CHAPTER 1

Introduction and Literature Review

1.1 Introduction

The insulator is material in which electric current cannot pass freely or whose electric charges do not flow freely. In our daily life, we use many insulator materials directly and indirectly like plastic, rubber, wood, cloths, and glass. Other material like semiconductors and conductors, which conduct electric current more efficiently. The electrical properties of material totally depend upon the motion of electron and hols within the bands(conduction and valence band). When an electric field is applied to the base material then the electron is flowing in the opposite direction of the applied electric field, then there is a formation of electric current. But when energy band is empty(no free electron) then it does not participate in the formation of electric current.

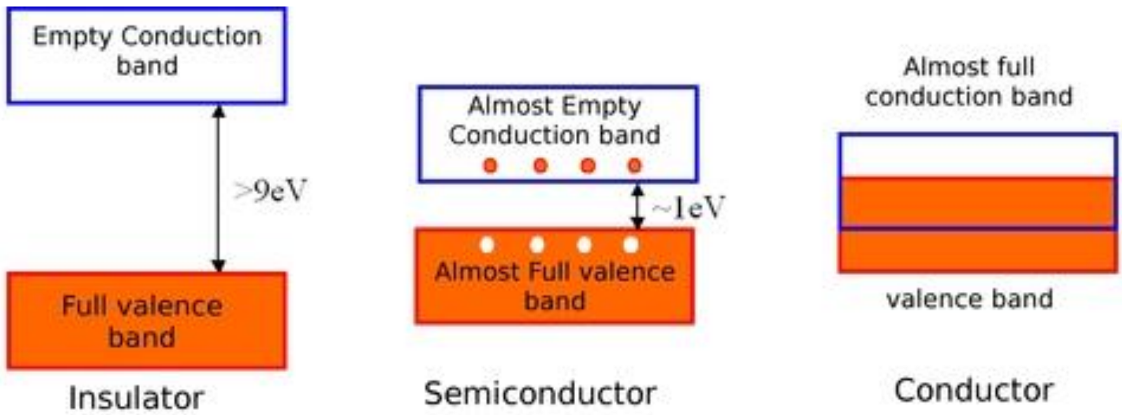

Figure 1. 1: Representation of energy bands

A material is having empty energy band it is called insulator. An insulator having larger energy gap (≈ 9eV), due to such gap, the thermal energy 300K (~25 meV) is inadequate to allow electrons an from the valence band to the conduction band. In this case, the valence band is fully occupied, and the conduction band is vacant, shown Figure 1. 1 of energy bands. In semiconduction the energy band gap is small it is near to 1eV, and in conductors energy band gap is overlapping (≈0eV) means electrons, holes motion within the bands. Another properties that differentiate insulator material to semiconductor and conductor is its specific resistance or resistivity (ρ in Ω cm).

An ideal insulator is not possible because it contains a small amount of mobile charge that current charge when a sufficient amount of voltage is applied that the electric field tears electron away from the atoms. It is called breakdown voltage of an insulator material. The material having high resistivity is perfect electrical insulators such as glass, porcelain, mica, polymer, composite material, and Teflon, etc. shown in Figure 1. 2. All they are used power industries such as electric power distribution or transmission lines to service poles and high voltage transmission towers. In recent years, electrical Ceramic Porcelain Insulators (CPI) are playing a vital role in microelectronic devices, power transmission, and in distribution lines.

(a) (b) (c)

Figure 1. 2: Different material insulators (a) porcelain, (b) glass and (c) polymer insulator.

Generally, for high voltage and transmission line application, we use porcelain, polymer, and glass insulator [Grigsby 2001 and Bakshi 2007]. In nowadays high strength CPI is anecessity for highly efficient overhead transmission lines [Liebermann 2002, Amigó et al. 2005, and Piva et al. 2013]. The CPI is preferred over the other types of insulators such as polymers, glasses, and other composites due to the extensive availability and low-cost of raw materials used for the manufacturing of CPI. Further, the strength of CPI is superior compared to other electrical insulators [Andreeva et al. 2003 and Lee et al. 2005]. In high voltage, porcelain insulator is used to support and separate the electrical conductor so that the electric current cannot pass through them, shown in Figure 1. 3 .

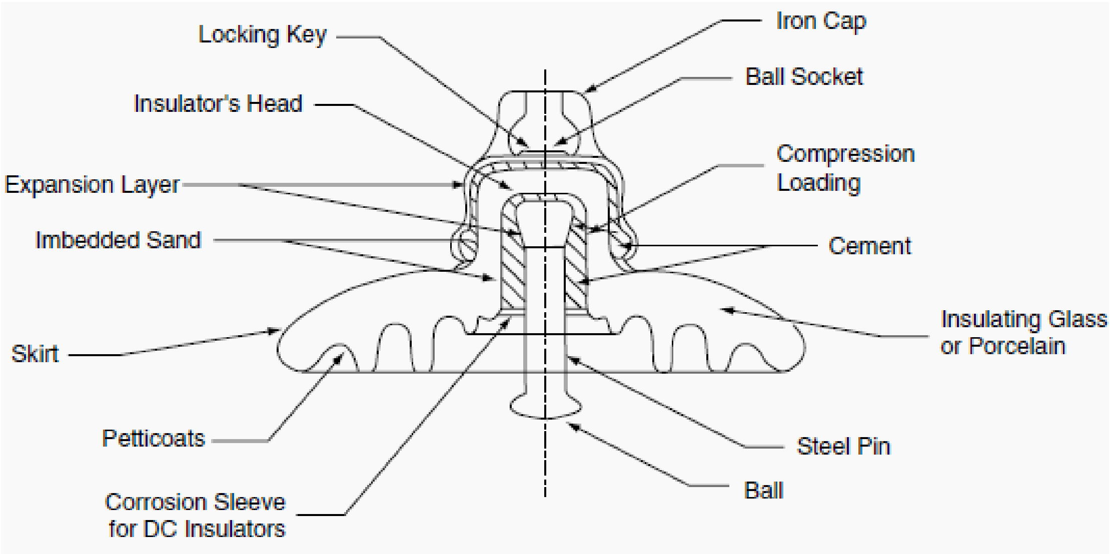

Figure 1. 3: Porcelain insulators which provide insulation between the iron cap and steel. (Internet Resource; IR1).

In another word, we can say insulator material is also used for a safety purpose. They also used as an insulation for materials such as electrical cables. The mixture of Quartz, silica and ball clays is used for low voltages application such as in distribution networks. In transmission line alumina based porcelain insulator is used because it provide high strength in porcelain composition. Glazing is the latter step in manufacturing of porcelain insulators which provide high strength, dectrase water absorption behaviour and having self cleaning ability to the insulators. The type of cement that used to bond with the metal pin to porcelain is an important parameter during fabrication of porcelain insulators. Basically portland cement is used in manufacturing porcelain insulators. The cement should be designed to handle the mechanical stress as well as the electrical stress.

Research has been made to enhance the mechanical and electrical properties of the CPI. High voltage insulators are the backbone of electrical power transmission lines. High voltage insulators are commonly fabricated using ceramic porcelain material and its various derivatives. The ceramic porcelain insulator (CPI) has multiple attractive properties such as enhanced mechanical strength and superior electrical properties (high resistance, high dielectric strength with a low dielectric loss). The CPI shows persistent behavior for nearly 30 years under adverse environmental conditions such as hot, saline, and humid environments [Kingery 1967, Buchanan 1986, Bribiesca et al, 1999 and Piva et al. 2016]. The raw materials used for the fabrication of CPIs are readily available, low-cost, and environment-friendly compared to expensive industrial chemicals used for the manufacture of insulators. The manufacture of ceramic porcelain insulators has been persistent for over 60 to 70 years, still there are some significant challenges can occur in porcelains related correct selection of raw materials, processing science, microstructure and phase (Carty and Senapati 1998). In this thesis, I am giving a research report on ceramic porcelain insulator and working interest to improving the mechanical and electrical strength of CPIs.

1.2 Historical of Porcelain

Porcelain was discovered in China during the Hou-Han Reign (A.D. 25-220). It was slowly refined over many years into the hard-paste porcelain that developed during the Tang Dynasty (A.D. 618-906) (Lane 1980). According to an wide study about the Chinese porcelain and technology [Kerr and Wood 2004], the world's first high-temperature hard-paste porcelains (hard-paste porcelain is also called real porcelain) were made in Hopei province in China in the 6th century. The hard-paste porcelain called Hsing ware had a firing temperature of about 1360°C. Kaolin became the primary source of porcelain since 1004. The finding made Jingdezhen, in south China, world famous as an imperial porcelain kiln. The name kaolin comes from a village "Kao-Ling (it means, a high hill in Chinese)" near Jingdezhen in China. The name survived in English as kaolin, or china clay. According to Gray 1952 [Gray 1952], Chinese porcelain was introduced to the Western parts of the world in A.D. 851 through a document entitled "The story of China and India" written by Sulieman, an Arab traveler. Porcelain is a vitreous ceramic whiteware. They are extensively used in domestic, laboratory and industrial uses. Generally, porcelain products are designated as electrical, chemical, mechanical, structural and thermal wares. The essential or primary raw material which is used for the fabrication of porcelain insulators is kaolin, ball clay, quartz, and feldspar.

The clay ($Al_2O_3.2SiO_2$) contain, provide plasticity in the prepared material, silica or quartz (SiO_2), keeps the shape of the prepared bodies during sintering and feldspar ($K_xNa_{1-x}(AlSi_3)O_8$) working as a flux. The clay content is a combination of kaolin and ball clay contents. The three constituents (i.e., clay, feldspar and quartz) term as triaxial porcelains, shown in Figure 1. 4 [Buchanan 1991, Iqbal and Lee 2000 and Correia et al. 2006]. The sintered product contains mullite ($Al_6Si_2O_{13}$) and SiO_2 (undissolved quartz) in a continuous glassy phase, originating from feldspar and other low melting impurities in the raw materials. By varying the proportions of the three main ingredients, it is possible to emphasize mechanical, thermal, electric properties [Thurnauer 1954 and Richerson 1992].

In Figure 1. 4 variying content of clay, felsphar and quartz it having different application in different area like bricks, stoneware, electrical and dental porcelain e.t.c . Porcelain stoneware is characterized by excellent technical and functional properties [Dondi et al. 1995, Sánchez et al. 2006, Brusa et al. 1994 and Manfredini et al. 1996], having high density, low water absorption property that provide more resistant from external effect and therefore extremely provide service for outdoor flooring and wall cladding in cold climates; high mechanical properties (hardness, abrasion resistance and bending strength) making it highly demandable in industrial areas.

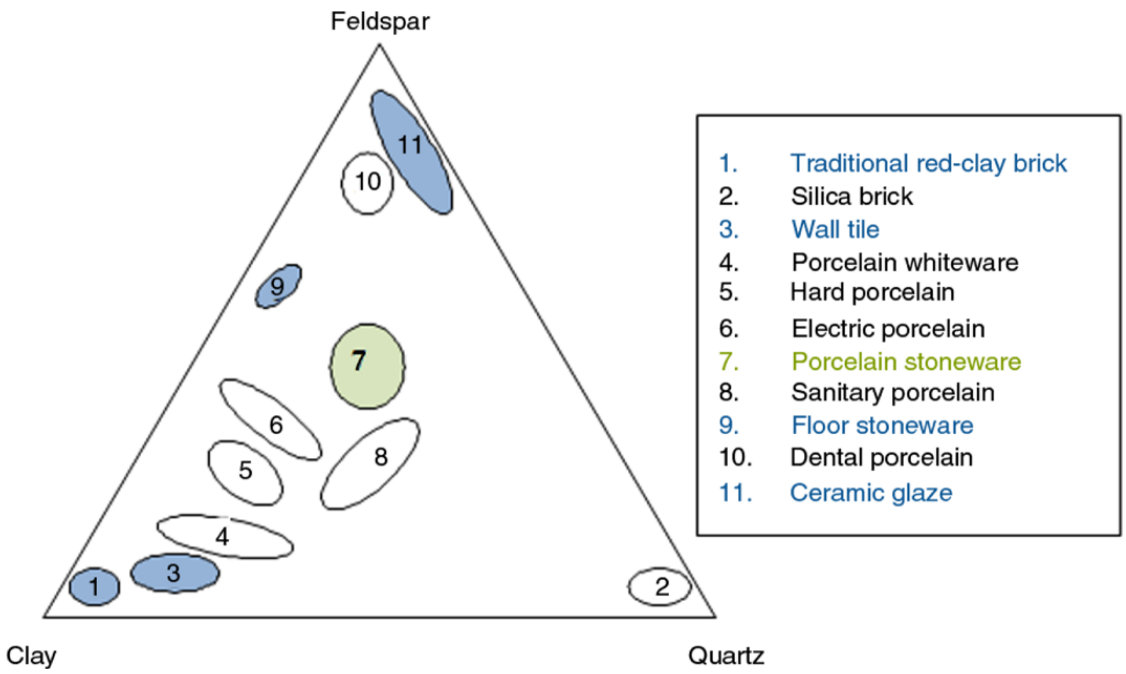

Figure 1. 4: Location of different ceramics materials in the feldspar-quartz-clay triaxial diagram [Romero and Pérez 2015]

The Insulators which is used for high-voltage power transmission are made from glass, porcelain and polymer material. CPI is preferred over other types of insulators like polymers, glass, and other composites due to the extensive availability and low-cost of raw materials. From different articles or literature conclude that silica, ball clay, kaolin, and feldspar are essential raw materials used for the manufacturing of CPI and It’s green body covered by a smooth glaze to shed the water.

1.3 Types of Porcelain Insulators

Selection of good insulator is the big challenge for the successful operation of overload lines. Various kinds of insulator which are commonly used in now days for power transmission and distribution are pin type insulator, suspension, strain insulator and shackle insulator.

1.3.1 Pin Type Insulators

- This type of insulator consist from a single and multiple shells which are arranged in parallel.
- The designing should be such that even when the external surface is wet due to rain, the inner dry surface provides adequate leakage resistance.

Figure 1. 5: Pin type insulator.

Advantages of Pin type insulators:

- Pin type insulators are simple in manufacture or design and inexpensive.
- It provides economic and most efficient method of supporting conductors.

1.3.2 Suspension Type Insulators

- At high voltages, the pin type insulators becomes more bulky, and uneconomical.
- In this case, suspension type insulators are used to insulate the high voltage transmission lines.
- By using different number of disc in Suspension type insulator made it suitable for any voltage level, normally these are used up to and including 400 KV.
- If any disc in suspension insulator is damaged, then it can easly replaced.
- In suspension type insulator the mechanical stresses is less.

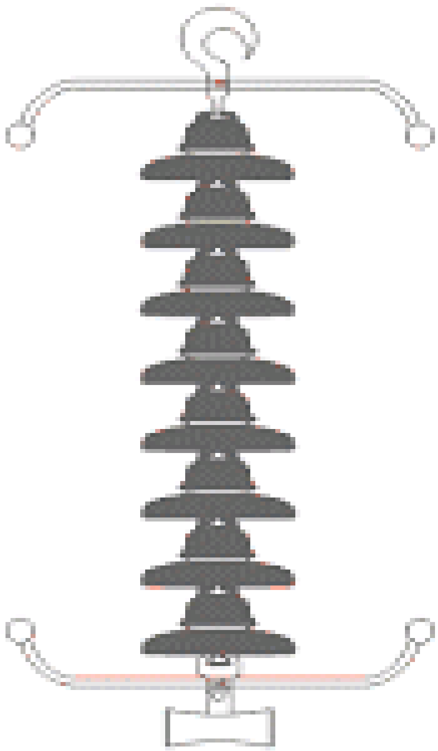

Figure 1. 6: Suspension type insulators.

1.3.3 Strain Type Insulators

- Strain type insulators are used when the line is subjected to greater tension such as
- At dead ends.

- At river crossings and when there is a change in the direction of line. The main function of this insulator is to reduce excessive tension on the line.

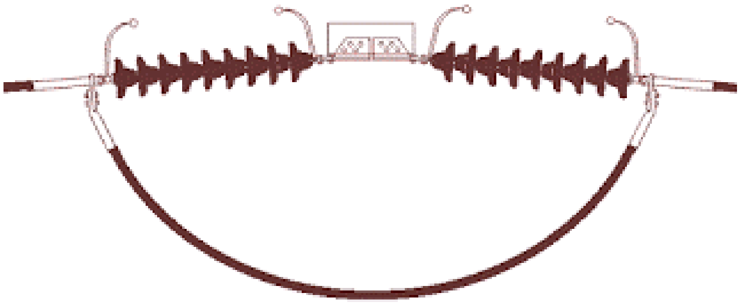

Figure 1. 7: Strain type insulators

1.4 Factors Affecting Insulation Properties

1.4.1 Temperature

As the temperature of the insulating material rises its insulation resistance keeps on falling.

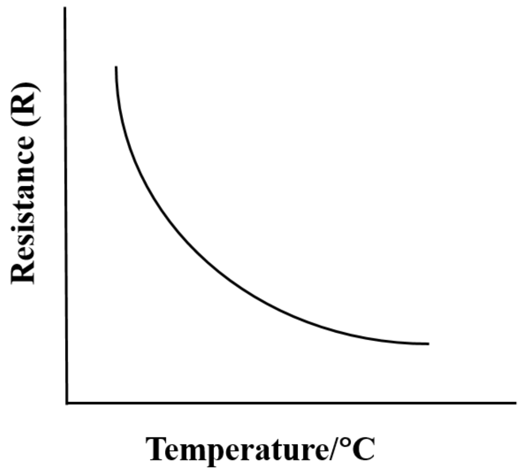

Figure 1. 8: Graph for temperature dependent resistance of the material.

1.4.2 Aging of Ceramic Porcelain Insulators

As the age of insulation material is increased, the insulation resistance decreases. Aging of an insulator means is the effect that formed on the body (outer sheath or shed) of the insulator after a specified period of service. Outdoor weathering is a natural phenomenon which effect the ages of the insulator. Mainly environmental factors were effect the breakdown strength of porcelain insulator shown Figure 1. 9. Various environmental factors i.e. due to pollutant: SiO_2, O_3 and NO_2 and environmental stresses i.e. heat, ultra violet light, moisture, wind, dust particles etc.

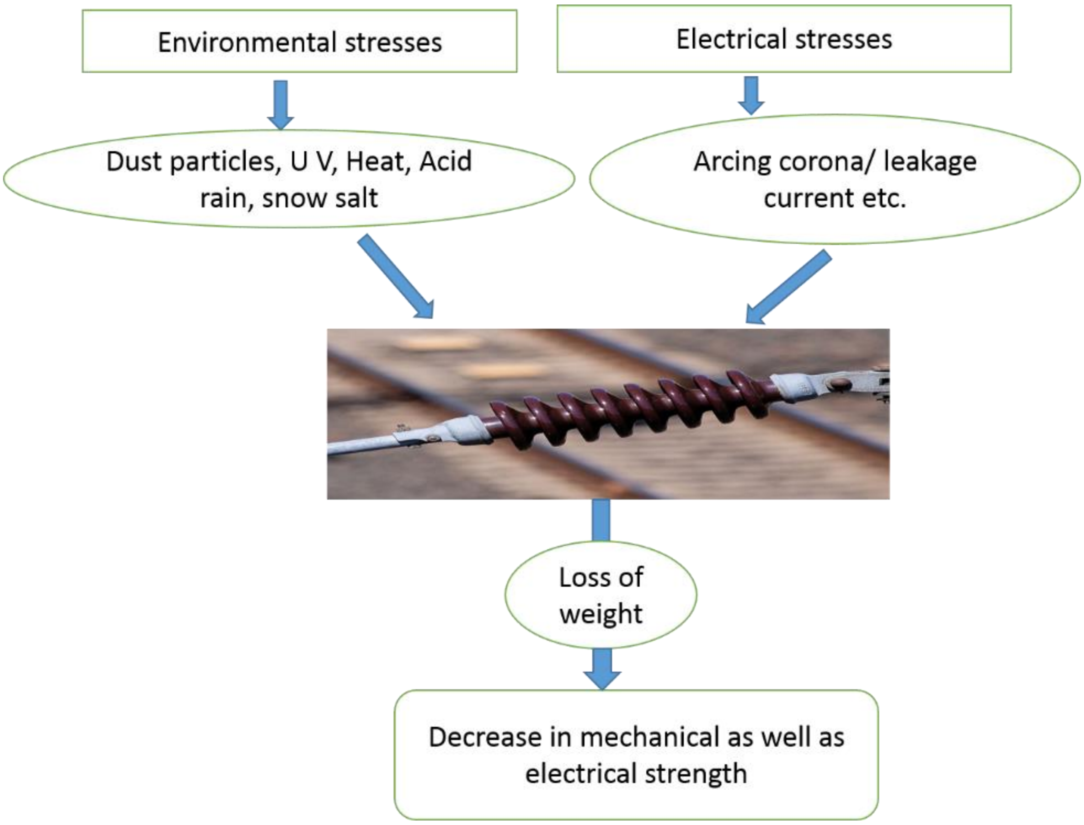

Figure 1. 9: Factors involved in aging ceramic porcelain insulator.

1.4.3 Biological Degradation

Microorganisms such as bacteria, germs etc. are always present outdoors, and nutrients may come from from its surroundings or the material itself. Adhesion to surfaces is a common microbiological strategy for survival in low nutrient environments, and Biofilms can thus be found in a wide range of environments. This is in direct consequence of biological growth on outdoor insulators, which means that, microbiological (R. Matsuoka, 2002) colonization of ceramic as well as composite insulators takes place in all parts of the world. The biological materials growth on insulators have identified most widely grown microorganisms as algae, fungi or lichen.

There are several different ways in which micro organisms can influence the outdoor ceramic porcelain insulator. The main effects that can be happen are:

- Fouling (due to contamination of material surface)
- Degradation of leaching components.
- Occur Corrosion
- Hydration.
- Discoloration.

1.4.4 Moisture

Insulation resistance is reduced if the material absorbs moisture, so insulation material should be non-hygroscopic.

1.4.5 Applied voltage

Applied voltage also affects the insulation resistance.

1.5 Properties of an Ideal Insulator

- The insulating material must be mechanically strong having high bending, compressive strength, enough to carry tension and weight of conductor
- It having high specific resistance also known as resistivity, high resistivity insulators means that offer such a huge resistance does not allow any electricity and having very low conductivity.
- High dielectric value with minimum loss.
- Less water absorption, less porosity, and excellent corrosion resistance.
- There physical as well as electrical properties must be less affected by changing temperature, Low thermal expansion and withstand at high temperature

- Good flash over behaviour.
- High break down voltage capability, insulator conduct electricity if subjected to apply extreme voltage. The voltage at which the material lost his insulating property is known as dielectric strength or breakdown voltage.

1.6 Application of Insulators

Insulators used as a protectors, also used to protect heat flow, sound and cannot pass electricity from the insulator materials. Different types of insulators are used for various purpose like Thermal insulators, sound insulators and electrical insulators to keeping houses warm, sound proofing rooms and to protecting electrical wires.

1.6.1 Thermal Insulator

This types of insulator are used to prevent heat from moving from one place to another. In other word it work as a barrier in the passage of a heat.

Figure 1.10: Different application of thermal insulator.

These materials include plastics, porcelain and reflective materials. These materials reduce thermal conduction by making thermal energy more difficult to travel. Thermal insulators having many application, may be used to keep liquids warm or cold like a thermos does or for insulating within a house, such as ceiling, wall and floor insulation, shown in Figure 1.10.

1.6.2 Sound Insulator

Insulators that reduce sounds are used for soundproofing rooms or for noise control. Sound insulators work to reduce sound energy that is reflected by room surfaces. Sound insulators include vinyl barriers that block noise from traffic, voices and music; foam cells that dampen noise as it passes through multiple foam cells; and acoustic tiles that absorb, echo and minimize reverberation. Soundproof your doors, walls and windows to absorb sound for quieter homes and rooms. The material used for sound insulator are cellular concrete, sound plaster and sound board etc., shown in Figure 1.11.

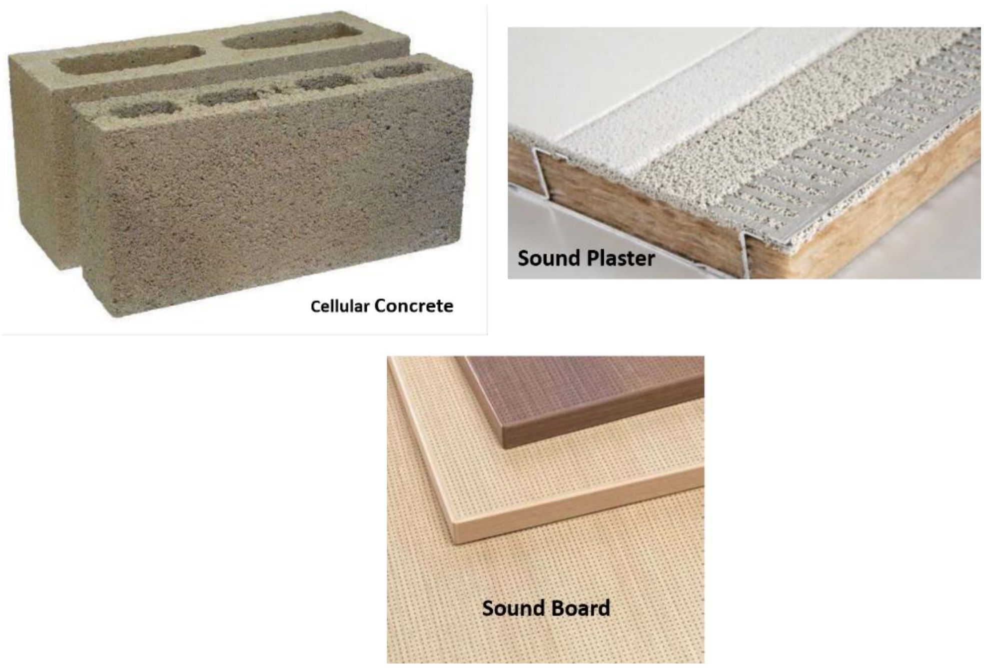

Figure 1. 11: Materials for sound insulators

1.6.3 Electrical Insulator

An electrical insulator, also known as a non-conducting materials, is used to prevent the flow of electric currents. Electrical insulators also used antennas, circuit boards, fuse, circuit breakers, high voltage systems and as coating on electric wire and cable, shown in Figure 1. 12. For high voltage trasmmission and distribution widely we used polymer, glass and porcelain insulator due to its high stability of their electrical, mechanical and thermal properties in the presence of harsh environment.

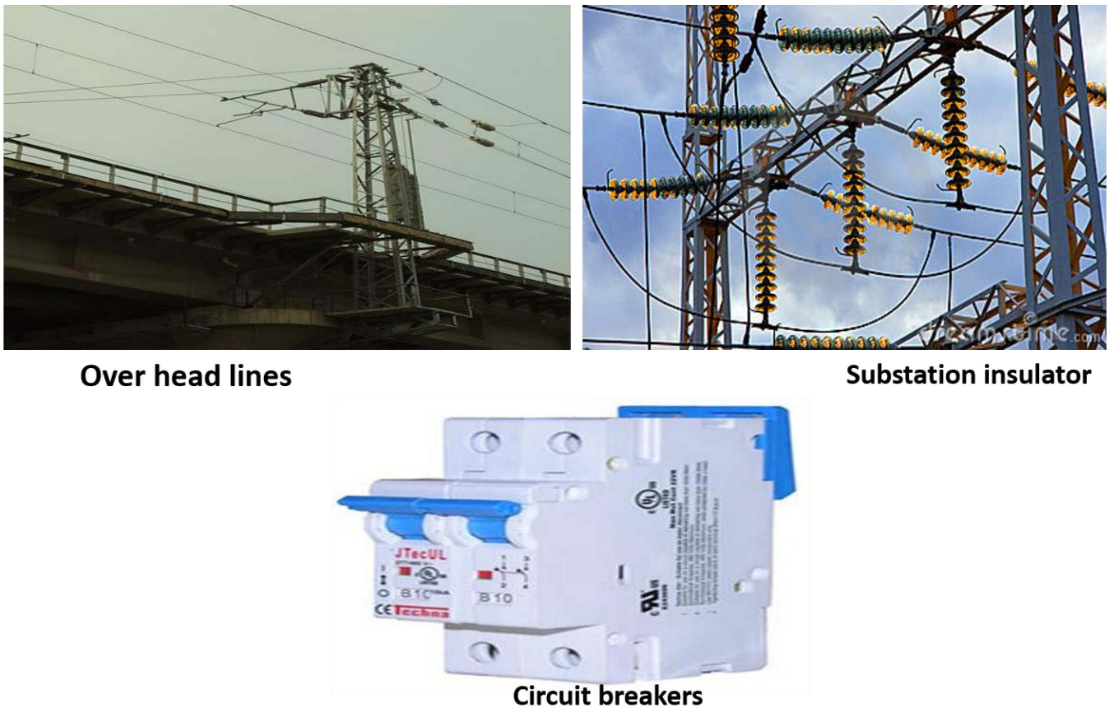

Figure 1. 12: Electrical Porcelain insulator application

1.7 Literature Review

Author	Year	Conclusion
P. TARTAJ et al.	1996	Study the formation of Zircon ($ZrO_2.SiO_2$), takes place by solid-state reaction between silica and tetragonal zirconia. This mechanism is independent of the degree of Si-Zr mixing, because silica and zirconia segregate before zircon formation.
Robert D. McAfee et al.	1997	Study the effect of biological contaminants (due to growth of algae and wetted by fog and rain) on high voltage porcelain insulators that effect its electrical performance.
S.P. Chaudhuri et al.	1999	Conclude that the resistivity of the porcelain material decrease with increase in temperature. Electrical Resistivity is controlled by phase configuration and microstructure of porcelain.
S.P. Chaudhuri et al.	2000	Study the effect of concentration of SiO_2, mullite, cristobalite and glass crystal size distribution on dielectric constant, loss factor and tanδ were analysed.
W.E. Lee	2001	Porcelain contains various forms of mullite. Primary mullite is formed by from the decomposition of pure clay. The reaction of feldspar, clay and quartz, form secondary mullite. Aluminous porcelains also contain secondary mullite.
Jose M. Amigo	2003	An increase of vitreous phase decreases the mechanical resistance of the sample. Raising the percentage of quartz present in the sample, it decreases the mechanical resistance.

Rashed Adnan Islam	2003	Mullite and quartz are two-phase which gives electric and mechanical properties of ceramic insulator. High glassy phase content reduces the mechanical property and dielectric property.
G Stathis	2003	Bending strength is affected by the grain size of quartz in two ways, directly through the induction of compressive stresses to the vitreous phase and indirectly through the development of a favorable microstructure.
S.M. Lee et al.	2005	Study the effects of ZnO addition on crystallization behavior and mechanical properties of porcelain. ZnO addition increases the phase of cristobalite formation, also enhance the wear resistance of the porcelain bodies.
Igor Stubna	2006	Revealed that micro cracking begins at the temperature of the glass transformation and is completed at room temperature. It also showed that β to α cristobalite transformation of unsolved quartz grains contribute towards micro cracking.
S.R. Braganc et al.	2006	Study the effect of the SiO_2 concentration on bending strength, compressive strength, and fracture toughness, of triaxial porcelain.
Muhammad Amin	2007	In this research, article presents a comprehensive survey pertaining to multi stress and field aging of polymeric insulators.

Noemi Montoya	2009	TiO_2 enhance the crystallization of both types II and III secondary mullites. The role of the TiO_2 is to reduce the viscosity of the melt and support mass-transport. The addition of small quantity of titanium oxide helps in increasing the mechanical properties of alumina-based porcelains.
Frantisek Chmelik	2011	This study is based on quartz porcelain; it reveals that several microcracking are generated during cooling which begins at a temperature of the glass transition of about 800^0C. At 573^0C there is β to α transition, cracking is temporarily interrupted. Below 500^0C circumferential cracks occur around the particles which having less intensity.
Peter Krupa	2014	This study analyses the thermal properties of alumina porcelain insulator using the transient plane source method. Measurements of thermal conductivity, thermal diffusivity, specific heat and bulk density were performed at room temperature and compared with the differential thermal analysis (DTA), thermodilatometry and thermogravimetry. Thermal conductivity and thermal diffusivity were dependent on structural changes. A small decrease in values during dihydroxylation of kaolinite and a rapid increase during sintering correlated with the bulk density measurements. The thermal conductivity was enhanced by about 700% thermal diffusivity by about 400% after sintering.
S. Kasrani et al.	2016	In this Study, manufacture technical porcelain, for the ceramic dielectric applications by using economical natural raw

		materials, was investigated. Dielectric measurements of technical porcelains have been carried out at 1 kHz from room temperature to 200°C.
D.H. Piva et al.	2016	Evaluate the effect of Fe_2O_3 on the electrical and mechanical properties of porcelain insulator. The electrical resistivity for the composition with 3 wt. % Fe_2O_3 was higher than those found in aluminous based porcelain, which was discussed in terms of the concentration of glassy and mullite phases. A reduction in the electrical resistivity was only observed in porcelain samples containing over 3 wt. % Fe_2O_3. The presence of hematite phase was considered responsible for this reduction.
W. Lerdprom et al.	2017	Study the conductivity of green porcelain bodies with temperature dependence. The electrical conductivity of green porcelain bodies divided in different reason and dissimilar conduction parts. At low-temperature area, the OH^-, H^+ and some monovalent ions are primary charge carriers. At high-temperature, the conduction is probably by due to the migration of cations.
Ujjwal Kumar Kalla et al.	2018	Study on high-voltage flashover by using the power quality parameters in the insulator testing industries at a remote location. The recommended method is suitable for the detection of high-voltage flashover phenomenon for ceramic insulator industries, without using of any high-voltage quantity measured from the test setup

1.8 Objectives of Work

To develop and improve the Physico-mechanical and electrical property of ceramic porcelain insulator by reinforcement of Al_2O_3, ZrO_2 and $BaTiO_3$.

- DTA, XRD and SEM/EDS analysis of the prepared samples.
- Measurement of bending, compressive and tensile strength.
- Measurement of densification and porosity.
- To measure the AC dielectric constant and dielectric loss value at low (20 Hz to 1 MHz) and microwave frequency range (1 to 20 GHz).
- Measure high voltage dielectric strength of insulator material.