The Development of the Power Transmission System for Fukushima FORWARD Project

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ABSTRACT Furukawa Electric Company (FEC) has proceeded with a Fukushima FORWARD Project (FF project) as one of the commissioning manufacturers of the Ministry of Economy, Trade and Industry. The Ministry has a plan of a floating wind turbine development for a powerful choice of renewable energies in Japan, which has the 6th largest exclusive economic zone (EEZ) in the world. Companies representing Japan entered into a consortium in which FEC is responsible of a transmission system. This paper reports the development condition of the power transmission system, mainly the development of a high voltage dynamic cable, which is considered as an essential technology. A behavior of dynamic cables subjected to under-water rolling caused by the steadily wave movement is different from that of the static submarine cables. Therefore a development point is the improvement of a fatigue withstands property. For a practical application of riser cables, a target is to achieve the similar endurance life of a floating body or of a windmill.

1. INTRODUCTION

An offshore floating wind turbine is a promising power generation method in Japan, because Japan has the 6th largest exclusive economic sea zone in the world and has few suitable shallow shores for the implantation of the offshore type wind power generations.

Offshore floating wind power generations are very few in the world.

The construction of a wind farm possessing complex floating windmills with an offshore floating substation will be a first in the world.

FEC is responsible for a transmission system (including a power and an optical transmission lines) for the whole project and plays a role in the system interconnection of a wind turbine power to a power utility by means of submarine cables and onshore associated cables.

This paper reports the development condition of the project dynamic cable system, which is an essential technology for the offshore floating system.

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The FF project is proceeding by establishing a prototype system for a demonstration research in Fukushima prefecture offshore.

The development of the demonstration results is designated as a new industrial job creation task originated in a renewable energy for the Great East Japan Earthquake restoration.

2. OVERVIEW OF THE FF PROJECT

2.1 Project Overview

The FF project consists of a 1st stage (2011-2013) and a 2nd stage (2014-2015).

In the 1st stage, a 2 MW down-wind type offshore floating wind turbine generator and a 25 MVA offshore floating substation, for the first time in the world, are planned to be constructed.

FEC installs a dynamic cable (referred to as riser cable) to connect between a floating body, a long distant submarine cable to reach an onshore facility and an onshore associated power line.

In the 2nd stage, it is planned to construct two new 7 MW floating wind turbine generation facilities and to install the riser cable toward an offshore substation.

Figure 1 shows the project overview.

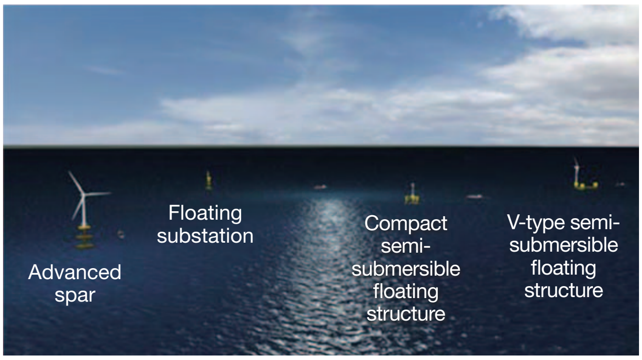

Figure 1 Project Overview.

2.2 Transmission and Substation System

The wind power generation capacities are 2 MW and 7 MW respectively.

A 22 kV cable (inter array cable) is selected for the transmission line towards the offshore substation.

The route distance from the propose shore position to a windmill installing potential position is approx.25 km long with a submarine cable.

It is planned in the FF project to construct an offshore substation and to raise the cable (export cable) voltage up to 66 kV for the transmission to the shore port because a 22 kV cable has higher transmission loss.

The export cable on shore is connected with an already installed nearby 66 kV overhead transmission line which is operated by a power utility, a transformer station will be installed on the way, and so a systematic grid link will be completed.

Figure 2 illustrates the transmission and substation system.

FEC is responsible for the transmission system part.

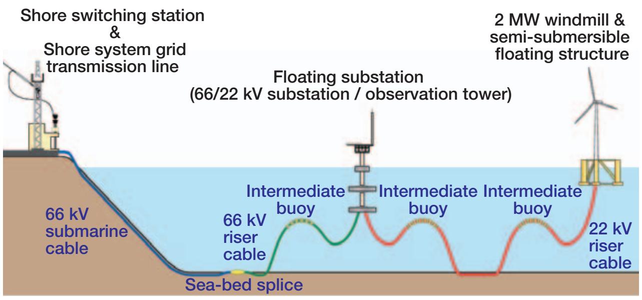

Figure 2 Transmission and substation system.

A riser cable developed by FEC is required for the dynamic movement, because the cable is affected by the sea current conditions caused by wave, current movements and the rolling of the floating body itself.

The FF project is designed with a submarine riser cable consisting of optical fibers to control a windmill, a floating body also to transmit measured data and images at each floating structure and an observation tower installed parallel to an offshore substation.

3. DEVELOPMENT OF THE RISER CABLE

3.1 Fundamental Design

FEC has a lot of experiences in submarine cables, submarine oil pipes, deep-sea water suction pipes etc., and wealth of investigation experiences in dynamic applications.

For submarine cable experiences in 6.6 kV voltage class, FEC has a lot of operational know-how in loading and unloading of floating berth for crude oil since 1992, starting from the "KAIMEI" in 1977 for wave turbine facilities on Yura offshore in Yamagata prefecture, and the "POSEIDON" in 1986.

An analytic simulation technology is also important for the dynamic application that an entire investigation of the submersible floating shape requires.

Figure 4 illustrates the riser cable design flow.

A fixed wave condition and a floating body's rolling condition are needed at first for external conditions.

A static behavior analysis, a dynamic behavior analysis and a fatigue analysis are in turn conducted combining of the various parameters and the shapes for a riser cable under above conditions.

The analysis and feedbacks are reiterated and finally the most suitable submersible shape design and its detailed riser cable design are defined.

The riser cable required in the FF project is different from the past experienced 6.6 kV cables, with respect to its application to a 22 kV and to a 66 kV voltage cables, because their cable outer diameters and weights become larger and their electrical stress are more severe.

The riser cable is therefore required for the power cable construction to provide a superior fatigue withstand characteristic.

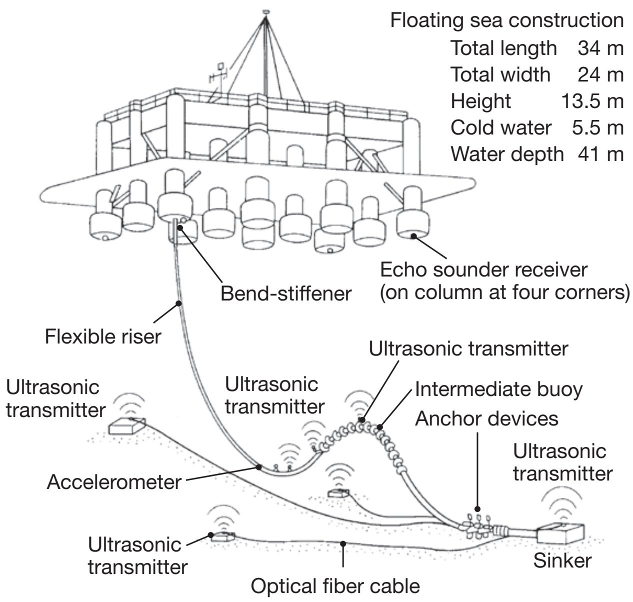

Figure 3 POSEIDON system.

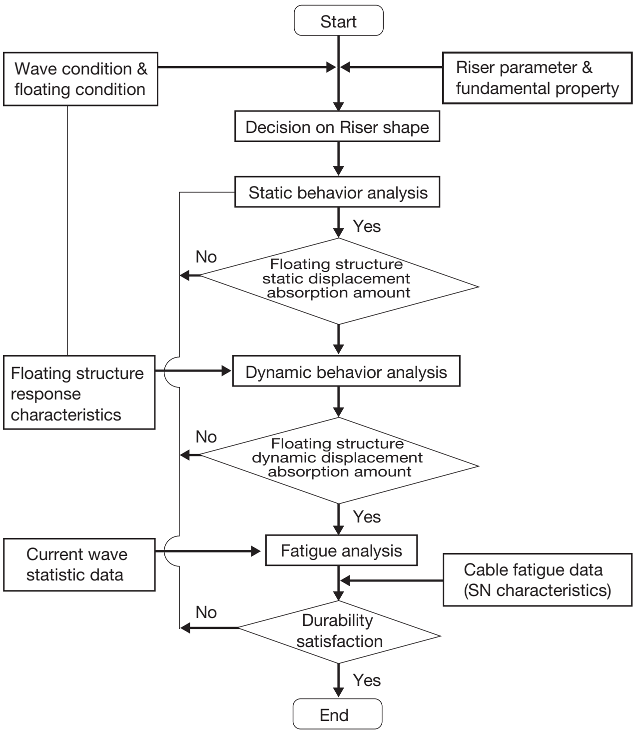

Figure 4 Design flow of riser cable.

It is essential for a conceptual construction of the submarine cable to meet the specification in accordance with the electrical equipment technical standards Clause 127 "Facilities of electric power line over water and under water" and for its electrical and mechanical characteristics to satisfy JEC-3408, CIGRE TB 490 and CIGRE Electra No.171. The requirements of the riser cable characteristics for dynamic cables are shown in table 1.

Table 1 Target characteristics.

Item	Target characteristics
Sea condition at installation site	・Meet allowable tension and minimum bending radius in floating condition ・Floating part of the cable should not touch the sea bed ・Cable should not be kinked
Floating structure rolling condition	
Fatigue life design	・Similar to windmill or floating structure

Based on the previous findings, the riser cable construction is defined as shown in figure 5. The cable has double layers of strand armor wires twisted in opposite directions in order to prevent cable torsion.

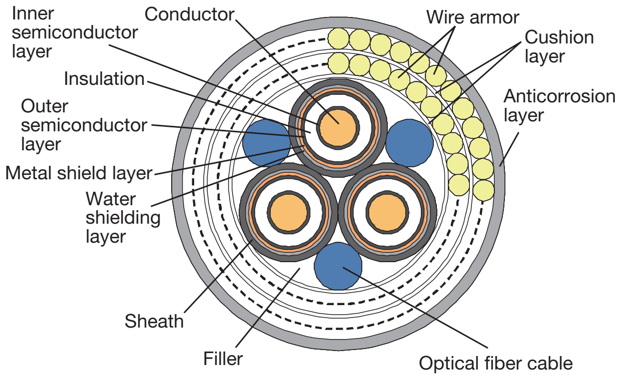

Figure 5 Structure of 66 kV riser cable.

3.2 Detailed Design and Behavior Analysis

3.2.1 Behavior analysis

There are three types of floating bodies, differing in structure and dimension, connected with the riser cables.

Behavior analysis is carried out for each floating body, as each floating body has different rolling characteristics.

Cable lightness was the first designated target of this development, in order to reduce the cable tension.

Static behavior analysis was conducted considering a wave and a floating rolling condition in the conceptual design of the applied riser cable.

Table 2 shows the wave conditions used for the analysis.

Table 2 Wave conditions.

Item	Adoption value
The 50-year-period-return value associated with a storm wave	Significant wave height(note) 11.71 m
	Significant wave period 13 sec.
Sea current	1.5 m/s (including drift current)

(Note) The average wave height is defined as the average values from the highest record and the consecutive values of 1/3 measurements of the total measurements recorded of the period of recording (for example 20 min) at a certain point.

It became clear that the riser cable was largely flown by tide current, so that a first cable lightness design could not be applied to the riser cable from the results of the analysis.

Another analysis was conducted by increasing the weight up to the maximum amount attainable in the cable construction.

However the cable design could not satisfy its property requirements, because a kink was formed at the sea-bed portion, irrespective of the intermediate buoy structure, as shown in Figure 6 and Figure 7 (refer to circle part).

Finally a submersible floating shape and a riser cable construction were confirmed to meet its characteristics requirements as illustrated in Figure 8 by increasing its cable weight with weight attached at its sea-bed portion.

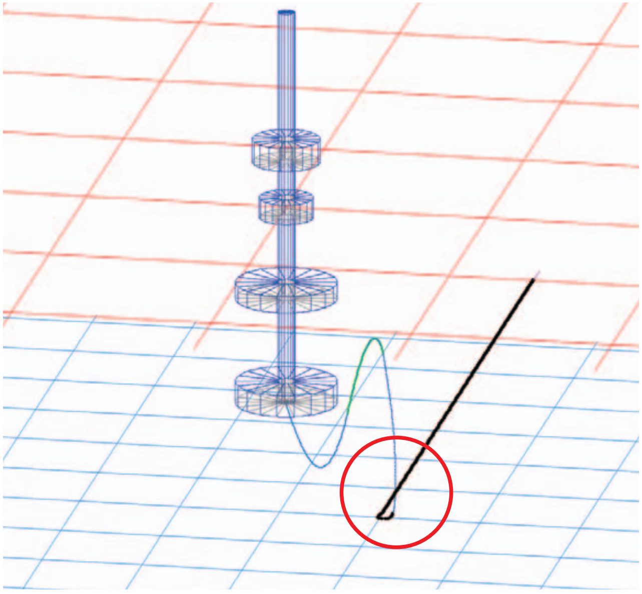

Figure 6 Cases where the submarine cable is kinked. (Modular buoy)

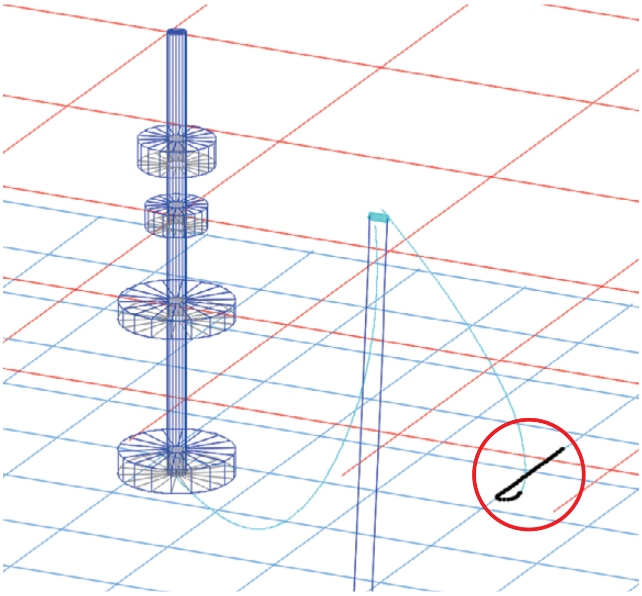

Figure 7 Cases where the submarine cable is kinked. (Mid arch buoy)

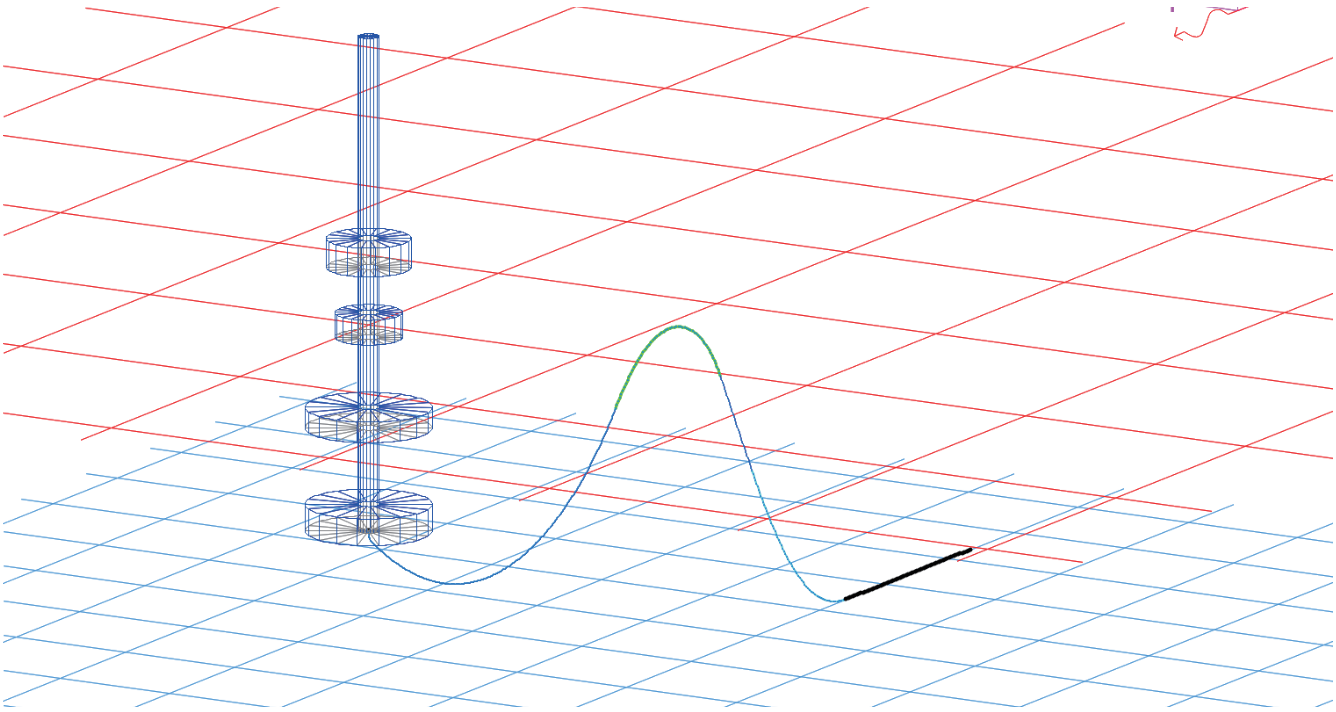

Figure 8 Cases where the submarine cable is not kinked. (Modular buoy)

For the next step, a dynamic behavior analysis was conducted based on the Response Amplitude Operator (RAO) data of each floating body and evaluated under the severest condition of the tension and the bending curvature. As a result, it became clear that no defective cable portion was found by the tension and the bending curvature.

However, a maximum tension was generated at a fixing part of the riser cable inside the floating body. Therefore a sufficient safety margin is necessary in the wire armor holding design of this portion. Hereafter, we are planning to evaluate the cable SN characteristics, and the fatigue analysis is carried out at the end.

Table 3 shows the conceptual design parameters for the riser cable.

Table 3 Specification of riser cable.

Item	22 kV cable	66 kV cable
Outer diameter	Approx.150 mm ϕ	Approx.180 mm ϕ
Weight (in the air)	Approx.45 kg/m	Approx.55 kg/m
Inside optical fiber number	1	3
Intermediate buoy	Modular type	

3.3 Prototype cable production and its evaluation

A 66 kV prototype riser cable was manufactured and its vertical stiffness and its bending stiffness were measured.

From now on, it is planned to determine the most suitable submersible riser cable shape based on the behavior analysis and the practical data obtained from the prototype cable.

Table 4 illustrates the main evaluation test items planned to be conducted from now on.

A similar evaluation test will be conducted on a 22 kV prototype cable, and the riser cable characteristics can be confirmed.

Table 4 Test items.

1.	Tensile test and tension-bending test
2.	Torsion test
3.	Side pressure test
4.	Repetitive bending fatigue test
5.	Dissection investigation after above tests
6.	Tension test of anchor portion

Since floating bodies are different on a case by case basis, the investigation of dragging-in a riser cable into a floating body has to be conducted for each floating body.

An operation procedure of a riser cable installation is illustrated in Figure 9.

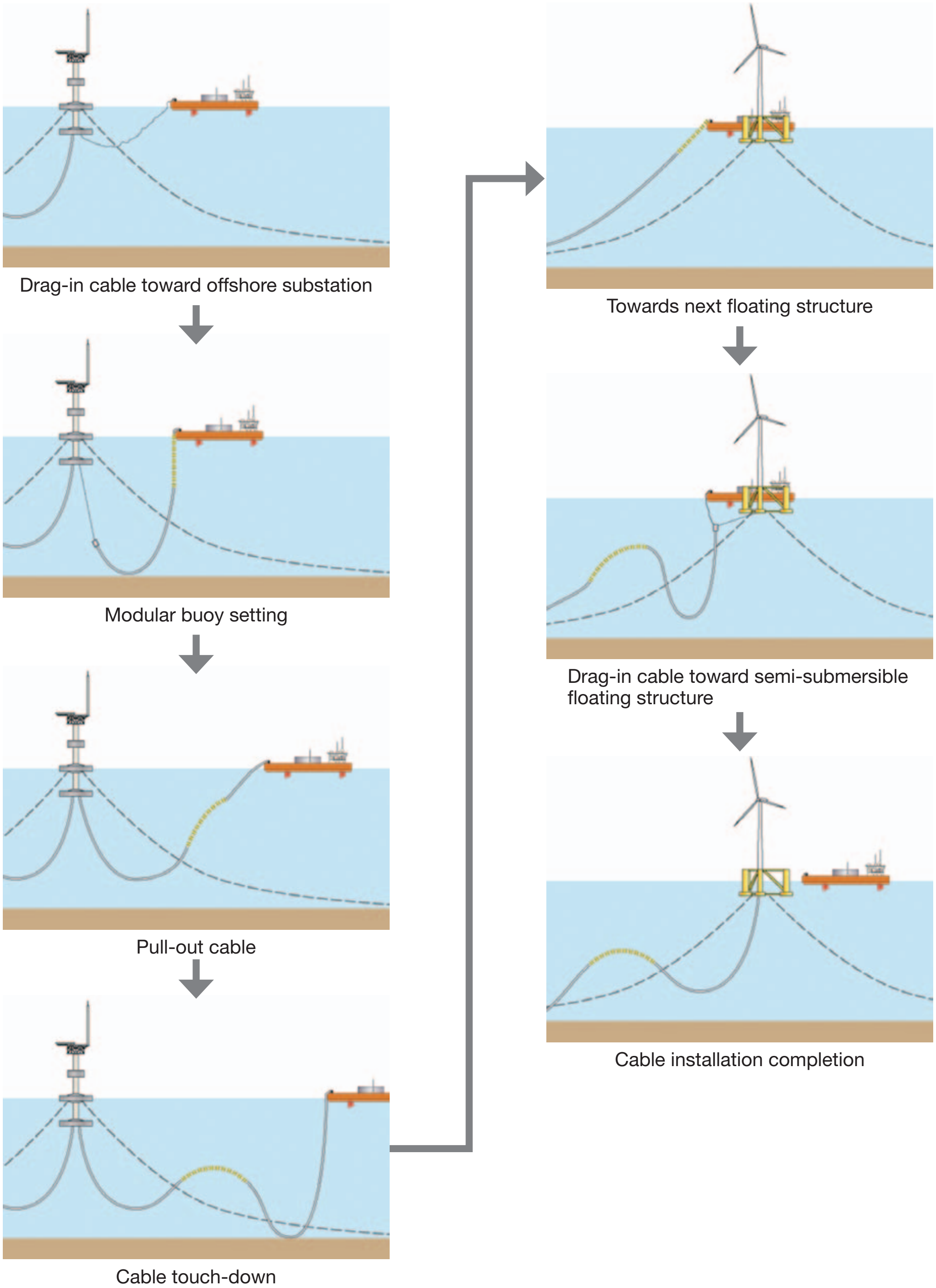

Figure 9 Construction process.

3.4 Towards Demonstration Test

Behavior measurement will be performed in the verification test, on the actual equipment by attaching an accelerometer in the riser cable installation.

Simultaneously, wave data and floating body rolling data are collected by Tokyo University and other companies. These data are analyzed by linking with actual measurement data of the riser cable. And the fatigue test will be carried out, comprehensively evaluating the desktop study result, the actual plant data and the prototype actual measurement data.

Then the maintenance method will be eventually established.

4. CONCLUSION

The FF project is proceeding on a very tight schedule.

At present, it is still at the stage of its prototype production and its property evaluation.

Then, the property of riser cable system will be confirmed and simultaneously the actual cable will be manufactured for the practical installation in the next year term.

Further study will be carried on for the successful installation of the first wind farm in the world with multiple floating bodies and an offshore floating substation.

REFERENCES

1) JEC-3408 "High voltage testing method for Special high voltage cross-linked polyethylene cable and its splice for 11-275 kV", 1997
2) CIGRE TB 490(Recommendations for Testing of Long AC Submarine Cables with Extruded Insulation for System Voltage above 30(36) to 500(550) kV)
3) CIGRE Electra No.171 (Recommendations for Mechanical Test on Sub-marine Cable)