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Effects of platforms and moorings concepts on the dynamics of floating offshore wind turbines

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SUMMARY:
In this contribution we present a systematic study aimed at understating the effects of different floating platforms on the dynamics of a 10MW FOWT. Since FOWTs are prone to dangerous resonance phenomena that can be overlooked if the mutual dynamic interactions are not properly considered, we place the focus on how the natural frequencies of some selected degrees of freedom (DoFs) are affected when different stabilizing platform concepts are considered as well as when, for a given platform, some key geometric parameters a changed. This is done by performing modal analyses of the system considering the contributions coming from the platform and the mooring system, varying the floater mass matrix, zero-frequency hydrodynamic added mass, hydrostatic stiffness matrix, and moorings stiffness matrix. Three different floaters are analysed: barge, spar and semi-submersible. Also the effects of the mooring system characteristics, such as cable length, anchor, and fairlead positions, are taken into account. The expected results of this study will help improve optimization-based designs carried out considering the actual metocean conditions at the installation site.

Keywords: offshore wind, floating wind turbines, floater concept, mooring lines, modal analysis

1. INTRODUCTION

Given the challenging targets in terms of wind energy production, the exploitation of the wind resource available in deep water sites represents nowadays the most promising strategy for the whole wind energy sector. Deep water sites are normally characterized by stronger and less turbulent winds, however, they bring some technical and economical challenges which still slow down the flourishing of the floating technologies. Among these challenges there is the choice of site-specific optimal floater and associated mooring system. The decision-making process must be supported by efficient, accurate and reliable simulation tools able to capture the complex interaction between the environmental actions and the elements composing the dynamic system (assembly of rigid and flexible bodies).

Generally, time-domain aero-hydro-servo-elastic models are used to simulate the system response under wind-wave loading. Most of them, such as the well-know OpenFAST (Jonkman and Buhl, 2007), require the results of wind turbine modal analysis as input to run the numerical simulations. In many cases, such as in the optimization procedures (see, e.g., Ferri, Marino, et al., 2022 and Ferri and Marino, 2023), this pre-process is simplified considering the isolated tower clamped at the tower-base (Yu et al., 2017). However, as shown in Koo et al., 2014, the properties of the floating foundation has a significant impact. In particular, when considering the effects of platform and moorings, the tower natural frequencies tend to increase because the system is allowed to move in the six platform rigid-body DoFs. Since the floater can be 10 times heavier than the wind turbine, the mass of the system significantly increases and therefore the platform eigenmodes (activating more mass than the flexible ones) are pushed towards the low frequencies whereas the flexible modes of the tower are shifted upwards, compared to a clamped system. Therefore, considering that the design of both floater and tower should be made to prevent resonances with the waves and the rotor, overly simplified estimations of the tower natural frequencies may lead to an erroneous prediction of the actual response of the system.

In this contribution we present and systematic study aimed at understating how the natural frequencies of some selected degrees of freedom (DoFs) are affected when different stabilizing platform concepts are considered as well as when, for a given concept, some key geometric parameters a changed. The study is carried out on three different floaters: a barge with moon-pool, a spar with variable diameter and a semi-submersible. As far as it regards the mooring lines, the effects of the cable length and the distance from the anchor to the fairlead point are investigated. The reference 10MW DTU wind turbine for offshore application is used (Yu et al., 2017). Actual metocean conditions of four different installation sites in the Mediterranean Sea are considered. Per each platform, the simulated configurations are evaluated in terms of platform and tower first Fore-Aft natural frequencies. Optimal layouts are identified by avoiding potential resonance phenomena both loads-system and system-system, such as rotor-tower. It is expected that the results of this study will provide a more grounded rationale to drive the choice of the floater and will help improve optimization-based designs carried out considering the actual metocean conditions.

2. METHODOLOGY

The modal analyses are performed using BModes (Bir, 2007), considering the contributions stemming from the platform and the mooring system. ANSYS AQWA is employed to evaluate the zero-frequency hydrodynamic added mass, while in-house developed codes are adopted to evaluate the mass and hydrostatic stiffness matrices of the floater, as well as the mooring system stiffness matrices. These contributions, together with the mechanical properties of the rotor and the tower, are used as input for the modal analysis, allowing to obtain the natural frequencies of the coupled system.

2.1. Floating systems

We consider the most popular concepts for supporting FOWTs. Namely, barge with moon-pool and eccentric tower, spar with variable diameter and a semi-submersible. The geometrical variables adopted for each of the concept are reported in Figure 1.

As far as it regards the mooring systems (see Figure 2), the horizontal distance between the anchor and fairlead position, x_{P0}, is adjusted according to the water depth of the installation site, varying from half and three times the water depth, while the cable length, L, varies from L_H to L_H+15m.

2.2. Installation sites

The four installation sites considered in this study are shown in Figure 3. They are located in areas of the Mediterranean Sea characterized by abundant wind resource and variable water depth, from

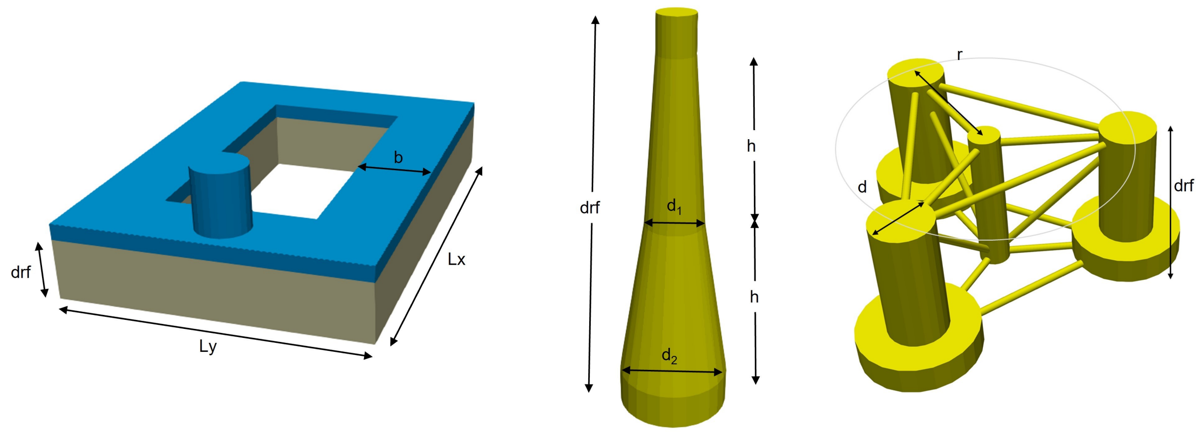

Figure 1. Floating platform concepts and geometrical variables adopted.

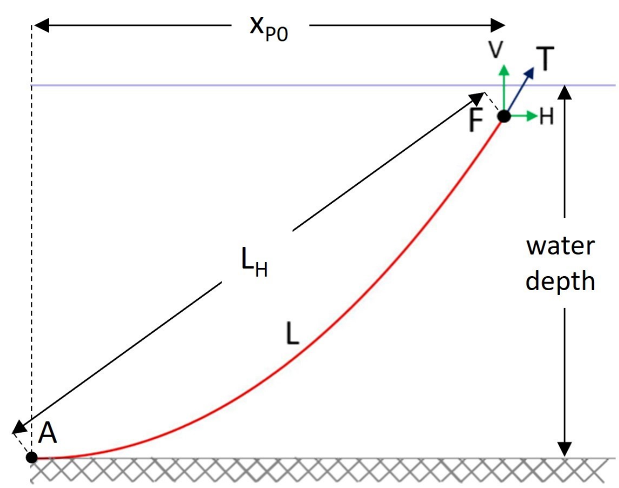

Figure 2. Mooring lines geometrical variables.

120m to 550m.

3. EXPECTED RESULTS

For each of the analyzed floater concept, simulations will be performed varying relevant geometrical parameters identified in Figure 1 and Figure 2. This will allow to assess the effects on platform and tower natural frequencies over a fine grid of values. Moreover, by considering the expected wave periods at the installation sites and the rotor rotating frequencies, solutions prone to resonance phenomena will be identified. The values that will be considered to assess the safety level of the system in terms of potential resonances (see Table 1) are the 1P and 3P rotor rotating frequencies (Yu et al., 2017), and the minimum and maximum expected wave peak frequencies characterizing the installation site.

Figure 3. Installation sites considered in the study.

Table 1. Rotor rotating and expected wave frequencies bounds

	Min f [Hz]	Max f [Hz]
Rotor 1P	0.100	0.150
Rotor 3P	0.3	0.35
FRA350	0.093	0.642
GRE550	0.101	0.799
SARD120	0.094	0.641
SIC200	0.083	0.706

4. CONCLUSIONS

This contribution will present a framework to estimate the natural frequencies of FOWTs, considering the effects of different floating systems. Expected results will provide a thorough insight into the dynamic properties of different coupled floating systems, which will serve as a solid basis for further optimization-based designs.

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