PO.ID 083

Unfavourable trends of rotor speed and systems dynamics for very large offshore wind turbines – Analysis of the 10MW INNWIND.EU reference turbine

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Abstract

In the scope of the INNWIND.EU project innovative design concepts for very large 10-20 MW turbines are developed. The design of the reference jacket is mainly governed by the wind induced fatigue loads and the resonances between the blade passing frequency and the first natural frequencies of the system. Whereas the rotor speed decreases due to the increased rotor diameter at almost constant maximum tip speed, the support structure fundamental natural frequency hardly changes even for a taller and heavier structure. A Campbell diagram of the three-bladed INNWIND.EU reference turbine reveals a resonance in the lower rotor speed range (Figure 1).

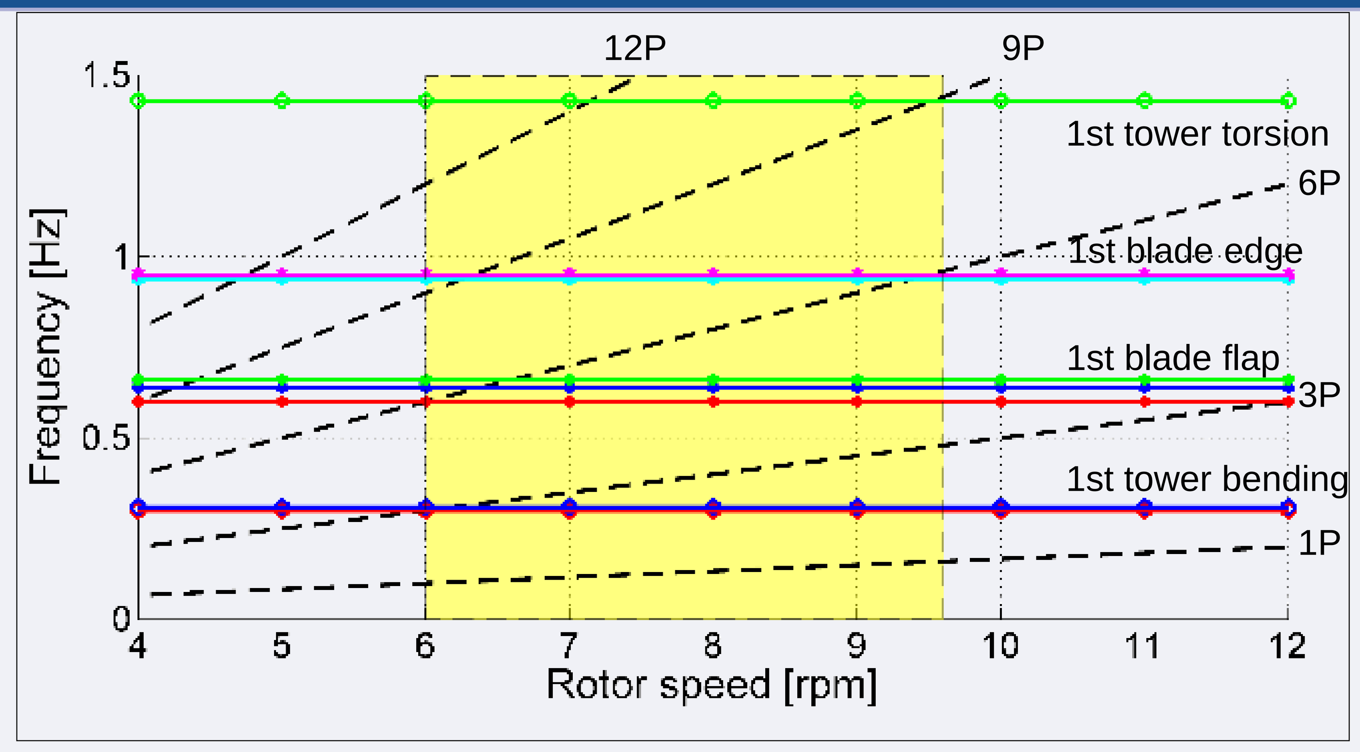

Figure 1: Campbell diagram of the INNWIND.EU 10 MW reference turbine

Approach / Methodology

The influence of the natural frequency and the blade passing frequency on support structure and wind turbine loading is assessed. Therefore, a parameter study is carried out with aero-elastic simulations of the initial 10 MW INNWIND.EU reference turbine (10 MW, 179 m diameter, rotor speed range from 6 rpm to 9.6 rpm [1]). Apparently this turbine is a typical example for resonance issues occurring for large offshore wind turbines recently. The study is carried out by variation of material parameters, instead of varying the geometry of the support structure.

Results

The results show, as expected, a strong amplification of the tower base damage equivalent moment in both directions. Significant differences between fore-aft (Figure 2) and sideways (Figure 3) moment can be found. The sideways direction is heavily resonating due to the missing aerodynamic damping. Furthermore, the maximum amplification compared to the minimal value in sideways direction is approximately three times as high as for the fore-aft moment in its direction. The resonance peak of the fore-aft moment is spread more widely. This leads to the fact that an operational point 10% apart of the natural frequency leads to only 30% load reduction in supercritical and 25% in subcritical operation for the fore-aft moment, whereas the sideways moment is already decreased by 60% with a 10% safety margin. The overall magnification is 3.7 for fore-aft and 10.9 for sideways direction.

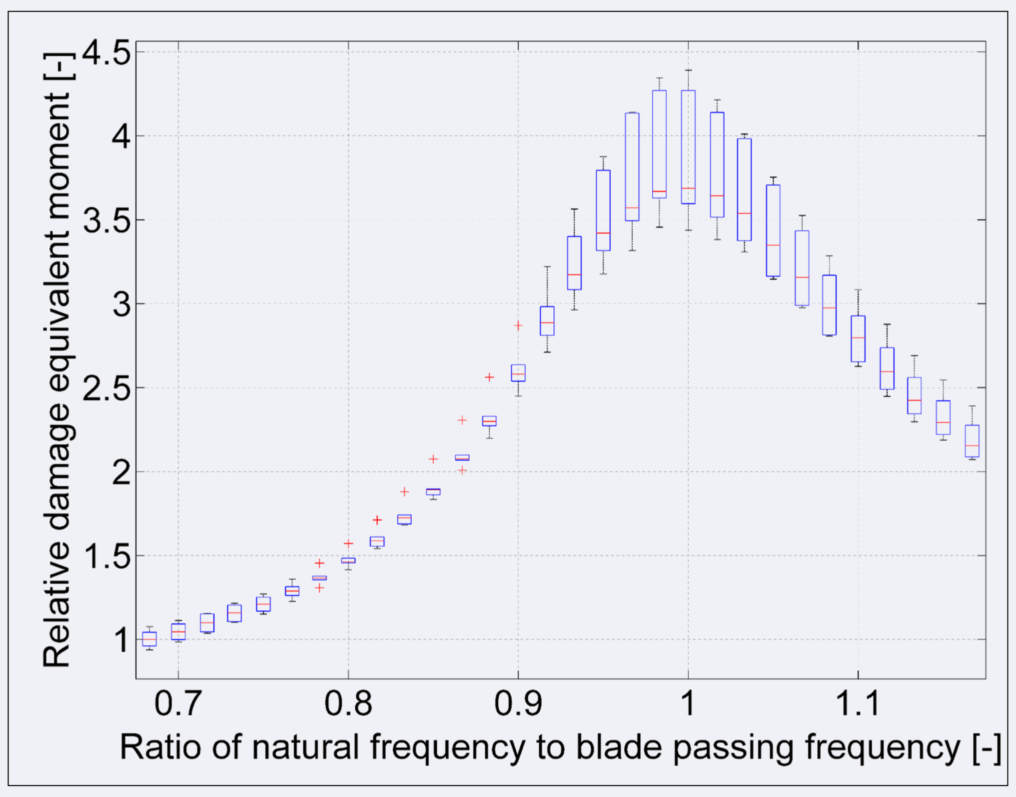

Figure 2: Damage equivalent moments over frequency in fore-aft direction (m=4)

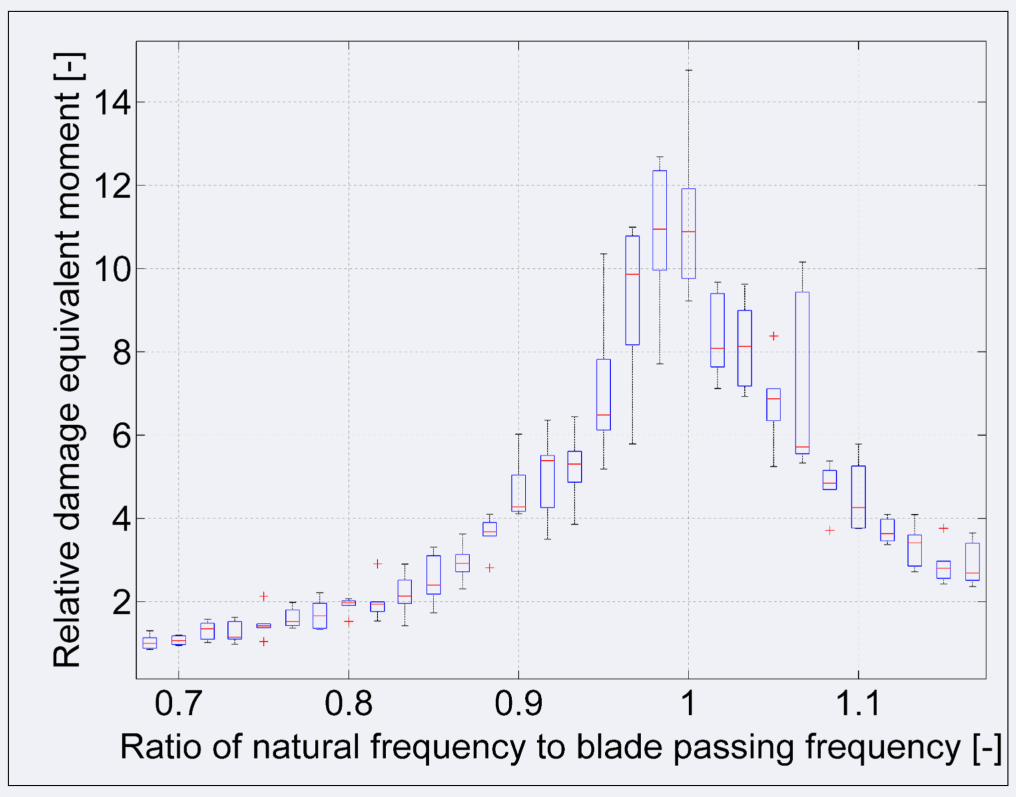

Figure 3: Damage equivalent moments over frequency in sideways direction (m=4)

Conclusions

The investigation proved the strong influence of the ratio of the operational point to the natural frequency of the system. Increasing wind turbine sizes lead to reducing rotor speeds and might lead to the necessity of operation in or near resonance regions. These resonances implicate fatigue load amplifications, which might lead to uneconomic exploitation of wind energy. To achieve cost effective design solutions, these fatigue load amplifications have to be considered very carefully and countermeasures have to be taken, e.g. operational and/or structural control (Figure 4) [2]. Especially concepts found in the area of structural control to increase the structural damping might be advantageous. An increase of the structural damping however seems to be beneficial in terms of magnifications. Nevertheless the downsides with respect to a broader peak have always to be considered, which results in already increasing fatigue loads in a region with a large safety margin between operational point and natural frequency.

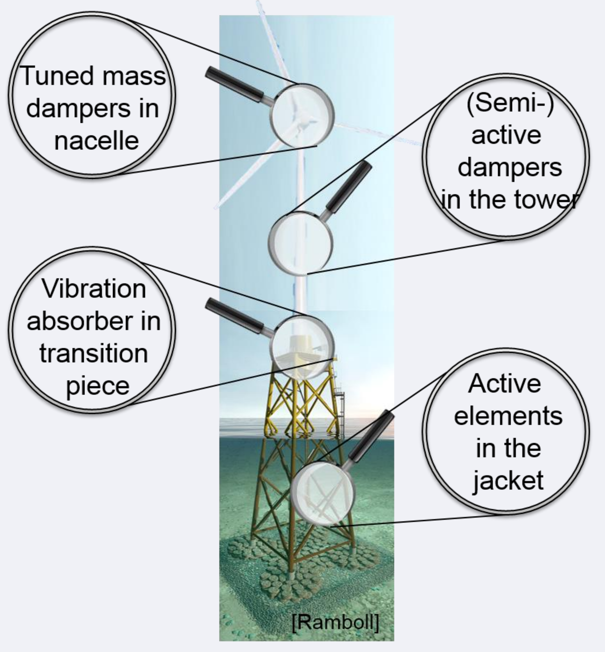

Figure 4: Structural control

References

[1] Scholle N. et al, Deliverable D4.21 – Innovations on component level for bottom-fixed support structures, INNWIND.EU project, pending, 2014.

[2] Chaviaropoulos T. et al, Deliverable D1.21 – Definition of the Reference Wind Turbine – Analysis of Rotor Design Parameters, 2013.

Acknowledgements

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7-ENERGY-2012-1-2STAGE under grant agreement No.308974 (INNWIND.EU).