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HAWCStab2 With Super Element Foundations: A New Tool For Frequency Analysis Of Offshore Wind Turbines

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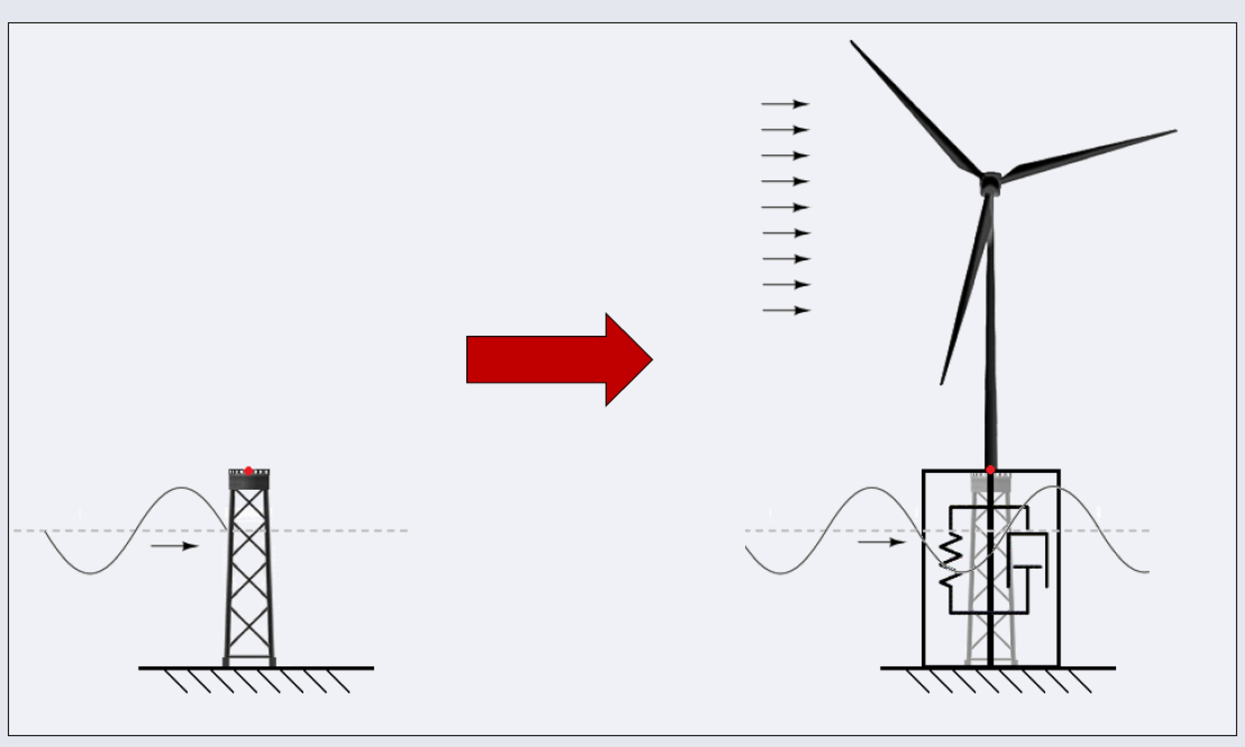
Abstract

HAWCStab2 is a linear frequency domain aero-elastic tool, developed by DTU Wind Energy, suitable for frequency and stability analysis of horizontal axis 3 bladed wind turbines [1]. This tool has now been extended to also handle complex offshore foundation types, such as jacket structures and floating structures with mooring lines, using super elements calculated by the nonlinear time domain aero-elastic code HAWC2 [2,3].

In this work the NREL 5MW Offshore RWT [4] mounted on a jacket support structure [5] is investigated using both HAWC2 and HAWCStab2.

Super Elements in HAWC2

A jacket structure consisting of many interconnected bodies greatly increases the computational burden of an aero-elastic code, such as HAWC2. Similar considerations apply for a floating wind turbine concept with nonlinear mooring lines and hydrodynamic interaction with the floating structure. In order to reduce the computational burden caused by the complex model, while still achieving high accuracy in the computations, super elements have been developed for HAWC2.



A super element is a reduced order model of a complex structure which seeks to reduce the number of degrees of freedom describing the structure while still maintaining the important dynamic properties of the structure.

Super Elements in HAWCStab2

HAWCStab2 has previously only been able to analyze wind turbines with normal tubular towers and monopile foundations modeled with Timoshenko beam elements. A newly developed extension to the HAWCStab2 code has enabled the inclusion of super element in the tower base, giving rise to new possibilities for frequency analysis of wind turbines with e.g. jacket structure foundations and soil-structure interaction, as well as various floating concepts.

HAWCStab2 is modeled with an external disturbances system (aerodynamics)

$$\dot{x}_d = f_d(x_d, q_a, \dot{q}_a) \tag{1a}$$
$$F_d = g_d(x_d, q_a, \dot{q}_a, \ddot{q}_a) \tag{1b}$$

Which is coupled to a mechanical system (wind turbine structure)

$$M_a\ddot{q}_a + D_a\dot{q}_a + K_a q_a = F_a + F_d \tag{1c}$$

A new system is introduced (super element)

$$M_b\ddot{q}_b + D_b\dot{q}_b + K_b q_b = F_b \tag{1d}$$

which is connected to the wind turbine through the equality constraint

$$c(q_a, q_b) = 0 \tag{1e}$$

The fully coupled linearized system can be written as

$$-\dot{x}_d + A_d x_d + D_d\dot{q} + K_d q = 0 \tag{2a}$$
$$G x_d + M\ddot{q} + D\dot{q} + Kq + C^T\lambda - F = 0 \tag{2b}$$
$$Cq = 0 \tag{2c}$$

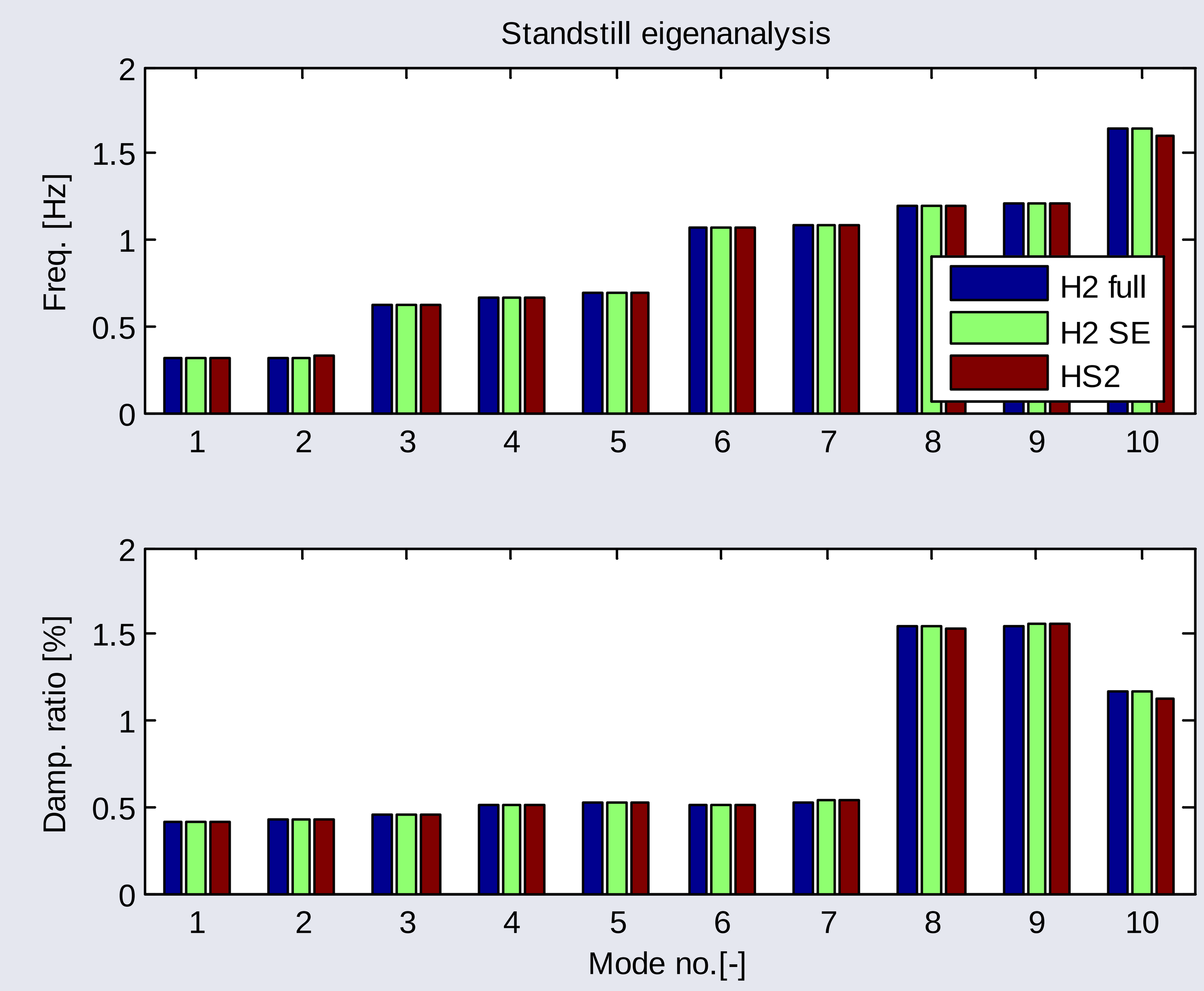
where

$$q \equiv [q_a^T \ q_b^T]^T$$

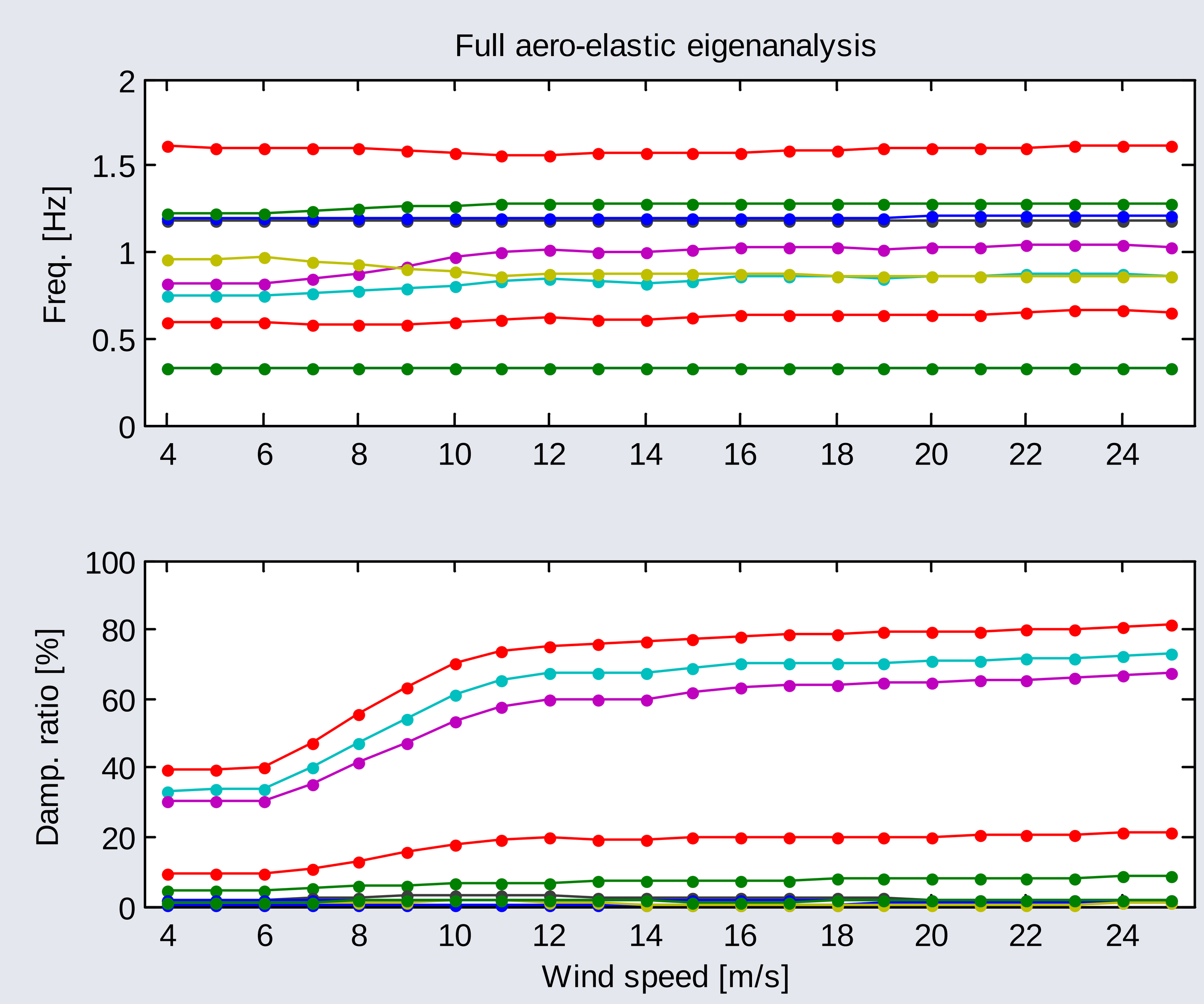
and the matrices are Jacobians with the respect to the appropriate variables.

Results

Standstill eigenanalysis has been computed for 3 different cases: The first is, **H2 full**, is the fully coupled jacket and wind turbine in HAWC2. The second, **H2 SE**, is the jacket condensed as a super element coupled with the wind turbine in HAWC2. The third, **HS2**, is the jacket condensed as a super element coupled with the wind turbine in HAWCStab2.



A full aero-elastic stability analysis for the entire operating range of wind speeds can then be performed taking the complex support structure into account.



Conclusions

The new development of HAWCStab2 enables frequency analysis of complex offshore wind turbines in operation where effects such as aerodynamic damping, gyroscopic forces and centrifugal stiffening of the blades are included in the analysis as opposed to standstill structural analysis, which is often the only option in time simulation codes such as HAWC2.

Future work will investigate the possibilities of coupling super element to nodes other than the tower base in HAWCStab2 and how super elements generated for different loading conditions can be handled.

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