Wind Tunnel Hybrid/HIL Tests of the OC5/Phase II Floating System

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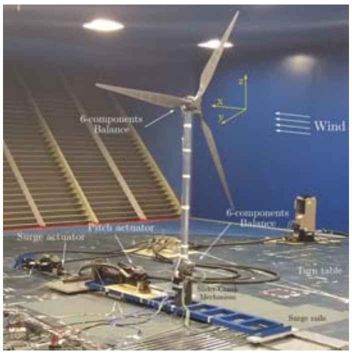
SUMMARY

- Numerical and experimental implementation of a 2 degrees-of-freedom (DoF) setup for simulating Surge and Pitch motion of the OC5 semi submersible floating offshore wind turbine, through the "hardware-in-the-loop" (HIL) approach in wind tunnel tests.
- Real-time combination of computations and measurements are carried out during the experiments: separatation of model testing of floating wind turbines into wave/ocean basin and wind tunnel tests (e.g. Marintek Ocean Basin & PoliMi Wind Tunnel - H2020/LIFES50+ project)
- Hybrid/HIL approach: exploiting the advantages of each facility and overcoming the scaling issues and conflicts of model tests of FOWTs
- In this work the modelling approach and experimental implementation are presented, with focus on the management of signals and data in the real-time HIL control system, aimed at minimizing the negative effect of model/full scale discrepancies, and the effective implementation.
- Results are shown for free decays, regular and irregular sea states in still air, showing promising results for the next 6-DoF system generation.

APPROACH



- Lifes50+ Polimi scale model: 1/53 (NREL 5MW)
- 1/3 velocity scale factor
- Hydraulic actuators for Surge and Pitch motion
- Aerodynamic forces measured by means of 6-components dynamometric balances
- dSPACE real-time controller

Approaching 6 DoF robot finalization

METHODOLOGY

$$[[M_s]+[A_\infty]]\ddot{\underline{x}}+[R_s]\dot{\underline{x}}+[K_s]\underline{x} = \underline{F}_{rad}+\underline{F}_{visc}+\underline{F}_{moor}+\underline{F}^{(1)}_{diff}+\underline{F}^{(2)}_{diff}+\underline{F}_{aero}$$

$$=\underline{F}_{hydro}+\underline{F}_{aero}$$

- Blue box: OC5 Semi-Submersible Floating System (IEA Task/Phase II): **SURGE** & **PITCH**
- Green box: Hydrodynamic Forces: **COMPUTED**
- Red box: Aerodynamic Forces: **MEASURED**

REAL-TIME IMPLEMENTATION

Hydrodynamic Forces (Computed)

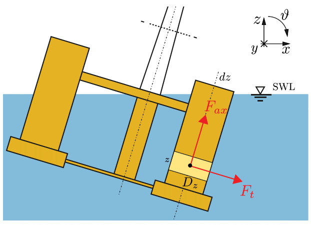
RADIATION

State Space approach

$$\underline{F}_{rad}=\underline{\mu}(t)=\int_0^t[K(t-\tau)]\dot{\underline{x}}(\tau)d\tau \approx \begin{cases}\dot{\underline{q}}_r=[A_r]\underline{q}_r-[B_r]\dot{\underline{x}}\\ \underline{\hat{\mu}}=[C_r]\underline{q}_r\end{cases}$$

VISCOUS

Morrison



$$F_t(t)=\int_z \frac{1}{2}C_d D_z|v_{rel,t}|v_{rel,t}dz$$

$$F_{ax}(t)=\int_z \frac{1}{2}C_{ax}\pi\frac{D_z^2}{4L_z}|v_{rel,ax}|v_{rel,ax}dz$$

DIFFRACTION 1ST ORDER

WAMIT

$$F^{(1)}_{diff}=\Re\left\{\sum_{k=1}^{N}A_k X_i(\omega_k)e^{j\omega_k t}\right\}$$

MOORING LINES

Look-up tables from FAST/MoorDyn

DIFFRACTION 2nd ORDER

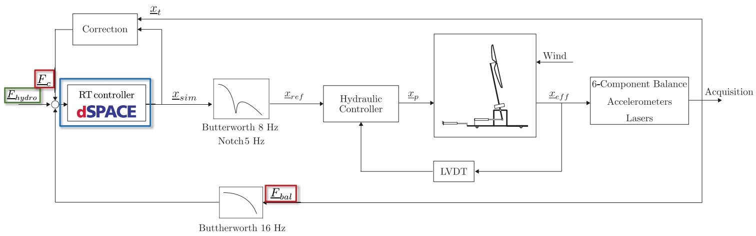
(Difference frequency only)

WAMIT

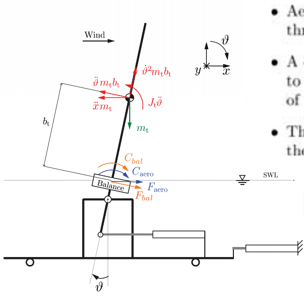
$$F^{(2)}_{diff}=\Re\left\{\sum_{k=1}^{N}\sum_{l=1}^{N}A_k A_l^* X_i^-(\omega_k,\omega_l)e^{j(\omega_k-\omega_l)t}\right\}$$

Validation of the hydrodynamic model within OC5 Phase II project

General Control Scheme



Aerodynamic Forces (Measured)



- Aerodynamic forces $\underline{F}_{aero}$ measured through the 6-components balance $\underline{F}_{bal}$
- A correction force $\underline{F}_c$ is needed to take into account the inertial and gravitational contribution of the scale model
- This correction force $\underline{F}_c$ is under the assumption $\underline{x}_{sim}\approx\underline{x}_t$: the simulated and real turbine states are the same

$$\underline{F}_{aero}=\underline{F}_{bal}+\underline{F}_c=$$

$$=\underline{F}_{bal}+\begin{bmatrix}m_t & b_t m_t\\ b_t m_t & b_t^2 m_t+J_t\end{bmatrix}\ddot{\underline{x}}_{sim}+\begin{bmatrix}0 & -m_t g\\ 0 & -m_t b_t g\end{bmatrix}\underline{x}_{sim}$$

Important issues to minimize the residual forces due to the methodology

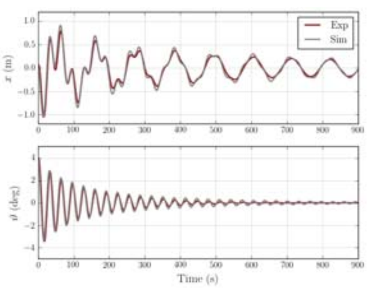
- Identification of the model's parameters (m_t,b_t,J_t)
- Identification of the control's transfer functions
- Effective management of numerical filters
- Identification of the measurement chain (phase shifts)

Still air tests to check the methodology (i.e. minimizing the residual forces)

$$\underline{F}_{bal}+\underline{F}_c=\underline{F}_{aero}\neq 0$$
$$=\underline{F}_{res}$$

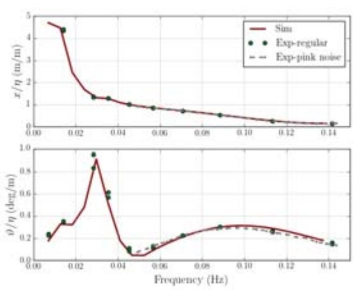
RESULTS

Free Decays



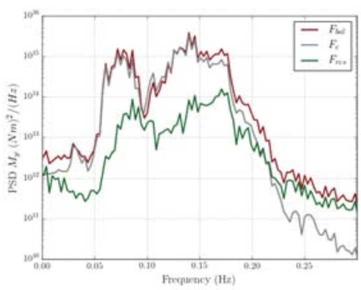
Initial displacement on Pitch ϑ

Regular Sea



Response Amplitude Operators (RAO) with respect to the incident wave η, for two different experimental conditions
- Regular waves
- Irregular pink noise in the wave frequency range

Irregular Sea



Irregular sea in OC5 operational condition, pitch moments My: the measured forces (*bal*) and the correction forces (*c*) are overlapped almost everywhere: the residual forces (*res*) are at least 1 order of magnitude lower