# FY18 Floating Offshore Wind Turbine Weight Sensitivity Study

## Analysis Goal

Determine system level sensitivity to weight reduction on a floating wind turbine. Sensitivity refers to the ratio of system mass reduction throughout the remainder of the turbine and substructure relative to the mass reduction in a specific component due to introduction of a new technology. Given the relative cost of mass reduction per kg and the cost savings per kg removed in the rest of the turbine, a cost breakeven point can also be determined. This project focuses specifically on weight reduction in the rotor nacelle assembly (RNA) and the tower. Note that with the current low-fidelity implementation of the static loading and stability, the results obtained here will be preliminary, and will be revisited as new capabilities and higher fidelity, in both the physics and light-weight technology models, are added over time.

## Program Goal

Since this the first analysis executed using the expanded WISDEM tool, this task will also give NREL and DOE familiarity with its personality. The review of optimization outputs by experienced researchers will reveal key design considerations and constraints that may have been overlooked and driven the results askew. In this way, the tool will be iteratively exercised and improved. Succinctly, we are demonstrating the current capabilities of the WISDEM floating tool to show its value and to identify gaps to focus future investments.

## Approach Overview

Use WISDEM optimization to create baseline spar, semisubmersible, and TLP substructure designs to support the DTU 10MW reference turbine used in a floating application. Next, re-optimize the designs assuming a set of parameterized weighted reduction values in the RNA and the tower. By comparing the baseline optimizations to the parameterized weight reduction optimizations, the cost value of weight savings can be determined.

## Key Outputs

A number of outputs will be used to capture the analysis findings and accomplish the primary and ancillary project goals. These include:

* Visual renderings of optimized substructure geometries
* Line plots of system weight reduction versus component weight reduction (one line for the RNA, one line for the tower)
* Line plots of breakeven cost premium per kg versus component weight reduction (one line for the RNA, one line for the tower)

## Detailed Analysis Procedure

**STEP 1:** Build a representation of the DTU 10MW reference turbine in WISDEM.

*Key WISDEM modules:*

|  |  |  |  |
| --- | --- | --- | --- |
| RotorSE | CommonSE | Turbine\_CostsSE | Plant\_FinanceSE |
| TowerSE | FloatingSE | Wind\_OBOS\_SE |  |

**STEP 2:** Build a spar, semisubmersible, and TLP substructures using WISDEM, starting from a randomized initial condition, where optimization works around the given constraints to an LCOE-optimal design. In this step, the turbine design is fixed at the DTU 10MW reference point, and only the substructure and mooring system are allowed to change.

*Design Variables:*

* Number of substructure columns and their spacing
* Substructure column lengths, diameters, wall thicknesses, and stiffener geometries
* Substructure truss elements and cross-sectional properties
* Substructure permanent ballast height
* Freeboard height
* Fairlead depth
* Mooring diameter, unstretched line length, and anchor point

*Number of system optimizations:* 3

**STEP 3:** Parameterize the mass of the DTU 10MW RNA from -50% to +10% of the original value. This mass reduction could occur through alternative drivetrain and/or generator technologies, such as superconducting generators, or alternative materials, such as carbon fiber composites. Holding the rotor design fixed, loop over each of the parameterized RNA mass values and substructure types and re-optimize the substructure using the same set of design variables and constraints as in Step 2. Compute the sensitivity of system mass reduction over RNA mass reduction relative to the baseline established in Step 2. From the total substructure cost difference, determine the maximum cost per kg that would make the component mass reduction premium cost neutral.

*RNA mass deltas:* [-50%, -33%, -25%, -10%, +10%]

*Number of system optimizations:* 3 x 5 = 15

**STEP 4:** Parameterize the mass density of the material used in the DTU 10MW tower, while holding all other material properties constant). This assumption does not reflect real-world materials, but does isolate the value of weight reduction along the tower. Using the same parameterization and procedure from Step 3, determine the sensitivity of system mass reduction over tower mass reduction relative to the baseline established in Step 2. From the total substructure cost difference, determine the maximum cost per kg that would make the tower mass reduction premium cost neutral.

*Number of system optimizations:* 3 x 5 = 15

**STEP 5:** (If time and budget allow) Parameterize the center of mass location (relative to the hub height) DTU 10MW RNA from -5m to +2m using the baseline RNA mass value in both the up/down and fore/aft directions. This captures the value of lowering or raising the center of mass of the system as well as increasing or lowering the bending moment on the tower. Holding the rotor design fixed, loop over each of the parameterized RNA center of mass values and substructure types and re-optimize the substructure using the same set of design variables and constraints as in Step 2. Compute the sensitivity of system mass reduction over RNA center of mass changes relative to the baseline established in Step 2. From the total substructure cost difference, determine the maximum cost per kg that would make the component center of mass change cost neutral.

*RNA center of mass deltas:* [-5m, -3m, -1m, +2m]

*Number of system optimizations:* 3 x 4 x 2 = 24

**ALL STEPS:** For all of the optimizations in steps 2-4, use the following metocean environment conditions, design load cases, and constraints cases

*Load Cases and their metocean environment:*

1. Max thrust loads
   1. Wind reference speed = 11 m/s
   2. Wind reference height = 119 m
   3. Wind shear exponent (power law) = 0.11
   4. Significant wave height = 10.8 m
   5. Wave period = 9.8 s
   6. Water depth = 320 m
2. (none other at this time)

*Constraints:*

* Substructure column draft:water depth limit
* Substructure column diameter:spacing limit
* Substructure column taper ratio limit
* Substructure column thickness:diameter ratio limit
* Substructure stiffener geometry limits
* Substructure column buckling margin
* Substructure column stress limits
* Mooring line tension limit
* Substructure neutral buoyancy requirement
* Substructure metacentric height limit
* Substructure variable (water) ballast mass limit
* Substructure restoring force requirement
* Substructure restoring moment requirement
* Tower buckling margin
* Tower stress limits
* System rigid body period limits relative to wave periods
* System modal eigenfrequency limits relative to wave periods
* System rigid body period limits relative to rotor frequencies
* System modal eigenfrequency limits relative to rotor frequencies
* Rotor tip deflection limit (tower strike)
* Rotor tip ground clearance limit