The Role of Damping in Offshore Wind Turbine Dynamics

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To reach the goal of generating 353 of electricity from wind by 2035, the U.S. must turn to offshore wind farms. The development of offshore wind turbines (OWTs) presents new challenges for the support structure not faced in onshore wind turbine development. Although offshore winds are more consistent than onshore winds, they also produce a greater random environmental load demand. These increased offshore wind speeds result in a much greater demand on monopile support structures, as resonance generated by stochastic wind, wave, and mechanical loading causes them to fall subject to accelerated cyclic fatigue. These resonance concerns increase monopile OWT stiffness requirements, thereby increasing material costs; approximately 20-303 of the capital cost for OWTs is specifically for the support structure.

As a result, it is important to determine the contribution each damping source (aerodynamic damping, hydrodynamic damping, structural damping, soil damping, and sometimes tuned mass dampers) on these types of loading. The least is known about soil damping, which is more aptly referred to as foundation damping (as it is inherently a function of hysteretic soil-foundation interaction). Even though literature suggests that foundation damping can contribute up to 1.53 critical damping to structural response, current design guidelines do not provide a method for estimating it and it is often conservatively neglected in structural design.

The purpose of this parameter study was to determine how foundation damping affects structural demands over a variety of wind, wave, and operating conditions. OWT behavior was analyzed using the National Renewable Energy Laboratory's (NREL) open-source wind turbine simulation software (FAST), which can model both stochastic environmental loading and mechanical load effects from turbine operation. The NREL 5MW turbine was used for the OWT model due to its prevalence in this field of research, and the effect of foundation damping was broadly modeled through structural damping of the OWT tower for damping ratios ranging from 03 to 53. Turbulent wind speeds of 3 m/s (cut-in), 11.4 m/s (rated), and 25 m/s (cut-out) were used for the operating cases, and wind speeds greater than 25 m/s were used for the parked and feathered cases. Examining the sensitivity of structural loading to damping may allow foundation damping to be advantageously incorporated into design guidelines, potentially leading to a more efficient OWT design and reduction in the large cost of the support structure.

Given that fatigue analysis is important for ensuring the design life of OWTs, the effective contribution of damping on fatigue damage accumulation was also estimated. Fatigue life of the OWT was analyzed using another open source NREL software called MLife, a Matlab-based program that calculates fatigue life and statistics for one or more time series. With this software, a similar parameter study was performed to evaluate the effect of foundation damping on short-term damage-equivalent loads (DELs), damage rates based on single time-series, and lifetime DEL results that are based on the entire set of time-series data. This influence of foundation damping on the accumulated lifetime damage and the time until failure will allow for a better estimation of OWT design life.