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Replacement by utilizing existing facilities for EHV Underground Transmission Lines

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SUMMARY

In Japan, underground transmission lines that were installed in the 1970s now need to be replaced. Transmission system operators (TSOs) must replace them appropriately in order to keep transmitting power safely and stably. When implementing the replacement, TSOs need to minimize the period under the N-1 condition, which is unavoidable during the replacement process, in order to keep supply reliability as high as possible. TSOs also need to reduce the environmental impact. These issues, which arise from social expectations, must be addressed in order to ensure the sustainable development of the electricity business.

The Transmission and Distribution Company in Kansai has experience with replacement projects in which existing facilities such as vacant ducts, free space in utility tunnels and some part of existing cables which could be diverted as a part of different line were used in order to minimize the outage period and environmental impact during the replacement work. In the conventional replacement method, the line to be replaced is put out of service first (the grid enters the N-1 condition). The aged cables are then removed from the ducts and new cables are installed in them. An alternative method is to lay new cables in vacant ducts and/or space in a utility tunnel first (called “pre-laying”) and then remove the aged cables. This avoids the N-1 condition during pre-laying work. In the pre-laying method it is important to install a duct system and/or a utility tunnel with appropriate room for future use and to draw up a detailed replacement plan from the perspective of optimizing the power grid. It is also mandatory to verify in advance that the specifications of the new facilities to be installed will interface well with the existing facilities in order to prevent the replacement from causing deterioration in quality.

This paper reports on practical examples of completed or ongoing replacement projects for extra high voltage (EHV) underground transmission lines performed by Company.

KEYWORDS
Conduit - Duct - Pre Laying - Urbanization - Environmental Impact

1. INTRODUCTION

In Japan, underground transmission lines have been actively installed since the 1970s and play an important role in supplying electricity in urban areas. The cables that entered operation in the 1970s and 1980s are now in the replacement phase, and the TSOs must replace them appropriately in order to transmit power safely and stably. When replacing aged cables, they focus on the power outage period of the line as one of the elements affecting the reliability of the power supply, and also consider the environment impact of the civil engineering work. Accordingly, they strive to minimize both the power outage period and environmental impact.

TSOs try to shorten the power outage period caused by accidents to the transmission system. Consequently, the power system in Japan suffers only very short outages compared with other countries, in spite of frequent natural disasters such as typhoons and earthquakes. It is especially crucial to shorten the period for extra high voltage (EHV) facilities to maintain the supply reliability over a wide area. Other voltage classes also need to satisfy increasing requests such as for connecting distributed power sources and new consumers to the power grid as soon as possible. In short, TSOs need to shorten the power outage period during the N-1 condition, which is unavoidable during replacement works.

Environment impact such as discharge of waste, noise and traffic congestion can occur, especially during excavation in the construction phase. In Japan, almost all underground facilities use a conduit system and utility tunnels in which the cables are laid, with the conduits and the tunnels usually buried under roads. Especially, in Kansai, a conduit system is sometimes applied to EHV cables. This system enables aged cables to be removed and new ones to be laid in the same duct without excavation when replacing cables, which is an advantage of the conduit system for mitigating environmental impact, compared with direct cable burial.

We report here on examples of replacement projects for EHV underground transmission lines with the duct system and explain how we minimize the power outage period and environmental impact.

2. OUTLINE OF CABLE REPLACEMENT PROCEDURE

This section explains the difference between cable replacement by the conventional method and by the pre-laying method, using a simple model. The model consists of four sections with two sets of terminations and three sets of joint boxes. The cables and joint boxes are assumed to be installed in the duct system (Fig. 1).

In conventional replacement, the aged cables are removed and the new ones are installed in a series of processes, and so this method requires a long outage. In contrast, the pre-laying method shortens the outage period, which is unavoidable during replacement. In this method, the new cables are laid in vacant ducts without stopping the power except for the sections at both ends, which have terminations. The line is then placed out of service, the aged facilities in both sections are removed, and the new ones are installed. Most of the removal work can be performed without stopping the power because the new facilities have already been completed. Thus, the pre-laying method helps minimize the outage period required for replacement, and this effect is even greater with a higher number of sections in the target line.

However, vacant ducts are needed for the pre-laying method. Therefore, the Company always considers the number of vacant ducts in addition to the cables to be installed when planning and constructing the duct system in order to facilitate cable replacement in the future.

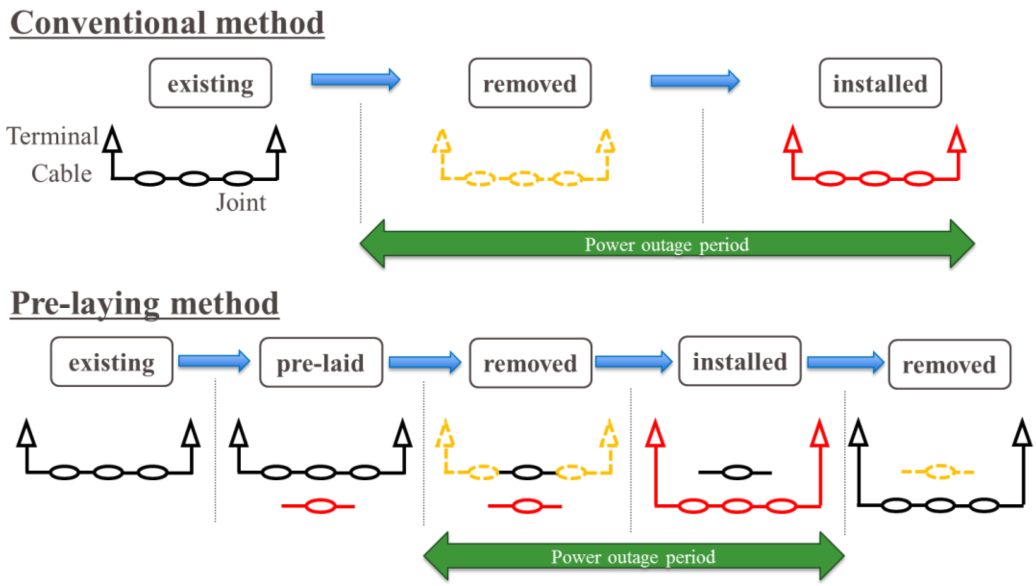


Fig. 1 Difference between conventional method and pre-laying method

3. PRACTICAL EXAMPLES

3.1 case A

Case A shows a cable replacement project in a 275 kV grid. This grid (Fig. 2) mainly consists of aged, self-contained fluid-filled (SCFF) cables, so they are being sequentially replaced by cross-linked polyethylene (XLPE) cables until 2025. Furthermore, in line with the progress of urbanization in the area, the overhead lines in the grid will be finally replaced by underground cables.

The replacement procedure of the K line is described here.(Fig. 3) The duct system for the cables of the K line had no vacant ducts for pre-laying, and so the replacement work was expected to require a long outage period. To shorten the period, we surveyed the soundness of facilities such as duct systems and/or utility tunnels around the K line and checked if they had available space as an alternative route. An alternative route was found, but involved a technical issue related to the dimensions of manholes through which to move the cables and joint boxes.

When comparing SCFF and XLPE cables, XLPE cables generally require much space for joints because of the difference in their extension characteristics when energized. The existing manholes on the alternative route were constructed of a size suitable for the joints of SCFF cables, so it was necessary to enlarge some manholes to avoid the XLPE cables from contacting the side walls of the manholes by a larger thermal expansion than that of SCFF cables. However, this measure could have increased the project cost and affected the environment due to the civil engineering work required. Instead, the application of a compact type premold one piece joint was studied using a model that simulated the existing narrow manholes [1].

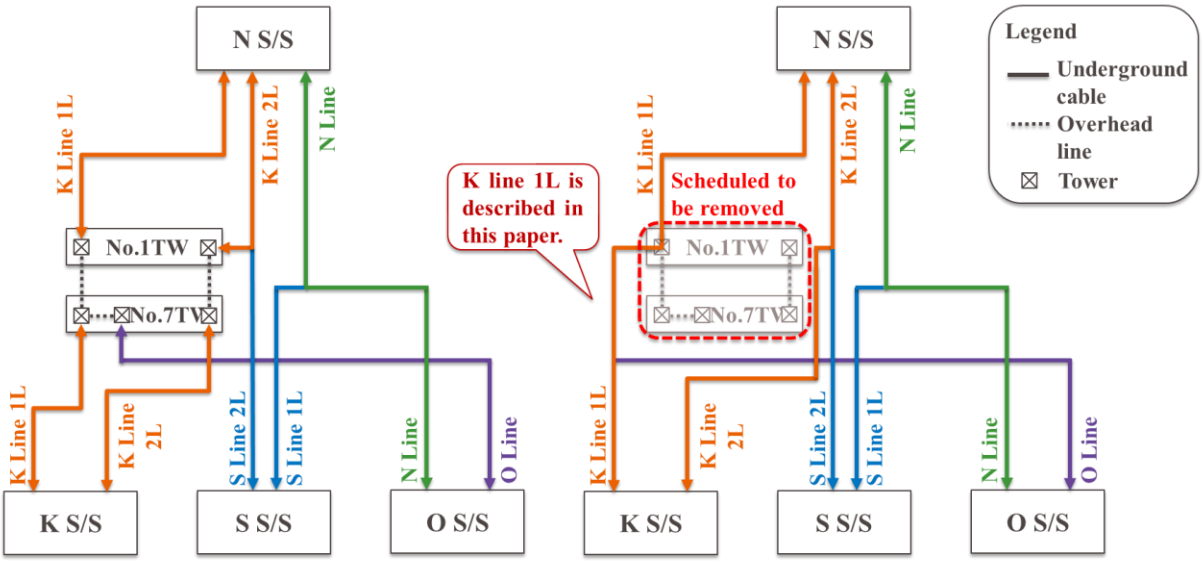
First, the insulation performance of the premold one piece joint was verified by taking the influence of thermal expansion of the cable into consideration. Specifically, the characteristics of the surface pressure and the electrical properties were obtained. The premold one piece joint and the cable used for the tests were assembled in the same arrangement and with the same dimensions as on site.

The surface pressure was measured as the pressure at the interface between the rubber of the premold one piece joint and the insulation layer of the cable while applying thermal expansion to the cable. The results showed that the surface pressure did not decline in the long-term test, which confirmed that premold one piece joint can be assembled and operated in existing manholes. Then, the electrical properties were examined under conditions equivalent to JEC-3408 and the test conditions were confirmed to be satisfied [2].

Finally, the workability in a narrow space was verified by jointing the cables with premold one piece joint in the manhole that simulated the existing ones (Fig. 4).

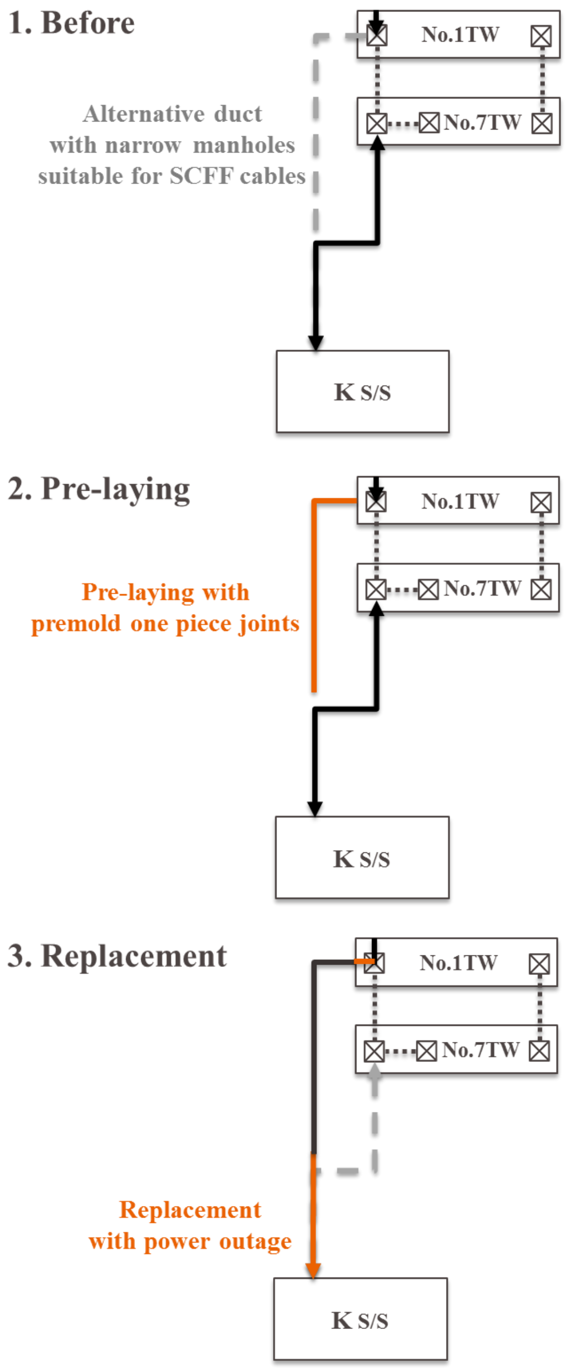
Consequently, by applying the premold one piece joints to XLPE cable, it is possible to install new XLPE cable into the existing alternative route with narrow manholes suitable for SCFF cables. This means that the large scale civil engineering works such as manhole expansion or duct construction could be avoided in the replacement project on the K line. As a result, the construction period , cost, and environmental impact can be reduced drastically. Actually, the pre-laying method on this alternative route was used for the project except for a few sections of all cable route. The actual power outage period was about three months, which was extremely short compared with the initial estimate of about 21 months. This case suggests that the pre-laying method can greatly shorten the duration of the power outage required for cable replacement and improve the supply reliability.

After beginning operation of the new XLPE cables, the existing old SCFF cables in original route were removed with careful attention to oil leaks. Then, an inspection was performed to check the soundness of the vacant conduits for their future use. It would be noted that these works had been completed without power outage requirement.



(a) All SCFF cables as of 2005 (b) All XLPE cables as of 2025

Fig. 2 275 kV line cable system



The K line should be replaced, but the original route had no capacity and the alternative route included narrow manholes.
So the large scale civil engineering works such as manhole expansion or duct construction were needed.

After the verifications of premold one piece joint, XLPE cables were pre-laid into the alternative route without the expansion.

Terminal sections of the new K line are installed.

Fig. 3 K line 1L replacement work utilizing alternative route

(a) Simulated environment (b) Assembly

Fig. 4 Workability test in a narrow space

3.2 case B

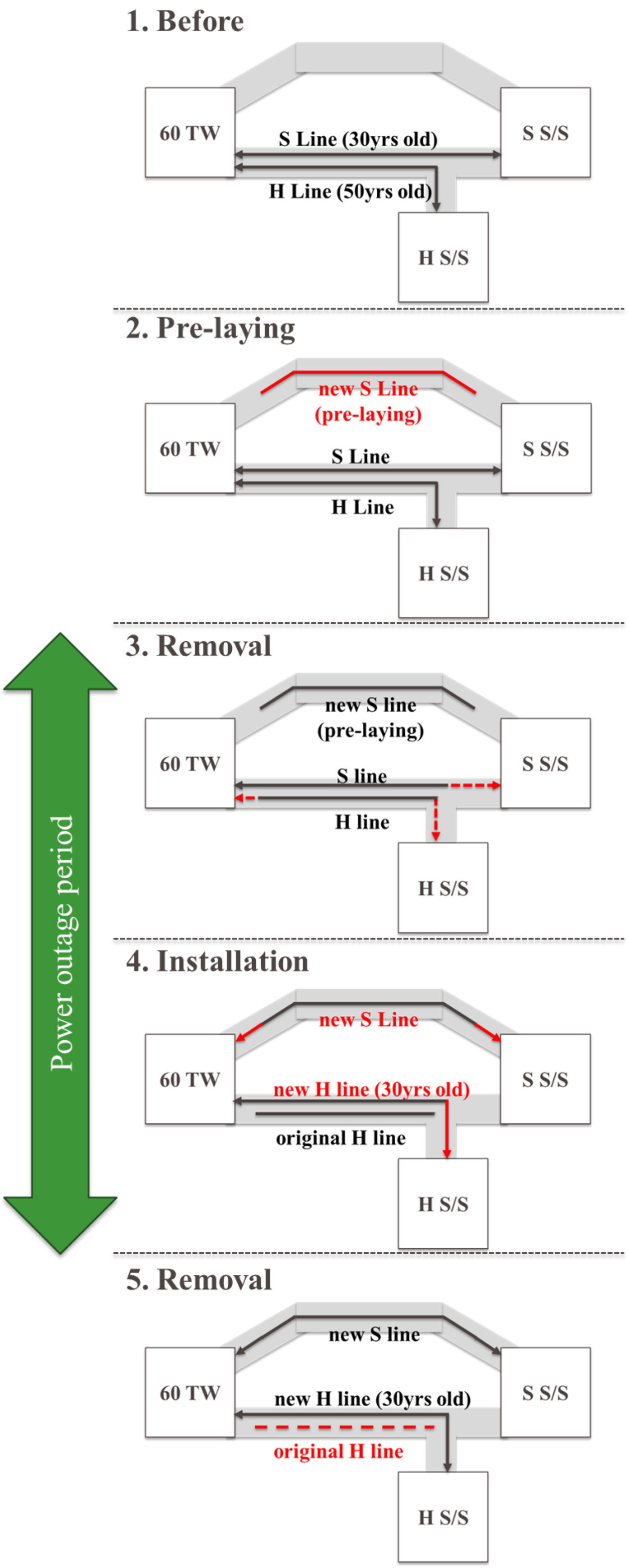
Case B shows an ongoing cable replacement project in a 154 kV grid. In this case, the replacement will be performed by using the cables of other lines after reviewing the whole equipment on the grid. This grid consists of H and S lines. They are connected to an overhead line at the No. 60 tower in a suburban area and transmit power to the H substation and S substation in an urban area, respectively. The H line, with a length of 10 km, needed to be replaced since it had been installed 50 years ago. However, it was difficult to use the pre-laying method for replacing the H line because there were no vacant ducts on the route. Unlike case A in which an alternative route existed that could be connected to original terminations, there was no alternative route that could connect the No. 60 tower and H substation. In general, there are two options in such a situation: use the conventional method, or install a new duct system between the No. 60 tower and H substation and use the pre-lay method. However, neither method is likely to minimize the power outage period and environmental impact at the same time.

Further investigation found a route for which the pre-laying method could be used: between the No. 60 tower and S substation. Considering this route and the soundness of the existing S line, the approach for cable replacement is as follows (Fig.5). First, install a new S line, and then connect between the No. 60 tower and H substation by using a large part of the original S line.

The pre-laying method will shorten duration of the power outage for laying the new S line. On the other hand, some power outage period will be required for the replacement work in the section between the H substation and the original S line because there are no choice but to apply the conventional method because there are no vacant ducts on the route of the H line. However, since the amount of work will be about one-fifth of that for the original 10 km, the actual power outage period will be sufficiently short compared to the original plan. Of course, the environmental impact will be reduced, too.

As a result of this project, the 30-year-old S line will be reborn and the H line will be rejuvenated from 50 to 30 years old.

The H line will be replaced in the future because a large part of the line consists of the original S line. At that time, the pre-laying method will be applied, using the vacant ducts provided by this project.



The H line should be replaced, but cables for it cannot be pre-laid on the original route.

The new S line is pre-laid in the alternative route.

Terminal sections of the original S and H lines are removed.

Terminal sections of the new S and H lines are installed.
A large part of the original S line is diverted as the new H line.

The original H line is removed.

Fig. 5 H line replacement work utilizing S line

3.3 comparison of replacement methods

For each of Case A and Case B, applicable replacement methods were evaluated in terms of the power outage period and environmental impact. For the environmental impact evaluation, considered elements included the amount of CO_2 generated by heavy machinery, impact on soil caused by civil engineering work, and temporary impacts on neighbors such as noise and traffic congestion during replacement work [3][4]. The environmental impact was estimated by referring to past construction records. In this report, the pre-laying method was found to be preferable.

Here, two kinds of replacement method are compared with the pre-laying method. One is to lay new cables in ducts after removing the original cables ("Conventional method A"), and the other is to construct a new conduit system for laying new cables ("Conventional method B").

Table I shows that the pre-laying method and Conventional method B have a much shorter power outage period due to replacement compared with Conventional method A, and thus reduce the impact on supply reliability.

It can also be seen that the pre-laying method and Conventional method A have less environmental impact than Conventional method B. This is because there is no need for civil engineering work associated with installing the duct system or minimizing the amount of such work.

The comparison shows that the pre-laying method is promising for shortening the power outage period and reducing the environmental impact at the same time.

Table I Comparison of replacement methods

	Case A			Case B		
Replacement method	**Pre-laying method**	**Conventional method A**	**Conventional method B**	**Pre-laying method**	**Conventional method A**	**Conventional method B**
Power outage period	**3 months**	**21 months**	**2 months**	**3 months**	**12 months**	**1 month**
Environmental impact	**Low**	**Low**	**High**	**Low**	**Low**	**High**
Assessment	**Excellent**	**Good**	**Poor**	**Excellent**	**Good**	**Poor**

4. CONCLUSIONS

In Japan, underground transmission lines installed in the 1970s are now in the replacement phase. In this report, we focused on two issues to be considered for cable replacement, and introduced specific solutions in actual replacement projects. One issue is to shorten the power outage time associated with the replacement work, and the other is to reduce the environmental impact caused by civil engineering work. It is indispensable for the sustainable development of the electricity business to address these issues for the benefit of society. The pre-laying method is one effective measure. In order to utilize this method, experience with actual cable replacement projects has shown the importance of the following: (a) design and construct equipment taking future replacement into consideration, (b) confirm if the original equipment and new equipment have a good interface, and (c) make a replacement plan that considers overall optimization of the grid. These points are always important for operating and maintaining facilities, regardless of the method used.

BIBLIOGRAPHY

[1] T. Yamamoto et al.: "Evaluation of 275kV Rubber Block Joint in Narrow Manhole," (Proceedings of IEEJ2015 7-105 (in Japanese))

[2] Standard of the Japanese electrotechnical committee: "High voltage tests on cross-linked polyethylene insulated cables and their accessories for rated voltages from 11 kV up to 500 kV," (JEC-3408:2015 (in Japanese))

[3] E. Serres et al.: "Environmental Impacts of Underground Links," (CIGRE2008 C3-301)

[4] E. Serres et al.: "Environmental Impacts in Rural Area of a HV Underground Link," (Jicable 2007 A83)