"Study of Di-Electric Properties of Porcelain Insulator with Nano Structured Super-Hydrophobic Coating"

By

RAMALLA ISAAC

(SAP ID: 500020670)

UNDER THE GUIDANCE

Dr. KAMAL BANSAL

Dr. RAJEEV GUPTA

Submitted

In partial fulfillment of the requirements of the award of degree of

Doctor of Philosophy

Department of Electrical, Power and Energy

COLLEGE OF ENGINEERING STUDIES

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES

DEHRADUN

February 2016.

COLLEGE OF ENGINEERING

CERTIFICATE

This is to certify that the thesis on **"STUDY OF DI-ELECTRIC PROPERTIES OF PORCELAIN INSULATOR WITH NANO STRUCTURED SUPER-HYDROPHOBIC COATING" by Ramalla Isaac (SAP ID: 500020670)** in partial completion of the requirement for the award of the degree of Doctor of Philosophy in Engineering is an original work carried out by him under our joint supervision and guidance.

It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this in any other university.

Internal Guide

Place: Dehradun, India **[Dr. Kamal Bansal]**

Date: [Professor, UPES]

Internal Co- Guide

Place: Dehradun, India **[Dr. Rajeev. K Gupta]**

Date: [Associate Professor, UPES]

RESEARCH DETAILS

TITLE OF RESEARCH PROPOSAL	**"Study of Di-Electric Properties of Porcelain Insulator with Nano Structured Super-Hydrophobic Coating"**
NAME OF RESEARCH SCHOLAR	**RAMALLA ISAAC**
NAME AND DESIGNATION OF THE GUIDE & CO-GUIDE	**Guide:** Dr. KAMAL BANSAL PROFESSOR AND DEAN UNIVERSITY OF PETROLEUM AND ENERGY STUDIES, INDIA kamalbansal@ddn.upes.ac.in **Co – Guide:** Dr. RAJEEV K GUPTA ASSOCIATE PROFESSOR UNIVERSITY OF PETROLEUM AND ENERGY STUDIES, INDIA rajeev@ddn.upes.ac.in
PLACE OF WORK	NANO TECHNOLOGY RESEARCH LABORATORY, UNIVERSITY OF PETROLEUM AND ENERGY STUDIES , DEHRADUN, INDIA

Dr. Kamal Bansal	Dr. Rajeev K Gupta	Isaac R
(Guide)	(Co-Guide)	(Research Scholar)

DECLARATION

I hereby declare that the submission is my own work and that, to the best of my knowledge and belief, it contains no matter previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgement has been made in the text.

Date:

Place: **(RAMALLA ISAAC)**

ACKNOWLEDGMENT

First of all, I render my thanks and glory to the **'LORD GOD ALMIGHTY'** for the divine providence and guidance all the way through my life.

I owe my sincere gratitude to my research supervisors **Dr. Kamal Bansal** Professor, UPES, Dehradun and **Dr. Rajeev Gupta**, Associate Professor, UPES, Dehradun for their valuable guidance and suggestions, as well as spending their valuable time in my research work. I feel proud and lucky to be part of their research group. I am thankful to the **University of Petroleum & Energy Studies**, Dehradun to admit me as research scholar for Ph.D. and work in the campus.

I wish to place on record, my profound gratitude to **Nano Lab at UPES**, Research and Development Cell, **Oblum Electrical Industries Private Limited Hyderabad** and **Power Transmission Corporation of Uttarakhand Limited**, Government of Uttarakhand for the support and assistance given to me for utilizing their computational and lab facilities to carry out my work. I record my deep sense of indebtedness to **Dr. G Philip**, Programme Head, Wadia institute of Himalayan Geology and **Dr. Mohan Reddy** for providing extraordinary guidance and support throughout my research.

My special thanks go to **Dr. Devender K Saini, Dr. Prasanti, and Dr. Praveen Kumar** for their helpful discussions and suggestions during the drafting of my document. I would like to express my hearty thanks to **Mr. Ram Mohan Sharma** for helping me in modeling the experimental setup for electrical testing in nano lab. I express my deepest appreciation to my friend **Dr. K N Dinesh Babu** Application Manager, GE - India who has been a pillar of support to me for the detailed analysis of hardware feasibility of this work which can be a future scope of this work.

It is my prime duty to acknowledge the inspiration and optimization encouragement given by my **Parents**, who have been a strong beam of light drawing me from the initial stage of learning. Also it is my privilege to thank my **wife** and **kids** for the unwavering moral and emotional support throughout my research period.

\- **ISAAC RAMALLA**

EXECUTIVE SUMMARY

In power engineering, nano technology has created an interest for researchers to improve the performance of different appliances and apparatus used in power industry. Insulators provide necessary insulation between line conductors and supports. Glass and polymer insulators are available in market. Due to the high cost of glass insulators and ageing problem of polymer insulators, porcelain insulators are abundantly used for insulation. Researchers focused on developing new insulating materials which exhibit, decent insulating properties by introducing nanotechnology as nanomaterials.

Various problems are occurred on these insulators and they get punctured and damaged. All the electrical insulators are kept in atmosphere with different pollution levels and exposed to various temperatures. The pollution form different dust and dirt layers on the surface of the insulators, which tends to surface flashover due to its conductivity on the surface. Different techniques are used to remove the dust and reduce the flashover which leads to economic loss on the utility companies and consumers.

To mitigate the flashover problem on insulators, the state of art in nanotechnology brought a concept of superhydrophobic coating that can be applied on electrical insulators. The presented work investigates new methods for the problem by introducing easily available materials and different possible methods to improve the efficiency, ageing of the insulators and natural dust removal process.

The concept of superhydrophobic coating is introduced in many applications in science and engineering. This concept is introduced in electrical power engineering application by researchers and scientist with different techniques to reduce the economic and technical losses for the above stated problem of dust formation on porcelain insulators. Superhydrophobic surfaces have a water repellant nature on the surface and during the water repellency, it collects the dust present on it and water rolls off the surface in the form of a bead or ball.

The sol-gel is developed as a powdered gel coating on the insulator surface by using simple air spray method. Coating on the insulator was done by simple process, as in spray painting; coated insulators and samples are tested for characterization to

confirm the particle size in the order of nano-size dimension and obtaining superhydrophobic nature of contact angle more than 150^o by conducting different tests available in the laboratory.

Six insulators are used for coating and carrying out the testing in the present thesis work is sponsored by Power Transmission Corporation of Uttarakhand Limited for doing the research work. These insulators at kept at different polluted conditions and compared with uncoated insulator sample for dust formation on the surface at different locations.

For comparative analysis and characterization of the real time observations, the superhydrophobic coated insulators and uncoated porcelain insulators were kept at selected locations. The locations were selected such that the dust formation on the insulators can be analyzed with real time conditions.

The insulators were kept for six months for the full duration in summer and rainy days. The season time is selected to know the durability and withstand capacity at different temperature and pressure on the nano-coated insulator surface. The results of continuous monitoring and testing were positive with very less dust formation on all selected locations on a nano coated insulators whereas thick dust formation was present on the uncoated insulators which can lead to flashover when regular cleaning is not done on the insulators.

After the observatory analysis on the three different sets of insulators, important industrial testing of the coated and uncoated set of insulators is done for standard electrical testing. As per the Indian and British standards the porcelain insulators are made to be tested in an approved testing agency, so the coated insulators were tested to know the feasibility of using in the real time scenarios for decreasing the failure rate due to dust and dirt formation on the insulator surface. The electrical insulators used were 11kV disc type porcelain insulator and are kept for viability of commercialization as per the request of the utility company.

The tests conducted on coated insulators were done according to the accepting norms for a normal new insulator. Acceptance tests, Routine tests, High voltage tests were done on both the insulators; the coated insulators could withstand all the tests done by the Oblum Electrical Industries in-house testing agency and were according to the

Indian Standard accepting norms. The uncoated insulator with dust formation on surface couldn’t withstand the tests due to surface conductivity and current leakages on the dusty thick layer.

Superhydrophobic concept on the porcelain insulator has shown various outcomes like improvement of the insulating property as the material used for coating on the insulators has an insulating property. Since the material used on the insulator has a nano-size in nature, the insulator dimension is not varied or changed with coated insulator has shown decent thermal withstand capability and mechanical stability. The life of the insulator is increased as the formation of dust is negligible and the flashover or puncture of insulator due to dust formation is reduced.

Elongated life with longer efficiency of the insulating property is obtained by superhydrophobic coated insulators. The presented thesis work on porcelain insulators can benefit electrical utility companies by using this superhydrophobic nano coating, which act as remedial measure for regular cleaning of the insulators and power interruption problems. Hence economic losses for the power companies can be reduced.

The effective method for flashover problems can be studied further by the future researchers on the insulators for various techniques to coat the insulators on the hot lines for installed insulators and waste disposal problems can be minimized for replacing the porcelain with polymer insulators. Coating on these existing porcelain insulators can reduce the costing effectively for maintenance on the power lines and power stability issues due to flashover problems can be reduced.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

TEOS -------------------------Tetraethyl orthosilicate

$Si(OEt)_4$ ----------------------Tetra ethoxysilane

$HOCH_2CH_3$ ------------------Ethyl Alcohol

HMS---------------------------Hexamethlye silane

HDTMS ----------------------Hexadecyltrimethoxysilane

PDTS--------------------------Perfluorodecyltriethoxysilane

HCL---------------------------Hycholric acid

HNO_3 -------------------------Nitric Acid

XRD --------------------------X Ray Diffraction

SEM---------------------------Scanning Electron Microscope

FTIR --------------------------Fourier transform infrared spectroscopy

AFM---------------------------Atomic Force Microscope

PSA----------------------------Particle Size Analyzer

PTCUL -----------------------Power Transmission Corporation of Uttarakhand Limited

THDC-------------------------Tehri Hydropower Distribution Corporation

OBLUM ----------------------Oblum Electrical Industries

UATR-------------------------Universal attenuated total reflectance

CHAPTER 1
INTRODUCTION

1.1 Problem statement and background

In power systems, for transmitting the generated electrical energy from generating station to load centers it requires some devices and equipment's which utilizes different insulators, conductors and semiconductors. The atmospheric conditions and other factors influence the life of the material which is further reduced or degraded. By using different techniques and methods the reduced life can be extended or increased so that the devices and equipment's are used for longer period.

1.2 Motivation

Due to different failures on the transmission and distribution system, the system block out occurs and the loss due to these failures and disturbances the maintenance cost and economic losses are more on power generating companies [1]. The majority of the problems are due to puncture of insulators. Because of these insulator breakdown the economic losses and reliability of the system is reduced on the transmission network and it becomes a critical factor.

Continuity of power supply is a major challenge by power engineers and scientists without economic losses to generating companies and users. Air pollution, dust and mist are creating a degrading effect on insulators of electric lines. The insulator placed in open space lot of dust deposited on it. When the dew drops touch the surface it become more sticky and next day this surface absorb more dust and the thickness of the dust layer become very high. As dust is a charge particle it creates a conducting layer then the insulator breakdown or puncture is occurred which is decreasing the efficiency and high maintenance cost and huge economic losses during the replacement of insulators are affecting the reliability on service continuity. The pollution present in air settles on the insulator surface which combines with dew, rain and fog these are prone to insulator puncture. Ancient methods of cleaning the insulators at regular intervals and preventing from flashover is one method and making the insulators as superhydrophobic water repellent surfaces is a major challenge which can provide dust prevention on surfaces and effective way for decreasing the cost of labor and flashover problems due to dust formation on the surface of the insulators.

1.3 Definition of the problem

In electric power generating companies the losses due to power interruption can be eliminated by service continuity. To maintain the service continuity, pollution on the insulators of electric power lines is to be maintained. The dew or fog settles on the insulators with the presence of dust formed on it in the day time, which later the next day due to natural sun heat the dust forms a sticky substance and gets hard to remove easily from surface. The hydrophobic nature of the surface is lost on the porcelain insulators and the insulator breakdown or puncture of insulators are seen. The dust formation removes the usability of insulators for longer period of time and the life of insulator is reduced.

The effect of dust and air pollution has been studied by many scientist [2,3] the solution by all the authors are studied in their own context and limited. Methods evolved to solve, polluted dust problem on insulator and porcelain insulator puncture problem are not effective. Superhydrophobic coating on the surface of the insulator is the better solution to this problem. These types of surfaces are to be modified and chemically treated; the surface morphology can be done by nano science [4] which should maintain specific insulating property to coat on the insulator. The dimension of the insulator should not vary in large values so the surface morphology is to be done with limited to 1 – 100nm. Nano particles exhibit different physical and chemical properties because of its size, shape and high surface to volume ratio. Nano structured thin coating layers also exhibits a superhydrophobic property on the surface of insulators [5]. Superhydrophobic surface layer creates the water droplet angle to be more than 150^{o} and makes it roll off with collecting the dust with it as a self-cleaning lotus leaf [6]. Between the solids and liquids, the high contact angles on rough surfaces results in air trapping as discussed by Cassie and Baxter [7–11]. The dust formation on the insulator surface is prevented when the bonding between dust and air is reduced.

1.4 Organization of thesis structure

Chapter 1: It details about the problem in power system and reveals the background of the system. This chapter expresses about the motivation for taking this topic as research work. In this chapter the reader knows about the structure of this thesis and the way it benefits and helps the reader. It summarizes the contributions made in by the authors and publication outcomes from this research work for future use.

Chapter 2: This chapter explains about the relevant studies and how the recent progress is going in the term superhydrophobicity its various applications and gap in the literature.

Chapter 3: Different preparation methods of superhydrophobic nano-composites and about porcelain insulators and different electrical testing methods and characterization are discussed in this chapter.

Chapter 4: Insulation property of porcelain insulators with and without nano composite coating is discussed and nano coating characterization is also discussed by conducting different tests for standardizing the nano material characterization.

Chapter 5: The different dimensions of porcelain insulators were selected and nano coating is done by various means and these insulators are characterized in different methods and standards by using different nano standard instruments.

Chapter 6: Comparative analysis is done on the coated and uncoated insulators based on nano characterization. Insulator coat analysis is also briefly discussed based on existing methods of insulators maintenance and breakdown clearance time.

Author clearly discussed about the total conclusion on the research based on different practical exposure done on the insulators and scope of the future work, so that the researchers interested in this area can take this work ahead and making it commercially viable.

1.5 Aim of the research

Based on the literature review and the work done on different electrical equipment's in transmission lines, the authors conclude the contributions as below:

1. Reasons on the insulators breakdown was discussed and taking the concepts of few researchers who has worked on nano material based insulators, the author have continued forward by taking few findings and make the work done on different material.

2. Nano composite was spread on tiny silica sheet and characterizes to prove as nano based material and the material could prove the necessary characterization and work was satisfactorily proved as superhydrophobic nano material.

3. The material coated on the insulators were proved and showed the insulating property when tested in laboratory and real time conditions, this reveals that the material is an insulating material.

4. After the laboratory testing is completed, the porcelain insulators were tested in laboratory and showed that the nanopowder does not affect the standards which has to be followed internationally according to specifications and dimensions.

5. A clear comparative analysis at polluted and different environment reveals that the insulators can withstand the polluted conditions and overcome the few problems of breakdown occurred in power industry. A comparative basic cost analysis also gives an added support for further commercialization of this research outcome by this enhanced product.

1.6 Publications from the Research

(1) I. Ramalla, K.Bansal, R.K.Gupta, "Research Papers Catenary Wire Protection Using Self Cleaning Property Nano Silica Coating And Impedance Protection," vol. 2, no. 2, pp. 33–41.

(2) K. Gupta, I. Ramalla, and K. Bansal, "AFM and FTIR studies of sol-gel silica nano coatings," *i Manag. J. Mater. Sci.*, vol. 2, no. 4, pp. 31–33, 2015.

(3) I. Ramalla, R. K. Gupta, and K. Bansal, "Effect on superhydrophobic surfaces on electrical porcelain insulator, improved technique at polluted areas for longer life and reliability," *Int. J. Eng. Technol.*, vol. 4, no. 4, pp. 509–519, 2015.

(4) K. Bansal and R. Gupta, "Development Of Nano Structured Super Hydrophobic Coating For The Electrical Safety Of Porcelain Insulator," *Int. J. Appl. Eng. Res. ISSN*, vol. 10, no. 19, pp. 973–4562, 2015.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this Chapter, porcelain insulators used on electrical power lines are discussed in detail. The reason for using porcelain insulators on power lines as commercial product and its properties the composition used to make the porcelain insulator to have a good mechanical strength is discussed. Recent Researches done on nanocomposite and dielectric materials are then presented. The existing solution and key problems faced in these materials are given. Development of nano composite material coated on porcelain insulator with superhydrophobic surface is a novel technique which is the thesis proposal as discussed. The variation with the existing technique and enhanced improved superhydrophobic technique is clearly discussed and reviewed clearly which makes the thesis with basic foundation and structure to this research work.

2.2 Glass and Porcelain Insulators

In Power System, the electricity carrying conductors are supported by cross arms where the conductor is placed on the insulators made of insulating material. The material which are commonly and mostly used for insulation for overhead lines are porcelain or glass. Porcelain insulators are made wet and processed with different ingredients like china clay, feldspar, ball clay, flint and talc. All these mixture is mixed and made in the form of paste and pressed in furnace and heated. The mold is placed in a kiln and cooled down, later metal fitting are done with Portland cement forming a porcelain insulators. Depending on the mechanical strength the insulators are machined into desired shape. Series of these insulators connected back to back is called as a string of insulators. The insulators are used at substations, on poles and towers; the insulators placed vertically are used for holding the conductor and placed horizontally at dead end of poles to hold the conductor with good mechanical strength.

Let us discuss in detail about the composites of porcelain insulators, as feldspar which is in the group of silica compounds and as the presence of silica and aluminum as a chemical structural compound it as an amount of 35% in the mixture composition of porcelain insulator preparation. Porcelain insulators originated from china. As the name originated, china clay has a rich material of kaolin which is white in color originated from rocks, these are of 29% composition [12, 13] while manufacturing the material. Abundantly available in earth crust is quartz which has a silica compound inbuilt in it for having an add-on insulating property for porcelain insulators. The porcelain insulators have a good ionic bond formation which has a good thermal stability, mechanical strength and longer life with ageing facilities.

Depending upon the composition of the clay and raw materials to make a porcelain insulator a good product for insulation on power lines, the insulators are fired at high temperatures. At different firing temperatures the clay turns into glassy formation which can hold its shape for better utilization. Since the material has different raw materials in which quartz, sand and opal are used as raw materials, silica contents is present in abundance with oxygen content where the material is amorphous and in impure form. The volatile contaminants are removed by applying low voltages to minimize shrinkage during heating and firing.

After high temperature heating in kiln, the insulators are glazed on the surface. These glazing is done to remove slurries and to have a good hydrophobic nature on the surface of the insulator. The insulators are spray coated or dip coat as per the convenience with mixture of alumina, calcia and silica. The mixture composition is based on the type of glaze formation for different applications. After the material achieves its desired shape and dimensions when heated at high temperatures, it is made to cool for forming a strong bond.

Efforts have made to recycle breakdown or outdated insulators; research is still under the way for dumping the material and reusing it for other product raw materials which can still give a good mechanical strength. The unfired scrap can be recycled at the manufacturing site, the scrap of fired insulators which are rejected at quality control and broken at site due to different reasons. The insulators should have another way than land dumping which is threat to ecologically and to the environmental regulations.

Annealed tough glass is used in transmission and distribution system which has become quite popular for its higher tensile strength, dielectric strength and high resistivity. The lives of these glass insulators are also longer when compared to conventional porcelain insulators. Since glass attracts dust particles very easily, the formation of dust on its surface and leakage current passed because of these thick conduction layer due to dust formation will make the insulator unreliable when compared with porcelain insulators.

A rod shaped core with dip cast steel covered with weather sheds are used these days, named as composite insulators or polymer insulators. It has many advantages one of them is a light weight when compared with both glass and ceramic insulators. The polymer insulators have a drawback of not able to withstand high temperature and salty wind areas.

2.2.1 Porcelain insulators problems

Porcelain insulators on overhead lines in transmission and distribution system are often affected with contamination and decomposition due to pollution, dust and mist formation on the surface of the insulators. Due to the contamination, the electric supply is affected due to flashovers and outages on the lines. Nearly about 500 interruptions are occurred on 220 kV transmission line [2].

The climate is characterized by dust, mist and air pollution which contains micro sized dust particles. When these sand particles are settled on the surface of these surfaces, it leads to erosion of the surface, which decreases the reliability of the power lines [14,15,16]. Based on the pollution level of the insulator surface, reasons for accumulation of dust are:

- Morning dew on the insulator surface makes them wet and creates a major source for creating a sticky layer with dust.
- High humidity conditions surrounding the insulator surface creates a worst condition for polluted insulators.
- Due to thick dust formation on the surface, near seashore areas the insulators are more affected with salt content this makes the insulators more miserable to maintain its insulating property and leads to insulator breakdown.

Effect of different climatic conditions also creates the insulator life to degrade and unreliable in the polluted areas.

A significant change is observed in the performance of insulators when they are subjected to different environmental conditions and dust formation with salt content and humid conditions, and these make the insulators to flashover or puncture. The flashover voltage on the insulators is also depended upon the charged dust particles present on the surface of the insulators. When the dust particles are with or without uncharged particles on its surface leads to variation in the flashover voltages. Various conductivity and flashover influencing factors [14] increases the rate of flashover probability and leads to more outages and unreliability of the electric power company.

The maintenance breakdown and installation breakdown of power supply is not accepted by electrical utility companies and consumers. The power lines are to be operated at full swing and without any disturbances or redundancies. Temporary alternatives [15] or reserves are to be kept in advance to make the system reliable, the existing system is to be upgraded which is discussed in detail in the subsequent section.

2.3 Nano composite insulating materials

Major research in nano technology comprises nanocomposites which have nano-sized materials are the next generation material. In nano materials, the nano materials are used for different application, as a part of that these nano materials are used in insulator surface for characterizing the amount of pollution and know the performance of insulators at pollution conditions.

'Lotus Leaf Effect' is popular terms which is discovered and well known as a superhydrophobic surface [5]. In this dynamic nanotechnology many researchers have started using these nanocomposites on different multidisciplinary research which revealed board applications and various functionalities. The mimicking nature of lotus leaf has designed various structural and integrations for this superhydrophobic surface [17]. Based on these surfaces different films, coating are prepared for self – cleaning applications.

Nano composites can be divided into different categories based on:

a) Surface area
   The overall property of the filler materials and dust particles with is a foreign material for insulator surface may lead to substantial impact. The specific surface area in the nanomaterial is to be maintained very less.

b) Particle size loading

The loading rate on the insulators with dust particles and conduction can increase to 50 wt%, where as in the nano composite the loading effect is very less up to 5 wt%. which cannot vary any loading problems in the porcelain insulators and the intrinsic properties of the insulators cannot also be varied.

c) Nano dimensions

Generally the dimension of the nanoparticle is less than 100nm. In a homogenous material size of nanoparticles, the neighboring particles also plays a very important role and the insulator dimension is not disturbed or varied which can make the insulator shed on a surface conductive material.

Dielectric strength decreases as the high loading on the electrical power lines increases variably. The above properties are considered to while using nano composites on the insulators to that the nanocomposites may not be interference for increased polarization effect due to nano-fillers on the surface of the insulator surface.

2.4 Relevant historical study on insulator problems

Different environment factors like temperature, pressure, humidity, wind and ice pressure effects the electrical, mechanical problems causing dynamic and static pressures leads to the failure of the insulators and other supporting equipment's in the power industry [18]. Many researchers and academic research publication were done for how to eliminate and control the insulator problems. Especially the surface flashover problems were studied by many researchers which is one of the main concern for insulator breakdown as the leakage of current are passed from the surface of insulators due to different reasons like covering of pollution by dust, formation of discharge on the dry surface clearance band [19, 20].

Various research groups have concentrated on the cap and pin of insulator where the spark is occurred on the insulator surface and the flashover and leakage of current is present through the insulators and leads to breakdown or puncture of insulators. Due to the thermal expansion of the cement present in the pin and porcelain material, the mechanical strength of the insulator is weakened and leads to breakage of the insulator [21, 22].

Other reasons for the breakdown of insulator is also due to the bird streamers where the researchers explains the problems effected on the power lines and suggested some rectification methods of the said issues [1, 12, 19, 20, 22–24]. Loss of retention, porcelain chipping [19] are another main issues for porcelain fracture and corrective measure was also suggested by the authors but it could not solve the dust and thermal disturbances on the insulators effectively.

The structural problems were studied and the remedy was done as a research by the J.Koustellis et.al [25] which some minor changes to the insulator manufacturers was suggested in firing the insulators at different temperatures [13]. During the switching operations the insulators operating personnel are affected with fatal injuries and the measures to avoid these injuries due to breakage of porcelain insulators were discussed in detail by J.Koustellis et.al [25].Artificial neural network was introduced by the authors as a part of solving the flashover problems on the porcelain insulators and mathematical formula is also derived further in later research work done by different authors [26, 27].

After researchers have shown their various methods, nanotechnology also entered the power industry. Introduction of nano coating was done in new millennium and later many variations on the chemical composition were done. A promising result was done by few researchers based on silicon nano materials and sol-gel methods for removing ice formation on insulators [28, 29]. This led to do research in this area, based on these material composites and chemical fundamentals we took our research forward and applied a nano sol-gel technique [30-31] on the insulators.

2.5 Existing methods and remedies to avoid insulator breakdown

As the contamination of the insulator surface is a major concern for electrical power industries, different methods are proposed by industrial experts and many academic and real time researchers. The methods summarized as below:

a) Washing of insulators periodically

   Periodic insulator washing is the best measure which is done by many maintenance companies on the power lines with hot line technique used by the shift engineers by water jet pressure pumps. This method is durable by very expensive method of cleaning.

b) Semiconductor glazing

The insulator surface creepage distance is increased which can reduce the leakage current passing through the surface. This method is not feasible to all types of rejoins as the standards are not followed.

c) Cleaning the insulator surfaces by mobs

Trained personnel are used to clean the surface of the insulators by linemen cleaning the insulator by climbing the tower and cleaning the insulators with cleaning material and liquids regularly at least twice a year near the industrial l areas where the pollution level is high.

d) Silicon rubber coating materials

Different type of insulating rubber which is of light weight is used so that the surface is acting as insulating rubber and the silicon can repel the water very easily.

e) Petroleum jelly surface coating

Since the petroleum jelly has the hydrophobic nature and water repellent nature, the cleaning of the dust on the insulator surface is done.

f) Replacement

Changing the insulators at regular intervals due to dust formation on the surface of the insulators may lead to waste management dumping. As discussed earlier replacement of insulators is been taken as the last measure for this problem.

Different insulators have come into existence to eliminate the problem occurred on the insulator breakdown. Superhydrophobic coating on the insulator is one of the promising cleaning methods which are discussed clearly with all electrical characterization and dimension analysis in later chapters.

The volume of liquid tries to adjust its shape into spherical nature so that it can have less contact with the surface which are seen in nature on different plants like a 'lotus leaf'[30-32]. Generally water droplets exhibit a distorted shape when it touches the surface because of its size and gravitational interactional forces. Surface tension, $\gamma_{(LV)}$, relates to interfacial tension of liquid and vapour, further the water droplet again interfaces with solid vapour $\gamma_{(SV)}$ and solid – liquid $\gamma_{(SL)}$. Gravitational forces dominate on mass of water and surface tension dominates on its size and length. In ponds, insects walk and skate on water due to morphology adaptions [33] on their legs breakthrough the surface of water and surface tension dominates and insects rest on water. Balancing of interfacial forces of all these solid – liquid – vapors decides if the water droplet should be pulled or rolled off as a droplet on the hard solid surface as shown in Figure 2.1. In the three phase interface, the tangent contact line liquid and solid is described by young's equation [34–36].

$$\cos\theta = \frac{r(\gamma sv - \gamma sl)}{\gamma lv} = r\cos\theta \text{------------------- Young's equation}$$

Where γ_{sv}, γ_{sl}, γ_{lv} are interfacial energies for solid, liquid and vapour respectively.

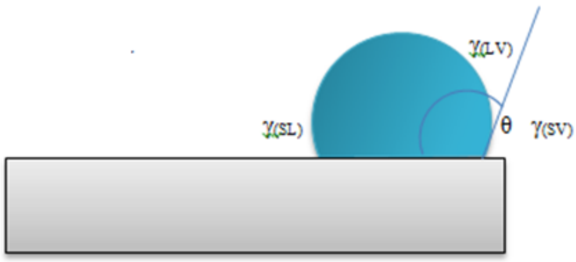

Figure 2-1 Forces acting on water drop on a solid surface

2.5.1 Hydrophobicity, hydrophilicity, superhydrophobicity

The water droplets which have a finite spherical contact angle from 0^o to 180^o are called partially wetting. If the contact angle is less than 90^o, it is called as hydrophilic and angle greater than 90^o are hydrophobic surface. By adding the roughness and topography by chemical amplification can make the hydrophobic nature to a superhydrophobic nature. When the droplet is on a hydrophobic surface, two types of possibilities are occurred. First possibility is, the droplet having contact with the entire rough surface (Wenzel state) [32, 33]. Second possibility is, the droplet could roll off the surface between the rough surfaces (Cassie State) [37, 38] with air interfaces below it. The young's equation for the two states can be written as $\cos\theta_w = r\cos\theta_e$ where 'r' is the roughness factor, which acts as amplification factor for surface chemistry.

2.5.2 Contact angle hysteresis and superhydrophobicity

The droplet rolling off the superhydrophobic surface has a connection with contact angle hysteresis since as the droplet size increases, the contact angle on both the tangent sides on the droplet changes when a surface is slightly tilted and greater contact angle on the droplet is called as advancing angle and smaller one as receding angle. The surface with low contact angle can easily sheds a higher contact angle surface, which depends on the magnitude of contact angle hysteresis. The pillar like structure reduces the size of droplet and density of the liquid is increased to make the surface area a fraction value which further makes the droplet to be superhydrophobic which neither effect contact angle or hysteresis.

2.6 Superhydrophobic Surfaces and material properties

Textiles are considered as artificial surface [39] which possess high roughness. Many researchers are working on these materials for effective superhydrophobic surface with very small fibre diameters for different applications in textile finishing as ever clean fibre without dust formation. Paints contain different particles which are applied to different surfaces with addition of binders to make the surface superhydrophobic. In market many of these particle binders are used as cleanable surface paints. Multiple roughness can be created on the surface by etching process in organic and inorganic materials by using acids, plasma and laser etching.

2.7 Summary

Successful applications have emerged from the term superhydrophobic surfaces based on mimicking and templating different natural concepts. Researchers are working on different applications for the past decade in different aspects and wide areas. Surface chemistry with roughness and surface spreading intercepts to superhydrophobicity. Based on these concepts research is done on electrical porcelain insulators for better performance by various means and materials. Silica nanocomposite [10], surface roughness by sputtering method using hafnium [40], RTV silicon rubber [41]resin coating surface [42] by using water jets, Alkyne (TOES) [28] chemical group composition to eliminate the icing problems on insulators are done on electrical porcelain insulators as nano technology as nano materials entered into electrical engineering and power engineering.

CHAPTER 3
MATERIALS AND EXPERIMENT

3.1 Introduction

Porcelain is one of the products that are from ceramic family, which are glassy, vitreous with low porosity, can be baked at high temperatures. Insulation is required between line conductor and supporting poles, tower for distributing or transmitting electric energy from one place to other. The insulators are used in between the conductor and poles so that it doesn't allow leakage current to pass through the poles or tower to ground or earth. Porcelain material is used in as insulators in electrical power lines as they possess with high mechanical strength and long life service.

3.2 Materials Selection

In the porcelain material, mixture of feldspar, clay and silica are all in small particle sizes. Most of the high-voltage lines use, ball-and-socket-type porcelain or toughened glass insulators. Disc and pin insulators are called as pin and cap type. Porcelain insulator cross-section is in Figure 3.1. The porcelain skirt of the Insulator works as insulation between the iron cap and steel pin. The top part of the porcelain insulator is made hydrophobic i.e., smooth glazing is done so that the rain water can wash the surface of the insulator when fine dust is collected on the top part of the insulator surface. The lower part is corrugated, which prevents getting insulator wet and also provides a longer protection from leakage path. Special type of Portland cement is used so that it can join the cap and pin and makes the insulator rigid and strong. Before the application of the cement, the porcelain material is sandblasted to generate a rough surface. Finally the whole porcelain surface is glazed so that the surface is smooth and the water or fine dust can be rolled off easily, but after a period of time, the reason making this glazing is lost as the oil, dust and water particles stick to the surface and does not make the surface as smooth as it during manufacture process.

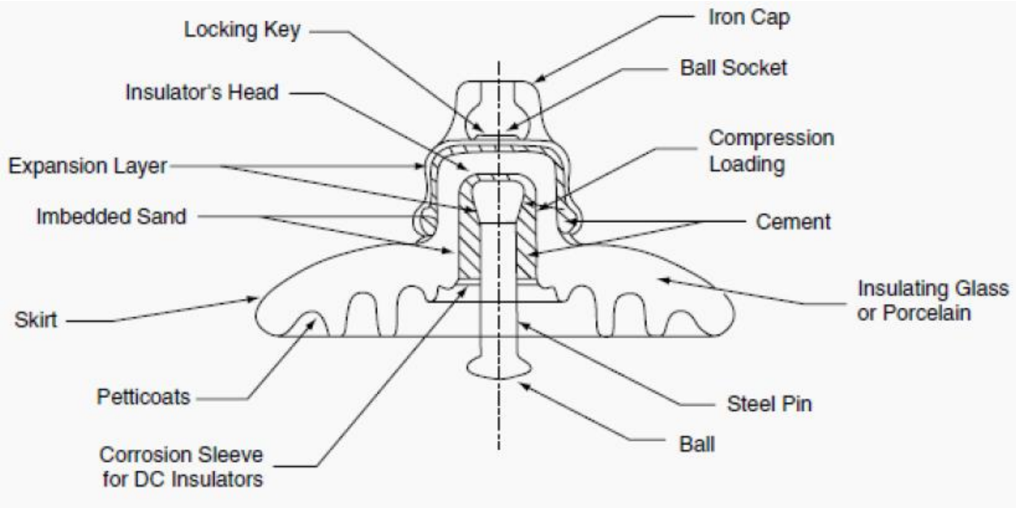

Figure 3-1: Porcelain Insulator (Post Type) Cross sectional view [43]

The manufacturing of porcelain insulators used in power industry and the materials used are discussed in detail below:

Clay:

China and ball clay are the important clay materials used to manufacture porcelain and china clay which have kaolinite, hydrous silicate. It has a glassy look with good mechanical strength and the shape holds is also maintained with low porosity. Manufacturing porcelain insulators are easily manufactured and best product in all conditions.

Feldspar:

The materials composition in porcelain makes it to withstand all weather conditions and temperatures. During short circuit faults on power lines the arc withstanding capability to these insulators are pretty good. It is a mineral consisting of hard quartz and aluminum silicate which can act as tough body on porcelain insulators.

Silica:

For fabricating and forming a shape as desired, silica is used as constituent to improve the fabrication and heating is done to make the finished product. Soap stone is present in the porcelain which has a compound of oxygen and alumina and bodies consisting of steatite and low alkali bodies.

3.3 Porcelain manufacturing process:

Making of porcelain insulator contains a different process and steps. The raw material is weighted and selected in desired proportions for making it to pass through different procedures. Initially it is crush properly and mixed in equal perfectly so that it can pass through four different steps like; soft plastic forming, stiff plastic forming, pressing, or casting; the choice depends upon the type of the standard drawing the customer requires. The mixture is pressed in a mold and pressed properly in desired shape as per the specified drawings. The insulator is neatly glazed on the whole body before it is sent for last purification process. Enamel paint is used as glaze to spray on surface and firing is done in kiln as a last manufacturing product.

3.3.1 Molding of a raw material

This process takes place by using sophisticated equipment's to grind, crush and mix the raw material. Jaw crushers are used primarily for crushing with the help of swinging metal jaws. In the later stage the crushing is done to less than 0.1 inch diameter by using rapidly moving steel hammers in hammer mill shop. For making the grinding properly, spherical shape large rotating cylinders are used in this section for smooth desired molding.

3.3.2 Cleaning and mixing

Raw material contains oversized or undersized materials which can be removed when passed through different filter screens. The screens are mechanically vibrated and passed through a slope surface so that these unwanted sizes can be removed easily from mixing. For desired shape the material is first sprayed with water so that it becomes wet and forms to its desired shape. In the raw material some iron parts and pieces are removed by using magnetic slurries. If the body is to be formed dry, shell mixers, ribbon mixers, or intensive mixers are typically used.

3.3.3 Making of porcelain material body

This can be done using by any of four methods; this is selected depending of the ware and feasibility of making:

- Method 1: Shapes of porcelain material can be done first by using clay. Clay can be shaped in desired shape by wheel throwing, ram pressing and jiggering. Potter uses the clay and turns the wheel and shapes according to the desired shape by using wheel throwing method. Two molds made of plaster in desired shape are used in ram pressing by keeping the clay in between making the water out. Similarly in jiggering method, the shape of the clay one side is done by mold and other side by heating die.
- Method 2: Clay is kept in a steel die which pressure for having uniform shape. This desired shape can be used for other purposes according to the different designs and applications.
- Method 3: A fixed mold or a flexible mold is used is used for the desired shape of the porcelain according to the drawings by the customer. Depending upon the pressure the process is varied like, pressure applied from one direction gives uniaxial pressing and when pressure is applied from all sides gives isostatic pressing.
- Method 4: In a porous mold, slurry is poured. Liquid is sent through a filtered mold. Water is drained from the mold layer until it gives a desired porcelain solidified shape. This process is called as solid casting.

3.3.4 Glazing

The raw material is mixed with water and perfectly glazed so that the glaze slurry is able to pass through all magnetic filters to be screened perfectly and remove the impurities present in it. The insulator is wared with spraying, pouring and painting. By varying the proportions of the ingredients, different glazes are produced. A matte glaze is produced by changing the proportion of calcia and silica.

3.3.5 Firing

In kiln or over, heating is taken place for firing the insulators. A sealed chamber consisting of burners and heating elements are fired in this system. The firing can be done at different products but one batch of firing can be done at one instant. From one zone to other, refractory chamber is very large in length in hundreds of feet and it can maintain the temperature continuously. Before it enters the cooling zone, the chamber enters into central firing zone and preheating zone. Firing in these types of kilns is efficient and economical.

Different process takes place during the firing. Initially, sulfate is decomposed at high temperatures when chemical water is evolved and carbon impurities are burnt properly at this stage. Some minerals are broken in this process as further heating is done and which evolves gases and decomposed liquid glassy minerals are obtained. After cooling the crystalline grains are formed with strong bong with a glassy look to form complete porcelain.

3.4 Nano Particles - Silica

3.4.1 Introduction

Silica known as silicon Dioxide is a compound. Chemically it is an oxide of silicon written as SiO_2. Silica is found in abundant and much known from decades in chemical history. This is available in the form of quartz in nature and living organisms. In the form of sand it is majorly available with a complex and abundant in materials and produced synthetically. These are also available fumed silica, silica gel and quartz fused silica. These are abundantly used in all forms in electronic components, structures and food industry. By varying the pH value the silica can be subtitled in different forms as silica gels and silica solutions.

3.4.2 Manufacturing of silica

Quartz is available in earth’s crust in abundance, by mining and further process of purification silicon dioxide is obtained. For many applications and fine purification processes this material is used and suitable for many other applications.

3.4.3 Laboratory method – (SiO_2)

Silicon dioxide can be easily prepared in laboratory by heating TEOS (tetraethyl orthosilicate) to 650^{o} K to 750^{o}K.

$$Si(OEt)_4 \rightarrow SiO_2 + 2\ O(Et)_2$$

Combustion of TEOS takes place ~ 400 °K

$$Si(OEt)_4 + 12\ O_2 \rightarrow SiO_2 + 10\ H_2O + 8\ CO_2$$

Sol – Gel hydrolysis process is done by using hydrolysis process. By using the base and catalyst the nature of the silicon dioxide is available in the below chemical form

$$Si(OEt)_4 + 2\ H_2O \rightarrow SiO_2 + 4\ HOCH_2CH_3$$

By using methane, silicon dioxide can be obtained by little combustion process.

$$SiH_4 + 2\ O_2 \rightarrow SiO_2 + 2\ H_2O$$

Structure:

In the silicate structure, the silicon atom is in tetrahedral coordination with four oxygen atoms around it. These silicates are observed in the quartz form of SiO_2. It is mostly thermodynamically stable form of silica as it has all four vertices with oxygen atoms of Tetrahedral SiO_4 shared by other identical atoms, resulting with chemical formula: SiO_2

The Si-O-Si bond angle is in between 144^{o} in α – Quartz – tridymite, up to 179^{o} in β - Quartz – tridymite. Silica is soluble in water at 340^{o} C temperature, solubility of silica depends upon its crystalline form and its solubility is four times greater than quartz.

3.4.4 Synthesis routes used for the superhydrophobic surfaces

Superhydrophobic surfaces can be fabricated with few advantages and limitations. To synthesize these surfaces, many physical and chemical changes and morphological changes have been applied. Few methods are costly and others are easy to prepare in the laboratory conditions as the author used on of the methods for preparing the superhydrophobic surface. Each method is explained in detail for synthesis.

3.4.4.1 Electrochemical Deposition

By using electrochemical deposition, micro/nano structured superhydrophobic surface is created and implemented. Electrochemical anodization method is applicable to produce in large scale by mixing two different materials like methanol electrolyte and hydrofluoric acid. By maintain the temperature, reaction time and electrochemical concentration, different kinds of nanostructures are obtained within fewer periods.

Huang *et al.*[44] utilized one-step decomposition process to fabricate the copper superhydrophobic surfaces. This method used copper electrode which could change the properties of the surface and the water contact angle is 153° ± 2° with the roll off properties. This type of method is not possible in this research, so the author has given less preference and the application of this method can be used on conductors.

3.4.4.2 Electrospinning Method

For fibers with nano scale, this method is preferred for continuous fibers. By applying electric bias and a grounding place with a nozzle by simple extrusion process the membrane can create a contact angle of about 155^{o} can be obtained by this method. The silicon fibers are synthesized [5] which exhibited superhydrophobicity as it has a unique structure formed on their surface as present on a lotus leaf.

3.4.4.3 Wet Chemical Reaction

For large scale industrial and commercial adoption, wet chemical coating to make a superhydrophobic functionality is ideal. Qi et.al [45] explained a technique for generating simple wafer-scale antireflective structured silicon and superhydrophobic surface. The surface can exhibit a contact angle of around 169°. Even for water and other corrosive liquids this method is simple and etching of superhydrophobic surface is very simple. In industrial copper superhydrophobic coatings this method is versatile. The author did not use this method because the chemicals used have an electric conductivity on the surface which is not suggested for a n insulator surfaces.

3.4.4.4 Phase Separation Method

A simple and preparation of porous polymer membrane are created by this phase separation method. Khoo *et al.* [46] successfully prepared superhydrophobic 3D surface on a glass through various reagent and synthesis methods. This method has a luminescent property which can act as self-cleaning road sign boards by using the superhydrophobic surface of light emitting sign boards and lights.

3.4.4.5 Self-Assembly and Layer-by-Layer Methods

Simple and economical method to prepare optically transparent superhydrophobic surfaces by Xu and Wang [31, 47] is by mixed dispersion self- assembly layer – by – layer process. This process can be completed in large scale within less period of time. This type of technique can be followed on a hydrophobic silicon smooth surface. The insulators in this regard can be used but the chemical available are very less and synthesis is not abundantly possible. The contact angles obtained on these surfaces are around 155°.

3.4.4.6 Plasma Treatment

By plasma etching process the plasma treatment is possible. Ji *et al.* [5] explained a method which is simple for fabricating on a glass slide to discharge a glow with plasma and create a superhydrophobic surface. The glass treated showed superhydrophobicity with water contact angle of about 150°. For optical applications, this technique is easily scaled and operated for treating the substrates with scaled up mode.

3.4.4.7 Solution Immersion Method

This method is economical because the reagents used for this process are very cheap and easily available. No special equipment is required. It can be fabricated easily. Kong *et al.* [81] reported a simple immersion method for fabricating on the copper surface. This method uses commercially available wax with slight modification in the process for low superhydrophobic surface morphology. Uniform nanoscale roughness is created in satisfactory durability and better surface creation for having superhydrophobic surface.

3.4.4.8 Casting Method

Superhydrophobic coating on polymers or plastics can be easily done by this process. Compared with different methods as discussed, this method is simple for polymer with less equipment's and reagents. Hou *et al.* [31, 48 , 49] successfully prepared a polypropylene/methyl-silicone based superhydrophobic surface by this method. By changing the ratio of methyl silicon and polypropylene the sliding angle can be varied.

3.4.4.9 Sol-Gel Method

By simple hydrolysis method and condensation process with reaction mixture of corresponding oxides and solvents, the composition of sol – gel is formed. The formed solution in the gel form can be applied on the substrate by combining with silica nano sized particles [5, 17, 28, 49–51]. Basu *et al.* [101]. This method is fabricated by sol- gel coatings process sprayed on a pre- cursor mixtures containing hydrophobically modified silica nanoparticles prepared with acid-catalyzed tetraethoxysilane (TEOS). By adding the concentration of fillers and HMS, hydrophobicity can be increased.

Water contact angle of 166° and roll off angle 2° can be obtained by optimizing the sol-gel processing parameters and the concentration of silica nanoparticles in the coating. After dip-coating with the silica solution onto cotton surfaces, the surfaces were modified with hexadecyltrimethoxysilane (HDTMS) to obtain a thin layer through self-assembly. A simple sol-gel dip coating method based on partially reversible aggregation of silica colloid particles are obtained. These aggregates were consequently assembled onto the glass substrate by dip coating. It was observed that the surface structure, superhydrophobicity, and transparency can be controlled by adjusting the concentration. The author used this process as the reagents are easily and abundantly available. The costs of the reagents are cheap which can be prepared in bulk. The process contains simple laboratory equipment's. The author used other reagents which are easily available and previously done by other researchers, making few changes in the synthesis and chemical composition; the author applied this process to further use it on porcelain insulators for testing it in live conditions.

After reviewing different methods, [28, 52] we applied this process with different reagents and synthesis by changing the concentration and adjusting the fillers to get the transparency on the material surface. The chemicals abundantly used in this method are silica which has an insulating property.

3.5 Sample preparation

By adding SiO_2 powder in aqueous solution of SiO_2 a hierarchical structure of preparing silica coating can be done by sol – gel process as discussed. The preparation is done by adding 45.6 ml of TEOS and 54.8 ml of ethanol is stirred rigorously for 30 minutes ate ambient room temperature. 3 ml of dilute HCl and HNO_3 with pH=1 are stirred and added in the solution. Hydrolysis is taken for one hour and while the stirring process is continuous on the magnetic stirrer. Powdered silica is mixed and with the solution in water bath of 70^{o} C for one hour. One drop of PDTS in 50ml of ethanol is dripped into the solution for one hour.

After the sol – gel solution is prepared; it is sprayed on the fine piece of porcelain insulator tiny sample (S_1), silicon wafer (S_2) and on 70 kN, 33 kV disc insulator bushing (S_3). The tiny insulators are dried in hot oven for 55^{o} C for 30 minutes. The porcelain insulator sample and microscopic slides are tested for characterization for super hydrophobic property as well. The coated and uncoated porcelain post insulator bushing was kept for observation in the different air polluted zones. After a six months period, the insulators are brought to laboratory and analysed for accumulation of dust formation on both the insulators with different polluted and subjected to various climatic conditions and electrical properties are also tested by sending high voltage to the insulators.

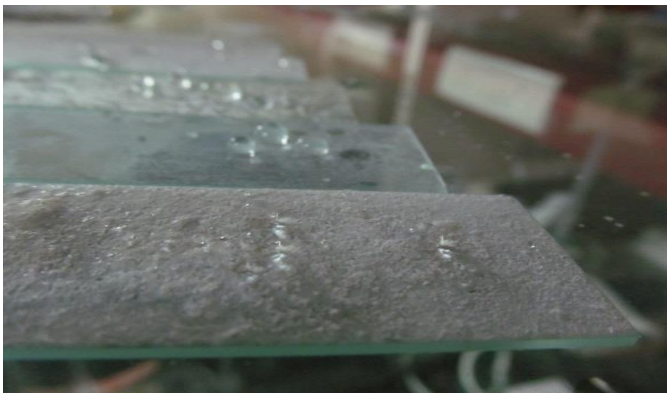

Figure 3-2: Coating done on glass slides (S_4)

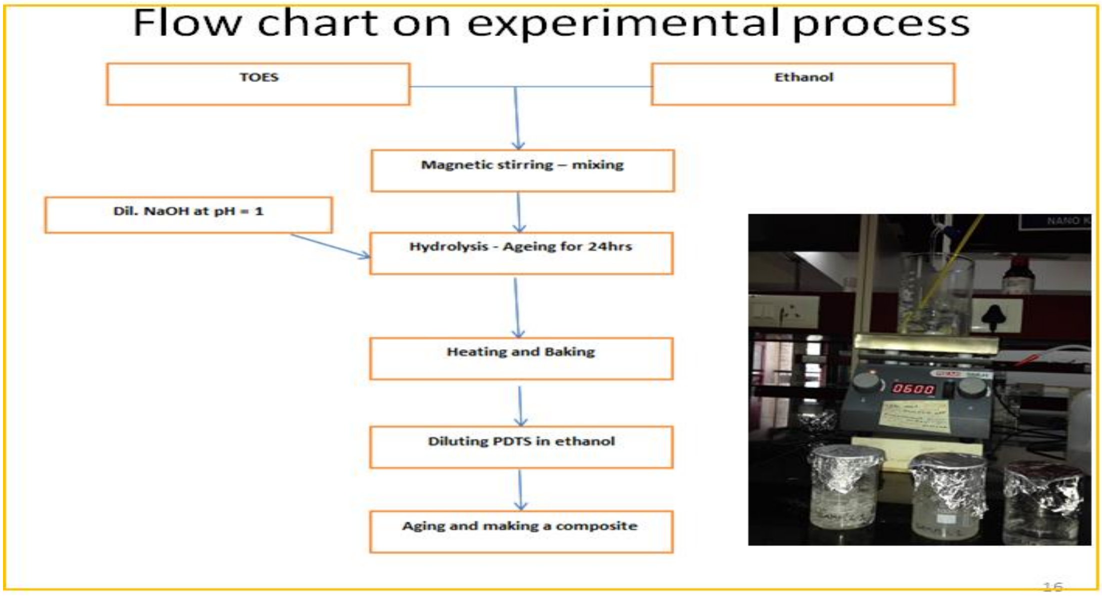

Figure 3-3: Experimental set up and set up flow chart

3.6 Material Characterization

To know the changes in the morphology and chemical structures macro-performance of the synthesized nanocomposites are to be verified based on various treatments, all materials need to be thoroughly characterized using various instruments. All the samples were characterized using various instrumental techniques XRD, SEM, FTIR and AFM which supports the sample as microscale and nanoscale SiO_2 particles of the sol-gel SiO_2 composite, which act as superhydrophobicity coated over glass and as well as porcelain electrical insulators.

SEM imaging, the nanoparticle samples are prepared by directly placing them. In contrast, the nanocomposite samples are prepared by spreading the nanocomposite powder and place them on adhesive tapes. In this case, the cross-section can be observed under the microscope. As the samples are insulating in nature, they were decorated with thin gold layers with the thickness less than 10 nm to prevent surface charging effects.

Fourier transform infrared (FTIR) spectroscopy is another technique for analyzing the composition and chemistry of the nanocomposites. This method involves applying infrared radiation on the sample. The transmitted or absorbed spectra yield the fingerprints of different molecules. As no different molecules share the same fingerprint spectrum, this technique is widely used to determine the chemical composition and the molecular structure in organic chemistry. Here, a Perkin Elmer

Spectrum 100 FTIR spectroscope is employed, of which the wave numbers range from 650 to 4000 cm^{-1}. During the analysis, the samples are directly placed on the crystal of the universal attenuated total reflectance (UATR) accessory with the pressing force of 80 units in the force gauge.

3.7 Electrical Testing (Laboratory Tests)

3.7.1 Partial Discharge

Between two conductors if an electric spark is bridged in a small part of insulation is called partial discharge. When the electric field strength exceeds the breakdown strength, the electric spark or discharge takes place. Within radio frequency range electromagnetic waves are generated and the discharge occurs in switchgear and high voltage insulation. The signal penetrates through any type of insulating components and materials. Small charges are conducted by metal surfaces and the metalwork is impulse onto the surface of the casing. The charges are between 0.1mV to 1V. In practice partial discharge can be used for detecting voids in the insulation.

Partial discharge is useful in finding the contamination of particles on the insulator surfaces. This can be detected by placing the probe on the surface of the insulating material which can be tested which is in service. In an insulation liquid, gas bubbles and floating particles with irregularities on the surfaces can be easily detected. Due to environmental activity, the discharge of charges is affected including humidity. The partial discharge activity can find the deteriorating evidence which can show the failure state. In our research work this type of test gave a good bench mark to show us the point of failure due to dust formation on the insulator surface.

In the laboratory conditions these tests were conducted on a voltage source inverter to find the charges and insulation resistance on the surface of the insulator. As shown in the Figure 3.4 and 3.5, the insulator surface resistivity is measured.

Figure 3-4: The picture above showing the presence of current flow when joined together.

The change in the resistance value is shown in the Figures 3.4 and Figures 3.5 which clearly show that the material used on the insulator surface for coating has an insulation property and does not have a conducting nature. The partial discharge or speak could not be transferred on the insulator surface of the nano-coated insulator.

Figure 3-5: The picture above showing the open circuit condition, hence no leakage currents.

3.7.2 Dielectric breakdown strength

Breakdown strength dielectric serves as below:

1. Higher resistance and capacitance is maintained and separated in smaller plates to keep the conducting medium away from contact.

2. At lower voltages, of same charges the effective capacitance can be increased by decreasing the field strength.

3. At high voltages, the dielectric breakdown due to short-circuit can be reduced.

Even the insulator can be a conduct layer in dielectric nature. This is called as dielectric breakdown. According to the molecular orbital theory, the intrinsic property that differentiates insulating materials from metals and semi-conductors is the wide band gap of the molecules of solid insulators. The electrons need to gain excessive energy to be freed from the highest valence band to the lowest conduction band and thereby become charge carriers. In general, the process of electrical breakdown starts from the acceleration of free electron in solid by high external field. After that, the accelerated electrons collide with atoms of the dielectric material and break chemical bonds and new free electrons are yielded as the result of the collision. Subsequently, these electrons further collide with other atoms of the dielectric. Finally the electron avalanche is yielded and ultimate breakdown takes place. The process of breakdown is normally accompanied with large current and heat, which may cause irreversible damage to the insulator.

Dielectric constant: The ratio of permittivity of a substance to the permittivity of free space is called as dielectric constant. An expression, to which a material concentrates electric flux, is the electrical equivalent of relative magnetic permeability. Dielectric constant, relative permittivity reflects the ability that one dielectric can be polarized by an external field and thereby store charges within the material. It highly depends on the molecular structure of the dielectric material. The dielectric constant is strongly dependent on frequency that it decreases as the frequency increases. Normally, polymers have relatively low dielectric constant (less than 10) due to the tangled chain structures and low chain mobility; whereas ceramic dielectrics have higher dielectric constant as high dipole moment is exhibited in their molecules. Materials with different dielectric constants are desired in specific applications.

3.8 Summary

This chapter has described the selection of raw materials and chemicals, the procedures of preparing nanocomposite samples, the characterization methods, and the electrical testing methods for the nanocomposites. However, more detailed procedures involved in specific experiments, according to the requirements. Experiments are performed in the following chapters. Additional measurements or tests are discussed in the following chapters, but have not been listed here as they do not apply to the whole thesis.

CHAPTER 4

CHARACTERISTICS OF SIO_2 NANOCOMPOSITES

4.1 Introduction

The surfaces which have water repellant characteristics are superhydrophobic surfaces. Lot of attention was received by many potential users for applications which can be done by these applications for instance, self – cleaning windows, solar panels, floor tiles etc. many articles were published based in this concept from past five years. Many papers were used based on the surface and the nature of the rolling droplet which are characterized by different instruments.

Surface tension

For making the water drop spherical in nature, they are subjected into two forces; they are surface tension and gravitational forces. The surface tension tries to decrease the surface area of the droplet and the gravitational force try the water droplet to attract it and tries the water to spread and flatten it. The water droplet experiences the interface between solid – air to solid – liquid [53, 54] when the droplet experiences the difference in the surface and chemically treated morphological surface.

Contact Angle

When a water droplet meets the solid surface, a tangential angle is drawn between the solid surface and the liquid droplet called as contact angle. Young's equation explains about the concept of wettability and pressure acted on the droplet in the system of solid, liquid and vapor state. Due to the tilt in the angle of a surface, the water droplet experiences a receding angle and an advancing angle which in practice called as contact angle hysteresis [42, 55].

4.2 Conditions for Superhydrophobic nature

For the surface to have its contact angle above 1200, surface roughness [33, 56–58] concept is introduced which has an water repellent nature and many natural materials and plants has paved a way for this surface roughness concept.

Nelumbo nucifera (lotus plant) has this tendency of surface roughness on the leaf and it exhibits the water repellency. This concept was explained in 1997 by Neinhuis and

Barthlott [59] about dual scale roughness present on the lotus leaf. The surface has a wax formation on its surface called as epicuticle wax tubular in structure which makes the water droplet to be in the form of a hydrophobic nature. The droplet on the lotus leaf is in Cassie – Baxter [36, 60–62] state with an angle of 164^o acting as a superhydrophobic natural surface. Due to the superhydrophobic nature, the water droplet beads up and rolls down the leaves and collects and drags the dust along its way on the lotus leaf surface which makes the leaf clean and dry. This property is called as self-cleaning 'lotus effect'[52, 53].

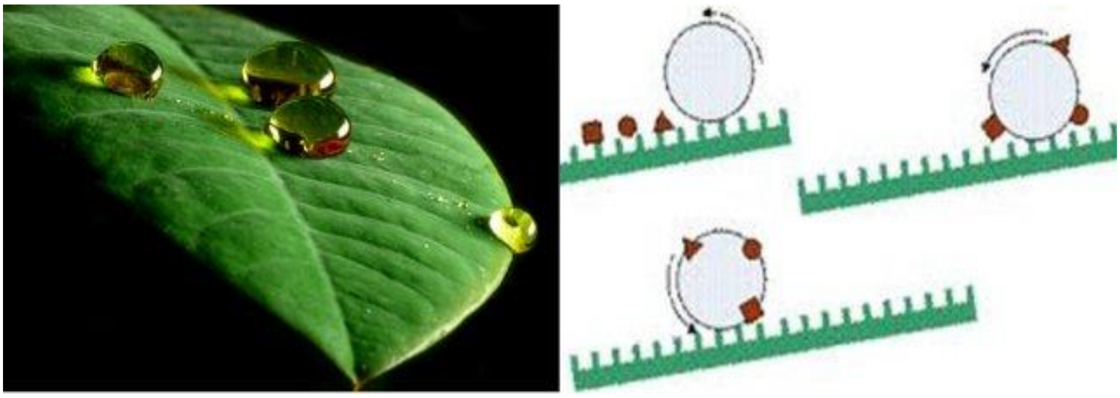

Figure 4-1: Lotus leaf with water drops, rolling water drop collecting the dust and dirt particles.

In many countries like India, lotus plant is referred to as secret flower since it does not make itself unclean staying in an unclean pond, which shows the purity and clean nature of the plant and the society. Plants and animals also possess the same nature of purity due to this superhydrophobic nature of the surfaces [17, 54, 57].

The morphology of mimicking the superhydrophobic surface which can be replicated can be done by nano structuring the surface with microstructure and hierarchical topography for obtaining best water repellency surface. High contact angle can be obtained by hydrophobic chemistry and nano structured scale on the surface. A complex hierarchical structure is required for obtaining a superhydrophobic surface at critical sliding angle.

4.3 Experimental

In this research work, two major types of experiments were done on conductor and insulator to find out the prepared precursor properties. The preparation concept was motivated from the future work of research work of researchers [28, 64, [65] on porcelain insulators but the heating process and composition is however changed and characterised for better approach for using the electrical insulators in real time applications. Aluminium conductor of 1 mm length and diameter of 0.25 $mm^2$is taken and coated with the nano powder, similarly post insulator of 70 kN is also used to analyse the dust formation on the conductor. The prepared precursor properties are also characterized by using analysing (Scanning Electron Microscope SEM, Atomic Force Microscopy AFM, and Particle Size Analyser PSA.

4.3.1 Reagents and materials selection

Silicon wafer of 12mm x 3mm size is taken and coated with the precursor with spray coating and similarly a fine piece of 0.5mm x 1mm size porcelain material is taken and spray coated with precursor of SiO_2 powder size of 15nm. Tetraethoxysilane (TEOS,AR) (Merck, Germany), Sulphuric acid, Silica Powder, 1H,1H,2H,2H-Perfluorodecyltriethoxysilane (PDTS,AR) (Merck, Germany), double distilled water, Ammonium hydroxide NH_4OH, Nitric acid (HNO_3), Hydrochloric acid (HCl).

4.3.2 Sample Preparation

As discussed in previous chapters about the different methods to do the morphology of surface to acquire superhydrophobic nature, advanced sol-gel technique[11], [28], [66], [67] was used as it is the simple and quick process which can create a morphology equivalent as lotus leaf effect, fabrication of superhydrophobic surfaces can be done by chemical changes with slight modification in the structure of the hydrophobic surfaces which makes the surfaces superhydrophobic with chemical modifications by using two main reagents tetraethoxysilane,(TOES) perflouorodiethlytrioxysilane (PDTFS). Silicon wafer of 12mm x 3mm size is taken and coated with the precursor with spray coating and similarly a fine piece of 0.5mm x 1mm size porcelain material is taken and spray coated with precursor of SiO_2 powder size of 15 nm. After heating furnace at 348 K for 30 minutes, natural cooling was done and finally diluted PDTS was spray coated. The modified both samples and again heated in hot air oven for 2 hours and cooled in room temperature.

4.4 Results and Discussion

4.4.1 Electrical Tests

The concept of Vandalism [55–58] resistivity measurement method is used to find the average resistivity of the samples. Since the material should also possess insulating property, the sample is tested with voltage and current so that the sample would get the primary readings with good resistive properties.

To know the insulating property of the material The sample was given with a voltage of 20 V and tested by using a keithley 2540 model source meter, the current of 100 mA was passed, the measured value for a coated sample was 0.3323 ohms, whereas the measurement for a bare conductor without any coating is 0.2434 ohms, with same source and current. The measurement of the coated image a) shows uncoated 1 cm long aluminium wire; b) nano coated silica powder with same measurement of 1 cm long length.

Figure 4-2: Aluminum conductor without coating indicating resistance.

From the Figures 4.2 and 4.3, we can understand that the coating material does not allow the current to pass easily through it, and it acts as a superhydrophobic nature. The nature of the coating material is to eliminate the dust and acts as a self-cleaning dust cleaner on it. The coating concept was taken from natural 'lotus effect' phenomenon.

Figure 4-3: Aluminum conductor showing the increase of resistance value.

4.4.2 Silica coating structure

The silica particle size are spherical and various researchers studied and concluded that these particles are depended upon the reaction rate of hydrolysis [72] and polycondensation [34, 46, 73–75]. Synthesis of the experiment is done in acidic condition which can be done in ammonia base solution leading to a polymer. The sol – gel method was done by multilevel hydrolysis condensation process by using TOES to obtain $Si(OH)_4$. Thermal decomposition was done by adding HNO_3 and HCl as base solution with nano sized SiO_2 solution is heated properly to obtain the nano sized SiO_2 powder. To analyse the internal and external structure of the coating different analysing methods are used here which shows the size and dimensional property of silica powder.

4.4.3 SEM Analysis

Particle size and morphology of the prepared sol-gel SiO_2 samples are predicted from SEM samples. As shown in Figure 4.4 to 4.8, the SEM image of SiO_2 nano powder is obtained by advanced sol–gel method. The experimental process is described in experimental section. SEM images are taken from Sigma Scanning Electron Microscope from Carl Zeiss at Wadia Geological Research Institute and in the SEM images a single SiO_2 particle is with a spherical size of around 7 – 8 nm. After clear observation sin the SEM it reveals that the SiO_2 powder is with an average size of 50 – 60 nm at a width of 100nm. Particle size from SEM Analysis shows the different spherical size morphology depending upon the various parameters taken for the observation.

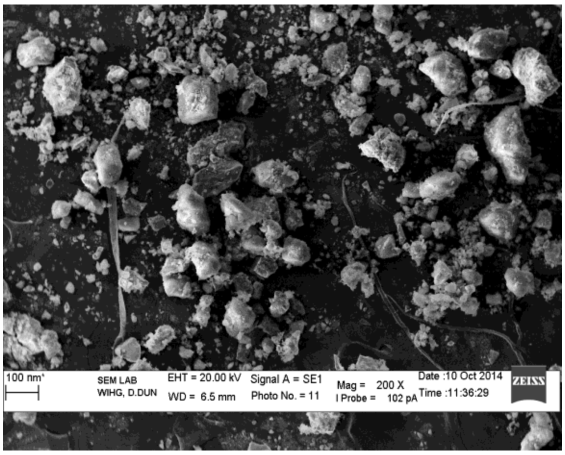

Figure 4-4: SEM images of nano coating used on insulators at 100nm range

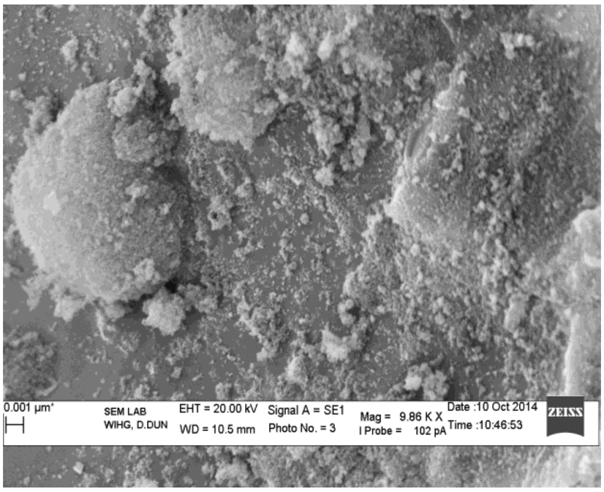

Figure 4-5: SEM image of powdered coating used on insulator

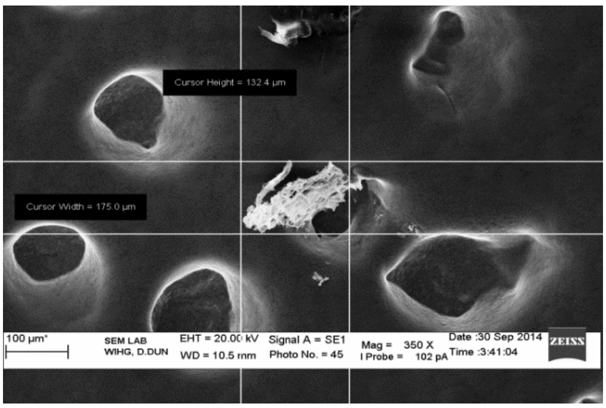

Figure 4-6: Tiny dust particle between the silica nano structures

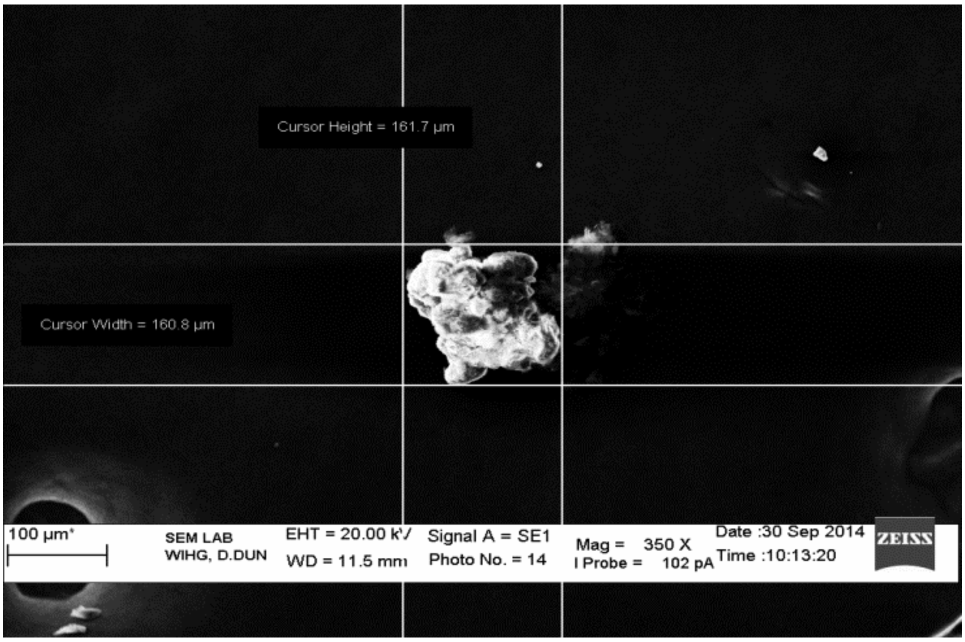

Figure 4-7: Size of each very fine dust particle on the surface of insulator

Another analysis done for the particle size characterisation is FT-IR Analysis. This analysis is also very transparent which shows a graphical property of the coating powder sample.

4.4.4 FT-IR Spectral Analysis

FT-IR spectrum (FT-IR model PerkinElmer Spectrum Version 10.03.09) of the as prepared composite is as shown in the Figure 4.8 the percentage of transmittance peaks at 1099.32cm^{-1} and 480-170 cm^{-1} are in the bonding of Si-O-Si bending vibrations and asymmetrical stretching. The band has a absorption peaks at 3440-3420 cm^{-1} and 1640 – 1630 cm^{-1} are because of the presence of the –OH groups of SiO_2. FT-IR spectrum of the as prepared sol-gel silica after calcination suggests that the prepared SiO_2 nanoparticles are pure and free from organic matter. Si-O-H-(H_2O) bending vibrations observed at near 966.37 cm^{-1} while peak at 804 cm^{-1} indicates in-plane bending vibrations of geminol groups. Peaks at 1099.32 cm^{-1} shows the bending vibration of Si-O-Si asymmetric stretching near 3454.31 cm^{-1} which indicates that the surface has a –OH group where the bending vibrations of –OH groups are at 1630 cm^{-1}.

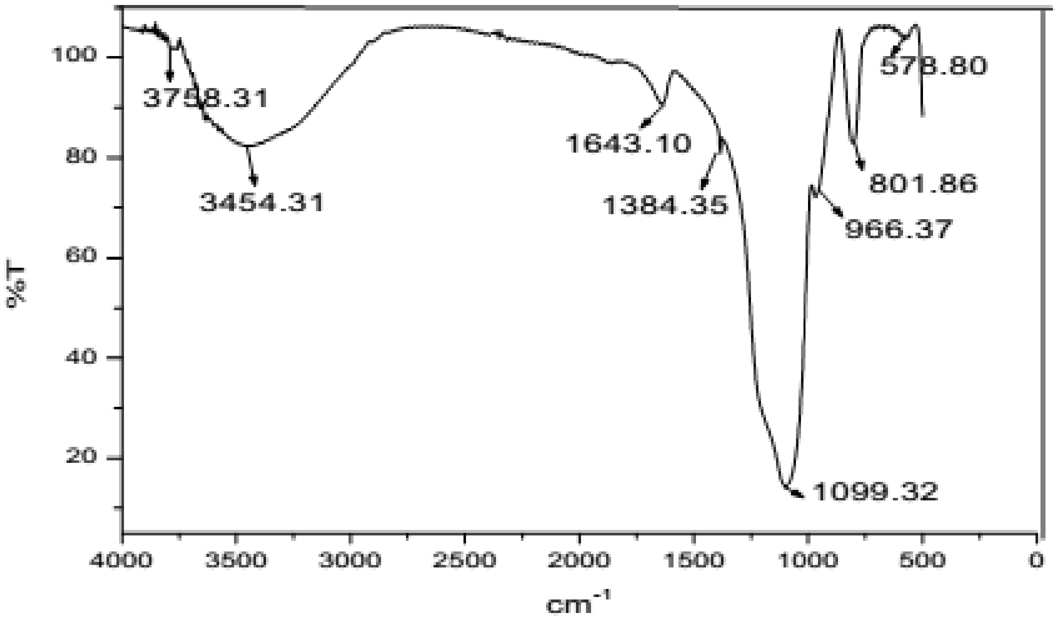

Figure 4-8: FTIR analysis of SiO_2 nano powder used on insulator

4.4.5 Contact Angle Gonio Meter: (DROP SHAPE ANALYZER)

Water droplet was analyzed in Nano Lab at UPES, Dehradun with different water droplets performed on the instrument Kruss – Model No: DSA25 (drop shape analyzer). This analyzer shows the spherical structure of the water droplet formed after the coating on the insulator. The Contact Angle Goniometer characterizes [76] the superhydrophobic nature on different samples with and without coating conditions.

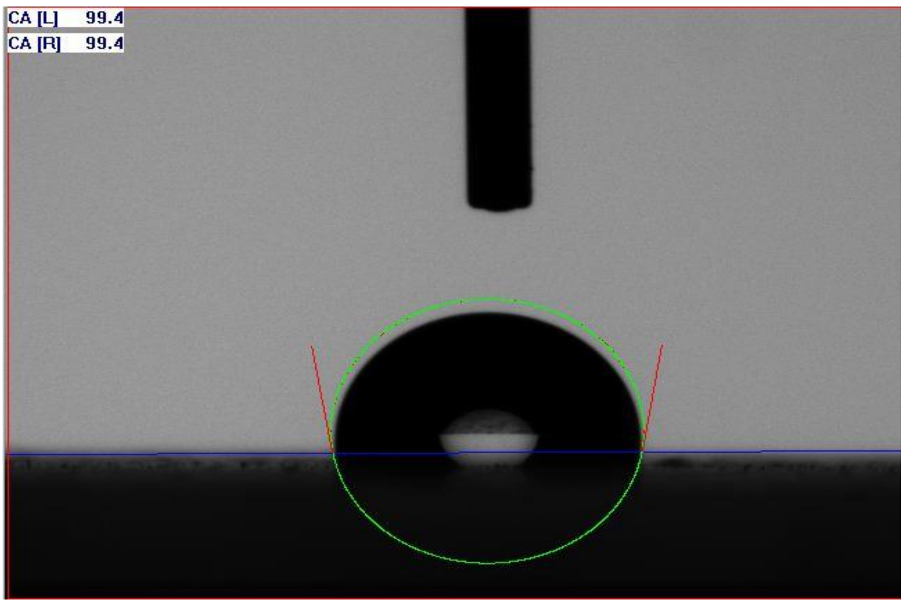

Figure 4-9: Contact angle on a glass slide kept in polluted conditions

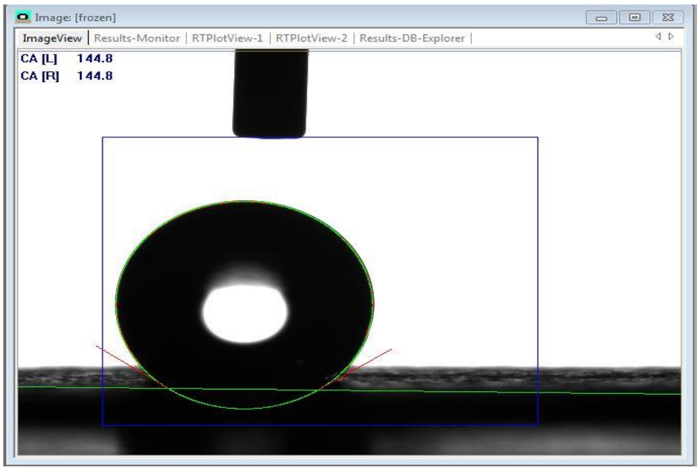

Figure 4-10: Contact angle of a nano powder coated glass surface.

Mimicking Super hydrophobic surface

The above Figure 4.10 indicate that the coated insulator surface has a static contact angle of water droplet at 144.8^{o} ±10% at a sliding angle less than 1.4^{0}

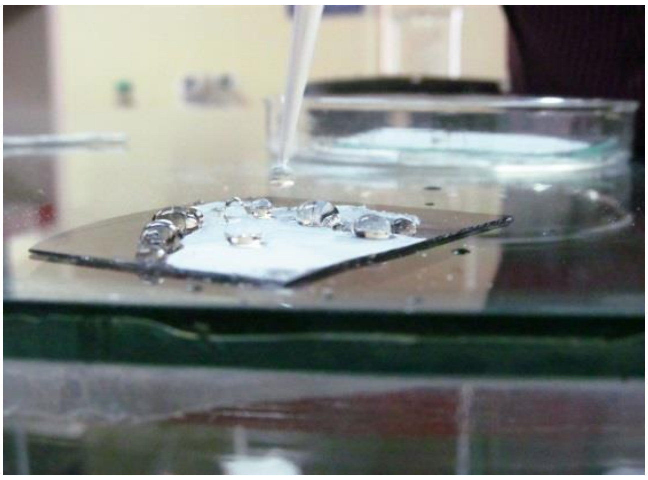

Figure 4-11: Water droplet on a nano powder coated silicon water

The water droplet on the superhydrophobic coated surface as see in Figure 4.11 repels the droplet since the surface is made rough and the water droplet is in between air pockets which could repel the water droplet to repel with low surface area contact angle and very low sliding angle. The water droplet cannot stay on the surface and bounces like a rubber ball and slides the surface due to the repelling action by the water droplets. The glass slide has an angle of 99^{o} when exposed to dusty conditions, show that it lost its hydrophobic property and the dust sticks to the surface. This figure of dusty layer contact angle reveals that the dust can make the hydrophobic surface into a hydrophilic surface and same presumptions can be assumed on the porcelain insulator which has a hydrophobic surface during installation and leads to hydrophilic surface.

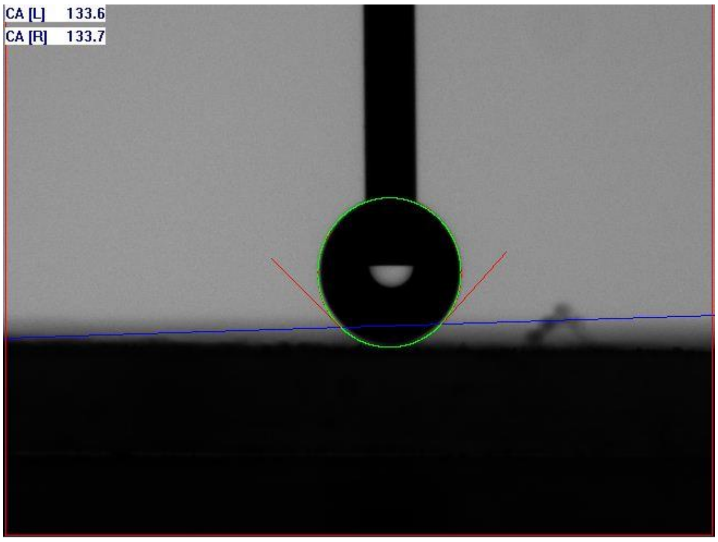

Figure 4-12: Nano coated glass slide when exposed to polluted conditions and water droplet contact angle.

After applying two layers of coating on the surface of the insulator again the contact angle was increased and reaches a mark of over 155^{o} which is more hydrophobic than previous one as shown in the Figure 4.13

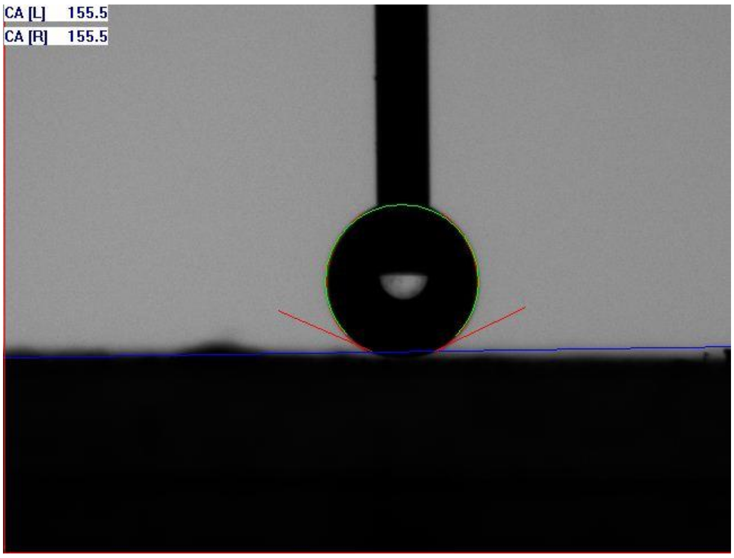

Figure 4-13: Water drop on a porcelain insulator with single nano coated slant surface kept at polluted conditions

In the similar fashion when three layers of coating was done on the insulator the contact angle was increased further and reached to approximately 156^{o}.

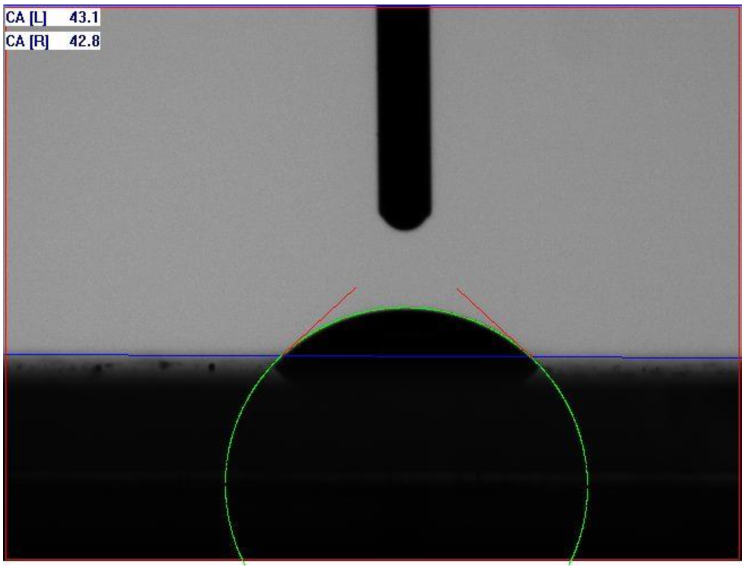

Figure 4-14: water drop on a porcelain insulator without coating surface kept at polluted conditions

The nature of the superhydrophobic surface on a porcelain insulator was also investigated in the laboratory of University of Petroleum and Energy Studies. Two insulators with superhydrophobic coating were kept in polluted construction site to watch different property. Result were examined after a certain period of time (six months), uncoated insulator was fully covered with dust but the insulator with coating was having no effect of dust on it after examining closely after six months duration. Water drop roll on this surface and it prepared coating also has an anti-moisture performance. Superhydrophobic surface on a porcelain insulator could be a best solution to eliminate the dust and flashover problem in power engineering.

Figure 4-15: Coated and uncoated porcelain insulator kept in atmospheric conditions for dusty layer formation

4.4.6 AFM Analysis

Atomic Force Microscope analyses the topographical analysis [77] of the surfaces. AFM image of the nano sample for both before and after coating is shown in Figure 4.16 surface morphology and roughness of the coatings was studied using AFM (model Nanosurf Naio AFM atomic force microscope system) with a Si tip (with a radius 7 nm, resonance frequency 299 kHz) in the non-contact mode under ambient conditions. Three Dimensional Atomic Force Microscopy (3D-AFM) image on surface coating (scan area 5x5 μm^2). AFM analysis revealed that thin film of layer is highly porous it is showed the superhydrophobicity of the advanced sol-gel SiO_2 nanoparticles coated on silicon sheet and ceramic material.

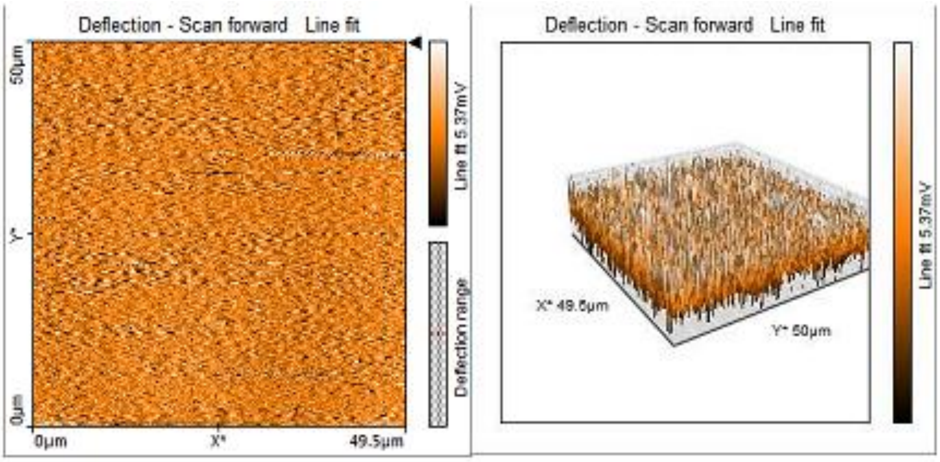

Figure 4-16: AFM of uncoated insulator sample

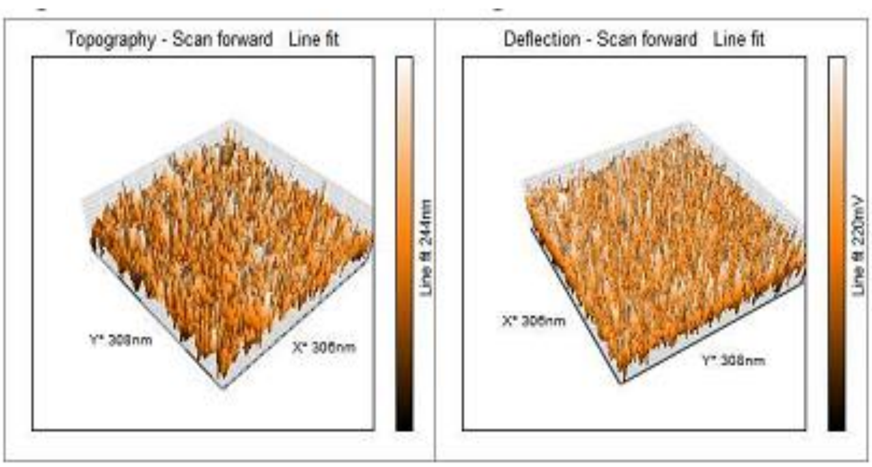

Figure 4-17: AFM of silicon powder coated porcelian insulator sample

4.5 Summary

Superhydrophobic coatings with sol-gel SiO_2 silica powder of about contact angle of more than 150^o with good adhesion on the glass or ceramic substrates were produced by a simple single step process and economical layer sol-gel method. Nano sized, highly dispersed spherical silica particles were produced using this method. The particles were separated to various sizes by ultra sonification and used in appropriate ratio to obtain superhydrophobicity. The acidic silica gel used as good adhesive by forming cross-links with the glass and ceramic substrate and silica particles. During the samples are used for testing one issue was considered that the powder on the insulator surface is not so sticky and it has to be taken utmost care during handling the insulator and other glass slides. The insulator was kept in different polluted industrial area where the dust formation on the insulator is negligible when compared with uncoated porcelain insulator. The dust layer formed on the insulator after duration of six months indicated very less dust formation on the surface because of the superhydrophobic nature on the coated insulator.

CHAPTER 5

OBSERVATIONS OF NANO COATED PORCELAIN INSULATORS ON HOT LINES

5.1 Introduction

One of the fastest growing fields in science and technology is nano technology [40]. Research focused on enhancing the insulating materials in power engineering. With the new technological changes in nano technology, the research emerged on the properties of ceramic insulating materials. It could be different to understand nanotechnology with electrical power engineering but the emergence of this technology by using nano materials has created a great difference and enhanced the life of the materials used in power systems.

The problem which is frequently occurred by power engineers on insulators are puncture or breakdown because of dust collection and leading to flashover of insulators. The industrial pollution areas and sea shore with salt fog is accumulated on the surface of these porcelain insulators which are holding the conductors on poles or towers. As the days go by, the insulators collect a thick layer with leads to current leakages and thereby flashover occurs [78]. To overcome these problems nano technology has a promising answer with a better applicable solution with we have proven it that we can use these initiations for solving the problem faces by power engineers and utility distributed companies and increasing their economy and make the system more efficient and reliable [79, 67].

5.2 Materials and experimental Setup

As discussed in previous chapters about the preparation of sol-gel method, the precursor is used and coated on high voltage ceramic porcelain insulators. The insulators were sponsored for this research activity by Power Transmission Corporation of Uttarakhand Limited. Six insulators with 70 kN were sponsored manufactured by THDL (Tehri Distribution Limited), India. All the insulators were of same type and the Chief Engineer of PTCUL has consented and agreed to use the coated insulator to connect it on live lines of 33 kV line. Three suspended insulators were hung at the dead end pole at the 33 kV line near substation at busy polluted traffic area at Dehradun. The insulators were selected and situated at such a areas so that maximum amount of dust formation is accumulated on the insulators. As seen in the Figure 5.3, coated insulator and uncoated insulators were hung on the same pole with three insulators on each side and tested it in real time conditions for six months period so that short time real time analyzation can be done. Another few of same 70 kN with same dimension (post insulators) insulators were also used for analyzation of dust formation at different pollution and non-pollution level areas but these insulators were used to find out only the dust formation.

5.3 Sample Preparation

Before coating on insulators, a mixed ratio of 1 drop of PDTS in 50 ml ethanol was added drop by drop and spray coating was done on the fine piece of porcelain insulator tiny sample (S_1), silicon wafer (S_2) and 70 kN post insulator bushing (S_3). In vacuum furnace the insulator was dried for 55^o at around 30 minutes, after that the same baking was done at 60^o at around one hour. At room temperature these samples are kept in observation and tested. Microscopic slides were taken by the author and coated is done in the same way as done on insulators to characterize on nano instruments to test the sample to understand and confirm the superhydrophobic property.

The coated and uncoated porcelain post insulator bushing was kept for observation in air polluted zones. After a six months period, the insulators are brought to laboratory and analysed for accumulation of dust formation on both the insulators with different polluted and climatic conditions and electrical properties are also tested by sending high voltages to the insulators.

5.4 Real Time Observations and Discussions

5.4.1 Insulator Specification

The post insulator bushing strings shall consist of standard discs for use in three phases, 50 Hz 33/11 kV substation and to hold hot electricity conductors on poles, these post insulators are kept in a moderately polluted atmosphere. The discs consisting of ball, cap and socket is dipped in zinc solution which has a purity of 99.95% the hot ferrous galvanized parts are dipped in this solution as per the latest edition IS:2629 [80]. The standards which are maintained by all the porcelain manufacturing companies given by Indian Standards are given in below Table 5.1.

S.No	Type of String	Size (mm)	Creepage Distance(mm)	Mechanical Strength (kN)
1	Single suspension	145	430	45
2	Double suspension	255	430	70

Table 5-1 Post porcelain bushing standards

Figure 5-1: Uncoated insulator post insulator bushing of 70kN from Tehri Distribution Power Limited, Power Transmission Corporation of Uttarakhand Limited.

5.4.2 Experimental Setup

<u>Location – 1</u>

This area is covered with trees and the level of the dust is low, at this place the setup is created in such a way that on the angular two insulators with coated and uncoated are hanged on either side and low voltage of 220V is passed through it. One insulator is connected with conductor connected to it. This set up is kept for same duration and the surface is checked at regular intervals and observed for any deposition of dust on both the insulators. The insulator was kept on iron angular to be first tested in the laboratory conditions (see Figure 5.2) for mechanical tests and after 30 days it was taken to the polluted location. This type of set up is kept to analyse the insulator performance for dust formation on both the surfaces of coated and uncoated insulators with fine dust. Duration of six months was kept on insulators to understand the durability of the coating on insulators, its performance to dust formation and its other changes when compared with both coated and uncoated insulators.

Figure 5-2: Above fig indicate the set up at location -1

Location – 2

At this location moderate dust level conditions, the location of these three insulator strings of coated and uncoated insulators were kept at heavy traffic road side. These insulators are connected to live power conditions of 33kV line [81] on a dead end double pole line where coated and uncoated insulators are connected on two different electric phases as shown in Figure 5.3. This type of set up to understand the performance of the insulator in live conditions due to the nano material and variations due to the chemical composition used on the surface of both coated and uncoated insulators. When high voltages of 33 kV is given to these insulators, the insulators behaviour due to the heat formation, the corona effect and the insulator property of the nano coated insulator is needed for analyzation and real time performance for the power engineers to use them directly on the field. This field test is done with respect to a uncoated normal porcelain insulator with same specifications so that at same dusty location and same voltages on both the insulators we want to consolidate and show the variations in both the nano coated and uncoated insulators and use this application in real time scenarios and help the power utility companies and power engineers.

Figure 5-3: Coated and uncoated post insulator was kept at dead end electric pole of 33kV hot line.

Location – 3

This location and setup of coated and uncoated insulators are kept at a commercial building construction side where the dust level is moderately high. The setup is kept on at a place where the dust can be accumulated on the insulators at the construction site. These insulators are just placed normally side by side with coated and uncoated insulator to know the dust formation and amount of dust collection. We also kept in our mind to find out the amount of dust present on these coated and uncoated insulators without the water falling on these insulators, so that to let us know the amount of dust where the wind cold clean the dust on these surfaces. In these both the insulators, no voltage is applied but these insulator's are kept in open so that the normal breeze could flow on these insulator surfaces and amount of dust it can take away from these surfaces because of normal wind pressure without rain fall on these surfaces.

Figure 5-4: Coated and uncoated insulator is kept for observation in a commercial building construction polluted area.

5.4.3 Observations and Discussions

Location – 1

After a period of six months period, the two insulators kept on an angular pole in outdoor laboratory conditions were taken, and after clear examination in bright light, a very fine dust layer was found on the uncoated insulator and in this location rains have cleared the dust formation on the coated insulator. There was no dust on the coated insulator and the coated insulator was looking like a new coated insulator with negligible amount of dust formation on the surface of nano coated surface. There was no change in the colour or thickness of the nano coating on the insulators. The insulator is free from visual defects and there were no voids and cracks on the coated insulator. Insulating property was maintained on this nano coated insulator and it could withstand the electrical potential of 220 volts and no changes were seen on the coated insulator as shown in the Figure 5.5. The uncoated insulator was having a layer of dust which was hard to remove from the surface.

Figure 5-5: Uncoated post insulator with formation of dust layer.

Figure 5-6: Coated insulator without any dust particle

<u>Location – 2</u>

The output at this location was very crucial since it was tested in live conditions. The insulator is found with a thick dusty layer on the uncoated insulator. The coated insulator is clear from dust it could withstand the high voltage of 33 kV for six months. The same insulator string was used for high voltage testing by testing agency for applying a voltage of power frequency is applied with a gradual increasing voltage upto 33000 volts. Five times both the insulators are applied with an impulse voltage of 1/50 milliseconds of amplitude impulse wave to find out the withstand properties of the insulator properties. After the tests both the coated and uncoated insulators were observed carefully, the nano coated insulator could withstand the impulse and uncoated insulator had a fine crack which was seen in Figure.5.7 when porosity test was done on it. The insulator surface can lead to puncture of insulator and the insulating property can be lost in due course of time. By this test we can observe and analyse that the nano coated insulator can be used in real time applications by the power engineers and utility company as it could pass both real time voltage and impulse voltage test. Insulator dimensions or characteristics were not at all effected as discussed in previous chapters the coating material has an insulating property and the size of the nano powder on the surface is in the order of nano size. By this the engineers can use the insulators directly on live lines and the reliability and problem raised due to power failures can be reduced and the economy of the power utility and distribution companies can be improved.

Bending test was performed on one of the coated insulator and rain test and wet test was also performed on one set of coated and uncoated insulators used at this site by the testing agency. The nano coated insulator could withstand all the testing's but since a dust was conducting on the surface of the uncoated insulator, puncture occurred on the insulator as show in the Figure 5.8. This concludes that the dusty particles can puncture at any time of dry of wet (rain) conditions and leading to failure of insulator and breakdown in the power utility.

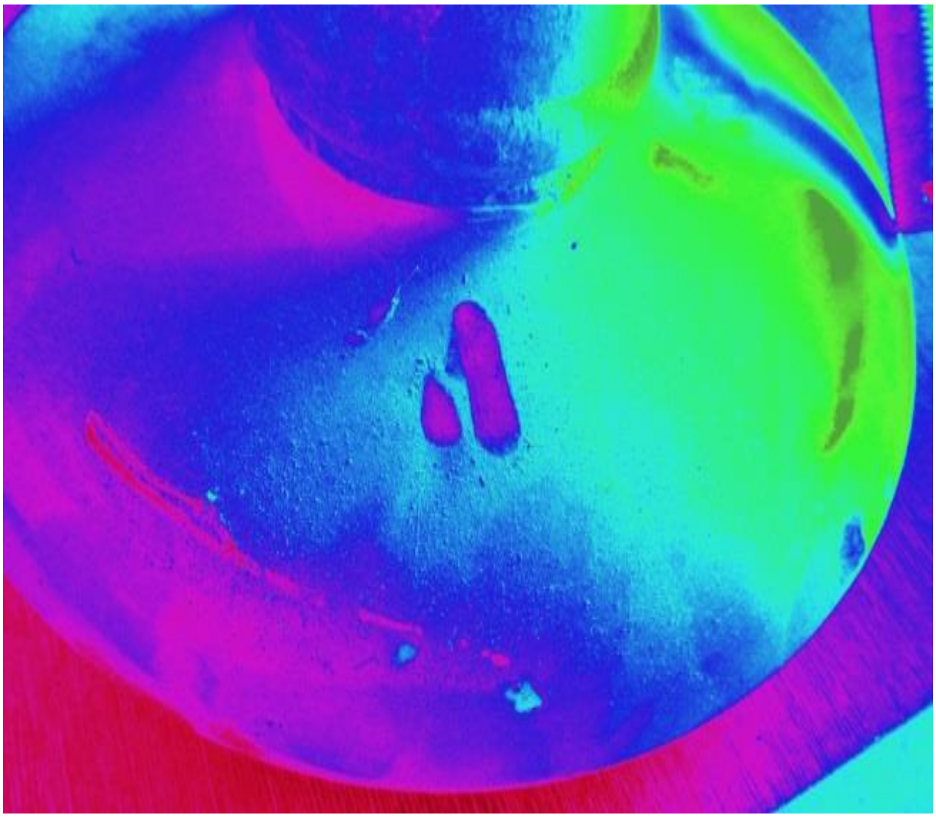

Figure 5-7: Insulator surface indicating a fine crack in presence of ultra violet light.

Location – 3

At this location the insulator set was covered with huge amount of dust as it was in a construction site with dust and dirt polluted environment. The uncoated insulator at this location was covered with various amount of sand, dust pollution which got deposited on the surface of the insulator with was in ash colour as seen in the Figure 5.9, the uncoated post insulator was puncture during the rain test done in the testing laboratory, water was sprayed with a resistance of 9000 ohm-cm at an angle of 45 degrees with a volume of water precipitation of 0.12 in per minute. Under these conditions the coated insulator could withstand the rain test and no dust formation or crack was observed. The uncoated insulator was punctured in the process of testing which reveals that the insulator could not satisfy the electrical property due to heavy dust accumulation on the insulator. Figure 5.9 indicates the accumulation of dust on both the insulator surface before it was taken to electrical testing laboratory.

Figure 5-8: Broken porcelain insulator during rain test

Figure 5-9: (a) uncoated insulator with deposition of mist and dust still on the surface.
(b) nano coated insulator with all the deposition of mist and dust roll off from the surface of the insulator.

5.5 Summary

Experiments at different locations and observations on the nano coated and uncoated porcelain insulators can clearly show that superhydrophobic coatings with sol-gel SiO_2 silica powder above 150^o with good adhesion on the glass or ceramic substrates. Nano sized, highly dispersed spherical silica particles were produced using this method. Spray coating method was used to coat the insulator which is a most economical and easily used process. The insulator was kept in different polluted industrial area where the dust formation on the insulator is negligible when compared with uncoated porcelain insulator.

The dust layer formed on the insulator after duration of six months was very less because of the superhydrophobic nature on the coated insulator. If this type of post insulators are coated with superhydrophobic powdered coating as per the observations and report of insulator testing agency, the breakdown of power/outages due to puncture of insulators can be reduced and improve the age of the insulators on overhead lines in all conditions. During the samples are used for testing one issue was considered that is the powder on the insulator surface is not so sticky and it has to be taken utmost care during handling the insulator and other glass slides.

To overcome the adhesive property further research has to be made on making it more adhesive with this nano composite and it is recommended that the insulator are to be coated on the poles with different other measures and appliances. Further research and study can be done on the above two issues where the insulators puncture problems can be reduced. The economic loss due to electric insulators breakdown can be neglected.

CHAPTER 6

HIGH VOLTAGE ELECTRICAL TESTING RESULTS

6.1 Introduction

An electrical porcelain insulator plays an eminent role in electrical power system. As the insulators have high resistance path so it acts as no insulation between conductor and supporting tower or pole. All the supporting towers used in transmission and distribution lines which are carrying current carrying conductors used to transfer energy from one place to other uses insulator as isolation between these conductors and supporting systems. These insulators prevent the current to pass through these supporting towers to ground or any other paths so that the system is more reliable and safe to transfer the electrical energy to transfer from generating stations to loads centers efficiently.

6.2 Causes and failures of electrical insulators

Flashover on porcelain insulators is due to the abnormal current passing through it from line to earth. Due to high currents present in the flashover, heat is produced on the insulator surroundings, leading to uneven temperature and leading the insulators to puncture.

The insulators should possess important properties for optimum utilization in electrical journey.

1. It should be mechanically rigid to carry conductor weight and tension of conductors.

2. Insulators should withstand high voltage stresses and dielectric strength.

3. Insulators should prevent leakages through it to earth or supporting systems.

4. It should not have impurities and free from conduction materials.

5. Insulators must not effected by change in the temperature of atmospheric conditions.

6.3 Types of Insulators

High voltage power line uses porcelain or glass insulators to carry or hold the conductors. As shown in the figure 6.1 the ball and socket post porcelain is used by the author for applying the nano coating on the insulator surface. Insulation between the iron cap and steel pin is separated by porcelain skirt filled with imbedded sand. The specially made Portland cement joins the cup and pin.

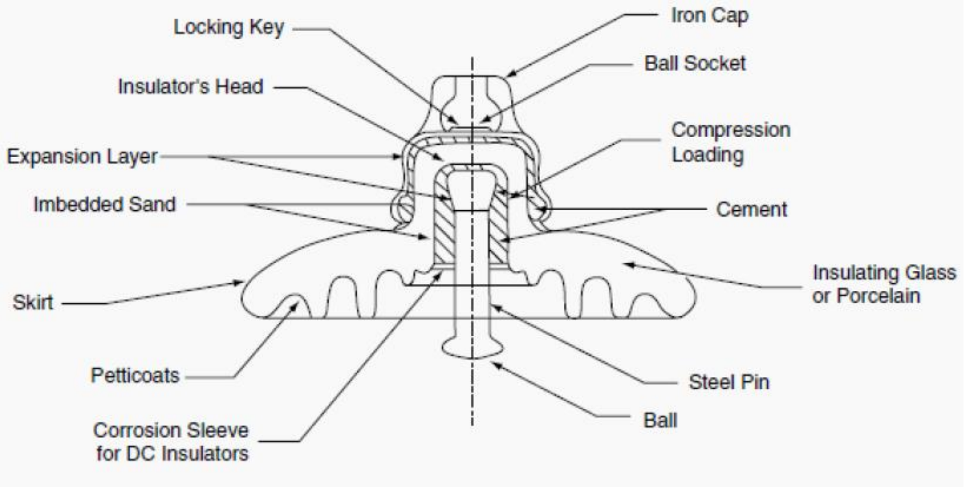

Figure 6-1: 11 kV Post Porcelain Insulator **Courtesy: electrical engineering portal**

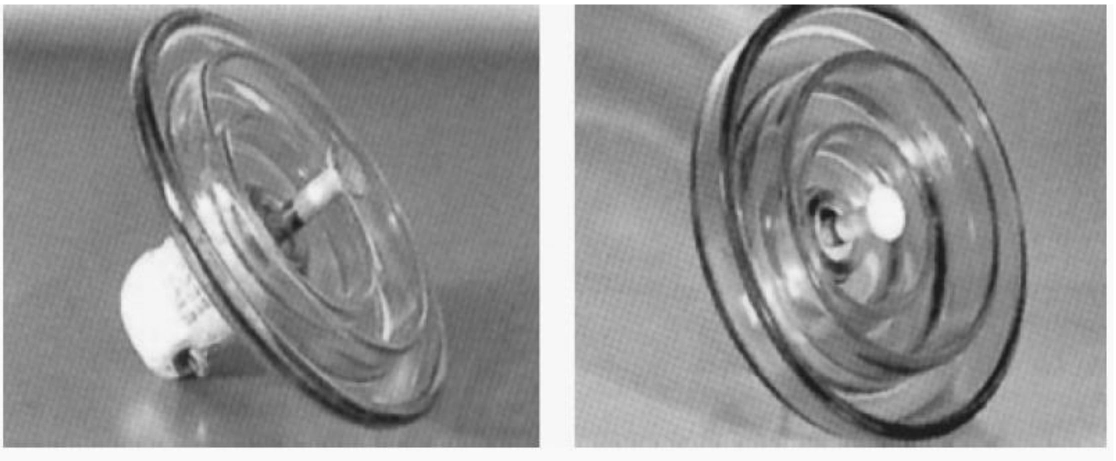

Figure 6-2: Glass Disc Insulator **picture courtesy**[82]

Porcelain insulators are kept on cross arms and in suspension string insulators for holding the conductors firmly and acting as insulation between the conduction and the supporting towers or poles. At some places pin type, shackle type insulators are used as per the applications, all these insulators also plays the same role of insulation in power industry.

6.4 Testing and Analysis on porcelain insulators

Coated Insulator Tests by testing agency

The post insulator bushing was subjected to various mechanical and electrical tests done by M/s: Oblum Electrical Industries according to document released by Bureau of Indian Standards [83] as enclosed in the *Appendix – 'A'*. The tests performed where Routine testing and Acceptance Testing. The discussed before in chapter 5.2, six post type insulators used by the author in the research is sponsored by Power Transmission Corporation of Uttarakhand Limited, Govt. of Uttarakhand by the Chief Engineer after confirming the results in the laboratory conditions.

6.4.1 ROUTINE TESTING

6.4.1.1 Visual Inspection

This test is done to check the shape and dimensions. Visual Inspection test provides data on any external damages on the disc insulation which might enhance or reduce the properties of the coating applied. The result (result certificate is attached in *Appendix-'B'*) from the visual inspection test conducted by M/s: Oblum Electrical Industries, with reference standards IS: 731-1971 stated that the disc insulators are free from visual defects. Since the powder is in nano size, the shape of the insulator is according to standards which could not vary the dimensions of the insulator and are within the acceptance norms.

6.4.1.2 Dimensional check-up

Dimensional check-up, a routine test are performed on the insulators to certify that the dimensions of the insulators provided are within the standards IEC 305 (see Appendix 'A' topic 10.5). These dimension tests are mainly done to eliminate the minimum creepage distance. The Standard dimensions for 70 kV disc insulators are 280mm and maximum tolerance is 293mm according to drawings of IEC-305. The result provided by the M/s: Oblum Electrical Industries provides a report that 2 samples were fired and the dimensions obtained was 286.7mm which are within the tolerance limits.

6.4.1.3 Electrical Test

Flash over test: The Flashover test conducted on all three types dry, wet and frequency. Electrodes are connected in dry flash over test and the power frequency applied is gradually increased and in the case of Wet Flashover test. During the test spraying of water was done at 45^o when the water precipitation was around 5.08mm per minute, the resistance of water sprayed is kept between 9 kΩ to 11 kΩ. In both the test insulators must withstand the voltage for one minute to 30 seconds without being punctured. The reference standards used for these tests are IS: 3121-1971 and IEC-383 [80]. The results provided by Oblum Ins has certified that the insulators with nano coating could withstand upto 35 kV.

6.4.1.4 Ultrasonic test

Ultrasonic test is used to detect the cracks and voids in insulator. The reference standard is as per FD-201B and the results from the Oblum Ins. are that there are no cracks in the coating as well as insulators. This test was done in dark room under infrared light conditions.

6.4.1.5 Bending load test

For one minute, 2.5 times of maximum working strength is applied on the insulator. Without any breakage of minor crack on the insulator, the insulator for one minute should withstand the mechanical stress. The reference standards are PS: OB-113B which specifies that the insulator can withstand the bending load on the surface. Since there is no much change in the shape or dimension of the insulator, the insulator was under the acceptance norms.

The results from Oblum Ins. displayed that the insulators with the coating withstood 112 Kg.m which clearly accepts the insulator is not defoliated because of the chemical action of coating done on the normal insulator.

6.4.2 ACCEPTANCE TEST

6.4.2.1 Temperature Cycle Test

Insulators are kept at a variation of cooling and heating at a temperature for one hour. Initially these insulators are cooled at 70^{o} C and next hour these are heated at 70^{o} C. This cycle is repeated for three times. After completion of these three temperature cycles, it is dried and the glazing of insulator is thoroughly observed. At the end of these tests there should not be any damage or deterioration in the glaze of the insulators. The reference standards for these tests are IS: 731-1971 As per IEC 233. In Oblum Ins. both the disc insulators with the coating had been fired and the results were that the insulators cleared the test without spalling.

6.4.2.2 Porosity Test

In Porosity test the insulators is broken into pieces and are immersed in 1% alcohol solution of fuchsine dye under pressure of about 140.7g/cm^2 for 24hrs. Then the sample is removed and tested. A deep penetration of the dye is seen when there is a slight porosity present on the surface. The reference standards used are IS: 731-1971 and IEC 815. Both the coated insulators are fired with condition of nil porosity at 475Kgs/Cm^2 for 4 hours. The results from Oblum Ins, stated that there is NIL porosity in the sample.

6.4.2.3 Burst pressure test

In burst pressure test the insulator is subjected to continuously raised pressure up to the test pressure which is minimum of 25Kgs/Cm^2. The reference standards for the test are PS: OB-113B. In Oblum Ins, both the insulators with the coating are fired with continuous pressure and the results obtained are that the insulators withstood 25Kgs/cm^2 without insulator breakage. These insulators could withstand the pressure.

6.4.2.4 Bending Load test:

In bending load test the sample is subjected to a load of 20% in excess of the specified maximum working load and the insulators have to withstand it for 1 minute. The substrate is kept between two pin like structures and a load is applied on the substrate. These are done according to the standard instruments. The reference standards are PS: OB-113B.

Summary

The above tests are done at R & D, M/s: Oblum Electrical Industries manufacturing unit Hyderabad. By the above results and certification given by the testing agency (Appendix ‘A’), we can conclude that the insulator could withstand all the preliminary tests which can be done on the insulators for giving the author a confidence to carry forward and get the data and observations on live hot power lines. After discussions with the chief engineer PTCUL, the insulators are kept for observation on 11kV line for one year to know the changes in the insulators parameters when compared with uncoated insulator and a new or unused porcelain insulator of same specifications. These above discussed test are useful for commercialization of the research outcome

CONCLUSION

This thesis work presents a new advancement in the field of power system where the continuity of power supply and economic losses can be reduced by using the concept of superhydrophobic surface from nano technological sciences and applying in the field of electrical energy. The main issue in the insulators is dust formation on the surface which leads to puncture of insulators. The author used the concept of superhydrophobic surface and nano sized coating was done on insulator surface by using spray method in laboratory by simple sol-gel method.

The surface modification by using nano-sized particles on the insulator surface could not affect the insulator properties required for electrical insulation and specifically the coated insulators could withstand all the electrical tests done by the testing agency. The nanopowder was structurally stable, eco-friendly, non-hazardous and could show the insulating property.

Nano powder coated insulators are tested at different polluted conditions to know the durability of the powder and effect of dust at different windy conditions and amount of dust collection on the coated surface. The unique nature of the superhydrophobicity on the coated insulators could show a good result of repelling the water and making the coated surface dust free, hence the insulators were clean even at polluted atmospheres and this reduces the puncture of insulators due to dust and contaminations.

Future Work

This research work involved different disciplines like electrical engineering, physics, chemistry and material science; it is wide open for researchers to continue the research work further on

- Commercialization, economic viability for utility companies to overcome the power loss due to insulator puncture and
- Durability of coating for long duration without
- Designing to coat the existing insulators on live poles, towers

Series of experiments can carried out on the coated methods on existing lines instead of increasing the waste disposal and replacing the insulators.

REFERENCES

[1] P. K. S.R. Sivarasu E. Chandira Sekaran, “Development of renewable energy based microgrid project implementations for residential consumers in India: Scope, challenges and possibilities,” *Renew. Sustain. Energy Rev.*, vol. 50, pp. 256 – 269, 2015.

[2] A.- Salam, H. A. Hamza, N. M. K. Abdelgawad, and B. A. Arafa, “Effect of desert environmental conditions on the flashover voltage of insulators,” *Energy Convers. Manag.*, 2002.

[3] B. S. Reddy, A. R. Verma, and B. S. Naik, “Performance Analysis of 1200kV Ceramic Disc Insulator String under Normal and Faulted Conditions,” *Energy Procedia*, 2015.

[4] M.-Y. Tsai, C.-C. Hsu, P.-H. Chen, C.-S. Lin, and A. Chen, “Surface modification on a glass surface with a combination technique of solgel and air brushing processes,” *Appl. Surf. Sci.*, vol. 257, pp. 8640–8646, 2011.

[5] S. Subhash Latthe, “Recent Progress in Preparation of Superhydrophobic Surfaces: A Review,” *J. Surf. Eng. Mater. Adv. Technol.*, vol. 02, no. 02, pp. 76–94, 2012.

[6] R. Liao, Z. Zuo, C. Guo, A. Zhuang, Y. Yuan, X. Zhao, and Y. Zhang, “Ice accretion on superhydrophobic insulators under freezing condition,” *Cold Reg. Sci. Technol.*, vol. 112, pp. 87–94, 2015.

[7] L. Mats, A. Bramwell, J. Dupont, G. Liu, and R. Oleschuk, “Electrowetting on superhydrophobic natural (Colocasia) and synthetic surfaces based upon fluorinated silica nanoparticles,” *MEE*, vol. 148, pp. 91–97, 2015.

[8] R. V Lakshmi, T. Bharathidasan, and B. J. Basu, “Superhydrophobic sol gel nanocomposite coatings with enhanced hardness,” *Appl. Surf. Sci.*, vol. 257, pp. 10421–10426, 2011.

[9] S. S. Latthe, S. L. Dhere, C. Kappenstein, H. Imai, V. Ganesan, A. V. Rao, P. B. Wagh, and S. C. Gupta, “Sliding behavior of water drops on sol–gel derived hydrophobic silica films,” *Appl. Surf. Sci.*, vol. 256, pp. 3259 – 3264, 2010.

[10] B. J. Basu, V. D. Kumar, and C. Anandan, “Surface studies on superhydrophobic and oleophobic polydimethylsiloxane–silica nanocomposite coating system,” *Appl. Surf. Sci.*, vol. 261, pp. 807–814, 2012.

[11] S. Liu, X. Liu, S. S. Latthe, L. Gao, S. An, S. S. Yoon, B. Liu, and R. Xing, “Self-cleaning transparent superhydrophobic coatings through simple sol–gel processing of fluoroalkylsilane,” *Appl. Surf. Sci.*, 2015.

[12] E. Ozel, G. Unluturk, and S. Turan, “Production of brown pigments for porcelain insulator applications,” *J. Eur. Ceram. Soc.*, vol. 26, pp. 735–740, 2006.

[13] R. A. Islam, Y. C. Chan, and M. F. Islam, “Structure–property relationship in high-tension ceramic insulator fired at high temperature,” *Mater. Sci. Eng. B*, vol. 106, no. 2, pp. 132–140, 2004.

[14] Y. Zhou, H. Hu, X. Xu, J. Cui, Y. Yuan, Z. Li, Y. Chen, D. Yu, Q. Nie, X. Liang, and Z. Guan, “High-risk region of bird streamer flashover in high-voltage transmission lines,” *J. Electrostat.*, vol. 67, pp. 311–315, 2009.

[15] A. Pagnano, M. Höpf, and R. Teti, “A Roadmap for Automated Power Line Inspection. Maintenance and Repair,” *Procedia CIRP*, vol. 12, pp. 234–239, 2013.

[16] M. T. Gençoğlu and M. Cebeci, “The pollution flashover on high voltage insulators,” *Electr. Power Syst. Res.*, vol. 78, no. 11, pp. 1914–1921, 2008.

[17] Y.-L. Zhang, H. Xia, E. Kim, and H.-B. Sun, “Recent developments in superhydrophobic surfaces with unique structural and functional properties,” *Soft Matter*, vol. 8, no. 44, p. 11217, 2012.

[18] M. P. Trivedi, “Environmental factors affecting wind energy generation in western coastal region of India,” *Renew. Energy*, 1999.

[19] P. Benetti, F. Pelogia, L. F. Valandro, M. A. Bottino, and A. Della Bona, “The effect of porcelain thickness and surface liner application on the fracture behavior of a ceramic system,” *Dent. Mater.*, vol. 27, pp. 948–953, 2011.

[20] N. Montoya, F. J. Serrano, M. M. Reventós, J. M. Amigo, and J. Alarcón, “Effect of TiO 2 on the mullite formation and mechanical properties of alumina porcelain,” *J. Eur. Ceram. Soc.*, vol. 30, pp. 839–846, 2010.

[21] V. A. Mantovani, C. S. Franco, S. D. Mancini, and H. L. Haseagawa, “Comparison of polymers and ceramics in new and discarded electrical insulators : reuse and recycling possibilities,” *Rev. Mater.*, vol. 18, no. 4, pp. 1549–1562, 2013.

[22] R. D. Mcafee, R. D. Heaton, J. M. King, and A. U. Falster, “A study of biological contaminants on high voltage porcelain insulators, I,” *Electr. Power Syst. Res.*, vol. 42, no. 35, 1997.

[23] S. Bribiesca, R. Equihua, and L. Villasenä Or, “Photoacoustic Thermal Characterization of Electrical Porcelains: E€ ect of Alumina Additions on Thermal Di€ usivity and Elastic Constants.”

[24] H.-S. Jang and S.-Y. So, “The properties of cement-based mortar using different particle size of grinding waste insulator powder,” *J. Build. Eng.*, vol. 3, pp. 48–57, 2015.

[25] J. Koustellis, C. Halevidis, A. Polykrati, and P. Bourkas, “Analysis of a fatal electrical injury due to improper switch operation,” *Saf. Sci.*, vol. 53, pp. 226–232, 2013.

[26] B. Porkar and M. Farzaneh, “New mathematical formulations for calculating residual resistance in a static arc model of ice-covered insulators,” *Cold Reg. Sci. Technol.*, vol. 117, pp. 34–42, 2015.

[27] V. T. Kontargyri, a. a. Gialketsi, G. J. Tsekouras, I. F. Gonos, and I. a. Stathopulos, “Design of an artificial neural network for the estimation of the flashover voltage on insulators,” *Electr. Power Syst. Res.*, vol. 77, no. 12, pp. 1532–1540, 2007.

[28] X. Li, B. Yang, Y. Zhang, G. Gu, M. Li, and L. Mao, “A study on superhydrophobic coating in anti-icing of glass/porcelain insulator,” *J. Sol-Gel Sci. Technol.*, vol. 69, no. 2, pp. 441–447, 2013.

[29] X.-F. Wen, K. Wang, P.-H. Pi, J.-X. Yang, Z.-Q. Cai, L.-J. Zhang, Y. Qian, Z.-R. Yang, D.-F. Zheng, and J. Cheng, “Organic inorganic hybrid superhydrophobic surfaces using methyltriethoxysilane and tetraethoxysilane sol gel derived materials in emulsion,” *Appl. Surf. Sci.*, vol. 258, pp. 991–998, 2011.

[30] S. S. Latthe, P. Sudhagar, C. Ravidhas, a. Jennifer Christy, D. David Kirubakaran, R. Venkatesh, A. Devadoss, C. Terashima, K. Nakata, and A. Fujishima, “Self-cleaning and superhydrophobic CuO coating by jet-nebulizer spray pyrolysis technique,” *CrystEngComm*, vol. 17, no. 13, pp. 2624–2628, 2015.

[31] D.-Y. Kim, J.-G. Lee, B. N. Joshi, S. S. Latthe, S. S. Al-Deyab, and S. S. Yoon, “Self-cleaning superhydrophobic films by supersonic-spraying polytetrafluoroethylene–titania nanoparticles,” *J. Mater. Chem. A*, vol. 3, no. 7, pp. 3975–3983, 2015.

[32] L. Yao and J. He, “Recent progress in antireflection and self-cleaning technology – From surface engineering to functional surfaces,” *Prog. Mater. Sci.*, vol. 61, pp. 94–143, 2014.

[33] E. Bormashenko, “Progress in understanding wetting transitions on rough surfaces,” *Adv. Colloid Interface Sci.*, vol. 222, pp. 92–103, 2015.

[34] S. S. Latthe, H. Imai, V. Ganesan, and A. V. Rao, “Superhydrophobic silica films by sol–gel co-precursor method,” *Appl. Surf. Sci.*, vol. 256, pp. 217–222, 2009.

[35] S. Wang, C. Liu, G. Liu, M. Zhang, J. Li, and C. Wang, “Fabrication of superhydrophobic wood surface by a solâ€“gel process,” *Appl. Surf. Sci.*, vol. 258, pp. 806–810, 2011.

[36] N. J. Shirtcliffe, G. McHale, S. Atherton, and M. I. Newton, “An introduction to superhydrophobicity,” *Adv. Colloid Interface Sci.*, vol. 161, no. 1–2, pp. 124–138, 2010.

[37] S. a Mahadik, P. D. Fernando, N. D. Hegade, P. B. Wagh, and S. C. Gupta, “Durability and

restoring of superhydrophobic properties in silica-based coatings.," *J. Colloid Interface Sci.*, vol. 405, pp. 262–8, 2013.

[38] M. Ferrari and A. Benedetti, "Superhydrophobic surfaces for applications in seawater," *Adv. Colloid Interface Sci.*, vol. 222, pp. 291–304, 2015.

[39] F. Ferrero and M. Periolatto, "Application of fluorinated compounds to cotton fabrics via sol–gel," *Appl. Surf. Sci.*, vol. 275, pp. 201–207, 2013.

[40] V. Dave, P. Dubey, H. O. Gupta, and R. Chandra, "Nanotechnology for outdoor High voltage insulator: An experimental investigation," *Int. J. ChemTech Res.*, vol. 5, no. 2, pp. 666–670, 2013.

[41] S. A. Seyedmehdi, H. Zhang, and J. Zhu, "Superhydrophobic RTV silicone rubber insulator coatings," *Appl. Surf. Sci.*, vol. 258, no. 7, pp. 2972–2976, 2012.

[42] J. Hu, K. Xu, Y. Wu, B. Lan, X. Jiang, and L. Shu, "The freezing process of continuously sprayed water droplets on the superhydrophobic silicone acrylate resin coating surface," *Appl. Surf. Sci.*, vol. 317, pp. 534–544, 2014.

[43] Edward, "Ceramic (Porcelain and Glass) Insulators | EEP," *Electrical Engineering Portal*, 2014. [Online]. Available: http://electrical-engineering-portal.com/ceramic-porcelain-and-glass-insulators.

[44] C. Liu, F. Su, J. Liang, and P. Huang, "Facile fabrication of superhydrophobic cerium coating with micro-nano flower-like structure and excellent corrosion resistance," *Surf. Coat. Technol.*, vol. 258, pp. 580–586, 2014.

[45] Y. Qing, C. Yang, Y. Sun, Y. Zheng, X. Wang, Y. Shang, L. Wang, and C. Liu, "Facile fabrication of superhydrophobic surfaces with corrosion resistance by nanocomposite coating of TiO2 and polydimethylsiloxane," *Colloids Surfaces A Physicochem. Eng. Asp.*, 2015.

[46] R. F. S. Lenza, E. H. M. Nunes, D. C. L. Vasconcelos, and W. L. Vasconcelos, "Preparation of sol–gel silica samples modified with drying control chemical additives," *J. Non. Cryst. Solids*, 2015.

[47] H. Liu, X. Wang, and H. Ji, "Fabrication of lotus-leaf-like superhydrophobic surfaces via Ni-based nano-composite electro-brush plating," *Appl. Surf. Sci.*, vol. 288, pp. 341–348, 2014.

[48] J. I. Lim, M. J. Kang, and W.-K. Lee, "Lotus-leaf-like structured chitosan–polyvinyl pyrrolidone films as an anti-adhesion barrier," *Appl. Surf. Sci.*, vol. 320, pp. 614–619, 2014.

[49] S. Liu, S. S. Latthe, H. Yang, B. Liu, and R. Xing, "CERAMICS INTERNATIONAL Raspberry-like superhydrophobic silica coatings with self-cleaning properties," *Ceram. Int.*, vol. 41, pp. 11719–11725, 2015.

[50] D. Kumar, X. Wu, Q. Fu, J. Weng, C. Ho, P. D. Kanhere, L. Li, and Z. Chen, "Hydrophobic sol–gel coatings based on polydimethylsiloxane for self-cleaning applications," *JMADE*, vol. 86, pp. 855–862, 2015.

[51] J. Lin, H. Chen, T. Fei, C. Liu, and J. Zhang, "Highly transparent and thermally stable superhydrophobic coatings from the deposition of silica aerogels," *Appl. Surf. Sci.*, vol. 273, pp. 776–786, 2013.

[52] N. Wang, D. Xiong, M. Li, Y. Deng, Y. Shi, and K. Wang, "Superhydrophobic surface on steel substrate and its anti-icing property in condensing conditions," *Appl. Surf. Sci.*, 2015.

[53] C. J. Brinker, "u p e r h y d r o p h o b i c C Coating o a t i n g Superhydrophobic Coating."

[54] T. Darmanin, F. Dé, and R. Guittard, "Superhydrophobic and superoleophobic properties in nature," *Biochem. Pharmacol.*, vol. 18, no. 5, pp. 273–285, 2015.

[55] C. Kosak Söz, E. Yilgör, and I. Yilgör, "Influence of the average surface roughness on the formation of superhydrophobic polymer surfaces through spin-coating with hydrophobic fumed silica," *Polymer (Guildf).*, vol. 62, pp. 118–128, 2015.

[56] X. Huang, X. Wen, J. Cheng, and Z. Yang, "Sticky superhydrophobic filter paper developed by dip-coating of fluorinated waterborne epoxy emulsion," *Appl. Surf. Sci.*, vol. 258, pp. 8739–8746, 2012.

[57] K. Liu, Y. Tian, and L. Jiang, "Bio-inspired superoleophobic and smart materials: Design, fabrication, and application," *Prog. Mater. Sci.*, vol. 58, pp. 503–564, 2013.

[58] L. Cao, "Superhydrophobic Surface Design Fabrication and Application," *Engineering*, 2010.

[59] H. Wang, E. Chen, X. Jia, L. Liang, and Q. Wang, "Superhydrophobic coatings fabricated with polytetrafluoroethylene and SiO2 nanoparticles by spraying process on carbon steel surfaces," *Appl. Surf. Sci.*, 2015.

[60] R. V Lakshmi, P. Bera, C. Anandan, and B. J. Basu, "Effect of the size of silica nanoparticles on wettability and surface chemistry of sol–gel superhydrophobic and oleophobic nanocomposite coatings," *Appl. Surf. Sci.*, vol. 320, pp. 780–786, 2014.

[61] M. Ramezani, M. R. Vaezi, and A. Kazemzadeh, "Preparation of silane-functionalized silica films via two-step dip coating sol–gel and evaluation of their superhydrophobic properties," *Appl. Surf. Sci.*, vol. 317, pp. 147–153, 2014.

[62] C. Cao, Y. Feng, J. Zang, G. P. López, and X. Zhao, "Tunable lotus-leaf and rose-petal effects via graphene paper origami," *Extrem. Mech. Lett.*, vol. 4, pp. 18–25, 2015.

[63] M. A. Samaha, H. V. Tafreshi, and M. Gad-El-Hak, "Novel method to characterize superhydrophobic coatings," *J. Colloid Interface Sci.*, vol. 395, pp. 315–321, 2013.

[64] X. Jiang, "Comparison-on-ac-icing-flashover-performance-of-porcelain-glass-and-composite-insulators_2014_Cold-Regions-Science-and-Technology," *Cold Reg. Sci. Technol.*, vol. 100, pp. 1–7, 2014.

[65] A. Ibrahim, L. Nasrat, and H. Elassal, "Improvement of Electrical Performance for Porcelain Insulators Using Silicone Rubber Coating," *IJIREEICE*, vol. 2, no. 8, pp. 1884–1888, 2014.

[66] A. V. Rao, A. B. Gurav, S. S. Latthe, R. S. Vhatkar, H. Imai, C. Kappenstein, P. B. Wagh, and S. C. Gupta, "Water repellent porous silica films by sol-gel dip coating method," *J. Colloid Interface Sci.*, vol. 352, pp. 30–35, 2010.

[67] K. Bansal and R. Gupta, "Development Of Nano Structured Super Hydrophobic Coating For The Electrical Safety Of Porcelain Insulator," *Int. J. Appl. Eng. Res. ISSN*, vol. 10, no. 19, pp. 973–4562, 2015.

[68] M. Ehsani, H. Borsi, E. Gockenbach, J. Morshedian, and G. R. Bakhshandeh, "An investigation of dynamic mechanical, thermal, and electrical properties of housing materials for outdoor polymeric insulators," 2004.

[69] L. S. Nasrat, A. F. Hamed, M. A. Hamid, and S. H. Mansour, "Study the flashover voltage for outdoor polymer insulators under desert climatic conditions," *Egypt. J. Pet.*, vol. 22, pp. 1–8, 2013.

[70] G. Montoya-Tena, R. Hernández-Corona, and I. Ramírez-Vázquez, "Experiences on pollution level measurement in Mexico," *Electr. Power Syst. Res.*, vol. 76, pp. 58–66, 2005.

[71] M. T. Gencoglu and M. Uyar, "Prediction of flashover voltage of insulators using least squares support vector machines," *Expert Syst. Appl.*, vol. 36, no. 7, pp. 10789–10798, 2009.

[72] A. Akbari, R. Yegani, and B. Pourabbas, "Synthesis of poly(ethylene glycol) (PEG) grafted silica nanoparticles with a minimum adhesion of proteins via one-pot one-step method," *Colloids Surfaces A Physicochem. Eng. Asp.*, vol. 484, no. 484, pp. 206–215, 2015.

[73] R. K. Das and M. Das, "Catalytic activity of acid and base with different concentration on sol gel kinetics of silica by ultrasonic method," *Ultrason. - Sonochemistry*, vol. 26, pp. 210–217, 2015.

[74] B. Li and J. Zhang, "Polysiloxane/multiwalled carbon nanotubes nanocomposites and their applications as ultrastable, healable and superhydrophobic coatings," *Carbon N. Y.*, vol. 93, pp. 648–658, 2015.

[75] W.-H. Huang and C.-S. Lin, "Robust superhydrophobic transparent coatings fabricated by a low-temperature sol–gel process," *Appl. Surf. Sci.*, vol. 305, pp. 702–709, 2014.

[76] R. Kumar, A. B. Kousaalya, and N. Garg, "Silica-based superhydrophobic coating by a single-

step process," *Surf. Innov.*, vol. 1, no. 3, pp. 173–180, 2013.

[77] R. Suriano, V. Oldani, C. L. Bianchi, and S. Turri, "AFM nanomechanical properties and durability of new hybrid fluorinated sol-gel coatings," *Surf. Coatings Technol.*, vol. 264, pp. 87–96, 2015.

[78] Y. Kitasako, M. F. Burrow, T. Nikaido, and J. Tagami, "Long-term tensile bond durability of two different 4-META containing resin cements to dentin," *Dent. Mater.*, vol. 18, pp. 276–280, 2002.

[79] R. Prado, G. Beobide, A. Marcaide, J. Goikoetxea, and A. Aranzabe, "Development of multifunctional sol–gel coatings: Anti-reflection coatings with enhanced self-cleaning capacity," *Sol. Energy Mater. Sol. Cells*, vol. 94, no. 6, pp. 1081–1088, 2010.

[80] E. International and A. Rods, "TECHNICAL SPECIFICATION OF 70KN & 45KNDISC INSULATOR (B & S)," 2007.

[81] I. a. Metwally, a. Al-Maqrashi, S. Al-Sumry, and S. Al-Harthy, "Performance improvement of 33kV line-post insulators in harsh environment," *Electr. Power Syst. Res.*, vol. 76, no. 9–10, pp. 778–785, 2006.

[82] L. Guide, "Nanostructured Surfaces – 4 . Superhydrophobic coatings and drag reduction," in *NANO LAB UNIMORE*, 2013, pp. 1–3.

[83] B. of I. Standards, "SPECIFICATION FOR PORCELAIN INSULATORS FOR OVERHEAD POWER LINES WITH A NOMINAL VOLTAGE GREATER THAN 1000V," 1972.

APPENDIX – A

Test Report

Test Report according to Bureau of Standards done at Oblum Testing agency on nano coated insulators

ITP-INP-11F **TEST REPORT FOR PORCELAIN BUSHING**

Rev No.: 2 Dt. 26.03.2008

Drg. No. 30KV (S+S) MPB-ZAB-30 C.D. 900

Test Report No: OI/93/14 Qty: 02 Nos. D.C. No: 90

Customer Name: Isaac **UPES** Date: 27/10/14

OBLUM

Sl.No.	CHARACTERISTICS	REFERENCE STANDARD	SAMPLING PLAN	ACCEPTANCE NORM	TESTING AGENCY	OBERSVATIONS
	Routine Testing					
1.	Visual Inspection	IS: 731-1971	100%	Free from visual defects	Oblum Ins.	No visual defects
2.	Dimensional checkup	As per Drawing IEC-305	2 samples for firing	Dimensions to be as per relevant drawing	Oblum Ins.	With in the tolerence
3.	Electrical Test	IS: 3121-1971 IEC-383	100%	Housing should withstand 35KV (min.) between material and external electrodes or 1.5KV/mm of wall thickness whichever is higher	Oblum Ins.	With stood for 35 KV
4	Ultrasonic Test	As per FD-201B	100%	No defects (cracks & voids) to be detected	Oblum Ins.	No defects
5.	Bending Load Test	PS:OB-113B	100%	9 to 30 KV – 112 Kg.m 36 to 90 KV – 250 Kg.m Above 96 KV – 500 Kg.m 250 Kg.F 500 Kg.F 1000 Kg.F	Oblum Ins.	With stood for 112 Kg.m.
	Acceptance Tests					
1.	Temp. Cycle Test	IS: 731-1971 As per IEC 233	2 samples per firing	Should withstand without spalling	Oblum Ins.	With out spaleing
2.	Posority Test	IS: 731-1971 IEC 815	2 samples per firing	Nil Porosity at 475 Kgs/Cm^2 for 4 Hous	Oblum Ins.	Nil Porosity
3.	Burst Pressure Test	PS: OB-113B	2 samples per firing	25 Kgs/Cm^2 (min)	Oblum Ins.	With stood for 25 kg/cm²
4.	Bending Load Test	PS: OB-113B	2 samples per firing	224 Kg-m – from 9KV to 30KV 500 Kg-m – from 36KV to 96KV 1000Kg-m – above 96KV	Oblum Ins.	With stood for 224 Kg-m.

Approved By: Checked By: Verified By:

OBLUM ELECTRICAL INDUSTRIES (P) LTD. HYDERABAD 500 037

APPENDIX – B

IS: 731 – 1971 Bureau of Indian Standards

The testing agency M/s Oblum electrical industries, Hyderabad has followed the different standards for testing two nano coated and uncoated porcelain insulators and the report was also given accordingly as mentioned in Appendix ‘A’.

For more information kindly go through the internet sources below for IS 731 – 1971 Indian Standards.

https://law.resource.org/pub/in/bis/S05/is.731.1971.pdf

the document contains, specifications for porcelain insulators for overhead power lines with a nominal voltage greater than 1000 V according to the IS: 731 – 1971; second revision ninth reprint, January 2006. These documents are available in internet to promote timely dissemination of this information and using the testing of the insulators as per the specifications given by the bureau of standards by all the different testing agencies.