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초고압 XLPE 케이블용 프리몰드형 접속함 (Premolded Joint) 개발

신두성, 최수걸, 고의곤, 지응서, 민병관, 강채홍 전승익

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Development of single piece premolded joint for EHV XLPE cable system

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Abstract - 초고압 CV 케이블용으로 다양한 형태의 접속함이 사용되고 있으나, 최근 케이블 시스템의 사용 전압이 초고압화됨에 따라 접속함 또한 고품질, 고신뢰성이 요구되고 있다. 따라서 공장에서 엄격한 품질 관리가 용이하고, 현장에서 쉽게 조립할 수 있는 프리몰드형 접속함(Premolded Joint: PMJ)의 사용이 급격하게 증대되고 있다. 본 논문에서는 국내에서 최초로 110kV ~ 170kV 전압급의 PMJ 접속함 개발에 관하여 소개하였다. 전기적, 기계적 및 열적 설계의 개념을 간략하게 소개하였으며, 접속함의 초기 성능 및 장기 신뢰성을 검증하기 위한 시험 및 평가 결과를 소개하였다.

1. Introduction

Crosslinked polyethylene (XLPE) insulated cables are now widely used all over the world for extra-high voltage underground transmission system. Also in Korea, the portion of XLPE cables has rapidly increased since they were introduced for 154kV cable line in 1983.

For XLPE cables, tape molded joint(TMJ) has been mainly applied due to its high reliability using the same insulation material with XLPE cables. However, as the cost of power transmission facilities reduces, simple premolded joint is preferred for EHV cable system.

This situation leads us to develop the premolded joint and it was achieved by improving material characteristics and manufacturing process.

Factory-made premolded joint is pre-tested and requires relatively simple and easy installation with a low degree of skill from the jointers.

2. Premolded Rubber Sleeve Design

2.1 Material for Rubber Sleeve

Premolded joint requires an elastomeric material that is mechanically, thermally and electrically compatible to the XLPE cables. Among the elastomeric materials, EPDM and silicone rubber have been used for EHV cable accessories.

We chose silicone rubber for EHV premolded sleeve in consideration of dielectric strength, tensile strength, permanent set, heat resistance and compatibility of manufacturing equipment. The summary of material properties of silicone rubber is given in table 1.

Table 1. Properties for silicone rubber

Item	Unit	Silicone
Elongation at break	%	594
Hardness	Shore A	30
Tensile strength	N/mm^2	7.1
Dielectric strength	kV/mm	40
Thermal conductivity	W/mK	0.17
Permanent set (250%)	%	2.1
Tear Strength	N/mm^2	40

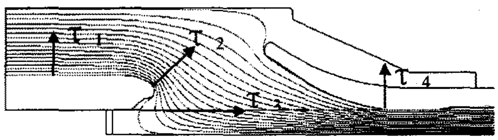
2.2 Electrical Design

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.



$\tau 1$: middle of HV electrode
$\tau 2$: tip of the HV electrode
$\tau 3$: interface between rubber and XLPE
$\tau 4$: start of the stress relief cone

Figure 1. Optimized equipotential line and major points

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 $1\sim4kgf/cm^2$ with rubber sleeve expansion ratio of 20 % ~ 40%.

The cable was heated up to the conductor temperature of 130℃ 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.

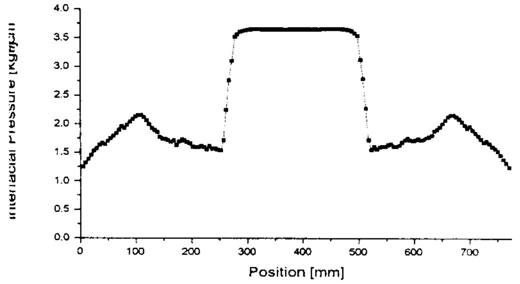


Figure 2. Profile of interfacial pressure distribution

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.

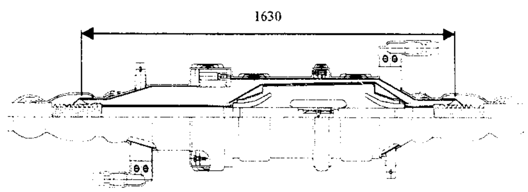


Figure 3. The construction of premolded joint

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.

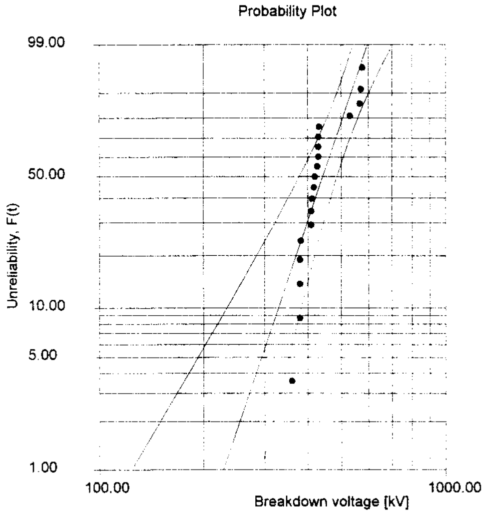


Figure 4. Weibull plots of AC test results.

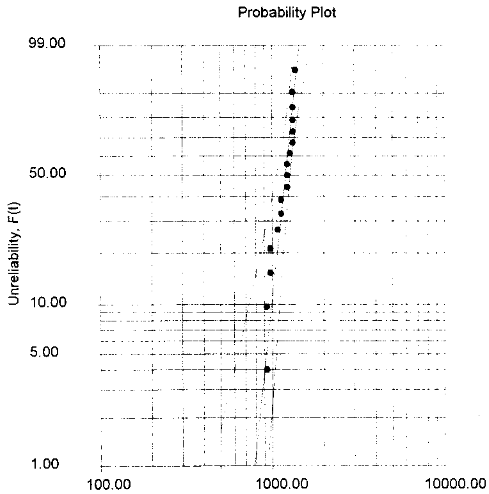


Figure 5. Weibull plots of Impulse test results.

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

$$P_F(V_{ac}) = 1 - \exp\left\{-\left(\frac{V_{ac}}{446.96}\right)^{6.15}\right\} \text{ ------------- (1)}$$

$$P_F(V_{imp}) = 1 - \exp\left\{-\left(\frac{V_{imp}}{1245.26}\right)^{10.02}\right\} \text{ ---------- (2)}$$

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 prempled 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 2. KEMA Type test results

Test Item	Requirements	Result
1. Partial Discharge	114kV, ≤ 5pC	passed
2. Tan δ measurement	$\leq 10^{-3}$	passed
3. Heating Cycle	152kV/20cycle Cond. Temp. 95℃	passed
4. Partial Discharge	114kV, ≤ 5pC	passed
5. Impulse withstand	±650kV/10 shot	passed
6. AC Voltage	190kV/15min	passed

5. Conclusion

The single piece premoled 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

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