Frequency Domain Method for Dynamic Response Analysis of the WindFloat Concept

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Problem

Floating wind turbines are at an early stage of development. The dynamic coupling effects from wind and wave excitations from full-scale experiments are limited. Consequently, time-domain analysis has been necessary for calculating the dynamic response of floating wind turbines. Therefore it is of interest to establish a frequency domain method for dynamic response analysis of the WindFloat concept.

Introduction

Bottom fixed wind turbines has been deployed in several sites with success, now development of floating wind turbines are also in progress. An example of a floating wind turbine that has been deployed is a 2.3MW WindFloat prototype. The WindFloat concept is a semi-submersible wind turbine with three connected columns where the wind turbine is situated on one of the columns. In order to commercialise offshore wind turbines, costs must be reduced. Several challenges are met within design, production, installation and maintenance. One action that would reduce the cost for preliminary design and fatigue assessment is a proper frequency domain method for dynamic response analysis. Therefore it is of interest to develop this for the WindFloat concept. Frequency domain methods has previously been developed by e.g. [1] for a bottom fixed turbine, and by [2] for the modified Windfloat. Specific obstacles that are met, is that time-domain analyses accounts for higher order effects, while the frequency domain method is dependent on a linear relation between force and motion. The higher order effects can be partially accounted for, and the quality of the frequency domain method is dependent on how well this is included. The WindFloat concept can be considered a large-volume structure, consequently the second order forces caused by difference-frequency effects are of the most significant. In addition linearisation of hydrodynamic drag and aerodynamic damping are important (ref.[2]). Following is an outline of the work performed in the thesis.

References

[1] Van Der Tempel,J. *Design of support structures for offshore wind turbines.* ISBN:9076468117. TU Delft, Delft University of Technology (2006)

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[3] Moan, T. *Nonlinear Stochastic Response Analysis of Marine Structures.* Lecture notes, Department of Marine Technology, NTNU, Trondheim (2009)

[4] Merz, K.O. *A Linear State-Space Model of an Offshore Wind Turbine, Implemented in the STAS Wind Power Plant Analysis Program.* Report at SINTEF Energi AS (2015)

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Methodology

The overall aim is to solve the dynamic equation of motion as presented in equation 1 (from [2]).

$$(\mathbf{M} + \mathbf{A}(\omega))\ddot{\mathbf{Y}}(\omega) + \mathbf{B}(\omega)\dot{\mathbf{Y}}(\omega) + \mathbf{C}\mathbf{Y}(\omega) = \mathbf{F}(\omega) \quad (1)$$

It is possible to separate the problem into motions due to wind and wave, and then apply superposition to get the complete solution. From the solution transfer functions that can relate the force to the motion, as shown in equation 2 (from [2]) can be obtained.

$$\mathbf{Y}(\omega) = \mathbf{H}_{FY}(\omega)\mathbf{F}(\omega) \quad (2)$$

Hydrodynamic Part:
The hydrodynamic part of the dynamic equation of motion is obtained by modelling the WindFloat concept in HydroD and running analysis using WADAM potential theory solver. In order to obtain the quadratic transfer functions related to difference frequency effects, a second order free surface model is needed. From the analysis, the content of equation 1 is obtained, in addition to the quadratic transfer-function and the linear transfer function. The forces can be divided into contributions from first order and second order excitations. Therefore, first order force spectrum can be described as : $S_{F_1F_1}(\omega) = |H_{YF_1}(\omega)|^2 S_{YY}(\omega)$ [3]. The second order force spectrum, which is dependent on the difference frequency is obtained from Fourier transformation of the autocorrelation function, and by substitution of the difference frequency, $\omega_i - \omega_j$, the spectrum for the second order force can be described by equation 3 (from [3]).

$$S_{F_2F_2}(\omega) = 2\int_\mu |H_2(\omega+\mu,\mu)|^2 S_{\zeta\zeta}(\omega+\mu)S_{\zeta\zeta}(\mu)e^{i\omega\tau}d\mu \quad (3)$$

The force spectrum can again be related to the motion spectrum by use of the transfer-function relating motion to force.
Aerodynamic Part:
Merz [4] has established a state-space method for calculating the linear dynamic equation of motion on an offshore wind turbine. The concept of the method is to describe the problem as a system of states, $\mathbf{x}$, input, $\mathbf{u}$ and output, $\mathbf{y}$. The relation is then written in the form of equation 4 and 5.

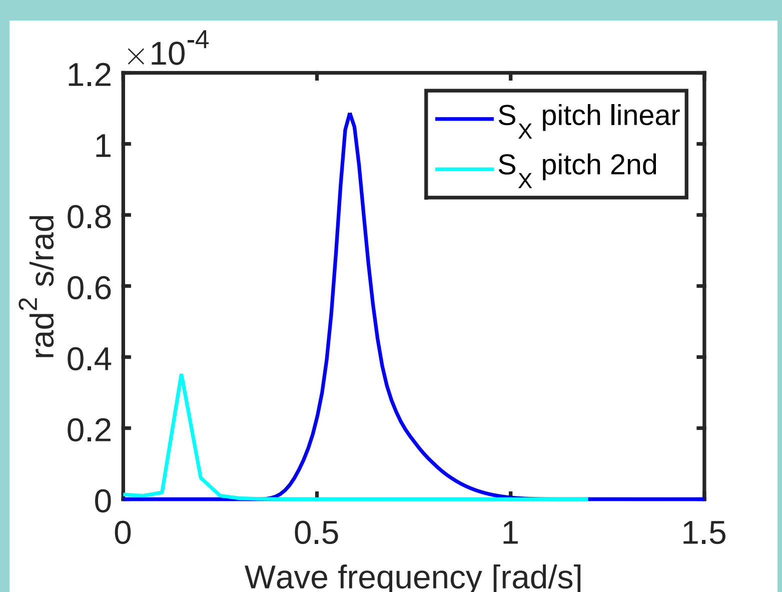
$$\frac{d\mathbf{x}}{dt} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u} \quad (4)$$

$$\mathbf{y} = \mathbf{C}\mathbf{x} + \mathbf{D}\mathbf{u} \quad (5)$$

The procedure is to describe the linear state space model as linked modules, by discretizing the system into modules, then establish the governing equation for each module, remove the higher order terms, differentiate between local and global inputs, and then manipulate this into the state-space form in equation 4 and 5. Complexity is dependent on calculation method, in [4] blade element momentum theory is used to represent the aerodynamic loads, dynamic inflow and dynamic stall are included.

Motion Spectrum

The figure below is an example of a spectrum of pitch motion obtained from the frequency domain method. As can be seen from the figure, one peak here represent the motion related to the linear transfer-function, while the second part represent the second order effect obtained from quadratic transfer functions. When validating the results towards simulation in SIMO-RIFLEX-Aerodyn, spectrum from time-domain analysis and frequency domain analysis are compared.



Result

Comparison for two sea-states between the frequency domain method and the mean standard deviation from 10 simulations in time-domain, gave the following result for the wave frequency-part of the solution;

Error in standard deviation		
Hs/Tp	2.2m/10.8s	4.2m/10.8s
Surge	1.1%	0.8%
Heave	1.3%	1.2%
Pitch	0.0%	-0.4%

Conclusion

The wave-frequency part of the motion spectrum has relatively small error compared to the time-domain solution. This part is however dependent on the first order excitations of the wind turbine, and is not considered the most difficult part of the task. It is hoped that the final frequency domain method, by including wind and low-frequency part of the wave spectrum will also coincide well with time-domain simulations.