Evaluation of the performances of a new multi-component hybrid experimental modeling of FOWTs

F. Bonnefoy, V. Leroy, S. Delacroix & M. R. Mojallizadeh

Nantes Université, Ecole Centrale Nantes, CNRS, LHEEA, UMR 6598, F-44000 Nantes, France

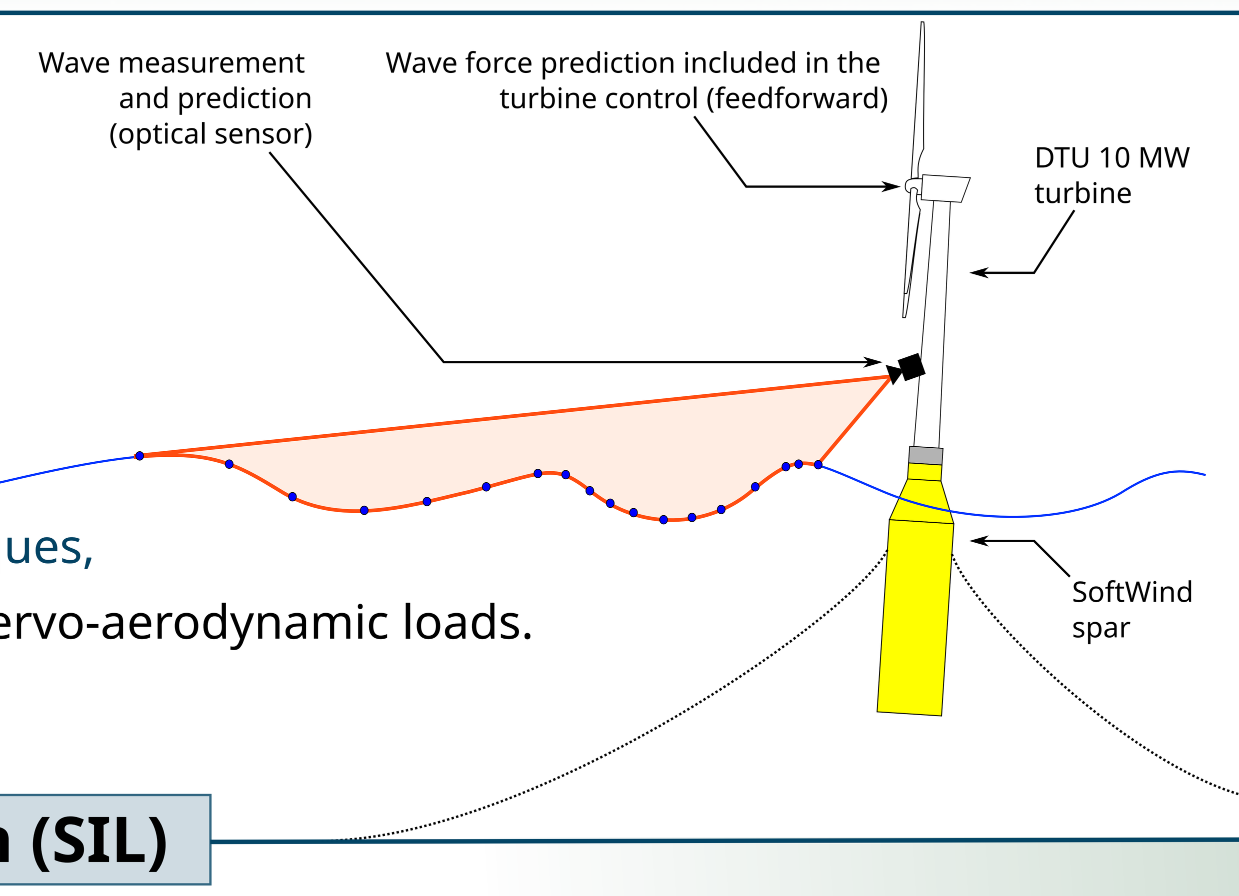
EERA DeepWind CONFERENCE 2024

Poster no. 133

Context

The **FLOATECH** project aims at increasing the technical maturity and the cost competitiveness of floating offshore wind energy. Amongst other tasks, **ECN** and **TU Delft** worked on the implementation and validation of a **wave-based feedforward control** for FOWT.

The experimental validation of controllers, including various environmental loads and couplings (e.g. hydrodynamic, aerodynamic, control and mooring) require advanced modeling approaches.



ECN's contribution : wave tank experiments for wave prediction and validation of the control techniques, including a Software In the Loop approach, and a multi-component force actuator to reproduce the servo-aerodynamic loads.

This poster presents the evaluation of the performance of the SIL actuator.

Hybrid testing: accurate multi-component Software In the Loop approach (SIL)

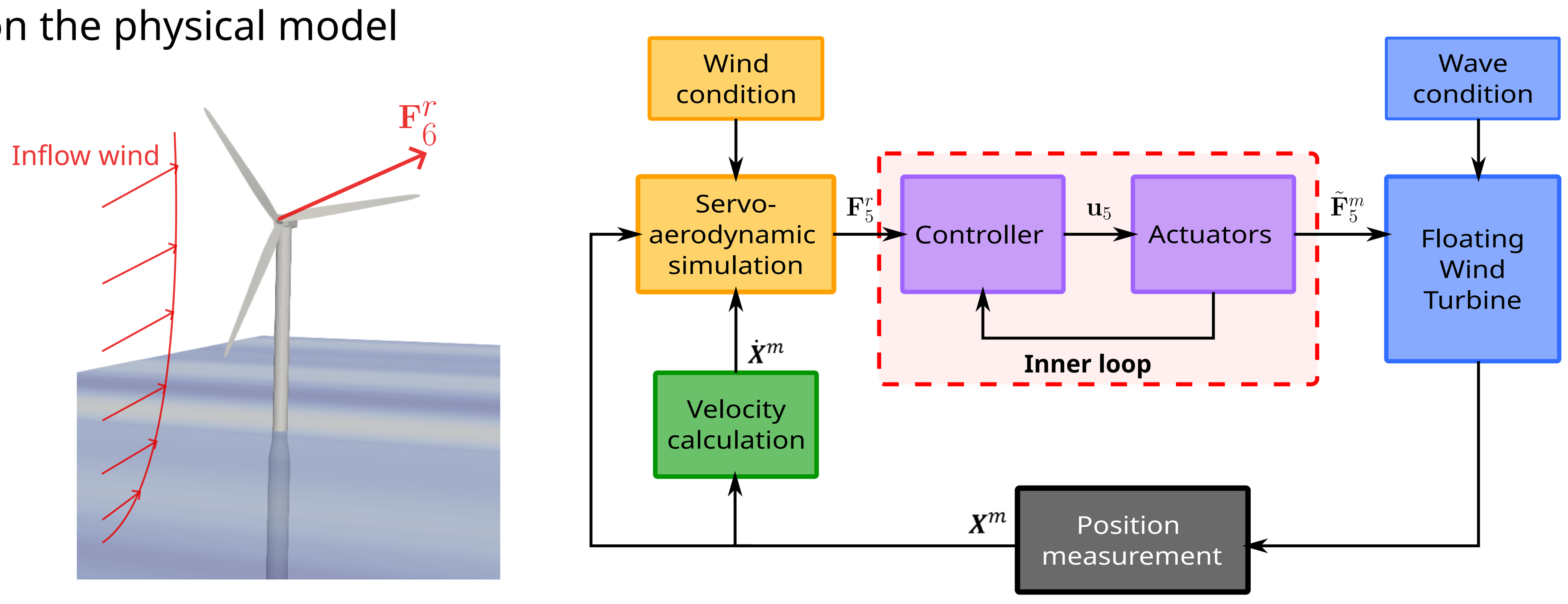
A FOWT was tested in a wave tank with an improved SIL method to replicate the full rotor loads at the tower top. The applied forces are measured and controlled using a feedback control loop.

1) Real-time simulation running on OpenFAST (at full scale, on a NI CompactRIO) with motions measured on the physical model

Features:

→ Steady or turbulent wind fields (TurbSim)

→ Effect of the torque and blade pitch controller (external DLL)



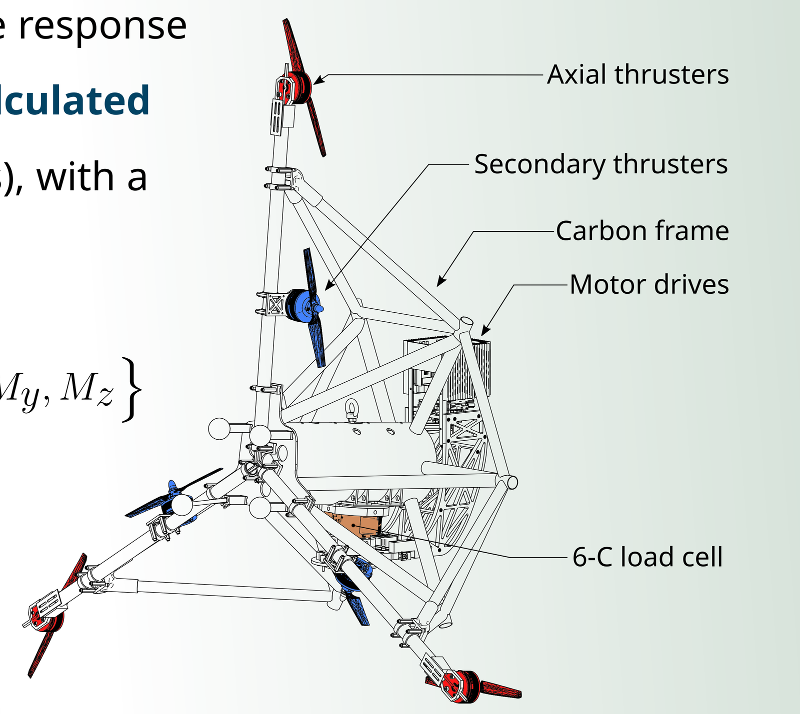
2) Physical model test (model scale) and multi-directional load application

→ Wave generation in the physical wave tank

→ Measurements of the response

→ Application of the **calculated loads** (5 components), with a closed control loop.

$$\mathbf{F}_5^r = \{F_x, F_y, [\cdot], M_x, M_y, M_z\}$$

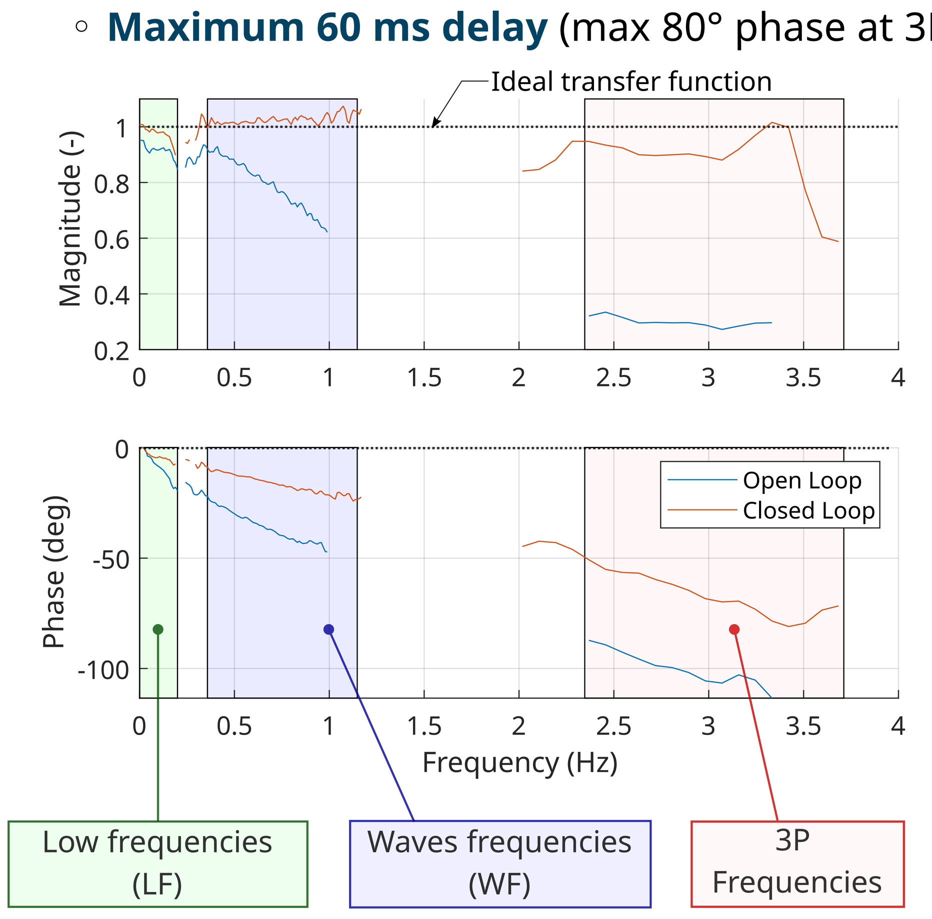


Evaluation of the accuracy of the aerodynamic force reproduction (inner control loop)

The experimental setup is validated in realistic waves (e.g. H_s = 7 m, T_p = 12 s) and wind (U = 14 m/s, TI = 7.1 %). The force spectra (reference and measured) are used to approximate the SIL system's transfer function. The force time series are filtered and decomposed into low, wave and 3P frequency domains to evaluate the ability of the system to follow the reference force.

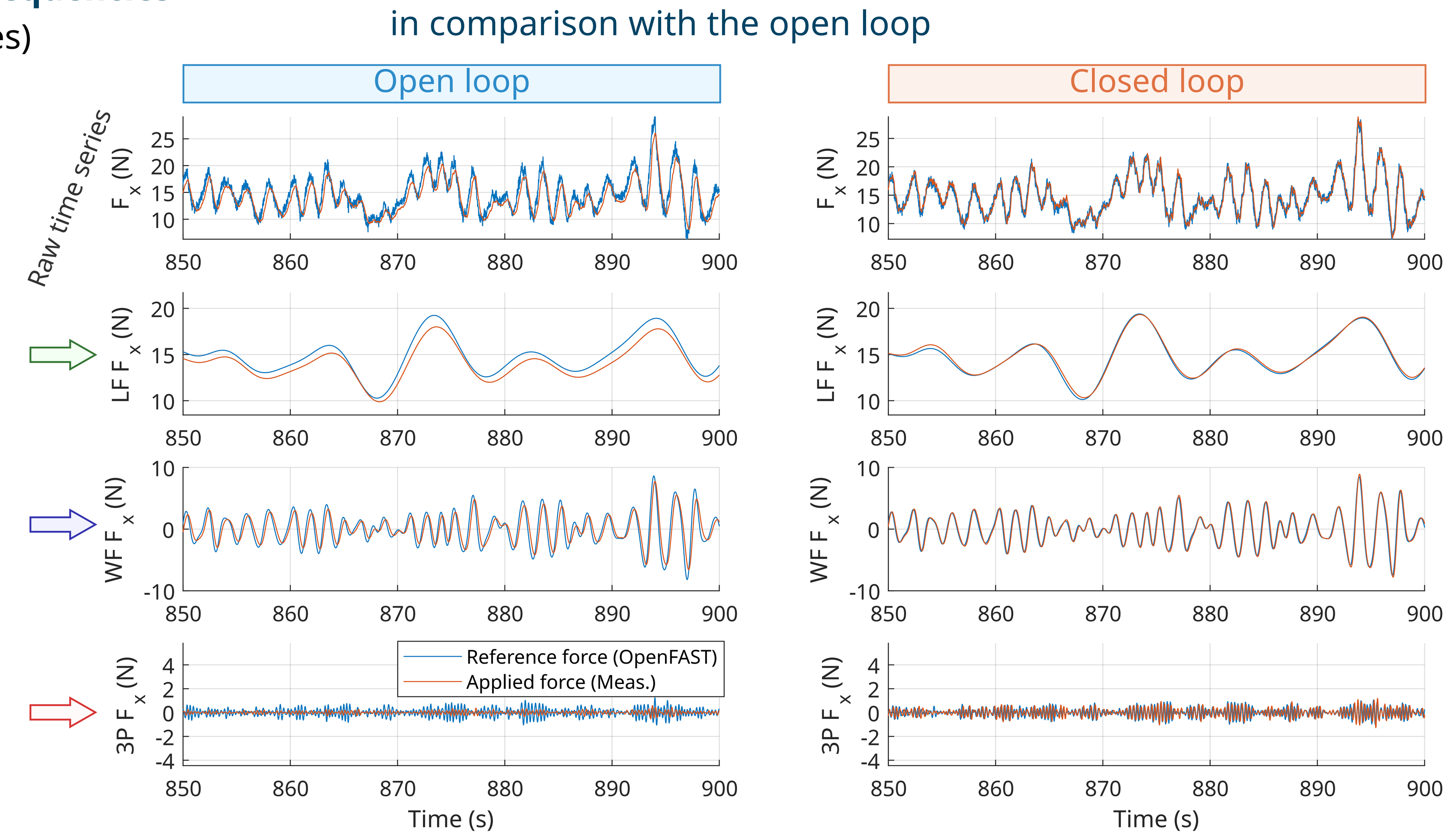
1) Estimation of the performance of the hybrid approach

- Transfer functions: reference → applied forces
  - **Better performance in closed loop at low and wave frequencies**
  - **Maximum 60 ms delay** (max 80° phase at 3P frequencies)

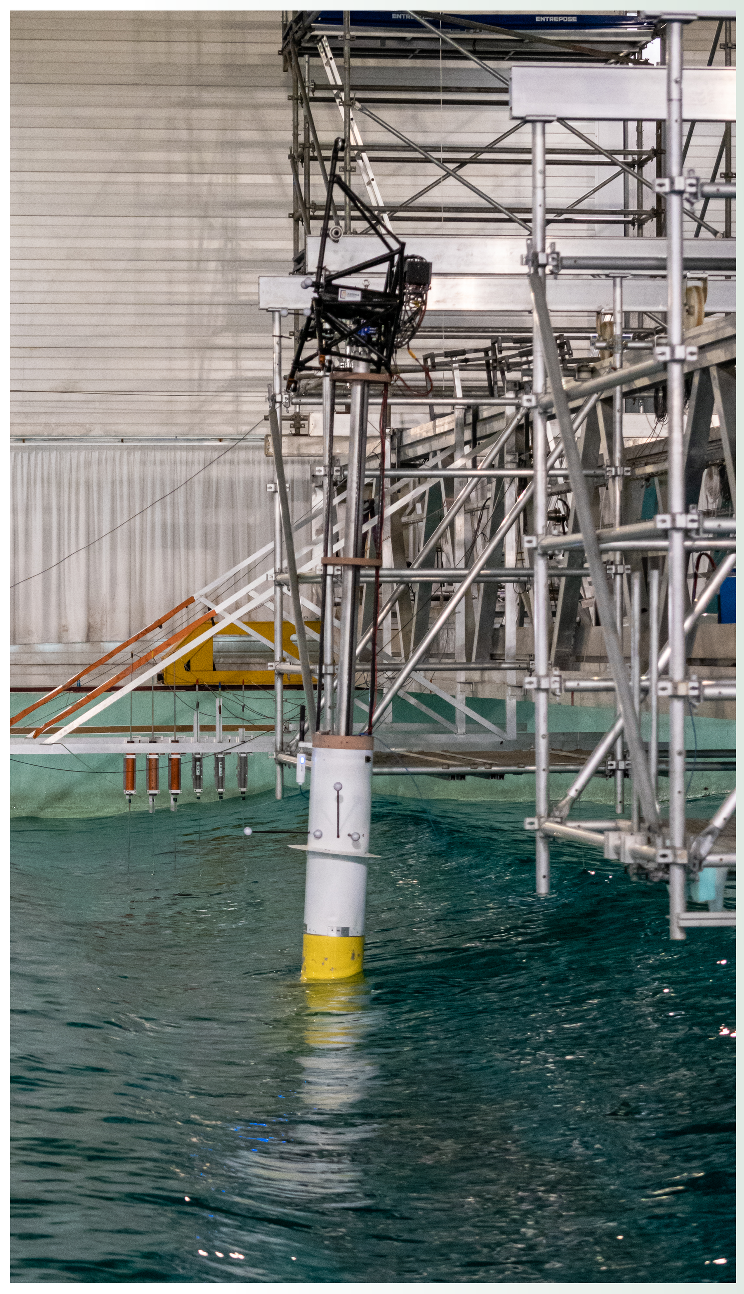


2) Time domain decomposition:

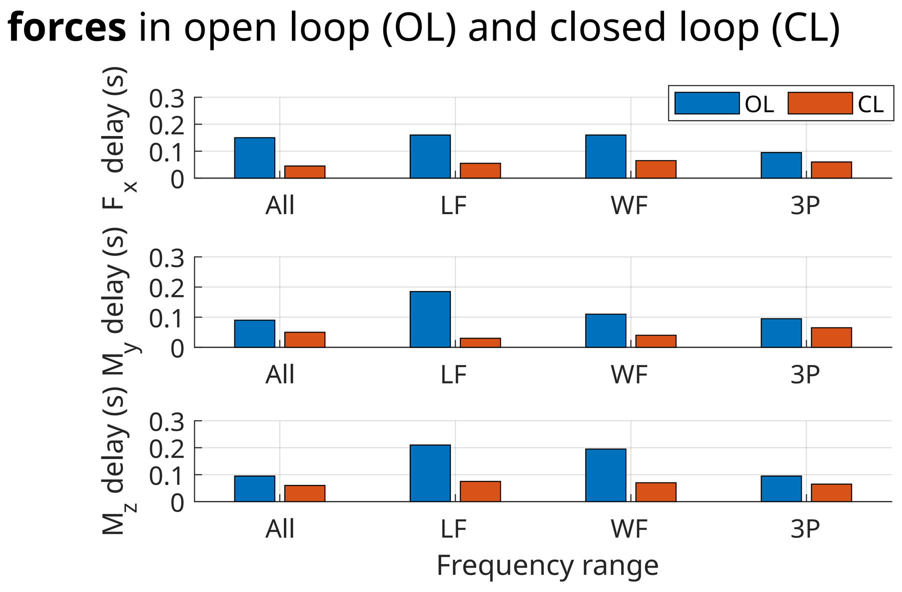
- Full time series, and band-pass filtered measurements
  - The closed loop control allows a better agreement at LF and WF in comparison with the open loop



1:40 scaled model of the DTU 10 MW turbine supported by the SoftWind spar



Approximated delay between **reference** and **applied forces** in open loop (OL) and closed loop (CL)

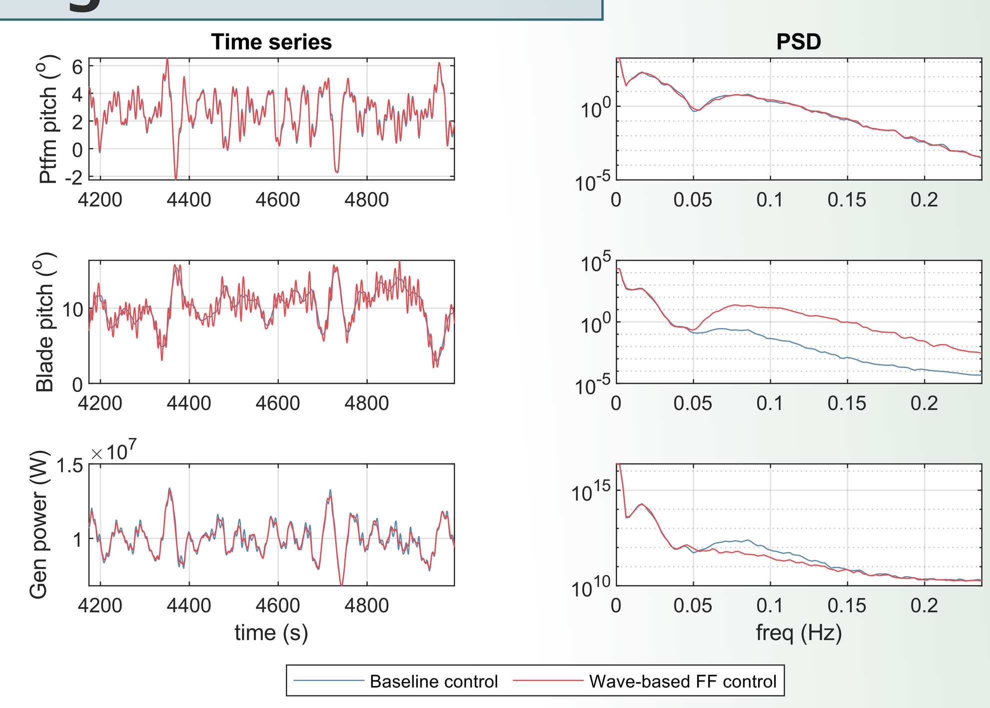


Maximum total delay in closed loop: 120 ms, including: **motion measurement**, **velocity calculation**, **OpenFAST simulation**, and **application of the forces**.

A new tool for experimental analysis of floating wind turbines

The SIL system is able to reproduce the five main components of the servo-aerodynamic loads calculated by OpenFAST in real-time. The feedback control loop allows an accurate reproduction of the loads compared to the open loop system, with a maximum total delay of ~120 ms. This delay could induce a significant phase shift at high frequencies, such as 3P frequency (~80°).

Nevertheless, the improved accuracy of the closed loop system at low and wave frequencies, allows extensive studies on the FOWTs' dynamics and control.



Effect of wave-based feedforward wind turbine control (U=14 m/s, TI=13.4 %, H_s=7 m, T_p=12 s)

The project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101007142.

The authors acknowledge the support of the French Agence Nationale de la Recherche (ANR), under grant ANR-20-CE05-0039 (project CREATIF).