الآية

قال تعالى:

﴿قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ﴾

صدق الله العظيم

سورة البقرة الاية (٣٢)

DEDICATION

To generous parents who cultivated in us the love of knowledge and patience over adversity, may god grant them health, wellness and long life.

To those who support us in our studies and shared our concerns as a memorial and appreciation

To dear teachers and colleagues

To family

To every engineering student

To everyone who is burning like a candle to enlighten the path for others

We dedicate this effort

ACKNOWLEDGMENT

First we thankful to our GOD for helping us to accomplish this project, we also thankful and fortunate enough to get constant encouragement, support and guidance from teaching staff of Electrical Engineering Department especially **Ust. Jafar** which helped us in successfully complete our project work. Also, I would like to extend our sincere esteems to all staff in Transformer Factory and Sudanese Electricity Distribution Company especially Maintenance Department for their timely support.

ABSTRACT

The performance of insulators used on overhead transmission lines and overhead distribution lines is a key factor in determining the reliability of power delivery systems. The insulators not only must withstand normal operating voltage, but also must withstand over voltages that may cause disturbances, flashovers and line outages.

Some power system networks designed without consideration to insulators length and characteristics which should adjusted according to the relevant contamination conditions of the area crossed by the lines to eliminate under design or over design scenarios. By analysis of the current networks and compare the installed insulators characteristics with the requirement of the international and local standards the insulators length and characteristics will be adjust to eliminate the possibilities of frequent flashover voltages alongside analysis the benefits of using new polymer insulators. Insulator selection for overhead transmission lines and overhead distribution lines is an exercise which requires specific considerations given the particularity of the application. Insulators for AC lines are made with specific dielectric materials, and this project presents the key and fundamental attributes of these insulators. Additionally, the insulator length and characteristics, such as leakage distance, have to be adjusted according to the relevant contamination conditions of the area crossed by the line hence the reduction in the performance of outdoor insulators occurs mainly by the pollution of the insulating surfaces from air-borne deposits that may form a conducting or partially conducting surface layer especially when wet.

Guidance is given in this project to help understand the process of definition of insulators for an AC application and its Electrical & Mechanical Ratings and testing. Using examples from Sudanese electricity Distribution Company and Sudanese transmission line company as case study.

المستخلص

يعد أداء العوازل المستخدمة في خطوط النقل و التوزيع عاملاً رئيسيًا في تحديد موثوقية أنظمة نقل الطاقة. لا يجب أن تتحمل العوازل جهد التشغيل العادي فحسب ، بل يجب أيضًا أن تتحمل الجهد الزائد الذي قد يتسبب في حدوث اضطرابات ، ومضات كهربائية ، وانقطاع في الخطوط. بعض انظمة القدرة الكهربية تم تصميمها دون النظر إلى طول العوازل وخصائصها والتي يجب تعديلها وفقًا لظروف التلوث ذات الصلة للمنطقة التي تعبرها الخطوط لإزالة سيناريوهات التصميم أو التصميم الزائد.

من خلال تحليل الشبكات الحالية ومقارنة خصائص العوازل المركبة بمتطلبات المعايير الدولية والمحلية ، سيتم تعديل طول وخصائص العوازل للتخلص من احتمالات تفريغ الجهد الكهربائي المتكرر إلى جانب تحليل فوائد استخدام العوازل الجديدة من مادة البوليمر.

يعد اختيار العازل لخطوط النقل و التوزيع الهوائية تمرينًا يتطلب اعتبارات محددة نظرًا لخصوصية التطبيق. يتم تصنيع عوازل خطوط التيار المتردد من مواد عازلة محددة ، ويقدم هذا المشروع السمات الأساسية والمفتاحية لهذه العوازل.

بالإضافة إلى ذلك ، يجب تعديل طول وخصائص العوازل ، مثل مسافة التسرب ، وفقًا لظروف التلوث ذات الصلة للمنطقة التي يعبرها الخط ،و التي تعتبرالعامل الرئيسي في إنخفاض أداء العوازل الخارجية بشكل أساسي عن طريق تلوث الأسطح العازلة من الهواء عن طريق الرواسب المحمولة التي قد تشكل طبقة سطحية موصلة أو موصلة جزئيًا خاصة عندما تكون رطبة.

يتم تقديم التوجيه في هذا المشروع للمساعدة في فهم عملية إختيار العوازل لشبكات التيار المتردد وتحليل خصائصها الكهربائية والميكانيكية وإختبارها.تم استخدام أمثلة من الشركة السودانية لتوزيع الكهرباء والشركة السودانية لنقل الكهرباء كدراسة حالة.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CRM	Certified Reference Material
ESDD	Equivalent Salt Deposit Density
FAT	Factory Acceptance Test
SAT	Site Acceptance Test
IEC	International Electro-technical Commission
NCIS	Non Ceramic Insulators
SEDC	Sudanese Electricity Distribution Company
SIR	Silicone Rubber

CHAPTER ONE

INTRODUCTION

1.1 Preface

The performance of insulators used on overhead transmission lines and overhead distribution lines is a key factor in determining the reliability of power delivery systems. The insulators not only must withstand normal operating voltage, but also must withstand over voltages that may cause disturbances, flashovers and line outages.

Insulator selection for overhead transmission lines and overhead distribution lines is an exercise which requires specific considerations given the particularity of the application. Insulators for overhead lines are made with specific dielectric materials, and this project presents the key and fundamental attributes of these insulators. Additionally, the insulator length and characteristics, such as leakage distance, have to be adjusted according to the relevant contamination conditions of the area crossed by the line hence the reduction in the performance of outdoor insulators occurs mainly by the pollution of the insulating surfaces from air-borne deposits that may form a conducting or partially conducting surface layer when wet. Guidance is given in this project to help understand the process of definition of insulators for an AC application and its Electrical & Mechanical Ratings and testing. Calculations were performed according to the international relevant standards values. Sudan national networks consist of many overhead lines from 11-33 KV in distribution network level and from 110 KV up to 500 KV in transmission network level which crossing a varying environmental climate, the reliability of this network depend on how effective its insulators behave in this different climates and how good they were designed and maintained, This reliability could be enhanced by designing a compatible network for every environmental case. Flashovers happening in high-voltage electric power transmission systems caused huge losses to Society, estimated at 80–100 billion dollars just in the USA [1], According to statistics from the power industry in China, Contamination flashovers ranked second in the occurrence of power accidents and ranked first in the cost of power accidents in 2001, in Brazil in 2009 a blackout cause by insulators failure left an estimated 87 million residents without power.

1.2 Problem Statement

Some power system networks designed without consideration to insulators length and characteristics which should adjusted according to the relevant contamination conditions of the area crossed by the lines to eliminate under design or over design scenarios.

1.3 objectives

- To analyze the design and selection criteria for overhead lines Insulators to be used in the design of the power system networks that are so reliable and flexible with the minimum contamination flashovers and outages.
- To reduce the overall cost when designing new networks and eliminate overdesign cases.

1.4 Methodology

First some references and related work have been collected and reviewed. Then the overhead line distribution line has been determined (Elhuda 11KV overhead line) located in Bahri) and the types of the insulator to be used was selected (polymeric and porcelain).After that the suspension was prepared according to IEC standard 60060-1 in order to achieve a layer with specific conductivity.

Finally practical test has been conducted and the behavior of the insulator has been observed.

1.5 Project Layout

Chapter one provides essential background. Chapter two discusses the electric field in general way and the basic insulators design & selection. Chapter three illustrates the pollution flashover process, effect of various aspects on pollution accumulation and provides an overview of power quality system. Chapter four with implementation of the IEC and SEDC testing procedures provides the data analysis of the typical insulators and their behavior under polluted condition. Chapter five provides recommendations and conclusion.

CHAPTER TWO

ELECTRICAL INSULATORS

2.1 Introduction

Insulator is defined as a material or an object that does not easily allow heat, electricity, light or sound to pass through it .Air, cloth and rubberier are good electrical insulators.

The purpose of the insulator or insulation is to insulate the electrically charged part of any equipment or machine from another charged part or uncharged metal part. At lower utilization voltage the insulation also completely covers the live conductor and acts as a barrier and keeps the live conductors unreachable from human being or animals. In case of the high voltage overhead transmission and distribution the transmission towers or poles support the lines, and insulators are used to insulate the live conductor from the transmission towers. The insulators used in transmission and distribution system are also required to carry large tensional or compressive load. Flashovers or High-voltage breakdown happening in high-voltage electric power transmission systems caused huge losses to Society, estimated at 80–100 billion dollars just in the USA [1].

2.2 Electrical Insulator History

Electrical insulator is a material which has a very small numbers of mobile electric charges, these electric charges under influence of an electric field will have a very little current to flow[8].The history of insulators began together with the development of electrical communications or the

Telegraph Lines. Ceramic materials and rubber have been used in insulators from late **1700s**, early **1800s** for low DC voltage, in **1840** glass plates used to insulate telegraph line DC to Baltimore; in **1850** the first porcelain post insulators were introduced. A few years later, in **1858**, glass pin-type insulators appeared ,in **1893** wet process porcelain developed for high voltage applications,. At the beginning of the 20th century, suspension insulators became available, and by **1910**, cap and pin insulators already had geometrical designs very similar to those seen today. Between **1920** and **1950**, there was an almost explosive development of different insulator types and designs with the overall goal to increase performance under contaminated conditions. The concepts employed to achieve this were different and sometimes quite unexpected. Most often, designers developed geometry of the insulator so as either to enlarge creepage or to increase the self-washing property [8].The history of polymeric insulators began in the 1940s when organic insulating materials were used to manufacture high voltage indoor electrical insulators from epoxy resins. These materials were light weight, impact resistant, and could be used to form large complex parts .Polymeric insulators for outdoor use were made feasible by the discovery in the **1950s** that alumina trihydrate filler increases the tracking and erosion resistance of the polymer material .However, polymeric insulators for outdoor application on transmission lines were not developed until the late **1960s** and **1970s**. Polymeric insulators finally came into general use on transmission lines in the **1980s**.The first polymers used for electrical insulation were bisphenol and cycloaliphatic epoxy resins. Introduced commercially in the mid **1940s**, bisphenol epoxy resins were the first polymers used for electrical insulation, and are still used to make electrical insulators for indoor applications. Cycloaliphatic epoxys (CE) were introduced in **1957**, and were introduced in England for outdoor insulation in **1963** .They is superior to bisphenol because of their greater resistance to carbon formation. However, the first commercial CE insulators in the U.S. failed shortly after installation in outdoor environments. Since then, new CE formulations have resulted in improved electrical performance .In the early **1960s**, distribution class (CE) insulators were first sold commercially in the U.S. under the name GEPOL. These units failed due to surface damage and punctures. CE was used later in experimental 500 kV station breaker bushings, and in 115 kV bushings in the **1970s**, and for suspension insulators by Transmission Development Limited (TDL) of England [1]. The TDL suspension insulators used slant sheds to provide natural washing of contamination. From the mid**1960s** on, CE insulators were tested at up to 400 kV service voltage as suspension/strain insulators and cross-arms in the United Kingdom. For various reasons, including poor cold temperature performance and insufficient weight reduction, CE did not gain acceptance in the US for outdoor high voltage suspension insulators. But today, CE is used in indoor and even semi-enclosed power systems [8],. In the **1960s** an insulator having porcelain sheds supported by an epoxy resin fiberglass rod was developed. It was not widely used because of developments in lighter weight polymeric insulating materials.

Polymeric outdoor insulators for transmission lines were developed as early as **1964** in Germany, and by other manufacturers in England, France, Italy, and the U.S. In Germany, units for field testing were provided in **1967**. In the late **1960s** and early **1970s**, manufacturers introduced the first generation of commercial polymeric transmission line insulators. The composite insulators were widely used from the **1980's** and the usage increased rapidly in the **1990's.** In **1980**, Furukawa Electric was engaged in the development of inter-phase spacers to prevent galloping in power transmission lines, and at that time developed composite insulators that had the required light weight and flexibility. In **1991** the first composite insulators having a SIR housing were used as inter-phase spacers for 66 kV duty, and in **1994** their use was extended to 275 kV service with a unit 7 m in length. Excellent contamination and wetting performance, high ratios of strength to weight, vandalism resistance, easy transport and installation and obvious cost advantages over conventional ceramic insulators, especially in extra HV and ultra HV lines, are great attractions for utilities.

2.3 Overview of Electrical Field Calculation

When the electric field in a system becomes high High-voltage breakdown occurs, Electric field is the potential gradient, or the rate at which the voltage changes per unit length. It has many names: electric field strength, electric field intensity, stress, or just *E*[13],. It is expressed in units of V m^{-1}, kV m^{-1}, kV mm^{-1}, kV cm^{-1} or MV m^{-1}.Materials with negligible electrical conductivity and high polarize ability are referred to as “dielectric materials.” Such materials do not possess free charges. However, they become polarized upon the application of an external electric field [13].The figure below shows illustration of electric field:

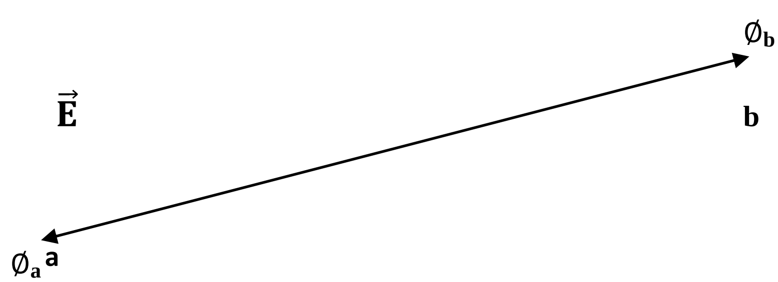


Figure 2.1: Illustration of electric field

In Figure2.1**,** the potential difference **Uab** between two points **a** and **b** having scalar potential ∅**a** and ∅**b** in an electric field $\vec{\mathbf{E}}$, is defined as the work done by an external source in moving a unit positive charge from **b** to **a**.

$$Uab=-\int_{b}^{a}[\vec{E}]dx=(\phi a-\phi a) \qquad (2.1)$$

The magnitude of electric field intensity is given by the rate of change of potential with distance. The maximum magnitude of the field intensity is obtained when the direction of $\vec{\mathbf{E}}$ is opposite to the direction in which the potential is increasing most rapidly,

$$\frac{duab}{dx}max=-[\vec{E}]max \qquad (2.2)$$

field intensity from the scalar potential ∅ . The operator ∅ on by which is $\vec{E}$ obtained is thus known as the gradient. The relationship between ∅ and $\vec{\mathbf{E}}$ is written as:

$$\vec{E}=-\nabla\emptyset \qquad (2.3)$$

Knowing the electric field strengths present in a high-voltage system is essential to predicting its performance. Electric fields can be calculated using equations.

- **Maxwell's equations for Static Fields**

Maxwell's equations are a set of four equations that completely describe the relationships between electric and magnetic fields. They define not only the shape and strength of the electromagnetic field, but also how it varies with time. The equations can be expressed in different ways, but the most compact form is in differential notation:

$$\nabla\times E=-\frac{\partial \mathbf{B}}{\partial t} \quad (2.4)$$

$$\nabla\times H=J+\frac{\partial \mathbf{D}}{\partial t} \quad (2.5)$$

$$\nabla\cdot B=0 \quad (2.6)$$

$$\nabla\cdot D=\rho \quad (2.7)$$

Where:

E is the electric field strength (V/m),

B is the magnetic flux density (Weber/m^2),

H is the magnetic field strength (ampere/m),

J is the current density (ampere /m^2),

D is the electric flux density (coulomb/m^2),

$\boldsymbol{\rho}$ is the charge density (coulomb /m^3),

Equation (2.1) describes how a time-varying magnetic field generates an electric field. It explains how electrical generators work. It is the differential form of Faraday's law of induction [13]. Equation (2.2) describes how electrical currents produce magnetic fields. It explains how electromagnets and motors work [13].Equation (2.3) describes the shape of the magnetic field, which states that the flux of B through a closed surface is zero[13].Equation (2.4) describes the shape of the electric field in the presence of electrical charges. Both point and diffuse charges can exist. It is the differential form of Gauss's law [13].When subjected to an external electric field, the molecules or atoms of a dielectric material undergo charge separation. The electron cloud of a molecule shifts in one direction and the positive ion core shifts in the opposite direction. Consequently, the molecules behave as electric dipoles, and the induced dipole field opposes the applied field. In the case of polar dielectric materials, the molecules or atoms possess a permanent dipole moment. These dipoles are randomly oriented in the absence of the external electric field. Upon the application of the electric field, the permanent dipoles become aligned with the applied field [13]. The key property of a dielectric material is the absolute dielectric permittivity (**ε**), which is related to electric susceptibility (**χ**) as follows:

$$\varepsilon=(1+\chi)\varepsilon_0 \tag{2.8}$$

The flux densities and the field densities are related through the constitutive relations. For linear and isotropic media, the constitutive equations are needed to fully describe the electromagnetic behavior of a given material medium. The constitutive equations are as follows:

$$D=\varepsilon E=\varepsilon_0\varepsilon_r E \tag{2.9}$$

$$B=\mu H=\mu_0\mu_r H \tag{2.10}$$

$$J=\sigma E \tag{2.11}$$

Where:

ε is the permittivity of the media (dielectric constant) (F/m),

ε_0 is the free space permittivity,

ε_r is the relative permittivity,

μ is the permeability of the media (H/m),

μ_0 is the free space permeability,

μ_r is the relative permeability,

σ is electrical conductivity,

2.4 Approach for Insulator Selection and Dimensioning

Electrical insulator is use to:

i. Maintains an air gap.
ii. Separates line from ground.
iii. Support the line mechanically.
iv. Resists mechanical stresses like everyday loads, extreme loads.
v. Resists electrical stresses like system voltage/fields, over voltages.
vi. Resists environmental stresses like heat, cold, UV, contamination, etc.

Insulator surfaces are the weakest point of any high-voltage system [8].and care must be taken in their design, the process of insulator selection and axial dimensioning together with its influencing parameters is shown in Figure 2.2.The flow chart in this figure forms the basis of this review document for which an overview is given below [11]. The process of insulator selection starts with the collection of the basic data consisting of information on:

- Insulator application.
-Insulator characteristics.
- Power system parameters.
-The environment.
- Constraints.
- Field performance.

- The application of the insulator is an important aspect from the pollution performance viewpoint as it determines both the radial dimension and the orientation of the insulator.
- An integral part of the basic data is the characteristics of the available insulators.
- Power system parameters that form part of the basic data consist of:
- The electrical environment in which the insulator is applied, i.e. AC or DC. Voltage; maximum system voltage; and lightning, switching and temporary over voltages and their effects on insulator performance.
- The performance required from the insulator. This is determined mainly by power quality criteria such as the power system’s sensitivity to outages [11].
- Each environment where the insulators are to be installed has a different set of conditions under which the insulator must operate reliably.

An insulator that has a good performance under one set of conditions might have a bad performance in a different set of conditions. It is therefore necessary to characterize the environment in terms specific to insulator performance [11].

- **Constraints** may also influence the selection of insulators. For example, limitations on the width of the right of way may dictate the use of structures for which special insulator designs are required. In such cases, the range of available insulators may be restricted [11].
- **Field performance** of insulators in service is an invaluable source of data for future applications. Unfortunately, these data are not always available; service experience is usually a very important component of the basic data since it forms the basis for determining whether the selection of a particular insulator leads to acceptable performance [11].

  The following flow chart provides an overview of process of insulator selection as shown in Figure 2.2 :

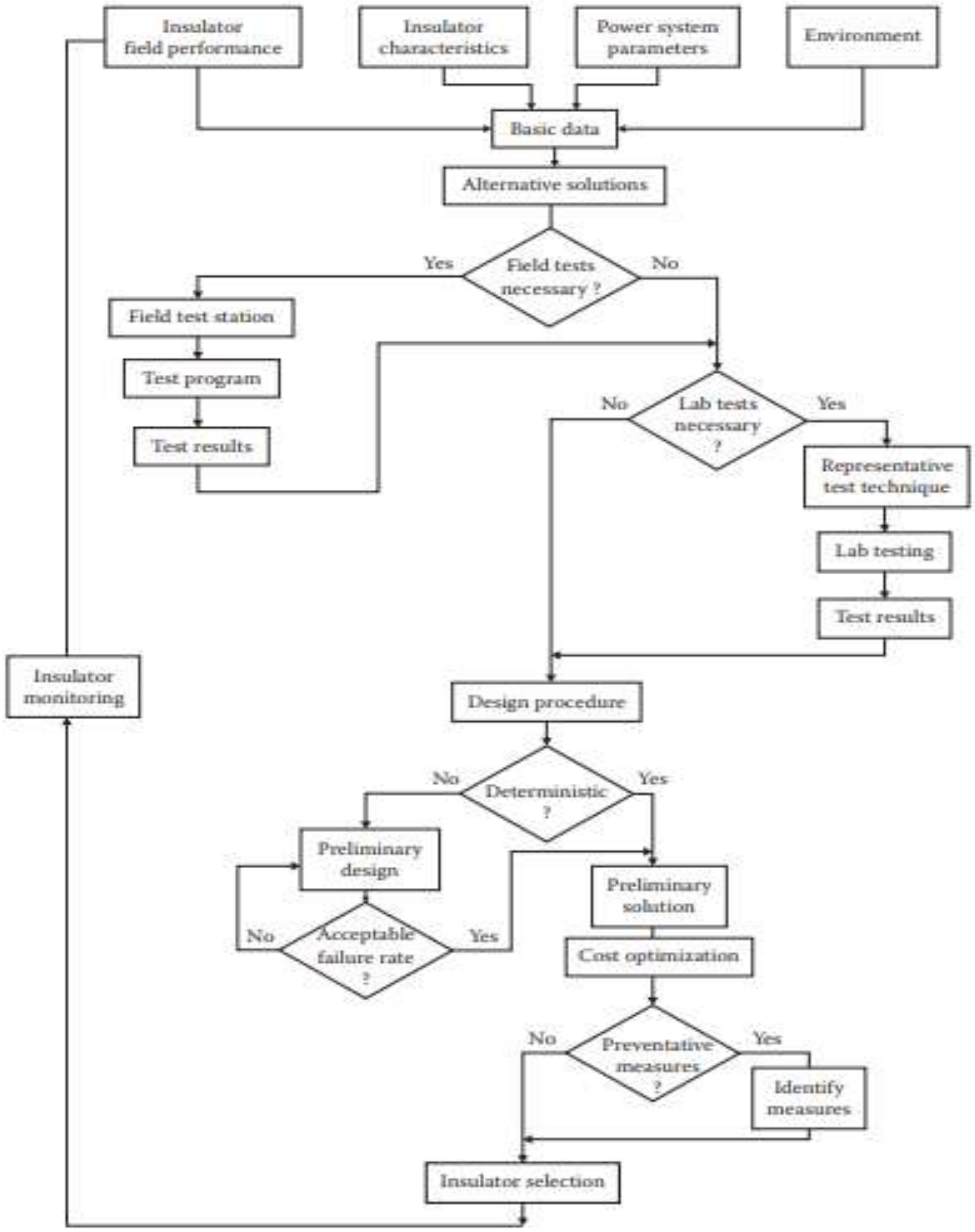


Figure 2.2: An overview of the process of insulator selection

Once these basic data are collected, the various options for insulator selection can be identified for further study. Depending on whether or not information is available on service experience, insulator characteristics and the environment, the need for further field tests should be determined.

However, it should be noted that these tests normally take 2-4 years [11]. Since the time required for field tests is very long, such tests are usually augmented with laboratory tests. When the basic data and field and laboratory test results have been compiled, the actual design procedure can begin.

2.5 Insulators Selection and Dimensioning

- Design criteria – mechanical

An insulator is a mechanical support its primary function is to support the line mechanically and we need to determine if insulators will support the line so we should determine The Maximum Load the Insulator Will Ever See [7].

- Design criteria – electrical

An insulator must prevent leakage current flow in normal operation condition; this is done by increasing Dry Arcing Distance or (Strike Distance) and Leakage Distance or (Creepage Distance).

Dry Arcing Distance or (Strike Distance):

- The IEEE STD 100 - 1992 define it by "The shortest distance through the surrounding medium between terminal electrodes…."
- The IEC 60815-1 define it by "The shortest distance in air external to the insulator between those parts which normally have the operating Voltage between them".

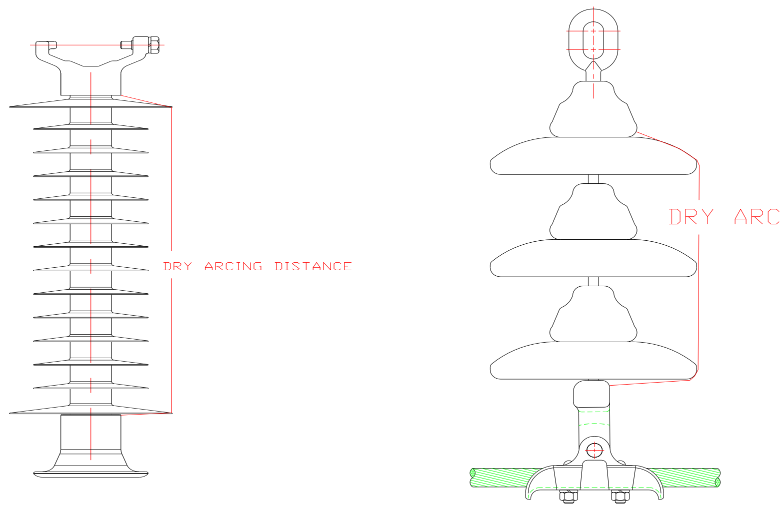


Figure 2.3: Dry Arcing Distance.

Leakage Distance or (Creepage Distance)

- The IEEE STD 100 - 1992 define it by "The sum of the shortest distances measured along the insulating surfaces between the conductive parts, as arranged for dry flashover test."
- The IEC 60815-1 define it by "The shortest distance, or the sum of the shortest distances, along the contours of the external surfaces of the insulating parts of the insulator between those parts which normally have the operating voltage between them".

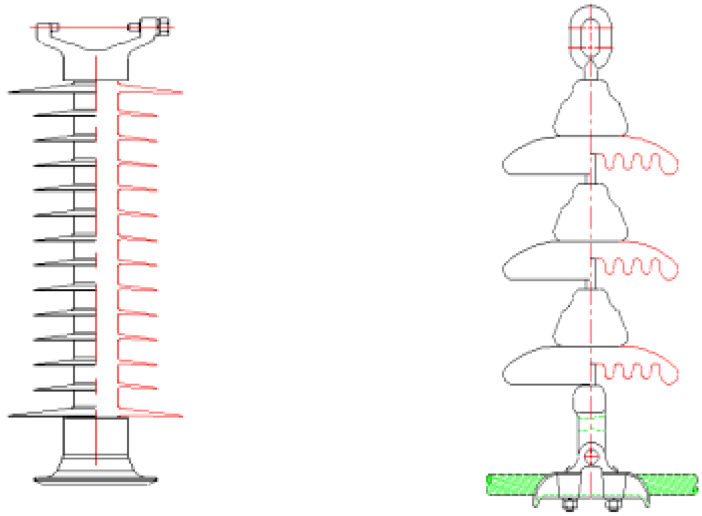


Figure 2.4: Creepage Distance.

CHAPTER THREE

POLLUTION FLASHOVER PROCESS

3.1 Introduction

Pollution flashover process of insulators is greatly affected by the insulator's surface properties [11]. Two surface conditions are recognized: either hydrophilic or hydrophobic. A hydrophilic surface is generally associated with ceramic insulators whereas a hydrophobic surface is generally associated with polymeric insulators, especially silicone rubber. Under wetting conditions - such as rain, mist etc. - hydrophilic surfaces will wet out completely so that an electrolyte film covers the insulator. In contrast, water beads into distinct droplets on a hydrophobic surface under such wetting conditions. Pollution flashover requires the occurrence of two events, a sufficient degree of the pollution composed of some ionic soluble salt, delivered to the insulator and deposited on its surface and a light rain or mist or fog that moistens the surface but does not create a washing effect. Although the pollution alone creates no problems, this mixture, contaminant and moisture, produces a conducting film such that a current flows through the contamination layer [11]. At locations Such as the narrow portion of a post insulator or in the rib area underneath a line insulator, the current is concentrated to the degree that the layer dries, i.e., a dry band is created. The total line-to-ground voltage now appears across these small dry bands, and flashover of the dry bands occurs. These arcs gradually grow outward, and flashover occurs when the arcs extend and meet [8].The Figure below shows pollution flashover process across a hydrophilic surface:

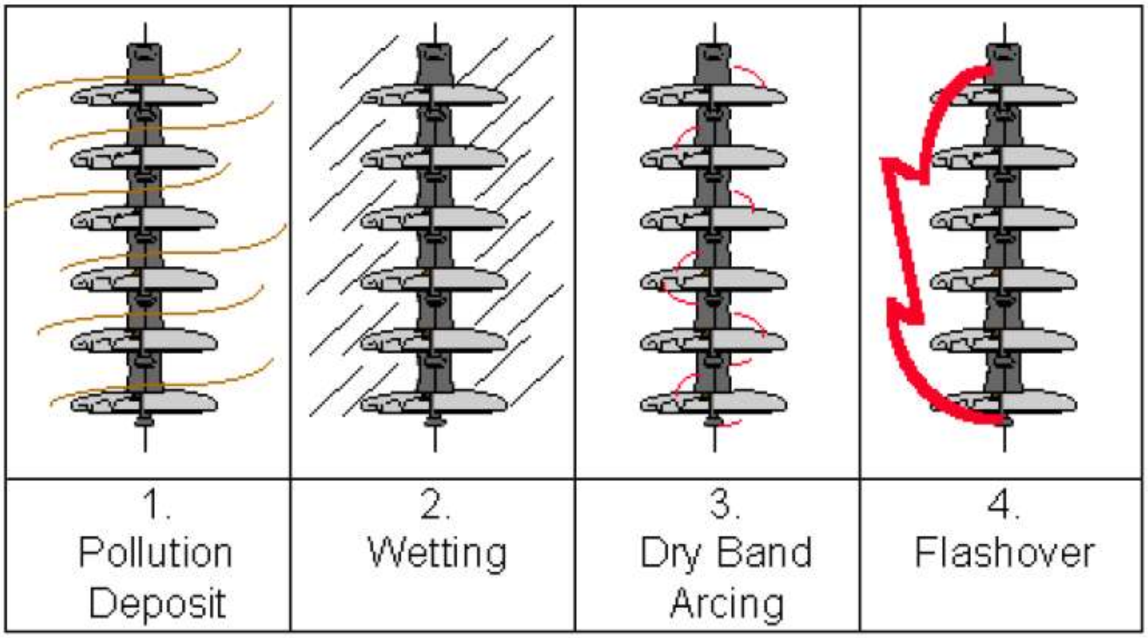


Figure3**.**1: Schematic representation of the pollution flashover process across a hydrophilic surface. The key processes involved in the flashover process are shown in Figure 3-1. The environment, in which the insulator must operate in, influences the first two processes - pollution deposit and wetting - whereas electrical aspects govern the last two processes. The conditions surrounding a HV insulator leading to the pollution deposit, and the wetting or cleaning of the insulator are caused by a set of atmospheric variables which interact among themselves and with the insulator surface. The most important atmospheric variables are: wind, rain, humidity, temperature and pressure. To assist in the selection and design of external insulation, typical environments have been defined. Some examples are:

Marine: Areas where the insulator pollution is dominated by the presence of the sea like the Red Sea state. The pollutants present on the insulators are, therefore, mostly NaCl and other marine salts that are easily soluble. On insulators close to the coast it is generally found that the inert component of the pollution is low [11].

Industrial: Areas in close proximity of polluting industries - such as steel mills, coke plants, cement factories, chemical plants and generating stations or quarries - are classified as industrially polluted. In these areas, the pollution types can be very diverse. The pollutants present may vary from dissolved acids - such as found close to power stations or chemical plants like in Khartoum - to slow dissolving salts - such as gypsum or cement like in Atbara- found close to quarries or cement factories. Generally, the pollution has a high inert component in areas close to industries [11].

Desert: In desert environments, the pollution tends to be sand based like in North State and the Nile River State. The desert sands may contain high amounts of salt, e.g. 18 % in Tunisia, resulting in a very conductive layer when wetted. The pollution on the insulator tends to be hygroscopic with a very high inert component. Inland desert areas are typically very dry, dusty, windy and hot. The large fluctuations between day and night raises the relative humidity to levels as high as 93% during early morning up to sunrise thereby leading to very heavy dew that causes frequent flashovers in some cases. If desert areas are close to the coast, the pollution problems are compounded.

Mixed: If industrial areas are situated close to the coast or desert like cement factories in Atbara, then the pollution can be described as mixed.

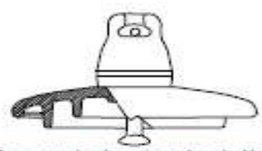
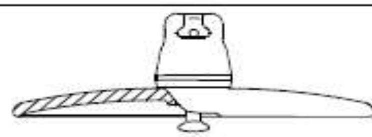
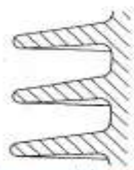
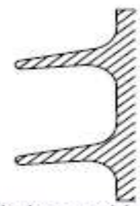
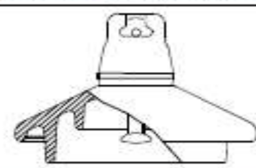
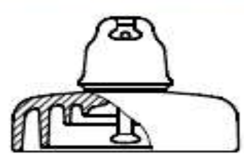
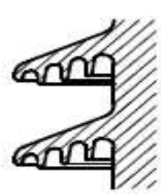
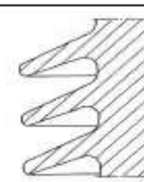
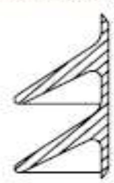
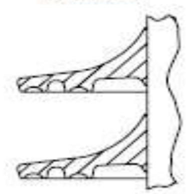
Agricultural: Localized insulator pollution may also be caused by agricultural activities such as crop spraying, ploughing etc. When lines cross land ready for harvesting like in Central Sudan states the structures may serve as perches for large birds - thereby leading to flashovers due to bird streamers.

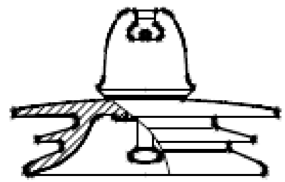
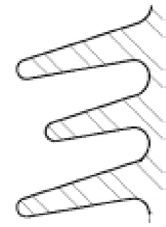
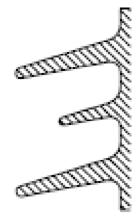
3.2 Effect of Various Aspects of the Insulator on its Pollution Accumulation

3.2.1 Profile

The contamination-collection processes on insulators in-service are very complex. In desert areas, the insulators having an aerodynamic profile are mostly less contaminated than are those with a more convoluted profile. The insulators which have a larger spacing between sheds and that the alternating profiles (i.e. one in which the ribs have different lengths) perform better than the box type (i.e. one in which all the ribs have the same length). The following table shows typical profiles and their characteristics:

Table 3.1: Typical profiles and their main characteristics

Standard profiles Standard profiles are effective for use in "very light" to "medium" polluted areas where a long creepage distance or an aerodynamically effective profile is not required	 Cap and pin standard disc insulators	 Porcelain standard profile, long rod insulators , post insulators, hollow insulators
Aerodynamic or open profiles Aerodynamic or open profiles prove to be beneficial in areas where the pollution is deposited onto the insulator by wind, such as deserts, heavily polluted industrial areas or coastal areas which are not directly exposed to salt spray. This type of profile is especially effective in areas that are characterized by extended dry periods. Open profiles have good self-cleaning properties and are also more easily cleaned under maintenance	 Aerodynamic disc insulators  Porcelain long rod insulators, post insulators, hollow insulators	 Polymeric long rod insulators, post insulators, hollow insulators
Anti fog profiles The use of anti fog profiles with steep sheds or deep under-ribs are beneficial in areas exposed to a salt water fog or spray, or to other pollutants in the dissolved state. These profiles may also be effective in areas with a particulate pollution precipitation containing slow dissolving salts. They can also be effective in areas with low NSDD and slow dissolving salts	 Steep anti-fog disc insulators  Deep under-ribs disc insulators  Deep under-ribs on porcelain long rod insulators, post insulators, hollow insulators	 Steep porcelain long rod insulators, hollow insulators, post insulators  Steep polymeric long rod insulators, hollow insulators, post insulators  Under-ribs on polymeric long rod insulators, hollow insulators, post insulators

Alternating shed profiles		
Alternating shed arrangements are in general feasible for all profiles, although steep sheds are less beneficial. They offer increased creepage distance per unit length without penalising performance in heavy rain or icing. Similar benefits to open profiles are also provided by simple alternating profiles	 Alternating shed disc insulators	 Porcelain long-rod insulators, post insulators, hollow insulators  Polymeric long rod insulators, post insulators, hollow insulators

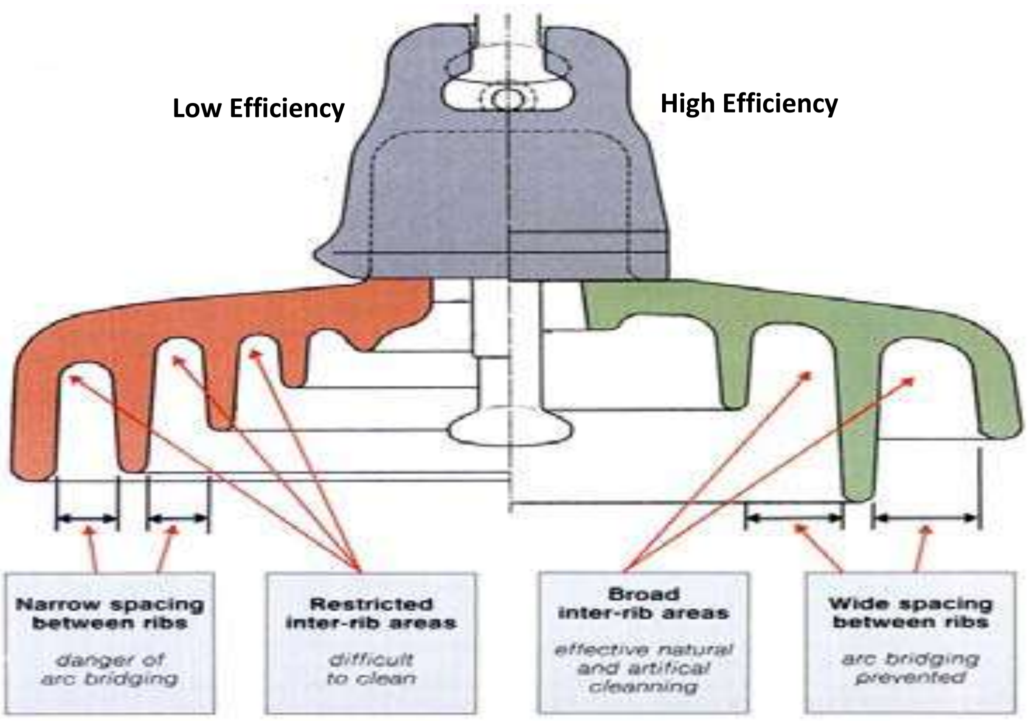


Figure 3.2: Rib distribution depending upon dielectric material processing

3.2.2 Orientation

Horizontally installed insulators collect less contaminant than the vertically mounted ones [8].

3.2.3 Diameter

The larger the diameter of an insulator, the smaller the ESDD level it accumulates over insulator surface. The relationship between the level of relative ESDD and the average diameter, D, of the insulator:

$ESDD = 13.9 \bullet D{-}0.55$

Equivalent salt deposit density ESDD amount of sodium chloride (NaCl) that, when dissolved in demineralized water, gives the same volume conductivity as that of the natural deposit removed from a given surface of the insulator divided by the area of this surface, generally expressed in mg/cm^2

3.2.4 Material

Another factor that influences the pollution deposit on insulators is the housing material, there are three main types Porcelain, Glass and Polymer**.** Ceramic insulators are said to be hydrophilic meaning that the surface wets completely under heavy fog or rain conditions [10].

- **Porcelain**

Electrical porcelain is made of a mixture of roughly 50% clay, 25% quartz or alumina, and 25% feldspar. Clays constitute some combination of hydrated aluminum silicate of one or more. Crystalline form, of a wide range of alumina (Al2O3) to silica (SiO2) ratio. Quartz is chemically pure silica (SiO2), while feldspar is a class of alkali–alumina–silicate minerals, for example, potash feldspar comprises K2O · Al2O3 6SiO2. The raw materials are mixed together and ground to the desired particle size. In the wet preparation process, these materials are mixed with water, and the resulting mixture is filtered to remove foreign particles. Actual forming is carried out by casting, extrusion, jiggering, and plunging. For the dry preparation process, forming is performed by dry and vacuum pressing. Forming is followed by drying, finishing, glazing, and firing, which is probably the most important operation in porcelain manufacturing. It is obvious that the quality of porcelain depends not only on the raw materials but also on the skill of the manufacturer and on quality control. Metal fittings are attached to porcelain by cementing. Fitting materials include malleable cast iron, ductile iron, and steel. The types of cement used include alumina cement, Portland cement and sulfur cement. Experience has shown that some problems could be encountered with sulfur cement in hot climates, while Portland cement could suffer in industrial environment that includes sulfates like sewage treatment plants, tanneries, and textile mills. Tables on physical properties of electrical porcelain are available in material science texts in IEC 60672. Some properties are summarized in the following [10]:

- Density: ≈2.5 g/cm^3.
- Tensile strength of porcelain depends on composition and varies in the range of 40–80 MPa.
- Compressive strength of porcelain is about an order of magnitude higher than its tensile strength.
- Volume resistivity is of the order of 10^{11} Ω · m.
- Relative permittivity εr at room temperature and power frequency: 6-7.
- Dielectric strength is typically 200 kV/cm but depends on the thickness of the specimen.
- Maximum safe operating temperature is approximately 160°C.

- Coefficient of linear expansion ≈5×10^{-6} (1/K).
- Thermal conductivity ≈1–4 W/m · K.
- Tan δ at power frequency: $1–3 \times 10^{-2}$.

The aforementioned properties lead to many advantages and some limitations of porcelain insulators. On the positive side, porcelain insulators are immune to degradation due to environmental factors, are resistant to surface damage due to leakage current, and have high compressive strength. They are, however, vulnerable to breakage and cracking due to power arcs and, when punctured, take specialized techniques to detect.

- Glass

The soda lime glass consists of a melt of a mix of silica (SiO2), limestone (CaO), feldspar (Na2O · Al2O3 · 6SiO2), and soda ash (Na2O). Difference from porcelain arises primarily from its method of forming rather than from its ultimate composition. In glass manufacturing, raw material mix is melted in a suitable furnace and then cooled to a lower temperature to become more viscous and can be worked into the desired shape. For cap and pin glass insulators, a heat treatment process called toughening is applied. This comprises reheating to a uniform temperature between transitions and softening temperatures, followed by rapid quenching by exposing the surface to jets of cold air.

Relevant physical properties of toughened glass are summarized in the following [10]:

- Density: ≈2.5 g/cm^3.
- Tensile strength is in the range of 100–120 MPa, somewhat higher than porcelain.
- Similar to porcelain, the compressive strength is considerably higher, reaching 700 MPa.

- Volume resistivity is similar to porcelain: $\approx 10^{11}\ \Omega \cdot m$.
- Relative permittivity at room temperature and power frequency: ≈7, close to porcelain.
- Dielectric strength somewhat higher than porcelain and, as other solids, decreases with sample thickness.
- Maximum operating temperature is somewhat lower than porcelain and could be as low as 110°C.
- Coefficient of linear expansion: $\approx 9 \times 10^{-6}$, significantly higher than porcelain.
- Thermal conductivity: ≈1 W/m · K, significantly lower than porcelain.
- Tan δ at power frequency: up to 6×10^{-2}, significantly higher than porcelain.

The positive features of glass insulators include high dielectric strength and resistance

to puncture, easy detection of damaged insulators due to shattering, and good compressive strength. On the other hand, glass insulators constitute a target for vandalism and are susceptible to erosion due to leakage current, which can precipitate shattering.

- Polymers

Polymeric insulators for high-voltage transmission lines comprise a resin-embedded fiberglass core, which provides mechanical strength and a polymeric cover for protection from adverse weather conditions. Two housing materials are presently in use: ethylene propylene diene methylene (EPDM) and silicone rubber (SIR). Silicone rubber is resistant to UV radiation and has hydrophobic property. This makes composite insulators with silicone rubber sheds a viable alternative to ceramic insulators in polluted regions. Silicone rubber is made from polydimethylsiloxane with the mere structure shown in Figure 3.3 which, as elastomers, is cross-linked.

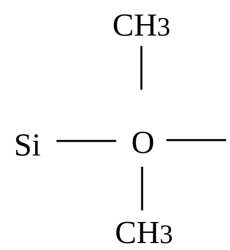


Figure 3.3: Chemical structure of polydimethylsiloxane.

Some relevant physical properties of silicone rubber material are given in the following:

- Density: ≈1.15 g/cm^3.
- Glass transition temperature Tg: −120°C. This means that the material retains its rubber behavior in very low temperatures.
- Maximum operating temperature: ≈350°C.
- Relative permittivity at room temperature under power frequency: ≈4.
- Tan δ at room temperature under power frequency: 2–3 × 10^{-2}.
- Dielectric strength at power frequency: 160–200 kV/cm.
- Volume resistivity: 10^{12} Ω · m.
- Elongation to rupture: 150%–300%.

Note that these numbers, as those given for porcelain and glass earlier, are material properties. Accordingly, figures such as maximum operating temperature cannot obviously be applied to characterize an insulator unit, which results from application of different materials and manufacturing processes. A typical design of a composite silicone rubber insulator is shown in Figure 3.4. It includes a fiber reinforced polymer (FRP) rod, which is chemically bonded to a high-temperature vulcanized (HTV) silicone rubber sheath. HTV silicone rubber sheds are vulcanized to the sheath. The FRP rod is attached to the end metal fittings by a cleaving wedge. The techniques used to attach the FRP rod to the end fittings include crimping, use of a cleaving wedge as in Figure 3.4, or application of an epoxy wedge within the end fitting. It is important to ensure proper sealing between the end fitting and the silicone rubber sheath to avoid ingress of moisture. This and the chemical bond between the FRP rod and the sheath are intended to produce a puncture-free interface zone.

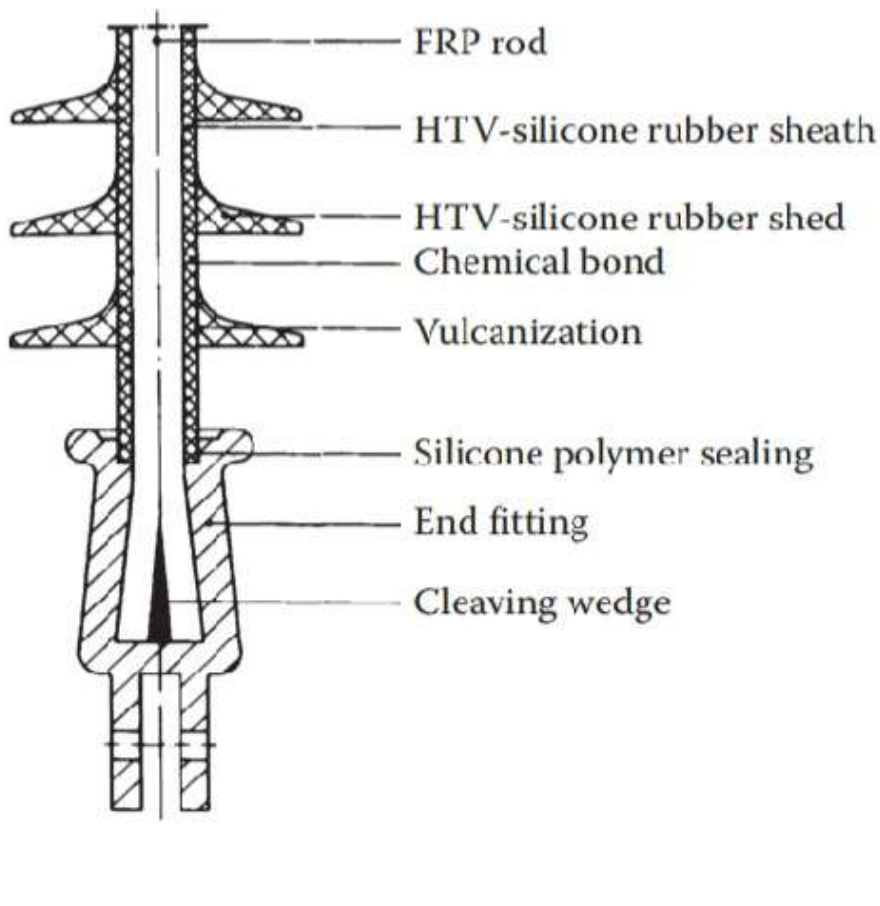


Figure 3.4 Typical details of a composite long-rod insulator

3.3 Power Quality of Electrical System

Power Quality It is the aim of a well-designed electricity system to provide voltage to customers that are stable, meet power demands under excessive loads variations and other disturbing waveforms. The term ‘power quality’ or ‘quality of power’ has come to be a collective term which includes electrical power parameters such as:

- Voltage variation outside of standards.
- Voltage sags and swells.
- Repeated fluctuations.
- Impulses (spikes).
- Momentary interruptions (sudden dips).
- Frequency variations and waveform distortion (harmonics).

High-quality components offer superior performance, are more durable and require replacing less often. In addition to decreasing device downtime, they also reduce costs associated with repairs and production loss. The insulator should be suitable for the intended purpose (fit for purpose) and errors/omission should be eliminated before putting the insulator in service. This chapter has been developed to capture various aspects/requirements of inspection and test thru Factory Acceptance Test (FAT), Site Acceptance Tests (SAT) [7]. The tests on equipment/system have been broadly categorized into two categories Factory Acceptance Test (FAT) and Site Acceptance Tests (SAT). These tests have been tailored to ensure design, construction and performance requirements of each equipment compliance to relevant international standards/specifications for example:

I. International Electrotechnical Commission **(IEC)**

II. Institution of Electrical and Electronics Engineers **(IEEE)**

III. National Electrical Manufacturers Association **(NEMA)**

IV. British Standards **(BS)**

V. American National Standards Institution **(ANSI)**

3.3.1 Factory Acceptance Test (FAT)

The Factory Acceptance tests shall be made to Electrical insulator at the manufacturer's to ensure that the product is in accordance with the insulator relevant standards.The factory acceptance tests consist of Routine, Type, sample and special tests as per company and International standards [7].

- **Routine test**

Routine tests are intended to detect faults in materials and workmanship and ascertain proper functioning of the insulator. They are made on each individual piece of insulator.

The routine test can be done to certain insulator at the factory after manufacturing and at the site during commissioning tests or troubleshooting tests.

- **Type test**

Are intended to verify compliance of the design of given insulator with this standard, where applicable, and the relevant product standard. They may comprise, as appropriate, the verification of, Constructional requirement, Temperature rise, Dielectric properties, Making and breaking capabilities, Operating Limits, Operational performance, Degree of protection of enclosed equipment. Type Tests are performed on single specified Electrical insulator of one type and are intended to check the design characteristics. Type test usually relates to the first unit or prototype manufactured by a firm to given specification.

- **Sample tests**

Are carried out to verify the characteristic of an insulator which can vary with the manufacturer's process and the quality of the component materials of the insulator. Sample tests are used as acceptance tests on a sample of insulators taken at random from a lot which has met the requirement of the relevant routine tests.

- **Special test**

A test done for electrical insulator other than a type test or a routine test agreed by the manufacturer and the purchaser. It can be carried out on one insulator or all insulators of a particular design as specified by the purchaser in the enquiry and order.

3.3.2 Site Acceptance Tests (SAT)

Site Acceptance Tests is the test defined in the Contract specification, are carried out by the vendor/contractor during commissioning /pre commissioning at site and are witnessed by Company Engineer.

3.4 Insulators Electrical and Mechanical Test

3.4.1 Type Test

I. Impulse Withstand Voltage Test.

An impulse withstand voltage test of an insulator is the crest value of an applied impulse voltage that under specific conditions does not cause a flashover, puncture or discharge on the insulator under test[6].

II. Dry & Wet impulse flash over Test.

An impulse flash over voltage of an insulator is the crest value of the impulse wave that under specific conditions causes flashover through the surrounding medium.

III. Dry & Wet power frequency withstand (one minute test).

An impulse withstand voltage of an insulator is the crest value of an applied withstand voltage that under specific conditions does not causes flashover through the surrounding medium.

IV. Verification of dimension.

The dimension verification of an insulator is the comparison process between the measured value and the relevant drawings and standards with regards to specific standards tolerance [6].

V. Mechanical failing load Test.

The maximum load reached when a string insulator unit is tested under the prescribed condition of the test.

3.4.2 Routine Test

I. Visual Inspection.
II. Identification of marking.
III. Dry & Wet power frequency withstand (five minute test) [4].

3.4.3 Sample Test

I. Verification of dimension.

The dimension verification of an insulator is the comparison process between the measured value and the relevant drawings and standards with regards to specific standards tolerance.

II. Mechanical failing load Test.

The maximum load reached when a string insulator unit is tested under the prescribed condition of the test.

III. Temperature cycle Test.

- The insulator is first heated in water at 70 ^{o}C for one hour.
- Then this insulator immediately cooled in water at 7 ^{o}C for another one hour.
- This cycle is repeated for three times.

After completion of these three temperature cycles, the insulator is dried and the glazing of insulator is thoroughly observed.

After this test there should not be any damaged or deterioration in the glaze of the insulator surface [10].

IV. Thermal shock test.

V. Puncture withstand test.

Puncture withstand voltage of an insulator is the crest value of the voltage which will not cause puncture of an insulator under the prescribed condition of the test [7].

The insulator is first suspended in insulating oil, voltage of 1.3 times of flash over voltage, is applied to the insulator.

VI. Porosity test.

Porosity is the ratio of voids to solids in a tile.

If the porcelain insulator is manufactured at low temperatures, it will make it porous, and due to this reason it will absorb moisture from air thus its insulation will decrease and leakage current will start to flow through the insulator which will lead to insulator failure

VII. Galvanizing test (when applicable).

3.5 Related work

A scientific paper by Apu Banik. Abhik Mukherjee. Sovan Dalai"Development of a pollution flashover model for 11 kV porcelain and silicon rubber insulator by using COMSOL multiphysics issued in March 2017 was reviewed and the analysis method used in this paper was carefully read.[14]

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The required tests were carried out at Transformer Factory for dry flashover voltage test and at Sudanese Electricity Distribution Company for wet flashover voltage test.

4.2 Experiment

The test object used were porcelain and polymeric insulator with the below characteristics:

- **porcelain**
  - Density: ≈2.5 g/cm^3.
  - Relative permittivity εr at room temperature and power frequency: 6–7.
  - Dielectric strength is typically 200 kV/cm but depends on the thickness of the specimen.
  - Volume resistivity is of the order of $10^{11}\ \Omega \cdot m$.
- **polymer**
  - Density: ≈1.15 g/cm^3.
  - Relative permittivity at room temperature under power frequency: ≈4.
  - Dielectric strength at power frequency: 160–200 kV/cm.
  - Volume resistivity: $10^{12}\ \Omega \cdot m$.

An experimental setup is developed according to IEC 60507; a test voltage is applied across the sample insulator.

4.3 Flash over Voltage Test

4.3.1 Test Requirements

i. Cascade transformer.
ii. Measurement circuit.
iii. Porcelain & polymeric insulator as test object.

4.3.2 Test Objects

The test objects were 2 of the 11-kV porcelain and polymeric insulators with creepage distances of 360mm for the porcelain insulators and 395 mm for the polymeric insulators as shown Fig 4-1

Table 4-1: Line Post Insulator parameter

Description	Line Post
Length	165 mm
Width	105 mm
Total Creepage	395 mm

Table4-2: Pin Insulator parameter

Description	Pin Insulator
Length	155 mm
Width	165 mm
Total Creepage	360 mm

Figure 4.1: Test Samples a) Line post b) Pin insulator

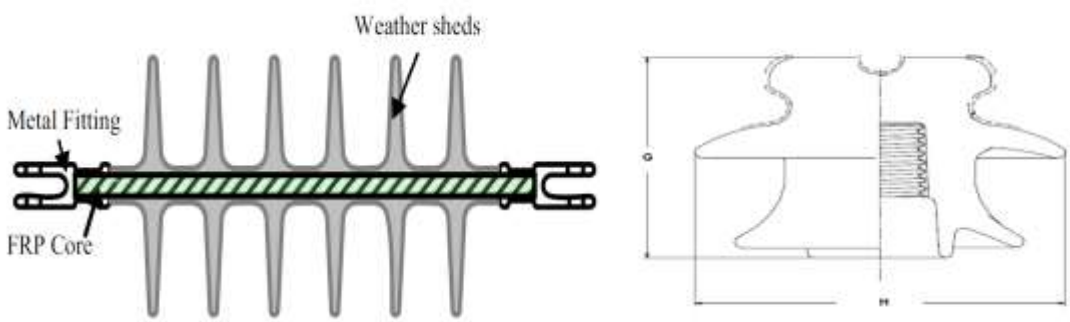


Figure 4.2: Models of Test Samples a) Line post b) Pin insulator

4.3.3 Arrangement of the Test Object

The test object was carefully cleaned by washing with tap water. It was not touched by hand.

The test objects was Contaminated by a pollution layer, first the insulators go through a pre-contamination procedure as per IEC60060-1. According to this procedure, kaolin powder is deposited after spraying a fine mist of water droplets on the surface. Afterward, the insulator is immersed in the slurry and dried for 24h. The pollution composition consisted of 40 g/L kaolin, 15 g/L NaCl, and 1000 ml distilled water with the volume conductivity of 23.4 mS/cm as shown in Fig 4-6.The test object was coated with a reasonably uniform layer of a conductive suspension and was left to dry. The ambient temperature in the test location was $30C^{O}$ and the test object was almost in thermal equilibrium with the ambient temperature. The disruptive-discharge characteristics of a test object with external insulation may be affected by its general arrangement (for example, proximity effects such as distance in air from other live or earthed structures, height above ground level and the arrangement of its high-voltage lead).

4.3.4 The Suspension Preparation Procedure

The conductive suspension was prepared in an ISO 17025 accredited laboratory, the suspension was prepared according to this steps:

I. The kaolin element was in a rock states as shown in Fig 4-3 *a)*, it was crushed and turned to a soft powder and then 40 g of the kaolin powder was weighted as shown in Fig 4-3 b*)*.

II. Laboratory pure NACL was obtained and 15 g was weighted as shown in Fig 4-4 a).

III. 1000ml of a distilled water was used as reaction medium, the suspension was stirred until the kaolin and NACL powder was fully mixed shown in Fig 4-4 b).

IV. The suspension conductivity was measured using calibrated conductivity meter as shown Fig 4-5 , the conductivity meter was calibrated before use following this procedure:

a. The conductivity meter probe cleaned with distilled water first and immersed in CRM (certified reference material) with known conductivity of 84 μS and the probe give a reading of 84 μS as shown in Fig4-5 a).
b. The probe was cleaned with distilled water again and immersed in CRM (certified reference material) with known conductivity of 1413 μS and the probe give a reading of 1412 μS as shown in Fig4.5 b).
c. The probe was then cleaned by distilled water before measuring the suspension conductivity as shown in Figure 4.6.

Figure 4.3: Preparation of coating material: a) solid Kaolin b) kaolin powder

Figure 4.4: Preparation of coating material: a) NaCl powder b) prepared suspension

Figure 4.5: Calibration of conductivity meter probe: a) 84 µS CRM   b) 1412 µS CRM

Figure 4.6 pollution composition conductivity

4.4 Test Procedure

4.4.1 Flashover Voltage Dry Test

I. The test object was coated with a reasonably uniform layer of a conductive suspension by immersion and was left for 24H to dry. The ambient temperature in the test location was 30C^{o} and the test object was almost in thermal equilibrium with the ambient.

II. The test object was connected to single phase 20KVA, 100KV transformer shown in Fig 4.7, high voltage cable connected to one terminal and ground cable connected to the other terminal for the ceramic and polymer samples under the test as shown in Fig 4.8

III. The voltage test was increased gradually by 5KV step until the flashover discharge occurs on the test object.

IV. The voltage and current readings in the flashover moment was recorded.

V. The voltage decreased automatically and any voltage charges were discharged.

Figure 4.7: single phase 20KVA, 100KV transformer test unit

Figure 4.8: test object connection: (a) Polymer (b) Ceramic

4.4.2 Flashover Voltage Wet Test

The same test sample and suspension was used and the test procedures was the same, the only different was a preparation of solution of 10g of NACL in 250ml of distilled water with a conductivity of 57.3 mS as in Figure 4.9

Figure 4.9: wet test solution: a) conductivity reading b) prepared solution

I. The NACL solution was sprayed on the test samples before each test sequence and the test started after 3 minutes from the spraying process as shown in Fig 4-12.

II. The test object was coated with a reasonably uniform layer of a conductive suspension by immersion and was left for 24H to dry. The ambient temperature in the test location was 30C^{o} and the test object was almost in thermal equilibrium with the ambient.

III. The test object was connected to single phase 100KV transformer shown in figure 4-10. High voltage cable connected to one terminal and ground cable connected to the other terminal for the ceramic and polymer samples under the test as shown in Fig 4-11

IV. The voltage test was increased gradually by 1.5KV step until the flashover discharge occurs on the test object.

V. The voltage and current readings in the flashover moment was recorded.

VI. The voltage decreased automatically and any voltage charges were discharged.

Figure 4.10: single phase 100KV Transformer control test unit

Figure 4.11: test object connection: a) ceramic b) polymer

Figure 4.12: test object wetting procedure

4.5 Results and Discussion

The flashover development process under 50Hz alternative current voltage was examined with non-uniform pollution distribution. The influence of the insulation surface pollution on the behavior of the insulator (porcelain and polymer sample) was investigated.

- **Dry flashover test result**

The electric discharge development with the increase of the applied voltage magnitude and for the test sample above the following was observed.

I. In porcelain insulator the flashover sparks was visually observe in 60 KV and the current meter showed a reading between 10-90 mA for each spark, corona sound was clearly heard when the applied voltage cross 40KV.

II. The polymeric insulator maintains it is high dielectric strength while test voltage was increased until 80KV; the test was stopped at 80 KV to avoid the electrical stress on the testing transformer windings.This test is intended to determine the insulators skirting potential of severity of pollution. To reach this objective, we increased voltage until obtaining flashover of the insulator. In composite insulator flashover voltage is higher than porcelain insulators.

- **Wet flashover test result**

I. For porcelain insulator the flashover spark was visually observed in 35 KV and the current meter showed a reading between 1-19 mA for each spark corona sound was clearly heard when the applied voltage reach 20 KV.

II. The polymeric maintain its high dielectric strength while test voltage was increased until 50 KV, the test was stopped at 50 KV to avoid the electrical stress on the testing transformer windings.

4.5.1 Dry Flashover Analysis

The flashover voltage decreases according to the conductivity of the polluted environment. Due to the high conductivity the leakage current is increased and flashover voltage value is decreased. The pollution severity depends on wind speed, temperature, humidity and the insulator material. So the sulfur cement used for porcelain metal fitting to be use in north Sudan state may effect by hot climate so technical consideration must be taken. Also The Portland cement used for porcelain metal fitting to be use close to industrial environment like sewage treatment plants, tanneries, and textile mills may effect by emitted sulfates. As main results, the conductivity of the polluting layer has practically a slight effect on the distributions of the potential and the electric field. On the other hand, the surface (polluted or clean) state of the insulator influences the distribution of the electric field. At the same contamination level of 23.4 mS/cm, the composite insulator performance is better than porcelain insulators as shown in table 4.3.

Table 4.3: Dry flashover of polluted insulators

Types of insulator	Voltage KV	Leakage Current mA
Pin	60	10-90
Line post	>80	--

4.5.2 Wet Flashover Analysis

The line post showed good dielectric strength up to 50KV and no sparks appeared across the insulator surface. The porcelain showed poor dielectric strength after 20 KV and small sparks produced across the insulator surface. While the applied voltage increased the sparks size and location increase across the insulator surface, in the 28 KV large sparks appears and kept increasing until it reached 35 KV then the voltage was reduced gradually to zero to protect the test equipment from the effect of the total flashover.

Table 4.4: wet flashover of polluted insulators

Types of insulator	Voltage KV	Leakage Current mA
Pin	35	1-19
Line post	>50	--

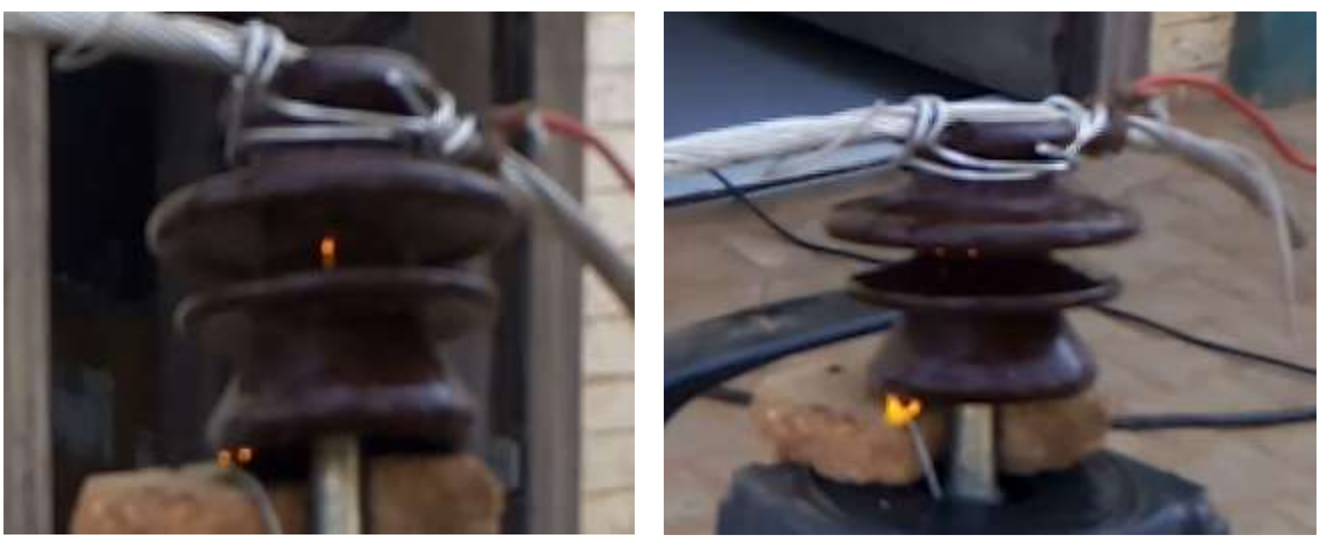


Figure 4.13: Flash over sparks a) at 20KV b) at 28KV

4.5.3 Design Analysis

The line post used in this research was installed as experimental design in Khartoum Bahri in Elqadisia 33 KV and AL Alhuda 11 KV double circuit line in 2014 figure 4-15,and since then this line didn't suffer from any flashover or insulator defects according to the record of MV Overhead department in Bahri. Using line post insulator improves the system efficiency and performance due to some aspects:

I. Line post use less metallic fitting materials compare to normal pin insulator as shown in figure 4-14 so reducing installation and maintenance cost.
II. Armless configuration reduces the line clearance distance required as shown Figure 4.15.
III. Eliminate the occurrence of conductor displacement or unseen conductor cutting as shown in figure 4.15

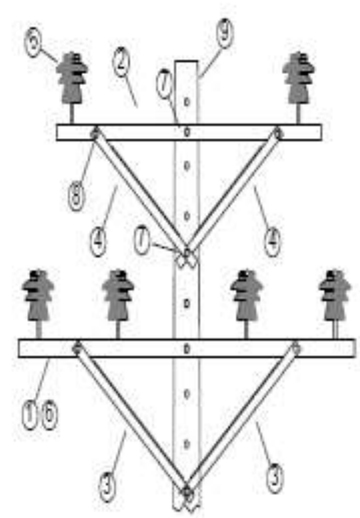
الرقم.	وصف المواد	الكميات	الرسم
1	Cross Arm 3x3x1/4 inch &3.0 m as length	1	
2	Cross Arm 3x3x1/4 inch &2.0 m as length	1	
3	Short Strap 2x2x1/4 Inch & 1.5 m length	2	
4	Short Strap 2x2x1/4 Inch & 0.85 m length	2	
5	Pin Insulator with spindle 33kV	6	
6	Bolt & nut: 12x5/8 Inch with washer	2	
7	Bolt & nut: 10x5/8 Inch with washer	2	
8	Bolt & nut: 1.5x5/8 Inch with washer	4	
9	Concrete pole 40 ft.	1	

Figure 4.14: spindle insulator configuration

Figure 4.15: line post insulator configuration

Figure 4.16: spindle insulator hidden conductor cutting

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The polymeric insulator showed high dielectric strength compare to the porcelain at the Dry test and Wet test. The polymeric insulator can withstand extremely polluted weather and will be suitable for coastal area or near heavy industrials plants.

From this work, some conclusions are listed:

- Polymeric insulators: As for new lines and stations, if contamination is severe, Polymer insulators is an option, although the cost of retrofitting may be large for transmission lines.
- Line post polymeric insulators: Is more efficiency and more economic and reduce the numbers of fittings to be use and show great working performance and reliability.
- To improve installed ceramic insulators performance, RTV coating may be applied.
- Periodic cleaning for insulator may prevent accumulate of pollution layer on insulator surface.

5.2 Recommendations

- Insulators in practice usually have a more complex structure and environments, which are different with the ideal condition in Lap test. Therefore, future work will aim to simulate a more realistic insulator and its surroundings with data collected from real pollution measurements stations distributed across the country. In the meanwhile, the practical measuring results will be used to verify the simulated results in this project.