Development of single piece premolded joint for EHV XLPE cable system

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Abstract - Premolded joint is made of silicone rubber, which incorporates an embedded high voltage electrode and two stress relief cones.

Aiming the voltage grade from 110kV up to 170kV, the actual performance was determined according to the latest IEC 60840 and IEEE 404.

The profile of electrical field for embedded HV electrode depends on the shape of HV electrode and stress relief cones. The electric field in the longitudinal direction at the interface between rubber and cable insulation is also important factor to influence the design.

Premolded sleeve was optimized by the aid of computer simulation and its result is shown in fig. 1.

![Diagram](image-url)

**Figure 1.** Optimized equipotential line and major points

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Silicone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elongation at break</td>
<td>%</td>
<td>594</td>
</tr>
<tr>
<td>Hardness</td>
<td>Shore A</td>
<td>30</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>N/mm²</td>
<td>7.1</td>
</tr>
<tr>
<td>Dielectric strength</td>
<td>kV/mm</td>
<td>40</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W/mK</td>
<td>0.17</td>
</tr>
<tr>
<td>Permanent set (250%)</td>
<td>%</td>
<td>2.1</td>
</tr>
<tr>
<td>Tear Strength</td>
<td>N/mm²</td>
<td>40</td>
</tr>
</tbody>
</table>

2.2 Electrical Design

Premolded joint is made of silicone rubber, which incorporates an embedded high voltage electrode and two stress relief cones.

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2.3 Mechanical Design & Thermal Design

To assure the electrical stability at the interface, the interfacial pressure was the key consideration. In this case, the interfacial pressure is ensured by the elastic retention of materials only without requiring any mechanical device. Thus, considering 30 years of safe operation, the definition of appropriate range of initial pressure has become essential. We determined the proper range as 1~4 kgf/cm² with rubber sleeve expansion ratio of 20% ~ 40%.

The cable was heated up to the conductor temperature of 130°C to investigate the change of interfacial pressure during heat cycle. The result shows that it is almost temperature-independent. It was also simulated by computer program and similar result was obtained.

![Figure 2. Profile of interfacial pressure distribution](image)

For a thermal design, avoiding the local hot spot is essential, especially where the conductor is connected. Thus, we used low thermal resistivity material to fill the gap between conductor ferrule and corona shield in order to help transferring the heat and avoiding local heat concentration.

3. Performance Test

For the uniform flow, we established control parameters of liquid silicone rubber using the dosing system during the manufacturing of a semi-conductive and insulation part.

With the adaptation of DoE (Design of Experiments) of molding temperature and time, we achieved improved manufacturing process.

![Figure 3. The construction of premolded joint](image)

After the molding process, visual inspection and X-ray analysis was performed in order to detect possible defects during the course of manufacturing process. Electrical tests such as AC withstand test and partial discharge test with the same cables and installation conditions were followed on each premolded sleeve.

Fig. 3 shows the construction of the developed premolded joint.

To evaluate the safety margin of design and reliability, the breakdown voltage tests were carried out numerous times. Fig. 4 and 5 show the results of AC and impulse breakdown voltage tests respectively.

![Figure 4. Weibull plots of AC test results.](image)

![Figure 5. Weibull plots of Impulse test results.](image)

The cumulative probability of failure (PF(t)) for both AC and impulse voltage tests are represented in equation (1) and (2), respectively.

\[
P_F(V_{ac}) = 1 - \exp\left(-\left(\frac{V_{ac}}{446.96}\right)^{6.15}\right) \quad (1)
\]

\[
P_F(V_{imp}) = 1 - \exp\left(-\left(\frac{V_{imp}}{1245.26}\right)^{10.02}\right) \quad (2)
\]
From these results, the newly developed premolded joint is proven to have excellent electrical performance for 170kV grade.

4. KEMA Type Test

The type test of single piece premolded joint in accordance with IEC standard 60840 was performed with witness of KEMA inspector. All tests were carried out successfully and proved the high reliability of the developed premolded joint. The test results are summarized in table 2.

<table>
<thead>
<tr>
<th>Test Item</th>
<th>Requirements</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Partial Discharge</td>
<td>114kV, ≤ 5pC</td>
<td>passed</td>
</tr>
<tr>
<td>2. Tan δ measurement</td>
<td>≤10⁻³</td>
<td>passed</td>
</tr>
<tr>
<td>3. Heating Cycle</td>
<td>152kV/20cycle cond. Temp. 95°C</td>
<td>passed</td>
</tr>
<tr>
<td>4. Partial Discharge</td>
<td>114kV, ≤ 5pC</td>
<td>passed</td>
</tr>
<tr>
<td>5. Impulse withstand</td>
<td>±650kV/10 shot</td>
<td>passed</td>
</tr>
<tr>
<td>6. AC Voltage</td>
<td>190kV/15min</td>
<td>passed</td>
</tr>
</tbody>
</table>

5. Conclusion

The single piece premolded joint made of silicone rubber was developed successfully for the first time in Korea. The high reliability was achieved through the strict quality control and numerous experiences of performance tests.

The developed premolded joint is cost-efficient and requires relatively simple and easy installation with a low degree of skill form the jointers. It will be expected to use widely in EHV underground transmission systems domestically as well as globally.

6. Reference