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DEVELOPMENT OF 400KV XLPE CABLE AND ACCESSORIES

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ABSTRACT

A rubber block insulated type joint (hereinafter referred to as RBJ), where the main insulation component is made of cold shrinkable rubber, has become widely used for straight through joints of XLPE cable throughout the world. We have developed factory-expanded RBJ for XLPE cable joints applicable to 400kV underground power transmission line projects. Moreover, an improved outdoor sealing end (hereinafter referred to as EB-A) with the application of the cold shrinkable technology of RBJ was also developed. With these development, 400kV XLPE cable system with our new technology was completed.

KEYWORDS

400kV, XLPE cable, accessory, pre-moulded one-piece type joint, cold shrinkable technology

1. PREFACE

RBJ, where the main insulation component is made of cold shrinkable rubber, has become widely used for straight through joints of XLPE cable throughout the world. RBJ is categorized as PMJ1P ("Pre-moulded One-piece" type Joint). We have previously developed factory-expanded RBJ (we refers to the Smart Power Splicer: SPS) for 110 - 230kV system use and it has been supplied for various customers in the world and used with excellent results.

The quality of the rubber block insulation of SPS can be assured with well-controlled manufacturing process and quality control. One of the noteworthy aspects of SPS is to allow reduction of construction times due to its skill-less assembly processes.

We developed SPS for XLPE cable joints applicable to 400kV underground power transmission lines. Moreover, the improved EB-A was accomplished with the application of the cold shrinkable technology of SPS. The developed cable and accessories underwent Prequalification Test in accordance with IEC62067 in attendance of the reputable independent third party certification authority (CESI, Italy) in 2005. The certificate has been issued from CESI upon successful completion of the test, which included one year heating cycle voltage test as well as a residual performance test, and an examination on the completed cable system. With the acknowledgement of the high quality performance and successful test results by clients, delivery of the product has begun.

This paper describes the specifications and the test results of the developed cable and accessories.

2. SUMMARY OF SPECIFICATION

2.1 Cable

400kV CLZE 1c X 2000mm^2 (insulation thickness 26mm, lead sheathed) as shown in figure 1 and table 1.

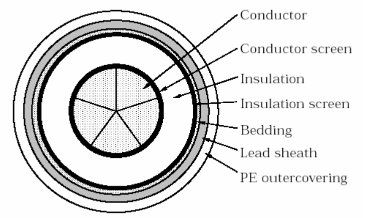


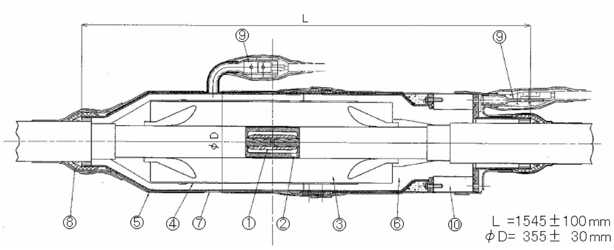
Figure 1: Structure of 400kV XLPE Cable

Table1: Construction of 400kV XLPE Cable

Conductor	Size	mm^2	2000
	Shape	—	Compacted segments
	Diameter	mm	54
Thickness of conductor screen		mm	1.8
Thickness of XLPE Insulation		mm	26
Thickness of insulation screen		mm	1.3
Thickness of bedding		mm	0.5
Thickness of lead sheath		mm	3.2
Thickness of PE outer-covering		mm	5.5
Overall diameter		mm	132
Weight		kg/m	43

2.2 Straight through Joint

SPS-A type (for culvert), shown in figure 2, and SPS-B type (for direct buried) were prepared. The rubber block insulation with cold shrinkable type is expanded and maintained on spiral cores at the factory. This spiral is pulled out from rubber block to form insulation component on the cable insulation at site.



①	Connector	⑥	Water-proof compound
②	Connector cover	⑦	Protector
③	Rubber block insulator	⑧	Taped seal
④	Shielding layer	⑨	Earthing terminal
⑤	Protection layer	⑩	Insulating section

Figure 2: Straight through Joint (SPS-A type)

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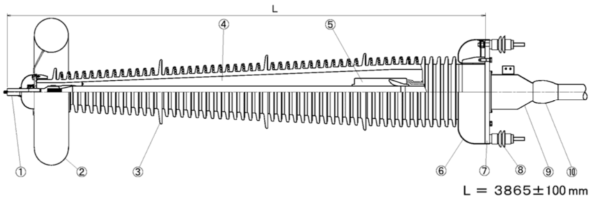
2.3 Outdoor Sealing End

EB-A-A type (Pollution level: Heavy), shown in figure 3, and EB-A-B type (Pollution level: Very heavy) were prepared. They serve as improved type of the EB-A prefabricated type with traditional epoxy bushing, rubber stress-relief cone, and compression device for the cone, as well as traditional oil-filled EB-A with electric field distribution by stress-relief cone.

The rubber stress-relief cone of the improved EB-A-A type is the cold shrinkable type like SPS.

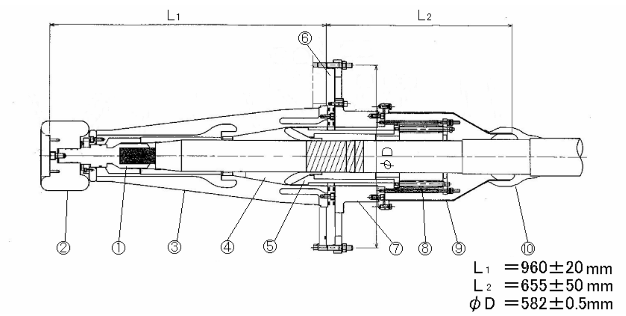


①	Conductor connecting rod	⑥	Under corona shield
②	Upper corona shield	⑦	Base Plate
③	Porcelain bushing	⑧	Supporting insulator
④	Insulating compound	⑨	Protection tube
⑤	Stress relief cone	⑩	Taped seal

Figure 3: Outdoor Sealing End (EB-A-A type)

2.4 SF_6 Gas Immersed Sealing End

SF_6 Gas Immersed Sealing End (hereinafter EB-G), shown in figure 4 was prepared. Improvement was made on prefabricated EB-G, used for the 275kV system before employment to the 400kV system.



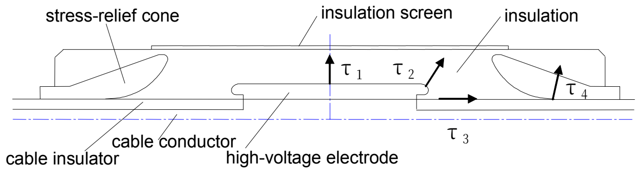
①	Conductor connecting rod	⑥	Base flange
②	Top adapter	⑦	Insulating section
③	Epoxy bushing	⑧	Compression unit
④	Stress relief cone	⑨	Protection tube
⑤	Compression pipe	⑩	Taped seal

Figure 4: SF6 Gas Immersed Sealing End (EB-G)

3. DESIGN OF SPS

3.1 Insulation Design

For designing of figures and dimensions of SPS, electric field analysis was carried out reflecting fundamental data accumulated by then. The most significant points of SPS in terms of electric fields are $\tau_1 \sim \tau_4$ as shown in figure 5. Table 2 indicates the electric stress of each point and figure 6 shows electric field distribution. As a result of the electric field analysis, it is confirmed that required performance levels are well-satisfied.



τ_1 : Radial stress on the flat part of high-voltage electrode

τ_2 : Stress on the edge of high-voltage electrode

τ_3 : Interfacial stress between the cable and rubber-block insulation

τ_4 : Stress of standing point of stress-relief corn

Figure 5: Insulation Design

Table 2: Analysis of Electric Field

Location	Electric stress (kV/mm)	
	AC(440kV)	Lightning Imp.(1425kV)
τ1	10.1	32.6
τ2	15.1	48.9
τ3	4.9	16.0
τ4	12.5	40.6

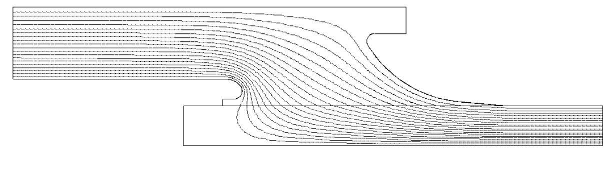
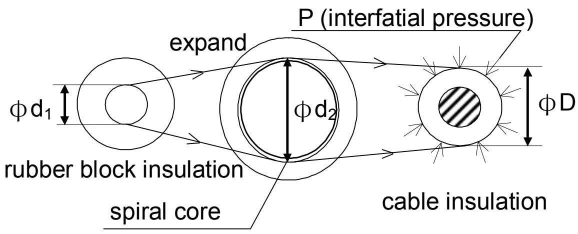


Figure 6: Potential Distribution in Rubber-block

3.2 Interfacial Pressure Design

As shown in figure 7, only interfacial pressure, arising out of the different diameter size of the outside insulation and the inside rubber-block, maintains insulation performance of SPS between rubber-block and cable insulation. Because rubber-block expanded at the factory is stored with the spiral core, it exhibits permanent stretch and gradual stress relief until the block is installed on the cables. Furthermore, gradual stress relief also occurs during its operation period. With consideration to above, interfacial pressure is designed to exceed the required pressure levels even after 30 years service operation.



ϕd_1 : Inner diameter of rubber-block insulation

ϕd_2 : Outer diameter of spiral core

ϕD : Outer diameter of cable insulation

Figure 7: Variation of Inner Diameter of Rubber-block

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3.3 Assembility and Performance

Silicone rubber was selected as rubber block insulation of SPS, with its superior electrical and mechanical properties. It satisfies above designed insulation and interfacial pressure. The following describe a precedent of jointing different size conductors by rubber-block of one size smaller than those for the 154kV to 230kV.

3.3.1 Size and Position of Rubber-block Installation

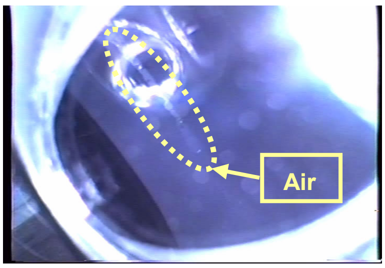
The length of the rubber-block changes when the cable diameter changes, and its length can be obtained by simulation. The simulation also allows obtaining the length of the rubber-block insulator after installation, even when the cables sizes to be jointed are different in diameter. The result of these simulation is confirmed as correct after a number of practical tests.

Therefore, the installation position of rubber block, especially the longitudinally length of the rubber- block, can be controlled with consideration to the tolerance of outside diameter of cable after insulation and rubber block length.

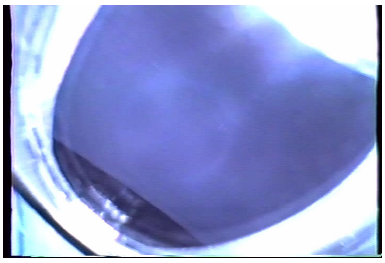
Hence, the over-wrap length between high-voltage electrode part and exposed cable insulation, as well as the over-wrap length between low-voltage electrode part (stress-relief cone) and cable semi-conductive insulation screen, are easily obtainable resulting in the improved assembility.

3.3.2 Examination after Installation

Interfacial pressure between rubber-block insulation and cable insulation was examined after installation of 1800mm^2 cables and 400mm^2 cables (both used for the 154kV system, and both have an insulation thickness of 17mm). It is confirmed that interfacial pressure is well-satisfied after two hours from installation even for 400mm^2 cable. Moreover, a transparent pipe of the same size was prepared to examine existence of any remaining minute air on installed rubber-block. Minute air containing in lubricant was observed helically along the spiral core, however, it was also confirmed that the air disappeared one hour after installation as shown in figure 8.



(a) Just after installation



(b) One hour after installation

Figure 8: Interfacial condition after installation

The result was the same for other tests at low temperatures (5℃) and also at high temperatures (35℃) carried out presuming practical assembly environment. The initial existence of the air followed by the disappearance after one hour of installation of rubber-block insulation does not cause an issue, because assembly of SPS would take another two hours for completion after the installation of the rubber-block. The material was proved proper by no appearance of partial discharge, the measurement carried out on assembling.

3.3.3 Long-term Loading Cycle Test with Thermo-mechanical Test

Long-term loading cycle test with thermo-mechanical test on the same cable, as shown in table 3 and figure 9, in considering elasticity of the cable, was completed satisfactorily as well as the following residual performance test. Examination on the completed cable system indicated no defects such as abnormal movement or deformation of the rubber-block insulation. It is confirmed that the rubber-block insulation can absorb large diameter differences in cable.

Table3: Test condition of Long-term Loading Cycle Test with Thermo-mechanical Test

Cables	154kV XLPE 1800mm^2 154kV XLPE 400mm^2 (insulation thickness 17mm)
Loading cycle test	Voltage : 145kV for 30days Conductor temperature : 90℃ for 25days 105℃ for 5days 8hrs ON,16hrs OFF
Thermo-mechanical test	Initial shape of offset : Length of offset 2400mm Width of offset 640mm Thermo-mechanical behaviour (simulating yearly displacement) 155mm X 30times Thermo-mechanical behaviour (simulating daily displacement) 31mm X 11000times

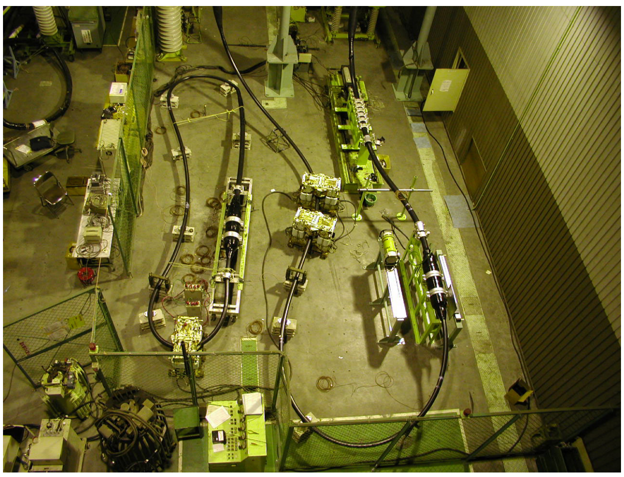


Figure 9: View of Long-term Loading Cycle Test with Thermo-mechanical Test

3.4 Rubber Stress-relief Cone for Improved EB-A

Cold shrinkable technology of SPS was applied to the stress-relief cone of EB-A-A type. It is made by removal of the high-voltage electrode and semi-conductive insulation screen of SPS's rubber-block insulation halved in longitudinal length. It is able to consider electric field strength of the improved EB-A in a similar manner as SPS, where the semi-conductive part inside the stress-relief cone ascends. Interfacial pressure design between the stress-relief cone and cable insulation also follows the design of SPS rubber-block insulation. Having a cold shrinkable stress-relief cone, assembly has become further simplified because there is no need for rubbing on the cable insulation at installation, and it is simply installed by pulling the spiral out.

4. RESULT OF INITIAL PERFORMANCE TEST

SPS of 400kV class has undergone the initial performance test in accordance with IEC62067 as shown in table 4, and it was proved to possess 400kV class performance as well as 500kV class performance.

Table 4: Results of Initial Performance Test

		Sample 1	Sample 2	Sample 3	Sample 4
Power frequency voltage test 440kV for 1hr 580kV for 1hr (500kV class)		With-stood	—	With-stood	—
Power frequency breakdown test Step up : 50kV for 1hr		880kV No BD	—	880kV No BD	—
Lightning impulse voltage test ±1425kV X 10 times ±1550kV X 10 times (500kV class)		—	With-stood	—	With-stood
Lightning impulse breakdown test Step up : -50kV X 3 times		—	-2300 kV No BD	—	-2300 kV No BD
Electric field at breakdown test (kV/mm)	τ_1	20.1↑	52.6↑	20.1↑	52.6↑
	τ_2	30.2↑	79.0↑	30.2↑	79.0↑
	τ_3	9.9↑	25.8↑	9.9↑	25.8↑
	τ_4	25.1↑	65.5↑	25.1↑	65.5↑

(Note) No BD : No breakdown, ↑ : more than

The additional test was carried out in accordance with IEC62067 on the rubber-block insulation that had been stored after expansion for one year at the ambient temperature (~40℃), then installed on XLPE cable. There was no breakdown at the interface of rubber-block insulation and cable insulation and confirmed that no deterioration in its performance before and after long-term storage.

On the other side, improved EB-A and EB-G had undergone initial performance test in accordance with IEC62067 and they were confirmed to possess 400kV class performance.

5. PQ TEST(PREQUARIFICATION TEST)

A series of tests for the PQ test in accordance with IEC62067, consists of a heat cycle voltage test, a residual performance test, and an examination of the completed cable system, was completed satisfactorily for the cable and accessories (two SPS, two EB-A, two EB-G) in the attendance of the reputable independent third party certification authority (CESI, Italy).

5.1 Heat Cycle Voltage Test

Layout of the cable system that had undergone one year heat cycle voltage test is shown in figure 10 and 11. The 115m test assembly contained one EB-A-A and one EB-A-B, two EB-G, and one SPS-A type (for culvert) and one SPS-B type (for direct buried). Temperature rise due to current flow was monitored by thermocouple attached to the separate dummy circuit. The test condition is shown in table 5. The test was watched in succession for one year and completed successfully without trouble in 2005.

Table 5: Test Condition of Heating Cycle Voltage Test

Test Voltage	374kV
Heat cycle	Conductor temperature : 90-95℃ at least 2hrs At least 8hrs ON, At least 16hrs OFF
No. of Heat Cycle	183cycles(8780hrs)
Requirement	No Breakdown

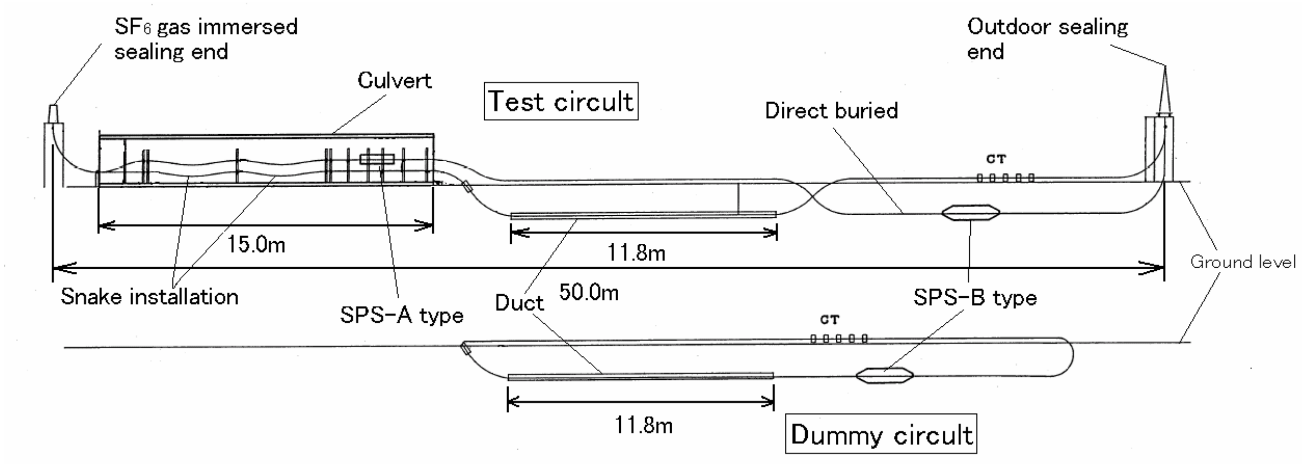


Figure 10: Cable Layout of Prequalification Test of 400kV XLPE cable and Accessories

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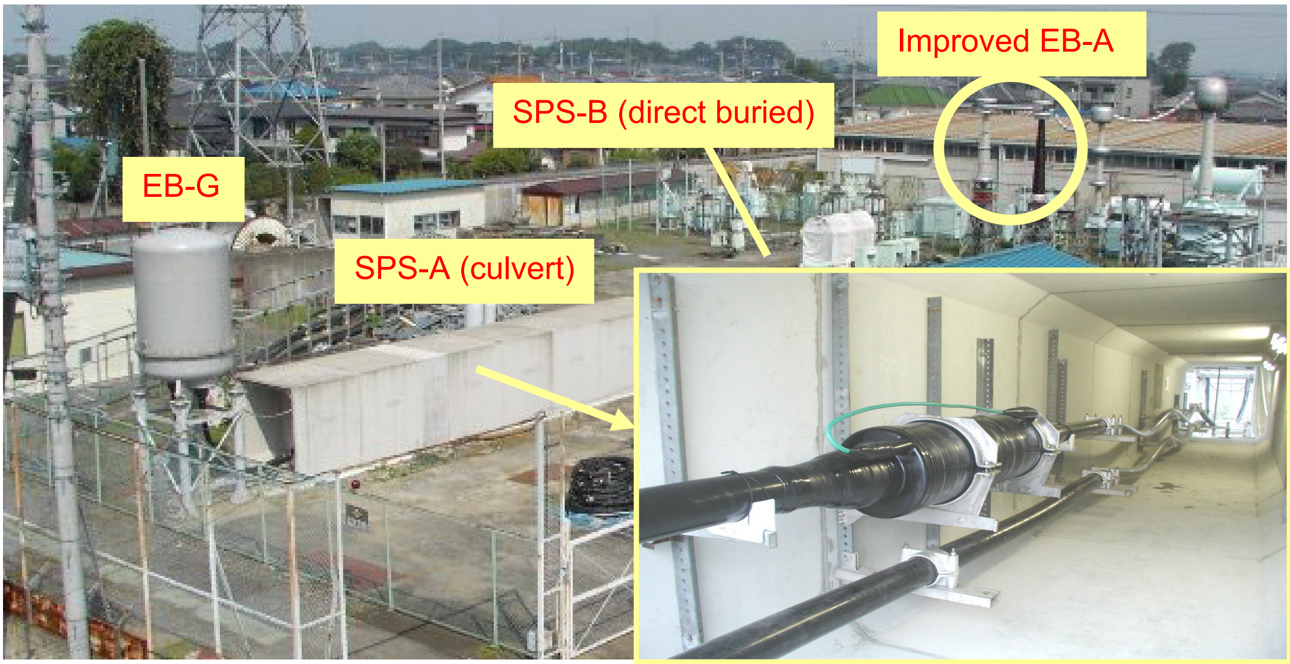

Figure 11: View of Prequalification Test of 400kV XLPE cable and Accessories

5.2 Residual Performance Test

After one year of the heat cycle test, the cable sample was taken, then assembled test terminations, and the residual performance test was executed. The test condition is shown in table 6. The sample satisfied lightning impulse voltage test at high temperature of ±1425kV 10 times for 400kV class, and also additional test of ±1550kV 10 times for 500kV class.

Table 6: Test Condition of Lightning Impulse Voltage Test after PQ Test

Test Voltage (Lightning Imp.)	±1425kV X 10 times ±1550kV X 10 times (for 500kV class)
Conductor temperature	90-95℃ at least 2hrs
Requirement	No Breakdown

5.3 Examination on completed system

The cable and the accessories were examined on completion of the above two tests. No defects or degradation was observed.

6. TYPE TEST

XLPE cable as well as SPS-A type and EB-A-A type of different samples were carried out type test of 400kV class in accordance with IEC62067. The test condition is shown in table 7. Furthermore, XLPE cable as well as two SPS-A type had taken a 500kV class test with test condition shown in table 7. Both tests completed successfully.

Table 7: Test Condition of Type Test

Test Voltage	440kV 580kV (for 500kV class)
Heat cycle	Conductor temperature : 90-95℃ at least 2hrs At least 8hrs ON, At least 16hrs OFF
No. of Heat Cycle	20 cycles
Requirement	No Breakdown

7. CONCLUSION

The developed 400kV class XLPE cable as well as accessories are satisfactorily applicable to 400kV underground power transmission line. With the acknowledgement of the high quality performance and subsequent successful test results, the delivery of the products for the project is in progress.

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GLOSSARY

RBJ: Rubber Block Insulated type Joint
PMJ1P: "Pre-moulded One-piece" type Joint
SPS: Smart Power Splicer
EB-A: Outdoor Sealing End
EB-G: SF_6 Gas Immersed Sealing End