Application of two passive strategies on the load mitigation of large offshore wind turbines

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Abstract
This study presents the results of two passive strategies to reduce the support structure loads of a large offshore wind turbine. In the first approach, an omnidirectional tuned mass damper is designed and implemented in the tower top to alleviate the structural vibrations. In the second approach, a viscous fluid damper model which is diagonally attached to the tower at two points is developed. Aeroelastic simulations are performed for the offshore 10MW INNWIND.EU reference wind turbine mounted on a jacket structure. Lifetime damage equivalent loads are evaluated at the tower base and compared with those for the reference wind turbine. The results show that the integrated design can extend the lifetime of the support structure.

1. Introduction

In recent years, the size of wind turbines is dramatically increased beyond the 5 MW class to reduce the cost of energy. The design of support structures for such a large machine is still a challenging task as the rotor diameter and tower dimension are exceeding 100 m. The support structure eigenfrequencies are analyzed in the early stage of the design procedure to prevent significant resonances between the structural frequencies and excitations from the waves, rotor frequency, and higher harmonics. This can be acquired via the Campbell diagram which plots the eigenfrequency of the entire wind turbine system against the rotor speed including the harmonic excitations 1P, 3P, etc. Therefore, the potential resonances can be identified if an intersection of the structural eigenfrequency with harmonic modes occurs within the operational rotor speed range. Figure 1, shows a typical Campbell diagram of the 10 MW INNWIND.EU reference turbine. It can be seen that at a rotor speed of 5.7 rpm, the blade passing frequency (3P) coincides with the first natural frequency of the system. The rotor frequency (1P) is however not problematic as it is found far outside of the operational region [1].

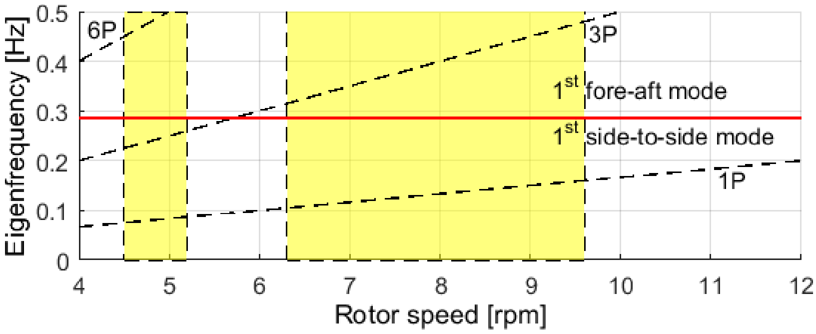

Figure 1: Campbell diagram of the INNWIND.EU 10 MW reference turbine

The larger the blades and the supporting structure of the wind turbine, the higher the bending loads and strongly increased fatigue loads are experienced by critical components e.g. tower base. Innovations are targeted in lowering the loads experienced by the support foundation. This goal can be met through a variety of load mitigation strategies e.g. implementation of passive or (semi)-active damping devices and different control and regulation concepts. Nowadays, the application of the tuned mass dampers (TMD) is becoming increasingly practical for the load mitigation of the large wind turbine structures. Previous works have shown the potential for integration of the TMDs in the tower top location [2]. In addition, different solutions have been proposed for the application of semi-active or active dampers, e.g. tuned liquid column damper (TLCD), magnetorheological (MR) damper and hybrid mass dampers [3,4,5]. However, the integration of both load mitigation strategies i.e. structural dampers and control concepts are not yet considered.

2. Approach

The considered wind turbine is the offshore 10 MW INNWIND.EU reference wind turbine [6] atop a jacket foundation with an average water depth of 50 m (LAT). A detailed specification of the turbine is available in [6]. The numerical modeling of the wind turbine and substructure is carried out in the hydro-servo-aero-elastic software DNV GL Bladed [7]. The 3D turbulent wind field with the Kaimal spectrum is generated at 6 random seeds while the wave kinematics is modeled based on the irregular wave model with JONSWAP spectrum. No yaw misalignment angle is assumed in this analysis. The design load case (DLC) 1.2 [8] based on wind class IA according to IEC61400-1 standard [9] is considered and fatigue loads are calculated during the full operating wind speed range.

Two innovative load mitigation concepts introduced in [10] can be integrated into the final design of the jacket to ensure more an optimised and affordable design. Figure 2 represents schematic models of two concepts.

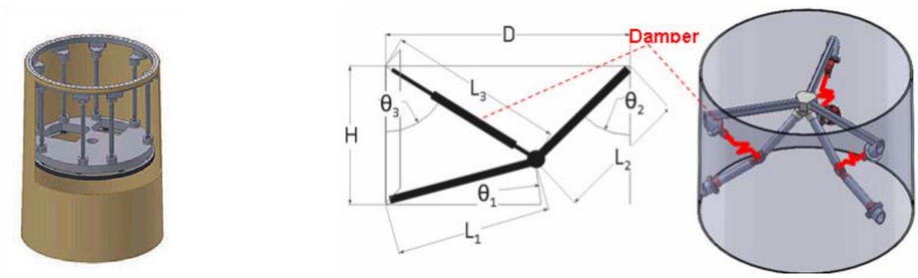

Figure. 2: Innovative concepts considered to be integrated in the tower of the 10MW INWWIND.EU RWT, passive TMD (left) and the toggle brace viscous fluid damper (right).

In the first study, the tower top is equipped with a tuned mass damper and the damage equivalent loads (DELs) are calculated at the tower base at different wind speeds. A passive TMD with the capability to vibrate in all directions is assumed. According to [2], the TMD mass is approximately either 8% of the nacelle mass or 6% of the tower top mass. Other studies propose to use a value between 2-4% of the modal mass of the support structure which is accepted in most commonly used civil structures [11]. In this paper, a parameter study for a TMD with mass ratios of 1% and 2% with respect to the modal mass is performed.

During the second concept, the numerical model of a toggle brace viscous fluid damper (VFD) is developed. The loads calculated for the innovative concepts are then compared with the reference turbine. The improved loads data obtained from the integrated design are most likely to extend the lifetime of the support structure with a positive impact on the economic aspects. The simulations are performed at different wind speeds and the corresponding DELs are calculated in both fore-aft and side-to-side directions.

3. Results

Figure 3 demonstrates the DEL of the tower base moment in the fore-aft force (My) and side-to-side (Mx) directions. The influence of the TMD is not significant in the fore-aft, especially near the rated wind speed, while the TMD can effectively mitigate the fatigue loads in the sideways direction.

The maximum reduction of DELs occurs in the sideways direction with a TMD with the mass ratio of 2% at the wind speed of 6 m/s which corresponds to a 60% reduction with respect to the reference turbine. Except for the region near the rated wind speed, the TMD effectively dissipates the side-to-side loads in whole operational range.
In the full paper, we will demonstrate the results of the combined TMD and innovative adjusted RNA by evaluating the DELs.

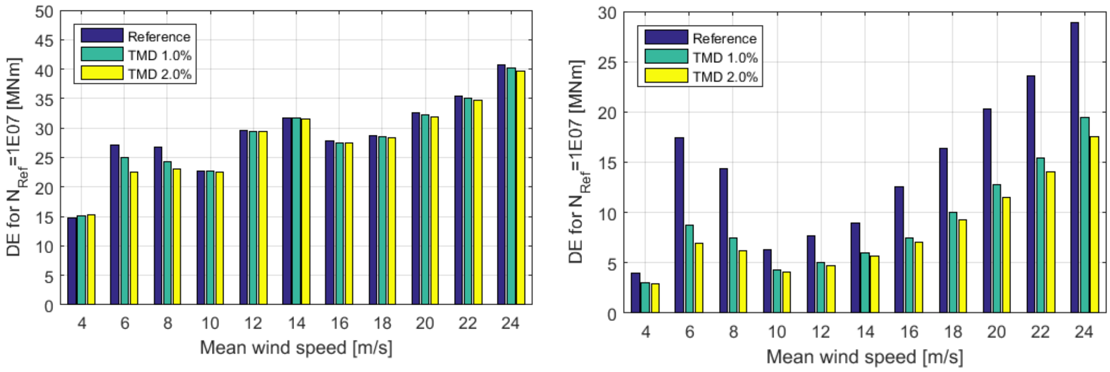

Figure. 3: DELs of the tower base moment in the fore-aft, My, (left) and sideways, Mx, (right) directions for different mass ratios of the TMD

4. Conclusion

This paper presents the results of the integration of two innovative concepts in the 10MW INNWIND.EU reference wind turbine. These two innovative concepts are: a passive tuned mass damper and a toggle brace viscous fluid damper. The improved tower base loads are obtained and compared with the reference design.

It can be concluded that for the load setup where inflow wind is aligned with the wave direction, the DELs in the sideways direction, where no aerodynamic damping is active, can be lowered up to 29% and 69% compared to the reference case for respectively a TMD and VFD. In this condition, the impact of the TMD in the fore-aft direction is however not significant while the viscous damper gives remarkably lowered loads in both directions. The integration of the innovative concepts could have a positive impact on the lifetime of the system. The integration of the developed innovative concepts could be considered for an optimized jacket design with reduced entire mass and applied loads for the INNWIND.EU 10MW RWT.

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