A method for the analysis of the aeroelastic stability of slender wind turbines and its validation

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Abstract. We present a method for the stability analysis of wind turbines as three-dimensional multi-flexible-body systems. Aerodynamic forces are linearized via numerical perturbation and linear regression fit from multiple points around quasi-static equilibrium status, and a novel coordinate transformation is proposed to convert the basis from the absolute frame of reference to the local frame of reference at the rotating center in a corotational formulation. The modal analysis is performed in the MBC generalised coordinate and damping ratios are extracted to assess the aeroelastic stability of wind turbine. A field validation is performed on two offshore prototype wind turbines, showing a good matching between predictions of unstable wind speed ranges and experimental data.

Introduction

As the blade grows longer and slenderer in the pursuit of lowest levelized cost of electricity (LCOE), the aeroelastic damping ratio of its edgewise mode moves toward zero. The aeroelastic stability has become a major constraint condition for blade design optimization, thus motivating detailed and reliable aeroelastic analyses to rule off the risk of instability.

Modal analysis is commonly used to assess the stability of system. The linearization of the aero-elastic dynamics of wind turbines is widely discussed [1] [2] [3], and custom software tools, for instance, GH Bladed, HAWCStab2, OpenFAST and BHAWC [4]have been developed to this purpose, but no straightforward unstable vibrations in the normal power production mode are measured and compared against their numerical predictions.

Results and discussion

In this work, the linearized dynamics of a wind turbine is established based on a corotational formulation. The analytical expression of the tangent matrices of structural dynamics is derived after transforming from the absolute frame of reference to the local frame of reference at the rotating center. The eigenvalues of the aeroelastic dynamics are computed on two wind turbine prototypes and the damping ratios of the rotor edgewise backward whirling mode are extracted to assess the stability at the determined operational points. A field experiment consisting of three test cases is conducted to validate the prediction. As shown in Figure 1, the scatter diagram of standard deviations of blade root edgewise moment (M_x) in case 1 and 2 indicates that the blade doesn't experience relevant edgewise vibrations: accordingly, the damping ratio in case 1 is positive in the entire wind speed ranges. In case 2 the damping ratio is slightly negative for a sub-interval of the $[W_1, W_2]$ wind speed range, which implies the prediction is conservative. Regarding case 3, the M_x blade root edgewise moment presents a remarkable higher standard deviation. The modal analysis in case 3 predicts a negative damping ratio in the $[W_1, W_2]$ wind speed range and shows a satisfying agreement with experimental data.

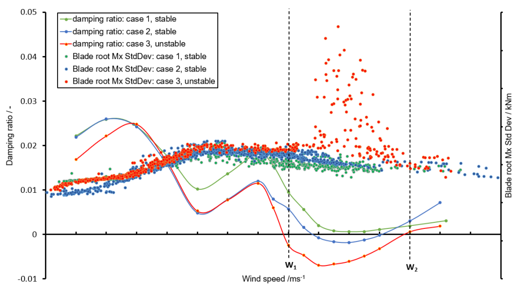

Figure 1: Comparison of measurement and computed damping ratios. Every scatter point represents the standard deviation of blade root edgewise moment (M_x) during a 10 minutes experimental test.

References

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