Transmission Line Insulation: Composites

The growing market for alternative materials in high voltage insulation components is spurred largely by the need to reduce overall costs. Therefore standards are required to be evolved to specify the dielectric and physical properties, and processing characteristics of the materials. In this respect, polymer insulators offer significant advantages over porcelain. And, with due care to the formulation, product manufacture and design, polymers will perform exceedingly well even in heavily contaminated regions. While the most accepted and applicable standard for polymers insulators will be IEC 61109 which stipulates design, type, sample and routine tests.

- **K.S. Sidhu**

The operating performance of any electrical network depends largely on insulation. Ceramic and glass have long been the materials of choice for high voltage insulators offering good resistance to electrical current and environmental exposure without significant degradation. However, in the past decade, there has been a shift from porcelain to insulators of polymeric materials. These Composite / polymer insulators have now found place in power transmissions upto 500KV and are being used in Africa, America, Asia, Australia, Canada, Europe, and Middle East. The increased world-wide use of composite insulators is based on some advantages of this new class of insulators. The chemistry of polymers being very fast, various insulator designs, materials and manufacturing methods have been developed and tested. Great strides have been made in the understanding of composite material properties, and insulator design weaknesses. However, and due largely to the lack of standardization, insulator designs have not reached the expected level of development. But, the emerging shift to composites calls for accelerated efforts by the researchers, engineers and manufacturers to study, analyze, debate and decide the right composition of polymeric materials, bring about perfection in manufacturing processes and specify the tests specific to polymer insulators so as to achieve the expected performance and longevity of composite insulators. This paper gives brief introduction of transmission line insulation with an emphasis on the selection of material, design criteria and test weakness to simulate in service performance of composite insulators.

Definitions

Composite – Physical blends of materials engineered to optimize the strong points of each component

Hydrophobicity – Water repellent surface property

Hydrophilic – Water attraction property

Polymer – Chemical compound with molecular weight

Insulator – material with infinite resistance to electric current (Air, glass, mica, porcelain, oil, varnish, rubber and polymers)

The electrical insulator has to perform dual function of electrical protection as well as mechanical support. The insulator must prevent an arc-over for practically any operating condition of humidity, temperature, rain, snow and air-borne surface contamination and be so designed to have sufficient mechanical strength against the greatest loads of ice and pressure of wind that may reasonably be expected. Thus the insulator service life can be affected by electrical, mechanical and environmental stresses. One of the biggest problems in outdoor applications is airborne contamination of industrial, coastal or agricultural or transportation origin that settles on the insulator surface. When contamination building up is exposed to moisture, a conductive film can develop resulting in the decrease of the surface resistance of the dry zones is much higher than that of wet areas. Consequently the voltage distribution over the insulator is non-uniform and if the pollution conditions persist, the spark discharges increase in intensity, air is ionized until ultimately the complete flashover occurs which damages the insulator. In some areas the pollution is severe e.g. coastal environments are characterized by increased ESDD (equivalent salt deposit density) values due to the salt pollution and other areas with dusty and sandy pollution have increased NSDD (non soluble deposit density) values of the pollution layer. Silicone housed composite insulators show outstanding service experiences in environments where high ESDD and high NSDD values exist.

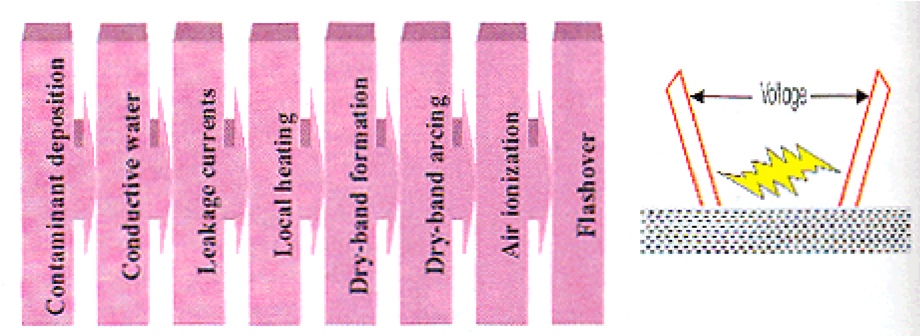


Fig.1: Comtamination/flashover mechanism

Ceramic/Glass Insulators

In the first half of the last century HV transmission lines had been insulated with insulator strings made of ceramic and glass material. High-grade electrical ceramic / glass of the proper composition free from laminations, holes and cooling stresses is the recognized dielectric for insulating high voltage lines. The perfection in manufacturing processes and specified tests have brought the product to a standard of uniformity. However, as discussed above, the main problem with ceramic and glass high voltage insulators are that water readily forms a continuous film on their surface. In the presence of contamination, leakage current then develops which may lead to flashover that could be followed by an outage of the power system.

Maintenance Measures

Utilities have developed a number of techniques for coping with contamination. High-pressure washing, silicone dielectric greases and RTV silicone coatings have all been applied to ceramic and glass insulators. Each method has its drawbacks. Washing of insulators is quite costly and more over there may be certain areas where the contaminant is so adherent that it does not wash off and where the contaminant simply overwhelms any reasonable amount of insulation. Silicon greases offer a longer –lasting solution, as silicone fluid within the grease formulation encapsulates contaminants, rendering them nonconductive and retaining a hydrophobic surface. However, the grease will eventually be overwhelmed by contamination, at which time it must be removed and replaced (generally from three months to five years, depending on the severity of the conditions).

RTV Coating

The room temperature vulcanizing RTV Spray-able coating, due to its low energy surface, offers water repellency (hydrophobicity) and helps prevent continuous water filming on the surface. This suppresses the development of leakage current and consequently the onset of flashover. The hydrophobic surface is maintained even after a layer of contamination has accumulated on the surface. This has been attributed to the diffusion of the low molecular weight (LMW) silicone fluid from the coating on to the polluted deposits. The photograph Fig. 2 shows water droplets on a RTV Silicon coated surface indicating the hydrophobicity of coating:

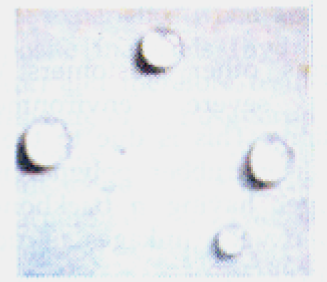


Fig.2: Water droplets on RTV Silicon Surface

Composite Insulators

The need to improve the reliability of power supply led to the development of alternative materials (polymers) for insulation and in the sixties test trials started with composite insulators. Polymer insulator in its generic form is a composite consisting of a central rod or hollow core, housing and metal end fittings with interfaces between them. The central rod is made of glass fiber reinforced plastic (FRP). It carries the mechanical strength and is lighter too. The housing of the composite insulators is made up of polymers, and it serves two main purposes viz. protects the FRP from direct exposure to moisture, contamination and also provides the Fig. 3: Composite Insulator Design required creepage length for the insulators. The end fittings are used for clamping the insulator to the cross arm of the tower at one end and for holding the conductor with other end.

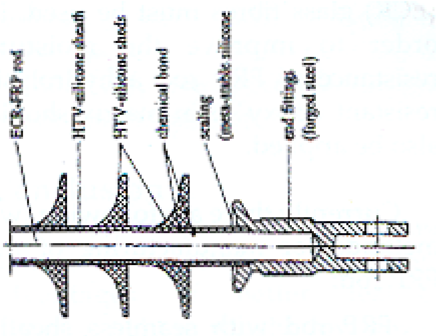


Fig.3: Composite Insulator Design

Design Criteria for Composite Insulators

Core material

In the role of the mechanical load bearing part, the FRP rod is the most important part of a composite insulator. The main problem with the FRP rod is brittle fracture of the fiberglass core, which leads to dangerous consequences. Brittle fracture (Fig. 4) arises in a composite insulator when moisture penetrates the core and resides near to the individual fibers. It is the chemical action of the water on the individual glass fibers in the rod that gives rise to brittle fracture failure of the core. The moisture ingress to the core takes place through micro cracks which develop either during attachment of the hardware to the core, damage to the end seal due to flashover, or constant action of corona on the housing or due to excessive torque or twisting of composite insulators by conductors. In order to avoid brittle fracture, Electrical grade chemical resistant (ECR) glass fibers must be used. In order to improve the moisture resistance of ERP rod a hydrolysis resistant epoxy resin matrix should also be applied.

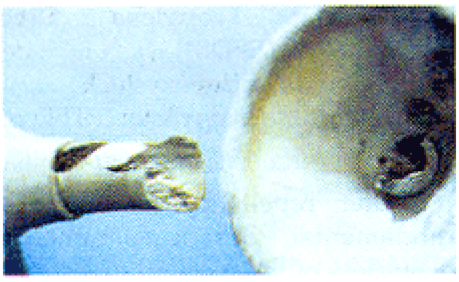


Fig. 4: Brittle fracture of FRP

Currently there are following two methods for manufacturing of the FRP rod:

- FRP rod with seamless sheath, single sheds vulcanized onto the sheath
- FRP rod encased with a shedded housing applied with one shot in a two partite mold

The first manufacturing process should be preferred because it results in no molding line along the sheath between the sheds.

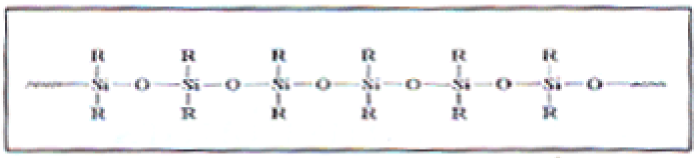
Housing material

In the world-wide development of composite insulators a lot of housing materials were tested, such as:

- Silicon rubber (SIR)
- Ethylene Propylene Rubber (ERP)
- Ethylene Propylene dine Monomer (EPDM)

- Cycloaliphatic epoxys (CE)
- Polytetrafluroethylene (PTEF or Teflon)

Water repellency has been a fundamental design parameter, regardless of the material or specific insulator design. Some of the very first composite polymer insulators employed cycloaliphatic epoxy-based materials. But now, the manufacturers overwhelmingly use elastomeric (rubber) materials such as SIR, EPR and EPDM for the housings. Today, two principal kinds of housing materials for composite insulators are in the use. These are families of silicone rubber (SIR) and ethylene propylene rubber (EPR). Insulator field experience and extensive, multi-stress lab testing of different elastomer formulations have shown that silicone outperforms other elastomers even under severe environmental conditions. This is due to the fact that silicon rubber polymer is an elastomer having a backbone of silicon oxygen linkages (structure shown below).



The bond is the same which is found in quartz, glass and sand. This is one of the main reasons that silicone rubber has such excellent properties such as stability in low and high temperatures (from 100^0 C to plus 500^0 C) and can withstand ozone, UV heat and other aging factors very well. Incidentally, the conventional insulators are also manufactured from sand (clay) and glass. Due to the property of hydrophobicity, silicone rubber is superior to any other polymeric material. SIR is the only housing material able to transformer its water-repellent property to a pollution layer on the surface. Therefore, leakage currents are suppressed and the risk of flashover is reduced.

Compounding

The mechanical strength of unfilled silicone rubber is very poor because forces between molecular chains are very low. On the other hand, the low intermolecular forces are the reason for high elasticity of SIR independent of temperature. Two types of filter are commonly used; silica is the reinforcement that lends tensile strength and tear resistance to the polymer, while alumina trihydrate (ATH) improves tracking and erosion resistance. Filler treatments, pigments and cure agents in small quantities are also part of the formulation. The filler content may amount to a total of 70 to 80% by weight.

Obviously, such a large amount of filler influences not only the mechanical and electrical performance but also other properties such as density; Shore A hardness, viscosity and hydrophobicity. Concerning the amount of filler there are two opposing statements:

- In order to improve tracking and erosion resistance the filler content has to be increased.
- In order to improve hydrophobicity performance the amount of filler has to be reduced.

Therefore a balance has to be struck to obtain the best characteristics of the compounded material. Optimizing the formulation in such a way that both requirements are fulfilled is part of both the insulator manufacturer's and the silicone manufacturer's know-how. In fact, high quality HTV (high temperature vulcanizing) silicone rubber material with well-balanced silica and ATH compounding should be used for the insulator housing. However, quite often the amount of filler is increased only for the purpose of reducing costs which is not fare.

Bonding of the Silicone Housing to the Core

Another important aspect of the composite insulators is the bonding of the molded rubber housing to the core and joints of FRP with end fittings. The joint between housing, core and end fittings includes three materials (rubber, metal and FRP) which show very different moduli of elasticity and different coefficient of thermal expansion. If the three materials are rigidly connected to each other, mechanical stresses will occur unavoidably in the interfaces in case of temperature changes and mechanical loading leading to the puncture of composite insulator housing (fig. – 5). Therefore, sealing material must be able to adjust itself to any alteration in this area. Metastable silicone acting like a sticky fluid with very high viscosity has been found to be successful in service since long time. The bonding, between FRP core and housing, can be done with three commonly adopted processes i.e., chemical bonding outperforms the other kinds of interfaces and today, most of the composite insulators offered in the market are manufactured with inter-faces resulting from chemical bond.

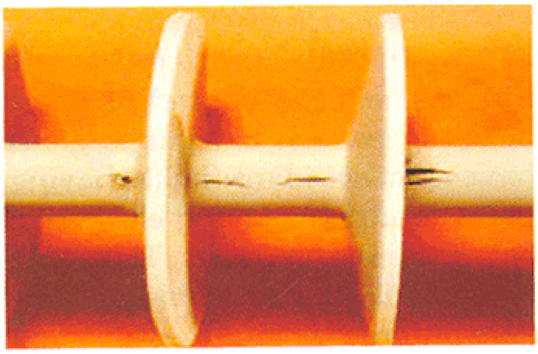


Fig. 5: Puncture of housing

End Fittings

In order to improve mechanical strength compression end fittings made from forged steel may be preferred and end fittings should be crimped onto the fiberglass rod.

Tests and standards for Polymer Insulators:

The most acceptable &applicable standard for polymer insulators is IEC 61109 which stipulates design, type, sample and routine tests. But actually speaking, the existing standards have been tailored from tests specified for porcelain (hydrophilic surface) that have not shown good correlation with actual service experience when applied to composite materials (hydrophobic surface) and therefore results from the tests are often misinterpreted. In particular, it has proven very difficult to develop test conditions that accurately duplicate material degradation which occurs during long term service. Further problem of existing laboratory tests is that they are long time consuming tests. However, EPRI, Research Center in the USA has set up Accelerated Aging Chamber in which a specific insulator design can be subjected to electrical, mechanical, and environmental stresses that closely resemble the actual service environment. A computer-controlled environmental system simulates predefined climatic conditions inside the chamber by varying temperature, clean fog, salt fog, clean rain, UV radiation, humidity and pollution. The computer-controlled accelerated multi-stress aging test allows simulating thirty years of aging in three years or so thus allowing to evaluate different types and designs of polymer insulators.

Conclusion

Polymeric transmission line insulators offer significant advantages of better leakage distance, light in weight, low power loss (1/10th of the conventional) etc over porcelain insulators. With due care to the formulation; product manufacture and design; polymer insulators will perform exceedingly well even in heavily-contaminated regions. But the word of caution is that the term silicone elastomer or rubber comprises a large family of synthetic rubbers which may have different properties depnding on chemical composition, vulcanization process, filler material, filler content and additives. The growing market for alternative materials in high-voltage insulation components is spurred largely by a need to reduce overall costs. Therefore, standards are required to be evolved to specify the dielectric properties, physical properties, and processing characteristics of the compounded silicon material. The crux is that the refinement of test apparatus and procedures specifically for polymeric materials remains an area of focus for utilities, manufacturers and research organizations.

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Reference Book

Electrical India 2006,
Vol. 46 No. 12