Study of the hydrodynamic loads on a floating wind turbine and its structural response in complex sea-states

IIHNE – LHEEA – Ecole Centrale de Nantes

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1 Context

Floating wind turbines are starting to be installed worldwide at prototype or pilot farm stages. In 2024, the largest floating wind farm, Hywind Tampen, is located in Norway and is composed of 11 turbines of 8 MW each. In France, the prototype of BW-IDEOL called FLOATGEN, supporting a 2 MW wind turbine, was installed at the SEM-REV test site in 2018. The three 8.4 MW turbines of the Provence Grand Large pilot farm were installed in 2023 off the Gulf of Fos in the Mediterranean Sea.

The growth of the floating wind sector is accompanied by an increase in the size of the machines and floaters in order to be competitive in the energy market by producing better and greener electricity. These gigantic floating systems are subjected to complex environments including waves, wind, and current. They are designed to have natural frequencies that are generally either lower or higher than wave frequencies, depending on the degree of freedom. However, in harsh sea states, these systems can experience significant motions, and hydrodynamic loads are usually nonlinear. These nonlinearities may induce structure responses at its natural frequencies, including significant tower vibrations [1]. These nonlinear structural behaviors remain a challenge for engineering design tools.

In engineering applications, various numerical tools are used to study these systems (e.g., structural strength, mooring line arrangement) and their responses to different sea states. Typically, low- or intermediate-fidelity tools consider hydrodynamic loads based on linear potential theory (with the possible inclusion of second-order terms) and/or loads calculated with Morison's equation. These tools generally assume a rigid platform and do not always allow direct assessment of internal loads in the platform structure. Some recent works have studied deformations and internal loads of the substructure in coupled calculations, but experimental validations are still often needed.

Numerous experimental campaigns have studied the response of floating wind turbines considering a rigid platform and a tower with a Froude-scale natural frequency. Few campaigns have focused on internal platform loads and/or deformations [2–4].

In this context, the Laboratory of Hydrodynamics, Energetics and Atmospheric Environment (LHEEA) of Ecole Centrale de Nantes has large-scale experimental facilities allowing the study of the behavior of floating structures, including an ocean engineering basin (50 m × 30 m × 5 m). Recently, several test campaigns have focused on bending moment analysis in a ship hull [5,6], and a floating spar-type wind turbine has been extensively studied with both rigid [7] and flexible platforms [4] (see Figure 1) to investigate the effects of waves on system vibrations.

The LHEEA is currently working on several research projects in the field of floating wind turbines, with numerous test campaigns studying floating wind turbines under various conditions and on different floater types. The development of high-fidelity numerical codes is also underway. In particular, this thesis will strongly interact with two projects :

- The CARNOT CIMSUB project, aimed at designing and instrumenting a scale model of a floating wind turbine to study its internal loads ;

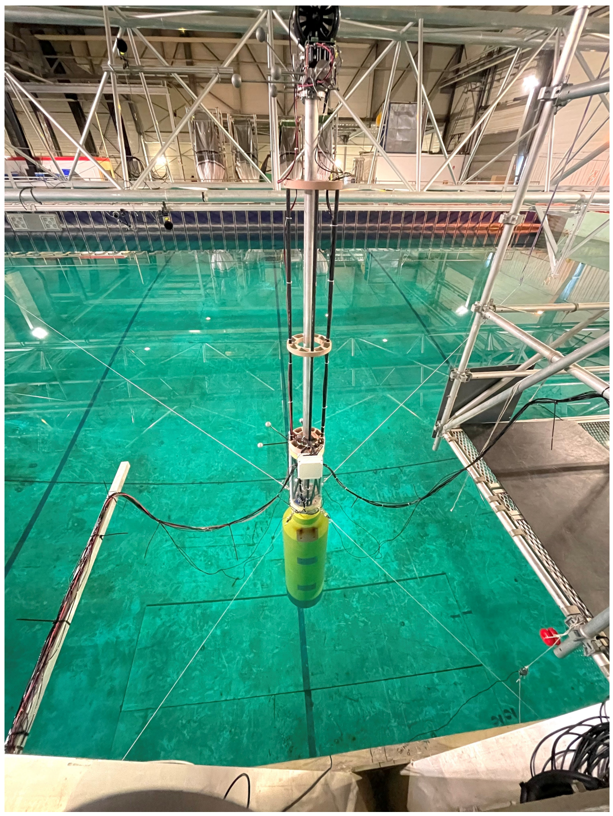

FIGURE 1 – HELOFOW test campaign in the wave tank of ECN [4]

- The Horizon 2020 FLOATFARM project, for which two test campaigns (focusing on internal loads and shared moorings) will take place at ECN's basins.

2 Thesis objectives and methods

This thesis aims to study the hydro-structure coupled dynamic response of a floating wind turbine subjected to waves and wind, following previous work on the subject at LHEEA [4, 8, 9].

The first task will involve developing a low-fidelity numerical model. The model aims to couple a simple structure model with a hydrodynamic model based on Morison's equation using a nonlinear wave field. The validation will be made by comparison with experimental results obtained in our basins on a 10 MW turbine supported by a spar [8, 9]. This new model will contribute to the design and instrumentation choices of a 15 MW wind turbine platform model (in connection with the CARNOT CIMSUB project).

Several test campaigns will subsequently be conducted during the thesis, in connection with other experimental projects at the laboratory, particularly in the ocean engineering basin. To date, there are very few public database on internal loads of a floating wind turbine platform in waves. Therefore, the measurements will allow : (1) exploration of the sensitivities of these loads to various parameters governing the sea states experienced by the structure, (2) validation of the low-fidelity model developed in the context of this thesis, and (3) validation of high-fidelity calculation codes developed at the laboratory. Several load cases can be studied :

- Fatigue loads (Fatigue Limit State, FLS) ;
- Extreme loads (Ultimate Limit State, ULS).

Initially, the response of an isolated wind turbine will be studied. In addition to the response induced by the hydrodynamic loads, the effect of aerodynamic forcing can also be included, especially for FLS cases. Nonlinear effects in the response will be investigated. This is important as these effects are often impossible to properly account for in classical engineering design tools. The best way to extrapolate the observed coupled wave-structure interaction at full-scale will be investigated. The developed analysis tools will be integrated into the procedure used at LHEEA's basins.

Secondly, the effects of a shared mooring system on the structural response of two floating wind turbines will be studied. A test campaign on this topic will be conducted as part of the Horizon 2020 FLOATFARM project. The study will compare the results of a single wind turbine with those of two turbines that share their mooring system, using both numerical (low fidelity) and experimental approaches. For example, the focus will be made on interactions between tensions in mooring lines and internal loads in structures.

A typical thesis timeline is depicted in Figure 2. These activities will be accompanied by various actions to promote scientific work : participation in international conferences, publication in scientific journals, and dissemination of experimental databases to the community.

3 Supervision

Workplace : The thesis will be carried out at Ecole Centrale de Nantes, within the IIHNE team of LHEEA [1], at the following address.
1 Rue de la Noë
44300 Nantes
France

1. IIHNE team page : https ://lheea.ec-nantes.fr/english-version/research-groups/iihne-interfaces-interactions-in-numerical-experimental-hydrodynamics ?l=1

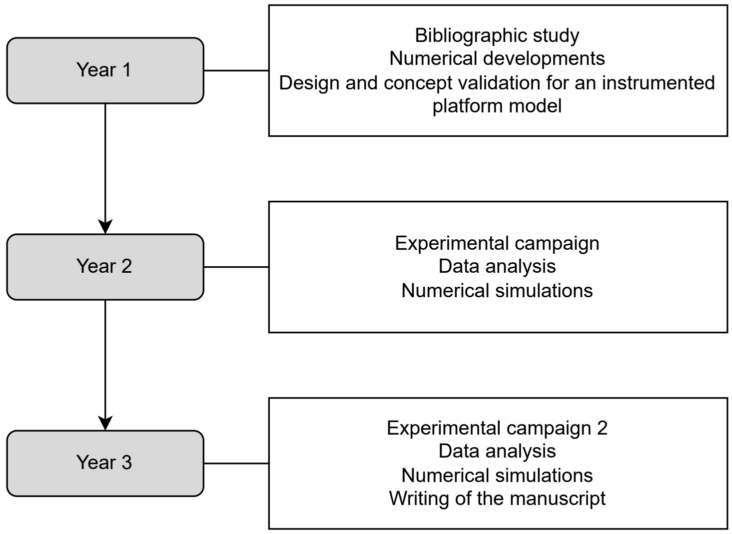

FIGURE 2 – Thesis schedule

Supervision :

- Main supervisor (directeur de thèse) : Prof. Guillaume Ducrozet
- Co-supervisor : Dr. Vincent Leroy
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Références

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