Development and Supply to Denmark's NKT of Prefabricated Joints for 420-kV XLPE Cable

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ABSTRACT In Denmark a massive project is under way to install underground UHV power transmission lines to replace aerial lines. In Phase I of this project Furukawa Electric has developed epoxy-unit prefabricated joints (PJs) for 420-kV XLPE cable. Prior to delivery, the PJs successfully passed type approval tests according to IEC standards as well as a 1-year loading test at CESI (Centro Elettrotecnico Sperimentale Italiano). Cable connection work began in April 1996 involving the installation of 72 phases, and the line went into commercial service in October 1997. These PJs are the first in this voltage class to be used with XLPE cable on long-distance lines.

1. INTRODUCTION

In Denmark during the years of 1991 to 1992, there was a heated controversy about the adverse effects of electromagnetic fields on human body, which might be caused by overhead transmission lines. The controversy developed into a social problem that included arguments about the beauty of supporting structures in addition to depreciation of real estates in the neighborhood of transmission lines. Against this background, "The Metropolitan Power Project", a 420-kV power grid construction plan for the eastern part of Denmark, was launched to install underground the transmission line linking the urban area of Copenhagen with its suburbs.

The construction project started in 1996, in which NKT Cable Co. and Furukawa Electric were in charge of developing a 420-kV XLPE cable and an epoxy-unit type prefabricated joint (PJ), respectively. The PJ of this type was the first in the world to be applied for such a long distance XLPE cable working in the 420-kV class[1)].

2. OUTLINE OF "THE METROPOLITAN POWER PROJECT"

Located in the North Sealand of Denmark as shown in Figure 1, the project comprises the southern transmission line, the northern 420-kV transmission line, and the substations, and it is scheduled to be completed by 2003, by installing all the transmission lines underground. "The Metropolitan Power Project" is planned and promoted jointly by Copenhagen Lighting Department Co. (CLD), a power utility company in Denmark and North East Electricity Supply Authority (NESA), its counterpart in the northeastern Denmark; and its first phase is the construction of the southern transmission line underground that extends from the city of Copenhagen westward linking to the 420-kV overhead transmission line in the suburbs.

Table 1 Outline of the 420 kV XLPE cable line

Voltage	420 kV
Cable	XLPE 1,600 mm^2
Number of joints	72 sets
Number of circuits	1 circuit
Route length	22 km
Transmission capacity	800 MW
Construction period	1996/4~1997/8 (1997/10 operation start)

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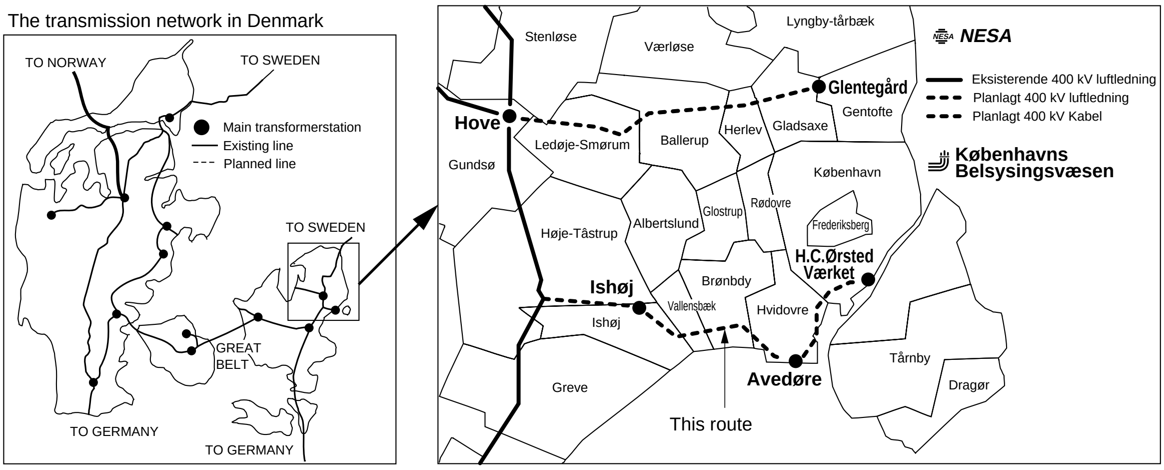


Figure 1 Route diagram of "The Metropolitan Power Project"

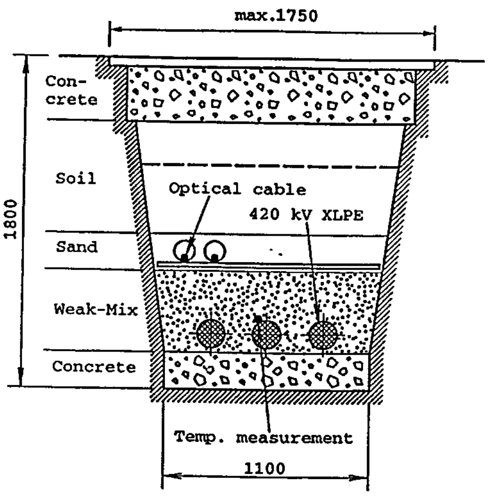


Figure 2 Cable layout

3. OUTLINE OF THE CABLE LINE

3.1 Outline

Table 1 gives the outline of the cable line[2]. The use of oil-filled cable was avoided because of possible environmental contamination in the case of an oil leakage, and XLPE cable was chosen to be applied for the line. The line is considerably large scaled for an XLPE cable of this class, with its 22 km cable length and 72 sets of joints. The cable laying follows a direct burial method with a layout as shown in Figure 2.

3.2 Structure of Joint

The joint adopted is epoxy-unit type PJ, with its structure shown in Figure 3 and exterior appearance in Photo 1. The insulator system of the joint consists of an epoxy-unit and pre-molded insulators, whereby the latter is compressed against the former by a compression device so that a specified surface pressure is provided at the interface to ensure insulation. The epoxy-unit, pre-molded insulators, and compression devices are all enclosed in a metal case, both ends of which are lead soldered onto the lead sheath of the cable.

4. DEVELOPMENT OF PJ

4.1 Selection of joint type

Two types of joints, extrusion-molded and prefabricated, were investigated as candidates for cable joint to be applied in this project. Extrusion-molded joints for 275 kV rating are already in practical use in actual lines and the development of those for 500 kV have completed successfully. In contrast, although PJs for 275 kV rating are in service in actual lines, those for 500 kV are now under development. However, we decided to employ PJ for the present project for the following reasons.

(1) Experienced jointers are not needed.
(2) Facilities for the work are not very expensive.
(3) Working hours can be shortened.
(4) Constituent parts are manufactured under quality control at the factory. Main insulators, the epoxy-unit and pre-molded insulators, are manufactured at the factory and are totally tested.
(5) PJ is equivalent to extrusion-molded joint in total performance.

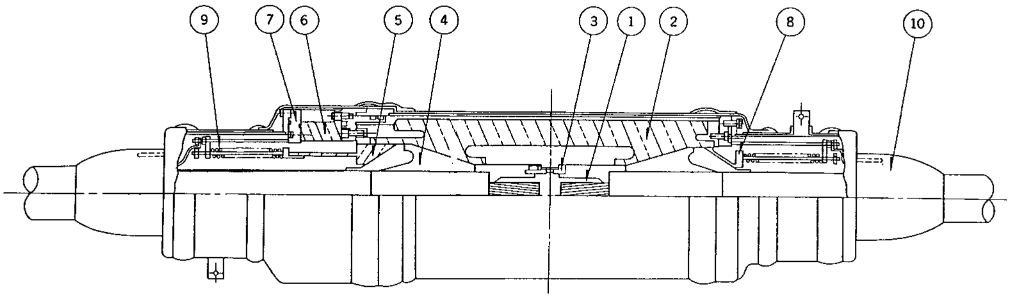
4.2 Design of PJ

4.2.1 Insulation Design

At the insulation design of 420-kV PJ, its electric stress distribution for each region was designed with reference to the stress obtained with the 275-kV PJs[3]. In the design of PJ, electric field stresses at epoxy-unit body (τ1), at the interface between pre-molded insulator and epoxy-unit (τ2), and at the rise-up region (τ3) are major design factors. Table 2 shows the comparison. Insulator geometry was finally determined by electric field analysis based on the data hitherto obtained. Figure 4 shows the results of electric field analysis.

4.2.2 Water Proof Design

Since the line is installed directly underground, the entire PJ is housed in an FRP coffin box prepared by NKT, which is then filled with water proof compound.



Mark	Parts name	Mark	Parts name
1	Ferrule	6	Insulating flange
2	Epoxy-unit	7	Intermediate flange
3	Fixture for epoxy-unit	8	Compression device A
4	Pre-molded insulator	9	Compression device B
5	Compression pipe	10	Anti-corrosion tape

Figure 3 Structure of 420-kV prefabricated joint

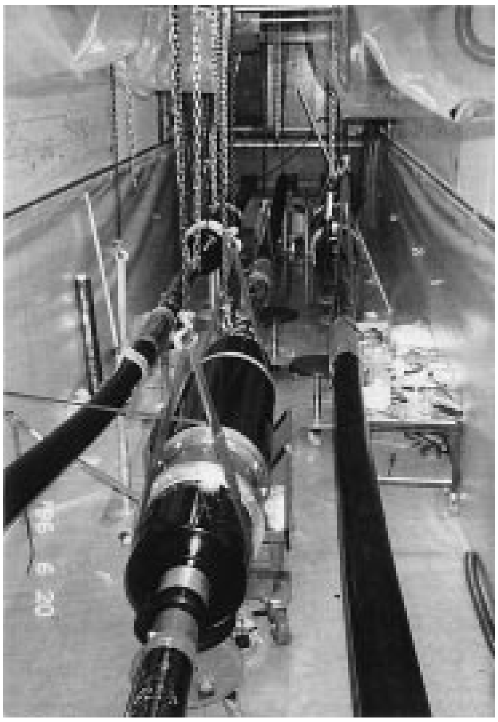


Photo 1 420-kV prefabricated joint

Table 2 Interface field strength of prefabricated joints

Position	Stress at working voltage or normal maximum voltage (kV/mm)	
	275kV	420kV
τ 1: Epoxy	5.8	5.8
τ 2: Interface between pre-molded insulator and epoxy-unit	1.4	1.9
τ 3: Rise-up region	5.5	6.0

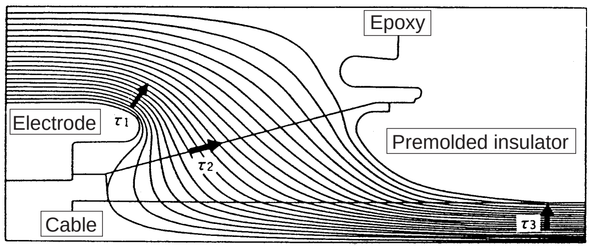


Figure 4 Electric field distribution for 420-kV prefabricated joint

5. TESTS OF PJ

Type tests of PJ were conducted by Furukawa in accordance with IEC (International Electrotechnical Commission) standards. Having succeeded in the test, the PJ was subjected to long term reliability tests at CESI (Centro Elettrotecnico Sperimentale Italiano) for one year according to CIGRE (Conference Internationale Des Grands Reseauz Electriques) recommendations. Good results were obtained, as shown in Table 3, validating the performance of the PJ.

6. WORK AT SITE

The installation of PJs was carried out by NKT Cable Co. It was required to do the installation work under a safe and sufficient level of quality control, so that the functions that the PJ was originally provided with were maintained. Following measures were taken prudentially.

Prior to the start of work, the jointers of NKT Cable Co. received a course of training, in which lectures and practices were given in terms of crucial checking points of quality control at installation. The skill of every jointer was evaluated to be satisfactory by checking the electrical performance of his achievements. Furthermore, at actual instal-

Table 3 Results of type and pre-qualification tests

Kind of test	Contents of test		Result
	Test item	Test conditions	
Type test (IEC 840)	Partial discharge test	· Should be 5 pC or lower at AC 330 kV, after a loading of AC 385 kV for 1 min	Good (Noise was 4 pC)
	tan δ	· Should be 0.1% or lower at a conductor temperature of 95~100 ˚C	Good (Voltage was 220 kV)
	Heat cycle test	· Voltage: AC 440 kV · Heat cycle: 8hr on/16hr off x 20 cycles Conductor temperature: 95~100˚C	Good
	Partial discharge test	· Should be 5 pC or lower at AC 330 kV, after a loading of AC 385 kV for 1 min	Good (Noise was 3 pC)
	Impulse withstand voltage test	· ±1425 kV x 10 repetitions · Conductor temperature: 95~100˚C	Good
	AC withstand voltage	· AC 550 kV x 15 min	Good
Pre-qualification test (CIGRE recommendations)	Long term reliability tests	· AC 375 kV x 1 year · Heat cycle: 16hr on/32hr off Conductor temperature: 90±3˚C	Good
		· ±1425 kV x 10 repetitions · Conductor temperature 95~100˚C	Good

Photo 2 Exterior view of joint house with the staff of NKT Cable

lation, a joint house with a simple clean room was used to control the temperature and humidity of the joint site. Photo 2 shows the external view of a joint house at actual site.

In this way, a multitude of 72 sets were successfully assembled and installed by NKT jointers, and the line went into operation in October, 1997.

7. CONCLUSION

The development and supply of prefabricated joint of 420-kV XLPE cable has been reported. We were successful in obtaining satisfactory results, which were confirmed by various tests including long-term reliability tests lasting for one year. After the assembly and installation of PJs by NKT Cable Co., the line passed the commissioning test carried out based on CIGRE recommendations. The transmission line went into commercial service in October 1997, and has since been in operation without any abnormalities.

The PJ developed this time is the first in the world that has been applied to a long distance transmission line of XLPE cable. While the product is expected to be capable of meeting the needs of long transmission lines of this voltage class, we are determined to proceed further to the development of PJs of 500 kV class.

Finally, we would like to express our deep appreciation to the personnel of NKT, CLD, and NESA for their guidance and cooperation that they offered at the development and supply of the PJ.

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