Application of Retrofit XLPE Cable for Existing Circuit

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A large number of high-pressure fluid-filled (HPFF) and high-pressure gas-filled (HPGF) pipe-type cables had formerly been installed in U.S. power transmission lines since 1930s. As the pipe-type cables age, corrosion of the steel pipes and leakage of the dielectric fluid have become a problem. Using technology patented in the U.S. and Japan, Sumitomo Electric Industries, Ltd. designed, delivered, and installed its new high-voltage cross-linked polyethylene (XLPE) triplex cable and its accessories for the existing transmission lines.

Keywords: power cable, replace, pipe-type cable, triplex

1. Introduction

In the U.S., the pipe-type cable system has been used in the existing power grid. The system consists of high-pressure fluid-filled (HPFF) and high-pressure gas-filled (HPGF) cables*1, both of which are likely to cause leakage of the dielectric fluid in steel conduits. The cables need to be replaced due to deterioration, but manufacturers have already discontinued the production of such cables. In addition, it was previously difficult to remove and newly install conduits because they were buried in close proximity to water and gas pipes as well as communication cables.

To solve the problem, we proposed using the triplex XLPE cable*2, which has been patented in the U.S. and Japan, for use in an existing HPGF cable line in the U.S. We designed and developed a cable system to utilize the existing steel conduits and completed on-site installation.

2. Overview of the Project in the U.S.

The HPGF cable line, which was the object of this project, came into service in 1973. It was necessary to replace the line. However, it was difficult to install new conduits because the line was buried under an expressway. The circuits are also in an environmentally sensitive area, so construction in this area is difficult because it requires various complex permissions. Thus, we developed a cable system to install the new triplex XLPE cable in the existing conduits. We removed the HPGF cables from the existing conduits, installed the new cable, and conducted a commissioning test.

2-1 Required specifications

Table 1 shows the specifications of the required cable system, and Fig. 1 shows the line configuration.

Table 1. Required specifications

Rated voltage	115 kV
Commercial frequency	60 Hz
Basic impulse voltage level (BIL)	550 kV
Cross-sectional area of the conductor	2500 kcmil
Existing HPGF pipe	Inside diameter: 8.125 inch Outside diameter: 8.625 inch
Route length	Approx. 1300 feet
Pipe burial depth	Approx. 35 feet

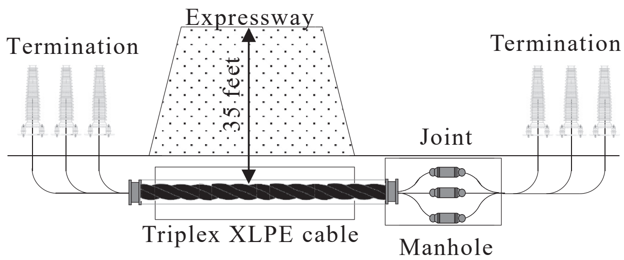

Fig. 1. Line configuration

2-2 Schedule

The schedule of this project is shown in Table 2.

(1) System design

We designed an installable cable system that meets the customer's specifications and received the approval.

(2) Type test

Cables and components were assembled to build a cable system that mocked up the existing line. A type test was conducted in accordance with AEIC*3 (a standard in the U.S.). It was confirmed that the performance was applicable to the existing circuit.

(3) Manufacture of the cable and accessories

A factory acceptance test was conducted in accordance with AEIC before shipment.

(4) On-site construction

The construction work started in January 2020. The power cables and a temperature measurement system for the power cable were installed. The construction work was completed on March 15, 2020 on schedule. The customer started operation on May 15, 2020. The project was successfully completed.

3. Main Equipment That Made Up the Cable System

3-1 Triplex XLPE cable

The structure of the triplex XLPE cable is shown in Photo 1. Three XLPE power cables, three aluminum pipes, and an earth continuity conductor (ECC) are stranded. The ECC is arranged in the center.

Table 2. Project schedule

	2018												2019												2020					
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6
(1) System design	■	■	■	■	■	■	■	■	■	■	■																			
(2) Type test												■	■	■	■															
(3) Manufacture of the cable and accessories																■	■	■	■	■	■						Commencement of operation			
(4) On-site construction																									■	■	■		☆	

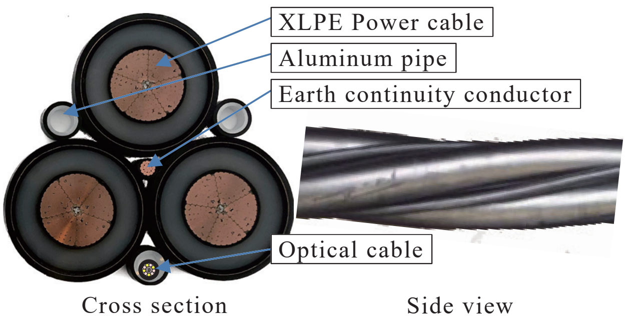

Photo 1. Structure of the triplex XLPE cable

(1) Increase in current capacity and short circuit withstand current

In general, when water barrier tape is used for a power cable, the short circuit current permissible capacity is ensured by using a wire shield. Our patent was used to distribute the short circuit current to the copper-laminated foil layer, aluminum pipes, and ECC to meet the capacity. Meanwhile, the wire shield was eliminated to maximize the conductor size and ensure large capacity.

(2) Triplex structure

The power cables, aluminum pipes, and ECC were stranded. This made it possible to absorb the thermal expansion of the cables due to temperature rise during operation by loosening of the strand. This also helped reduce the expansion toward the joints and terminal joints as well as the axial force (Fig. 2).

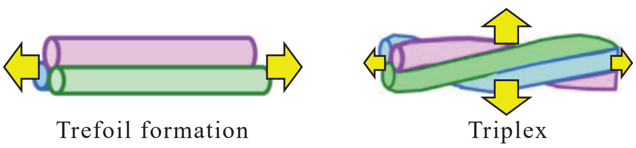

Fig. 2. Trefoil formation and Triplex structure

(3) Aluminum pipes

Hollow aluminum pipes were combined, and an optical cable was inserted. This enabled temperature monitoring without causing stress damage to the optical cable.

3-2 Joint

In general, a power cable system is formed by connecting cables using joints in manholes (see Photo 2).

Photo 2. Joint

Our cable is characterized by a triplex structure, which helped reduce the axial force and cable expansion toward the conduits. It does not require an offset, making it possible to reduce the manhole size. It is provided with a support for grounding and securing an aluminum pipe.

3-3 Outdoor termination

Outdoor termination met the specifications in Table 1. It was confirmed that the termination had sufficient mechanical strength for antiseismic performance by conducting a tensile test and a cantilever flexural test as specified in IEEE 693. As in the case of a joint, the termination was provided with a support for grounding and securing an aluminum pipe.

3-4 Temperature monitoring system

In this project, we used our fiber-optic distributed temperature sensing system OPTHERMO*4 FTR3000. This system is generally referred to as a distributed temperature sensing system (DTS). It can measure the temperature distribution along the entire length of an optical fiber. Thus, it is used for monitoring long-distance and large-scale equipment, including power cables. Figure 3 shows the appearance and working principle diagram of the system. The main specifications of FTR3000 are shown in Table 3.

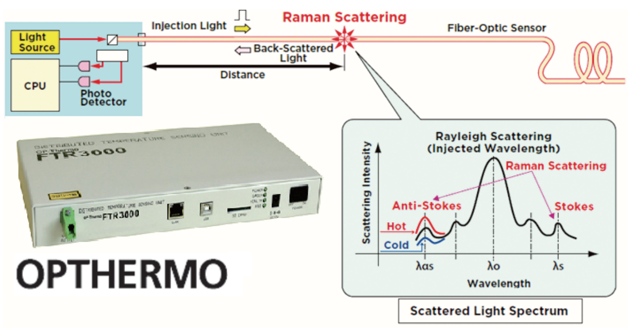

Fig. 3. Overview of the DTS

Table 3. Specification of OPTHERMO FTR3000

Item	Specification
Maximum measurement distance	2 km
Sampling interval	1 m
Temperature accuracy (standard deviation)	≤ 1.0°C
Measurement time	≥ 8 sec
Response distance	1.5 m
Optical fiber type	Multi-mode (GI 50/125)
Dimensions	300 (W) ×160 (D) ×37 (H) mm
Weight	3 kg

The temperature of underground cables varies at respective locations due to the soil around the cables and the burial environment. There may be hot locations that have not been taken into account in the design (hereinafter "hot spots"). At hot spots, the conductor temperature may exceed the specified value and cause the insulators to deteriorate rapidly. This may result in dielectric breakdown before the expected service life of the cables. OPTHERMO measures the temperature distribution along the entire length of a cable to detect hot spots and contribute to the sound operation of the cable.

An optical fiber for temperature measurement was inserted into the aluminum pipe of the triplex cable after installation of the power cable. The aluminum pipe was arranged spirally toward the longitudinal direction. It was difficult to install the cable by winching due to the high friction of the internal surface of the pipe. Thus, it was decided to force-feed the cable using air blown equipment (Fig. 4).

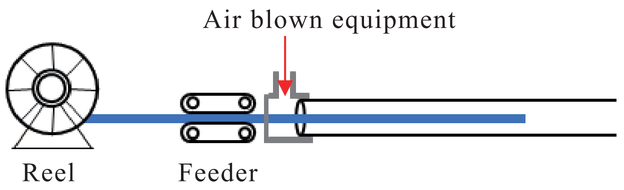

Fig. 4. Air blown equipment

4. Type Test of the Cable System

A type test was conducted in accordance with AEIC CS9-15 (Table 4) as a demonstration test. Figure 5 shows the configuration of the verification system. An eight-inch steel pipe was installed for the line. Joints were installed in a mockup manhole, whose size was the same as that of the existing manhole, and outdoor terminations were installed on both ends of the line.

(1) Test to confirm the rated performance

Partial discharge and dielectric loss tangent were measured using the cable system, on which a bending test was conducted to simulate the influence of on-site installation.

(2) Heat cycle test

The cable line was subject to a load of allowable limit temperature (105°C), which was higher than the maximum operation temperature of the cable (90°C). A long-term electrical test (AC133 kV) was carried out for 20 days.

(3) Test to confirm the remaining performance

A partial discharge measurement, lightning impulse voltage test, and power frequency voltage test were conducted. After that, the cables, joints and outdoor terminations were disassembled, and it was confirmed that there were no abnormalities.

Table 4. Type test items

No.	Test name	Details of test
1	Bending test	Cable shall be bent with 25 x (d + D) for 3 times.
2	Partial discharge test	1.75 U_0 (117 kV) 10 sec → 1.5 U_0 (100 kV), 5 pC
3	Dielectric loss angle measurement	1.0 U_0 (67 kV), 105-110°C, Max. 0.001
4	Heat cycle voltage test	2 U_0 (133 kV), Heat Cycle: 20 times
5	Partial discharge test	1.75 U_0 (117 kV) 10 sec →1.5 U_0 (100 kV), 5 pC
6	Lightning impulse voltage test	±550 kV, 10 times
7	Power frequency voltage test	2.5 U_0 (166 kV) for 15 minutes
8	Examination test	No abnormalities

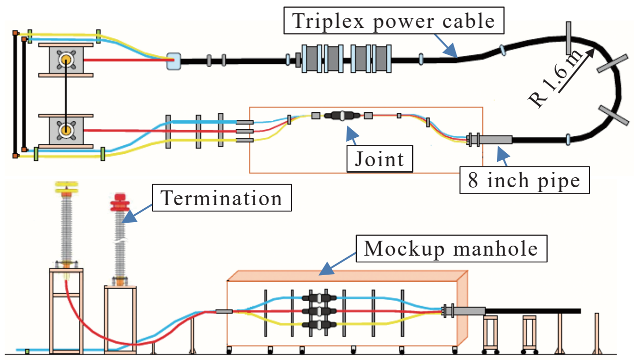

Fig. 5. Configuration of Type test circuit

5. On-site Construction

5-1 Removal of existing HPGF cables

All existing HPGF cables were removed (Photo 3), and the space inside the pipes was cleaned. A test piece was introduced into the pipes to verify the installability of the new cable. Smart Pig*5 was used to investigate the deterioration status of the pipes. It was confirmed that the cable could be installed properly.

5-2 Transport of the cable

The power cable was coiled around a large drum (4.2 m in diameter × 3.5 m in width). A route that did not interfere with overhead power lines was chosen on site. The drum was transported to the construction site at night (Photo 4).

5-3 Installation of the cable

Taking into consideration the inclination of the installation section, it was decided to introduce the cable from the termination to the manhole. The site was adjacent to aerial lines, other feeders, and buildings. The pass line for installation was arranged by examining the drum layout and transfer method (Photo 5). A cable test piece 5 m long was introduced into a pipe on a trial basis. This cable was confirmed to be installed properly. Subsequently, a new cable was installed.

Photo 3. Removal of existing cable

Photo 4. Transport of the cable

Photo 5. Cable installation

5-4 Assembly of joints

The design and materials of the joint support were certified under the Professional Engineering Stamp*6 of the U.S. The joints were assembled in the manhole. The completed status is shown in Photo 6.

Photo 6. Assembled Joint

5-5 Assembly of Outdoor terminations

An open pit was provided under the trestle of outdoor termination. The triplex cable was branched without using a riser pipe to construct the terminations. Photo 7 shows the completed status. The existing line was equipped with cathodic protection (CP) to prevent corrosion of the steel pipes. The system was designed so that CP would work after the replacement and the steel pipes can be effectively utilized in the event of cable replacement in the future.

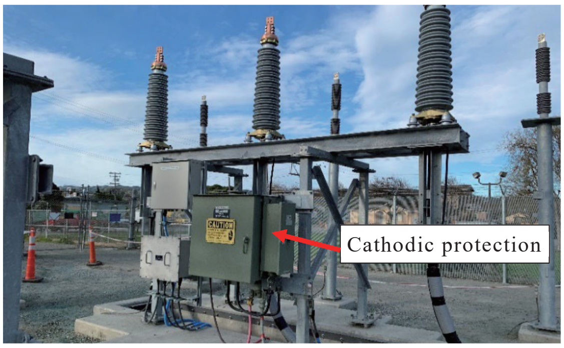

Photo 7. Assembled termination

5-6 Air blown installation of an optical cable

After installation of the triplex cable, air blown equipment was used to introduce an optical cable into the aluminum pipe (Photo 8).

Photo 8. Installation of Optic cable

5-7 Construction of Temperature monitoring system

DTS was installed in the control room on the premises where the termination were installed. The optical cable was introduced and connected. Alarms can be set at two levels (alert and warning) in the temperature monitoring software. They were set based on the permissible design temperatures.

The temperature distribution graph of OPTHERMO is shown in Fig. 6. The route of the optical cable was from the substation control room to the cable end (near end), cable section, interconnecting manhole, and cable end (far end). An optical cable bundle for temperature calibration was set up at the cable end. The temperature distribution in the figure shows a superimposition of the daytime and nighttime graphs. It shows that the temperature at the buried location does not change but that the temperature of the temperature calibration bundle in the air does. The temperature under the expressway is high due to the presence of asphalt. There were no singular points (hot spots) along the route that raised concern.

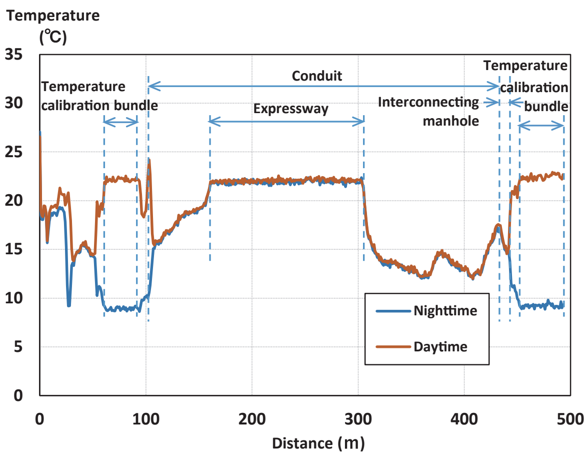

Fig. 6. Temperature distribution graph

With the start of operation of the cable, the soil temperature would gradually increase due to heat generation by energization. Comparison between temperature distributions before and after energization helps detect singular points of temperature increase and the formulation of measures, such as improvement of the soil environment and control of the energization current.

6. Commissioning Test

After installation of the cable and assembly of all the components, an anticorrosion withstand voltage test, an AC withstand voltage test (1.7 U_0: 113 kV × 1 hour), and partial discharge measurement (0.8 U_0: 54 kV, 1.0 U_0: 67 kV, 1.7 U_0: 113 kV) were conducted for the power cable system. For the DTS, an optical loss measurement test and an operation check test were conducted. Commissioning test was completed satisfactory on March 15, 2020. The status of commissioning test is shown in Photo 9.

Photo 9. Commissioning test

7. Conclusion

We launched the first project to apply the triplex XLPE cable to an existing line to replace HPGF cables. We developed a cable system with performance required for the existing grid. The performance was confirmed by conducting a type test. On-site installation of the cable and components was completed, and the on-site completion test was completed on March 15, 2020. The line went into operation on May 15, 2020 without any problems.

There are five other feeders. In this project, one of the six lines was replaced. In 2021, the second line will be replaced.

HPFF/HPGF cables will continue to deteriorate into the future and as a result, the demand for replacement is expected to grow further. This project has attracted the attention of potential customers. We will make efforts to increase the performance and reduce the size and cost of the triplex XLPE cable.

Technical Terms

*1 High-pressure fluid-filled (HPFF)/High-pressure gas-filled (HPGF) cable: HPFF/HPGF cable refers to a cable that uses insulating paper as an insulator and is introduced into a steel pipe, which is filled with insulating oil or gas.

*2 Crosslinked polyethylene insulated, polyethylene sheathed (XLPE) cable: The cable uses crosslinked polyethylene as an insulator and has a water barrier layer and polyethylene anticorrosion layer on the outside.

*3 AEIC standard: The standard is issued by the Association of Edison Illuminating Companies (AEIC) in the U.S. and applies to power cables.

*4 OPTHERMO: OPTHERMO is a trademark or registered trademark of Sumitomo Electric Industries, Ltd. *FTR3000 is the model number. OPTHERMO can be found in the overview in English.

*5 Smart Pig: This is a machine that goes through a pipe for internal maintenance and cleaning. It inspects internal damage while moving inside a pipe.

*6 Professional Engineering Stamp: The reliability of technology can be proven by receiving approval from engineers licensed by the federal/state government.

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