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# DEVELOPMENT OF ONE PIECE TYPE JOINT( SELF PRESSURIZED JOINT) FOR 400KV XLPE CABLE

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## ABSTRACT

*One piece type joint for 220kV class XLPE cable system has been developed and widely used all over the world. Main features of this joint are 1) Compactness, 2) High reliability, 3) Long storage period, and 4) Less jointing skill comparing with conventional joint. From the above point of view, we have determined to develop the new joint for 400kV XLPE cable system by taking over the basic technology of 220kV class joint.*

## KEYWORDS

One piece joint, EHV, XLPE, self pressurized, SPJ

## 1. INTRODUCTION

There is a growing demand of more compact and easier assembling joints than conventional joints. In recent years, the key word for extra high voltage jointing is skill reduction.

One piece type joint as we called self pressurized joint (here in after SPJ) up to 220kV class, has been developed and widely used all over the world since 1995 and supplied more than 12,000 sets totally. This SPJ consists of one pre-molded insulator (rubber unit), which contains the main insulation, insulation screen and HV electrode layer made of EP rubber molded in one piece at the factory. Main features of SPJ are as follows, 1) Compactness, 2) High reliability, 3) Long storage period. 4) Furthermore this joint can be assembled by less jointing skill comparing with conventional straight through joints, such as Extrusion Molded Joint (here in after EMJ) and/or Prefabricated Composite Joint (here in after PJ). EMJ is compact and has excellent electrical property, but requires more assembling time and well-trained jointers. PJ, which consists of an epoxy insulator and rubber molded stress cones with spring unit, achieved shorter assembling time and less jointing skill than EMJ, but still complicated and is required to be assembled by skilled jointers.

From the above point of view, we have determined to develop the SPJ for 400kV XLPE cable system by taking over the basic technology of 220kV class SPJ. The electrical performance required on the new joints shall comply with IEC 62067 (rated voltage 400kV).

The pre-qualification and type test have been carried out and successfully completed. A view of the long-trem heat cycle voltage testing is shows in Fig. 10.

This paper introduces the design, electrical performance and installation workability of SPJ in comparison with the conventional 400kV class joints.

## 2. CONSTRUCTION AND FEATURE OF SPJ

The cross sectional view of the SPJ is shown in Fig. 1. The SPJ is superior to conventional EMJ or PJ in the following points.

(1) Ensuring reliable performance: The main insulation unit is manufactured at the factory and tested for AC withstand voltage with partial discharge measurement (routine test), prior to the shipping (see Fig. 2).

(2) Shorter overall joint length and construction period than EMJ or PJ as shown in Table 1.

(3) Stable quality of installation work is assured: The main insulation is a factory- tested integral unit. It does not require special skills except for controlling the interface between the unit and cable insulation. This can reduce human errors in assembling. In other words, the SPJ is less dependent on the worker's skill and can provide reliable performance.

Figure 1. Cross section for the SPJ

Figure 2. Electrical routine test of a SPJ

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Table.1 Comparison between EMJ, PJ and SPJ

| | | EMJ | PJ | SPJ |
|---|---|---|---|---|
| Size*1 (Length ×Diameter) (mm) | | 2,300 x ϕ240 | 2,200 x ϕ390 | 1,300 x ϕ240 |
| Jointing work | Skill | Very High | High | Low |
| | Tool | Much | Few | Few |
| | Period *2 | Approx. 50 days | Approx. 26 days | Approx. 20 days |

Note*1) In case of 400kV XLPE 2,500mm$^2$ cable.
Note*2) An example. Depend on the several conditions.

## 3. TARGET PERFORMANCE

We have designed new one piece joint to comply with IEC 62067 (rated voltage 400kV). The individual target performance is shown in Table 2.

Table 2. Target of electrical performance

| Item | Target of electrical performance |
|---|---|
| Partial discharge | No partial discharge occurred at 330kV |
| AC Voltage | 440kV / 1h |
| Lightning Impulse Voltage | ±1425kV / 10times (hot) |
| Switching Impulse Voltage | ±1050kV / 10times (hot) |
| Heating Cycle Voltage(Long term) | 440kV / heat cycle 20times<br>max conductor temp. 95-100$^{O}$C |
| Prequalification test | 400kV / 8760h<br>heat cycle 180times<br>max conductor temp. 90-95$^{O}$C |

## 4. DESIGN

4.1 Insulation Design

Parameters affecting the insulation performance consist of the insulation thickness of the rubber unit, insulation length of the interface, shape of the conductor shield and insulation shield. An optimum combination of these parameters was determined by electrical field mappings to obtain the targeted electrical performances and dimensional conditions can be satisfied.

(1) The design stress
The design stress of the insulator (the rubber unit) was determined from the latest results of breakdown tests.

(2) Insulation length of interface, and shape of electrode
The insulation length of the interface and the shape of the electrode were determined by comparing electrical field mappings for various combinations of the length and shape assuming that the insulation thickness is determined as in (1) above, while referring to the typical insulation length and typical shape of internal electrode of PJs for 154 kV –275 kV systems. Figure 3 shows the typical electrical field mappings.

(3) Long-term performance
The long-term performance of the SPJ has been

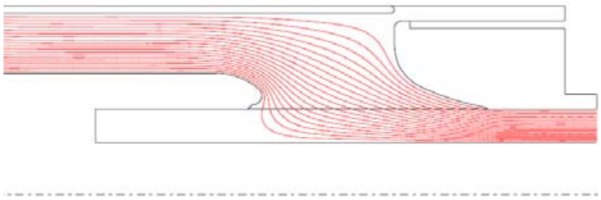


Figure 3 Typical electrical field mapping of SPJ

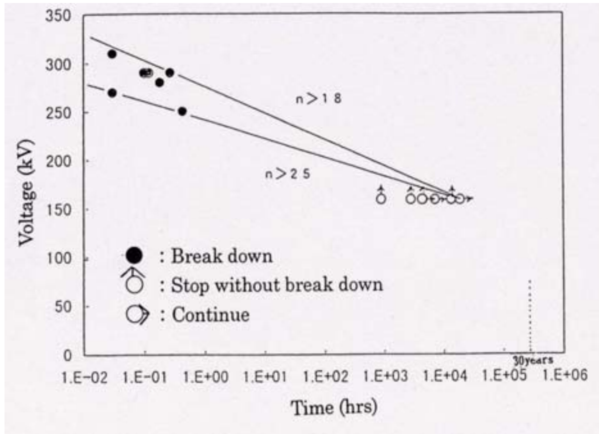
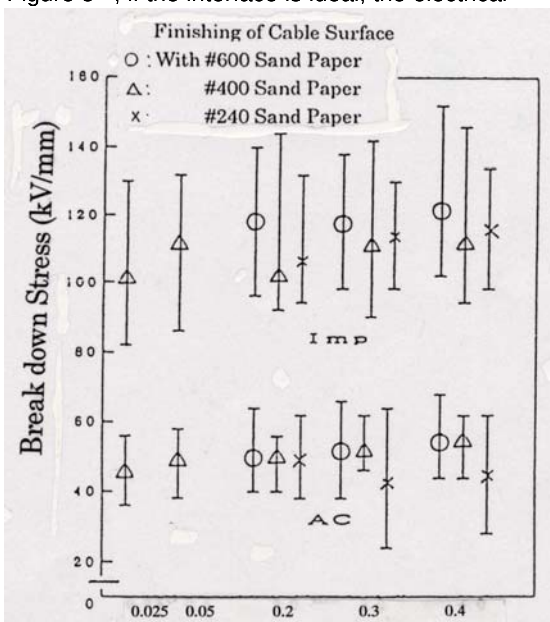



Figure 4 Long Term performance of commercial SPJ

confirmed sufficiently by practical application of SPJ for 110-132 kV XLPE cable before developing 220 kV SPJ as shown in Figure 4. The life exponential "n" of the SPJ is estimated at over 18, which indicates the stability for long years operations.

4.2 Interface Pressure design

To maintain the interface electrical performance mentioned in 4.1 above, it is necessary to keep the interface pressure over the entire parts of the interface throughout the design life of the joint, 30 years. As shown in Figure 5[1], if the interface is ideal, the electrical




Interface Pressure (Mpa)

Figure 5 The effect of interface pressure on B.D. voltage performance can be favorably maintained even with a lower interface pressure than 0.2 Mpa, such as 0.025 MPa or so. Unlike PJs, the SPJ has an ideal structure in which the direction of rubber contraction is the same direction of pressurization.

Thus, the SPJ requires less interface pressure than the PJ. However, the present design of the SPJ are based on the same philosophy as that of PJ to keep an interface pressure over 0.2 MPa for 30 years [(2)]. We will continue to investigate most optimum interface pressure.

Major parameters that define the interface pressure are the initial interface pressure and long-term stress relaxation characteristic of rubber. The results of our studies on these parameters are shown below.

(1) Initial interface pressure

The interface pressure is defined by the following equation [1] depending on the difference in diameter between the cable core and rubber unit. The initial interface pressure of the SPJ was determined so that the interface pressure calculated based on the stress relaxation characteristic mentioned in (2) can be kept more than 0.2 MPa after 30 years.

$$p = \frac{\varepsilon_0 \delta}{r_1\left(\dfrac{r_1^2 + r_2^2}{r_2^2 - r_1^2} + \nu\right)} \quad \cdot\ \cdot\ \cdot [1]$$

Where,

P = Interface pressure

$\delta$ = Difference in diameter between the outer surface of the cable and the inner surface of the rubber unit ($r_o$ - $r_I$)

$\varepsilon_o$ = E-modulus (Young's modulus)

$\nu$ = Poisson's ratio of rubber

$r_o$ = Inside diameter of the rubber unit

$r_I$ = Outside diameter of the cable insulator

$r_2$ = Outside diameter of the rubber unit

(2) Stress relaxation characteristic of the rubber

Stress relaxation of the rubber material is mainly caused by slippage of its molecular. Figure 6 shows a measurement of the long-term stress relaxation characteristic of a rubber sheet at the elongation of 30%. Points marked with a black symbol in the figure show converted values of actual high-temperature data using

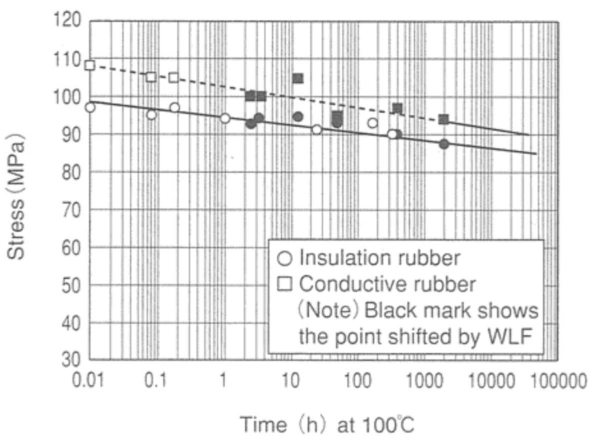



Figure 6 Stress relaxation characteristics of the rubber sheet

the WLF equation[(3)]. Points marked with a white symbol show values obtained by actual measurement. It can be seen in this figure, the black points correspond with the white points well. This indicates that the WLF equation is available for evaluating the long-term stress relaxation characteristic of rubber material. This figure indicates that the stress relaxation after 30 years is 15 to 20%. Using this stress relaxation value, we can estimate the initial interface pressure required for maintaining the pressure level above the specified value during the life of 30 years.

(3) Actual measurements of the interface pressure of SPJ

Figure 7 shows actual measurements of the interface pressure of actual samples of the rubber unit. The method of measurement is described here; install the rubber unit onto a pipe which is similar to actual cables;
keep the sample temperature at 100 ℃ for 12 hours, 70 hours, 100 hours, 370 hours and 850 hours respectively; insert the samples in a pipe equipped with a pressure sensor; then measure the interface pressure at normal temperature. Results indicate that the stress relaxation characteristic of these samples is almost the same as that shown in Figure 6 showing the characteristic of a rubber sheet. We concluded that the reduction of interface pressure due to stress relaxation is 20%. Our design criteria for the initial interface pressure are based on this stress reduction factor.

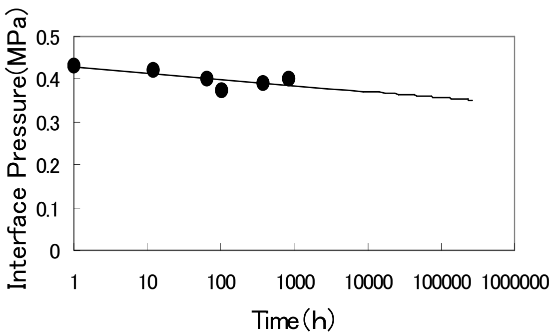



Figure 7 Actual measurements of the interface pressure of SPJ

## 5 CONSTRUCTION OF 400KV SPJ

Figure 8 shows the construction of the SPJ for 400 kV XLPE cable. The dimension is smaller than that of EMJ or PJ.

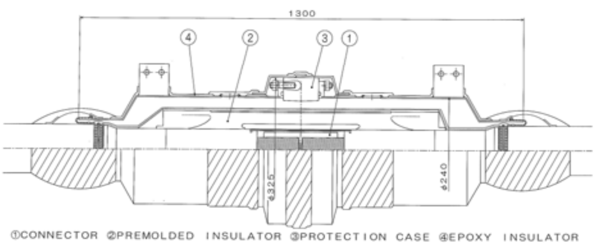
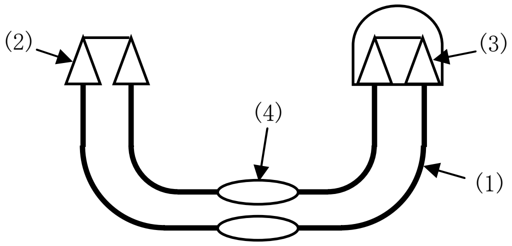



Figure 8 Construction of 400kV SPJ

## 6 RESULT OF PERFORMANCE TEST

6.1 Layout

Fig. 9 shows the layout of performance test. Fig. 10 shows the view of testing line in Hidaka works.




(1) 400kV 1500mm$^2$ XLPE cable
(2) EBA (One is polymeric bushing, another one is porcelain bushing.)
(3) EBG, (4) SPJ

Figure 9. Layout of performance test

Figure 10 View of Test Line

6.2 Pre-qualification test

Table 3 shows the results of pre-qualification test conducted on developed SPJ with new EB-A and EB-G. It is ensure that developed accessories comply with pre-qualification test requirement of IEC 62067.

Table 3. Result of Pre-qualification test

| Item | Specification | Result |
|---|---|---|
| Heating cycle voltage | 400kV/8760h | Withstood |
| Examination | No sign of deterioration | No sign |

6.3 Type test

Table 4 shows the results of type test conducted on developed new SPJ, EB-A and EB-G. All of results satisfied with type test requirement of IEC 62067.

As the results, certificate of pre-qualification and type tests for developed SPJ, EB-A and EB-G have been obtained by third-party organization.

Table 4. Results of type test

| Item | Specification | Result |
|---|---|---|
| Partial discharge | No partial discharge occurred at 330kV | Withstood |
| AC voltage | 440kV / 1h | Withstood |
| Lightning impulse voltage | ±1425kV / 10times (hot) | Withstood |
| Switching impulse voltage | ±1050kV / 10times (hot) | Withstood |
| Heating cycle voltage | 440kV/heat cycle 20times | Withstood |
| Examination | No sign of deterioration | No sign |

## 7. Installation of SPJ

Figure 11 shows the installation procedure of the SPJ. The SPJ installation requires expanding and contracting the rubber unit. We have already developed simple tools for these procedures to make at easier and simpler.

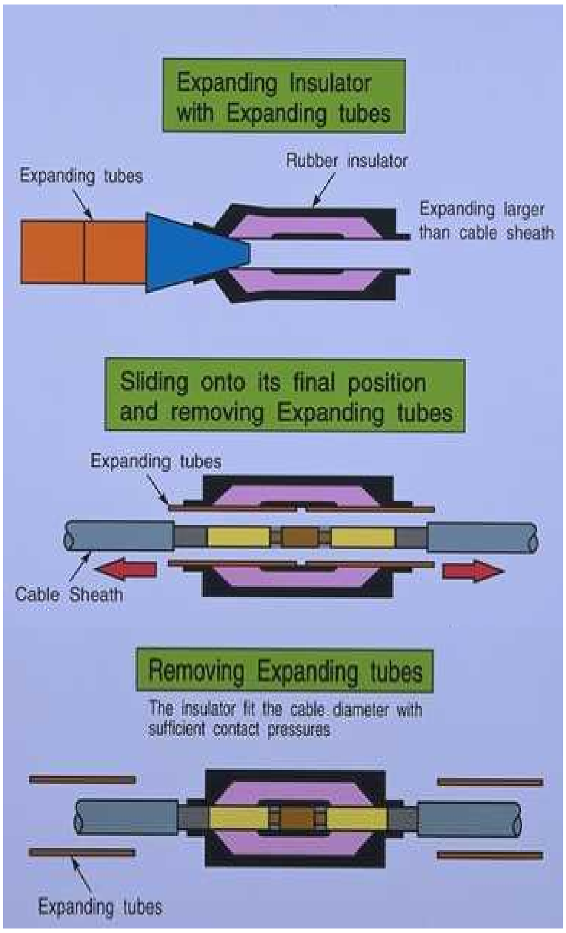



Figure 11 Installation procedure of SPJ

## 8. Conclusions

The SPJ can reduce installation costs extremely because of the reduction in installation period, and space requirements. The SPJ can contribute to the reduction of total facility costs through, for example, enabling more efficient use of existing manhole. The SPJ is applicable not only for long distance transmission lines but also for various installations and circumstances including urgent situations and applications in small joint bays where conventional joints can not be applicable.

The authors believe that the SPJ will be used widely in the world.

## 9.Reference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