Evolution of Insulator Technologies

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Worldwide Market Survey (Goulden Reports)

Markets Predict that Energy Demand in India and China will increase 7% and 10.3% cagr (compound annual growth rate) for few more years
All three insulator types have extremely low failure rates and will co-exist. The seminar will focus on problems encountered, consequences and solutions
## Insulator comparison at a glance

<table>
<thead>
<tr>
<th>Insulator</th>
<th>Positive Attributes</th>
<th>Negative Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite</td>
<td>Weight, small profile Contamination withstand Low installed cost Impact strength Unique, economic designs</td>
<td>E-Field control critical, no standards, aging Hidden defects, hard to detect Mechanical failures (Brittle fracture, rod degradation)</td>
</tr>
<tr>
<td>Porcelain</td>
<td>Performance quantified Long history of use High level of standardization</td>
<td>Heavy, wettable Flashover in contaminated locations</td>
</tr>
<tr>
<td>Glass</td>
<td>Same as porcelain Spotting defective and damaged units</td>
<td>Same as porcelain negative perception of vandal damage</td>
</tr>
</tbody>
</table>

Selection will depend on what positive attributes you desire and negative attributes you can tolerate.
Porcelain insulators

- Used since the early days of outdoor power delivery
- Dominant among all types
- Used at all voltages (ac and dc) for lines, stations, equipment bushings
- Many suppliers worldwide
Porcelain Insulators

Made by wet process

Variations in raw material quality and processing details amongst manufacturers

Energy intensive, labor extensive, many steps

Manufacturing is usually 24X7

Alumina (high strength) composition used for transmission insulators

Quartz (low strength) composition used for distribution insulators

Routine testing eliminates defective insulators in factory
Glass Insulators

• Used since 1800s on telegraph lines (pin type)
• Used since beginning of outdoor power delivery
• Glass toughened for insulator use
• Suspension insulator discs used at all voltages (ac and dc) for lines
• Available in same shapes as porcelain
• Dominated by one manufacturer, but now 3-4 more have entered market. None in India
Glass Insulators

- Fewer steps than porcelain
- Variation in raw materials quality, composition and processing (toughening) amongst manufacturers
- Homogenous material, better dielectric, so shells thinner than porcelain
- Energy intensive
- Toughening process is a hard mastered skill
- Toughening process eliminates most defective insulators in factory
Composite Insulators

• Introduced for transmission during 1970s
• Used at all voltages (ac and dc) for lines
• Largest use is for voltages below 230 kV
• Longest user base is USA, largest user is China
• Many suppliers worldwide
• Use in station apparatus started around 1990s. Faster acceptance for EHV and UHV apparatus than for lines
**Composite v Porcelain**

- Long fiber glass rod has low weight, good electrical+mechanical strength, housing provides hydrophobicity
- NOT interchangeable, each manufacturer has different dimensions for same voltage
- Long rod makes electric field highly nonlinear, corona rings needed
- Long rod makes routine electrical testing expensive – not done
- Long rod covered with rubber and hardware makes defect detection extremely difficult

- Insulator string made of many modular units (discs, bells)
- Units interchangeable, follow common standards
- Electric field more linear due to intermediate cap and pin electrodes
- Modular construction makes routine electrical testing possible
- Modular construction makes detecting internal defects possible
Flashover due to contamination is a problem common to porcelain and glass. Countermeasures are mature.
Making Porcelain Work in Contaminated Locations

- Water washing
- Adding more bells (creepage)
- Dry cleaning
- RTV Coating
Deterioration due to flashover is minimal, not a concern for healthy strings
Failure modes observed with porcelain (happens after many years)

Cracking due to cement expansion

Degradation due to surges

Puncture

Decapping
Pin corrosion problem (in some locations) in porcelain and glass and its cure
Reduction of strength with time (courtesy: Powerlink)
Missing glass shell due to spontaneous shattering

Usually not a concern for string strength
Reduction in mechanical strength with time is minimal for Glass insulators

Tensile Load Tests on Glass Insulators (Intact and Stubs) Normalized to M&E ratings

![Graph showing normalized failure load vs insulator number with two traces labeled F1 and F2.](image-url)
Reasons for Using Composites in USA (EPRI survey 2002)
Majority of use: Line posts, Dead-end usage is lowest

65 out of 75 utilities use polymer insulators.
Evolution of Composite Insulators

- Insulators with central fiber glass core and housings made from epoxy, teflon and elastomers introduced in 1970s. Of these, only those with elastomeric housings survived and flourished.

- Early generation insulators experienced failures due to many reasons. Many US utilities became reluctant to use composites for transmission in the 1980s.

- Constant quality improvement by few dedicated suppliers and gradual use increased confidence for voltages up to 230 kV.

- Today’s insulators have improved significantly and industry standards have been (or being) developed. But utilities are still cautious about using composites for EHV and UHV lines for reasons of reliability, premature failures and lack of live line working standards.

- There is greater comfort in using composites at lower voltages where outages are not as critical as on EHV and UHV lines. Commodity item for distribution voltages (low price) in North America.
Pultrusion Process for Composite Insulators

Continuous fiber reinforcement is drawn through a resin bath to coat each fiber. The coated fibers are then drawn through a heated die. Cure of thermosetting resin is initiated by heat in the die and catalyst in the resin mix. The rate of reaction is controlled by heating and cooling zones in the die. The resulting high strength profile is cut to length, ready for use as it leaves the pultrusion machine.

Epoxy molecule
Things that can go wrong during manufacturing that are not detected...

- Cracked rod due to crimping
- Voids in glass fibers
- Voids between glass fibers

...Until they are energized in service
Diagnostics for detecting defective insulators

- Glass: None required, visual inspection from ground is sufficient
- Porcelain: Several tools commercially available and used routinely by utilities
  - All require climbing up the tower (or bucket truck)
  - Reasonably inexpensive
  - Instruments detect punctured bells, measure resistance

  **International Standards exist for live line working on porcelain/glass insulators**

Composite insulators: Instruments are expensive, unclear results, require expertise, still in research stage

  **International standards have not been developed for live line working with composites**

Live Line working is a requirement for EHV/UHV lines in USA (and many countries worldwide)
## The rule of nines for reliability (availability)

<table>
<thead>
<tr>
<th>Availability (%)</th>
<th>“Nines”</th>
<th>Annual Interruption Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>1</td>
<td>36.5 days</td>
</tr>
<tr>
<td>99</td>
<td>2</td>
<td>3.7 days</td>
</tr>
<tr>
<td>99.9</td>
<td>3</td>
<td>8.8 hours</td>
</tr>
<tr>
<td>99.99</td>
<td>4</td>
<td>52.6 minutes</td>
</tr>
<tr>
<td>99.999</td>
<td>5</td>
<td>5.3 minutes</td>
</tr>
<tr>
<td>99.9999</td>
<td>6</td>
<td>31.5 seconds</td>
</tr>
<tr>
<td>99.99999</td>
<td>7</td>
<td>3.2 seconds</td>
</tr>
<tr>
<td>99.999999</td>
<td>8</td>
<td>0.3 second</td>
</tr>
<tr>
<td>99.9999999</td>
<td>9</td>
<td>1.5 cycles (50 Hz)</td>
</tr>
</tbody>
</table>

What is your target for Reliability?