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LIST OF ACRONYMS

Name	Description
LC	Leakage current
LMW	Low Molecular Weight
DC	Direct Current
AC	Alternating Current
RMS	Root Mean Square
SiR	Silicone Rubber
ATH	Alumina Tri-Hydrate
ESDD	Equivalent Salt Deposit Density
UV	Ultra violet
HV	High Voltage
EHV	Extra High Voltage
EPDM	Ethylene Propylene Diene Monomer
BIL	Basic Lighting Impulse Insulation Level
FOV	Flash Over Voltage
CFC	Chloro Fluoro Carbons

LIST OF SYMBOLS

Symbol	Description
kV	kilo volts
A	Amperes
Hz	Hertz
mm	milli metres
mg/cm^2	milli grams per square centimeter
KVA	kilo volt amperes
μA	micro amperes

ABSTRACT

In a power system, insulator plays an important role to isolate among live parts and between live part and ground and as mechanical protector. The insulators are widely used at substations, transmission as well as distribution networks. Due to some superior properties such as lightweight, good water repellence and resistance to pollution, recently, polymeric insulating materials are introduced to substitute conventionally used insulators like porcelains and glasses. The level of insulation safety provided by an insulator depends on the amount of leakage current flowing on its surface. Actually increased leakage current causes a part of high voltage to appear at dead end of insulator. This voltage may sometimes be of order of 1000 to 5000 Volts depending upon weather conditions. Such a level of leakage current causes hazards to public safety as well as losses. So to monitor and keep the leakage current low is an important parameter to be considered by designers and electric supply companies. During service, several severe conditions such as high humidity, coastal and industrial pollutions as well as biological contaminations may be exposed to the outdoor insulators. Additionally they might suffer from erosion and tracking in the presence of severe contamination and sustained moisture.

In this project 33kV and 11kV polymeric insulator samples were subjected to natural atmospheric pollution conditions and their leakage current and breakdown voltage values are monitored in winter and summer seasons to study the variation of the characteristics of the polymeric insulators under coastal atmospheric conditions. These results can be useful to understand the effect of natural atmospheric pollution on the polymeric insulators as until now there are no specific methods to understand the service life of these insulators.

CHAPTER 1
INTRODUCTION

1.1 Overview

In the power grid the outdoor insulation plays an important role in maintaining the reliability and security of the system. The performance of an electrical power system mainly depends upon its insulation. A good insulation system will decide the better product of the designed apparatus and its performance. Today, polymeric insulators are widely being used in both the transmission and distribution of high voltage ranges and are steadily capturing a wider share of market. Insulators maintain electrical insulation and support the mechanical load between the conductor and ground in the power apparatus. So, electrical insulation plays an important role in all parts of electrical systems. Insulators are being subjected to sustained moisture, soluble and non-soluble contaminants(i.e., salt, certain chemicals, dust and sand).

A widely accepted insulating material is ceramics (porcelains), having a long history over 100 years. Ceramics are generally hydrophilic, allowing the moisture produced on a ceramic insulating surface to be in a film state. The development and use of polymeric insulators started during the 1960s. Since the early 1990s, they can be considered a mature product, with a good service record. This has been accompanied by an increased commercial interest and increased research activities. The failures in the earliest designs are still a holdback for polymeric insulators and lacks of service experiences are often listed as the reason not to purchase polymeric insulators. In the past 20 years, polymeric insulators have begun to be used as an alternative to ceramic insulators. Polymer insulators employing silicone rubber (SiR) housings are exhibiting strong field performances and so they have been produced in greater numbers. SiRs have very stable and recoverable hydrophobicity, allowing the moisture on SiR surfaces to be in the form of droplets. The level and the nature of leakage currents on polymeric insulating surfaces are closely related to their hydrophobic variations as well as their contamination level.

The insulator material which must provide a long working lifetime under high field strengths and in heavily polluted areas, will adsorb significant quantities of pollution. Flashover will not occur for insulators in a dry environment. However, in a humid environment, the surface contamination of insulators becomes moist, leading to the ionisation of soluble salts, a rapid increase of leakage current, and, ultimately, contamination and flashover will occur. Contamination flashover threatens the security and reliability of the electricity supply and causes significant losses to the power system. As is widely the case in wild areas, the surface contamination of insulators is inevitable, meaning that pollution flashover can only be predicted, but not eliminated. A number of studies have provided insights into how to prevent contamination flashover, but these findings have not fundamentally solved the problem. A characteristic parameter that can be used to fully reflect the level of contamination is required. Some of the common indicators required for this purpose are equivalent salt deposit density, the current pulse counting, the flashover voltage gradient, the surface conductance and the leakage current. Here in our project we used the leakage current as the parameter in understanding the characteristics of the polymeric insulators.

1.2 . Importance of Leakage Current:

Any current that is flowing from hot conductor to ground over the surface of a device is called as Leakage current. In case of insulators on transmission lines, it is the current that flows over the surface of insulator, and, if no ground exists, the current flowing from conductive portion of a device to a portion that is intended to be non-conductive portion under normal conditions. The main concern in the overhead line insulators is the AC leakage current, as it is clear from its name that the leakage current for a device or an insulator is drawn from the main supply and it never contributes to develop useful power in the load and it causes only waste of power.

1.3 Effect of Leakage current on Composite Insulators:

In the case of composite insulators, the leakage current is also an important factor to consider. However, the design of these insulators is such that they offer a very high surface leakage resistance. Their structure has a fibre reinforced rod as the main strength member, which is covered on outside by a polymeric rubber. The whole structure is then fitted with two end fittings to make a complete insulator in one assembly. This is the reason they are called composite insulators since the complete insulator is one unit as shown in Fig.1. The rubber covering the rod is not straight but moulded to give a shape of what is called a weather shed. Many types of polymeric rubber have been used by different manufacturers of polymeric insulators. But since all them belong to rubber family, so they have good leakage current suppression ability. The beautiful feature of these insulators is their uniform distribution of electric field and, hence, the stress over their surface. This is due to the fact that all the

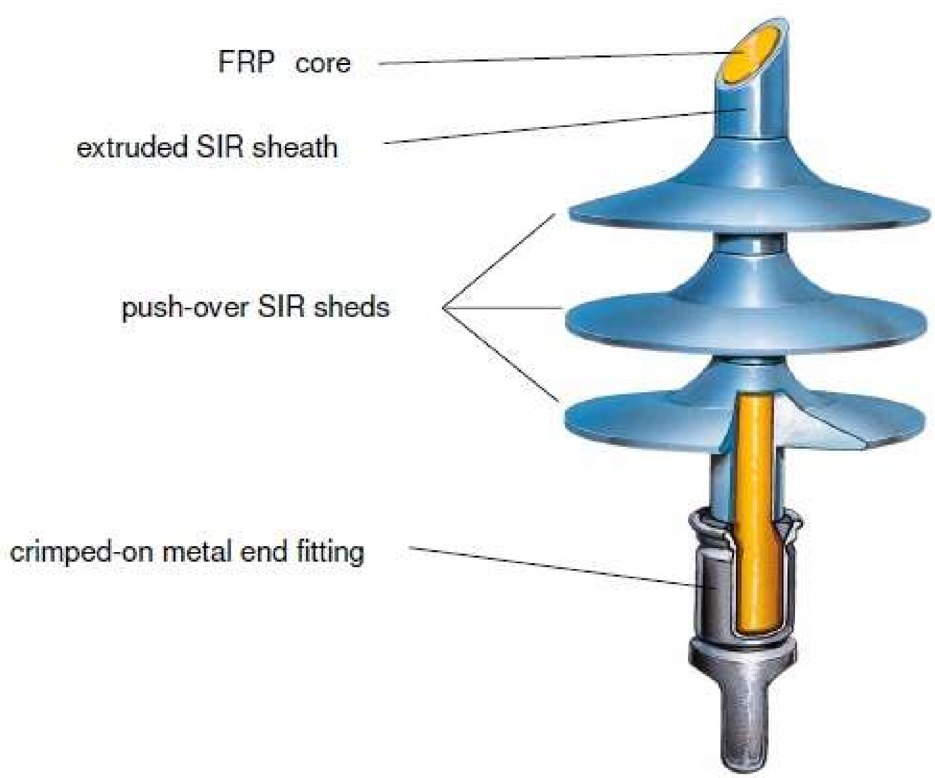

Fig. 1.1 Composite insulator elements

insulator surface from energized end to dead end is of same material and moulded in one cast. Increasing pollution deposits with time do not always increase the leakage current of composite insulators. Instead there is a complex phenomena involved in it. Composite insulators are made up of polymeric materials which are organic and these decay in natural environment. This process is called aging of insulators. The Leakage current depends upon the surface resistance of these insulators which in turn depends on the insulator's hydrophobicity. These insulators have shown a cyclic decrease and then recovery of hydrophobicity with time. Even when the pollution deposits become heavy, these insulators make them hydrophobic. Due to this reason the leakage current doesn't increase continuously. The obvious advantage with these insulators is that without maintenance and even under heavy pollution deposits they maintain the leakage current in the considerable limits for a long time. Due to the leakage currents and discharges, the degradation process can develop significantly on the polymeric insulating material surface. However, there may be temporary variations in the leakage currents due to variations in environmental conditions.

1.4. Allowable levels of Leakage current for insulators:

The Leakage current values for insulators are not fixed and yet not defined strictly by any standards organisation. The major reason is that the insulators are mounted at a height therefore, their leakage current limit is set according to the reliability of operation rather than safety. So, we cannot state an exact value of maximum leakage current for any insulator. Instead, a limit is defined by the power companies which varies from country to country and even sometimes with in a country. For any transmission line, this limit is defined regarding the type of insulator used, voltage rating, and quality of service required and limits of losses for that line. However, the maximum limit in any case is 100 mA, although observed values in dry weather condition lie from a few microamperes to 5mA. In the wet weather conditions the leakage current value may rise up to 50mA or so are considerably of safe value.

1.5 Concept of Leakage Current analysis:

The Leakage current (LC) which is driven by the source voltage and collected at the grounded end of the insulator, provides much useful information about the condition of the polluted insulator. When the insulator surface is hydrophobic, the LC is usually capacitive in nature and the waveform would be sinusoidal. Once the surface looses hydrophobicity, the LC becomes more resistive. Dry-band discharges may cause the appearance of spikes in the LC signal crest. This can cause the deformation of current waveform as well as an increase in the harmonic content. It is reported that the transition of LC waveforms, until flashover occurs is classified into different stages. The possibility of flashover occurrence becomes higher when the magnitudes of the harmonic contents exceeds a particular level. This surface discharge activity will ultimately lead to the deterioration of electrical and mechanical properties of the material due to the chemical reactions. The modes of the degradation are tracking, cracking as well as progressive material weight loss. The changes in the surface condition of the polymeric insulators affect the magnitude and shape of the leakage current. If the extension of surface discharge is beyond air breakdown electrical stress, the arc will takes place. This results in the change of shape and magnitude of the leakage current.

1.6.Relationship between Leakage Current and other Parameters:

Leakage current has a direct impact on different parameters involved with the composite insulators which can be explained as:

1.6.1 Leakage current and Hydrophobicity:

Leakage current is directly proportional to hydrophobicity loss, especially for composite insulators. The more is the loss of Hydrophobicity, the more the leakage current becomes; this fact has been reported in many studies in the literature. The leakage current monitoring requires no need to use complex image processing softwares to estimate surface deterioration. The measurement of leakage current just needs the computer to record its values after a certain time intervals or after some certain changes in value of current for monitoring purpose.

1.6.2. Leakage current and degradation of insulators:

A distorted waveform of leakage current is a sign of degradation. A correlation between progressive degradation and changes of leakage current components can be observed from waveform of leakage current. The extent of distortion can be found quantitatively by measuring the ratio of Peak to RMS value of leakage current.

1.6.3.Leakage current and Equivalent Salt deposit density (ESDD):

Leakage current was found directly proportional to ESDD. The lower is the leakage current, the lower is the ESDD and vice-versa. The surface resistance is inversely proportional to ESDD.

1.6.4. Leakage current and flashover voltage:

The flashover voltage decreases with ESDD increase. But ESDD is directly proportional to leakage current, so we can conclude that as the leakage current increases, the voltage at which flashover will occur decreases. In other words, leakage current is inversely proportional to flashover voltage.

1.6.5. Leakage Current and Humidity:

If humidity in the environment increases Leakage current increases. The impact of this condition is more severe in coastal areas.

1.6.6. Leakage current and UV radiation:

UV radiation applied on composite as well as ceramic insulators causes a reduction in value of leakage current.

1.6.7. Leakage current and insulator length:

Increasing of the surface creepage distance of ceramic insulator helps to reduce the leakage current, the same is valid for composite insulators; however, the composite insulators in some places have shown a very slight effect of surface creep age distance on leakage current. Investigation on decreasing in the length of a certain SiR composite insulator from 6112 mm to 4801 mm caused a very slight increase in leakage current only.

1.6.8. Leakage current and temperature:

Temperature changes produce negligible effect on leakage current value.

1.6.9. Effect of fillers adding on leakage current of composite insulators:

It was seen that adding ATH (Alumina Tri-Hydrate) up to 50 ppm decreased leakage current value, but adding a very high amount of ATH again increased it. So a low amount of filler is suggested helpful if one is wishing to make a material with reduced leakage currents. Adding to much filler destroys the purpose.

1.6.10.Leakage current, corona, and dry band arcing :

Under a case when a small dry band arcing starts, the leakage current becomes resistive in nature and its waveform becomes non-linear. The waveform shows distortion from the basic sinusoidal shape. Leakage current waveform also has spikes which correspond to occurring of corona.

1.7. Summary of effect on Leakage current:

The significance of leakage current for all electrical devices and insulators can never be ignored. Leakage current in case of high voltage insulators are important to consider even they may not always pose safety hazard for public. The reason is that insulators are also affected a lot with the amount of leakage current flowing on their surface. Increase in leakage current causes a net generation of heat on surface. This heat damages the insulator surface and also causes a slightly burned path with low resistance over the surface. Such a path gives rise to dry band arcing. This can lead to failure or flash over of insulator. Ceramic insulators can shatter upon excessive dry band arcing and composite insulators although will never shatter, but are affected in a more complicated way as the heat of excessive dry band arcing causes scission and loss of the low molecular weight components (LMW) chains in silicon rubber layer of composite insulators. The loss of LMW's causes a reduction in surface resistance. Even it was found that ceramic insulators coated with thin layer of silicon rubber performed excellent in contaminated conditions. The reason is transfer of LMW from rubber layer to surface of pollution deposit same as it occurs in case of composite insulators. The other diagnostic techniques currently in use for accessing insulator surface degradation are surface conductivity test, hydrophobicity measurement, equivalent salt deposit density (ESDD), method of measurement of flashover voltage (FOV), leakage current monitoring, etc. Among these, leakage current monitoring is considered most suitable as it is easy and possible while insulators are energized on-line.

The major environmental factors effecting leakage current are humidity, rain, and salt/pollution deposits. On newly installed insulator, leakage current is low but as the pollution deposits on the surface and insulator is wetted by humidity/rain, the leakage current increases. The initial values of leakage current for SiR composite insulators were observed approximately half of those for the EPDM and quarter of those for ceramic insulator. For composite insulators, there is a small variation in leakage current values observed with time. Generally, it is known that the leakage current is divided into three parts, first one caused by dry band arcing, second by presence of some electrolyte on surface which cause conductivity and third one is pulsive. Pulsive part is contributed due to lightening and other switching surges and lasts only for short times and least dangerous. The current caused by electrolytic conductivity is not considered dangerous because heat generated by it is transferred to the surface indirectly from the liquid film. Only dry band arcing is considered most Before developing a laboratory aging cycle, it is necessary to conduct outdoor leakage current monitoring effect of dry-band arcing on actual insulators. The dry band arcing has been found major degradation factor and dangerous because it directly heats the surface and thus results in larger degradation. Visual inspection results from leakage current sites have shown that the degraded surface is divided into two different areas depending on the erosion level; less eroded grounded top area and significantly eroded energized bottom area. To create best insulator designs, it is necessary to study in detail the establishment of dry-band arcing current on material samples and full size insulators. Many studies are still in progress at different areas of world. The aging cycles simulated in laboratory setup sometimes apply too much simultaneous stresses which are never encountered in filed. Such tests yield a failure of insulator but are not realistic. Ceramic insulators are known to increase their leakage current with increasing surface pollution deposits. The same does not exactly applies to composite insulators which are well known for their degradation and then recovery of surface resistance. In general, it is reported form many sites that leakage current values are lower in actual field conditions, as compared to those obtained in laboratory aging cycles. Based on this, we can say that periods of maintenance predicted from laboratory aging tests can be increased for in service insulators.

CHAPTER – 2
LITERATURE REVIEW

2.1. Review on Polymeric insulators:

The failure of high voltage insulators on transmission lines can lead to transmission line outages, thereby reducing system reliability. One form of insulator failure is flashover, the unintended disruptive electric discharge over or around the insulator. Contamination on the surface of the insulators, such as from salts for de-icing streets, coastal areas atmospheric conditions and sidewalks, enhances the chances of flashover. Currently there are no standardized tests for understanding the contamination flashover performance of polymeric insulators. The flashover voltage can be predicted and flashover dynamics explained for contaminated polymeric insulators. The principle dielectrics used for outdoor insulators are ceramics and polymers. In early high voltage transmission and distribution system designs, ceramic insulators made of porcelain or glass were used principally. Since the 1960's, however, polymers have been preferred for the housing of high voltage outdoor materials. In the last twenty-five years, the use of polymeric materials, particularly silicone rubber and ethylene propylene diene monomer, as weathersheds on outdoor insulators has increased substantially. Filters are used to reinforce the silicone rubber and can improve tensile strength, modulus, tear strength and abrasion resistance of the silicon rubber. Contamination on outdoor insulators enhances the chances of flashover. Under dry conditions, contaminated surfaces do not conduct so contamination is of little concern. Due to silicon rubber polymer insulators made from polymeric materials, the environmental conditions are major problems to aging for silicon rubber such as salt fog, humidity, dust, rain and UV etc. Under environmental conditions of light rain, fog or dew, surface contamination dissolves. This promotes a conducting layer on an insulator's surface which facilitates a leakage current. High current density near the electrodes results in the heating and drying of the pollution layer. Due to many advantages the ceramic insulators which have been used since ages are being replaced by the polymeric insulators and the reasons for the use of polymeric insulators can be depicted as shown below.

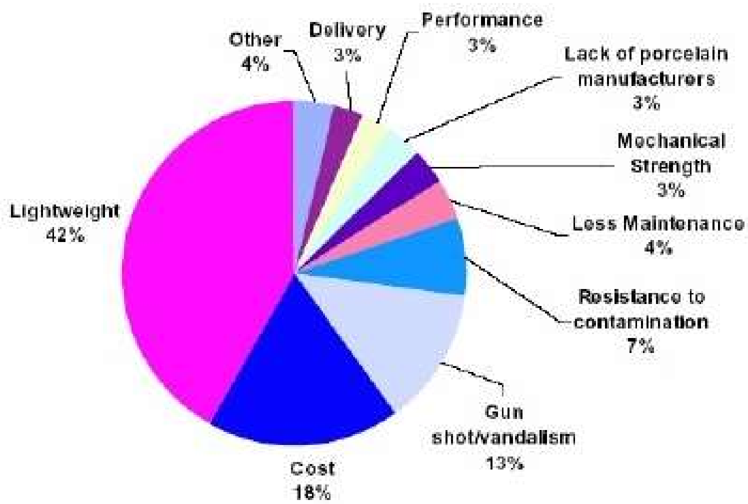

Fig.2.1. Reasons for applying Polymeric insulators

An arc is initiated if the voltage stress across the insulator's dry band exceeds its withstand capability. Extension of the arc across the insulator ultimately results in flashover. The contamination severity determines the frequency and intensity of arcing and, thus, the probability of flashover. In practice, there are various contaminant types that settle on outdoor insulators. These contaminants can be classified as soluble and insoluble. Insulators located near coastal regions are typically contaminated by soluble contaminants, especially salt (or sodium chloride). Insulators located near cement or paper industries are typically contaminated by non-soluble contaminants such as calcium chloride, carbon and cement dust. The type of fog and rate of wetting of the insulators also affects the surface resistance of non-ceramic insulators. Irrespective of the type of contaminant, flashover can occur as long as the salts in the contaminant are soluble enough to form a conducting layer on the insulator's surface. Salts used for de-icing streets, roads and sidewalks include sodium chloride, calcium chloride, potassium chloride, calcium magnesium acetate, and magnesium chloride. Of these chemical compounds, the most commonly used road salts are sodium chloride and calcium chloride. After application, these road salts tend to be deposited on insulator surfaces by the effects of atmospheric wind and vehicle movement. The effect these road salts have on insulators depends on the physical state in their application to the road. De-icing streets with a liquid form of salt is a new practice and is expected to have the worst effect on insulator performance. Due to the hydrophobic nature of non-ceramic insulators, the best flashover prediction method may not be measurement of the amount of salt contaminate on the insulator's surface. A hydrophobic surface can have high contaminate levels with negligible leakage current because water formation on such a surface is in the form of discrete droplets as opposed to a continuous film.

2.2. Objectives of the thesis:

The main objectives of our thesis are:

1. To study the affect of pollution on polymeric insulators in coastal areas.
2. To conduct the experiment on 33kV and 11 kV polymeric insulators to measure the variation of leakage current and break down voltage of polymeric insulators under the pollution in coastal areas.
3. To measure the performance of these insulators under the natural atmospheric pollution.

2.3. Organisation of the thesis:

1. Chapter one discuss the introduction of the project which includes the necessity of leakage current measurement, importance of leakage current on insulators, affect of leakage current on polymeric insulators, safe levels of leakage current on polymeric insulators etc.
2. Chapter two presents the objective of the project and organization of the thesis.
3. Chapter three provides the different types of insulators, terminology used in insulators and their advantages and disadvantages.
4. Chapter four gives the information regarding the different pollutions in the different areas and their limits on the insulators.
5. Chapter five present the experimental details, results and analysis of plots.
6. Chapter six explains the concluding remarks and analysis of the thesis.

CHAPTER 3

INSULATORS FOR ELECTRIC POWER SYSTEMS

This chapter describes the general nature of electrical insulation, with a focus on high - voltage (HV) and extra- high - voltage (EHV) systems. This chapter identifies terms used to describe the insulator characteristics, the various stresses encountered in service, and the standard tests used to quantify electrical strength. In the contaminated environment, the insulator serves merely as an insulating substrate on which a pollution layer may accumulate. It is mainly the shape, size, and surface finish of the insulator rather than the material that affects the accumulation process. The response of the insulator to wetting is influenced by the insulator surface material, with a distinction between hydrophilic (ceramic) materials that sheet water, and hydrophobic (non ceramic or polymer) materials that bead water.

3.1 Classification of Insulators:

High voltage insulators have developed rapidly since early. Today, modern polymeric insulators are used, as well as the earlier materials. A classification of the main types of insulators is shown schematically in fig 3.1

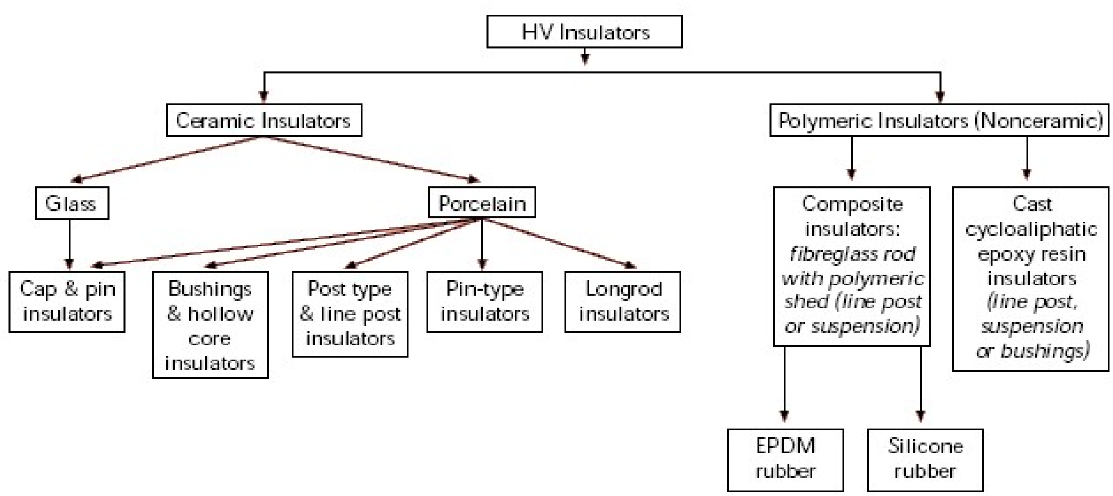

Fig 3.1 Classification of power line insulators

3.2 Composite polymeric insulators:

These insulators are similar to long rod insulators but consist of:

- A glass fibre reinforced resin core to provide the mechanical strength, while resisting the electrical stress
- Elastomer sheds to provide the required creepage and stress reduction to withstand the stresses prevailing on the system. Two commonly used materials are silicone rubber and EPDM (ethylene propylene diene monomer) rubber.
- A typical method of construction is shown schematically in Fig 3.2 The metal end fittings are usually crimped onto the glass fibre rod from the environment and the interfaces between the elastomer and the metal fittings are very important. Tests to ensure the quality of composite insulators are contained in IEC 1109.

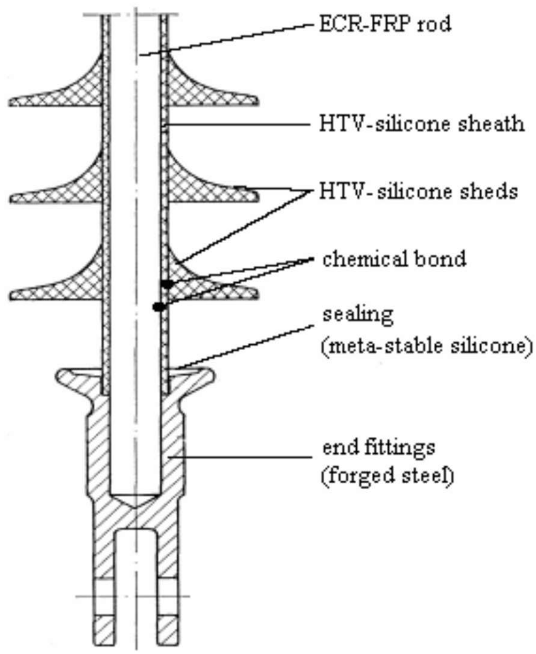

Fig. 3.2 Structure of a Composite insulator

A major advantage of composite polymeric insulators is an up to 90% weight reduction when compared to ceramic equivalents. They are also reasonably vandal-proof.

3.3 Terminology for Insulators:

An efficient electrical system makes more use of high voltage rather than high current. It is much more effective to provide adequate high-voltage insulation than to increase conductor cross section. The different terminologies used in the high voltage insulators are mentioned below:

3.3.1 Electrical Flashover:

The dielectric insulation between metal fittings offers a high resistance to the passage of current and also resists disruptive discharge (flashover). Flashover is defined as a disruptive discharge through air around or over the surface of a solid or liquid insulation, between parts of different potential or polarity, produced by the application of voltage wherein the breakdown path becomes sufficiently ionized to maintain an electric arc. The disruptive discharge completely bridges the insulation under test, reducing the voltage between the electrodes to practically zero.

Insulation is self - restoring if it completely recovers its insulating properties after a disruptive discharge; insulation of this kind is generally, but not necessarily, gas or liquid rather than solid insulation. Once a disruptive discharge has been interrupted, the air around a solid insulator will be self – restoring within a fraction of a second.

The electrical performance of power system insulators is normally tested using procedures such as those found in IEEE Standard 4 and IEC Standard 60060 – 1. These standards specify the voltage wave shapes and other test details to be used in the evaluation of insulator performance. The critical flashover level is defined as the amplitude of voltage of a given wave shape that, under specified conditions, causes flashover through the surrounding medium on 50% of the voltage applications.

3.3.2 Insulator Dimensions:

The flashover performance of a self - restoring insulator is established by the dimensions of the insulator, the shape of the sheds or convolutions on its surface, the environmental conditions, and the nature of the surface material.

- Dry arc distance is the shortest distance in air between the line (high voltage) and the ground electrodes. The dry arc distance of an insulator determines the BIL (basic lightning impulse insulation level) of the system. This BIL in turn is used to establish safety clearances in national electric safety codes and is also an important aspect in guides to insulation coordination.
- Shaft diameter is the measure of the insulator size at its most narrow part. For ceramic post and long - rod insulators, shaft diameter normally determines the material cross section, the contact area and size of metal end fittings. These areas, to a large extent, establish the mechanical breaking strength of the insulator. Some ceramic insulators have tapered profiles, with increasing shaft diameter toward the base of the post to provide additional strength where the mechanical stresses are greatest. Polymer insulators have a central core member with a rubber sheath. The shaft diameter and mechanical breaking strength for a polymer insulator are usually defined by the core member diameter, which is normally a fibreglass rod. The rubber sheath does not usually add much strength or thickness, and the shaft diameter is constant along the entire length.
- A solid cylinder of insulating material with adequate dry arc distance would perform well in dry conditions, but would be susceptible to electrical flashovers whenever the surface became wet. The sheds break up columns of water that might otherwise run down as continuous vertical channels along the insulator's entire length. The sheds work as multiple umbrellas to keep some parts of the surface dry. Properly designed sheds increase the wet flashover strength of insulators in heavy rain conditions.
- Shed diameter is the measure of the insulator size at its widest part. This dimension is usually of more interest than shaft diameter in conditions of heavy ice or snow accretion. A crescent of ice can accumulate on the windward side, spanning the full outer diameter of the insulator.
- Insulator sheds have another benefit in outdoor conditions. The electric field stress along the surface of the complete length of the insulator is reduced. This means that the insulators tolerate a higher degree of pollution accumulation before partial discharge activity is initiated. The electrical stress across the surface of the complete length of the insulator is given by the normal power system operating voltage, divided by the leakage distance.

- Leakage distance is the shortest distance, or sum of the shortest distances, along the insulating surface between the line and ground electrodes. The distance across any cement or conducting jointing material is not counted, but distance across any high - resistance coating is included. Surfaces coated with semiconducting glaze are considered as effective leakage surfaces.
- Leakage distance is typically selected on the basis of the maximum contamination levels expected in the installed field location. For chains of standard porcelain or glass disks, the shed spacing and diameter are fixed. However, leakage distance can be increased by incorporating several ribs on the under surface of the disk or by adding additional disks to the chain. Deep under surface ribs may have diminishing returns, as numerous deep ribs will tend to load up with contamination over time and impede natural or high – pressure washing. If there is sufficient clearance, insulators with larger diameters or alternating diameters can also be used.
- At average voltage stresses above 25 kV RMS per meter of leakage distance, for high levels of surface pollution level, discharges will be initiated, propagate, and extinguish in a process called " dry - band arcing. " The arc current is usually not more than 1 A but is still sufficient to maintain arc plasma with a temperature of about 4000 K. At this temperature, the arc is electrically conductive and can short out portions of the leakage distance. If an arc grows to a sufficient length along the insulator, the remaining air gap will become too weak to withstand the line voltage.
- Shed-to-shed separation is measured from the bottom of one shed surface to the top of another. For station post insulators with thick ribs, the shed-to-shed separation can be half of the shed spacing. The ratio of shed-to-shed separation to shed depth measured from the outer diameter is of some interest in contamination performance. The air space in the shed-to-shed separation distance can break down if there is too much voltage drop along the portion of leakage distance between the sheds. The shed-to-shed separation also influences how much ice accretion is needed to bridge the dry arc distance with a continuous ice layer.
- Form factor of an insulator is one measure used to quantify the relation between the shed-to-shed separation and shed depth (shed overhang). It is defined as the

integral of incremental leakage distance dl divided at each measurement point by the insulator circumference $2\pi r$. The form factor of a cylinder of length 1 m and radius 10 mm is 15.9; if the radius is increased to 100 mm, the form factor reduces to 1.59. Form factor is used in electrical testing to ensure that the desired pre contamination and wetting conditions have been achieved. Form factor may also be used when comparing the performance of insulators with the same length, diameter, and leakage distance but different profiles. Disks with lower form factor tend to make full use of their leakage distance, but they also tend to have lower leakage distances than disks with high form factors.

- Wall thickness of hollow insulators, used to enclose high - voltage equipment (surge arrester blocks, instrumentation) or to transfer potentials into the interior of metal housings, establishes both the electrical and mechanical strength. The thickness is selected so that an external flashover will occur in air across the outer surface of the insulator, rather than a puncture, a disruptive discharge through the solid insulation or an internal flashover along the inside surface. Puncture can also occur through the cement and shell of porcelain

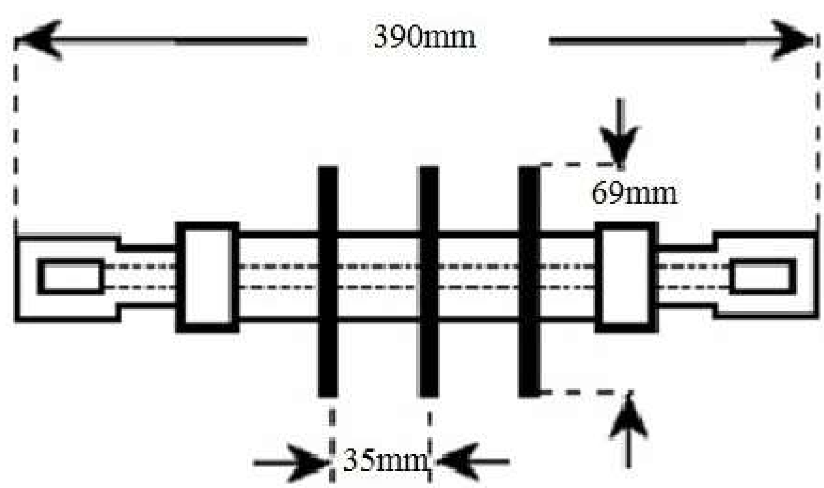

Fig.3.3 Dimensions of the 33kV polymeric insulator sample under test

insulators, or through the individual sheds of polymer insulators. Flashover through the insulating parts of an insulator, such as between the rubber cover and fibreglass core of a polymer insulator, has recently been labelled as a flash under phenomenon.

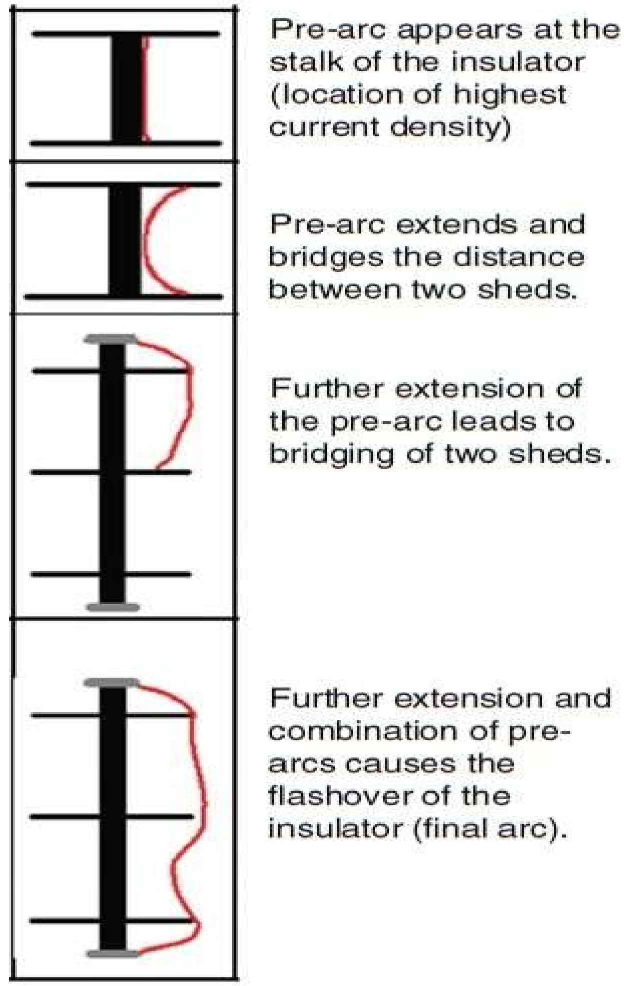

Fig.3.4 Phases in the flashover of insulators

3.4. Flashover in the insulators :

The most common cause of insulation failure is the presence of discharges either within the voids in the insulation or over the surface of the insulation. Flashover can also occur due to chemical degradation caused by the heat generated due to dielectric losses in the insulating material. When the conducting path is formed, it is called "tracking", and results in the degradation of the material. The phases in the flashover of the insulators can be visualised as shown in fig 3.4. The various causes for these pollutions is explained in the next chapter.

CHAPTER 4

ENVIRONMENTAL EXPOSURE OF INSULATORS

This chapter introduces the methods and terminology used to describe the effects of the natural environment on insulation systems. The role of environmental pollution in the electrical conductivity of the polymeric insulator samples can be understood by having a sound knowledge on these conditions. The surface of the insulators is covered by airborne pollutants due to natural or industrial or even mixed pollution. Contamination on the surface of the insulators enhances the chances of flashover.

4.1 Pollution:

Outdoor insulators are being subjected to various operating conditions and environments. To maintain the continuity of the insulators, one of the main problems that have been found is the effect produced by pollution in the insulators of electric lines. The pollution is one of the main causes of flashover in the insulators. The insulator begins to fail when the pollutants that exist in the air settle in the surface of the insulator and combine with the humidity of the fog, rain, or dew. The mixture of pollutants, plus the humidity form a layer that can become conductor and allow passing currents that will facilitate the conditions of short circuit. This is due to a decrease of the resistance of the insulator surface. In other words, the pollution degrades the insulators and affects severely to their electric characteristics, being one of the main causes of mis-operation of the insulators.

Air Pollution is the release of chemicals and particulates into the atmosphere. Common examples include carbon monoxide(CO), sulphur dioxide(SO_2), and nitrogen oxides(NO_x) produced by industry and motor vehicles. Photochemical smog and ground level ozone(O_3) are formed by electrical arcing and corona activity on high voltage transmission lines in wet conditions. Chemicals that attack the ozone layer, such as chlorofluorocarbons (CFCs) or the electrically insulating sulphur hexafluoride (SF_6) gas, are also treated as pollutants.

Water Pollution occurs through processes of surface runoff and leaching to ground water. The increased electrical conductivity and decreased pH of precipitation are also factors in the reliability of outdoor insulators and the service life of metal components.

Soil Contamination occurs when chemicals released by spill or leakage are retained for long periods of time. Examples of soil contaminants with long persistence are long chain and chlorinated hydrocarbons, heavy metals, herbicides, and pesticides. Electric utilities have been aggressive users of herbicides to ensure safe substations and reliable transmission rights of way, free from vegetation.

Radioactive Contamination, often in combination with heavy metal contamination, became prevalent during the development phases of atomic physics. Air, water, and soil pollution with radioactivity have all been problems, leading to some resolutions such as the censure of atmospheric nuclear testing. The ongoing use nuclear power to produce electricity is accompanied by nonzero risk of radioactive release. The reality of continuous radioactive release from burning of coal or wood is seldom acknowledged with the same fervour. For some types of wood, fireplace ash with caesium and strontium had 100 times more than 1 picocurie per kilogram limit used to classify low grade nuclear waste at nuclear power plants.

Noise Pollution includes roadway noise, aircraft noise, and industrial noise from steam management, cooling tower fans, and coal conveyors. Substation transformer hum is another source of annoyance from power systems. Audible noise from high voltage transmission lines also occurs near many homes, both from conductor corona in rain and from arcing activity on insulators in fog.

Visual Pollution refers to the presence of overhead power lines, advertising boards, scarred landforms (from strip mining or highway construction), or open storage of trash. It is interesting that bridges with construction similar to overhead power lines, fast food restaurants that are essentially billboards enclosing an interior volume, and the Grand Canyon are not considered visual pollution. A complex psychology related to the origin and purpose of the feature and the possibility for interaction plays a role in these perceptions. Arcing on contaminated insulators draws visual attention to power lines at night, and single disk flashovers on dc lines are also a form of visual pollution.

Thermal pollution is the temperature change in natural bodies of water caused by human activity. Locally, cooling water is used at most thermal plants to maximize thermal efficiency. With super heated steam working between 310 and 800 K, the theoretical efficiency. Of the Carnot cycle is (800-310)/800=60%. Practical coal-fired power plants can achieve 38%, leaving about 62% of the total heat energy in the local environment. Cooling ponds provide a large surface area to allow for radiative and evaporative cooling prior to returning water to nearby lakes or rivers. In wet cooling towers, hot water is sprayed into a cool air stream, with heat of vaporization providing highly efficient heat transfer to the atmosphere. Both of these tend to produce microclimate effects of fog and rain downwind. All of the energy produced by electric power plants will eventually appear in the environment as heat after use. Globally, warming from increased CO_2 in the atmosphere is another form of indirect thermal pollution.

While electrical power utilities and countries work with varying degrees of diligence to minimize their various forms of pollution, this is not the primary focus of our work here. Air and water pollution degrades the reliability of critical power system amenities in the long term through accelerated corrosion rates of metal and insulating polymer components. Pollution also impairs the electrical performance of critical power system components in the short term, typically under winter conditions, through electrical flashovers and faults on insulators.

4.2 Pollution Deposits on Power System Insulators:

Power systems must deliver reliable service under a wide range of outdoor conditions. The insulators used in outdoor substations and overhead transmission and distribution lines must withstand normal service voltage, without flashover failures and their related network disturbance. These insulators must also withstand some over voltages, power system transients being the most relevant in the winter environment but lightning transients are also considered in the polluted operating environment.

Electrical station equipment and line equipment located near generating stations have a wide range of associated problems, including accelerated corrosion damage, high rate of buildup of surface pollution, and heavy localized wetting from cooling tower plumes.

4.2.1 Typical Sources:

The level and the type of pollution of a region are associated with the sources of pollution, as well as with weather factors of the place. Independently, of the existing pollution type, the normal phases in which a flashover can appear in the insulator by pollution are:

- The pollution is placed on the surface of the insulator and a contaminant layer appears. The pollution can be caused by a great variety of sources (sea salt, industries, ashes, etc…). The wind is the main bearer of the particles.
- By the action of rain, fog, etc., the layer on the surface is dampened and enlarges the conductivity.
- The contaminant layer dries. Thus, there is an increase of conductivity and leakage current.
- Dry bands are formed as a consequence of the warming up of the layer on the insulator surface.
- Partial arches appear through the dry bands. Partial discharges are produced which in turn produce the audible noise. Finally, the total discharge is produced.

For the flashover to be produced these phases need not happen consecutively but several phases can occur at the same time. When the contaminated layer is dampened, the resistance diminishes and the current of filtration that passes through it is increased. With this increase, the temperature of the contaminant layer is elevated, and that still diminishes the resistance. The resistance will diminish until the temperature reaches the boiling point, beginning to lose humidity. From this point the layer resistance begins to enlarge little by little until its total drying. Then the maximum value of resistance will be reached. This phenomenon is a lot more feasible in narrow parts of the insulator where the density of current is higher.

The increase in the resistance makes the current to diminish, but its formation implies that most tensions applied to the insulator appear through it with the remainder of the layer still humid. An increase of pollution produces the increase in the leakage current and then the flashover of the insulator is more probable. But if we could distribute the pollution over the entire insulator, the voltage would be forced to be more lineal, so we would avoid the electric concentration in any point of the insulator and the probability of flashover would diminish. In some locations very close to large sources of pollution, the entire insulator is covered with contaminant, but this situation is an exception more than a rule. Because of it, the most typical guideline is a non-uniform distribution. The surfaces, exposed or protected, of the insulator are affected in different ways by the forces that are responsible for placing the contaminant and to clean that surface. Thus in many cases the most exposed areas are most contaminated than areas protected, but there are cases where the contrary is also certain. Although many factors can define the insulator pollution, three main types of pollution can be highlighted: the industrial, marine and desert.

4.2.2 Industrial Pollution:

People in their daily work generate smoke, dust or particles that are in suspension in the air. These particles, mainly by the action of the wind, spread over zones where the electric lines exist. The industrial pollution of the insulators appears with the industrial development and by the contaminants generated and expelled to the atmosphere like metallurgical, chemical substances, dust, smoke, cement. These substances will settle for the action of the wind, weight, electric fields, etc., on the insulators creating a contaminant layer. The layer that is settled on the insulator is formed slowly during a period that can last for months or years. The most direct way to establish the behaviour of the insulator during this type of pollution is to control the behaviour of the amplitude of the leakage current with respect to time, or the load of the leakage current accumulated during a certain period of time. Then it will be possible to see whether the activity of the pollution enlarges with the time and also the effect of the rain will be seen. In this way, we will be able to decide whether we have to do an artificial cleaning (maintenance) or the natural wash is sufficient to avoid the dangerous layer to be formed.

Among the contaminant sources that characterize this type of pollution, we have to keep in mind the characteristics sources of industrial pollution as well as other sources that enlarge the problem:

- The typical contaminant sources are the smoke of industries, vehicles, buildings, etc. Heavy industries such as fertilizing plants, oil refineries, businesses, cement works, can have severe emissions of contaminant particles.
- If the electric line is near the coast, we have to keep in mind the action of the waves, breezes or winds coming from the sea, the fogbanks and the particles of salt that are in suspension in the outskirts of the zone where the insulators are located.

4.2.3 Marine Pollution:

The insulators exposed to coastal or marine environments, can become to be conductors due to the formation of a conductive layer on its surface. This layer will be formed on account of the salted dew of the mornings in these zones close to the coasts. When dried with the heat produced in the same insulator or with the environment temperature, the evaporated salt that had been absorbed before is deposited on the insulator. The particles on the insulator are not dangerous in the dry weather conditions but the problem arises when the environmental weather is humid, rains, there is dew, fog, then the layer can become conductor. The conductivity of this will depend on the kind of salt that forms on it. The weather conditions vary considerably from the coastal areas to the interior areas and they play a very important role in the contaminants deposition rate and in the operation of the insulator. The problem of the pollution depends mainly on the environment.

Also, we must keep in mind the evaporated salt in the environment. With the passage of time, this layer will become thick enough to be dampened and to become conductor. The danger of the pollution will depend on the type of material and on the form of the surface. Also the sources of pollution must be investigated and the way of deposition of pollution on the insulator. The wind is the main bearer of the pollution, being others, the gravity and electric fields. The pollution will also depend on the direction of wind for a greater or smaller pollution of the insulators. The severity of the pollution in a location is quantified in terms of Equivalent Salt Deposit Density (ESDD) measure in units of NaCl mg/cm^2, in which the following five factors are taken into account: Temperature, humidity, pressure, rain and velocity of the wind. The marine pollution is located not only in the surrounding area of the coast, but also to considerable distances by the action of the wind.

4.2.4 Desert Pollution:

In some zones, the insulators of the electric lines are often subject to deposition of contaminants substances of the deserts. This can cause a serious reduction in the efficacy of the insulator, as a result the flashover and electric supply lack. Also the storms of sand must be kept in mind. The type of environmental conditions will affect considerably to the insulators. The predominant elements in this type of pollution are: the sand and the salty dust in the atmosphere. The desert climate is characterized for sands storms and hurricanes that contain particles that move to a high speed. These particles strike to the surface of the insulator causing the material erosion. The storms of sand are an important factor that causes a decrease of reliability in electrical lines.

The performance of ceramic insulators under desert conditions is satisfactory compared with the performance in other zones with industrial or coastal environments. Nevertheless the use of insulators of SiR is not so acceptable due to the hydrophobic characteristics change depending on the conditions of weather and humidity.

4.3 Deposit Processes:

Two different deposition processes led to the accumulation of pollution on insulator surfaces.

- Dry Deposition build-up on insulating surfaces of the ions that are electrically conductive when in solution with water. Dry deposition mass flux due to turbulence affects both top and bottom insulator surfaces. Mass flux due to gravitational settling affects mainly the upward-facing surfaces, leading to more rapid rates of increase in dry conditions. Accumulation of sodium chloride, sulphate, nitrate and ammonium ions are most important although a range of other salts and metals can accumulate.
- Occult Deposition of precipitation such as fog, rain, ice, or snow. Depending on the conditions, polluted ice, snow or fog can be an important additional source of electrically conductive ions as well as a stable source of water to dissolve existing surface pollution.

4.4 Cleaning Processes:

There are two main processes that naturally remove pollution from insulator surfaces-wind and rain. In addition, winter precipitation such as snow or ice can also dissolve surface ions and release them into drip water during melting or shedding.

Wind was also identified as a dominant factor in the accumulation of pollution, especially in wind tunnels and near the sea. Looms suggest that the time to reach equilibrium between accumulation and cleaning by wind action varies from days to years. Rain is very effective for cleaning the upward facing surfaces of insulators but the efficiency for the bottom surface varies with intensity and quantity. For upper surfaces and cylindrical posts, 10mm or more of rain removes 90% of the salt deposit.

4.5 Other Factors Affecting Insulators:

The presence of pollution alone does not necessarily lead to electrical flashover problems. There are some additional factors which include:

- Wetting of the polluted surface, through hygroscopic scavenging from the atmosphere, accumulation or melting of natural precipitation, local fog from cooling towers, or other means. Surface deposits of insoluble materials play an important role in stabilizing the wetting process. The ability of a surface to repel water affects the continuous or discrete drop nature of the wetted area.

- Heating of the electrically conductive pollution layer by resistive heating from leakage current. The electrical resistance of the pollution decreases with increasing temperature. Also, the power dissipation causes local evaporation and formation of dry bands that interrupt the flow of current. The high voltage distribution along the insulator from line to ground end changes, with most electric field stress across the dry bands.
- High local electric stress across dry bands causes initiation and propagation of arcing. Arcing produces local ozone (O_3) that reacts quickly to NO_x, and also produces distinctive audible noise pollution. If arc plasma bridges all the way across an insulator, it will short circuit the power system, causing current flow to local grounding.

4.6 Maintenance of the insulator:

In zones where there is pollution, besides a good election of the insulator, it is advisable to have a maintenance plan. In other words, we need to wash or clean the insulator. This is more important in areas with severe environments of pollution or low rain probability; bring necessary the elimination of the pollutant layer placed on the insulator. This maintenance can be carried out with the system energized, wash in hot or de-energized. The later method is used when other methods cannot be applied due to technical reasons or when the adhesive characteristics of the pollutant require the use of wash with chemical solutions to recover the insulation level. Many times, the wash is carried out by hand. In general the most employed methods are: the wash by water to high, average or low pressure, with dry air compressed or with spurts of abrasive materials and more recently the use of ultrasonic. Any of the techniques used has to guarantee that the insulator will not suffer damage, neither that we are going to get worse the present situation.

The wash with spurts of water is the most effective and economic method, if the contaminant is dust, salt or land, or if these pollutants are not much adhered to the surface. If the contaminant element has a high adhesion, we have to wash the insulator with abrasive elements. They can be smooth elements, as shattered shell of cobs of corn or shells of nut, fine dust of lime, or more abrasive elements as the fine sand.

To prevent the flashover during the wash, the following observations have to be considered:

- The wash of the insulator will begin from the lowest phase conductive.
- When we wash, the water should not fall directly on a dirty insulator.
- We will begin to wash from the lower part of the insulator until finishing in the upper part.
- It is very important to keep in mind the direction of wind.

4.7 Reduction of Pollution:

Generally, research has been directed toward the pollution reduction methods. It is owed to the fact that the elimination of the source of contaminant is industrial, because of the difficulty to eliminate other contaminant sources

In this project, the insulators were subjected to natural pollution. The results of leakage currents and breakdown voltages are provided in the next chapter.

CHAPTER 5
EXPERIMENTAL RESULTS

5.1 Introduction:

The insulators were tested in High Voltage Engineering Laboratory at our college University College of Engineering Kakinada, JNTUK Kakinada. The measurement of the Leakage current and breakdown voltage set up consisted of cascading transformer, HV bus bar, insulators to be tested, control panel with required metering. The specifications of the cascaded transformer are:

Number of stages	: 2
KVA rating	: 100 KVA
Voltage generated per unit	: 250 KV
Total Voltage generated	: 500 KV
Maximum Current	: 0.2 A, 5 minutes
Maker Class	: HOCHSPANNUNGS, Gesellschaft, West Germany

5.2 Details of the Insulator samples :

The composite insulators used are 33 KV and 11 KV samples :

5.2.1. 33 KV Samples :

1) 33 KV Polymeric Insulator (Sample - A)
2) 33 KV Polymeric Insulator (Sample - B)
3) 33 KV Polymeric Insulator (Sample - C)
4) 33 KV Polymeric Insulator (Sample - D)

5.2.2. 11 KV Samples :

1) 11 KV Polymeric Insulator (Sample - 1)
2) 11 KV Polymeric Insulator (Sample - 2)
3) 11 KV Polymeric Insulator (Sample - 3)
4) 11 KV Polymeric Insulator (Sample - 4)
5) 11 KV Polymeric Insulator (Sample - 1′)

5.3. Setup For Natural Pollution of the Composite Insulators :

The 33 KV and 11 KV Polymeric insulators were kept in our department, which is nearer to the coastal atmospheric conditions, and by this means these were subjected to their natural working conditions and were subjected to natural pollution as shown in below fig 5.1. The insulators were kept again at the site after the testing. These insulators were subjected to the coastal atmospheric conditions to observe the variation in the characteristics of the Composite insulators in the coastal areas where the average absolute humidity is about 70% in the atmosphere. In these conditions both sea and industrial pollution produce uniform contamination layers on the surface of SiR insulators.

- The standard atmospheric conditions according to IEC 60060-1 are:

Temperature	:	20 °C
Pressure	:	1013 hPa
Absolute Humidity	:	11 g/m^3

Fig. 5.1 Setup of Polymeric Insulator samples at test site under natural atmospheric pollution

5.4. Circuit Diagram:

The insulators are tested in the High Voltage Laboratory and in the testing process the Leakage current corresponding to the applied voltage are noted down until the breakdown of the insulator occurs. The circuit diagram for the leakage current measurement is as shown in fig.5.2.

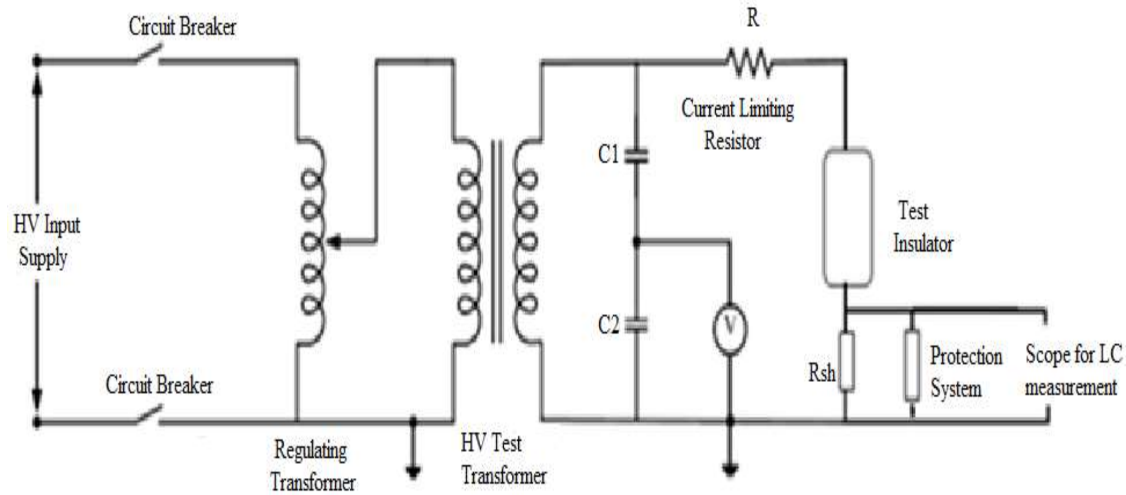

Fig. 5.2 Circuit Diagram for Testing of Insulators in the HV laboratory showing different equipments used in the testing of polymeric insulators.

5.5. General Procedure :

The first step of the laboratory procedure was to measure the LC of all the insulators in the HV laboratory. No artificial solid contaminant was used, the only solid contaminant was the natural one. insulators had accumulated various amounts of pollution.

- It was observed that the initial virgin samples which were given to us were not free from dust and it was fair to believe that the insulators had accumulated various amounts of pollution and as the main aim of the laboratory investigations was to study the properties of the material itself, all the insulators were washed.

- This washing of the insulators was done by putting the insulators for approximately 5 minutes but not more than 6 minutes, into a container filled with slowly flowing tap water. The temperature of the water was held constant at about 28 °C.
- The purpose of the washing was to remove loose and soluble dirt in order to better study the effect of the surface material properties on the Leakage current.
- The pollutants on the surface were removed by gently wiping the insulators by hand.
- The insulators were left to dry for at least one week in the laboratory after the washing.
- The third step was to study the LC under clean fog again, to determine whether the washing had had any effect on the leakage current behaviour. After the second LC measurement the voltage withstand of the insulators was studied.
- There were two main objectives of the flashover tests of the insulators. They were to compare the flashover voltages of the energized, weathered and reference insulators and to investigate whether the flashover affected the surface properties.
- Next the insulators were kept at the pollution site and the flashover tests were performed for every 15 days. This procedure was performed for each of the insulator samples. The insulators were again kept at the pollution site after every test measurement. The testing process was represented in a flow chart as shown below in the fig. 5.3 for easy understanding of the test procedure.

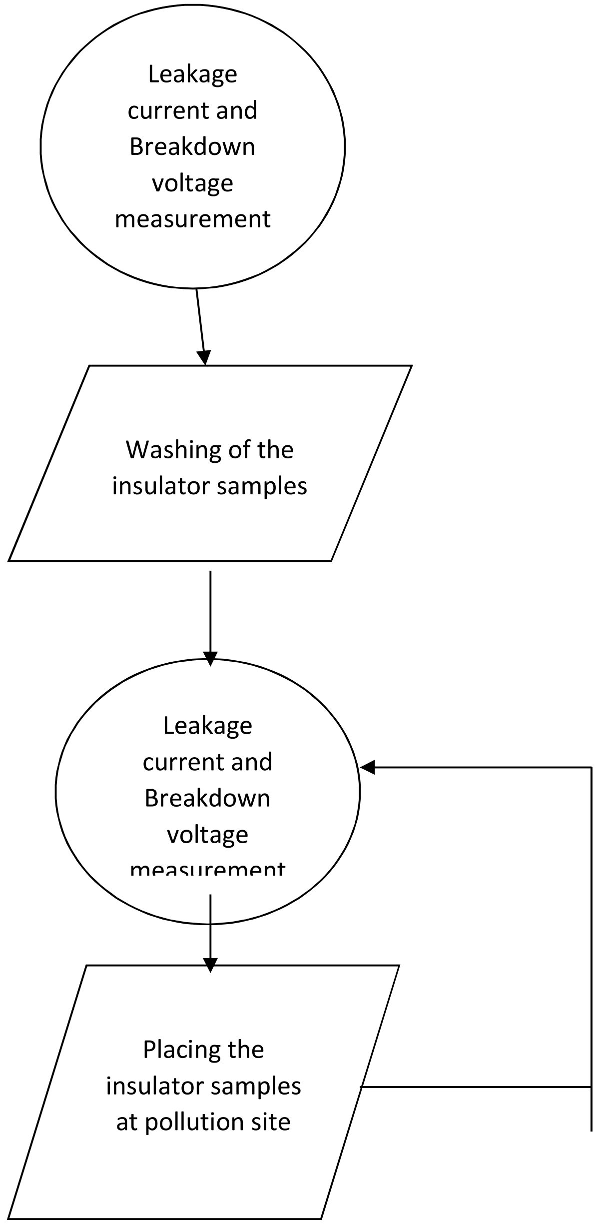

Fig. 5.3 Flow chart representing the test procedure

5.5.1. Procedure for measuring the Leakage current and Breakdown Voltage :

The procedure for measuring the leakage current and break down voltage in the HV Laboratory is as follows :

1. The test specimen (33 kV and 11 kV polymeric insulators) is connected its one end to high voltage conductor and other end to the ground as shown in fig 5.4
2. Source voltage of power frequency is applied across the insulator. by Increasing the source voltage at uniform rate gradually in steps of 10 kV until breakdown voltage is reached.
3. The leakage current corresponding to the applied voltage is measured using the ammeter provided in the control panel, by opening the ammeter switch and the switch is closed after measuring the Leakage current.
4. The above procedure is repeated for different values of voltage and corresponding leakage currents are noted.
5. Increase the voltage till break down occurs.
6. Observe the breakdown voltage accurately as it suddenly goes off to zero after breakdown.
7. Tabulate the reading of voltage and leakage current.
8. Repeat the same process for all sets of 33 kV and 11 kV insulators.
9. The main precaution is that the grounding must be proper given and also the readings should be noted down with care.

The control room where the leakage current and breakdown voltage are measured is shown fig 5.6.

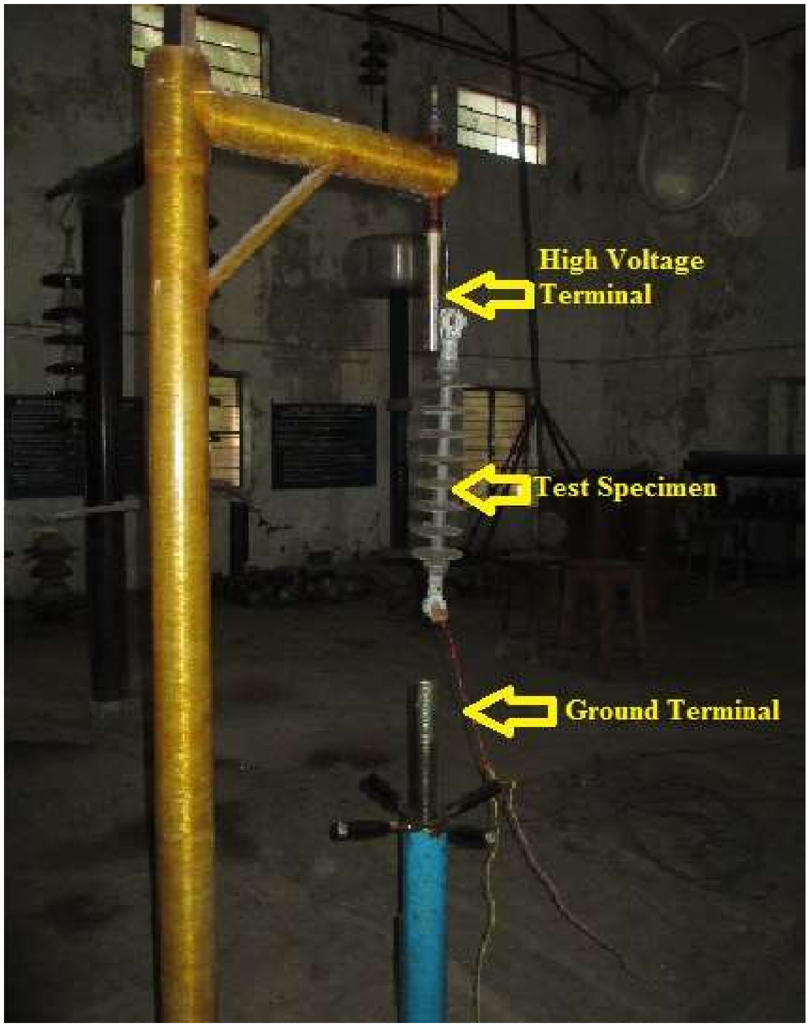

Fig.5.4 Experimental set up of Test Specimen for Leakage current and Breakdown voltage measurement in the High Voltage Laboratory

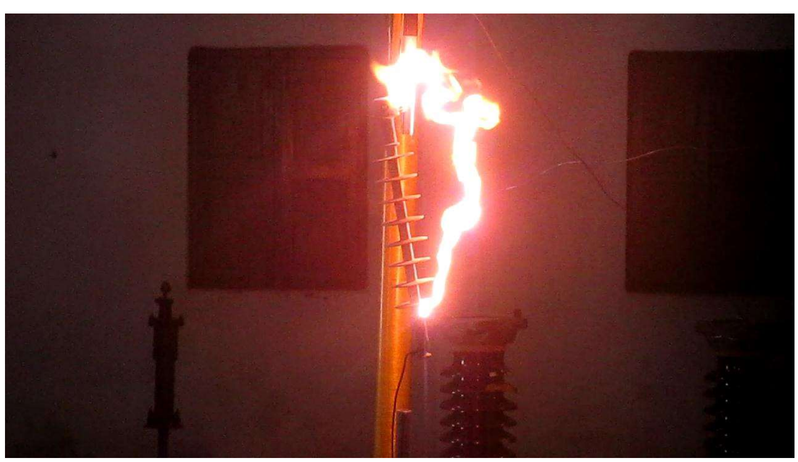

Fig. 5.5 Occurrence of flashover on 33kV insulator sample during the test

Fig.5.6 Control Room where the Leakage Current and Breakdown Voltage were measured

5.6. Leakage Current and Breakdown voltage values :

As mentioned earlier the samples were initially tested without any pollution then they are washed thoroughly and again tested and are made to dry for 15 days are repeatedly tested for every 15 days. Here these samples are subjected high voltage until their breakdown is reached and the corresponding variation of the Leakage current with breakdown voltage are noted and the graphs are plotted to study the variation.

5.6.1. Without Pollution :

Initially the insulators are tested without any application of pollution to study the variation of leakage current with the breakdown voltage. These are the samples without any contamination on their surface levels. The values of the Leakage current and breakdown voltage without any pollution i.e., the initial virgin samples are as follows :

Table 5.1: Variation of Leakage current with break down voltage on 33kV polymeric insulator samples without pollution on 21-12-2013

Date: 21-12-2013 Temperature : 28°C

Applied Voltage (kV)	**LC of Sample A** (μA)	**LC of Sample B (μA)**	**LC of Sample C (μA)**	**LC of Sample D (μA)**	**Average LC of 4 samples (μA)**
10	3.8	3	3.1	1	2.725
20	9.8	7.4	7	4.7	7.225
30	16	12.5	12.1	9	12.4
40	22.7	17.7	17.1	15.2	18.175
50	30.8	24.3	23.5	22.6	25.3
60	39.6	30.7	30.2	30.4	32.725
70	50.3	38.6	38.2	39.7	41.7
80	64.2	49.2	48.3	50.1	52.95
90	81.5	58.9	58.4	65.7	66.125
100	99.9	71.8	74.1	81	81.7
110	117.3	84.5	87.9	97.4	96.775
120	139.1	102.2	104	116.4	115.425
130	170.5	116.2	126.5	144.9	139.525
140	210	138.9	146.2	171.5	166.65
150		164	174	207.1	181.7
160		193			193
Breakdown voltage(kV)	145kV	166kV	162kV	160kV	158.25kV

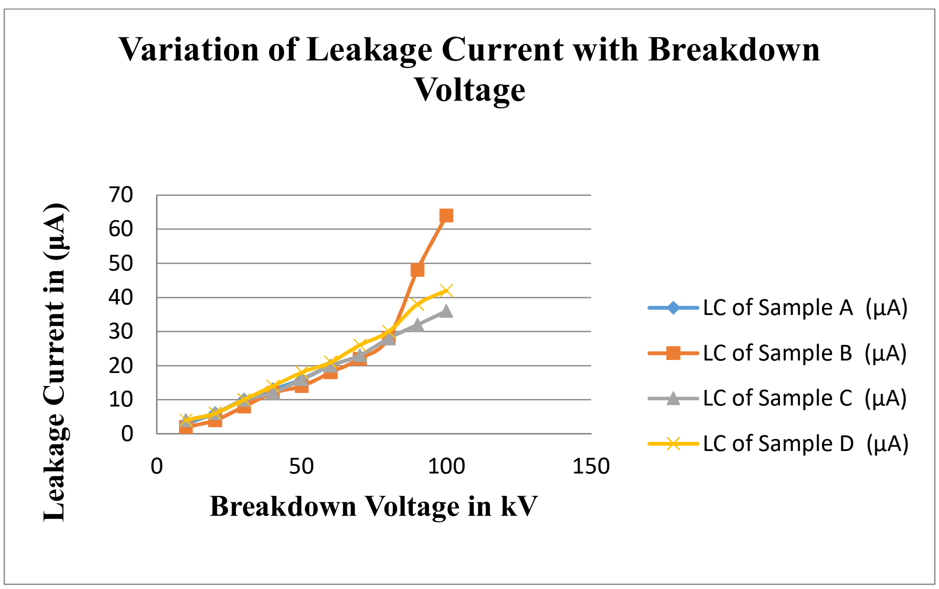

Fig.5.7 Variation of Leakage Current with Breakdown Voltage for 33 kV samples on 21-12-13.

Table 5.2: Variation of Leakage current with break down voltage on 11kV polymeric insulator samples without pollution on 21-12-2013

Date: 21-12-2013 Temperature : 28°C

Applied Voltage (kV)	**LC of Sample 1' (µA)**	**LC of Sample 2 (µA)**	**LC of Sample 1 (µA)**	**LC of Sample 3 (µA)**	**LC of Sample 4 (µA)**	**Average LC of 4 samples (µA)**
10	4	4.5	5	4.6	5.2	4.66
20	8	10	9.4	8.3	10	9.14
30	13	14	14.7	12.8	15.1	13.92
40	18	18	20.1	17.5	20.1	18.74
50	22	24	26.6	22.3	25.7	24.12
60	26	28	34.4	29.1	31.6	29.82
70			45.3	41.2	38.7	41.73
Breakdown voltage(kV)	80kV	80kV	79kV	78kV	77kV	78.8kV

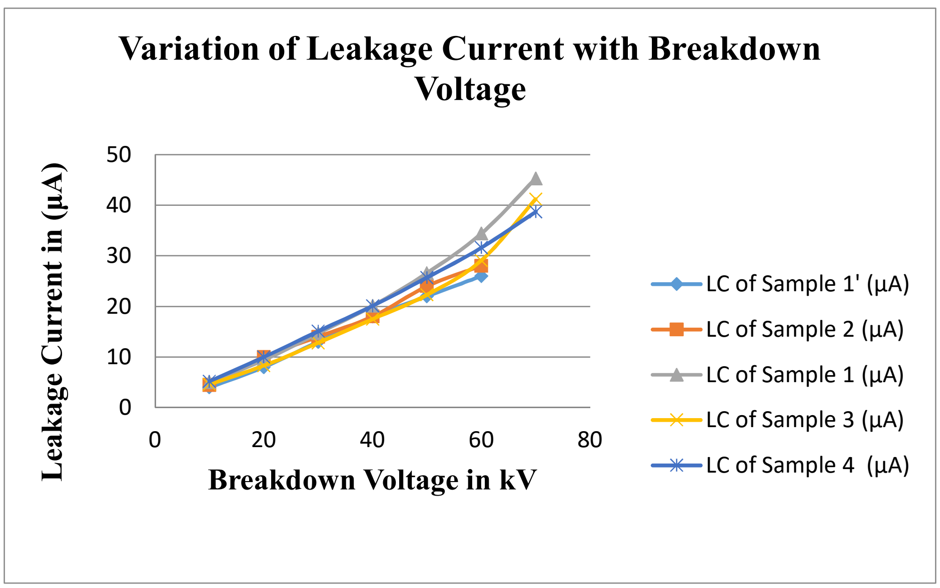

Fig.5.8 Variation of Leakage Current with Breakdown Voltage for 11 kV samples on 21-12-13.

5.6.2.After Washing the insulators:

The insulator samples were carefully washed under slowly running tap water at a temperature of 28°C to remove any soluble impurities. The insulators were washed for about 5 to 6 minutes and left for one week to dry. Then again the breakdown test was performed and the results were as follows:

Table 5.3: Variation of Leakage current with break down voltage on 33kV polymeric insulator samples without pollution on 07-01-2014

Date: 07-01-2014 Temperature : 28°C

Applied Voltage (kV)	LC of Sample A (μA)	LC of Sample B (μA)	LC of Sample C (μA)	LC of Sample D (μA)	Average LC of 4 samples (μA)
10	5	5	5	8	5.75
20	10	10	10	15	11.25
30	20	20	15	21	19
40	25	25	25	29	26
50	35	35	35	37	35.5
60	45	45	40	45.4	43.85
70	55	55	50	54.8	53.7
80	65	65	65	69.2	66.05
90	80	80	80	83.3	80.82
100	95	95	90	97.4	94.35
110	110	110	105	113.4	109.6
120	125	125	125	134	127.25
130	145	150	150	168.2	153.3
140	170	180	172	192.3	178.57
150	205	210	202	193.3	202.57
160	240	250	319.9		269.97
Breakdown voltage(kV)	166kV	170kV	160kV	160kV	164kV

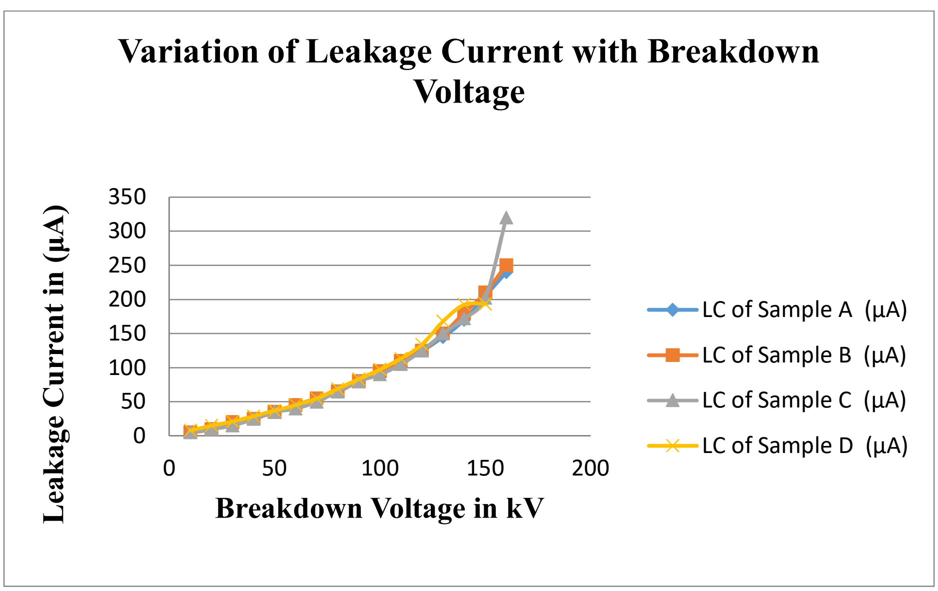

Fig.5.9 Variation of Leakage Current with Breakdown Voltage for 33kV samples on 07-01-14.

Table 5.4: Variation of Leakage current with break down voltage on 11kV polymeric insulator samples without pollution on 07-01-2014

Date: 07-01-2014 Temperature : 28°C

Applied Voltage (kV)	**LC of Sample 1'** (μA)	**LC Sample 2 (μA)**	**LC of Sample 1 (μA)**	**LC of Sample 3 (μA)**	**LC of Sample 4 (μA)**	**Average LC of 4 samples (μA)**
10	10	10	3.6	3	3.2	5.96
20	15	15	8.7	8.9	9.7	11.46
30	25	30	18.4	16.9	18.4	21.74
40	35	40	28.3	25.2	26.6	31.02
50	45	50	39.6	35.1	38	41.54
60	60	65	52.7	46.6	50	54.86
70	75	85	68.8	60.5	66	71.06
Breakdown voltage(kV)	79kV	78kV	79kV	80kV	79kV	79kV

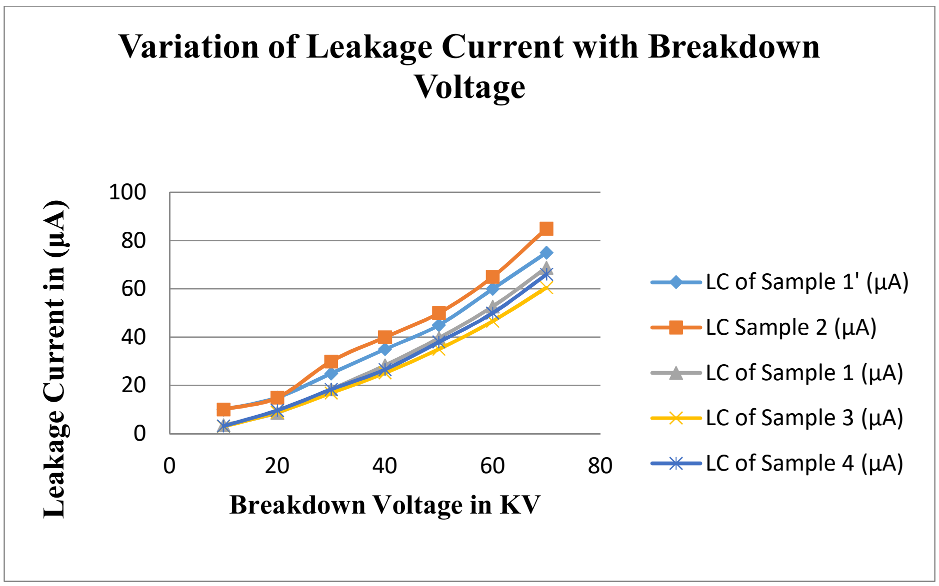

Fig.5.10 Variation of Leakage Current with Breakdown Voltage for 11kV samples on 07-01-14.

5.6.3. With Pollution:

The insulator samples are then placed at the pollution site and for every 15 days the breakdown tests are performed and readings are tabulated for both 11KV and 33KV insulator samples. The results were as follows:

Table 5.5.: Variation of Leakage current with break down voltage on 33kV polymeric insulator samples with pollution on 22-01-2014

Date: 22-01-2014 Temperature : 28°C

Applied Voltage (kV)	**LC of Sample A** (μA)	**LC of Sample B (μA)**	**LC of Sample C (μA)**	**LC of Sample D (μA)**	**Average LC of 4 samples (μA)**
10	3.8	3	3.1	1	2.725
20	9.8	7.4	7	4.7	7.225
30	16	12.5	12.1	9	12.4
40	22.7	17.7	17.1	15.2	18.175
50	30.8	24.3	23.5	22.6	25.3
60	39.6	30.7	30.2	30.4	32.725
70	50.3	38.6	38.2	39.7	41.7
80	64.2	49.2	48.3	50.1	52.95
90	81.5	58.9	58.4	65.7	66.125
100	99.9	71.8	74.1	81	81.7
110	117.3	84.5	87.9	97.4	96.775
120	139.1	102.2	104	116.4	115.425
130	170.5	116.2	126.5	144.9	139.525
140	210	138.9	146.2	171.5	166.65
150		164	174	207.1	181.7
160		193			193
Breakdown voltage(kV)	145kV	166kV	162kV	160kV	158.25kV

Table 5.6.: Variation of Leakage current with break down voltage on 11kV polymeric insulator samples with pollution on 22-01-2014

Date: 22-01-2014 Temperature : 28°C

Applied Voltage (kV)	**LC of Sample 1'** (μA)	**LC of Sample 2 (μA)**	**LC of Sample 1 (μA)**	**LC of Sample 3 (μA)**	**LC of Sample 4 (μA)**	**Average LC of 4 samples (μA)**
10	4	3.8	3.5	3.3	3.9	3.7
20	7.2	7.5	7	6.6	7.2	7.1
30	11.5	11.6	10.4	10.1	11.1	10.94
40	15.9	16.4	14.1	13.4	15.2	15
50	21.6	22.3	18.3	17.4	19.9	19.9
60	30.4	30.8	22.9	22.2	25.4	26.34
70	40.5	42.9	29.4	31.5	33.2	35.5
Breakdown voltage(kV)	77kV	80kV	77kV	79kV	79kV	78.4kV

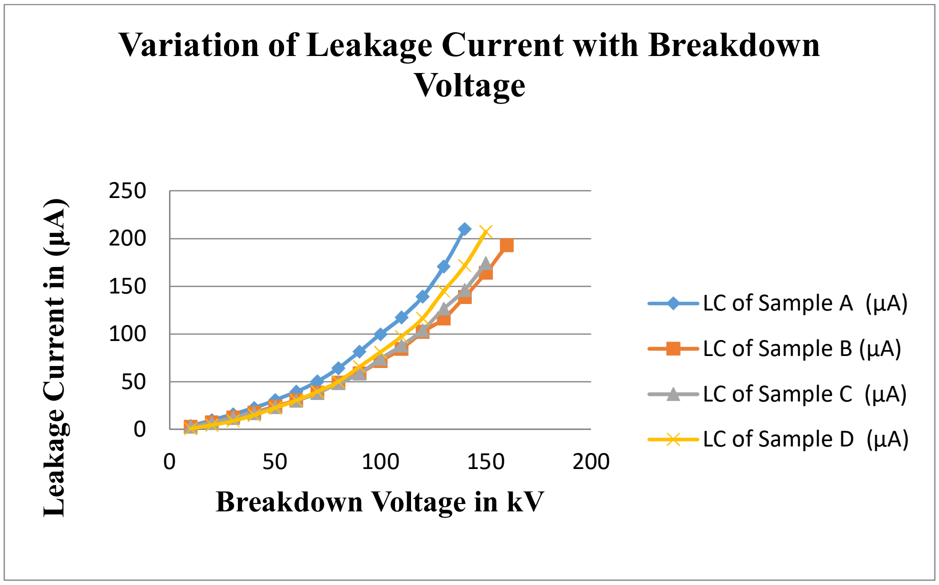

Fig.5.11 Variation of Leakage Current with Breakdown Voltage for 33KV samples on 22-01-14.

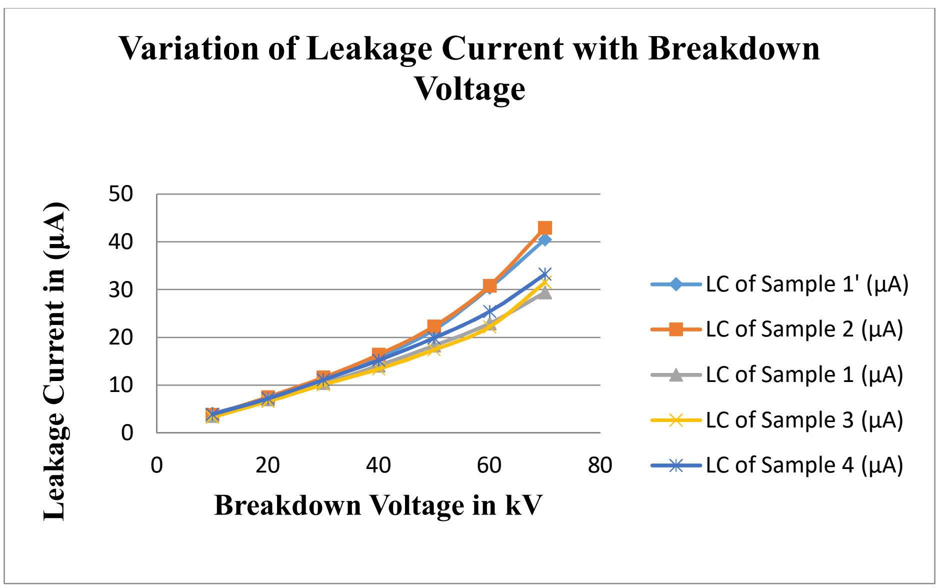

Fig.5.12 Variation of Leakage Current with Breakdown Voltage for 11kV samples on 22-01-14.

Now the insulators are again placed at the pollution site and after 15 days they were again tested to study the variation of leakage current with breakdown voltage.

Table 5.7.: Variation of Leakage current with break down voltage on 33kV polymeric insulator samples with pollution on 06-02-2014

Date: 06-02-2014 Temperature : 27°C

Applied Voltage (kV)	**LC of Sample A** (μA)	**LC of Sample B (μA)**	**LC of Sample C (μA)**	**LC of Sample D (μA)**	**Average LC of 4 samples (μA)**
10	1.1	1.9	1.9	1.7	1.65
20	4.1	4.1	4.1	3.7	4
30	8.1	6.2	6.2	5.8	6.575
40	12.2	8.5	8.7	8	9.35
50	17.3	11.2	11.1	10.2	12.45
60	22.9	13.8	14.1	13	15.95
70	29.2	17.4	17	16.3	19.975
80	38.2	21.3	20.1	20	24.9
90	47.6	26.2	25.2	24.7	30.925
100	59.5	30.5	30.1	30	37.525
110	71.2	36.6	35.8	36.4	45
120	83.7	43	42.5	44	53.3
130	102.4	49.9	50.6	54.3	64.3
140	121	58.6	58.3	65.6	75.875
150	136.6	67.9	69	84	89.375
160	170		82.2		126.1
170	184.4				184.4
Breakdown voltage(kV)	175kV	155kV	170kV	152kV	163kV

Table 5.8.: Variation of Leakage current with break down voltage on 11KV polymeric insulator samples with pollution on 06-02-2014

Date: 06-02-2014 Temperature : 27°C

Applied Voltage (kV)	**LC of Sample 1'** (μA)	**LC of Sample 2 (μA)**	**LC of Sample 1 (μA)**	**LC of Sample 3 (μA)**	**LC of Sample 4 (μA)**	**Average LC of 4 samples (μA)**
10	4	3.8	3.5	3.3	3.9	3.7
20	7.2	7.5	7	6.6	7.2	7.1
30	11.5	11.6	10.4	10.1	11.1	10.94
40	15.9	16.4	14.1	13.4	15.2	15
50	21.6	22.3	18.3	17.4	19.9	19.9
60	30.4	30.8	22.9	22.2	25.4	26.34
70	40.5	42.9	29.4	31.5	33.2	35.5
Breakdown voltage(kV)	77kV	80kV	77kV	79kV	79kV	78.4kV

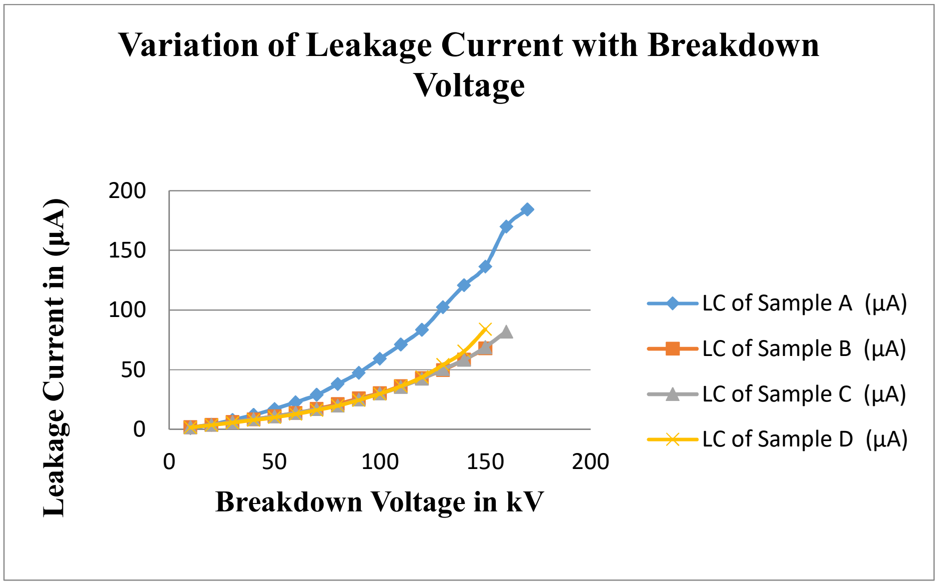

Fig.5.13 Variation of Leakage Current with Breakdown Voltage for 33kV samples on 06-02-14.

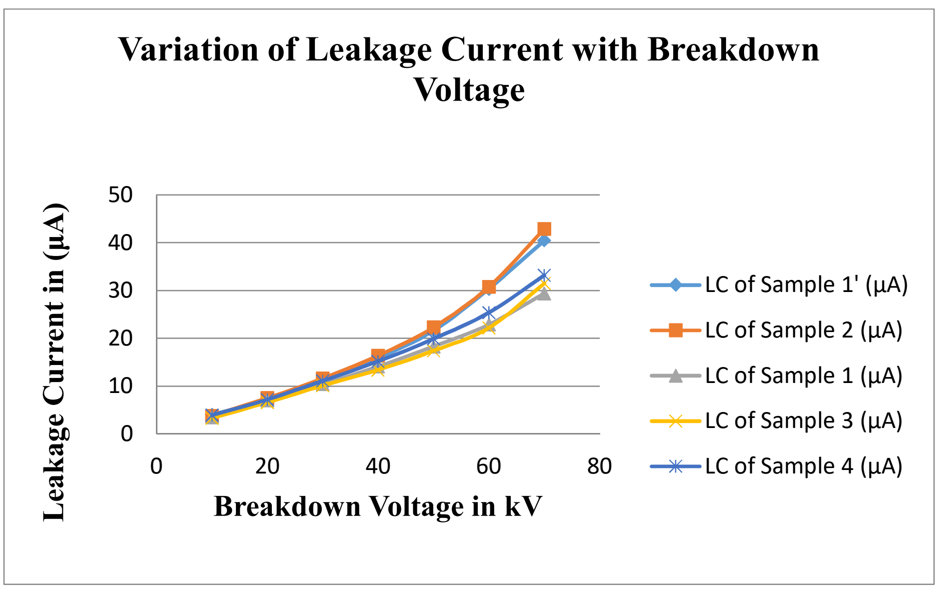

Fig.5.14 Variation of Leakage Current with Breakdown Voltage for 11kV samples on 06-02-14.

Table 5.9.: Variation of Leakage current with break down voltage on 33kV polymeric insulator samples with pollution on 21-02-2014

Date: 21-02-2014 Temperature : 27°C

Applied Voltage (kV)	**LC of Sample A** (μA)	**LC of Sample B (μA)**	**LC of Sample C (μA)**	**LC of Sample D (μA)**	**Average LC of 4 samples (μA)**
10	1.8	1.8	2.1	1.1	1.7
20	4.1	4	3.9	3.2	3.8
30	7	6.6	6.5	5.7	6.45
40	10	9	9	8.2	9.05
50	12.5	12.1	11.6	10.9	11.775
60	16.7	14.7	15	14.1	15.125
70	20.9	18.7	18.4	18	19
80	27	23.1	23	22.9	24
90	23.5	28.1	27.4	28.4	26.85
100	38.5	32.7	32.4	34.8	34.6
110	43.8	38.1	37.2	40.7	39.95
120	51	43.4	42.4	49.5	46.575
130	60.5	50.2	50	60.4	55.275
140	68	58.3	58.3	73.5	64.525
150	78	67.5	67.8	83.2	74.125
160		77.5	79		78.25
Breakdown voltage(kV)	151kV	165kV	165kV	153kV	158.5kV

Table 5.10.: Variation of Leakage current with break down voltage on 11kV polymeric insulator samples with pollution on 21-02-2014

Date: 21-02-2014 Temperature : 27°C

Applied Voltage (kV)	**LC of Sample 1'** (μA)	**LC of Sample 2 (μA)**	**LC of Sample 1 (μA)**	**LC of Sample 3 (μA)**	**LC of Sample 4 (μA)**	**Average LC of 4 samples (μA)**
10	3.6	3.5	2.5	6.4	3.9	3.98
20	6.2	6.5	6	12.1	8.9	7.94
30	10.4	10.5	9.6	18.9	14.5	12.78
40	14.2	15	14.4	26.9	22.6	18.62
50	18.3	19.8	19.2	37.2	31.5	25.2
60	24.5	24.7	24.9	50.2	45.1	33.88
70	31.4	32.9	30.2	68.2		40.675
Breakdown voltage(kV)	73kV	72kV	74kV	80kV	70kV	73.8kV

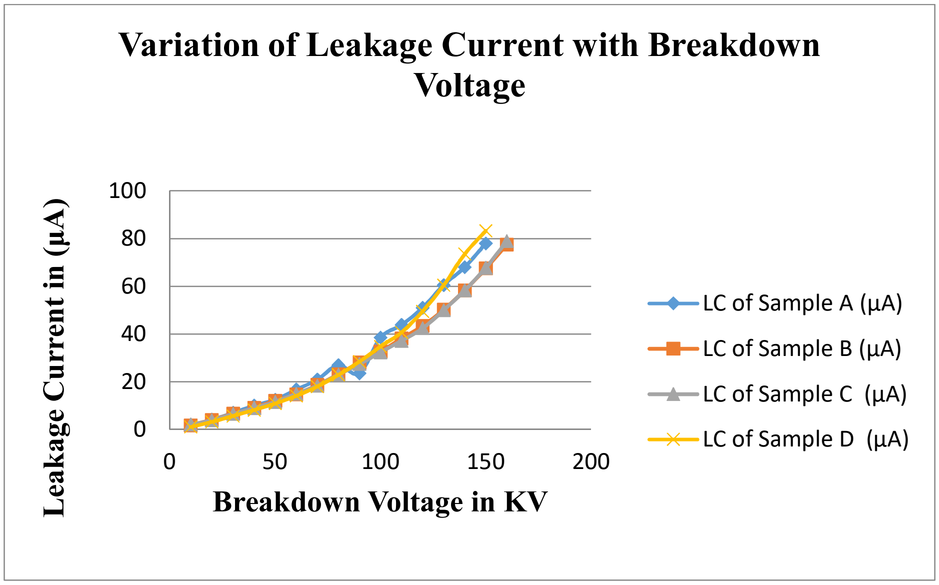

Fig.5.15 Variation of Leakage Current with Breakdown Voltage for 33kV samples on 21-02-14.

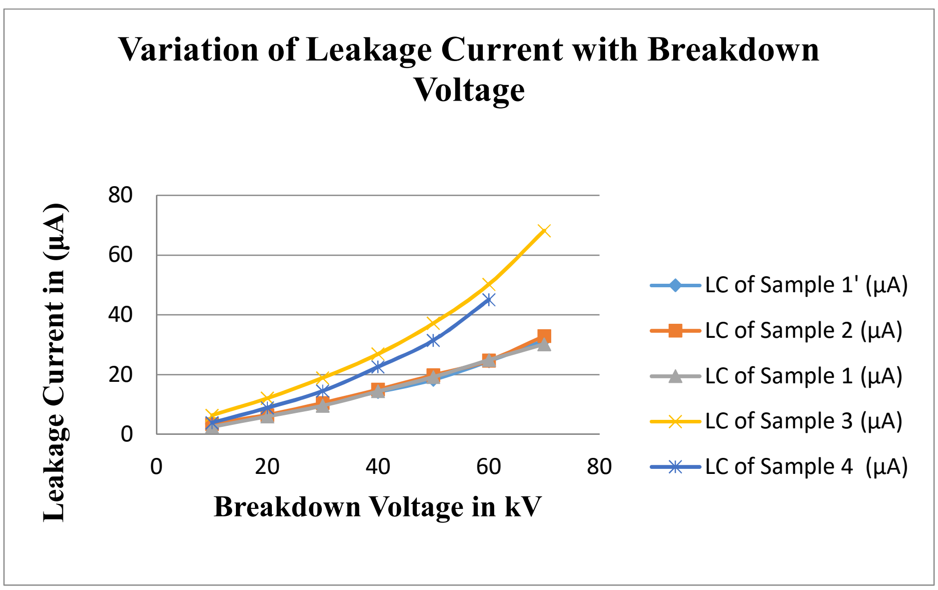

Fig.5.16 Variation of Leakage Current with Breakdown Voltage for 11kV samples on 21-02-14.

Table 5.11.: Variation of Leakage current with break down voltage on 33kV polymeric insulator samples with pollution on 07-03-2014

Date: 07-03-2014 Temperature : 29°C

Applied Voltage (kV)	**LC of Sample A** (μA)	**LC of Sample B (μA)**	**LC of Sample C (μA)**	**LC of Sample D (μA)**	**Average LC of 4 samples (μA)**
10	2.4	2	2.5	2.3	2.3
20	3.6	14.1	4.4	4.2	6.575
30	6	5.8	6.2	6	6
40	8.5	8.1	8.6	8.4	8.4
50	10.4	10.5	11.3	10.7	10.725
60	13.5	12.9	14.3	13.9	13.65
70	16.4	16	17.5	16.9	16.7
80	19.7	19.2	21.7	20.5	20.275
90	23.4	22.7	25.8	25.3	24.3
100	27.6	26.4	30.5	30.4	28.725
110	31.3	30.2	34.7	35.7	32.975
120	35.2	34.2	40	40.7	37.525
130	39.9	40	45.5	48.5	43.475
140	45.1	44.9	52.7	58	50.175
150	51.2	53.6	62	70	59.2
160	58.5	68.1	71.5	85.4	70.875
170	69.8	82.7	85.7		79.4
Breakdown voltage(kV)	180kV	173kV	175kV	162kV	172.5kV

Table 5.12.: Variation of Leakage current with break down voltage on 11kV polymeric insulator samples with pollution on 07-03-2014

Date: 07-03-2014 Temperature : 29°C

Applied Voltage (kV)	LC of Sample 1' (µA)	LC of Sample 2 (µA)	LC of Sample 1 (µA)	LC of Sample 3 (µA)	LC of Sample 4 (µA)	Average LC of 4 samples (µA)
10	4.2	4.2	3.9	3.9	4.1	4.06
20	7.4	7.4	6.8	7.1	6.9	7.12
30	11.7	11.7	10.8	11	11	11.24
40	15.5	15.7	14.6	15.9	14.9	15.32
50	20.9	21	20.2	20.5	19.7	20.46
60	28.5	27.8	25.5	27.2	25.5	26.9
70	37.8	36.9	32.7	37.6	32.1	35.42
Breakdown voltage(kV)	76kV	74kV	75kV	76kV	75kV	75.2kV

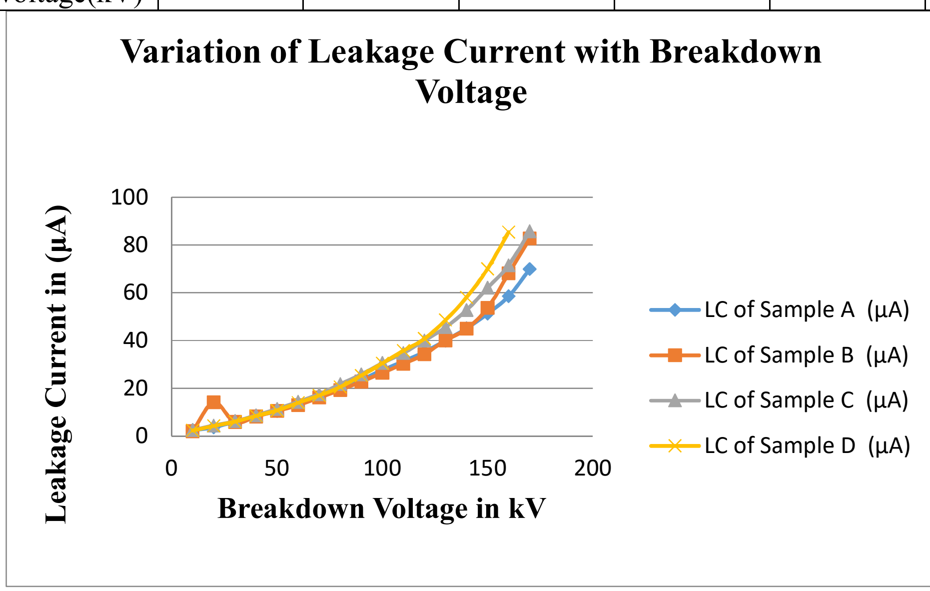

Fig.5.17 Variation of Leakage Current with Breakdown Voltage for 33kV samples on 07-03-14.

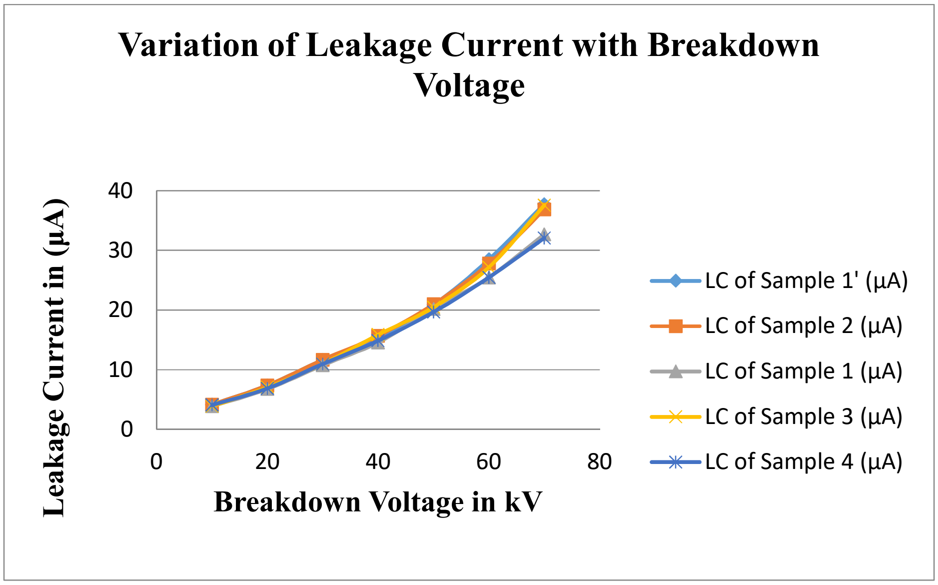

Fig.5.18 Variation of Leakage Current with Breakdown Voltage for 11kV samples on 07-03-14.

Table 5.13.: Variation of Leakage current with break down voltage on 33kV polymeric insulator samples with pollution on 22-03-2014

Date: 22-03-2014 Temperature : 30°C

Applied Voltage (kV)	LC of Sample A (µA)	LC of Sample B (µA)	LC of Sample C (µA)	LC of Sample D (µA)	Average LC of 4 samples (µA)
10	2.1	2.4	2.1	3.1	2.425
20	3.9	4.5	4	5.3	4.425
30	6.2	5.6	5.8	6.7	6.075
40	8.1	8.8	7.8	8.8	8.375
50	10.5	11.1	10.2	11.4	10.8
60	12.5	13.7	12.7	14	13.225
70	15.4	16.8	15.5	18	16.425
80	19.1	21	19.5	22.5	20.525
90	22.5	24.8	23.6	27.2	24.525
100	26.2	29.3	28.3	33.8	29.4
110	29.7	33.8	31.9	41	34.1
120	33.5	39.4	37.4	48.4	39.675
130	38.1	45.4	43.6	56.9	46
140	43	50.8	49.7	66.3	52.45
150	47.6	60.7	58.4	79.4	61.525
160	54.1	71.9	67.2		64.4
170		81.5	77.4		79.45

Breakdown voltage(kV)	167kV	175kV	176kV	160kV	169.5kV

Table 5.14.: Variation of Leakage current with break down voltage on 11kV polymeric insulator samples with pollution on 22-03-2014

Date: 22-03-2014 Temperature : 30°C

Applied Voltage (kV)	LC of Sample 1' (μA)	LC of Sample 2 (μA)	LC of Sample 1 (μA)	LC of Sample 3 (μA)	LC of Sample 4 (μA)	Average LC of 4 samples (μA)
10	4.6	4.1	3.8	3.7	4.3	4.1
20	8.4	7.4	7.6	6.8	7.3	7.5
30	13.2	11.4	11.3	10.3	11.7	11.58
40	18.8	15.8	15.4	14.4	16.8	16.24
50	26.7	20.7	20.4	19.2	22.8	21.96
60	36.5	26.1	26.3	24.8	29.5	28.64
70	49.5	34.9	33.2	30.9	41.2	37.94
Breakdown voltage(kV)	76kV	79kV	79kV	80kV	76kV	78kV

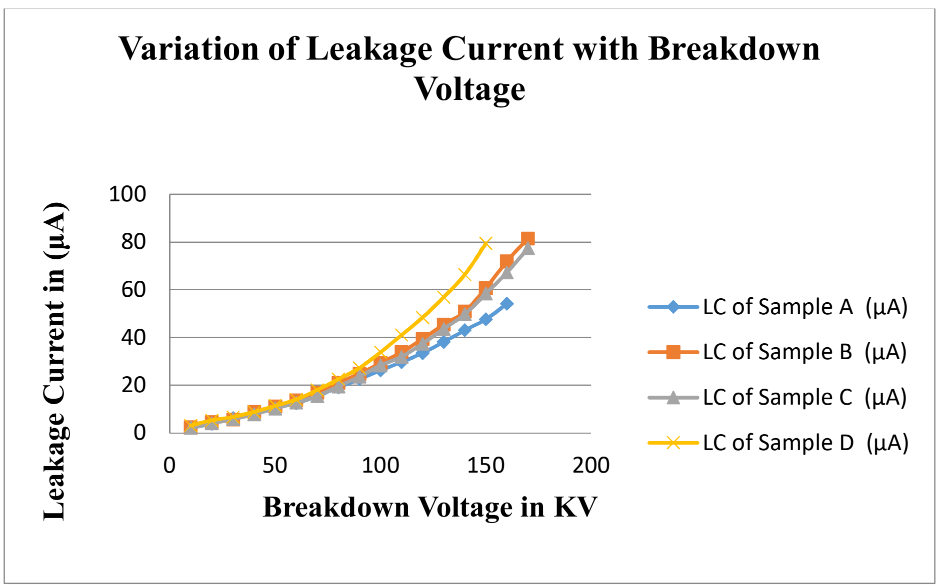

Fig.5.19 Variation of Leakage Current with Breakdown Voltage for 33kV samples on 22-03-14.

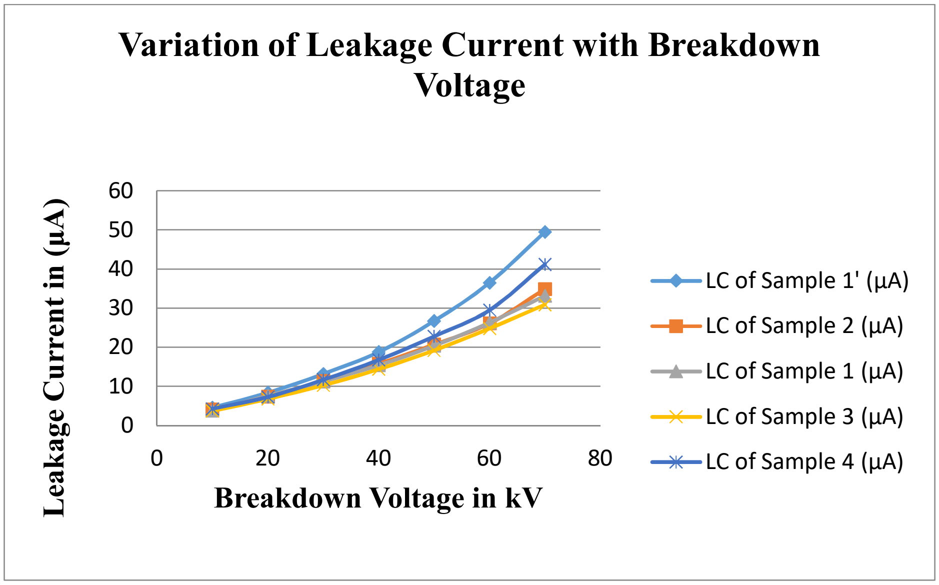

Fig.5.20 Variation of Leakage Current with Breakdown Voltage for 11kV samples on 22-03-14.

Table 5.15.: Variation of Leakage current with break down voltage on 33kV polymeric insulator samples with pollution on 10-04-2014

Date: 10-04-2014 Temperature : 35°C

Applied Voltage (kV)	**LC of Sample A** (µA)	**LC of Sample B (µA)**	**LC of Sample C (µA)**	**LC of Sample D (µA)**	**Average LC of 4 samples (µA)**
10	3	2.8	3.3	3.7	3.2
20	6	5.1	5.8	6.8	5.925
30	8.6	8.2	9.2	10	9
40	11.5	10.5	12.2	13.4	11.9
50	14.5	13.9	15.5	16.4	15.075
60	17.9	16.9	19.3	20.9	18.75
70	21.4	20.5	23.3	25.4	22.65
80	26	24.2	28.2	30.4	27.2
90	31.4	28.8	33.6	37.2	32.75
100	36.1	33.8	38.4	43.2	37.875
110	40.7	37.9	44.5	50	43.275
120	45.3	42.6	52.2	59.4	49.875
130	51.7	48.5	61.5	70.2	57.975
140	58.4	55.3	69.8	83.1	66.65
150	65.7	63.9	80	98.9	77.125

160	73.9	75.2	93		80.7
170	83.7				83.7
180	93.3				93.3
Breakdown voltage(kV)	185kV	165kV	170kV	155kV	168.75kV

Table 5.16.: Variation of Leakage current with break down voltage on 11kV polymeric insulator samples with pollution on 10-04-2014

Date: 10-04-2014 Temperature : 35°C

Applied Voltage (kV)	**LC of Sample 1' (µA)**	**LC of Sample 2 (µA)**	**LC of Sample 1 (µA)**	**LC of Sample 3 (µA)**	**LC of Sample 4 (µA)**	**Average LC of 4 samples (µA)**
10	5.7	5.8	5.6	5.2	5.4	5.54
20	10.6	10.2	10.2	9.6	10.5	10.22
30	15.4	15.6	14.9	13.7	15.5	15.02
40	20.6	21.3	20.9	18.6	20.4	20.36
50	27.2	26.1	27.3	24.3	25.8	26.14
60	35	34	34.1	30.2	33.1	33.28
70	47.5	43	45.2	42.5	42.9	44.22
Breakdown voltage(kV)	76kV	80kV	80kV	78kV	75kV	77.8kV

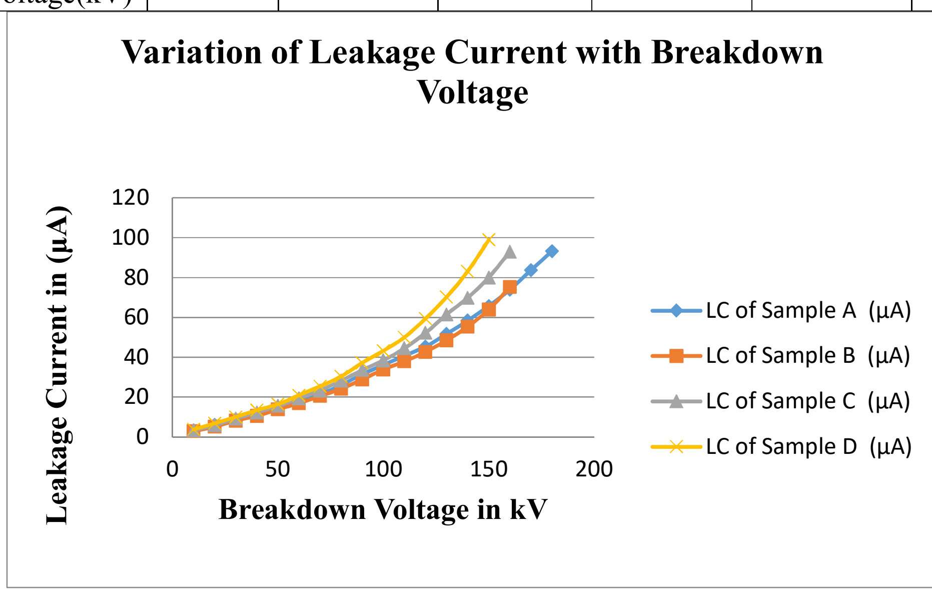

Fig.5.21 Variation of Leakage Current with Breakdown Voltage for 33kV samples on 10-04-14.

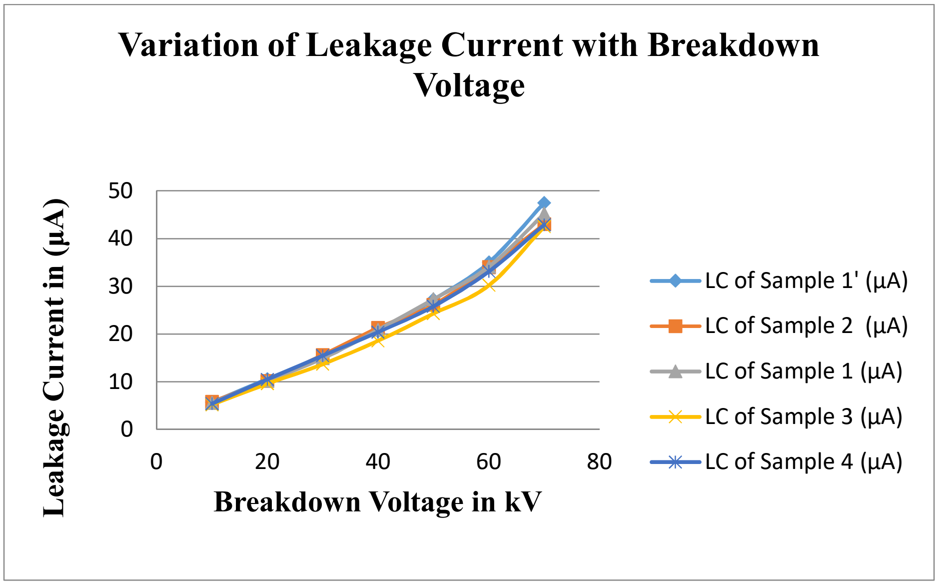

Fig.5.22 Variation of Leakage Current with Breakdown Voltage for 11kV samples on 10-04-14.

5.7. Variation of Leakage current and Breakdown voltage with Climate:

5.7.1. During Winter Season:

A plot is drawn between leakage current and applied voltage for the polymeric insulator samples in winter season. The winter season in Andhra Pradesh starts from December to February, with the tabulated from December to February, a plot is drawn between applied voltage and average leakage current value of four samples for the insulator samples. By this graph it is observed that the leakage current increases with number of days but due to temperature variations and wind flows on the surface of the insulator contamination layer becomes thin, which will results in decrease of leakage current.

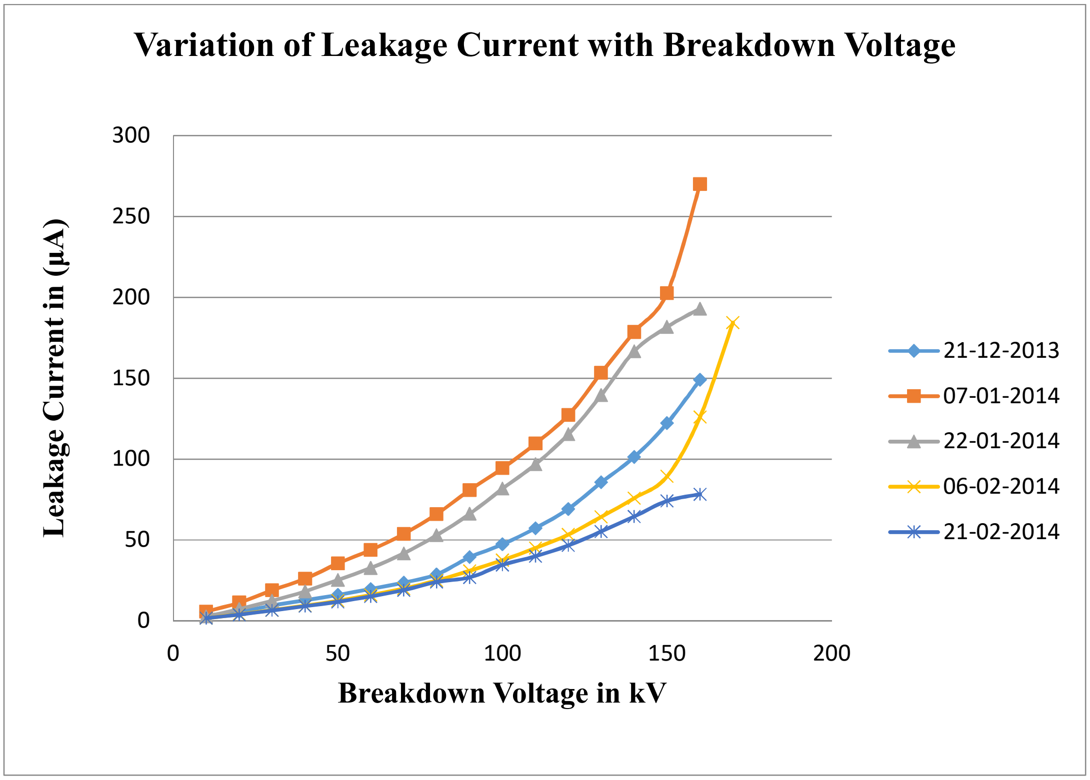

Fig.5.23 Variation of Leakage Current with Breakdown Voltage for 33kV samples in winter season

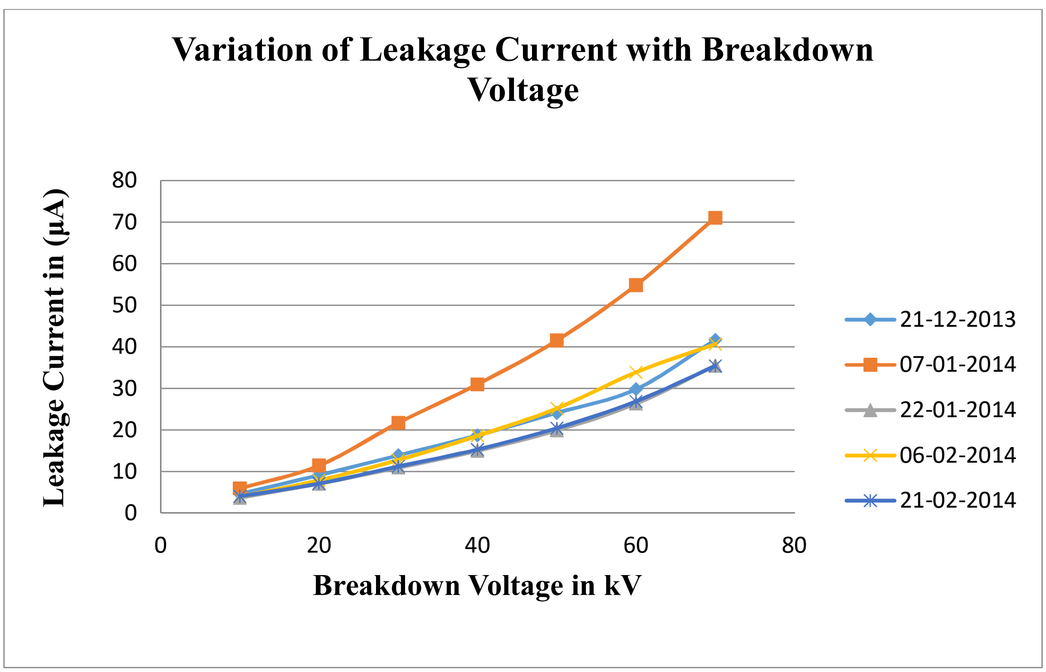

Fig.5.24 Variation of Leakage Current with Breakdown Voltage for 11kV samples in winter season

5.7.2. During Summer Season:

A plot is drawn between leakage current and applied voltage for polymeric insulator samples in winter season. The summer season in Andhra Pradesh starts from March to June, with the tabulated data above a plot is drawn between applied voltage and average leakage current of the insulator samples. By this graph it is observed that the leakage current increases with number of days but due to temperature variations and wind flows on the surface of the insulator contamination layer becomes thin, which will results in decrease of leakage current. The graphs of these variations are as shown below:

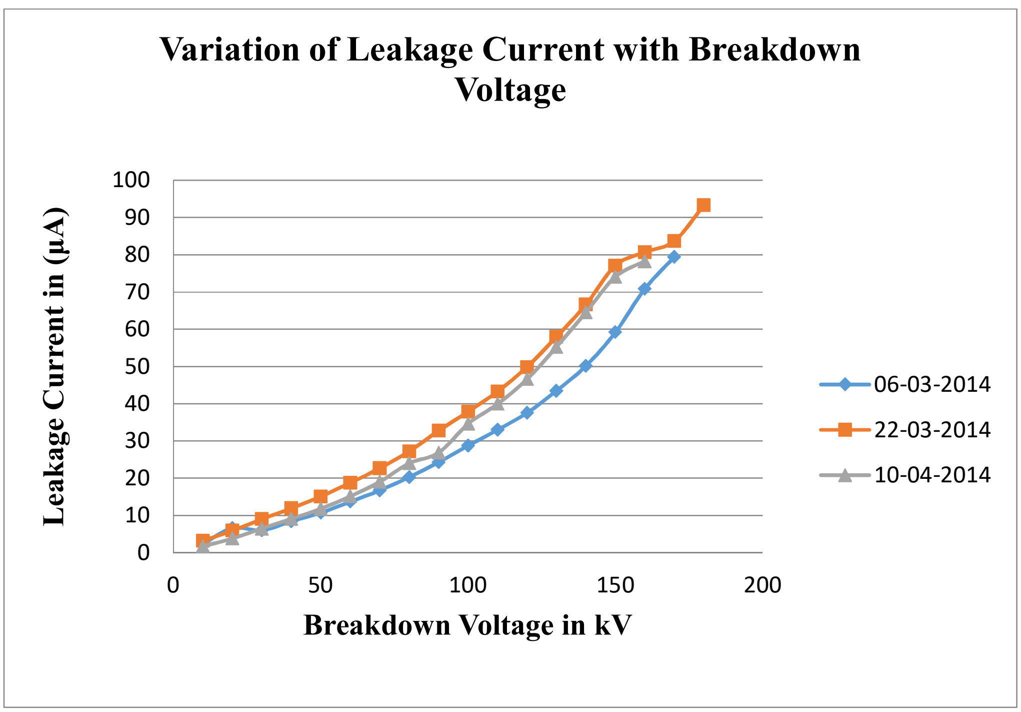

Fig.5.25 Variation of Leakage Current with Breakdown Voltage for 33 kV samples in summer season

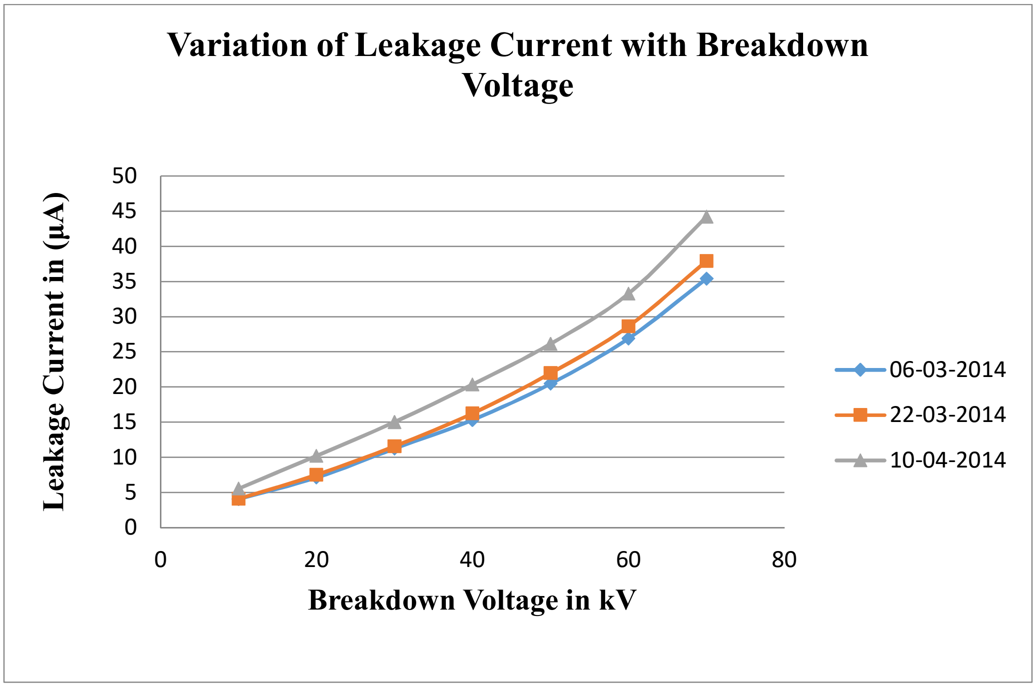

Fig.5.26 Variation of Leakage Current with Breakdown Voltage for 11kV samples in summer season

5.8. Variation of Breakdown Voltage:

The break down voltage of an insulator is the minimum voltage that causes a portion of an insulator to become electrically conductive. Break down voltage is the characteristic of an insulator that defines the maximum voltage difference that can be applied across the material before the insulator fails. In solid insulating materials, this usually creates a weakened path within the material by creating permanent molecular or physical changes by the sudden current. A plot is drawn between the average break down voltage of the polymer insulator samples for the two seasons .

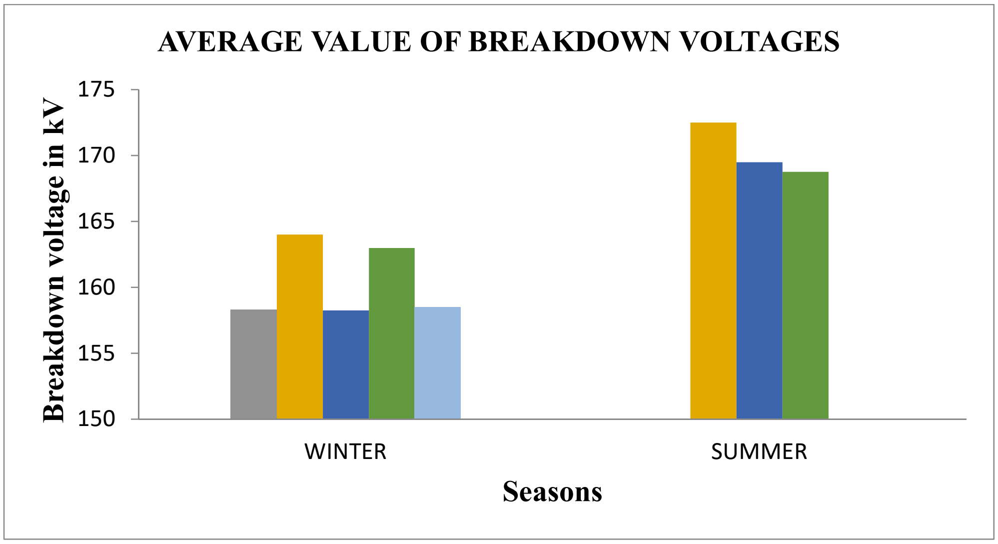

Fig.5.27 Variation of Breakdown Voltage for 33 kV samples with seasons

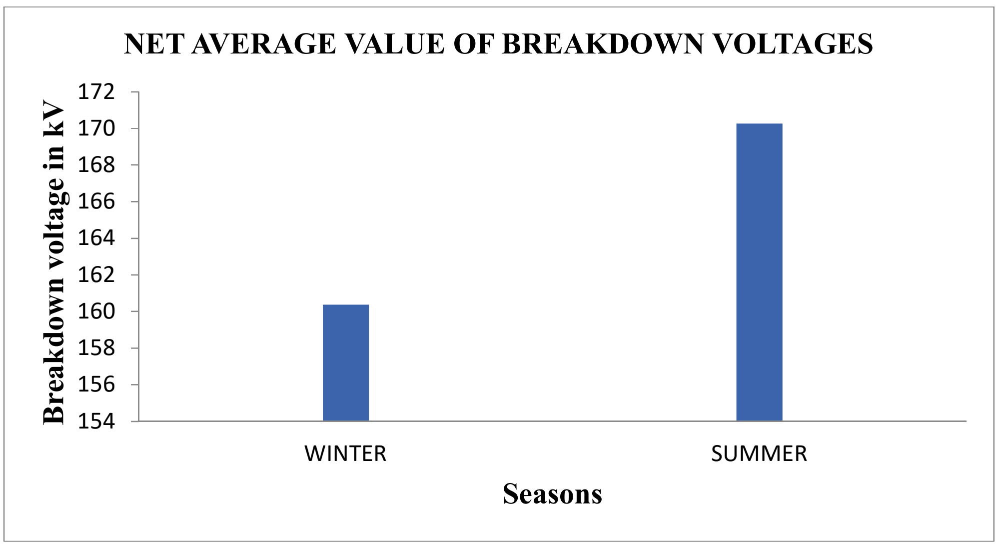

Fig.5.28 Variation of Net Average Breakdown Voltage for 33 kV samples with seasons

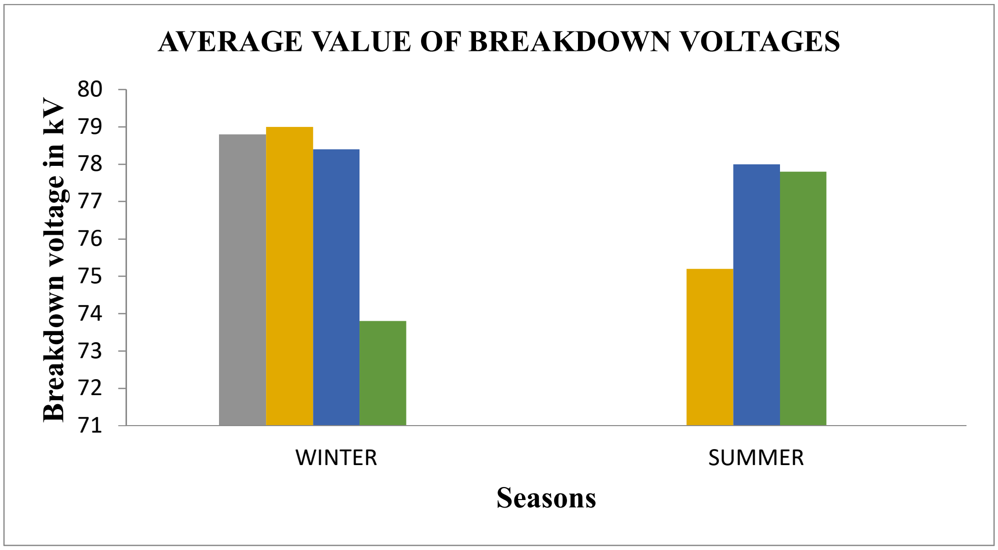

Fig.5.29 Variation of Breakdown Voltage for 11 kV samples with seasons

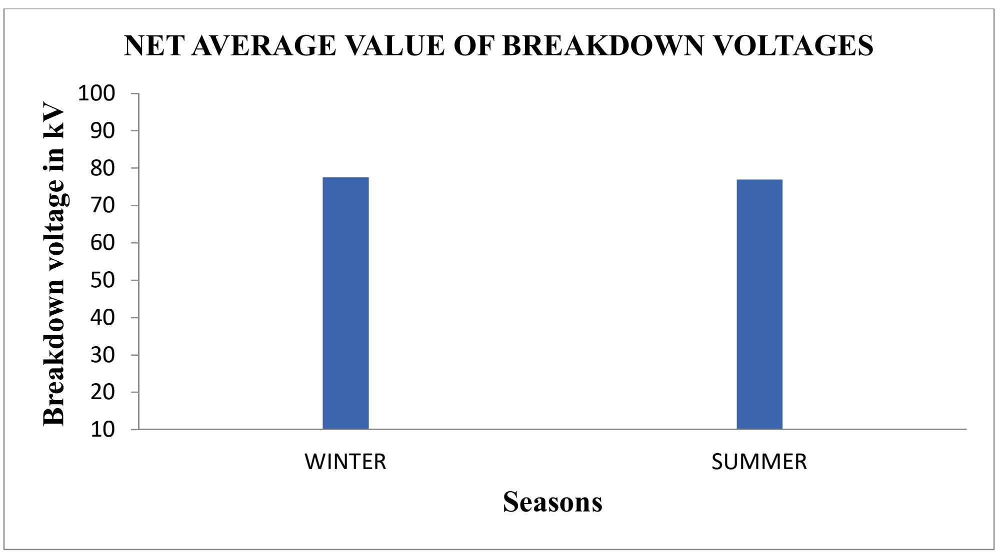

Fig.5.30 Variation of Net Average Breakdown Voltage for 11 kV samples with seasons

We can observe that there is a rise in the net average breakdown strength of the polymeric insulator of about 6.16% for the 33 kV polymeric insulators from winter to summer season and there isn't a considerable change in the breakdown strength for the 11kV insulator samples from winter to summer season.

5.8.1 For 33kV Insulator Samples:

We can obtain the relation between the variation of the breakdown voltage with the number of testing days for 33kV insulator samples during winter season from fig.5.31 :

$$BDV_w = -0.003d^2 + 0.184d + 159$$

where,

BDV_w = Breakdown voltage in kV for winter season

d = Number of testing days

In the same way for the 33 kV samples as shown in fig.5.32 during summer season the relation between the variation of the breakdown voltage with the number of testing days is as follows:

$$BDV_s = -0.004d^2 - 0.255d + 172.5$$

where,

BDV_s = Breakdown voltage in kV for summer season

d = Number of testing days

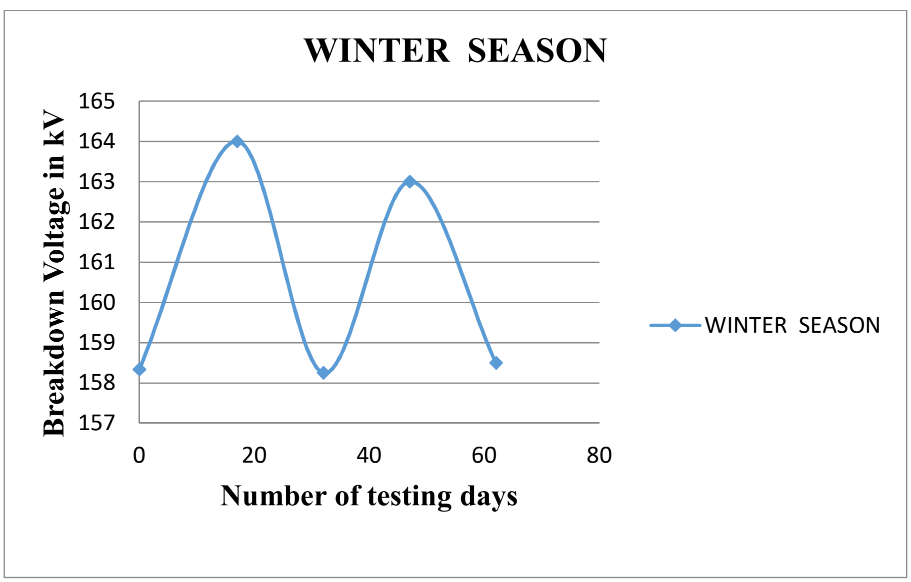

Fig.5.31 Variation of Breakdown Voltage for 33 kV samples in winter season with Number of testing days

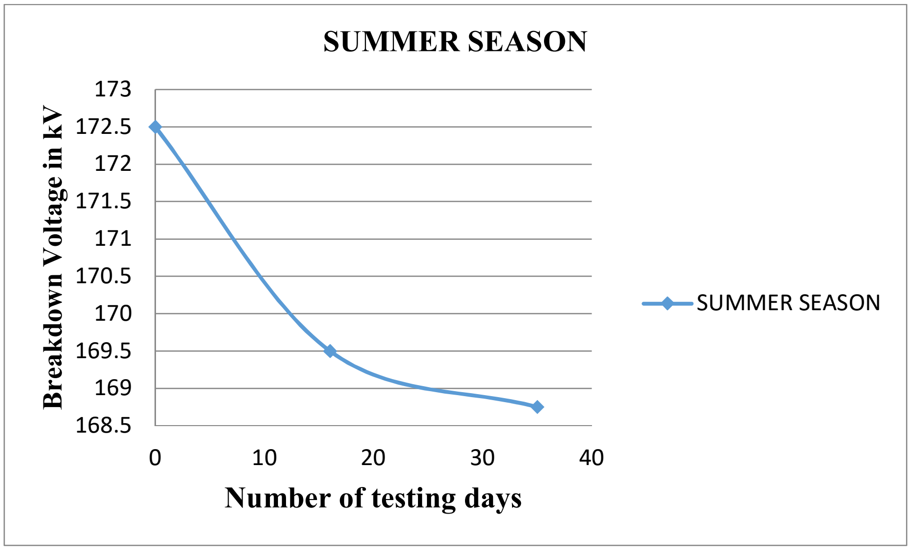

Fig.5.32 Variation of Breakdown Voltage for 33 kV samples in summer season with Number of testing days

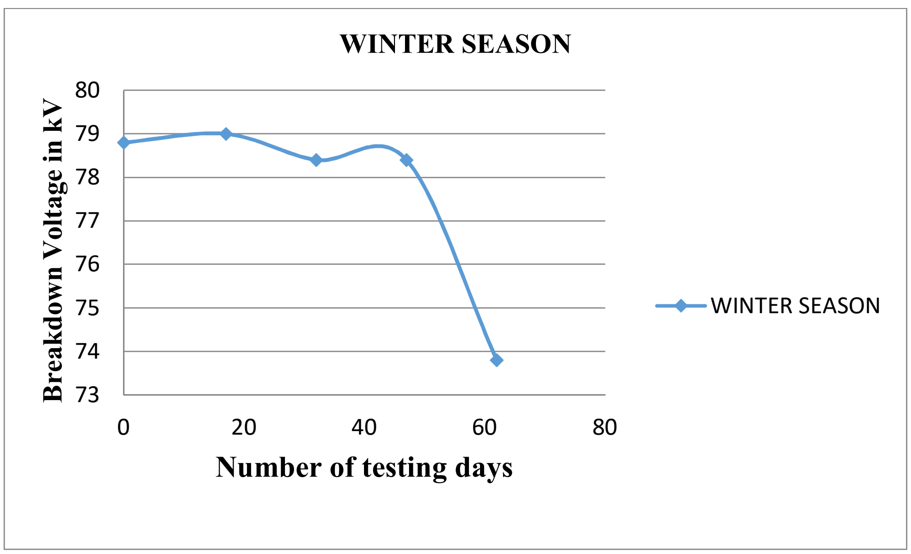

Fig.5.33 Variation of Breakdown Voltage for 11 kV samples in winter season with Number of testing days

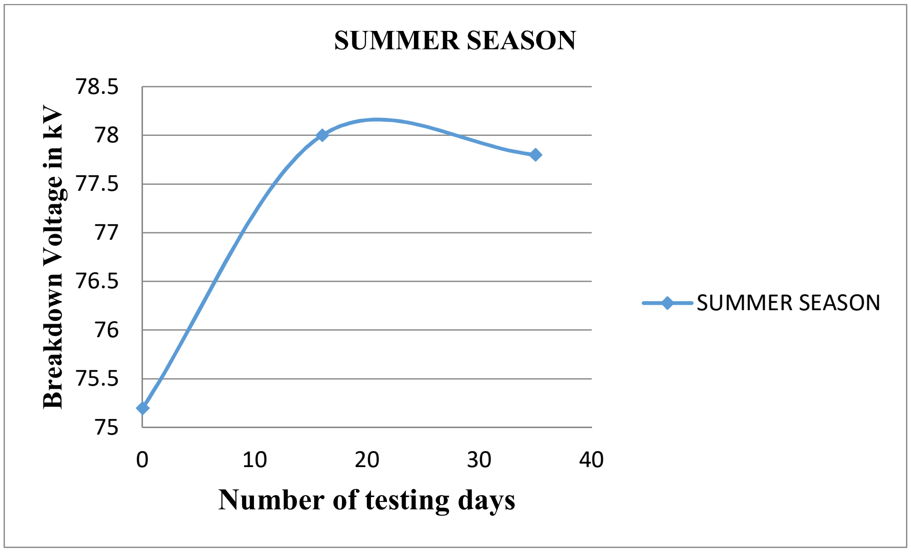

Fig.5.34 Variation of Breakdown Voltage for 11 kV samples in summer season with Number of testing days

5.8.2 For 11kV Insulator Samples:

We can obtain the relation between the variation of the breakdown voltage with the number of testing days for 11kV insulator samples during winter season as shown in fig.5.33 :

$$BDV_W = -0.002d^2 + 0.098d + 78.52$$

where,

BDV_W = Breakdown voltage in kV for winter season

d = Number of testing days

During summer season for the 11kV insulator samples the relation between the variation of the breakdown voltage with the number of testing days is shown in fig 5.34 and the relation is as follows:

$$BDV_S = -0.005d^2 + 0.259d + 75.2$$

where,

BDV_S = Breakdown voltage in kV for summer season

d = Number of testing days

CHAPTER 6

CONCLUSIONS AND ANALYSIS

- Pollution on silicon rubber insulators forms a thin layer consisting of dust and other particulate matter. Polymeric insulators exhibit property of hydrophobicity i.e. tending to repel water.
- The leakage current values are increased corresponding to the thickness of pollution layer and the breakdown voltage values are decreased with the increase of pollution layer.
- The maximum value of leakage current for 33 kV insulators was 269.97 μA while for 11 kV insulators was 71.06 μA.
- There was a rise of 6.16% in the breakdown strength for the 33kV insulators from winter to summer season while for the 11 kV insulators there was not a considerable change in the breakdown strength.
- The variation of the breakdown strengths of the 33 kV insulator samples with the number of testing days during winter season is given by:

$$BDV_w = -0.003\,d^2 + 0.184\,d + 159$$

where,

BDV_w = Breakdown voltage in kV for winter season

d = Number of testing days

- The variation of the breakdown strengths of the 33 kV insulator samples with the number of testing days during summer season is given by:

$$BDV_s = -0.004d^2 - 0.255d + 172.5$$

where,

BDV_s = Breakdown voltage in kV for summer season

d = Number of testing days

- The variation of the breakdown strengths of the 11 kV insulator samples with the number of testing days during winter season is given by:

$$BDV_W = -0.002d^2 + 0.098d + 78.52$$

where,

BDV_w = Breakdown voltage in kV for winter season

d = Number of testing days

- The variation of the breakdown strengths of the 11 kV insulator samples with the number of testing days during summer season is given by:

$$BDV_S = -0.005d^2 + 0.259d + 75.2$$

where,

BDV_s = Breakdown voltage in kV for summer season

d = Number of testing days

- The graphs are drawn for winter and summer seasons, in which the leakage current values and break down voltage values are varying periodically and it is due to the variations in temperature and weather conditions
- The leakage current values for summer season are less compared to winter season
- The break down voltage values of polymeric insulators for summer seasons are higher compared to winter season.
- These results will be useful as a benchmark for the new transmission lines and substations near coastal area.

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