Fukushima Floating Offshore Wind Farm Demonstration Project (Fukushima FORWARD)
Fukushima Floating Offshore Wind Farm Demonstration Project

Fukushima offshore wind consortium, which consists of Marubeni Corporation (Project integrator), the University of Tokyo (Technical advisor), Mitsubishi Corporation, Mitsubishi Heavy Industries, Japan Marine United Corporation, Mitsui Engineering & Shipbuilding, Nippon Steel & Sumitomo Metal Corporation, Ltd., Hitachi Ltd., Furukawa Electric Co., Ltd., Shimizu Corporation and Mizuo information & Research, is proceeding with Fukushima floating offshore wind farm demonstration project (Fukushima FORWARD) funded by the Ministry of Economy, Trade and Industry.

In this project, three floating wind turbines and one floating power sub-station will be installed off the coast of Fukushima. The first phase of the project consists of the 2MW floating wind turbine, the world first 25MVA floating substation and submarine cable, and will be completed in 2013. In the second phase the world largest 7MW floating wind turbine and 5MW floating wind turbine will be installed before 2015.

This project will establish the business-model of the floating wind farm and contribute to future commercial projects. The consortium members are also expected to learn know-how of floating offshore wind farm, which will be one of the major export industries in Japan.

The Fukushima FORWARD project believes to help Fukushima to become the center of new industry which will create new employment in this region to recover from the damage of the Great East Japan Earthquake in 2011.
Vision of Fukushima Floating Offshore Wind Farm

Two decades have passed since the first bottom-mounted offshore wind turbine was installed in Europe and many large scale commercial projects are in operation now. On the other hand, a few floating offshore wind turbine (FOWT) has been installed as a pilot project in Norway and Portugal. Several technical questions such as floater optimization and transmission system need to be solved for future large scale projects.

A V-Shape semi-sub floater with the world largest 7MW turbine, the world first 25MVA floating substation and the 66kV undersea cable will be implemented in Fukushima project and the economical feasibility will be studied.

A metocean measurement system considering the floater motion compensation will be developed in order to evaluate the performance and the motion of FOWT. Furthermore, the characteristics of each floater and the wind turbine, and the effect of control system on floater motion will be investigated.

In addition, the advanced steel material against corrosion and fatigue and construction technology under severe weather condition will be developed.

The project will not only focus on technical challenges but also on collaboration with fishery industry, marine navigation safety and environmental assessment, which are needed for the future large offshore floating wind farm. Public relations work will be carried out so that the status and results of this project will be open to public.

FORWARD member and Main role

<table>
<thead>
<tr>
<th>FORWARD member</th>
<th>Main role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marubeni Corporation [ Project integrator ]</td>
<td>Feasibility study, Approval and licensing, O &amp; M, Collaboration with fishery industry</td>
</tr>
<tr>
<td>The University of Tokyo [ Technical adviser ]</td>
<td>Metocean measurement and prediction Technology, Marine navigation safety, Public relation</td>
</tr>
<tr>
<td>Mitsubishi Corporation</td>
<td>Coordination for grid integration, Environmental impact assessment</td>
</tr>
<tr>
<td>Mitsubishi Heavy industries, Ltd.</td>
<td>V-shape semi-sub(7MW)</td>
</tr>
<tr>
<td>Japan Marine United Corporation</td>
<td>Advanced Spar, Floating Substation</td>
</tr>
<tr>
<td>Mitsui Engineering &amp; Shipbuilding Co., Ltd.</td>
<td>Compact Semi-sub(2MW)</td>
</tr>
<tr>
<td>Nippon Steel &amp; Sumitomo Metal</td>
<td>Advanced steel material</td>
</tr>
<tr>
<td>Hitachi Ltd.</td>
<td>Floating Substation</td>
</tr>
<tr>
<td>Furukawa Electric Co., Ltd.</td>
<td>Large capacity undersea cable</td>
</tr>
<tr>
<td>Shimizu Corporation</td>
<td>Pre-survey of ocean area, Construction technology</td>
</tr>
<tr>
<td>Mizuho Information &amp; Research institute, Inc</td>
<td>Documentation, Committee Operation</td>
</tr>
</tbody>
</table>

Vision of FORWARD

Fukushima Recovery
- Wind energy industrial accumulation
- Employment creation
- Offshore wind energy introduction

Fukushima Project

Technical challenge
- Floater concept
- Measurement and prediction
- Floating substation
- Advanced steel material

Social acceptance
- Marine navigation safety
- Environmental assessment
- Collaboration with fishery industry
- Public relation
# Metocean Measurement and Floater Motion Prediction

A metocean measurement system is developed by considering the floater motion compensation. Wind speed profile and wind direction are measured by anemometers on a met mast and a lider on the floater and are compared each other. The motion of the floater is measured using gyro, compass, accelerometer and GPS, and used for the motion compensation.

Also, in this project a dynamic analysis model of FOWT is developed. The model is improved by comparing the model results with water tank test and measurement data at the site.

## Measurement system on the floating substation

### Items
- **Metocean measurement**
  - Development of a metocean measurement system considering the floater motion compensation.
- **Floater motion measurement**
  - Development of accurate floater motion measurement system by combining gyro, compass, accelerometer and GPS.

### Scopes
- **Measurement system**
  - meteometry: cup anemometer, wind vane, thermometer, barometer, lider
  - oceanography: wave buoy, ADCP
  - motion: accelerometer, GPS, gyro, compass

### Lider
- Able to measure wind speed up to 200m above sea level.
- Convenient and economical than conventional tower measurement.

## Water tank test

<table>
<thead>
<tr>
<th>Case</th>
<th>Current</th>
<th>Wave</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>2</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>3</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

## Floating Wind Turbine Technology

In the first phase of this project, minimization of floater motion, safety and power generation efficiency are attempted by using a compact semi-submersible floater with 2MW downwind wind turbine.

In the second phase, optimization and verification of the design is attempted by using V-Shape semi-submersible floater with the world largest 7MW wind turbine. These studies will establish technologies for a future large scale offshore floating wind farm.

## Compact semi-sub floater with 2MW down wind turbine

### Items
- **Turbine**
  - Verification of 2MW down wind turbine.

### Scopes
- **Floating**
  - Development of compact semi-sub floater.
  - Minimization of floater motion and optimization of power generation by turbine control.
  - Minimization of floater motion by optimization of ballast

### Mooring
- 6 pieces catenary.

## V-Shape semi-sub floater with 7MW turbine

### Items
- **Turbine**
  - Verification of 7MW hydraulic turbine.

### Scopes
- **Floating**
  - Development of V-shape semi-sub floating.
  - Development of the reduction of floating motion by turbine control and O&M program.

### Mooring
- 8 pieces catenary.
An offshore floating transformer system which is both durable and unsusceptible to motion is developed by evaluating its performance against vibration and inclination through the shaking table tests. Furthermore, a large capacity water proof riser cable superior to fatigue is developed and optimized by motion analysis. The goal of these studies is to establish the world first floating offshore transformer system against severe metocean conditions.

1 Transmission system for floating offshore wind farm
   - Design and test: Establishment of design criteria under motion, Vibration test, inclination test.
   - Verification of GIS: Comparison of two type (GIS and Vacuum circuit breaker).
   - O & M: Periodical cut on & off of equipment and continuous observation.

2 Riser cable, cable joint and motion analysis
   - Riser cable: Development of water proof cable superior to fatigue under high voltage (22/66kV) condition.
   - Joint device for riser cable: Development of joint device between different materials and development of anchor device, Design of sub system (intermediate buoy, terminal reinforcement) by motion analysis.

Grid integration system

Pre-survey and Construction Technology for Floating Offshore Wind Farm

Optimal construction method which can be conducted under severe weather and minimize the impact on fishery environment is developed based on preliminary survey and estimation of metocean condition. Furthermore, optimal construction method for windfarm which consists of multiple floating wind turbines will be established.

1 Pre-survey and environmental evaluation
   - Offshore area: Sounding, seabed surface, core sampling.
   - Environmental condition for construction: Estimation of wind velocity and wave height.

2 Development of construction technology
   - Construction technology for offshore floating wind turbine: Optimization of construction method, workfleet and construction equipment, Development of construction method minimizing deployment area of mooring for large scale of floating offshore wind farm.

Construction method of floating offshore wind turbine
Advanced Steel Material

The TMCP and UIT developed in Japan are applied into steel material for the world first FOWT and the welding efficiency, corrosion resistance and fatigue for the long operation under the severe metocean condition are verified.

These studies will achieve shortening of the construction time and reduction of the construction cost.

<table>
<thead>
<tr>
<th>Items</th>
<th>Scopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>High tension steel for offshore wind turbine</td>
<td>• Application of TMCP to floating offshore wind turbine steel material and clarification of improvement of welding efficiency. TMCP (Thermo-mechanical Control Process): High heat input welding to be utilized for high tension steel among ship building and construction field and featured to be as high efficiency welding and easy construction control.</td>
</tr>
<tr>
<td>Fatigue solution</td>
<td>• Application of UIT technology into ultrasonic blow wave treatment and clarification. UIT (Ultrasonic Impact Treatment): Promising technology which improve dramatically fatigue feature of welding joint.</td>
</tr>
<tr>
<td>Catenary chain</td>
<td>• Development of steel material for catenary superior to durability and corrosion.</td>
</tr>
</tbody>
</table>

Marine Navigation Safety

For floating offshore wind turbines, collisions between ships or collisions between ships and turbines might occur. Development of a collision risk model is carried out and the quantitative collision risk is assessed. Actual traffic data in the coast area along Fukushima are collected. The collision risk assessment makes it possible to take appropriate safety measures.

If mooring is failed by severe storms or accidents, drifting floaters may collide with other wind turbines and ships. A simulation method based on actual response of floating turbines is developed and the consequences of drifting of floating turbines is confirmed.

<table>
<thead>
<tr>
<th>Items</th>
<th>Scopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision risk analysis and risk control option</td>
<td>• Quantitative risk analysis for collision based on risk model and traffic data. • Adoption of appropriate risk controllution (safety measures)</td>
</tr>
<tr>
<td>Collection of traffic data in the coast area</td>
<td>• Analysis of oceangoing vessels’ traffic by AIS data. (past and daily data) • Observation for domestic and fishing vessels’ traffic by Rader.</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Items</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Response of moored floating offshore wind turbine</td>
<td>• Development of analysis method of low frequency, wave frequency and high frequency motion of moored floating offshore wind turbine.</td>
</tr>
<tr>
<td>Analysis method of drifting risk of floating wind turbine</td>
<td>• Development of a simulator for risk analysis of drifting floating offshore wind turbines considering coupled response of a floater, a wind turbine and mooring system.</td>
</tr>
</tbody>
</table>

Safety verification by drifting risk

Concurrent drifting

Drifting test
Environmental Impact Assessment

The environmental impact assessment is implemented around the sea where FOWT and seabed cable are installed. The habits for seabirds, marine mammal and fish in addition to noise, scenery and radio disturbance will be surveyed and the environmental impact from the installation of the turbine and seabed cable will be clarified.

<table>
<thead>
<tr>
<th>Items</th>
<th>Detail (in habiting situation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine mammal</td>
<td>Whale, Dolphin</td>
</tr>
<tr>
<td>Underwater sound</td>
<td>Background noise and horizontal component in normal condition water</td>
</tr>
<tr>
<td>Fish</td>
<td>Fish, prawn/crab, squid octopus</td>
</tr>
<tr>
<td>Fish egg larval</td>
<td>Fish, egg, young fish</td>
</tr>
<tr>
<td>Plankton</td>
<td>Zooplankton &amp; phytoplankton</td>
</tr>
<tr>
<td>Intertidal organism</td>
<td>Attached organism and benthic living from seashore to 3m deep water.</td>
</tr>
<tr>
<td>Marine plant</td>
<td>Brown algae such as sea grape and Ecklonia stolonifera.</td>
</tr>
<tr>
<td>Macrobentos</td>
<td>Benthic activity such as bivalve, univalveshee and shell fish.</td>
</tr>
<tr>
<td>Attached Organism</td>
<td>Benthic activity such as sea chestnut, sea cucumber and sand star.</td>
</tr>
<tr>
<td>Others</td>
<td>Sediment made of seawater, earth and sand.</td>
</tr>
</tbody>
</table>

Collaboration with Fishery Industry

A committee formed by the government, Fukushima prefecture, local public entity and fishermen’s union is organized. The impact on the sea and fishery operation around the project after installation of FOWT and a new fishing method are investigated working together with the special consultant of fishery industry.

After that, a proposal for fish gathering effect by marine farm, marine fertilization and culture raft and providing sea information will be discussed.

<table>
<thead>
<tr>
<th>Items</th>
<th>Scopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine farm</td>
<td>• Construction of new fishery farm by automatic feeder, sound and fishing bank using floater and mooring</td>
</tr>
<tr>
<td>Marine fertilization and culture raft</td>
<td>• Cultivation of shellfish and seaweed by marine fertilization through water pumping of deep sea by density diffusion equipment and marine fertilizer</td>
</tr>
<tr>
<td>Fish gathering effect</td>
<td>• Observation of fish gathering around floater by ROV</td>
</tr>
<tr>
<td>Sea information</td>
<td>• Providing of real time sea information through observation equipment on floater to fisherman and disaster control center</td>
</tr>
</tbody>
</table>
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