Development of Cold-Shrinkable Terminations for 6600-V XLPE Cable

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ABSTRACT Slip-on terminations used heretofore on 6600-V XLPE cables come in two types depending on the level of pollution in the area where they are to be used--the pothead type for areas of heavy pollution and the outdoor type for ordinary areas. Pothead terminations have the disadvantages of being heavy and difficult to handle and when EP rubber out-door-type terminations were incorrectly substituted in areas of heavy pollution, instances of insulation breakdown occurred. And since both are of the slip-on type, incidents of breakdown have also occurred, though infrequently, due to insufficient insertion of the cable. Against this background the authors have developed a new type of termination made of silicone rubber for 6600-V XLPE cables which is easy to assemble, guards against problems of improper installation on the cable, and can be used in both ordinary and heavily polluted areas.

1. INTRODUCTION

Slip-on terminations used heretofore on 6600-V XLPE cables come in two types--a pothead type made of porcelain and outdoor type made of EP rubber. Figure 1 shows an example of slip-on termination of the type currently in use. Normally the pothead type is used in areas of heavy pollution and the outdoor type is used in other areas. Because of its porcelain construction the pothead terminations offer outstanding contamination performance, but are heavy and difficult to handle. Outdoor type terminations, being made of EP rubber, suffer dielectric breakdown if they are incorrectly selected and used in areas of heavy pollution. And since both are of the slip-on type, incidents of breakdown still occur, though infrequently, due to insufficient insertion of the cable.

The authors have therefore developed a new type of termination made of silicone rubber for 6600-V XLPE cables which is easy to assemble, guards against problems of improper installation on the cable, and can be used in both ordinary and heavily polluted areas.

This paper gives an overview of the process of developing the new terminations.

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2. DESIGNING THE NEW TERMINATIONS

2.1 Target Specifications

Table 1 shows the target specifications. The objective was a termination that could be used without distinction, in both

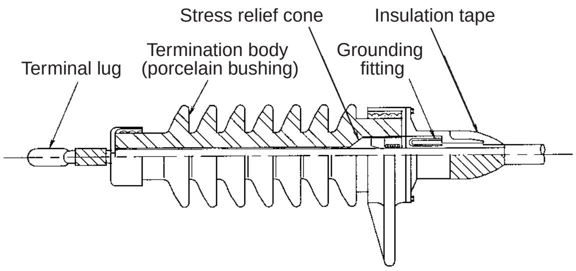


Figure 1 Pothead type slip-on termination

Table 1 Target Specifications

Item	Specification
Initial performance AC partial discharge voltage	Max 10 pC at 6.9 kV
AC withstand voltage	35 kV for 1 hr
Impulse withstand voltage	-95 kV, 3 times
Watertightness	49 kPa for 24 hr
Contamination performance Wet AC flashover voltage	17 kV or more
Contaminated flashover voltage	More than 7.2 kV at ESDD 0.35mg/cm^2
Ease of installation	No special skills required Suppression of installation errors

ordinary and heavily polluted areas, so all performance specifications were set with reference to the current pothead type. With respect to installation operations, the objective was to improve procedures requiring a high degree of skill, and to suppress installation errors due to insufficient cable insertion. Photo 1 shows the new termination developed to satisfy these target specifications.

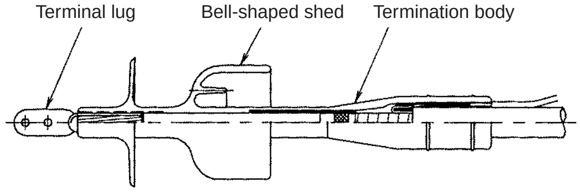


Photo 1 Newly-developed cold-shrinkable termination

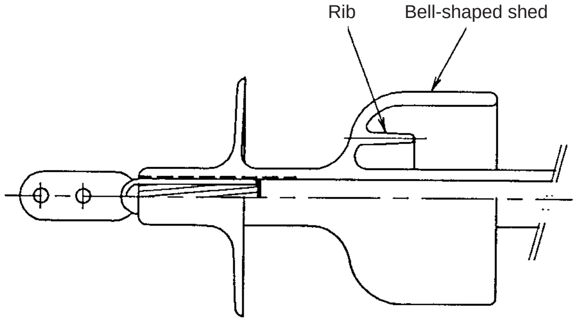


Figure 2 Shed shape

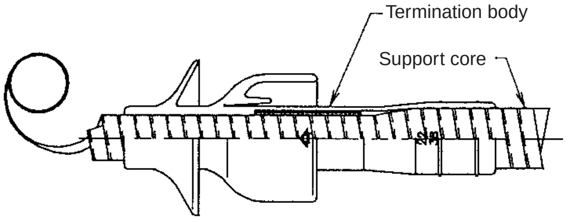


Photo 2 Expanded state

2.2 Details of the Design

2.2.1 Material

For the new termination to be used in areas of heavy pollution, it was necessary for it to overcome the disadvantages of the existing pothead termination in terms of weight and difficulty in handling. It was therefore decided to make it using silicone rubber, which has excellent contamination performance, as the main insulating material. This had the effect of reducing its weight to about 1 kg, versus about 5 kg for the pothead termination.

2.2.2 Structure

Because of the decision to use insulating rubber in areas of heavy pollution, it was necessary to assure contamination performance by means of the shape of the shed as well as by proper material selection. Accordingly a bell-shaped shed was adopted in addition to the horizontal shed (Figure 2). Dimensions were also reduced, and a rib was provided on the inside of the bell-shaped shed so as to obtain the requisite creepage distance.

By means of these measures relating to the material and the structure, it was possible to achieve contamination performance equivalent to those of the existing pothead terminations (see Table 2).

2.2.3 Method of Installation

The installation method adopted was cold shrinkable type utilizing the inherent elasticity of rubber, in which the cable is attached by keeping the inner diameter of the termina-

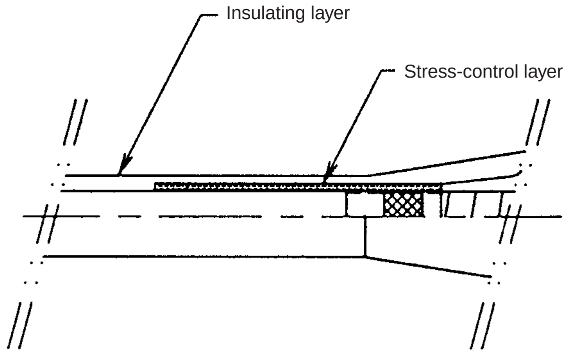


Figure 3 Method for controlling electrical stress

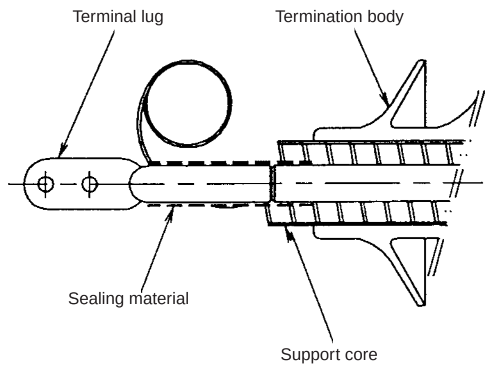


Figure 4 Separating terminal lug from termination body

tion several times larger than the outer diameter of the cable and then releasing it at the designated point of attachment (Photo 2). This method made it possible to eliminate the insertion force of the slip-on termination to the cable.

2.2.4 Method for Controlling Electrical Stress
Because the adoption of the cold shrinkable type requires that the termination body be expanded, the body should be as thin as possible. However the conventional geometric method of stress control using stress relief cones requires at least that part to be thickened. In the termination developed here, stress control was provided by a stress control layer of high permittivity (see Figure 3). This made it possible to reduce the thickness of the termination body.

2.2.5 Elimination of Insufficient Cable Insertion
As was stated above, one problem with the slip-on terminations now in use is the continuing occurrence of breakdown faults, though infrequently, resulting from insufficient insertion of the cable. One reason for this is that the terminal lug of the conventional slip-on is molded integral with the termination body so that the terminal lug must be crimped on the assumption that the cable is fully inserted into the termination body. Accordingly it was decided in the newly developed termination to separate the body and the terminal lug (Figure 4), thereby making it possible to confirm that the conductor was completely inserted into the lug and crimped before going on to the next operation, and to eliminate incomplete insertion as a cause of breakdowns.

2.2.6 Common Sizes
In addition to separating the terminal lug and the termination body, the adoption of the previously described method whereby the inner diameter of the body was first expanded and held to several times that of the cable insulation made it possible to use a single type of termination body for more than one size of cable. In the case of the terminations developed here, each type serves two sizes of cable in common: 22 and 38 mm^2, and 60 and 100 mm^2.

2.2.7 Improving Ease of Installation
Grounding is accomplished using a coil spring (Figure 5), rendering soldering unnecessary. Watertightness is accomplished by applying sealing material between the body and the cable sheath and between the body and the terminal lug, eliminating the taping used previously.

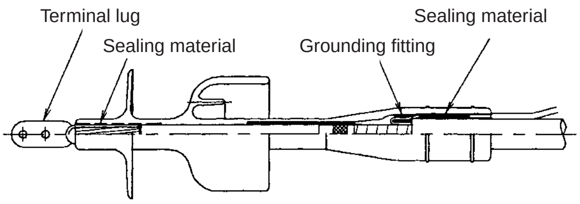
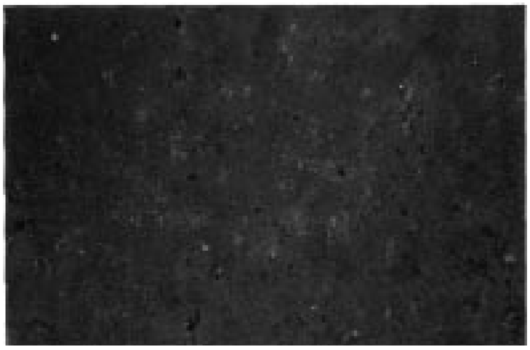


Figure 5 Method of grounding and waterproofing



a) Original

b) After 500 hr

Photo 3 Specimen surface before and after ozone resistance test

3. EVALUATION

Since the termination developed in this project was intended for use in heavily polluted areas, it was necessary to evaluate not only performance in the completed state, but also the weathering and tracking resistance of the material of which it was made.

3.1 Evaluation of Material

All terminations, including this one, that are to be used outdoors are subject to the effects of ozone and sunshine, as well as wind and rain. If the surface becomes wet, the well-known phenomenon of dry band arcing occurs. Accordingly the silicone rubber of which these terminations were to be made was evaluated for resistance to weathering and tracking in accordance with the accelerated tests described below.

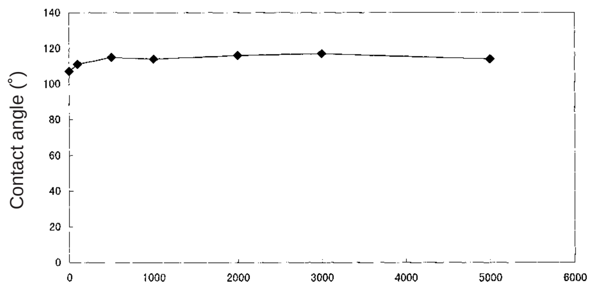


Figure 6 Change in contact angle to sample surface by sunshine weathering test

3.1.1 Ozone Resistance

Normally ozone is present in the air in concentrations ranging from 1 to 5 pphm[1). Under polluted conditions, however, dry band arcing generates even more. In these tests, therefore, ozone concentration was set high at 150 ppm; otherwise, in accordance with JIS K 6301, test samples were elongated by 50% at 40°C, and the surface was examined for cracking, etc.

Photo 3 shows the condition of the specimen surface before the start of the ozone resistance test, and after the elapse of 500 hr. At 500 hr, no particular cracks or other abnormalities were observed.

Table 2 Results of Tracking-Resistance Test (IEC587)

Test voltage (kV)	Length of test (hr)						
	0	100	500	1000	2000	3000	5000
3.5	Passed	Passed	Passed	Passed	---	Passed	Passed
4.5	Passed	---	---	Passed	---	Passed	Passed

Target specification:
All 5 test samples to withstand 6 hr without breakdown

Criterion:
The end point is reached when the value of the current in the high voltage circuit through the specimen exceeds 60 mA, or when the track reaches a mark on the specimen surface 25 mm from the lower electrode.

Table 3 Result of Initial and Contamination Performance Tests

Item	Evaluation
Initial performance	
AC partial discharge	None
AC withstand voltage	Passed
Impulse withstand voltage	Passed
Watertightness	Passed
Contamination performance	
Wet flashover voltage	Passed
Contaminated flashover voltage	Passed
Ease of installation	Passed

3.1.2 Sunshine Weathering and Tracking Resistance Tests

Tests using the weatherometer are to determine weatherability--primarily ultraviolet light. Around the light source is provided a rotating frame to which the test samples are mounted so that they are rotated.

Previous research has already demonstrated the superior contamination performance of silicone rubber: the hydrophobic properties of its surface are maintained for extended periods, and even if lost due to dry band arcing, are regained rapidly[2). The contact angle method is normally used to determine hydrophobicity. Accordingly using a maximum irradiation period of 5000 hr, several samples were extracted from time to time and the contact angle to their surfaces was measured. Tracking resistance was measured using the inclined plane test of IEC 587.

Figure 6 shows the change in contact angle, and Table 2 shows the results of the tracking-resistance tests. There was no great change in contact angle in the course of the test, and the fact that the value was not much different from that for original samples suggests that the hydrophobicity of the material was fully maintained. Tracking-resistance was also fully maintained, and even samples that had been irradiated for 5000 hr showed values similar to those for original samples.

3.2 Evaluation of the Installed Termination

Evaluations were also made of the initial performance and contamination performance of terminations that were installed under conditions similar to those of actual use. And to confirm long-term performance under conditions of actual use, samples were mounted in distribution systems actually in service in areas of heavy, medium and light pollution and subjected to outdoor exposure tests for a period of approximately one year.

Photo 4 Outdoor exposure test (heavy pollution area)

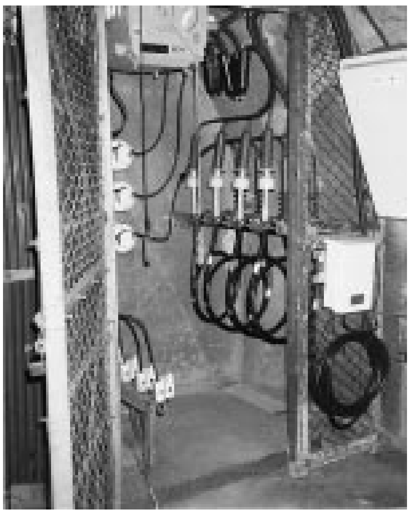


Photo 5 Outdoor exposure test (medium pollution area)

Photo 6 Outdoor exposure test (light pollution area)

Photo 7 Sample after exposure for 1 year in area of medium pollution

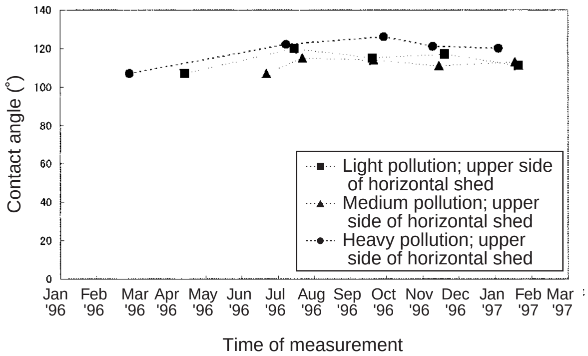


Figure 7 Changes in contact angle to sample surface at each test site

3.2.1 Initial and Contamination Performance

It was confirmed that the initial performance of the terminations developed in this project satisfied the performance targets for all common-use sizes. No abnormalities were found in the new waterproofing structure, in which taping was eliminated in favor of the use of sealing material. In terms of contamination performance as well, performance was equal to or better than that of the conventional pothead terminations. Table 3 shows the results obtained.

3.2.2 Long-term Characteristics

The sites selected for the tests were: an area located on the sea about 10 m distant from the water and subject to heavy pollution from sea water and salt-laden winds; an area of medium pollution where conditions were extremely severe owing to the presence of diesel train exhaust, dust and iron powder from brakes, without the cleansing effect of rain; and an area of light pollution located in a railway station parking lot subject to the effects of exhaust gases, dust and dirt. The three sites are pictured in Photos 4 through 6. Four samples were exposed at each site, and at regular intervals one was removed for evaluation.

Photo 7 shows a sample which was removed after one year's exposure at the area of medium pollution. No abnormalities due to erosion or tracking were found. The other samples were also found to be free of observable abnormalities during the course of the exposure tests, irrespective of the environment in which they were placed.

Table 4 Results of outdoor exposure tests

Item		Evaluation
Appearance		No abnormality
AC partial discharge		None
AC withstand voltage		Passed
Impulse withstand voltage		Passed
Leakage current (10 kV DC applied)	Dry	Dry 0.1 mA or less
	Wet	Wet 0.1 mA or less

After removal, all samples were subjected to the tests shown in Table 4, and were confirmed to be without problems.

When removed, the samples were also examined for changes in the contact angle as a sign of change in hydrophobicity. Figure 7 shows the results. There was no major change in contact angle, irrespective of the environment, suggesting that the hydrophobicity of the surface of terminations made of silicone rubber was retained throughout the test period.

3.2.3 Verification of Ease of Installation

The working time required to install the newly developed terminations on the cable was 23% shorter than that for the conventional type, reflecting the elimination of the waterproof taping process and other skilled procedures. In addition to eliminating the skill requirement, installation was simplified by the fact that no insertion force was required for slip-on, making it possible to confirm that the conductor was firmly inserted in the terminal before going on to the next operation, and to eliminate incomplete insertion as a cause of breakdowns.

4. CONCLUSION

A new type of termination has been developed for 6600-V XLPE cable which offers outstanding ease of installation, prevents breakdowns due to incorrect work procedures and can be used in both ordinary and heavily polluted areas. The new terminations went into commercial service in 1998.

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