Supply of Dry Type Terminations for 275-kV XLPE Cables

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ABSTRACT Conventionally, an oil-immersed type termination has been generally used for 275-kV XLPE cables, but because of the use of oil, thoroughgoing review has been requested from viewpoints of maintenance problems and installation. As the research on composite prefabricated insulation advances, actual applications at super-high voltage have increased, and the reliability has been improved, a completely dry type termination free of insulation oil has been developed and applied to the actual lines of Tokyo Electric Power Company.

With this technique applied, an inverted termination that can reduce the size of substation facilities was developed, and was applied to the actual lines of the Kansai Electric Power Company. In this line, a semiconductive-layer shaver of lightweight and high-performance was developed achieving --ahead of other companies--smooth and high-performance cable treatment in the vertical direction.

1. INTRODUCTION

For direct-coupling type termination for XLPE cables, a so-called dry type using a compound prefabricated insulation structure is generally applied for 66-154 kV XLPE cables and a so-called oil-immersed type insulation system using silicone insulation oil is popularly applied for the 275-kV XLPE cables.

The oil-immersed type termination must have an oil pressure compensator equipped as ancillary facilities because insulation oil is used, and requests for developing a dry type termination have been increased from viewpoints of both maintenance and installation. On the other hand, in the laboratory, development of a straight-line termination (PJ) in a prefabricated insulation structure using the epoxy unit and rubber pre-molded insulator for XLPE cables has been advanced for the application to 500 kV, and in the actual line, the technique has been able to be applied to the voltage as high as 275 kV, and the reliability has been remarkably improved. With these as backgrounds, the authors began development of a completely dry type termination using this technique, and have supplied terminations for SF_6 gas (EB-G) and terminations for oil (EB-O) for application to actual lines.

In these actual lines, a "semiconductive-layer shaver" was applied for achieving the stabilized installation quality and shortening the working time for the Kansai Electric Power Company, and various kinds of terminations such as inverted termination that can downsize the cable layout of underground substation facilities were developed and supplied to meet diversified customers' needs. The "semiconductive-layer shaver" which enables vertical shaping for the termination provides satisfactory shaping performance irrespective of the normal or the inverted, and our case was the Japan's first application in super-high voltage.

For the main insulation parts comprising the termination, the quality was verified at the plant in conformity to the acceptance test set forth in JEC 3408-1997 [1)] newly instituted.

This paper introduces the design, performance verification, and supply of the equipment-directly-coupled termination.

2. DEVELOPMENT

2.1 Target Specifications

2.1.1 Profile and Dimensions

The profile, structure, and dimensions were determined with compatibility with conventional oil-immersed type termination taken into account as well as in conformity to the dimensional standard for interconnection with equipment.

(1) Termination for Gas

Figure 1 shows the structure of termination for gas.

(2) Termination for Oil

Figure 2 shows the structure of termination for oil. The total length is the same as for prefabricated units thereby achieving compactness.

2.1.2 Electrical Performance

The objective performance was set as shown in Table 1 in conformity to the 275-kV XLPE cables as well as to the prefabricated type straight-line termination (PJ).

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2.1.3 Mechanical Performance

The mechanical performance was set as shown in Table 2 with short-circuit electromagnetic force, seismic force, and spring force taken into account. The applicable standard is JEC 3408-1997 [1].

2.2 Design

2.2.1 Design Elements

The insulation structure of the termination must achieve the objective performance under the restrictions of the interconnection geometry. The epoxy insulator specified for interconnection was equivalent to or greater than the outside diameter of 275-kV PJ unit, thus the insulation structure of the unit was adopted. Consequently, it was assumed satisfactory as long as insulation harmony with the facilities and mechanical performance represented by bending stress generated by earthquakes, etc. are obtained by the termination structure.

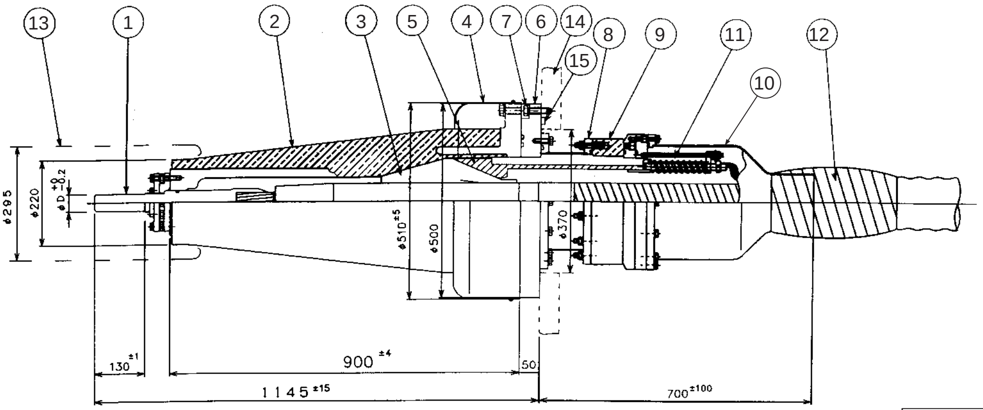
2.2.2 Insulation Design

Based on the previously demonstrated capability and performance, insulation was designed. The electric field analysis results are shown in Table 3 and equi-potential lines of electric field are shown in Figures 3 and 4.

The results shown in Table 3 indicate that all values are lower than the previously demonstrated working stresses and the insulation is free of any problem.

2.2.3 Mechanical Design

For mechanical properties of the termination, based on the conditions shown in Table 2, the bending stress generated in the epoxy insulator base was computed, and it was confirmed that the termination satisfied allowable values. It was also confirmed experimentally that the actual epoxy insulator possessed the objective bending withstand load.

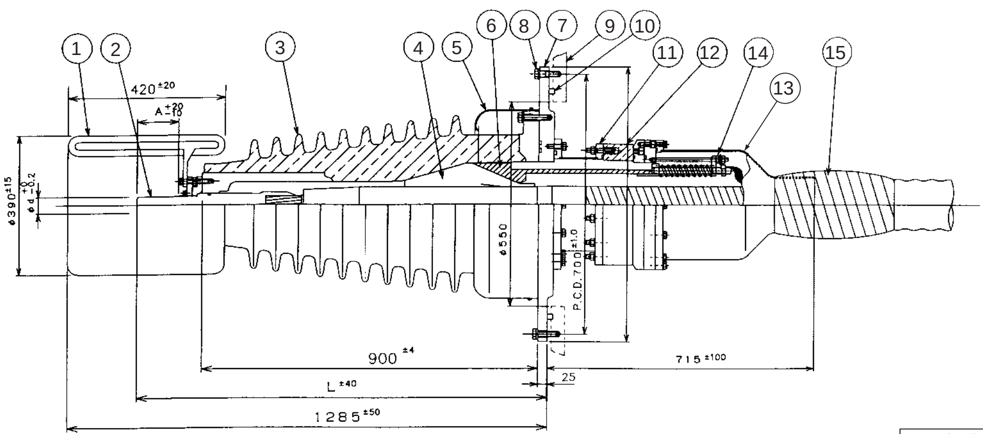


No.	Parts name
15	Gasket for base plate *
14	Equipment bottom plate *
13	Shield *
12	Water-proof tape layer
11	Compression device for stress-relief cone
10	Cable protection tube
9	Insulating flange
8	Adapter
7	Fixing bolt
6	Fitting
5	FRP pipe
4	Lower shield
3	Stress-relief cone
2	Epoxy insulator
1	Conductor rod

* To be supplied by transformer manufacturer

Nominal cross sectional area of conductor (mm^2)	Dimensions (mm)
	D
800~2000	44
2500	60

Figure 1 Structure of EB-G



No.	Parts name
15	Water-proof tape layer
14	Compression device for stress-relief cone
13	Cable protection tube
12	Epoxy insulator
11	Adapter
10	Packing for base plate *
9	Base plate *
8	Fixing bolt
7	Fitting
6	FRP pipe
5	Lower shield
4	Stress-relief cone
3	Epoxy insulator
2	Conductor rod
1	Shield ring

* To be supplied by transformer manufacturer

Nominal cross sectional area of conductor (mm^2)	Dimensions (mm)		
	A	L	d
1000 or less	85	1085	45
1000~2000	110	1110	60

Figure 2 Structure of EB-O

3. ACTUAL DEVICE EVALUATION

3.1 Electrical Performance

Results of electrical tests using actual devices were satisfactory, and both initial and long-term performance sufficiently satisfied the objective performance.

3.1.1 Initial Performance

It was confirmed that the initial performance satisfied the objective performance. In addition, marginal performance was grasped by breakdown tests, in which the termination did not breakdown at 910-960 kV for power frequency voltage and at 2195 kV for lightning impulse voltage with respect to the objective electrical properties shown in Table 1, and satisfactory initial properties of as much as 1.4-1.5 times the specified values were obtained. Table 4 shows the results.

Table 1 Objective electrical performance

Item	Performance
Lighting impulse withstand voltage	±1445 kV/ 3 cycles 1) -1590 kV/ 3 cycles 2)
Power-frequency long-term withstand voltage	525 kV/ 1 hr 1) 610 kV/ 12 hr 2)
Lightning impulse withstand voltage of insulation between shielded layers	-55 kV/ 3 cycles 1) -50 kV/ 3 cycles 2)
Power-frequency partial discharge 1)	1 st: 220 kV/ 5 pC or lower 2 nd: 310 kV/ 30 pC or lower 3 rd: 220 kV/ 5 pC or lower

Note 1: Objective electrical properties of Electric Power Company A
Note 2: Objective electrical properties of Electric Power Company B

Table 2 Objective mechanical performance of epoxy insulator

Item	Performance
Heat shock	10°C/ 60 min ←→ 100°C/ 60 min 1) 0°C/ 60 min ←→100°C/ 60 min 2) 10 cycles
Power frequency partial discharge	300 kV/ 10 min 1) 220 kV/ 10 min 2) Detection sensitivity: 5 pC or lower
Bending withstand loading	11.8 (kN)

Note 1: Objective electrical performance of Electric Power Company A
Note 2: Objective electrical performance of Electric Power Company B

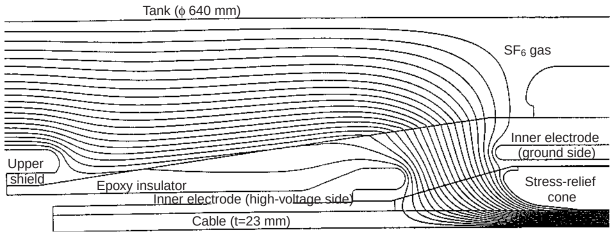


Figure 3 Equi-potential line of electric field of dry type gas immersed termination

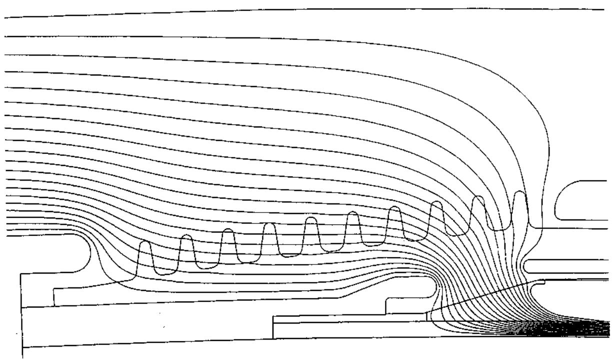
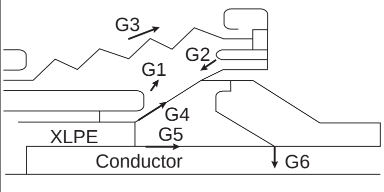


Figure 4 Equi-potential line of electric field of dry type oil immersed termination

Table 4 Breakdown voltage of dry type termination

Sample No.	Type	Test results: Breakdown voltage	Test results: Place of breakdown	Size (mm^2)
1	EB-G	960 kV/ 8 min	Epoxy/rubber interface	2500
2	EB-G	910 kV/ 8 min	Test terminal	2500
3	EB-O	-2195 kV/ 3 times	Not broken	2000

Table 3 Working stress on major elements

Mark	Portion	Working stress on elements: AC Dry type EB-G	AC Dry type EB-O	AC PJ	Imp Dry type EB-G	Imp Dry type EB-O	Imp PJ	Evaluated portion
G1	Epoxy insulator High-voltage end of embedded electrode	2.6	3.0	5.9	16.9	20.1	39.2	
G2	Epoxy insulator Grounding end of embedded electrode	2.2	2.1	-	14.9	13.7	-	
G3	EB-G: gas interface EB-O: insulation oil interface	0.9	0.7	-	6.1	4.6	-	
G4	Epoxy/rubber interface	1.2	1.1	1.4	8.1	7.0	9.5	
G5	XLPE/rubber interface	1.0	0.9	0.9	6.6	6.0	5.7	
G6	Building-up (XLPE)	5.4	5.4	5.4	35.5	35.5	35.5	

[Evaluation voltage] AC: $275/\sqrt{3}$, Imp: 1050 kV
Cable: 275 kV 1x2500 mm^2 (t=23)

3.1.2 Long-term Performance

In developing the present termination, it was confirmed that a deterioration index n=15 was able to be adopted for the design value based on basic examinations, etc. of PJ developed in the similar period, but in verifying the long-term performance, evaluation at deterioration index n=9 which had been adopted until then was carried out in addition to the evaluation at deterioration index n=15.

(1) Long-term loading cycle test (No. 1)

In order to confirm that the termination satisfies the long-term performance requirements, in-plant long-term loading cycle tests were carried out. The termination withstood the tests equivalent to 30-year service life at deterioration index n=9 by voltage acceleration, and proved that it possessed satisfactory properties.

(2) Long-term loading cycle test (No. 2)

In the Yokosuka Laboratory of Central Research Institute of Electric Power Industry, the termination was used as a terminal of PJ developed in the similar period for long-term loading cycle tests, and the termination withstood the tests equivalent to 30-year service life at deterioration index n=15 by voltage acceleration, thereby proving that it possessed satisfactory properties.

Table 5 Test conditions of in-plant long-term loading cycle tests

Item		Characteristic value	Remarks
Cable specifications		2500 mm^2 t=23	
Termination class		EB-G	
Loading	Voltage	320 kV	Equivalent to 30 years, with n=9
	Period	30 day	
Current loading heat cycle and result	Temperature and period	RT~90°C 1 cycle/day x 25 days RT~105°C 1 cycle/day x 5 days	Good

Table 6 Results of long-term loading cycle tests

Item		Characteristic value	Remarks
Cable specifications		2500 mm^2 t=23	
Termination class		EB-G	
Loading conditions	Voltage	245 kV	Equivalent to 30 years, with n=15
	Period	6 months * Loading efficiency 80% taken into account	
Loading result	Voltage	245 kV	Equivalent to 31.6 years, with n=15
	Time	3474.5 hr	
Current loading heat cycle and result	Temperature and period	RT~90°C 1 cycle/day x 132 days RT~105°C 1 cycle/day x 12 days	Good

Tables 5 and 6 show test conditions and results of the tests described in Paragraphs (1) and (2).

3.2 Mechanical Properties

Using epoxy insulator comprising the termination, mechanical properties were verified.

In heat shock tests and the subsequent partial discharge tests, satisfactory mechanical properties were verified. In addition, in the tensile and bending withstand load test after heat shock tests, favorable results that satisfied specified values were also verified. Bending tests were carried out to failure, and the termination did not break at 19.6 kN for the specified values, indicating that it provided satisfactory mechanical properties.

4. TYPE TEST

4.1 Structures of EB-G and EB-O

In applying the termination to the actual 275-kV local link line, type tests were carried out on EB-G (including inverted type) and EB-O by sample assembly in the structures shown in Figures 1 and 2. The inverted type is of the same structure as the normal type, but a new engineering method specific for the inverted type was developed and applied for installation and maintenance.

4.2 Type Test Conditions

Typical type test conditions and the results of EB-G and EB-O are shown in Tables 7 and 8 for type A (EB-G, EB-O) and for type B (normal and inverted EB-G), respectively, because test conditions are different.

For all types, satisfactory results were obtained in all the test items.

Table 7 Test conditions and results (Type A)

Test item	Test conditions	Results
Power-frequency withstand voltage partial discharge test	300 kV, 10 min 5 pC or lower (room temperature)	Good
Power-frequency long-term withstand voltage test	525 kV, 1 hr (room temperature)	Good
Lightning impulse withstand voltage test	±1445 kV, 3 times each (room temperature)	Good
Lightning impulse withstand voltage test of insulation between shielded layers 1)	-55 kV, 3 times (room temperature)	Good
Air-tightness test	588 kPa/ G, 30 min	Good

* Cable specifications: 2500 mm^2 t=23 (EB-G)
1400 mm^2 t=23 (EB-O)

1) Executed on EB-G only

Table 8 Test conditions and results (Type B)

Test item	Test conditions	Results
Switching impulse withstand voltage test	±925 kV, 3 times each (room temperature)	Good
DC withstand voltage test	-500 kV, 1 hr (room temperature)	Good
Partial discharge test	1 st: 220 kV/ 1 min; 5 pC or lower 2 nd: 310 kV/ 1 min; 30 pC or lower 3 rd: 220 kV/ 1 min; 5 pC or lower	Good
Power-frequency long-term withstand voltage test	610 kV, 12 hr (room temperature)	Good
Breakdown test for the above	50 kV for 1 hr to failure by voltage step-ups	Broken at 1160 kV for 5 min
Lightning impulse withstand voltage test for insulation between termination metal sheaths	-50 kV, 3 times each (room temperature)	Good
Breakdown test for the above	Voltage increased three times by -5 kV steps up to failure	-90 kV, Broken at the first application
Lightning impulse withstand voltage test	±1590 kV, 3 times each (room temperature)	Good
Breakdown test for the above	Voltage increased three times by -5 kV steps up to failure	-2540 kV, Broken at the first application
Pressure proof test and air-tightness test	1080 kPa/ G, 30 min	Good

* Cable specifications: 2000 mm^2 t=23

Table 9 Supply records

Customer	Line name	Cable size	Type	Semiconductive layer shaver	Quantity
Tokyo Electric Power	Chiba Central Substation	800 mm^2 CAZV	Normal EB-G	—	6 phases
Tokyo Electric Power	Chiba Central Substation	800 mm^2 CAZV	Normal EB-G	—	6 phases
Kansai Electric Power	Sannomiya Substation	1000 mm^2 CAZV	Normal EB-G	Applied	6 phases
Kansai Electric Power	Sannomiya Substation	1000 mm^2 CAZV	Inverted EB-G	Applied	6 phases
Kansai Electric Power	Sannomiya Line	2000 mm^2 CSZV	Normal EB-G	Applied	6 phases

5. ACCEPTANCE TEST

For the acceptance test at the time of shipment from the plant, 100% heat shock and partial discharge tests were performed on epoxy products, 100% radiographic inspection and partial discharge tests on stress-relief cones, and 100% spring force characteristic tests on the compression device under the conditions of as discrete component and as assembled, thus confirming the quality of each component.

6. INSTALLATION METHOD

The installation methods are based on the conventional PJ engineering method. Of these, the semiconductive-layer shaving method falls into two general broad categories: "glass shaving + paper finish + mirror finish" and "semiconductive-layer shaver + mirror finish". In the lines to which the termination was supplied this time, both of these two engineering methods were adopted.

In applying the semiconductive-layer shaver to EB-G and EB-O, since cables must be longitudinally arranged as against the case of PJ --for which cables are arranged horizontally, a lightweight and high-performance semiconductive-layer shaver which can move not only horizontally but also vertically was developed. By applying this machine, the cable insulator surface obtained satisfactory smoothness before mirror finish.

In the finish by glass shaving in which no semiconductive-layer shaver is used, providing mirror-finish after paper-finish secured satisfactory performance.

7. SUPPLY RECORDS

Table 9 shows the supply records of 275-kV dry-type termination for 275-kV XLPE cables.

8. SUMMARY

Based on the techniques applied to actual lines, after developing 275-kV PJ, a dry-type termination, which can replace the conventional oil-immersion type, was developed and supplied to actual lines. The inverted type recently developed in addition to the normal type will contribute to downsizing of substation facilities and increased applications are expected.

Finally, the authors thank the personnel of Tokyo Electric Power Company and the Kansai Electric Power Company, for their advice and cooperation in constructing the line.

REFERENCES

1) JEC 3408-1997; High Voltage Tests on Cross-linked Polyethylene Insulted Cables and their Accessories for Rated Voltages from 11 kV up to 275 kV.
2) Shirai et al.; Study on the installation of dry-type EB-G for 500-kV CV cables, Proc. of Energy Group of IEEJ, No.336, August 1999. (in Japanese)

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