Research methodology for the life evaluation of Hollow polymer insulators for High Voltage Applications

1. S.Farook, Research scholar, SVU, Tirupathi, farook_208@yahoo.co.in
2. Dr. P.Sangameswara raju, Professor, SVU, Tirupathi, psraju_2000@yahoo.com

Abstract: Life prediction of polymeric materials is the most important yet an uncertain aspect that often requires the extrapolation of the ageing data with suitable modeling and reliability. This paper emphasis on accelerated aging research scheme for the life evaluation studies of polymer insulation materials. The insulators are subjected to higher than usual levels of one or more accelerating variables such as voltage, temperature, or stress. The acceleration test results are then used to predict the life of the insulators at its service conditions. The work involves the designing of polymer housed lighting arresters for 9 KV voltage class, designing of external housing, accelerated aging test setup for the prediction of life of insulator. The work also involves the study of various polymer materials suitable for insulation purpose in high voltage applications.

Key words: study of polymer materials, design of LA, Environmental stress on insulators, artificial aging test setup.

Introduction: Polymer insulators also known as composite insulators are proliferating on transmission and distribution systems due to their ease of handling, resistance to vandalism, impact and seismic performance and relatively low cost. The polymer materials have high elasticity which will compensate the different expansions of the end fittings due to material temperature variations and mechanical loading and thus there will be no critical forces acting at the interfaces. The polymer insulators basically consists of fiber reinforced plastic core which will provide the necessary mechanical and load handling capabilities and this core is covered with polymer materials which will provide necessary electrical creepage and protects the core against the environmental stresses. The polymer insulators have high strength to weight ratio than the porcelain insulators, which provides easy installation and maintenance.

Polymers for high voltage applications

The polymer material used for external housing should withstand the environmental and electrical stress and the core should withstand the mechanical and electrical stress. The polymer material for high voltage applications should have

- Good dielectric and mechanical strength
- The housing material should provide good environmental protection against Ultraviolet radiations and contaminations
- It should have high tracking and arc resistance
- Good hydrophobic properties
- Impervious to moisture penetration

The fast vulcanizing and cross linking properties of polymer makes them vincible over porcelain insulating materials. Good mechanical properties and excellent performance under ultraviolet radiations, good hydrophobic stability properties with regard to climatic and electrical aging process and compactable with the environmental stress makes the polymer materials as an emerging alternative for ceramic insulators.

Various materials were considered for use as the elastomeric covering. Three materials emerged as most suitable for high voltage applications. These are:

- EPDM rubber
- Heat shrinkable EPDM
- Silicone rubber
**Silicone polymer**
Silicone rubber is manufactured from the direct process of methyl chloride and elemental silicon. Silicone rubber contains repetitive silicone – oxygen backbone and has organic methyl groups attached to a significant portion of the silicon atoms by silicon carbon bonds. Because of the silicon – oxygen backbone silicone rubber is resistant to sunlight, heat and is flexible over wide range of temperature. Silicone rubber is a hydrophobic material, which is due to organic groups attached to the silicone atoms. The silicone rubber has good transferable hydrophobicity as a result of which the SiO₂ layer becomes hydrophobic property and thus leading to increase in insulation behavior.

**Ethylene propylene diene monomer:**
Ethylene propylene copolymers can be obtained by co-polymerizing ethylene and propylene. The resulting, so-called EPMs are amorphous and rubbery, but since they do not contain unsaturation, they can only be crosslinked with peroxides. If, during the polymerization of ethylene and propylene, a third monomer, a diene, is added the resulting rubber is known as Ethylene propylene diene monomer rubber that will have unsaturation, they can be crosslinked with peroxides or sulfurs. In EPDM the unsaturation resides in side groups and the polymer backbone is completely saturated this gives the polymer an excellent resistance to degradation from oxygen, ozone and chemicals. For good aging resistance of EPDM protective agents such as aromatic amines, P-phenylene diamine is used.

The –Si–O– backbone of Silicone rubber has a higher bonding energy than the –C–C– backbone of EPDM and is highly stable under influence of ultraviolet radiation (sunlight), ozone and nitrogen oxide (Pollutants) and other environmental Stresses.

**Heat shrinkable EPDM:**
The heat shrinkable EPDM is manufactured in the similar manner as EPDM, in heat shrinkable polymer additional plastizers are added which is used in expansion and shrinking of the polymer. The plastizer mainly used are Ethylene vinyl acetate.

**Design of Hallow insulators:**
The composite insulator hollow insulator consists of a glass fiber reinforced resin bounded core commonly referred as FRP (fiber reinforced plastic) on to which two metal end fittings (flanges) are attached for fixture. The insulator tube is mechanically defined by tube inner diameter, the wall thickness of the tube, the tube lamination process, method of attachment and material of the metal end fittings and the manufacturing process. The insulator tube is designed by considering the dimensions for housing the arrester ZnO blocks and the arcing distance required for the required voltage class of the arrester, the mechanical considerations such as load withstand capabilities and pressure withstand capabilities. The insulator is designed for the 11 KV voltage class and considering severe environmental conditions. The dimensions of the FRP is designed as
Table 1: FRP dimensions

<table>
<thead>
<tr>
<th>FRP Dimensions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner diameter</td>
<td>50 mm</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>60 mm</td>
</tr>
<tr>
<td>Thickness of tube</td>
<td>5 mm</td>
</tr>
<tr>
<td>Length</td>
<td>200 mm</td>
</tr>
</tbody>
</table>

Shed profile
To improve the resistance of FRP to environmental stress, the FRP is covered with a polymer cover known as housing. The housing provides protection against environmental stress and also provides the necessary creepage distance. The housing is made in the form of sheds so as to provide the necessary creepage distance. The insulator is electrically defined by arcing distance, creepage distance, shed diameter, shed inclinations, and shed spacing. The creepage distance is determined by considering the pollution of the site according to IEC 815. The dimensions of the shed profile are designed as per the recommendations of IEC 815. The design features are

Table 2: Comparison of porcelain and polymer insulator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>IEC 815 Specification</th>
<th>Existing porcelain</th>
<th>Polymer insulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creepage factor</td>
<td>≤3.5</td>
<td>2.55</td>
<td>2.57</td>
</tr>
<tr>
<td>Profile factor</td>
<td>≥0.8</td>
<td>1.09</td>
<td>1.07</td>
</tr>
<tr>
<td>S/P ratio</td>
<td>≥0.65</td>
<td>0.945</td>
<td>0.809</td>
</tr>
</tbody>
</table>

End fittings:
The end flanges are the part of the composite hollow insulator which is intended to connect it to a supporting structure. The life of the composite insulators depends on the sealing of the tube with the metal flanges, thus the bonding between the tube and metal flanges should tight during the service conditions. End fittings are made of metal and the most common materials are cast iron or cast of machined aluminum. The dimensions of the end fittings are designed to accommodate the Fiber reinforced plastic tube on either ends of the tube. The End flanges are attached to the FRP tube with resin based adhesives. The locking between the flanges and FRP is made effectively by providing grooves on the tube and also in the flanges.

Stress on polymer insulators
Insulator service life can be affected by electrical, mechanical and environmental stresses. The greatest physical threats are generally mechanical loads, UV exposure, pollutants etc.

Corona:
Corona discharges form at the surface of an insulator when the electric field intensity on the surface exceeds the breakdown strength of air, which is about 15 kV/cm. Corona generation is dependent on atmospheric conditions such as air...
density, humidity, and geometry of the insulator. Corona accelerates the aging of polymers, by generating ozone and UV light. The UV light produced is of short wavelengths and includes the spectra of light damaging to polymers. The electric discharge subjects the insulator to severe electrical strain and chemical degradation. Continued degradation may render the polymer unusable.

**Leakage Current:**
Most polymer outdoor insulator may suffer from surface tracking phenomenon due to the leakage current that flows on the insulator surface. The magnitude of leakage current depends on the surface wetting and degree of contamination. When the insulator is wetted, resistive surface leakage current flows, which is generally many orders of magnitude higher than the capacitive current in the case of dry insulator. The leakage current increased with increase in contamination. The surface leakage current results in non-uniform heating of the pollution layer due to the non-uniform resistivity of the conducting film. The distribution of non-uniform current along the insulator surface eventually causes dry band to be formed where the surface leakage current density is highest. The existing of dry band in series with conducting film can caused the voltage distribution along the surface of wet polluted insulator is very non-uniform. The whole voltage applied across the insulator appears across the high resistive dry band and can result in breakdown of the air above the dry band. Arc created from this repeated breakdown phenomenon burns on the insulator surface to create carbonized region.

**Ultraviolet**

Ultraviolet light that falls directly on the polymer surface affects a chemical reaction between the oxygen in air and the unsaturated (double) carbon = carbon bonds in the polymer chain. This causes a scission of the carbon “backbone” of the polymer, resulting in a crack. The absorption of UV radiation results in mechanical and chemical degradation of the polymer structure, which can affect the dielectric and weathering properties of that polymer. The rate at which the degradation occurs is dependent upon the intensity and wavelength of the radiation. These factors vary with season, time of day, elevation and latitude. The negative effects of UV radiation for a polymer are cracking of the surface, Loss of hydrophobicity, Discoloration.

**Thermal Effects:**
The actual temperature of the insulation depends upon the temperature rise due to internally generated heat, which is added to the ambient. High temperature alone may cause chemical changes in the material through thermal activation of reactions. These changes may divide as
- Depolymerization reactions which lead to breaking of the main chain
- Crosslinking reactions between the chains and Reactions of the chain substituent

**Moisture:**
Water appears in the outdoor environment in the form of humidity, fog, rain, snow, or hail. The presence of water / moisture is an important feature in determining the surface wetness and the rate of breakdown of polymeric materials. Moisture can attack and degrade different polymers in a number of ways:
- Chemical hydrolysis resulting in the production of hydroxyl radicals in presence of sunlight which can further participate in radical reactions in the polymer leading to degradation.
- Freezing of water in surface imperfections can cause cracks in which more water may lodge causing further cracking on freezing.
- Dissolved pollutants and moisture as surface film can cause loss of electrical integrity e.g. by tracking or dielectric puncture.
- In certain polymers moisture may dissolve out plasticizers and stabilizers which will affect the physical properties of polymers.

**Pollutants:**
Atmospheric pollutants, such as nitrogen oxides, sulfur oxides, hydrocarbons provide a hostile chemical environment that degrades the polymeric materials. Nearly all fuels contain some sulfur and when these fuels are burnt, sulfur dioxide is released into the air. In the presence of UV light, sulfur dioxide reacts with a hydrocarbon material to yield sulfonic acids, which may be deleterious, hence wetting will occur more readily and electrical properties may be impaired.

**Experimental**
For artificial pollution studies of the polymeric insulators hollow insulators were made for the rated voltage in each polymer material and slabs of 150 X 150 X 6 mm of different material were made to study the effect of aging on the slabs placed in the pollution chamber.

**Artificial pollution chamber**
For pollution studies a special pollution chamber of 4 X 4 X 3 m was designed of the environmental studies for polymer materials. Inside the chamber a metallic structure was erected for the purpose of mounting of insulators and the insulator slabs. A specially designed spray nozzles for water spray and salt spray were installed at appropriate position inside the chamber to simulate the coastal pollution. Electric heaters were fixed at the bottom for heating and were suitably covered with metal foil to protect from rain and salt spray. Ultra violet lamps were mounted vertically on the sides of the chamber to simulate the UV radiations. The electric heaters and UV lamps were operated automatically through the temperature controllers and timers for the desired period. An 11 kV/ 100 kVA transformer is used as high voltage source.

The insulators were subjected to dry power frequency withstand test as preliminary test before commencing the pollution study. The pollution study is studied by considering 8 months of summer, 3 months rainy season, and 3 months of winter. The various environmental parameters used of simulating the severe conditions are

<table>
<thead>
<tr>
<th>Characteristic parameter</th>
<th>Specified conditions</th>
<th>Duration per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>7 kV</td>
<td>24 h</td>
</tr>
<tr>
<td>Temperature</td>
<td>45°C</td>
<td>24 h</td>
</tr>
<tr>
<td>Rain</td>
<td>3 mm/ min 45° with vertical 100 µs conductivity</td>
<td>1 h</td>
</tr>
<tr>
<td>Salt fog</td>
<td>28 kg/m³</td>
<td>3 h</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>UV of wavelength 313 nm</td>
<td>8 h</td>
</tr>
</tbody>
</table>

Figure 2: Artificial pollution chamber layout

![Artificial pollution chamber layout](image-url)
Dry power frequency test:
The test specimen is placed in between the electrodes and the power frequency voltage is applied as in steps from zero to 2.5 times the rated voltage as per IEC60. The voltage and the current are measured by voltmeter and an ammeter. The voltage is increased gradually from zero to 30 KV, all insulators under test has withstood the voltage applied and the leakage current is measured.

Conclusions
Due to the organic nature of polymer insulators the degradation due to the environmental stresses is more rapid than that of porcelain insulators. In order to predict the life of polymer insulators it is necessary to carry the acceleration test with enhanced levels of stress experienced by the insulators as in its service conditions. The accelerated testing at high level of stress reduces the test duration and helps in developing an appropriate degradation model for predicting the life of insulators.

References
3. IEC Specifications 1109, Composite insulators for a.c. overhead lines with nominal voltage greater than 1000 V – Definitions, test methods and acceptance criteria.
5. Insulators for high voltages- J.S.T.Looms
6. STRI; Guide for visual identification of deterioration and damages on suspension composite insulators.
7. Standards: IEC,ASTM