Introduction

Currently, there are only 3 fully operational full-scale prototypes of floating offshore wind turbines installed in the word; Hywind, off the coast of Norway, WindFloat in the Atlantic Ocean, Portugal and Fukushima Mirai, on the East coast of Japan. Most turbines installed on land continue to the ‘Danish-model’ i.e. 3-bladed up-wind and most recent turbines employ a Doubly-Fed Induction Generator. However, it is not yet clear which type of design is most likely to succeed when floating support becomes necessary. In light of the recent Japan’s nuclear disaster and its push for offshore wind, the competition is likely to intensify.

The three existing floating wind turbines are adaptations of existing wind turbines designed for bottom-mounted offshore installation. These in turn are quite often just ‘marinised’ versions of their land-based counterparts. In the future, as floating offshore wind turbines evolve, engineers will probably need to redesign turbines completely, integrated with their floating support. For such a design process, it is not enough to be able to analyse an existing design; they will need to know what can be simplified and/or ignored in the initial designs. In particular, as a step towards determining which types of motion are the most damaging, it becomes necessary to find out how important unsteady aerodynamics are.

Methodology

Theodorsen’s model [1] and an analytical model of Van der Wall and Leishman [2], discretised in the time domain and coded in MATLAB, were used to analyse the fully-attached unsteady aerodynamics. Quasi-steady and fully-attached unsteady models were matched by comparing loads on the NREL 5 MW base turbine blade [3]. Also investigated was the phase difference that arises from using unsteady aerodynamic models.

A parallel study was performed in FAST [4] using the OC3-Hywind model [5]. This study included the whole spectrum of unsteady aerodynamics (dynamic inflow, attached flow, separated flow and dynamic stall). Using a full aero-elastic structural code enabled the investigation of aerodynamic damping, and how it varies between the quasi-steady and unsteady simulations.

Results

Reduced frequency analysis shows that, for an excitation frequency of 0.2 Hz, different blade sections of an NREL 5 MW turbine’s blade would see varying flow states over its span, including unsteady and highly-unsteady (Fig. 1).

Fig. 2 shows thrust force on the NREL 5 MW turbine’s blade in plunging (a) and pitching (b) motion calculated using Theodorsen’s function.

Reduction in the thrust force amplitude and phase shift are clearly seen in both motions.

OC3-Hywind was analysed using FAST. Each DoF was simulated separately, and loads on the turbine compared between the quasi-steady and unsteady aerodynamic models.

In Fig. 3 amplitudes of displacement (a) are almost identical, while the amplitude of thrust force on the rotor (b) is significantly larger in the unsteady aerodynamics simulations, which, partially, is the result of the aerodynamic damping, which for 1.57 m displacement in surge, was calculated (using logarithmic decrement method) to be 2.3 and 3.7 % for the quasi-steady and unsteady simulations.

Tower base side-side moment and the corresponding amplitude spectrum are shown in Fig. 4. Fully-unsteady results show a much large loading on the tower base with many more frequency components present in the amplitude spectrum.

A combination of the 7th wave harmonic and tower side-side mode results in a significant increase of the amplitude of that frequency component.

Conclusions

Two different theories were used to compare quasi-steady and fully-attached unsteady loads on a turbine. Both theories showed a very good agreement of results with fully-attached unsteady loads having a slightly larger mean thrust load, smaller thrust amplitude and a phase lag compared to the quasi-steady results.

Fully-unsteady results, obtained using FAST, showed some similarities to the fully-attached codes, mainly in the higher mean loads compared to the quasi-steady results. However, the amplitude of the loading was always larger in the fully-unsteady aerodynamics, when compared to the quasi-steady loads.

A much higher aerodynamic damping was obtained using fully-unsteady aerodynamics assumption (3.7 % vs. 2.3 % in the quasi-steady).

High non-linearity of dynamic inflow leads to more pronounced wave harmonics, which, when coinciding with other natural frequencies, can be very damaging to the system.

References