Installation of the World's First 500-kV XLPE Cable with Intermediate Joints

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ABSTRACT Tokyo Electric Power's Kazunogawa Power Station will, when completed, be Japan's largest pumped-storage hydroelectric power station, with an output of 1.6 GW. The first phase is currently under construction, with two 400-MW machines and one cable circuit. Using leading-edge technology Furukawa Electric has provided 500-kV XLPE cable and associated extrusion-molded joints (EMJs) and horizontal gas-immersed sealing ends (EBGs) for the No. 1 and No. 2 machines. Construction was completed in November 1998 and voltage withstand tests have also been performed.

The cable for this line is 2300 m in length, longer than has ever been used in a power station interconnect. Because of transportation constraints, insulation-type EMJs are installed at intermediate points. The line is being built under the same basic design concept and installation conditions as the Shin-Keiyo-Toyosu Line now under construction, and reflects the expertise and knowhow acquired there.

The equipment covered here is scheduled to go into service in December, 1999.

1. INTRODUCTION

Tokyo Electric Power's Kazunogawa Power Station was planned for Yamanashi Prefecture to provide the capacity to satisfy future power requirements, and, when completed, will be Japan's largest pumped-storage hydroelectric power station. Work is currently under way on the No. 1 and No. 2 machines (together with one cable circuit), and construction of the No. 3 and No. 4 machines (with one cable circuit) is scheduled.

Each of machines No. 1 through No. 4 will have an output of 400 MW for a maximum of 1.6 GW. Output of 400 MW is scheduled to go on line in December, 1999 with a further 400 MW in July, 2000, followed by the remaining 800 MW at a future date.

Furukawa Electric received an order for the interconnect for the No. 1 and No. 2 machines, comprising approximately 7000 m of 1 x 1000-mm^2 flame-retardant XLPE cable with reduced insulation thickness, together with six gas-immersed sealing ends (three of which are horizontal) and three extrusion-molded joints (EMJs).

Basic and developmental research on the cable and accessories was begun in 1988, and long-term loading cycle verification research targeted at overall verification of the reliability of technology for the manufacture, shipment inspection and installation of long-span cables, together with on-site verification tests, have been carried out, confirming that technology for on-site application is in place.

Accepting these research results, Tokyo Electric Power made a decision to apply them to the Shin-Keiyo-Toyosu Line, which is the world's first long-distance, large-capacity line into a metropolitan center, and construction has been under way since 1996 with Furukawa Electric's participation.

The experience gained is fully reflected in the equipment for the Kazunogawa power station, with suitable improvements in installation conditions to match the environment at the site. Furukawa Electric thus approached the actual installation work after conducting full-scale in-house tests to confirm performance.

The following describes the cable, accessories, construction methods and so on.

2. GENERAL DESCRIPTION OF THE ROUTE

As can be seen from Figure 1, the 2.3-km route--from the horizontal gas-immersed sealing end (EBG) of the underground power station to the outdoor (vertical) EBG--is covered by a 2.3 km cable, laid entirely within a tunnel in a

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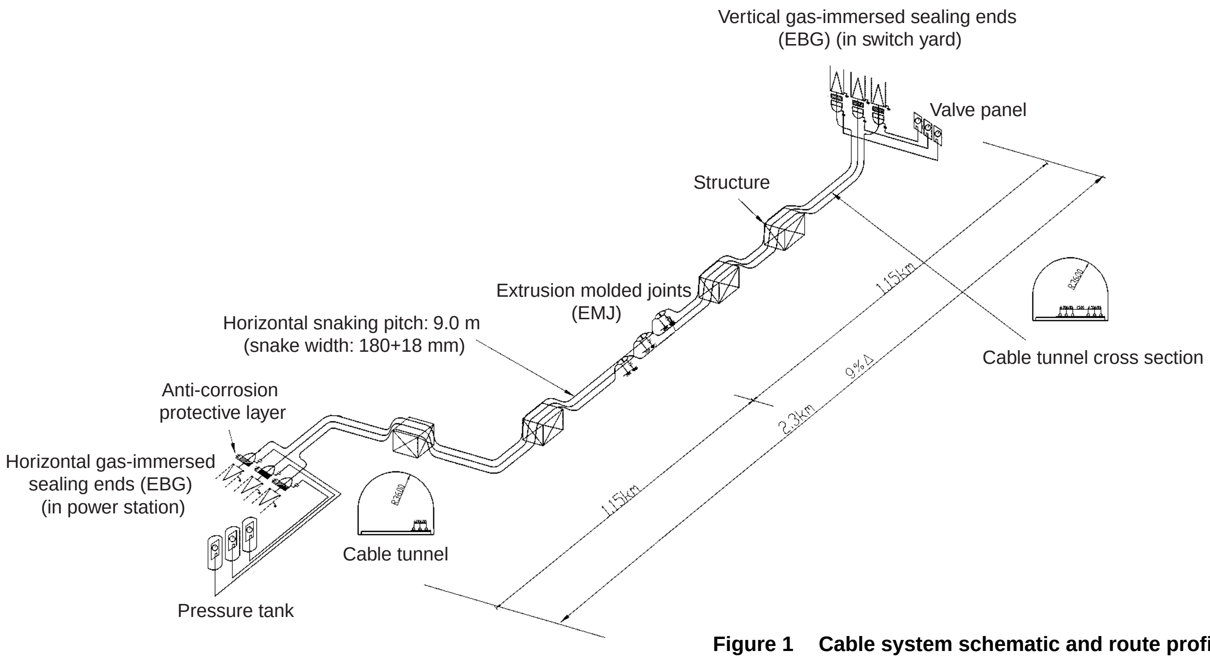


Figure 1 Cable system schematic and route profile

Table 1 Structure of cable

Code		–	CAZV-F
Nominal voltage		kV	500
No. of cores		–	1
Conductor	Nominal cross-sectional area	mm²	1000
	Configuration	–	Miliken type with shaped segments
	Outer diameter	mm	38.0
Approx. conductor screen thickness		mm	2.0
Minimum insulation thickness		mm	27.0
Nominal outer diameter of insulation		mm	102.0
Approx. insulation screen thickness		mm	1.0
Approx. cushion and shielding layer thickness		mm	3.0
Aluminum sheath thickness		mm	2.8
Anti-corrosion (PVC) jacket thickness		mm	6.0
Nominal outer diameter of completed cable		mm	141
Nominal weight per meter		kg m	25.0
Maximum DC resistance of conductor at 20°C		Ω/km	0.0187
Dielectric resistivity of insulation at 20°C		MΩ·km	4000
Dielectric resistivity of anti-corrosion (flame-retardant) layer at 20°C		MΩ·km	1
Electrostatic capacitance		μF/km	0.17

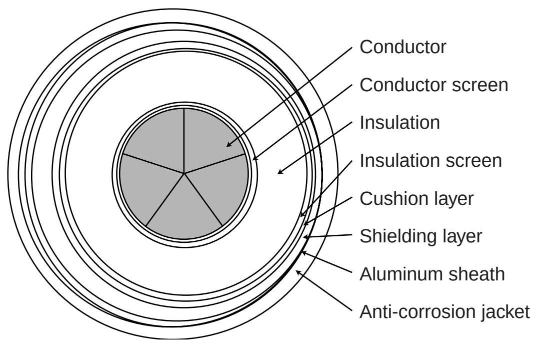


Figure 2 Cross-section of 500-kV XLPE cable (1 x 1000 mm² conductor)

phase-spaced parallel configuration. EMJs are provided at intermediate points. The route has a continuous gradient of 9% and a difference in elevation of 190 m. There is no danger to the cable from falling objects and a flame-retardant anti-corrosion sheath is used. Thus a snaked method of installation is adopted, constrained when exposed on the supporting frames by cleats at points of curvature.

As a measure against problems arising after completion, the design provides for overage at each joint.

Installation was characterized by severe working conditions, in that there was a continuous gradient of 9%, laying was carried out in a temporary ventilation, and power outages could be expected during lightning strikes.

3. THE CABLE

3.1 Cable Structure

The structure of the cable used is shown in Table 1 and Figure 2.

The cable route lay in a mountainous area and transportation access was restricted in both width and height. Thus the 500-kV XLPE cable normally used for power station interconnects, which has a 32-mm insulation thickness, was found inconvenient to handle, and it was decided to adopt a cable with reduced insulation thickness (27-mm specification) [1] that was developed for long-distance lines, was more compact, and had been confirmed to match the EMJs.

Table 2 Manufacturing quality control procedures for factors governing performance

Factor	QC concerns and preventive measure	
Impurities	Do not allow entry	Mesh of extruding machine screen
	Not present	100% inspection of polyethylene resin at extrusion
	Not present	Slice inspection (front and rear ends)

3.2 Cable Manufacture and Quality Control

The factor controlling the performance of 500-kV XLPE cable is impurities, and the countermeasures adopted in the manufacturing process are set forth in Table 2.

On this cable route, the maximum length of one span was approximately 1200 m, and using Furukawa Electric's long-span manufacturing facilities it was possible to achieve 2-span (2400-m) continuous manufacture (extrusion).

Furthermore, at shipment from the factory the cable was subjected to electrical tests (465 kV AC for 15 min with partial discharge measurement at a detection sensitivity of 5 pC or more) to confirm quality.

3.3 Grounding Design

As has already been stated, the length of the cable was approximately 2300 m, making it impossible to transport it all at once. Based on the use of a single joint, and on an estimation of the voltage induced in the sheath and the partial discharge test to be conducted at the completion of installation, it was decided to use an EMJ with insulated flange (insulated joint).

To reduce the voltage induction in the accompanying communication and other cables, an IV 500-mm^2 parallel grounding wire was installed.

4. ACCESSORIES

4.1 Accessory Performance

The performance characteristics of the accessories (gas-immersed sealing ends and mid-span joints) used on this line are shown in Table 3.

4.2 Mid-span Joints (EMJs)

4.2.1 EMJ Design

The mid-span joints represent an extension of the extrusion-molded joint (EMJ) [3] previously developed for 500-kV XLPE cable.

(1) Designed breakdown stress (EL)

- For reinforcing insulation:
  AC 27 kV/mm; Imp 60 kV/mm
- For treated portion of insulation screen:
  AC 27.6 kV/mm; Imp 57.5 kV/mm

(2) Harmful level of impurities, voids and protrusions

There is a high probability that the presence of impurities or voids in the insulation or of protrusions from the semiconducting screen will give rise to tree formations. Accordingly the permissible dimensions have been calculated and the following limit values determined:

- For metallic impurities and protrusions:
  100 μm or less
- For fibrous impurities:
  2 mm or less
- For voids:
  25 μm or less (Note: voids are controlled in the extrusion and curing stages)

Table 3 Main performance characteristics of accessories

Characteristic	Performance	EMJ	EBG
AC withstand voltage	970 kV for 1 hr	○	○
Impulse withstand voltage	±1960 kV for 3 times	○	○
Long-term current- carrying capacity	475 kV AC for 30 days RT-90°C for 25 cycles RT-105°C for 5 cycles	○	○
Air-tightness	590 kPa(G) for 30 min (gauge pressure)	–	○
Internal pressure	440 kPa(G) for 30 min (gauge pressure)	–	○
Impulse withstand voltage between shielding layers	65 kV for 3 times, at RT, negative polarity	○	○
Water-tightness	Water-tightness 98 kPa for 1 hr	○	–

4.2.2 EMJ Structure

The structure of the extrusion-molded joint (EMJ) is shown in Figure 3.

4.2.3 Installation Conditions

(1) Extrusion conditions

During preheating, the temperature of the conductor screen, the penciled portion of the cable and the cable surface is controlled so as to satisfy the conditions for void suppression. In addition the internal pressure in the mold after extrusion is controlled to suppress voids.

(2) Curing conditions

The pressure in the curing tube is controlled and the temperature is regulated in all areas to suppress voids.

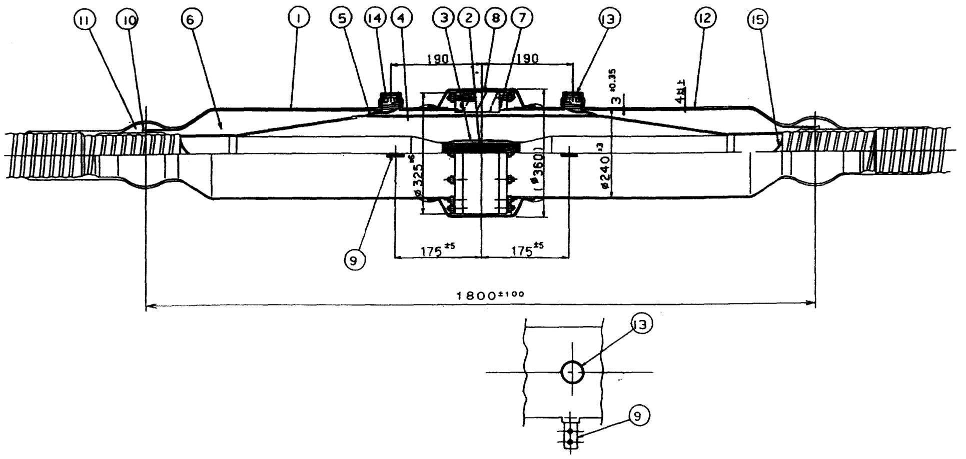
4.3 Gas-immersed Sealing Ends (EBGs)

4.3.1 Structure of EBG

In these gas-immersed sealing ends, silicone insulating oil is used as the main insulation and an oil-impregnated stress relief cone is used in combination with an epoxy bell mouth. Figure 4 shows the structure.

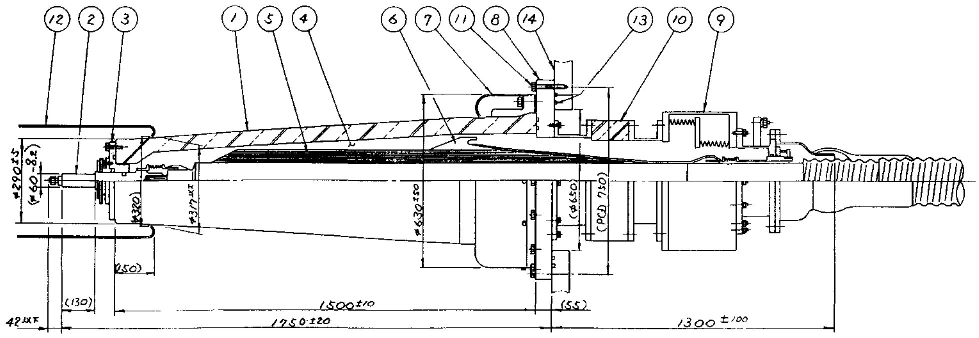
In this underground power station the space available for the cable and machinery is restricted, and this required development of a new type of EBG to allow direct connection between machinery and the cable, which exits horizontally from the tunnel. This structure is shown in Figure 5.

There are thus two types of EBG structure, depending on the direction of installation, and for convenience the first described is referred to in this paper as "vertical", and the second as "horizontal".



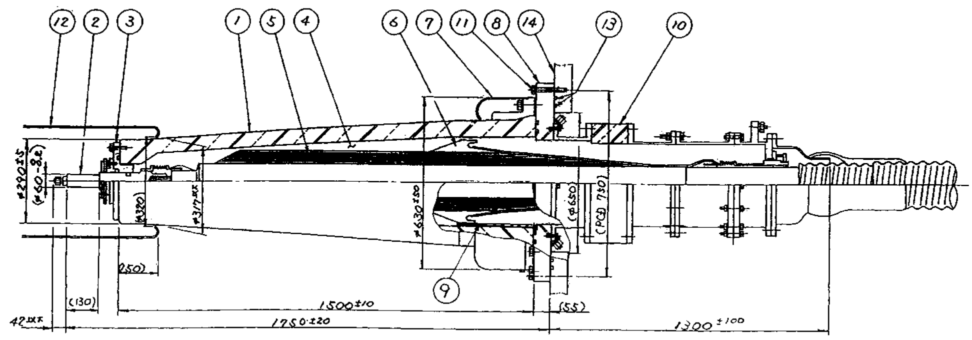
No.	Name
1	Outer sleeve (copper)
2	Ferrule
3	Conductor screen
4	Insulation
5	Outer shielding layer
6	Waterproofing compound
7	O-ring
8	Insulator
9	Grounding terminal seat
10	Spacer
11	Epoxy resin + glass tape
12	Anti-corrosion layer
13	Gas-collecting port
14	O-ring
15	Teflon tube (for inspection)

Figure 3 Cross-section of extrusion-molded joint (EMJ)



No.	Name
1	Epoxy insulator
2	Conductor rod
3	Upper metal fitting
4	Insulating oil
5	Stress-relief cone
6	Bell mouth
7	Lower shield
8	Mounting metal
9	Oil reservoir
10	Insulator
11	Mounting bolts
12	Upper metal shield
13	Gasket
14	Base plate

Figure 4 Cross-section of vertical gas-immersed sealing end (EGB)



No.	Name
1	Epoxy insulator
2	Conductor rod
3	Upper metal fitting
4	Insulating oil
5	Stress-relief cone
6	Bell mouth
7	Lower shield
8	Mounting metal
9	Epoxy spacer
10	Insulator
11	Mounting bolts
12	Upper metal shield
13	Gasket
14	Base plate

Figure 5 Cross-section of horizontal gas-immersed sealing end (EGB)

4.3.2 Design of the Horizontal EBG

(1) Basic structure

The basic structure is an extension of that for the vertical type.

(2) Oil pressure compensation

With the built-in reservoir of the vertical type, there is a chance that the friction action of the built-in bellows tank could be impaired by deflection of the bellows. For this reason a separately installed cell oil tank was adopted for greater safety.

(3) Measures to prevent cable sag

The length of cable within this sealing end totals about 3 m, and there is comparatively large clearance between the outer diameter of the inner insulation and the inner diameter of the epoxy insulator. This raises concerns about deflection of the inner cable due to the weight of the inner insulation or to thermal expansion, and performance degradation due to distortion of the inner insulation.

In this sealing end, epoxy spacers are inserted into this clearance to suppress such deflection. Their effectiveness

Photo 1 Transporting the cable drum

Photo 2 Laying cable on the ground

has been verified by long-term loading cycle tests (475 kV for 1 month) conducted at the factory.

(4) Miscellaneous

Because installation is horizontal, the mounting metal is provided with oil-filling connectors at top and bottom.

5. CABLE-LAYING WORK

5.1 Transporting the Cable Drum

Because of the large dimensions of the cable drum (flange diameter of 3.2 m, width of 8.1 m and cable length of 1184 m) part of the flanges were removed during overland transport from Furukawa Electric's Chiba Plant to the outdoor switch yard of the Kazunogawa power station where cable-laying was to start (see Photo 1).

5.2 Laying the Cable

Because the cable length was so great and the cable laying site so small, the cable was paid out using a cable drum shifter and hauling machines.

Photo 3 Laying cable in the tunnel

To keep the lateral shift of the drum within the allowable angle of incidence of the hauling machine and thereby assure stable pay-out, a roller-type control device was used with the shifter (see Figure 6 and Photos 2 and 3).

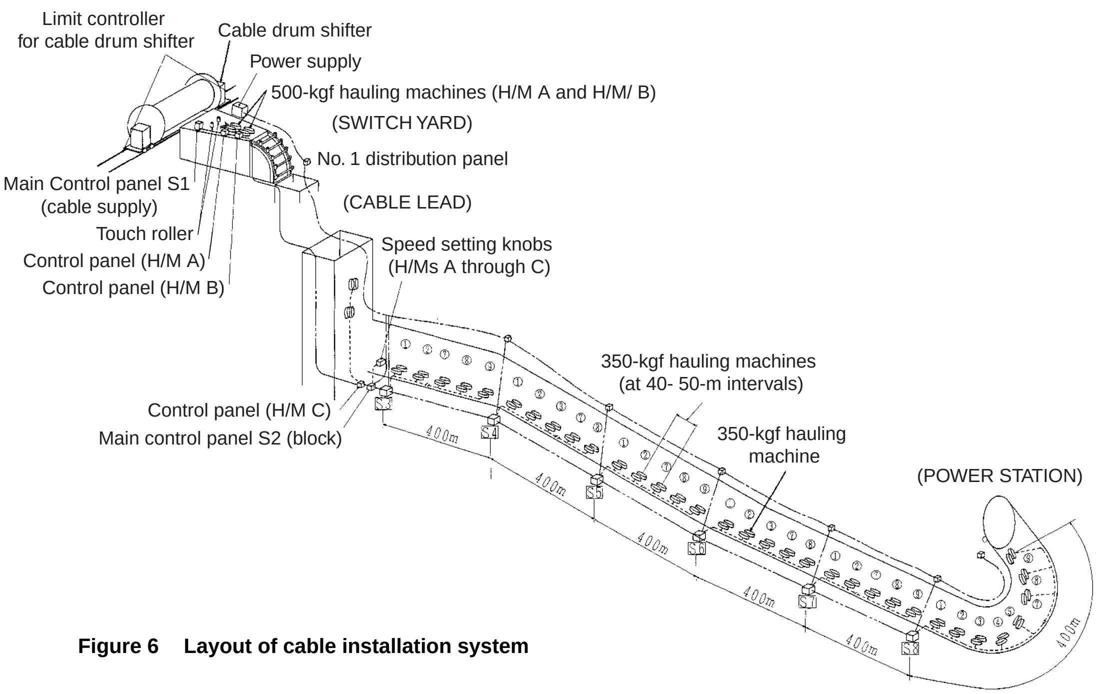


Figure 6 Layout of cable installation system

Photo 4 Laying cable in the tunnel

5.3 Snaking

A method of snaking was employed because of the continuous 9% cable gradient to prevent the cable sliding down and to compensate for thermal expansion or contraction. The snaking configuration is shown in Photo 4.

6. INSTALLATION OF ACCESSORIES

6.1 EBG Installation Techniques

Techniques for adapting to 500-kV service and for the installation of the horizontal gas-immersed sealing ends (EBGs) are as described below.

6.1.1 500-kV Adaptation

Furukawa Electric installed the vertical EBGs in the outdoor switch yard and the horizontal EBGs in the underground power station. The use of horizontal EBGs was particularly effective underground in reducing the space required for installation and the cost of the work.

The working environment was particularly unfavorable in that the vertical (outdoor) EBGs had to be installed during the monsoon rains, and there was considerable dust generated by other construction during installation of the horizontal (underground) EBGs. Thus a "work room," which prevented the adherence of moisture and impurities, was built for the installation work.

6.1.2 Horizontal EBGs

Installation of the horizontal gas-immersed sealing ends was attended by three main problems: 1) inserting the 350-kg insulator tube into the cable; 2) preventing the entry of impurities during insertion; and 3) sagging of the cable under its own weight during insertion of the insulator tube.

New equipment and methods were developed and adopted to overcome these problems. The specifics (see Photo 5) are described below.

(1) Adjusting dolly: An adjusting dolly was developed to allow fine adjustments (up-down, left-right and rotational) during insertion of the insulator tube. This also prevented the settling and adherence of impurities.

(2) Use of a holding device for the conductor: A holding device is attached to the conductor rod when the joint is made, preventing cable sag.

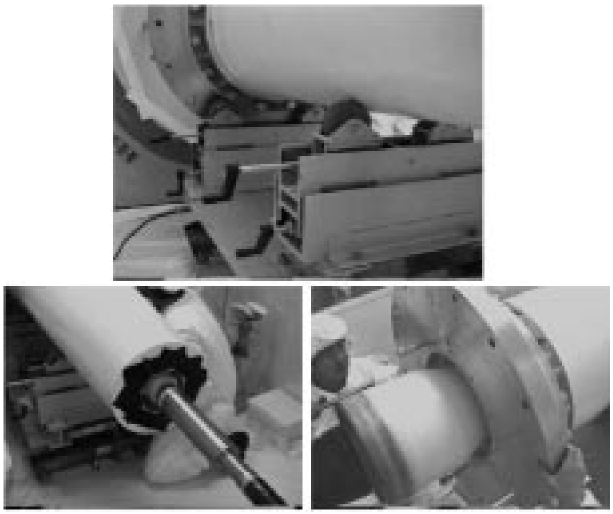


Photo 5 Techniques for laying the horizontal gas-immersed sealing end

(3) Use of an assembly guide rod: An insertion guide rod is pre-attached, and the insulator tube is inserted along it.

6.2 EMJ Installation Techniques

Extrusion-molded joints have already been developed for 500-kV lines and are being installed for commercial service. Prior to installing the EMJs for the present project, we reconfirmed the installation conditions imposed by the difference in conductor size, checked installation procedures by creating a factory model of the work site, and confirmed electrical performance. The actual line was assembled based on these confirmations.

6.2.1 500-kV Adaptation

Cleanroom specifications were tightened over those used for 275 kV, for stricter control of impurities. A high-performance inspection system designed to eliminate impurities (see Photos 6 and 7) was also developed and applied.

(1) Development of a 100% inspection system for impurities in the polyethylene resin: A system was developed that inspects the resin being extruded for impurities by laser scanning. It was thus possible to confirm that there were no harmful impurities whatever introduced during extrusion.

(2) Development of an IP photographic inspection system: Joints are X-rayed after extrusion and curing to confirm that there are no harmful impurities present. In the new system, an imaging plate (IP) is used instead of film, providing a more sensitive and more accurate image, and improving the repeatability and efficiency of the inspection.

6.2.2 Adaptation to the Kazunogawa Power Station

The tunnel in which the cable is installed is also used as a temporary ventilation duct for the underground power station, creating air drafts with a velocity of 3-4 m/s. The tun-

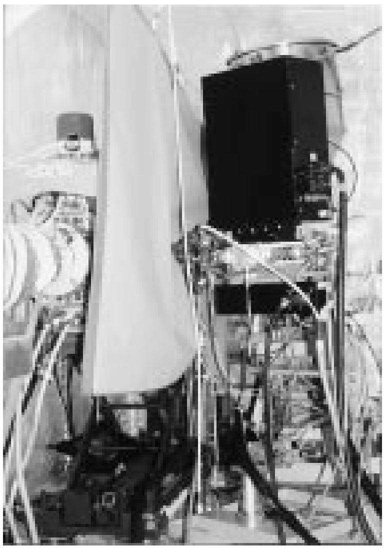


Photo 6 System for 100% inspection for impurities in the polyethylene resin

nel also slopes at 9%, and a stable installation environment has to be maintained in it. Since assembly was carried out during the summer season, provision had to be made for power outages caused by lightning and typhoons.

(1) Measures to prevent drafts: PVC slate outer wall was erected, and a cleanroom was built inside for the jointing work.

(2) Measures against slope: A scaffolding was erected to provide a level area in which to work, thereby negating the effect of the 9% slope.

(3) Measures in the event of power outage: An electrical generator was installed that would start automatically in the event of power outages.

7. TESTING

7.1 Test Conditions

Partial discharge measurement tests using high-frequency tuning were conducted on two occasions. The first, during the dielectric strength test, involved application of 1.1 E for 10 min to each phase in turn; the second, during the preliminary charging test, involved a 3-phase (batched) test with preliminary charging voltage for 3.5 hrs.

7.2 Measuring Circuit

Local stations were set up near the measurement points (for outdoor EBG, EMJ and power station EBG measurement), and the measurement signal was converted into an optical signal for batched monitoring at the master station in the pit at the Kazunogawa power station (see Figure 7).

The circuit that was adopted provided for optical relaying of all frequencies from 1 to 50 MHz from foil electrodes mounted on the surface of each insulated joint to the master station. This allowed identification of noise, changing of measurement frequency, etc. to be accomplished easily, while bi-directional communication made it possible to change the phase being measured and insert simulated pulses.

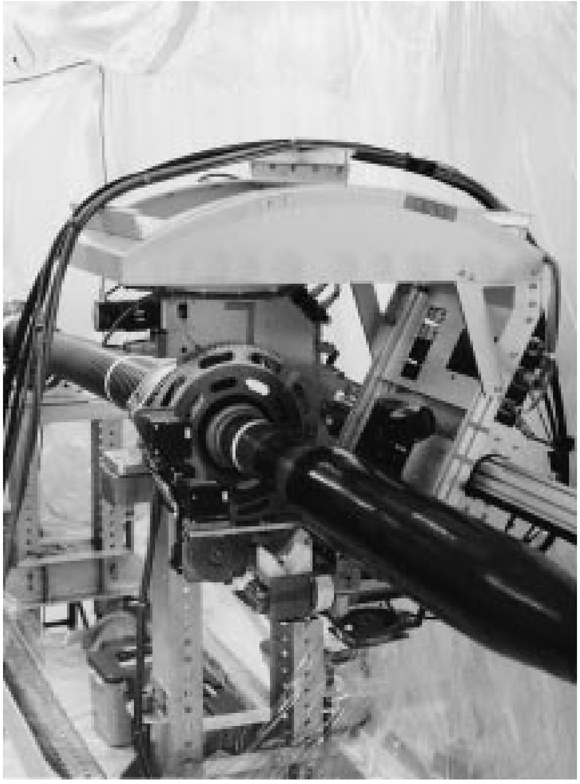


Photo 7 System for photographic inspection using imaging plates

7.3 Test Results

Measurements carried out on the 500-kV XLPE cable for Kazunogawa No.1 produced satisfactory results on both the first and second passes. Table 4 shows the respective measurement frequencies and detection sensitivities.

8. CONCLUSION

The on-site installation of 500-kV XLPE cable for the Kazunogawa power station was completed without misadventure or accident in November, 1998.

From basic research of 500-kV XLPE cable to its commercialization took approximately 10 years, and commercial operation is scheduled to commence in December, 1999. It is anticipated that the results obtained will be fully reflected in the Shin-Keiyo-Toyosu line, the laying of which is currently in progress, and that further use of these techniques will be made in underground trunk lines to be installed in the future.

In closing the authors would like to express their deep appreciation to persons involved at both Tokyo Electric Power Co.,Inc. and Furukawa Electric.

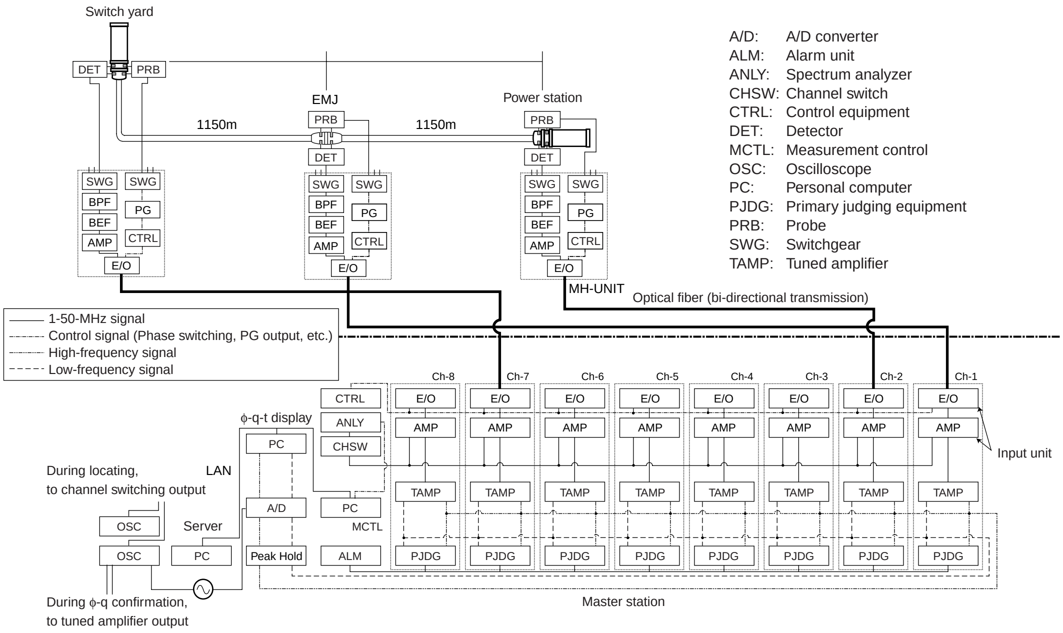


Figure 7 Block diagram of system for measurement of partial discharge

Table 4 Measurement frequencies and detection sensitivities in partial discharge tests

1st pass	Outdoor gas-immersed sealing end		
Phase	Black	Red	White
Measurement frequency	20.0	21.0	21.5
Detection sensitivity	1.8	1.8	1.6

1st pass	Extrusion-molded joint		
Phase	Black	Red	White
Measurement frequency	23.1	23.2	23.1
Detection sensitivity	1.9	2.1	2.6

1st pass	Power station gas-immersed sealing end		
Phase	Black	Red	White
Measurement frequency	21.2	23.2	21.2
Detection sensitivity	1.0	0.9	0.9

2nd pass	3 phases (batched)		
Phase	Switch yard	EMJ	Power station
Measurement frequency	21.5	23.1	24.4
Detection sensitivity	6.5	4.3	2.4

Unit of
Measurement frequency: MHz
Detection sensitivity: pC

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