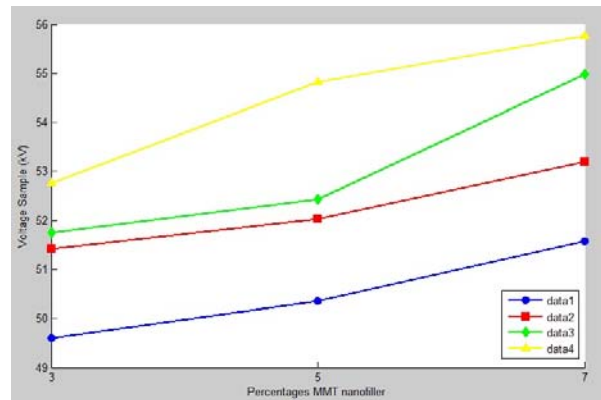


Figure-2. Graph of comparison between different arrangements of electrodes for impulse test.

Based on all Figure-1 and Figure-2, it can be seen that all of the patterns from all of the graphs was increased in pattern and it also almost if compared with the other graph. It can be concluded that although the electrodes conductors have a different electrode arrangement, the voltage sample that have been discharged will increased as the percentages of the MMT nanofiller was increased inside the LLDPE-NR polymer nanocomposite insulator which has percentage of 7% of nanofiller will make the voltage discharged in a quite larger amount compared to the 5% and also 3% percentages of MMT nanofiller content to make it pass through the tested insulator to the other side of the electrode conductor that connected to ground side. From that, it shows that between those three different percentages of MMT nanofiller contents in LLDPE-NR, the 7% percentages MMT nanofiller was the most effective value regarding the insulation characteristic on withstanding the high voltage supply. It was because after the nanofiller was added inside of the polymer nanocomposite, which base material is LLDPE-NR insulator, the nanofiller will create an interaction between the base material to make a new composition of new material of insulator and thus improving the insulator to become much stronger than the regular one. with 1%, 3% and 5% with nanofiller. Based on the three sample thickness obtained after carrying out the experiment, 7% with nanofiller shows better result than the percentage of nanofiller 1%, 3% and 5%. It was clearly shown that the total weight percentage of nanofiller that had been affecting the important characteristics of the material.



CONCLUSIONS

The main objective of this research was to investigate the insulation characteristics of sample Linear Low-Density Polyethylene (LLDPE) polymer with natural rubber at different amount of percentages Montmorillonite (MMT/Clay) nanofiller by using high voltage techniques. There were three kind of samples which are LLDPE-NR/MMT at 3%, 5% and 7%. These three samples had shown their own significant results after being tested by the high voltage tests.

After the testing procedure had been carried out, the sample of LLDPE-NR/MMT 7% shows that it has the highest insulation characteristics compared with the other two samples. The sample produced higher voltage to allow the discharged voltage to travel from one side to another side of the electrode conductor. The nanofiller will enhance the insulation characteristic of the base LLDPE-NR polymer nanocomposite where the nanofiller will strengthen the chemical composition of the tested insulator material. Thus, it can be concluded that the insulation characteristic of LLDPE-NR/MMT depends on the percentages of MMT nanofiller.

All of the research objectives were achieved successfully at the end of this project research. The tests were carried out under the vision from the supervisor and also the laboratory technician himself. Thus, every problem regarding this project research can be solved by the discussing with them.

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