Frequency-domain method for global dynamic response analysis of a semi-submersible floating wind turbine

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Introduction

Renewable energy has shown an significant growth in the energy market. Besides solar and hydroelectric energy, wind energy is also a considerable resource. Land-based wind turbines have been used for decades. However, advantages from space availability, avoidance from noise, stronger and more stable wind load, make it worth developing offshore wind power generation devices. When it comes to the response analysis of floating wind turbine, time-domain methods are usually preferred because of the strong coupling effect between wind and waves, which requires significant computational effort. Frequency-domain methods have been developed for offshore oil and gas platform. Similarly, it is considered that if the dominant environmental conditions are moderate and the induced non-linear effects are not significant, frequency-domain methods with linearized model might be sufficient in the response analysis, especially in the preliminary design stage.

Objective

The main purpose is to develop a linear dynamic model for structural response analysis of the WindFloat semi-submersible floating wind turbine.

1. Develop the linear dynamic model and calculate its dynamic responses.
2. Perform dynamic response analysis for same floating wind turbine model with time-domain method.
3. Compare the results from step 1 and step 2 and validate the developed dynamic model.

Figure 1: Semi-submersible floating wind turbine (WindFloat)

Methodology

The overall equation of motion is:

$$[\boldsymbol{M} + \boldsymbol{A}(\omega)] \cdot \ddot{x}(t) + \boldsymbol{B}(\omega) \cdot \dot{x}(t) + \boldsymbol{C} \cdot x(t) = f(t)$$

Which can be written in state-space format and solved in frequency-domain.

$$\boldsymbol{X}(\omega) = \boldsymbol{H}_{FX}(\omega) \cdot \boldsymbol{F}(\omega)$$

With turbulent wind and irregular waves as environmental conditions, spectrum analyses are performed for both developed linear dynamic model and the time-domain simulations.

$$\boldsymbol{S}_{XX}(\omega) = \boldsymbol{S}_{\xi\xi}(\omega)\left|\boldsymbol{H}_{\xi F}(\omega)\right|^2 |\boldsymbol{H}_{FX}(\omega)|^2 + \boldsymbol{S}_{uu}(\omega)|\boldsymbol{H}_{uF}(\omega)|^2|\boldsymbol{H}_{FX}(\omega)|^2$$

Procedure

Floater model

The floater model is developed based on the Master thesis work of a previous student, in which hydrodynamic analysis for the same model has been performed in SESAM HydroD with WADAM potential theory solver. The result .SIF file is read in MATLAB and hydrodynamic characteristics have been collected and assembled as matrices. Mooring system in the model has been simplified as horizontal spring constraints.

Wind turbine model

Dr. Karl Merz has established a state-space method for calculating the linear dynamic equation of motion on an offshore wind turbine. A simplified wind turbine model is provided in the format of state-space matrices. The aerodynamic loads acting on the blades are simplified as thrust force and torque acting on the top of the tower. Then the transfer functions between mean wind speed and the wind loads have been computed from constant wind test and also verified in SIMA workbench. TurbSim has been used to generate turbulent wind field files. The wind speeds of grid points inside the rotor plane have been averaged to get a rotor-averaged wind speed time series. The resulting wind speed spectrum has been used in the spectrum analysis.

Connection between floater and wind turbine

The floater is assumed to be rigid. Constraint equations between the floater reference node and the foundation reference node (on the turbine) have been established in order to connect the floater and wind turbine together. Since the equation group is non-linear, it has been linearized at the assumed operating point to be fit in the linear dynamic model. The constraint equation group has been assembled together with the equations of motion from floater and wind turbine (in state space format). Then the transfer functions from load to motion response have been computed.

$$\boldsymbol{H}_{FX}(\omega) = [i\omega\boldsymbol{N}(\omega) - \boldsymbol{A}(\omega)]^{-1}$$

Results

Results from time-domain simulations

For the below-rated wind speed 8 m/s, 12 simulations have been run in SIMA with combinations of different turbulent wind files and random wave seeds. The spectra have been generated from time series of certain variables and shown below. These spectra will be compared with results from the linear dynamic model.

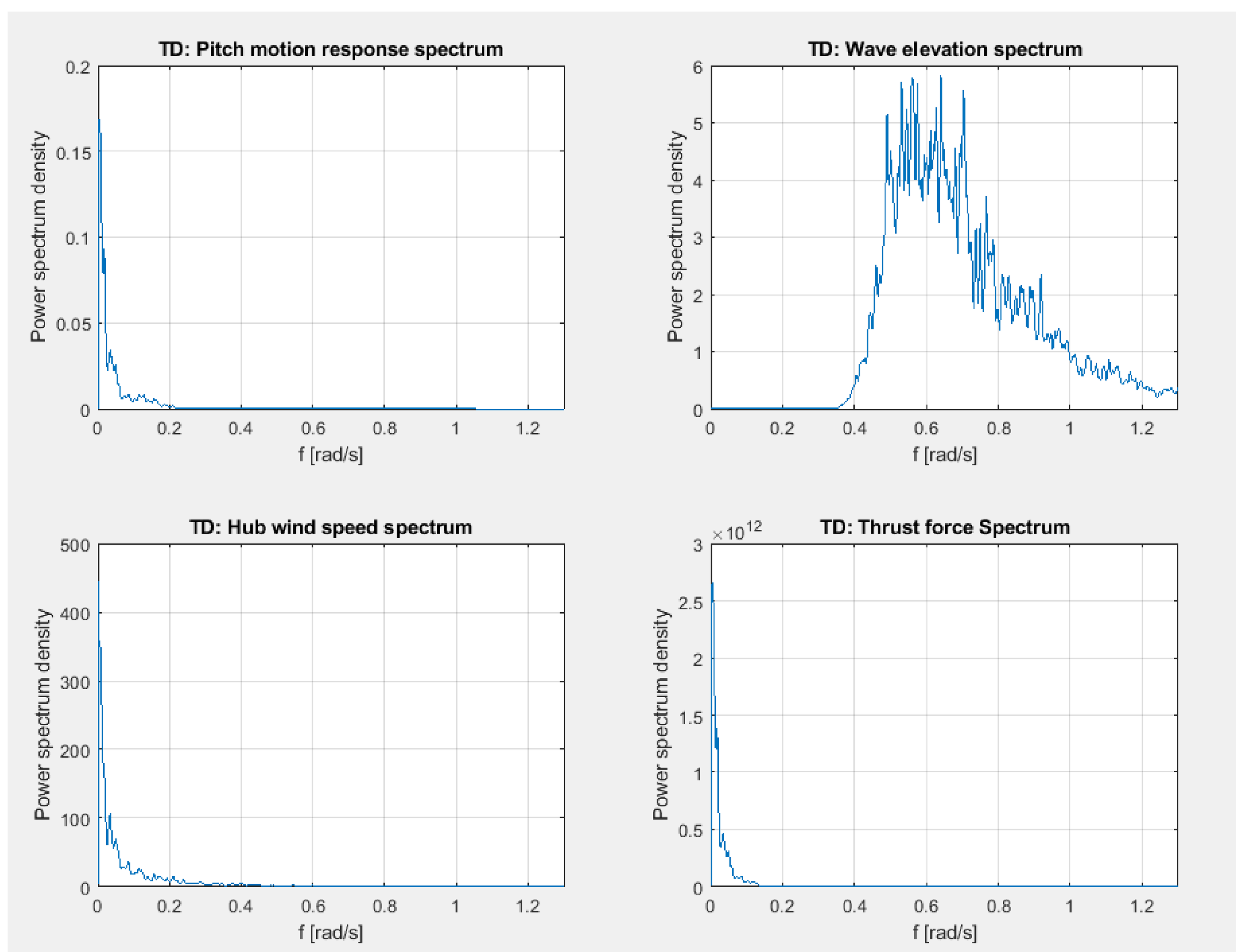

Figure 2: Spectra from time-domain simulation

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