Development of Cold-Shrinkable Joint for 110-kV XLPE Cables

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ABSTRACT One-piece, pre-molded joints have been used all over the world for (extra) high voltage ((E)HV) XLPE cables. For those pre-molded joints, ethylene-propylene rubber (EPR) has mainly been applied for many years because of its favorable electrical and mechanical properties.

With research on mechanical and electrical properties, we have succeeded to apply a new cold-shrink technology on those pre-molded joints using silicone rubber which has lower elasticity, better mechanical properties, such as lower permanent set, and so on. With this cold-shrink technology, pre-molded sleeves can be shipped expanded onto the carrier pipes. So the customer needs no tools for assembly at the jointing site and just needs to pull out the carrier pipes.

All the type tests required on IEC standards 840 were carried out including water immersion and heat cycling tests on our newly developed 110-kV cold-shrinkable joints (CSJ) and have shown good performance in all the tests, which means we became the first manufacturer in the world to put cold-shrinkable joints using silicone rubber for (E)HV XLPE cables on the market.

1. INTRODUCTION

Accessories for (E)HV XLPE cables, such as normal and insulation joints have a significant role on reliability of all the cable systems which are now going up in voltage to as high as 500 kV. For those joints, there are various kinds of structures like extrusion-molded type (EMJ), pre-fabricated type (PJ), tape wrapping type (TJ) and so on. With significant improvements in molding, one-piece, pre-molded joints has been widely used in this decade. Those pre-molded joints have an advantage of quality control because most of their parts are manufactured, tested and composed at the factory site. For pre-molded joints, ethylene-propylene rubber (EPR) has mainly been applied.

On the other hand, there have been achieved significant improvements in mechanical properties of silicone rubber this decade. This enables us not only to apply silicone rubber for cable accessories but gives an added dimension with its lower elasticity, lower permanent set than EPR.

We have taken advantage of those performances in silicone rubber and have developed cold-shrinkable joints for (extra) high voltage XLPE cables up to above 110 kV for the first time in the world. We also have developed a new technology in which those rubber-molded sleeves are expanded and fitted onto carrier-pipes --which can be

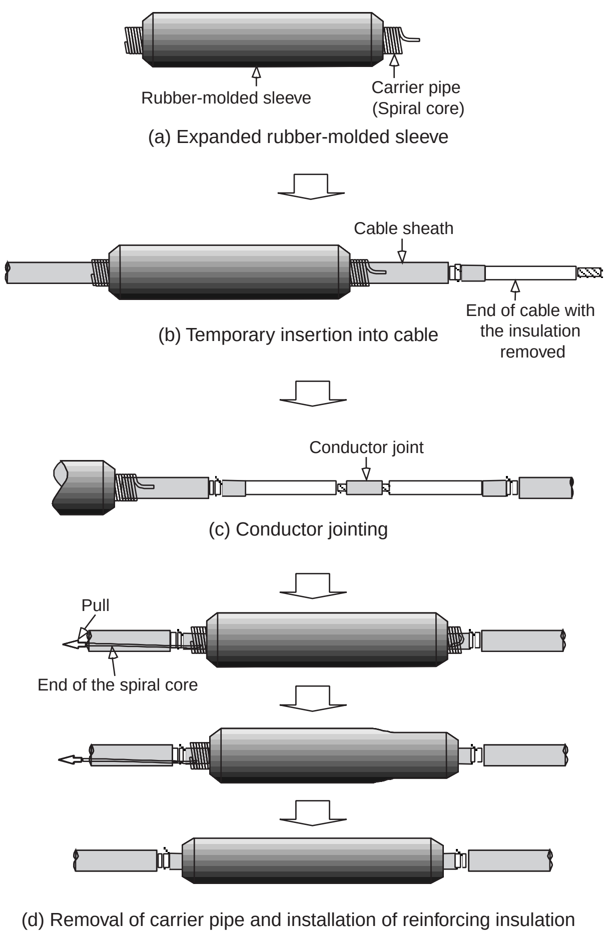

Figure 1 Assembly of cold shrinkable joints

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"pulled out" easily during assembly-- at the factory site as well as the pipes themselves.

2. COLD-SHRINKABLE JOINTS FOR (E)HV XLPE CABLES [1)]

Cold-shrinkable joints which should be shipped from the factory site with its rubber-molded sleeves expanded have significant advantages over any other pre-molded joints. Assembly of the rubber sleeves which is shown in Figure 1 should be easier because nothing except "pulling-out" the carrier-pipes is required. Moreover, the inner diameter of carrier-pipes which is larger than the outer diameter of the cable jackets enables it to remove the sheath at minimum length. It should give minimum size in joints including protection boxes in every case.

Previous technology which expands rubber molded sleeves at the assembly site generally requires expansion/shrinking equipment at the site. This contributed not only to the assembly cost including the equipment, but to the chances of imparting defects onto the interface between the rubber molded sleeve and the cable insulation.

We are the first manufacturer in the world who has introduced cold-shrinkable joints for (E)HV XLPE cables.

3. MATERIAL RESEARCH

3.1 Mechanical Properties

Silicone rubber had a limited applicability for cable accessories because of its low tear strength for many years since it was developed. But recent technology enables us to produce one which has high enough tear strength.

Table 1 Material properties of silicone rubber

Item	Silicone rubber	EPR
Elongation at break	790%	750%
Tensile strength	10 MPa	9.3 MPa
Stiffness (JIS-A)	34	60
Tear strength (JIS-A)	21.5 N/mm	11.8 N/mm
Permanent set at 100%	2.6%	32.4%

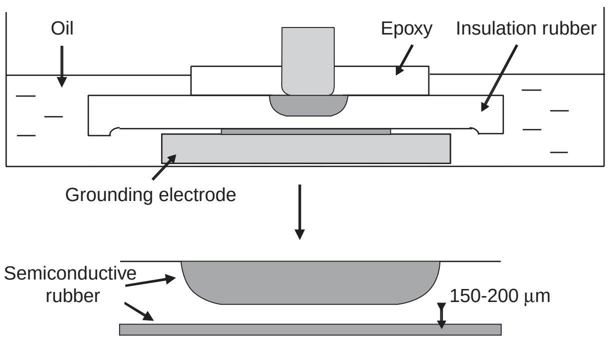


Figure 2 Electrical test setup with recessed specimen

Silicone rubber also has a significant advantage in stability over EPR in its properties at much higher temperatures, lower elasticity and permanent set, especially. So, we have decided to take advantage of its performance and chosen silicone rubber for our new accessories.

On the other hand, it should be excellent in its properties of elongation and permanent set when applied on cold-shrinkable joints. See Table 1.

3.2 Electrical Properties

3.2.1 Test Setup

To estimate its dielectric strength, we modified recessed specimens with a surface area of 153 mm^2 and tested them with an electrode which has a round shape and is embedded into epoxy as shown in Figure 2.

The electrical tests were also carried out in oil on more than 5 specimens for each condition. After the breakdown, thickness of the insulation layer was measured under a microscope and dielectric strength was calculated.

3.2.2 AC Voltage Breakdown Test

Test condition

Initial voltage: 6 kV/10 min
Step up voltage: 1 kV/10 min
Temperature: ambient, 90°C, 105°C

Test results

Figure 3 shows no temperature dependence of dielectric strength on AC voltage observed up to 105°C.

3.2.3 Impulse Voltage Breakdown Test

Impulse tests were carried out for each of the negative and positive pulses on different specimens.

Test condition

Initial voltage: + or -14 kV/3 times
Step up voltage: + or -1 kV/3 times
Temperature: ambient, 90°C, 105°C

Test results

No effect of polarity on lightning impulse voltage was observed. But temperature dependence was observed for each of the positive and negative impulses (Figure 4). The temperature coefficient on dielectric strength for impulse voltage was 1.1 (ambient/105°C) which is lower than other materials such as XLPE.

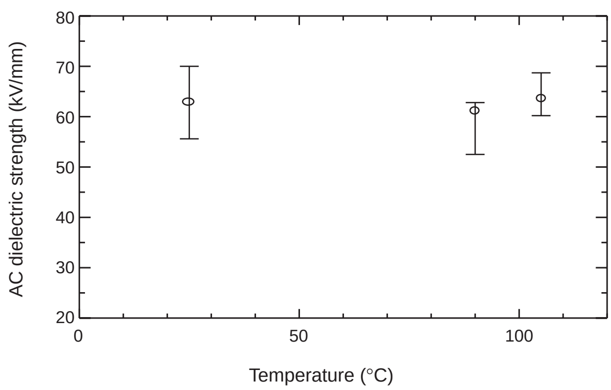


Figure 3 Temperature dependence of AC dielectric strength for silicone rubber

3.2.4 Long Term Test

Long term test has been carried out under certain AC voltage conditions for more than a year and is still continuing.

Life index "n" for this silicone rubber is more than 17, which is higher than other materials such as EPR and epoxy. See Figure 5.

With all the tests, we found out that the silicone rubber we have chosen has good enough electrical properties for cable accessories from short term point of view to long term.

4. DESIGN BASIS OF CSJ

4.1 Electrical Design

Electric field in the rubber-molded sleeve of CSJ was optimized by means of a computer. Stress-relief configuration is so well designed that the size of the rubber-molded sleeve is minimized. The designing features of CSJ are limited to four major points (τ1-τ4) as shown in Figure 6 because of its simple composure.

Figure 7 shows the result of electric field calculation for optimized CSJ which is set onto the cable.

τ1: surface of the inner stress relief layer
τ2: tip of the inner stress relief layer
τ3: interface between XLPE/rubber molded sleeve
τ4: edge of the stress relief cone

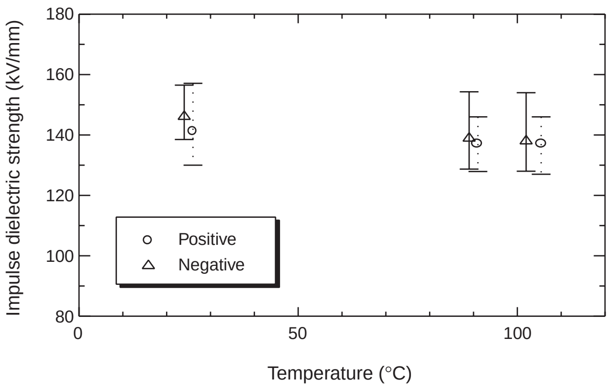


Figure 4 Temperature dependence of lightning impulse dielectric strength for silicone rubber

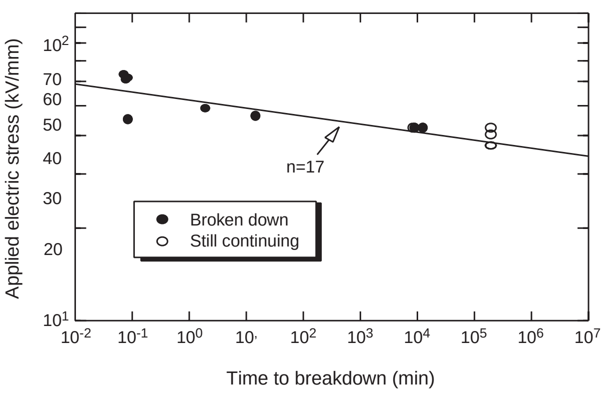


Figure 5 V-t characteristics of silicone rubber

4.2 Design of Interfacial Pressure

For any cable joints, interfacial design is the most important part. It is known that the stability in interfacial dielectric performance for pre-molded joints is mainly affected by interfacial pressure [2].

We established the design concept of interfacial pressure for our CSJ including its reduction in pressure during expansion state and operation period for about 30 years as shown in Figure 8. With applying silicone rubber which has better performance in permanent set for CSJ, the reduction in the interfacial pressure is suppressed to minimum. To estimate the reliability on designed interfacial pressure for CSJ, we used the models for each τ4 as shown in Figure 9 and τ3 as shown in Figure 10.

We also modified the rubber molded sleeve for (E)HV itself as shown in Figures 11 and 12 for testing at lower interfacial pressures. The cables which has a smaller outer diameter were used to maintain that lower pressure. In a modified rubber sleeve as shown in Figure 11, we

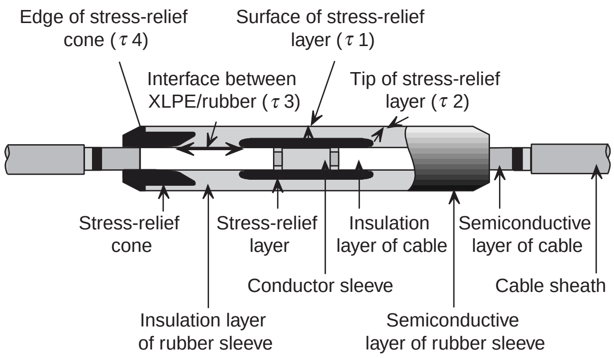


Figure 6 Electrical design of rubber sleeve of CSJ

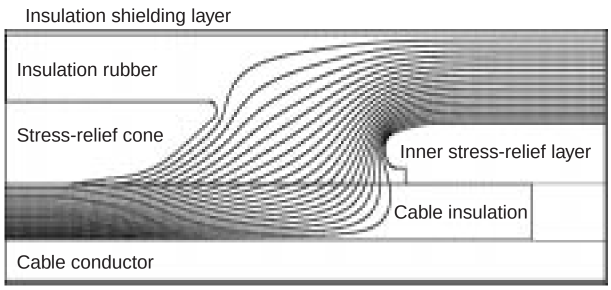


Figure 7 Result of electric field calculation for designing rubber-molded sleeve

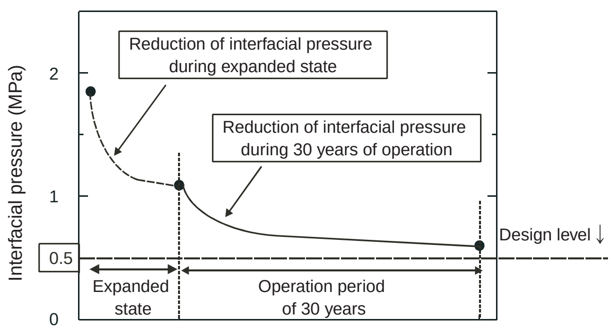


Figure 8 Reduction of interfacial pressure between rubber molded sleeve and XLPE cable in CSJ

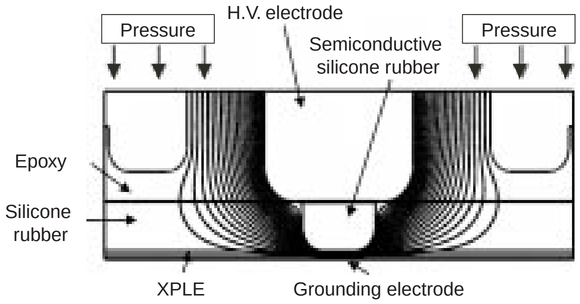


Figure 9 Sample setup which models electrical stress distribution at τ4

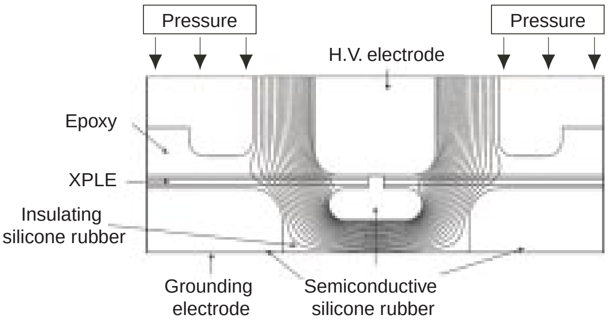


Figure 10 Sample setup which models electrical stress distribution at τ3

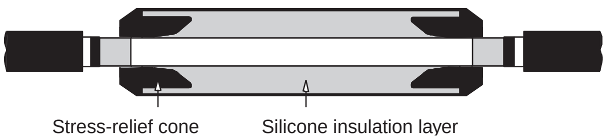


Figure 11 Modified sample to evaluate the dielectric strength at the edge of the stress-relief cone

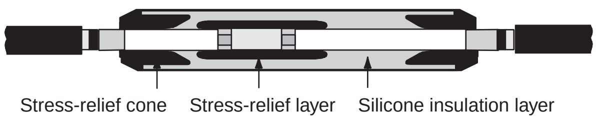


Figure 12 Modified sample to evaluate the dielectric strength of interface between XLPE and silicone rubber

Photo 1 Assembly of rubber molded sleeve for CSJ onto bonded cable

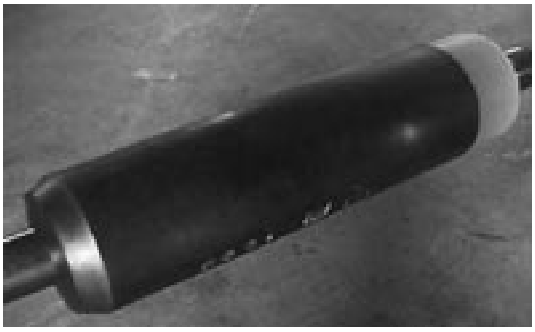


Photo 2 Rubber-molded unit shrunk onto the cable

Photo 3 Appearance of the completed 110-kV CSJ

could measure the effect of interfacial pressure on dielectric strength of the interface between rubber insulation and XLPE (τ3).

As a result, we found out that even with 0.04 MPa which is well below the designated level of 0.05 MPa, our CSJ can offer excellent dielectric strength at the interface. Thus, we confirmed the designated interfacial pressure level of 0.05 MPa at minimum.

5. EXPANSION TECHNOLOGY FOR CSJ

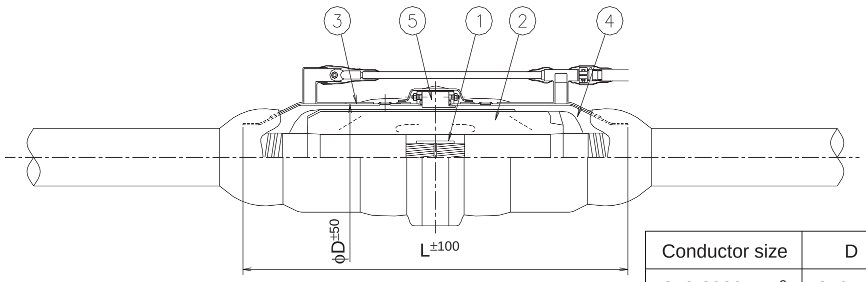
5.1 Design of "Pull-Out" Carrier-Pipes

To ease the assembly, rubber molded sleeves of newly developed CSJ should be shipped expanded onto the "pull-out" carrier pipes which are composed only of a plastic string as shown in Figure 1.

This carrier-pipe not only keeps the rubber-molded sleeve expanded at any state from expansion to shrinking but is pulled out easily by hand during shrinking state. To apply these "pull-out" carrier-pipes onto rubber molded sleeves for (E)HV joints which usually impart much bigger pressure onto the joints because of their thickness, it was necessary to optimize the shape of the string as well as bonded strength of its L-shaped edge.

5.2 Development of Special Equipment for Expansion

We also have developed special equipment to expand the rubber-molded sleeves onto carrier-pipes at the factory site. With newly developed equipment which has lower friction between the expansion rod and rubber molded sleeves, it becomes possible to expand quite easily the sleeves without any damage onto them in a short time.



Conductor size	D	L
240-2000 mm²	250 mm	1300 mm

① Conductive sleeve ② Rubber molded sleeve ③ Protection box
④ Waterproof compound ⑤ Bonding wire

Figure 13 Structure of CSJ for 110-kV XLPE cable

Table 2 Summary of the cable

Voltage class		110 kV
Conductor		Cu 400 mm²
XLPE insulation	Thickness	17.5 mm
	Outer diameter	61 mm
Metallic sheath		Aluminum
Outer jacket	Material	Polyethylene
	Outer diameter	89 mm

Table 3 Type test program and results

No.	Contents	Results
1.	Partial discharge test at 96 kV and ambient temperature after 112 kV x 10 sec loading was conducted. Requirement: less than 5 pC	Passed
2.	tan δ measurement at 64 kV and 95-100°C Requirement: less than 10^{-3}	Passed
3.	Heating cycle voltage test 20 cycles comprising 8 hrs heating to a conductor temperature of 95-100°C with the temperature maintained at least during the last 2 hrs followed by 16 hrs cooling. A test voltage of 128 kV was applied during the above heat test.	Passed
4.	Partial discharge test at 96 kV and ambient temperature and 95-100°C after 112 kV for 10 sec was conducted. Requirement: less than 5 pC	Passed
5.	Lightning impulse test 10 impulses 5/59 µs with ±550 kV of each polarity at a conductor temperature of 95-100°C	Passed
6.	AC voltage test with 160 kV for 15 min.	Passed

6. ASSEMBLY INSPECTION

Expanded rubber molded sleeve for (E)HV CSJ was fitted onto the sheath of the prepared cable end. After splicing the connector, preset rubber-molded sleeve was shrunk by pulling out the string of carrier-pipe as shown in Photo 1 through Photo 3. It took less than 10 minutes to shrink the rubber sleeve onto the cable. Figure 13 shows the structure of CSJ for 110-kV XLPE cables.

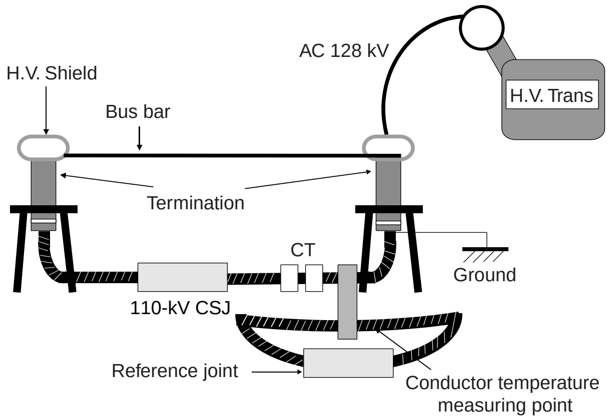


Figure 14 Test circuit for heating cycle test

7. IEC TYPE TEST

Tests in accordance with IEC standard 840 and IEC committee draft SC20A were performed in the presence of a representative of the third party inspection.

All the tests were carried out successfully and proved that newly developed CSJ has quite high reliability for 110-kV XLPE cables.

7.1 Heating Cycle Voltage Test

We applied our CSJ onto the cable which is summarized in Table 2 and carried out each required test in the order shown in Table 3. Figure 14 and Photo 4 show the test circuit for heating cycle test which includes reference joint.

After all those tests, the protection box and waterproof compound were removed and all the parts including rubber-molded sleeve were found to have no damage.

7.2 Water Immersion and Heat Cycling Tests

7.2.1 Test Condition

Water immersion and heat cycling test on the cold-shrinkable insulation joints (IJ) were carried out under the regulated condition of IEC 840 committee draft SC20A.

Photo 4 Test circuit for heating cycle test

7.2.2 Test Results

After the water immersion and heat cycling test summarized in Table 4, the electrical tests shown in Table 5 were carried out.

No significant changes inside the protection including the joint and the cable were detected.

8. CONCLUSION

We have successfully developed cold-shrinkable joints for (E)HV XLPE cables.

With its cold shrinking technology, we can guarantee the easiest assembly, the smallest body size as well as best performance for (extra) high voltage class in best price.

Table 4 Summary of water immersion tests

Heating cycle in air	More than 3 cycles comprising 8 hrs heating to a conductor temperature of 95-100°C with the temperature maintained for at least during the last 2 hrs followed by 16 hrs cooling
Heating cycle in water	20 cycles comprising heating to a water temperature of 70-75 °C with the temperature maintained for at least 5 hrs followed by cooling to within 10°C of ambient temperature

Table 5 Electrical test results after water immersion and heat cycling

Test	Requirement	Results
D.C. withstand (Tolerance)	20 kV for 1 min	Passed
Impulse withstand	±75 kV/10 times between parts	Passed
	±37.5 kV/10 times to earth	Passed

REFERENCE

1) Nozawa et al.; Development of intermediate joint for 66-kV CV cable with improved workability, '98 Annual meeting of IEEJ. p.460. (in Japanese)
2) Dang et al.; CEIDP, p.518, (1994).

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