MULTI-PURPOSE OCEAN ENERGY PLATFORMS FOR OFFSHORE AQUACULTURE FARMS

K. A. Abhinav, *University of Strathclyde, UK*
M. Collu, *University of Strathclyde, UK*
J.I. Baquero Gómez, *Cranfield University, UK*

ABSTRACT

The Blue Growth strategy was laid out by the European Union (EU) in 2012 [1], with a view to realize sustainable development of the blue economy - based on the oceans, seas and coasts. Along the lines of the Blue Growth strategy, the present work investigates the performance of a multi-purpose platform (MPP) for use in an offshore aquaculture farm. The elements of offshore wind and fish feed storage are integrated in the same platform to support the energy demands of closely co-located aquaculture farms, at a location off the Scottish coast, with a water depth of 81 m. The work presented herein is part of the UK-China Investigation of the novel challenges of an integrated offshore multi-purpose platform (INNO-MPP) project [2] (EPSRC Grant no. EP/R007497/1).

Concepts involving MPPs in the range of multi-megawatts have been explored in previous studies funded by the EU – namely, the MARINA, ORECCA, TROPOS, H2OCEAN, and MERMAID projects [3-5]. While deriving from the above mentioned concepts, the present study attempts to identify the suitability of platforms with low power ratings for use in offshore fish farms. The long term goal is to make remote island communities self-sufficient with regards to their economic aspects (via aquaculture) and power needs. The performance of the MPP under coupled aerodynamic-hydrodynamic loading has been investigated within a non-linear time-domain framework. Initial results indicate the suitability of a feed barge as a support platform for a small rated wind turbine to cater to the energy needs of an offshore aquaculture farm.

1. INTRODUCTION

The Blue Growth strategy has been envisaged by the European Union [1], with a view to develop the blue economy (i.e. oceans, seas and costs), while considering the limited reserves of land based resources. Within the umbrella of Blue Growth, two of the key sectors identified as having significant economic potential are – ocean energy and aquaculture.

According to the Food and Agriculture Organization [6], global seafood demand is expected to exceed the supply by 40 million metric tonnes, by 2030. Nearshore aquaculture is facing threats from different fronts – decades of overfishing has led to a steep decline in fish stock and serious environmental concerns arise from the discarded by-catch [7]. While the demand for seafood is growing, nearshore fisheries are unable to expand in proportion, owing to a combination of legal, aesthetic, land-use and ecological aspects. A potential solution to the problems faced by nearshore aquaculture, is to move offshore, into deeper waters.

Fish farms are traditionally powered by diesel, which could be demanding on the environment. There have been few studies on the feasibility of using renewable energy to support aquaculture. Buck *et al.* [8] proposed the use of fixed offshore wind structures to support the cultivation of seaweeds and mussels. Syse [9] investigated the possibility of supporting salmon farms with renewable energy. Justad [10] compared the power consumption of an offshore fish farm with the power production from a wind turbine in the vicinity. However, there is a notable absence of literature pertaining to the integration of renewable energy production to the aquaculture system.

2. PROBLEM DEFINITION

The present work investigates the suitability of supporting the energy needs of an offshore aquaculture farm, by means of renewable resources – wind, wave and/or solar. The site under consideration is off the west coast of Scotland, with a water depth of 81 m and the energy requirements are to be met with a closely co-located multi-purpose platform (MPP). The 10 m mean wind speed at the site is 8.25 m/s.

Power requirements for an aquaculture farm have been modelled on the basis of the Rataren fish farm [10], about 50 km off the Norway coast. With 14 fish cages, each 160 m in circumference, a peak power consumption of 195 kW was observed.

3. CONCEPT SELECTION

While the previous European projects studied MPPs, the wind turbines involved were of high rated power – in the MW range. On the other hand, the power requirements of an aquaculture farm are significantly lower – in the kW range. The present section reviews the concepts proposed by the previous projects and attempts to select a suitable MPP configuration, based on the requirements specified in the problem statement.

A total of 10 MPP concepts have been considered in the present study, before arriving at the final configuration. They are – Sea Star Spar [11], Spar Torus Combination [12], W2Power semi-submersible based concept [12], Semi-submersible Flap Combination [12], Oscillating Water Column array with wind turbine [12], the Poseidon [13], TROPOS wind satellite platform [14, 15], Cantabria Offshore Site multi-use platform [16], wind turbine on feed barge [17] and the SALMAR platform [18, 19]. Detailed information on these MPPs are available in the references mentioned.

The MPP concepts mentioned above were studied with respect to a set of assessment criteria, comprising of several factors – the availability of experimental data, technological readiness levels (for renewable energy and aquaculture), ease of numerical modelling, suitability for experimental validation and ease of operation and maintenance for aquaculture activities. In accordance with the problem statement, higher weights were assigned to the aquaculture related factors and on the utilizing a TOPSIS analysis procedure, the ideal solution was observed to be the wind turbine on a feed barge. Integration of wave energy converters to the MPP may be neglected due to the low power requirements of an offshore aquaculture farm.

Feed barges are floating structures located in the vicinity of a fish farm with multiple uses – to store fish feed, house workers and to serve as a control base for aquaculture operations. Utilizing a feed barge to support the OWT has several inherent advantages: It is economical, as the need for a separate support structure for the OWT is eliminated; the technology is proven and is in use; it affords easier access for maintenance and underwater cables are not required. Further, using a turbine of small mass will not significantly impact the configuration of the barge. However, there are technical challenges as well. For instance, turbines obstructing access to feed silos and the influence of vibration on the feed silos.

4. DESIGN SPECIFICATION

In the present study, the feed barge is designed on the basis of the commercial AB 650 model developed by AKVA. The main design characteristics are given in Table 1.

Table 1. Feed Barge Characteristics [20]

Capacity	**AB 650**
Feed storage capacity	650 tons (8 silos)
Silage	Up to 90 tons
Fuel Oil	Up to 30 tons
Fresh water	Up to 10 m^3
Sewage	Up to 10 m^3
Main dimensions	
Length	30 m
Beam	19 m
Hull height	3.6 m
Minimum freeboard	1.210 m

Keeping in mind, the low power requirements for the offshore aquaculture farm, the 2-bladed AWT-27 turbine [21], with a downwind orientation, has been chosen for the present study. Its specifications are presented in Table 2.

The mooring system of the feed barge – wind turbine ensemble is formed by 8 catenary lines, with a pretension of 1 MN each. The mooring lines are formed by a combination of chain and polyester rope.

Table 2. AWT-27 turbine specifications [21]

Rated power	275 kW
Rated wind speed	17 m/s
Rotor diameter	27.2 m
Rotor orientation	Downwind
Cut-in, cut-out wind speeds	6 m/s, 22.5 m/s
Rotor rpm	54 rpm
Hub height	42 m
Pitch	Fixed
Yaw	Passive
Generator type	300 kW, induction

5. NUMERICAL ANALYSIS

Numerical studies on the MPP model are carried out using DNV.GL's SIMA (Simulation of Marine operations) environment. Initially, as a validation exercise, the suitability of SIMA to model floating offshore wind turbines is ascertained by comparison with NREL's FAST [22] and HAWC2 [23] for the OC3 SPAR configuration. As shown in Figure 1, a close match was observed between the predictions, over a range of hub-height wind speeds.

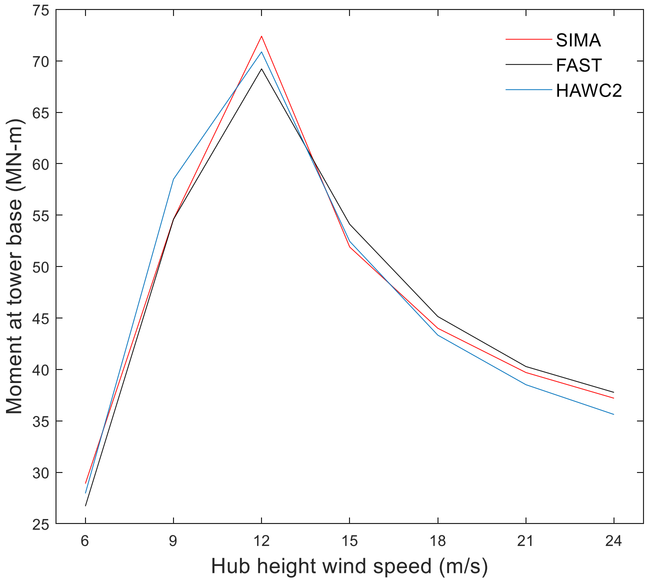

Figure 2. Code-to-code comparison

SIMA makes use of the blade element momentum (BEM) theory [24] to calculate the aerodynamic loads on the wind turbine. Herein the blades are subdivided into elements and the total force on the blade is obtained as the sum of the forces on the individual elements.

The model is developed in SESAM GeniE and is analysed in the frequency domain using HydroD and in the time domain utilizing SIMA. Figure 2 shows the MPP configuration in GeniE (left) and SIMA (right).

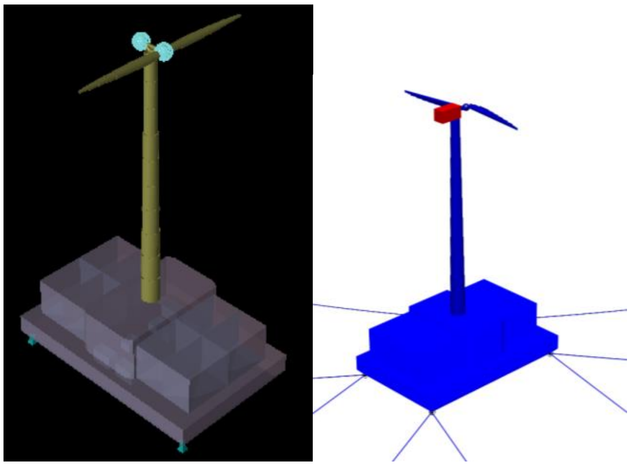

Figure 2. MPP model in GeniE and SIMA

Stability criteria with respect to the Norwegian Maritime Directorate (NMD) and NS 9415 [25] (specifically for aquaculture installations) have been satisfied and the results from the latter are presented in Table 3.

Table 3: Stability criteria - NS 9415 [25]

Analysis Variables	Analysis	Requirements
Area below GZ-curve from 0 deg to maximum righting arm	0.457 [m-rad]	0.08 [m-rad]
Static heel angle due to wind	1.5°	8.98°
Last angle of positive GZ	56.89°	15°

The performance of the feed barge supporting the turbine with respect to safety and serviceability criteria has been studied by means of coupled aerodynamic-hydrodynamic analysis. A hub-height wind speed of 18 m/s, which closer to the rated wind speed was chosen. The limiting values for acceleration and displacement have been adopted from Krokstad and Lønseth [26] for the feed barge and Collu and Borg [27] for the wind turbine. The comparison has been reported in

Table 4 and the values were observed to fall within the prescribed limits.

Table 3: Serviceability check

Constraints	Criterion	Value (RMS)
Feed Barge		
Vertical Acceleration	0.15 g	0.12 g
Lateral Acceleration	0.07 g	0.05 g
Roll	4°	3.9°
Wind Turbine		
Acceleration	0.5-0.6 g	0.52 g
Inclination	10°	5.8°

6. CONCLUSIONS

A feed barge supporting a small 2-bladed wind turbine to cater to the needs of an offshore aquaculture farm has been analysed in the present work.

Preliminary analyses gives favourable results, indicating the feasibility of the feed barge to act as a support for the wind turbine. This will be followed up with detailed case studies involving the most probable sea states and further experimental analysis, as part of future work.

ACKNOWLEDGEMENTS

This research work was supported by the EPSRC, through the UK-China Investigation of the novel challenges of an integrated offshore multi-purpose platform (INNO-MPP) project [2] (EPSRC Grant no. EP/R007497/1).

REFERENCES

1. European Commission, 2012, Blue growth. Opportunities for marine and maritime sustainable growth, *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*.
2.http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/R007497/1
3. Muliawan, M J, Karimirad, M and Moan, T, 2013, Dynamic response and power performance of a combined spar-type floating wind turbine and coaxial floating wave energy converter, *Renewable Energy*, 50, 47–57.
4. Carlberg, L K, Christensen, E D, Rockmann, C, Stuiver, M, and van den Burg, S, 2015, Go offshore-Combining food and energy production.
5. http://www.h2ocean-project.eu/
6. FAO, 2006, State of World Aquaculture, Food & Agriculture Organization.
7. Holm, P, Buck, B H and Langan, R, 2017, Introduction: New approaches to sustainable offshore food production and the development of offshore platforms, in: *Aquaculture Perspective of Multi-Use Sites in the Open Ocean*, Springer, pp. 1-20.
8. Buck, B H, Krause, G, Michler-Cieluch, T, Brenner, M, Buchholz, C M, Busch, J A, Fisch, R, Geisen, M and Zielinski, O, 2008, Meeting the quest for spatial efficiency: progress and prospects of extensive aquaculture within offshore wind farms, *Helgoland Marine Research*, 62(3), 269-281.
9. Syse, H L, 2016, Investigating off-grid energy solutions for the salmon farming industry, *Master's thesis*, University of Strathclyde and University of Stavanger.
10. Justad, A A, 2017, Wind Turbines for the Power Supply for Offshore Fish Farms, *Master's thesis*, University of Agder.
11. ECOFYS, 2008, Marine Parks: Sketch for sustainable energy and biomass at sea, *Tech. Rep. No. 08.2.168* [in Dutch].
12. MARIBE, 2016, Deliverable D5.1 Review of multi-use of space and multi-use platform projects.
13. Casale, C, Serri, L R, Stolk, N E, Yildiz, I, Innovazione, C, 2012, Synergies, innovative designs and concepts for multipurpose use of conversion platforms, *Tech. Rep.*, Results of ORECCA Project WP4 (FP7).
14. TROPOS, 2014, Deliverable 3.4 Technical concept dossier for the satellite units.
15. Papandroulakis, N, Thomsen, C, Mintenbeck, K, Mayorga, P and Hernández-Brito J J, 2017, The EU-Project "TROPOS" in *Aquaculture Perspective of Multi-Use Sites in the Open Ocean*, Springer.
16. MERMAID, 2015, Deliverable 3.4 Integration of energy converters in multi-use offshore platforms.

17. Syse, H L, 2016, Investigating Off-Grid Energy Solutions for the Salmon Farming Industry, *MSc Thesis*, University of Strathclyde and University of Stavanger.
18. Leira, B J, 2017, Multi-purpose offshore-platforms: past, present and future research and developments, *Proc. 36th International Conference on Offshore Mechanics and Arctic Engineering - OMAE2017*, June 25-30, 2017, Trondheim, Norway.
19.SALMAR, https://www.salmar.no/en/offshore-fish-farming-a-new-era, accessed on 15-06-2018.
20. AKVA, http://www.akvagroup.com/cage-farming-aquaculture/feed-barges/ab-650-450-comfort-panorama, accessed on 30-06-2018.
21. Wilson, R E, Walker, S N and Heh, P, 1999, Technical and User's Manual for the FAST_AD Advanced Dynamics Code. *Tech. Rep.* OSU/NREL-99-01, Oregon State University.
22. Jonkman, J M and Buhl Jr, M L 2005, FAST – User's guide. *Tech. Rep. NREL/EL-500-38230*, National Renewable Energy Laboratory, Golden, Colorado.
23. Larsen, T J and Hansen, A M, 2015, How 2 HAWC2 – the Users' Manual, Riso National Laboratory, Technical University Denmark.
24. Hansen, M O, 2000, *Aerodynamics of Wind Turbines*. Earthscan.
25. Standards Norway, 2009, NS 9415.E:2009 - Marine fish farms - Requirements for site survey, risk analyses, design, dimensioning, production, installation and operation.
26. Krokstad, J and Lønseth, M, 2003, 'Stabilitet og sikkerhet for havbruksflåten i sjøgang, SINTEF Fiskeri og Havbruk: 19.
27. Collu, M and Borg, M, 2016, Design of Floating Offshore Wind Turbines, in A Guide to the project management body of knowledge, pp. 359–385.