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COMPACT TRANSITION JOINTS FOR UP TO 154KV POWER CABLE

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ABSTRACT

Transition joints are classified into the straight through joint (DJ, Differential type joint,), the Y-branch type joint (YJ) for 154kV cable, and 3 core straight through joint (3cDJ) for 77kV cable in this paper. Each joint was designed compact compared with the conventional joint, and they have an advantage applicable even in narrow existing manhole for straight through joint to connect oil-filled cables. The development tests of both types for 154 kV class cables have been completed according to JEC3408. The 6 months loading test results for 154kV joint satisfied the requirement in IEC60840 (170kV) with estimating V-t characteristics. 154kV DJs were supplied to service lines in Japan. The initial electric characteristics for 77kV 3cDJ were acceptable according to JEC3401 and also satisfied the equivalent requirement compared with specification of IEC60840 (115kV), and now the development test is being executed.

KEYWORDS

Transition joint, XLPE cable, Oil-filled cable, Interfacial pressure, Y-branch

1. INTRODUCTION

The electric power demand in the world has been increasing continuously. In order to meet the needs for replacing part of existing oil-filled cables from a certain section in the underground power transmission system by XLPE cables, the transition joint[1][2][3][4] between XLPE and oil-filled cables is indispensable because oil-filled cables were used for a long time and the environmental problems of the leakage of oil etc. are involved. However, the space in existing manholes is large enough to install only the existing straight through joint for oil-filled cables, and so the size and weight of the conventional transition joint will impede the connection work and impose restrictions on the cable offset dimensions. And Y-branch transition joint[5][6] permits the additional link by XLPE cables to existing oil-filled cables system.

The authors have therefore developed compact joints that are less than the size of the conventional joint using high electric field technology to cope with the increase in voltage of XLPE cables and joints in recent years.

The development process and examination results are described below.

2. TYPE AND FEATURES OF 154KV JOINTS

The structures of 154kV DJ and YJ are shown in Figure-1 and Figure-2 respectively. DJ directly connects an oil-filled cable and an XLPE cable. And all three ports of the YJ are compatible with both XLPE and oil-filled cables to permit the replacement of existing oil-filled cables, pi-lead-in cables, and many other installation patterns.

The prefabricated XLPE cable side has an insulation structure in which the insulation thickness of the epoxy unit has been reduced and the rubber stress cone has been made compact through research and development of the prefabricated structure based on the electric performance confirmation data[7][8][9] and the design electric field concerning each component element of 154-

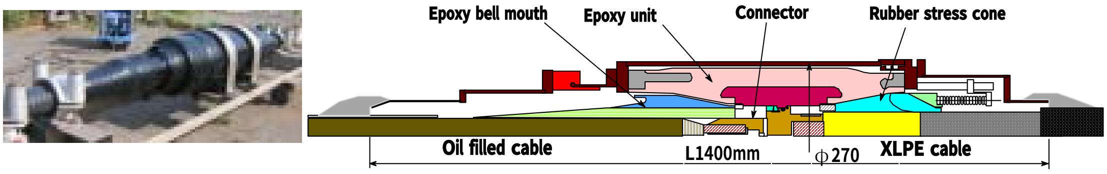

Figure-1. 154kV straight through joint

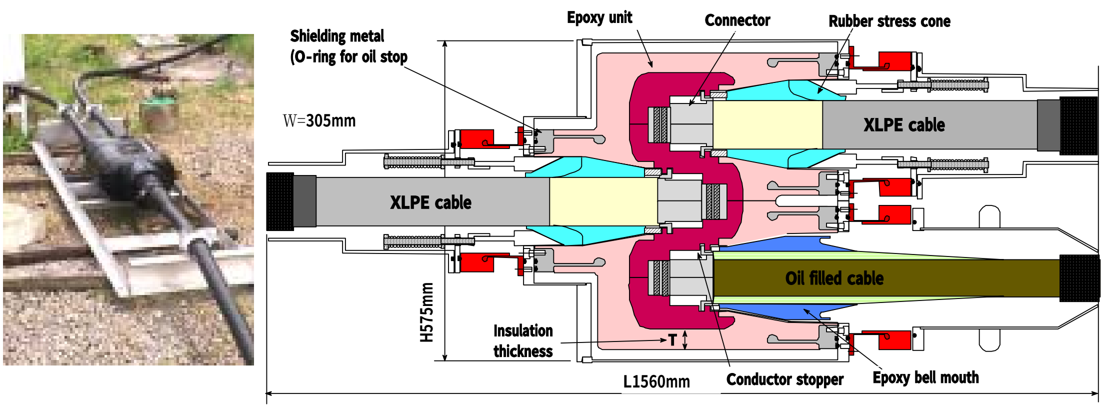

Figure-2. 154kV Y-branch type joint

500 kV PJ.
Furthermore, an electric field shielding structure with an epoxy bell mouth is used for oil-filled cable, and the XLPE cable side is made compact to decrease the interfacial electric field of the epoxy unit and epoxy bell mouth, which used to be the bottleneck in insulation design, so that the interface electric field will not exceed the design electric field.
For connecting the electrode inside the epoxy unit and the cable conductor, an ordinary type conductive connecting sleeve is used in the DJ, while a compressed multi-contact is used in the YJ, to shorten the length of the epoxy unit.
Table-1 compares the structure between the new and conventional joints.

Table-1. Size comparison of the product

Item	154kV YJ		154kV DJ	
	Design in the past	Under development	Past product	Developed product
Length	1700	1560	1600	1400
Height	605	575	–	–
Diameter (Width)	335	305	335	270

Unit (mm)

(2.1) Connection of conductor
A tulip contact was used to connect and disconnect the conductor in the existing YJ. The pulling-out force is approximately 2.5 kN, and a stopper mechanism must be provided for an extraction force of 10 kN or more, which has prevented miniaturization.
Therefore, the authors designed a connecting terminal with a multi-band at the tip, which enables the dimension in the longitudinal direction to be reduced by approximately 20%. The cable pulling-out force in the conductor stopper (Figure-2) secured to the connecting terminal was measured, and the cable was pulled out by the force of 26.95 kN, thus achieving the expected performance.
On the assumption that cables would be disconnected and reconnected every year in the field, the number of connection times was set at 30, and a connecting terminal was inserted into both ports on the two-port side to measure the contact resistance between connecting terminals. As shown in Figure-3, there was no abnormal increase in resistance.

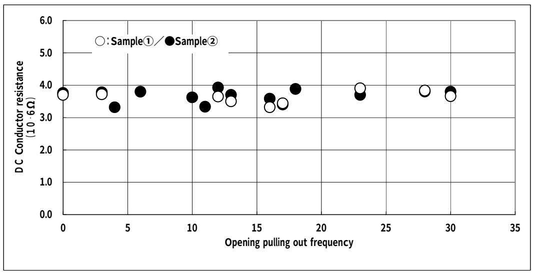

Figure-3. Connection times and DC resistance

(2.2) Epoxy unit
As illustrated in Figure-2, each cable insertion port of the epoxy unit has a shielding metal and an O-ring for stopping oil to allow both XLPE and oil-filled cables to be connected. If the conventional 66 kV YJ insulation design were to be used as a base, the reduction in epoxy insulation thickness would be a bottleneck. Therefore, the design electric field was planned on the basis of the recent high-performance technology[8], and a flat epoxy electrode (oval radius section: insulation thickness of T in Figure-2) was used to reduce the insulation thickness. The result was reflected also in the 154 DJ to reduce the conventional dimensions.

(2.3) Insulation structure of XLPE cable side
A reduction in the epoxy insulation thickness causes an increase in the interface electric field in the rubber stress cone, as well as in its interface section (rubber stress cone/epoxy unit and rubber stress cone/cable insulating material). However, as a result of an increase in the stress based on the recent interface performance verification test[10], a compact structure was achieved without exceeding the design electric field.

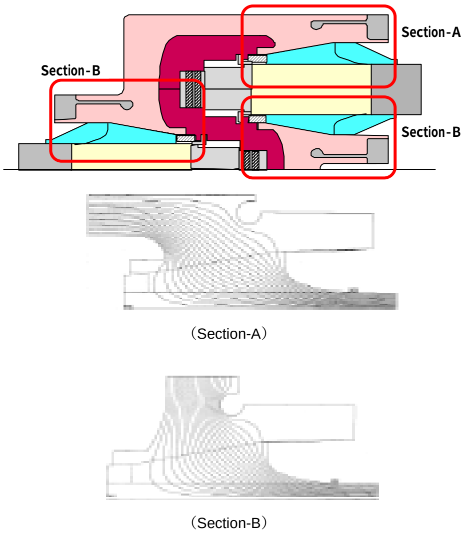

Figure-4. Electric field map of XLPE cable side

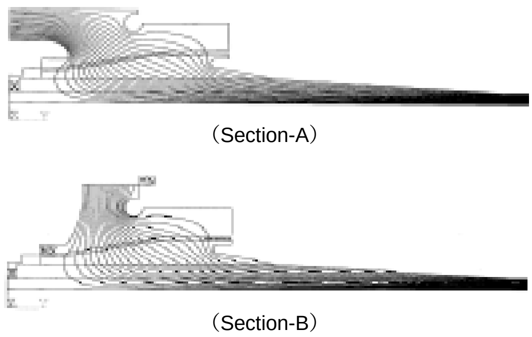

Figure-5 Electric field map of oil-filled cable side

As a result of electric field analysis, it was confirmed that the electric field strength in the epoxy unit and in the interface section would not exceed the design value. Figure-4 shows an example of electric field maps. The cross sections A and B were analyzed based on the three-dimensional structure peculiar to the YJ.

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(2.4) Insulation structure of oil-filled cable side

In the unit structure for XLPE and oil-filled cables, the oil-filled cable side has an electric field shielding structure with an epoxy bell mouth as shown in Figure-1 to match the shape of the rubber/epoxy interface on the XLPE side. Since the tolerance for the design electric field is small in the oil/epoxy interface electric field, the shape of the epoxy bell mouth is made to equalize the oil/epoxy interface electric field, thereby improving the electric potential sharing near the interface. Figure-5 shows the electric field map on the oil-filled cable side.

3. DEVELOPMENT TEST FOR 154KV JOINTS

(3.1) Development target performance

The target performance of the test is shown in Table-2.

Table-2. Target performance

Item		Requirement
XLPE cable (JEC3408)	AC	295kV×1hour（RT）
	Imp.	±1035kV×3shots（RT）
Oil-filled cable	AC	300kV×3hours（（RT）
	Imp.	-900kV×3shots（RT）
Loading Test (JEC3408)	AC	130kV×6months (145kV×1 month) Heat-cycling condition： RT〜90°C×5months RT〜105°C×1month 1 cycle for 1 day with holding more than 2 hours in max. temperature

Room Temperature = RT

(3.2) Initial electric test

The initial electric performance of the designed 154 kV YJ was evaluated. Two 154 kV 1800 mm^2 XLPE cables and a 154 kV 800 mm^2 oil-filled cable was connected.

The result of the initial electric tests is shown in Table-3.

All samples met the AC and Impulse withstand voltage requirements. The breakdown voltage was 450 kV for AV and -1140 kV for Impulse, indicating that the performance was equivalent to or better than the conventional oil-filled part. The oil/epoxy interface on the oil-filled cable side broke in all samples.

In a sample fabricated solely by XLPE cables for checking the Impulse breakdown performance on the XLPE side, the starting point to relieve the electric stress of the rubber stress cone broke when a voltage that substantially exceeded the withstand voltage was applied. As a result of these initial electric tests, the appropriateness of the downsized 154 kV YJ design was verified.

In the Impulse test of the 154 kV DJ, the result exceeded -1100kV (no breakdown in the DJ part).

The test results of DJ and YJ satisfied the equivalent requirement in accordance with IEC62067(230kV).

(3.3) Long-term loading cycle test for 154kV YJ

In succession to the initial electric test, a loading cycle test was conducted to evaluate the long-term electric performance.

In the same way as the initial electric test, a YJ with two XLPE cables and an oil-filled cable was used as a sample. The test line is shown in Figure-6. A loading heat cycle test was conducted using a loop composed of testing termination (EB-A), XLPE cable, YJ, XLPE cable, and EB-A under the specified conditions.

Table-3. Result of initial performance test for YJ

Sample	Item	Result
Oil-filled /XLPE	AC	300kV×3hours withstood Step-up15kV×1hour 450kV×10minutes breakdown (Oil/Epoxy interface on OF side)
Oil-filled /XLPE	Imp.	-900kV×3shots withstood Step-up20kV×3shots -1140kV×1shot breakdown (Oil/Epoxy interface on OF side)
XLPE /XLPE	Imp.	±1035kV×3shots withstood Step-up-50kV×3shots -1485kV×1shot breakdown (Starting point of rubber stress cone)

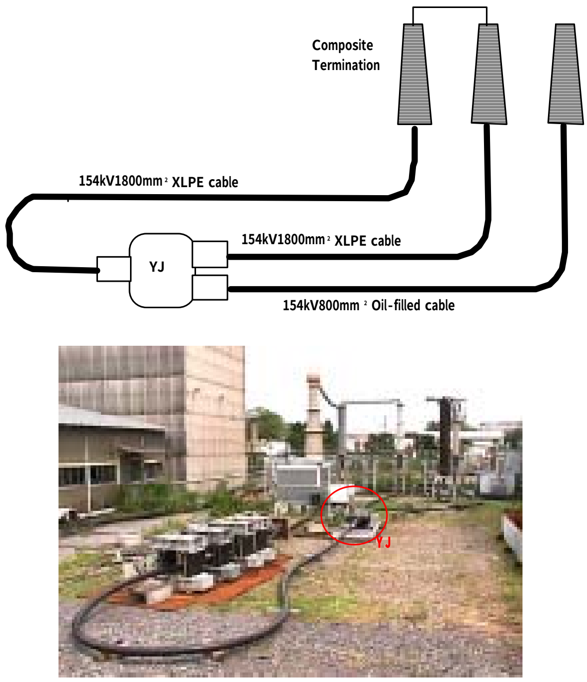

Figure-6. Loading test line for 154kV YJ

Table-4. Result of long-term loading test for 154kV YJ

Item		Result
Loading test		Pass
YJ	OF /XLPE	Imp. -900kV×3shots withstood ⇒ AC200kV×10minutes withstood Oil-filled cable was replaced by XLPE cable, and the following tests are executed.
	XLPE /XLPE	Imp. ±1035kV×3shots withstood ⇒ AC175kV×10minutes withstood Breakdown test AC695kV×10minutes No breakdown

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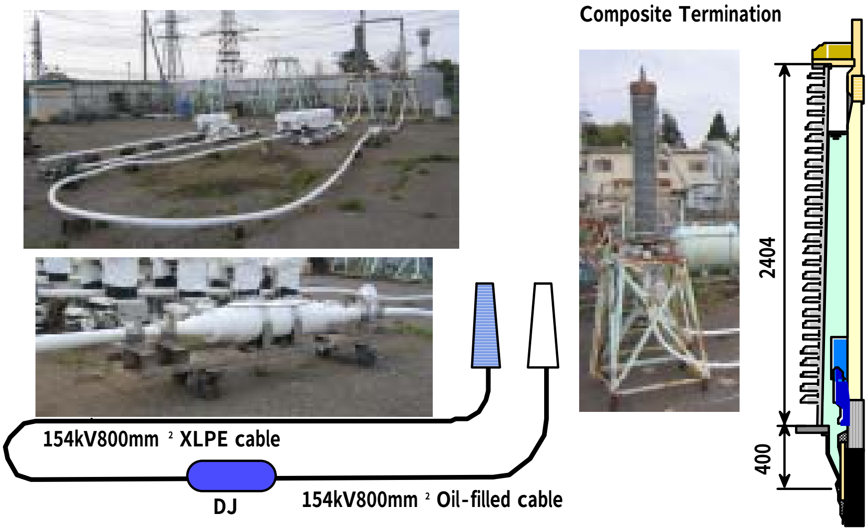

Figure-7. Long-term loading test line for 154kV DJ

The test voltage was set at 150 kV in view of the required performance of the oil-filled cable side, and 90°C×5 months/105°C×1 month was set as the loading condition according to JEC3408 because the current loop was formed by the XLPE cables.
The result of the long-term loading cycle test was satisfactory as shown in Table-4, and an Impulse test was conducted in succession to the loading cycle test. It was verified that 154kV YJ had the performance equivalent to IEC60840(170kV), provided that the applied voltage and time are estimated with V-t characteristics which life exponent (n=15) were studied. [11] During the residual voltage test, the withstand voltage on the oil-filled cable side was confirmed, and the oil-filled cable was replaced by new XLPE cable to continue the test, avoiding the break-down in the oil-filled cable side. As a result of checking the withstand voltage on the XLPE cable side, it was found that the YJ would not break down even in an AC breakdown test.

(3.4) Long-term aging test for 154kV DJ

Next, the DJ was evaluated in the test line shown in Figure-7. A one-month type test was conducted in accordance with JEC3408, assuming that the half-year loading performance of the DJ had been confirmed based on the result of the YJ test. The test terminal on the XLPE cable side was provided with a composite termination[12][13].

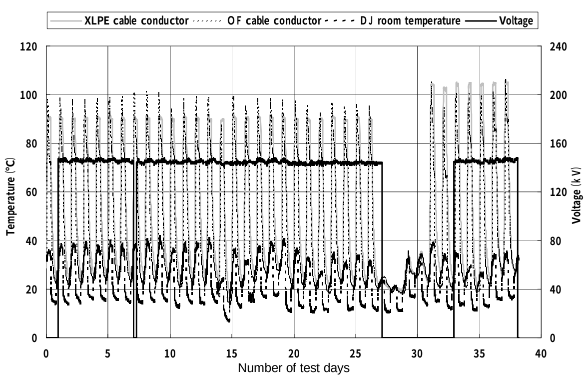

Figure-8. Test record of 154kV DJ

The test record is shown in Figure-8. Loading was controlled according to the temperature of the XLPE cable conductor. In order to suppress the rise in the oil-filled cable temperature, heat-cycling measures were taken for the XLPE cable side.
It was confirmed that both the initial and long-term performance of the DJ were satisfactory and that all the requirements were met. The results of these tests verify the reliability of the newly developed compact joint.

4. STABILITY EVALUATION OF RUBBER INTERFACE

In the prefabricated structure used for the XLPE cable side, the distribution of the interface pressure is also an important design factor, and so the interface pressure and its distribution in the direction of the interface were confirmed by stress analysis. An example of the analysis is shown in Figure-9.

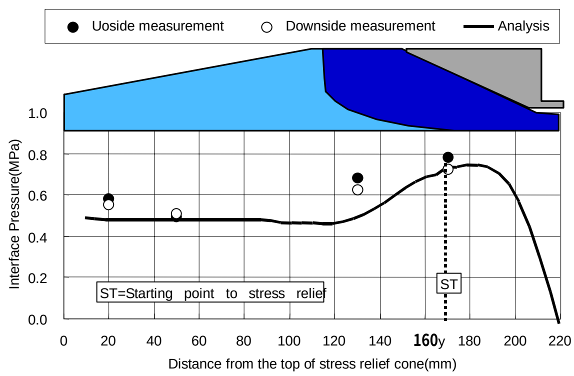

Figure-9. Measurement and analysis result of cable interface pressure

In Figure-9, the values actually measured this time are also plotted, indicating a trend approximately consistent with the analysis. In the interface section within the range of the electric field, the pressure was 0.5 MPa. It is known that the interface pressure of approximately 0.05 MPa ensures sufficient electric performance because the

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rubber will fit in (adhesion) after formation of an interface[(10)(14)], and it was judged that the pressure level set this time would ensure sufficient interface electric performance.
Furthermore, a test was conducted to confirm whether or not the pressure would drop due to depletion of silicone oil under the condition shown in Table-5 in order to examine the long-term stability of pressure. As shown in Figure-10, a sample with sensors set at the specified locations to check the pressure, displacement, and temperature was prepared to measure the heat cycle pressure.

Table-5 Sample condition for DJ

Sample	Measured item	Surface Oil Applying condition
(1)	Pressure/Temperature/ Spring change	Usual applying
(2)		Dryness
Heat-cycling condition		105°C×10cycles

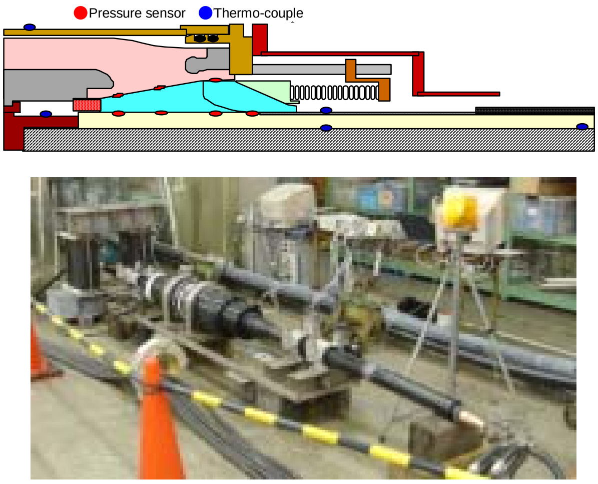

Figure-10. Measurement sample of the interface pressure

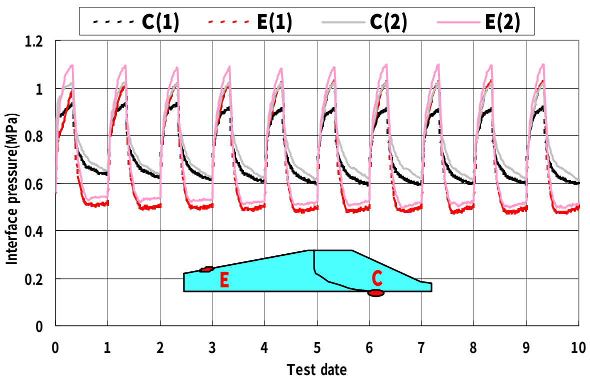

Figure-11. Change of the interface pressure
<Sample (1)&(2)>

Figure 11 shows the change in pressure with the passage of time. The graph shows that the interface pressure behaviour is stable from the initial stage of the heat cycle.
Comparing sample (1) with sample (2), the interface pressures are almost identical to each other after 10 cycles. A conspicuous drop in the interface pressure was not observed either in sample (2), which simulated the interface oil depletion state assuming the condition after long-term use, and it was confirmed that the interface pressure was sufficient in the normal temperature state when the heat cycle was off.
The rubber stress cone used for the DJ showed stable interface pressure during a heat cycle, verifying that it had rubber elasticity and interface characteristics with high mechanical reliability.

5. STRUCTURE OF 77KV JOINT

The conventional transition joint[(1)] is composed of a paper-covered reinforcing insulation material on the oil-filled side and a prefabricated insulation material and an epoxy unit on the XLPE cable side.
An epoxy bell-mouth used in new compact 3cDJ as shown in Figure-12 was used on the oil-filled cable side this time. A 3-core packaged copper structure was used to limit the increase in outer diameter. Using the latest downsizing technology, the new joint was provided with an epoxy unit used the same design value of a 154 kV transition joint, and a compact stress cone as large as the conventional 22 kV class cone was used on a XLPE cable side.

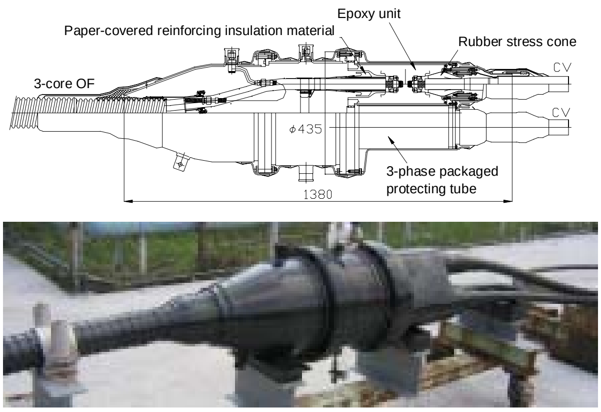

Figure-12. Developed structure (77kV 3cDJ)

Table-6 shows the result of the compact design. The length of the new joint is equivalent to that of the conventional joint for oil-filled cable.

Table-6. Comparison of dimensions

Item	Size (mm)		
	Conventional DJ	Conventional Oil-filled Joint	Developed DJ
Length	2000	1450	1380
Outside diameter	480	236	435

6. DEVELOPMENT TEST FOR 77KV JOINT

Table-7 shows the condition of an electric test of the developed joint conducted in conformity with JEC3401-2006.
A working space that simulated the existing manhole (1.4 m in width × 5.5 m in length × 1.8 m in height) was used. Figure-13 shows connection work of oil-filled cable side in the narrow space and it was confirmed that a 3cDJ could be installed without problem.
Since the result of the initial test was satisfactory, a line as shown in Figure-14 was installed for a long-term

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development test, and the loading characteristics are being studied from Nov.2006. The additional test will be conducted according to IEC60840(110kV) after finishing the above 6 months test.

Table-7 Required performance

Item		Requirement
XLPE Cable	AC	150kV×1hour（RT）
	Imp.	±550kV×3shots（RT）
OF Cable	AC	150kV×3hours（（RT）
	Imp.	±480kV×3shots（RT）
Loading Test	AC	65kV×6months Heat-cycling condition： RT〜90°C×5months RT〜105°C×1month

Room Temperature = RT

The change of the conductor temperature of the oil filled cable side is monitored at one core of 3 cores during the heat cycling, and the loading test loop is formed using the other two cores. The temperature of XLPE cable conductor to control the loading current is measured.

Figure-13. Jointing work in the imitated narrow manhole

Figure-14. Loading test sample for 77kV 3cDJ

7. CONCLUSION

The compact 154kV YJ and DJ developed this time showed satisfactory performance and thermo-mechanical behaviour on the interface of the XLPE cable side. 154kV DJs were already supplied in service lines in Japan.
The 77kV 3cDJ applicable to the existing narrow manhole for the straight through joint to connect existing oil-filled cables was developed, and its initial electrical characteristics and workability in simulated narrow working space were shown to be satisfactory. When the whole development test is completed, the new joint is expected to greatly contribute to the replacement of existing oil-filled cable lines by XLPE cable lines.

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