11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

Jacket substructure fatigue mitigation through active control

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Key Words: *Fatigue load, extreme load, active control, foundation structure*

Introduction – The modern trend in wind power production is to install wind farms further off shore using new, larger and more sophisticated marine foundation substructures. Installation locations are aimed at transient offshore area with water depth of 50 meters. This gives rise to foundation substructures comparable to tower lengths in size. Modal frequencies of such large structures approach 3p and modal frequencies of turbine itself, which leads to a modal coupling and even resonances. It is therefore essential to develop an active control system providing a sufficient structural damping and consequently a fatigue reduction at the foundation substructure and the wind turbine structure itself. Such a control system will be presented in this paper.

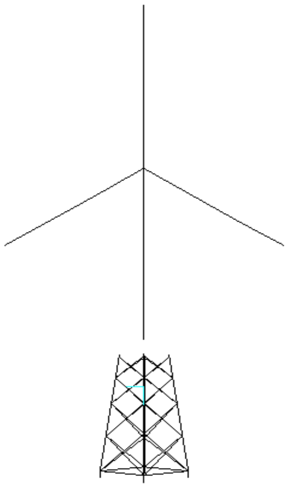

Figure 1: Offshore wind turbine beam model (HAWC2)

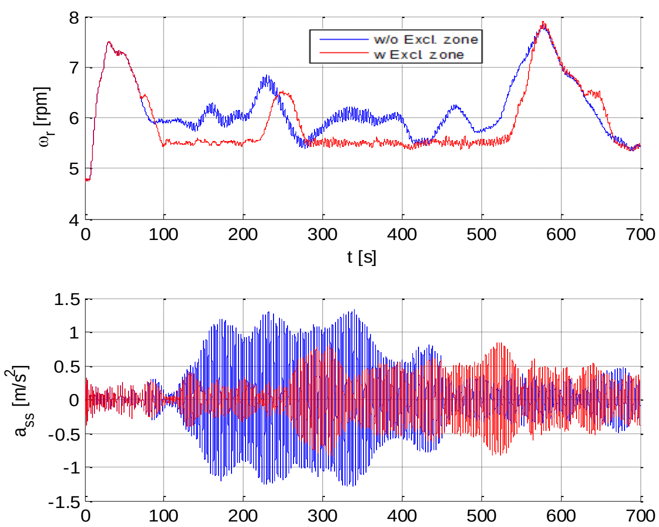

Figure 2: Exclusion zone – rotor speed (up) and tower side to side acceleration time responses (down)

The wind turbine model used in this paper is an upwind, three-bladed offshore machine with the rated power of 10 MW; for more details see [1]. The installation area with 50 meters of water depth and a hub height of 119 meters gives 89 meters of tower length and 76 meters of jacket substructure. The jacket to tower-base interface is considered stiff and is neglected. Jacket is considered rigidly connected to the sea bed and therefore jacket's piles and soil effects are also neglected. The wind turbine's aero-servo-dynamic model (see Figure 1) was implemented and simulations were performed in HAWC2 solver [2, 3].

The developed control system consists of power production controller and structural dampers. The power controller is based on a conventional collective pitch and generator torque PID controllers sensing 'just' the generator angular velocity. Such control provides an optimal Cp tracking in the variable speed regime and rotor speed stabilization in the constant speed regime. On top of that, structural damper functionalities are introduced to mitigate the extreme and fatigue loads. Namely the drivetrain damper (sensor – high speed shaft, control signal – generator torque), the exclusion zone (sensor – high speed shaft, control signal – generator torque, avoiding tower side-to-side excitation see Figure 2), tower top fore-aft damper (sensor – tower top acceleration, control signal – collective pitch) and thrust force peak shaver (sensor – high speed shaft, control signal – collective pitch) functionalities were implemented.

Finally, an evaluation of fatigue loads on the foundation structure, namely at K-braces (see Figure 3) is presented to demonstrate the capabilities and performance of structural control. One can see a significant overall fatigue reduction of up to 19% for side-to-side motion (M_x moments), reaching even higher values for low wind speeds.

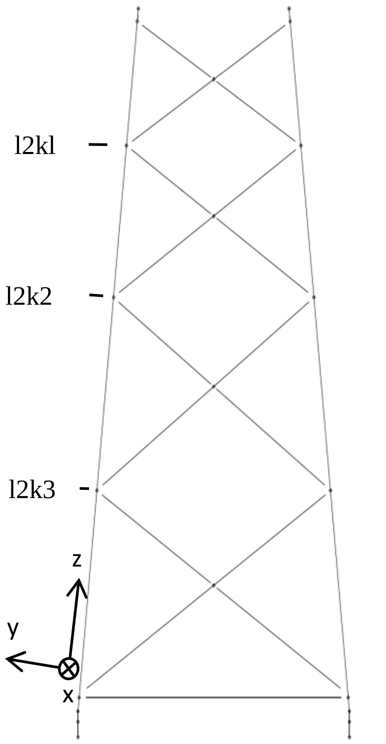

Figure 3: Foundation structure

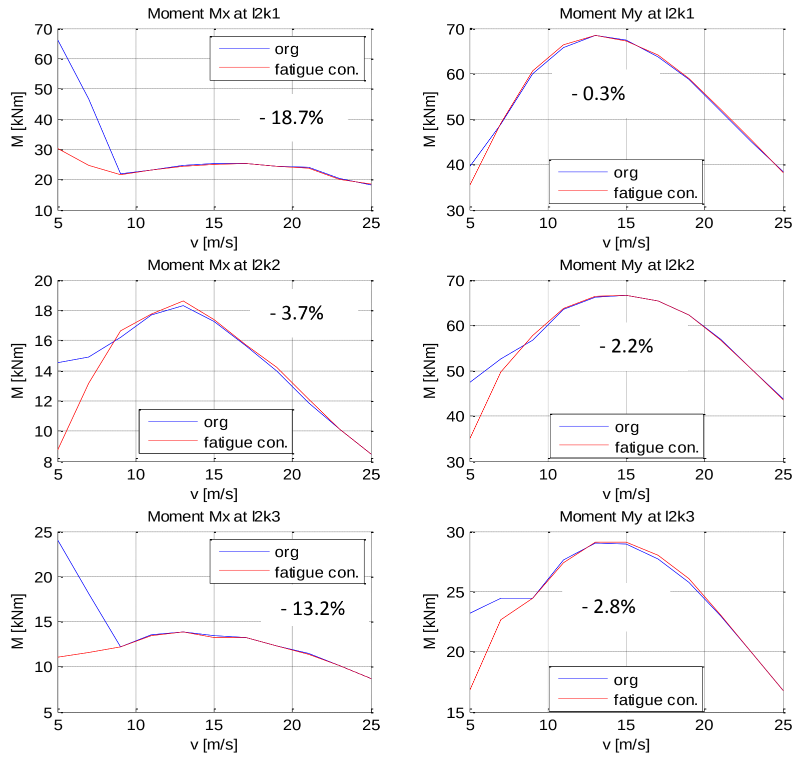

Figure 4: Equiv. load range for damage exponents m = 3, baseline control (blue) and advance control (red)

Conclusion – the augmented wind turbine control system has been introduced. Controller robust performance has been evaluated by presenting the fatigue level reduction (overall reduction up to 19% over several operational conditions) at the critical foundation substructure locations, namely K-braces. The presented novel control approach gives the possibility to significantly reduce the foundation structure mass and therefore the price.

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