Faculty of Electrical and Electronic Engineering Technology

TREEING AND TRACKING OBSERVATION ON THE SURFACE OF TRANSMISSION LINE INSULATOR FOR SOLVING LINE-TO-GROUND FAULT IN DC HIGH VOLTAGE APPLICATION

YEE LU HUAN

Bachelor of Electrical Engineering Technology (Industrial Power) with Honours

2023

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YEE LU HUAN

A project report submitted
in partial fulfillment of the requirements for the degree of
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DEDICATION

To special feeling gratitude to my loving parents, Yee Yep Meng and Loo Swee Lim, whose words of encouragement and push for tenacity ring in my ears.
And my most respectful supervisor Ts Dr Zikri Abadi Bin Baharudin for helping me a lot in develop my technology skills.
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Thank you also to my supervisor that always caring, support and guide me throughout this journey on completing this thesis report. Hopes everything will always going smoothly in the future.

ABSTRACT

Throughout the proposal of this final year project is regarding on the photographic observation for electrical treeing and tracking observation on the surface of transmission line insulator for solving line-to-ground fault in DC high voltage application via high-speed camera. Since formation of electrical treeing and contamination of tracking may lead to breakdown in high voltage system. The observation of the existence of electrical treeing may provide insight into how to diminish the risk of a breakdown occurring in a high voltage system of the line to ground fault as a precaution to prevent the breakdown triggered phenomenon in a high voltage system. The main purpose of this final year project is to investigate the propagation progress of electrical treeing and tracking on the surface of the ceramic insulator by using the combination of electric field measurement and high-speed photographic camera. This project was conducted in Universiti Institut Voltan Dan Arus Tinggi (IVAT) lab from Universiti Teknologi Malaysia, Skudai, Malaysia. A ceramic insulator KN120 used to see the formation of electric treeing and tracking by applying high voltage DC ranging from 30 to 50 kV. For the purpose of photographic and electric field observation and measurement, this project used Choronos 1.4 High speed camera and broadband electric field measurement. The resolution of high-speed camera was set to 1000 frame per second (fps) within the duration of 2 seconds. Electrical breakdown voltage was recorded by using high defination of transient recorder (Lecroy HDO4024) with the resolution ranging from 10 to 20 MS/s for 2 seconds duration. The results of this project comprises three important findings: a) When the DC voltage exceed up to 20 kV, treeing and tracking start forming at the bottom of the insulator that being terminated by HV terminal (+); b) Treeing and tracking appeared as train pulses ranging from 9 to 10 MHz between the two peaks (as summarized in Table 4.1); c) Peak voltage due to treeing and tracking variation associated in DC input and not consistence or not uniform range (as summarized in Table 4.2).

ABSTRAK

Cadangan projek tahun akhir ini adalah mengenai pemerhatian fotografi dalam bentuk pokok elektrik dan pemerhatian pengesanan pada permukaan penebat talian penghantaran untuk menjejak kesalahan talian ke tanah menggunakan aplikasi voltan tinggi DC melalui kamera berkelajuan tinggi. Disebabkan pembentukan pepohonan elektrik dan pencemaran penjejakan boleh menyebabkan kerosakan dalam sistem voltan tinggi, pemerhatian kewujudan pepohonan elektrik boleh memberikan gambaran tentang cara mengurangkan risiko kerosakan yang berlaku dalam sistem voltan tinggi sesar ke tanah sebagai langkah berjaga-jaga untuk mengelakkan fenomena kerosakan dalam sistem voltan tinggi. Tujuan utama penyelidikan ini adalah untuk memerhatikan menggunakan kamera berkelajuan tinggi bagi memerhatikan pembentukan pokok elektrik berkaitan dengan peningkatan bekalan voltan boleh menjadi pembentukan semak, cawangan, cabang belukar dan sebagainya. Projek ini akan dijalankan di Universiti Teknology Skudai, Malaysia (UTM) dan menjalankan hasilnya dengan menggunakan radas daripada Institut Voltan Dan Arus Tinggi (IVAT) lab UTM. Proses akan dijalankan untuk bekalan voltan lebih daripada 33kV disebabkan atas bantuan daripada Universiti Teknology Skudai, Malaysia (UTM) dan radas-radas dari lab Institut Voltan Dan Arus Tinggi (IVAT). Projek ini perlu menggunakan Choronos 1.4 High speed camera untuk rekod pembentukan pokok elektrik. Penebat seramik KN120 dari High Voltage UTeM juga akan digunakan untuk permerhatian cara pembentukan pokok elektrik. Pemerhatian jarak akan dijalankan dalam halangan sekitar 2 hingga 5 meter di dalam sangkar keselamatan. Ujian ini akan menganalisis masa yang terpaksa berlaku kerana pecahnya berlaku disebabkan oleh peningkatan voltan tinggi yang terjejas oleh peningkatan gerakan rel berkelajuan tinggi.

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$\boldsymbol{Emax}$	-	Electric field
$\boldsymbol{r}$	-	weighted mean average of tip radius of curvature of the needle electrode
$\boldsymbol{\alpha}$	-	Townsend ionization coefficient
$\boldsymbol{N}$	-	Negative ions in the avalanche
$\boldsymbol{U}$	-	Applied Voltage magnitude
$\boldsymbol{x}$	-	Distance from avalanche starting point
$\boldsymbol{d}$	-	Insulation thickness from the needle tip to the center
$\boldsymbol{Lm}$	-	Maximum or final tree branch length
τe	-	Time constant
$\boldsymbol{L(t)}$	-	Tree length growth
$\boldsymbol{Tm}$	-	Total bond energy of the molecules
$\boldsymbol{t\text{-}t1}$	-	Period followed the inception at t1
$\boldsymbol{Tc}$	-	Breaking produce free carbon

LIST OF ABBREVIATIONS

UTeM	-	Universiti Teknikal Melaka Malaysia
FTK	-	Fakulti Teknologi Kejuruteraan
PD	-	Partial Discharge
UTM	-	Universiti Teknology Skudai Malaysia
IVAT	-	Institut Voltan Dan Arus Tinggi
	-	

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CHAPTER 1

INTRODUCTION

1.1 Background

An insulator's solid non-conducting constituent is known to exhibit electrical treeing, a physical dielectric phenomena. On the either, it is also well recognised that electrical treeing, which occurs in solid insulation before failure due to partial discharges in high voltage engineering, is a phenomena. Failure of high voltage insulation systems is frequently caused by electrical treeing. The insulator's dielectric stress causes electrical treeing. Figure 1.1 depicts the development of electrical treeing, which is one of the pathways to failure in polymeric cable insulation because it causes material breakdown in areas of higher electric stress, such voids, protrusions, and water trees. Due to a high electrical field during a breakdown, there is electrical treeing.The encouragement or repulsion of one electric charge by another at any location is quantified as an electric field. the appositive charge's proximity to the charge vector and the amount of force applied therein in relation to that charge. As a result, the strength of the electric field is derived from electric charge. According to Farr et al. (2001), it is hypothesised that tree development occurs along an active, conductive tree channel with a local growth probability that is correlated with electric field strength. In a high voltage system with an insulator, electrical tree growth is a sign of impending electrical breakdown. As a result, the electrical tree growth was split into three stages: beginning stage, intermediate stage, and pre-breakdown stage. Furthermore, electrical treeing growth is classified into two different types: Vented Type and Bow-tie Type trees. Vented Type trees are more frequently found than a Bow-tie Type trees and are also more dangerous compare with it. Vented trees are classified into three types which is Branch Type, Bush Type, andBush-branch Type (Malik et al 2005).

Figure 1.1 Branch Type, Bush Type, andBush-branch Type (Malik et al 2005)

According to (Bao et al. 2011), the Electrical Treeing tree structure characteristics shown in Figure 1.2 include distribution and transformation character. Furthermore, voltage injection, frequency, and pin-plane spacing will all have an effect on tree structure characteristics. The development of tree structures is frequently influenced by local electric field and frequency. Electrical tree propagation characteristics are sensitive and affective with too many elements in polymer. An injection of stress voltage and frequency can impact the pace of development and the structure of treeing creation because frequency accelerates the growth process whenever the number of gas discharges increases but has no effect on the type of the discharge. In other words, the applied voltage determines the amplitude of the local electric field at the tip of the discharge columns. The applied voltage has a direct influence on the geometry of electrical trees.

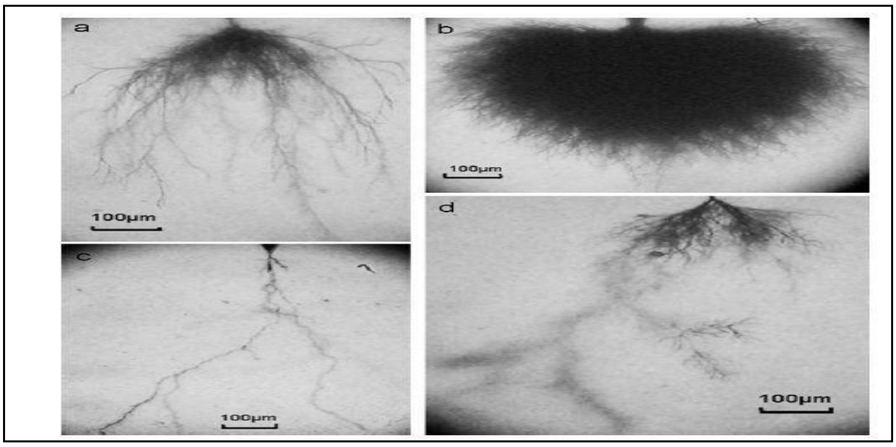

Figure 1.2 Electrical Treeing with different structure adapted from (Bao et al. 2011)

Suspension Disc Insulator Ceramic Insulator, as seen in Figure 1.3, are generally implemented in power systems to provide electrical insulation and mechanically support for high-voltage transmission lines. These insulators are subjected to a variety of stresses, including mechanical, electrical and environmental. These stresses act in unison. The exact nature and magnitude of these stresses vary significantly and depends on insulator design, application and its location. Due to various reasons the insulator disc can lose its electrical insulation properties without any noticeable mechanical failure. Such a condition while difficult to recognize, can enhance the stress on remaining healthy insulator discs in the string further may lead to a flashover. To understand the stress enhancement due to faulty discs in a string, attempt has been made to simulate the potential and electric field profiles for various disc insulators presently used in the country. The results of potential and electric filed stress obtained for normal and strings with faulty insulator discs are presented(Kumar and Satish et al 2012.

Figure 1.3Suspension Disc Insulator Ceramic Insulator adapted from (https://www.powertelcom.com/electrical-insulator/suspension-insulator/https://www.tciinsulator.com/home/productdetail/Porcelain-Disc-Insulator_74.html)

Minimal of level electrical stress and a certain time that can contribute to the onset of electrical treeing are characterized as the initial infection following voltage application. During the experimental period, charge carriers travel back and forth among the electrodes and the dielectric stress. This repetitive courier charge is the main cause of the onset of electrical tress. After going through the electrical treeing process, measurable partial discharge will trigger tree growth and finally dielectric collapse. Trees can sometimes be initiated and propagated by contaminated particles or cavities (Malik et al. 2005). The partial discharge that occurs in dry dielectric isolates this contaminating particle from the surface of the insulation and void.

Formation of vented trees are apparent, and their visual appearance varies widely based to the situation whereby a initiation and growth are monitored using a high-speed camera. Formation Vented tree development begins at an electrode interface on the inner or outer surface of the insulation layer, with a contact between the insulation and its semi-conductive layer. The growth of bow-tie trees is symmetrical with the nucleus and extends in both necessarily involve to the electric field. Furthermore, these bow-tie tree growths are caused by a lack of unrestricted air supply to sustain partial discharge and progress the tiny filamentary way. The development of bow-tie trees could be seen to be sporadic. These apparent discharges alternate with extended periods of extinction. (Malik et al. 2005). Extinction is the result of increasing void stress caused by ionisation in the void. Whereas the transmission of electrical treeing branches occurs related to the existence of electrical discharge, light phenomena are also a factor that supports them. (Laurent and Mayoux 1980).

Ceramic outdoor insulators also play an important role in electrical insulation and mechanical support because of good chemical and thermal stability, which have been widely used in power systems. However, the brittleness and surface discharge of ceramic material greatly limit the application of ceramic insulators. From the perspective of sintering technology, flash sintering technology is used to improve the performance of ceramic insulators. In this paper, the simulation model of producing the ceramic insulator by the flash sintering technology was set up. Material Studio was used to study the influence of electric field intensity and temperature on the alumina unit cell. COMSOL was used to study the influence of electric field intensity and current density on sintering speed, density and grain size. Obtained results showed that under high temperature and high voltage, the volume of the unit cell becomes smaller and the atoms are arranged more closely. The increase of current density can result in higher ceramic density and larger grain size. With the electric field intensity increasing, incubation time shows a decreasing tendency and energy consumption is reduced. Ceramic insulators with a higher uniform structure and a smaller grain size can show better dielectric performance and higher flashover voltage.High-speed cameras will be used to help and support researchers in the fields of high- speed aerodynamics, ballistics, and other high-speed phenomena. Taking pictures at rapid speeds do not need the use of film that travels intermittently. Due to the split and when accelerating to the right speed, the magazine cannot provide film in extremely high speed situations

Electrical tracking is defined as partial breakdown in any gas mixture and the interaction of vacuum with solid and liquid dielectrics, which can result in the formation of a conducting path due to various factors such as humidity, pollution, local voltage increment, and ice load, which might affect the dielectric surface. As a result, estimating the insulator's lifespan is challenging. As a result, the presence of surface discharge on an organic solid insulator is the main source of failure in high voltage systems (İbrahim Gü neş 2015). In other words, the interaction of a high tangential component of an electric field along a diagonal with a solid, liquid, or gaseous medium causes surface partial breakdown.

Organic insulating materials have gained wide acceptance for use as electrical insulation in high voltage electrical appliances. As a result, surface tracking breakdown of an organic insulating material is a serious concern that can have a significant impact on the safety and reliability of an electrical appliance when it exceeds high local temperatures caused by discharge, which causes carbonization on the surface of organic insulating materials until breakdown(Yoshimura et al. 1981). Surface discharge occurs when the field component located at the surface exceeds the medium of electric strength caused by a conducting layer over the surface of the dielectric due to an obstruction of the creepage current channel. Others, such as creepage currents through the conducting film, cause mechanism interruptions that are influenced by discharge operations. The tracking phenomena changes with the strength of the field, the strength of the current, and the conditions of discharges on the surface caused by wet surfaces, which are connected to the degree of contamination. Contaminants that can cause breakdown include salt content, dust particles, and humidity that react with air chemical agents. (Yoshimura and Kumagai et al. 1997).

Fault is important in power system analysis and is categorized into three types: phase balanced fault, unbalanced fault, and fault detection and fault diagnosis for improving reliability, safety, and efficiency in technical processes such as aircraft, trains, motorcars, power plants, and chemical plants in order to maintain operation and prevent damage or an accident (Isermann et al. 2009). Unbalance faults are classified as phase to ground, phase to phase, or double phase to ground. In order to determine the rating of protective switchgear, the fault current will be calculated by comparing the internal impedance of the generator to the impedance of the intervening circuit. In a fault, generator behaviour is split into three phases sub-transient, transient, and steady state.

1.2 Problem Statement

Although electrical treeing and tracking are the primary causes of electrical breakdown that can lead to failure in high voltage insulation systems, the initiation and spread of electrical tree growth is the primary issue that can lead to high voltage system failure. Several prior researches acknowledged the characteristic structure, and determined that it appeared in a variety of forms. Lightning is not only spectacular, but also dangerous. Every year, over 2,000 people are killed worldwide by lightning. Hundreds more survive but suffer with variety of lasting symptoms such as memory loss, dizziness, weakness, numbness, and other life-altering ailments. Strikes might cause in cardiac arrest and serious burns, although nine out of 10 victims survive. In a lifetime, the average people have a 1 in 5,000 chance of getting hit by lightning. The most life-threatening trees frequently result from vented-type trees. In order to enhance reliability, safety, and technical method, surface discharge was also a factor that influenced breakdown 9 phenomena caused by pollution, humidity, and an enhancement in local voltage. Such issues may result in a disruption in operation as a result of damage or an accident. As a result, the character and shape of treeing and tracking are essential in preventing the first sign of breakdown and identifying which type of treeing. As a result, a high-speed camera will be utilised to record the character of the tree's development and form. Although high-speed cameras are expensive, they must be secured and the distance among them and the sample must be restricted. Capturing the formation of an electrical tree is difficult because it requires a reasonable resolution to provide a better defined resolution of the tree structure. Otherwise, the applied voltage and time elapsed for the breakdown will be recorded in order to capture the shape of the electrical treeing and tracking.

Furthermore, electrical treeing tests will be conducted through high voltage injection, high speedcamera will be used to capture the character of tree growth and how's the shape is form in different voltage injection. Otherwise, the applied voltage and the time elapsed for the breakdown will be collected to capture the shape of electrical treeing and tracking.

1.3 Problem Objective

The objective is the purpose at the end of the project. In this part gives a brief explanation about the purpose.

There are three main objectives of this project:

i) To observe the shape and the way of electrical treeing type that most dangerous and frequently occur can cause breakdown in line to ground fault due to the lengthof electrical tree growth and whether the breakdown form from ground to neutral.

ii) To conduct a tracking test for contamination that triggers an electrical surface discharge due to a line breakdown to a ground fault for distribution system protection.

iii) To investigate the time elapsed and applied voltage waveform due to the existence of discharge that might cause electrical breakdown in line to ground fault for distribution system protection.

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1.4 Scope of Project

Since the apparatus in High Voltage Lab in UTeM is has been spoiled by the unexpected flood in last semester, my supervisor: TS. Dr. Zikri decided to bring us heading to UniversitiTeknology Skudai, Malaysia (UTM) and trying his effort to conduct the exact result by usingapparatus from Institut Voltan Dan Arus Tinggi (IVAT) lab from UTM. In order, surface discharge alsoone of the factor that affected breakdown phenomena to conduct due to the contamination, humidity and increase in local voltage for the improvement in reliability, safety and technical process. Such problems might cause interruption in operation due to the damage or an accident. Therefore, the character and shape of treeing and tracking is very important to prevent the initiation of breakdown in order to determine the type of treeing. So, high speedcamera will be used to capture the character of tree growth and how's the shape is form in different voltage injection. Otherwise, the applied voltage and the time elapsed for the breakdown will be collected to capture the shape of electrical treeing and tracking. Since the cooper film as conductor in IVAT is oxidized. Hence, electrical treeing test will be conductvia injection of high voltage but it cannot higher than 100kV due to constrain of the apparatusfrom high voltage lab in UTM and be done in IVAT at UTM. Therefore, high voltage testing needs to use a suitable insulator material those lower than 100kV.

In this project, kit for high voltage in Faculty of Engineering Technology from Universiti Teknology Malaysia will be combined with high speed camerato determine the presence of discharge due to the electrical breakdown in line to ground fault for protection in distribution system in IVAT, UTM. Test will conduct with a suitable voltage from 11kV to 46kV using ceramic insulator KN120 as a suitable insulator which acts as a cloud for the voltage supply under 100kVdue to the constrain of equipment in High Voltage Lab using high voltage kit owned by UTeM and IVAT at UTM. This project will use Choronos 1.4 High speed camera determine the presence of discharge due to the electrical breakdown in line to ground fault for protection in distribution system and broadband electric field measurement. The distance of observation for high speed camera will be limited at the distance of 2 to 5 meters inside the safety cage. The resolution of highspeed camera will be set up to 5000 frame per second (fps) for the duration of 2 seconds. The breakdown voltage will be recorded with resolution from 800 to 1000 ns (10 to 20 MS/s)for 2 seconds duration. The electric field breakdown will be recorded by using high defination of transient recorder (Lecroy HDO4024). The external channel from high speed camera will be used as triggering channel since the propagation of light is greater than the radiowave. Apps Filmora will use as determine each frame from the capture of high-speed camera.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In the literature review, it will cover the formation of electrical treeing and electrical treeing due to its classification, in addition to the formation shape of treeing with unique features that tend to happen in similar research. This involves the beginning and propagation of electrical treeing as a result of applied voltage. Likewise, it discusses the contamination that might result in electrical tracking phenomena. These two phenomena could result in a breakdown. Even though this research is about detecting faults in the clouds, an explanation of faults and ceramic insulators is included. Several high-speed camera discussions are also given.

2.2 Electrical Treeing

Through Boxue (2018) the electrical tree inception process is associated with the formation of low-density region, where the chain scissions are more easily to occur when charge carriers are accelerated by electric field to gain sufficient kinetic energies. The charge carriers are either injected from the needle tip or excited via an Auger-type process when non-radiative transition of energy is occurred by trapping and recombination of charge carriers. In the research, there is no observed electrical tree structure as the pulse voltage is less than 15 kV in 60 minutes. Almost all the samples are observed electrical tree structure in less than 1 minute with the pulse voltage of 20 kV. The electrical trees are quickly gone to breakdown when the pulse voltage reaches 30 kV. Therefore, the pulse voltage of 17 kV is chosen to investigate tree inception probability, 20 and 25 kV are selected to clarify the electrical tree propagation tendency. The tree inception probability tendency tested with negative voltage is similar to the positive voltage one except a smaller value. The electrical tree propagation period consists of tree extension and trunk widening by erosion due to partial discharge attack in tree channels. When the electrical tree is propagated under negative pulse voltage, the injected charges from the needle tip or hot electrons excited via an Auger-type process are captured by electron-type traps. The hot electrons or injected charges are easier to be captured during the electrical tree propagation process. Thus, electrical tree is more difficult to propagate as negative voltage is applied on the sample than the positive voltage. The experimental system consists of a power source system to trigger the electrical tree, an image processing system to capture the image during the electrical treeing process. Power source system is a high voltage generator, which can provide repetitive pulse voltage with pulse amplitude ranging from 0 to 30 kV. The pulse frequency is 200 Hz in the experiment. In conclusion, the deeper trapped charge level and larger trapped charge density can modulate charge carrier transport, which are benefit to restrain electrical tree propagation and improve the lifetime of polymer dielectrics. According to several research (Alapati and Thomas 2009), electrical treeing is a long-term breakdown process of polymeric insulation caused by sustained stress in an electric field. Electrical treeing is a phenomenon that could also cause electrical failure by causing athin erosion channel to form from an area of electrical stress in the insulation caused by a partial discharge. It will cause insulating material failure owing to the tree channel contactingthe opposing electrode, a phenomenon is known as treeing.

Electrical treeing is classified as an electrical pre-breakdown phenomena caused by damage to a solid dielectric. This phenomenon is known as treeing because it progresses under electrical stress in a severely non-uniform field and seems to be tree propagation. Electrical treeing can occur swiftly owing to partial breakdown in the presence of applied voltage, but it can grow slowly whenmoisture is present. Electrical treeing coupled with an AC impulse voltage will normally occur under high DC pressures (Ravindra and Wolfgang 2011). As a result, electrical treeing of the involvement of water, moisture, chemical environment, and pollution as a foreign particle in the formation of breakdown, electrical treeing might be more pleasant.

2.3 Electrical Treeing Initiation

Due to the electrical breakdown in polymeric materials, electrical treeing is one of the primary causes. Due to a large dissimilarity of electrical stress leakage at metallic or semiconducting as well as gaps produced by the form of partial discharge in the dry dielectric, electrical treeing phenomena are reported and starting to spread. Such a tree consists of empty channels created by the permanent partial discharge, which will causes the dielectric material going to breakdown. The situation during the construction of the tree give birth to a remarkable variety of channel shapes. Electrical treeing starts because of a contaminant and particle called a cavity that is separated on the surface of the insulator, as shown in Figure 2.1. (Malik et al. 2006) Early breakdown detection may detect such setbacks, and receiving a preventative steps makes it possible to increase the dependability and activity of the control framework. Electrical tree action is tightly linked to the injection of ions into the polymer caused by a high field cathode or by gas emissions in an empty space (Dissado 2001).

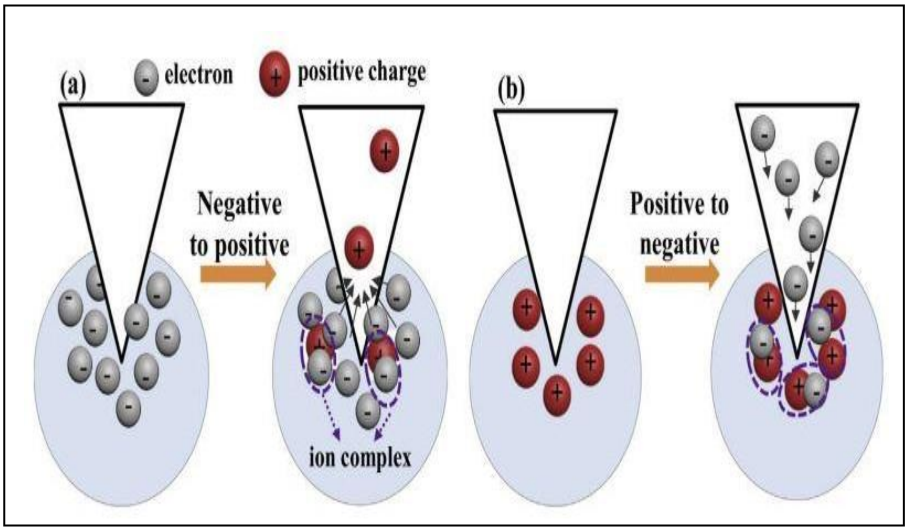


Figure 2.1 Electrical tree starting under polarity-reversal voltage transfer adapted from (Yunxiao et al. 2017)

According to (T. Tanaka et al. 2006), electrical treeing is divided into three stages, which include an incubation time, an initiation period, and a growth or propagation period. Once the incubation time is through, tree starts appear in high or small fields. The former process happens as a result of long-term tree initiation, but the former process is caused by it. In order to start a partial discharge in a micrometre or sub-micrometer range where the cavies are located at the needle tip, a number of mechanisms known as enormous stress created in a stress concentration are responsible for the beginning of an electrical tree. Comparative start tree architectures have shown that the start mechanism is the same for many types of electrical trees. While their final forms are uncommon, the majority of the beginning tree formations are branch-like. Investigations into electrical treeing use various definitions for the beginning stage.

The most common defining technique is based on the length of the electrical tree, which describes how things start off and how long it takes for things to progress after that (Bao et al. 2012). Because of the effect of the microstructure close to the needle tip, the beginning of the electrical tree is more likely when the voltage is low. The initiation and propagation of an electrical tree are more difficult when the needle tip of a high voltage electrode is within a large crystal as opposed to when it is at a weak section of the crystal's boundary, according to these studies.

An initiatory electron can be produced by natural radiation in large-sized cavities, according to several prior research. When electrical treeing is initiated, the producedmagnitude discharge will be insufficient. Natural radiation, changes in cavity density, and size distribution are a few of the factors that might cause electrical treeing to begin. Small cavities that experience partial discharge can quickly erode the insulation, creating adischarge channel that terminates at the needle tip and takes the form of an electrical tree (Densley 1979).

2.3.1 Partial Discharge in Electrical Treeing

The part of the gap between two conducting elements acts as a bridge, causing partial discharge, or discharge phenomenon. This is because partial discharges often dissipate as heat as a result of an insulating system overheat. This happens when the insulation's ozone layer is attacked, causing a crack in combination with chemical breakdown, which may lead to an increase in the void of electrical conductivity as a result of the deterioration of the insulating material. Due to an electrical stress beyond the critical value caused by a combination of high electrical stress and an explosion off an electric field, ionisation in a small area will cause the insulation to be released.

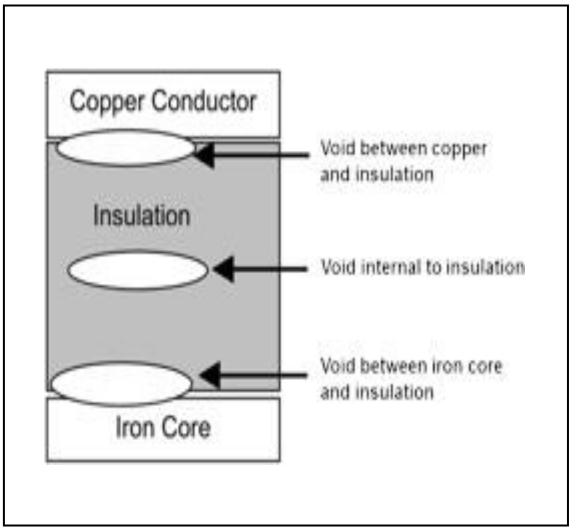


Figure 2.2 Electrical tree starting Partial Discharge in copper conductor adapted from (https://electrominst.com/test-technology/partial-discharge-test/partial-discharge-bad/)

Due to its beginning and propagation as a vital instrument to determine the characterisation for defection in an insulator, partial discharge is a significant process as for detection of electrical treeing. It is possible to manage individual partial discharge circulations and reject the entire disturbance when they are produced by different partial discharge sources that are dynamic in nature. It is also the primary source of insulator deterioration in insulating cables with low density, which can result in breakdown phenomena in an electrical system brought on by electrical treeing Around the needle tip, there is a lot of pressure on cavities to form and spread. The entire tree structure doesn't always need to be covered by integrated light emission at once. With variations in tree form, the percentage of the tree discharging changes (Dissado 2001). Electrical tree growth can result from local intrinsic breakdown at cavity extremities as a result of partial discharge, which can happen immediately after high voltage is applied. This phenomenon is heavily impacted by the partial discharge, which is referred to as an electrical phenomenon because it occurs in conjunction with electrical treeing and partial discharge (PD), which is the development of the tree (Suwarno et al. 1996)

By injecting electrons into the insulation from the needle electrode in a negative high cycle condition, electron bombardment can result in the generation of cavities, while during a positive high cycle, the electron will return to the electrode and cause the electron to become trapped in the insulation. This is in accordance with earlier research by (Densley 1979). From this, the electron can accelerate owing to the applied electric field, which can result in an elastic collision. This electron can also be injected and trapped. No considerable amount of energy will be lost by this electron. In order for a polymer to obtain enough energy, an energetic or hot electron must ionise it. Chain scissions will be present as hot electrons are ionised. The beginning and development of tree channels are greatly influenced by trapped charges, and treeing by partial discharge is a plausible theory. One of the most encouraging methods for determining electrical protection is partial discharge (PD) calculations (Yang and Zhang 2006).

The partial discharge phenomena won't always result in the insulating system failing. Previous studies have shown that internal partial discharge may sustain some insulating systems for an extended period of time without electrical treeing. The internal cavities have reached or beyond a particular level, which might cause the partial discharge phenomenon to happen quickly. When the voltage is increased, the partial discharge quickly increases (Densley 1979). The onset of ionisation in small gaps or blocked voids is dependent on the availability of a free electron within the shielding material. The growth of electrons as a torrential slide within the quality of the pit or short hole is known as discharge propagation. The concept of nonconductive dividers also has an influence on the final event.

It is challenging to visually identify the Partial Discharge pulse associated with these tiny volume voids or gaps (Mayoux and Laurent 1995). When partial discharge is formed during tree growth and tree commencement is present, the degradation rate is often greater. Due to the weakening phenomena, the likelihood of a breakdown in this circumstance is increased. Early diagnosis is therefore crucial when a breakdown occurs quickly. This definition showed that the partial discharge caused by the cavity from the internal discharge caused the electrical tree to commence (Cavallini et al. 2004).

According to prior study, a single or two partial discharge pulses will occur during tree start. These will also have an impact on the quantity and cost of positive and negative cycles, with positive cycles having a somewhat higher quantity and cost than negative cycles. In contrast to the growth of the tree, the number and charge of the negative cycle is greater than that of the positive cycle because the length of the discharge channel was dispersed across a wide range. Since the distribution of discharge path length and partial discharge amplitude are correlated, this will have an impact on the partial discharge's broad distribution (Suwarno et al. 1996).

2.3.1.1 Electrical Treeing of Mechanical Strain

Due to the application of mechanical and internal strain, which can result in extended exposure to internal electrostatic forces and the creation of micro-voids where partial discharges might occur, electrical treeing that can lead to failure occurs. The strong electric field that surrounds the stress concentration can cause mechanical strain. These can induce compression and fatigue of the insulation subjected to the Maxwell Strain by resulting in the creation of stress fractures from pre-existing flaws or micro-cavities. When there is partial discharge within the cracks, there is a concentrated electric field at their edges. This can cause local intrinsic breakdowns, which cause the cracks to widen and lead to the construction of electrical trees (Densley 1979).

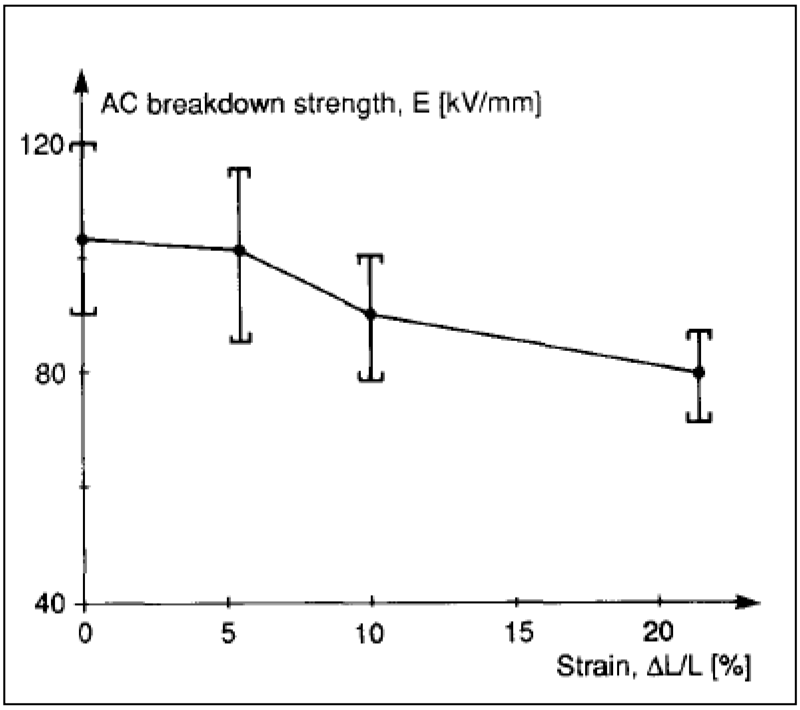


Figure 2.3 Effect of mechanical strain in AC breakdown strength adapted from (Ildstad 1992).

According to (E. Ildstad 1992) defines strain as an elongation route that is split by the starting portion of the sample, as shown in Figures 2.4 and 2.5 of a hydraulic press. A mechanical press will be used to mechanically push sphere-shaped steel into the test item. 90% of breakdown events are said to take place in the object's stress zone, whereas the remaining 10% are said to happen on similar surface territory nearby that is not in the object's stress zone. In AC breakdown strength, mechanical strain is shown to have an impact in Figure 2.3 .

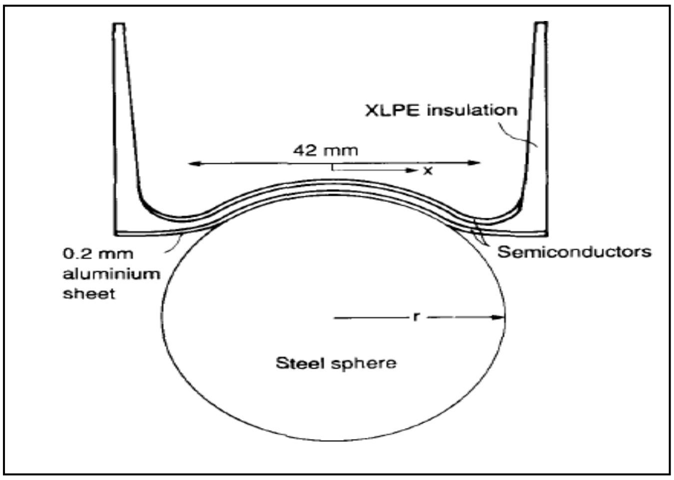


Figure 2.4 Mechanical stress using Rogowski type test adapted from

(Ildstad 1992).

The breakdown locations in cases of samples without strain were haphazardly scattered around the object's energised portion. Lessening the short-term AC breakdown quality is the effect of increasing the mechanical strain. Decreased time to breakdown results as a result of increasing mechanical strain.

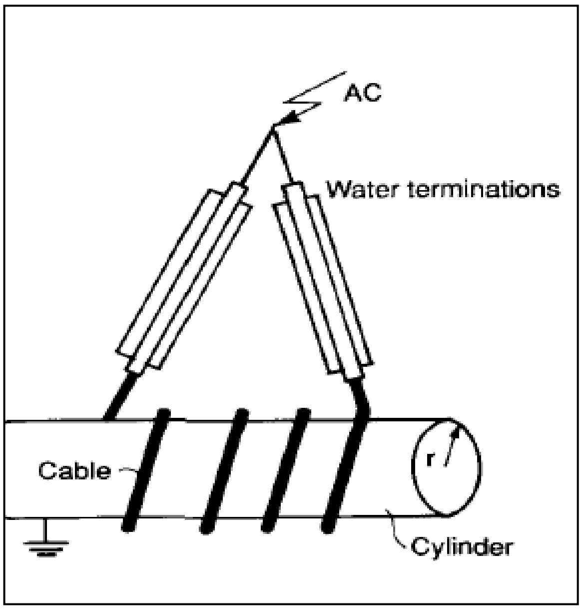


Figure 2.5 Mechanical stress test of cable sample adapted from

(Ildstad1992)

2.3.1.2 Electrical Treeing of Mechanical Strain

Generally at least, during tree commencement of AC, formation field distortion is the dominant actor. Electron-induced voltage may increase tree inception voltage by causing the quantity and/or charge of electrons in a high field to decrease (Densley, 1979). Due to polarity reversal and the presence of stressing voltage, electrical treeing will initiate quickly under negative voltage to positive voltage. This probability of tree initiation during electric stress will be possible to occur in conjunction with electrical treeing shape distribution, as shown in Figure 2.6. (Yunxhiao et al. 2017). Electrical trees begin to form when partial discharge is present in a gas vacuum or gas crack, or when a strong electric field causes degradation.

Generally at least, during tree commencement of AC, formation field distortion is the dominant actor. Electron-induced voltage may increase tree inception voltage by causingthe quantity and/or charge of electrons in a high field to decrease (Densley, 1979). Due to polarity reversal and the presence of stressing voltage, electrical treeing will initiate quicklyunder negative voltage to positive voltage. This probability of tree initiation during electricstress will be possible to occur in conjunction with electrical treeing shape distribution, as shown in Figure 2.6. (Yunxhiao et al. 2017). Electrical trees begin to form when partial discharge is present in a gas vacuum or gas crack, or when a strong electric field causes degradation if under electrical stress, contaminants are impacted. The beginning of electrical trees dispersing, as it were happening precisely when the voltage decreases. The beginning time's diffusing lowers as voltage increases. This may be due to the fact that the effects of material microstructure at the needle tip on the commencement of electrical trees are larger precisely after the voltage is decreased (Bao et al. 2012).

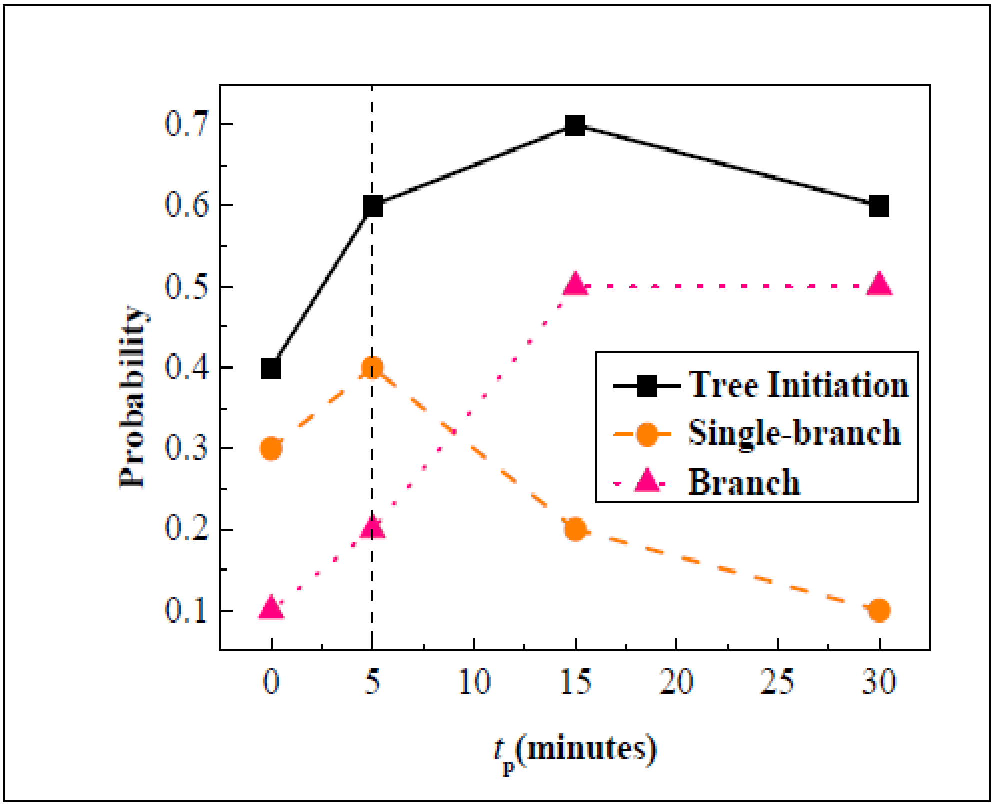


Figure 2.6 Probability tree start and form distribution under various stress voltages adapt from (Yunxiao et al. 2017)

According to earlier studies by (Sarathi et al. 2012), the dimension and shape of the malformation will affects to the the local electric field, which changes the morphology of the tree and its mechanism of propagation. Electrical tree generation happens as a result of applied voltage magnitude determination. Electric stress can cause failure or pre-breakdown if the magnitude of the intrinsic type is wider; alternatively, if the magnitude of the electric stress is lower, no branches will appear in the insulating formation. The electric field (Emax) at the needle's tip may be determined as follows.

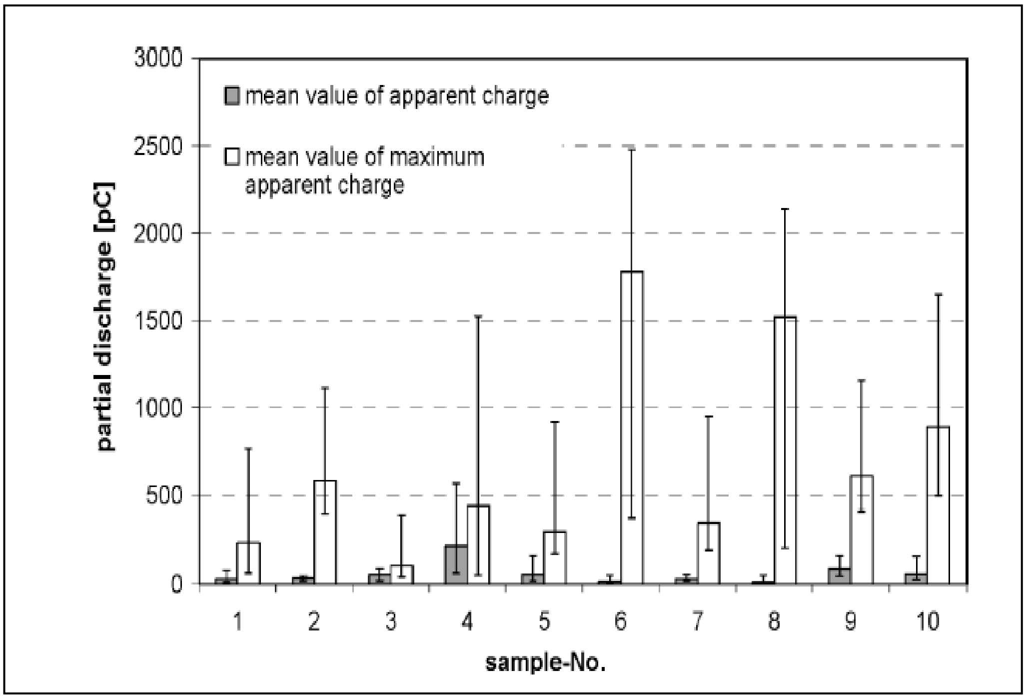
$$Emax = \frac{2\,Ud}{r\ln(1+\frac{4d}{r})}$$

Emax= Electric field

r	=	weighted mean average of tip radius of curvature of the needle electrode
d	=	insulation thickness from the needle tip to the center conductor of the cable insulation
U	=	Applied Voltage magnitude

Figure 2.7 Electric field at the tip of needle electrode adapted from (Sarathiet al. 2012)

Before breakdown, an electrical tree will goes through three phases. These tree stages include the incubation stage, initiation stage, and propagation stages before breakdown happens as a result of insulation failure or insulator deterioration in high voltage cable insulation. Partial discharges that commence at the needle's tip trigger tree propagation processes to actually happen. Then, this mechanism will result in one or more than three channels, which may result in the three channels being subjected to excessive electric stress. As a result of the local intrinsic strength being surpassed in the volume at the tip due to the construction of these mechanisms, there will be a breakdown brought on by partial discharge from the tree growth. These processes commonly turn gaseous when insulation deteriorates. While both substance and the surrounding temperature have an effect on the composition of gases. Both the initiation and elimination voltages will be produced in this way. According to prior research, tree growth is caused by a change in the electric field caused by charges from a discharge becoming stored on the walls of the tree channel as the diameter of the tree channel increases under AC, DC, and voltage impulses. An increase in the electric field will arise from the decomposition of the resultant surface charge during the first half of an AC



voltage cycle. Discharges therefore happened sooner in the cycle (Densley 1979).

Figure 2.8 Partial Discharge at propagation tree channel adapted from (Vogelsang et al. 2005).

The presence of current heartbeats due to releases in a gas-filled tubule or channel iscommonly accepted as the pointer indicating the move from initiation to propagation (L. A. Dissado 2001). Due to this discharge that would inject surges into the polymer, the smallest size cavity will support partial discharge at the smallest cavity field. The proliferation of the electric tree would be well-ordered and result from a repetition of comparable harm-causingshapes. Discharge occurs at the channel tip when electrical trees begin to grow from the tipof the channel. Sometimes the discharge would end on the channel walls without any chargebeing injected. Therefore, a critical field level is required for continued propagation of discharge. A critical field level may not be reliable over the entire tree framework in the differing field geometry of electrical tree propagation due to differences in dischargemovement as the tree expands, with changes in local space charge fields attempting to dictate the discharge length and thereby its commitment to tree augmentation. Since the role of charge injection from conducting channel walls is the same as that of injection from a pointelectrode, the electrical tree's process produces an extension. The viability of high voltage cable insulation might be compromised by an increase in applied voltage since it could enhance tree growth (Ramanujam Sarathi, Arya Nandini and Michael Danikas 2011). By increasing the amount of partial discharges, the high voltage insulation cable's tree structurecan change, and electricaltree propagation can be utilised to identify this change (Vogelsanget al. 2005).

2.4 Electrical Treeing Shape

Due to areas of high electrical stress caused by structural imperfections, metallic asperities, or conducting impurities, electrical trees form. Various shapes can be taken by other electrical trees. Several categories will be created from this form., including:

- Bow-tie trees
- Branch trees
- Bush trees
- Branch-bush trees
- Branch-vine trees
- Branch-pine trees
- Vented trees
- Vine trees
- Tree-like tree or Fibrillar tree
- Radial

Vented trees are electrical trees that start out by growing in an electric direction toward the others. When the tree connects two electrodes, complete discharge and failure take place. Ithappens when there is an unrestricted air supply. They begin at the interface of one electrodeand move in the direction of the other electrode. Additionally, vented trees are made up of anetwork of linked hollow tubes, each of which acts as a vent for the system as a whole when it interacts with the environment outside. Due of the unrestricted air supply, they grow consistently. Typically, the amplitude of the applied voltage, the conductivity of the discharge channel, trapped charges in the discharge path, and the local electric causing the development of an electrical tree of the fibrillar, branch, or bush types (Sarathi 2015).

A Bow-Tie Tree is an electrical tree that is created in the insulation's body and has branches that are generally orientated along the field lines. It mainly comes from metallic contaminants or impurities and expands symmetrically away from the electrode. These treesshould be simple for others to avoid. Bowtie trees do not have access to an air supply, thus their development is erratic and they often do not grow long enough to link two electrodes and cause total failure. Comparing Vented Trees to Bow-Tie Trees, the former are more frequent and harmful. Based on the figure 2.8 below, the literature research (Paolo 2017) discovered that vented trees can be categorised into three types: branched type, bush-like type, and bush-branch type. Other, branches of the electrical tree plants have a variety of branching structures. In the tiny filamentary channels near the tip, a succession of channelswith diameters ranging from a few tens of micrometres to one micrometre are also responsible for the formation of branch trees (figure 2.8(b)). Bush-like trees have tightlypacked channels that give the structure the impression of a solid bush-like mass, whereas bush-branch trees have the same look as bush-like type trees but have branches that extend beyond the main bush-like type structure.

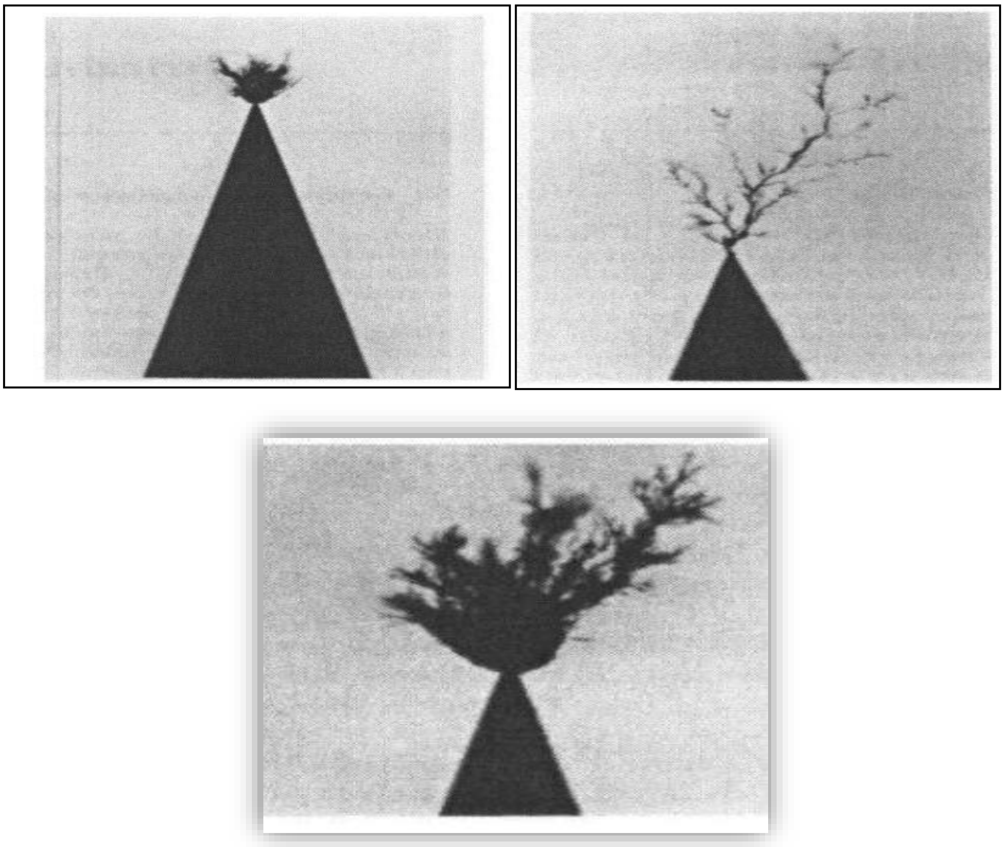


Figure 2.9 Bush-Branced Type

Because it is necessary to explain the concepts of fractal number and fractal structures in order to have a better understanding, these three categories are not entirely different from one another. Importantly, the dimension dt, also known as the fractal number, may be used to identify the failure generated by trees as shown by the tree shape. Consider the volume or mass of tree destruction *S(L)*, which is contained within the same cube of side *L*, to provide a definition of this quantity:

$$\mathbf{S(L)\ a\ Ldt} \qquad \mathbf{(1)}$$

Furthermore, an exponential law may be used to describe any object's dimension:

$$\mathbf{N(x) = N(0)}e^{\alpha x} \qquad \textbf{(2)}$$

Where:

N : Negative Ions in the alanvanche

x : Distance from alanvanche starting point

α : Townsend ionization coefficient

In addition, this formula expresses the quantity of ions pairs produced per unit length as a result of an electron switching from a cathode ion to an anode ion. The fractal number of a cube, or dt dimension, is 3. Additionally, being non-integer objects, fractals belong to a class of objects whose dimension is less than that of Euclidean space.

In other words, the form of an electrical tree may likewise be compared to a statistical fractal. Contrary to geometrical fractal, which are abstract structures demonstrating perfect scale invariance, statistical fractal does not demonstrate an accurate geometrical scalability. Additionally, properties of statistical fractals include the mass S(L), which exhibits scale invariance. Assume that the value "Fractal number" is dt, which may also be used to define the form of trees. For instance, branching type trees have a lower fractal number, dt more than2. (Paolo 2017).

The knowledge of electrical tree development in solids is studied in great detail in the body of extant research. By using fractal dimension, it is possible to distinguish between bush trees and trees with branches. As an illustration, the fractal dimensions of branching and bushed trees are $1< df < 2$ and $2 \leq df \geq 3$, respectively. The lengthening of the tree's fractal dimension results in a slowing of its rate of radial expansion, which lengthens the time it takes for it to cross the insulator. In Dissado (2001).

2.5 Vented Tree

Before cable insulation breaks down, vented trees are frequently observed in it; they are a result of the water treeing. These kinds of trees make clear the beginning of electrical treeing and the lowering of breakdown strength. When a high AC voltage supply is provided to an electrical high voltage system, a breakdown phenomenon known as a "vented tree" or "water tree" will started to breaks loose. In other words, in order to fully characterise the susceptibility of insulating material, vented trees required examination of their density and length of distribution in relation to the length of time they had to develop throughout the electrical treeing process (Dissado 1986).

The vented trees are described in many research (Skorepová Terézia 2013) as developing from the insulation material boundaries along the axis of electrical stress to the opposite side of the insulation. Mechanical tension or damage to the wire insulation that can start an electrical treeing phenomenon causes vented trees to form. In general, vented trees that are grown outside of insulation have branches that are spread out, whereas huge vented trees have distinct branches that also have a pencil-like appearance. Vented trees caused by water treeing are seen in Figure 2.9. When the slice of an old XLPE MV cable was heated, a vented water tree began to sprout from the conductor screen.

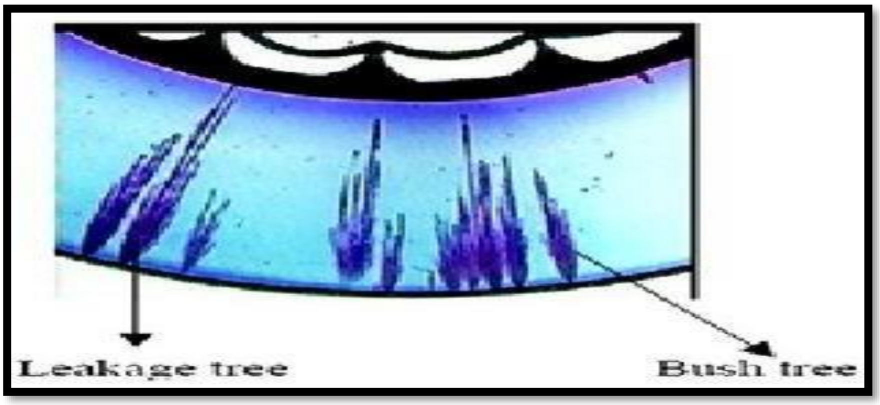


Figure 2.10 Example of vented trees in high voltage cable adapted from

(Skoršepová Terézia 2013)

In other words, there are porous structure in XLPE cables can develop and serve path for contaminants and corrosion products from the aluminium conductor initiating vented water trees in the conductor screen. It was found that a prerequisite for the formation of such structures due to the presence of liquids water at the interface between the conductor and causing corrosion in conductor screen. According to (Hallvard Faremo et al. 2012), porous channels are generated by an electrochemical reaction between the aluminium conductor and the semi-conductive layer under the influence of mechanical stress known as stress-induced electrochemical degradation (SIED). Since vented trees are initiated when microcracks or crazes at the semiconductor/insulation interface become filled with water field enhancement leads to mechanical stresses high enough can slice submerged in water. The prime source of water treeing in the field and a contributing cause in fault are vented trees (Chen 2015). Additionally, stress may lead to the beginning and spread of vented trees. Due to their larger lengths and more frequent appearances than bow-tie trees, vented trees also take longer to start than bow-tie trees (lldstad et al. 1990).

2.6 Mechanical Damage Theory in Vented Water Treeing

According to some mechanical fatigue theory, mechanical stress is a good indicator of mechanical damage in electrical wiring and can have an impact on the insulation due to water infiltration. This phenomena is brought on by environmental stress cracking, which may cause of the tree initiation and mechanical overstressing, or overgrowth of the tree. The onset and growth of trees are facilitated by polymer crazing, another crucial precursor. According to this fracture behaviour, cracking can occur at loads lower than those required to induce bulk shear yield (lldstad et al. 1990). The term "crazing" refers to a localised area of plastically deformed polymer that contains voids and polymer fibrils. Both of these precursors are brought about by a condensed water reaction coupled with mechanical and electrical.

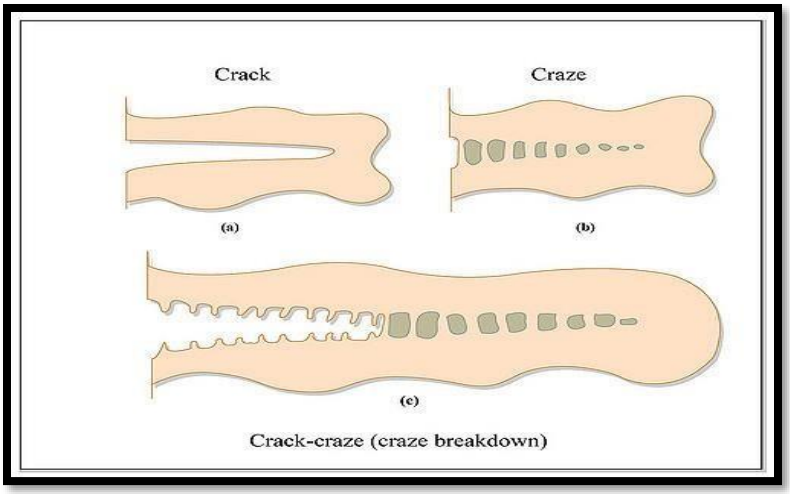


Figure 2.11 Cracking and crazing breakdown process adapted from (https://www.flickr.com/photos/mitopencourseware/3350795749)

Generating an electric field might cause the water-filled channel's tip to get crazy innew places (lldstad et al. 2015). When significant concentrations of mechanical stress form at certain locations within micro-voids, vented water stresses begin to form. Additionally, in order to lessen environmental stress-cracking, it is important to measure the molecular weight, anneal the material, and add copolymers. Enviromental stress-cracking is illustrated in figure 2.10 and is caused by liquid environments that can encourage the formation of cracks and crazing. Due to mechanical stress, the internal stresses experienced during the XLPE cable insulation production process may be rather severe. These stresses can affect both the tension and compression stresses. As a result, following the manufacturing process,crazes and micro-cracks appear in the insulation at the semiconducting interfaces, and the existence of the elongated zone of a curved cables, stresses might result in the creation of micro-voids (lldstad et al. 1990).

2.7 Initiation and tree growth of Vented Water Tree

The semiconducting screen has been sufficiently permeated by water to generate liquid water in the microcracks or crazes at the insulating surface, according to earlier study results, which explain why the Vented water treeing shown in figure 2.11 is encouraged. Due to the Maxwell stresses at the crack's tip in the applied AC voltage field, pulsating compressive stress acting perpendicular to the fracture surface arises. (lldstad 1990).

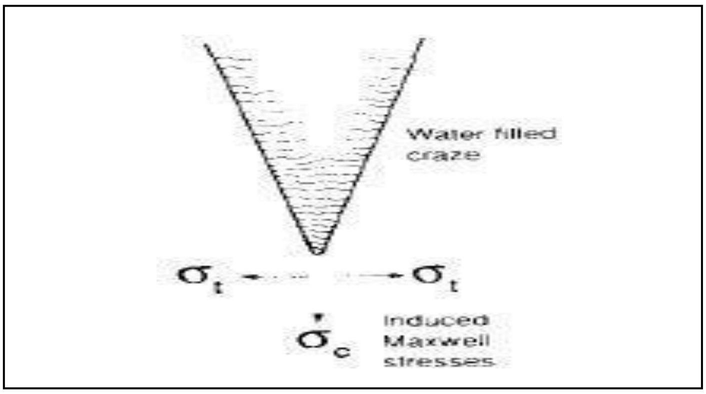


Figure 2.12 Mechanical model initiation and growth of vented tree adapted

from E lldstad (1990)

A crack cannot growth without the presence of tensile stresses character at the crack tip cause by driving force for the creation of new craze region that will affect the thintip of a conducting water filled crack or craze via the highly inhomogeneous field. Vented tree also initiate via the presenT stresses-cracking agent. As noted previously, water tree resistant insulation should have high to environmental stress -cracking or fracturing and increasing the applied electric stress is to strongly increase the number of water tree initiation sites.

2.8 Bow-tie Tree

Several researchers have noted that bow-tie tree is also type of electrical water treeingknown as initiation of insulation volume. These trees will growth in opposite direction alongthe electric field lines. Bow tie tree will reduced after a certain time. According to the previous research (Skoršepová Terézia 2013), the length of bow-tie trees is related to the size of the location containing the impurities. The restricted total length is almost never the origin of cable breakdown in bow-tie tree. Near surface insulation is one of the transformations of bow-tie tree where it is grow from insulation outwards towards the surface of the insulation in the direction of the electric field in both directions. These studies indicate that bow-tie trees have quicker initiatory growth compared to vented trees. Since the bow-tie tree not able to grow in large scale size, therefore the cannot cause large or serious insulation failure.

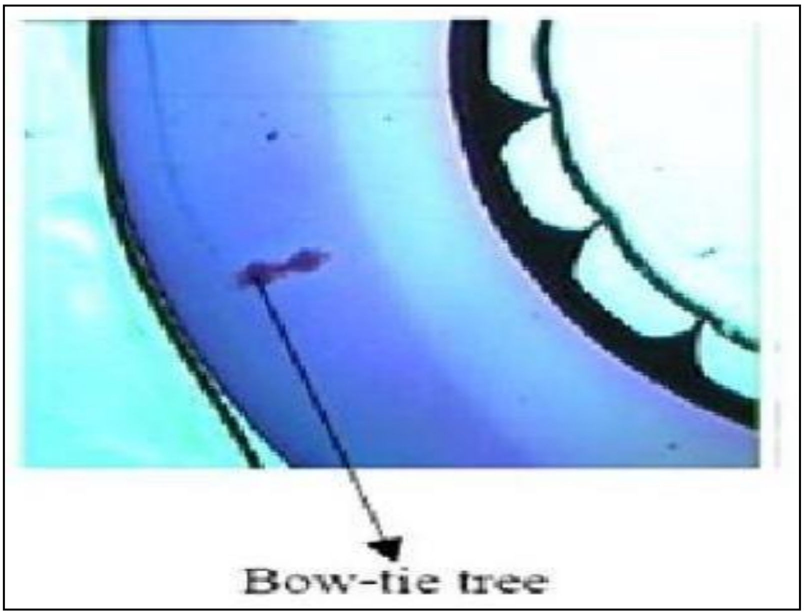


Figure 2.13 Formation of bow-tie tree adapted from

(Skoršepová Terézia 2013)

Top of that, Bow-tie trees are in central insulation and vented trees show on interface of insulation screen and insulation. Figure 2.12 show the formation of Bow-tie tree in central insulation. Several studies point out that bow-tie trees are the initiated in the bulk of insulating material that grows towards the conducting screens in figure 2.13 from a void and it grow symmetrically outwards from the electrode within the dielectric insulation. These type of tree consists of divergent straight branches radiating in opposite directions from a central point known as the initiating in the insulation volume and can grow in opposite directions, along the electrical field lines (Yanuar Z. Arief et al. 2015). Bow-tie tree are also generated from contaminant, such as metal, carbon, amber or void that can cause a deterioration factor of XLPE cable. Bow tie trees will contact the inner or outer semi-conductive shield and it considers slowing down the dielectric breakdown voltage.

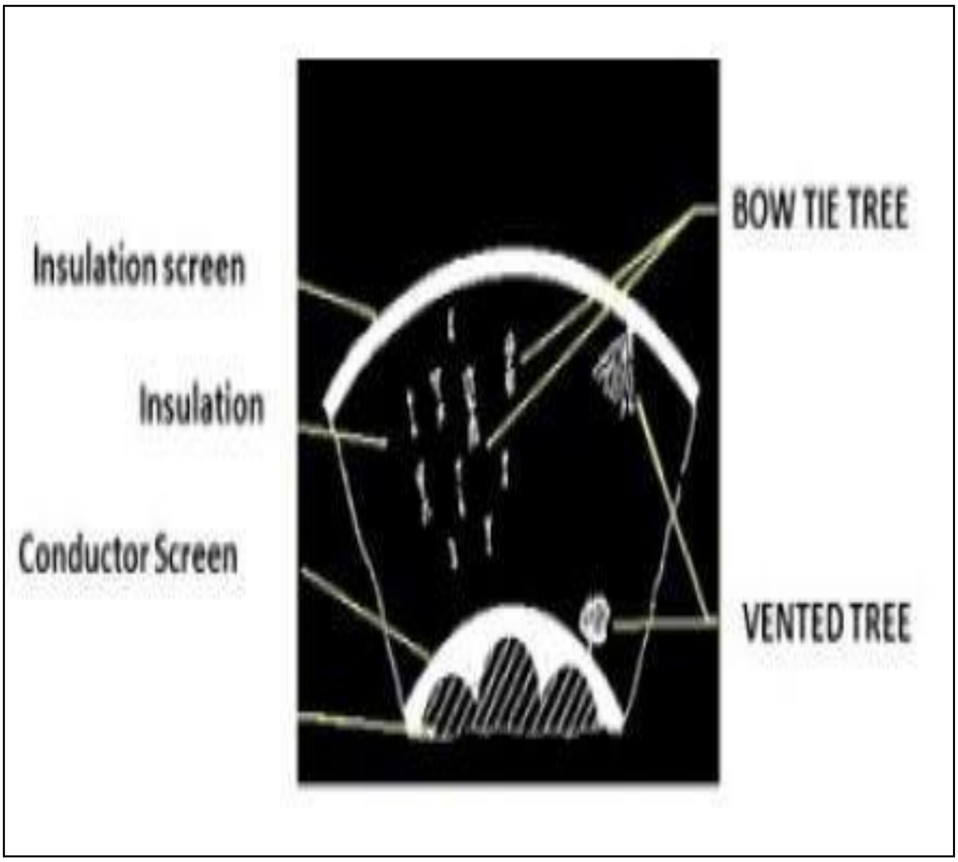
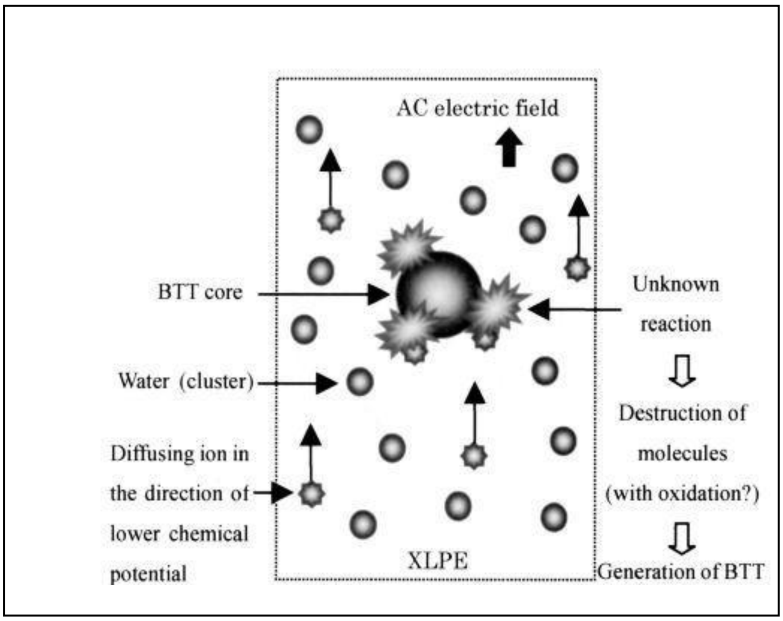


Figure 2.14 Differences between vented tree and bow-tie tree in High voltage cable adapted from (Skoršepová Terézia 2013)

These studies indicate that number of bow-tie trees increase rapidly due to the saturation of the water contents in cross-linked polyethylene (XLPE) and purpose water condensation and liquefaction where gaseous moisture existing in XLPE as saturated vapour condenses. It can liquefies on the periphery of contaminants concentrated with the electric field. As a result, a high-pressure jet that leads to molecular chain cleavage will produce due to the catalytic action of metal ions (contaminants) in XLPE oxidizes. Bow-tie type tree are affected by the oxidation stability and rigidity of the molecular linkage of the polymer that can reduce considerably by increasing the rigidity of polymer molecular linkage. According to (Takao Kumazawa 2009), Bow-tie tree are generated via the contaminant of metal, carbon, amber or void which is can cause deterioration in XLPE cable inside the bulk ofinsulator and related closely to moisture and ion diffusion.

2.8.1.1 ION DIFFUSION IN BOW-TIE TREE

Ion diffusion in figure 2.14 is caused by the presence of salt (ion) and water according to the chemical and physical process discovered in earlier study, which is found this to be the case (Sanniyati et al 2015). The diffusion profile of different compounds and ions varies. Additionally, bow-tie trees develop as a result of water and ion diffusion for the diffusion process connected to chemical or physical interactions. Thus, in contrast to water, ion diffusion plays a significant role in the development of bow tie trees. The results of several research conducted by (Takao Kumazawa et al. 2015) revealed that changes in water content had no impact on the growth of bow-tie trees because the production of compared to ion diffusion, contaminant ions and water diffusion have no direct or observable impact on the formation of bow-tie trees. Ion diffusion is also influenced by the electric field, ion mass and



radius, and by the ion. Water and cations act differently and appear to exhibit dehydration in the sample, although deionization does not, due to variations in the mechanisms of water diffusion and ion diffusion's chemical potential.

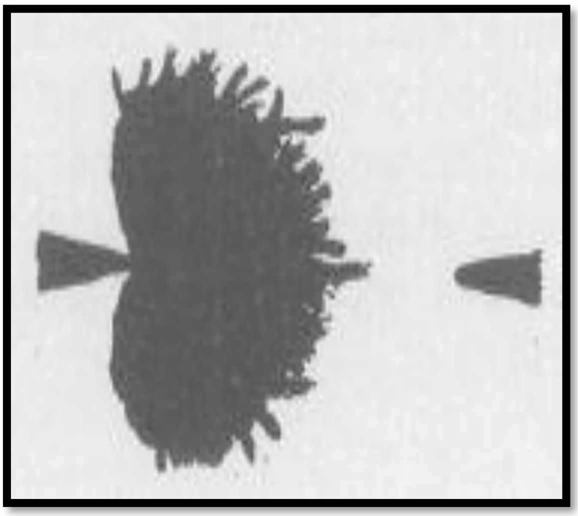
Figure 2.15 Ion diffusion in bow-tie tree adapted from

(Takao Kumazawa2015)

The motion of metal ions in water exhibits a strong connection with mass number and notable variations in the isotopic structure of key aspects. The study implies that unidentified processes involving metal ions exist. Unknown reactions are more likely to occur when metal ions travel in a direction rather than randomly, and this is due to their intense electric field-frequency oscillations. Bow-tie trees therefore need an inorganic pollutant called ionic diffusion maintained by the environment.

2.8.1.2 BUSH-LIKE TREE

Since there are three main types of vented trees—bush-like, branch-like, and bush branch-like trees—bush-like trees can be explained as being the most dangerous kind of electrical treeing because they are more likely to occur and take on the most dangerous shapes during the spread of electrical treeing breakdown than bow-tie trees. Numerous investigations have shown that light that is visible owing to the commencement of bush-like trees appears as a narrow section and that the discharge in Figure 2.15 captured when the whole tree region of the discharge channel approach the ground electrode produce total breakdown. The applied voltage that causes breakdown during the presence of discharge in



bush-tree type also affects the length of form. Others than that, the shape of these trees, develop when space charge dispersion with various types of material (Laurent and Mayoux 1980).

Figure 2.16 Bush-type discharge character adapted from

(Laurent and Mayoux 1980)

For usage as insulation material in XLPE cable, bush-type trees are often found at applied voltages of 16 kV (kilo Volts) and 50 Hz (Hz). Additionally, these tree shapes existat lower harmonic voltages with various THDs (THDs). Electrical bush-type trees are also present at high frequencies, and as the frequency rises, so does the breadth of the breakdownchannel. In other words, the existence of form during the growth of electrical trees is significantly influenced by the applied voltage profile (Sarathi et al. 2015). High applied voltage can also result in the formation of bushes (Sarathi and Nandini 2012). According toearlier study, a bush-type tree can withstand a high continuous stress of 385 kVrms/mm. If not, as the tree growth rate has increased and is beginning to show indications for the beginning of the runway stage and the interval between the initial self-limiting growth stage experiencing a degradation because of the high applied stress Although the maximum partialdischarge size following the beginning of bush-type trees grows linearly proportionate to thelength of trees, it tends to stabilize afterwards having a decrease at subsequent lengths. The following equation predicts the length of tree development for each bush type. (Malik 2006). Predicted length of tree growth bush-type can be found from the equation below:

$$L(t) = Lm(1\text{-}e^{-(\frac{(t-t1)}{\tau e})})$$

$L(t)$ = Tree length growth

Lm = Maximum or final tree branch length

$t - t1$ = Period followed the inception at t1

τe = Time constant

Figure 2.17 Measured tree length growth adapted from (N. H. Malik 2006)

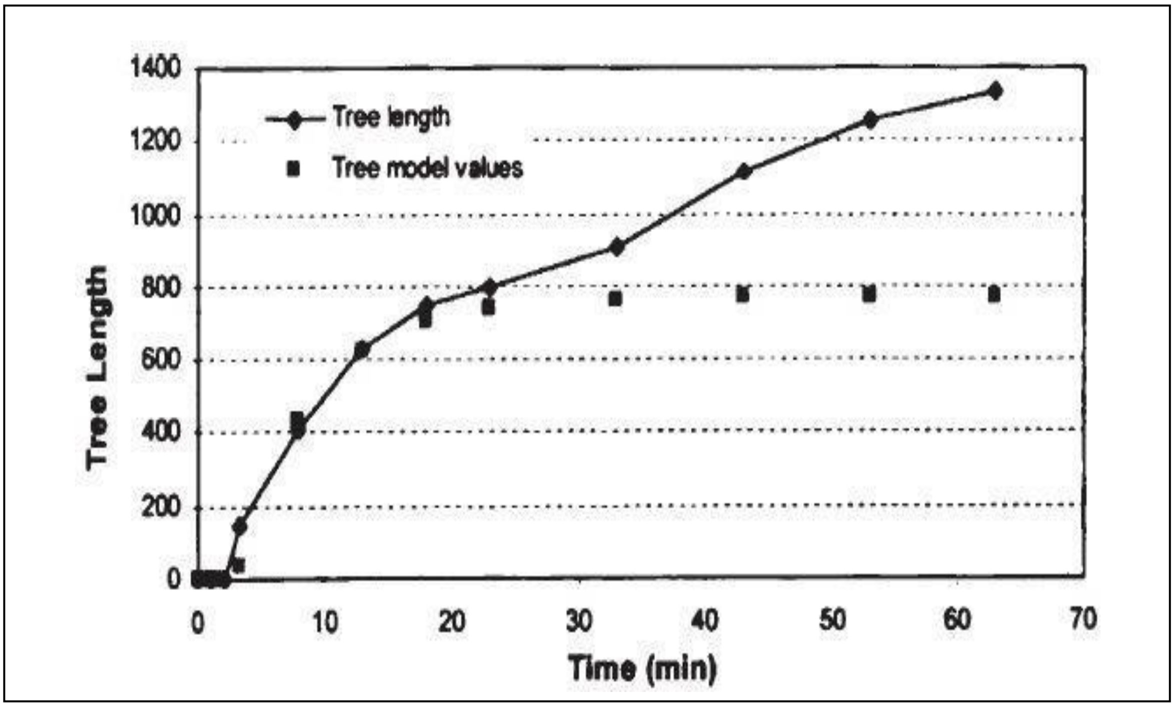
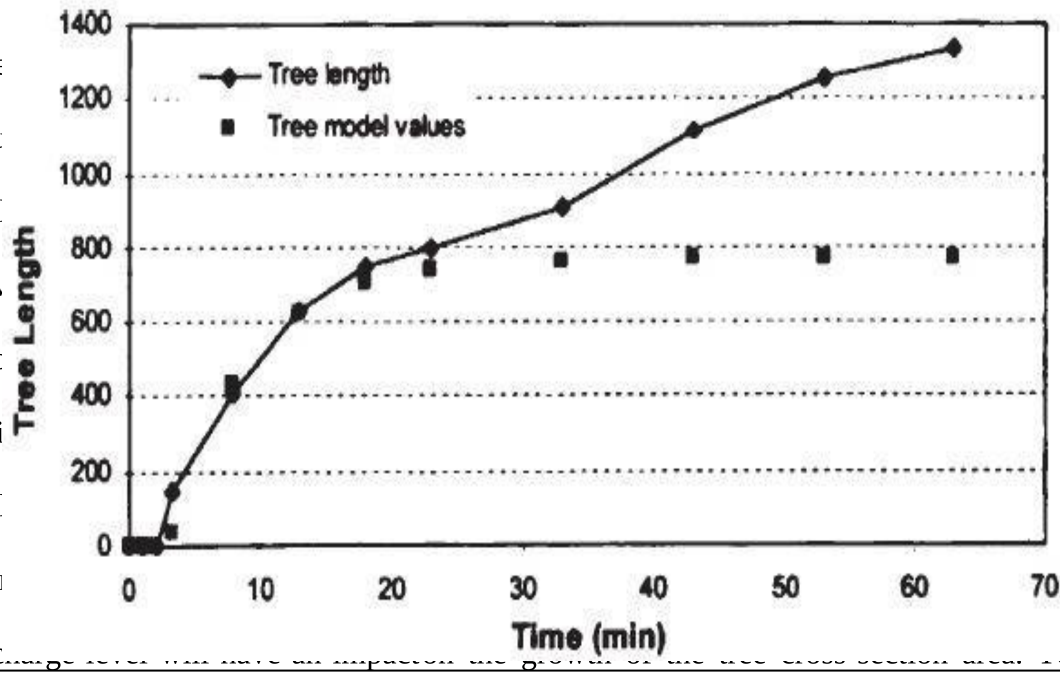


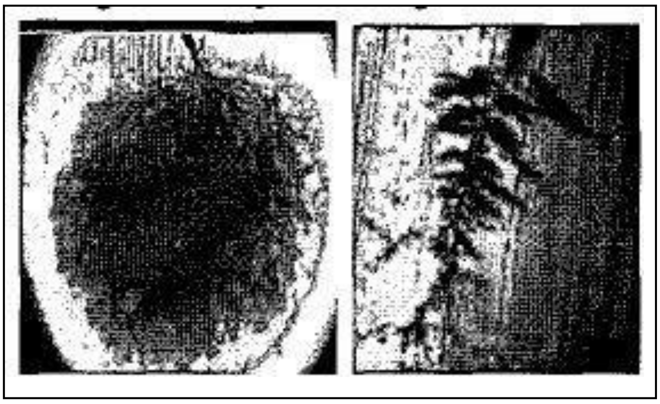
Figure 2.18 Tree length propagation with time for bush-type adapted from

(N. H. Malik 2006)

Due to the stress-induced incubation period, the incubation time for the bush



prolong the life and dependability of the cable, it will keep small-scale impurities, protrusions, cavities, and other faults in the insulation so that the maximum stress at any location is reduced below this level (Malik 2006). Due to the greater partial discharge magnitude of the bush-like tree than the maximum fortree-like trees, the frequency of partial discharge decreases happening later in phase decreased. When a tree transformed from a tree-like tree to a bush-like tree, the frequency of short discharge routes decreased, and the change in the magnitude of the partial dischargedistribution likely had an impact on the length distribution of discharge paths (Suwarno et al. 1996These tree-like presences are caused by tree propagation, which is seen in figure 2.17, and occur under

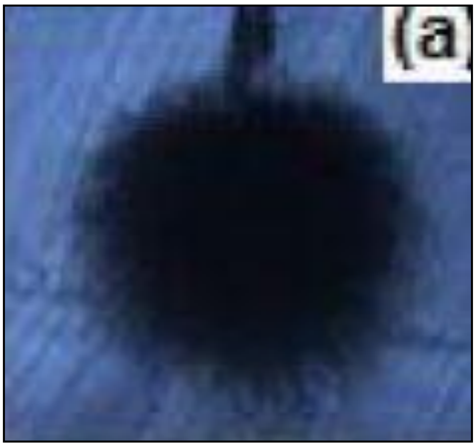


composite voltages regardless of the DC voltage's amplitude and polarity. Additionally, the appearance of a Bush-type tree structure is degraded locally due to the response of trapped charge(Sarathi et al. 2003).

Figure 2.19 Electrical Tree Pattern under composite voltage adapted from

(R. Sarathi et al. 2003)

Bush-type trees that grow when high voltage is introduced do so regardless of the frequencyof supply voltage. This indicates that it will occur when high applied voltage and high frequencies are present. The charge injection will cause material to be extracted from the needle at greater frequencies. If the treed zone's surface is made of a non-conductive material, charge recombination will be constrained and the electrical tree's tip's field enhancement will be reduced(Sarathi and A. Nandini 2012). It will slow the growth of the electrical tree that can grow into a bush-like tree in figure 2.18 during this time. As the electrons from the bulk dielectric migrate to the positive point, the holes will not be as concentrated at the needle point as they would be in the event of negative polarity and would



instead be dispersed across the border zone. As a result of the effective field, which is greater than the material's breakdown strength, the space charge field, which opposes the applied electric field, can initiate the development of trees(Sarathi et al. 2003).

Figure 2.20 Bush-type tree adapted from (R. Sarathi et al. 2015)

According to Bao et al. (2011) claim that bush-like trees are propagated practically uniformly from the tip of the needle. Due to earlier study, it was discovered that trees that resemble bushes grow when voltages are higher than 7 kV. If the applied voltage is higher than the critical voltage, which is the result of the higher voltage applied, the chance of bush-like trees growing is higher than it is for other types of trees. Figure 2.19 depicts the bush-like trees that were discovered in the XLPE cable's outer layer of insulation when it came to electrical trees in 66kV-rated cables. These kind of trees can also grow in dark-colored, 110kV XLPE cable insulation, suggesting a distinct propagation process from those used for the light-colored trees in those cables in the outer coating of the insulation of the 66 kV cable. As with 500kV XLPE cable insulation, bush-like trees may also be seen in 220kV

XLPE insulation cables where they are created on both sides of the layer (Xie et al 2009). This study demonstrates that bush-like trees are common, which can cause high voltage electrical systems to fail.

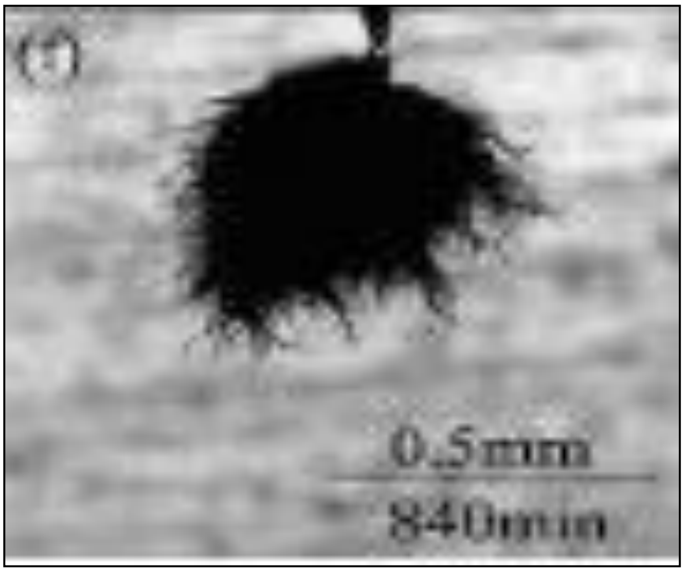


Figure 2.21 Bush-like tree in 66kV XLPE cable insulation adapted from (A. Xie 2009)

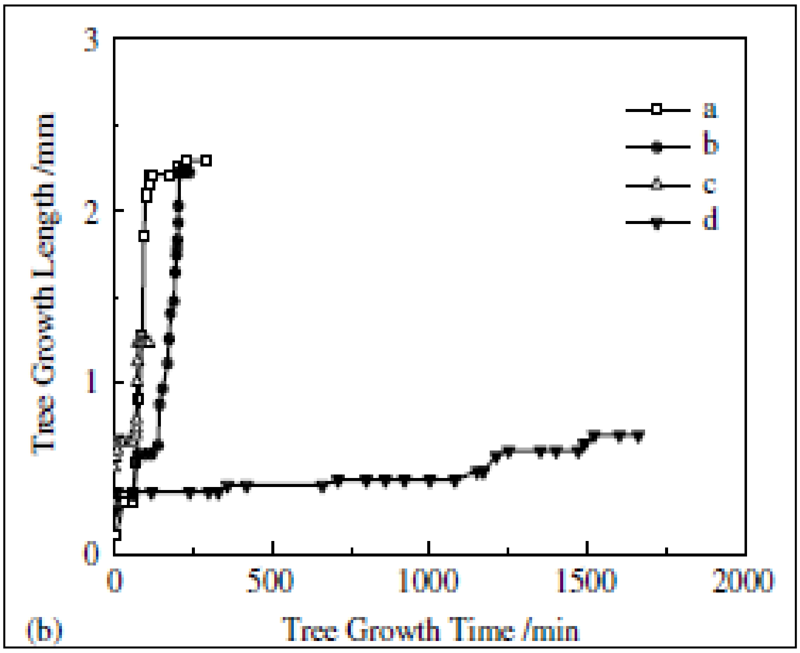


Figure 2.22 Propagation characteristic for Bush-like tree in 110kV XLPE cable insulator adapted from (A. Xie 2009)

Dissado's (2001) earlier research revealed that when the quantity of such bursts as bush-like trees decreases, the fractal dimension would grow. These events happen because of the massive discharge that is linked to a lengthy discharge channel during the burst phase and will reach the tree tops, favouring tree expansion. As burst condition declines, fractal dimension rises as a result of the diminished incidence of fast lengthy tree expansions during propagation as the tree shape transforms from branch-like to bush-like. As opposed to trees created at higher frequencies and lower voltages, these trees have quite distinct features. According to these studies, a normal growth pattern with a quick start was discovered. Since the trees didn't grow at all over the time period, this was essentially followed by. These demonstrate that an increase in the amount of voltage applied at the tree tips causes a tree to change from being bush-like to branch-like. Bush-like trees have traditionally been assumed to have a bush-like starting structure for their electrical treeing process. (Bao et al 2012).

Since the electrical tree shape are changed due to application of high voltage, availability of injected charge around the tree tips for avalanche participation is an important role in controlling the tree shape. Bush tree will presence due to these condition when it was increased via high pin voltage. Simple structure for bush-like tree can be simplified by characterization of fractal dimension. For bush like tree, fractal dimension for this electrical is exist with range $2 \leq \mathrm{d}f < 3$, where $\mathrm{d}f$ stand for fractal dimension. The electric field driving the advance of the filament would be due to space charge supplied from the bush tree reservoir. Consequently the filament could be a conducting extension of the tree, although this is less likely as the progress of the filaments would be expected to accelerate in this case as the filament extended clear of the bush (Dissado 2001).

Besides, the development of electrical tree shapes happens as a result of the correlation between the requirement of a minimal field for tree expansion and what is anticipated during the commencement of a tree. As soon as a bush-like tree forms, the value of propagation stops, which is one of the factors that might lead to its creation. This factor is controlled by the maximum field around the tree tips, which is smaller than predicted during the initiation phase. That is to say, the electrical tree has reached its final stage of development before fully breaking down.

A breakdown phenomenon known as a "vented tree" or"water tree" will started to breaks loose. In other words, in order to fully characterise the susceptibility of insulating material, vented trees required examination of their density and length of distribution in relation to the length of time they had to develop throughout the electrical treeing process (Dissado 1986).

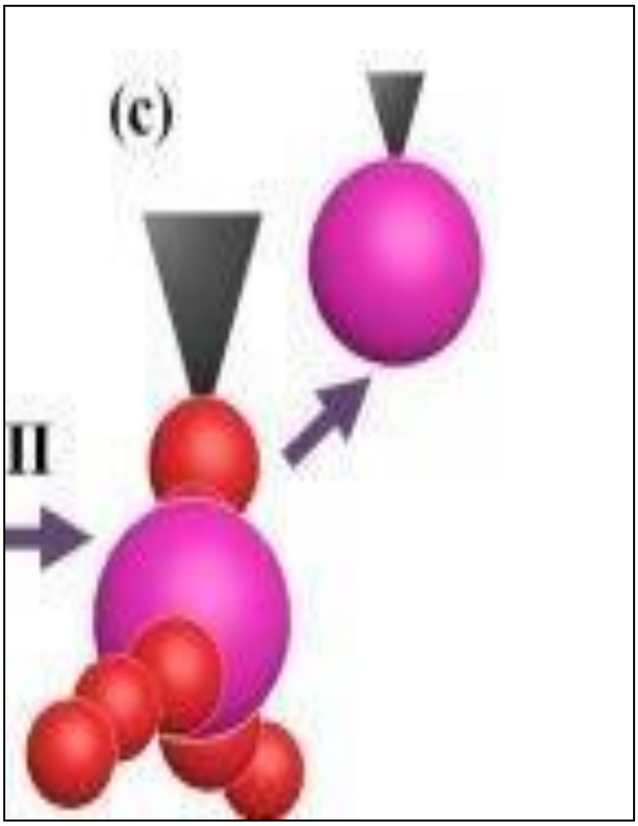


Figure 2.23 Bubble grow when the frequencies greater than 100kHz adapted

from (Yunxiao Zhang et al. 2018)

According to (Yunxiao Zhang et al. 2018), when the applied frequency exceeded 100 kHz in silicon rubber, a special type of bubble-shaped deterioration can be detected in silicon rubber cause by a large number of small channels gathered around the needle tip, andthe bush-like trees were dense. A bubble grew after the bush-like tree is initiated as show infigure 2.21 after a few second. Bush-like tree will become denser when the applied voltage frequency is increase. Bush-tree also will presence when the applied voltage frequency reach 10kHz or greater than 10kHz and bubble deterioration will form when it reach about 100kHz.These bubble growths will cause the sample to breakdown. Since the bush-like tree is develop, the duration of sample to break down exceed 90 minutes from the development offorming bush-like tree. Therefore, bush-like tree will take longer time latency for the sampleto breakdown during it high voltage system operation.

2.8.1.3 BRANCH-LIKE TREE

Branch-like tree is a type electrical treeing known as tree-like tree due to it shape looking similarly as a branch grow tree in electrical treeing breakdown phenomena. In order research branch-like tree are describe as fibrillar type due to the structure form consist of relatively few tubules most of which grow generally in the direction of the field. Generally, these type of tree called as fibrillar type tree when there is a few of branch emanates from the defect and spreading with thin fine light coloured branches. Branch tree will know as intrinsic type tree when the grow of tree is incepts and a single branch starts propagating towards the ground electrode show in figure 2.22, figure 2.23 and figure 2.24 (Sarathi and

Nandini 2012). All of these trees are classify under branch-like type of electrical treeing phenomena.

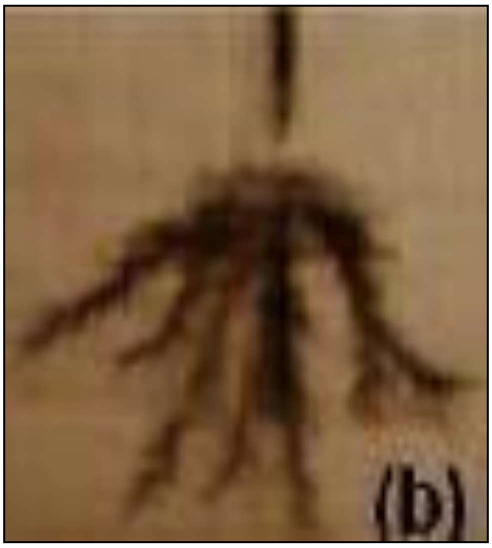


Figure 2.24 Branch like tree or tree-like tree adapted from

(Sarathi and Nandini 2012)

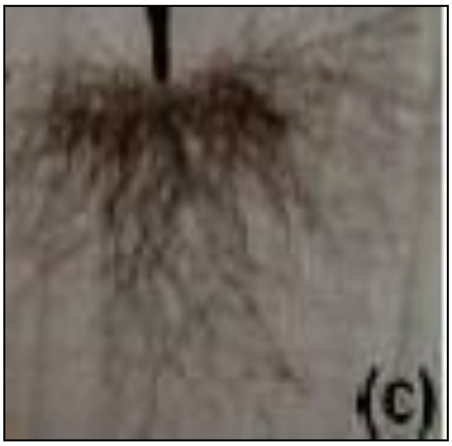


Figure 2.25 Fabrillar tree type adapted from (Sarathi and Nandini 2012)

Figure 2.26 Intrinsic tree type adapted from (Sarathi and Nandini 2012)

Referred to the figure above, these entire trees have a similar shape but have different structure due to it different character. Others, this type of tree are categorized in branch type tree. Moreover, all of these trees can presence depends on the magnitude of applied voltage and frequency. Branches type trees are also known as the initiation of electrical treeing. Means that initiation of tree structure generally Branch type tree due to different of their final structure (Bao et al. 2012). steady rate of increment in the PD size at the prior phases of tree engendering. In any case, the expansion in the PD size is restricted at additionally arranges and at that point tends to diminish after a specific era Thus, at steady voltage, with the exception of the underlying tree development organize where PD level means that the tree length, at later stages, longer trees can show littler PD levels and the other way around (Malik et al. 2009).

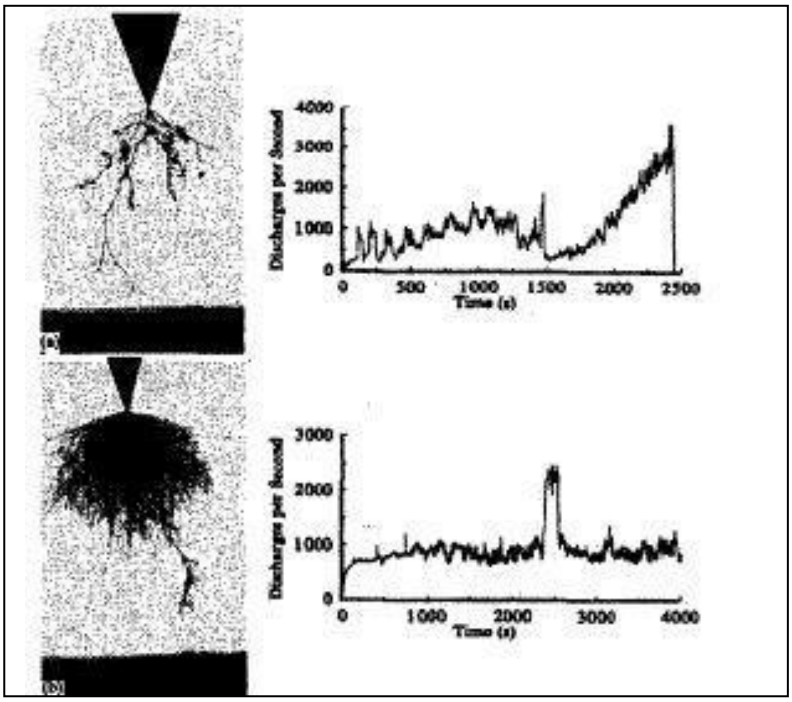


Figure 2.27 Time dependence of number of discharges per second between

bush type and branched type adapted from (Dissado 2001)

According to (Dissado 2001), the previous research found that discharges involved in growth movement of branch-type tree transfer their charge to the tree tips over long paths. Branch type tree required restriction amount of available charge for back avalanches to the tree tip due to the reflection of initiation process in which electron extraction events not involve in all of the injected charge, which is some of charge remained trapped. Figure 2.23 show the difference in time dependence of number discharge per second between bush type and branch type.

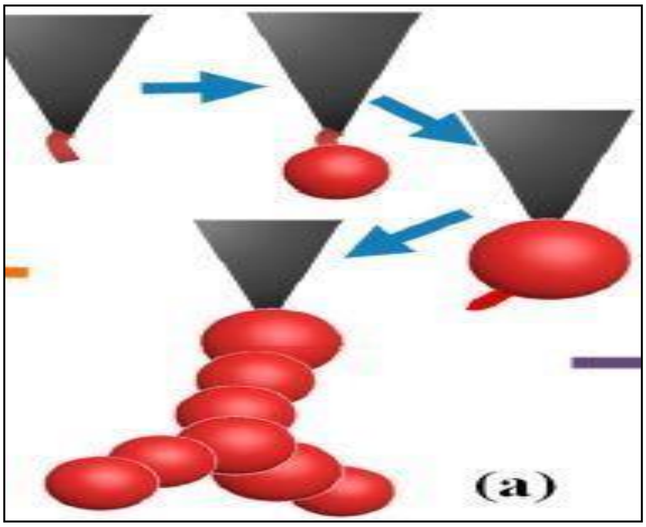
During higher frequencies, the charge injection and enhancement of extraction will transfer from the needle to material. If the treed zone is of conductive in nature, it will affect the electrical field at the tree having an increment it will cause the formation of tree like trees or fibrillar type electrical trees (Sarathi and Nandini 2012). Branch like tree seem to be more likely to propagate from the needle tip. Moreover, branch like tree will presence when the applied voltage are below than 6kV. Meanwhile branch like tree is an initiation process of electrical tree formation due to it condition below than critical voltage (Bao et al. 2011).

According to previous research of (Dissado 2001), found that Fibrillar tree type or Branch tree type form due to the voltage further that will cause an increment discharge at the tree tip. Other than that, commonly branch-tree type are frequently occur due to the most chaotic discharge sequence and in consequence will vary most in detail from the tree-like tree formation. Branch tree type has the lightest shading, demonstrating that the tree channels are non-conducting (Xie 2009).

Formation of branch like tree also grow same as to the counter electrode cause an increasing field due to image charges, without going through a period of quiescence. Usually, crack propagation tends to be affected via the micro-morphology of the material cause material will orientated growth and branching (Sarathi and Nandini 2012). At first, the electric field is sufficiently high close to the needle tip, new branches can form and the energy is expended in the arrangement of new branches from the needle tip that can cause formation of branch-like tree (Bao et al. 2011).

From previous research also found that, Dull Tree like tree track with thick structure shapes close the needle tip and harmonic voltage with higher THD (Total Harmonic Distortion) demonstrating Fibrillar type tree with expanded tree development and also increase organized by harmonic in supply voltage produces electrical tree much like to high frequency ac voltage (Sarathi and Nandini 2012).

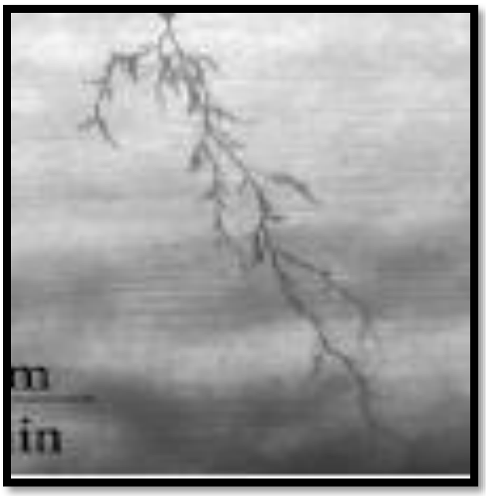
Length of channel in branch type as show in figure 2.26 will increase rapidly due tothe limited charge in the main channel. Fibrillar tree type will increase rapidly due to the increment of supply frequency cause by enhancement of partial discharge activity during electrical treeing process (Sarathi and Nandini 2012). Additionally it is to be specified that with voltage wave (higher request harmonic ac voltages) with high dv/dt improves the movement of partial discharge, which it is could quicken the development of electrical treeing. Formation of Fibrillar type can be found when high total harmonic distortion is



presence without consideration of order of harmonic that react in the ac voltage. Frequently, tree like tree formation can be found without consideration of level total harmonic distortion due to occupancy of odd harmonics.

Figure 2.28 Initiation process of branch like tree adapted from
(Yunxiao etal. 2018)

Previous research of (Xie et al. 2009) perform four stage testing for detecting presence of electrical treeing in XLPE insulation cable which is consist of 66kV, 110kV, 220kV and 500kV. There is four type of branch type electrical treeing was found in this testing which is consist of branch type, branch-vine type, branch-bush and branch-pine in 66kV XLPE insulation cable in figure 2.27, figure 2.28, figure 2.29 and figure 2.30 with 85% growth rate of inner layer faster compare to outer layer as the propagating trees from the outer layer dominate 80% between outer and the inner layer due to the presence in the inner layer. From this research, the branch-vine like and the pure branch-like electrical trees possess the lightest colour, indicating that the tree channels are non-conducting while the



branch-bush type commonly found at the outer layer of cable insulator. Branch-bush types frequently form in darker colour and implying a semiconducting property of the electrical treeing.

Figure 2.29 Branch type tree in 66kV XLPE insulation cable adapted from (Xie et al. 2009)

According to previous research found that branchlike, branch-pine like, branch-bush-like was presence in the inner layer of 110kV XLPE insulation cable. Compared to 66kV of XLPE insulation cable, there are no formations of branch-vine type during the electrical tree growth with a different propagation mechanism and have a dark colour.

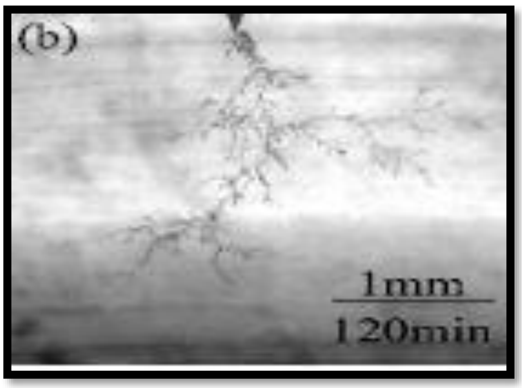


Figure 2.30 Branch vine in 66kV XLPE insulation cable adapted from

(Xie et al. 2009)

Meanwhile in 220kV XLPE cable insulation found that there is only branch-bush were presence during this condition in both part of the layer which is in the inner and the outer layer of the cable. During this condition there are two propagations phase were found with better resisting character compared to 110kV. Branch bush type also can be found in the inner layer and the outer layer of 500kV XLPE insulation cable.

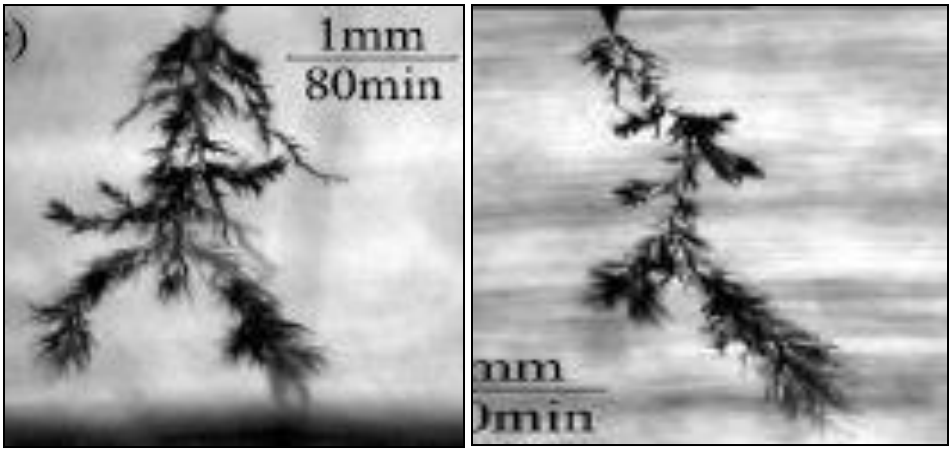


Figure 2.31 Branch-pine type in 66kV XLPE insulation cable adapted from

(Xie et al. 2009)

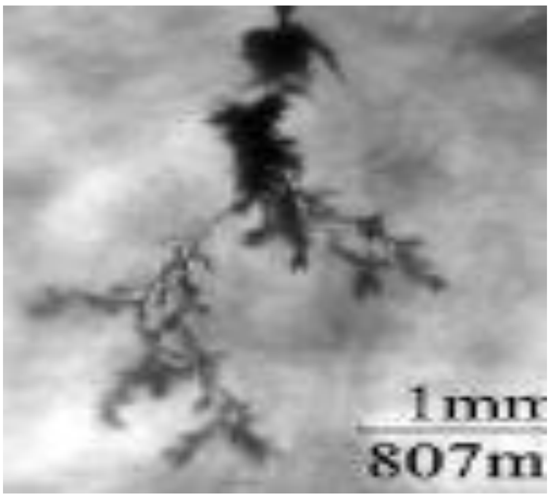


Figure 2.32 Branch-bush type in 66kV XLPE insulation cable adapted from

(Xie et al. 2009)

According to (Bao et al. 2011) conclude that voltage, frequency, an pin-plan space are will influence the structure of electrical tree. Tree structure frequently will affected via the voltage and also the apply frequency. Since electrical tree propagation influenced by presence of too any factor, stressing voltage and frequency affected the tree growth rate and also the structure of forming tree. Formation of vine type can be presence proportionally with branch type due to the smaller applied voltage. Besides that, vine-like tree are frequently occur under high frequency and below critical frequency and grow from a grown of the branch formation which is energy can effectively transfer from the tip.

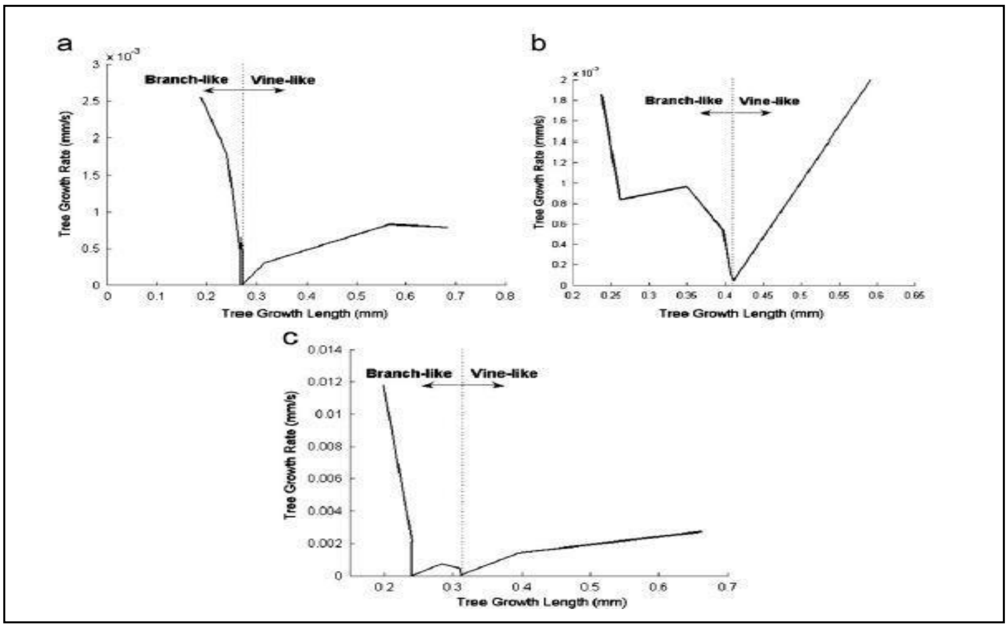


Figure 2.33 Growth rate of branch like tree to vine like tree adapted from

(Bao et al. 2011)

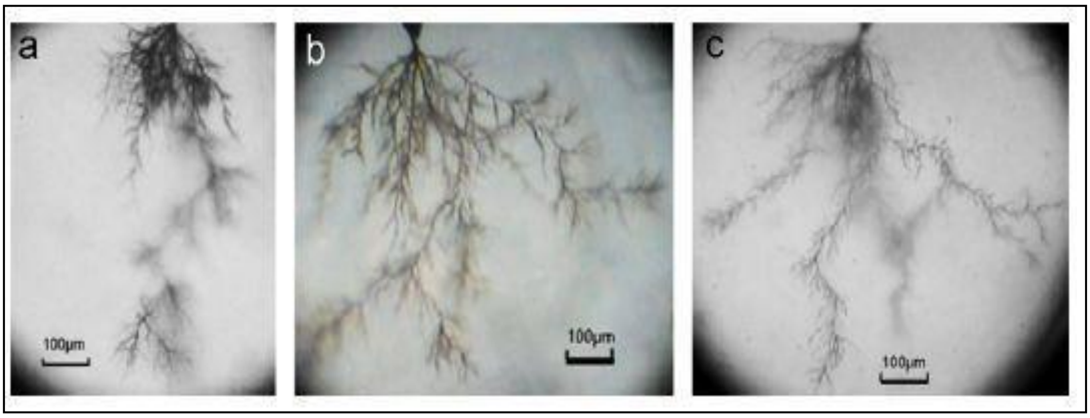


Figure 2.34 Vine-like tree growth under a) 5 kV,10 kHz,1 mm, (b) 5 kV, 5kHz,1 mm, and (c) 7 kV, 4 kHz, 2 mm respectively adapted from (Bao et al.2011)

Increasing value of applied voltage will affected value of local electrical field around the tip as the value are also increase and these will consume more energy around the formation of vine tree that can cease the formation of vine type tree under high voltage. Vine type tree will degrade from the branch like tree when the local electrical field is decrease which can cause new branch are difficult to presence due to the concentrated energy. During this situation, growth rate of vine like tree will increase due to the higher electric field. Although, energy threshold for vine-like trees are much smaller than branch-like trees as vine like tree need less energy compared to branch type energy.

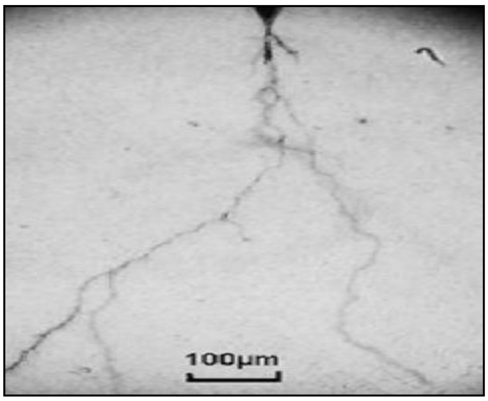


Figure 2.35 Vine like tree formation under lower frequency adapted from (Bao et al. 2011)

Dielectric divided into three stages which is gaseous or vacuum dielectric, liquid dielectric and solid dielectric. Solid dielectric material are widely used in electrical circuit and device as insulation material to carry a current operates at different voltage. Character of good dielectric must in low dielectric loss, high mechanical strength, free from gaseous inclusion, moisture resistant to thermal and chemical deterioration. In other side, solid dielectric has higher breakdown strength compared to liquids and gases. During breakdown of solid dielectric, solids get permanently damaged while gases fully and liquids partly recover their dielectric strength after the applied electric field removed.

Breakdown occur due to tracking in which dry conducting tracks act as conducting paths on the insulator surfaces leading to gradual breakdown along the surface of the insulator. In additional, electrochemical breakdown caused by chemical transformations such as electrolysis, formation of ozone and others factor that may lead to breakdown. Referring to previous research, failure that occurs to the partial discharge brought in the air pockets inside the insulation. Whenever tidy and like contaminants are stored on an insulation between terminals to which electric power is provided, and the moisture in the environment gathers on the insulating material, an electric current moves through the store of wet contaminants, delivering joule warmth to vanish the water. As of now, a concentrated electric field is shaped at the subsequent break of the electric way, offering ascend to shine which gives out warmth to logically carbonize a moment segment of the surface of the insulating material. Such phenomena, when rehashed in the end carbonize the whole surface of the insulator between the electrode, present a carbonized conductive way (track) between the electrode lead to breakdown (Saito et al. 1982).

There are some important mechanism of chemical reaction occur due to the Chemical and Electrochemical Deterioration that may lead to breakdown when subjected to continuous stress. First mechanism known as oxidation occur due to the presence of air or oxygen, material such as rubber and polyethylene undergo oxidation may cause crack on the surface. Next mechanism is hydrolysis occur due to moisture on the surface of dielectric when the material loses their electrical and mechanical properties. Electrical properties consist of paper, tape and any cellulose material such as fabric, paper, and wood. These material will deteriorate rapid rapidly when undergo hydrolysis phenomena that my decrease the life span of material use. Next, chemical reaction is on the mechanism can lead to breakdown when undergo electrochemical process (Benha University 2014). This mechanism occurs due to the absence of electric field. These progressive chemical degradation of insulating materials can occur due to a variety of processes such as chemical instability at high temperatures, oxidation and cracking in the presence of air and ozone, and hydrolysis cause by moisture and heat.

According to (Ravindra Arora and Wolfgang Mosch 2011), limited electrical breakdown inside a protection framework limited just to a specific piece of the dielectric known as Partial Breakdown that occur due to combination of gaseous, liquid and solid I insulation system that extremely non-uniform field locations above a particular intensity of field include of corona in gaseous dielectrics, internal breakdown at voids or cavities within a liquid or solid dielectric, and surface discharge. Figure2.34 show the time elapsed of variation of breakdown strength occur due to the applied voltage. Partial breakdown can be measure using two method which is indirect method consist of EMI detection, Acoustic, Optical and gas analysis while direct method is the measurement of pulse current or the magnitude of discharge due to local or partial breakdown and its analysis.

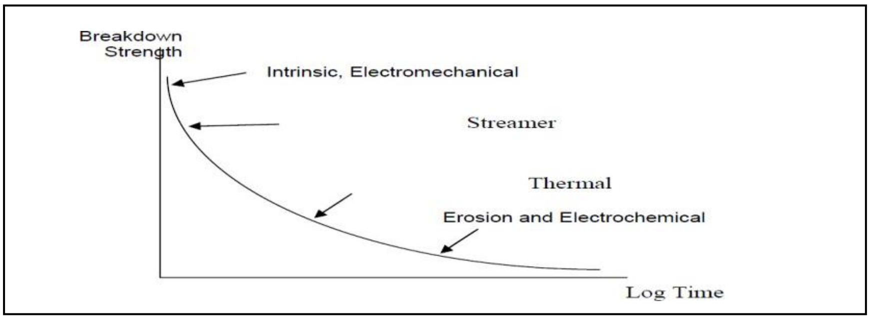


Figure 2.36 Variation of breakdown strength related with time elapsed due to applied voltage adapted from (Benha University 2014)

Optical detection is an indirect method to measure partial breakdown due to the light emission via photon-counting technique. These will cause the resulting amplitude of the total number of photon count per second through the optical detector using photomultiplier tube due to high sensitivity of optical detection and not affected by the surrounding electromagnetic interferences (Ravindra Arora and Wolfgang Mosch 2011).

According to (Ravindra Arora and Wolfgang Mosch 2011), degradation in solid dielectric occurs due to the internal partial breakdown that may cause to formation of solid, liquid and gaseous. Formation of these three mechanism lead to synthesis taking place within the dielectric. Degradation that occur in the insulating cable such as XLPE cable described as discharge synthesis reactions within the electrode gap space. An organic compound contain oxygen synthesize from mixtures of CO2 , CO and H2O undergoing local internal breakdown. Compounding of an oxalic acid and other non – aromatic occur due to discharge from synthesize of reactions involving CO and H2O. Formation of partial breakdown may cause the presence of oxalic acid when such cavities are not vented. As the partial breakdown being suppressed by the oxalic acid, formation amount of generation lead to disappearance of partial breakdown. Therefore partial breakdown in solid dielectric affected the physical changes cause by chemical synthesize reaction.

Electrical tracking known as Partial Breakdown on the surface occur due to the interface with solid and liquid dielectric in gaseous and vacuum when high tangential component of electric field presence along the a diagonal interface between any solid or liquid and a gaseous. An expanded tangential component of the field is brought about the vaporous medium, which stresses it with higher field force. Surface discharges are occur when an intrusion of the creepage current way happens over the surface of the dielectric. Under this condition the field part at the area at first glance may surpass the electric strength of the medium (Ravindra Arora and Wolfgang Mosch 2011). These phenomena also accelerates due to accumulation of contaminants and subsequent dew formation of the air moisture on the surface of insulators cause by an applied electrical energy. Tracking phenomena also can occur in household electrical appliance of low voltage and low current as the insulator need minimum power during ignition due to power above the minimum power make carbonized track ohmic and powers below the minimum power make the track non-ohmic (Saito and Sakurai 1979).

Formation of surface discharge occurs when conducting path presence on the surface of dielectric resulting from the degradation of the dielectric surface or by deposition of a contamination layer on it. There will be two mechanism presence before tracking breakdown of surface discharge occur. Firstly, it will be a conducting film across to the surface of dielectric. Next, interruption creepage current of mechanism through the conducting film due to discharge on the surface. Tracking that occur on the insulation surface lead to creepage discharge from surface contamination. Surface leakage current on wetted insulating materials in non-uniform heating of the pollution layer occur due to the non-uniform resistivity of the conducting film. Figure 2.35 show the difference time elapsed of output waveform between dry band discharge and tracking signal. Since the surface current density having an increment, formation of dry band will presence through the distribution of non-uniform current along the insulator surface known as scintilillation phenomena (Rajini et al.2004).

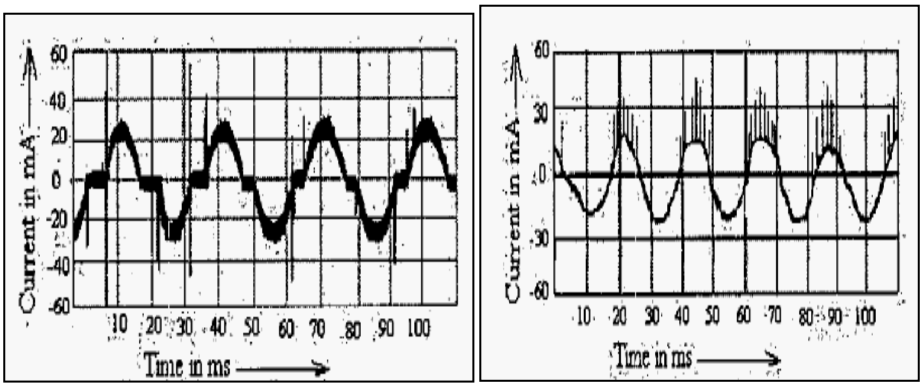


Figure 2.37 a) Dry band discharge b) Tracking signal adapted from (Rajini etal 2004)

Formation of surface discharge occurs when conducting path presence on the surfaceof dielectric resulting from the degradation of the dielectric surface or by deposition of a contamination layer on it. There will be two mechanism presence before tracking breakdownof surface discharge occur. Firstly, it will be a conducting film across to the surface of dielectric. Next, interruption creepage current of mechanism through the conducting film due to discharge on the surface. Tracking that occur on the insulation surface lead to creepagedischarge from surface contamination. Surface leakage current on wetted insulating materials in non-uniform heating of the pollution layer occur due to the non-uniform resistivity of the conducting film. Figure 2.35 show the difference time elapsed of output waveform between dry band discharge and tracking signal. Since the surface current densityhaving an increment, formation of dry band will presence through the distribution of non- uniform current along the insulator surface known as scintillation phenomena (Rajini et al. 2004).

According to (Ravindra Arora and Wolfgang Mosch 2011), conducting film occur due to form of contamination such as salt deposition (in coastal areas), carbonaceous dust from fuels and industrial or cellulose fibre deposits along with moisture. In other word, interruption moisture occurs when surface is dried due to the heating effect of the surface current. Since amount of contamination having an increment, it resulting the joule heating in the layer causes it to dry out locally on the surface current that may cause initiating partial breakdown between the receding edges of the wet film. Tracking also cannot occur on the surface of dielectric. Tracking breakdown occur when there are combination of discharge inception, carbon formation and carbon path propagation. These phenomena affected via applied voltage, type of electrode, location of discharge, energy of discharge, electrolyte and molecular composition of the materials. Since tracking breakdown can occur under wetting and contamination condition, it will be several stage of the process will lead to breakdown through formation of dry band via the Joules heat. Next, there is an inception of corona discharge, violet in colour, across the dry band and cause the formation initiation of carbon. Since the initiation formation of carbon occur, there will be the propagation of carbon path due to the scintillation discharge (Yoshimura et al. 1981).

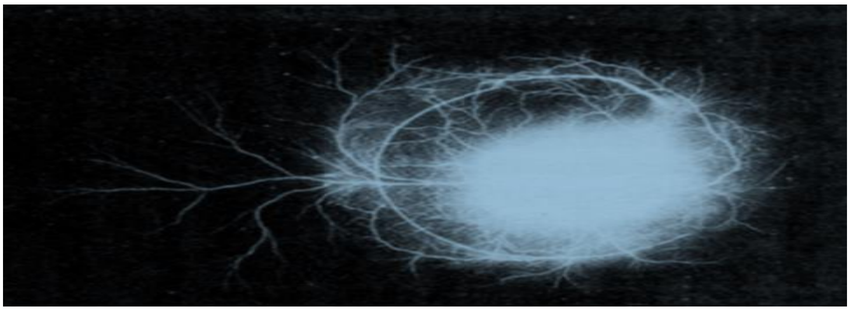


Figure 2.38 Stable streamer of surface breakdown as well as leader corona adapted from (Ravindra Arora and Wolfgang Mosch 2011)

Figure 2.38 shows a stable streamer of surface breakdown as well as leader corona. An increasing of applied voltage may cause an increment of discharge mechanism on the surface as in case of gaseous and liquid dielectric consist of star, streamer and leader corona on the surface. Increment of discharge occur due to the trapped charge over the surface depend on discharge magnitudes track lengths with formation of numerous branches due toan undesirable property of the material. Material of insulation have tendency to track the theoretical consideration in term of chemical bond energies of the material. Essential bondsare important while considering thermal stability of polymers. Propensity to track relies on the extent of bond that produces free carbon on pyrolysis affected by chemical decomposition of molecules lead to exposure of high temperature.

The smaller the number of dissociation of energy, the tendency of dielectric to trackwill affected as the tendency also will decrease as the value less than 0.3 there are no trackingoccur during this dissociation energy while when the number of fraction is exceed 0.5 tracking phenomena will occur rapidly (Ravindra Arora and Wolfgang Mosch 2011). Dissociation of energy can be determine as follow:

$$\frac{Tc}{Tm} = \frac{breaking\ produce\ free\ carbon\ \left(\frac{kcal}{mole}\right)}{Total\ bond\ energy\ of\ the\ molecules\ \left(\frac{kcal}{mole}\right)}$$

2.9 Fault Detection

In Power system analysis fault is important to determining bus voltage and line current. Fault consists of two types such as three phase balance fault and unbalance fault. Unbalance fault divide into three parts consists of single line to ground fault, line to line fault and double line to ground fault. Short circuit of current may affected equipment and transmission that can lead to thermal stress and mechanical stress (Rodríguez et al. 2010). Earlier fault detection and prescient maintenance are greatly critical for the cost funds they give, particularly in huge and complex frameworks with numerous bits of equipment (Branco et al. 2003).

2.9.1 Balance Three Phase Fault

Synchronous short circuit across all the three phase defined as balance three phase fault. This type of fault occur rarely compare to unbalanced fault or unsymmetrical fault and solve on per-phase basis due to it balance network while the other two-phases carry an identical current exclude the phase shift. According to (Saadat 1990), first few cycle of short circuit current known as subtransient reactance (X’’d). On the next thirty (30) cycle known as transient reactance (X’d) while the synchronous reactance (Xd) define for the balance cycle.

Period of short circuit current depends on the time operation for the protection system. Therefore, it hard to determine the a suitable reactance to use. Subtransient reactance defines as method to determine the interrupting of capacity in the circuit breaker. Terms of bolted fault or solid fault use for describe the fault when it indicate zero value which can cause high fault current. In other word, balance power consist of three phase balanced voltage sources, three phase symmetrical loads, three phase transposed feeders and three phase equal self-impedances (Rodríguez et al. 2010). If all of these component are not complete, it cannot be consider as balance power system but it known as unbalance power system.

2.9.2 Unbalance Fault

According to (Glover et al. 2012), unsymmetrically fault or unbalance fault occur due to the interconnection of uncouple zero-, positive-, and negative sequence networks before the fault at the fault location. This may affected the positive sequence internal voltages value of all machines same equal with pre-fault voltage. Unbalanced fault occur due to the their constructive and operational characteristics. Unbalanced fault known as unsymmetrically or Asymmetric faults. These fault will divided into three consist of line to line fault, line to ground fault and double-line to ground fault through and impedance (Zf) (Rodríguez et al. 2010).

2.9.3 Line to line Fault

Line to line fault occur when two conductors being short circuited. These occur when two phases from three phase conductor being short circuit simultaneously that can lead to symmetrical fault through fault impedance assumed as Zf as show in figure 2.37. Negative sequence that presence in the fault current demonstrate that line to line fault occur as line current use to enhance the performance (Wang and Keerthipala 1998).

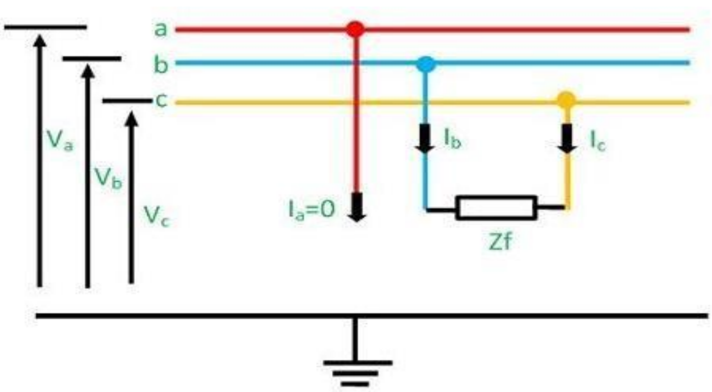


Figure 2.39 Line to Line fault adapted from (https://circuitglobe.com/line-to-

line-fault.html)

2.9.4 Line to line Fault

Double line to ground fault or double phase to ground fault means two phase of conducting being short circuit and contacting with ground as refer to figure 2.38. Probability for this fault to occur in range between 15% to 25% (Chegg Inc 2018). Double line current are greater than triple line current and it occur when there have a presence of negative and zero components (Wang and Keerthipala 1998).

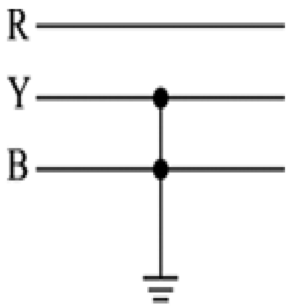


Figure 2.40 Transmission Line to Ground Fault adapted from (https://www.chegg.com/homework-help/definitions/unsymmetrical-faults-and-symmetrical-components-4)

2.9.5 Single line to Ground Fault

According to (Chegg 2018), phase to ground fault one of the fault that frequently occur in the unbalance fault in contact with neutral conductor as show in figure 2.40. Thesetype of fault occur when associated with the presence of negative and zero in fault current lead to one line current increase rapidly (Wang and Keerthipala 1998). Figure 2.39 shows the output waveform current in single line to ground. According to the previous research found that fault of single line to ground fault in ungrounded distribution system larger current flow due to the minimum fault and cause minimum current fault. Since line to ground faultoccur, the also may affected voltage of these phase to ground fault for two other phases in phase to phase fault or line to line fault (Nam et al.2012).

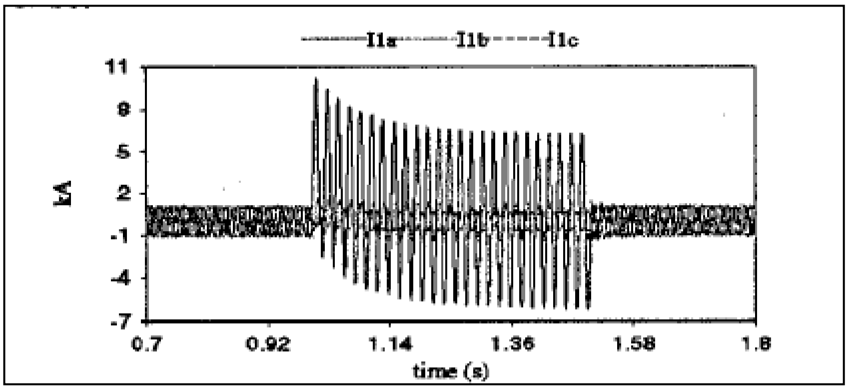


Figure 2.41 Single line to ground Current waveform using Fuzzy-Neuro for

transmission line protection adapted from (Wang and Keerthipala 1998)

Generally, reliable problem in the system occur due to the single line to ground fault. Otherwise, the fault phase recognition is directly when the ground fault weaker due to the symmetrical distribution network. During phase to ground fault, voltage of the fault will consequent to the three phase to ground fault (Meng et al. 2018). Phase to ground fault can be calculate using impedance matrix Z_{bus} method in smaller or larger power system due to it efficient method in order to estimate voltage and current during fault phenomena. Besides, diagonal element in Z_{bus} known as calculation of Thevenin equivalent impedance to analyse fault in bus (Rodríguez et al. 2010).

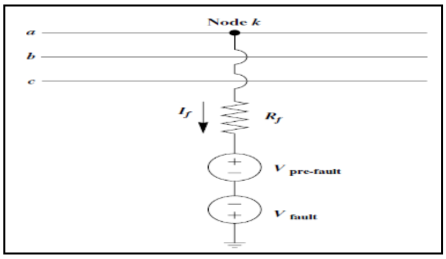


Figure 2.42 Transmission line to ground fault model adapted from

(Rodríguez et al.2010)

Since high speed camera widely used in research, military, aerospace and any other observation activity, it also an important tools in order to observe any visible character for analysis the shape and the formation. High speed camera cannot do two objectives in one time due to it limitation in technique where it cannot record any observation and transfer to the PC in one time during high frame rates. Electronic construction for high speed camera has limitation technique due to the time interval of video record will depends on the number of the recorded frame. Thus, the spatial resolution may affect the total number size file of the recorded video. Since the high speed camera have an ability to store large amount of data in file size but it can transfer with high extremely fast (Antunes et al. 2015). High speed camera also cannot record and transfers video file to the pc at the same time when operated at high time rates at high resolution .The number of recorded frame and their spatial resolution are related with the time interval between video records due to the total size file of each individual video(Atunes et al. 2014). There three mechanism in high speed camera consist of film movement, shutter mechanism and also illumination.

occur photo occur due to the continuous motion, relative movement of the image and the film during each exposure. These problem solved via short exposure cause by time elapsed for film to transfer the diameter of one frame. Moving optical system has rotating mirror or prism in and mounted lens on a rotating disc in the structure of camera. Good picture will obtain with rate exceed fifty thousand per second that may cause illumination will decrease (Baird 1946). High speed camera processes limited when spatial resolution ofthe high speed camera have limited resolution as well as compare with the cost. Spatial resolution and temporal resolution exceed very good level at the 200 x 400 pixel at 13,837 frame per second (Bizjan et al. 2016). Relative movement of the image during each exposure can cause blurred picture due to the continuous motion unless each exposure is very shotcompared to the time elapsed for the film to travel diameter of a frame (Baird 1947).

2.10 CMOS Image Sensor

CMOS image sensor design with image sensor with high quality image associated with high grey scale resolution and 10,000 frame per second of analogue parallel output in 512×512 pixel while for 3000 frame per second will associated 1024×1024 pixel. Others, the development of CMOS high speed also associated with on chip analogue to digital converter and construct with 8 to 9 bit resolution. For this CMOS image sensor are built with an image array include vertical shift register, column readout circuits with 12-bit ADC arrays, column-wise memories for buffering, and controllers. An access of array pixel in standard row-wise fashion occur due to the parallel column ADC (FURUTA et al. 2007).

CHAPTER 3

METHODOLOGY

3.1 Introduction

In general, there must be various steps to complete the project and achieve the objective of the project. Flow chart indicates the progress of the project to make sure all the project work in progress followed the step and all the planning before start the project in order to get a better result from the data analysis at the end of this project. Therefore, it required to implement the project at the beginning of the stage, the software tool, kit and equipment use to ensure it work smooth during it progress.

3.2 Methodology

Treeing and tracking observation on the surface of transmission line insulators for solving line-to-ground faults in DC high voltage applications involves several essential steps. A proper safety precautions must be followed, keep a 3-5 meters from the equipment while capturing the triggering progress from ceramic insulator and close the safety cage to prevent interruption from external cause. The preparation phase involves identifying the insulators requiring observation, setting up a cleaning and inspection platform, and thoroughly cleaning the insulator surface to remove any dirt or debris. Visual inspection will using a high-speed camera Chronos 1.4 Gigapixel-per-second spatial resolution and 1.3 megapixel image sensor of 1280×1024 resolution and 200MHz high definition Lecroy oscilloscope from UteM is conducted. Systematically scanning the entire surface of the insulator and capturing videos of any suspected treeing or tracking patterns. The captured data is then analyzed and interpreted, comparing the observed patterns with known indicators of treeing and tracking. A mitigation plan is developed based on the severity and extent of the issues, and corrective actions are implemented accordingly. High voltage 46kV is injected from IVAT Lab Equipment that connected with ceramic insulator (KN120) to observe the profile during the increment of injection voltage. By following this methodology, potential line-to-ground faults can be promptly identified and addressed, ensuring the safe and reliable operation of the transmission line in DC high voltage applications and contributing to overall maintenance and system reliability in IVAT, UTM.

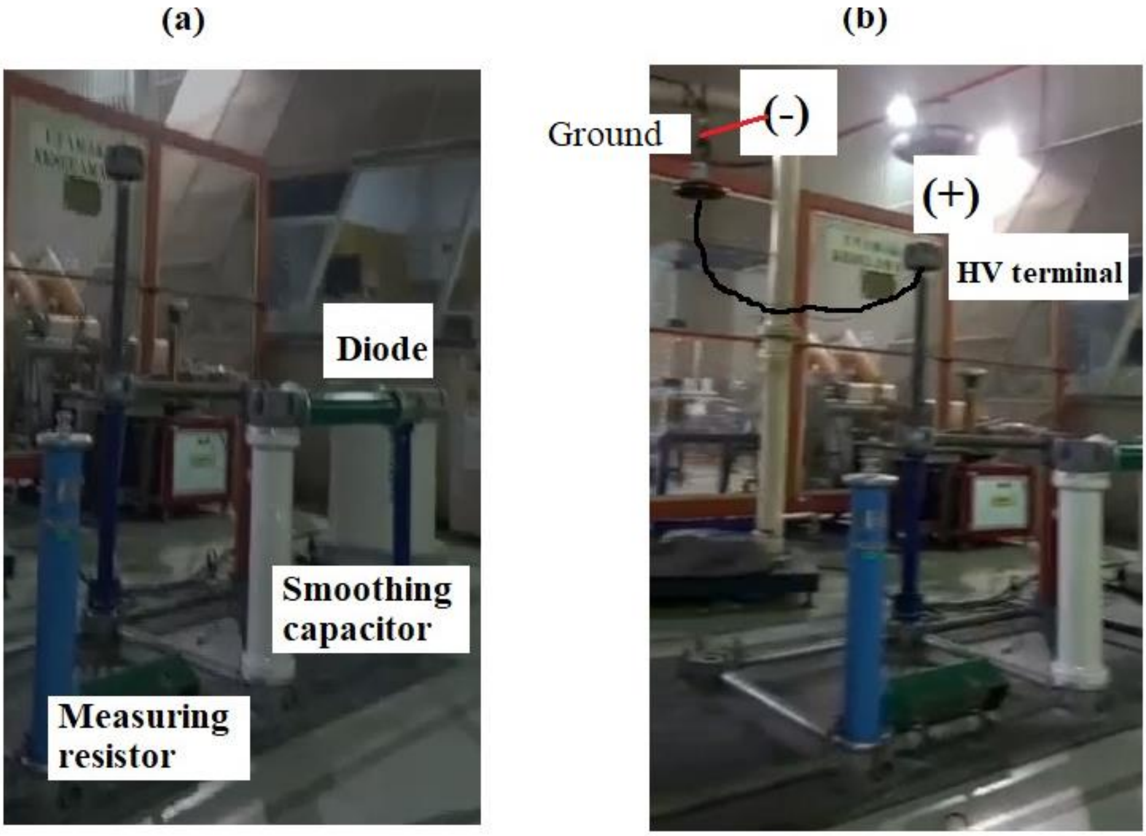


Figure 3.1 (a) High Voltage dc generator layout; (b) shows taping point from High voltage terminal (+) to grounding (-)

3.3 Project Methodology for Overall System

Entire of this project is focus on the photographic observation of electrical treeing formation and contamination of tracking for detecting line to ground fault in order to calculate the amount of time it has been passed since the applied voltage for the distribution system below 33kV in the high-speed rail power system. According to the flowchart in figure 3.2, the project's progress and efforts will be discussed in order to carry out this project and fulfil the stated objectives. All of the plan's requirements must be followed for this project's progress to go along more smoothly and to ensure that all of the objectives are met. Planning the research project's goal is the first step, and then a literature review is used to identify and retrieve all the data.

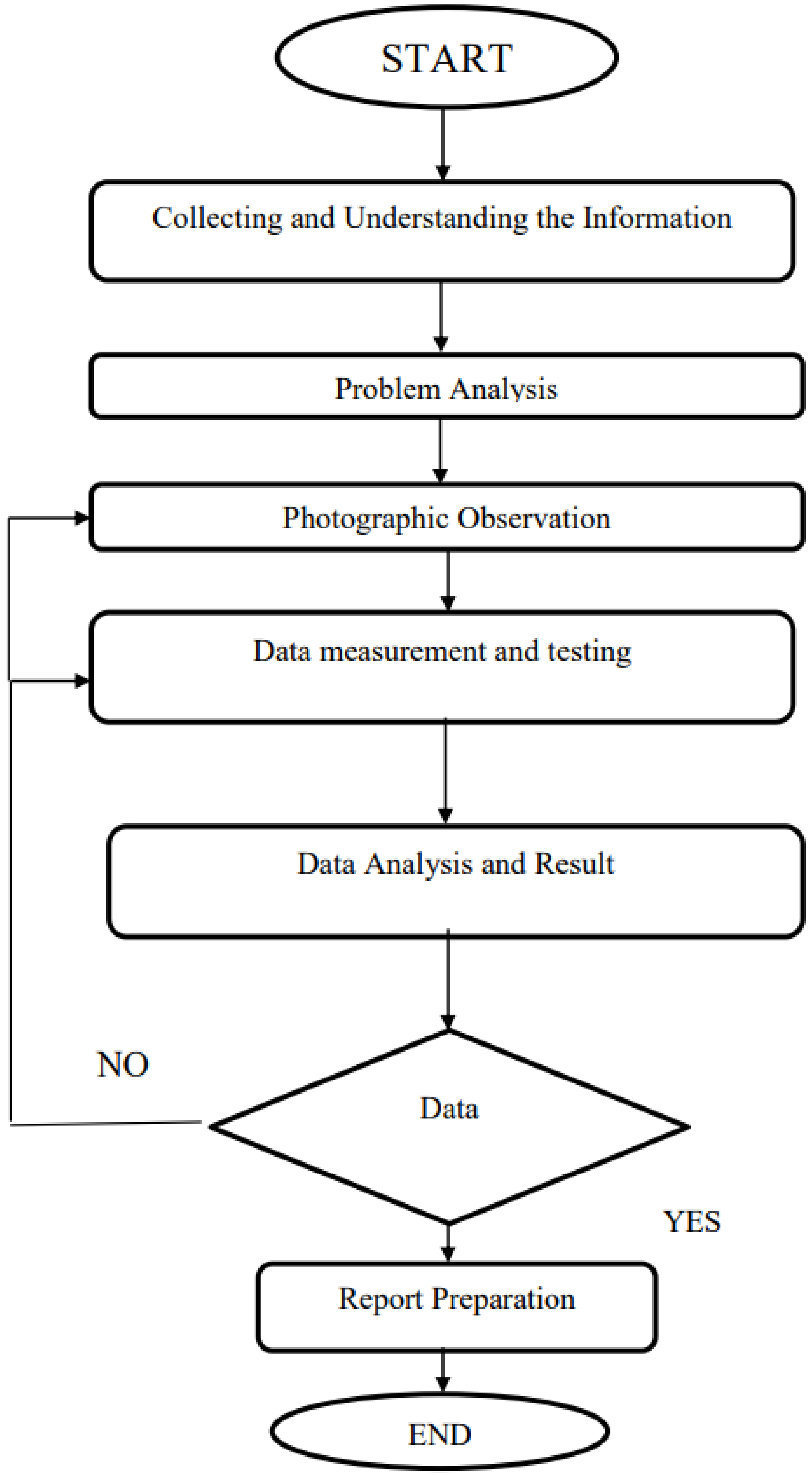


Figure 3.2 Flowchart

3.4 Gantt Chart of Project

Gantt chart will be the reference for the progress within the time limit that has been provided.From the Figure 3.3 below shows the overall schedule to complete the project for the Final Year Project 1 and Final Year Project 2.

Project Planning												
List major activities involved. Indecate duration of each activity to the related month(s)												
	2022											2023
Project activities	2	3	4	5	6	7	8	9	10	11	12	1
Briefing on PSM1	■											
Meeting with supervisor	■	■	■	■	■	■	■	■	■	■	■	
Study project background		■	■									
Search and get the information	■	■	■	■								
Preparation & submission of Chapter 1, 2, 3		■	■	■								
Prepare for presentation				■								
Presentation of PSM1				■								
Preparation of chapter 4 & 5					■	■	■	■	■	■	■	
Prepare & submit reports												■

Figure 3.3 Table overall schedule

3.5 High Voltage Apparatus

High voltage apparatus will be conducted in Universiti Teknology Skudai, Malaysia (UTM) and conduct the result by using apparatus from Institut Voltan Dan Arus Tinggi (IVAT) lab from UTM. Test will conduct for the voltage supply more than 33kV due to the assist from Institut Voltan Dan Arus Tinggi (IVAT) lab from UTM equipment. This project will use Choronos 1.4 High speed camera and broadband electric field measurement. The observation of distance will be contrained around 2 to 5 meters in the safety cage. A ceramic insulator KN120 will be use to see the formation of electric treeing on it. The resolution of high-speed camera will be set up to 800 to 1000 frame per second (fps) for the duration of 2 seconds. Breakdown of the voltage will be recorded with resolution from 10 to 20 MS/s for 2 seconds duration. And the electric field breakdown will be recorded by using high defination of transient recorder (Lecroy HDO4024).

3.6 Wondershare FILMORA Software

This PC software is using to check the frame of photo in high speed camera video, it is a video editor for Windows. Filmora's is a editing platform which could allows us to edit on a desktop or on the go built-in editing features. This software is not only a video editting software, it also could conduct our own video and capture the frame photo clearly. The video recorded by High Speed Camera Chronous 1.4 also could be catch the exact output frame by Filmora which PC original video edtting software not able to capture.

Figure 3.4 Wondershare Filmora Video editor

3.7 Teledyne LeCroy WaveStudio

Teledyne PC software is used associated the data from the LeCroy oscilloscope which had been triggered by the high voltage. Teledyne will resulting waveform data and performing file transfer to load the waveform data from the output result. Moreover, it also can display the waveform in main view, zoomed view, history view and cursor view. Main feature of this software is to display the waveform data and analysis the output waveform from the testing project. It have same feature with DL series instrument such as calculation of waveform parameter, cursor measurement and calculate complex waveform. This software also can easily to convert in CSV, Excel or Floating-Point Decimal Format.

3.8 High Speed Camera Chronos 1.4

High speed camera used for observing the formation of electrical treeing and contamination of electrical tracking in high voltage system due to it character. It will observe different in shape in initiation and propagation of the tree growth before reach breakdown phenomena in order to measure it length associated with broadband electric 81 field measurement at distance 2 to 5 meter in safety cage from the sample. Therefore, high speed camera used is Chronous 1.4. Figure 3.5 shows the high speed camera used easy to handle, not heavy to carry and simple to assemble as standalone camera.

Figure 3.5 Kron Technologies Chronous 1.4 High Speed Camera

The Kron Technologies Chronos 1.4 is a high-speed camera designed for capturing slow-motion footage at incredibly high frame rates. The Chronos 1.4 features a 1.4-gigapixel-per-second throughput, allowing it to capture high-resolution videos at extremely fast frame rates. It is capable of recording at resolutions up to 1280x1024 pixels, and its frame rate range varies depending on the resolution selected. At the maximum resolution, it can record at a frame rate of 1,057 frames per second (fps). However, lower resolutions can achieve even higher frame rates, potentially exceeding 40,000 fps. The camera's image sensor is a 1.4-megapixel CMOS sensor with global shutter functionality. The global shutter eliminates the rolling shutter effect, commonly seen in cameras that capture fast-moving subjects, by capturing the entire frame simultaneously. This ensures that each individual frame is free from distortion caused by the rolling shutter. The Chronos 1.4 comes with a built-in touchscreen interface that allows for easy camera control and settings adjustments. It also provides a variety of connectivity options, including HDMI, Gigabit Ethernet, and USB, enabling live monitoring and data transfer.

Since the distance for observe the sample is limited, resolution of high speed camera will be set until exceed 5000 frame per second (fps).

Resolution	Max FPS	Record time (sec) (8GB)	Record time (sec) (16GB)
1280 x 1024	1 057	4.13	8.26
1280 x 720	1 502	4.13	8.27
1280 x 512	2 111	4.14	8.27
1280 x 360	2 999	4.14	8.28
1280 x 240	4 489	4.15	8.30
1280 x 120	8 923	4.17	8.35
1280 x 96	11 119	4.19	8.38
1024 x 768	1 771	4.11	8.22
1024 x 576	2 359	4.11	8.23
800 x 600	2 873	4.15	8.30
800 x 480	3 587	4.15	8.31
640 x 480	4 436	4.20	8.40
640 x 360	5 903	4.21	8.42
640 x 240	8 816	4.23	8.45
640 x 120	17 424	4.28	8.56
640 x 96	21 649	4.30	8.61
336 x 252	15 200	4.43	8.87
336 x 190	20 020	4.47	8.94
336 x 120	31 192	4.53	9.07
336 x 96	38 565	4.60	9.20

Figure 3.6 Chronous 1.4 specification

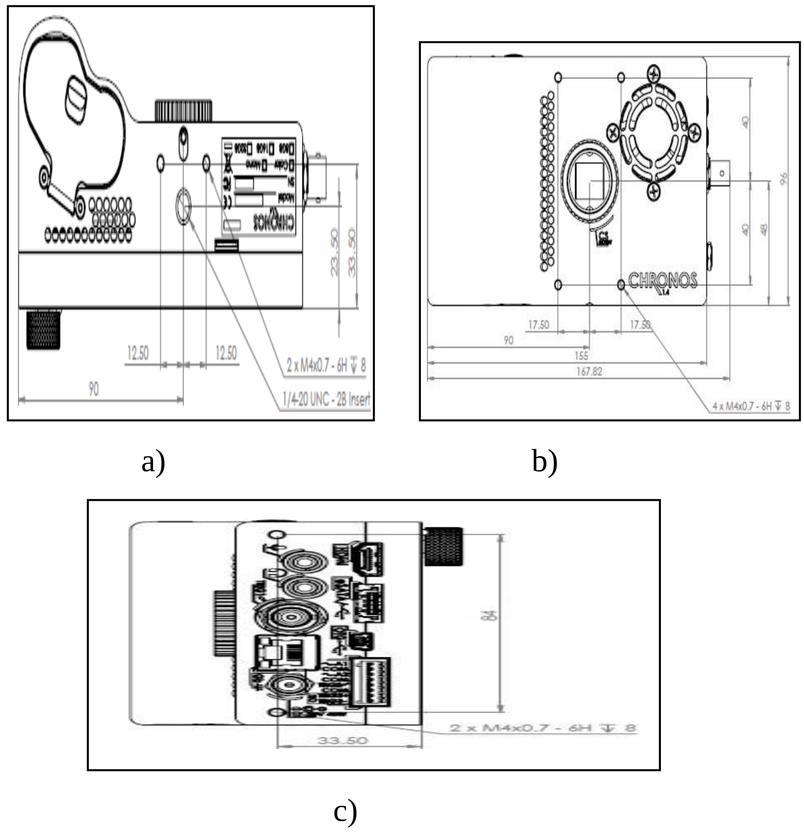


Figure 3.7 Geometry Drawing for Chronous 1.4

a) Top view b)Front view c) Side view

3.9 Overall Project Flow

Using high voltage kit, which is ceramic insulator KN120 and electric field stand. The first step of this research will be to observe how electrical treeing forms and how electrical tracking becomes infected as a result of applied power. Using a Chronous 1.4 high speed camera, with 3-5meters distance while capturing the formation of electric treeing. We will be able to see the formation and existence of electrical treeing and tracking for the purpose of identifying line to ground fault. Electrical tracking and treeing formation will be observed. Because of the prolongation of the tree and the contamination in the tracking phenomenon, the output waveform characteristic electrical treeing and tracking will show at oscilloscope LECROY HDO4024 for the observation and output waveform will then be measured. When a breakdown occurs, the analysis of the output data measure will be redone. The general flow of Figure 3.8 is illustrated.

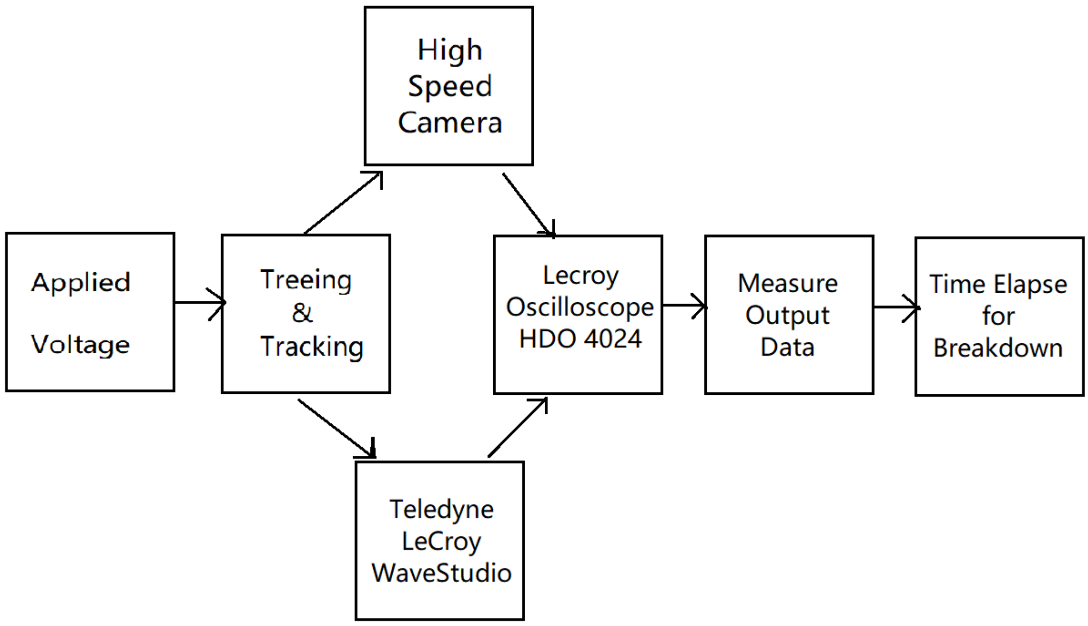


Figure 3.8 General Flow

3.10 Data Measured and Testing

The process of measuring tree growth using a high-speed camera, specifically the Kron Technologies Chronos 1.4, and analyzing the output waveform with the Lecroy HDO4024 oscilloscope involves setting up the camera to capture the growth, connecting the oscilloscope to the camera's external channel, recording the footage while simultaneously capturing the output waveform, transferring the data for analysis, extracting the relevant portion of the footage, configuring the oscilloscope to trigger on light propagation, analyzing the output waveform and measuring parameters using the oscilloscope's tools, and ensuring proper equipment maintenance for optimal performance. This comprehensive approach allows for accurate measurements and insights into tree growth patterns, contributing to our understanding of this natural phenomenon.

Figure 3.9 Teledyne Lecroy Wavesurfer 4000hd High Performance

4-Channel 12-Bit Oscilloscope

3.11 Data Analysis and Result

In this stage, the analysis of the output data and waveform obtained from the formation of electrical treeing and contamination of tracking phenomena will be conducted. The objective is to compare these findings with previous research to ensure consistency and validate the collected data. By comparing the output data, parameters, and waveform characteristics with the results of prior studies, we can verify that our data aligns with established findings. This comparative analysis serves as a crucial step in confirming the reliability and accuracy of the collected data. During the process of collecting the data, it is important to address any problems or issues that may arise. These challenges need to be discussed to prevent any potential discrepancies or biases that could impact the outcomes of subsequent research in this field. By conducting a thorough analysis, comparing results with previous research, we can validate the collected data and contribute to the existing body of knowledge on electrical treeing and contamination of tracking phenomena. This rigorous approach promotes scientific progress and enables future researchers to confidently utilize and build upon the findings of this study.

3.12 Data Verification

The measurement results play a crucial role in verifying the data and achieving the objectives of the project, aligning with the project title as a means of data confirmation. These results serve as a guideline for this research, ensuring the accuracy and reliability of the collected data. In cases where discrepancies or errors occur, testing and measurements will be repeated to rectify any inaccuracies and ensure consistency with the data obtained from previous research. Special attention will be given to preventing data corruption, employing various techniques during the formation of electrical treeing and contamination of electrical tracking using the high-speed camera. This research aims to avoid any disruptions to the high-speed rail service caused by line-to-ground faults, making it imperative to produce acceptable and reliable data.

3.13 Expected Result

According to previous studies, it is expected that the formation of electrical treeing will be directly proportional to the applied voltage. Higher applied voltages will increase the likelihood of breakdown occurrences. The initiation of electrical treeing typically begins with branch-type trees. Furthermore, with higher applied voltages, the time required for breakdown to occur increases due to the rising breakdown voltage indicated by the recorded electric field breakdown. The motion of the high-speed rail can impact the applied voltage, causing an increase in light propagation compared to radio waves. As the electric field breakdown intensifies, light propagation from the applied voltage also increases. This tracking and treeing formation monitoring helps minimise disruptions, especially in electrical distribution networks that might suffer from failures. Additionally, this helps prevent disruptions in high-speed rail transportation services.

3.14 Preparation Report

Once all the data has been thoroughly verified, the final step in this research project is to prepare a comprehensive report. This report will compile all the data analysis findings, focusing on improving the quality of the data compared to previous research. In addition to presenting the analyzed data, the report will also include recommendations for future improvements. These recommendations will serve as a valuable reference for subsequent researchers who wish to build upon and expand this study. By incorporating these recommendations, the report will provide a valuable resource of information for future research endeavors in this field.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

In this section, we will analyse into the comprehensive findings of the project, focusing on the formation of treeing in relation to the elapsed time between applied voltage and the initiation of treeing. This phenomenon leads to the propagation of a treeing channel known as corona discharge, which is directly influenced by the increasing applied voltage. The primary emphasis of this study revolves around the visual observation of treeing formation alongside tracking, as well as the analysis of waveform changes resulting from varying applied voltage. There will be a discussion of parameters related to this study, including peak voltage, amplitude, spike voltage caused by the preliminary breakdown, frame rate for high-speed cameras, and the use of the shutter in high-speed cameras when recording formation treeing and tracking formation due to an increase in applied voltage. The nominal and rated voltages of the ceramic insulator utilised during voltage injection in IVAT Test in UTM, Skudai Johor.

4.2 Results and Analysis

By examining the applied voltage injected through the high voltage apparatus in IVAT in UTM, Skudai Johor and analysing the voltage waveform profile, it is possible to determine when treeing and tracking or the creation of corona discharges initially started. This section will specifically focus to identifying the development of treeing and tracking waveforms, regardless of if they come from line-to-ground or ground-to-line locations, based on their initial ionization-induced manifestation at the ceramic insulator. The Lecroy Oscilloscope HDO4024 and the Chronous 1.4 High-Speed Camera were used to record the data in order to measure the triggered spike voltage and the of treeing and tracking.

4.3 Data Results and Analysis

All of the recorded data has been collected and analysed in this part. The waveform profile for applied voltage, also known as injection voltage, is shown in Figure 4.1. It was captured using a Lecroy HDO4024 oscilloscope. This waveform data was gathered on December 12, 2022, which assisted at the Institut Voltan Dan Arus Tinggi (IVAT) at Universiti Teknology Malaysia (UTM), by using some equipment of Faculty of Engineering Technologies (FTK), UTeM, High Voltage Lab. Teledyne WaveStudio software was used to examine this data. Other data may be analysed by photographic observation with a high-speed camera like the Chronous 1.4 High Speed Camera to see how the ionisation process affects treeing and tracking during corona discharge.

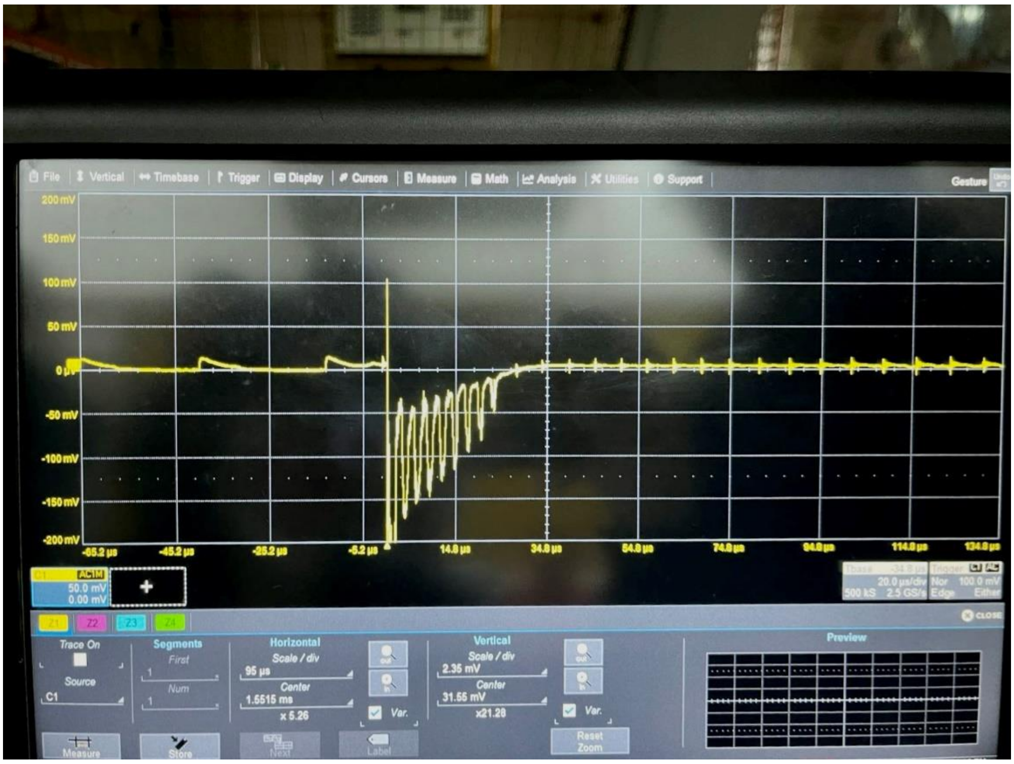


Figure 4.1 Waveform triggerred in Lecroy Oscilloscope

4.4 High Voltage Injection

High voltage will be injected to the ceramic insulator (KN120) to observe the formation of treeing and tracking path during the increment of injection voltage. This project is focused on treeing and tracking of electrical spark which current flow of the spark will be form from High Voltage Terminal(+ve) to the Ground(-ve) of insulator. The ceramic insulator will start sparkles referred in Figure 4.2(a) while voltage injected from 40kV and triggerred at 46kV in wet condition Figure 4.2(b). The humidity also play an important role in this case, if ceramic is in clean and dry condition, there is a few or no spark will be formed. However, ceramic insulator will triggerred and spark easily in wet condition.

(a) (b)

Figure 4.2 (a) Ceramic Insulator start sparkling

(b) Ceramic insulator triggerred in 46kV

The recommended voltage for the particular type of insulator utilised is 33kV, hence the rated voltage of the ceramic insulator employed is 46kV. Since the rated voltage is substantially higher than the nominal voltage, 46kV has been chosen as the appropriate rated voltage for withstand voltage in one minute and is now being installed. With the use of this information, it is possible to establish how ionisation began, whether it was from ground to line or line to ground. By utilising the table of estimation of frequency content from the activity of treeing and tracking, it can be seen that the stage of treeing and tracking was caused by cumulative ionisation, which started from the negative cycle.

4.4.1 Waveform Result of Very High Frequency (VHF)

Based on the table 4.1, the cause of the corona activity starting from ground to line is explained in Figure 4.3, Figure 4.4, Figure 4.5 and Figure 4.6. Given that the mobility of the ions flowing from the ground is lower than that of the ions flowing from the line or positive charge, which creates the spark channel during tracking and causes the formation of tree branches known as treeing, ionisation that causes treeing and tracking start from the ground to the line.

Table 4.1 Estimation of Frequency Content from the Waveform of Activity Treeing And Tracking

Estimation of Frequency Content from the Activity of Treeing And Tracking				
DC INPUT HIGH VOLTAGE RECORD	HIGH VOLTAGE VERY HIGH FREQUENCY (TIME RECORD)	Range of Close up Picture(ms)	Estimation of Time Descrepency between the Interval of 2 Peaks (ns)	Frequency between Interval of 2 Peaks (MHz)
1069	12:27:42	50.24-50.44	100.4, 102.4, 129.2	9.96, 9.76, 7.73
1075	12:27:42	50.24-50.58	82.8, 98.4, 102.4	12.08, 10.2, 9.76
1081	12:27:44	50.31-50.639896	100.4, 104, 130	9.96, 9.6, 7.7
1092	12:27:44	50.4213548-50.7363308	99.2, 104.8, 128.8	10.08, 9.5, 7.8

Figure 4.3 Close-up Peak to peak of waveform Input Pulse 1069.

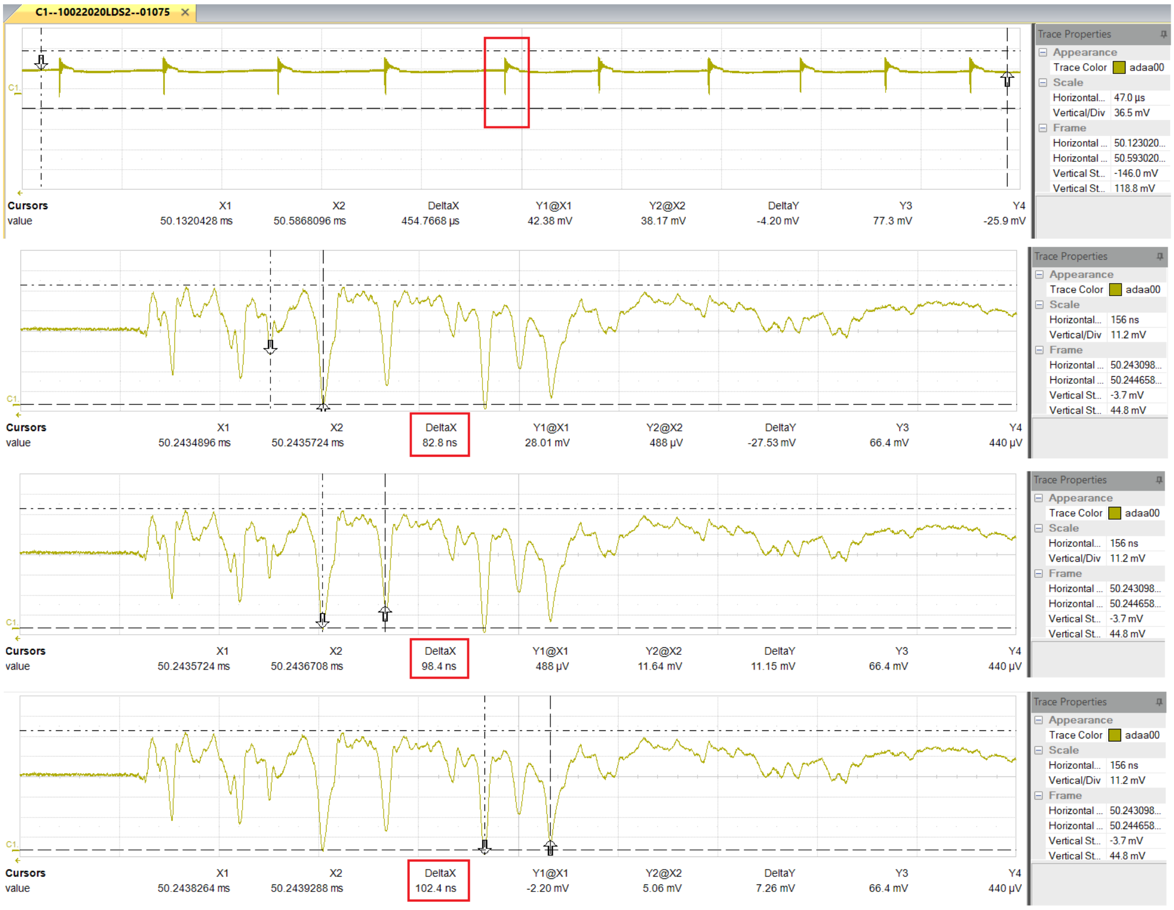


Figure 4.4 Close-up Peak to peak of waveform Input Pulse 1075.

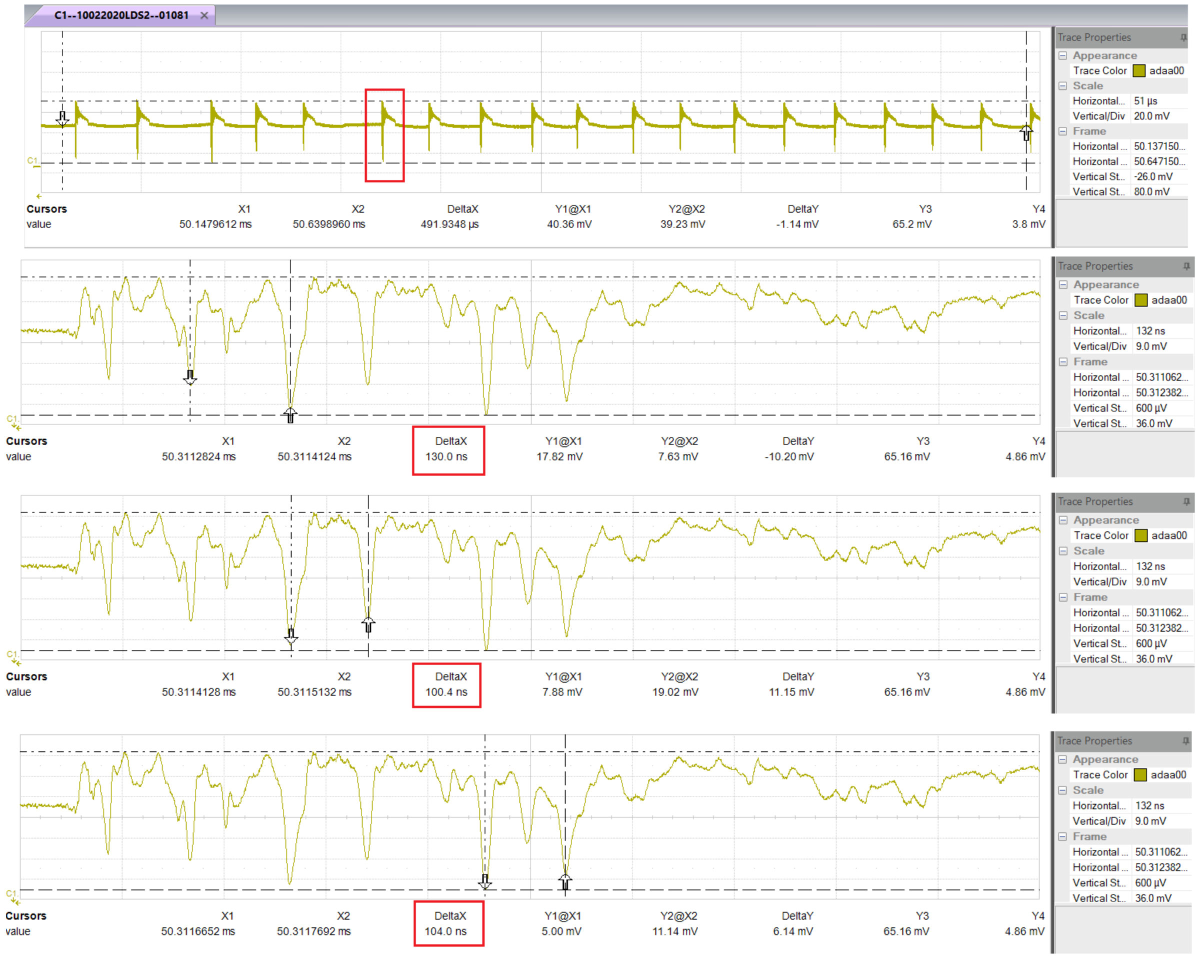


Figure 4.5 Close-up Peak to peak of waveform Input Pulse 1081.

Figure 4.6 Close-up Peak to peak of waveform Input Pulse 1092.

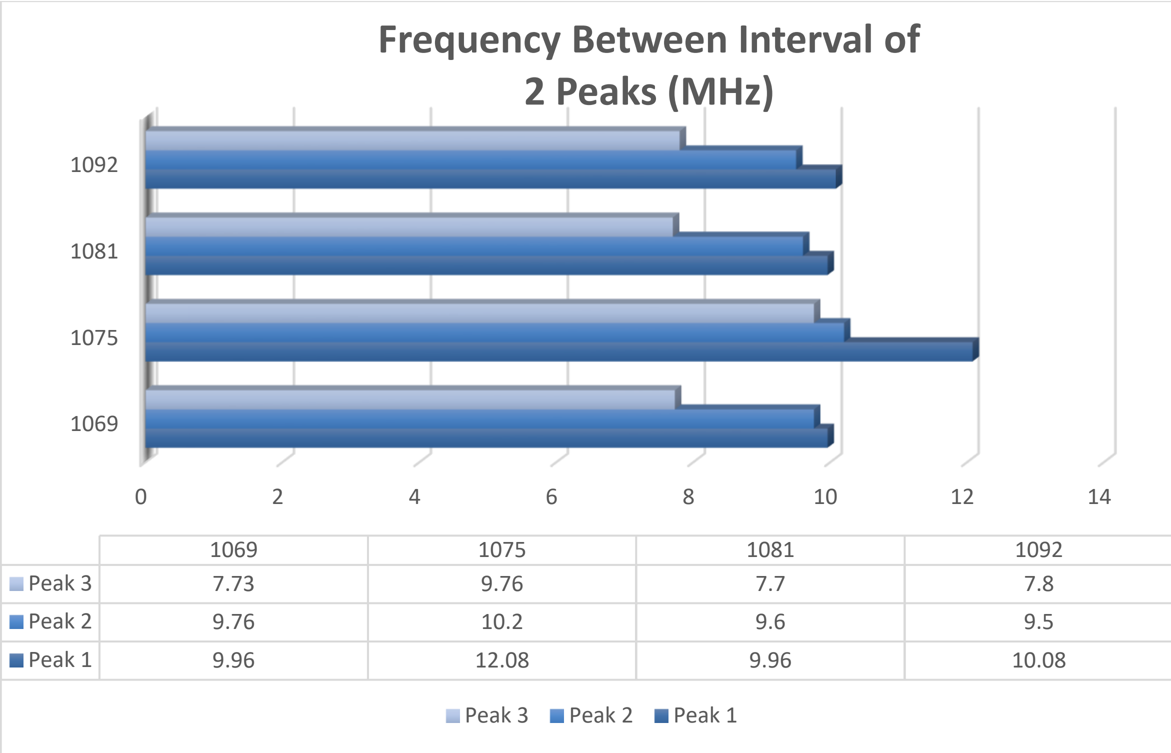


Figure 4.7 Frequency bar chat between interval of 2 peaks

This bar chart in Figure 4.7 is expressing the frequency between the interval of 2 peaks for a waveform and representing voltage triggering at 46kV. There are 4 result which are 1069, 1075,1081 and 1092 contained as refrences. In the case of voltage triggering, the frequency may refer to the rate at which the triggerred insulator is occured. If the waveform represents repetitive voltage triggers occurring at a fixed rate, the frequency between 2 peaks would be equivalent to the repetition rate of the triggers. For example, if the waveform exhibits a consistent pattern with a distinct peak for each voltage trigger and there are 2 such peaks within a specific time interval, then the frequency would be the reciprocal of that time interval.

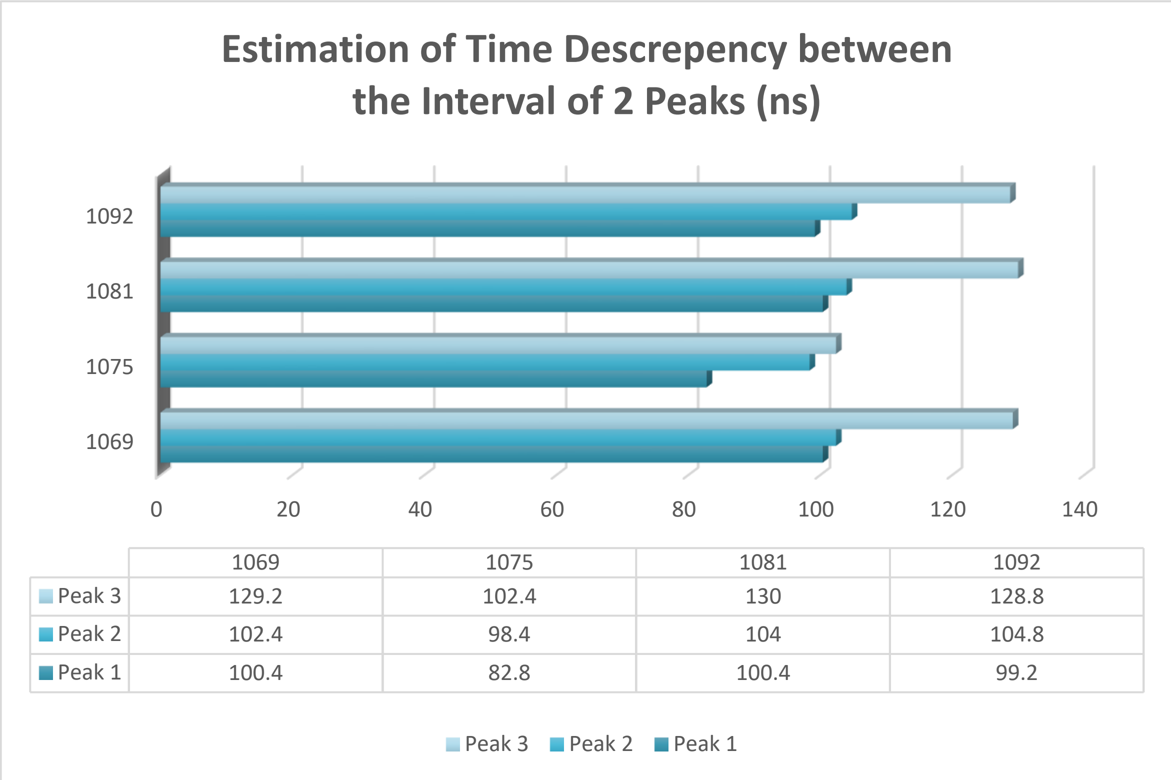


Figure 4.8 Bar Chart of Estimation time descrepancy between interval of 2 peaks

Time discrepancy bar chart Figure 4.8 is expressed the time estimation between the interval of 2 peaks in a waveform. Locate the 2 peaks on the waveform and measure the time discrepancy between to identify the 2 peaks and mark these peaks for reference. The time scale on the waveform display or is for understand the time units being used in nanoseconds (ns). The distance represents the time discrepancy between the 2 peaks could be measure the time difference by the cursor in Teledyne WaveStudio. The time differences of these 4 results have been conducted as the table for easier result compare. The measured distance was onverted into the corresponding time discrepancy based on the time units indicated on the time axis.

4.4.2 Waveform Result of Input Pulse

Based on the table 4.2, the waveform result of an input pulse typically represents the variation of a signal over time. Waveform 1208, 1256, 1304 and 1337 will be shown as references. The shape of the pulse waveform shows the signal changes over time. It can vary depending on the specific pulse characteristics, such as the rise time, the pulse width and the fall time. To get DC voltage input will need to *1.4142 which rely from AC voltage input. It indicates the maximum voltage or current reached during the pulse. The duration of the pulse waveform refers to the time interval over which the pulse occurs. It can be measured from the beginning of the rise time to the end of the fall time. The pulse waveform may be subject to noise, interference, or distortions that can affect its shape or clarity. These factors can introduce additional variations and make it challenging to accurately analyze the pulse characteristics. The result are contained in Figure 4.9, Figure 4.10, Figure 4.11 and Figure 4.12.

$$\boxed{\textit{DC Output Voltage} = \textit{AC Input Voltage} \times 1.4142}$$

Figure 4.9 Equation of AC voltage convert to DC voltage.

Table 4.2 Triggerring Time with AC input voltage

No File	Triggering time	Input Voltage (AC)kV	Input Voltage (DC)kV	Average Input Voltage(DC)	Peak Voltage Variation due to Treeing & Tracking Activity
1208	**12:14:06**	**19.53**	**27.62**	27.64	24.68-29.12
1256	**12:14:22**	**20.78**	**29.38**	28.88	27.59-30.01
1304	**12:14:38**	**30.95**	**43.77**	30.02	24.57-43.77
1337	**12:14:50**	**15.35**	**21.71**	23.04	21.71-25.38

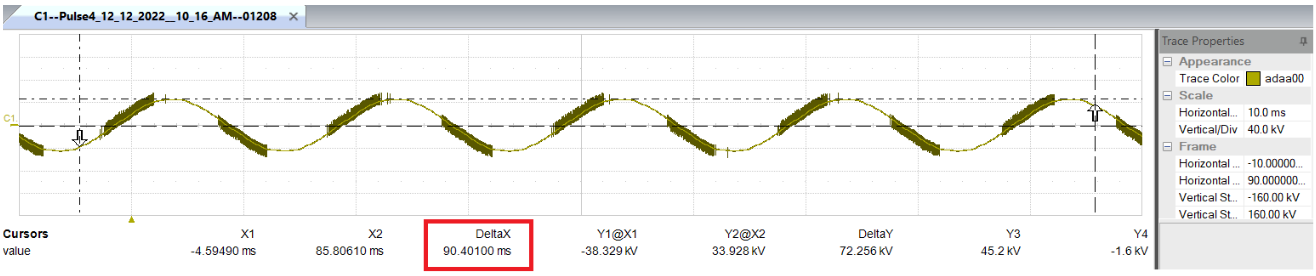


Figure 4.10 Close-up Waveform result AC input voltage 1208.

Figure 4.11 Close-up Waveform result AC input voltage 1256.

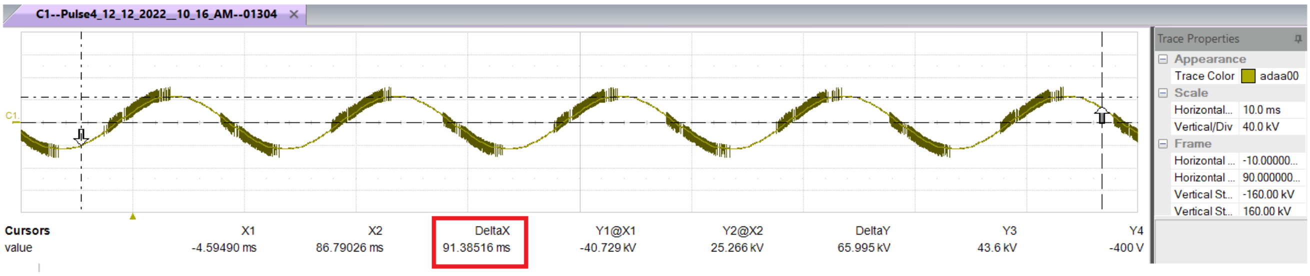


Figure 4.12 Close-up Waveform result AC input voltage 1304.

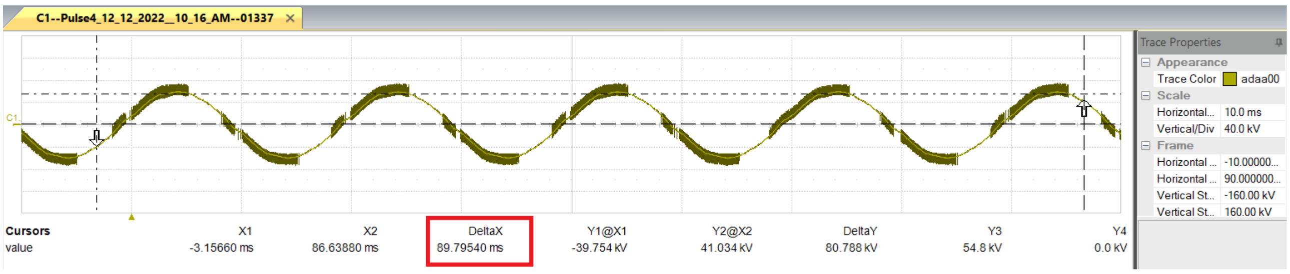
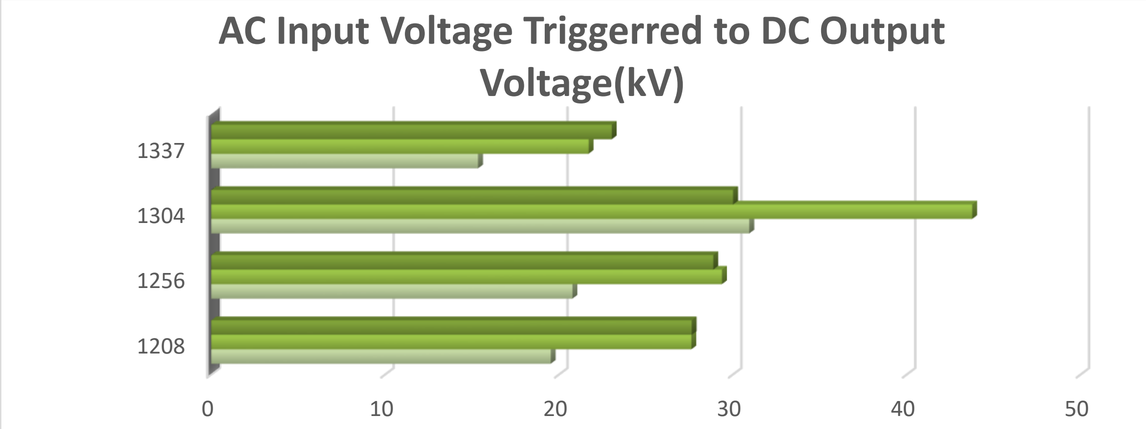


Figure 4.13 Close-up Waveform result AC input voltage 1337.



	1208	1256	1304	1337
Average VDC	27.64	28.88	30.02	23.04
Output VDC	27.62	29.38	43.77	21.71
Input VDC	19.53	20.78	30.95	15.35

Average VDC Output VDC Input VDC

Figure 4.14 Waveform Bar Chart AC input triggerred to DC output voltage.

This AC input voltage is conduct from Lecroy Oscilloscope HDO4024. The amplitude (peak voltage) and frequency of the AC input voltage depend on the electrical system's specifications. To convert from AC to DC, it's involves converting the negative half-cycles (-) of the AC waveform into positive half-cycles (+). This process is achieved using a diode or a combination of diodes in a rectifier circuit. The diode allows current flow in only one direction, effectively removing the negative portion of the input waveform. As a result, the output waveform consists of positive half-cycles. output waveform still contains ripple voltage even after the current flow. A smoothing capacitor is employed to smooth out this ripple and obtain a more constant DC voltage. The capacitor stores charge during the peaks of the rectified waveform and releases it during the lower points, effectively reducing the voltage variations.

4.5 Treeing Triggered at 46kV

This part will presents about the ceramic insulator's ability to resist 33 kV of rated power for one minute. The type of insulator employed during the testing is 33kV since the nominal voltage is the voltage that has been established by the producer of ceramic insulator. The nominal voltage must be higher than the rated voltage. Ceramic insulators for overhead power lines with nominal voltages more than 10 kV have been designated as having an appropriate rated voltage of 46 kV. To ensure that there will be no interruption when the voltage exceeds the 46kV rated voltage and to prevent any corona activity under these circumstances, withstand voltage testing for the 46kV rated voltage is conducted in one minute.

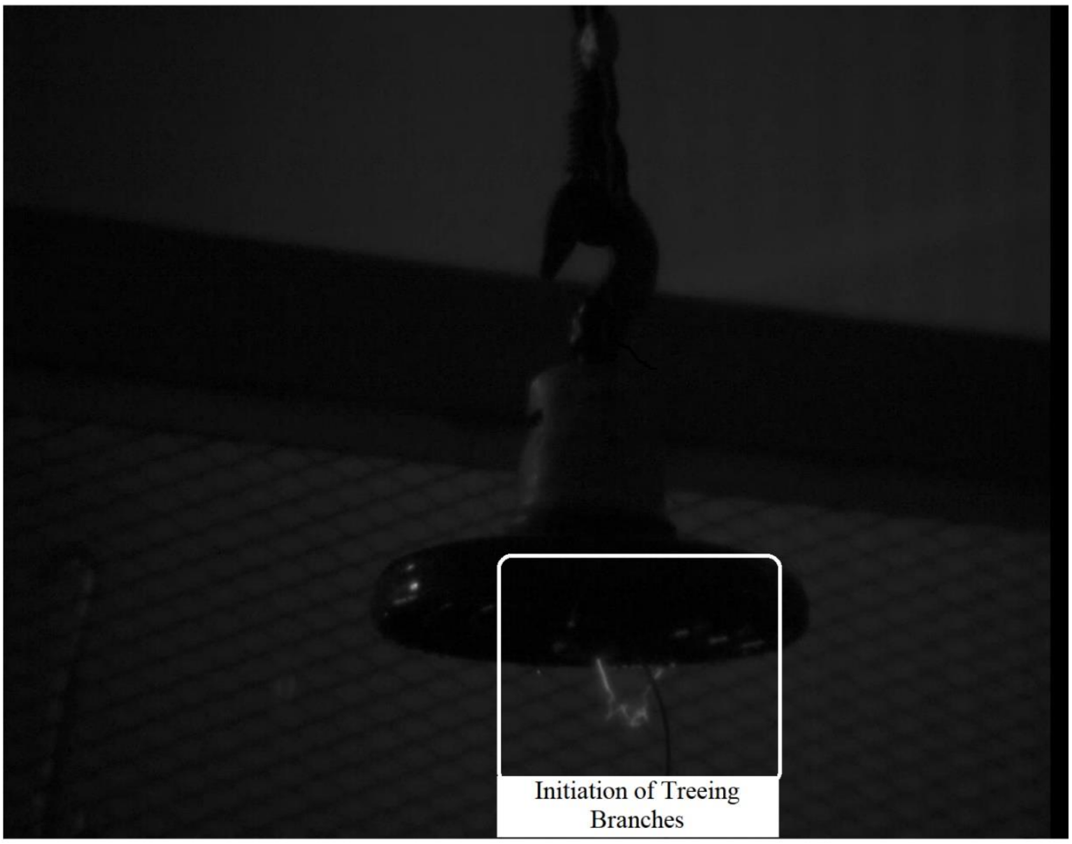


Figure 4.15 Branch-Bush tree of is formed at insulator.

The presence of formation for treeing and tracking is form due to the ionization process while injection of 46kV voltage. Hence, the insulator is in good condition due to the properties of the insulator has no any interruption during the withstand voltage testing of 33kV in one minutes. Figure 4.9 prove that the measured waveform using Lecroy Oscilloscope is same with the character that has been recorded with the Chronous 1.4 High Speed Camera with frame rate 5 frame per second with frame resolution 1280x1024 1057 fps which is there is triggerred of high voltage which presence the formation of treeing and tracking at the ceramic insulator during in IVAT, UTM. The process of onization cannot observe using human eyes. Therefore, high speed camera is used to observed the formation associated with the Lecroy Oscilloscope HDO4024.

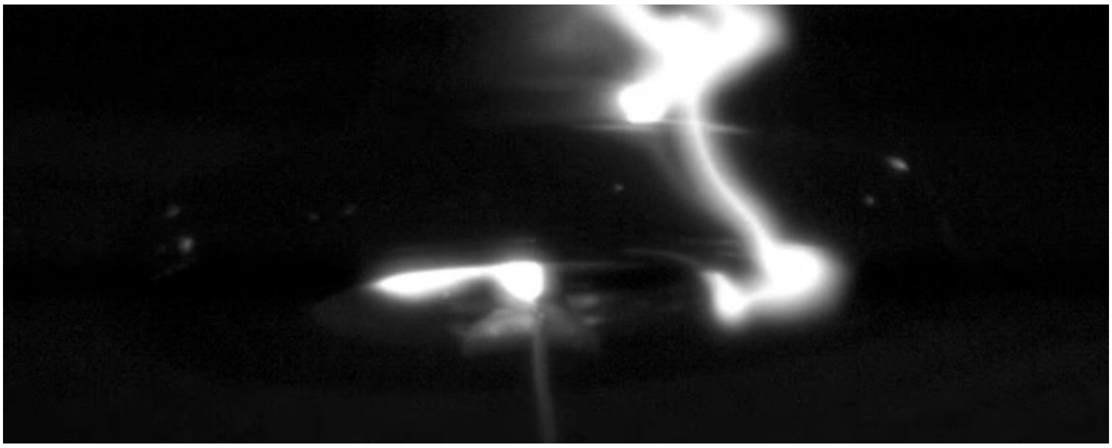


Figure 4.16 Vented Type of Treeing

Vented type lightning is a specific form of cloud-to-ground lightning discharge that exhibits a distinct channel or vent structure during its formation. Figure 4.15 shows formation in vented type has been recorded by Chronos 1.4 High-Speed Camera during the voltage injection at 46kV with frame rate 5 frame per second with 1280 x 1024 1057 fps resolution.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter provides a comprehensive overview and final analysis of the research conducted. It encompasses the entire process involved in completing the study, including the challenges encountered and the limitations encountered while observing the formation of treeing and tracking resulting from the corona discharge's ionization process. Additionally, it covers pertinent details concerning the duration of the corona activity.

5.2 Project Summary

The occurrence of electrical treeing and tracking, along with the resulting contamination, can lead to breakdowns in high voltage systems. By observing the formation of electrical treeing, it is possible to gain insights into reducing the likelihood of breakdowns in high voltage systems, especially in the context of line-to-ground faults and high-speed rail operations. It is crucial to control the applied voltage within permissible limits to prevent the formation of vented tree structures that can ultimately cause breakdowns. This project focused on observing the formation of electrical treeing and tracking to determine the duration of corona activity and measure the spark voltage generated during the ionization process, which leads to the formation of treeing structures. The elapsed time of the corona activity was determined to be 20 milliseconds per division. The Chronous 1.4 High-Speed Camera was utilized for observing treeing and tracking formation resulting from corona activity. The Lecroy Oscilloscope HDO 4024 was used to record data for measuring the elapsed time of treeing and tracking formation in relation to the spark voltage produced. Lecroy HDO4024 oscilloscope also recorded the initiation of corona activity. The research took place at the Institusi Voltan dan Arus Tinggi(IVAT), Universiti Teknologi Malaysia. Overall, the collected and recorded data were processed to determine important parameters related to the duration of corona activity and the spark voltage. Xviewer software was utilized for data analysis, focusing on parameters such as peak amplitude breakdown voltage level, elapsed time, and duration of corona activity. Additionally, WaveStudio Software was used to identify the initiation of the ionization process leading to corona discharge activity.

5.3 Project Objective Achievement

The objective of this project was to observe the forming of electrical treeing patterns as they developed, leading to breakdown, based on the puncture voltage. The project successfully achieved all its goals, as both the high-speed camera and oscilloscope performed effectively in capturing and recording the signals. Before commencing the research, a thorough understanding of solid dielectric breakdown and high voltage systems was acquired to enhance knowledge and comprehension. document the formation of treeing and tracking caused by contamination on the porcelain disc insulator, the Chronos 1.4 high-speed camera was employed. By analyzing the data captured by the oscilloscope, the duration of treeing formation due to contamination tracking, along with the highest peak of corona activity, was determined through basic calculations and simulations using oscilloscope software. This project expanded knowledge and understanding of solid dielectric breakdown, high voltage systems, and the methodologies involved in capturing and analyzing relevant data.

5.4 Constraint While Project Running

During conducting this research, there are numerous issues were encountered while doing the research. First, High Voltage Lab in UTeM has been contraint due to the unexpected flood in pass year, Project will be conduct in IVAT UTM, Johor. Althought the project will be conduct in IVAT, their cooper was oxidize due to the humidity because there’s long raining season at Johor. As a result, the usage of high-speed cameras is restricted to 10000 frames per second, tree structures are growing too quick to be observed. High speed cameras require manual recording since they could not automatically activate. It would be unsafe to record thus close to an insulator. Others must utilise more than one high-speed camera to examine the ceramic insulator's both sides which is the view of iron cap and the pin in order to capture the creation of treeing and tracking.

5.5 Suggestion in Future Research of This Project's

In terms of future research, there are several recommendations based on the identified issues and areas for improvement. Firstly, it is suggested to enhance the functionality of the high-speed camera by incorporating automatic triggering of signal recording in parallel with the noise generated by corona activities. This would enable more precise synchronization and accurate data capture. Additionally, it is advisable to utilize at least two high-speed cameras in order to observe the formation of treeing at different locations. Specifically, attention should be given to the iron cap of the insulator, situated at the bottom of the ceramic insulator, as well as the area near the ball pin located at the bottom of the ceramic insulator. By incorporating multiple camera angles, a more comprehensive understanding of the treeing formation can be obtained. These proposed modifications and refinements will contribute to enhancing the accuracy and effectiveness of future research endeavors in this field.

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APPENDICES