BREAKDOWN VOLTAGE OF POLYMERIC MATERIAL UNDER DIFFERENT SHAPE OF ELECTRODE

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” I hereby declare that I have read this fully report entitled ”*Breakdown Volatge of Polymeric Material Under Different Shape of Electrode”* and found that it has comply the partial fulfillment for awarding the *Bachelor of Electrical Engineering (Industrial Power)”*

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Date : ....

I declare that this report entitled "*Breakdown Voltage of Polymeric Material Under Different Shape of Electrode*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

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Date : ....

Dedicated to my beloved family, friends and lecturers for their never ending support, encouragement and understanding towards the completion of my work.

Thank you for your support.

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ABSTRACT

The technology of insulation has been evolved from the use of porcelain and glass to the polymeric materials. Since polymeric materials has been accepted as the high voltage application. A lot of study has been conducted to make an improvement to its properties, understand it performance and to develop a new composites as well and it involves in designing, monitoring and practical testing. This study will be focused on practical testing of Silicone rubber (SIR) thermoset type of polymeric material. The electrical SIR parameter to be investigated are its dielectric strength performance. In order to determine this parameter, standard test of dielectric strength is conducted, where it complying to International Standard BS EN 60243-1 : 1998 test method. All the testing procedure and specimen preparation are following this standard. The test was conducted for determining long-term dielectric strength of solid insulation material at power frequency of 50 Hertz (Hz). Three different shapes of electrode were used which are flat end shape electrode, spherical end shape electrode and pin end shape electrode. From the analysis carried out, dielectric strength of SIR using all shapes of electrode meet the minimum requirements of breakdown field strength which must exceed 10kV/mm with reference to International Standards BS EN 62039 : 2007. Then, this results of breakdown voltage can be used for determine the properties of ageing conditions, manufacturing design and other environmental condition in HV insulation application using polymeric materials.

ABSTRAK

Teknologi penebat telah berkembang daripada penggunaan porselin dan kaca kepada bahan polimer. Sejak bahan polimer telah diterima pakai sebagai aplikasi dalam voltan tinggi. Banyak kajian telah dijalankan untuk membuat penambahbaikan terhadap sifat-sifatnya, memahami prestasinya dan juga untuk menghasilkan bahan komposit yang baharu dan ia termasuk juga dalam mereka bentuk, pemantauan dan ujian praktikal. Kajian ini akan memberi tumpuan kepada ujian praktikal terhadap getah silikon (SIR) bahan polimer jenis termoset. Parameter elektrik SIR yang akan dikaji adalah prestasi kekuatan dielektrik nya. Untuk menentukan parameter ini, ujian standard kekuatan dielektrik dijalankan, di mana ia mematuhi Standard Antarabangsa BS EN 60243-1 : 1998 kaedah ujian. Semua kaedah ujian dan penyediaan spesimen adalah mengikuti standard ini. Ujian ini akan dijalankan untuk menentukan kekuatan dielektrik jangka panjang bahan penebat pepejal pada frekuensi kuasa 50 Hertz(Hz). Tiga bentuk elektrod yang berbeza digunakan seperti elektrod hujung berbentuk rata, elektrod hujung berbentuk sfera dan elektrod hujung berbentuk pin. Daripada analisis yang telah dijalankan, kekuatan dielektrik SIR dengan menggunakan kesemua bentuk elektrod memenuhi tahap minima kekuatan medan pecahan iaitu mesti melebihi 10kV/mm dengan merujuk kepada Standard Antarabangsa BS EN 62039 : 2007. Kemudian, keputusan voltan pecahan ini boleh digunakan untuk menentukan ciri- ciri keadaan penuaan, reka bentuk pembuatan dan keadaan persekitaran yang lain di dalam aplikasi penebat HV menggunakan bahan polimer.

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Hz	-	Hertz
HV	-	High voltage
SIR	-	Silicone rubber
HDPE	-	High density polyethylene
EPR	-	Ethylene propylene rubber
BSI	-	British Standard Institution
UV	-	Ultraviolet
AC	-	Alternating Current
OT	-	Operating Terminal
DMI	-	Digital Measuring Instrument
kV	-	Kilo volt
R.M.S	-	Root mean

CHAPTER 1

INTRODUCTION

1.1 Introduction

Electricity supply is a must and one of the most important things in the world. Basically, most of the equipment are using electricity. Electricity can be distributed into several parts which are generation, transmission and distribution.

In order to supply the electricity, two important things are needed which are conductor to carry the current and the other one is the insulation to prevent current from flowing to undesired paths and also as the protection to the human being and living things from the electrical shock [1]. In modern times, high voltages are used in many applications including the power system industry and research laboratories. Moreover, in the high voltage engineering (HV), the insulation is the most important thing that needs to be concerned because any insulation failure will cause an electrical shock, burns and fatalities to human beings.

Previously, the outdoor insulation material was dominated by porcelain and glass material. Even though glass and porcelain-type insulations both have good insulation properties and weather resistance but they also have the disadvantages of their weight that are heavy, easily to fractured, non-hydrophobic characteristic and will undergo degradation of their strength to withstand high voltage stress [2]. However, in the middle of the twenty century a new concept of composite insulator introducing polymeric materials was developed in USA [3]. Non-ceramic (polymeric) insulators are well accepted by the industry and utilities to replace the old-type porcelain and glass insulators due to their advantages such as light in weight, easy to handle, better contamination performance and low installation and maintenance costs [4]. Therefore, polymer has been widely used and accepted in the HV insulation as a replacement of glass and porcelain insulation that have been used for decades before.

One of the advantages of the polymer insulation is its hydrophobicity characteristic against fog, dew and rain. The hydrophobic characteristic of polymeric insulation is defined as the water repellent ability on the surface of the polymeric insulation especially in highly contaminated area [1][5]. It means that this property does not allow the water droplets to spread all over the surface of the polymeric insulation and cause the surface to polluted and contaminated. Currently used polymeric materials in the insulation field are high density polyethylene (HDPE), silicone rubber (SIR), Ethylene propylene rubber (EPR) and many more [6].

Furthermore, insulation not only must withstand at the rated voltage for the operation, but it must have high dielectric strength that strong enough to hold whenever overvoltage stress occur such as by the lightning strike and by fluctuations in the load or generations [7]. Dielectric strength of the insulation material defined as the maximum level of voltage that it can withstand under ideal condition without loss its insulating properties from high voltage stress. If the injected voltage to the material is steadily increased until it comes at one point where the dielectric strength of the insulating material have passed it limit, a short circuit breakdown channel or track is formed [8]. Electric breakdown describe as the severe loss of the insulation material when exposed to the electric stress that cause the current during test to operate an appropriate circuit breaker [9].

Next, in order to determine the electrical strength of the polymeric material, one test called as the dielectric strength test will be conducted on the polymeric material. In this project work, the dielectric strength test will be carried out using different types of electrode shape. There are three types of the electrode use which are flat end shaped electrode, spherical shaped electrode and another one is pin shaped electrode. The difference of the electrode shape will give the difference in the radius of the electrode end touching with the polymeric material surface. As a result, this condition affects the dielectric strength of the sample tested. In addition, the dielectric strength test will be conducted by using the selected polymeric material sample which is SIR from thermoset type of polymer.

Lastly, SIR was selected as the test material for this project because of its unique characteristic among others polymer and have superior properties to electrical stress, heat resistance, hydrophobicity, fire retardancy, radiation resistance, low surface energy and flexible for wide range of temperature and weather resistance which is resist to degradation cause by ultraviolet radiation [2] [5]. The study of dielectric strength test of the polymeric insulating material will be associated with the British Standard Institution, BS EN 60243-1: 1998, electrical strength of insulating materials – Test methods – Part 1: Test at power frequencies test standard as the testing and work procedure to obtain the result.

1.2 Project Motivation

Insulation plays a crucial part in determining the prolong performance and lifespan of a high voltage equipment. Nowadays, a lot of high voltage test was conducted. The high voltage testing were used to investigate the withstands capability of the insulation or other study cases. However, these tests have to follow the standard to get a reliable results. By complying to the standard test procedure, behaviour of insulation material in actual application can be determined. The result obtained can be used to determine the aging condition, characteristic of processing variable, manufacturing or environmental condition in high voltage polymeric insulation application. In addition, under standard test procedure, the testing laboratory recognized for the safety features, the testing results of polymeric specimen is valid and used for benchmarking of performance. Therefore, the standard test accordingly to the international standard is crucial to be complied for the use of polymeric insulation material research and a safety is vital since using high voltage application.

1.3 Problem Statement

Dielectric strength of the insulation material is an important properties that need to be consider as well as the other properties of the insulation materials. Previously, a lot of research has been done for the electrical properties test of the different types of polymeric materials. However, this project will focus on the dielectric strength performance of one type of thermoset polymer material only which is SIR to test this polymeric material using different shape of electrode attached to the polymeric insulation material surface.

The different shape of electrode that involves in this study are flat type, spherical and pin type shape to determine which type of electrode shape affect the most to the dielectric strength of this polymeric material. For the test of dielectric strength of the insulation material, the minimum requirement of the electrical strength of the material for the outdoor insulation usage purpose must at least exceed 10kV / mm. Therefore, in order to carry out this experiment, all the procedure that need to be taken are following the standard of testing which is following standard procedure of International Standard, BS EN 60243-1 : 1998 to validate the result obtain.

1.4 Objectives

The objectives of this project are as follows:

1. To investigate the electrical strength of the polymeric material under high voltage supply based on BS EN 60243-1: 1998 test standard.
2. To determine the dielectric strength performance of SIR insulation using different shape of electrodes.
3. To compare the data and verify the most influence shape of electrode to the dielectric strength of the SIR polymer.

1.5 Scope Of Research

This project will be focused as follow:

1. SIR polymeric thermoset material is used as the test subject for the dielectric strength test.
2. Material is to be tested at power frequency of 50Hz with rapid high voltage injection in the short-time (rapid-rise) testing method.
3. Four different types of electrode shape to be used which are spherical shape, pin shape, equal diameter flat shape and unequal diameter flat shape electrode.
4. Method of testing will follow accordingly to the British Standard Institution, BS EN 60243-1: 1998 test method with requirement of flat sheet.

1.6 Report Outline

Generally, this report consist of five chapters :

Chapter 1: Introduction

Chapter 2: Literature Review

Chapter 3: Project Methodology

Chapter 4: Results and Discussion

Chapter 5: Conclusion and Recommendation

Chapter 1 is about the overview of this project and consist of problem statement, objectives, project scopes and the purpose of this project conducted as shown above.

Chapter 2 provide literature review and the theoretical knowledge regarding this project. All the details, facts and terms that related to the dielectric strength test will be presented in this chapter.

Chapter 3 presents the method carry out to obtain the result of this project. Involving all the steps and procedure taken for the electrical strength of polymeric insulation material test. All the set up and the sample dimensioning and specification are follow the British Standard Institution, BS EN 60243-1 : 1998 standard.

Chapter 4 shows the result of the project. . The result obtain from difference type of the electrode use in the testing and discussion of the effect to the polymer electrical strength will be discussed.

Chapter 5 is the conclusion and recommendation of the achievement from the finding study that have been made.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Insulation is as important as conductor because the insulation will prevent the electric from flow to the undesired path and at once deliver the electrical supplies to the equipment and loads in the transmission system. Recently, polymeric material has been choose over the porcelain and glass as the HV insulator due to its advantages and unique characteristic. Therefore, a lot of study has been conducted among the researcher and technologist to study and make an improvement of this material performance. Improvement on this material can be classified into several part such as development and performance of newly invented polymeric materials, electrical and mechanical stresses, proper dimensioning, design and manufacturing process of its composite materials and lastly the practical test of dielectric strength of the material itself in order to monitor, measure and verify its performance [1]. The following sub-sections in this chapter explain about the insulation materials, selected material, testing method, dielectric strength of material and type of electrode used.

2.2 Insulation Materials

Insulation are very important to separate the conductor from another conductor or living things. Practically, insulation material are divided into three parts which are solid, liquid and gas. In this study will be focus on solid type of insulation material only. Then, in the solid materials, it have three types which is organic materials, inorganic materials and synthetic materials or called as polymeric material. While, this study focuses on polymeric materials.

2.2.1 Polymeric Materials

Synthetic material are better for electrical insulation and more reliable and less weight. It can be divided into three groups which is thermoset, thermoplastic and elastomer. Common widely use polymeric material in practical are high density polyethylene (HDPE), silicone rubber (SIR), Ethylene propylene rubber (EPR) and more [6]. In this project are focus on SIR. These polymeric composite are apply as the cap and pin, supporters, bushings, surge arrestor, wires and cables and energy storage and savings [10].

2.2.1.1 Silicone Rubber

SIR compound have very good properties among other polymer materials. It have advantages of low surface energy, heat and radiation resistance, flame retardancy, good electrical properties and water repellent properties. Besides, SIR have high elasticity and excellent compressibility when given stress. While it have the hydrophobicity surface that does not allow water droplet to spread all over the surface. This properties are important especially at the polluted area. This type of polymeric material are selected as the project sample for the dielectric test. [2][4][5].

2.2.1.2 Classes Of Polymer

Thermoset, thermoplastic and elastomer are three classes of polymeric material. Thermoset polymer can be define as material that cannot be remould once have been cured with heat or with high energy irradiation. This type of material usually need to be heated at

200 degrees and above during curing process. While, thermoplastic are the type that can be remould by applying specific degrees of heat. Then, elastomer have the characteristic of flexible polymer unlike thermoplastic and thermoset material [2].

2.2.2 Advantages Of Polymer

Polymeric material have several advantages as it is has excellent electrical and weather resistance properties, wide range of working temperature, low surface energy, hydrophobicity surface and resist to degradation due to ultraviolet (UV) radiation [2]. Besides, it is less weight, and stronger while easy to moulded and cost efficient.

2.3 Deterioration And Breakdown

Deterioration of material is the degradation of the polymeric material properties. This matter cause when it services in a long time. Where it affect the structural, mechanical integrity and ability of withstand voltage under polluted conditions. Regarding this problem, a lot of study and practical test has been conducted to overcome the problems. Including ageing test by leakage current, dielectric strength or breakdown voltage and tracking and erosion test to determine their performance under high voltage stress [4].

2.3.1 Electrical Strength Breakdown

Electrical breakdown of the insulation material is when the given electrical stress to the insulation material are too high and pass it limit of resistivity and cause severe loss of insulating properties of the material that cause the current in the circuit to operate the circuit breaker during the test. It consider as the failure of the insulation material under high voltages stress [9][11]. Where, electrical strength or dielectric strength of the material is the capability of the insulation material to withstand the electrical stress without loss it properties as the insulation.

2.3.2 Solid Dielectric Breakdown

For the insulation material that are free from imperfection and truly homogenous, breakdown voltage of it can be as high as 10MV/mm for its dielectric strength. But, in practice, no material can obtain the electrical stress like that and usually much lower than that. Breakdown generally happens over the surface of the material than in the solid itself and most of frequent trouble in practice cause by surface insulation failure [12]. There are other several type of breakdown which are electromechanical breakdown that happen due to the mechanical failure cause by mechanical stress produced by electrical fields. Then, tracking effect occur when a conducting path is formed on the surface of the insulation material when given electrical stress [13]. Besides that, surface flash over and partial discharges also kinds of breakdown occur due to high electrical stress with the different of experiment set up.

2.3.2.1 Long-Term Breakdown

Long-term breakdown also known as ageing process of the insulation material that will degrade the performance of the material itself. It also cause the damage to the material and loss its properties. Long term breakdown can be divide into two types which are first is ageing and breakdown due to partial discharge and second is ageing and breakdown due to changes of insulations surface [14].

2.3.2.2 Short-Term Breakdown

Short-term breakdown is the breakdown that happen due to a very high electric stress supplied that will cause the insulation material loss it properties as the insulation at that particular time and it happen in the seconds without damaging the insulation surface before failure [14].

2.3.3 Accelerated Ageing Test

There are different field of ageing test of the polymer which are electrical properties test, physical properties test, mechanical properties test and chemical and environment test. Process of ageing are due to the long-term breakdown of the insulation material properties that affect by the partial discharge and changes of the surface of the insulation material.. The accelerated ageing test were conducted usually on materials or sample of finish good of the polymeric insulating material. For the test of the electrical properties of the material, kind of testing method usually used are dielectric strength test, tracking and erosion, arc resistance insulation resist and dissipation factor test. All of this kind of test are to reveal and improve the performance and ageing factor of the polymeric insulation materials as shown in the Figure 2.1 below [4].

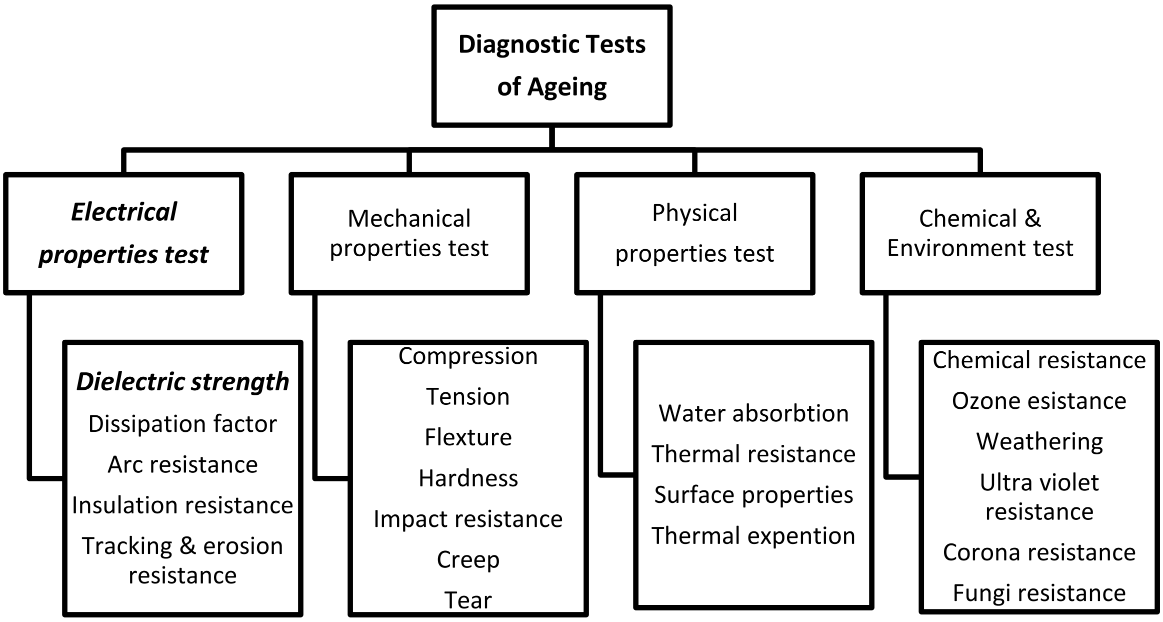


Figure 2.1 : Types of test for ageing study [1]

2.4 Electrodes

The electrodes use must have high strength, electrical conductivity, resistance to corrosion and have high thermal. Then, electrodes are available in many kind of materials such as aluminium electrode, stainless steel electrode and copper electrode. Each type of material used for the electrode have different properties and performance level. However, this project only use stainless steel type of electrodes.

2.4.1 Stainless Steel Material

Stainless steel type of materials usually are made of compound from aluminium, vanadium and iron. These combination of raw material produced the stainless steel material and it is widely use as the high voltage equipment. Because it is the most stable and suitable material with reasonable prices. The special characteristic of stainless steel electrode is high resistance to corrosion. This type of material are selected for the electrode in this project [15].

2.4.2 Copper Material

Copper metal are not from the combination of other raw materials, only itself and called as pure copper. It is the most excellent electricity conductor material. It have properties of dull surface but have high price in the markets. Copper material commonly used as the heat conductor and constituent of many alloy metal [15].

2.4.3 Aluminium Material

Aluminium materials have the highest strength compared to other type of electrodes. It also have the characteristic of corrosion resistance from chemicals, good electrical and high thermal conductivity also easy to fold and change shapes [15].

Table 2.1 : Characteristic of stainless steeel, copper and aluminium metal

Material type	Thermal conductivity (W/m^{-}K)	Melting point (K)
Stainless steel	24	1425.20
Copper	401	1357.76
Aluminium	237	933.49

2.4.4 Types Of Electrode Shapes

There are several types of electrode shape produced which are flat end shape, spherical end shape and pin end shape electrode. The flat end type electrode comes in two types which are equal diameter electrode couple and the other one are unequal diameter electrode couple. Then, all of the types of electrode have different height and diameter for each type of electrode to prevent flash over during the operation. All of these shape of electrode are selected and used in this project [9].

2.5 Reviews Of Electrical Properties Test

In previous research that have been conducted before, IEEE Application Guide Evaluating Non-Ceramic Materials for High Voltage – External Applications (IEEE 1133-1998) was used as a reference for the polymeric materials insulation purposes [4].

From the existing guidelines such as BS EN 62039 – 2007 User-Polymer Materials Selection for Outside use under HV stress. It used to determine and evaluate the performance of the polymeric materials for selection as the external application in high voltage equipment.

These guidelines have listed the physical parameters related to its characteristic and the minimum requirement for the polymeric materials performance. The standard testing option and its minimum requirements for outdoor use under HV stress accordance to BS EN 62039 – 2007 standards are presented in the table below [4]:

Table 2.2 : Testing properties and its minimum requirement of polymeric insulation.

No.	Property to Test	Minimum requirement	Test Standard
1	Breakdown field strength	> 10kV/mm	IEC 60243-1*
2	Resistance to tracking and erosion	1A 3,5b	IEC 60587*
3	Tear strength	> 6N/mm	ISO 34-1*
4	Volume resistivity	> 10MΩ	IEC 60093*
5	Water diffusion	Voltage test–12kV-1min Or tan δ < 0.2	IEC 62217* IEC 60250*
6	Arc resistance	> 180s	IEC 61621*

2.6 Summary

The figure below shows the overview of the project:

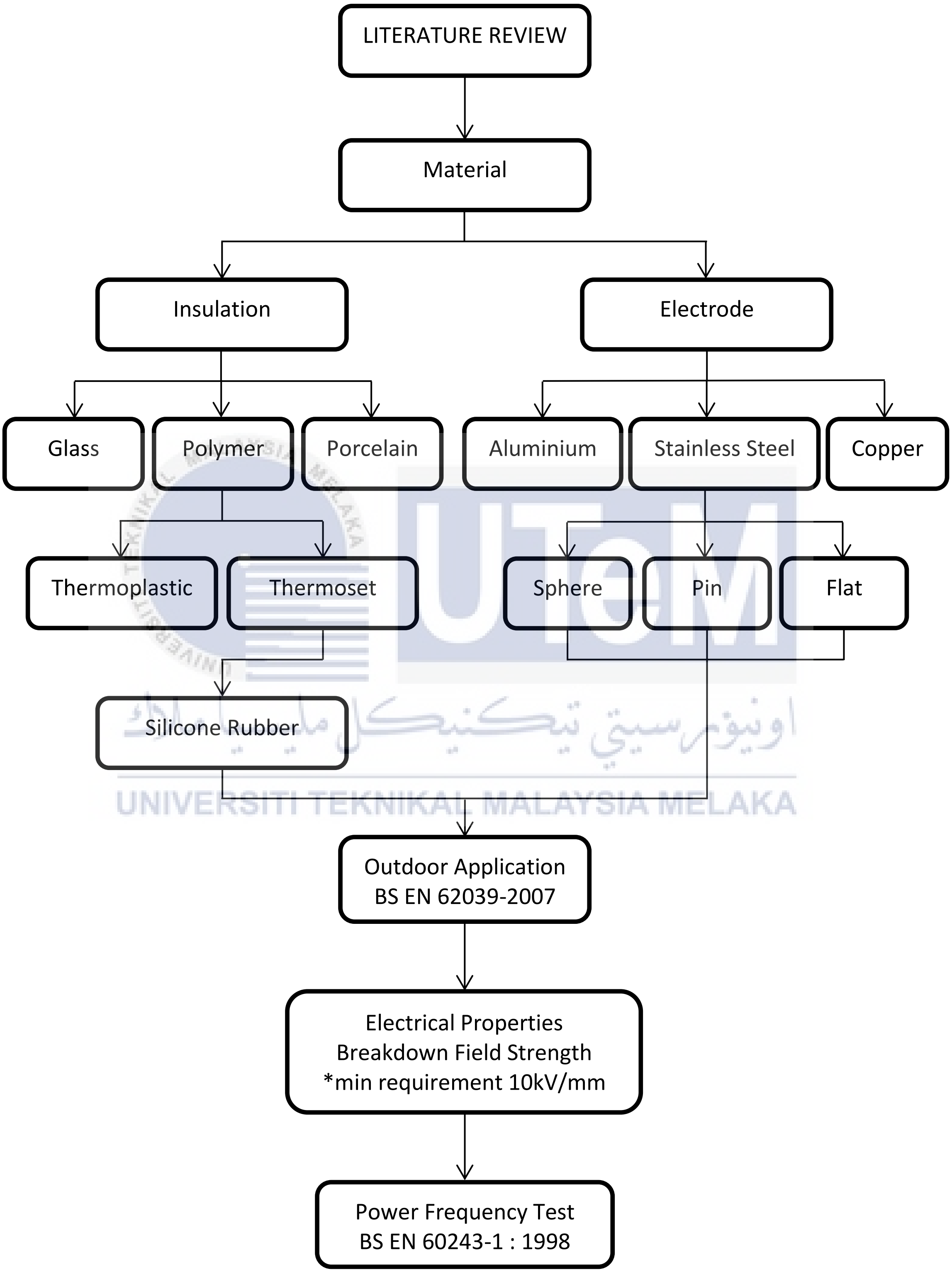


Figure 2.2 : Figure above shows the overview of the project.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The procedure carry out for this project are following the British Standard BS EN 60243-1 : 1998 standard. All the steps, specimen dimensioning, measuring parameters and appropriate tools are referring to the standard for determine the dielectric strength of the polymeric insulator material at the power frequency of 50 Hz for the short-time testing method. In this part, it does not include the testing for liquid and gases although both of it were surrounding the area for this insulating test of solid specimen [9].

3.2 Flow Chart Of Methodology

Figure below shows the work flow of Final Year Project 1:

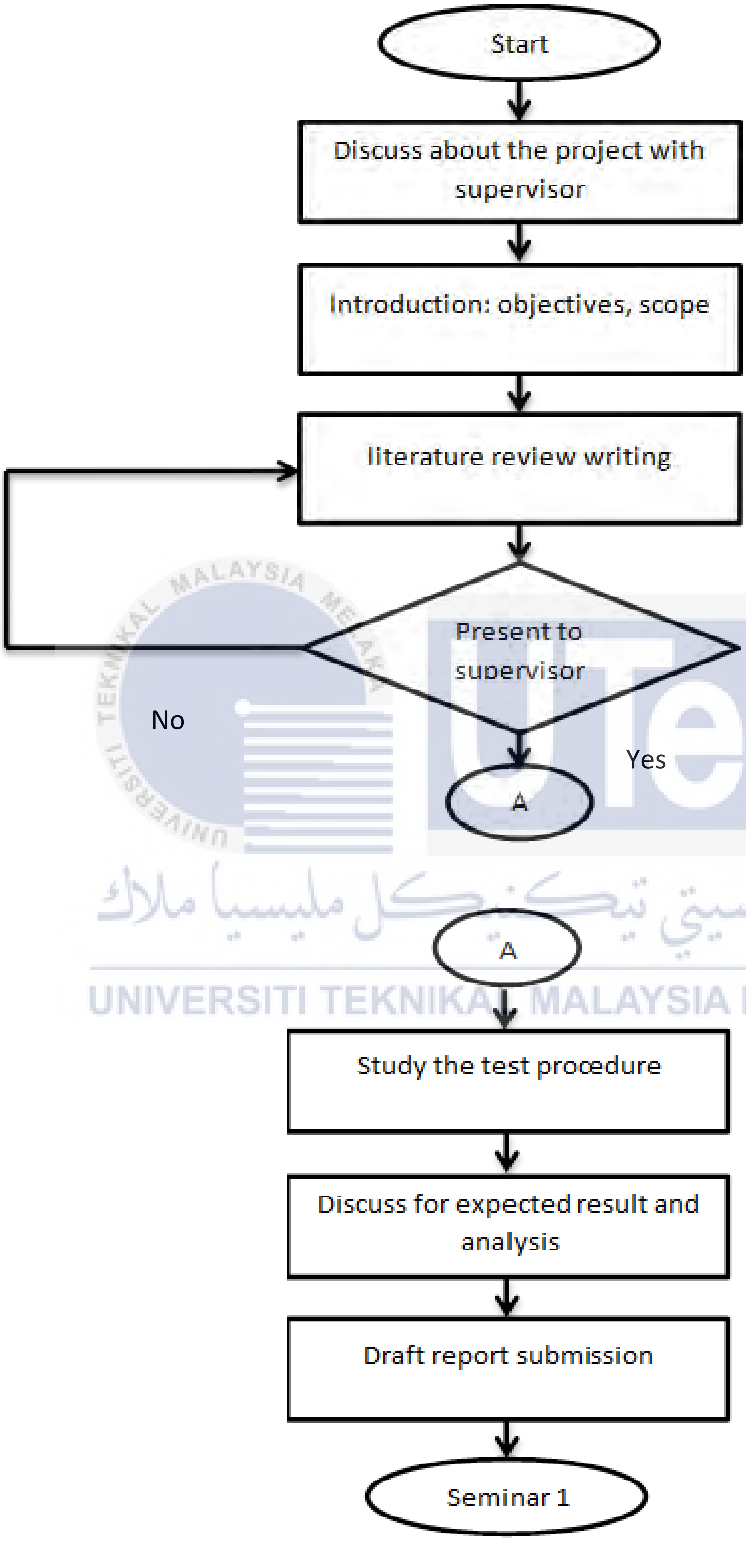


Figure 3.1 : Flowchart of the Final Year Project 1.

Figure below shows the work flow of Final Year Project 2:

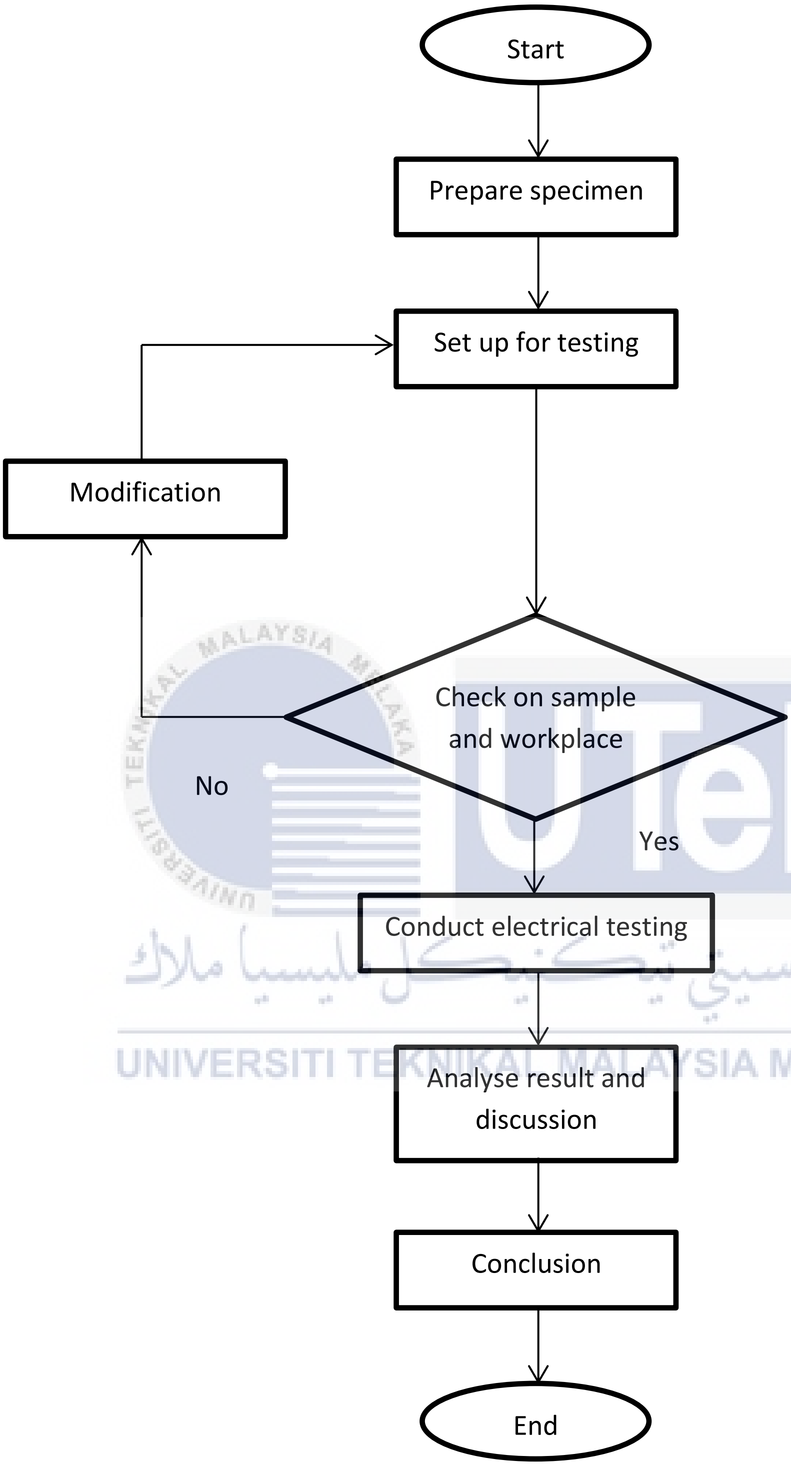


Figure 3.2 : Flowchart of Final Year Project 2.

3.3 Standard Test Procedure

Before the testing of the specimen or sample begin, condition for the test specimen and the test condition must be examine and consider. All the procedure are complying the International Standard of BS EN 60243-1:1998 test standard.

3.3.1 Condition For Test Specimen

The condition of specimen that use must be checked of its thickness and homogeneity and the presence of mechanical pressure. The specimen ought to be loose from the presence of gaseous inclusions or moisture and contamination [9].

3.3.2 Test Stipulation

For the test conditions, the frequency rate, waveform and rate of rise of the injection voltage and time of application of the voltage must follow the BSI standard. Also, the configuration set up, dimension, and thermal conductivity of the test electrodes must follow the standard use as well [9].

3.3.3 Electrode And Specimen

The condition of metal electrode must be maintain in the smooth, clean and free from dust and defect at all time. It becomes more important to keep it well maintain when it comes to the more thin specimen being tested. The electrode lead must not slanted, otherwise it will move the electrode or pressure on the specimen will be affected, nor appreciably affect the electric field surround the specimen [9].

3.3.3.1 Test Perpendicularly To The Specimen

For the test of thick sample or specimen. Board and sheets that have thickness more than 3 mm thickness have to be reduced by machining on one side only. The sample must be machining until it have thickness of 3 mm ± 0.2 mm and then it can be tested with the use of high potential electrode on the other side of the sample or non-machined side [9].

3.3.3.2 Unequal Diameter Flat Electrode

This type of electrode apply to the flat end type electrode. Both of the upper and lower electrode must have rounded edges with a radius of 3 mm ± 0.2 mm. The specification of the electrode are the upper electrode must have diameter of 25 mm ± 1.0 mm and approximately 25 mm high and couple with lower electrode with diameter and high of 75 mm ± 1.0 mm and 15 mm respectively and it must be set up coaxially within 2 mm [9]. The set up as shown in the Figure 3.3 below:

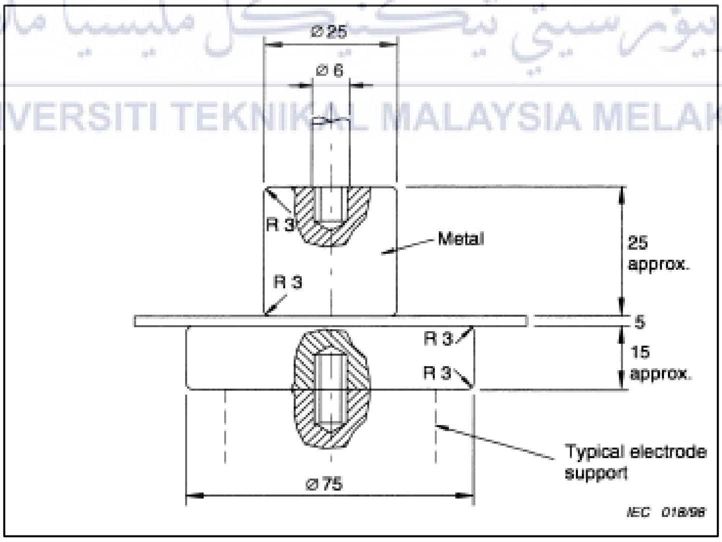


Figure 3.3 : Flat shape electrode with unequal diameter [9]

3.3.3.3 Equal Diameter Flat Electrode

This type of electrode apply to the flat end, spherical and pin type electrode. The upper and lower electrode have same diameter and high of 25 mm ± 1.0 mm and 25 mm respectively. The difference of the diameter of this two electrode must not more than 0.2 mm and must be assemble accurately align together with tolerance of 0.1 mm as in the Figure 3.4 below [9]:

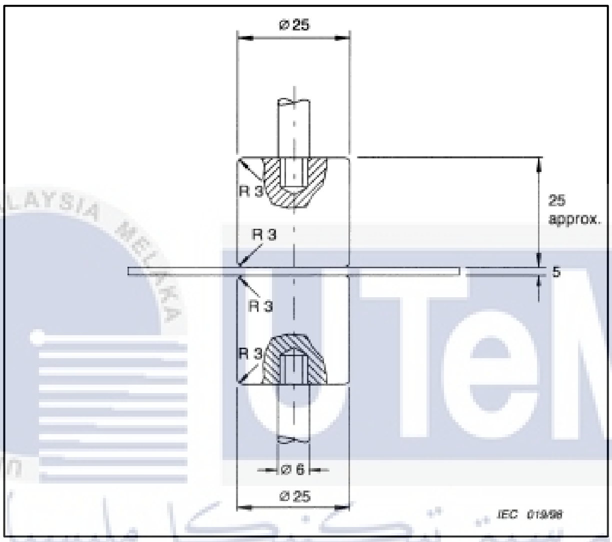


Figure 3.4 : Flat shape electrode with equal diameter [9]

3.3.3.4 Spherical Shape Electrode

The spherical electrode must have of 20 mm ± 0.1 mm in diameter for both upper and lower electrodes. Both of it must be placed on common axis. Upper electrode are connected to the high potential cable while the lower electrode connect to the zero potential cable as shown in the figure 3.5 below [9]:

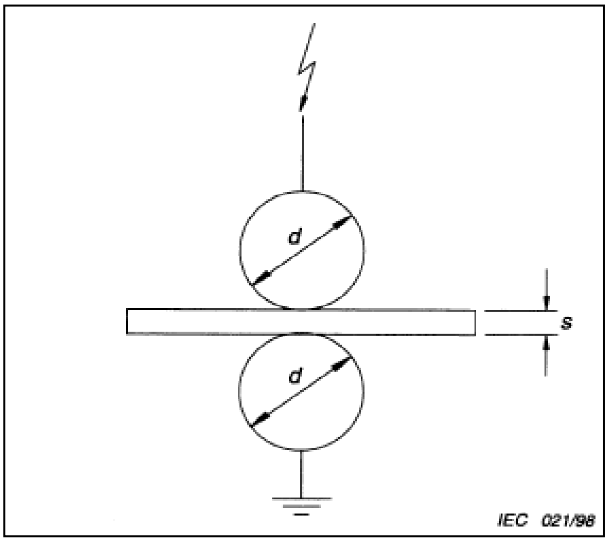


Figure 3.5 : Spherical electrode with specific diameter [9]

3.3.3.5 Pin Shape Electrode

The pin shaped electrode must have the end edges of 5 mm ± 0.5 mm approximately as required in the International standard. The thickness of the specimen used for this type of electrode are 3 mm ± 0.2 mm thick, not more or less than the tolerance. otherwise, need to be machined. The upper electrode attach to high potential while the lower attach to zero potential [9].

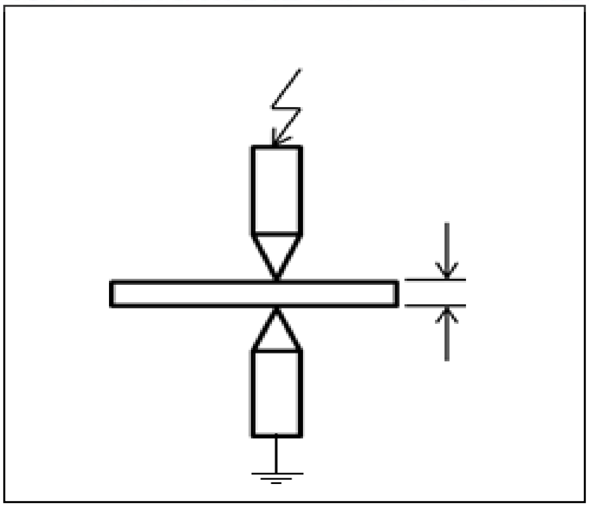


Figure 3.6 : Pin shape electrode with specific diameter of the pointer [9]

Table 3.1 : Specification for the electrodes and sample.

Electrode shape	Flat end		Spherical end	Pin end
	Equal size	Unequal size		
Electrode size (mm)	Lower = upper 6 ± 1	Upper : 25 ± 1 Lower : 75 ± 1	Lower = upper 20 ± 1	Lower = upper 5 ± 0.5
Specimen thickness (mm)	3 ± 0.2	3 ± 0.2	3 ± 0.2	3 ± 0.2
Specimen type	Thick sample	Thick sample	Thick sample	Thick sample

3.3.4 Method Of Voltage Increment

There are several method of voltage incremental during the test conducted such as short time test, 20s step by step test, slow rate of rise test, 60s step by step test and very slow rate of rise test method. However, short time test are selected as the rate of voltage rise method for this project [9].

3.3.4.1 Short Time (Rapid-Rise) Test

For this method, the voltage supply to the electrode are raised in the uniform rate starting from zero until the breakdown of the specimen occurs. From this method, the breakdown of the material should occur in between of 10s to 20s of testing time. It is consider done when the majority of the test sample had the breakdown time as in between of 10s to 20s. The voltage selection for this method are as follow, 100V/s, 200V/s, 500V/s, 1kV/s, 2kV/s and 5kV/s and as the test material of this project are moulded material type. Therefore, the selection of voltage are 2kV/s [9].

3.3.5 Electrical Devices

It involves the voltage source to conduct the experiment while some of measurement tools are needed to capture and measure the breakdown voltage and the effect to the sample during the test conducted.

3.3.5.1 Voltage Supply

The supplied voltage shall provide from the step-up transformer from the low voltage supply The ratio of root mean square (R.M.S) must be same as $\sqrt{2} \pm 5$ % (1.34 – 1.48) with the test sample in the circuit. It is applied to all voltages include breakdown voltage. Output current of 40mA are enough with the power vary from 0.5kVA for voltages up to 10kV until 5kVA for voltages up to 100kV [9].

3.3.5.1.1 Voltage Supply Protection

To protect the supply, usage of several series resistor can be the protection to the voltage supply as the resistor will restrict the overflow current in the circuit. Especially during the breakdown occurs. The resistor use can be select for the high value in resistance, so it can withstand higher current without failure [9].

3.3.5.2 Measuring Voltage

The voltage measure are in the R.M.S value during the breakdown using the voltmeter. But, also recommended to measure in peak value and then divide it with $\sqrt{2}$. Also the waveform of the breakdown voltage can be capture using the oscilloscope to present the waveform.

3.3.6 Test Breakdown Criteria

The expanded current may trip the circuit breaker or blow up the fuse. In any case, stumbling of an circuit breaker can sometimes be affected by flashover, example charging current, spillage or incomplete release streams, gear polarizing present or failing. It is accordingly fundamental that the circuit breaker is well coordinated with the attributes of the test gear and the material under test, generally the circuit breaker may work without breakdown of the example, or neglect to work when breakdown has happened and subsequently not give a positive measure of breakdown. Indeed, even under the best conditions, untimely breakdowns in the surrounding medium may happen, and perceptions might be made to distinguish them amid tests [9].

3.3.7 Repetitions Of Test

For each type of the electrode shape will undergo five test using five sample of SIR to determine the dielectric strength. The result will be taken from the median of the total five sample. If the results get more than 15% deviate from the median, another five sample should be test again and take the result of 10 sample [9].

3.4 Test Specimen Preparation

The preparation of the specimen begin with cutting the specimen into specified length, wide and thickness followed to the standard. The specimen in preparation is silicone rubber, SIR that prepared for 20 pieces for the testing.

3.4.1 Category And Test Parameters

Table 3.2 : Category and test parameters of specimen and electrode.

Shape of electrode	Size of electrode	Type of specimen	Size of specimen
Flat : Equal diameter	25mm ± 1mm	Thick	200mm x 200mm x 3mm ± 0.2mm
Flat : Unequal diameter	25mm ± 1mm Lower:75mm ± 1mm	Thick	200mm x 200mm x 3mm ± 0.2mm
Spherical	20mm ± 1mm	Thick	200mm x 200mm x 3mm ± 0.2mm
Pin	5mm ± 1mm	Thick	200mm x 200mm x 3mm ± 0.2mm

3.4.2 Sample Of Specimen And Electrodes

Figure 3.7 shows the specimen of silicone rubber, SIR that have been prepared while Figure 3.8, Figure 3.9, Figure 3.10 and Figure 3.11 shows the unequal, equal, spherical and pin electrode respectively.

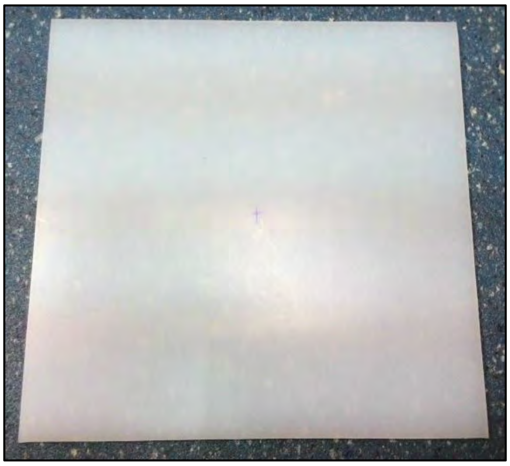


Figure 3.7 : Specimen of SIR polymer material.

Figure 3.8 : Unequal diameter flat shape electrode.

Figure 3.9 : Equal diameter flat shape electrode.

Figure 3.10 : Spherical shape electrode.

Figure 3.11 : Pin shape electrode.

3.5 High Voltage Test Setup

The equipment setup for the HV test are shown in the schematic diagram below. There are power supply connected to the power transformer with two capacitor connected to it.

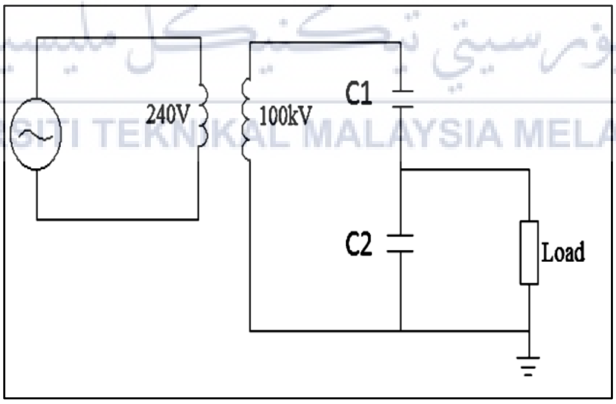


Figure 3.12 : Figure above shows the schematic diagram of HV test setup.

Transformer rating : 240:100kV

Measuring capacitor, C1 : 100pF/100kV AC

Secondary capacitor, C2 : 68nF/100kV AC

3.5.1 Equipment Of High Voltage Test

i. Operating Terminal, OT276

ii. Single phase step-up transformer, PZT100

iii. Digital Measuring Instrument, DMI551

iv. Digital Phosphor Oscilloscope, DPO4034

v. Faraday Cage with Interlock system

vi. Measuring Capacitor

vii. Grounding Switch

viii. Discharge Rod

In dielectric strength test, there are two types of test electrodes that is available which are perpendicular and parallel to the sample type. For this project, it used perpendicular type of electrode to carried out dielectric strength test using flat sheet specimen with comply to the standard BS EN 60243-1 :1998 as in the figure below [9]:

Figure 3.13 : Actual setup of the electrode and specimen for the test.

Other important equipment that was used in summation to the test electrode are Operating Terminal OT 276, Digital Measuring Instrument DMI 551, Digital Oscilloscope and Single phase Transformer that can generates output voltage until 100kV. Figure 3.14,

Figure 3.15, Figure 3.16 and Figure 3.17 shows the OT 276, DMI 551, Oscilloscope and Transformer respectively [1].

Figure 3.14 : Operating Terminal OT 276.

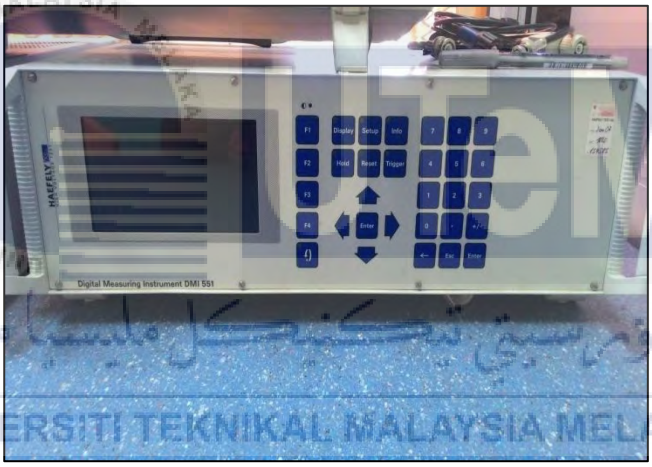


Figure 3.15 : Digital Measuring Instrument DMI 551.

Figure 3.16 : Digital Phosphor Oscilloscope, DPO 4034.

Figure 3.17 : Single phase step-up transformer, PZT100-1

3.5.2 Dielectric Strength Test Procedure

1. The apparatus of stage one HV was setup as in figure 3.18 and figure 3.19 shows the actual setup.

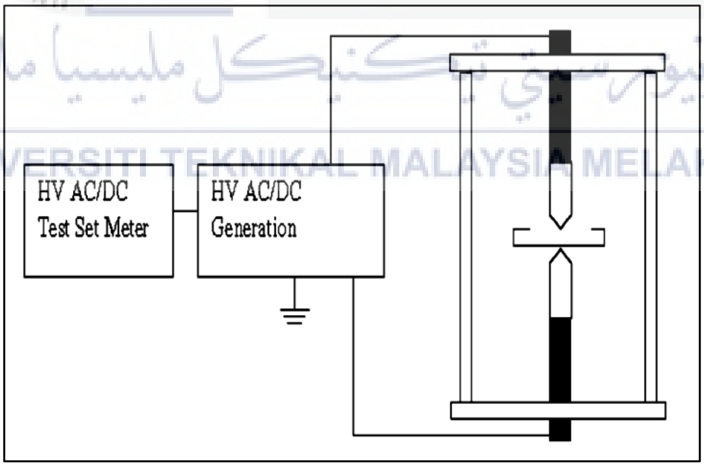


Figure 3.18 : Dielectric strength setup.

Figure 3.19 : The actual setup of the dielectric strength test.

2. The Operating Terminal and Digital Measuring Instrument were switched on.
3. The specimen placed at the testing electrode chamber.
4. Increase voltage 10V at the OT 276 and rest for 5seconds, then repeat the increasing of voltage until breakdown occurs as shown in figure below.

Figure 3.20 : Breakdown occurs during testing.

5. The indicator RESET at DMI 551 was ON when breakdown occurs.
6. Once breakdown occurs, voltage was then decreased to 0V.
7. Operating Terminal then was switched off.
8. Breakdown voltage value was read and recorded from the DMI 551.

9. RESET button was pushed.
10. The apparatus was then discharged using discharge rod.
11. The specimen was replaced and steps were repeated for remaining specimens.

3.6 Safety

During the testing in the high voltage laboratory, safety is the most crucial thing. All aspects must be taken in order to avoid any harm and injuries happen during testing experimental work. Operation and safety precaution must be observed to ensure safety to individual and to prevents damage to the equipment. Always wear safety shoes and not wearing any accessories while handling high voltage testing.

3.6.1 User Safety

1. No student is permitted to work in Laboratory in the absence of either lecturers or technician.
2. No student should be allowed to charge the connection of the generator without supervision of the lecturer or technician.
3. Don’t work alone; in case of an emergency another person’s presence may be essential.
4. Wear rubber shoes or sneakers as protection to user.
5. Have a fire extinguisher rated for electrical fires readily accessible in a location.
6. Connect or disconnect any test leads with the equipment unpowered.
7. The experimental work cannot be done when the user is tired to avoid careless happen during testing.
8. All the supplies must switch off before leaving the laboratory.

3.6.2 Faraday Cage With Interlock System

In the laboratory, the installation of the high voltage generator itself should also enclosed by the safety system. The purpose of the system use is to provide protection to human being, livestock or even the equipment itself from any harm and damage. For the testing area of generator must be covered by cage to prevent undesired movement or act by human. The area must be isolated with strong metal cage with height at least 1.8meters and a maximum grid spacing of 50milimeters.

The area arounds the generator must all be grounded to the earth and equipped with additional safety system such as interlocking system. This will provide more safety because the system will not operate if the cage are considered open or unsafe by the system. Faraday cage system was equipped with the contact at the door that will automatically shut down the generator and terminate the voltage if it is triggered during testing period. The discharge rod are essential to discharge all the equipment after testing to avoid any injuries and must be put at proper place. Figure below shows the Faraday Cage:

Figure 3.21 : Faraday Cage with interlock system.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter of this report presents the results gains of the project conducted regarding the dielectric strength of the SIR under different shapes of electrode with the high voltage stress conditions. The results are measured and collected from the testing procedure complying the International standard BS EN 60243-1:1998, method 1 - test at power frequency of 50Hz. The result obtained from the test will be shown in the table and graph and the result will be analysed and discussed in this chapter. Then, the performance of dielectric strength of the polymeric material will be assessed.

4.2 Test Condition For Dielectric Test

By referring to the previous chapter, in order to obtain the accurate result, pre-test was conducted and electrode surface to be cleaned with ethanol between two successive voltage application. Electrode surface cleaned with ethanol to ensure that it surface is free from dust, scratches and other impurities. It is important to ensure the electrode is clean because any other impurities or defect will affect the result obtain during dielectric test. Table below shows the condition for the specimen under test.

Table 4.1 : Parameters and condition for specimen under dielectric strength test [1].

Test condition	Remarks
Specimen material	Silicone rubber
Sample type	Flat sheet
Specimen thickness	3 ± 0.2 mm
Number of sample	20 samples
Power frequency	50 Hz
Ambient temperature	25 ± 3 °C
Surrounding humidity	70 %
Electrode type	Stainless steel
Electrode diameter	Flat : Unequal : 25/75 ± 1mm ø Flat : Equal : 25/25 ± 1mm ø Spherical : 20/20 ± 1mm ø Tapper pin : 5/5 ± 0.5mm ø
Voltage supply	0 - 2kV (uniform rate of rise)
Mode of voltage increment	Short-time (rapid rise)
Measurement unit	kV/mm

4.3 Test Results

The result of dielectric strength test of SIR obtain during testing was recorded and tabulated according to each type of electrode which are equal flat shape, unequal flat shape, sphere shape and pin shape electrode used. Then, it will be compared, analysed and discussed for better understandings.

4.3.1 Breakdown Voltage Of Sir

Dielectric strength test is done to determine the maximum voltage stress that can be withstand by the SIR specimen under different shape of electrode used. The maximum voltage stress an insulation can withstand is called as breakdown voltage. From the test carried out using unequal diameter flat shape electrode, equal diameter flat shape electrode, sphere shape electrode and pin shape electrode. The breakdown voltage and dielectric strength of the SIR specimen has been recorded. The result are as shown in the Table 4.2, Table 4.3, Table 4.4 and Table 4.5 below.

Table 4.2 : Breakdown voltage of SIR under unequal flat shape electrode.

Breakdown voltage of SIR, (kV)			
Specimen number	kV (Peak)	kV (R.M.S)	kV/mm (R.M.S)
Specimen 1	62.37	44.10	14.70
Specimen 2	62.45	44.16	14.72
Specimen 3	62.92	44.49	14.83
Specimen 4	62.07	43.89	14.63
Specimen 5	63.17	44.67	14.89
Average	**62.59**	**44.26**	**14.75**

Table 4.3 : Breakdown voltage of SIR under equal flat shape electrode.

Breakdown voltage of SIR, (kV)			
Specimen number	kV (Peak)	kV (R.M.S)	kV/mm (R.M.S)
Specimen 1	60.12	42.51	14.17
Specimen 2	60.50	42.78	14.26
Specimen 3	61.22	43.29	14.43
Specimen 4	60.97	43.11	14.37
Specimen 5	60.88	43.05	14.35
Average	**60.74**	**42.95**	**14.32**

Table 4.4 : Breakdown voltage of SIR under sphere shape electrode.

Breakdown voltage of SIR, (kV)			
Specimen number	kV (Peak)	kV (R.M.S)	kV/mm (R.M.S)
Specimen 1	58.29	41.22	13.74
Specimen 2	56.85	40.20	13.40
Specimen 3	55.88	39.51	13.17
Specimen 4	55.37	39.15	13.05
Specimen 5	57.45	40.62	13.54
Average	**56.77**	**40.14**	**13.38**

Table 4.5 : Breakdown voltage of SIR under pin shape electrode.

Breakdown voltage of SIR, (kV)			
Specimen number	kV (Peak)	kV (R.M.S)	kV/mm (R.M.S)
Specimen 1	51.76	36.60	12.20
Specimen 2	53.71	37.98	12.66
Specimen 3	54.81	38.76	12.92
Specimen 4	51.93	36.72	12.24
Specimen 5	54.48	38.52	12.84
Average	**52.85**	**37.72**	**12.57**

The Table 4.6 below shows the comparison of the breakdown voltage value recorded for each shapes of electrode. The value use to be compared taken from the average of five test for each shapes of electrode. The average value was taken to improve the accuracy for the readings taken. The results are as shown in the table below.

Table 4.6 : Comparison of breakdown voltage for each type of electrode.

Average breakdown voltage of SIR, (kV)			
Type of electrode shape	kV (Peak)	kV (R.M.S)	kV/mm (R.M.S)
Flat shape – unequal diameter	62.59	44.26	14.75
Flat shape – equal diameter	60.74	42.95	14.32
Sphere shape	56.77	40.14	13.38
Pin shape	53.34	37.72	12.57

4.4 Analyse And Discussion

This section explain the analyse and discussion of the result in the previous chapter. The tabulated data are converted into line graph and bar chart to ease the viewing analysing process. The difference of the breakdown voltage for each type of electrode used are discussed in this section.

4.4.1 Breakdown Voltage Using Unequal Diameter Flat Electrode

The voltage increasing mode used are short time – rapid rise test with injection voltage of 2000V per second for each type of electrode shapes used. The waveform and value of breakdown occurs on a specimen are captured using oscilloscope DPO 4034 and read with DMI 551. The waveform captured are cropped and taken to show the region of waveform during breakdown only. The breakdown voltage for the SIR specimen using the unequal diameter flat shape type of electrode occurs when supplied with the AC high voltage at 62.59kV peak or 44.26kV in the R.M.S. value. The waveform captured are as shown in Figure 4.1 and Figure 4.2 shows graph of plotting waveform in MATLAB by using data from the oscilloscope.

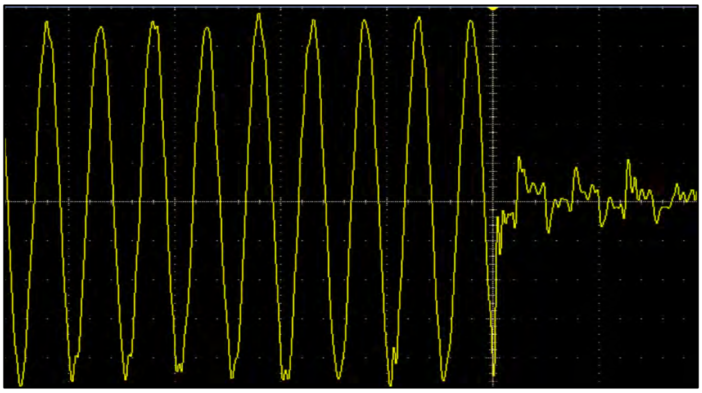


Figure 4.1 : Captured breakdown waveforms using unequal diameter flat electrode.

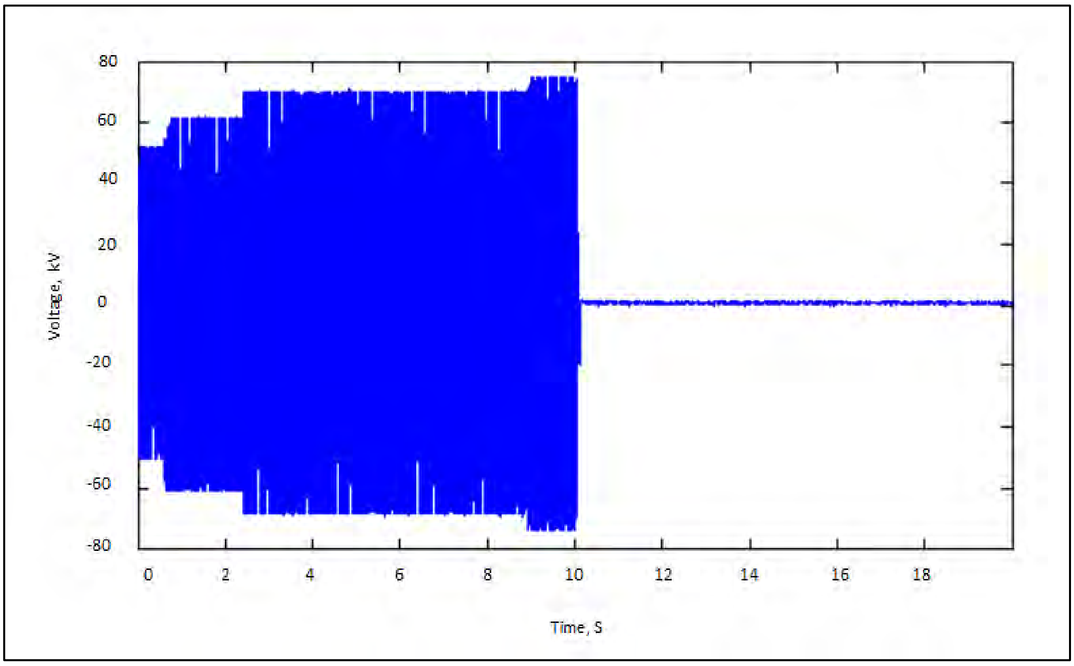


Figure 4.2 : Plotted graph of breakdown waveforms using unequal diameter flat electrode.

4.4.2 Breakdown Voltage Using Equal Diameter Flat Electrode

For the breakdown voltage of SIR using equal diameter flat shape electrode, the breakdown occurs at the 60.74kV peak or in the R.M.S value at 42.95kV. The captured waveform of AC voltage during breakdown as shown in the Figure 4.3 below and Figure 4.4 shows graph of plotting waveform in MATLAB by using data from the oscilloscope.

Figure 4.3 : Captured breakdown waveforms using equal diameter flat electrode.

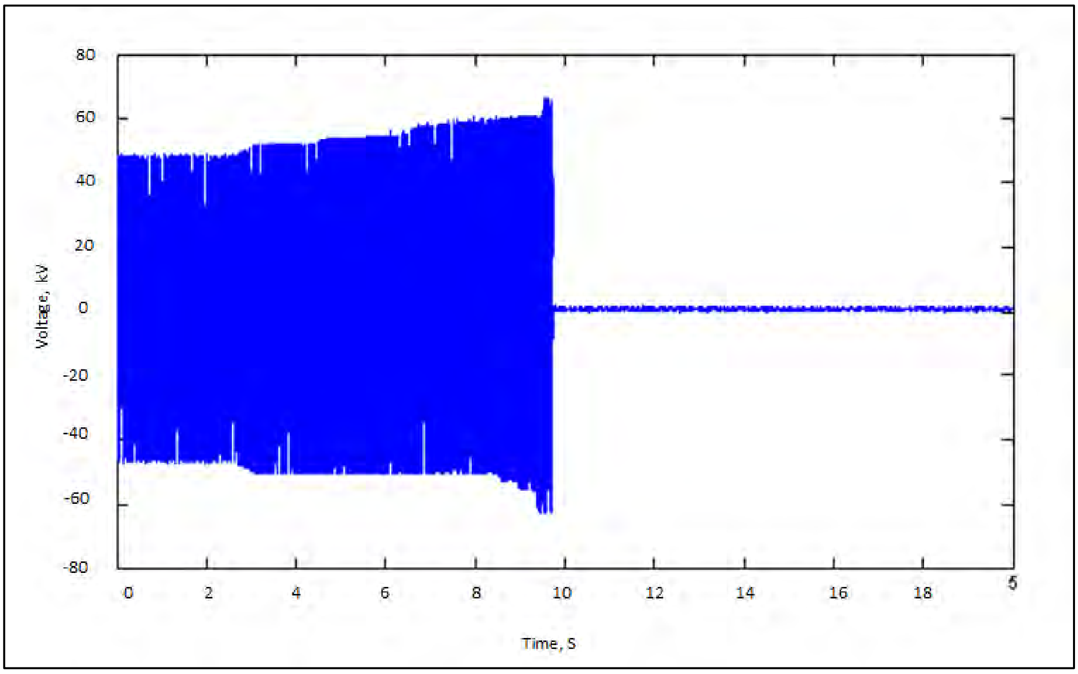


Figure 4.4 : Captured breakdown waveforms using equal diameter flat electrode.

4.4.3 Breakdown Voltage Using Sphere Electrode

Next, the Figure 4.5 below shows the captured waveform of breakdown voltage of the SIR using sphere shape electrode and Figure 4.6 shows graph of plotting waveform in MATLAB by using data from the oscilloscope. The breakdown voltage occur using this type of electrode are at 56.77V peak value or at 40.14kV in the R.M.S value.

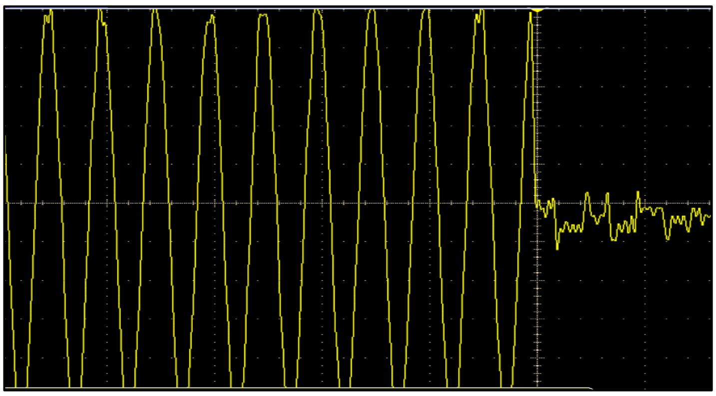


Figure 4.5 : Captured breakdown waveforms using sphere shape electrode.

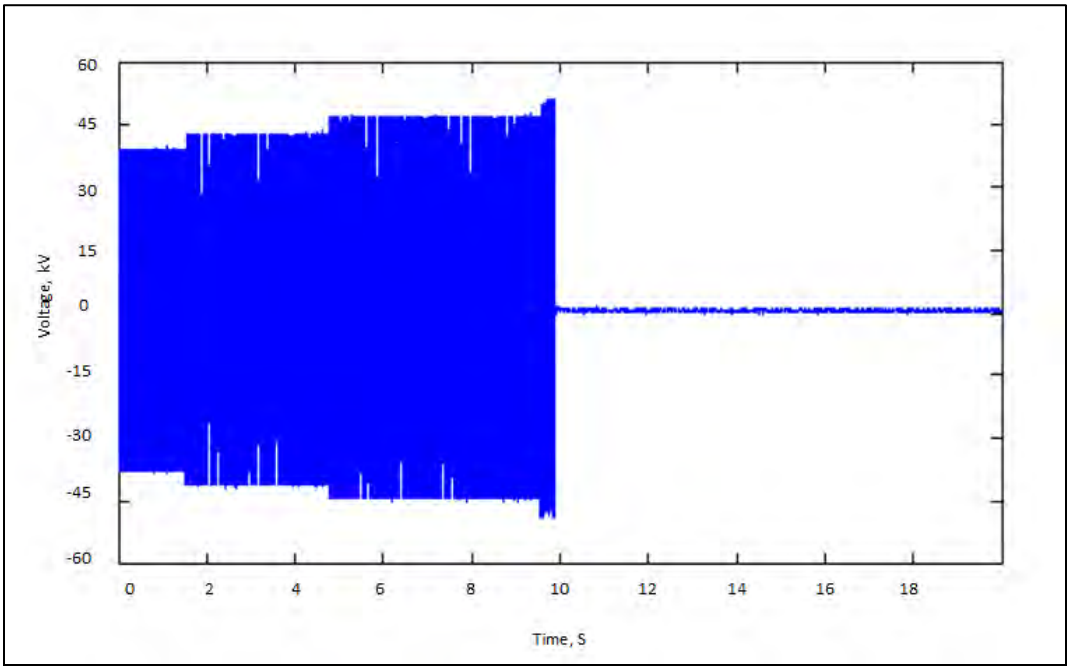


Figure 4.6 : Captured breakdown waveforms using sphere shape electrode.

4.4.4 Breakdown Voltage Using Pin Electrode

For the testing using pin shape type of electrode, the breakdown voltage occurs at 53.34kV peak value while for the R.M.S value are 37.72kV. The breakdown voltage waveform captured during testing are as shown in the Figure 4.7 below and Figure 4.8 shows graph of plotting waveform in MATLAB by using data from the oscilloscope.

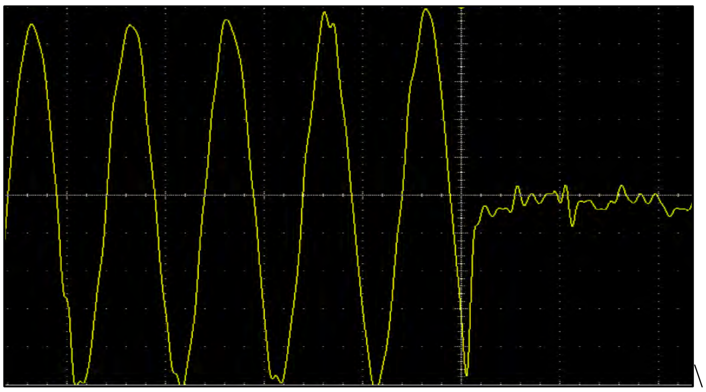


Figure 4.7 : Captured breakdown waveforms using pin shape electrode.

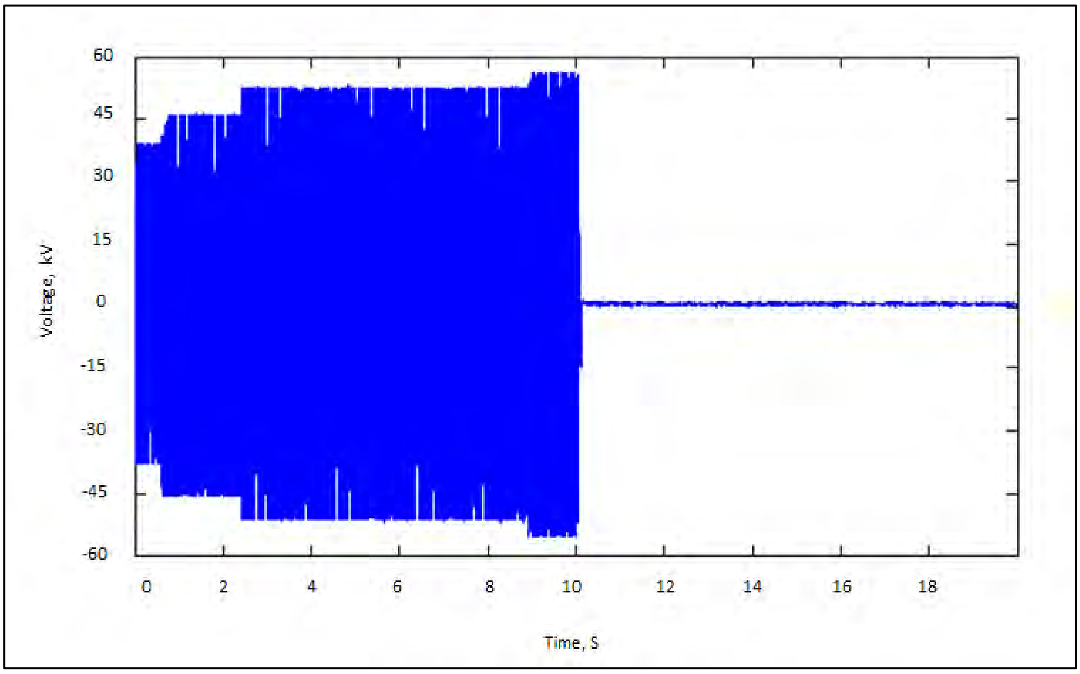
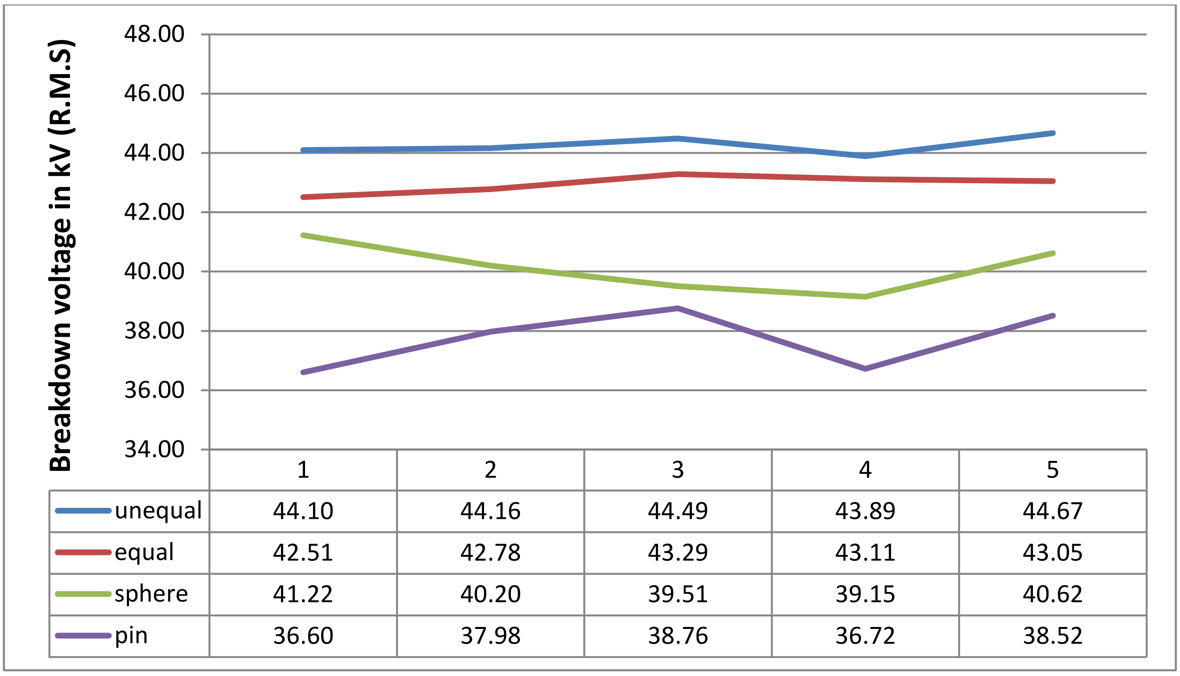


Figure 4.8 : Captured breakdown waveforms using pin shape electrode.

4.5 Comparison Of Breakdown Voltage of SIR

From all of the breakdown voltage of SIR results recorded for all type of electrode shapes used, a line graph constructed to represent all the value taken from the readings of the breakdown voltage. For each shapes of electrode used, five specimen of SIR polymer are tested. The line graph in the Figure 4.9 below shows the comparison of breakdown voltage readings for all shapes of electrode used. The horizontal axis represent the number of specimen used while vertical axis shows the scale of breakdown voltage in R.M.S.



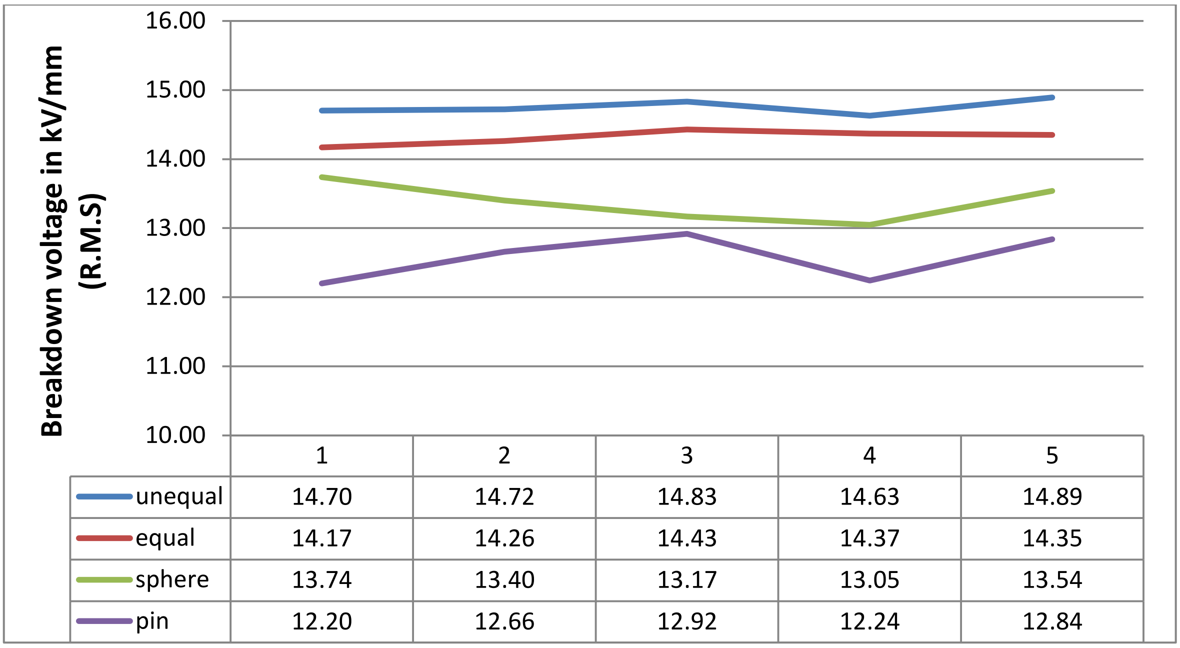
	1	2	3	4	5
unequal	44.10	44.16	44.49	43.89	44.67
equal	42.51	42.78	43.29	43.11	43.05
sphere	41.22	40.20	39.51	39.15	40.62
pin	36.60	37.98	38.76	36.72	38.52

Figure 4.9 : Comparison of breakdown voltage of SIR in kV.

4.6 Comparison Of Dielectric Strength of SIR

Dielectric strength performance of the SIR material can be determined from the value of breakdown voltage recorded earlier, but the breakdown voltage are in kV, by referring to the standard the dielectric strength are measured in kV/mm. Therefore, following the equation 4.1 below, V are the breakdown voltage value while d are the specimen thickness value. Then, the value of breakdown voltage are divided with the thickness of the SIR specimen which is 3mm to obtain the dielectric strength of the SIR. Figure 4.10 below shows the dielectric strength of the SIR polymeric material for each types of electrode. The horizontal axis represent the number of specimen used while vertical axis shows the scale of breakdown voltage in kV/mm in R.M.S value.

$$\mathbf{E} = \frac{V}{d} \tag{4.1}$$



	1	2	3	4	5
unequal	14.70	14.72	14.83	14.63	14.89
equal	14.17	14.26	14.43	14.37	14.35
sphere	13.74	13.40	13.17	13.05	13.54
pin	12.20	12.66	12.92	12.24	12.84

Figure 4.10 : Comparison of breakdown voltage of SIR in kV/mm.

From the result of testing carried out earlier comply to the International Standard BS EN 60243 –1: 1998 and the minimum requirement for the dielectric strength based on BS EN 62039 : 2007 must exceed 10kV/mm. The voltage breakdown test result of SIR specimen using different shape of electrode was calculated to determine the average value in kV and kV/mm and the value measured in R.M.S. The data as shown in the Figure 4.11 below. For the breakdown voltage of SIR specimen, the average breakdown voltage and dielectric strength values are 44.26kV, 42.95kV, 40.14kV, 37.27kV and 14.75kV/mm, 14.32kV/mm, 13.38kV/mm, 12.57kV/mm using unequal diameter flat shape electrode, equal diameter flat shape electrode, spherical shape electrode and pin shape electrode respectively. Then, the dielectric strength performance of SIR can be judge from this result. From the bar chart below, the average value of pin shape electrode is the highest followed by sphere electrode then equal diameter electrode and the lowest is unequal diameter electrode. Fortunately, the dielectric strength performance of SIR for all shape of electrode used are passed the minimum requirement of the standard.

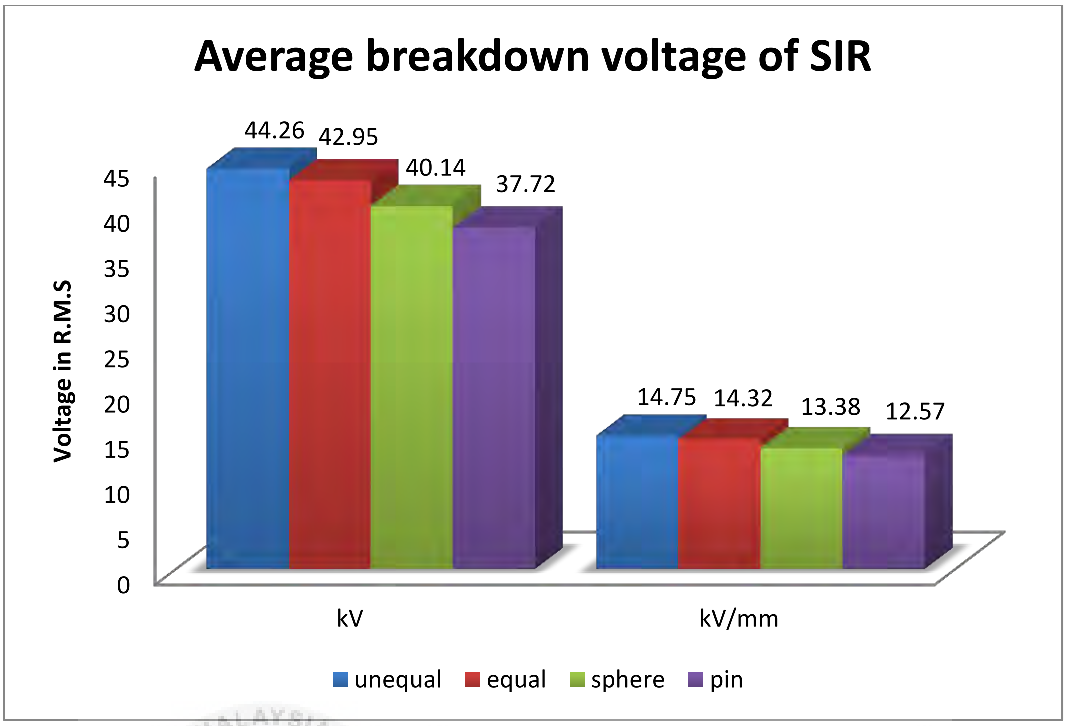


Figure 4.11 : Average breakdown voltage of SIR in kV and kV/mm.

4.7 Phenomenon During AC High Voltage Test

After an insulation supplied with high voltage over a period of time, the insulation will achieved it maximum capability and will breakdown due to high voltage stress applied. When a high voltage stress flow through electrode to the solid insulation material, it will energized the free moving electron in voids and this electron will collide with insulation molecules. As the apply voltage increasing, more free moving electron increase, thus will produce a process called as ionization process or corona as shown in Figure 4.12 below.

This continuing process of ionization will lead to breakdown of the insulation material as shown in the Figure 4.13 below. The ionization process or corona produce a blueish purple colour and hissing sound that can be heard during the test. There are also another phenomenon that can happen during the testing conducted that is called as flashover or failure as shown in the Figure 4.14 below. The flashover occur due to the over potential stress given to the insulation material. The flashover occur with jumps to the air and produce the conduction bridge between the electrode.

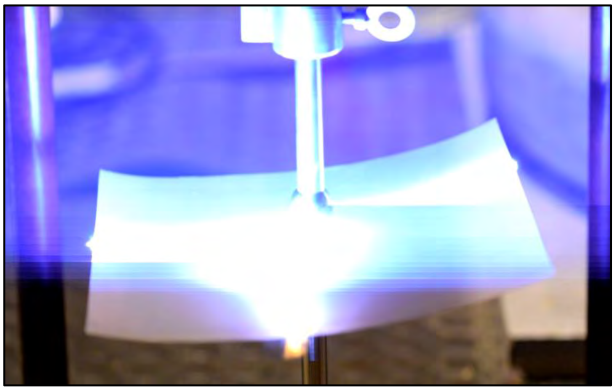


Figure 4.12 : The breakdown of the SIR insulation material.

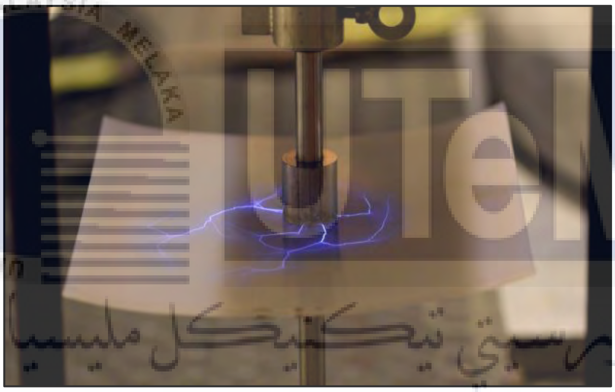


Figure 4.13 : The ionization process or corona with blueish purple colour.

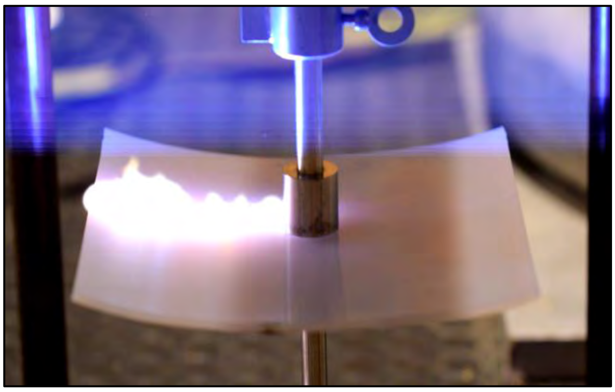


Figure 4.14 : The flashover due to over potential stress applied.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Since, polymeric material are well accepted, a lot of study has been conducted regarding this material to study and optimize it performance in the HV application. The most popular polymeric material used nowadays are SIR because of its excellent performance as the insulation material. Dielectric strength are one of the crucial parameters that must be considered for the insulation application. Furthermore, dielectric strength test that has been standardized by International Standard which are BS EN 60243-1:1998 to determine the capabilities of insulation material under high voltage stress.

Therefore, this experiment revealed the electrical strength of the SIR polymer as the selected material used under HV testing at the power frequency of 50 Hz using accelerated ageing test method comply to the International standard of test. It is also, form the data collected, the dielectric strength performance of SIR insulation material using different shape of electrode are determined. Data obtain from test using different shape of electrode are compared and verify which shape of electrode that affect the most to the dielectric strength of the SIR material. Besides, the electrical strength of the SIR material must exceed the minimum requirement of dielectric strength for the outdoor used of 10kV/mm based on International standard BS EN 62039 : 2007.

The method of testing using the rapid rise of voltage increment mode using stage one HV AC voltage supply. The equipment used are operating terminal OT 276, oscilloscope DPO 4034 and digital measuring instrument DMI 551 to conduct the test and record the data. The breakdown voltage test conducted in the faraday cage with interlocking system to avoid any disturbance and ensure the safety during the testing carry out.

From the finding of this project, the performance of the SIR polymer material using different shape of electrode are meet the requirements of the breakdown field strength as the HV insulation application. Four type of electrode used which are unequal diameter flat shape electrode, equal diameter flat shape electrode, sphere shape electrode and pin shape electrode exceed the requirement of dielectric strength of 10kV/mm. It can be verify that the pin shape electrode influence the most to the breakdown voltage of the SIR polymer insulation. This breakdown voltage are influence by the diameter of the electrode used, the smaller the diameter of the electrode, more charged are focus on its tip. Thus, lead to breakdown faster.

Based on the result and finding of this work, the objectives of this research in breakdown voltage of polymeric material under different shape of electrode in order to obtain and compare the dielectric strength of the SIR insulation according to the type of electrode used with comply to the international standard has been achieved.

5.2 Recommendation

There are some recommendation for the further study to make improvement of this project. To increase the dielectric strength of the SIR material, development of the SIR added with filler might be used to increase its performance. Other polymeric material also can be used to verify it performance under different shape of electrode use. Other test also can be conduct in determine the performance of an insulation material such as ultraviolet exposure test, salt fogging test and oxidation stability test or other test to study the ageing of the insulation material.

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APPENDIX A

AC CONFIGURATION 1 STAGE

APPENDIX B

THE INTERNATIONAL STANDARD BS EN 60343-1:1998