Proceedings of the ASME 2019 38th International Conference on Ocean, Offshore and Arctic Engineering
OMAE2019
June 9-14, 2019, Glasgow, Scotland

OMAE2019-96212

ANALYSIS OF THE COUPLED DYNAMICS OF AN OFFSHORE FLOATING MULTI-PURPOSE PLATFORM, PART A: RIGID BODY ANALYSIS

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ABSTRACT

A multi-purpose platform (MPP) is an offshore system designed to serve the purposes of more than one offshore industry. Indeed, over the past decades, a number of industries have expanded, or are expanding, from onshore to offshore locations (renewables, aquaculture, tourism, mineral extractions, etc.), and the research on these type of platform is increasing. In the present work, a MPP able to accommodate wind turbines, wave energy converters, and aquaculture systems are considered. This work presents the first part (Part A) of the analyses of the dynamics of the floating support structure for this MPP, focusing on the rigid body dynamic response, while its complementary hydroelastic analysis is presented in Part B (OMAE2019-96282).

The aim here is to assess the dynamic response of the platform with respect to the preliminary requirements imposed by the wind turbine, the aquaculture system, and the other ancillary systems. After describing the platform analyzed, and explaining the aero-hydro coupled model of dynamics approach adopted, two independent analyses are conducted, one using the SESAM package by DNV-GL, and another using ANSYS AQWA, in order to verify the results, in absence of experimental data. Considering a severe, but still operational, load case, the preliminary results seem to demonstrate that the chosen platform can satisfy the dynamics constraints imposed by the payload systems.

INTRODUCTION

The “blue growth” economy, already in 2012, represented 5.4 million jobs in Europe, generating a gross added value of 500 billion euros/year [1]. Apart from the mature activities (short sea shipping, oil and gas, coastline tourism, etc.), the ocean is providing new opportunities, in terms of aquatic products, renewable energy and maritime monitoring [1]. Actually, the research community has concentrated on these new opportunities for a long time.

The OC3–Hywind [2] project sparked the interest in offshore renewable energy. Hu et al. [3] simulated the dynamic responses of a floating wind turbine under operation and fault condition. Li et al. [4] proposed a free rotation approach to measure the dynamic motions of a floating wind turbine in the experimental condition. Other researchers are working on ocean wave energy. Li et al. [5] proposed an artificial intelligence control algorithm based on wave force prediction to maximize the energy conversion of a heaving-point absorber. The effect of prediction was further investigated in [6]. In addition to the offshore energy, the oceans also provide a huge amount of aquatic products, promoting the development of the offshore fish farm. Kristiansen and Faltinsen [7] proposed a screen type of force model for the current loads on net cages. Bai et al. [8] assessed the fatigue life to the floating collar of a fish cage under random wave loads. The basic idea behind multi-purpose platforms is to devise a platform able to exploit the synergies among different offshore industries, providing a cheaper alternative than single-use platforms.

Multi-purpose offshore structures for ocean resource exploitation have been documented in previous works. Muliawan et al [9] combined a floating wind turbine and a wave energy converter. Li et al. [10] proposed a hybrid offshore renewable energy system HWNC, which combines a floating wind turbine, a wave energy converter and two tidal turbines. The fatigue damage loads and the long-term extreme structural loads of the HWNC is further investigated in [11, 12]. Wan et al. [13] conducted both numerical and experimental examinations on a combined wind and wave energy concept. In the meanwhile, the investigation on multi-purpose platforms has received financial support from the European Commission. The H2Ocean is a project aimed at developing an innovative design for an economically and environmentally sustainable multi-use open-sea platform [14]. The MERMAID project develops concepts for the next generation of offshore platforms which can be used for multiple purposes [15]. The Tropos project is funded by the European Commission to develop a floating modular multi-use platform system for use in deep waters [16].

More recently, the 'Blue Growth Farm' project has been started to provide a universal solution to the full exploitation of ocean resource, by proposing a multi-purpose offshore platform. This platform aims to integrate wind and wave energy devices (renewable energy generation), an aquaculture system (produce fish at industrial level), a maritime surveillance unit (provide meteorological and oceanographic data) and a docking system (accommodate specialized vessels).

This work presents the outcomes of the preliminary stage of the Blue Growth Farm-concept design, focusing on the aero-hydro-servo coupled analysis. A rigid-body approach is adopted in this paper, while the complementary hydro-elastic analysis is reported in a companion paper [17]. Please refer to [18, 19] for the detailed design methodology of the multi-purpose platform The structure of this research is outlined as follows. First, the requirements produced by multiple purposes will be briefly introduced before the final main characteristics are given. Afterward, the set-up of the numerical model is interpreted in details. Finally, this paper investigates the payload of the multi-purpose platform.

MULTI-PURPOSE PLATFORM

Design requirements

The multi-purpose platform is designed with four primary functions: (1) energy production; (2) fish farming; (3) environment monitoring; (4) vessel docking station. Considering these purposes, the platform should guarantee the following functions:

- Able to accommodate the various payloads (energy system, fish feed, control rooms, and cranes, etc.)
- Sufficiently large internal pool size for the aquaculture cages
- Good dynamic response

Main characteristics

Fig. 1 sketches the multi-purpose platform considered in the present research, which is a simplified draft proposed in the Blue Growth Farm. Please note that the current model should not be taken as representative of its final design. The main infrastructure is a semi-submersible platform with inner water pool. In order to meet all the platform's own energy needs and export the excess energy to the onshore grid, the DTU 10 MW wind turbine [20] and a set of oscillating-water-column wave energy converters based on the REWEC3 patent [21] are equipped. Six fish cages are located in the inner water pool. Two cranes and several other docking equipment are also installed on the port and starboard respectively to support the regular maintenance so that the facility can be used as a sea-based recharging station.

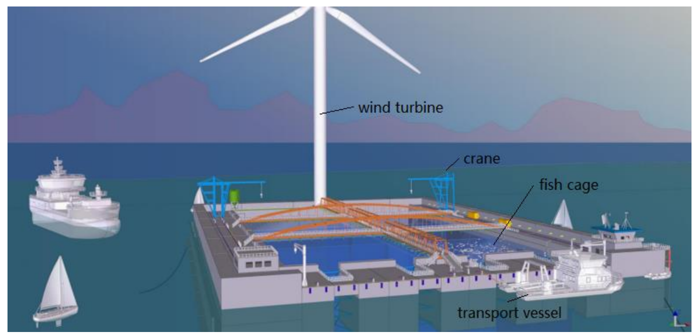

Fig. 1. Sketch of the multi-purpose platform.

Table 3 summarizes some critical characteristics of the multi-purpose platform. The main size of the platform is 204 m×156 m and the inner water pool has a dimension of 156 m×108 m. The designed draft is 20 m, providing a total of 1.73×10^8 m^3 buoyancy volume. The large deck area and buoyancy volume allow the platform to carry a set of equipment.

Table 1 Main characteristics of the platform

Item	Value
Platform size	204 m×156 m
Inner pool size	156 m×108 m
Draft	20 m
Buoyancy Volume	168,657 m^3
Platform Mass	1.73×10^8 kg
I_{xx}	5.05×10^{11} kg·m^2
I_{yy}	9.31×10^{11} kg·m^2
I_{zz}	1.39×10^{12} kg·m^2

Regarding the mooring system, a simplified model of a catenary mooring system is adopted, since the design plan is not available yet. In this paper, the mooring system is represented by the following linear restoring matrix:

$$K = \begin{Bmatrix} 5500\text{kN/m} & 0 & 0 & 0 & 0 & 0 \\ 0 & 5500\text{kN/m} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 3.75\text{E+07kN}\cdot\text{m/rad} \end{Bmatrix} \quad (1)$$

Only horizontal restoring stiffness is modeled and the coupling elements are not considered.

MODELING APPROACH

The present work focuses on the development of the aero-hydro coupled model for the dynamics of the multi-purpose platform, and the assessment of its dynamic response under the joint excitations of offshore wind and ocean waves. Considering its large size (204 m × 156 m), the hydro-elastic dynamics of the platform could not be ignored but, as demonstrated in the companion paper [17], its impact on the global response can be considered ad negligible at first approximation. Therefore, all the structures (including the wind turbine tower) are treated as a rigid body.

Kinetics

The kinetics of the multi-purpose platform is given by

$$\begin{aligned} \boldsymbol{P}' + \boldsymbol{w} \times \boldsymbol{P} &= \boldsymbol{F} \\ \boldsymbol{L}' + \boldsymbol{w} \times \boldsymbol{L} + \boldsymbol{v} \times \boldsymbol{P} &= \boldsymbol{M} \end{aligned} \quad (2)$$

where $\boldsymbol{F}$ and $\boldsymbol{M}$ are the external force and moment vectors, respectively. In the present research, they are the resultant loads of wind and wave. $'$ denotes the time derivatives. $\boldsymbol{P}$ and $\boldsymbol{L}$ are the linear and angular momenta matrix:

$$\begin{aligned} \boldsymbol{P} &= \boldsymbol{m}(\boldsymbol{v} + \boldsymbol{w} \times \boldsymbol{r}) \\ \boldsymbol{L} &= \boldsymbol{I}\boldsymbol{w} + \boldsymbol{m}\boldsymbol{r} \times \boldsymbol{v} \end{aligned} \quad (3)$$

where $\boldsymbol{m}$ is the mass matrix and $\boldsymbol{I}$ is the inertial moment matrix; $\boldsymbol{v}$ is the translation velocity vector and $\boldsymbol{w}$ is the rotation velocity vector; $\boldsymbol{r}$ is the center of mass. The external loads $\boldsymbol{F}$ and $\boldsymbol{M}$ include the aerodynamic force, the hydrodynamic force, the hydrostatic restoring force, and the mooring restoring force.

Aerodynamics

The aerodynamic loads on the wind turbine are based on the blade element momentum (BEM) approach. For a floating wind turbine, the air inflow seen by the rotor is unsteady so that the aerodynamic hysteresis will occur. The Stig Øye dynamic wake model [22] is used to model the hysteresis effect. Additionally, the Glauert correction and the Prandtl factor are included to correct the BEM model in the case of large induced velocity and finite blades. Please note that the aerodynamic load is only considered in the time-domain simulation.

Hydrodynamics

Hydrodynamic loads are estimated with a linear potential flow theory approach. The first order linear wave excitation forces are generated based on the linear impulse response function ψ

$$f_{ext}(t) = \frac{1}{2\pi}\int_0^t \psi(\tau)\zeta(t-\tau)d\tau \quad (4)$$

where ζ is the wave elevation.

The radiation wave force is calculated using a convolution model

$$f_{rad}(t) = \int_0^t h(t-\tau)x(\tau)d\tau \quad (5)$$

h is known as the retardation function, which can be estimated by either the added mass or the potential damping. $x(t)$ is the velocity.

All the hydrodynamic coefficients appearing in the wave load model are calculated in the frequency-domain using the boundary element analysis software Wadam [23]. The panel model is sketched in Fig. 2. The application of potential flow theory inherently implies that any viscous effect is ignored, and the dynamic responses predicted are conservative. It is one of the limitations in the present numerical modeling.

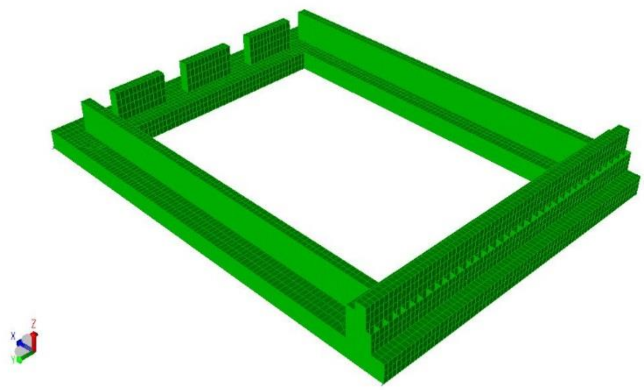

Fig. 2. Panel model of the multi-purpose platform.

Structural dynamics

In the present work, a rigid-body approach is adopted, while in the companion paper [17] the hydro-elastic behavior of the platform is presented. The rigid-body assumption may lead to an overestimated dynamic response, e.g. the nacelle acceleration and the hub velocity so that the estimations are conservative. Since the present research mainly aims to examine the safety of the multi-purpose platform, the overestimation is acceptable.

Control strategy

A variable-speed torque controller and a blade pitch controller are incorporated into the wind turbine. The two control systems are designed to work independently, for the most part, in the below-rated and above-rated wind speed range, respectively. The goal of the variable-speed torque controller is to maximize the power capture below the rated operation point. The blade-pitch controller is to regulate the generator power above the rated operation point.

Limitations

The following aspects are not considered in the present numerical model of the multi-purpose platform:

- Oscillating-wave-column wave energy converters. The WEC contains an air chamber, which is currently neglected in the present dynamic model ("open chamber" analysis).
- Fish cages. The viscous forces acting on the fish cages and transmitted to the floating support platform are, in the present approach, neglected.
- No viscous damping is accounted for. This is considered a conservative hypothesis.

PAYLOAD REQUIREMENTS

As presented before, the multi-purpose platform should accommodate the needs of all the systems supported. In the present research, we mainly focus on three aspects:

1. Nacelle acceleration. The generator located inside the nacelle is subject to substantial inertial loads due to the nacelle acceleration. Based on the design requirement, the nacelle acceleration should be less than $0.4g$ ($g = 9.85$ m^2/s).
2. Hub velocity. From the wind turbine power production point of view, the hub global velocity should be as low as possible to ensure a stable and smooth power output. Based on the design requirement, the oscillation range of hub velocity should be less 2 m/s.
3. Platform global motions. Due to the presence of the cranes, of the control and monitoring systems, and of the aquaculture systems, further limitations on the motions are imposed.

To estimate the performance of the platform under the joint excitations of wind and wave, an aero-hydro-servo coupled time-domain simulation model has been developed, using the package Simo of the SESAM software, by DNV GL. The environmental condition is listed in Table 2. Uniform wind is used and the random wave elevations are generated based on the JONSWAP wave spectrum. Only head sea is considered, and the wind propagates in the same direction. The overall simulation length is 4000 s and the time step is 0.05 s. Only the last 3600 s data will be collected for analysis to get rid of the transient effects in the early simulation stage.

Table 2 Environmental conditions

U_w	H_s	T_p
11 m/s	6 m	11 s

Hydrodynamic coefficients

First, the frequency-domain hydrodynamic coefficients of the multi-purpose platform are compared. These have been obtained using the hydrodynamic analysis software Wadam [23] by DNV GL and AQWA, by ANSYS. The hydrodynamic coefficients with respect to AQWA is provided by paper Part B (OMAE2019-96282), in which the hydrodynamic coefficients are used to perform the hydroelastic analysis. Therefore, the comparison between the two codes is also the cross-verification between the two papers. Fig. 3 plots the added mass coefficient of the platform. Due to the inner water pool, negative added mass values are observed at some frequency values [24]. The response amplitude operators (RAO) of the platform global motions are shown in Fig. 4. Generally, the patterns of the hydrodynamic coefficients agree well between the two codes, despite slight discrepancies of the response peaks. According to the frequency-domain comparison, the hydrodynamic models developed in the two papers can be considered verified.

In addition to the hydrodynamic coefficients, the time-domain dynamic model is also compared. Table 3 compares the standard deviations of the platform global motions based on the random wave condition in Table 2. As shown, the agreement between the two models is good. Please note that the aerodynamic loads are not considered here since AQWA is unable to model the wind turbine force. Nevertheless, the wind force acting on the wind turbine will be included in the following part of this paper.

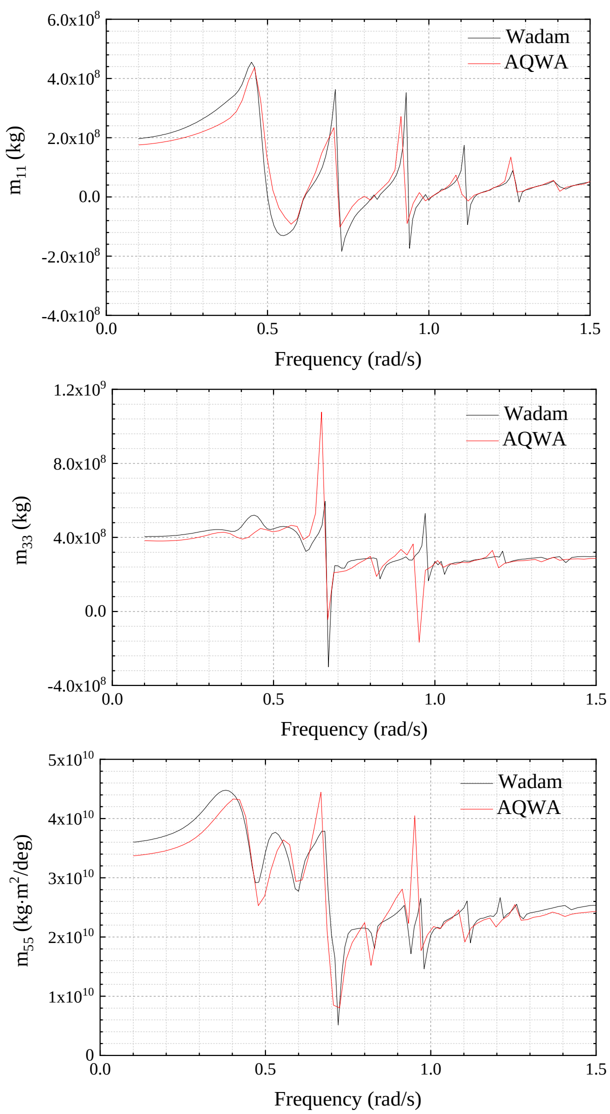

Fig. 3. Added mass of the platform.

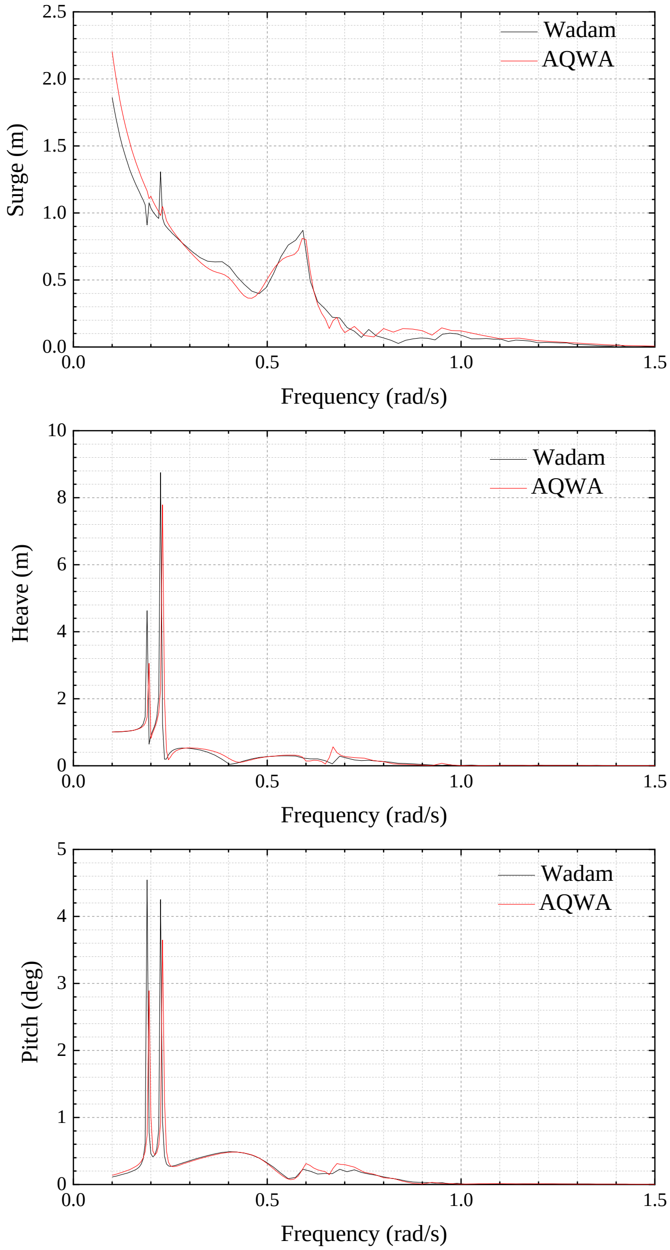

Fig. 4. Response amplitude operator of the platform global motions (without mooring lines).

Table 3 Standard deviations of platform motions

DoF	Standard deviation	
	Simo	AQWA
Surge (m)	0.86	0.76
Heave (m)	0.33	0.35
Pitch (deg)	0.32	0.31

Nacelle acceleration

Due to the platform motions, some mechanical components (gear, generator, etc.) in the nacelle are subject to substantial inertial loads. Fig. 5 plots a time series of normalized nacelle acceleration a ($a = \sqrt{a_x^2 + a_z^2}/g$, a_x is the acceleration along surge direction and a_z is the acceleration along heave direction). Over the 1-hour period, the maximum normalized nacelle acceleration observed is as low as 0.311. Fig. 6 plots the acceleration power spectra. As shown, the acceleration is mainly induced by the wave frequency.

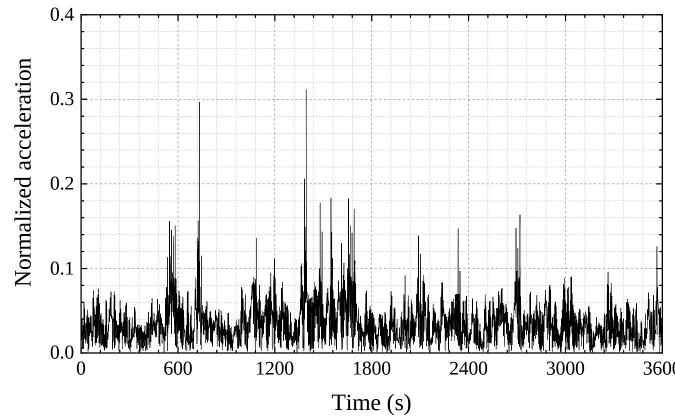

Fig. 5. Time series of normalized nacelle acceleration.

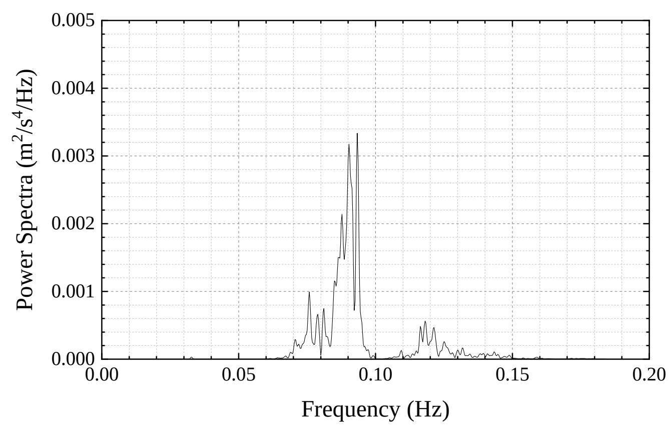

Fig. 6. Power spectra of horizontal nacelle acceleration.

Hub velocity

In order to acquire a smooth wind turbine power production, the hub velocity along incident wind direction should be restricted within an acceptable range. Otherwise, the power transported to the grid may become very unstable even in the presence of wind turbine control.

Fig. 7 plots the time history of hub velocity along the inflow direction. The standard deviation is as low as 0.49 m/s. Given that the rated wind speed is 11.4 m/s, such small velocity variation will not have a considerable effect on the wind turbine power output. According to the frequency analysis presented in Fig. 8, the response is mostly induced by wave loads. Based on the simulation results, the design requirement imposed on the hub velocity is fulfilled.

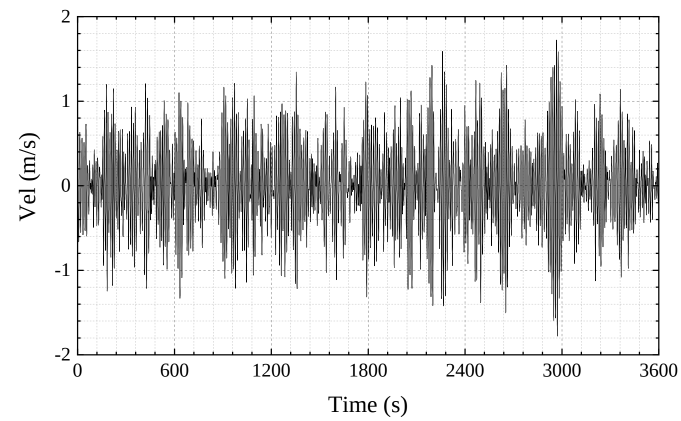

Fig. 7. Time series of hub horizontal velocity.

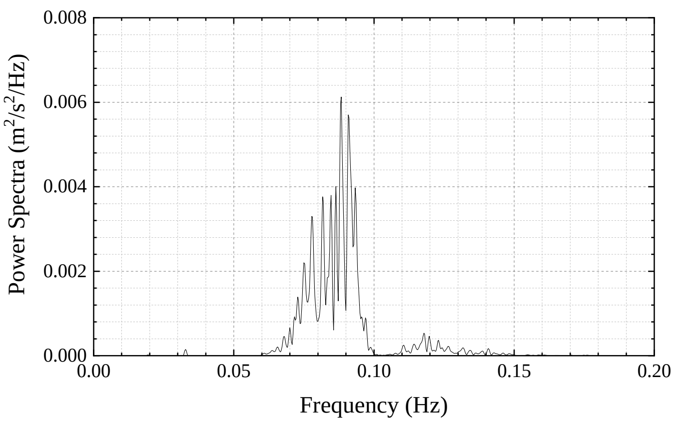

Fig. 8. Power spectra of hub horizontal velocity.

Platform global motions

Table 4 lists the statistics of the platform global motions. As shown, the movement range in surge, heave, and pitch are restricted within an acceptable level. In particular, the pitch motion is very small, due to the large restoring stiffness and the huge inertia. In pitch, the average platform inclination is as low as 0.06 deg, so that the rotor plane is nearly normal to the wind inflow. It prevents the reduction of power production due to inflow inclination effect [25]. Nevertheless, the platform heave seems to be somewhat large. It is mainly attributed to the large water area of the platform (about 2700 m^2). To investigate the heave motion in detail, the power spectra is plotted in Fig. 9. The platform heave motion is mainly induced within [0.05 Hz~0.15 Hz], namely the dominating frequency range of the random waves. It indicates that the heave motion is mainly induced by wave loads. A heave-pitch coupling is also observed at the pitch resonant frequency (0.035 Hz). Please note that the WEC and the fish net are not modelled in the present numerical model. Since the WEC extracts energy from the waves so that it can be regarded as a damper. Also, the wave flow will induce drag force when it passes through the net. Both factors will help reduce the platform motions. Future work will take the WEC and the fish net into account.

Table 4 Statistics of platform global motions

DoF	Max	Min	Mean	Standard deviation
Surge (m)	3.35	-2.90	0.22	0.90
Heave (m)	1.19	-1.09	0.00	0.32
Pitch (deg)	1.24	-1.09	0.06	0.34

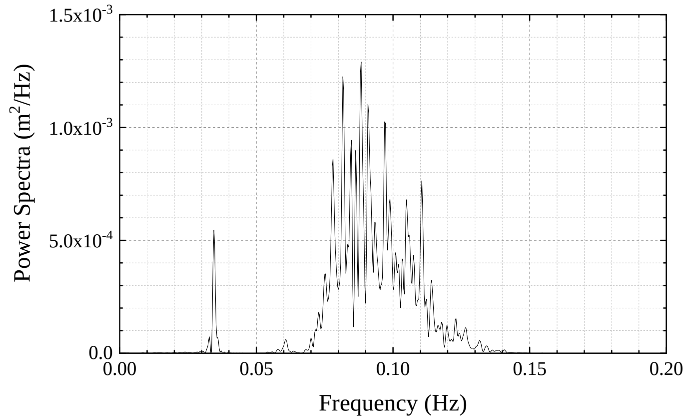

Fig. 9. FFT analysis of platform heave motion.

CONCLUSIONS

The present research aims to assess the dynamic response of the multi-purpose platform proposed in the "Blue Growth Farm" project, judging if the requirements imposed by the different systems are satisfied under the joint excitation of wind and waves. As a preliminary analysis, only the aero-hydro-servo couplings are considered and the whole structure is assumed rigid. The hydro-elastic analysis is presented in the companion paper [17].

The design requirements are briefly introduced in this study, and the main characteristics are given. The multi-purpose platform is required to provide a sufficiently large buoyancy to support a variety of systems. Meanwhile, specific requirements are imposed on the dynamic response to ensure that the functional equipment can work properly.

A numerical model of the floating platform is built using the software package Wadam/Simo, and is verified against a hydrodynamic model implemented in Ansys AQWA. Aero-hydro-servo coupled analyses are carried out in time-domain, to investigate the dynamic response of the multi-purpose platform. The maximum nacelle acceleration recorded under the environmental condition considered is as low as 0.311*g*, indicating that the wind turbine generator is subject to sufficiently small inertial loads. The variation range of the hub velocity is restricted to a range between -1.37 m/s and 1.25 m/s, so that the wind turbine power output will be stable. In general, the platform global response is sufficiently small, and the cranes, the fish cages, and other functional equipment can work properly.

Future work

- A more advanced numerical model of the multi-purpose platform will be developed, considering the second order wave force and the dynamics of the mooring lines.

Also, the fish net-platform coupling and the WEC will be modelled.

- Carry out a model-scale experiment. The hydrodynamic model in the present research is based on potential flow theory so that the viscous forces are neglected. Model tests are scheduled to investigate the viscous damping and validate the numerical model.

ACKNOWLEDGMENTS

This work has been produced in the framework of the Blue Growth Farm project (http://www.thebluegrowthfarm.eu/), which has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement number 774426. The content of the work does not report the opinion of the European Commission and reflects only the views of the author(s), including errors or omissions. The European Commission is also not liable for any use that may be made of the information contained herein.

REFERENCES

[1] D.M. European Commission, Blue Growth-Scenarios and drivers for Sustainable Growth from the Oceans, Seas and Coasts, Rotterdam/Brussels, 2012.
[2] P. Passon, M. Kühn, S. Butterfield, J. Jonkman, T. Camp, T.J. Larsen, OC3—benchmark exercise of aero-elastic offshore wind turbine codes, Journal of Physics: Conference Series, IOP Publishing, 2007, p. 012071.
[3] Z.Q. Hu, L. Li, J. Wang, Q.H. Hu, M.C. Shen, Dynamic responses of a semi-type offshore floating wind turbine during normal state and emergency shutdown, China Ocean Engineering 30(1) (2016) 97-112.
[4] L. Li, Y. Gao, Z.Q. Hu, Z.M. Yuan, S. Day, H.R. Li, Model test research of a semisubmersible floating wind turbine with an improved deficient thrust force correction approach, Renew Energ 119 (2018) 95-105.
[5] L. Li, Z. Yuan, Y. Gao, Maximization of energy absorption for a wave energy converter using the deep machine learning, Energy 165 (2018) 340-349.
[6] L. Li, Z. Yuan, Y. Gao, X. Zhang, Wave force prediction effect on the energy absorption of a wave energy converter with real-time control, IEEE T Sustain Energ (2018) 1-1.
[7] T. Kristiansen, O.M. Faltinsen, Modelling of current loads on aquaculture net cages, J Fluid Struct 34 (2012) 218-235.
[8] X. Bai, Y. Zhao, G. Dong, C. Bi, Probabilistic analysis and fatigue life assessment of floating collar of fish cage due to random wave loads, Applied Ocean Research 81 (2018) 93-105.
[9] M.J. Muliawan, M. Karimirad, T. Moan, Dynamic response and power performance of a combined Spar-type floating wind turbine and coaxial floating wave energy converter, Renew Energ 50 (2013) 47-57.
[10] L. Li, Y. Gao, Z.M. Yuan, S. Day, Z.Q. Hu, Dynamic response and power production of a floating integrated wind, wave and tidal energy system, Renew Energ 116 (2018) 412-422.
[11] L. Li, Z.S. Cheng, Z.M. Yuan, Y. Gao, Short-term extreme response and fatigue damage of an integrated offshore renewable energy system, Renew Energ 126 (2018) 617-629.
[12] L. Li, Z.-M. Yuan, Y. Gao, X. Zhang, T. Tezdogan, Investigation on long-term extreme response of an integrated offshore renewable energy device with a modified environmental contour method, Renew Energ 132 (2019) 33-42.
[13] L. Wan, Z. Gao, T. Moan, C. Lugni, Experimental and numerical comparisons of hydrodynamic responses for a combined wind and wave energy converter concept under operational conditions, Renew Energ 93 (2016) 87-100.
[14] H2Ocean, 2012. http://www.h2ocean-project.eu/. Accessed 28 December 2018.
[15] MERMAID, 2014. http://www.vliz.be/projects/mermaidproject/index.html. Accessed 28 December 2018.
[16] Tropos, 2012. http://www.troposplatform.eu/. Accessed 18 December 2018.
[17] C. Ruzzo, G. Failla, F. Arena, M.Collu, L. Li, A. Mariotti, Analysis of the coupled dynamics of an offshore floating multi-purpose platform, Part B: hydro-elastic analysis with flexible support platform, 38th International Conference on Ocean, Offshore and Arctic Engineering, Glasgow, Scotland, 2019.
[18] A. Fontanella, F. Taruffi, S. Muggiasca, M. Belloli, Design methodology for a floating offshore wind turbine large-scale outdoor prototype, 38th International Conference on Ocean, Offshore and Arctic Engineering, Glasgow, UK, 2019.
[19] F. Lagasco, F. Vassalli, R. Pennino, G. Gentile, L. Fiacco, P. G. Urbano, New engineering approach for the development and demonstration of a multi-purpose platform for the blue growth economy, 38th International Conference on Ocean, Offshore and Arctic Engineering, Glasgow, UK, 2019.
[20] C. Bak, F. Zahle, R. Bitsche, T. Kim, A. Yde, L.C. Henriksen, M.H. Hansen, J.P.A.A. Blasques, M. Gaunaa, A. Natarajan, The DTU 10-MW reference wind turbine, Danish Wind Power Research 2013, 2013.
[21] G. Malara, A. Romolo, V. Fiamma, F. Arena, On the modelling of water column oscillations in U-OWC energy harvesters, Renew Energ 101 (2017) 964-972.
[22] S. Øye, Dynamic stall simulated as time lag of separation, Proceedings of the 4th IEA Symposium on the aerodynamics of wind turbines, 1991.
[23] D.N. Veritas, WADAM—Wave Analysis by Diffraction and Morison Theory, SESAM user's manual, Høvik, 1994.
[24] J.N. Newman, Radiation and diffraction analysis of the McIver toroid, J Eng Math 35(1-2) (1999) 135-147.
[25] C. Tsalicoglou, S. Barber, N. Chokani, R.S. Abhari, Effect of Flow Inclination on Wind Turbine Performance, Journal of Engineering for Gas Turbines and Power 134(12) (2012) 122601-122601-8.