Substation Outdoor Insulation Solutions and Application

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SHEMAR
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1. BACKGROUND
2. CHALLENGES
3. SOLUTIONS
4. APPLICATION
Background—History Contribution of Substation Porcelain Insulator

Since high voltage transmission started, porcelain insulators had been adopted to outdoor insulation, and substation porcelain insulators made a historic contribution.
Background—Malignant Accidents of Substation Porcelain Insulator

**Pollution Flashover**
Hydrophilic, causing pollution flashover accident

**Icing**
Covering ice, causing flashover accidents

**Fracture**
Brittle materials, causing fracture when earthquake disaster and equipment movements

**Explosion**
Brittle materials, causing explosion accident
Background—High Maintenance costs Of Substation Porcelain Insulator

Huge maintenance costs every year
Energy consumption and carbon emissions are high on manufacturing process.

Raw materials are non-renewable resources bauxite, aggravating soil erosion problems.
Background——Development process Of Substation Composite Insulator

- Malignant Accidents
- High Maintenance Costs
- Manufacture Difficulty
- Environment Influence

Substation Composite Insulator
Background——Short Lifespan of Room Temperature Vulcanized (RTV) Silicone Rubber Composite Insulator

- Low molecular weight, only \((1-10) \times 10^4\) g/mol
- Hydroxyl at the end, easy to be depredated
- Aging in harsh areas, hard to meet the use requirements of the whole life-cycle.

- **Failure case**  Aging happened on SF\(_6\) CT RTV hollow composite insulator manufactured by China.
Background——LSR Composite Insulator Poor Erosion Property and High Cost

- Low molecular weight, 
  \((1-10) \times 10^4 \text{g/mol}\).
- Less frame retardants in formula
- Poor erosion property and high cost

Failure case
Aging on LSR bushing in EHV ±800kV Fengxian and Guizhou Mawo converter station.
Continuous discharge poor hydrophobicity recovery property on LSR bushing in EHV Suidong converter station.
Background—— Poor hydrophobicity and Mechanical Properties of HTV Spiral Composite Insulator

- Shed and sheath restricted by manufacturing process, inadequately vulcanized.
- Poor mechanical properties, such as elongation at break, tear strength, etc.
- Failure case: Loss of hydrophobicity happened on DC voltage divider composite insulator in ±500kV converter station in Hubei, China.
Background—— low-quality formula HTV silicone rubber

In recent years, the appearance of a large number of low-quality formula high temperature vulcanized silicone rubber produced the illusion of short life of HTV silicone rubber.
USERS:
WE WANT
PERFECT INSULATORS!
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Application requirements of composite insulators for substation
— Environment

Composite insulators in substations need to face different special environments, such as some regions with strong ultraviolet, strong sandstorm, large temperature difference between day and night, coastal salt-fog and so on.
Application requirements of composite insulators for substation —— Mechanical properties

Composite insulators in substations need to meet various mechanical requirements for different equipment.

**Bending requirements:**
- MML, SML (hollow);
- MDCL, SCL (post);

**Deflection requirement:**
- MSP, SIP.

**Internal pressure requirements (hollow):**
- SToL, MDToL.

**Torsion requirements:**
- SCoL, MDCoL.

**Compression requirements:**
Application requirements of composite insulators for substation
—— Special Properties

The inside liner is resistant to HF and transient high temperature. Such as LTB, DTB.

Resistance to various types of insulating oil. Such as CVT, oil CT.

Eddy current and temperature rise requirement. Such as Reactor.
Challenge of Technology

1. Research of shed and sheath materials on substation composite insulator
   meet the requirements of application:
   Hydrophobicity and hydrophobicity transform resistance performance
   Erosion aging resistance performance
   Ultraviolet radiation resistance performance
   Sand abrasion performance

2. Research of FRP materials on substation composite insulator
   meet the requirements of application:
   Mechanical properties
   High temperature arc erosion and HF gas corrosion performance resistance
   Oil resistance performance

3. Research of sealing structure design on substation composite insulator

4. Research of manufacturing process on substation composite insulator
   How to make silicone rubber overall compression molding, adequately
   vulcanized, reliably bonding with FRP

5. Technology supplemental notes
   meet the requirements of application:
   Salt fog aging resistance performance
   Acid rain corrosion resistance performance
   Low temperature and temperature difference resistance performance
   Effectively prevent bird pecking and rat bite
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**Solutions——Housing Material**

*Ageing resistance performance*

- **Environmental Factor**
  - UV
  - Acid rain
  - Sand
  - Salt spray

- **Electrical Factors**
  - Arc, leakage current

- **Types of materials——HTV**

- **Material formulation——Homemade formula**

- **Vulcanizing process——whole vacuum injection molding process**
Solutions——Housing Material

Hydrophobicity and hydrophobicity transform performance

◆ Requirements:
Silicone rubber should have excellent hydrophobicity and hydrophobicity transform performance. Hydrophobicity of composite insulator in service should reach HC6 under Chinese industry standard DL/T 864.

◆ Solutions:
We selected one kind of HTV whose molecular mass was 720 thousand g/mol, and developed a reasonable formula.
Solution——FRP Materials
Structure, Formula and Technology Design of FRP Tube

How to design a FRP tube?

- Geometric Construction
- Fiber Orientation Structure
- Materials Formula
- Moulding Technology

Higher MML, SML, MSP, SIP, Compression Strength, and lower Deflection
The geometric construction of FRP tube can be designed to meet the technical requirements of electrical equipment.
The relationship of fiber orientation structure and mechanical properties can be established based on finite element simulation analysis.
3.2.3 Materials Formula Design

Solution——FRP Materials

Resin
- Mechanical property
- Heat resistance
- Compatibility
- Corrosion resistance

Additive
- Functionality
- Manufacturability
- Interfacial infiltration

Raw Material
- Curing Agent
- Flexibilizer
- Coupling Agent

Fiber
- Modulus
- Electrical performance
- Impregnating compound

Raw Material:
- UP
- PU
- EP
Solution—FRP Materials

3.2.4 Moulding Technology Design

Technological Process

Winding

Impregnation

Curing

Spreading

Demoulding

Turning

Critical Control Point

Curing Process

Flexure Strength (MPa)

Modulus (GPa)

55%

Reasonable moulding technology

Better mechanical properties

FRP Materials
Solutions— Outdoor insulation
The First Generation
(2007)
Solid Type

The Second Generation
(2012)
Perfusion Type

The Third Generation
(2015)
Inflatable Type

The Fourth Generation
(2018)
Unpressured Type

- Safer
- More economical
- More environmentally friendly
Product Structure Design

Technical solutions:

- Post insulator adopts hollow core structure.
- Inside is an atmospheric pressure dry nitrogen.
- Desiccant inside the product (micro water control double guarantee)
The composite crossarm is applied in the 500kV Leizhou Power Plant to the Hong Kong City power transmission line project, totaling 36.

Capacitor support insulators at Zhumadian Station in Qinghai Henan Project, a total of 30.

The busbar insulators in the Wudongde project.
Hollow insulator

- DTB
- LTB
- CT
- CVT
- Cable accessories
- Surge arrester
- Transformer
Solution of Composite Insulator for Live Tank Circuit Breaker

The interrupter of breaker is of self-compressed construction. When the circuit breaker is opening state, the arc is extinguished by high pressure heat expanded gas flow.

LTB equipment photo

There is a possibility that the arc will be blown to the inner surface of the insulator by air flow.
Solution of Composite Insulator for Live Tank Circuit Breaker

Requirements for arc extinguishing chambers
1. HF acid corrosion resistance.
2. High temperature arc resistance. (Partial chamber requirements)

Solution A: Insulator lining of arc extinguishing chamber is made of polyester material resistant to HF corrosion.

Solution B: The insulator of arc extinguishing chamber is lined with special composite materials which are resistant to high temperature, electric corrosion and HF corrosion.
reliability demonstration test

Spray Arc Ablation Test of Acetylene at 1000 ℃

Burning lining

Burning results

After surface cleaning

Side image

The lining material, bonding surface and FPR pipe are all intact.
The 252kV and 550kV auxiliary switches developed in cooperation with Xian XD Switchgear Electric Co., Ltd. have been operated in XIHARI\(^1\) for nearly two years.

The figure shows the inner surface of insulator during the repair of 550 kV auxiliary switch. After experiencing the test of breaking frequency far exceeding the normal power plant circuit breaker, the inner layer has hardly changed and no burning phenomenon has been found.

1: XIHARI: Xian High Voltage Apparatus Research Institute Co., Ltd
Composite OIP (COIP) Transformer Bushing

Transformer Bushing

Shemar oil-impregnated-paper capacitive composite bushing
Introductions of COIP Bushing

Shemar oil-impregnated-paper capacitive composite bushing is a combination of the hollow composite insulator, capacitor core, metal accessories, oil insulating tube, transformer oil and other components.

Comparing with the traditional porcelain bushing, Shemar bushing has better performance. Meanwhile, our integral sealing structural design and superior producing technology of the capacitor core secure the bushing’s electrical, mechanical and sealing performance.
Design of COIP Bushing

Traditional Connecting Joint (Screw)  Shemar Connecting Joint (Spring)

Traditional spring tighten sealing structure  Shemar’s integral bending sealing structure

Porcelain Shield  FRP cylinder

Traditional paper tape winding  Wide cable insulating paper winding
## Advantages of COIP

<table>
<thead>
<tr>
<th>Shemar COIP Bushing</th>
<th>Traditional Porcelain Bushing</th>
</tr>
</thead>
<tbody>
<tr>
<td>➤ Integral sealing design</td>
<td>➤ Pull-on seal structure not reliable</td>
</tr>
<tr>
<td>➤ Waterproof</td>
<td>➤ Sealing parts aging</td>
</tr>
<tr>
<td>➤ Spring contact structure</td>
<td>➤ Material issues</td>
</tr>
<tr>
<td>➤ Anti-flashover</td>
<td>➤ Explosion</td>
</tr>
<tr>
<td>➤ Shock resistance</td>
<td>➤ Breakdown and explosion caused by sealing issues</td>
</tr>
<tr>
<td>➤ Long-term capable materials</td>
<td>➤ Secondary damage and fire</td>
</tr>
<tr>
<td>➤ Quality controls</td>
<td>➤ The reverse parts are mostly screwed or thimble-connected, overheating could be easily caused</td>
</tr>
<tr>
<td></td>
<td>➤ Flashover</td>
</tr>
<tr>
<td></td>
<td>➤ RTV spraying with high cost</td>
</tr>
<tr>
<td></td>
<td>➤ Easily damaged during delivery, low shock resistance</td>
</tr>
<tr>
<td></td>
<td>➤ Offset of the porcelain bushing</td>
</tr>
<tr>
<td></td>
<td>➤ Abnormal gas releasing</td>
</tr>
<tr>
<td></td>
<td>➤ Dielectric loss, partial discharge</td>
</tr>
</tbody>
</table>
Economic Advantage of Composite Insulator

1 Saving purchase cost
Composite insulators for all equipment of all voltages are cheaper than porcelain insulators.

Form 1. How cheap comparing with porcelain insulators

<table>
<thead>
<tr>
<th>Equipment</th>
<th>110kV</th>
<th>220kV</th>
<th>330kV</th>
<th>500kV</th>
<th>750kV</th>
<th>1000kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>GIS</td>
<td>5.0%</td>
<td>20.6%</td>
<td>54.0%</td>
<td>35.6%</td>
<td>60.0%</td>
<td>62.5%</td>
</tr>
<tr>
<td>SF₆ CT</td>
<td>2.6%</td>
<td>7.4%</td>
<td>15.2%</td>
<td>42.5%</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>LTB</td>
<td>4.0%</td>
<td>2.0%</td>
<td>11.8%</td>
<td>10.3%</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>SA</td>
<td>12.0%</td>
<td>9.8%</td>
<td>8.0%</td>
<td>13.3%</td>
<td>7.1%</td>
<td>13.8%</td>
</tr>
<tr>
<td>Transformer</td>
<td>5.6%</td>
<td>9.5%</td>
<td>17.6%</td>
<td>25.0%</td>
<td>21.0%</td>
<td>32.8%</td>
</tr>
<tr>
<td>CT</td>
<td>20.0%</td>
<td>7.4%</td>
<td>3.6%</td>
<td>5.6%</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>CVT</td>
<td>11.1%</td>
<td>11.1%</td>
<td>9.5%</td>
<td>15.6%</td>
<td>13.3%</td>
<td>22.0%</td>
</tr>
</tbody>
</table>

2 Low Maintenance Cost
During the whole life circle of composite insulator, cleanness and antifouling coating is not necessary due to the hydrophobicity and migration of hydrophobicity of the composite material. It saves large amount of maintenance cost and also shortens the repair time.

Take 750KV Qianxian Substation for example: painting all insulator PRTV will cost 12 million RMB (not including power cut losses). During the whole life circle, it need four times painting, the total cost of which is 48 million RMB. Statistic shows that, in China, the maintenance costs large amount of money. It is 10% more than profit of the Grid. Using composite insulator can surely save this part of cost, showing the obvious economic advantage.
3 Saving Transportation and Installation Cost

<table>
<thead>
<tr>
<th>Material</th>
<th>Weight (500kV chamber as example /kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porcelain</td>
<td>460</td>
</tr>
<tr>
<td>Composite</td>
<td>180</td>
</tr>
</tbody>
</table>

Composite insulators relay on machines to shape and to control the dimension. The lead-time is shorter and the weight is lighter, so it will not damaged easily during transportation. Large amount of money can be saved during transportation and installation.

Installation becomes easier. Take 750kv DS post insulator as an example, porcelain insulators need infrared locator. One porcelain DS need 20 days for installation, while composite one Only need 3 days.

4 No Accident cost

Composite insulator, relay on its technology advantage, has no accident like porcelain ones: explosion, brittle, flashover…Therefore, there is no accident cost. (including cost for changing equipment, off-line maintenance, and labor.)

The explosion of 500kV LTB

The explosion of 500kV LTB

The explosion of 800kV oil CT
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Application of composite insulators in substation for SHEMAR since 2011

- GIS
- Pass
- Oil CT
- Bus-bar supporting
- Optical instrument transformer
- DTB
- CVT
- Capacitor
- Cable terminal
- Transformer
- Reactor
- Arrester
- SF6 CT
Application of composite insulators in substation —— Earliest operation

500kV Substation in Minfeng, Hunan. SF6 instrument transformer was in operation in 2002.
SHEMAR tested the 500kV hollow composite insulator used for more than 15 years. Shemar cooperated with equipment manufacturer to carry back a hollow composite insulator which has been running for 15 years and has been replaced from 500kV Minfeng substation in Loudi, Hunan province. Then we shipped it back to the factory for overall test and component material test. The results showed that the product performance was basically unchanged.

**Mechanical and electrical properties before and after operation**

<table>
<thead>
<tr>
<th>Items</th>
<th>New product</th>
<th>Running 15 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum offset at the top of the 4kN bending load (mm)</td>
<td>6mm</td>
<td>6.4mm</td>
</tr>
<tr>
<td>Maximum offset at the top of the 36kN bending load (mm)</td>
<td>12mm</td>
<td>11.6mm</td>
</tr>
<tr>
<td>Intrinsic pressure(1.6MPa，5min)</td>
<td>No leakage</td>
<td>No leakage</td>
</tr>
<tr>
<td>Seal test (annual leakage rate)</td>
<td>0.001</td>
<td>0.0012</td>
</tr>
<tr>
<td>Power frequency withstand voltage (kV)</td>
<td>680</td>
<td>680</td>
</tr>
</tbody>
</table>

**Performance of silicone rubber before and after operation**

<table>
<thead>
<tr>
<th>Items</th>
<th>New product</th>
<th>Running 15 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness（HSD）</td>
<td>62</td>
<td>63</td>
</tr>
<tr>
<td>Tensile strength（MPa）</td>
<td>5.1</td>
<td>4.9</td>
</tr>
<tr>
<td>Elongation at break（%）</td>
<td>282</td>
<td>268</td>
</tr>
<tr>
<td>Hydrophobicity</td>
<td>HC1</td>
<td>HC1~HC2</td>
</tr>
<tr>
<td>Tracking resistance</td>
<td>1A4.5</td>
<td>1A4.5</td>
</tr>
<tr>
<td>Flame resistance</td>
<td>FV-0</td>
<td>FV-0</td>
</tr>
</tbody>
</table>

Minfeng substation put into operation at the end of 1995. When it expanded in 2002 it used SF6 current transformer produced by Hunan power electric porcelain electrical appliance factory which used hollow composite insulator produced by SHEMAR and has been worked well so far.
SHEMAR electric power carries on the experiment to the Qinghai-Tibet project composite insulators shed material:

The Qinghai Tibet 750kV/±400kV AC and DC interconnection project was commissioned in 2011. The total length of the line is 1038km, with a maximum altitude of 5231 meters, with an average altitude of 4650 meters. Up to now, this is the largest DC transmission project built at the highest altitude in the world. Most of the line composite insulators are provided by SHEMAR. From 23 to 25 in September 2017, during the blackout of the line, SHEMAR changed the line insulators on the #636 and #637 two towers, and obtained 16 samples that had been running for more than 6 years, and then tested the shed material performance.

Performance of silicone rubber before and after operation

<table>
<thead>
<tr>
<th>Items</th>
<th>New product</th>
<th>Running 6 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (HSD)</td>
<td>68</td>
<td>71</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>4.3</td>
<td>4.15</td>
</tr>
<tr>
<td>Elongation at break (%)</td>
<td>336</td>
<td>301</td>
</tr>
<tr>
<td>Tear strength, kN/m</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>Hydrophobicity</td>
<td>HC1</td>
<td>HC2</td>
</tr>
<tr>
<td>Tracking resistance</td>
<td>1A4.5</td>
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</tr>
<tr>
<td>Flame resistance</td>
<td>FV-0</td>
<td>FV-0</td>
</tr>
</tbody>
</table>
In 2013, the 750kV Shazhou all-compound substation was in northwest China.
Application of composite insulators in substation —— UHV projects

Huidong 800kV converter station, Guangzhou
The support of smoothing reactor, Start operation in 2007

Jingmen 1000kV substation, Hubei province
HGIS lead-out bushing, Start operation in 2009
Application of composite insulators in substation —— Acid rain areas

500kV Substation in Xiangtan Hunan

It was in operation in 2006 and has been in operation for 11 years.

The frequency of acid rain is above 60%, and the average range of pH values is 4.56-4.90.
Application of composite insulators in substation —— High salt fog areas

500kV Substation in Datang Lusi power plant, Jiangsu

It was in operation in 2010 and has been in operation for 7 years.

The coastal salt fog area has long sunshine duration.
Application of composite insulators in substation —— Large temperature difference between day and night

750kV Phoenix Substation in Xinjiang

It was in operation in 2010 and has been in operation for 7 years.

The highest surface temperature in summer is higher than 50 degrees, and the lowest temperature in winter is low than -20 degrees. The maximum temperature difference between day and night is up to 40 degrees.
Application of composite insulators in substation —— Sandy areas

750kV substation in Riyue mountain, Qinghai

It was in operation in 2011 and has been in operation for 6 years.

It is in the strong sandstorm area.
Application of composite insulators in substation —— Sandy areas

750kV Substation in Shazhou

It was in operation in 2013 and has been in operation for 4 years.

It is in strong sandstorm area.
Application of composite insulators in substation —— Strong ultraviolet region

750kV Substation in Guanting, Qinghai

It was in operation in 2008 and has been in operation for 9 years.

It is in a strong ultraviolet region.
Shemar substation composite insulator servicing more than 90% of the global power transmission equipment manufacturers
Thanks!