

# Final report

## 1. Project details

<b>Project title</b>	Floating Offshore Substation - FOSS
<b>File no.</b>	640222-497111
<b>Name of the funding scheme</b>	EUDP
<b>Project managing company / institution</b>	Energy Cluster Denmark
<b>CVR number</b> (central business register)	41343788
<b>Project partners</b>	Semco Maritime, ISC Engineering, Inocean, Aalborg University
<b>Submission date</b>	02 December 2024

## 2. Summary

Floating offshore substations (FOSS) have become a key topic of interest over the years since fixed bottom substations and wind turbines have water depth limitations in depths above approximately 60 meters. However, 80% of the world's offshore wind resources are located in water deeper than 60 meters creating a need for alternative foundations such as floaters. At the moment no floating offshore substations have been utilized besides one built for a Japanese wind farm which will be decommissioned this year.

There is therefore a need in the market to develop a floating offshore substation which can be used to harvest energy offshore in areas where it hasn't been possible before.

The focus of this funding application is therefor to:

- Develop a conceptual design for FOSS with focus on:
  - Floating structure
  - Topside and layout
  - Electrical design
  - Cable management and mooring lines
- Construct a scalable model of the FOSS to validate the numerical models of the floating system, cables, and mooring lines based on experimentation.

The project partners are: Semco Maritime who will act as the consortium lead, ISC Consulting Engineers A/S, Inocean, Aalborg University, and Energy Cluster Denmark.

Flydende offshore transformerstationer (FOSS) er de senere år blevet et hovedemne i relation til offshore vindmølleparker. De klassiske offshore vindmølleparker er installeret på havbunden men ved over ca. 60 meters dybde bliver denne installationsmetode udfordrende og dyr. Dog findes 80% af verdens offshore vind på lokationer med mere end 60 meters dybde, hvilket gør det brug for en alternativ løsning såsom et flydende fundament for offshore transformerstationer. Hidtil er der ikke blevet anvendt eller produceret flydende offshore transformerstationer, bortset fra en lille transformerstation, som er blevet brugt på et projekt i Japan. Denne transformerstation vil dog blive lukket ned år.

Der er derfor behov for, at der bliver udviklet og produceret en flydende transformerstation som kan bruges på lokationer hvor det indtil nu ikke har været muligt at producere vindenergi grundet større havdybder.

Fokus på denne ansøgning er derfor:

- At udvikle et konceptuelt design for en flydende transformerstation med design fokus på
  - Den flydende struktur
  - Topside og layout af komponenter
  - Det elektriske design
  - Kabel håndtering og fortøjningslinjer
- Konstruering af en nedskaleret model af en flydende transformerstation til at validere den numeriske model af det flydende system, kabler, og fortøjningslinjer baseret på eksperimentelle forsøg.

Parterne i projektet er: Semco Maritime som er consortium lead, ISC Rådgivende Ingeniører A/S, Inocean, Aalborg universitetet og Energy Cluster Danmark.

### 3. Project objectives

The project objectives are to develop a conceptual design for a floating offshore substation, as well as construct a scaled model to validate numerical models through experimental trials.

The consortia managed to design a floating offshore substation as well as demonstrate the pilot scale model in 1:100 at Aalborg University's wave basin.

Conceptual design for a floating offshore substation has been developed and demonstrated in Aalborg University's wave basin. It is estimated that TRL has been improved from around 3 to 5-6 for a Floating Offshore Substation, with the design packages and experimental trials that validate the models developed. However, it is difficult to use the TRL scale on a floating platform for HV equipment. The innovative part is to make sure that the FOSS platform is stable in a variety of weather and sea conditions, while making sure that the FOSS maintains its overall structural integrity throughout its lifetime.

### 4. Project implementation

The project culture encouraged an innovative environment and a forum where industrial partners could improve their knowledge on important aspects that weren't necessarily core business for them. Especially interfaces between pontoons, topside structure and primary and auxiliary equipment in the FOSS has been a pivotal conversation.

The project has basically been split into 3 phases, where the first phase was defining the basis conceptual design for the FOSS. It was important to reach a design freeze, so that work packages 2, 3 and 4 could initiate and the three elements that the FOSS consists of could be designed individually (topside layout, hull design and electrical design). In this design transport and maintenance was also considered. Once the FOSS was designed, AAU could start developing their numerical models and validate these through experimental testing in the wave basin at AAU.

An ongoing risk that especially AAU worked with was comparing and validating the numerical models developed with the constructed scaled lab model. The consortia discussed the scale of the constructed model throughout the project period. The results demonstrated that the numerical models are reliable and describe/predict the behaviour of FOSS.

Parallel to the EUDP project, the industry partners have been working on a floating solution commercially. It is the partners assessment that the market has not accelerated how the industry expected in 2022, when this project was developed. The risk of losing an offshore substation and therefore potentially the output from a large part of the offshore wind park, is too expensive, compared to how large of a cost a jacket structure for a fixed bottom offshore substation would be. Until a floating solution is demonstrated in full scale, this risk is very large/expensive for developers to gamble on.

The consortia requested, and got approved, two changes. One regarding redistribution of funds between partners and one regarding an extension of the deadline of the project. The project got extended 5 months.

Shortly after receiving the EUDP grant, the project consortia began a process of crafting a collaboration agreement. This process was more difficult due to a variety of reasons. The main one being discussions between the university and industrial partners. We had to request for an extension of the deadline for finalizing this agreement.

## 5. Project results

The objective of work package 1 was to develop a conceptual basis design of the Floating Offshore Substation. The outcome was a design basis document which was used as the foundation for all the other subsequent work packages for the three major design elements (electrical equipment, topside structure and floater/hull), as well as for requirements on simulations and testing.

The objective of work package 2 was to develop a topside design and layout. A layout for the triangular topside has been developed, where all necessary MV and HV equipment, as well as UPS and HVAC, Fire & Safety and drainage systems are included. The layout also contains handling of all equipment such as cable and escape routes. The layout is presented in a set of 2D drawing and illustrated in a 3D model.

Based on the layout a FE-model for the supporting structure, which is dimensioned for both operative phase and transport & installation phase, has been built. The primary steel structure is built as an 3D model which is used to estimate the required steel weight and center of gravity.

Fire and safety philosophy are described, and passive fire protection plans, as well as escape routes are developed.

WP2 also contains an evaluation of fatigue lifetime of the top side structure for both transport- and operational phase. However, the fatigue evaluation in the operational phase is based on some simplifications concerning the hull and topside interaction. To evaluate the fatigue in the operational phase better, it is investigated how

an integrated model for hull and topside can be developed. This work is carried out according to all other documentation for WP2 and documented in doc file # EUDP-FOSS-030.

Work package 3 focuses specifically on the hull design and its interfaces with the topside and main circuit, as well as auxiliary systems essential for hull functionality.

**Purpose and Scope:** Defining the fundamental conditions and requirements for the hull, ensuring synchronization with topside and main circuit designs. The design includes a topside structure supported by three interface points to the hull, ensuring stability and durability in offshore environments. The developed hull design is based on metocean data from offshore South Korea, adaptable to various sea conditions globally. The structural integrity of the hull design adheres to relevant DNV standards and ISO weight management requirements for offshore structures. Furthermore, the global platform cable routing utilizes separate I-tubes for mechanical protection, designed to withstand harsh sea conditions, placed on the inside of the pontoon ring (triangle) and running on the inside of the three columns. In terms of marine systems, a passive ballast system with portable pumps and essential auxiliary systems for safety and functionality has been designed for the hull along with a catenary mooring system with fairleads supports, compliant with DNV standards. From a hydrodynamical perspective, DNV's Wadam software analyzes the platform responses to environmental loading (wind and wave) whilst the stability analysis ensures intact and damage stability per DNV standards, demonstrating robustness and adaptability.

Work package 3 challenged Inocean's internal simulation processes as the hull design is different from any prior designs. Hydrodynamically it is similar to the FOWT INO12 design but structurally and from a stability perspective it is novel. This brought about new knowledge both for Inocean as to the design challenges but also about the operational benefits of the hull. This knowledge could then directly be transferred to AAU and later the larger academic community. WP3 concludes that the FOSS concept is robust and adaptable to various global offshore environments, with recommendations for further verification and optimization for specific sites.

Work Package 4 was pivotal in evaluating and selecting the main and auxiliary electrical equipment essential for the FOSS, focusing on:

- High Voltage & Medium Voltage (HV&MV) Equipment validation in collaboration with Original Equipment Manufacturers (OEMs),
- Assessment of HV&MV cables and accessories,
- Suitability of Auxiliary (Aux) equipment for dynamic installations,
- Seamless integration with other work packages concerning equipment responsibilities.

**Challenges and Adaptations:**

The uniqueness of developing a novel product like the FOSS introduced specific challenges. Given the preliminary nature of OEM inputs for HV&MV equipment, which were based more on projections than confirmed data, we incorporated a conservative contingency to fortify the design's reliability. This adjustment was critical in transitioning from theoretical assumptions to a practical, robust framework.

**Technological Confirmations and Discoveries:**

Our engagements with OEMs affirmed the suitability of topside HV&MV cables and accessories, enhancing our confidence in these components for their intended purposes. Furthermore, the collaboration helped identify a supplier for Export and Array cables, enriching our resource network with valuable data contributions. It's imperative to emphasize to all suppliers that the Aux equipment must be compatible with the dynamic nature of FOSS installations.

**Integrative Insights and Regulatory Compliance:**

The project highlighted several key insights:

- FOSS-specific regulations, including adherence to DNV rules and international standards, which differ significantly from those for fixed-bottom OSS due to the unique demands of motion and inclination.
- The necessity to define inclination angles under DNV-RU-OU-0101 and SOLAS, which stipulate maximum operational angles for equipment, ensuring compatibility and safety.
- Confirmation that essential components like transformers, GIS, shunts, and diesel generators meet the requirements for use in floating installations.

Collaborative Synergies and Commercial Implications:

Our collaboration with Inocean yielded profound insights into their design approaches, uncovering critical interface considerations and equipment needs for the hull. This knowledge not only enhances our technical prowess but also strengthens our commercial strategy by providing a more integrated and attractive offering to potential clients.

The enhanced dialogue with OEMs, facilitated by the project's collaborative framework, differs significantly from typical EPC contract discussions, fostering a more open and solution-focused exchange. This is invaluable as it not only strengthens our design but also enhances our market readiness by reducing uncertainties and aligning our assumptions with practical realities.

While Work Package 4 focuses narrowly on equipment, its contribution is far from isolated. By securing the reliability and integration of electrical components within the broader FOSS design, this package has played a crucial role in advancing the project towards a cohesive and commercially viable solution. The clarity and integration achieved here significantly diminishes the uncertainties that typically shadow groundbreaking projects like ours.

Work Package 5 focused on developing numerical models to analyze the structural integrity of floating platforms, mooring lines, and cables. Using OrcaFlex and OrcaWave software, the project team worked to simulate how these systems interact with forces in the marine environment. The first steps involved defining input parameters and computing hydrodynamic coefficients with OrcaWave, which are essential for accurately representing the water-structure interactions. These foundational tasks ensured the numerical models could reliably simulate real-world conditions.

Following this, a series of models were developed and refined to achieve both lab-scale and full-scale accuracy. The first full-scale design model in OrcaFlex included the floating platform, both with and without cables, providing a baseline for detailed analysis. A lab-scale design model was then created to study the system at a smaller, more manageable scale. Modifications to the lab-scale model improved its reliability, allowing for better testing and validation of design concepts before scaling up.

Finally, insights gained from the lab-scale studies were incorporated into the full-scale model. This final model in OrcaFlex is a comprehensive tool for evaluating the performance and safety of floating platforms and their components. The outcomes of WP5 have provided the project with robust numerical tools to support the structural analysis of offshore systems, ensuring they can operate efficiently and withstand challenging marine conditions.

Work Package 6 focused on building and testing a lab-scale physical model to validate the numerical simulations developed in WP5. To begin, the team identified specific case studies to serve as the basis for validation. A physical prototype was then constructed at a reduced scale to match the key characteristics of FOSS. The mooring line properties were carefully scaled and modified based on the findings from WP5 to ensure the physical model accurately represented real-world conditions.

Next, sensors and a data collection system were installed and tested to capture critical performance data from the physical prototype during experiments. The mooring line components were built and tested to ensure they met the required standards and behaved as expected. These steps provided the tools and systems needed to gather reliable information about how the lab-scale model performed under controlled experimental conditions.

Finally, the experimental data from the physical model was compared with the numerical models developed in WP5. This comparison allowed the team to calibrate the lab-scale model for better accuracy and validate the numerical simulations. The results demonstrated that the numerical models are reliable and can predict the behaviour of the FOSS system effectively. WP6 successfully bridged the gap between experimental testing and numerical analysis, ensuring confidence in the project's designs for mooring lines and the floating platform.

The objective of work package 7 was to describe a concept for transport, installation and maintenance for the FOSS400.

The topside and hull will be built individually and later assembled to one unit. Different methods to installation of the topside and hull have been evaluated. The choice is to assemble the FOSS in a lifting operation of the topside onto the hull. This installation method is also incorporated into the design of the FOSS.

The effects of structure and equipment from a longer sea transport from e.g. the far east to the Mediterranean has been evaluated in terms of fatigue (FLS) and carrying capacity (ULS).

A concept for pulling in submarine cables is described.

A material handling plan has been drawn up describing the lifting and transport of all equipment that requires maintenance, from the operational location of the equipment to the dedicated landing area that the platform crane can reach for onward transport to the supply ship.

A strategy for handling rainwater and diesel has also been drawn up.

The objective of work package 8 was project management & dissemination. The management part went very smooth, with Semco Maritime and Energy Cluster Denmark as lead. The natural area of responsibility was Semco Maritime as the technical lead and ECD as the administrative lead. The project structure has been regularly meetings with all WP leads, as well as bilateral meetings where there have been interfaces between partners and work packages. The consortia also established a steering group, which especially helped push decisions regarding the collaboration agreement. This group was held informed also with regularly meetings.

With regards to the small project extension, all work packages and deliverables were finalized successfully within budget and time.

The project has been widely disseminated through several channels. Energy Cluster Denmark have been lead on making sure the message about FOSS gets out to all relevant stakeholders. A project movie has been published, an interactive webpage on Semco Maritimes homepage has been made to disseminate the different parts of the FOSS. The consortia are also working on finalizing a short movie here at the end, where the constructed model is being demonstrated at AAU. Furthermore, AAU has worked on publishing papers.

## 6. Utilisation of project results

The findings from the project will serve as the foundation for future developments in real-world projects. This knowledge will be crucial for developers of floating wind farms, particularly in the area of floating substations.

The project lays the groundwork for the commercialization of floating substations. The subsequent stages, including pre-FEEDs and FEEDs, will precede EPCs, using the knowledge gained from the project as a starting point for developing specific project solutions for developers.

Inocean will continue to develop their simulation tools for the design with the goal set on benchmarking against conventional designs (semi-submersible four columns, SPARs and barge type platform hulls). Inocean will also seek to increase the simulation envelope for the three-column design in terms of sub-station rating i.e. how the hull size and weight increases with an increased payload from topside, cable and mooring loads.

The hull design of three columns has yet to see any direct competitors on the market, however alternative designs are commonly being offered as of now. Being a more novel design, the three-column hull requires a bit more “proof of concept”-discussion with potential clients to get to its realisation than more conventional approaches.

The floating wind market is currently facing challenges due to macroeconomic factors, similar to the broader offshore wind sector. However, many companies are actively working to advance developments.

Two notable competitors with existing solutions are:

- **BW Ideol:** BW Ideol Floating Substation
- **Saipem/Siemens:** Saipem and Siemens Energy Floating Substation Concept

The project is essential for unlocking the vast potential of floating offshore wind, which can access wind resources in waters deeper than 100 meters—representing approximately 70% of the global offshore wind potential. According to the Global Wind Energy Council, floating wind could unlock over 7,000 GW of energy capacity worldwide, compared to the roughly 2,000 GW available in shallow waters for fixed-bottom turbines.

By enabling floating substations, the project facilitates the development of wind farms in new regions, including deep-water areas of the Atlantic, the Mediterranean, and the Pacific. This innovation directly supports global energy policies by expanding renewable energy capacity, which is vital for meeting net-zero targets and ensuring energy security. Floating offshore wind could significantly contribute to achieving offshore wind targets, such as the EU's 300 GW by 2050, with floating projects expected to account for 30-40% of the total capacity.

## 7. Project conclusion and perspective

Overall, we have proven that combining the company's knowledge on topside, equipment and hull is possible from a conceptual angle. Furthermore, the design was validated in a scale 1:100 against the engineering design with a positive conclusion.

Semco got confirmation that the Original Equipment Manufacturers on critical components have solutions or can mitigate the simulated data created in the project.

We have demonstrated that integrating the company's expertise in topside, equipment, and hull design is feasible from a conceptual standpoint. Additionally, the design was successfully validated at a 1:100 scale against the engineering design, yielding positive results.

Semco received confirmation that the Original Equipment Manufacturers (OEMs) for critical components have solutions or can address the simulated data generated in the project.

From Inoceans point of view the project has been nothing other than positive. The broad base of competences from both industry and academia has created a dynamic innovation environment, and the larger risk we faced initially in the project, not having a Cable Manufacturer tied to the project was solved as NKT joined the project as an external partner and observer to the project.

The market for floating wind technology is still emerging, and there is hesitancy to adopt new technologies due to perceived risks. However, if market conditions change, development may need to proceed on a commercial track.

One issue identified in the project is the 1:100 scale of the model, whereas the market typically uses 1:40 scale tests. An interesting approach would be to conduct 1:40 scale tests and compare them with the 1:100 scale results.

Future steps should include the certification process, involving a third-party certifying body to help mature the design and address potential approval challenges.

There are opportunities to explore the fatigue aspects of the structure from an academic perspective to predict future issues.

Implementing a Failure Mode and Effect Analysis (FMEA) within a system engineering methodology could provide a better understanding of the design.

Through this project, we have matured the design and fostered collaboration among partners, enhancing our understanding of each other's strengths. This collaboration could lead to further joint development opportunities.

During the project, we observed a rapid market acceleration, followed by a sudden deceleration. Currently, the market is moving steadily but more slowly. This indicates a need to further mature our design to convince the market of the low risk associated with continuing the floating wind technology development.

## 8. Appendices

- Add link to relevant documents, publications, home pages etc.

<https://www.energycluster.dk/projekter/foss/>

[Semco Maritime - Floating Offshore Substation](#)

[Funding for development of Floating Offshore Substation](#)