The Development of the Power Transmission System for the Fukushima FORWARD Project (2)

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ABSTRACT In the Fukushima Floating Offshore Wind Farm Demonstration Project (Fukushima FORWARD Project), which is a commissioned business from Ministry of Economy, Trade and Industry, Furukawa Electric (FEC) is in charge of a power cable transmission system. FEC have designed a riser cable which has been connected to the world's largest 7 MW class floating offshore wind turbine generator. Pursuant to the completion of the project, we are issuing this report.

1. INTRODUCTION

Recently, research and development projects on renewable energy including ocean energy utilization technology such as the offshore wind power generation system, as well as ocean current, tide or wave power generations and ocean thermal energy conversion, are being promoted by industry- government-academia. Among them, as for the offshore wind turbine generation, based on the very few narrow shallow coastal zones characteristically of Japan, a research and development project for the offshore floating wind power generation with a high energy potential is in development.

FEC received the commissioned business of the Fukushima Floating Offshore Wind Farm Demonstration Project (Fukushima FORWARD Project, here in after Fukushima PJ) from the Ministry of Economy, Trade and Industry and FEC is in charge of the power cable transmission system (Power transmission and optical telecommunication) [1].

In the 1st construction stage (2013), the construction of a connection using a 66 kV cable from the onshore to the offshore floating substation, and the construction of a connection using a 22 kV cable from the offshore floating substation to the 2 MW offshore floating wind turbine generator [2] have been completed. Now, for the 2nd construction stage (2014-2015), the construction of a connection from the offshore floating substation to the world largest class of 7 MW class offshore floating wind turbine generator is completed and power receiving has started.

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2. OVERVIEW OF THE FUKUSHIMA PJ

2.1 Project Overview

The PJ consists of the 1st stage (2011-2013) and the 2nd stage (2014-2015).

In the 1st stage, a 2 MW class down-wind type offshore floating wind turbine generator and a 25 MVA offshore floating substation - the first time in the world - were constructed. We laid a dynamic cable (referred to as the riser cable) to connect the floating bodies to each other, also laid a long distance submarine cable between an onshore facility and an associated power line.

In the 2nd stage, two 7 MW class floating wind turbine generation facilities were newly constructed and we laid the riser cable toward an offshore substation. Figure 1 shows the overview of the project[3].

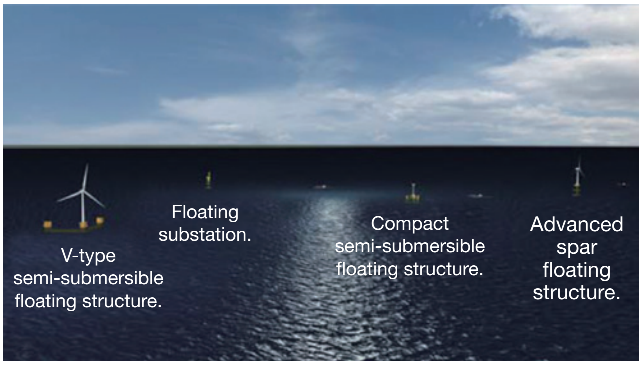

Figure 1 Project overview.

2.2 Transmission and Substation System Overview

The wind power generation capacities are 2 MW and 7 MW respectively. The 22 kV cable (inter array cable) was selected for the transmission line towards the offshore substation. The route distance from the scheduled landing position to a scheduled windmill installation position was approx. 25 km long, to be connected with a submarine cable. In this project, it was decided to construct an offshore substation and to raise the voltage to 66 kV (Export cable) for the transmission to the shore port, since the 22 kV transmission generates a higher transmission loss. After landing, the export cable was connected with the most nearby 66 kV overhead transmission line which has been already installed and operated by a power utility, thus a systematic grid link was completed. By the end of the project, 3 wind turbines are planned to be connected from the off shore substation as shown in Figure 2. The 7MW class floating wind turbine generation facility is shown as a representation.

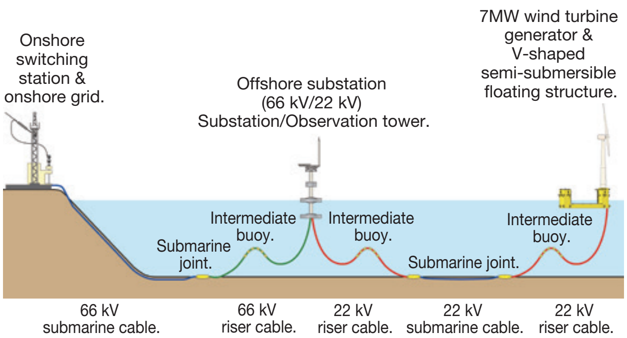

Figure 2 Transmission and substation system.

3. RISER CABLE SYSTEM DESIGN

3.1 Cable System Design

The riser cable is suspended from the floating structure (substation, wind turbine generator) into the sea. Then, unlike the conventional static submarine cables, the underwater line shape dynamically changes influenced by the swing of the floating structure, tide and others, then causing the mechanical fatigue by its repetitive bending. Therefore, a structure, which has an excellent resistance to fatigue, was investigated. The cable design was based on the structure provisions of “The electrical equipment technical standards” clause 127 “Facilities of electric power line over water and under water”. Each member of the cable was reviewed, and then a structure having a high durability was designed. Electrical and mechanical designing conditions were in compliant with JEC-3408, CIGRE TB 490 and CIGRE Electra No.171.

In the riser cable system designing, the undersea behavior was predicted by simulations based on the oceanographic condition, the floating structure shaking property and the floating structure anchoring design condition, and we investigated the necessary accessories (members to withstand the bending moment at the upper part of the riser: bend stiffener, buoy, members to withstand the friction with the seabed: protective tube) and the riser cable shape which satisfy the mechanical strength, the radius of curvature, the durability and others. In particularly, the riser cable shape is selected based on the riser cable system designing flow shown in Figure 3, then the static behavior analysis against the maximum displacement of the floating structure and the dynamic behavior analysis against the maximum shaking of the floating structure were carried out to confirm the feasibility and, finally, the fatigue performance analysis was carried out to decide the final system.

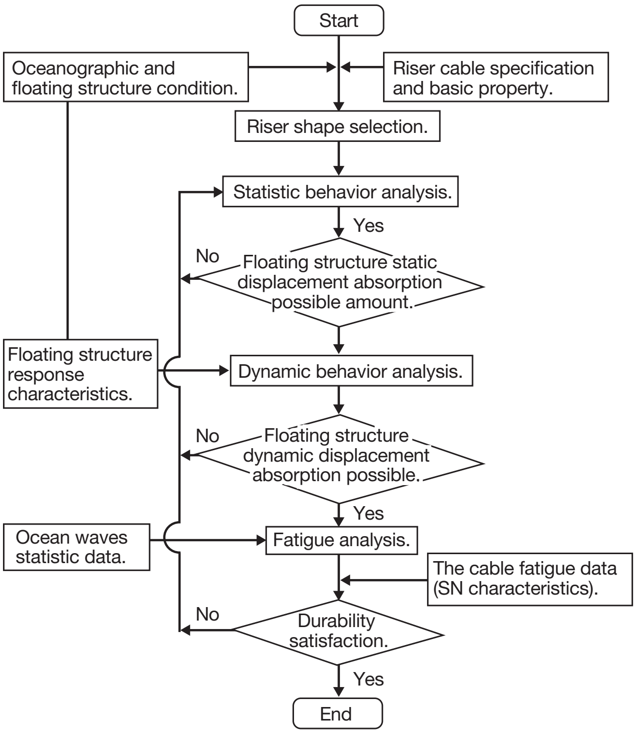

Figure 3 Designing flow of the riser cable system.

Based on the above written designing flow, the basic structure of the cable was decided and the basic mechanical property, the fatigue property, the water shielding performance test and other various evaluations were carried out using the trial products[4]. For example, the finally determined riser cable specification is shown in Table 1, and the structure of 22 kV riser cable is shown in Figure 4.

3.2 Submarine joint Design

A different kind cables joint unit (the riser cable and the submarine cable) was developed. Figure 2 shows the requested characteristics of the joint unit.

The structure of the submarine joint for the 22 kV consisted of the approximately 4 m length of protection tube boxing 3 power conductor core wire joint units and one optical fiber joint. And the joint unit for the 66 kV consisted of the approximately 7 m length of protection tube boxing 3 power conductor core wire joint units and one optical fiber joint. As a characteristic of the protective tube, the resistance to outer scratch was sought to avoid damages on the power conductor core wire joint unit and on the optical fiber joint when embedding and in other conditions. Waterproof characteristic was sought for the joint unit, as well as for the cable structure. Especially, as described later, the joint unit for the 22 kV was installed

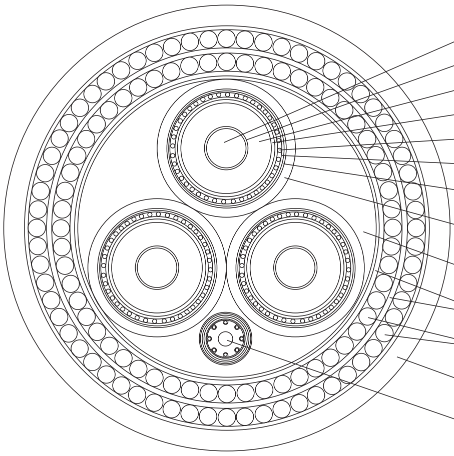

Figure 4 Structure of the 22 kV riser cable.

Table 1 Specification of the riser cable.

Item	66 kV riser cable	22 kV riser cable
Nominal voltage	66000 V	22000 V
Power conductor core wire count	3	3
Nominal cross sectional area	100 mm^2	150 mm^2
Optical fiber count	SM 8 × 3	SM 8
Armor	6 mm double galvanized steel wires	6mm double galvanized steel wires
Finished outside diameter	Approx. 175 mm	Approx. 147 mm
Approx. weight (in the air)	52600 kg/km	43400 kg/km
Approx. weight (in water)	29300 kg/km	27100 kg/km
Max. conductor resistance (20°C)	0.197 Ω /km	0.121 Ω /km
Min. insulation resistance (room temp.)	4000 MΩ·km	2000 MΩ·km
Max. capacitance	0.16 μF/km	0.30 μF/km

Table 2 Target characteristics.

Item	Requested characteristics
Connection	The submarine cable and the riser cable can be jointed.
Withstand Voltage	Joint unit for 22 kV Commercial frequency withstand voltage : 57 kV·3 hours (room temp.) Lightning impulse withstand voltage : -230 kV·3 times (room temp.) Joint unit for 66 kV Commercial frequency withstand voltage : 130 kV·3 hours (room temp.) Lightning impulse withstand voltage : ±485 kV·3 times (room temp.)
Bearing Water Pressure	Capable of withstanding maximum depth 130 m. Only for the 22 kV joint portion. Moisture permeability : Less than or equal to 1×10^{-7} [g·(cm/cm^2)·day·mmHg]
Bearing Tensile Strength	Capable of withstanding approx. 93.1 kN of laying tension.
Assembly	Available to assemble on a laying vessel.

by two methods. One was to lay the submarine joint in the catenary shape, the other was to lay the submarine joint by hanging in horizontally. Therefore, the mechanical properties to withstand in both methods were incorporated into the design condition. For the power conductor core wire joint unit, a tape winding insulation was applied in the case of the 22 kV and a rubber block was applied in the case of the 66 kV. Thus, the watertight structures were applied to the protective copper tube in the joint units. Also, a suppression device (a bend restrictor) was applied to the end of the submarine joint to avoid concealed bending to the cable in the submarine joint laying operation.

Trial production of the designed joint unit, as described above, was performed and a water pressure test also a water permeability test were carried out at 1.3 MPa. Then, it was confirmed that there was no issue. A photograph of the submarine joint for 22 kV, after installation, is shown in Figure 5.

Figure 5 Appearance of the submarine joint.

4. CABLE LAYING

4.1 Laying Procedure

Figure 6 shows the laying procedure in the 2nd construction stage.

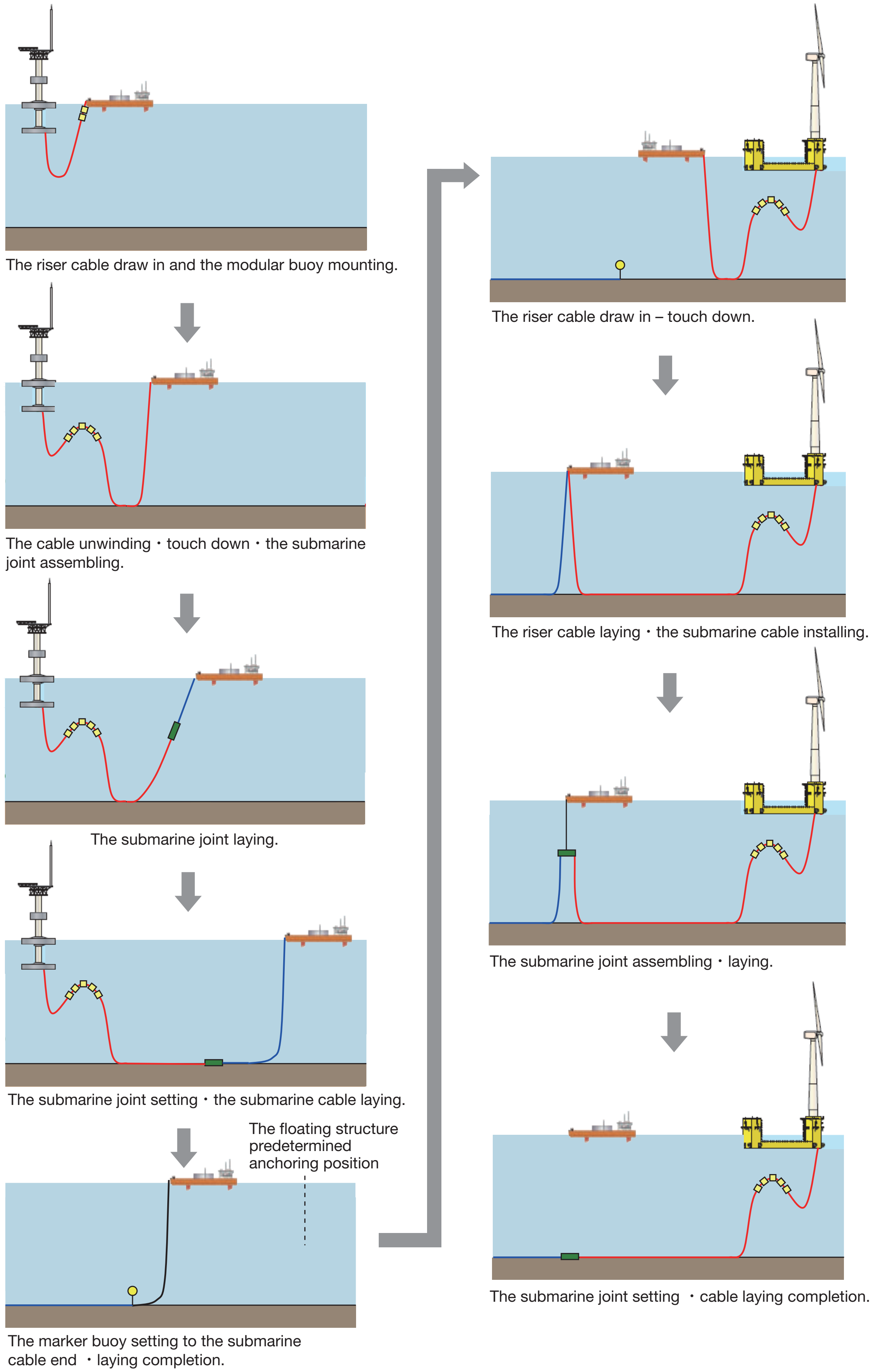

Figure 6 Cable laying procedure of the 22 kV riser cable and the submarine cable.

At first, the riser cable was pulled into the floating structure and while unwinding the cable accessories, such as modular buoy, were attached. Then, the cable was unwound to the predetermined position after a cable touch down point has been confirmed, and the submarine joint was assembled on the laying vessel. The submarine joint was sunk in a catenary shape, and after confirming the seabed touch down state, the submarine cable was laid to the predetermined position, where is a neighborhood of the floating structure anchoring position, and a marker buoy was attached.

Then, the riser cable was drawn into the floating structure of the wind turbine generator following the same procedure as the drawing into the substation. After laying the riser cable to the predetermined position, the submarine cable was lifted to the laying vessel and the submarine joint was assembled. The submarine joint was horizontally suspended by using a balancing beam, and was set to the seabed by the laying operation. Necessary burying work were carried out in each year and the laying operation was completed.

In addition, DC withstand voltage test to the power conductor core wires and OTDR measurement of optical fiber was carried out and it was confirmed that there was no problem, respectively.

4.2 Construction overview in each year

The construction has been implemented for three years. The construction overview in each year is shown in Table 3.

Table 3 Construction overview in each year.

Year	Construction overview	Remarks
2013	Construction of the onshore transmission line. The 66 kV cable laying between the onshore switching station and the offshore substation. The 22 kV cable laying between offshore substation and offshore wind turbine generator (2 MW).	2 MW wind turbine generator operation start.
2014	The 22 kV two cables laying between the offshore substation and the offshore wind turbine generator (7 MW) floating structure predetermined anchoring position.	
2015	The 22 kV cable laying to the offshore wind turbine (7 MW) floating structure	The 7 MW wind turbine generator operation was planned.

“KAIYO”, which is a cable laying vessel equipped with a turntable and operated by Dynamic Positioning System (DPS), was used for the cable laying. The laying vessel, loaded with the cable, the equipment and the materials, is shown in Figure 7. The riser cable, the submarine cable, accessories, such and a modular buoy, were loaded to “KAIYO”. Figure 8 shows the cable laying condition.

Figure 7 Laying vessel “KAIYO”.

Figure 8 The cable laying to the offshore wind turbine (7 MW class).

The submarine joint was assembled on “KAIYO”, and laid into the sea from a shooter of the laying vessel by using a crane and a winch. Two laying methods were used, one was the catenary shape laying method (Figure 9) the other was the balancing beam laying method (Figure 10). When the submarine joint reached to the seabed, the operation was carefully carried out while observing the cable curvature and others by using Remotely Operated Vehicle (ROV).

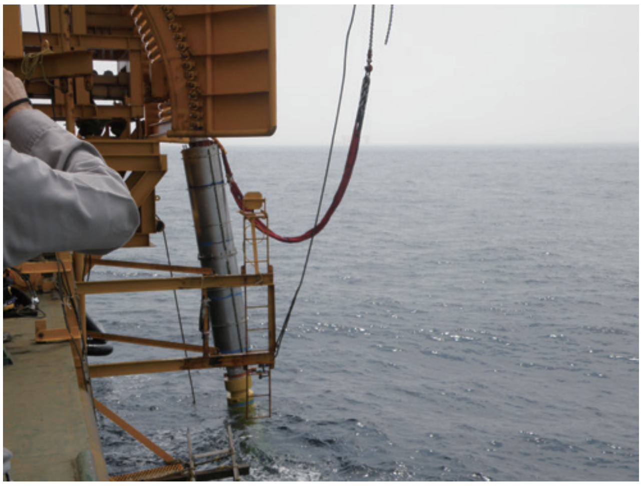

Figure 9 Submarine Joint Laying.

Figure 10 Submarine joint laying.

Figure 11 shows the ROV photograph when the submarine joint reached the seabed.

Figure 11 Submarine joint on the seabed.

After the cable laying, DC withstand voltage test to the power conductor core wires and OTDR measurement of optical fiber was carried out and it was confirmed that there was no problem, respectively. In addition, the line shape of the riser cable after the laying and the laying state were confirmed then positions of the major points were confirmed by using ROV, and finally it was confirmed that those results were in compliance with the designed values. As an example, a photograph confirming the modular buoy is shown in Figure 12.

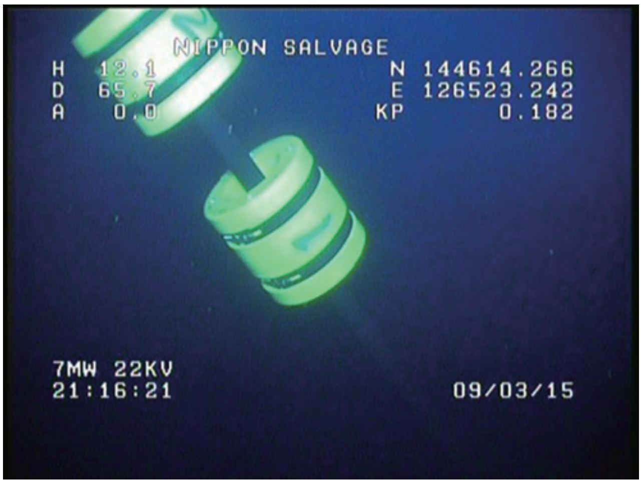

Figure 12 Line shape confirmation by ROV.

5. CONCLUSION

In FUKUSHIMA PJ, the cable connection work to the world largest class 7 MW class offshore wind turbine generator was completed. On the transmission line, the power receiving work on the wind turbine generator, was completed on September 2015 and the operation will be started after a commissioning work.

Although, still the riser cable has not enough sufficient track record in the world, we are planning to establish the optimum system design and maintenance techniques by taking advantages of the knowledge obtained in this PJ.

This research and development has been conducted at The Fukushima Floating Offshore Wind Farm Demonstration Project (Fukushima FORWARD Project) of Ministry of Economy, Trade and Industry. We would like to thank and to express our sincere gratitude to the involved people for their help and support.

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