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COMPARATIVE STUDY OF LEAKAGE CURRENT ON INSULATION SURFACE CONDITION

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**A report submitted in partial fulfillment of the requirements for the degree of Bachelor of
Electrical Engineering (Industrial Power)**



Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

I declare this project entitled “ Comparative Study of Leakage Current on Insulation Surface Condition” is the results of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.



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Specially dedicated to my late beloved father and mother, sisters and friends who always give me strength, guidance, and encouraged throughout my journey of education.



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In the name of Allah, Most Gracious, Most Merciful

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ABSTRACT

Electrical insulation is a significant component in all electrical systems. It is really important in parliamentary procedure to maintain the functioning and the refuge of the electrical appliances and creature. The demands for polymer insulator are much higher and have become a replacement for all traditional insulators such as porcelain, glass, and ceramics. Due to its advantage in the ratio of strength-to-weight is better than the other insulator, it has attracted lots of users to use polymer insulator as to reduce cost on insulator installations. Glass insulator has been widely used in high voltage engineering such as in distribution system. The utilization of glass/ ceramic insulators on the electrical energy transmission system which tend to accept higher voltage are no longer profitable because the glass/ceramics density is great, long, fragile and losses. However, pages still have the ability better than other polymer insulation because it is not eroded. The purpose of the study is to investigate the leakage current patterns for classification of Glass, Polypropylene and High Density Polyethylene surface degradation. The test follows the standard of BS EN 60587:2007 as a guideline to conduct the Incline Plane Tracking (IPT) test. The test is conducted to determine the pattern and value of leakage current of the Glass, Polypropylene and High Density Polyethylene. The patterns of leakage current can be classified into 4 phases which are capacitive, resistive, symmetrical and unsymmetrical. As a result, the pattern and value of leakage current for each of the insulation materials used can be seen. From the study, Glass is proven to be a good material for insulation compare to Polypropylene and High Density Polyethylene.

ABSTRAK

Penebat elektrik adalah satu komponen penting dalam semua sistem elektrik. Ia merupakan satu perkara penting dalam prosedur utama untuk mengekalkan fungsi dan perlindungan terhadap peralatan elektrik dan benda hidup yang lain. Permintaan untuk penebat polimer adalah lebih tinggi dan telah menjadi pengganti untuk semua penebat tradisional seperti tembikar, kaca dan seramik. Oleh kerana mempunyai kelebihan dalam nisbah kekuatan-kepada-berat adalah lebih baik berbanding dengan penebat yang lain, ia telah menarik banyak pengguna untuk menggunakan penebat polimer dalam usaha mengurangkan kos pada pemasangan penebat. Penebat kaca telah digunakan secara meluas dalam bidang kejuruteraan voltan tinggi seperti dalam sistem pengagihan. Penggunaan kaca / penebat seramik pada sistem penghantaran tenaga elektrik yang cenderung untuk menerima voltan yang lebih tinggi tidak lagi menguntungkan kerana ketumpatan kaca / seramik yang besar, panjang, rapuh dan kerugian. Akan tetapi, kaca masih lagi mempunyai keupayaan yang lebih baik daripada penebat polimer yang lain oleh kerana sifatnya yang tidak terhakis. Tujuan kajian ini adalah untuk mengkaji corak arus bocor untuk pengelasan degradasi permukaan Kaca, Polipropilena (PP) dan Polietilena berketumpatan tinggi (HDPE). Ujian dijalankan mengikut standard BS EN 60587: 2007 sebagai garis panduan untuk mengendalikan ujian Incline Plane Tracking (IPT). Corak kebocoran arus boleh dikelaskan kepada 4 fasa iaitu kapasitif, rintangan, simetri dan tidak simetri. Hasilnya, corak dan nilai kebocoran arus bagi setiap satu daripada bahan penebat yang digunakan dapat dikenalpasti. Dari kajian ini, kaca terbukti sebagai bahan yang terbaik untuk penebat berbanding Polipropilena (PP) dan Polietilena berketumpatan tinggi (HDPE).

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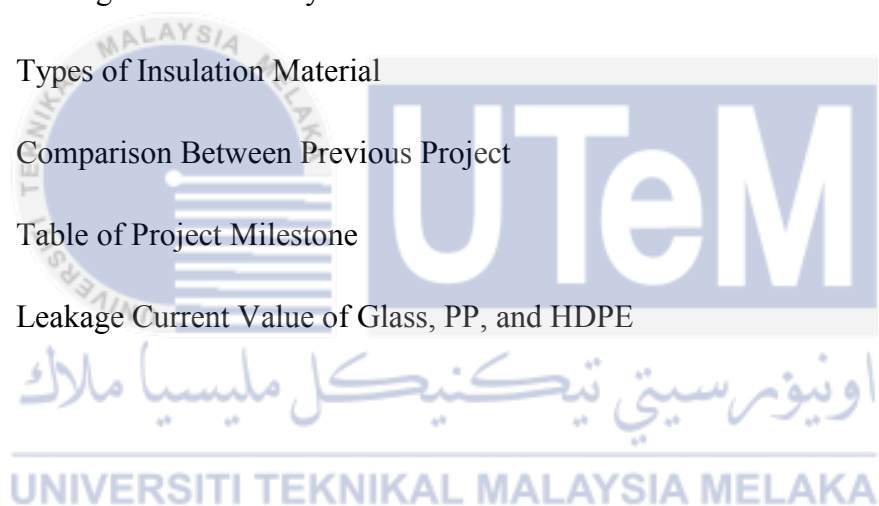
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LIST OF ABBREVIATIONS

PP	-	Polypropylene
HDPE	-	High Density Polyethylene
LC	-	Leakage Current
BS	-	British Standard
IEEE	-	Institute of Electrical and Electronic Engineering
IPT	-	Incline Plane Tracking
DAQ	-	Data Acquisition Card
AC	-	Alternating Current
DC	-	Direct Current
HV	-	High Voltage
SiO ₂	-	Silicate Oxide
A	-	Ampere
V	-	Voltage

CHAPTER 1

INTRODUCTION

1.1 Research Background

Electrical insulation is a significant component in all electrical systems. It is really important in the main procedure to maintain the functioning and the refuge of the electrical appliances and creature. Nowadays, the use of polymer as an insulator is widely used all over the world, despite using the glass or ceramic as an insulator in the electrical system. This is due to the polymer insulator have better ease of handling and installation, not causing pollution and resistance to vandalism rather than the glass or ceramic insulator.

Nowadays, the demands for polymer insulator are much higher and have become a replacement for all traditional insulators such as porcelain, glass, and ceramics. Due to its advantage in the ratio of strength-to-weight is better than the other insulator, it has attracted lots of users to use polymer insulator as to reduce cost on insulator installations.

The utilization of glass/ ceramic insulators on the electrical energy transmission system which tend to accept higher voltage are no longer profitable because the glass/ceramics density is great, long, fragile and losses. It has a higher cost of construction and maintenance of electric power network [1].

The degree of effectiveness of insulator actually depends on how much leakage current that flow through the insulator itself. Leakage current is any current that can flow either through the body or over the insulator when the idle current is zero. In electrical systems and

the use of home appliances, the leakage current is often associated with the user's safety and the public. To better understand the situation, taking the example of an electric motor that has a weak winding insulation. Insulation may wear at some point and mostly due to long time running, heating or some other factor. The voltages at that stage will be shifted to the core of the motor.

The core is linked to motor body so, a voltage will appear along the outer surface of the motor body. If the body is grounded, this potential difference will make a net current flow to ground. This current is passed directly from point of insulation failure. The magnitude of this current depends only on the resistance of ground [2].

1.2 Motivation

In high voltage engineering and distribution system, a lot of test need to be conducted in order to maintain the performance of insulator. By following the several standard to achieve the reliable result, a lot of tests can be conducted. In this project, the IPT test is conducted and the standard BS EN 60587:2007 is used as a guideline to obtain accurate and reliable results of leakage current on the surface of the insulation material. The specimen used as the materials which is glass, polypropylene and high density polyethylene are the most use material as an insulator nowadays. The result of this project explains more about the leakage current patterns, behaviour and value of the leakage current. Besides, the length of carbon tracking on the surface of the specimen at the end of the test conducted will determine whether the material is passed or failed, according to the specifications given in the standard BS EN 60587 : 2007.

1.3 Problem Statement

Insulator plays an important role in the electrical system. Most common problems in High Voltage (HV) application or system is the insulation failure. A lack or bad in insulation might cause problems for electrical application or might injure people who deal with electrical system itself. One of the causes that led to failure in insulation is the surface of the insulator have been deteriorated. Basically, this condition happened when there is a leakage current. There are two types of leakage current which is AC leakage current and DC leakage current. Therefore the leakage current should be handled seriously. In this project, the leakage current was analysed based on their leakage current pattern, whether it is a capacitive pattern, resistive pattern, symmetrical pattern or unsymmetrical pattern. Also from the project, the reliability of an insulator on handling HV can be identified.

1.4 Objective

The objectives of this project are:

1. To investigate the Leakage Current (LC) patterns for classification of glass, Polypropylene (PP) and High Density Polyethylene (HDPE) surface degradation.
2. To analyze using MATLAB to gain the information on AC leakage current for the glass, Polypropylene (PP) and High Density Polyethylene (HDPE).
3. To determine the tracking on the surface of the glass, Polypropylene (PP) and High Density Polyethylene (HDPE) in High Voltage (HV) application.

1.5 Scope of Work

This project focuses on the following scope:

1. Usage of the glass, Polypropylene (PP) and High Density Polyethylene (HDPE) as an insulation material according to electrical discharge behavior and the insulator surface condition.
2. The Inclined Plane Test (IPT) method has been used to evaluate the tracking and erosion resistance based on BS EN 60587:2007.
3. Usage of the „Method 1“ as stated in BS EN 60587:2007 with constant tracking voltage and contaminant flow rates.
4. LabVIEW software used as an On Line monitoring leakage current system in order to study the leakage current waveform signal.
5. The contaminant use of the IPT test is ammonium chloride, NH_4Cl , and also isooctylphenoxypolyethoxyethanol (a non-ionic wetting agent)

1.6 Thesis Outline

This report consist of five chapters. For Chapter 1, it consists of an introduction, problem statement, objectives, and scopes of the project. This chapter explained the overview of the research project and this research is done by based on the objectives and scope.

Meanwhile, Chapter 2 discussed about the type of materials used in the project and its properties. Besides, the properties of leakage current, patterns, and the The Incline Plane Tracking test and the previous project about the leakage current also being discussed. Chapter 3 begins with the explanation of the tracking and erosion test, and followed by the IPT set up. The On-Line monitoring system that used in measuring and analyse the leakgae current also being explained in this chapter.

In this thesis, Chapter 4 represents all the results and discussion gain from the experiment conducted. The leakage current model and the analysis of the leakage current

explains about the pattern and the behaviour of all the materials used in the project. Other than that, the tracking and erosion test result which leads to pass and fail of the specimen is also being showed in this chapter. Finally, Chapter 5 is the conclusion of the project and also recommendation that can be done in the future.



CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Polymeric and glass insulator nowadays has become one of the most wanted materials in developing or manufacturing of insulator. This section will discuss about the overview of polymeric and glass insulation material of its development, the important of leakage current and the causes of the leakage current.

2.2 Polymeric Insulator

Polymeric insulators were considered as a replacement for porcelain and glass for special applications such as areas with high incidences of vandalism, urban locations with limitations on the right of way and areas of severe contamination problems due to their superior properties such as light weight, superior in mechanical strength and high hydrophobicity. When silicon rubber is used as an outdoor insulator, different environmental factors such as ultraviolet light, rain and air pollutant deteriorate the material properties. Then, tracking and erosion are caused by electrical factors such as arc and corona partial discharges. It happens when the power system is in operation tracking and erosion of polymer sheds, chalking and crazing of sheds which lead to increased contamination, arcing and flashover,

bonding failures and electrical breakdowns along the rod-shed interface and corona splitting of sheds. This condition will lead to electrical breakdown. It is well realized that aging, which leads either to tracking or erosion or to flashover under defiled conditions at normal working voltage, is still the major problems of failures for non-ceramic insulators [3].

Nowadays, electrical appliances accept polymer as an insulator proportionate to traditional insulator. This kind of insulator is widely used due to its advantages such as light in weight, low surface energy, better performance in wet condition and also great mechanical strength to weight ratio which means it is sturdy although it was light in weight.

When subjected to a range of in-service electrical, mechanical and environmental stresses, polymeric materials are more likely to predispose against chemical changes. The electrical stress is important to polymeric insulator which is under both normal and transient overvoltage conditions which are imposed under lightning and switching operations. In the high field locales, the initiate corona and surface electrical discharges that can prompt premature degradation, and under extreme conditions, a complete protection flashover, especially close to the HV transmitter and the earth terminal. Electric field distribution on the insulator surface are one of the main factors that contributed to the development of discharges on insulating surfaces, which will then be, control the current density. The surface of the insulation will reach its maximum level when the dry pond surface is formed on it as well as the insulation is starting to erode and leave traces on the surface of the insulation material. To reduce the effects of surface discharges on polymer outdoor insulator, the field control is required by considering these undesirable consequences [4].

2.3 Properties of Glass

Nowadays, glass has been widely used as an insulator in transmission and distribution system. Glass is a thermoplastic inorganic material comprising a complex system of oxides (SiO_2) [5]. The main reason glass is used as an is due to its ability to operate in a very long period of time. In addition, the glass also will not undergo a process of erosion of the surface which also been known as surface degradation.

The dielectric strength of a glass is around 3000 to 5000 kV/cm depends on temperature. If the temperature increases the value will decrease [5]. Besides, glass has very high resistivity if compared to porcelain and polymer. Glass also has very high dielectric strength compared to any other compound such as polymer and porcelain. Glass properties which are transparent to light, which does not get hot when under extremely hot conditions or exposed to direct sunlight [6]. Because of its nature, it is transparent to light so that the resulting air bubbles in it can be detected easily. The resulting air bubbles in the glass insulation will result in a partial discharge of which would cause it breakdown to occur [7].

However, glass also has disadvantages which is when moisture condensed on its surface it will provide a path of leakage current of the system. This is due to, when the moisture condensed, it might contain contaminant which can allow the leakage current to flow.



Figure 2.1: Glass Specimen

2.4 Properties of Polypropylene

The thermoplastic polypropylene (PP) is used as a specimen in this project. Polypropylene (PP) has good balance between electrical and mechanical properties. It also has high dielectric strength [8]. Polypropylene (PP) has the best balance of electrical and mechanical properties. Because of Polypropylene can be synthesized from a low-cost

petrochemical raw materials, it makes the PP become a very versatile resin that suitable for processing in the mold or extruded parts by using a Ziegler type catalyst [9]. PP also has good attractive properties such as good in heat resistance, good surface hardness and also protected from moisture. Other than that, PP is much easier to fabricate if compared to the other insulator such as ceramic or glass. Due to its advantages, PP has become a key element in the production of insulation.

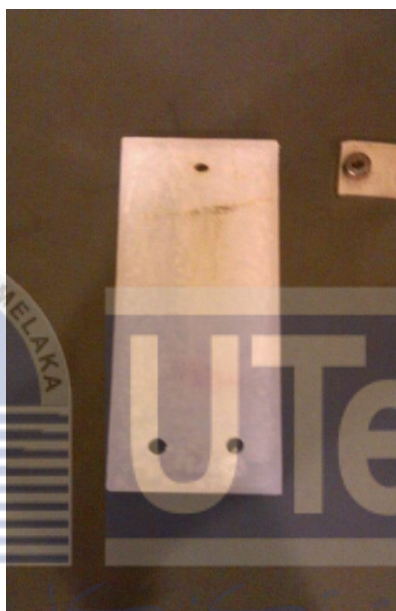


Figure 2.2: Polypropylene (PP) Specimen

2.5 Properties of High Density Polyethylene

Polyethylene is a thermoplastic material which is also being used widely as an insulator in high voltage system. Due to its versatility, the percentage of it to break is very low. It can elongate more before its break. Despite being very good in strength, it is light in weight compared to glass and porcelain [10]. Due to its weight is light, it gives less load to the supporting structure compared to glass insulator which is much heavier.

High Density Polyethylene or also known as HDPE has the dielectric strength of 180 to 240 kV/cm [5]. The dielectric constant of HDPE is 2.32 to 2.35 at 73°F based on the IEC 60250 standard and the volume resistivity is 10 to 1.3×10^{16} Ω/cm at 73°C based on the IEC 60093 standard.

However, HDPE is subjected to surface cracking and also bad in temperature capability. HDPE can only withstand at temperature of 120°C for a short period but can withstand heat at 110°C for a continuous time. Besides, HDPE is flammable and are difficult to bond.



Figure 2.3: High Density Polyethylene (HDPE) Specimen

2.6 Leakage Current

Current that flow through the protective ground conductor to ground is called leakage current. This current could flow from any conductive part or the surface of non-conductive part to ground if the conductive part is available and there is an absence of grounding

connection. The magnitude of leakage current depends on the surface wetting and the degree of contamination [6]. There are extraneous currents that always flowing in the safety ground conductor. The grounding system usually consists of a grounding conductor that bonds the equipment to the service ground (land). If there is a catastrophic failure of the insulation between the hot (power) line and touchable conductive parts, the voltage is shunted to ground. The resulting current flow will have a fuse to blow or open a circuit breaker; preventing a shock hazard. Apparently, a possible shock hazard exists if the grounding connection is broken, either deliberately or unintentionally. The shock hazard may be greater than imagined because of the leakage flows. Even if at that point there is no insulation failure, disruption of the leakage currents flowing through the ground conductor could pose a shock risk to someone coming to the ungrounded equipment and soil (or other grounded equipment) at the same time. This possibility is of a great deal more concern in medical applications, where a patient may be the receiver of the blow. A fatal shock could result if the patient is in a weakened condition or unconscious, or if the leakage flow is given to internal organs through patient contacts. The double insulation provided in non-grounded equipment provides protection by applying two separate layers of insulation. Because of both layers of insulation are unlikely to fail the protection in this case is ensured [11]. Despite being have insulation in all electrical appliances the condition of having leakage current to produce still need to be considered.

Leakage current (LC) happens when airborne particles are deposited on insulators during wet weather conditions such as dew, fog or drizzle that comes from near industrial, agricultural or coastal areas. The LC density is non-uniform and in some areas, sufficient heat is developed leading to the formation of dry ponds and partial arcs is formed when voltage redistribution along the insulator causes high electric field across dry ponds. These partial discharges will elongate along the insulator profile when the surface resistance is sufficiently low which may eventually cause the insulator flashover. To reduce flashover risk, preventive maintenance by insulator surface washing is fundamental, but it is very costly. Many surveys have concentrated on finding an efficient and convenient path to predict flashover due to contamination [12].

In the case of insulation, the leakage current is not always poses a danger to public safety. But it has become a crucial factor to be considered in the design, selection, and

installation of transmission lines. The reason for this is the insulation itself, with the increased of leakage current, it is dramatically impaired the performances of the insulator. Even though a path of relatively low resistance exists over the surface, the current cannot pass inside the insulator. This is actually the interface between the insulator surface and the air. Around the insulator, there is much lower resistance than the air on this path. When there is surface leakage current path, the small amount of leakage current flows and can never be excluded at all. However, low levels of leakage currents have been achieved by using the modern insulators. The most common insulators used in electrical systems are the ceramic insulators and nowadays it have been replaced with polymeric insulators. These kind of insulators can become an insulators for any kind of voltage level when they are attached together because it is available in the form of different sizes and diameters [2].

2.7 DC and AC Leakage Current

AC leakage and DC leakage are the two kinds of leakage current. AC leakage current is brought along with a parallel combination of capacitance and DC resistance between a voltage source and the grounded conductive parts of the supplies. DC leakage current did not apply to the power supplies, but generally applies only to final item supplies. The leakage created by the DC resistance normally is inconsequential contrasted with the AC resistance of different parallel capacitances.

2.7.1 DC Leakage Current

It can be induced when a source of DC voltage is shorted directly or with a very low resistance onto itself; it normally gives only to appliances using high DC voltages only. Many consumer appliances use low voltage DC levels below 48 V, at these voltage leakage current is not an event to debate. For example, a radio using 6 V DC from AC gets developed a partial

short path between its DC voltage and neutral of step down transformer. Such a fault will only cause a few milliamperes (mA) of current to flow [2].

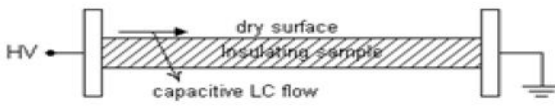
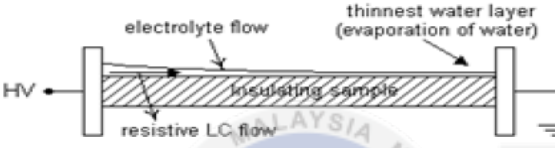
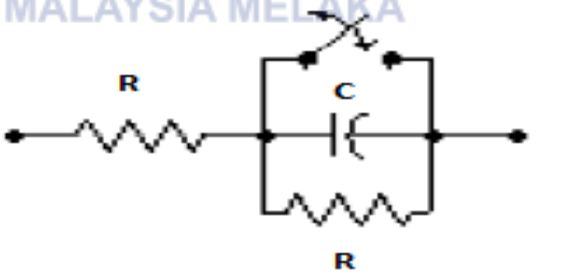
2.7.2 AC Leakage Current

AC is the current that is brought nigh by the parallel combination of leakage capacitance and DC resistance between a voltage source and grounded conductive parts of electrical appliances. All electrical appliances, leakage current brought about by capacitance overwhelms over the leakage current brought about by DC resistance. The cause is that DC resistance is made sufficiently high amid configuration to minimize DC leakage current. Thereby, usually in leakage capacitance, the major LC will normally occur.

Nevertheless, the capacitance excited some parts of hot and grounded parts of electrical devices are sometimes deliberate and occasionally not. Intentional capacitance is deliberately caused by using a capacitive filter. Always unintentional and causes a flow of either leakage current or short circuit current makes the insulation to fail. The short circuit current cannot flow for a long time. If this condition occurs, it may either operate the safety breakers or burns out the appliances. However, the leakage current cannot be observed easily. This is why there are times when it is called as “silent current”. It is independent of capacitances when the leakage current is due to the insulation failure [2].

2.8 Classification Of Leakage Current Behavior

Table 2.1: LC Phenomena and dry band arcing development [13]

Physical Conditions	Equivalent Circuit
a-i 	a-ii 
b-i 	b-ii 
c-i 	c-ii 
d-i 	d-ii 

Referring to Table 2.1, for the a-i condition, the insulator is in a dry state. This is because the surface area of the insulator is dry, the capacitive LC can flow on the surface. The equivalent circuit of this condition is in a-ii, which is the circuit has the capacitor. But for the b-i, the insulator is in wet state. This is due to a thin layer of water on the insulator acts as an insulator which allowed the resistive LC to flow through it. As for the c-i, the insulator has a dry and wet condition on it. This causes some flashover to occur on the surface area of the insulator, which will produce the symmetrical pattern of leakage current. For d-i, the arcing starts to occur and then the erosion takes place. The insulator will erode and the leakage current pattern will be unsymmetrical. The eroded part will act as a circuit which is will cut and connect the current that flow through it.

2.9 Surface Tracking And Erosion Test

There are a few methods used to test the insulation materials for high voltage applications, for example, tracking wheel test, dust and fog test, plane tracking test, and salt-fog test. But in this project, inclined-plane test is used to test the insulating material.

The inclined-plane test is directed in parliamentary procedure to investigate resistance to tracking and erode. Plate samples are mostly employed in the IPT test. During inclined-plane test, the plate specimen is drilled and electrodes are bonded. Then, the specimen is washed with a suitable solvent, rinsed with distilled water and mounted at certain angles (proposed: 45 degrees). A contaminant of certain composition and resistivity is allowed to flow, at a certain flow rate, from high voltage (higher) to ground (lower) electrode. With the contaminant flowing uniformly, voltage is applied to the specimen and timing starts until tracking is observed (or after 6 hours have passed). During this examination, leakage current flows through the conductive path formed by the meanness of the contaminant and may cause partial evaporation of the contaminant, formation of dry bands and arcing [14].

IPT is normally utilized to evaluate the tracking and erosion resistance of insulating materials. It is a valuable instrument for the comparison and valuation of new and different materials under controlled electrical stress, to compare the suitability of fabrics for the dielectric surface of an insulator. It also has simplicity in the test procedure and low equipment cost. IPT complies with BS EN 60587 [15].

There are four types of method used to determine the insulating material reliability of a High Voltage application. Table 2.2 shows all the methods and its advantages and disadvantages in order to test the insulation.

Table 2.2: Testing Method of Insulation Material [16]

Method	Properties Measured	Advantages	Disadvantages
Inclined-Plane Test	Time to track Tracking voltage Erosion Research Material	Fast result; Good educational tool; Required close attention	Initial tracking voltage is difficult to measure; Erosion end point is too deep Cheaper installation
Dust And Fog Test	Time to track Erosion	Reliable; All materials	Long time Erosion method vague
Tracking Wheel Test	Time to track Erosion Research Material	Reproducible; Easy to run; Good at finding defects	Interactions between different materials
Salt And Fog Test	Erosion	Guide for future; Imitate natural condition of seacoast area	Very long time to rest Not good for silicone Expensive installation

The table 2.3 shows some example of a common material that has been used nowadays as an insulation material in developing an insulator for the High Voltage application. Polypropylene (PP), High Density Polyethylene (HDPE), ceramics and glass are some of the common insulation material used. In this project, three materials which is Glass, PP and HDPE is used as the insulation material.

Table 2.3: Types of Insulation Material

Material	Advantages	Disadvantages
Polypropylene (PP)	Low cost; Excellent balance of mechanical properties; Stiff, hard, and inflexible; Higher temperature range than PE	Flammable Erodible
High Density Polyethylene (HDPE)	Low cost; High resistance to cracking; Stiff, hard, and inflexible; High temperature range	Flammable Erodible
Ceramics	Non-Hydrophobic High cost	Large density Easily fragile High cost in production and maintenance
Glass	Non-Hydrophobic High cost	Large density Easily fragile High cost in production and maintenance

2.10 Inclined-Plane Test

The tracking and erosion resistance of insulating materials can be evaluated by using Inclined Plane Test (IPT). This test is a valuable instrument which uses to compare and evaluate new and different materials under controlled electrical stress. Other than that, this test is also used to compare the suitability of fabrics for the dielectric surface of an insulator. The advantage of this test is the procedure of the IPT is simple and the cost of equipment is also low [17]. It complies with BS EN 60587:2007 and the materials used for this project are glass, Polypropylene (PP), and High Density Polyethylene (HDPE).

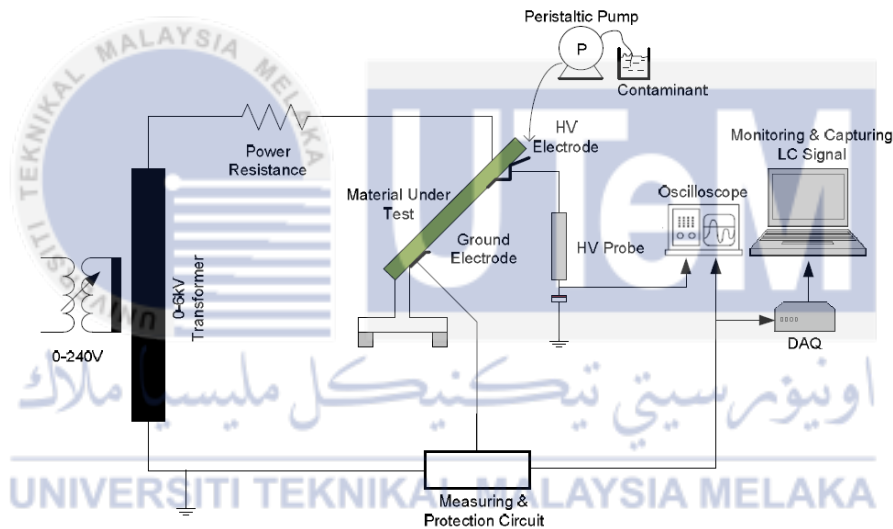


Figure 2.4: IPT schematic diagram [17]

Figure 2.4 shows the set-up of the Incline Plane Test for this project. This setup of the IPT test is exactly following the BS EN 60587:2007. The specimens, which is Glass, PP, and HDPE are used in this project will be mounted at an angle of $45^\circ \pm 2^\circ$ from the horizontal as shown in Figure 2.1, Figure 2.2 and Figure 2.3. The On-Line monitoring system used is LabVIEW.

2.11 Previous Project

Table 2.4: Comparison Between Previous Project [3,18,15]

TITLE	AUTHOR	ABOUT THE JOURNAL
Leakage Current Analysis and FFT Calculation on Polluted Polymer Insulator	I. A. Joneidi, A. A. Shayegani, H. Mohseni, S. Mohseni, and M. Jebeli-Javan	Study about the effect of leakage current on polluted silicone rubber insulator and analyze using FFT
High Voltage Insulation Surface Condition Analysis using Time Frequency Distribution	Nurbahirah Norddin, Abdul Rahim Abdullah, Nur Qamarina Zainal Abidin and Aminudin Aman	Analysis of high voltage insulation surface condition under high contamination level using an experimental test of tracking and erosion according to BS EN 60587 standard
Leakage Current Analysis on Polymeric Surface Condition using Time-Frequency Distribution	N. Q. Zainal Abidin, A. R. Abdullah, N. Norddin, A. Aman, and K. A. Ibrahim	The reliability method (TFD) to measure loss of hydrophobicity on polymeric insulation, which leads to tracking and erosion as well as to flashover under contaminated condition

There are several studies about the leakage current effect on insulators. Some of these studies use the same test which is the Incline Plane Test but with different method to analyse, the different material used as the specimen and also with different condition of the environment. The study about “Leakage Current Analysis and FFT Calculation on Polluted Polymer Insulator” by I. A. Joneidi, A. A. Shayegani, H. Mohseni, S. Mohseni, and M. Jebeli-Javan, is about the effect on leakage current in polluted silicone rubber insulator and the

results was analysed using Fast Fourier Transform, FFT. Third harmonic components of the leakage current waveform are closely related to the pollution on the insulator. Under clean conditions, no flashover occurred during the tests, When 3rd harmonic is lower than 5th harmonic, the insulators have no or very light contamination. Therefore, harmonic analysis of leakage current will be an efficient approach to determine the pollution severity of outdoor polymer insulators [3]. The study of “Leakage Current Analysis on Polymeric Surface Condition using Time-Frequency Distribution” shows that Spectrogram and s-transform intime representation present information on frequency component with respect to time, frequency, and magnitude. The frequency component level of the signal can be used as an indicator of a surface condition event. Also, with higher content of harmonic and inter-harmonic will demonstrate the severity of the LC signal distortion [15]. For the study about “High Voltage Insulation Surface Condition Analysis using Time Frequency Distribution” it was found that late aging period state with unsymmetrical discharge pattern on polymeric insulation material can be use as erosion indicator occurred on the surface of the insulator [18].

2.12 Conclusion

Now, polymer materials are mostly applied as a constituent of the advancement of high voltage insulators due to the favorable circumstances of this fabric which is light in weight, higher mechanical quality to weight ratio, opposition to vandalism and better performance in the existence of wet polluted conditions. The developers of LC and its characteristic are subject to the electrical and environmental strains. Under wet and contaminated conditions, the existed LC that streams along the material surface could bring close to the evolution of electrical discharges because of the development of dry band. The Inclined-Plane Test used to quantify the leakage current and analyse are the best means to gather information about leakage current and the insulation surface condition.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The experiment has been carried out using The Inclined-Plane Test that follow BS EN 60587:2007 as standard provides test methods for finding the pattern waveforms of LC. This experiment consists of two parts:

1. Surface tracking which is application of constant tracking voltage based on the inclined plane tracking method of standard of BS EN 60587:2007.
2. On-line leakage current monitoring system which is LabVIEW software and MATLAB programme.

3.2 Tracking and Erosion Test

Tracking is the procedure that creates tracks as the effect of the action of electrical discharge on or close to a polluted surface of an insulation material. The degradation of the surface of an insulating material was created during conducting path. Erosion is the breaking away of electrical insulating material from the natural action of electrical arcs and it may record upon the air foil of the material or burrowing erosion on the insulating material surface.

This alteration in the air foil of the insulating material can be tied up with the existence of LC on the insulating material.

The Inclined-Plane Test (IPT) standard BS 60587:2007– Electrical Insulating Material Used under Severe Ambient Conditions- Test Methods for Evaluating Resistance to Tracking and Erosion is applied in this project.

3.2.1 Incline Plane Tracking Test Set Up

To evaluate the tracking and erosion resistance of insulating materials, the Incline plane Test (IPT) is mainly used. It is a valuable instrument for the comparison and valuation of new and different materials under controlled electrical stress, to compare the suitability of fabrics for the dielectric surface of an insulator. It also has simplicity in the test procedure and low equipment cost [18]. IPT complies with BS EN 60587, and three material are used as the material under test which are glass, PP and HDPE. The contaminant use is ammonium chloride and distilled water. LABVIEW program is built up for LC data monitoring and store for analysis purpose [17]. In this study, Method 1 „time to track method“ is applied. The full set-up of the IPT test is shown in Appendix A.

There are two methods for testing the carrying out of polymeric insulation specimen according to BS EN 60587:2007 IPT tests;

1. **Method 1:** Application of constant tracking voltage with a uniform contaminant flowing at specified rate. The constant tracking voltage is the highest voltage withstood by the specimens for 6 hours without failure and named as „time to track method“
2. **Method 2:** Stepwise tracking voltage or „variable voltage method“. The stepwise tracking voltage is the highest voltage withstood by the specimens for an hour without fail [18].

The experiments focus on investigating the surface condition monitoring methods for Glass, Polypropylene (PP) and High Density Polyethylene (HDPE) as insulation material for

high potential difference application, hence the test is conducted with Method 1 which is with variable contaminant and constant electric potential.



Figure 3.1: The Incline Plane Tracking Test Set-Up

3.3 On-line Leakage Current Monitoring System

By performing the On-Line measurements, the result and information along the insulating performances can be furnished. An LC data acquisition scheme is produced to analyse the LC flowing on the sample surface [20]. It consists of two components, which are :

1. The measuring units
2. The digital signal analysis system utilizing a personal or lab computer

The measuring unit is used to detect the LC and measure its value are consists of a variable shunt resistor that can be changed from 50Ω to $1k\Omega$, a fuse of 60 mA , a 9V Zener diode, and a gas discharge tube rated at 90V. This element in the measurement unit is to protect the circuit from any short circuit that might occur throughout the experiment. In this

experiment, the shunt resistor is set at $250\ \Omega$. A 9V back to back Zener diode is installed in the measurement unit because to protect the Data Acquisition System (DAQ) from damage because the DAQ can only read 10V and below. The function of the DAQ is to read the LC signal base on the LabVIEW software with 10k/s sampling rate is chosen. The DAQ model used in the experiment is the NI 6009 developed and manufactured by the National Instrument.

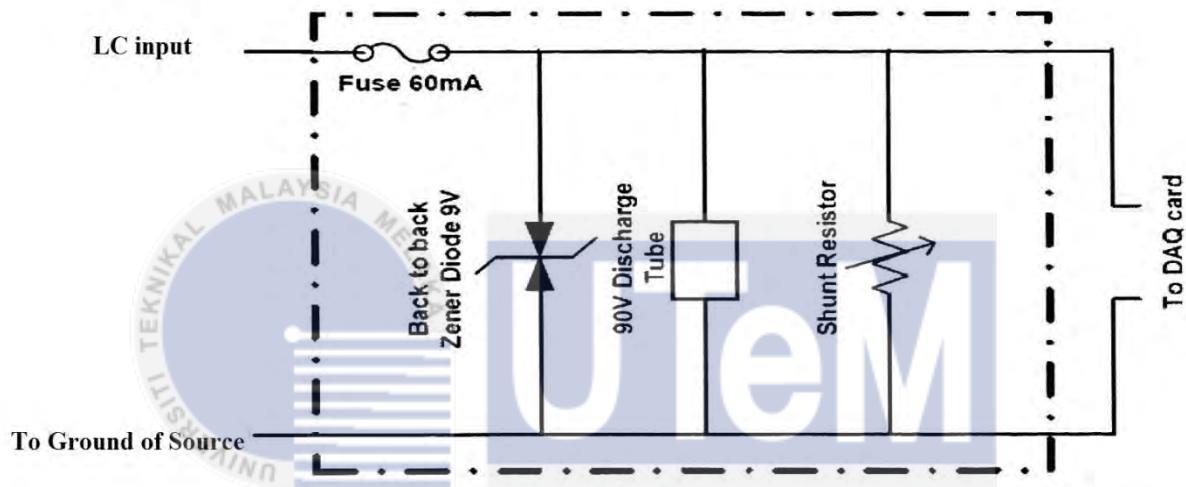


Figure 3.2: Measuring unit and protection schematic diagram

3.3.1 Software Development and Signal Analysis

LabVIEW is a graphical programming that uses symbols rather than lines of substance to produce applications. The LabVIEW is used in this project to execute the data or information from the IPT test. All the information gathered will be transmuted into a block diagram before being reassigned to another program which is MATLAB to produce LC signal waveform [21].

3.4 Material

Glass, Polypropylene (PP) and High Density Polyethylene (HDPE) are used in this experiment. The dimension of all insulation material must with a size of 50 mm x 120 mm. The thickness of the insulation material should be 6 mm by following the standard of BS EN 60587:2007 [18].

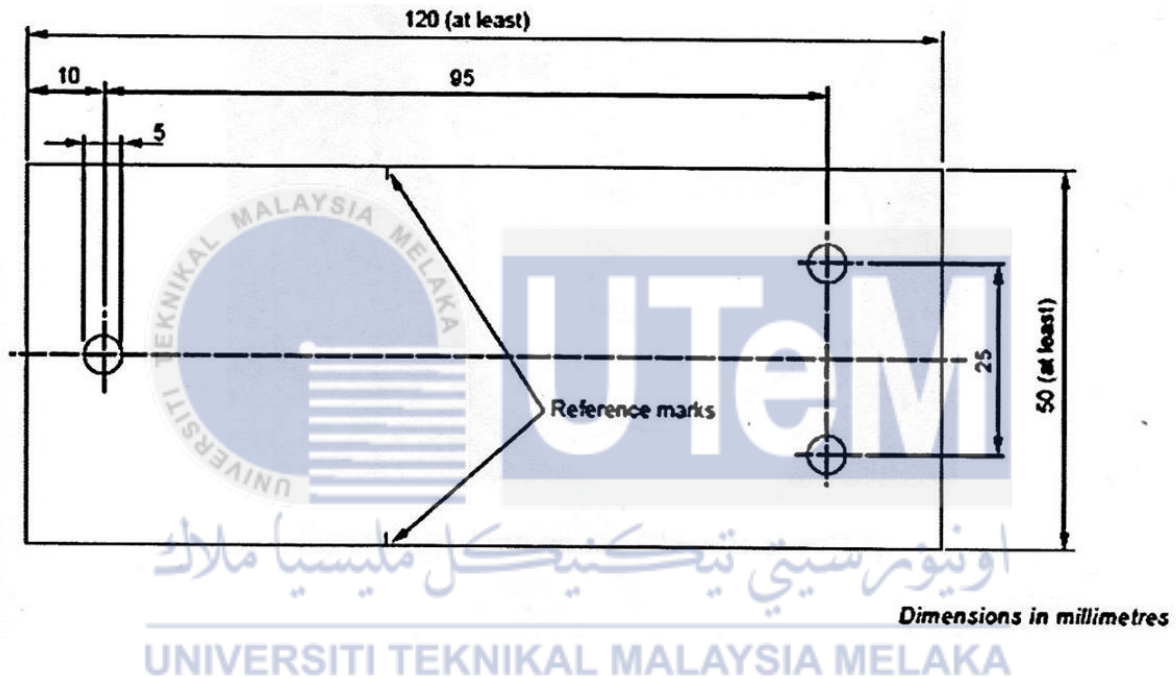


Figure 3.3: Dimension of Specimen

3.5 Flowchart

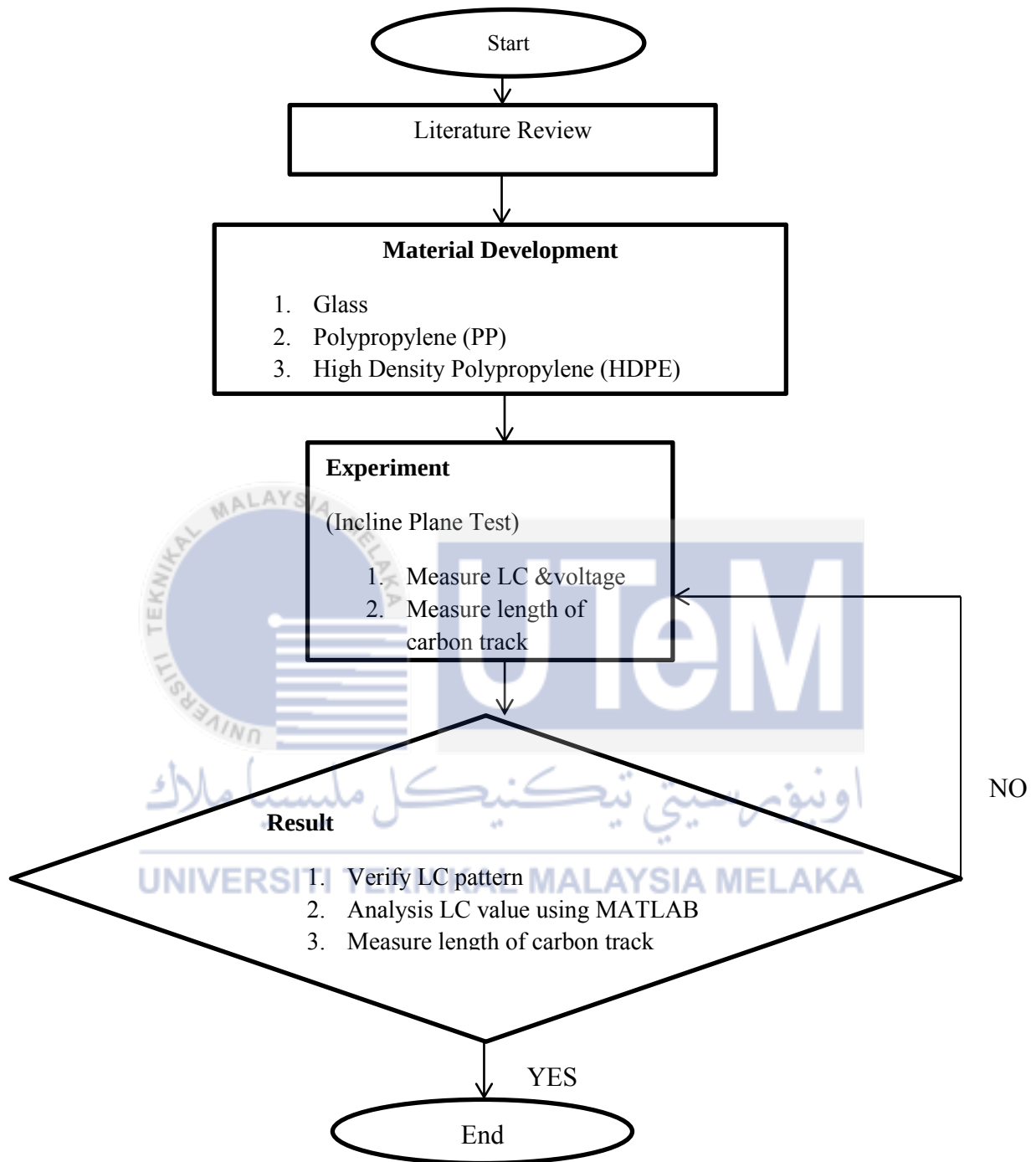


Figure 3.4: Flowchart of the Methodology

3.6 Project Milestone

Table 3.1: Table of Project Milestone

Project Task	Expected Date
Literature Review	Mid Of October 2014
Material Selection	End Of October 2014
Understanding BS EN 60587:2007	Early November 2014
Order raw material and preparing the specimen	February 2015
Conduct Inclined Plane Test (IPT)	Mac 2015
Verification of result and analyse the information	April 2015 & May 2015
Report writing and preparing presentations	June 2015

3.7 Conclusion

The generation of the surface tracking system with the usage of LabVIEW is used in the project to analyse the data of the LC under the IPT test. Then, the data will be transformed into a graphical result which is built by using the MATLAB software.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter discusses the result of this project of Glass, Polypropylene (PP) and High Density Polyethylene (HDPE) as insulating material of LC on insulation surface condition. This chapter consists of the results, analysis, data evaluation and discussion of the research. It is split into two sections which are leakage current analysis and tracking and erosion analysis.

4.2 Leakage Current Model

The insulating material will undergo the IPT test and the condition of the insulating material when the test is conducted will be observed. Value of 3.5 kV is injected to the Glass, PP and HDPE by following exactly the BS EN 60587:2007.

A 3.5 kV, 50 Hz sine-wave signal from a 6 kV generator is connected to the measurement and protection in the circuit in parallel. The value of voltage drop at the shunt resistor will represent the leakage current through the circuit. The variable resistor which is known as the shunt resistor is set at 250 k Ω and the voltage drop at the shunt resistor is measured by using the analogue to digital acquisition card (DAQ) model NI 6009. The signal and value of leakage current are displayed on computer by using the LabVIEW software. The following graphs are the type leakage current pattern produce from the specimens.

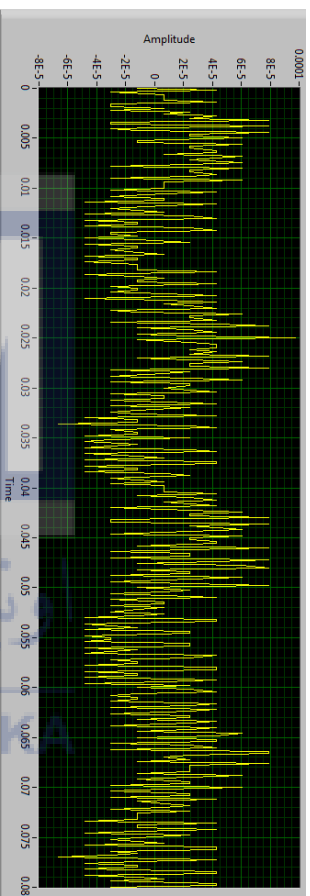


Figure 4.1: Capacitive Leakage Current Pattern on LabVIEW

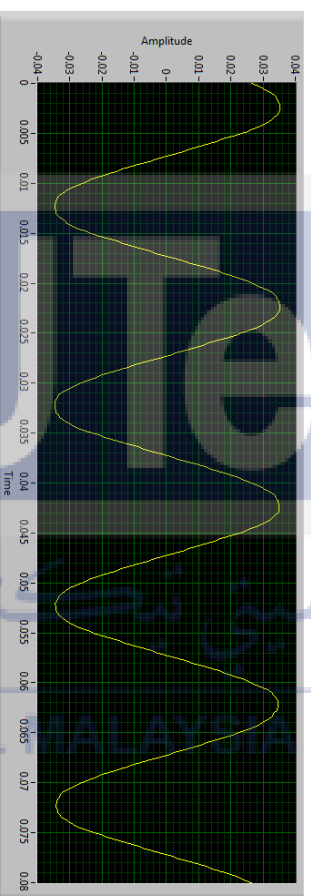


Figure 4.2: Resistive Leakage Current Pattern on LabVIEW

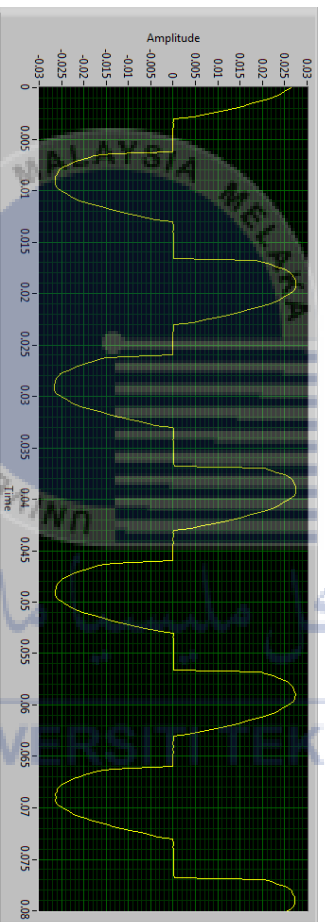


Figure 4.3: Symmetrical Leakage Current Pattern on LabVIEW

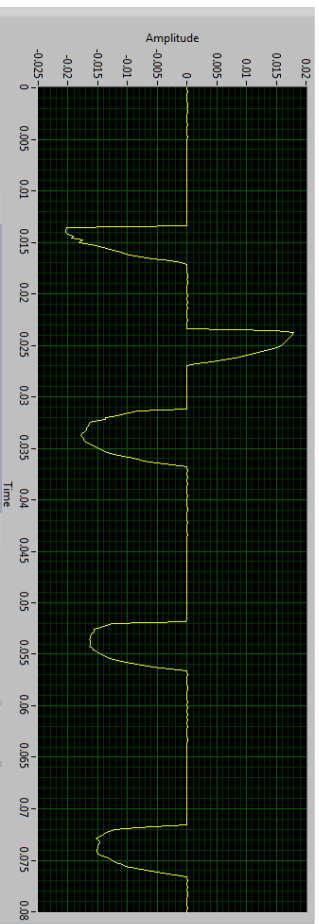


Figure 4.4: Unsymmetrical Leakage Current Pattern on LabVIEW

Figure 4.1 shows the capacitive waveform when analyzing by using the LabVIEW software. This can be seen that in the capacitive state, the sinusoidal waveform is produced but with higher distortion occur. Meanwhile, Figure 4.2 shows the sinusoidal waveform while in the resistive state. There is no distortion that occurs and mainly this kind of waveform occur when all the surface of the specimen is completely wet. In Figure 4.3, the symmetrical waveform occurs and arcing sound is produced. This condition is likely to happen when the surface of the specimen is wet and also have a dry area on its surface. For figure 4.4, the condition that might lead to the production of unsymmetrical waveform is due to the surface of the specimen has eroded and still there are wet and dry area on its surface. Therefore, the leakage current pattern is in the unsymmetrical waveform because the path for leakage current to flow always changes.

4.3 Leakage Current Analysis

The leakage current behaviour that flows on the insulator investigated based on the inclined lane tracking (IPT) test based on BS EN 60587:2007. The analysis of the Leakage Current is based on the waveform from the MATLAB and the value of the leakage current.

4.4 Glass

4.4.1 Capacitive

The capacitive leakage current occurs at the earlier stage of the test and have the leakage current values with the amplitude of $\times 10^{-6}$ A. The result shown in Figure 4.5.

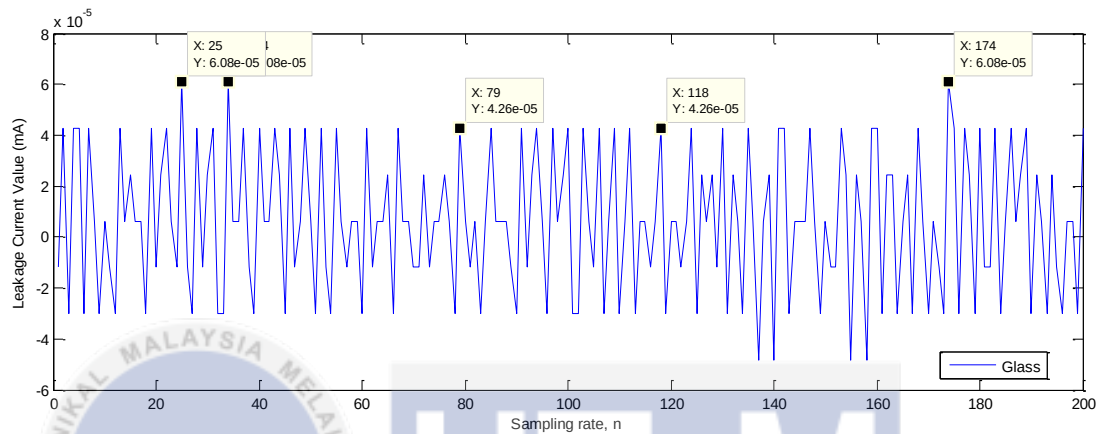


Figure 4.5: Capacitive Waveform of Glass

$$\text{Leakage Current, A} = \frac{6.08 \times 10^{-5} + 6.08 \times 10^{-5} + 4.26 \times 10^{-5} + 4.26 \times 10^{-5} + 6.08 \times 10^{-5}}{5}$$

$$= 53.52 \mu \text{ A}$$

At capacitive state, the waveform is in sinusoidal, but with high distortion. There is no arcing sound that occurs during this state. The average value of the leakage current for glass in the capacitive state is $53.52 \mu \text{ A}$.

4.4.2 Resistive

At resistive state, the surface of the glass is hydrophilic. This state occurs when the insulator surface is completely wet, therefore it creates a pathway for the leakage current to flow.

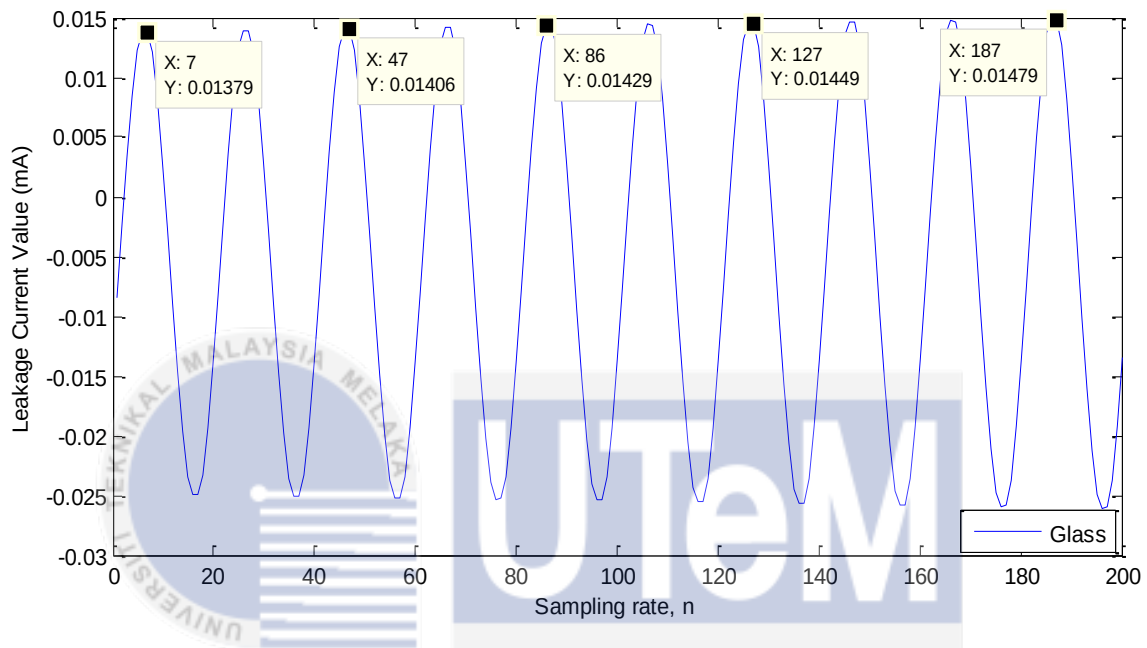


Figure 4.6: Resistive Waveform of Glass

$$\text{Leakage Current, A} = \frac{0.01379 + 0.01406 + 0.01429 + 0.01449 + 0.01479}{5}$$

$$= 0.014284 \text{ mA}$$

The leakage current appears to be in sinusoidal, higher amplitude and resistive. The average value of the leakage current for glass in the resistive state is 0.014284 mA.

4.4.3 Symmetrical

During symmetrical condition, the leakage current waveform is shown in Figure 4.7. This pattern of symmetrical occurs because the surface area of the insulation is wet and there is also a dry area.

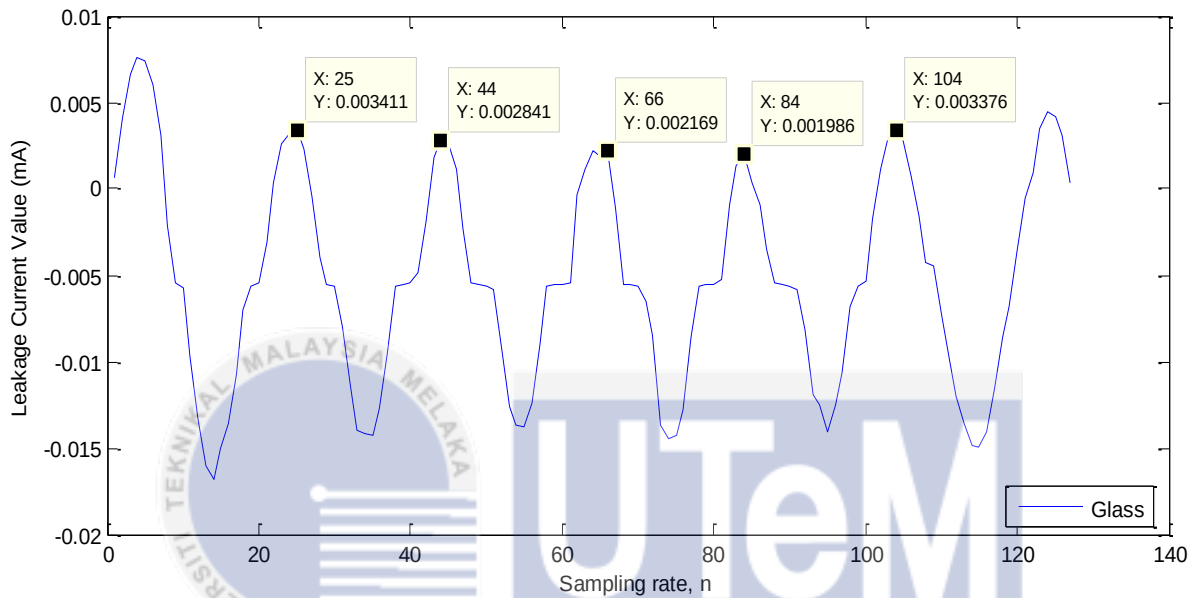


Figure 4.7: Symmetrical Waveform of Glass

$$\text{Leakage Current, } A = \frac{0.003411 + 0.002841 + 0.002169 + 0.001986 + 0.003376}{5}$$

$$= 0.0027566 \text{ mA}$$

At this condition, arcing sound emerged and the average value of the leakage current is 0.0027566 mA.

4.5 Polypropylene (PP)

4.5.1 Capacitive

The capacitive leakage current occurs at the earlier stage of the test and have the leakage current values with the amplitude of $\times 10^{-5}$ A. The result shown in Figure 4.8.

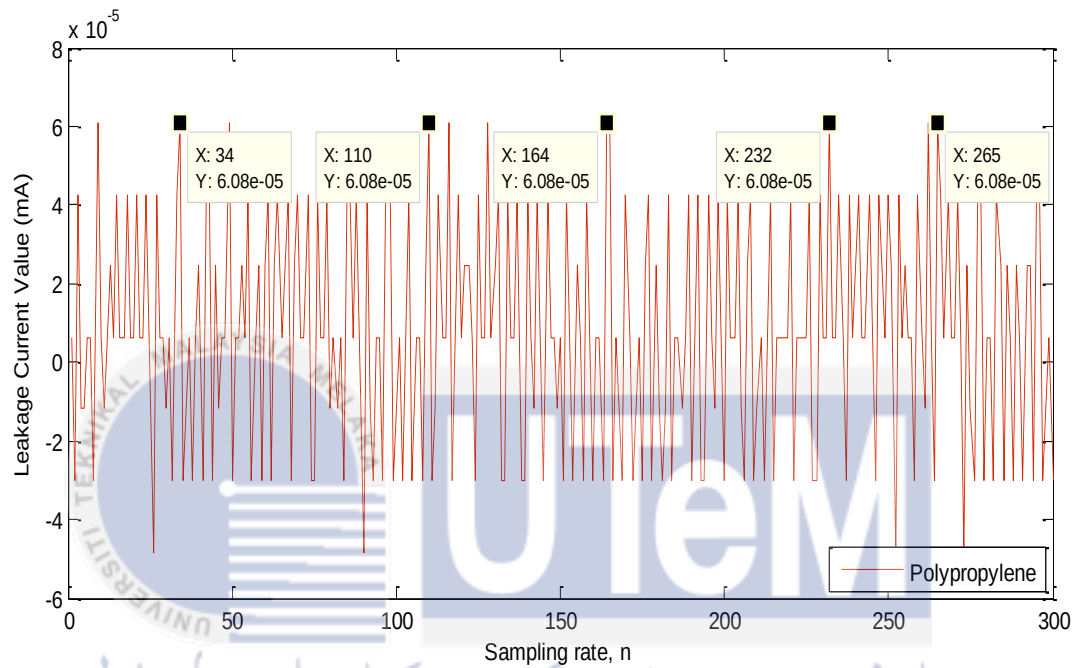


Figure 4.8: Capacitive Waveform of Polypropylene

$$\text{Leakage Current, A} = \frac{6.08 \times 10^{-5} + 6.08 \times 10^{-5} + 6.08 \times 10^{-5} + 6.08 \times 10^{-5} + 6.08 \times 10^{-5}}{5}$$

$$= 60.8 \mu \text{ A}$$

At capacitive state, the waveform is in sinusoidal, but with high distortion. There is no arcing sound that occurs during this state. The average value of the leakage current for PP in the capacitive state is $60.8 \mu \text{ A}$.

4.5.2 Resistive

At resistive state, the surface of the PP is hydrophilic. This state occurs when the insulator surface is completely wet, therefore it creates a pathway for the leakage current to flow.

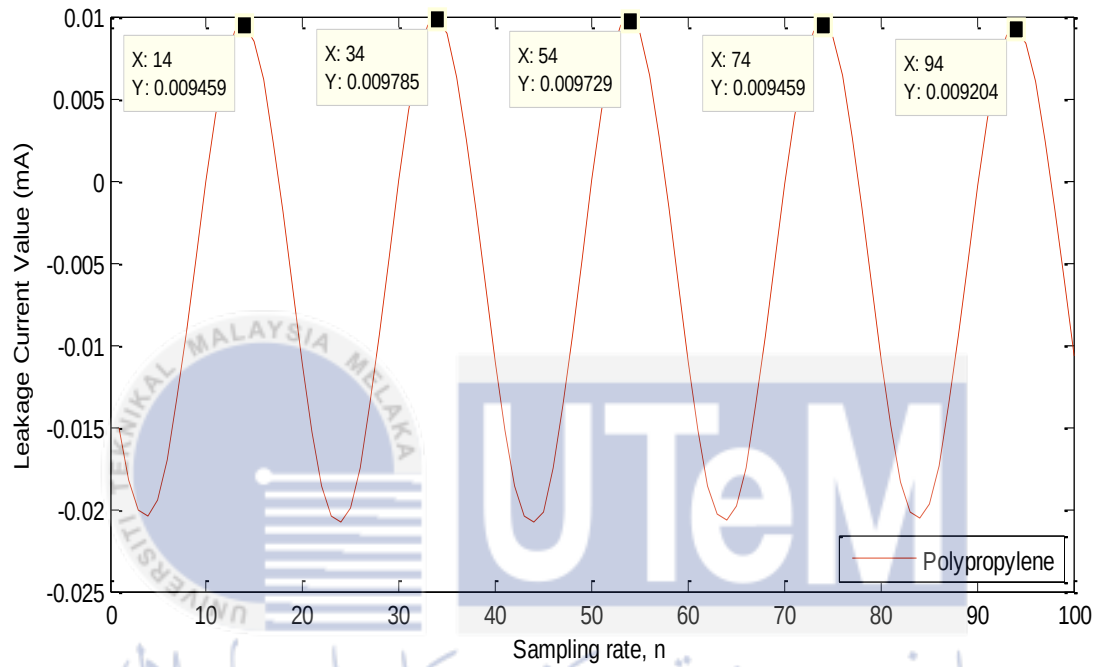


Figure 4.9: Resistive Waveform of Polypropylene

$$\text{Leakage Current, A} = \frac{0.009459 + 0.009785 + 0.009729 + 0.009459 + 0.009204}{5}$$

$$= 0.0095272 \text{ mA}$$

The leakage current appears to be in sinusoidal, higher amplitude and resistive. The average value of the leakage current for PP in the resistive state is 0.0095272 mA.

4.5.3 Symmetrical

During symmetrical condition, the leakage current waveform is shown in Figure 4.10. This pattern of symmetrical occurs because the surface area of the insulation is wet and there is also a dry area. At this condition also, arcing sound emerged.

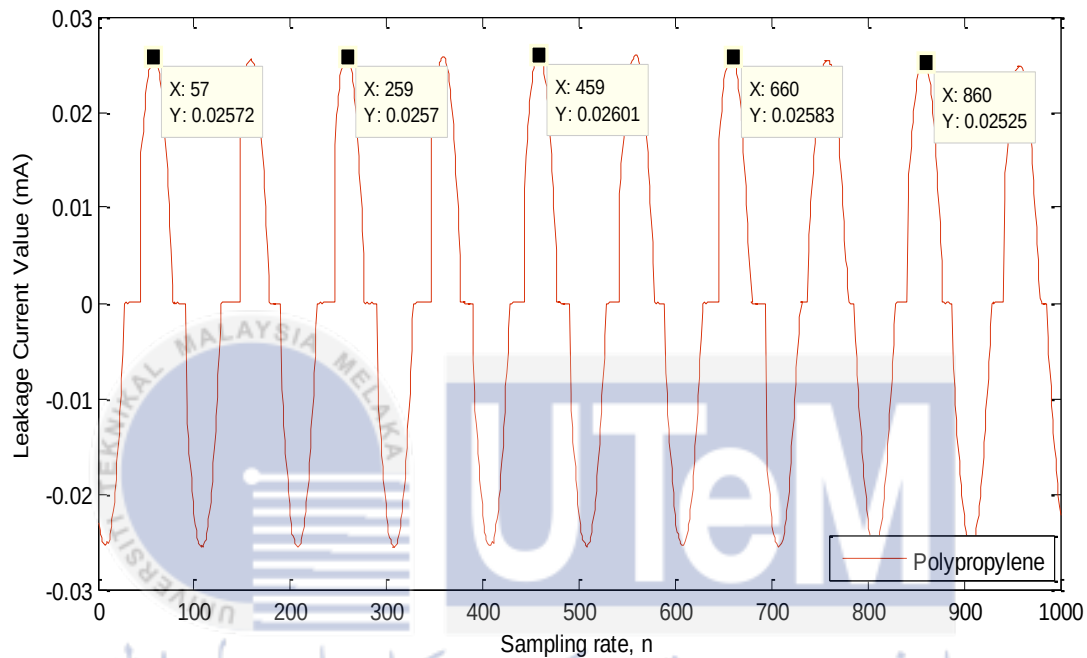


Figure 4.10: Symmetrical Waveform of Polypropylene

$$\text{Leakage Current, A} = \frac{0.02572 + 0.0257 + 0.02601 + 0.02583 + 0.02525}{5}$$

$$= 0.025702 \text{ mA}$$

At this condition, arcing sound emerged and the average value of the leakage current is 0.025702 mA.

4.5.4 Unsymmetrical

In Figure 4.11, the condition occurs when the surface condition of the insulation is wet, dry and have eroded areas as a result of discharge activity.

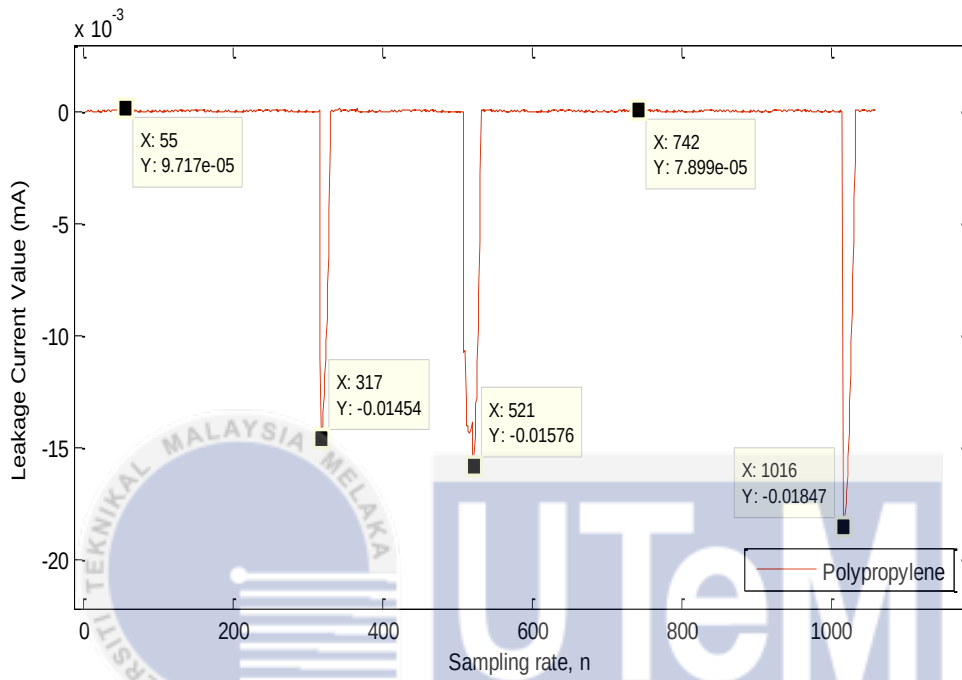


Figure 4.11: Unsymmetrical Waveform of Polypropylene

$$\begin{aligned}
 \text{Leakage Current, A} &= \frac{9.717 \times 10^{-5} + -0.01454 + -0.01576 + 7.899 \times 10^{-5} + -0.01847}{5} \\
 &= |-9.718768 \times 10^{-3}| \\
 &= 0.009757 \text{ mA}
 \end{aligned}$$

All types of waveform appear and causes the production of the unsymmetrical waveform. Arcing sound activities emerged when this condition occurs. The average value of leakage current when the unsymmetrical condition occurs for PP is 0.009757 mA.

4.6 High Density Polyethylene (HDPE)

4.6.1 Capacitive

The capacitive leakage current occurs at the earlier stage of the test and have the leakage current values with the amplitude of $\times 10^{-6}$ A. The result shown in Figure 4.12.

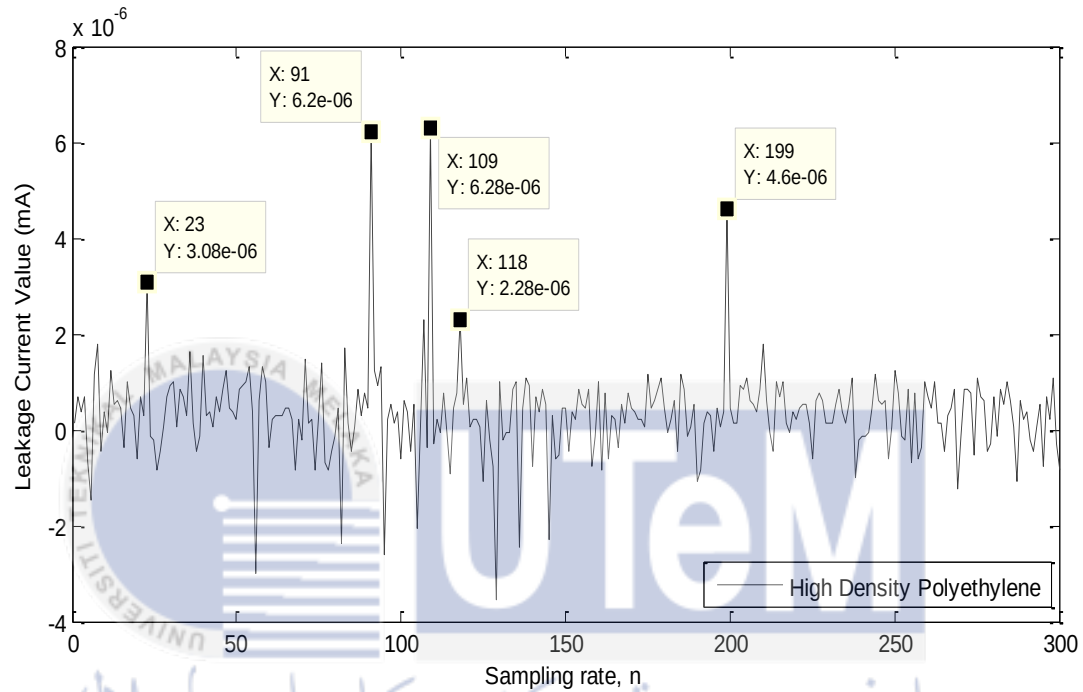


Figure 4.12: Capacitive Waveform of High Density Polyethylene

$$\text{Leakage Current, A} = \frac{3.08 \times 10^{-6} + 6.2 \times 10^{-6} + 6.28 \times 10^{-6} + 2.28 \times 10^{-6} + 4.6 \times 10^{-6}}{5}$$

$$= 4.488 \mu \text{ A}$$

At capacitive state, the waveform is in sinusoidal, but with high distortion. There is no arcing sound that occurs during this state. The average value of the leakage current for HDPE in the capacitive state is $4.488 \mu \text{ A}$.

4.6.2 Resistive

At resistive state, the surface of the HDPE is hydrophilic. This state occurs when the insulator surface is completely wet, therefore it creates a pathway for the leakage current to flow.

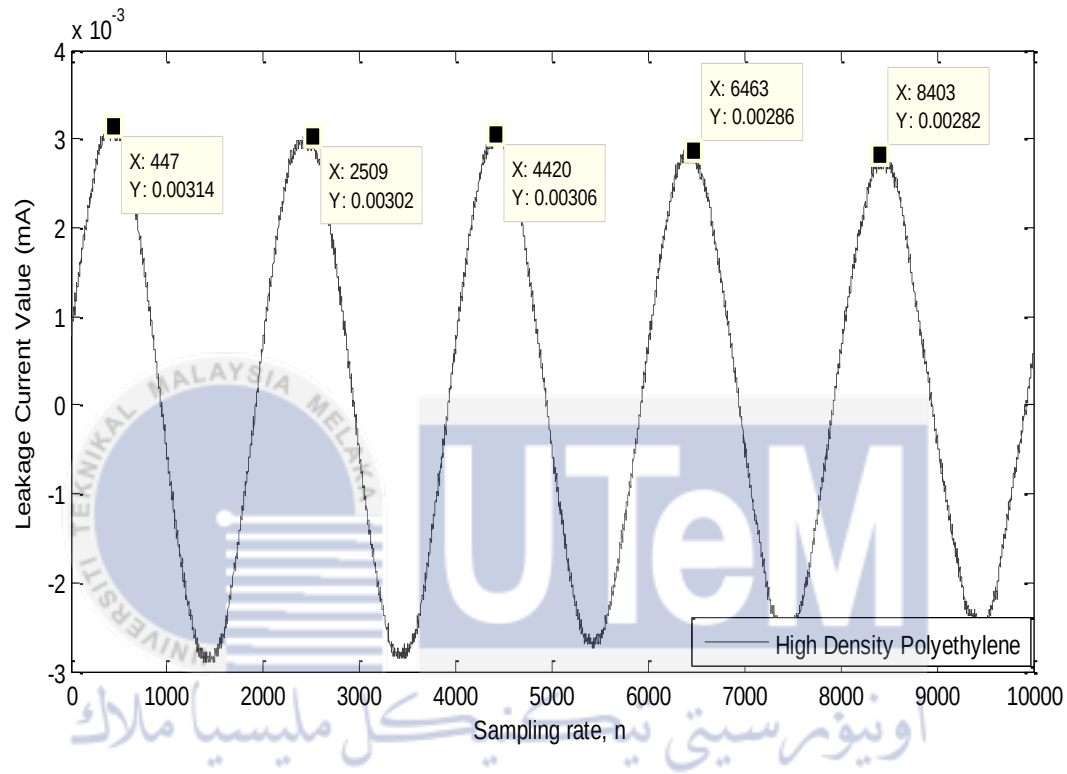


Figure 4.13: Resistive Waveform of High Density Polyethylene

$$\text{Leakage Current, A} = \frac{0.00314 + 0.00302 + 0.00306 + 0.00286 + 0.00282}{5}$$

$$= 0.00298 \text{ mA}$$

The leakage current appears to be in sinusoidal, higher amplitude and resistive. The average value of the leakage current for HDPE in the resistive state is 0.00298 mA.

4.6.3 Symmetrical

During symmetrical condition, the leakage current waveform is shown in Figure 4.14. This pattern of symmetrical occurs because the surface area of the insulation is wet and there is also a dry area. At this condition also, arcing sound emerged.

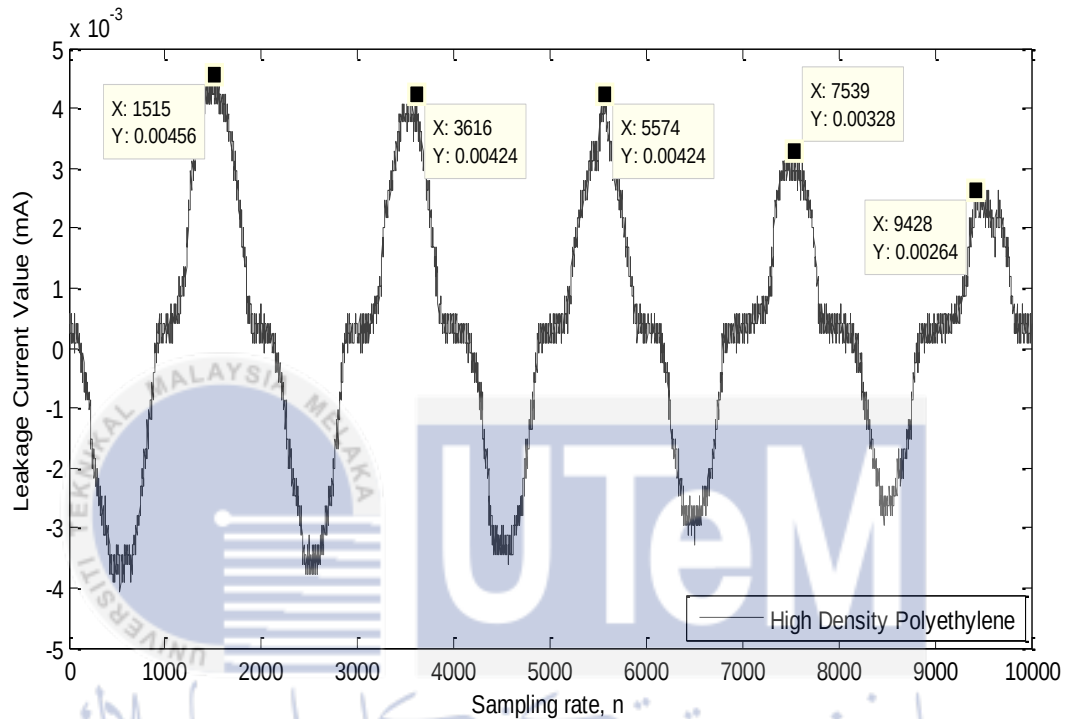


Figure 4.14: Symmetrical Waveform of High Density Polyethylene

$$\text{Leakage Current, A} = \frac{0.00456 + 0.00424 + 0.00424 + 0.00328 + 0.00264}{5}$$

$$= 0.003792 \text{ mA}$$

At this condition, arcing sound emerged and the average value of the leakage current is 0.003792 mA.

4.6.4 Unsymmetrical

In Figure 4.15, the condition occurs when the surface condition of the insulation is wet, dry and have eroded areas as a result of discharge activity.

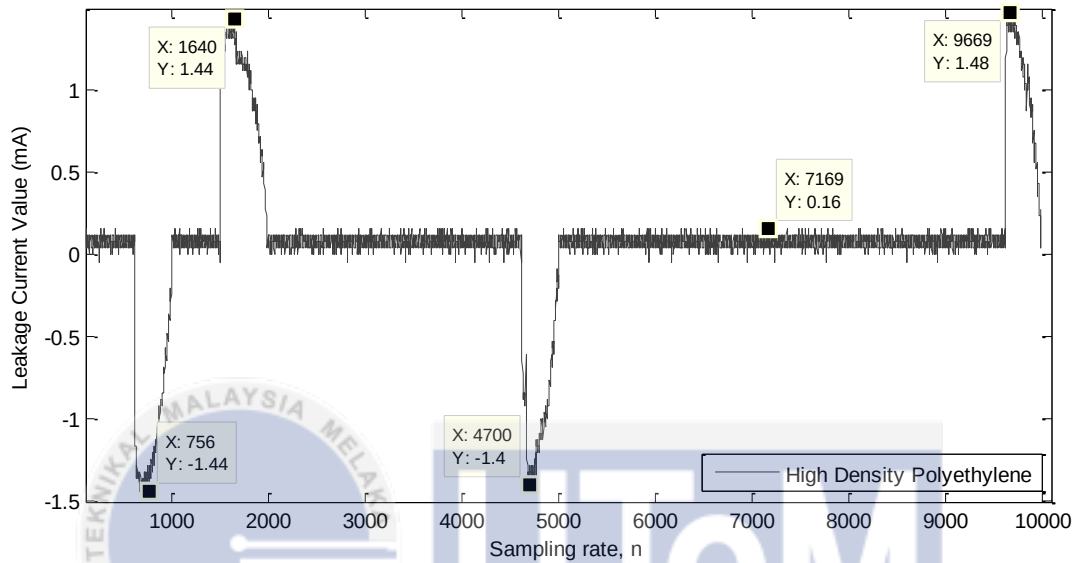


Figure 4.15: Unsymmetrical Waveform of High Density Polyethylene

$$\text{Leakage Current, A} = \frac{-1.44 + 1.44 + -1.4 + 0.16 + 1.48}{5} = 0.0048 \text{ mA}$$

All types of waveform appears and causes the production of the unsymmetrical waveform. Arcing sound activities emerged when this condition occurs. The average value of leakage current when the unsymmetrical condition occurs for HDPE is 0.0048 mA.

4.7 Comparison of Leakage Current

The value of leakage current from the glass, Polypropylene and High Density Polyethylene is recorded in table 4.1. Each of the leakage current patterns has different value of leakage current.

Table 4.1: Leakage Current Value of Glass, PP, and HDPE

Pattern Material	Leakage Current Value (mA)			
	Capacitive	Resistive	Symmetrical	Unsymmetrical
Glass	0.05352	0.014286	0.0027816	-
Polypropylene	0.0608	0.0095272	0.025662	0.009757
High Density Polyethylene	0.004488	0.00298	0.003792	0.048

In capacitive state, HDPE has the smallest value of leakage current which is 4.488 μA compare to PP and glass with 60.8 μA and 53.52 μA respectively. During the resistive state, Glass has the highest value of leakage current of 0.014286 mA while HDPE has the lowest value of leakage current of 0.00298 mA. PP has the highest value of leakage current when it is in symmetrical state with 0.025662 mA while glass is the lowest value of leakage current with 0.0027816 mA. During unsymmetrical condition, glass have no value because the unsymmetrical pattern of leakage current never occurred on the surface of the glass but it occurs on both polymeric insulator, PP and HDPE. HDPE has the highest value of leakage current during unsymmetrical condition which is 0.048 mA, followed by PP with 0.009757 mA.

4.8 Tracking and Erosion Test

The tracking effect that occurred on the insulation materials which are Glass, Polypropylene (PP) and High Density Polyethylene (HDPE) are measured.

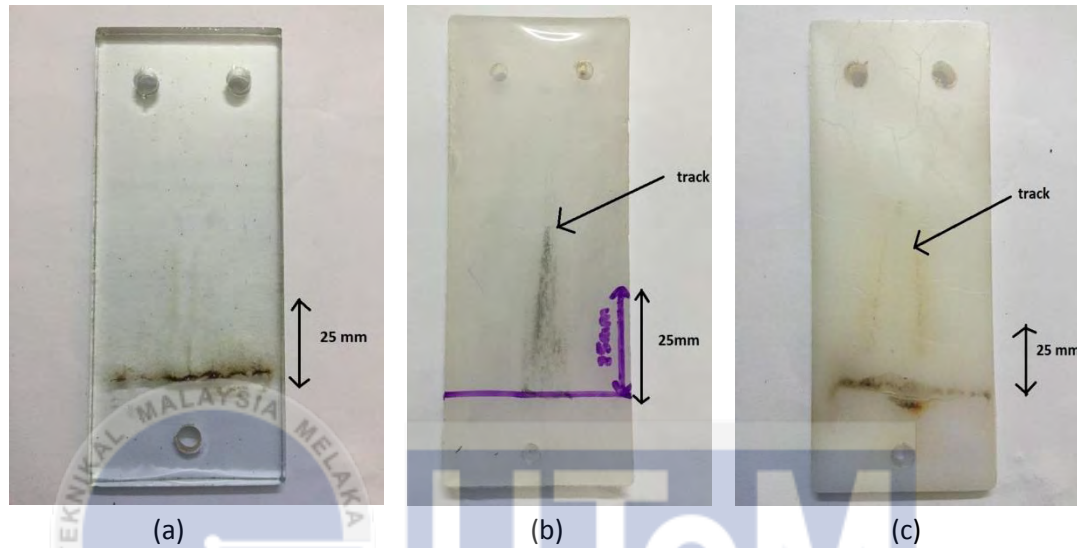


Figure 4.16: condition of specimen after test; (a) glass; (b) PP; (c) HDPE

The glass specimen has no carbon track on its surface. Therefore, it passes the test. The glass can withstand 3.5 kV injected voltage and no carbon track occurred on the surface. The Polypropylene (PP) has tracking occurred on its surface. Therefore, the specimen failed the test. This is because the length of carbon track on the surface of PP exceeds 25 mm. Tracking occurred on the surface of the High Density Polyethylene (HDPE). Therefore the specimen failed the test because the length of carbon track on the surface exceeds 25 mm. Glass has no carbon tracking occurred on it while PP and HDPE has carbon tracking on its surface. The tracking that occurred on surface of PP is much longer than tracking that occurred on the surface of HDPE. The glass can withstand greater electrical discharge followed by HDPE and PP respectively.

4.9 Conclusion

Electricity and pollution effects on the behaviour of the LC and the voltage level applied per unit length was investigated under conditions of tracking and erosion by following the standard of BS EN60587: 2007. During the analysis, different type of leakage current waveform and value are investigated. By using the on-line monitoring system, the type of LC pattern can be determined effectively. For the analysis of tracking and erosion, the Glass has better performance compared to HDPE and PP because there is no erosion and carbon tracking that occur on the surface of the material. Meanwhile, PP has the longest carbon track on its surface compare to HDPE. This can be concluded that glass has better performance than PP and HDPE.



CHAPTER 5

CONCLUSION

5.1 Conclusion

The objectives and scope of the project has achieved. The leakage current behaviour and surface tracking of Glass, Polypropylene (PP) and High Density Polyethylene (HDPE) as insulation material have been investigated and analysis in this project. The inclined planed test (IPT) is employed in this experiment by following BS EN 60587:2007 standard.

These report have been explaining the leakage current waveform and its pattern, the leakage current value of different material with different type of condition and also the tracking and erosion of the specimen. From the result gain in Chapter 4, it can conclude that Glass is proven to be a good material for insulation compare to HDPE and PP. Although glass easily broken and heavy compared to HDPE and PP, it will not completely eroded, while HDPE and PP will be eroded in the long term. Glass is also resistant to heat and will not burn compared HDPE and PP. This will save maintenance costs if the glass is used as insulating material in high voltage systems and distribution systems.

5.2 Future Work

Suggestion for future works to be considered for improvement of this project is by using different material such as Low Density Polyethylene (LDPE) and compare it with the glass. This is due to produce an insulator that has better performance than glass and can be used in future in high voltage system.



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APPENDIX A



Figure A: Incline Plane Test Setup

APPENDIX B



Figure B : Glass specimen ongoing test

APPENDIX C

Project Task	Final Year Project 1					Final Year Project 2				
	Sep	Oct	Nov	Dec	Jan	Feb	Mac	Apr	May	June
Literature Review										
Material Selection										
Understanding BS EN 60587:2007										
Order raw material and preparing the specimen										
Conduct the Inclined Plane Tracking (IPT) test										
Verification of result and analyze the information										
Report writing and preparing presentations										

Figure C : Gantt Chart of the Project



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